Demonstration Report

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AIRBUS(Lead); EUROCONTROL; INDRA; NATS, SKYGUIDE; THALES	

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Abstract

This document is the demonstration report of the PEGASE (**P**roviding **E**ffective **G**round & **A**ir data **S**haring via **E**PP) large scale demonstration project. The purpose of the project was to assess the potential benefits of using ADS-C EPP reported data to enhance air traffic management ground-systems operations.
A series of flight trials were performed in which real ADS-C EPP reports from Airbus A320 aircraft were downlinked and then distributed to project partners via SWIM. The performance of the EPP data was analysed offline to understand potential applications in the ATM system. Project conclusions are presented and recommendations for R&D next-steps are made.

The project was conducted by a consortium comprising Airbus, EUROCONTROL (supported by Indra), NATS, skyguide and Thales.

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Rational for rejection

None.

Document History

Edition	Date	Status	Author	Justification
00.01.00	15/09/2016	Official version V01	[redacted]	Main modification : §6.4.7.1.1 §6.4.7.1.3.2 §6.4.7.1.3.4 §6.4.7.1.5.1.3 (paragraphs updated) Figure 36 added
00.02.00	15/10/2016	Final	[redacted]	Abstract Executive summary §2.1 § 5.1, §5.1.1, §5.1.2, §5.1.3, §5.1.4 & §5.1.5 added §8 modified §9 modified

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This deliverable consists of SJU foreground.

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Executive summary

This document is the demonstration report for the SESAR PEGASE (Providing Effective Ground and Air data Sharing via EPP) large-scale demonstration project. The purpose of the project was to assess the potential benefits of using ADS-C EPP reported data to enhance air traffic management ground-systems operations.

The project was conducted by a consortium comprising Airbus, EUROCONTROL (supported by Indra), NATS, skyguide and Thales.

The demonstration project conducted a flight campaign using Airbus A320 aircraft and comprised 59 flights over a 15 month period, downlinking real ADS-C EPP data. This is the first significant assessment of the application of real downlinked EPP data, and builds on previous studies, including the simulation-based EPP research
For each flight, ADS-C contracts were established by EUROCONTROL for the real-time downlink of EPP reports, which were then distributed to project partners in real-time via a SWIM web service. Surveillance data, flight plan information and meteorological data were also recorded and shared to support subsequent trajectory analysis.
Off-line statistical analysis was performed on the downlinked EPP data to assess its potential to improve the performance of existing ATM processes, and to support new functionalities. The EPP data analysis covered two main areas: the use of the aircraft FMS' trajectory prediction in the ground ATM system, and the use of downlinked trajectory prediction input parameters (actual aircraft mass and planned speed schedule) to improve ground trajectory predictors.
Initial results indicate that downlinked EPP data in its current form can improve the performance of ground-based trajectory predictors, which may in turn increase airspace capacity and reduce controller workload. FMS trajectory prediction output also shows potential to be used to support longer-range processes such as AMAN and DCB. The value of EPP data may be improved if combined with greater alignment between air and ground planning trajectories.

As an initial flight test campaign, the size and diversity of the dataset was limited. This report presents a number of recommendations for R&D next-steps, with respect to format and extent of future flight trials, and to the EPP data analysis required. These will inform the development path towards deployment to meet the obligations of ATM Functionality 6 of the pilot common project implementing regulation EU 716/2014.

The conclusions and recommendations of the PEGASE project are detailed in §8

1 Introduction

1.1 Purpose of the document

This document provides the Demonstration report for *PEGASE* (**P**roviding **E**ffective **G**round & **A**ir data **S**haring via **E**PP). It describes the results of demonstration exercises defined in PEGASE Demonstration Plan edition 00.03.01 of the 19/01/2015 and how they have been conducted.

1.2 Intended readership

The main intended readership of this report is:

- The consortium members participating in the project,
- The SESAR Joint Undertaking,
- General stakeholders of the SJU,
- The SESAR OFA (ENB03.01.01, OFA03.01.03, OFA03.01.04, OFA03.03.01, OFA03.03.02, OFA04.01.01, OFA04.01.02) leaders and additional parties involved in demonstration and validation activities for SESAR,
- Other projects in the Demonstration Program.

1.3 Structure of the document

Section 1 introduces the document.

Section 2 provides the context and scope of the demonstrations with reference to the overall SESAR programme and stakeholders involved in the flight trials.

Section 3 provides an overview of the project management aspects of PEGASE; including the work and resource breakdowns, project milestones, pre-financing and risks.

Section 4 details the demonstration approach to be taken in the PEGASE simulated exercise and flight trials.

Section 5 Summarizes exercises results

Section 6 details the results of each of the demonstration exercises individually.

Section 7 describes the communications activities that were undertaken by the project.

Section 8 describes the overall conclusions and recommendations for the next steps.

Section 9 contains the references.

1.4 Acronyms and Terminology

Term	Definition
A/C or ACFT	Aircraft
ACARS	Aircraft Communications Addressing and Reporting System
ACQ	ACQuired
ADS-C	Automatic Dependent Surveillance – Contract
ALT	Altitude
AMAN	Arrival MANager
AMI	Airline Modification Information
ANSP	Air Navigation Service Provider
AOC	Airline Operational Communication / Centre
AOI	Area of Interest
AOR	Area of Responsibility
ARCID	AiRCraft IDentifier
ARM	Acceptance Review Meeting
ARR	Arrival
ARTAS	ATM suRveillance Tracker And Server
ASE	Application Service Element
ASN	Aviation Safety Network
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATO	Actual Time Over
ATSU	Air Traffic Services Unit (aircraft equipment)
BADA	Base of Aircraft DAta

Term	Definition
BIS/ES	Boundary Intermediate System / End System
CBA	Cost Benefit Analysis
CFL	Cleared Flight Level
CFMU	Central Flow Management Unit
CM	Context Management
CNS	Communication Navigation Surveillance
COM	Communication
CONF	Configuration
COP	COordination Point
CPDLC	Controller Pilot Data Link Communication
CPR	Correlated Position Report
CTA	Controlled Time of Arrival
CTC	Corporate and Technical Centre
CWP	Controller Working Position
DCB	Dynamic demand and Capacity Balancing
DCDU	Datalink Control & Display Unit
DCT	DireCT
DEP	Departure
DIRTO	DIRect TO
D/L FEP	Datalink Front End Processor
DOD	Detailed Operational Description
DSP	Dispatch
E-ATMS	European Air Traffic Management System
EDHI	Hamburg –ICAO code
EEC	Eurocontrol Experimental Centre
EFD	Electronic Flight Data

Term	Definition
EIS	Electronic Instrument System
E-OCVM	European Operational Concept Validation Methodology
EOBD	Estimated Off-Blocks Date
EOBT	Estimated Off-Blocks Time
EPP	Extended Projected Profile
ETO	Estimated Time Over
EUROCAE	European Civil Aviation Equipment
F-PLN	Flight Plan
FAA	Federal Aviation Administration (USA)
FANS	Future Air Navigation System
FDPS	Flight Data Processing System
FDR	Flight Data Recorder
FEP	Front End Processor
FER-T	Ferry flight to Toulouse
FF	Ferry Flight
FIB	Functional Integration Bench
FIR	Flight Information Region
FL	Flight Level
FMGC	Flight Management and Guidance Computer
FMS	Flight Management System
FTR	Flight Test Request
FSA	First System Activation
HAM	Hamburg (IATA code)
HST/DST	Horizontal Scanning Tool/Dynamic Scanning Tool
i4D	Initial 4 Dimension
IAS	Indicated AirSpeed

Term	Definition
IBP	Industry Based Platform
ICAO	International Civil Aviation Organization
iFACTS	interim Future Area Controls Tools Support
ILS	Instrument Landing System
IP	Internet Protocol
IQR	Inter Quartile Range
KoM	Kick off Meeting
KPI	Key Performance Indicators
LACC	London Area Control Centre
LAT	Latitude
LFBO	Toulouse – ICAO code
LONG	Longitude
LSSD	Large Scale SESAR Demonstrator
MCDU	Multipurpose Control and Display Unit
MNPS	Minimum Navigation Performance Specification
MoM	Minutes of Meeting
MTCD	Medium Term Conflict Detection
MUAC	Maastricht Upper Area Control Centre
MSSR	Monopulse Secondary Surveillance Radar
NAT	North Atlantic
NATS	National Air Traffic Services
NAV	Navigation
NFDPS	National Flight Data Processing System
NM	Network Manager
NOTAM	Notice to Airmen
O4D	Orthogon 4 Dimension (Trajectory Predictor)

Term	Definition
OFA	Operational Focus Area
OLDI	On-Line Data Interchange
OSED	Operational Services & Environment Description
OTS	Organized Track Structure / System
PA	Provider Abort
PEGASE	Providing Effective Ground & Air data Sharing via EPP
PFR	Post Flight Report
PCP	Pilot Common Project
PSR	Primary Surveillance Radar
RAVE	Replay Aided Validation Environment
RBT	Reference Business Trajectory
R&D	Research & Development
RFL	Requested Flight Level
ROCD	Rate Of Climb/Descent
RTCA	Radio Telecommunication Communication for Aeronautics
RWY	Runway
SA	Single Aisle (A320 family)
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SI	System Installation
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SQL	Structured Query Language
SNDCF	SubNetwork Dependent Convergence Facility.
STAR	Standard Terminal Arrival Route

Term	Definition
SWIM	System Wide Information Management
SOP	Standard Operating Procedure
TBC	To Be Confirmed
TGF	Transatlantic Green Flights
TLS	Toulouse (IATA code)
TMA	Terminal Manoeuvring Area
ToC	Top of Climb
ToD	Top of Descent
TP	Trajectory Prediction
TPRT	Trajectory Prediction Research Tool
VDL	VHF Data Link
VIF	Validation InFrastructrure (Department inside ECTL)
VLD	Very Large Demonstrator
WP	Work Package (SESAR term)
WPT	Waypoint
WSN	Wireless Sensor Network
Z	Zulu Time (UTC)

2 Context of the Demonstrations

2.1 Scope of the demonstration and complementarity with the SESAR Programme

In the scope of the PEGASE project, the consortium took advantage of Airbus Ferry flights (production Aircraft) flying between Hamburg and Toulouse to gather Extended Projected Profile (EPP) data via ADS-C. EUROCONTROL disseminated the EPP data to several end-users. The EPP data along with pertinent flight data as elaborated by ground systems (flight plans, radar tracks, predicted trajectories) were also recorded for off-line analysis purposes and used to build confidence in the performance and benefits of using airborne data (in particular the EPP) on the ground. Refer to §6.4.4

PEGASE project objectives were:
- Downlink the intended aircraft route [EPP] through ADS-C datalink application.
- Collect extended Flight plan information in order to complement the statistical analysis.
- Perform offline statistical analysis of EPP accuracy and reliability versus the real flown route and the ground based predictions for that flight. This analysis will result in a baseline which will be of paramount importance to support further trajectory prediction improvement initiatives.
- Share the EPP information using System Wide Information Management services (Web service / yellow profile)
- Provide EPP data to several end users for their own evaluation and experimental needs such as enhanced estimation of flight plan elapsed time
- Be as close as possible to a real ATM environment for realistic analysis and conclusions.
- Increase ANSP's confidence in benefits brought by the EPP.

In the frame of 04.03 i4D validation exercises (VP-029, VP-330, VP-204 and VP-279) (VP-029, VP-323, VP-330, VP-324, VP-204, VP-463, VP-472 and VP-279), initial use of downlinked EPP was validated. Refer also to Work Package 5.5.2 [10]. From these exercises, possible uses of the EPP in ground systems were identified [2] along with the potential benefits. The i4D exercises included two live flight trials.

For more details about I4D and CTA refer to [4].

Building on the experience gained during these exercises and their results, PEGASE demonstrated the uses of EPP in ground systems based on a significant number of ADS-C equipped flights which allowed the potential operational benefits to be demonstrated.

Extended Projected Profile (EPP) is a technical enabler of i4D which consists in providing to the ground the 4D trajectory (3D route + Estimated Time of Arrival) and others information (flight modes, speed schedule, …) produced by the aircraft. Benefits expected of ground use of the EPP are the following:

- Detect conflicts by advance in En-Route and TMA (and resolve them)
    - Reduce fuel consumption (and fuel planning)
    - Reduce delays
    - Increase airspace capacity
    - Increase airport capacity
    - Increase Safety
- Decrease controller and pilot workload
- Increase flight efficiency facilitating the flight optimal profile

EPP report is based on the predictions computed by the FMS and based on the flight plan defined by the flight crew. The EPP report includes some general data not associated to waypoints.

- The EPP report includes a list of up to 128 points of significance for construction of the 4D Trajectory.
- The points are reported in the order the A/C will sequence them.
- Only points ahead of the A/C are reported (FROM and PPOS are not part of EPP)
- Waypoints are not only F-PLN waypoints, also other relevant points computed by the FMS.

PEGASE objectives were twofold:

- Perform demonstration in a real environment of how the EPP data can efficiently be used and contribute to improving the overall ATM system
- Enable to collect real data that could then be used to confirm assumptions on EPP concept, measure EPP impact on performance, improve simulation modelling of EPP data exchange and contribute to present and future validation exercises.

Please refer to PEGASE demonstration plan [2].

The PEGASE demonstration contributes to the following SESAR OFA:

- ENB 03.01.01 (TMF and IOP): PEGASE demonstrated the sharing of the airborne reference profile with the ground systems. PEGASE also demonstrated important aspects of sharing airborne data between ground systems (e.g. the setup of common contracts).
- OFA 03.01.04 (Business and Mission Trajectory) Airborne data is a key input to development (update/revision) of the business trajectory during the execution phase. Through offline study and the assessment of the differences between the stakeholder views, PEGASE demonstrated how airborne data can be used to improve the reference trajectory.
- OFA 05.03.04 (Enhanced ATFM Processes) The early availability of airborne data including the EPP can potentially improve load prediction on the traffic volumes.

A task force was setup, in the frame of preparation of PCP AF#6, to identify the gaps in validation activities related to the use of EPP required to reach V3 maturity. The task force identified a list of applications of EPP data. PEGASE will demonstrate and complement some of these applications (provide a list in function of the exercises described below…)

One of the major benefits brought by downlinking airborne data is its use in trajectory prediction. PEGASE built on the work done in 5.6.2 and 6.4.7.2 and provided data and analysis that will support further Trajectory Predictor improvements.

PEGASE used single aisle (A320 family) ferry flights between Hamburg and Toulouse operated by Airbus to collect and demonstrate the use of airborne data (Extended Projected Profile) in ground systems and identified the potential operational benefits the use of airborne data are expected to bring. The project initially anticipated that at least 80 ferry flights could be used for the flight demonstrations, scheduled from February 2015 to September 2016.

Different routes were used between Hamburg and Toulouse, the ferry flights crossed different ANSP (MUAC, NATS, Skyguide and Thales[1]) giving the opportunity to demonstrate operations in different contexts. In function of the airspace crossed, different exercises were run demonstrating different operational benefits. The different exercises used are detailed in subsequent sub-paragraphs.

2.1.1 Preparation and Verification

This step consists of:

- End to end technical verification in order to provide the "GO" for flight, validation of the contract, EPP distribution, scenario refinement, data analysis tool validation.
- Simulation of full flight operation in high density area (including planning and execution), with data distributed and received. 14 lab sessions achieved.

2.1.2 Demo Flight activities

The Demo flight activities includes:

- Airbus led, providing a significant number of EPP capable flights in a real ATM environment (OBJ-0106-001 & 002), with representative ADS-C contracts (OBJ-0106-003) and demonstration of online distribution on ground (OBJ-0106-007).
- Addressing ENB03.01.01, OFA03.03.01, the exercise included full flight operation in high density area (including planning and execution (SCN-0106-001, 002 & 003), with optional Real Time Simulation

The following objectives, from the Demonstration Plan, are addressed in chapter 6.

2.1.2.1 OBJ-0106-001

Identifier	**OBJ-0106-001**
Objective	Assess performance characteristics of EPP data provided live by real flights in high density continental airspace
Success Criterion	For more than 60% of the ferry flights, EPP data is collected that can be compared with the ground systems predictions.

2.1.2.2 OBJ-0106-002

Identifier	**OBJ-0106-002**
Objective	Measure end to end performance of the Ground/Ground and Air/Ground communication channels.

1 In the frame of the PEGASE demonstration, Thales plays the role of a pseudo ANSP covering Paris Area (LFFF) in France.

Success Criterion	Statistically significant set of data indicating end to end operational response time.

2.1.2.3 OBJ-0106-003

Identifier	**OBJ-0106-003**
Objective	Provide recommendation about EPP contract types and contents
Success Criterion	Provide recommendation with supporting rationales

2.1.2.4 OBJ-0106-004

Identifier	**OBJ-0106-004**
Objective	Demonstrate operational and useful ground TP improvement using EPP data
Success Criterion	Produce evidence based on practical cases of TP benefits brought by using EPP data elements.

2.1.2.5 OBJ-0106-005

Identifier	**OBJ-0106-005**
Objective	Collect consistent flight data
Success Criterion	For 60% of the ferry flights, consistent set of data has been collected including ADS-C exchanges, track data, flight plan data, NM data and operational inputs

2.1.2.6 OBJ-0106-006

Identifier	**OBJ-0106-006**
Objective	Establish ADS-C contracts
Success Criterion	For more than 60% of the ferry flights, ADS-C contracts can be established from at least one ground station for more than 50% of the flight duration

2.1.2.7 OBJ-0106-007

Identifier	**OBJ-0106-007**
Objective	EPP ground distribution

Success Criterion	More than 80% of the ADS-C messages received by the EEC ground ATSU are correctly distributed to the connected parties.

3 Programme management

3.1 Organisation

The PEGASE Consortium includes:

- One project coordinator (Airbus)
- Four other project partners [EUROCONTROL (with the support of Indra), NATS, Skyguide, Thales]

The project is also supported by Honeywell, SITA & Thales avionics.

Each entity was fully responsible of the proper and timely performance of their activities as presented in the table below.

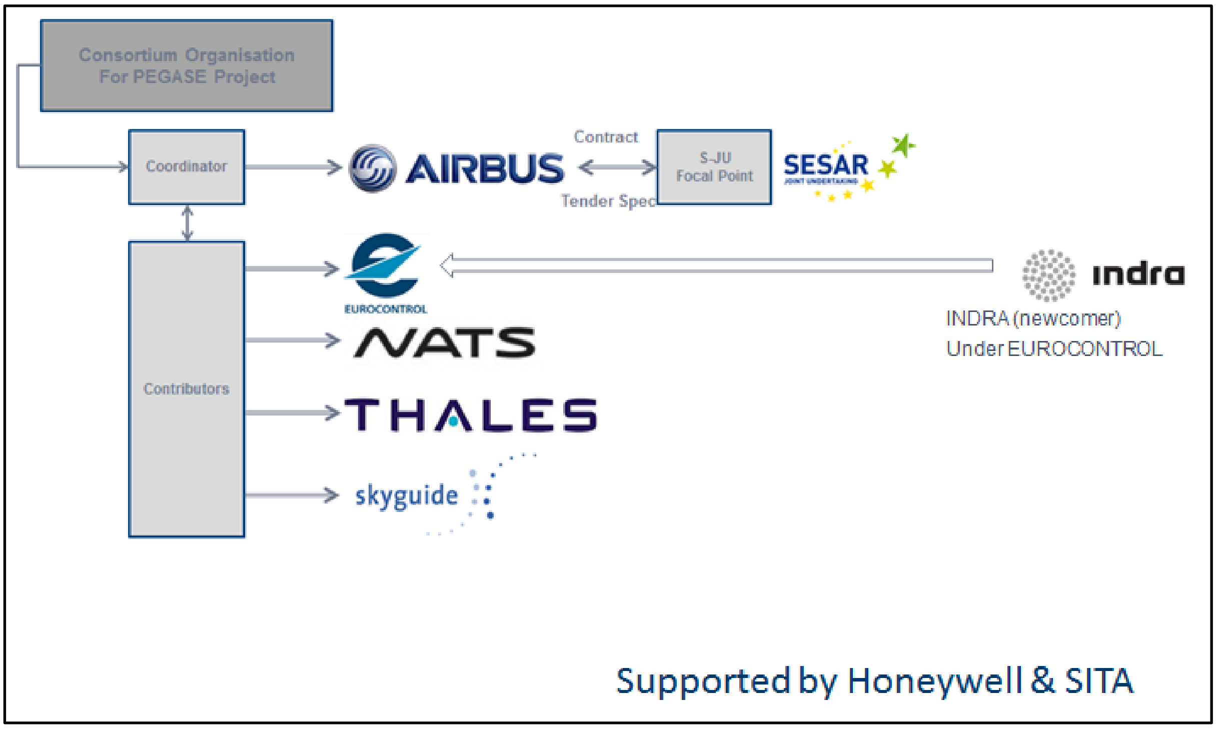


Figure 1 PEGASE consortium

Consortium Partner	Role and activities

Airbus	○ Project Coordinator
	○ Provide the flights to support the project:
	    ○ ferry flights between Hamburg and Toulouse equipped with the prototype equipment allowing transmitting the EPP data.
	    ○ flights, often on other routes, performed by development aircraft

	○ Provides the requested support coming from design office, laboratory and flight test.

EUROCONTROL	○ Project partner
	○ Provide Air Traffic Services when the ferry flights are under MUAC jurisdiction
	○ Through its ATC facility in Maastricht, modified in the scope of i4D validation exercises, it establishes ADS-C contract with the ferry flight in order to receive EPP.
	○ Records surveillance tracks, EPP and Trajectory Prediction data for each ferry flight flying in the MUAC airspace
	○ Through its datalink testbed facility located in the EUROCONTROL Experimental centre in Brétigny-Sur-Orge, it establishes a second ADS-C contract with the ferry flights. The EPP data is recorded and distributed in near-real time to the partners through web services (SWIM yellow profile).
	○ Supports the off-line data analysis of recorded data, on behalf of the other partners in the project
	○ Is supported by Indra (subcontractor), whose activities were:
	  ○ Design of high level algorithms for the EPP usage on ground BADA-based TPs
	  ○ Development of a BADA-based TP prototype following those algorithms
	  ○ Reproduction of EPP flights on the prototype, measuring the benefits on Trajectory Prediction, and defining recommendations for future usage in ground TPs
	  ○ In parallel, development of a MUAC TP prototype and tools where the downlinked mass can be injected, allowing MUAC to perform further analysis of EPP flights

NATS	○ Project partner ○ Provide Air Traffic Services when the ferry flights are under its jurisdiction. ○ Records surveillance tracks, ATC instructions, flight data updates, meteo data and EPP (received from EUROCONTROL for each ferry flight flying in the London Area Control airspace). ○ Provides recorded data to the PEGASE partners for off-line analysis. ○ Performs own off-line data analysis of recorded data and conducts workshops with controllers to assess impacts of using EPP data.
Skyguide	○ Project partner ○ Provide Air Traffic Services when the ferry flights are under its jurisdiction. ○ Records surveillance tracks, ATC instructions, flight data updates, weather data and EPP (received from EUROCONTROL) for each ferry flight flying in the Geneva and Zurich Area Control airspace. ○ Provides recorded data to EUROCONTROL for off-line analysis. ○ Performs own off-line data analysis of recorded data to assess impacts of using EPP data.
Thales	○ Project partner ○ Using its TopSky-ATC IBP located in its facility in Rungis, France, modified in the scope of i4D validation exercises with NORACON, fed by Thales radar and ADS-B ground stations, it

	establishes surveillance tracks and Trajectory Prediction data when ferry flights are flying in the airspace covered by those surveillances means, namely in the west of Paris, France. ○ Records surveillance tracks, in a second time and if available, EPP received from EUROCONTROL and possibly Trajectory Prediction data for each ferry flight flying in the airspace covered by Thales surveillance means. ○ Provides recorded data to EUROCONTROL for off-line analysis.

3.2 Work Breakdown Structure

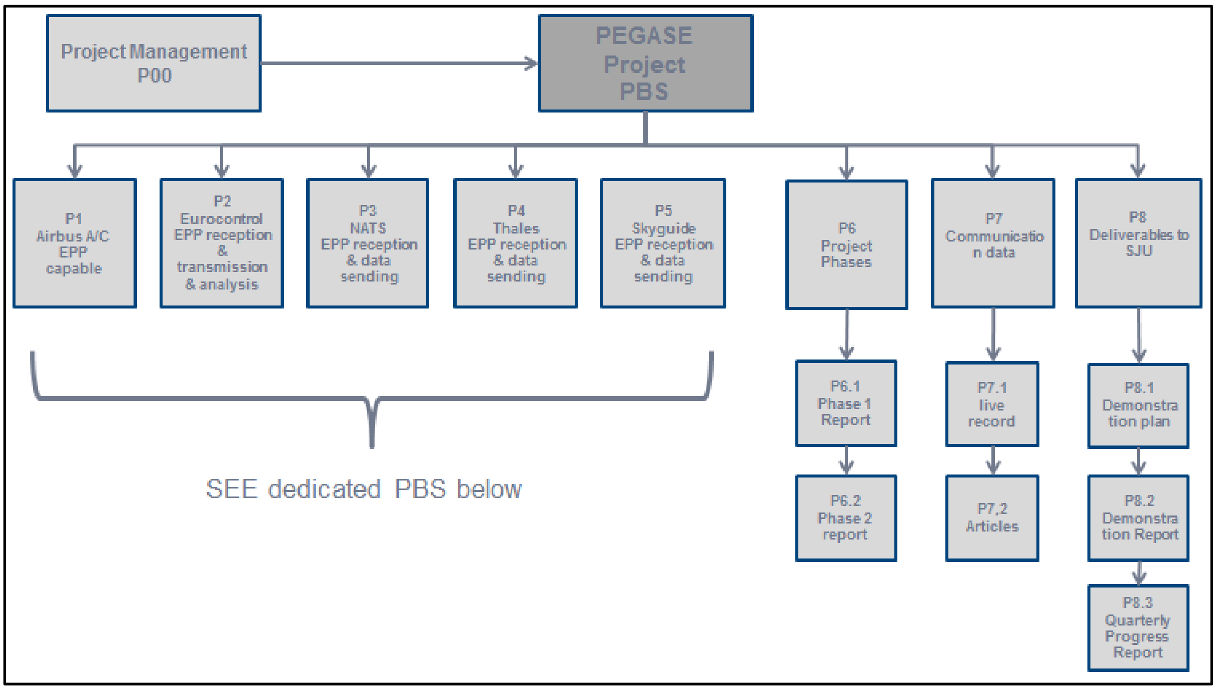


Figure 2 Work break down structure

3.3 Deliverables

Deliverable name	Date
Demonstration Plan (A1)	19/01/15
Demonstration Report (B1)	01/09/16 for review and 22/09/2016 official version

3.3.1 S-JU GATEs

Deliverable/Milestone name	Date
S-JU Gate 1	Face to Face for Demo Plan issue 03 and simulator session with S-JU the 04th of February 2015.
S-JU Gate 2	Face to Face for Demonstration Report the 22/09/2016

3.3.2 Quarterly reporting

Deadline
Quarterly report #1: 15/01/2015
quarterly report #2: 15/04/2015
quarterly report #3: 15/07/2015
quarterly report #4: 15/10/2015
quarterly report #5: 15/01/2016
quarterly report #6: 15/04/2016
quarterly report #7: 15/07/2016

3.4 Risk Management

All the risks have been closed because they didn't occur or because they have been successfully mitigated.

The list below shows all the risks during the project and their closure dates.

Risk ID: 5532
Issued from: LSD.01.04 Pegase
Creation Date: 08/01/2015
By: [redacted]
Domain: Development
Family: Lack of buy-in or ineffective collaboration of various stakeholders
Risk Type: Lack of involvement from end users (airspace, military, etc)
Risk Description:
Controllers in London Area Control or in the preceding ATC centre coordinate to provide the flight with a more expeditious route that does not enter the airspace of London Area Control.

Description of impacts:
EPP data not used over NATS area. No NATS recording data to feed the EUROCONTROL data base for EPP performance analysis

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 2
Likelihood: 1 - Low
Severity: 2 - Medium
Net criticality: 2
Target Net criticality: 2
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

Risk ID: 5533
Issued from: LSD.01.04 Pegase
Creation Date: 08/01/2015
By: [redacted]
Domain: Performance
Family: Performance/quality issues in development of activities/solutions
Risk Type: Lack of data allowing to achieve activities properly/interoperability
Risk Description:
During a flight we could face unexpected event due to prototypes usage during these flights test (i.e. communication lost) meaning that we could lost all or part of data.

Description of impacts:
Partial or total lack of data for a specific flight.

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 6
Likelihood: 2 - Medium
Severity: 3 - High
Net criticality: 6
Target Net criticality: 6
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

Risk ID: 5534
Issued from: LSD.01.04 Pegase
Creation Date: 08/01/2015
By: [redacted]
Domain: Other
Family: Other
Risk Type: Other
Risk Description:
Flight planning over specific areas as NATS or Skyguide could be modified at any time by Airbus EVR delivery centre because of EVR constraints or Weather constraint

Description of impacts:
Potetial impact of data rocording for analysis.

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 4
Likelihood: 2 - Medium
Severity: 2 - Medium
Net criticality: 4
Target Net criticality: 4
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

Risk ID:	5535	**Owner:**	LSD.01.04 Pegase
Issued from:	LSD.01.04 Pegase	**Risk Status:**	Closed
Creation Date:	08/01/2015	**(Gross) criticality:**	4 — Likelihood: 2 - Medium; Severity: 2 - Medium
By:	[redacted]	**Net criticality:**	4
Domain:	Performance	Target Net criticality:	4
Family:	Performance/quality issues in development of activities/solutions	**Actions completion rate:**	0%
Risk Type:	Lack of data allowing to achieve activities properly/interoperability	**Nbr Actions:**	0
Risk Description:	Integration risk: the demonstration encompasses many different systems and communications paths amongst them (A/C to Ground, Ground to ground). Careful coordination and integration is required.	Nbr Actions Open:	0
		Nbr Actions In Progress:	0
Description of impacts:	Potetial lost/lack of data froom a dedicated flight.	Nbr Actions Completed:	0
		Target:	LSD.01.04 Pegase

Risk ID:	5536	**Owner:**	LSD.01.04 Pegase
Issued from:	LSD.01.04 Pegase	**Risk Status:**	Closed
Creation Date:	08/01/2015	**(Gross) criticality:**	2 — Likelihood: 2 - Medium; Severity: 1 - Low
By:	[redacted]	**Net criticality:**	2
Domain:	Performance	Target Net criticality:	2
Family:	Performance/quality issues in development of activities/solutions	**Actions completion rate:**	0%
Risk Type:	Required input not delivered by project(s) at the expected quality level	**Nbr Actions:**	0
Risk Description:	Lack of visibility on operational tactical clearances for platforms not connected to the ATC centres in charge of operational control of the flight may have an impact on the accuracy of the Trajectory Predictor	Nbr Actions Open:	0
		Nbr Actions In Progress:	0
Description of impacts:	Data partially correct for analysis	Nbr Actions Completed:	0
		Target:	LSD.01.04 Pegase

Risk ID:	5537	**Owner:**	LSD.01.04 Pegase
Issued from:	LSD.01.04 Pegase	**Risk Status:**	Closed
Creation Date:	08/01/2015	**(Gross) criticality:**	2 — Likelihood: 1 - Low; Severity: 2 - Medium
By:	[redacted]	**Net criticality:**	2
Domain:	Other	Target Net criticality:	2
Family:	Lack of buy-in or ineffective collaboration of various stakeholders	**Actions completion rate:**	0%
Risk Type:	Lack of involvement of different partners	**Nbr Actions:**	0
Risk Description:	Resource availability: the project makes an intensive use of quite specific resources both in term of personnel and equipment.	Nbr Actions Open:	0
		Nbr Actions In Progress:	0
Description of impacts:	data partially available or analysed	Nbr Actions Completed:	0
		Target:	LSD.01.04 Pegase

Risk ID: 5538
Issued from: LSD.01.04 Pegase
Creation Date: 08/01/2015
By: [redacted]
Domain: Development
Family: Planning issues causing delays
Risk Type: Input/output not delivered on time
Risk Description:
Aircraft equipment not delivered on time

Description of impacts:
Delays on ferry flights start

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 12
Likelihood: 3 - High
Severity: 4 - Very High
Net criticality: 12
Target Net criticality: 12
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

Risk ID: 5603
Issued from: LSD.01.04 Pegase
Creation Date: 03/02/2015
By: [redacted]
Domain: Performance
Family: Other
Risk Type: Other
Risk Description:
Data Link communication loss in high density. Not a PEGASE issue but colateral impact due to datalink communication need.

Description of impacts:
Loss of datalink need (if possible) a reconnection.The impact is the loss of EPP data.

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 6
Likelihood: 3 - High
Severity: 2 - Medium
Net criticality: 6
Target Net criticality: 6
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

Risk ID: 5749
Issued from: LSD.01.04 Pegase
Creation Date: 08/07/2015
By: [redacted]
Domain: Other
Family: Other
Risk Type: Other
Risk Description:
A/C computer modification (Hard & Soft) to cope with multiple A/C configuration versus single PEGASE prototypes

Description of impacts:
If no modification, a lot of A/C can't be targetted. The delays associated with these modifications will impact the restart of PEGASE flights.

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 1
Likelihood: 1 - Low
Severity: 1 - Low
Net criticality: 1
Target Net criticality: 1
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

Risk ID: 5805
Issued from: LSD.01.04 Pegase
Creation Date: 09/10/2015
By: [redacted]
Domain: Performance
Family: Other
Risk Type: Other
Risk Description:
After one FMS damaged, delay to expertise and repair could reduce the number of possible flight form FM HWL with CFM engines.

Description of impacts:
A maximun of 43 flights could be cancelled.

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 6
Likelihood: 2 - Medium
Severity: 3 - High
Net criticality: 6
Target Net criticality: 6
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

Risk ID: 5841
Issued from: LSD.01.04 Pegase
Creation Date: 12/01/2016
By: [redacted]
Domain: Performance
Family: Performance/quality issues in development of activities/solutions
Risk Type: Lack of data allowing to achieve activities properly/interoperability
Risk Description:
Production aircrafts for PEGASE flights imply more constraints than expected. Several flight cancellation could impact the 50 flights request. New logistics process has been put in place with rapid positive impact on number of flight performed.

Description of impacts:
50 flights could not be achieved.

Owner: LSD.01.04 Pegase
Risk Status: Closed
(Gross) criticality: 6
Likelihood: 3 - High
Severity: 2 - Medium
Net criticality: 6
Target Net criticality: 6
Actions completion rate: 0%
Nbr Actions: 0
Nbr Actions Open: 0
Nbr Actions In Progress: 0
Nbr Actions Completed: 0
Target: LSD.01.04 Pegase

4 Execution of Demonstration Exercises

In the PEGASE project there is only one phase. However it falls into two major activities:

- Preparation of the exercise
- Execution of the exercise

Preparation of the exercise was set in order to prepare and validate all the hardware and software used during the project. The preparation exercise is described below. The objective of the preparation exercise was to determine if the systems were ready for the live flights. There were no results associated with this exercised produced.

Execution of the exercises involved many flights with numerous stakeholders. This part will be detailed around objectives associated with and results that are yet to be completed.

The demonstration results focus on the objectives associated with the Execution exercise.

4.1 Exercises Preparation

Exercise ID	Exercise Title	Actual Exercise execution start date	Actual Exercise execution end date	Actual Exercise start analysis date	Actual Exercise end date
EXE-01.06-D-001	Simulator session	21/11/14	01/04/15	21/11/14	01/04/15

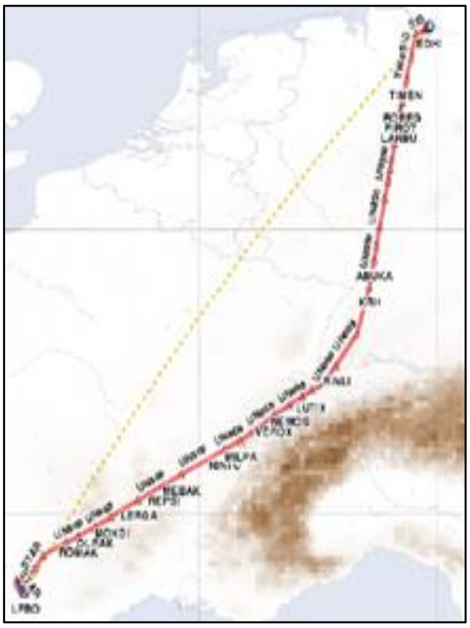
Table of simulator sessions:

Date	*Ground Facility*	*Nature of test*	*Route*	*EEC*	*MUAC*	*NATS*	*kyguide*	*Thales*
19-11-2014	*EEC*	*Interoperability*	*central*	☐				
21-11-2014	*MUAC*	*Interoperability*	*central*		☐			
21-11-2014	*2 x EEC*	*Interoperability*	*central*	☐☐				
26-11-2014	*MUAC*	*Interoperability*	*central*		☐			
28-11-2014	*EEC + MUAC*	*EPP content*	*central*	☐	☐			
15-12-2014	*EEC*	*Online distribution, FMS1*	*west*	☐				☐
16-12-2014	*MUAC*	*MUAC automation*	*central*		☐			☐
08-01-2015	*EEC + MUAC*	*MUAC automation*	*central*	☐	☐			☐

15-01-2015	*EEC + MUAC*	*MUAC – Abort robustness*	*south*	☐	☐		☐	☐
22-01-2015	*EEC + MUAC*	*EPP content*	*south*	☐	☐	☐	☐	☐
03-02-2015	*EEC + MUAC*	*Rehearsal*	*central*	☐	☐	☐	☐	☐
05-02-2015	*EEC + MUAC*	*Presentation to SJU*	*central*	☐	☐	☐	☐	☐
12-02-2015	*EEC + MUAC*	*Anomaly correction + FMS1*	*west*	☐	☐	☐	☐	☐
05-03-2015	*EEC + MUAC*	*DCDU dependence, resilience during contract creation.*	*west*	☐	☐	☐	☐	☐
12-03-2015	*EEC + MUAC*	*Provider abort resilience*	*west*	☐	☐	☐	☐	☐
01-04-2015	*EEC + MUAC*	*EEC automation*	*south*	☐	☐	☐	☐	☐

Table 1 Simulator sessions

Routes:



East route 53

West route 51


Centre route 52

Figure 3 Routes

4.2 Exercises Execution

Only one phase is considered covering several "identical" flights.

The project execution is share between execution, results, conclusion & recommendation described in §6.1

4.2.1 A/C equipment configuration

Airbus has used during this project a set of specific equipment:

2 ATSUs

8 FMGCs [2 FMGCs per A/C; 2FM suppliers Honeywell & Thales, each adapted for each of the 2 engines suppliers (CFM & IAE)]. (FM are specific to engine types as regards their Performance data bases).

These prototypes have been developed in order to support EPP sending to ground.

These prototypes, used during PEGASE project, have known limitations that for some of them are already corrected and are planned to be removed in the next production standard for the other.

4.2.1.1 ATSU prototype limitations

- After start, if several ADS-C contract requests are received in a short time from different ground centers, the system only answers to the first request. After a new manual Notification, the system can answer to a new contract request. Another occurrence of this anomaly with an ADS-C freeze has been also observed
- An offset between negative lat/long values sent to the ground and corresponding lat/long values sent by the FMS is observed. The offset is known and false values can be corrected with a simple rule.
- In ADS-C application LAT and LONG between -1° and 0° are considered invalid
- Randomly, the ADS-C application stops and no contract acknowledgment or report is sent
- Occurrence of no answer to ADS-C contract requests were observed after an ATN Loss
- The name of WPT or runway is limited to 5 characters in the ASN1 whereas it is possible to have a 7 characters name in the FMS. If the parameter is longer than 5 characters it will be sent truncated to the ground.
- Some flight plan modifications ADS-C event reports are not sent on ground due to a latency in the recalculation of predicted data from the FMS (frames that should generate an event and that contains an invalid EPP Group due to the FMS recalculation latency do not lead to the sending of an event report)
- No ADS-C reports are sent if a waypoint is inserted between PPOS and TO waypoint
- ADS-C can freeze if a D-Abort is received too quickly after the sending of the first report in response to a periodic contract request from the ground

4.2.1.2 FMS prototype limitations

4.2.1.2.1 FMS 1

- Altitude constraints
  - The AT OR BELOW altitude constraint is not implemented

4.2.1.2.2 FMS 2

- With one FMS: in Trajectory Intent Status, the attribute "vertical managed" is false when in Open Climb mode ("true" instead of "false")
- The speed changes position is provided in EPP contracts with the tactical assumption. In case of selected mode (vertical or lateral) this could lead to a discontinuity in the vertical or lateral trajectory

4.2.1.2.3 Both FMS

- The AT OR BELOW altitude and window constraint are not implemented
- Time constraints:
  - A time constraint has a tolerance parameter (+/-10s or +/-30s). This one does not appear
  - EPP report contains only the lower bound of the constraint
  - impossible to determine the type of time constraint (at, at or before, at or after)
  - In case of "at or after" the value is spurious
- The EPP report contains only one SPEED CHANGE and for current phase only
- Manual legs are not implemented and cause:
  - Spurious pseudo in case of clearance level off
  - Spurious speed change after a hold

4.3 Deviations from the planned activities

4.3.1 Airbus deviation

4.3.1.1 Scheduling

The deviations from the planned activities are only associated with Airbus flight scheduling:

- First flight date
- Ferry flight planning

The issues that the PEGASE project faced are:

- Numerous A320 under delivery were not FANS equipped. Initially this was found to prevent EPP transmission. This problem was not evident in test sessions as it relates to the aircraft wiring. This necessitated PEGASE equipment modifications, which took some time to effect because the equipment had to be returned to the supplier for ad hoc modifications.
  - 2 ATSU needed to be adapted to allow EPP transmission in non FANS aircraft.
  - 8 Specific FMGCS were acquired then modified for non FANS aircraft.
- Logistic processes between the Toulouse and Hamburg site were not used to handling prototype equipment. Some adaptation in the Airbus process was needed to handle 'non production' (i.e. experimental) equipment.
- Hamburg flight preparation process required the PEGASE prototypes at least the day before the flight. This reduced the number of flights that could be achieved. Similarly, when the prototypes arrive in Toulouse, the process to extract them and return them to Hamburg takes another whole day. These delays had not been included in the original planning.
- The PEGASE initial plan was to buy standard FMS (standard hardware in particularas for the two ATSU, and use these. However the i4D software configuration needed by PEGASE is only available for the FMS that were currently being made in February 2012 when the software was developed. Since then the FMS hardware has evolved, both the Chassis of the FMS, and the FMS processor from Honeywell. i4D compatible FMS were no longer available for sale. Old FMS needed to be obtained, by borrowing spares from development aircraft, and similar.
- As mentioned above, A320 exist with two possible engine configurations and two possible FMS configurations. Initially PEGASE planned to have one pair of each FMS type. However the FMS sits in a chassis with a dedicated Flight Guidance board which is specific to the engine type of the aircraft, hence the number of FMGC (the chassis) needed is four pairs. The PEGASE project has slowly increased the number of available FMGC prototypes over 2015, from two pairs to four pairs, as shown in the schedule below.
- One FMGC was damaged during handling, reducing the number of available FMS/Engine combinations to three. One pair of the remaining FMS was reconfigured so as to cover the most common combinations expected in the next few months while the damaged unit is repaired.
- Another FMGC had a failure reducing the number of available FMS/Engine combinations to three. An additional FMGC has been loan by Airbus "Mise Au Point" to cover the reparation time. These issues had repercussion on targeted flight
- Very few flights could be held over NATS area mainly due Airbus ferry flights delivery time constraints

4.3.1.2 Flight plan

We have noticed that during ferry flight we could have some A/C checks (ex. A/C performance checks necessitating ad hoc specific combinations of altitude and speed or Mach) during the flight in accordance with Airbus delivery needs.

Some of these checks impacted the EPP behaviour it's the reason why we have had the opportunity to have specific flights that support us to follow closely the flight plan provided.

Note: NATS have been able to minimize the ground ATC instructions when PEGASE flights were performed over NATS area.

4.3.2 EUROCONTROL changes to execution process:

- New automatic tools have been developed to manage the late departure flight in order to be able to records EPP data, after the EEC closure at 20h00.
- Technique of “forcing” log-on by the ground has been put in place to cover lack of voice communication between PEGASE team and flight crew.
- Finally, Indra joined the Demonstration not as a Consortium partner, but as an associated partner to EUROCONTROL. Indra activities (as described in section 6.2.3) are to be considered a (positive) deviation compared to the PEGASE Demonstration Plan..

4.3.3 NATS changes to demonstration plan:

- NATS could not upgrade of the training facility datalink front end processor (D/L FEP) which would have allowed NATS to receive EPP data directly from the aircraft. This was due to the equipment supplier and integration costs being in excess of initial estimates made at the time of bidding. The EPP data remained available to NATS via the ground distribution service provided by EUROCONTROL.

5 Exercises Results

This section briefly summarises the results presented in section **Error! Reference source not found.** and highlights the operational benefits of the results

5.1 Summary of exercise results by theme

This section briefly summarises the results presented in section **Error! Reference source not found.** and highlights the operational benefits of the results

5.1.1 Data collection

PEGASE aimed to collect a significant amount of ADS-C and supporting data. This was expressed in several objectives of the project, see **Error! Reference source not found.**. The aim was achieved, as described in detail in sections 6.4.1, **Error! Reference source not found.** and 6.4.3. The benefits of collecting a significant amount of data are that the results in this document are presented with more confidence than would have otherwise been possible, and that this data remains available to provide further insight to researchers.

Descriptions of and statistics about the data distribution can be found in sections **Error! Reference source not found.** and 6.4.6.2.2 as well as parts of section 6.2.

5.1.2 EPP in Vertical Prediction

The EPP contains predicted positions, altitudes, speeds and times over. The predicted vertical path is of interest in climb and descent.

Early PEGASE flights suffered from problems of lost connections in climb, hence it became standard practice to only establish the ADS-C connection part-way-through or after the climb, For this reason PEGASE produced more data for descent than climb, thus descent was more studied.

Some climbs were captured and many showed the effects of controller instructions to level off, a relatively common instruction in the area where the PEGASE flights passed. See for example Figure 81. This is an "unknown intent" problem similar to that mentioned above, for which the aircraft cannot predict.

There was a related problem with the RFL; section **Error! Reference source not found.** presents two possible crew behaviours when the aircraft is prevented from climbing to its requested flight level. At their discretion they can enter the current level as the cruise level or leave the level which was planned.

The EPP includes a predicted Top-of-descent point, the stability of the prediction of which is studied in section 6.4.7.1.6. As section 6.4.7.2.1.1 explains, the aircraft usually descends before this top-of-descent point, but still it is an interesting piece of information which the PEGASE team believe should be shown to the controller.

Descents of PEGASE flights were studied in detail in section 6.4.7.2.1 in support of ground TP improvement.

5.1.3 EPP in Lateral Prediction

The EPP contains predicted positions, altitudes, speeds and times over. The predicted horizontal track was compared with:

- Later predictions for the same flight.

- Later aircraft position reports, either ADS-B or position reports within the ADS-C for the same flight
- Radar reports.

Horizontal track accuracy is discussed in sections 6.4.7.1, especially 6.4.7.1.2 and 6.4.7.1.3.

The most important lesson was that the accuracy of the predictions depends on the intent (plan) on which the prediction was made being followed. Section 6.4.7.1.4 studies the effect of "direct" segments. *Instances where the ATCO instructs a flight to fly direct are fairly common today in the region where the PEGASE flights occurred*.

The ADS-C data also indicates the current modes of flight management, and in PEGASE these were cross checked with data from the aircraft in section 6.4.7.1.8.2. The observable effect of modes are discussed in section 6.4.7.1.1.

A frequent "intent change" was the insertion of the STAR into the aircraft's plan, which usually happened shortly after the flight entered French airspace. Typically before STAR insertion the aircraft's plan went to the boundary point of the TMA and then directly to the runway. Adding the STAR would usually lengthen the path by several minutes, Very often near Toulouse the aircraft would be given a shortcut and these extra minutes would not be flown.

5.1.4 EPP in Temporal Prediction

The EPP contains predicted positions, altitudes, speeds and times over. The predicted time over points was studied for three cases.

- For flight dependent points like "Top of Descent"
- For published points that were eventually overflown by the flight
- For published points that were eventually flown past

As far as the aircraft is concerned, a published point is overflown if the aircraft comes within 7 nautical miles of it. *Ground systems may use other parameters*. In each case the time over is taken at the closest point of approach.

An analysis of the prediction of time over flight dependent points is presented in 6.4.7.1.8.4.

Time over or abeam published points is analysed in sections 6.4.7.1.5 and 6.4.7.3.4. In section 6.4.7.3.2 the EPP time over predictions are shown to be better than those coming from current EFD.

The main conclusions again relate to intent changes with directs and other ATCO instructions causing the plan on which the EPP prediction is based not to be followed.

5.1.5 EPP in Ground Trajectory Prediction

Ground TP (trajectory prediction) was compared with EPP in sections 6.4.7.2 and 6.4.7.3. Sections 6.4.7.2.1, 6.4.7.3.1 and 6.4.7.3.3 propose improvements to Ground TP by incorporating information from EPP.

Sections 6.4.7.3.1.2, 6.4.7.3.3.4.1, and 1536.4.7.2.1.7 show improvements in ground TP climb prediction performance by incorporating ADS-C mass and speed schedule information.

Section 6.4.7.2.1.5 shows experimental results that demonstrate improvements in ground TP descent prediction by incorporating EPP data.

Section 6.4.7.3.4 compares the performance of an existing ground TP with the EPP in regard to predicting time over published points. It raises some questions about the weather information loaded into the FMS used in PEGASE flights, as the errors seen in some EPP decrease linearly.

5.2 Summary of Exercises Results

Exercise ID	Demonstration Objective Tittle	Demonstration Objective ID	Success Criterion	Exercise Results	Demonstration Objective Status
OBJ-0106-001	Assess performance characteristics of EPP data provided live by real flights through high density continental airspace	§ 6.4	For more than 60% of the ferry flights, EPP data is collected that can be compared with the ground systems predictions.	76%	OK
… **OBJ-0106-002**	… Measure end to end performance of the Ground/Ground and Air/Ground communication channels.	§ 6.4.6.2	… Statistically significant set of data indicating end to end operational response time.	Ground/ground transmission time is and failure rate are TBC Air ground communication transmission time is and failure rate are TBC	OK
OBJ-0106-003	Provide recommendation about EPP contract types and contents	§6.4.8.1	Provide recommendation with supporting rationales	See §6.4.8	OK

Exercise ID	Demonstration Objective Tittle	Demonstration Objective ID	Success Criterion	Exercise Results	Demonstration Objective Status
OBJ-0106-004	Demonstrate operational useful ground TP improvement using EPP data	§ 6.4.8.2	Produce evidence based on practical cases of TP benefits brought by using EPP data elements.	See § **Error! Reference source not found.**	OK
OBJ-0106-005	Collect consistent flight data	§ 6.4.2	For 60% of the ferry flights, consistent set of data has been collected including ADS-C exchanges, track data, flight plan data, NM data and operational inputs	Above 60%	OK
OBJ-0106-006	Establish ADS-C contracts	§ 6.4.3	For more than 60% of the ferry flights, ADS-C contracts can be established from at least one ground station for more than 50% of the flight duration	79%	OK

Exercise ID	Demonstration Objective Tittle	Demonstration Objective ID	Success Criterion	Exercise Results	Demonstration Objective Status
OBJ-0106-007	EPP ground distribution	§ 6.4.6.2.2	More than 80% of the ADS-C messages received by the EEC ground ATSU are correctly distributed to the connected parties.	More than 96.2%	OK

Table 2: Summary of Demonstration Exercises Results

5.3 Choice of metrics and indicators

OBJ-0106-001	Capacity (predictability)	Improve the A/C position prediction for the ToC .	With EPP the prediction is in the range of 12Nm see § 6.4.7.1.8.4.2 (c)
	Capacity (predictability)	<u>Reduction of uncertainty in RoC and RoD.</u>	*6.4.7.3.1– see NATS TP analysis.*

Table 3: Summary of metrics and indicators

5.4 Summary of Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment
	Number of flights									
	A/C able to follow the Flight plan		A/C checks							
	ANSP able to avoid vectoring and dir to									
	Prototype limitation									
	Provider abort									
	Schedule									

Table 3: Demonstration Assumptions

5.4.1 Results per KPA

Exercise	Object identifier	Success criterion	Result of demonstration
PEGASE	OBJ-0106-001	Capacity (predictability)	With EPP the prediction at the ToC is in the range of 12Nm see § 6.4.7.1.8.4.2 (c)

5.4.2 Impact on Safety, Capacity and Human Factors

These items were not assessed during the project

5.4.3 Description of assessment methodology

Not applicable

5.4.4 Results impacting regulation and standardisation initiatives

Regulation was not impacted during the project.

Standardisation for EPP: The data structure of the EPP was amended in ATN baseline 2 rev A to incorporate a flag indicating a discontinuity as a result of PEGASE experience.

5.5 Analysis of Exercises Results

Not applicable

Exercise ID	Objective ID	Scenario ID	Scenario Title	KPI ID	Measure Value

Table 4: Performance Indicators

5.5.1 Unexpected Behaviours/Results

Refer to § 4.3

5.6 Confidence in Results of Demonstration Exercises

5.6.1 Quality of Demonstration Exercises Results

See § 4.3.1.2

5.6.2 Significance of Demonstration Exercises Results

The target of number of flight has been exceeded (50 targeted and 59 performed) and so the initial assumption about significance has been met.

The consortium assessed that the number of flights has been sufficient to perform all the analysis except:

- Regarding the number of flights over the NATS area (see § 4.3.1.1). The flights planned over NATS have been rerouted to the centre or east route.
- The climb phase impacted by transmission losses.

5.6.3 Conclusions and recommendations

Refer to §8.1 and §8.2

6 Demonstration Exercises reports

6.1 Introduction

The scope of the exercise is explained below followed by a description of the preparation, then the execution, results and finally recommendation. The objectives are covered in the respective sections:

Execution

- OBJ 0106-005 Collect consistent flight data
- OBJ 0106-006 Establish ADS-C contracts
- OBJ 0106-007 EPP ground distribution

Results

- OBJ 0106-001 Assess performance characteristics of EPP data provided live by real flights through high density continental airspace
- OBJ 0106-002 Measure end to end performance of the Ground/Ground and Air/Ground communication channels.
- OBJ 0106-004 Demonstrate operational useful ground TP improvement using EPP data

Recommendation:

- OBJ 0106-003 Provide recommendation about EPP contract types and contents

6.2 Exercise Scope

The following diagram shows the overall exercise topology. Descriptions of the parts follow.

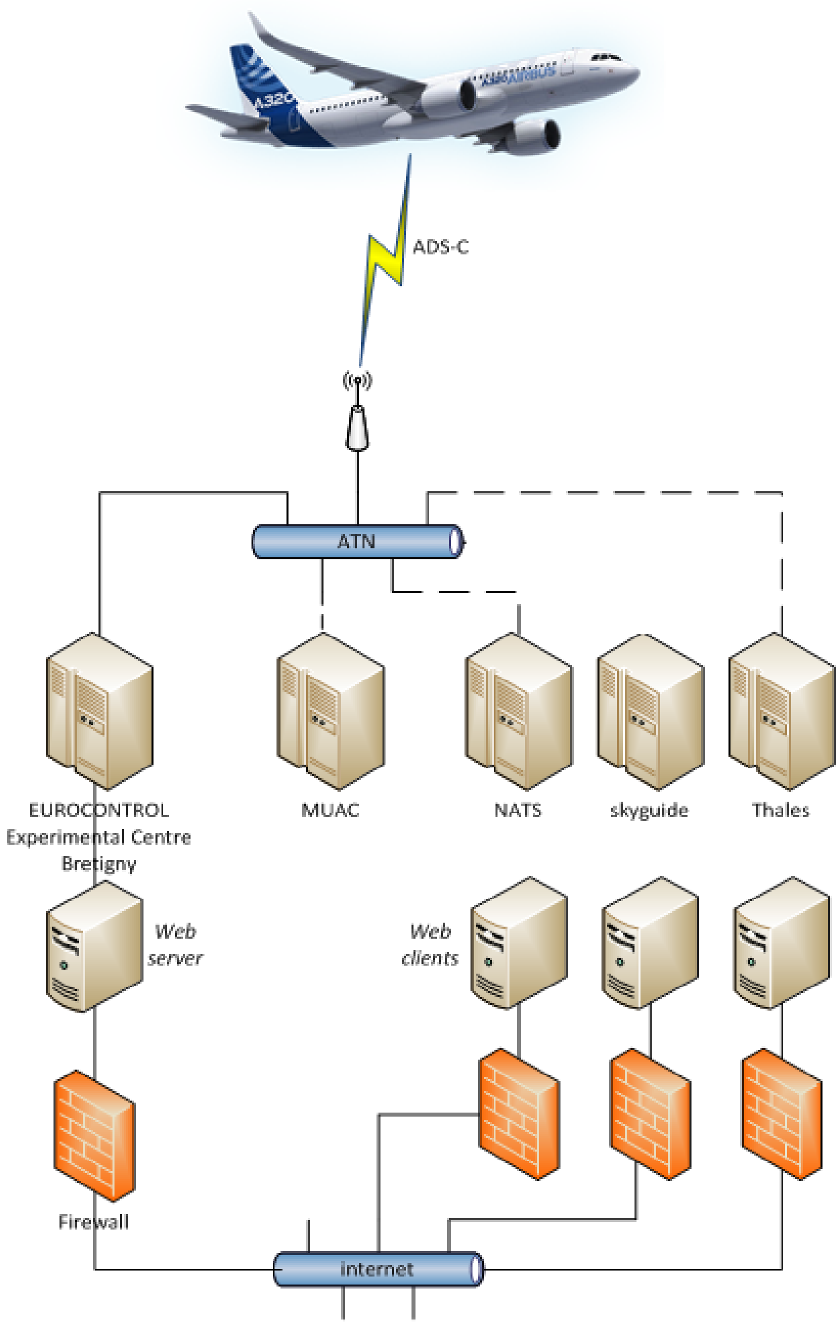


Figure 4 PEGASE topology

6.2.1 Airbus Contribution

Tool / equipment description:

Airbus used the following facilities and systems for the project:

- The Test benches for simulation preparation
- The SA integration simulator in order to demonstrate the dry run with EUROCONTROL and all the end user to secure the Flights
- FMS and ATSU prototypes modified for EPP capability.

- The ATM Functional Integration Bench for Real Time Simulation and based on real aircraft prototypes, located on the ground with representative flight dynamic simulation and capacities.
- ATM FIB (dedicated to Single Aisle AIRBUS program).

Objectives:

- Systems and functional validation and integration, based on real system components;
- Global system integration at aircraft level of real component of various aircraft systems to alleviate the need for validation on test aircraft on ground and in flight, to perform aircraft tests in operational conditions and to participate in the certification and qualification process;
- Optimization of live trials campaign and use of integration simulators;
- Contribution to the reduction of development cycles and costs, and
- Increase in the maturity of the systems for the Entry Into Service.

The ATM FIB is available for prototypes testing and flight trial preparation. ATM FIB was also used to assess concepts, prepare & validate flight trials exercises with other partners.

The ATM FIB is not only representative of an aircraft behaviour but it allows also to go further in the validation by providing capacities to test systems and functions in degraded situations and environment (that could not be done in real aircraft operations).

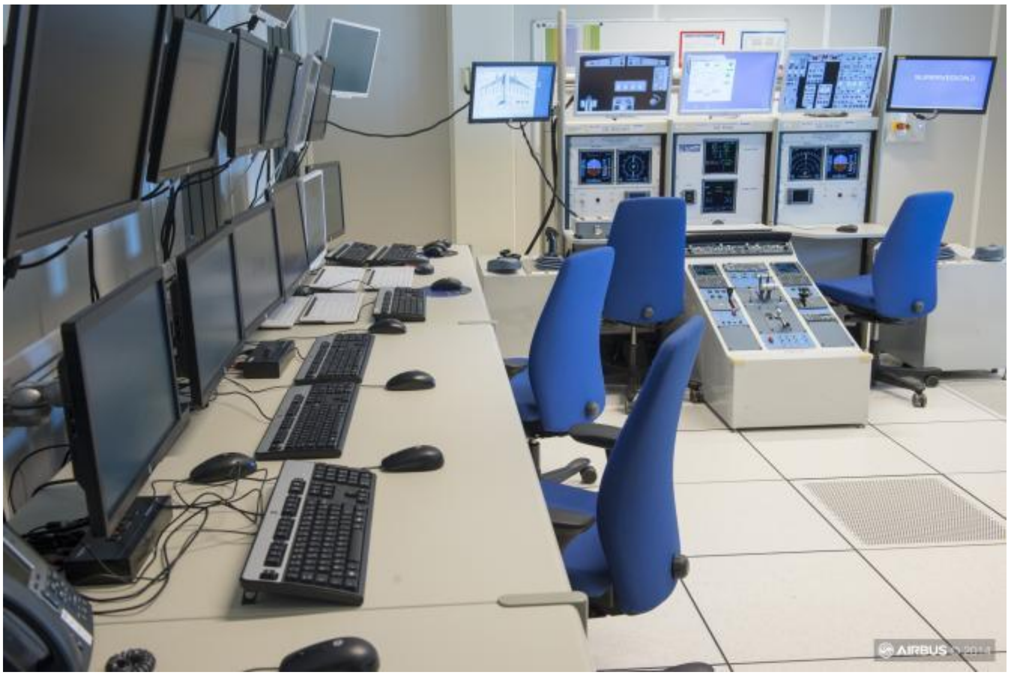


Figure 5 Airbus ATM FIB

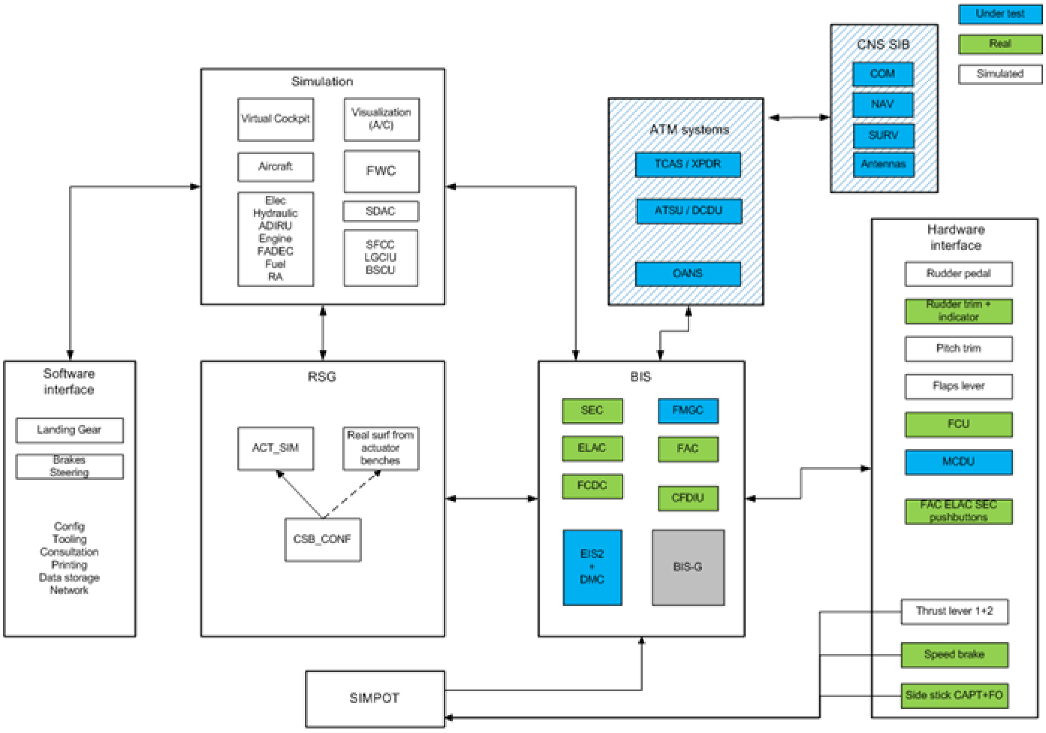


Figure 6 Airbus ATM FIB Architecture

6.2.2 EUROCONTROL Contribution

6.2.2.1 EEC

6.2.2.1.1 Test Tools and End Systems involved

The validation activities at EEC make use of automated CM/ADS-C applications (Airtel ATN applications) Test Tools. In automated mode CM and ADS-C test tools are able to automatically setup pre-configured ADS-C event and periodic contracts after successful CM Logon process from an aircraft.

The tools are hosted on the experimental BIS/ES ATN systems (Airtel ATN stack Lower Layers and Upper Layers architecture). A CPDLC manual test tool is also hosted on the BIS/ES and it could be used during the validation and flights trials phases.

The Test Tools implement the versions of the CM, CPDLC and ADS-C applications shown in the table below.

Application	Version
CM	Version 1 (ICAO Doc 9880)
ADS-C	SC214/WG78 INTEROP Version H (03Feb10) + PDRs (as defined in ASN.1 file ADSasn1_STD3_v2.asn)
CPDLC	SC214/WG78 INTEROP Version H (03Feb10) + PDRs (as defined in ASN.1 file CpdlcPDUsasn1_8_3_dtaxi_stepC.asn)

Table 5 EEC datalink tool configuration for PEGASE

Airtel BIS/ES systems are based on PC Linux architecture. Integrated LAN cards are used either in conjunction with the Linux IP stack to allow ATN communication via IP-SNDCF, or for use of LAN-SNDCF. The architecture of the tools is described in the picture below.

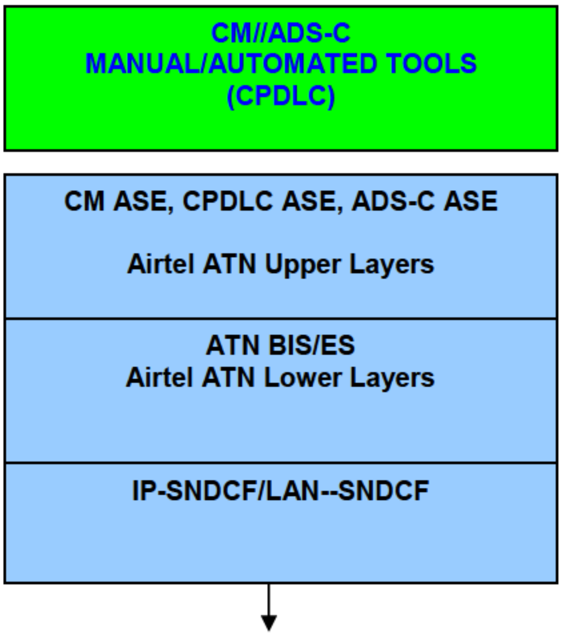


Figure 7 EEC datalink architecture for PEGASE

6.2.2.1.2 Network architecture

Two different datalink chains are setup at EEC as represented in the diagram below.

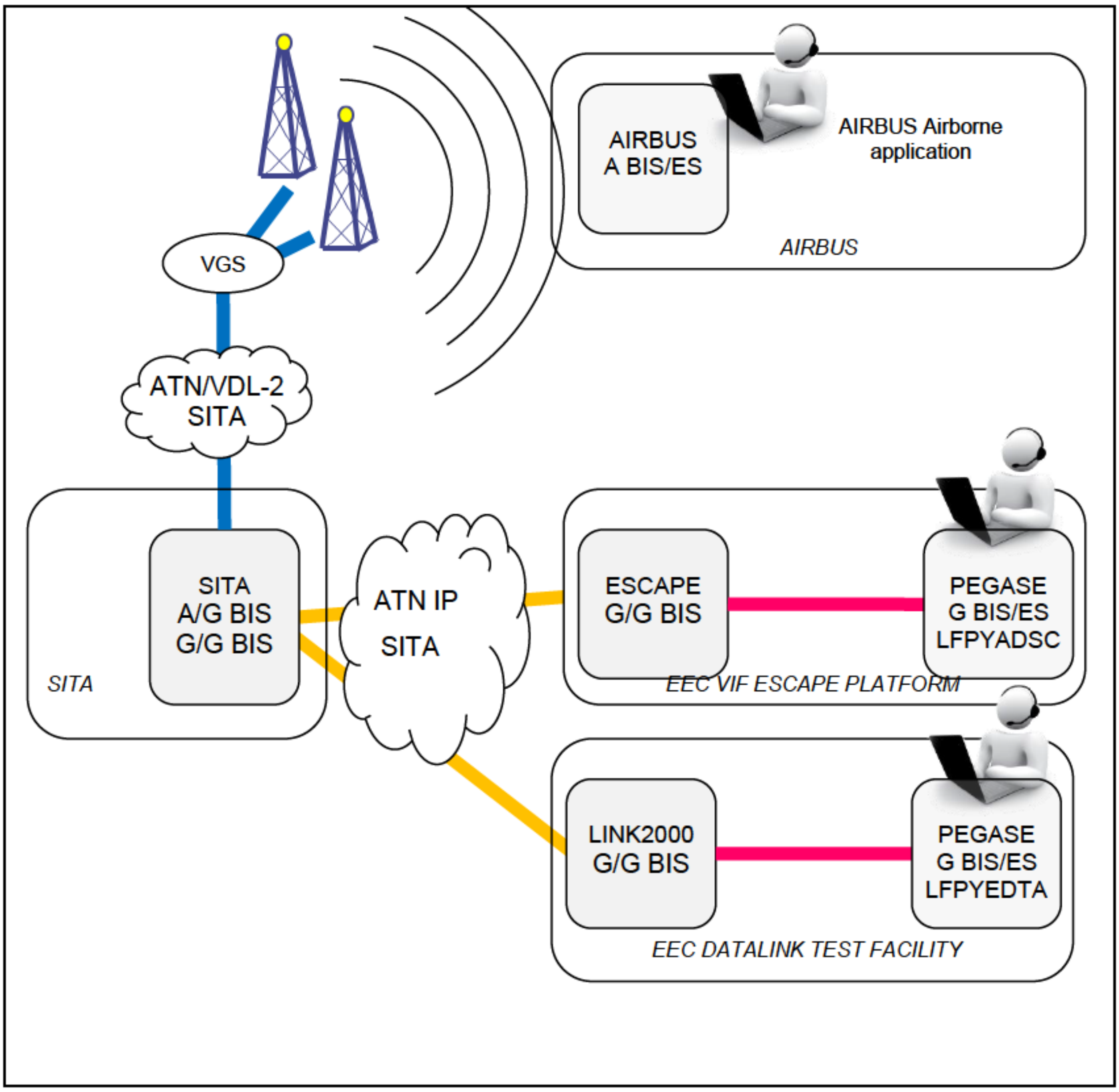


Figure 8 EEC overall datalink configuration

- One chain is installed on the Datalink Test Facility, the Ground Facility Designator associated to the ATN End System (ES) is LFPYEDTA. The intent is to use this ES mainly during the validation phase as a potential backup during the flight trials phase.
- One chain is installed on the VIF ESCAPE platform, the Ground Facility Designator associated to the ATN ES is LFPYADSC. This ATN ES was used during PEGASE execution and was connected to the online distribution.

The LINK2000+ ATN Ground/Ground BIS is connected through:

- the SITA IP network to SITA Ground/Ground BIS
- the Datalink Test Facility Ethernet/IP network to the ATN ES LFPYEDTA

The EEC ESCAPE ATN Ground/Ground BIS is connected through:

- the SITA IP network to SITA Ground/Ground BIS
- the VIF Escape Platform Ethernet network to the ATN ES LFPYADSC

The second datalink chain connected to the online distribution is depicted in the diagram below.

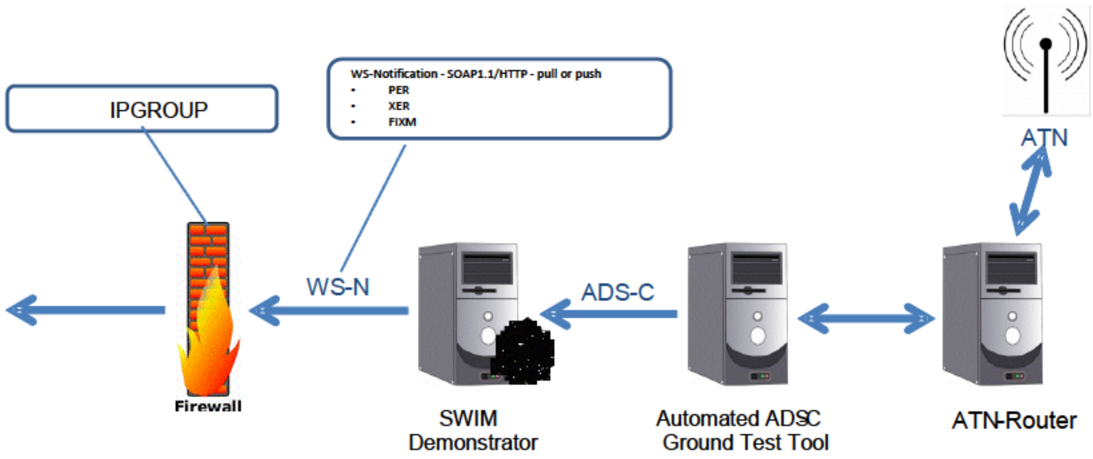


Figure 9 EEC EPP redistribution chain

6.2.2.2 MUAC

Demonstration Ferry Flight Configuration

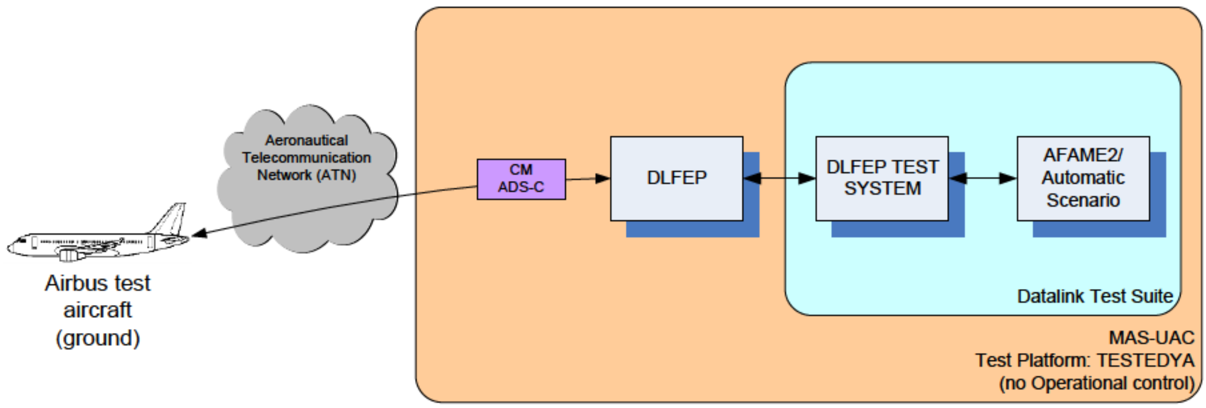


Figure 10 MUAC configuration for PEGASE

Same default scenario ran for each aircraft, including:

- CMLogon Request Processing
- Predefined scenario for ADS-C contract establishment, and ADS-C report processing (event, periodic)
- Optionally, non-operational, CPDLC messages

The scenario can be controlled per individual aircraft during the run-time (ADS-C demand contract)

ADS-C data recorded at DLFEP level and at AFAME2 (MUAC test tool) level.

6.2.3 Indra Contribution

The participation of Indra is twofold:

- First, through the development and provision of a NFDPS TP prototype to MUAC allowing the injection of actual mass information, for their own EPP/TP analysis activities.
- Second, through the usage of an Indra Test Bench BADA-based TP for the evaluation (and quantification) of the benefits that can be obtained in ground TPs thanks to the usage of ADS-C data (in particular, the actual mass and the flight-specific preferred speed).

This way, Indra activities are aligned with OBJ-0106-004.

For the first part, since the TP analysis itself was done by EUROCONTROL (MUAC), please refer to section §6.4.7.2 for the details on the analysis that was performed.

For the second part, the advantages of using the Indra Test Bench TP were the following ones:

- It constitutes a rapid prototyping platform, where concepts can be easily and quickly implemented and tested.
- It is focused on the TP, and is better prepared to perform pure TP analysis for the flights in terms of available tools (both for preparation and analysis phase).
- It is not limited to a certain adaptation/environment/airspace. Instead, the TP can be used to compute trajectories at any geographic coordinates. This way, for example, the descent phase at Toulouse for (almost) all flights is also analyzed.
- Even if not an operational TP, the Test Bench TP performances are quite representative of the Indra provided operational/pre-operational TPs. So, the results obtained in this analysis can be perfectly extrapolated to other TPs such as EUROCONTROL MUAC NFDPS & iTEC TPs.
- Finally, and being a pure BADA implementation, results could be also understood as a BADA model analysis (for its version 3.9), so this study could provide useful information to any BADA-based TP on the benefits that could be achieved.

This flexibility implies also a limitation, which is the lack of adaptation/airspace data and constraints of the environment. This way, and for each and every flight, ad-hoc simplified adaptation data needs to be prepared (fortunately, this activity is not too effort consuming for the Test Bench TP).

There is another small limitation. Even if the TP is fully representative of Indra operational & pre-operational TPs, the Constraint Manager is quite different. This way, when reproducing the flights, the approach is not a dynamic approach where you first introduce the initial flight plan and then you feed the system with the same tracks and controller orders, since the system output would be different. Instead, the approach was more a static approach:

- First, to select a set of key scenarios for each flight (the most representative ones in terms of trajectory prediction objective for each flight).
- Then, to create a flight plan with a route and strategic/tactical constraints aligned with the remaining part of the flight (available EPP points), and to compute a trajectory with and without using the ADS-C data.

Finally, it must be noted that the TP analysis is performed by comparing predicted trajectories versus EPP trajectories instead of ground predicted trajectories versus real flown trajectories (surveillance data), since the first ones (EPP trajectories) were considered more appropriate considering the objective of this TP accuracy assessment. A more detailed explanation of the rationale for this decision is given on section 6.4.7.2.1.1.

6.2.4 NATS Contribution

NATS has used the following facilities and systems for the project:

- The operational data recording subsystem of the London Area Control Centre (LACC) located at Swanwick is used to retrieve flight data, surveillance tracks, coordination conditions and ATC instructions applicable to the ferry flights in LAC airspace. Additionally, the meteo information input to the iFACTS trajectory predictor is recorded.
- A web-service network node located at NATS Corporate and Technical Centre (CTC) is used to receive EPP data published by Eurocontrol Experimental Centre.
- All of the recorded flight data, surveillance data, ATC instructions and EPP data is stored in an SQL server database. The database provides the capability to query and compare the recorded data to support the analysis activities.
- The database analysis query results are exported into Excel spreadsheets to provide tabular and graphical plots of results. The recorded data is also exported into Python programs for data processing and analysis.
- NATS Trajectory Prediction Research Tool (TPRT) provides a fast-time test harness that allows the deterministic prediction of trajectories from a user specified set of input data. The tool contains a copy of the iFACTS trajectory prediction algorithms and has development branches to allow modifications to be assessed. A branch that integrates EPP information into the prediction of the iFACTS tactical trajectory is used and the output trajectories are assessed in an objective analysis

6.2.5 Skyguide Contribution

Several tools have been used to prepare and to operate during the live trials.

- A WebService architecture based on the existing CRYSTAL/SCONE (Skyguide tools) architecture has been implemented.
- Complete radar track data for the participating ferry flights has been provided by RECDATA + ANALYZE systems (Skyguide tools). Radar track has not been limited to Swiss Area of Interest but to full extend of the RADAR sources used in Switzerland.
- Time estimates provided by skyguide ground ATM system's engine has been compared to the Flight Plan estimates from EPP. STEM tool (Skyguide tool) has been used to compare with EPP.
- Several tools : LogBrowser, LogViewer, OPS History Viewer have been used to analyse FDP logs

6.2.6 Thales Contribution

The demonstration configuration was described hereafter:

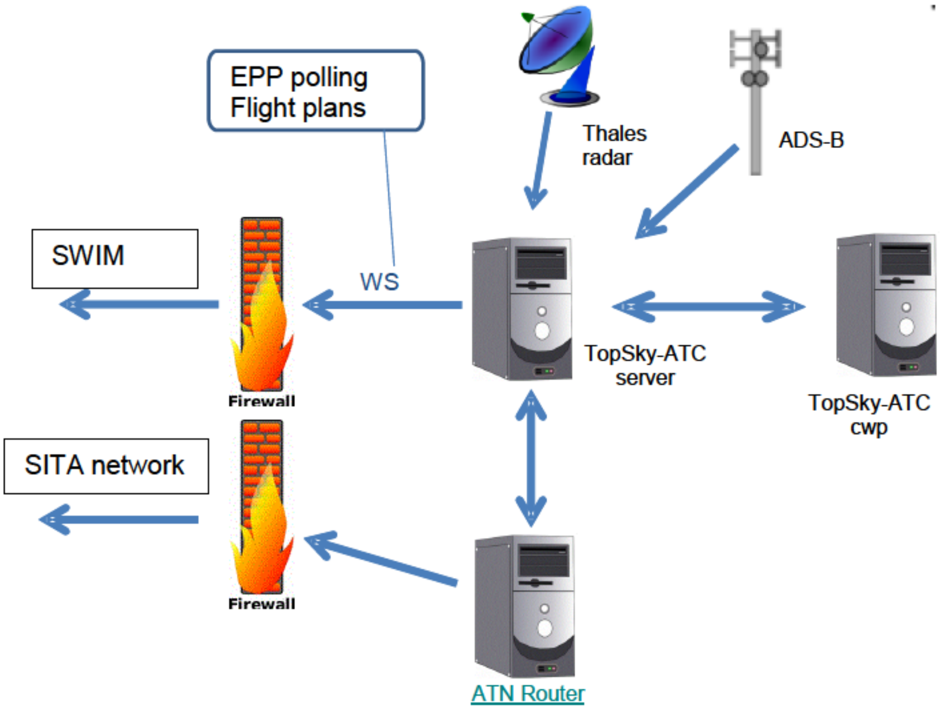


Figure 11 Thales configuration for PEGASE

The following infrastructure was set-up and used to conduct the exercise:

- TopSky-ATC automation system IBP installed in Thales Rungis premises, replicating the IBP used for the SESAR I4D validation exercises by NORACON in Malmö.

- Several data sources
  - Live surveillance data from the Thales PSR/MSSR radar located in Rouen and ADS-B Ground Station located in Rungis. As Thales radar installed in Rouen premises is not an operational system, several unavailability periods occurred. ADS-B ground station was fully available and dedicated to the exercise.
  - Flight Plans received from the EUROCONTROL NOP
  - EPP received from EUROCONTROL
  - EPP received from the aircraft through SITA ATN connection. This SITA connection is not available the time current draft report is issued. While it's not available, only EPP received from Eurocontrol will are used.

- The SkyCentre lab was equipped in data recording tools to collect track and prediction data when the flights are overflying the defined area

As Thales is not an ANSP and did then not take any flight in charge as an air traffic control point of view, no ATC tactical information was be available to get accurate ground prediction results live. Missing information was mainly ATC tactical clearances given by operational controllers and meteo data on the route.

EPP analysis has been done off-line.

Thales received EPP through SWIM web services. Thales was initially keen to have a direct ATN connection with the aircraft during the second half of the project but, despite the technical feasibility was assessed together with SITA and given the reduced number of PEGASE flights at that time, it was decided not to put in place this connection in order to avoid any risk of ATSU freeze possibly caused by additional ADS-C connections to the aircraft.

6.3 Exercise Preparation

The start of PEGASE Ferry flight was authorised by the Airbus laboratory "GO for flight" decision based on the results at the end of laboratory test sessions. The lab test schedule is shown in the table below (extract).

The configuration of the laboratory sessions is shown in the figure immediately below.

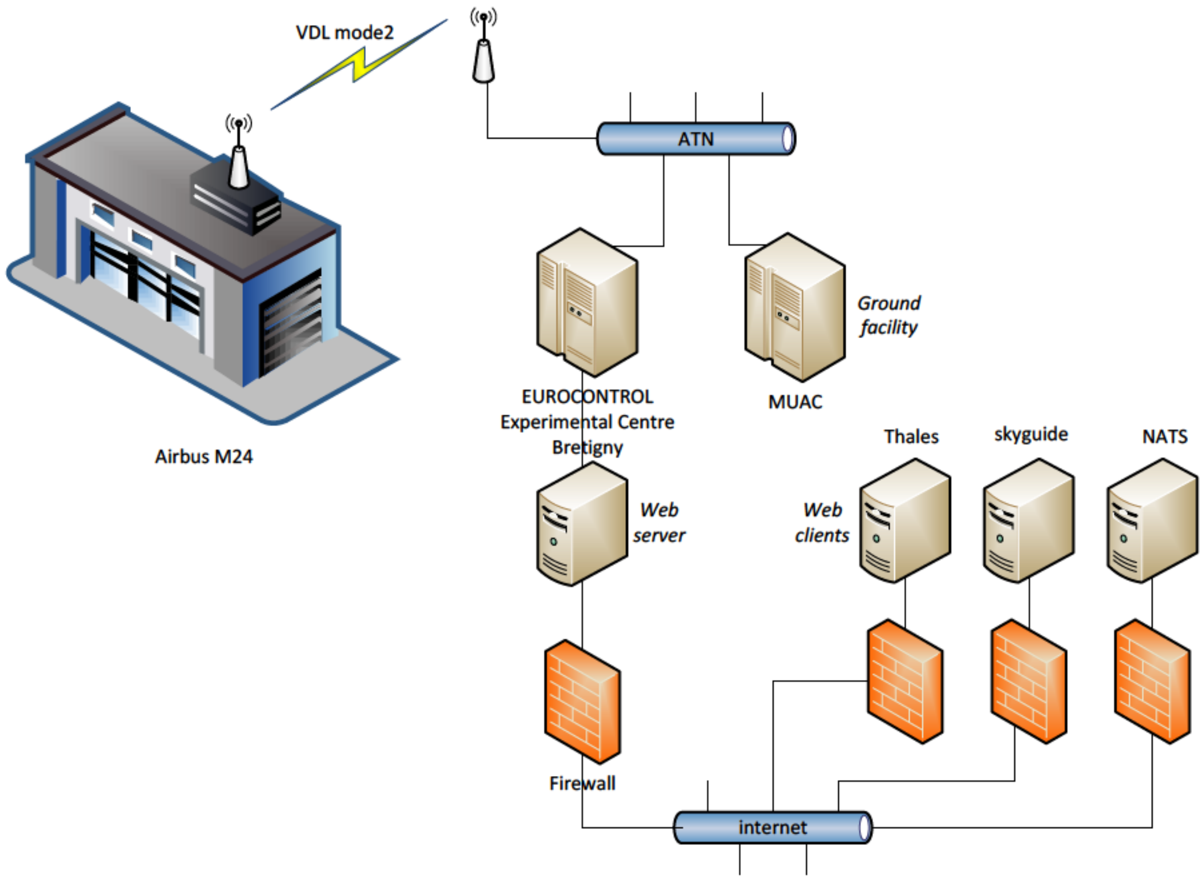


Figure 12 Test topology

This "GO for flight" assessed the correct behaviour of the modified computer (FMS and ATSU) that are installed on Aircraft. The "GO for Flight" was achieved on the 05 of February 2015

In addition, the simulator sessions performed between Airbus and all the partners confirmed the usage of the PEGASE routes over each partner's responsibility. These routes were declared "open" as soon as the partners were ready. (Routes are described in Chap 4.1)

During the exercise, the route choice was performed by Airbus in accordance with flight ops capability as the partners were available all of the time. The following table summarises the test sessions that were performed:

Date	Nature of test	Route	EEC	MUAC	NATS	skyguide	Thales
19-11-2014	Interoperability	central	☐				
21-11-2014	Interoperability	central		☐			
21-11-2014	Interoperability	central	☐☐				
26-11-2014	Interoperability	central		☐			
28-11-2014	EPP content	central	☐	☐			
15-12-2014	Online distribution, Honeywell FMS	west	☐				☐
16-12-2014	MUAC automation	central		☐			☐
08-01-2015	MUAC automation	central	☐	☐			☐
15-01-2015	MUAC – Abort robustness	south	☐	☐		☐	☐
22-01-2015	EPP content	south	☐	☐	☐	☐	☐
03-02-2015	Rehearsal	central	☐	☐	☐	☐	☐
05-02-2015	Presentation to SJU	central	☐	☐	☐	☐	☐
12-02-2015	Anomaly correction + Honeywell FMS	west	☐	☐	☐	☐	☐
05-03-2015	DCDU dependence, resilience during contract creation.	west	☐	☐	☐	☐	☐
12-03-2015	Provider abort resilience	west	☐	☐	☐	☐	☐
01-04-2015	EEC automation	south	☐	☐	☐	☐	☐

Table 6 Test session overview

6.4 Exercise execution

This section addresses the three objectives

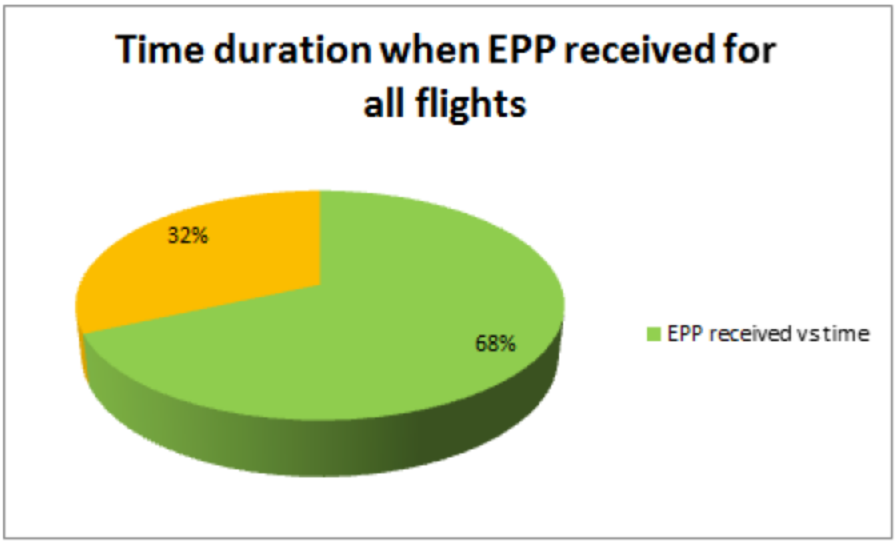
- OBJ 106-005 Collect consistent flight data
- OBJ 106-006 Establish ADS-C contracts
- OBJ 106-007 EPP ground distribution

A number of 59 flights have been performed in the scope of PEGASE project and 52 have been analysed.

All of these flights have been managed by a FTR (Flight Test Request) to inform the flight test crew about PEGASE intent and needs.

Among these 59 flights some of them have been more accurately followed (see § 6.4.7.1.8).

For all these flights the average percentage of EPP transmitted between the contract establishing and the end of the contract is: 68%



6.4.1 Traffic sample description

Table 7 lists the flights that took place during the PEGASE project, and that were subject of this demonstration report.

For these flights, the average duration is 1 hour and 50 minutes. ADS-C contracts were established with EUROCONTROL EEC on the average for 72.6% of the flight duration. The following two tables detail the flight duration and the coverage:

	n	Mean	Std	Min	25%	50%	75%	Max
Duration	56	01:50:51	00:20:16	00:57:09	01:44:22	01:51:49	01:59:00	02:34:47

	n	Mean	Std	Min	25%	50%	75%	Max
Coverage	56	68.3%	31.6%	0.0%	67.1%	79.2%	90.5%	100.0%

The distribution of the flights in term of route flown and FMS is shown in the following figure:

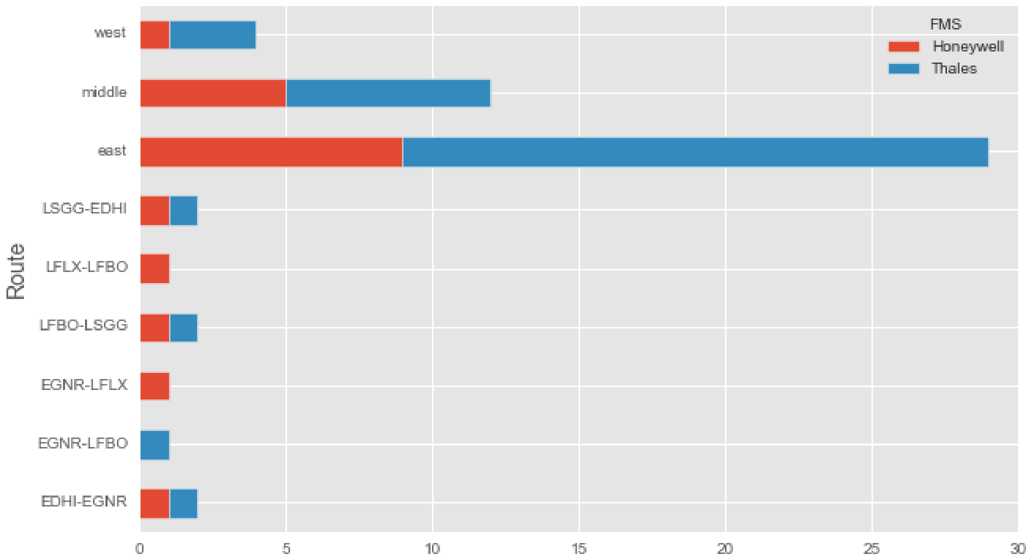


Figure 13: Flight distribution per route and FMS

The detailed counts are reported in the following table:

		FMS		
		2	**1**	*Total*
Route	**EDHI-EGNR**	1	1	2
	EGNR-LFBO	0	1	1
	EGNR-LFLX	1	0	1
	LFBO-LSGG	1	1	2
	LFLX-LFBO	1	0	1
	LSGG-EDHI	1	1	2
	east	9	20	29
	middle	5	7	12
	west	1	3	4
	Total	20	34	54

The East route which is the natural route for the ferry flights is the most flown one. The middle route is the second choice but it is less flown because there is usually more traffic on it. The west route over UK has been rarely flown because it caused organisational problem given the often late take off times. Due to technical problems (defective unit), fewer flights could be executed using one brand of FMS.

The following flights have occurred up to August 2016:

date	ARCID	Take-off	total time	coverage	flavour
05/06/2015	AIB02DM	13:26:32	02:30:17	28%	west
17/06/2015	AIB02BM	14:30:03	01:45:05	85%	east
08/09/2015	AIB02IH	18:30:35	01:45:25	0%	middle
28/09/2015	AIB02DN	16:05:54	01:42:15	28%	middle
28/10/2015	AIB02IN	17:45:09	01:52:49	85%	east
10/11/2015	AIB02IE	19:49:33	01:50:51	71%	east
12/11/2015	AIB02DJ	19:14:36	01:55:20	48%	middle
18/11/2015	AIB02BU	14:23:41	02:32:31	99%	west
30/11/2015	AIB214A	08:44:32	00:57:09	73%	LFBO-LSGG
30/11/2015	AIB214B	09:42:45	01:34:04	100%	LSGG-EDHI
30/11/2015	AIB214C	11:16:54	01:48:15	59%	EDHI-EGNR
30/11/2015	AIB214D	12:56:01	01:14:00	64%	EGNR-LFLX
30/11/2015	AIB214E	14:03:10	01:01:57	79%	LFLX-LFBO
02/12/2015	AIB02BI	18:25:54	01:52:06	95%	east
08/12/2015	AIB02IT	19:30:00	01:57:57	82%	east
11/12/2015	AIB214F	07:53:40	01:05:43	100%	LFBO-LSGG
11/12/2015	AIB214G	08:59:12	01:25:21	86%	LSGG-EDHI
11/12/2015	AIB214H	10:24:53	01:43:16	74%	EDHI-EGNR
11/12/2015	AIB214I	12:08:25	02:13:56	100%	EGNR-LFBO
21/12/2015	AIB03DO	19:04:49	01:46:27	94%	east
13/01/2016	AIB02DF	16:32:30	01:59:59	82%	middle
15/01/2016	AIB04IH	17:13:51	01:49:46	72%	east
29/01/2016	AIB02DR	16:23:44	01:53:41	85%	middle
01/02/2016	AIB02DT	17:15:44	02:01:44	95%	middle
09/02/2016	AIB02BO	20:14:41	02:01:06	91%	east
16/02/2016	AIB02BD	19:18:25	01:39:46	93%	east
24/02/2016	AIB02IA	19:56:54	01:51:32	77%	east
25/02/2016	AIB02IE	18:11:29	01:51:18	69%	east
26/02/2016	AIB03IR	16:08:11	01:58:59	74%	east
02/03/2016	AIB03DX	16:34:02	01:59:15	69%	east
04/03/2016	AIB02BQ	15:39:27	02:27:33	17%	middle
11/03/2016	AIB02BX	17:00:20	01:44:45	90%	east
11/03/2016	AIB02DS	17:11:33	01:46:05	28%	east
18/03/2016	AIB02DH	15:50:19	01:41:42	95%	middle
30/03/2016	AIB02IC	14:46:20	01:59:12	92%	east
04/04/2016	AIB04DU	18:44:26	01:58:04	87%	east
05/04/2016	AIB02DA	17:29:10	01:57:02	73%	east
19/04/2016	AIB03IS	17:28:16	01:49:55	95%	east
22/04/2016	AIB02IK	16:51:22	01:53:41	79%	east
25/04/2016	AIB02DR	18:48:15	01:52:23	75%	middle
29/04/2016	AIB02BH	15:18:52	01:59:05	80%	middle

03/05/2016	AIB02IO	13:52:58	02:13:09	97%	west
04/05/2016	AIB02BY	16:46:19	01:39:13	88%	east
12/05/2016	AIB02DL	18:30:21	01:52:26	90%	middle
19/05/2016	AIB02BT	19:06:17	01:40:43	0%	east
27/05/2016	AIB02IN	18:03:15	01:55:45	0%	middle
01/06/2016	AIB04IM	17:50:53	01:49:39	68%	east
08/06/2016	AIB02DH	18:16:52	01:51:08	0%	east
08/06/2016	AIB12	09:39:13	02:34:47	75%	LIRF-LIMC
10/06/2016	AIB14	09:48:09	01:04:16	68%	LIMC-LFBO
30/06/2016	AIB03DM	18:23:12	01:52:20	87%	east
04/07/2016	AIB02IY	17:47:14	01:57:46	0%	east
12/07/2016	AIB04IT	14:49:29	02:08:31	0%	east
15/07/2016	AIB04IZ	15:45:07	01:39:21	83%	east
22/07/2016	AIB02IS	16:46:30	01:51:27	92%	east
04/08/2016	AIB02BB	14:28:07	02:25:53	6%	west
12/08/2016	AIB02BD	16:41:45	01:36:15	0%	east
26/08/2016	AIB02BH	15:15:41	01:51:47	60%	middle
29/08/2016	AIB02IG	16:05:58	01:50:31	76%	east

Table 7 PEGASE flights achieved so far

Various issues have prevented EPP data collection for 100% of the duration of each flight, including lack of VDL-mode-2 network coverage, as well as specific problems on the aircraft and on the ground.

6.4.2 OBJ-0106-005: Collect consistent flight data

The collection of consistent sets of data representing the operational context in which the PEGASE flights took place is central to present and future ground TP improvement initiatives.

To that effect, a repository has been setup to store all the data collected for each of the flights. This repository is currently hosted on the EUROCONTROL's One Sky Team platform.

The different collected data are identified and described in the PEGASE data dictionary. (see annexe Appendix F) The main data collected include:

- A/C identification and on-board data: Flight plans, A/C information, Flight crew logs, FDR (Flight data recorder) data.
- ADS-C Data: All the reports collected in both EEC and MUAC in different formats (PER, XER and csv) along with original datalink tools logs.
- Track data originating both from radars (in decoded ASTERIX format) and from ADS-B
- ATC Data: controller inputs while the flight was under responsibility of PEGASE ATC partners.
- ATFCM Data: the different profiles computed by the Network Manager for the flight.
- Meteorological predictions and data during the flight.

6.4.3 OBJ-0106-006 Establish ADS-C Contract

The agreed process was to establish ADS-C contracts with the Ferry Flight from both EEC and MUAC, periodic and event, automatically set up from each ground facility.

As a back-up process the ground are able to "force" the A/C log-on and establish the connection.

6.4.3.1 ADS-C Coverage

The following table[2] shows statistics regarding the percentage of the flight duration for which ADS-C reports have been collected by the EEC infrastructure and distributed online. This percentage is called ADS-C coverage.

	n	Mean	Std	Min	25%	50%	75%	Max
Coverage	56	68.3%	31.6%	0.0%	67.1%	79.2%	90.5%	100.0%

The ADS-C coverage distribution is shown in Figure 14.

This means that for 75% of the flights ADS-C reports have been collected during more than 67.1% of the flight time (1st quartile/25% being 67.1%) and for 50% they were collected for more than 79.2% of the flight duration (median/2nd quartile/50% = 79.2%). The maximum value of 100% means that full coverage was achieved for some flights.

[2] Tables reporting statistics share the same format: n is the size of the reported sample, followed by the mean, the standard deviation, the minimum value, the first (25%), second (50%/median), third (75%) quartiles and the maximum value of the sample.

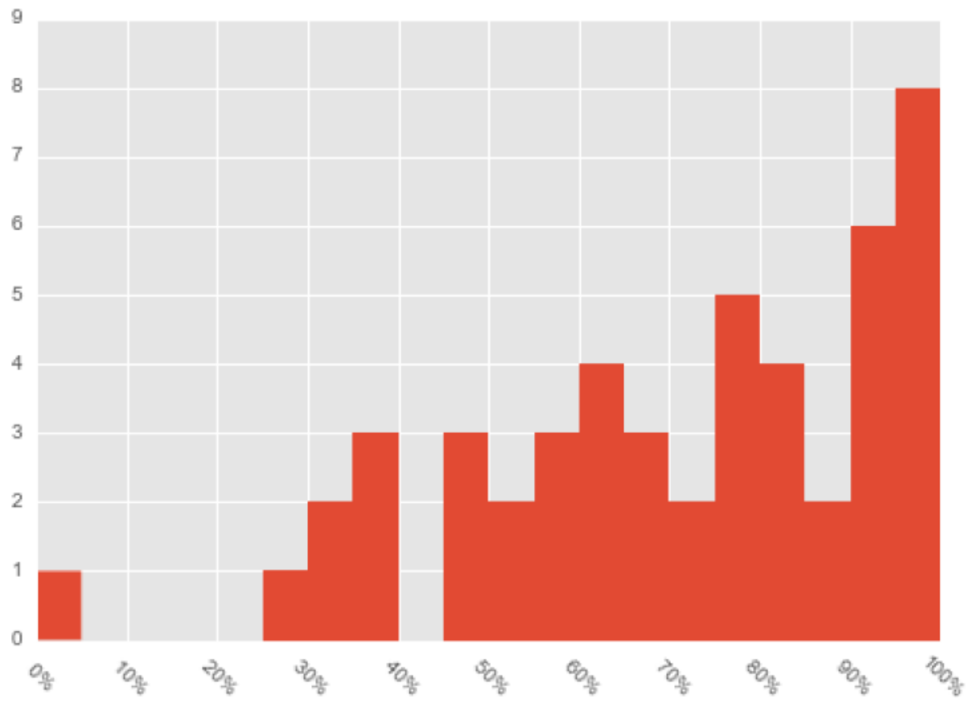


Figure 14: ADS-C coverage distribution

For three quarters of the PEGASE flights, ADS-C reports were collected during more than 70% of the flight duration.

For three flights, no ADS-C contract could be established due to ATSU problems. These flights are AIB02BT on 19/05/2016, AIB02IN on 27/05/2016 and AIB02IR on 03/06/2016. Another 5 flights have coverage less than 50%. These low coverages are mainly due to ATSU issues.

15 flights have coverage greater than 90%. The main reason why coverage is not 100% is that due to VDL availability problems in Hamburg, it was decided that the A/C would notify the ground after having taken-off. Another reason for lower percentage is linked to losses of communications in the busy area (mainly approaching Frankfurt).

6.4.3.2 ADS-C Reports

During the PEGASE demonstration, a total of 5666 ADS-C report were received by the EUROCONTROL EEC infrastructure, recorded for further analysis and distributed online. 36% of these are periodic reports (requested every 2 minutes in EEC) and the remaining 64% are event reports (see Appendix E PEGASE Contract definition).

The following table lists the statistics regarding the number of reports received per PEGASE flight:

	n	Mean	Std	Min	25%	50%	75%	Max
Total	51	111	50	0	80	109	146	210
Periodic	51	43	17	0	34	47	55	79

Event	51	68	36	0	45	60	96	145

The average number of ADS-C reports received during a PEGASE flight is 111 (43 periodic and 68 event reports). For three quarters of the flights, more than 80 reports were received (1st quartile/25% = 80). The distribution of the number of report received per flight is relatively well centred with the median (2nd quartile/50% = 109) close to the mean.

By design the number of periodic reports received is proportional to the coverage of the corresponding flight and show variability similar to the one of the coverage. The number of event reports, on the other hand, are much more variable and depends if the ADS-C reports were received or not during the climb and descent phases (where the A/C state varies more and more event reports are generated).

The distribution of the number of reports per flight and there variability is illustrated by the boxplots in Figure 15.

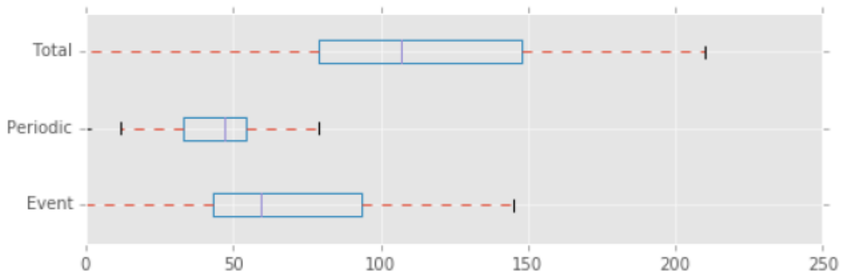


Figure 15: Number of report per flight boxplots.

6.4.4 OBJ-0106-007 Ground distribution of EPP

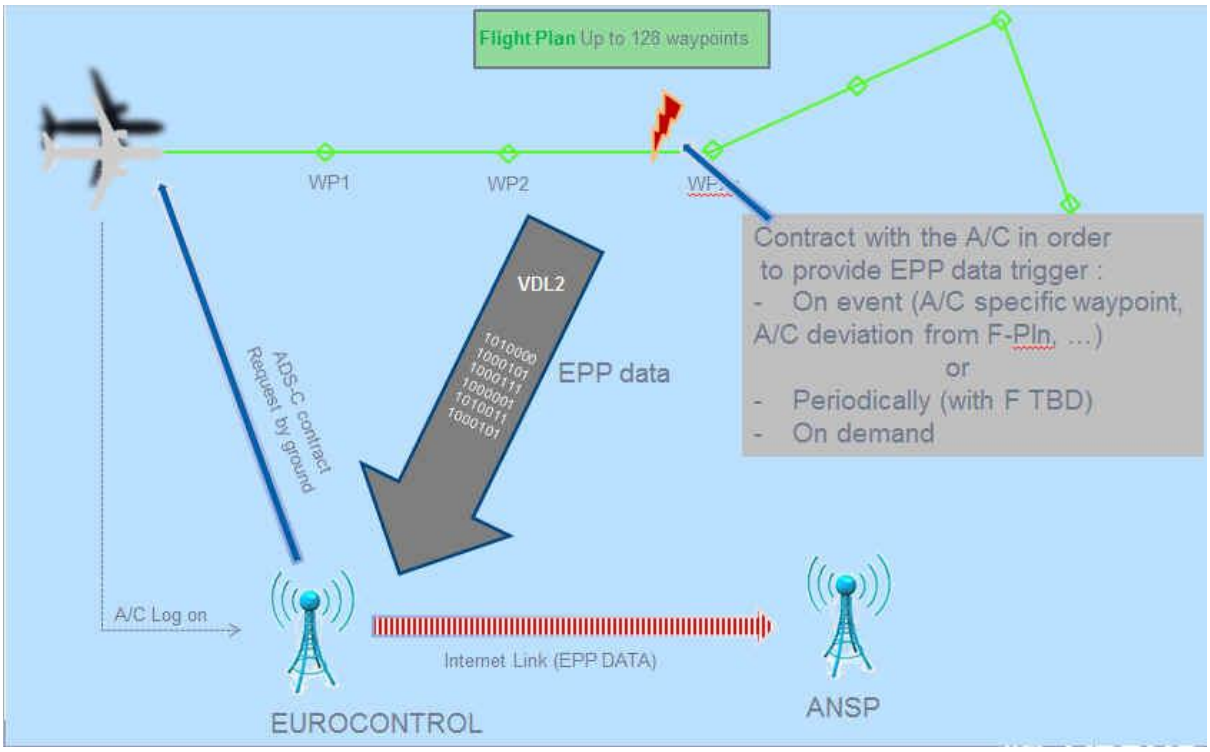


Figure 16: EPP ground distribution

The ADS-C data is distributed on the ground as described earlier and is summarised in the image above, Figure 16

For 91.4% for the PEGASE flights, all the downlinked reports were successfully distributed on the ground through the Web Service Notification service.

For the remaining 8.6% of the flights (4 flights) not all downlinked reports could be distributed online. The problems encountered included:

- Required distribution tool configuration changes due to late and uncommunicated A/C configuration changes
- Software or hardware problems requiring restarting the online distribution tool: e.g. loss of connectivity between the datalink tool machine and the machine handling online distribution.
- Simultaneous flights: one of the current limitations of the online distribution tool is that it is not able to handle more than one flight at the time. This happened in one single occasion.

Even in these cases, the number of reports lost remained extremely low: on average 0.35% if an 8% outlier is included or 0.13% otherwise.

Even if a relatively simple prototype and protocol were used (i.e. best effort giving no guarantee in term of delivery or real-time), it showed as very efficient way to share in quasi real-time the downlinked reports amongst the PEGASE partners: for each flight up to 4 WSN clients were simultaneously connected each potentially subscribing to two different topics.

6.4.5 Deviation from the planned activities

Deviations for the whole project have been covered in chapter 4.3.

6.4.6 Exercise Results

The exercise results are managed by partners and by objectives described in the execution phase (cf §6.4.7)

6.4.6.1 OBJ-0106-001 Assess Performance Characteristics of EPP

The performance characteristic of EPP was assessed against recorded ground trajectory predictions and radar data. In order to assess the performance of the EPP its predictions were compared with the actual conduct of the flight. One assessment will be made by the PEGASE consortium.

6.4.6.2 OBJ-0106-002 Measure End to End Performance

Note: the PEGASE project had to face several provider abort. The analysis is described in § 6.4.9.1

6.4.6.2.1 Air to ground

See § 6.4.9.1Partial: An assessment was made by measuring the performance of the air/ground link and comparing against the requirements defined in the EUROCAE Standard ED-228.

6.4.6.2.2 Ground to ground

6.4.6.2.2.1 NATS

NATS collected EPP data through the EUROCONTROL Web service (SWIM yellow profile compliant) via the public Internet.

The NATS EPP consumer used a pull method to request the EPP data; the pull period was set as 5 seconds.

The time taken to receive the EPP data via the web service was measured. The time measurement is the difference in seconds between the time the data was read by the EPP consumer and the time the data was sent from the aircraft, as reported in each EPP message.

The measurement results for 5115 EPP reports received from the PEGASE flights are summarised in the following table:

Mean	Std Dev	Min	Max	Count
24.6	36.5	2	384	5115

Table 8: EPP reception time difference measurements (seconds)

6.4.6.2.2.2 Skyguide

skyguide collected EPP data through the EUROCONTROL Web service (yellow profile compliant) via public Internet. Data analysis was performed posteriori and not in real time.

As this configuration did not represent the way EPP data shall be received by ANSP, the End to End performance assessment was not part of the skyguide analysis.

The following table displays the average time to transmit an EPP from its sending from the aircraft until its reception on the Web service client. EPP messages are retrieved every 5 seconds so results below are at +/- 5 seconds.

The analysis started on the 2nd December because, before that data, EPP were retrieved every 2 minutes.

Flight trial date	Average time of transmission (second)
02.12.2015	7.97
08.12.2015	13.60
11.12.2015	9.54
13.01.2016	16.73
15.01.2016	5.61
29.01.2016	6.86
01.02.2016	14.15
16.02.2016	9.12
24.02.2016	14.54
25.02.2016	35.69
26.02.2016	15.83
02.03.2016	10.83
04.03.2016	28.42
11.03.2016	24.75
18.03.2016	30.13
30.03.2016	34.00
04.04.2016	8.95
05.04.2016	7.29
19.04.2016	20.42
22.04.2016	20.85
25.04.2016	6.22
26.04.2016	12.31
04.05.2016	12.28
12.05.2016	7.53
01.06.2016	10.32
30.06.2016	28.13
15.07.2016	29.57

Table 9: Average time of transmission

6.4.6.2.2.3 Thales

Due to security constraints, Thales selected the pull method for the ground to ground reception of the EPPs rather than the push one.

The EPPs were requested using a 5 seconds pull period.

Over 5945 ADS-C reports received from June 2015 to mid-August 2016 (with the exception of dedicated flights performed in June 2016), the analysis of the difference between the time the EPP was received and the time it was sent by the aircraft ("time" field of the ADS data report) shows:

- an average delta of 16.7 seconds
- with a minimum of 2 second
- and a maximum of 8.6 minutes

Comparing with the number of ADS-C reports that should have been distributed during the same period, it appears that 96.2% of the reports have been received. Most of the 3.8% report loss was due to web proxy maintenance that occurred during non-business hours.

6.4.7 Results per KPA

6.4.7.1 Measure EPP accuracy

6.4.7.1.1 A/C mode repartition

The extended projected profile is based on the predictions computed by the FMS and sent to the ATSU. These predictions are available on board for the crew. When the A/C flies in full managed mode, the A/C guidance system follows the targets (lateral, vertical and speed) computed by the FMS to follow the 4D trajectory theoretical profile. In reality during flight, the A/C will be subject to ATC clearances and instructions that are not (immediately nor systematically) reflected in the FMS flight plan and will result in the A/C being flown in selected mode instead of managed mode. In these conditions, the EPP not necessarily correctly represents the future (unknown to it) intentions of the stakeholders (both ATC and crew) and can show major deviations from what will be eventually flown.
To help the ground user to assess these conditions, the ADS-C reports contain the three current mode settings (lateral, vertical, speed). One of the FMS-ATSU combinations used in PEGASE reported the vertical mode as engaged while in climb even if it was not the case. This issue affected the climb phase for more than 50% of the PEGASE flights and required to analyse data from the A/C FDR in order to recover the real settings.

The following three tables reports on the percentage of time the different flight guidance modes (respectively lateral, vertical and speed) were in managed mode. Due to the problem described above, the data is reported for the 25 flights for which FDR data is currently available:

	n	Mean	Std	Min	25%	50%	75%	Max
Lateral	25	80.3%	18.6%	0.0%	79.8%	85.0%	89.4%	95.6%

	n	Mean	Std	Min	25%	50%	75%	Max
Vertical	25	52.9%	20.2%	3.1%	39.5%	50.5%	67.7%	91.2%

	n	Mean	Std	Min	25%	50%	75%	Max
Speed	25	55.7%	25.2%	0.0%	40.2%	51.6%	80.2%	100.0%

Figure 17 gives the distributions of the "time spent in managed mode" in percentage of the total flight time for the three guidance modes. The lateral managed mode is consistently used during significant parts of the flights: from 60% to 100% of the total flight duration.

The dispersion of the durations for the vertical and speed managed mode is higher. These two modes are used during shorter intervals. Interestingly, the distribution of the speed managed mode shows two modes: one around 40% and another one around 80% (further increasing the dispersion).

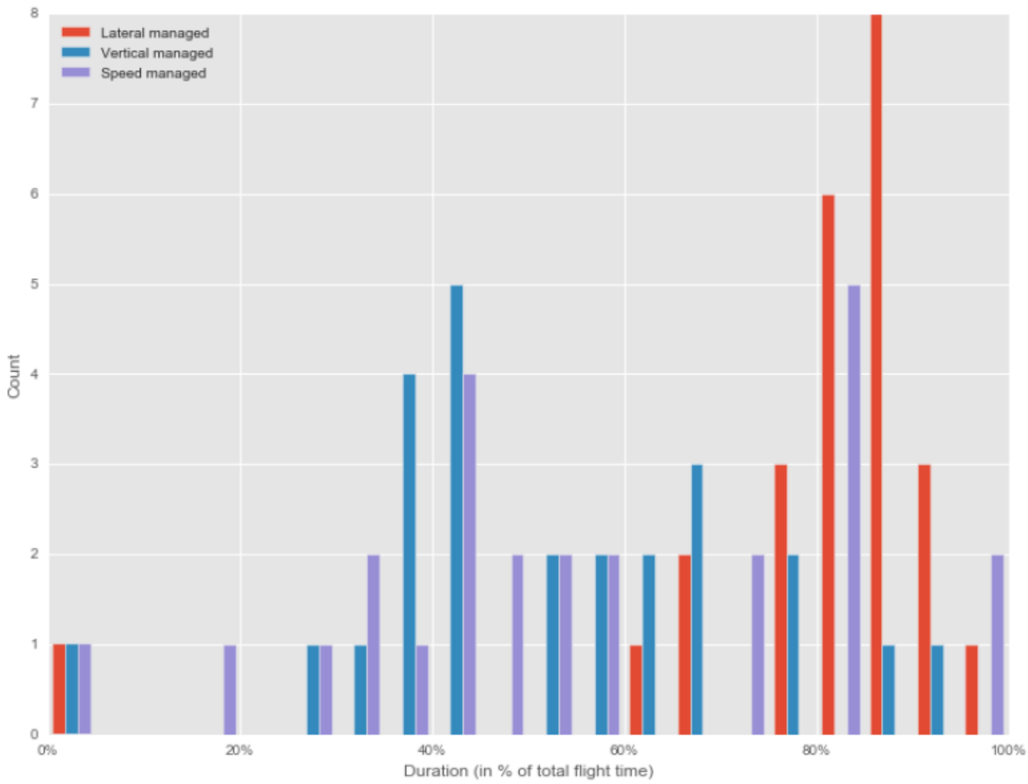


Figure 17: Time in mode distribution

The next sections details two flights: AIB02IT that took place on the 8th of December 2015 which could be flown in managed more for a relatively high part of the flight and AIB02DF (flown on the 13th of January 2016) where several directs have been detected.

6.4.7.1.1.1 AIB02IT (08/12/2015)

The following timeline displays the periods in which the vertical, speed and lateral guidance modes for flight AIB02IT were in managed mode.

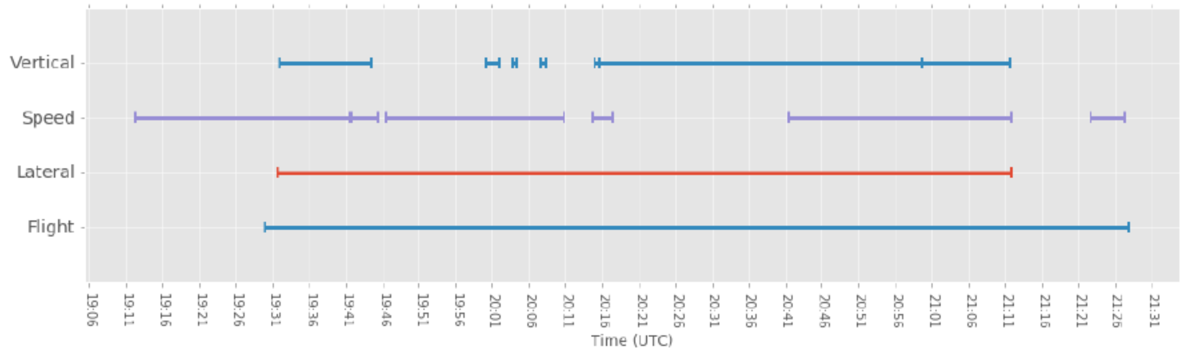


Figure 18: Timeline of the guidance modes for AIB02IT (source = FDR data)

The percentage of the flight time spent in managed mode is listed in the table hereafter:

Mode	% flight time
Lateral	85.0%
Vertical	61.4%
Speed[3]	65.5%

The impacts on lateral and longitudinal accuracy are detailed in sections 6.4.7.1.2.1 and 6.4.7.1.4.1 respectively.

6.4.7.1.1.2 AIB02DF (13/01/2016)

Figure 19 indicates the periods during which flight AIB02DF was flown in managed mode:

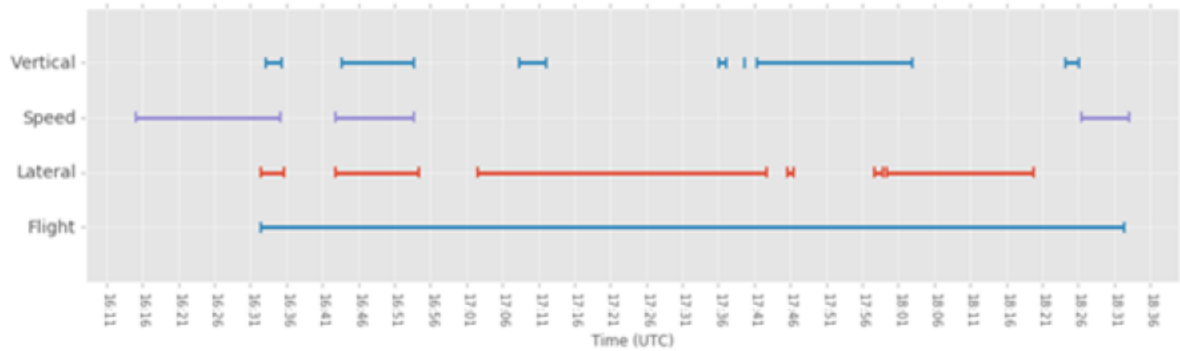


Figure 19: Timeline of the guidance modes for AIB02DF (source = FDR Data)

The percentage of total flight time spent in manage mode are the following:

Mode	% flight time
Lateral	64.6%
Vertical	33.7%
Speed	16.3%

The impacts on lateral and longitudinal accuracy are detailed in sections 6.4.7.1.2.2 and 6.4.7.1.4.2 respectively.

6.4.7.1.2 Airborne capability to FLY the EPP 1

[3] The periods outside the "Flight execution" (i.e. before take-off or after landing) are not counted toward this percentage.

The following table reports the statistics about the proportion of fixes appearing in the EPPs that are approached by a distance inferior to 2.5nm during flight (they are "flown"):

	n	Mean	Std	Min	25%	50%	75%	Max
% flown	48	71.6%	21.5%	28.6%	57.6%	75.0%	92.9%	100.0%

On average 71.6% of the fixes appearing in the extended projected profiles were overflown by the flights. For three quarters of the flights (1st quartile/25%) more than 57.1% of the fixes were flown and for half of them (2nd quartile/median) more than 75% were flown.
The distribution of the point flown per flight proportions is shown in the following histogram (Figure 20):

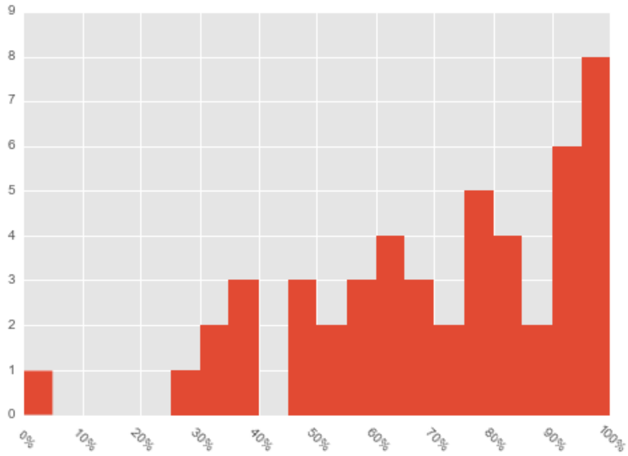


Figure 20: Distribution of the number of points flown

Reasons for not flying close to points appearing in the EPP include:

- ATC instructions. Essentially direct instructions. The impact of the instruction is greater if less data (smaller predictions) is recorded for a flight.
- Flight plan changes. Mainly STAR changes.

List of flights with lateral accuracy below the average are:

Date	Flight	Lateral coverag e	Possible discrepancy reason
05-06-2015	AIB02D	65,00%	Direct over the Netherlands
17-06-2015	AIB02B M	57,14%	Direct over Germany, STAR change
28-09-2015	AIB02DN	28,57%	Direct over France, Small dataset
28-10-2015	AIB02IN	58,06%	Direct over Germany, STAR change
10-11-2015	AIB02IE	57,69%	Probable direct over Germany, Small dataset
11-12-2015	AIB214D	63,04%	Direct over UK, Flight plan change
13-01-2016	AIB02DF	47,62%	Directs over Belgium/Luxemburg and France
29-01-2016	AIB02DR	46,67%	Direct over Germany, Direct over France
01-02-2016	AIB02DT	50,00%	Directs over Belgium/Luxemburg and France
24-02-2016	AIB02IA	31,25%	Directs over Germany and Switzerland, STAR change

26-02-2016	AIB03IR	35,71%	Directs over Germany, Switzerland and France, STAR change
02-03-2016	AIB03DX	46,67%	Direct over Switzerland, STAR change
04-03-2016	AIB02BQ	38,71%	Directs over Belgium/Luxemburg and France
11-03-2016	AIB02DS	36,36%	Small dataset
18-03-2016	AIB02DH	51,22%	Direct over Germany, STAR change
04-04-2016	AIB04DU	66,00%	Direct over Switzerland, STAR change
25-04-2016	AIB02DR	61,36%	Direct over Luxemburg/France
29-04-2016	AIB02BH	34,04%	Directs over Germany/Luxemburg and France, STAR change
12-05-2016	AUB02DL	60,87%	Direct over Luxemburg, STAR change

Figure 21 shows the link between the lateral managed mode and the overall lateral accuracy. The different points in the figure represents the percentage of flight time spent in managed lateral mode on x and the percentage of predicted points which are actually overflown (y axis). This number increases with the time spent in managed lateral mode:

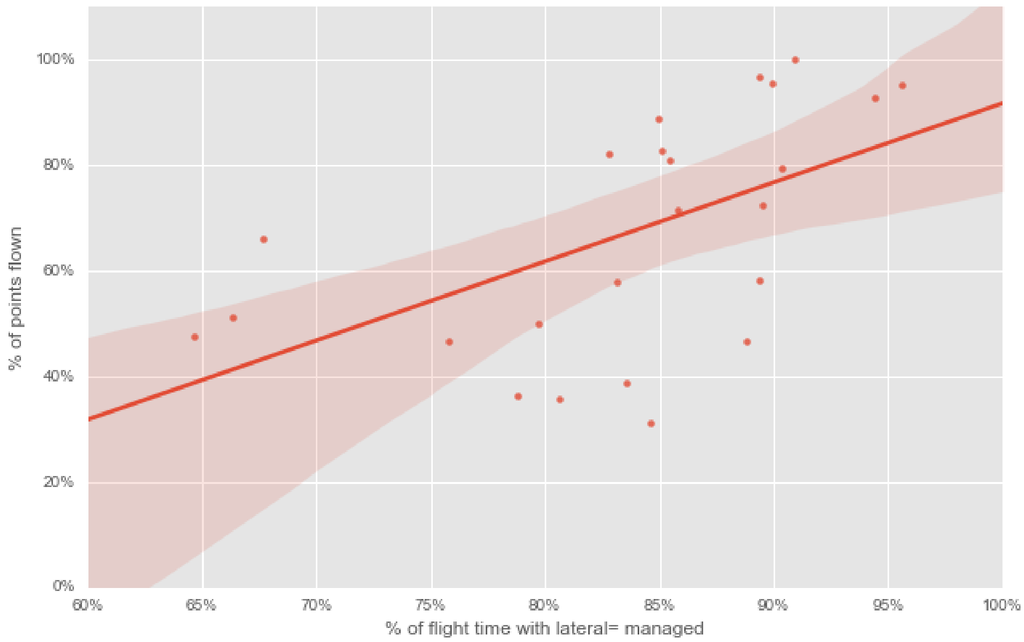


Figure 21: Link between lateral mode and lateral accuracy

6.4.7.1.2.1 Lateral accuracy for AIB02IT

Figure 22 shows the lateral profile for flight AIB02IT. The blue line plots the actual path of the A/C (here ADS-B data). All the points ever appearing in ADS-C reports are shown in the figure. The points which were flown over during the flight are printer in bold red. The flight could be flown in lateral managed mode for 85% of the total flight duration and 32 of the 34 points (92%) for which prediction were made and which appeared in EPP reports where actually flown over. Only at the end of flight discrepancies appear due to a STAR change.

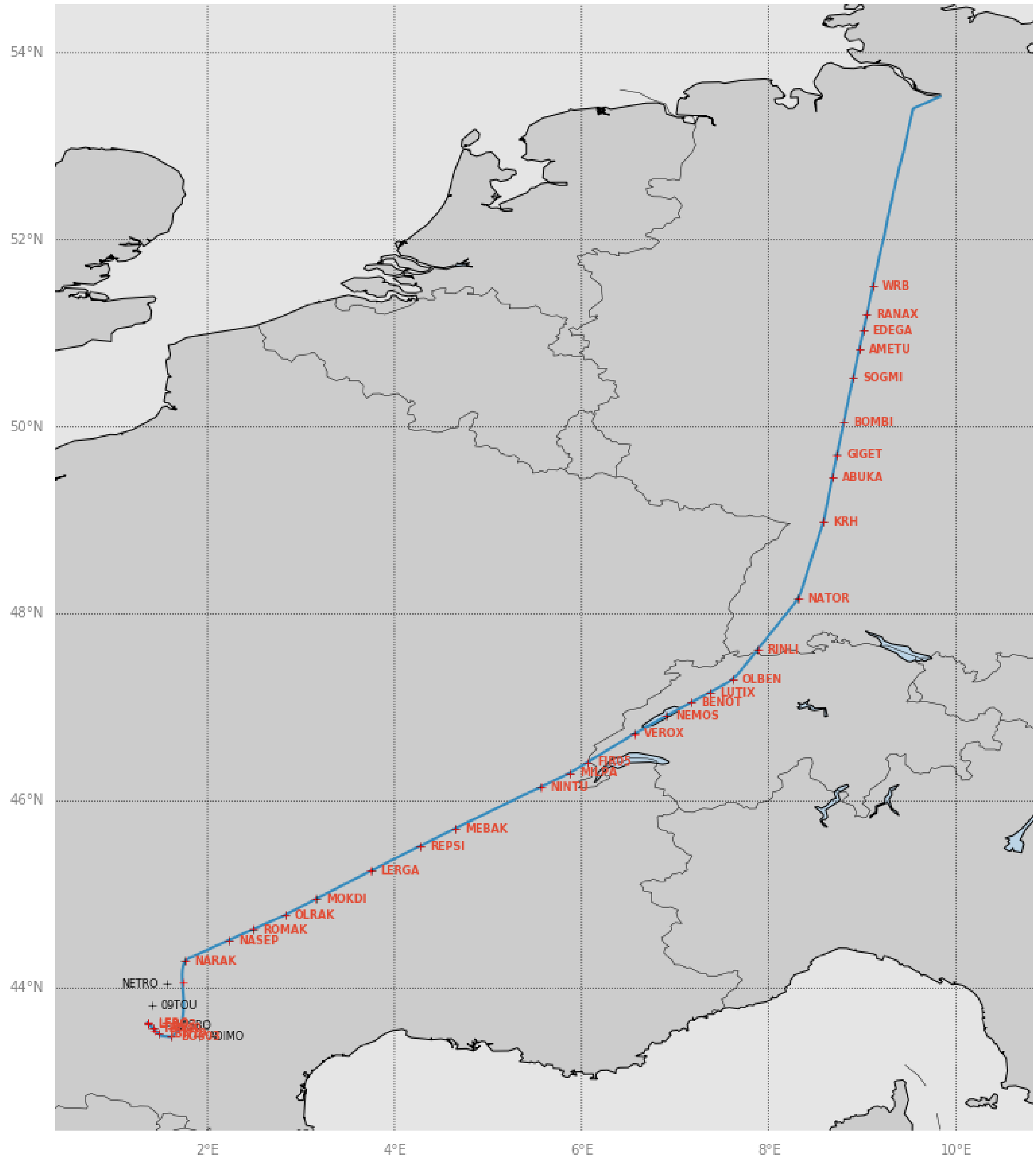


Figure 22: Lateral profile for AIB02IT

6.4.7.1.2.2 Lateral accuracy for AIB02DF

In contrast, AIB02DF was subject to directs over Germany, Belgium, Luxemburg and France and could only be flown in lateral managed mode for 64% of the flight time. Only 20 of 42 points (42%) appearing in the EPP predictions were actually flown over:

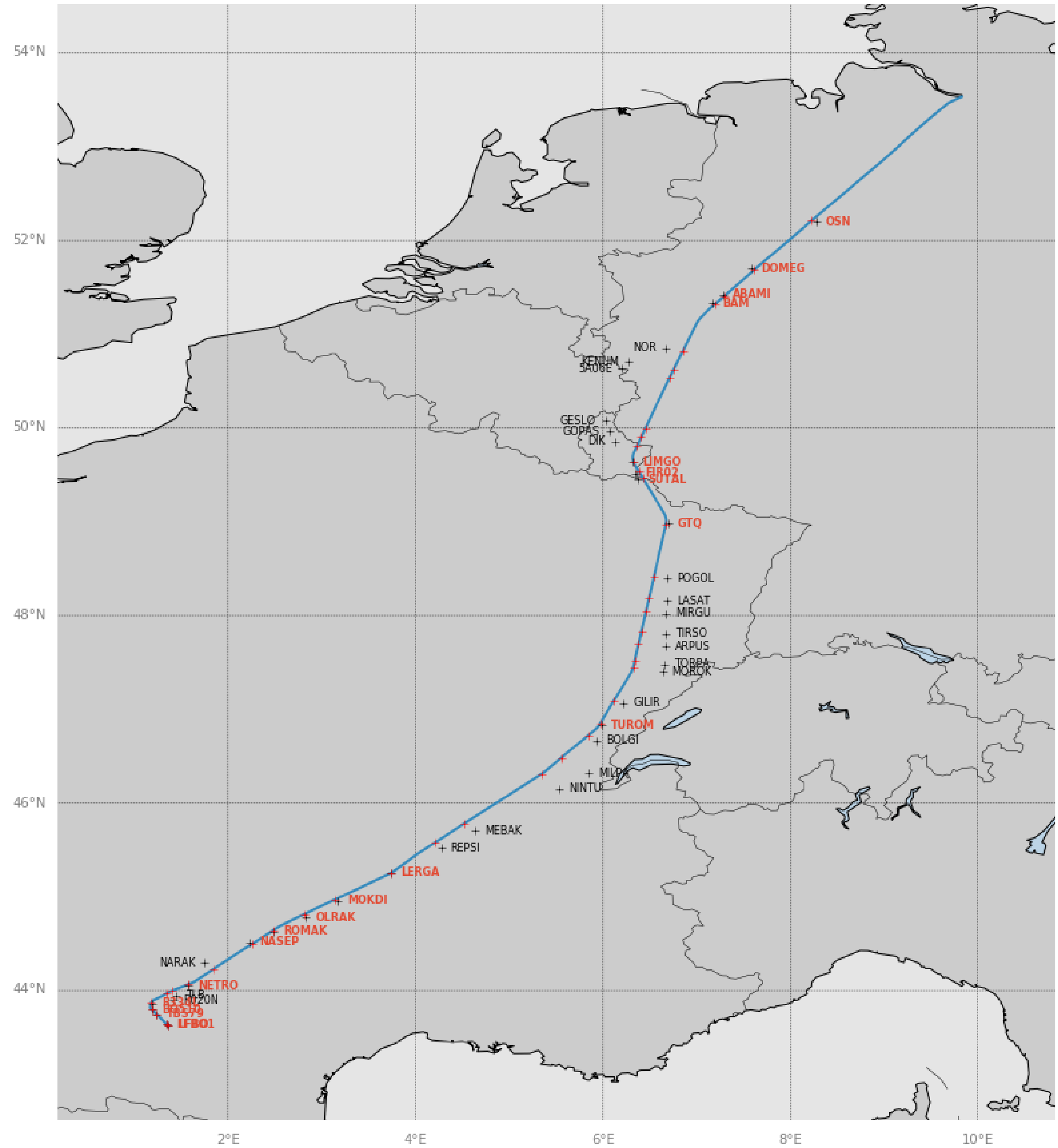


Figure 23: Lateral profile for AIB02DF

6.4.7.1.3 Airborne capability to FLY the EPP 1 (NATS)

The NATS post-flight analysis activity performed a visual comparison of the recorded EPP reports for each flight-trial to the corresponding recorded surveillance data for the flight.

The objective of the visualisation analysis is to provide an understanding of the detailed operation of the EPP under real flight conditions and the limitations of EPP data in different circumstances; so that informed design decisions may be made about incorporating EPP data in ground-systems.

This analysis corresponds to previous work conducted for SESAR exercise VP771 documented in EXE-04.05-VP-771 Initial validation of enhanced ground trajectory prediction using EPP Validation Report (VALR)[5]. The VP771 exercise was conducted using simulated flights. For the PEGASE project the EPP visualisation analysis considers similar scenarios, but under real flight conditions.

The EPP visualisation analysis was performed using an Excel spreadsheet to display graphical plots of the recorded data from each PEGASE flight-trial. The data displayed in the spreadsheet is read from the SQL database storing the recorded data from all of the flight-trials. The visualisation spreadsheet displays the EPP predicted latitude-longitude positions, vertical levels and estimated speeds at each EPP waypoint along with waypoint fix names, vertical/lateral types and level constraints.

Each EPP report during a flight can be selected, and the predicted EPP trajectory data for the selected report can be viewed, alongside the corresponding recorded surveillance data for the flight, enabling the EPP predicted trajectory to be compared with the actual path flown by the aircraft. The EPP behaviour under different operational conditions has been investigated; such as SIDs, STARs, ATC instructions and flight crew procedures. Observations were recorded for each flight trial.

6.4.7.1.3.1 Example EPP visualisation plots

The following figures show an example of the EPP predicted trajectory for AIB214C (1/12/2015), EDHI to EGNR.

The EPP predicted trajectory is downlinked from the aircraft at an early stage of the flight 6 minutes after take-off. The figures below show a very close correspondence between the EPP predicted trajectory (red plot) and the actual flight path flown by the aircraft as observed by the surveillance data (Radar and ADS-B, blue plots).

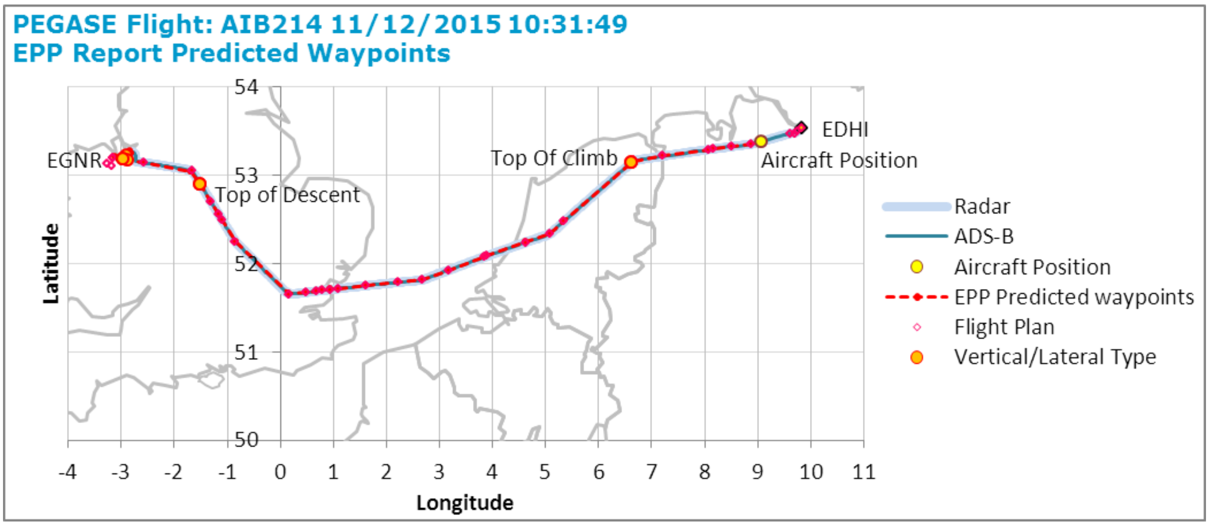


Figure 24 EPP predicted waypoints for AIB214C

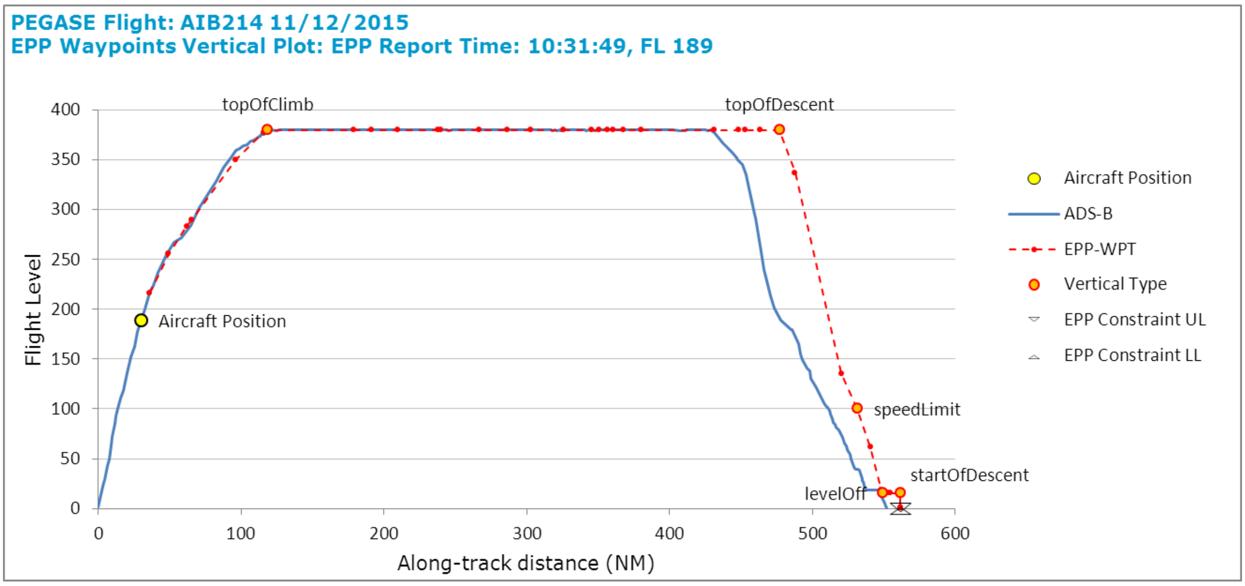


Figure 25 EPP predicted vertical profile for AIB214C

The vertical profile of the EPP predicted trajectory shown in the figure indicates an accurate prediction of the climb phase and top-of-climb waypoint.

For the descent stage, the EPP trajectory shows the predicted top-of-descent waypoint and the descent profile determined by the FMS. From the surveillance data it can be seen that the aircraft commenced descent earlier than the predicted top-of-descent waypoint. This behaviour was observed for all of the PEGASE flight-trials; that the aircraft commence descent before the EPP predicted top-of-descent point. The explanation for this behaviour is that this is caused either by an ATC instruction to commence descent, or alternatively an ATC descend when ready instruction, and the pilot decision to commence descent.

The example shown in the figures above represents a flight under nearly ideal conditions, where the flight closely follows its planned trajectory. This example illustrates the potential ability of the EPP trajectory to predict the aircraft behaviour.

The EPP visualisation analysis has also identified a number of different cases where the EPP predicted trajectory may not closely represent the actual path of flight. These scenarios are described in the following sections.

6.4.7.1.3.2 Effects of ATC operations

The aircraft FMS predicted trajectory represents the expected future 4D flight path of the aircraft. The planned trajectory is derived from the route waypoints and the cruise level defined in the flight plan.

However, the actual flight path flown by an aircraft can deviate significantly from the optimal flight path due to ATC operations. These can include procedural level restrictions and routeing, due to the airspace structure, such as boundaries between ATC sectors or adjacent FIRs; and can also include tactical level, heading or speed instructions by ATC to resolve potential conflicts with other flights, or to manage traffic flows.

Effect of heading instructions

The Figure 1provides an example showing the effects of ATC intervention from the PEGASE flight-trials. The figure shows an example of the EPP predicted trajectory for AIB02DR (25/04/2016, EDHI-LFBO).

The example shows the EPP predicted trajectory at time 19:33, it can be seen that the path flown by the aircraft, as reported by the surveillance data, diverges from the planned route of flight. This was caused by an ATC heading 180° instruction to the aircraft at 19:27.

When the pilot selects the heading the aircraft FMS switches to lateral selected mode.

In case the distance from the planned trajectory is significant, the FMS does not considers the waypoints as sequenced by the A/C and do not remove them from the FPLN. As a result, the EPP trajectory retains the waypoints behind the A/C position and predicts the A/C will go back to sequence them.

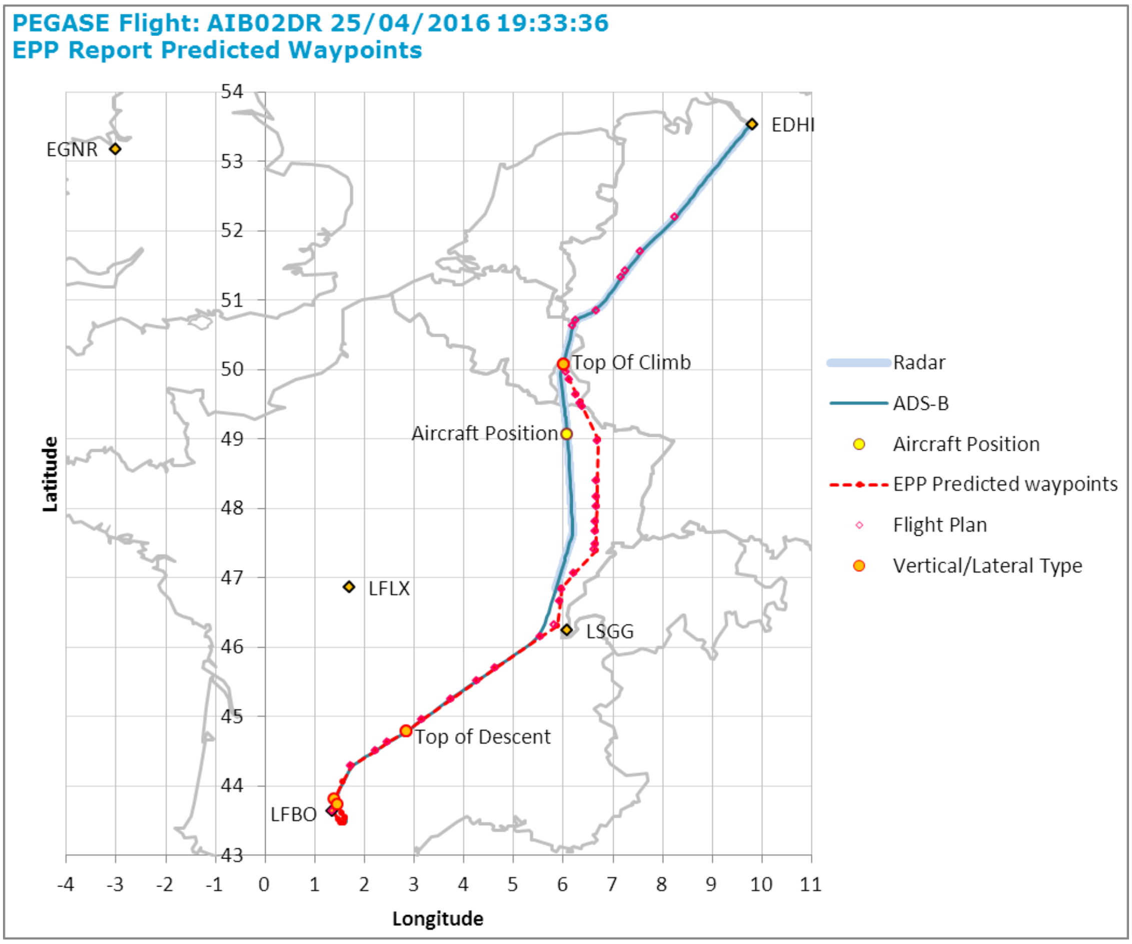


Figure 26 EPP predicted path for AIB02DR

Whilst the FMS is in lateral selected mode and retaining waypoints behind the aircraft, the predicted EPP trajectory is no longer representative of the actual flight path that will be flown.

This situation persists until the ATC heading instruction is superseded with a new ATC instruction to re-join the route at a waypoint. When this occurs, the pilot enters a DIRTO to the instructed waypoint, the FMS returns to lateral managed mode, and the EPP trajectory is updated.

This example case demonstrates the effects of ATC heading instructions. ATC heading instructions are used routinely in current operations, and this will continue to be the case for the foreseeable future in high-density airspace. These effects were also observed and recorded by SESAR exercise VP771[5]

This has implications for the potential use of EPP data in ground systems, that there will be periods of time where the aircraft will be operating in lateral selected mode, and during these times the EPP predicted trajectory waypoint positions and estimated times may no longer represent the path of flight.

Effect of cleared level instructions

ATC level clearances during climb can cause the aircraft to level off below the planned cruise level, and the aircraft FMS will then continuously update its prediction of the top-of-climb position. When in level flight below the cruise level, the aircraft will fly at a different ground-speed, and the aircraft FMS will continually update the predicted times at waypoints. The continuous recalculation of the EPP trajectory will continue until the aircraft is instructed to re-commence climb to the planned cruise level.

We therefore analysed the flight profile of each of the East routes (using ADS-B data) to investigate the flight variance due to ATC level clearances. In Figure 27 we show and measure the variance in the altitude as a function of the along-track distance. The upper panel shows each of the 16 East route flights, divided into the Climb, initial Cruise, Cruise and Descent phases. We then calculate the moving average of the altitude using along-track windows of 100 km (marked in black in the upper panel of Figure 27). In the lower panel we show the residual (or difference) between each of the flights and the average altitude.

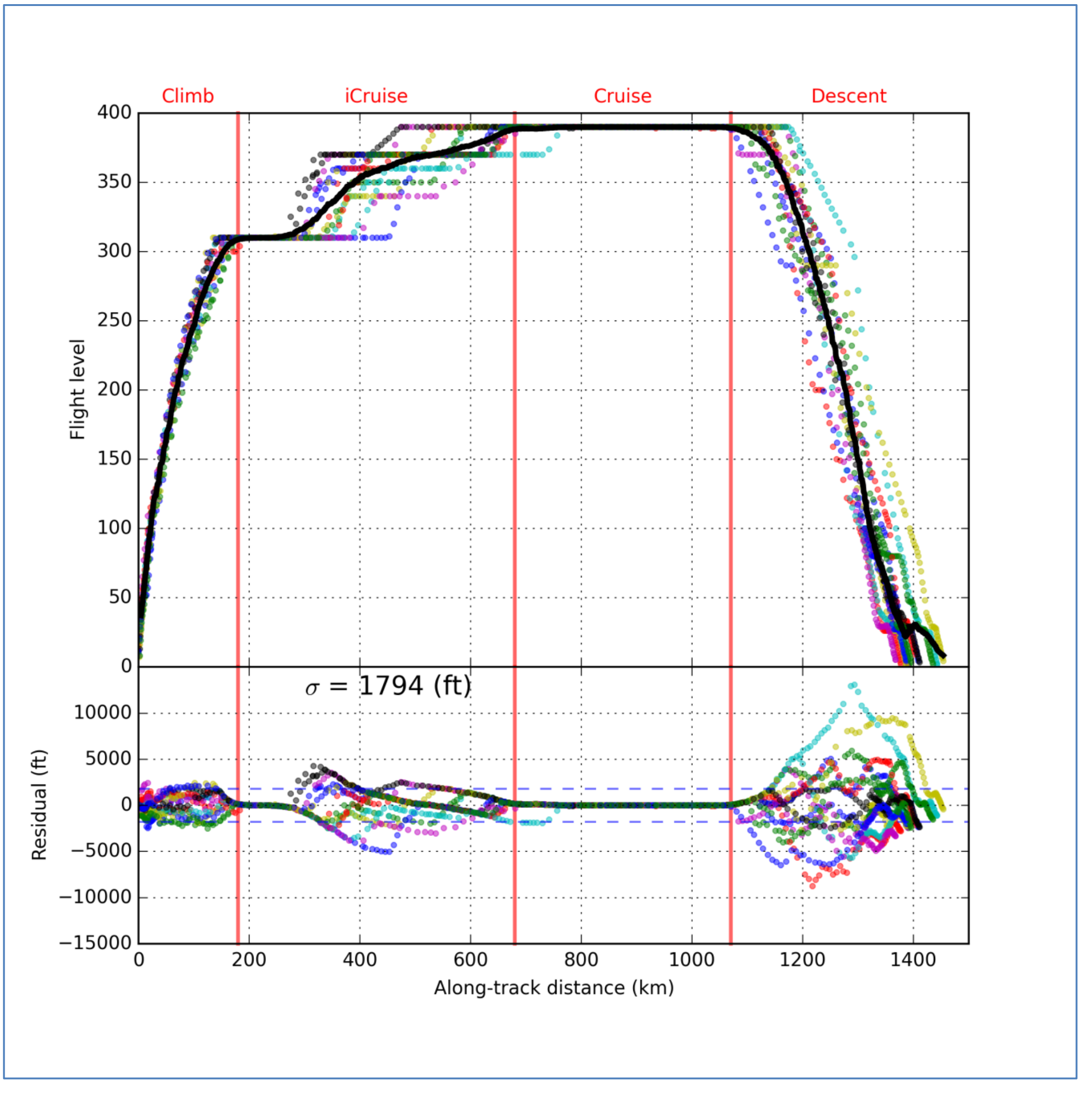


Figure 27 Upper panel: The altitude of each East route flight along their respective tracks.

The black line shows the moving average. Lower panel: The altitude of each flight minus the mean (i.e. residual). The dotted blue lines show ± 1σ (i.e. standard deviation).

We found that despite that each of East flights planned to fly the same route; there is significant variance in particular sections of their profile. For example, in the climb of each flight there is scatter around the mean by up to ~1800 ft until reaching about 180 km along the route. Then, due to what is likely a sector restriction all flights levelled off around FL310. Depending on the individual flight, the aircraft continued to climb to a maximum cruising altitude, giving considerable scatter in reaching the final cruise altitude. Finally, the highest variation in the profiles was found during the descent phase, with up to ±10,000 ft difference in the altitude despite aircraft flying the same distance. The variance in flight profiles therefore highlights day-to-day differences that tactical processes and weather variability place on a particular flight-route (e.g. in this route the overall standard deviation was found to be about 1800 ft).

Effect of speed instructions

ATC speed instructions may also lead to the aircraft FMS recalculating the estimated times and speeds at waypoints, this will be based on the FMS assuming that the selected speed will be maintained until the next speed transition point.

The effects of ATC instructions on aircraft EPP data will need to be considered in the future development of ground-systems. The specific details will depend on the particular ground-system application

6.4.7.1.3.3 Effects of Flight Crew Operations

The EPP visualisation analysis identified a number of cases where flight crew operations can affect the EPP predicted trajectory.

Selection of cruise level

The flight between Hamburg and Toulouse entails a change in the cruise level. At the beginning of the flight the cruise level is normally below FL335 and is usually set to FL310, whereas for the latter half of the flight the cruise level is FL390.

With the PEGASE flight trials, it has been observed that a single cruise level is selected by the flight crew at the beginning of flight, and for some flights the initial cruise level of FL310 was selected, whereas for other flights the final cruise level of FL390 was selected.

This is illustrated in the following plots:

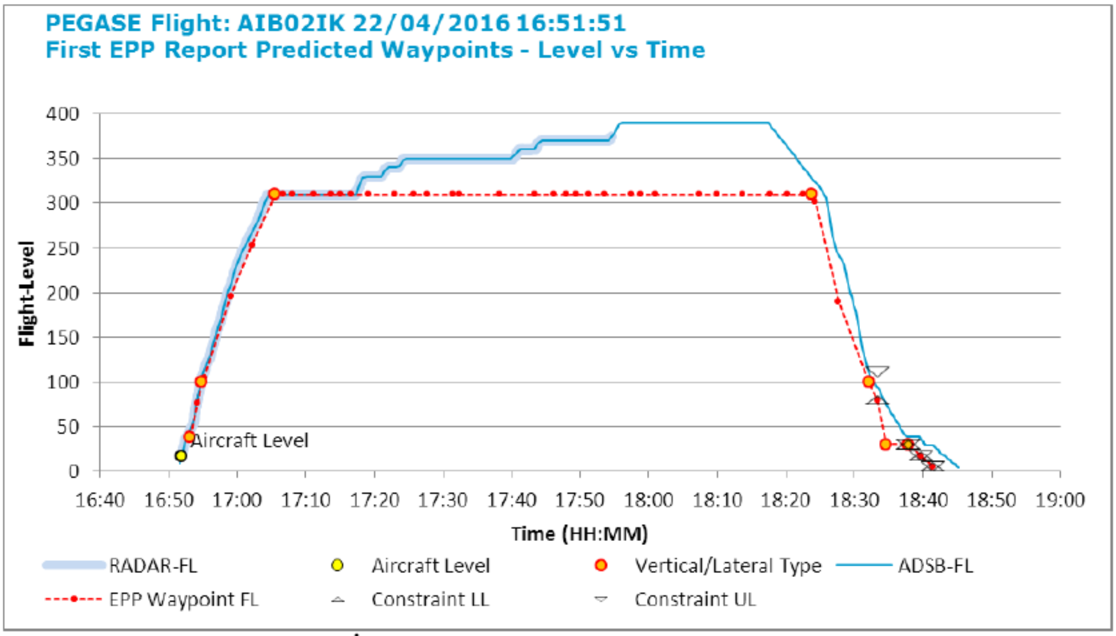


Figure 28 Flight AIB02IK on 22/04/2016, cruise level set to FL310

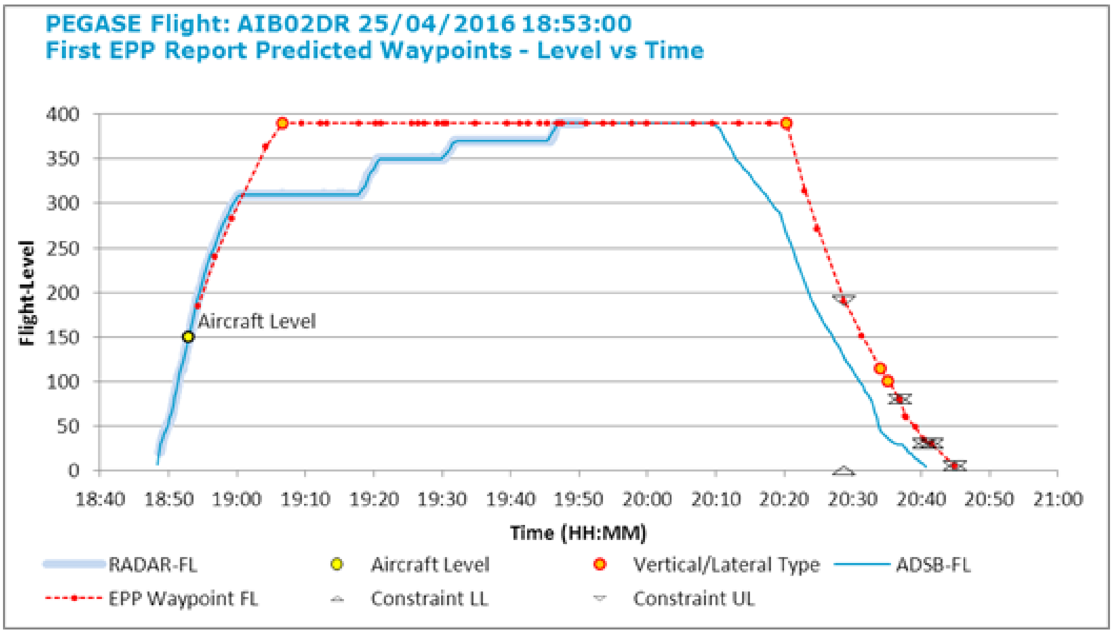


Figure 29 Flight AIB02DR on 25/04/2016 cruise level set to FL390

The figures show the effect on the EPP of the different cruise level settings by the flight crew. The cruise level setting chosen by the flight crew impacts the cruise level predicted by the FMS. This in turn affects the EPP waypoint predictions, including the determination of the top-of-climb and top-of-descent waypoints, and the prediction of estimated times at waypoints.

This example raises implications for the design of ground-systems using EPP, and for the management of flight plan information. In order to ensure conformance between the ground based planned trajectory and the aircraft EPP trajectory, it will be necessary to ensure that the flight plan information in the ground system exactly matches the flight plan information loaded into the FMS, and that both of these flight plans accurately represent the planned vertical profile of the flight, including any planned step climbs or descents.

Effect of flight crew route amendments

During the PEGASE flight trials, it has been observed that the EPP trajectory can be temporarily incorrect whilst the flight crew is amending the route.

This effect is illustrated in the following figures.

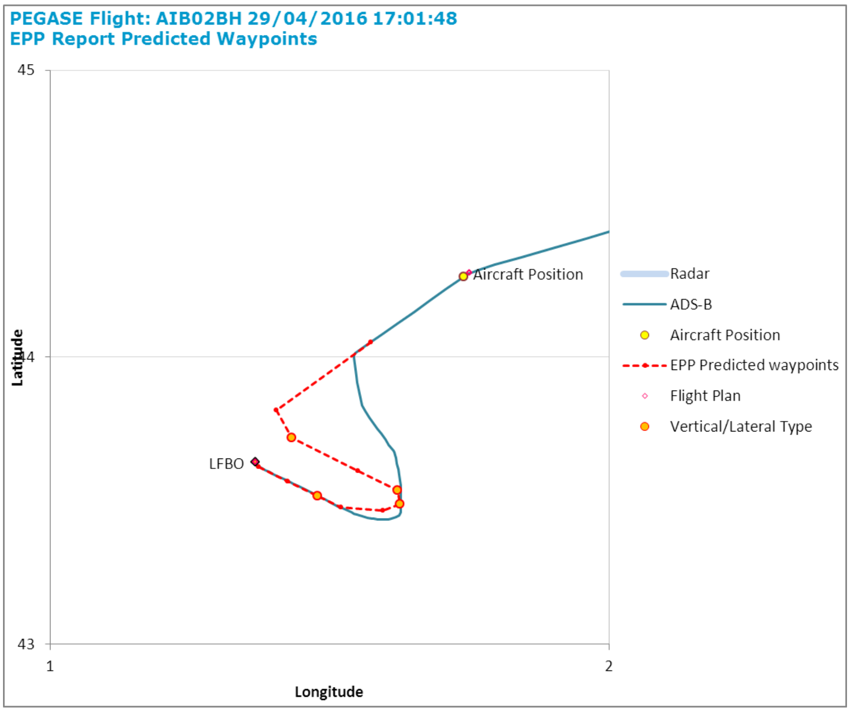


Figure 30 Flight AIB02BH 29/04/2016 EPP before route amendment

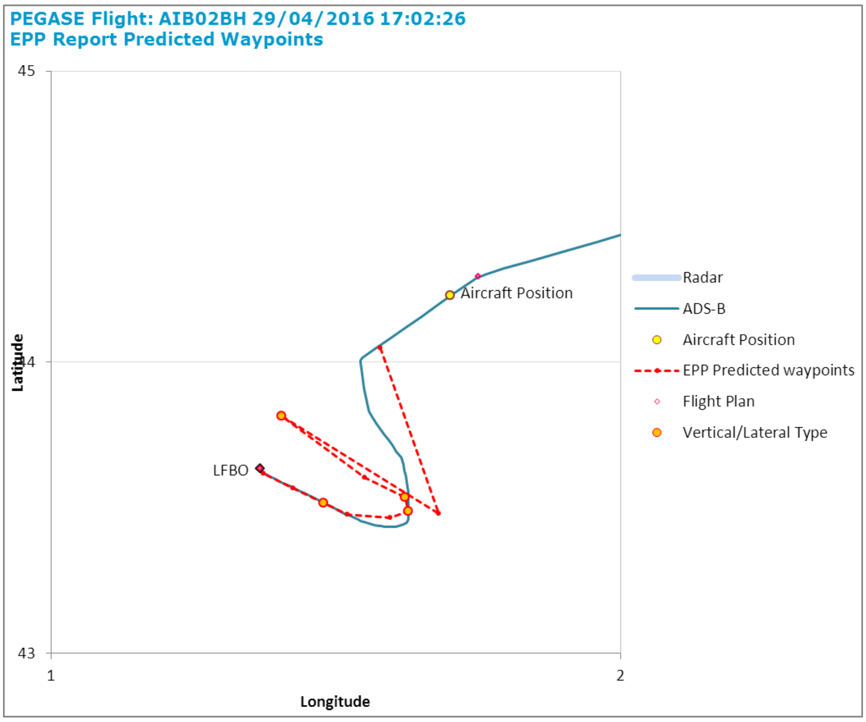


Figure 31 Flight AIB02BH 29/04/2016 EPP during route amendment

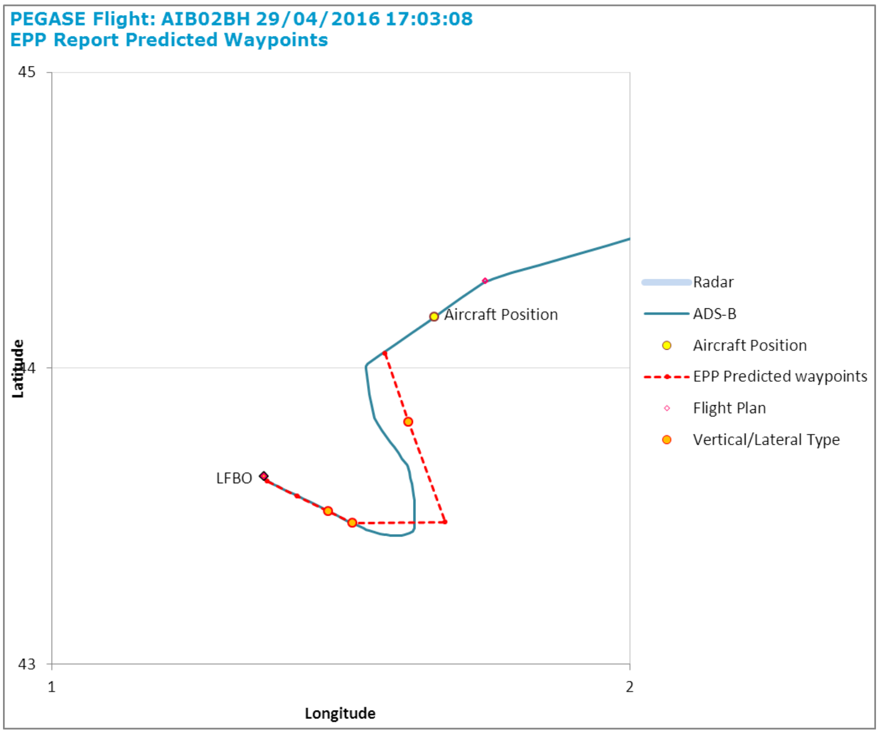


Figure 32 Flight AIB02BH 29/04/2016 EPP after route amendment

The figures above show the effect of a flight crew route amendment. This route amendment was entered by the crew to update the path of flight to approach the destination airport. The amendment involved the insertion of new waypoints, and the deletion of existing waypoints to adjust the route. In this example this process took 1 minute and 20 seconds to complete. Observations of other flights indicate that this process can take a period of minutes to complete.

Whilst the route is being manually updated, the downlinked EPP trajectory can include out of sequence waypoints, and the predicted times at the waypoints will not be accurate, due to the extra distance of flight of the out of sequence waypoints.

It should be noted that the FMS may remain in lateral managed mode throughout the route amendment process.

An implication of this observed EPP behaviour is that ground systems will need to incorporate integrity checking of the EPP data received from the aircraft before using the data in ground system applications. This will include conformance checks between the ground-system planned waypoints and the EPP waypoints, it may also be necessary to check for the angles of turn at EPP waypoints to identify this type of anomalous sequence. The methods of conformance checking, and the handling of non-conformance events will depend on the specifics of the ground-system application.

6.4.7.1.3.4 Effects of prototype system implementation

The PEGASE flight trials have been conducted using Thales and Honeywell FMS and ATSU systems providing prototype EPP functionality based on the draft standard (version H). During the flight trials, cases have been observed where the invalid or unexpected EPP data has been produced. It is expected that many of these cases are a result of the prototype operation, and will be improved in future FMS/ATSU implementations of EPP functions.

These include the following observations:

- There is a known issue with the prototype ATSU avionic component for EPP data that is downlinked west of the Greenwich Meridian. The longitude data has an error within the data. For the PEGASE flight-trials a post downlink correction is applied to the EPP data; this is described in the PEGASE Demonstration Plan[2].
- There is also a known issue with reporting the vertical managed mode value when the A/C is in climb and in vertical selected mode in the EPP messages, so that for some of the flight-trials the vertical managed state is not reported correctly in the downlinked EPP data for the climb phase.
- During some of the flights it was observed that an occasional EPP report can contain an invalid EPP waypoint lat-long position (for example 0, 0 has been observed).
- During some of the flights it was observed that an occasional EPP report may contain an invalid waypoint with no name or type values, or a waypoint which is behind the aircraft position. These appear to be points internally computed by the FMS, for example extrapolated points used to compute the vertical profile.
- Some flights were observed to have vertical discontinuities in the projected profile, for example two waypoints with the same lat-long position, but with different predicted altitude and times. It is understood that this is allowed behaviour for FMS systems. When the flight crew enters a STAR, it is possible that the FMS can introduce a vertical discontinuity in the predicted descent profile.
- Some flights were observed to occasionally produce empty EPP reports with no predicted waypoints, or waypoints with blank predicted altitude and time values. It is thought these empty EPP reports may be produced at times when the FMS is in mid-process of re-calculating and updating the trajectory.
- There are also some known differences between the detailed operation of EPP in the Thales and Honeywell FMSs. For example, in one FMS the waypoint reference lat-long position is reported, whereas in the other FMS, the predicted abeam position at the turn is reported.

It is expected that many of these issues will be addressed in future implementations of aircraft EPP functions. However, it is possible that there will remain specific aspects of the operation of different FMS manufacturers, and these may need to be considered for ground-system developments.

For the PEGASE analysis tasks, where these data anomalies can be detected, and for those that would affect the analysis results, then filtering rules have been applied to exclude the data from the analysis. These filtering rules are described in the relevant sections of this document (see 6.4.7.1.5.1 and 6.4.7.3.1.1).

6.4.7.1.3.5 Conclusions of EPP observation analysis

The analysis from the PEGASE flight trials indicates that there can be operational situations where the EPP predicted trajectory does not accurately represent the aircraft behaviour, and therefore there will need to be integrity checks, and conformance checks applied before the EPP data may be incorporated into the ground-based trajectory management systems.

There will also need to be improved processes to ensure that the flight-plan information loaded into aircraft and any data entered by the flight crew exactly matches the flight-plan/business trajectory information in ground systems. It will be necessary to ensure that the flight-plan information loaded into the aircraft precisely represents the planned profile of flight, including any changes to cruise level during the flight.

6.4.7.1.4 Stability of EPP ETO prediction

The following two sections detail the differences in term of time accuracy (and dispersion) between two cases: the first case is a flight where a significant proportion of the flight could be flown in managed mode (AIB02IT on 08/12/15) while the second is a flight where several directs interfered with the use of managed guidance modes.

6.4.7.1.4.1 AIB02IT

The evolution of the predicted times at fix is given in Figure 33. The vertical axis gives the time at which the prediction was computed: it represents the real time. The time of prediction increases down. The horizontal axis shows the predicted time for the different fixes in the recorded EPPs. For each of these fixes the (mostly) vertical line gives the evolution of the predicted time over for that fix. The down dashed diagonal represents the "now time". On this line, the green points indicate when a given fix is overflown.

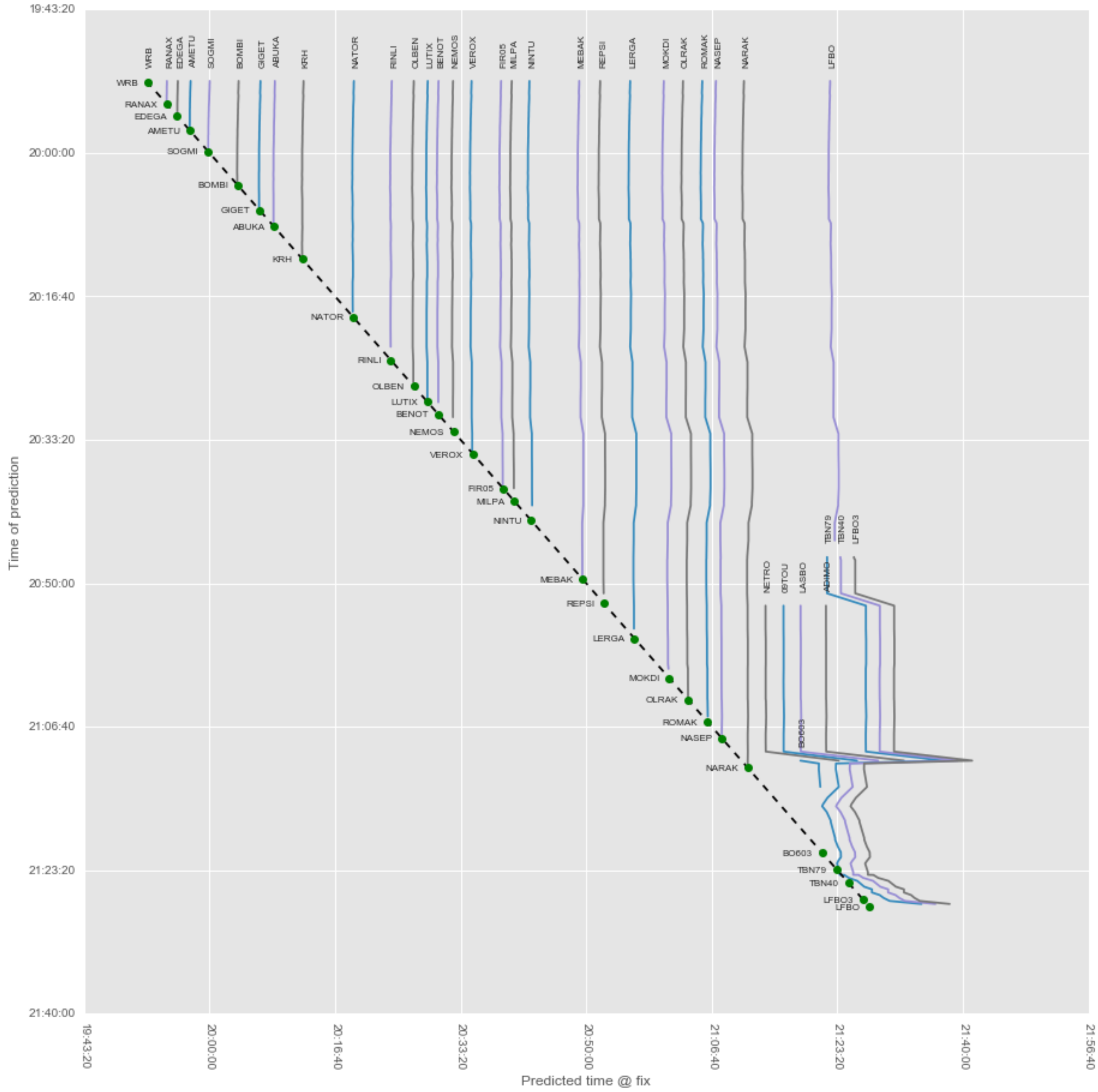


Figure 33: Predicted times evolution for AIB02IT

Figure 33 shows the stability and accuracy of the prediction time till point NARAK (initial STAR point). Around 20:20, the STAR is changed (selected?) causing the introduction of additional fixes in the FMS flight plan and the appearance of significant predicted time changes for the points after NARAK.
This is further reflected in Figure 34 which shows the time and altitude variability distributions. Variability is expressed both as standard deviation and with the more robust estimators that are the inter-quartile range and the range.
It shows that except from a few outliers (linked to the STAR change) the variability of the predictions stays low and essentially distributed towards zero.

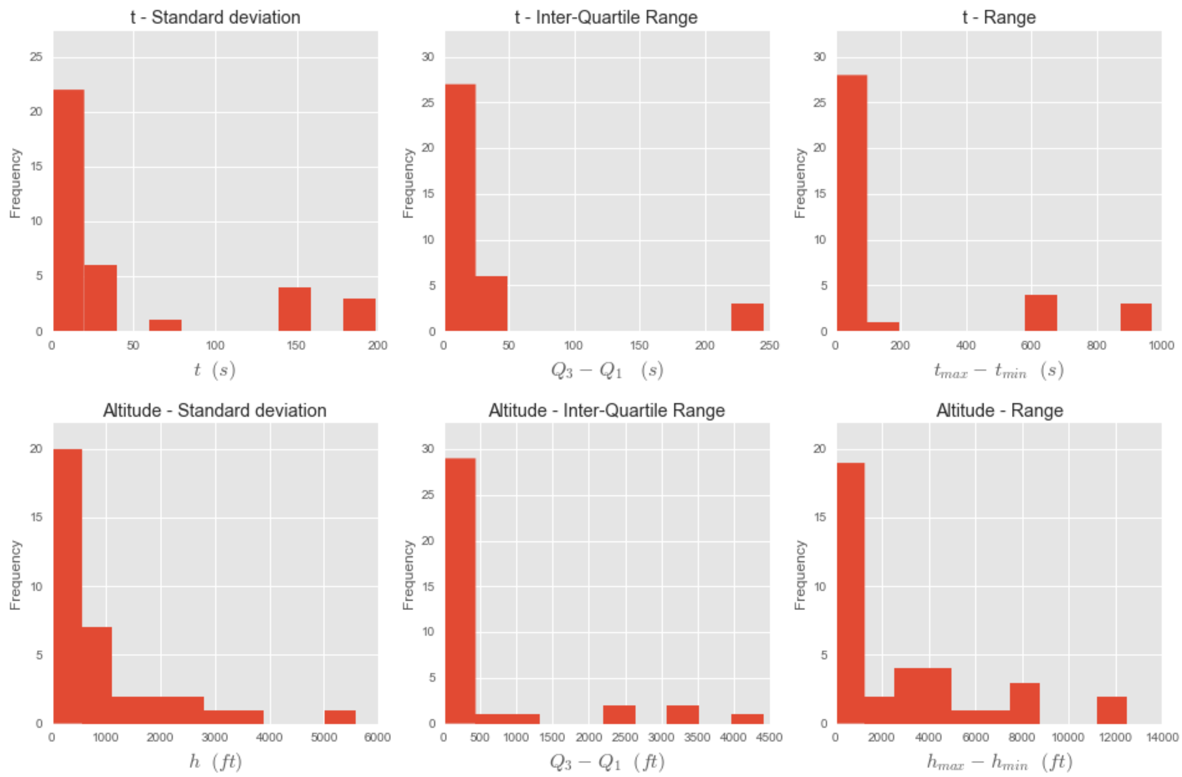


Figure 34: Time and altitude variability for AIB02IT

6.4.7.1.4.2 AIB02DF

The AIB02DF flight was subject of several directs (see Figure 23). This is reflected by a greater variability of the predicted times at fix. Moreover, many fixes are sequenced and not overflown (Figure 35). For example, the direct from BAM to LIMGO (around 17:00) cause the sequencing of the intermediate points and a (backward) time shift for the subsequent points. Similar effects are visible for the direct from GTQ to TUROM (around 17:20) and from TUROM to LERGA (around 17:40).

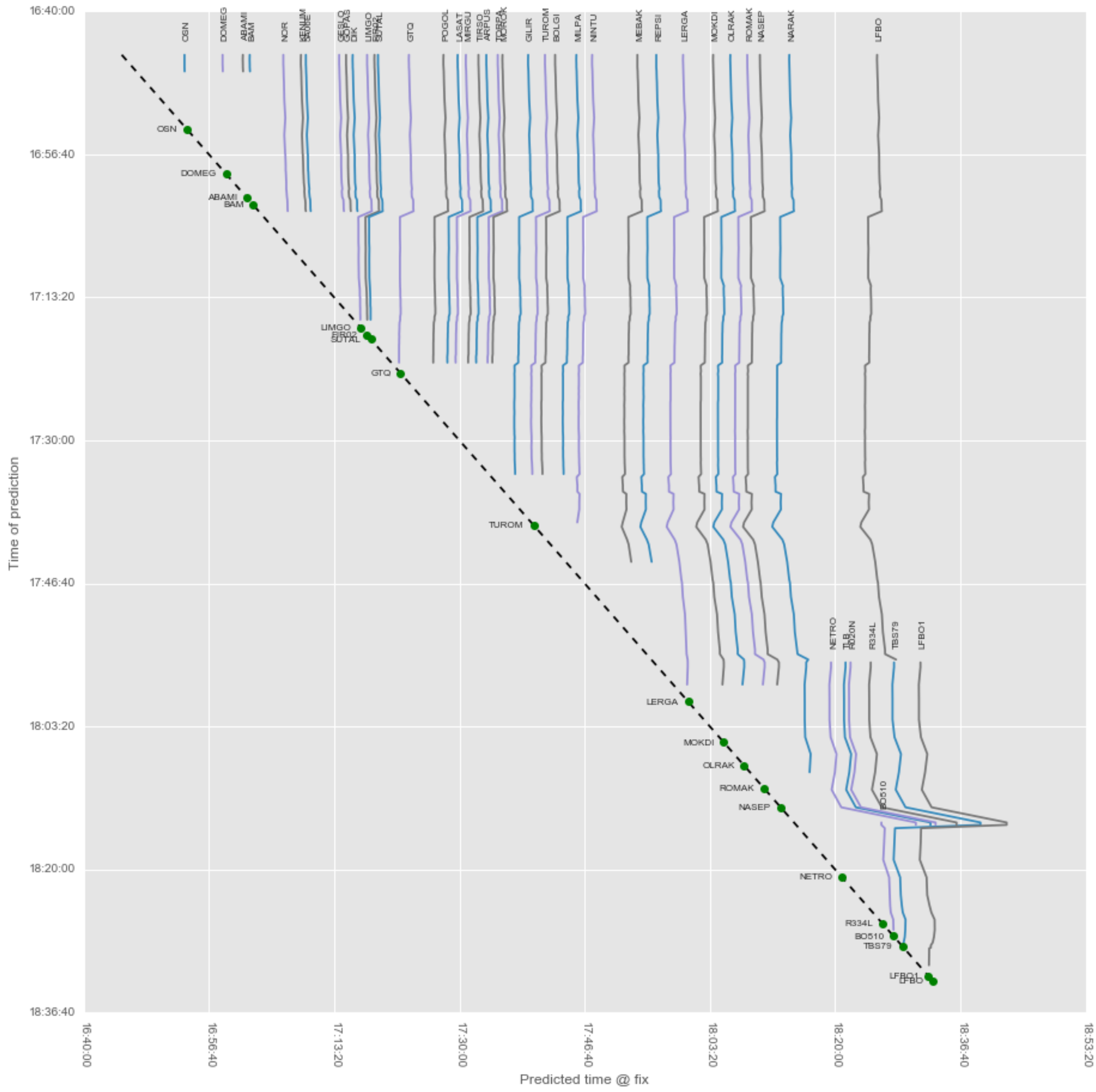


Figure 35: Predicted times evolution for AIB02DF

These changes in the lateral profile have a direct effect in the time profiles. This increase in variability is apparent in the variability distribution in Figure 36: the standard deviation, inter-quartile range and range distributions are much more spread for this flight.

Figure 36: Time and altitude variability for AIB02DF

6.4.7.1.5 Accuracy of EPP-derived ETO Predictions

A number of ATM processes require estimates of a flight's time of arrival (ETO) over a given waypoint, to inform their planning. These processes cover a spectrum of look-ahead time, from the short term (tactical and planner controller tasks), through Arrival and Flow Management functions, to longer term processes such as demand and capacity balancing at a regional level. Currently these ETOs are derived by ground-based trajectory predictors, both locally and at a network level, and are updated with surveillance-derived data as the flight progresses.

EPP provides the possibility to access FMS-generated ETOs during the flight execution phase. The short-term tactical and planner controlling tasks are likely to be more efficient thanks to higher fidelity, short-range ground-based trajectory predictions tools. However FMS-generated estimates also have the potential to feed arrival and flow management processes. This analysis considers the use of such data to support these processes. SESAR project 5.6.4 [11] proposed an operational concept for an arrival Manager (AMAN) with a capture horizon of 200-400nm (~25-50 min at jet cruise speed); there are currently AMANs operating up to 350nm horizon.

For the demonstration report 42 PEGASE flights were included in the data analysis, up to and including AIB2BY (04/05/16). This study investigated the operational behaviours (ATC and flight-crew) that affect the usefulness of FMS-derived trajectory data transmitted via ADS-C. The purpose is to understand the conditions under which EPP data can and cannot be used in an ATC operation. The performance of the FMS' trajectory prediction was not directly investigated here

6.4.7.1.5.1 Data Preparation

To perform meaningful analysis a clean dataset is required. The raw data from the EPP reports and other external sources was processed so it generated a robust and credible reference and removed faulty data which can be attributed to FMS prototype behaviour. Examples of faulty data include reports where waypoint information is corrupted or missing.

6.4.7.1.5.1.1 Reference data

To compare the accuracy of the predictions made by the FMS the actual time a waypoint was overflown (or its abeam) has to be known. An unambiguous value for this was generated by combining the ADS-B information with the geographic locations of the waypoints as contained in the flight plan. ADS-B was chosen as the reference because this dataset covers the whole flight, including the latter part of the typical ferry flight. Radar information, although available in higher resolution only covers the first part of the typical ferry flight.

For each waypoint given in the flight plan, the location is matched to the ADS-B trajectory. This gives a geographical location for the waypoint and the abeam distance to the waypoint as well as the time the plane was closest to the waypoint. This timestamp is the reference value for the time error calculations.

To ensure that the waypoints are all in the correct location, each flight's reference locations are only calculated based on waypoints which are in the flight plan. Waypoints which are in the EPP reports but are not in the flight plan are ignored. Roughly 38% of waypoint predictions are lost because of this approach but the approach does ensure an unambiguous reference location for a planned waypoint.

6.4.7.1.5.1.2 Test behaviour

Some of the ferry flights show "flight test like" behaviour at the start of the flight. This will include manoeuvres and speed changes at a lower altitude as well as spending a prolonged time at a lower altitude. Usually no EPP reports are generated during this flight phase but the ones that are generated often show large time discrepancies. To avoid these 'rogue' reports to skew the results unfairly any reports generated before the plane has crossed an altitude of 15000ft are discarded. This is only done during the start of each dataset; no reports are removed from the descent phase.

6.4.7.1.5.1.3 Cruise levels

Rarely will an aeroplane remain at the same flight level for the duration of the flight.

For the purposes of this analysis a cruise level is defined as a flight level above 15000ft which is held by more than 180 seconds by the aeroplane. This filter is used to exclude any flight test behaviour as well as intermediate level offs during the climb. The time at which the first flight level is reached is seen as the start of the 'iCruise' phase as described below.

6.4.7.1.5.1.4 Flight Phases

For the ETO analysis each flight was divided up in four phases: Climb, before the aeroplane reaches its first cruise level, initial Cruise (iCruise), when the aeroplane is cruising but not at its final cruise level, Cruise when the aeroplane has reached its final cruise level and descent. The timings for these phases are extracted from the cruise levels, which are defined as per section 6.4.7.1.5.1.3 and applied to the data. The flight phases are illustrated graphically in Figure 37.

The Climb phase starts at FL150; this is to filter out low-level flight-test-related behaviour that was observed at the start of a number of ferry flights. The initial Cruise (iCruise) phase was introduced to isolate the period of flight in which the aircraft can be considered to be in cruise flight, but has not yet reached its final cruise level. The start of iCruise phase is defined as the start of the 1st period of level flight of ≥3mins duration that occurs at or above FL150. The Cruise phase starts at the point at which the ADS-B return is first observed to reach the highest observed (ADS-B) FL. The descent phase starts at the point of the last ADS-B return observed at the highest observed (ADS-B) FL.

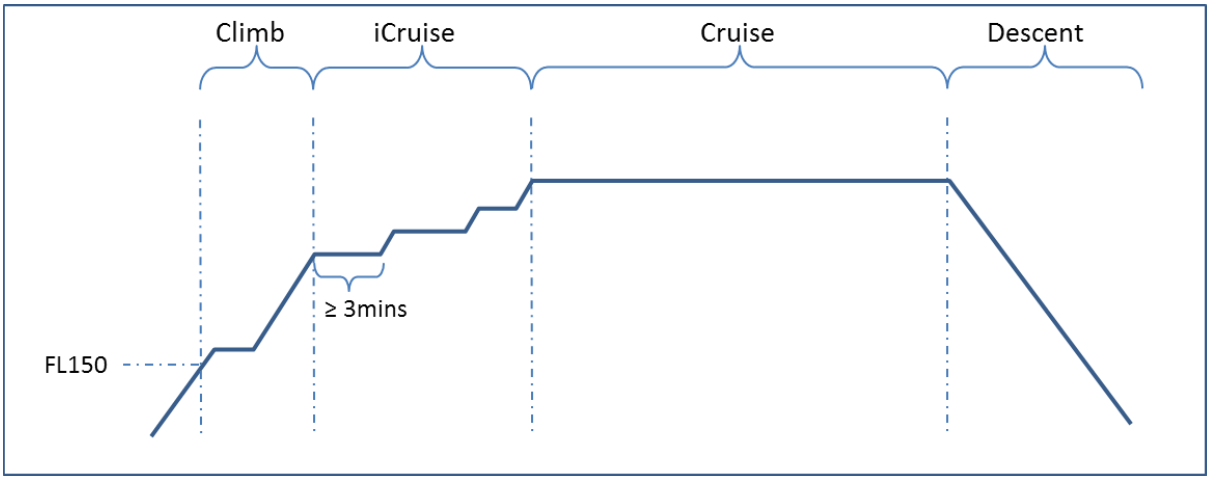


Figure 37 Flight phase definition

6.4.7.1.5.2 Analysis Method

A top-down analysis process was followed. Initially data was calculated for the whole set of flights, with only basic data cleaning performed. The purpose of this was to understand the quality of data received 'as-is', regardless of alignment of the FMS input data with the ground ATC plan. To limit variability the analysis was only performed on reports that were generated when the aeroplane's lateral navigation mode was managed.

Individual factors that may affect the usefulness of EPP data were then isolated and investigated. For example, the impact on FMS predictions of having the STAR entered into the FMS was assessed. Some of these factors have been identified for future research.

Firstly the absolute time error in EPP ETO prediction was calculated for each flight-plan waypoint, for each EPP report of each flight:

$$Absolute\ time\ error\ (s) = ATO_{ADS-B} - ETO_{EPP}$$

Sign convention: A negative value indicates that the predicted ETO was after the Actual Time Over (ATO). The aeroplane was abeam the waypoint before the predicted time.

6.4.7.1.5.3 Categorisation by Flight Phase

These time errors were then categorised by combination of

a) the flight phase of the EPP report location, and

b) the flight phase of the location of the predicted WPT,

as per Table 10.

Report location		Climb	iCruise	Cruise	Descent
Predicted point location	Climb	✓			
	iCruise	✓	✓		
	Cruise	✓	✓	✓	
	Descent	✓	✓	✓	✓

Table 10: Categorisation of Results

For each category, the mean of the absolute time errors for a given flight was calculated. This was then repeated for each flight, resulting in ten mean errors for each flight: one per flight-phase permutation. The resulting theoretical maximum number of data points per category is 42 (one per flight). However data was not received for the entirety of all flights, resulting in some flights not having data for a given category. Table 11 contains the actual number of flights included in each category. The primary way of presenting the results is in the form of box plots. A key to the box plots used in the ETO analysis is presented in Figure 38.

The categories are named according to the flight phase in which the EPP report was generated, and the phase in which the subject waypoint is located – for example 'Cruise-Descent' refers to predicted ETOs for WPTs that are located in the descent phase, that are part of EPP reports that were generated in the cruise phase.

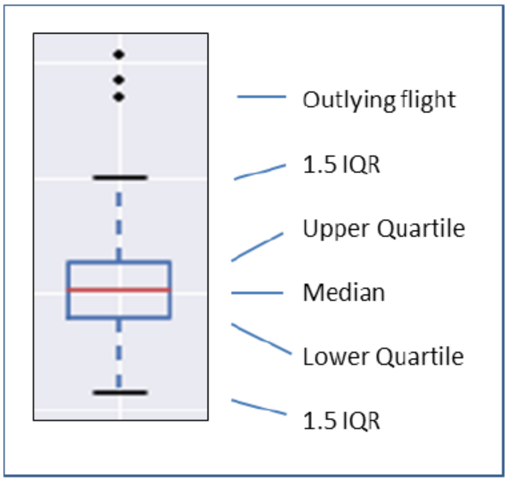


Figure 38: Key to Box Plots

Results

The results are presented per category in Table 11 and Figure 39. The sample sizes in Table 11 indicate a similar level of confidence in each category. Each of the data points plotted in Figure 39 is the mean error for a specific flight. Therefore the values in the mean column in Table 11 are 'mean of means'.

For clarity of presentation, six extreme outlying flights (with mean errors >600s) are not shown in Figure 39; these are instead listed in Table 12 and discussed in the results discussion below.

Category	Number of flights	Median (s)	Mean (s)	Std (s)	Min (s)	Max (s)
CLB-CLB	18	4	-7	56	-229	32
CLB-iCRZ	18	-22	-13	166	-555	273
CLB-CRZ	27	49	94	323	-902	1185
CLB-DS	28	-58	-49	300	-996	471
iCRZ-iCRZ	26	5	12	67	-169	201
iCRZ-CRZ	28	56	70	152	-307	465
iCRZ-DS	28	-43	-28	189	-383	354
CRZ-CRZ	33	5	12	35	-53	150
CRZ-DS	38	-32	-13	93	-145	353
DS-DS	36	-5	-13	74	-212	186

Table 11: Mean absolute time error in ETO prediction per category

Flight	Category	error (s)
AIB02BY Route East	CLB-CRZ1	-902
AIB04IH Route East	CLB-CRZ1	1185
AIB02BY Route East	CLB-DS	-996

Table 12: Outlying Flights with mean absolute error >600s

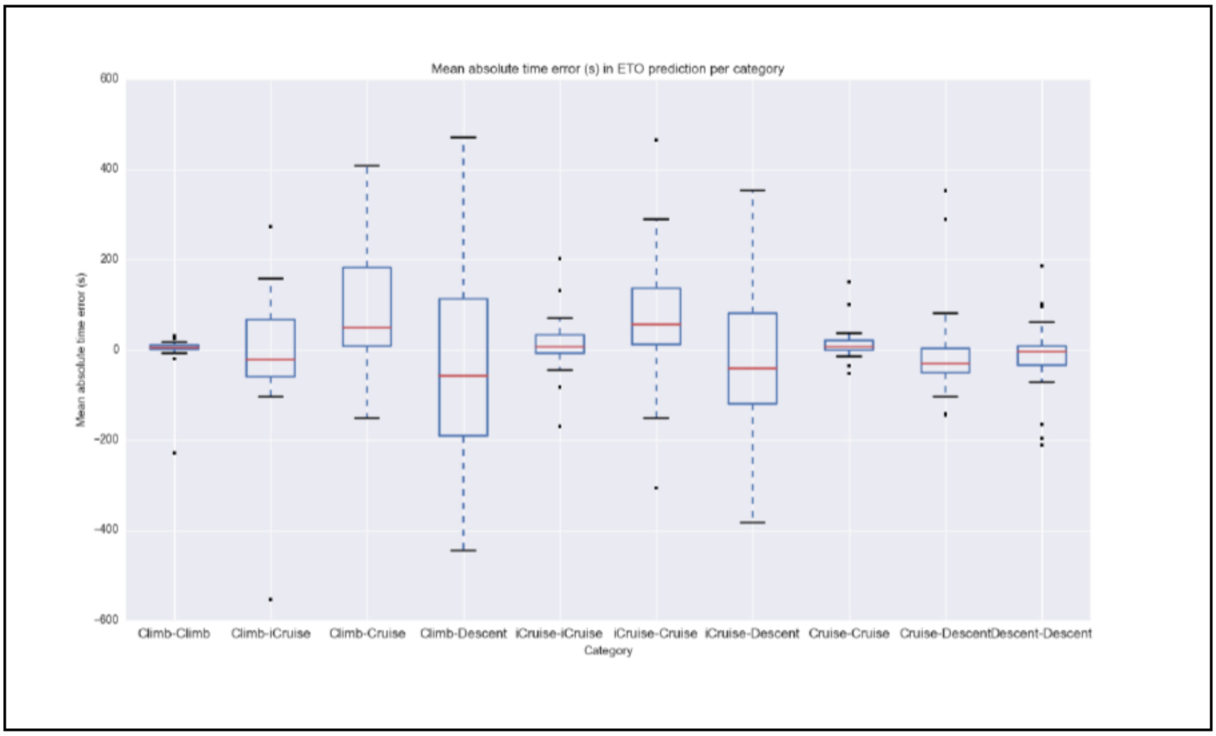


Figure 39: Mean absolute time error in ETO prediction per category

The first observation is that the predicted errors made for waypoints in the current flight phase (Climb-Climb, iCruise-iCruise, Cruise-Cruise and Descent-Descent) are noticeably smaller than for other categories. The climb-descent category shows the largest spread. This will be influenced in part by the length of the prediction horizon, but there is also some unpredictable behaviour around the transition between flight phases that affects the accuracy of the prediction.

Climb-Climb

This category shows the narrowest spread of results of all the categories, closely centred on zero error. Note that the climb phase covers a relatively short time period, as a filter below FL150 is used to remove flight-test behaviours from the dataset.

Climb-iCruise

This category shows a moderate spread of results with a slightly negative (-22s, Table 11) median error. The spread of results was wider than for the climb-climb category; this is caused by significant periods of cruise at lower cruise levels before reaching the FMS cruise level (defined as initial Cruise), as seen on a number of flights on the EDHI-LFBO (ferry-flight) routes. During this period, the FMS cruise level was frequently observed to differ from the cleared flight level (CFL).

Climb-Cruise

This category shows a slightly positive (49s, Table 11) median error, and the widest spread of outliers. AIB02BY showed an error of-902s, due to an extended period of iCruise at FL310 and FL340, during which the FMS was calculating a trajectory for a cruise level of FL390 (see Figure 40). AIB04IH showed an error of 1185s; the cause of which is not immediately clear.

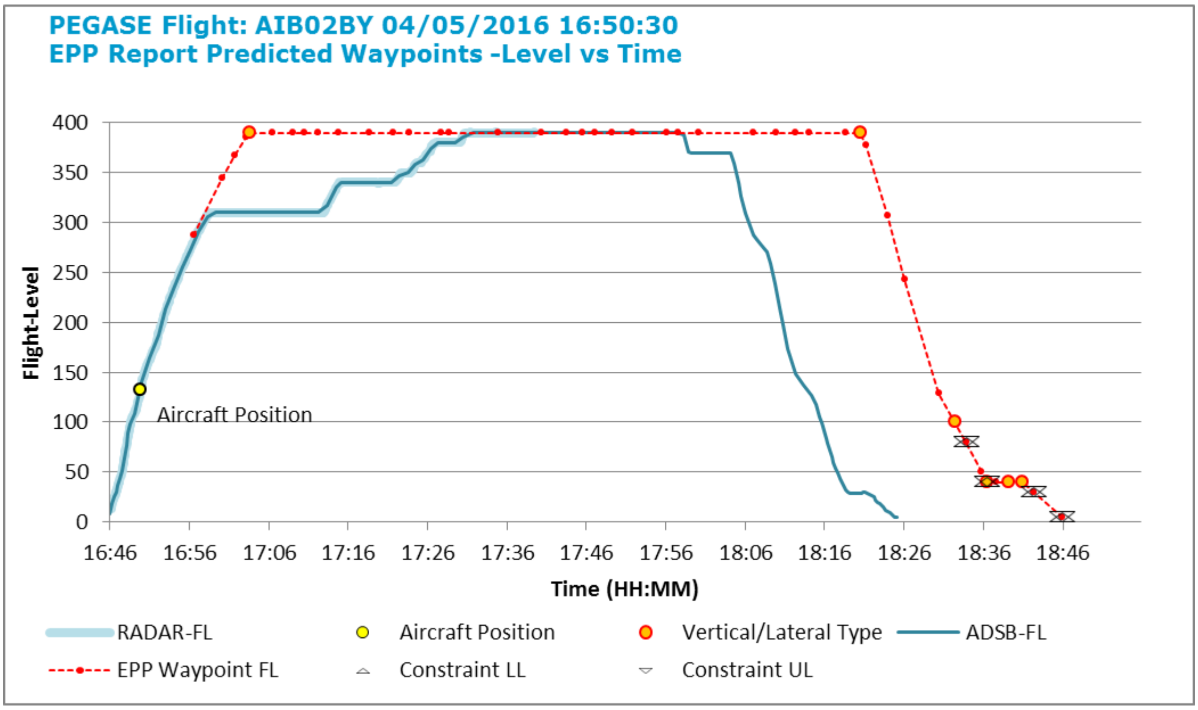


Figure 40: AIB02BY: Disparity between Flown and predicted profile during initial cruise

Climb-Descent

This category exhibited a wide spread of errors, around a median value of -58s (Table 11). This wide spread may be due to the flights being subject to a large number of operational variables over a typically longer period of flight (e.g. ~80 mins). These include step-climbs below the FMS cruise level, DCT routings given by ATC, update of the FMS route with the STAR, and pilot or controller-initiated early descent before FMS-calculated ToD.

One significant outlier was seen: AIB02BY (Figure 40), -902s error. This flight had its STAR entered prior to the analysed climb phase; the error was primarily due to the disparity between flown and predicted cruise level during the initial cruise phase.

iCruise-iCruise

This category shows a relatively narrow spread of errors, with a median of 5s, and a mean of 12s (Table 11). The vast majority of reported predictions in this category are based on an FMS cruise level that is different to the actual flown level (Figure 40 illustrates). However the relatively short time period, coupled with limited level difference (typically <8000ft difference) limits the propagation of ETO error. These initial results suggest that predictions in this category may be suitable for supporting Arrival and Network Management processes.

iCruise-Cruise

This category showed a moderate spread of errors, with a median of 56s and mean of 70s (Table 11).

iCruise-Descent

This category shows a wide spread of results with a median of -43s and mean of -28s. This wide spread may in part be due to a range of STAR entry times in the FMS; this effect is explored further below.

Cruise-Cruise

This category shows one of the narrowest spreads of any category. This is to be expected, as aircraft are in level flight in the phase. The main source of prediction errors in this category is likely to be DCT routings given to flights in cruise. These initial results suggest that predictions in this category may be suitable for supporting Arrival and Network Management processes.

Cruise-Descent

This category shows a wider spread of errors than the previous category, with median and mean errors of -32s and -13s respectively (Table 11). The spread of errors is likely to be due to a number of operational factors associated with arrival planning and execution: STAR not entered in FMS, descent initiated before FMS-planned ToD, and ATC vectoring in approach phase. An initial investigation into the effect of the STAR entry on ETO accuracy is presented in the following section.

Descent-Descent

The Descent-Descent category showed one of the narrowest spread of results of the ten categories. This category is also very closely centred on zero error, with median and mean errors of -5 and -13s respectively (Table 11). This indicates that once an aircraft has started its descent, the time errors for subsequent WPTs tend to reduce, compared to the Predictions made in either Climb or Cruise phases. This is because the FMS is seen to re-calculate its profile when it detects a deviation of flown behaviour from the FMS plan, resulting in an EPP trajectory that is closer to the flown profile. Some flights downlinked EPP reports with predicted times for waypoints that were behind the aircraft which has an adverse effect on the accuracy of predictions. These have not been excluded from the dataset at this stage as it is believed to be legitimate FMS behaviour; however this requires further investigation.

Having analysed the whole EPP dataset, we then isolated individual operational factors and investigated their effect on the usefulness of EPP-derived ETOs. These factors were the entry of the STAR in the FMS (6.4.7.1.5.4), the prediction horizon (6.4.7.1.5.5) and lateral route alignment between FMS and flown trajectories (6.4.7.1.5.6).

6.4.7.1.5.4 Effect of STAR entry in FMS on ETO

In current operations, the flight-crew is not obliged to enter the STAR in the FMS until it is required for descent planning. In addition, in some cases the STAR is known to the crew before departure, whilst in other cases the STAR may not be received until well into the cruise phase (for example long haul flights, or in the event of an arrival runway change mid-flight).

The entry of the STAR into the FMS will change the planned route and level constraints in the arrival phase of the flight, and in turn affect the EPP predicted decent profile and ETOs for waypoints in the arrival phase. This may have implications for ground-system applications potential usage of EPP data, such as AMAN systems.

Across the 42 flights analysed, the point at which the STAR was entered was seen to vary considerably; around a quarter of flights had the STAR entered prior to top of climb, rising to around 75% of flights by ToD. The received EPP reports were classified according to whether they were generated before or after the STAR was entered in the FMS.

To investigate the effect that STAR entry has on the accuracy of EPP-derived ETOs, the analysis per flight phase, as described in section 6.4.7.1.5.3, was repeated for

a) Waypoint predictions generated *without* the STAR entered in the FMS, and

b) Waypoint predictions generated *with* the STAR entered in the FMS.

Results

Results are presented without STAR in **Table 13** and **Figure 41**, and with STAR in Table 14 and Figure 42. Outlying flights that are beyond the scale of the plots are listed in Table 15 and Table 16.

Category	Number of Flights	Median (s)	Mean (s)	Std (s)	Min (s)	Max (s)
CLB-CLB	15	4	-10	62	-229	32
CLB-iCRZ	13	-17	15	106	-104	273
CLB-CRZ	21	64	150	286	-152	1185
CLB-DS	22	13	12	250	-445	471
iCRZ-iCRZ	19	8	14	47	-83	130
iCRZ-CRZ	20	45	88	151	-153	465
iCRZ-DS	20	-43	-15	186	-337	354
CRZ-CRZ	23	5	14	42	-53	150
CRZ-DS	24	-29	1	118	-145	353
DS-DS	5	1	-3	46	-72	52

Table 13: Mean absolute time error in ETO prediction per category: Predictions made when STAR has not been entered

Category	Number of Flights	Median (s)	Mean (s)	Std (s)	Min (s)	Max (s)
CLB-CLB	4	5	5	2	2	7
CLB-iCRZ	5	-28	-85	274	-555	157
CLB-CRZ	8	35	-68	340	-902	116
CLB-DS	8	-85	-206	348	-996	66
iCRZ-iCRZ	8	-3	-2	103	-169	201
iCRZ-CRZ	9	62	24	146	-307	206
iCRZ-DS	9	-6	-53	195	-383	225
CRZ-CRZ	21	3	6	10	-6	37
CRZ-DS	29	-35	-28	75	-211	255
DS-DS	31	-7	-15	78	-212	186

Table 14: Mean absolute time error in ETO prediction per category: Predictions made when STAR has been entered

Flight	Category	Error (s)
AIB04IH Route East	CLB-CRZ1	1185

Table 15: Outlying Flights with mean absolute error >600s; Predictions with no STAR entered

Flight	Category	Error (s)
AIB02BY Route East	CLB-CRZ1	-902
AIB02BY Route East	CLB-DS	-996

Table 16: Outlying Flights with mean absolute error >600s; Predictions with STAR entered

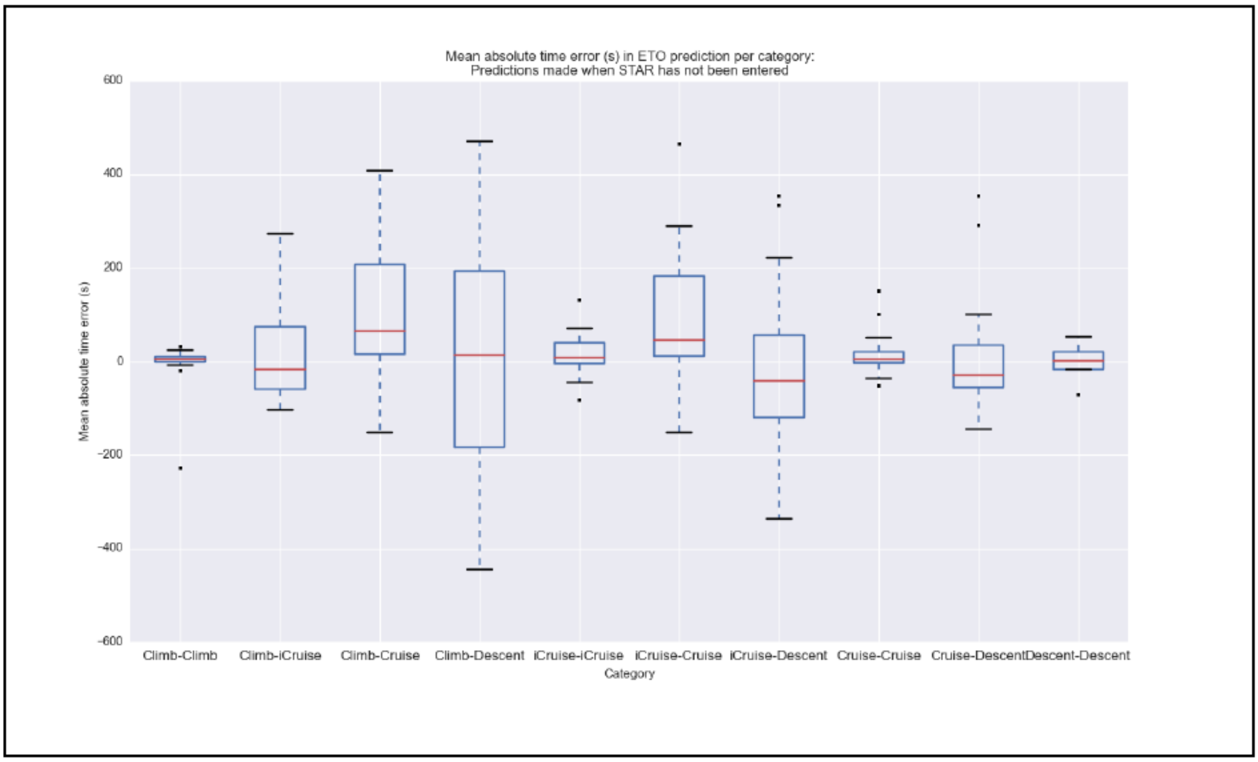


Figure 41: Mean absolute time error in ETO prediction per category: Predictions made when STAR has not been entered

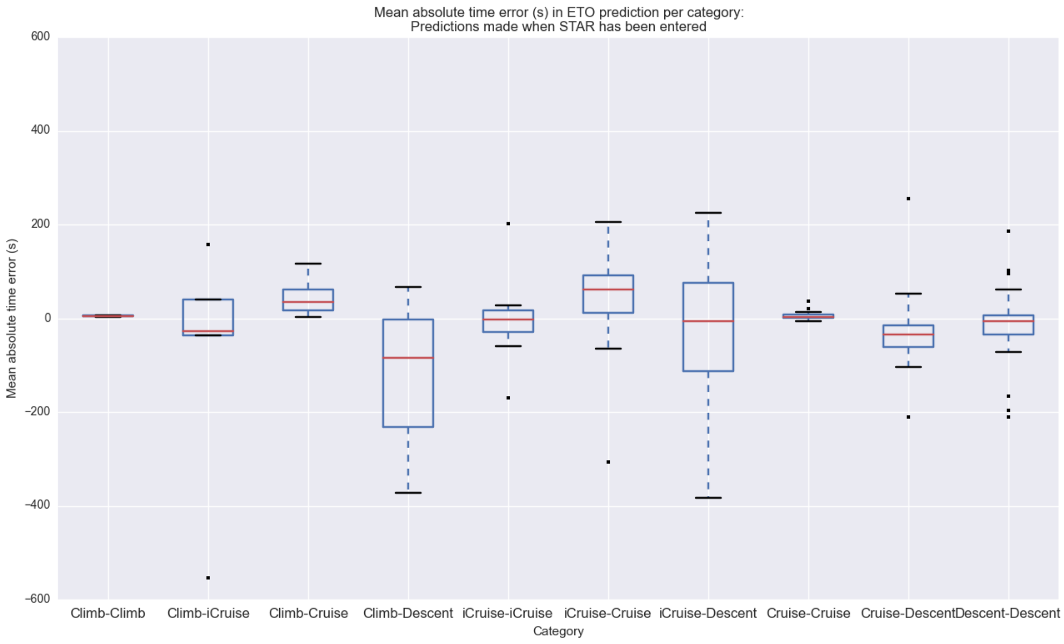


Figure 42: Mean absolute time error in ETO prediction per category: Predictions made when STAR has been entered

The entry of the STAR in the FMS shows a general trend for narrowing the total spread of results (max-min) for the majority of categories (Table 15 and Table 16), and an improvement in the median and mean results. Notable observations and exceptions are listed below:

Climb-Descent

Although the spread of results shows a strong improvement, the median error has deteriorated.

iCruise-iCruise

This category showed no appreciable difference between STAR and no STAR entry.

iCruise-Descent

This category showed a similar spread of results, but a noticeable improvement in median error (from -43s to -6s) when the STAR was included.

It was observed that the majority of flights did not have the STAR entered during climb or iCruise phase, with the majority entering the STAR during the Cruise phase. It is unclear why the STAR entry appears to improve the results for predicted ETOs for waypoints located in climb or iCruise, as the STAR would not be expected to affect the calculation of these ETOs.

These initial results suggest that entry of the STAR in the FMS in the early phases of flight has an appreciable benefit on the accuracy of down-stream ETOs which in turn may improve the performance of arrival and network management processes.

6.4.7.1.5.5 Categorisation by Prediction Horizon (time)

To investigate the viability of using EPP-derived ETOs in arrival and flow managment processes, the effect of prediction horizon on the accuracy of EPP-reported ETOs was analysed. The dataset including all flights was re-categorised by grouping prediction horizons into time boxes. These results are then reported against prediction horizons centred on each of these boxes as shown in Table 17. The time horizons of 40 and 60 mins are, for jet transport aircraft, approximately representative of 200 and 400nm ranges that an AMAN may be interested in.

Prediction horizon range, min	<10	10-30	30-50	50-70	70-90	>90
Reported prediction horizon, mins	<10	20	40	60	80	>90

Table 17: ETO measurement prediction horizon categorisation

Results

The absolute error results are presented in Table 18 and Figure 43; percentage errors are presented in Table 19 and Figure 43. Outliers are presented in Table 20.

Prediction Horizon (mins)	Number of Flights	Median (s)	Mean (s)	Std (s)	Min (s)	Max (s)
<10	41	1	-14	72	-375	63
20	41	6	5	81	-206	296
40	38	13	15	155	-301	545
60	35	42	12	213	-471	418
80	32	59	24	312	-753	608
>90	12	80	187	345	-284	712

Table 18: Absolute time errors categorised by prediction horizon

Prediction Horizon (mins)	Number of Flights	Median (%)	Mean (%)	Std (%)	Min (%)	Max (%)
<10	41	2	-18	76	-421	53
20	41	1	0	7	-18	25
40	38	1	1	7	-13	27
60	35	1	0	6	-13	12
80	32	1	0	7	-17	14
>90	12	2	3	6	-5	12

Table 19: Percentage time errors categorised by prediction horizon

The following results are not visible in Figure 43 as they are beyond the range of the plots:

Flight	Category	error
AIB214-I, EGNR-LFBO	% Error, <10min horizon	-421%
AIB02DR Route Central	% Error, <10min horizon	-135%
AIB02DH Route Central	% Error, <10min horizon	-204%

Table 20: Flights with absolute or percentage errors greater than the plotted chart ranges

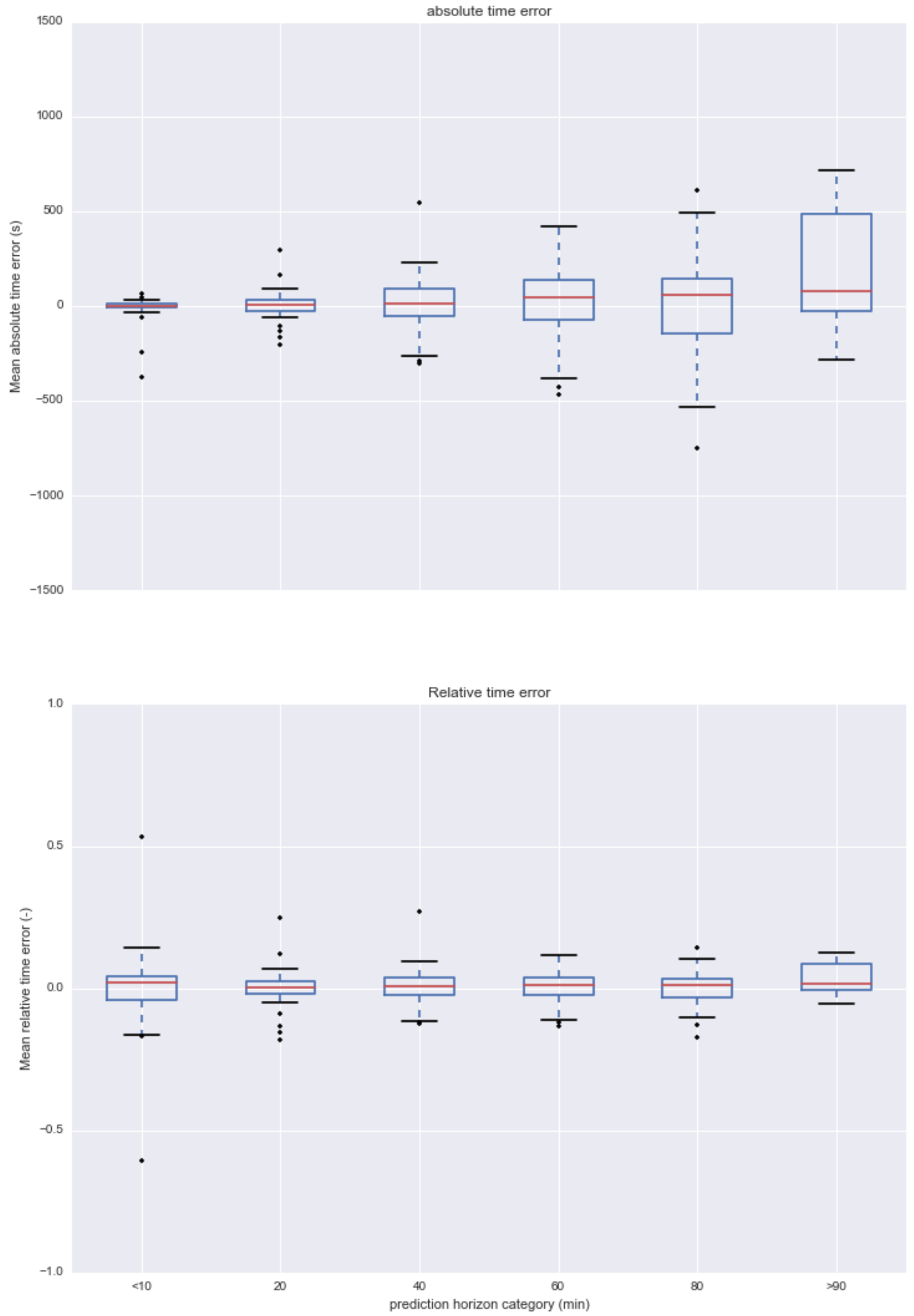


Figure 43: Mean absolute and relative time errors categorised by prediction horizon

The dataset shows a clear trend of reducing time error as the prediction horizon reduces, with errors reasonably centred on zero, for prediction horizons below 80 min (Figure 43). The spread of percentage time error is seen to be approximately constant across the categories up to 80 min, suggesting an approximately linear improvement in error as prediction horizon reduces. The > 90min time box exhibited errors skewed towards a positive error; the predictions in this time box will all be Climb-Descent category, the results of which were discussed in section 6.4.7.1.5.3. At 60 min horizon the median and mean results are 42 and 12s respectively; At 40 min horizon the median and mean results are similar, at 32 and -15s respectively. These results suggest that EPP-derived ETOs have the potential to support AMAN sequence-building. However, the results include a number of flights with significant prediction errors; further exploration is required to understand the cause of these.

6.4.7.1.5.6 Effect of Alignment of lateral route between FMS and ground on EPP ETO prediction error

A source of error in FMS prediction of ETO is a misalignment between the FMS planned lateral route, and the actual lateral path that is instructed by ATC. This misalignment is caused by ATC issuing direct (closed loop) instructions and heading (open loop) instructions. For example, vectoring will be always in open loop and DIRTO could in closed loop if it refers to a Waypoint contained in the current Flight Plan and in Open loop if it refers to a Waypoint out of the Flight Plan (refer to Figure 127).

This section investigates whether FMS-generated ETOs would be more accurate if the aircraft is allowed to follow its flight-planned route.

6.4.7.1.5.6.1 Method

The aim of the analysis in this section was to see how much more accurate the predictions are if the aeroplane is flown laterally the way the FMS desires. For this, each flight was divided into periods of time in which the lateral instruction state is constant (a valid prediction lifetime). Each period is bounded by two lateral ATC instructions.

The lateral instructions issued to the flight were inferred from FMS flight-crew inputs, as recorded by the Flight Data Recorder (FDR). The need for FDR data limits the usable dataset to only 24 flights.

A cleaning process removed any predictions which had been superseded by subsequent lateral clearances as well as predictions for times when the aeroplane was not in lateral managed mode. This process resulted in slightly more than 9000 waypoint predictions distributed over 33 valid prediction lifetimes. Only 18 out of the 24 flights contained segments which could be analysed. The ETO accuracy of the 'clean' dataset is compared to the accuracy of all the predictions from those 18 flights.

Of the 33 valid prediction lifetimes (time between ATC instructions) included in the study, 2 were shorter than 10 minutes, 20 were between 10 and 40 minutes, and 11 were longer than 40 minutes.

The length of prediction horizon is primarily determined by the combination of flight phases. As a result, the prediction horizons observed in the filtered dataset were not dissimilar to the unfiltered set; however the sample size is considerably reduced (see Table 21 and Table 22).

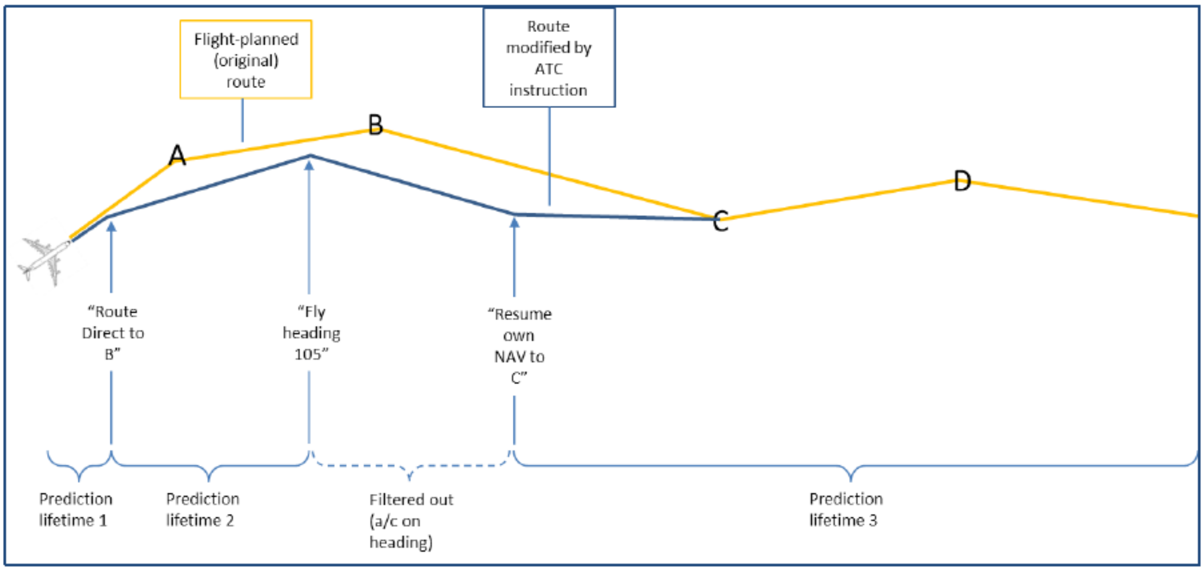


Figure 44 Definition of lateral valid prediction lifetimes

Each EPP report and each WPT prediction was labelled according to the prediction lifetime in which it is located. The WPT predictions were then filtered to remove any that occurred in a different lifetime to the report in which they were downlinked.

6.4.7.1.5.6.2 Results

The absolute error results for filtered and unfiltered datasets are presented in Table 21 and Table 22. As FDR data was not available for all PEGASE flights, only 18 flights were included in this analysis. Figure 45 presents the prediction lifetime-filtered results alongside unfiltered results for a dataset containing the same 18 flights.

Category	Number of Flights	Median (s)	Mean (s)	Std (s)	Min (s)	Max (s)
CLB-CLB	5	4	-2	12	-24	5
CLB-iCRZ	7	41	58	97	-51	192
CLB-CRZ	3	116	98	94	-5	181
CLB-DS	2	85	85	92	19	150
iCRZ-iCRZ	15	8	21	28	-18	96
iCRZ-CRZ	11	11	4	68	-153	105
iCRZ-DS	3	46	-57	210	-299	82
CRZ-CRZ	12	5	3	18	-53	21
CRZ-DS	10	2	-10	39	-118	15
DS-DS	12	3	3	4	-5	11

Table 21 Mean absolute time error in ETO prediction per category, filtered for lateral valid prediction lifetime, 18 flights

Category	Number of Flights	median	mean	std	min	max
CLB-CLB	7	4	-2	14	-24	10
CLB-iCRZ	11	-16	35	115	-83	273
CLB-CRZ	10	42	95	202	-152	409
CLB-DS	11	-132	14	350	-445	665
iCRZ-iCRZ	17	7	5	73	-223	130
iCRZ-CRZ	17	49	36	129	-226	247
iCRZ-DS	17	-36	-14	231	-398	391
CRZ-CRZ	17	4	8	35	-53	98
CRZ-DS	18	-32	-20	79	-145	210
DS-DS	18	-4	-6	26	-73	62

Table 22 Mean absolute time error in ETO prediction per category, unfiltered, 18 flights

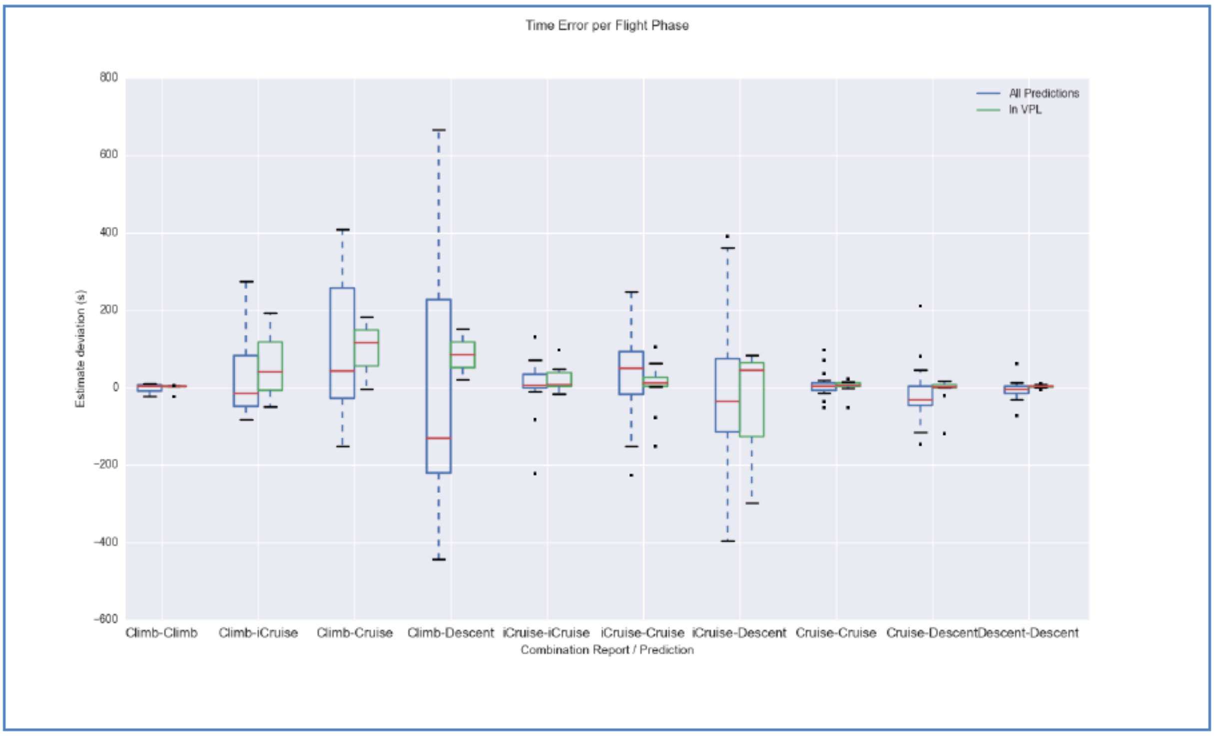


Figure 45 Mean absolute time error in ETO prediction per category: Comparison between results filtered for lateral valid prediction lifetime, and unfiltered results

In every category, filtering for prediction lifetime led to a reduction in spread of errors. This may in part be due to analysing a subset of an already-small dataset. In all categories, the median error was positive (flight arrived at a waypoint later than the EPP prediction). Reports generated in Climb for predictions in iCruise, Cruise and Descent show a noticeable shift in median error in the positive sense, increasing the magnitude of the median error in most categories. The cause for this is not clear. The dataset used for this part of the analysis is very limited and further research with an enlarged dataset is required.

6.4.7.1.5.7 Conclusions - ETO

From this initial study, ETO accuracy is seen to improve with reducing prediction horizon but it can potentially also support AMAN sequence building and longer-range DCB.

ETO predictions that span two or more flight phases are less accurate than those that occur in the same flight phase. Initial results suggest that the entry of the STAR in the FMS has a positive influence on ETO accuracy, although the dataset is limited and the results are not conclusive.

Legitimate operational behaviours in the descent phase limit the representativeness of EPP-derived ETOs. As an example, the entry in the FMS of trajectory initiation data (particular RFL and STAR) has a noticeable effect on the accuracy of reported ETOs.

Filtering EPP-reported ETOs to include only those for which the FMS aligns with lateral instructions has the potential to improve the accuracy of such ETO predictions. This suggests that EPP predictions could offer improvements to processes such as queue and network management if ATM moves towards systemised airspace where aircraft are able to remain route-following on their flight-planned route. However the dataset is very limited and so the confidence in observed trends is correspondingly limited.

Further work is required to isolate factors that may influence the ETO performance. The following future steps are identified:

- Investigating the effect of correct entry of filed levels in the FMS (n the ATC Flight Plan before departure) on ETO prediction performance.
- Extending the valid prediction lifetime study to include vertical and speed instructions. This would provide a theoretic best-case EPP performance against which to assess the influence of real-world operational behaviours.
- Further investigation into the effects of ATC vectors in the descent phase. This could include requests to allow some flights to fly the published procedural arrival. Future work could include analysis of EPP data received from flights flying point merge procedures.

6.4.7.1.6 Accuracy of Top of Descent along-track Position

6.4.7.1.6.1 ToD Along-track Position Error

Knowledge of the position at which a flight is predicted to start its descent is of high interest to the controller team as it can assist in planning the execution of the controlling task. The planner controller is likely to be interested in this information at around 100nm before ToD to assist in the task of coordinating the flight into and out of their sector. A tactical controller may be interested in this information at around 50nm, to help to predict level occupancy in the context of the tactical controlling task. For the purposes of this analysis, it is judged that the accuracy of prediction required to usefully support the planner and tactical tasks is ~ ± 20 and 5 nm respectively.

The potential for EPP–derived data to support these tasks was investigated by calculating the error in prediction of ToD along-track position at a range of prediction horizons. The entry of the STAR in the FMS will affect the planned along-track distance to destination, and therefore also affect the FMS' ToD calculation. The effect of the STAR entry was therefore investigated by comparing along-track ToD predictions generated when the STAR had been entered, against those generated when the STAR had not been entered.

6.4.7.1.6.1.1 Data Preparation

To analyse the accuracy of the ToD predictions the actual ToD has to be determined. This is done through the use of the ADS-B data as described in section 6.4.7.1.5.1.1. The ToD for this analysis is defined as the last ADS-B point at which the aeroplane was at the last cruise level. The along track distance along the actual aircraft trajectory is used to define this.

Equally for the predicted ToD, the 3D location at which the aeroplane would be abeam the ToD is calculated. This is then used to calculate the along track distance of the ToD prediction.

6.4.7.1.6.1.2 Analysis Method

The absolute error in along-track position of EPP-reported ToD was calculated for each TOD prediction received:

$$Alongtrack\ error\ (nm) = Actual\ Alongtrack\ position - Predicted\ alongtrack\ position$$

Where the Actual Along-track Position = the position of last ADS-B report whose level matches the level reported in the EPP ToD prediction.

The track along which all along-track positions (predicted and actual) are calculated is the lateral ADS-B trajectory - Figure 46 illustrates.

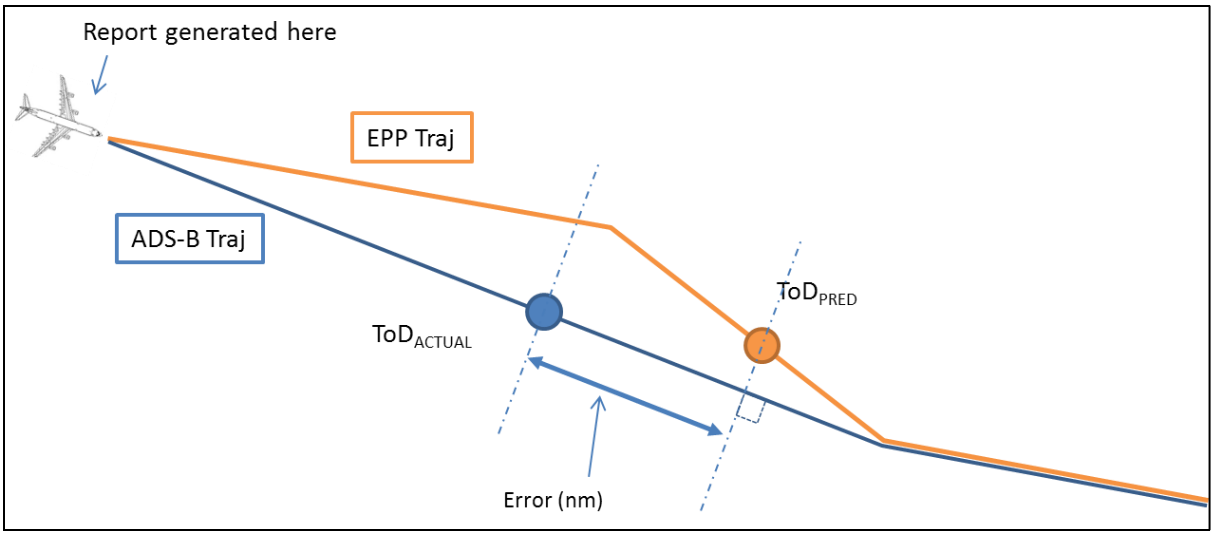


Figure 46: Calculation of Top of Descent Position Error

Sign convention: A negative error value indicates that the predicted ToD was further along-track than the actual ToD position.

Note: along-track error was chosen as a metric to assess ToD position, as it was judged that at the ToD a flight will usually be heading in the general direction of the destination airfield, and this is a useful assessment of ToD error in the context of controller tasks.

Predictions were categorised according to whether or not the STAR had been entered into the FMS at the time that the prediction was generated. To investigate the effect of prediction horizon on ToD position error, the dataset was then further categorised into groups of prediction horizons according to Table 23: ToD measurement prediction horizon categorisation For example a set of results was generated for 50nm horizon by averaging all the predictions made at a prediction horizon between 30 and 70nm. The groupings used, and the corresponding reported prediction horizons, are shown in Table 23. Finally these groups of predictions were then collated per flight and an average along track distance error was calculated per flight.

Prediction horizon group range, nm	<30	30-70	70-130	130-270	270-530
Plotted prediction horizon label, nm	<30	50	100	200	400

Table 23: ToD measurement prediction horizon categorisation

6.4.7.1.6.1.3 Results

The ToD prediction errors categorised by prediction horizon, generated with and without STAR, are presented in Table 24 and Table 25, and Figure 47.

Prediction Horizon	number of flights	Median (nm)	Mean (nm)	Std (nm)	Min (nm)	Max (nm)
<30	3	-13	-15	6	-22	-10
50	8	-21	-23	19	-57	11
100	20	-27	-23	26	-63	41
200	25	-23	-22	26	-61	51
400	25	-25	-24	30	-86	49

Table 24: ToD position error categorised by prediction horizon: Predictions made when STAR has not been entered

Prediction Horizon	number of flights	Median (nm)	Mean (nm)	Std (nm)	Min (nm)	Max (nm)
<30	6	-12	-11	8	-21	0
50	24	-38	-30	22	-55	18
100	26	-40	-34	26	-75	18
200	18	-26	-29	26	-73	17
400	12	-32	-32	23	-72	5

Table 25: ToD position error categorised by prediction horizon: Predictions made when STAR has been entered

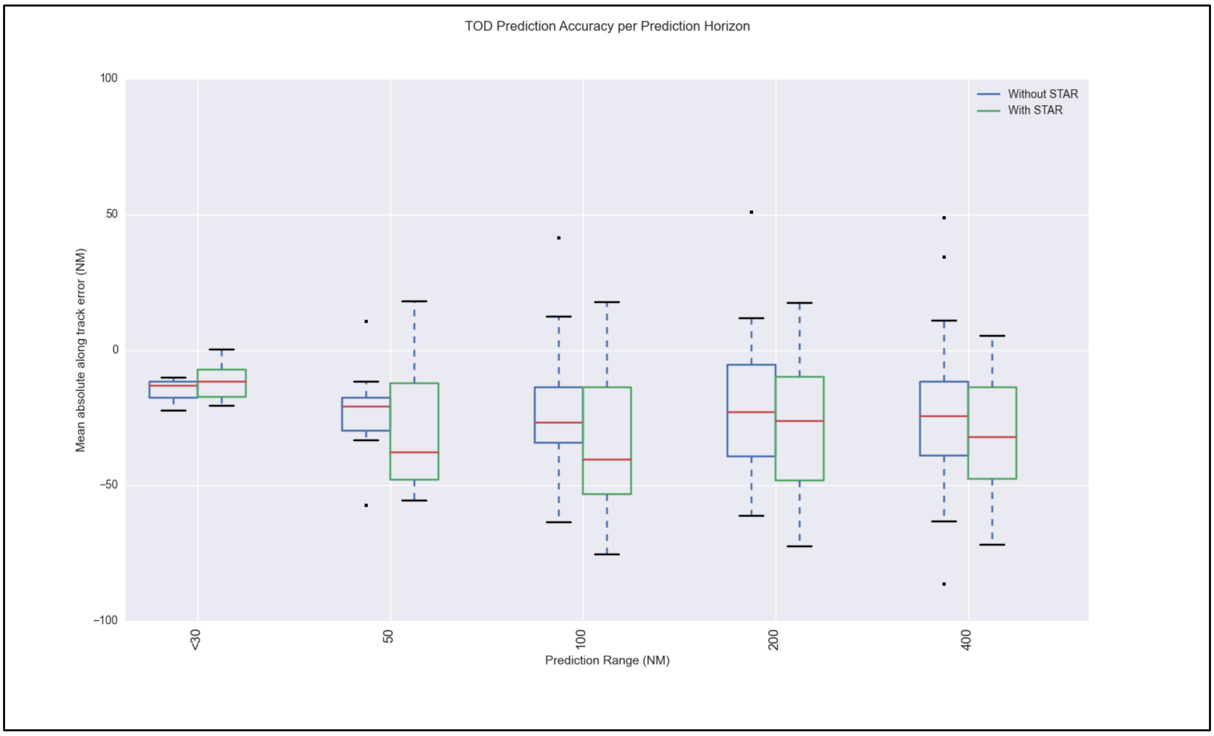


Figure 47: ToD position error (nm) categorised by prediction horizon

All of the along-track error results presented show a negative error bias. This indicates that flights are consistently starting their descent prior to the EPP-derived ToD prediction. It was observed that in the case of the majority of flights, the flight crew manually initiated their descent prior to the FMS-calculated ToD. The FMS subsequently managed the vertical profile to re-capture its calculated profile. Figure 48 illustrates this behaviour. This manual intervention may be due to a controller giving an immediate descent instruction prior to the optimum ToD point, or due to the flight crew initiating the descent early following the receipt of a 'when ready' descent instruction. These behaviours are very common, and acceptable in today's ATC operations.

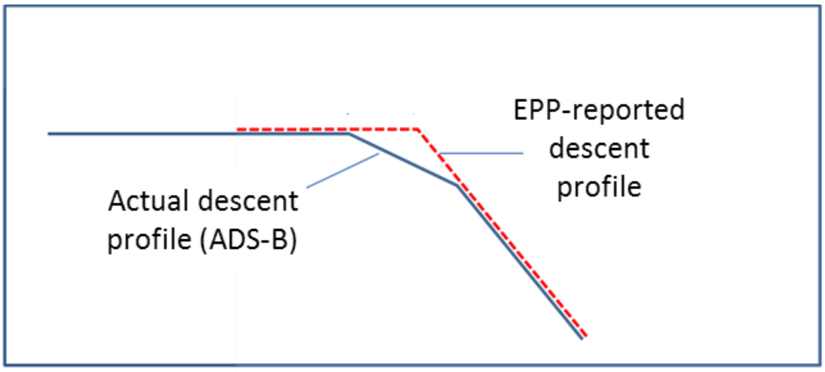


Figure 48: Typical Actual vs planned ToD behaviour

It should be noted that the ToD results are based on a limited dataset and the trends presented above are not strongly defined. In particular, the data samples included in the shorter prediction horizon categories are limited. An enlarged dataset would help to increase confidence in observed patterns.

It was seen that the correct entry of the STAR in the FMS tends to increase the spread of results for predictions made at 200nm or less, but reduce the number of outlying flights. It is not clear why the entry of the STAR causes this; further research with a larger dataset is required.

The correct entry of the STAR leads to a degradation in the mean and median of errors in at most prediction horizons, the notable exception being predictions made at less than 30nm (Figure 47). Note that the sample sizes in this latter category are small when compared to other categories; this is due to the early descent phenomenon described above.

Predictions made at 100nm before ToD with the correct STAR entered give a median and mean of -40 and -34 nm respectively. This suggests that EPP has the *potential* to provide the required accuracy to support the planner task. However, the spread of results (max-min) at this look-ahead time is ~100nm wide; further work is required to understand how to isolate the various factors contributing to these extreme results.

At 50nm prediction horizon, the entry of the STAR increases the spread of prediction errors. The median and mean errors are reduced to -38 and -30 nm respectively. The spread of results (max-min) is ~70nm wide. The results suggest that the EPP-derived data received during this study are not sufficiently accurate to support the tactical control task. However, the magnitude of the negative error is partly due to manually-initiated early descents. If the operational behaviours that lead to this can be understood and isolated, the prediction errors could potentially be reduced (or taken into account by the ground systems).

6.4.7.1.6.2 Conclusions – Top of Descent

This initial study supports the conclusion that EPP-derived predictions of ToD location have the *potential* to support planner and tactical controller tasks. However, the current results set has a negative bias, and a wide spread of errors that would currently prevent use of the data in this manner. Current common operational practises lead to frequent manually-initiated early descents which induce negative errors. In using EPP-reported ToD predictions in ATC operations, it should be understood that the aircraft is reporting its *optimum* ToD point, and not the ToD point that is likely to be realised in reality, and the data should be treated as such. Additionally, the correct entry of the STAR in the FMS increases the spread of ToD position errors, which is counter-intuitive and requires further research.

Note that the dataset used is currently limited and therefore any conclusions drawn are similarly limited. The routes flown as part of this study were also limited.

The following next steps are identified:

- An extended flight test campaign to capture a larger dataset from a wider range of operational scenarios would increase confidence in results.
- Investigate the operational behaviours that drive controllers and flight crew to initiate earlier-than-optimum descents, and consider whether they can be modified or isolated to allow such ToD predictions to be usefully used by ATC.
- Investigate the factors leading to the STAR entry increasing the spread of error results; for example by inspection of the flight visualisation data.
- The FMS calculates its ToD position by building a trajectory back from the next trajectory constraint. Where a controller issues a 'when ready' descent clearance, it is often issued with a level constraint at a specified waypoint (e.g. "When ready descend

FL270, level by WPT XYZ"). The accuracy of EPP-derived predictions following such an instruction could be investigated. This will require the capture of a suitable sample size of this particular operational scenario, which is likely to require an extended flight campaign.

6.4.7.1.7 Accuracy and stability of other EPP data

6.4.7.1.7.1 Accuracy of Speed-Schedule Parameters

This section presents the results of the EPP speed-schedule accuracy analysis. The purpose of this analysis is to assess how accurately the speed-schedule parameters provided in the ADS-C EPP reports predict the IAS and Mach speeds flown by the aircraft. This analysis will then provide information on the potential benefits of using the EPP speed-schedule parameters to enhance ground based TP.

The EPP reports provide the following speed-schedule parameters, for each parameter, the EPP report contains values for the nominal, the minimum and the maximum values:

- Climb IAS
- Climb Mach
- Initial Cruise Mach
- Final Cruise Mach
- Descent IAS
- Descent Mach

The analysis was conducted by comparing the nominal speed-schedule IAS and Mach parameters to the actual values of IAS and Mach observed during the PEGASE flight trials as reported by Mode S radar surveillance data.

The accuracy measurement involved the following steps:

- For each radar track message, the current phase of flight was determined; climb, initial-cruise, final-cruise or descent.
- Accuracy measurements were only calculated for levels above FL150, since below FL100 aircraft fly at IAS of 250 knots, above FL100 aircraft accelerate to their planned speed-schedule, FL150 was chosen as the level where the aircraft has reached the planned schedule speed.

  Also, it was observed that some of the PEGASE flight trials conducted flight tests at levels below FL150; these tests exhibited unexpected low speeds, and these have been excluded from the speed-schedule accuracy measurements.
- The predicted IAS-Mach crossover levels for climb and descent were calculated using the speed-schedule IAS and Mach values for climb and descent. The IAS speed-schedule accuracy was calculated for levels below the crossover level, and the Mach speed-schedule accuracy was calculated above the crossover level. For cruise, the EPP speed-schedule is specified using only a Mach value, so only Mach speed-schedule accuracy was calculated for cruise.
- The accuracy measurements were only made when the aircraft FMS was in speed-managed mode as reported in the EPP. It is expected that the speed-schedule values will no longer be applicable when pilot selected speeds are being flown.
- It was observed that for some of PEGASE flights, the initial cruise Mach speed schedule parameter reported by EPP changed to 0.5 during cruise. The 0.5 Mach value resulted in large percentage errors when compared to the actual Mach reported by Mode S. It was therefore assumed that the 0.5 Mach speed-schedule

value reports in the EPP data were invalid, and these cases were excluded from the error measurements.

- The accuracy is calculated as a percentage value as follows:

$$\text{speed\_error } (\%) = \frac{(observed\_speed\ -\ schedule\_speed)}{observed\_speed}\ x\ 100\%$$

The accuracy values are calculated as percentages in order to normalise the data for calculating the statistical values of the mean and standard deviation.

6.4.7.1.7.2 Results

The following table provides the overall average EPP speed-schedule accuracy measurement figures for the overall set of PEGASE flights:

Row Labels	Average IAS error (%)	Average Mach error (%)	StdDev IAS error (%)	StdDev Mach error (%)
1. Climb	0.00	0.02	1.57	1.32
2. Initial cruise		0.07		0.58
3. Final cruise		0.04		0.54
4. Descent	0.52	0.22	1.90	1.16

Table 26 Overall EPP speed schedule accuracy results

The distribution of the error measurements is shown in the following box and whisker plots:

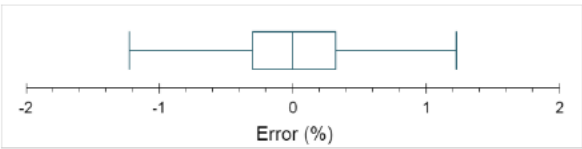


Figure 49 Distribution of IAS speed schedule errors (%) - Climb

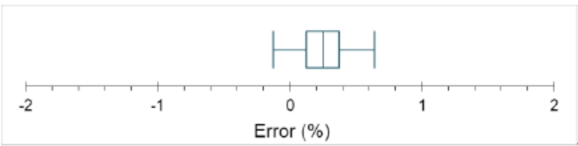


Figure 50 Distribution of Mach speed schedule errors (%) - Climb

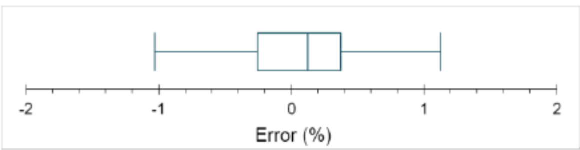


Figure 51 Distribution of Mach speed schedule errors (%) - Initial Cruise

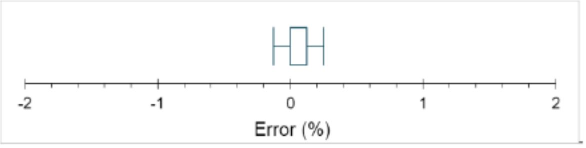


Figure 52 Distribution of Mach speed schedule errors (%) - Final Cruise

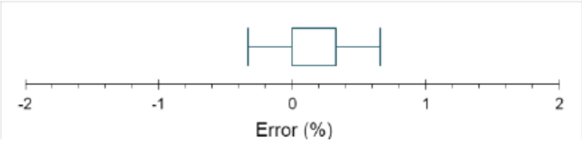


Figure 53 Distribution of IAS speed schedule errors (%) - Descent

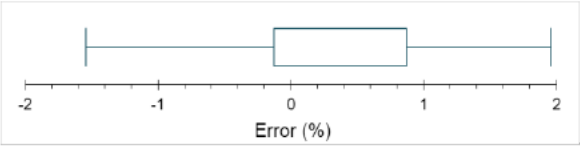


Figure 54 Distribution of Mach speed schedule errors (%) - Descent

The box and whisker plots shown in the figures above do not show the outlier values that were observed for some of the flights.

The outlier cases can be seen in the following table which shows the average accuracy measurements for each individual flight trial, measured during the different phases of flight (climb, initial-cruise, final-cruise and descent)

Note that in the table, and in the overall accuracy figures, not all of the flights have measurements available, and not all phases of flight are always available. This is because the ability to measure the EPP speed-schedule accuracy depends on the availability of EPP data and of Mode S radar data throughout the flight. Also the flight must be in speed managed mode for an accuracy measurement to be made. It was observed that a number of the PEGASE flights operated in selected speed mode for quite long periods during flight.

The main outlier cases can be seen in the table.

- AIB02DM on 05/06/2015 exhibits quite large differences between the speed-schedule and the observed speed during the climb phase, The speed-schedule IAS value was 272kts, whilst the observed mode S IAS varied from 286kts to 310kts for a period of time during the climb. Above the Mach crossover, the Mach speed-schedule was 0.8, whilst the observed Mach speed varied from 0.712 to 0.768. These differences occurred despite the aircraft being in speed managed mode. It is not known why these differences occurred for this flight.
- AIB214G on 11/12/2015 exhibits quite large IAS differences during the descent phase. The speed-schedule IAS was 311kts, whilst the observed IAS speed varied from 309kts to 336kts. Again, it is not known why these larger differences occurred for this flight.

dataset_id	date	callsign	route	phase	Average IAS error (%)	Average Mach error (%)	StdDev IAS error (%)	StdDev Mach error (%)
1	05/06/2015	AIB02DM	NATS	1. Climb	2.37	-9.71	4.24	2.58
2	17/06/2015	AIB02BM	Skyguide	1. Climb	0.01		0.73	
3	28/09/2015	AIB02DN	Central	1. Climb		0.14		0.67
				2. Initial cruise		-0.43		0.65
				3. Final cruise		0.17		0.47
				4. Descent		0.19		0.84
5	10/11/2015	AIB02IE	Skyguide	1. Climb		0.31		0.33
				2. Initial cruise		0.41		0.17
				3. Final cruise		0.21		0.06
7	18/11/2015	AIB02BU	NATS	1. Climb	0.36		1.24	
8	30/11/2015	AIB214A	LFBO-LSGG	2. Initial cruise		0.51		0.00
				3. Final cruise		-0.13		0.28
				4. Descent	0.42	2.27	1.02	0.48
9	30/11/2015	AIB214B	LSGG-EDHI	1. Climb	0.29	0.46	0.31	0.35
				2. Initial cruise		0.11		0.21
				3. Final cruise		0.02		0.26
				4. Descent	-1.09	-0.24	0.77	0.53
10	30/11/2015	AIB214C	EDHI-EGNR	1. Climb	-0.05	0.34	0.56	0.44
				2. Initial cruise		0.18		0.50
				4. Descent	-0.56		2.12	
11	30/11/2015	AIB214D	EGNR-LFLX	1. Climb	-1.69		3.79	
13	02/12/2015	AIB02BI	Skyguide	1. Climb	-0.71	-1.29	1.51	2.17
14	08/12/2015	AIB04IT	Skyguide	1. Climb		0.33		0.44
				3. Final cruise		0.07		0.37
15	11/12/2015	AIB214F	LFBO-LSGG	3. Final cruise		0.15		0.52
				4. Descent	0.30	0.09	0.35	0.43
16	11/12/2015	AIB214G	LSGG-EDHI	1. Climb	0.01	0.64	0.44	0.33
				2. Initial cruise		0.26		0.51
				3. Final cruise		0.24		0.48
				4. Descent	4.01	0.16	2.67	1.53
17	11/12/2015	AIB214H	EDHI-EGNR	1. Climb	-0.44	-0.40	2.25	1.80
				3. Final cruise		0.18		0.38
				4. Descent	0.18		0.55	
19	21/12/2015	AIB03DO	Skyguide	1. Climb	0.06	-0.08	0.23	0.42
				3. Final cruise		0.00		0.55
20	13/01/2016	AIB02DF	Central	1. Climb	0.25	0.40	0.37	0.50
21	15/01/2016	AIB04IH	Skyguide	1. Climb		0.44		0.79
				2. Initial cruise		-0.85		1.22
				3. Final cruise		0.14		0.39
22	29/01/2016	AIB02DR	Central	1. Climb	0.21		0.35	
23	01/02/2016	AIB02DT	Skyguide	1. Climb	-0.73	-0.60	2.00	2.02
				3. Final cruise		0.01		0.12
24	09/02/2016	AIB02BO	Skyguide	4. Descent		-0.38		1.35
26	24/02/2016	AIB02IA	Skyguide	3. Final cruise		-0.24		0.86
27	25/02/2016	AIB02IE	Skyguide	1. Climb		0.16		0.26
28	26/02/2016	AIB03IR	Skyguide	1. Climb	1.53	0.24	0.24	0.69
29	02/03/2016	AIB03DX	Skyguide	1. Climb		-1.34		0.72
				3. Final cruise		-0.15		0.93
				4. Descent		-0.03		0.52
31	11/03/2016	AIB02BX	Skyguide	1. Climb	0.13	-0.43	0.51	2.28
33	18/03/2016	AIB02DH	Central	1. Climb	0.05	0.23	0.38	0.51
34	30/03/2016	AIB02IC	Skyguide	1. Climb	-1.18		1.78	
35	04/04/2016	AIB04DU	Skyguide	1. Climb	0.00	-0.21	0.20	0.86
37	19/04/2016	AIB03IS	Skyguide	1. Climb	-0.06	0.64	0.51	0.00
38	22/04/2016	AIB02IK	Skyguide	1. Climb	0.23		0.58	
39	25/04/2016	AIB02DR	Central	1. Climb	0.13		0.61	
40	29/04/2016	AIB02BH	Central	1. Climb		0.13		0.00
42	04/05/2016	AIB02BY	Skyguide	1. Climb	-1.10		0.67	

Table 27 EPP speed schedule accuracy results for individual flights

6.4.7.1.7.3 Conclusions of speed-schedule accuracy analysis

The results of the EPP speed-schedule accuracy measurements indicate that the EPP speed-schedule parameters are accurate to within ± 2% compared with the observed IAS and Mach speeds flown by the aircraft, across all phases of flight.

These results indicate that the EPP speed-schedule parameters represent an accurate source of information to support ground based trajectory prediction. This analysis will be followed up by further work to assess the effects of incorporating EPP mass and speed-schedule parameter into NATS TP algorithms.

The use of EPP speed-schedule data to improve the accuracy of IAS and Mach speeds and the IAS-Mach crossover level in TP will bring benefits to ATC operations. Controllers will have increased confidence in the controller tools; the improved accuracy of speed predictions will provide better support for streaming traffic, with the potential to reduce the number of ATC speed instructions that must be issued.

6.4.7.1.8 Stability of 4D predictions

6.4.7.1.8.1 Full manage mode definition

The FMS is in full managed mode if the lateral, vertical and speed mode are managed.

The **LATERAL** Mode is managed if

- (Runway mode = engaged) AND (Nav Mode = armed)
  OR
- (Nav Mode = engaged)
  OR
- (Loc capture mode = engaged)
  OR
- (Loc track mode = engaged)
  OR
- (Land track mode = engaged)

The **VERTICAL** Mode is managed if

- (ALT ACQ mode = engaged)
  OR
- (ALT hold mode = engaged)
  OR
- (Pitch Take Off mode = engaged)
  OR
- (Pitch Go Around mode = engaged)
  OR
- (Climb mode = engaged)
  OR
- (Descent mode = engaged)
  OR
- (Final Descent mode = engaged)
  OR
- (Climb mode = armed)
  OR
- (Descent mode = armed)
  OR
- (ALT Mode = engaged at FM Altitude Target)

The **SPEED** Mode is managed if
- (**SPEED AUTO CONTROL** = engaged)

6.4.7.1.8.2 Stability of predictions

To verify the stability of predictions on each analysed flight, the EPP values were compared to FDR (Flight Data Recorder) data

The aim was to compare, for some specific waypoints, the Waypoint crossing predicted time and the effective time the aircraft pass through it.

For the specific need of the PEGASE project, several Airbus flights were realised. We can distinguish two kinds of flights:

- 38 Normal Ferry flights: these flights were realised without strictly respecting the flight plan and without always using the full managed mode
- 13 Specifics ferry flights: these flights were realised with respecting the initial flight plan and using the full managed mode. That's why these flights are particularly interesting.

  These 13 flights occurred at the following dates:

  - 5 flights in November 2015
  - 4 flights in December 2015
  - 4 flights in June 2016

For these flights the study focused on two kinds of Way Points:

- Fixed Way Point: This is a Way Point with a fixed geographical position. It corresponds to a geographical Way Point crossed by the aircraft during its cruise.
- Movable Way Points: This is a Way Point which corresponds to a specific moment of the flight (for example the Top of Climb). The geographical position of this Way Point will evolve during the flight. This is why it is called a movable Way Point.

6.4.7.1.8.3 Prediction on Fixed Way Points

This part of this analysis focuses on the study of 28 fixed Way Points.

It is important to note that the EPP prediction is fully reliable when the Aircraft is in full Managed mode (Lateral managed, vertical managed, speed managed) and when no flight plan modification has been realised.

So for the 38 ferry flights, the analysed fixed way points were selected in the way to respect these criteria during at least ten minutes before the Waypoint crossing. Regarding the criteria described above, 16 segments from the normal PEGASE ferry flights were analysed.

For the 13 Specifics ferry flights, these criteria are always valid, so the chosen fixed Way Point is the last Way Point of the cruise. On these 13 specific flights, there is one flight on which the EPP value is not available during an important part of the cruise. That's why this analysis will provide results corresponding to 12 segments corresponding to the Last cruise Way Points.

So, this part will focus on these 28 segments (16+12) and particularly on the Delta between the predicted time of Way Point check and the effective Way Point time.

6.4.7.1.8.3.1 One flight Example

The graph below presents an example of one of the analysed flight segment.

- The Red curve presents the vertical profile (pressure altitude in feet) of the aircraft during all the flight.
- The Blue curve presents the delta between the EPP prediction and the real pass time to a specific WayPoint (in seconds)

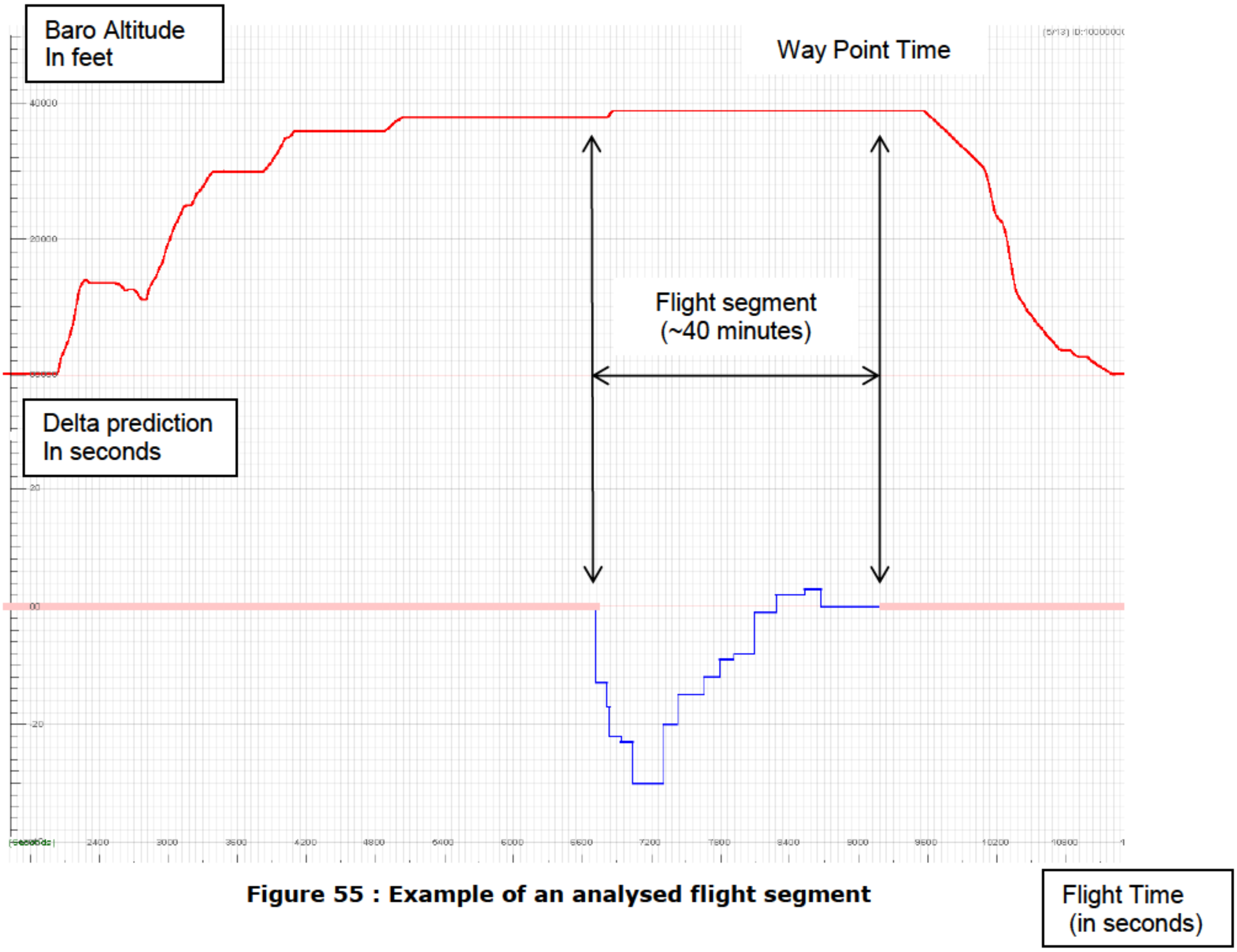


Figure 55 : Example of an analysed flight segment

This specific example clearly shows that the Delta EPP value reach an extreme value of 30 seconds delay around 30 minutes before the Way Point time and become more and more precise when approaching the Way Point.

6.4.7.1.8.3.2 Statistics on Fixed Way Point

For each segments, the study focused on the delta prediction precision of Way Points and also on these particular points

- The maximum value of this delta during the entire flight segment (from the beginning of the segment period to the Way Point time).
- The time of the segment during which the delta prediction is below 60 seconds and 15 seconds

- The distance from the aircraft to the Way Point when the aircraft pass closed to the Way Point.

a) Maximum Delta Value

The graph below presents, for the 28 analysed cases, the Maximum Delta prediction values detected during the last 10 minutes before the Way Point.

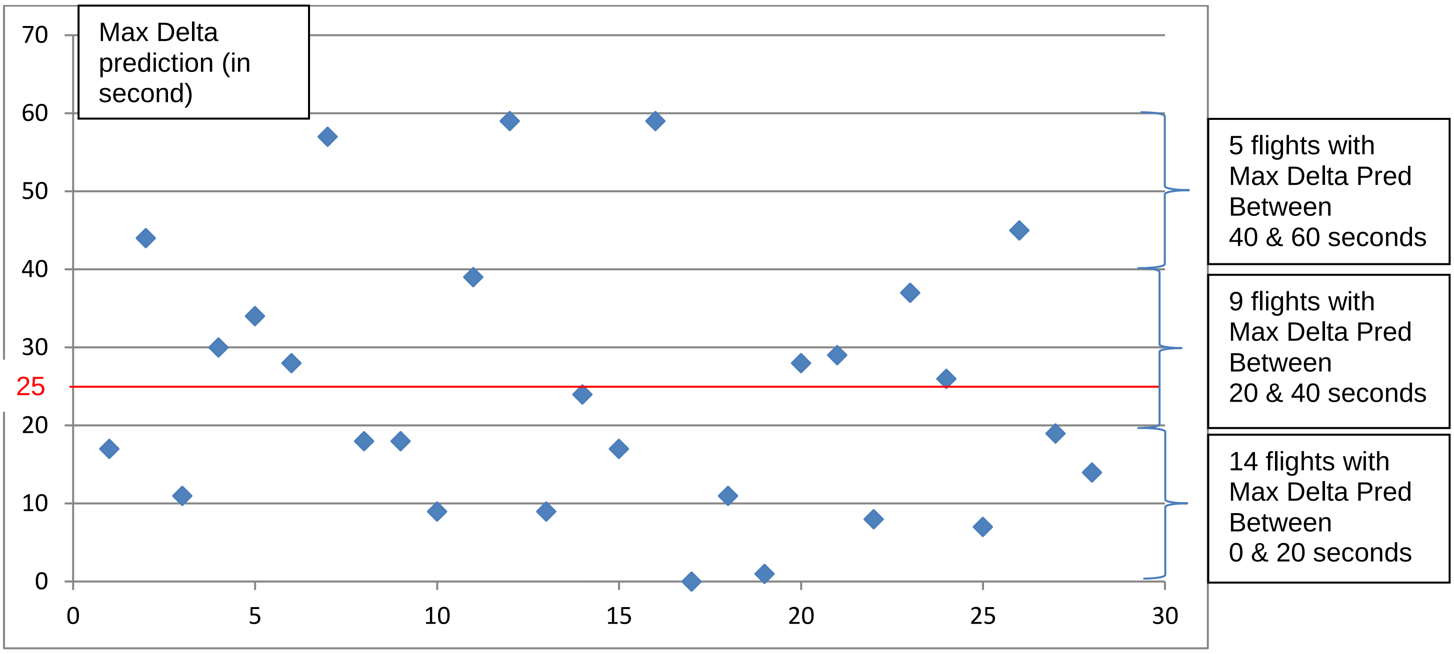


Figure 56 : Maximum Delta prediction values

This graph shows that predictions are below a delta of 1 minute.

The average value of this Maximum delta value is **25** Seconds (red line).

b) Maximum Delta value evolution before the Way Point

The graph below presents, for the 28 analysed cases, the evolution of the Maximum Delta between the predicted time until 60 minutes before The Way Point and the Way Point time.

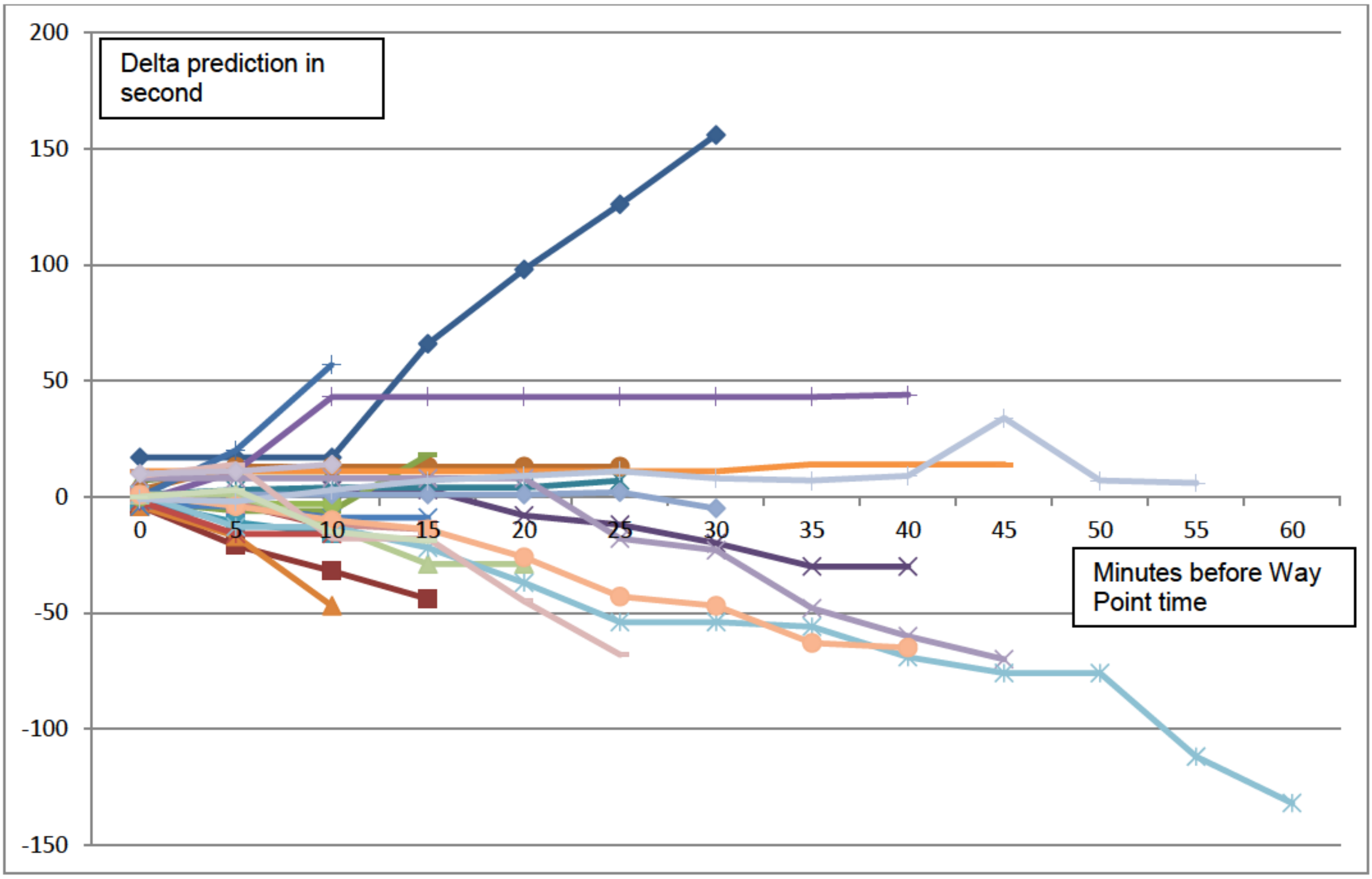


Figure 57 : Maximum delta values evolution before Way Point

The graph clearly show that the delta prediction become more precise when approaching the Way Point (~5-10 minutes before).

The table below give the mean and the standard deviation of the absolute delta prediction values from 0 to 30 minutes before the Way Point Time.

Minutes before Way Point Time	0	5	10	15	20	25	30
delta prediction Mean (in seconds)	3.39	8.25	15.44	19.06	25.54	34.00	40.78
Standard deviation (in seconds)	4.16	6.40	13.73	16.87	26.46	35.90	46.75

We can notice that the delta prediction mean and its standard deviation decrease when approaching the Way Point.

The graph below presents, for the 28 analysed cases, the time prediction error percentage calculated from 0 until 60 minutes before the Way Point.

This time prediction error percentage is calculated according to this formula

$$\text{prediction error} = \frac{|(WayPoin\ time\ predicted) - (Real\ Way\ Point\ Time)|}{(Time\ before\ WayPoint)} * 100$$

With each time in second

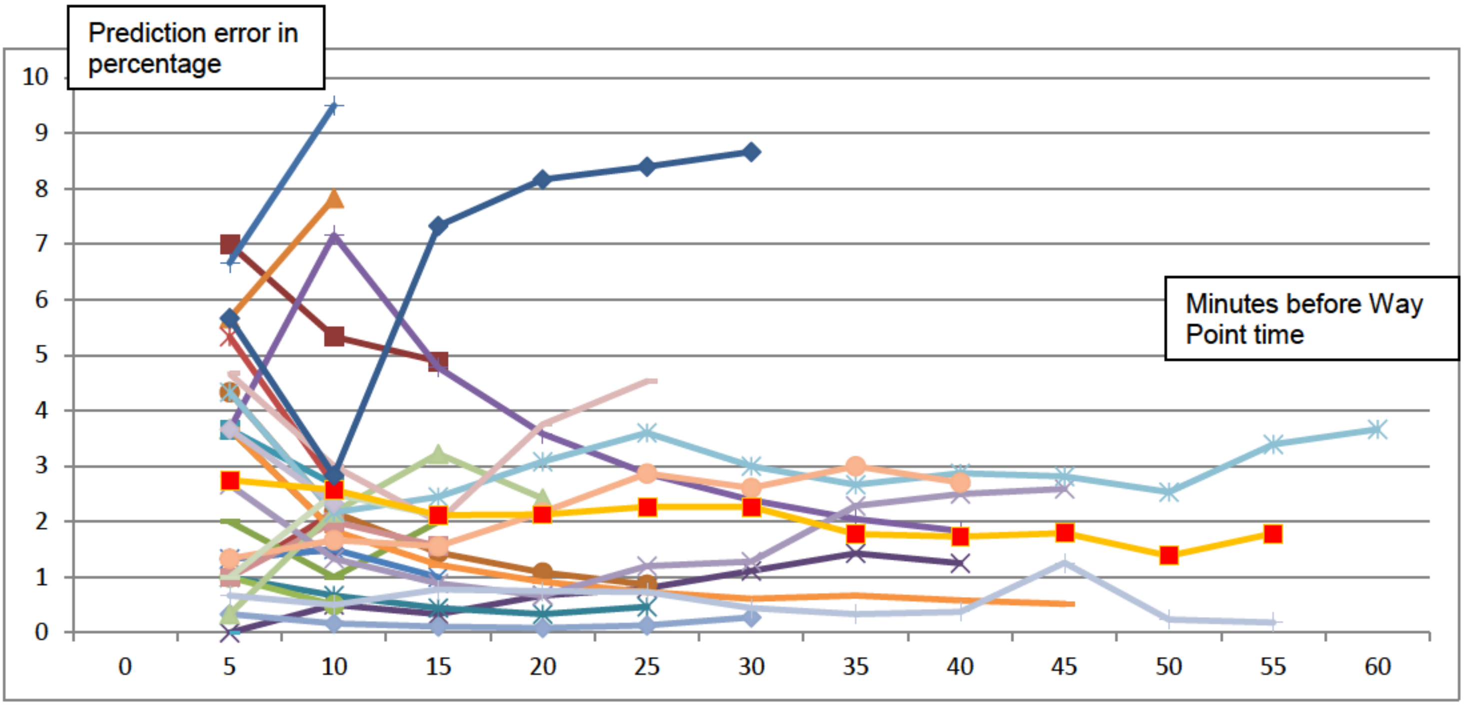


Figure 58: Prediction error in percentage

The orange and red curve represents, for each instant before the Way Point, the mean of the error prediction percentage.

This curve is almost linear which proves that the global EPP error percentage is continuous during the time.

The table below give the mean and the standard deviation of the error percentage prediction from 0 to 55 minutes before the Way Point Time.

Minutes before Way Point Time	0	5	10	15	20	25	30	35	40	45	50	55
Error percentage prediction Mean (in %)	2.75	2.574	2.117	2.128	2.2667	2.265	1.78	1.7321	1.796	1.383	1.79	1.78
Standard deviation (in %)	2.13	2.289	1.875	2.205	2.3931	2.597	1	1.0209	1.094	1.626	2.27	2.27

We can notice that the Error percentage prediction Mean and the standard deviation are always below 3%, which proves that the prediction error percentage is low and that the EPP predictions are accurate.

c) Time with delta prediction values below threshold

The bar graph below presents, for the 28 analysed cases, the repartition of the Time before the Way Point cross during which the Maximum Delta prediction values are below **60 seconds.**

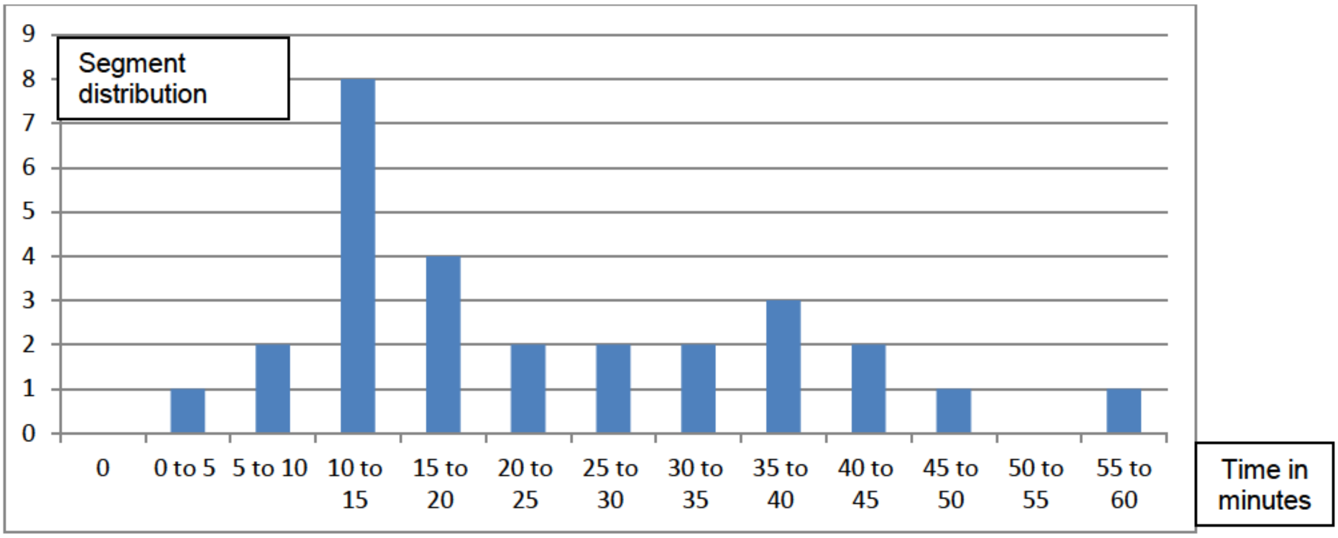


Figure 59 : Distribution of time with delta prediction values below 60 seconds

This graph shows that all predictions maintain their accuracy during at least 3 minutes, lots of them until 15 minutes and some of them until almost one hour (max 56 minutes).

The second bar graph presents, the same repartition of time with a Maximum Delta prediction values below **15 seconds.**

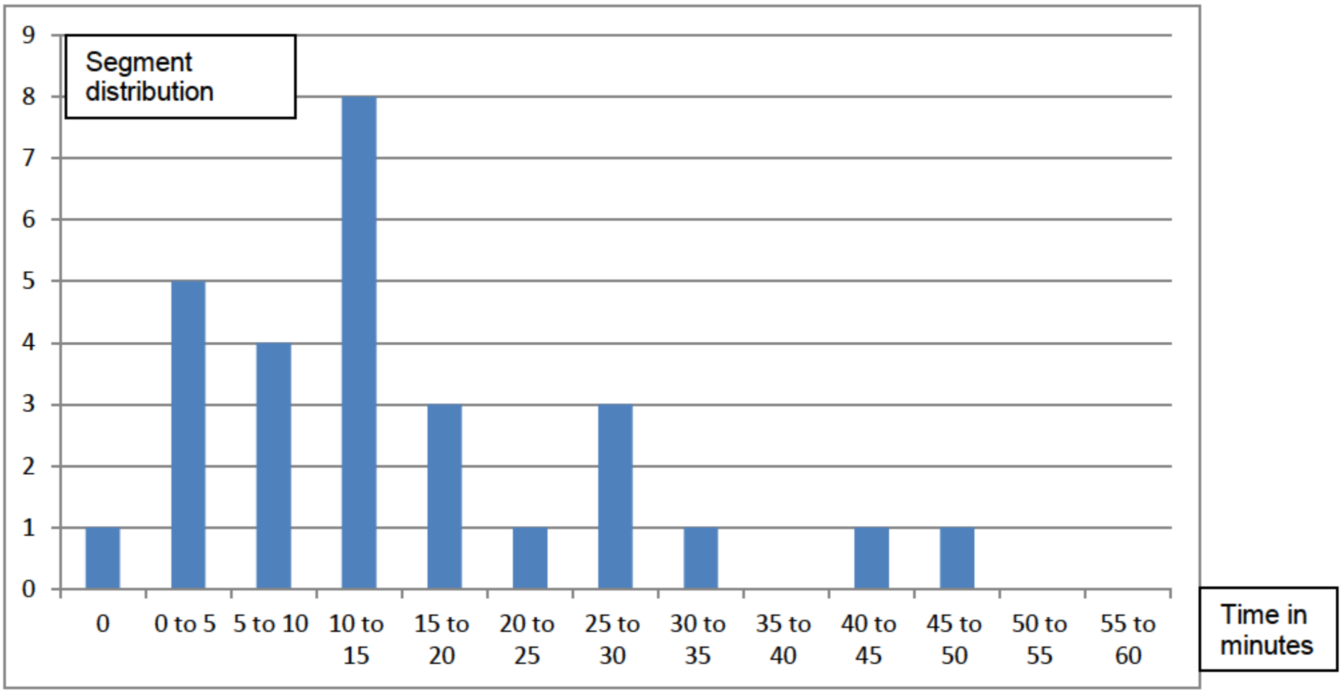


Figure 60 : Distribution of time with delta prediction values below 15 seconds

The graph informs that there is one segment whose prediction values are never below 15 seconds (its minimum delta is 17 seconds). For the others this accuracy is maintained between 0 and 50 minutes.

The average value of this time below threshold is 23 minutes (for a threshold at 60 seconds) and 15 minutes (for a threshold at 15 seconds).

d) Distance from aircraft to Way Point.

The graph below presents, for the 28 analysed cases, the distance (in nautical miles) between the Waypoint and the aircraft when it pass through it.

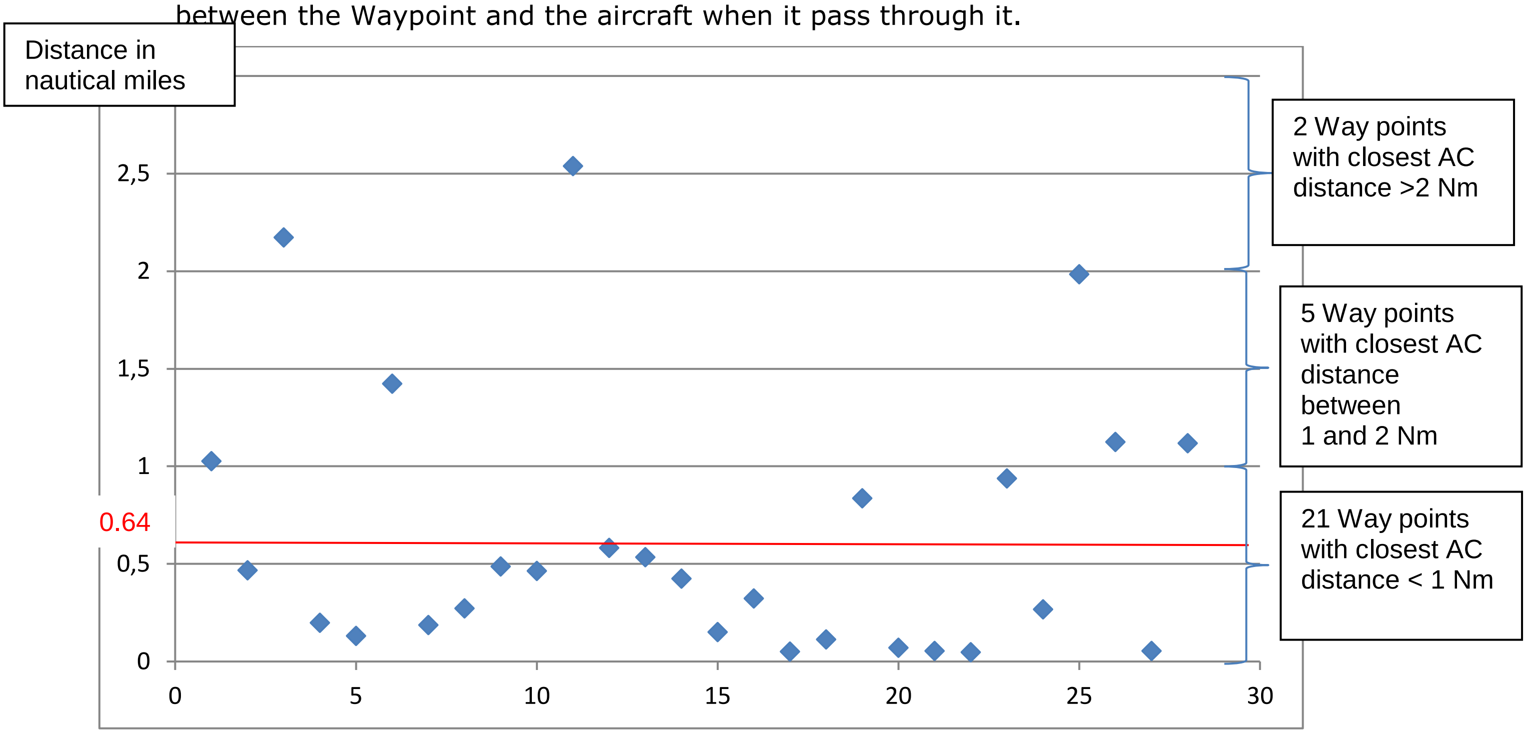


Figure 61 : Distance from aircraft to Way Point

This graph shows a god accuracy of the aircraft lateral managed mode according to the Way Point position. All distances are below 7 nautical miles (which is the threshold to consider that the aircraft has sequenced the Way Point) and most of them are below 1 nm (21/28).

The average value of this distance is **0.64** nm (red line).

6.4.7.1.8.4 Prediction on Movable Way Points

This part of this analysis focuses on the study of 11 movable Points.

For this analysis the chosen Way Point is the Top of Climb. This Way Point corresponds to the moment when the aircraft finished its climb and started its cruise phase. Its geographical position is not fixed and may evolve during the climb. The analysis of the Top of Descent prediction has also been realised and is presented in Appendix C.

For the 13 Specifics ferry flights, the initial flight plan and using was respected and the FMS was almost always in full managed mode. So for these flights the ToC Way Point should not change too much. That's why it's interesting to analyse the EPP prediction to this point for these specific flights.

On them, there is two flights on which the EPP value is not available during the climb. That's why this analysis will provide results corresponding to 11 ToC Way Points.

6.4.7.1.8.4.1 On flight Example

The graph bellow presents an example of one of this analysed specific flight.

- The **Red** curve presents the vertical profile (pressure altitude in feet) of the aircraft during all the flight.
- The **green** curve presents the delta between the EPP prediction and the real pass time to the Top of Climb Way Point (in seconds)
- The **Blue** curve presents the delta between the EPP prediction and the real pass time to the last cruise Way Point (in seconds)
- The last three Boolean informed whether the FMS mode (respectively **vertical**, **lateral** and **speed**) are managed (1) or not (0).

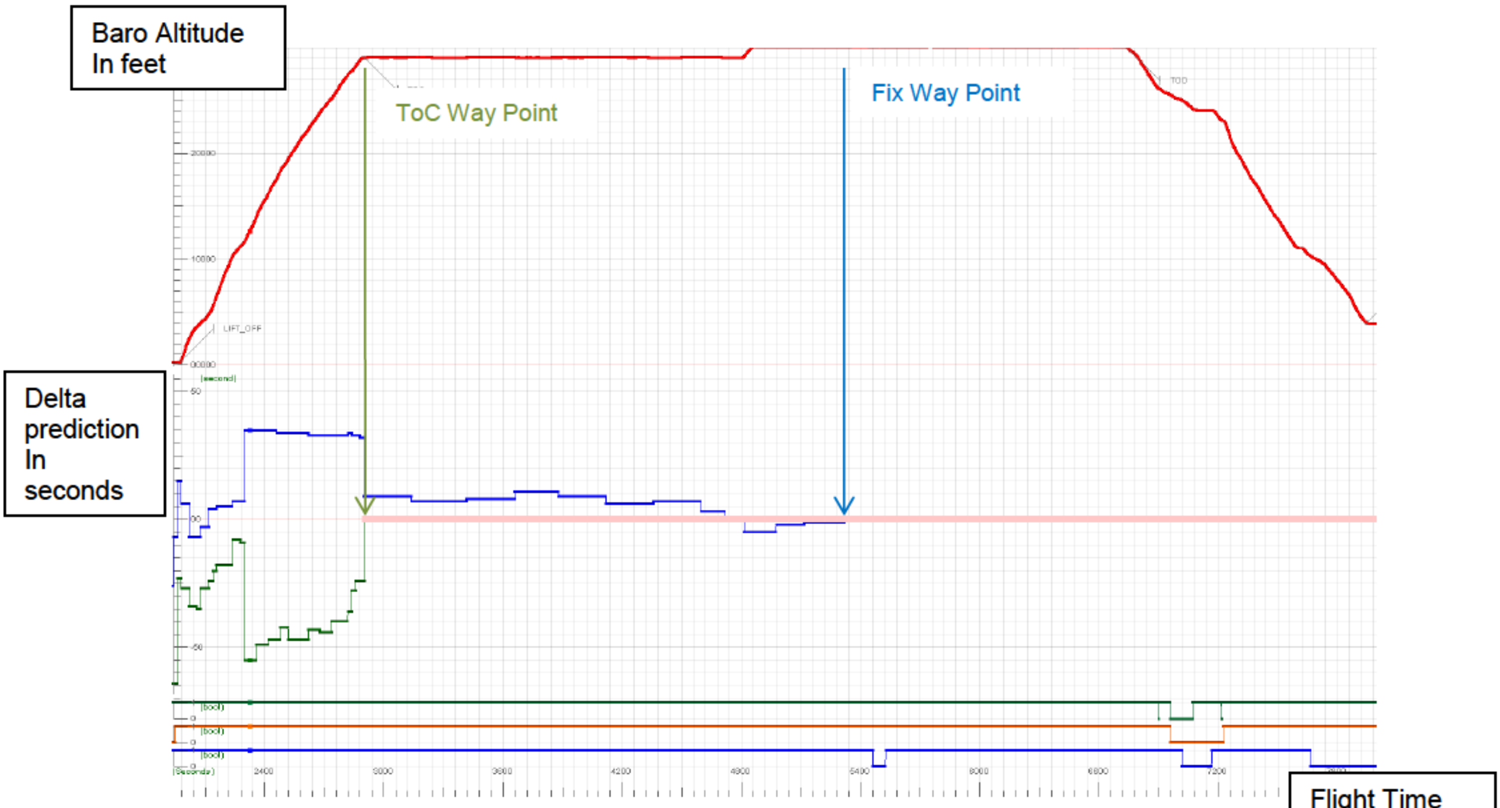


Figure 62 : example of one analysed specific flight

As assumed, the aircraft is in full managed mode during almost all the flight.

In this example the prediction of the **fix Way Point** is clearly more precise than the one of the **movable Way Point**. This is due to the fact that the aircraft Top of climb position may evolve during the climb).

6.4.7.1.8.4.2 Statistics on Movable Way Points

For each flight, the study focused on the delta prediction precision of ToC Way Points, and also on this information:

- The maximum value of this delta prediction.
- The time during which the delta prediction is below 60 seconds (respectively 15 seconds)
- The position prediction of the Way Point.

a) Maximum Delta Value

The graph below presents, for each ToC Way Point, the Maximum Delta prediction time values.

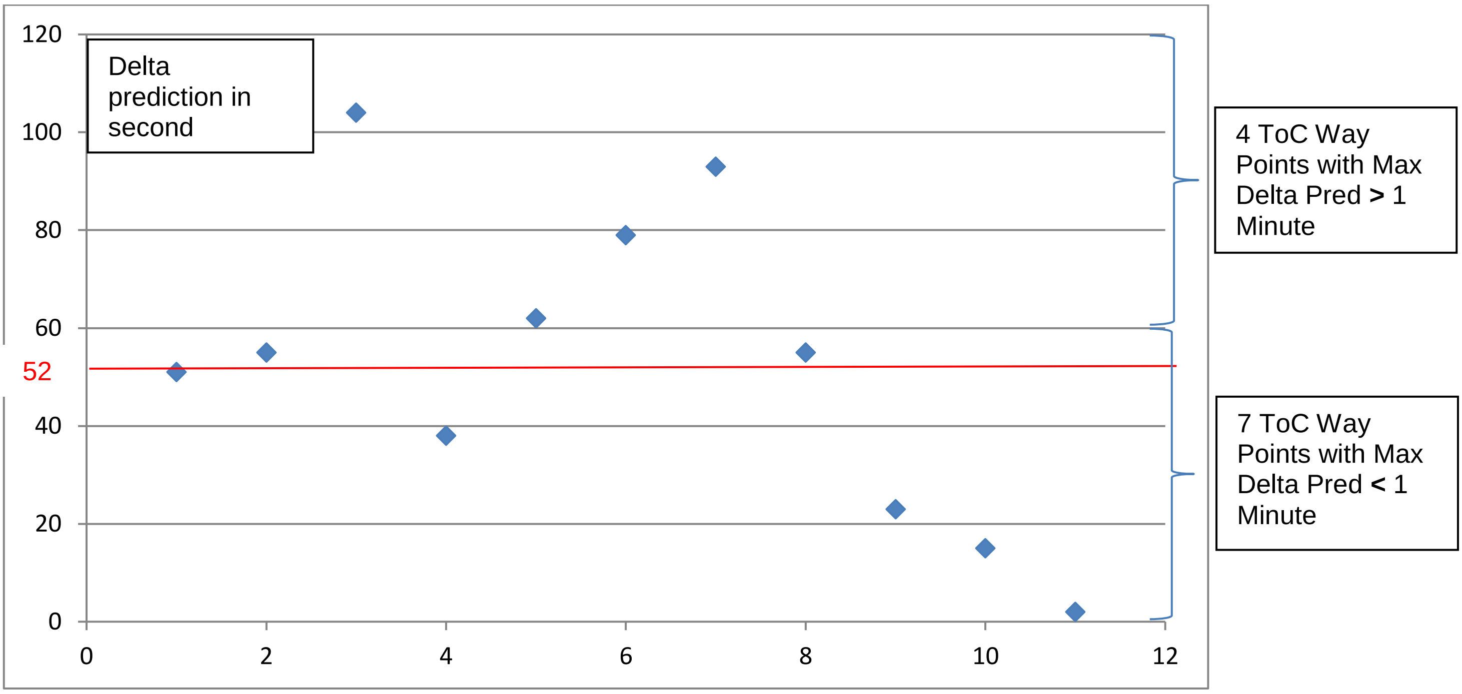


Figure 63 : Maximum Delta Value Distribution for ToC Way Points

This graph shows that the prediction is no so accurate for Movable Way Points.

The average of maximum delta values for the ToC Way Points is **52** seconds.

b) Maximum Delta value evolution before the ToC Way Point

The graph below presents, for the 11 ToC Way Points, the evolution of the Maximum Delta between the predicted time until 20 minutes before The Way Point and the Way Point time

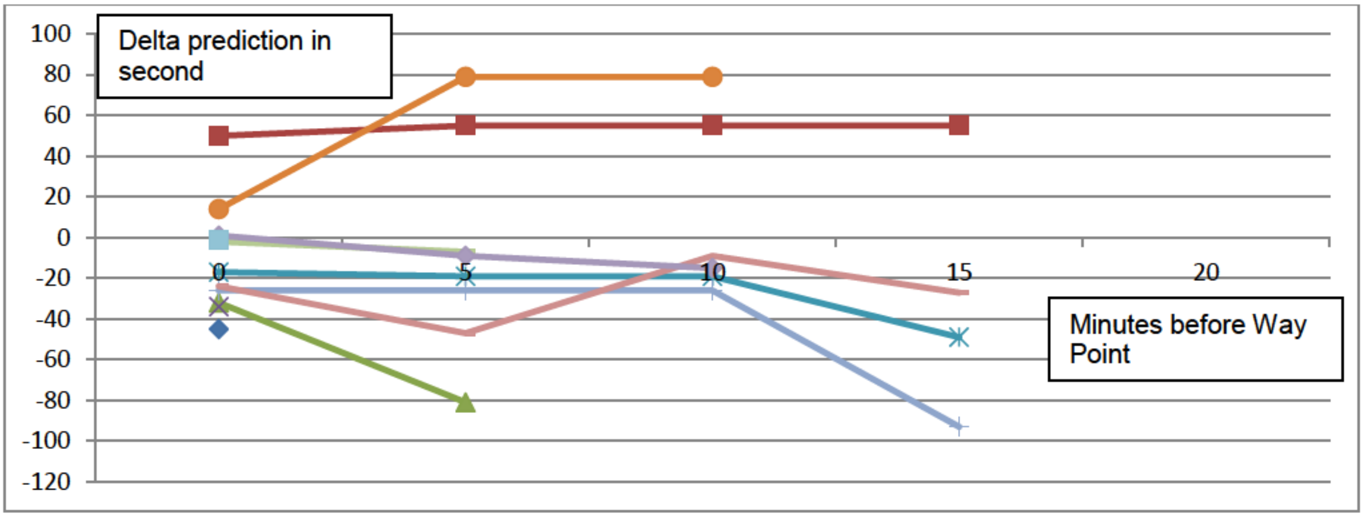


Figure 64 : Maximum Delta value evolution before the ToC Way Points

The graph clearly show that the delta prediction become more precise when approaching the Way Point (~5 before).

These graphs confirm that the EPP prediction is less precise for a Movable Way Point and that this accuracy is reached some minutes before the Way Point. They also show that most flight don't access to an accuracy below 15 seconds. To understand these observations, it is important to take into consideration that the ToC prediction evolve during the climb and that the ToC occurs at the beginning of the flight (~20 minutes after the Lift off) and that the EPP need some minutes to be correctly calculated after the flight plan update. It is also important to notice that during the climb phase the aircraft go through several external modifications (temperature, wind, pressure) which could have an impact on the EPP accuracy.

c) Prediction of Way Point position.

The aim of this part is to study the accuracy of the EPP prediction of the Way Point position.

For a Movable Way Point (as the ToC), the geographical coordinates of the point are predicted by the EPP. This part focuses on the accuracy of the geographical prediction of the 11 analysed ToC Way Points.

To check this accuracy, it's interesting to observe, for each way point, the distance between the real ToC position and the predicted positions.

The graph bellow presents, for each of the 11 ToC Way Points, the evolution of the distances (in nautical miles) between the real ToC position and the different predicted positions during the climb (from 20 minutes before the Top of Climb to the Top of Climb). A negative value means that the ToC position was predicted before its real position and a positive value means that the ToC position was predicted after.

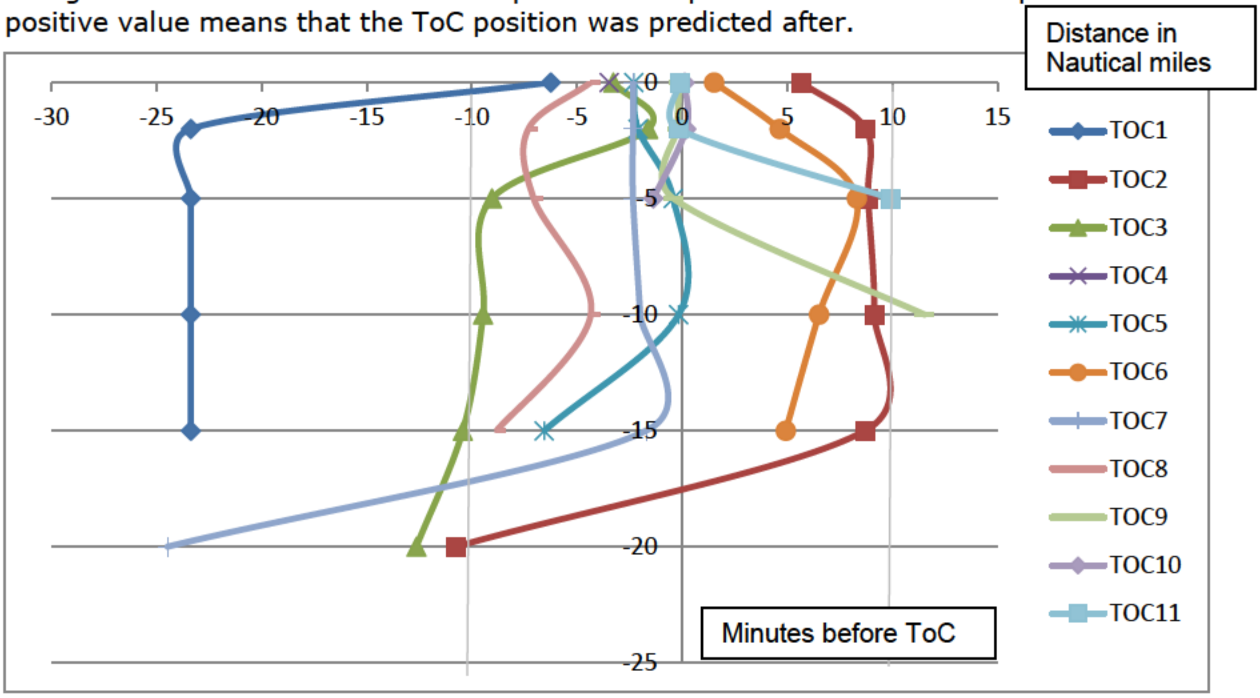


Figure 65 : Distances evolution between real ToC position and predicted positions

This graph shows that the accuracy of the position prediction become more precise during the last minutes before the Top of Climb (~5 minutes before).

Observed values distribution is between -24 and +12 nautical miles at the beginning of the climb, and between -6 and 6 nautical miles at the Top of Climb.

These results can be compared to the uncertainty range of position distance without EPP estimated at 110 NM (cf figure below).

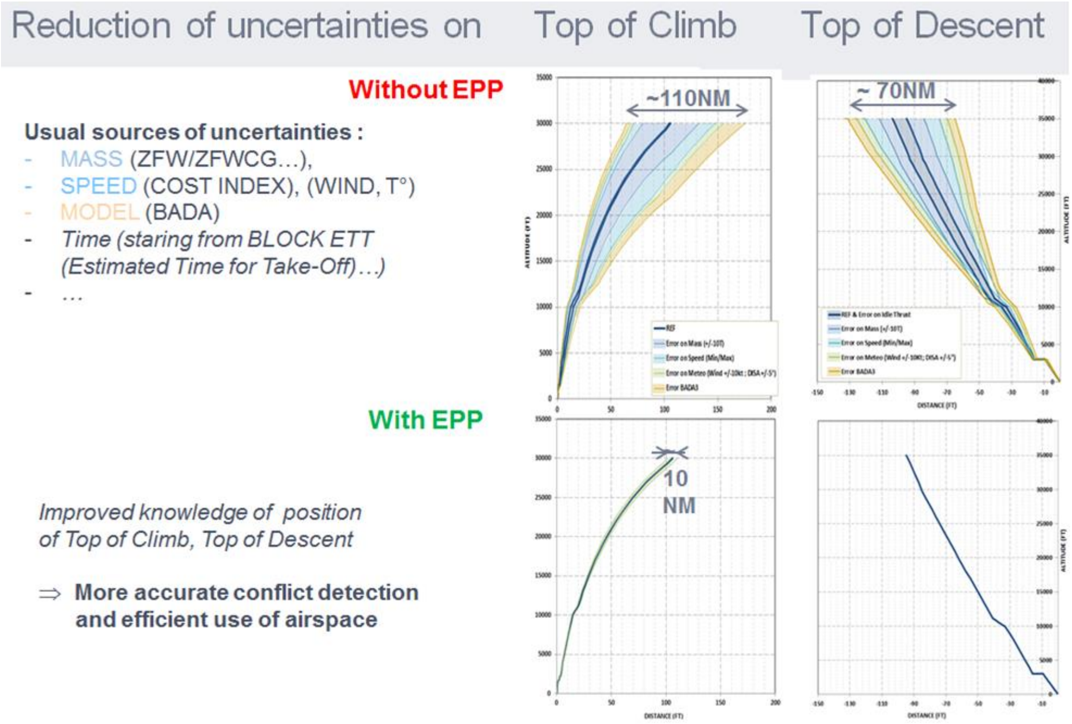


Figure 66 : Uncertainties position on fixed points

The next graph presents, for each of the 11 ToC Way Points, the range of the calculated distance between the real ToC position and the different predicted positions during the climb

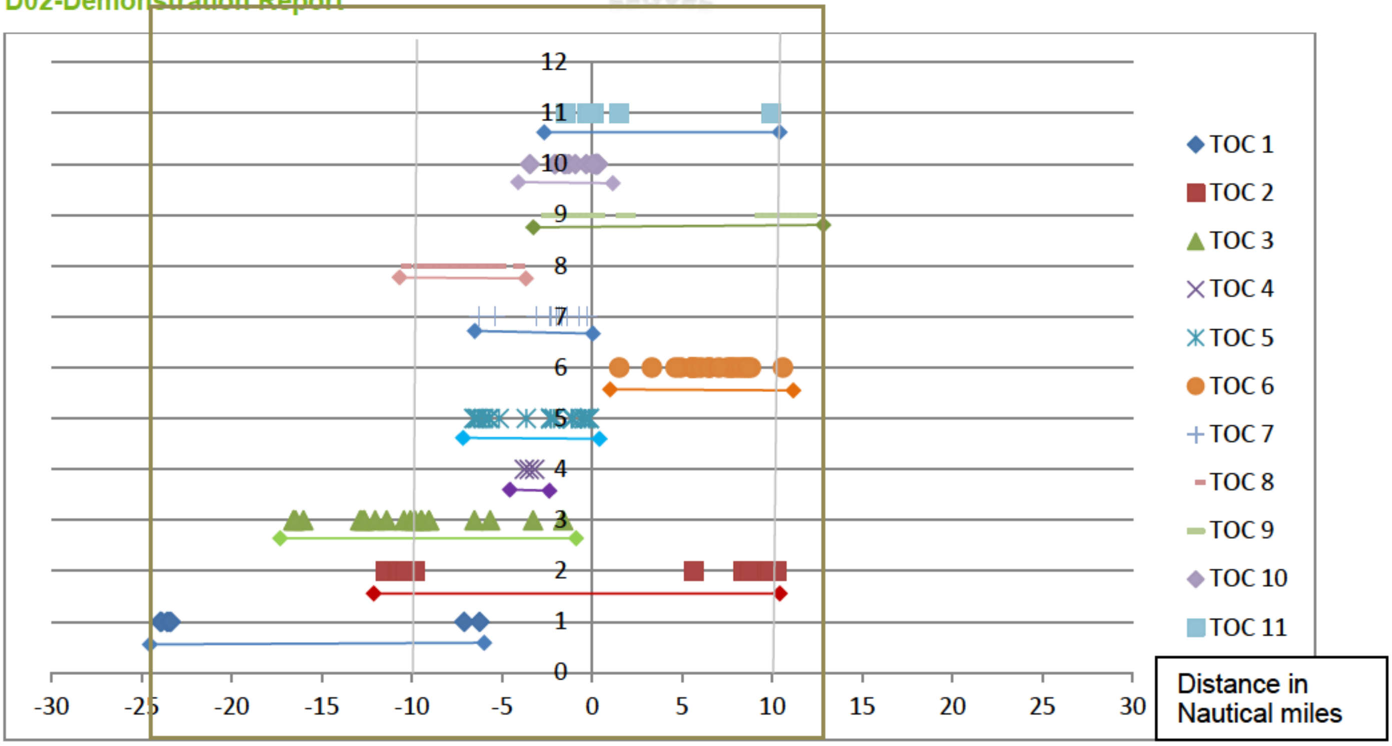


Figure 67 : Distances between real ToC position and predicted positions

This graph shows that the prediction of the position evolves during the climb. Observed values are distributed between -24 and +12 nautical miles (Total Range = 36 nm).

6.4.7.1.8.5 EPP Prediction Precision

As observed in this study, the precision of the EPP prediction may be disturbed by different reasons:

- The EPP signal may be truncated during the beginning of the flight until the ATSU reset, that's why it is important to realise this operation early during the climb.
- After the ATSU reset or after the loading of a new Flight plan, the computer need some time to recalculate the EPP (until 5 minutes), so the prediction value may be inaccurate during this calculation time.
- Even if the EPP is continually received, the prediction time to a Way Point may suddenly change if:
  - The crew changes the aircraft flight level
  - The crew changes the aircraft speed
  - The crew modifies the moment of the top of climb or top of descent.
  - The crew changes the direction (ex. DirTo)
  - The crew changes the weather hypothesis

  ⇨ To avoid big step of prediction values, the FMS should be in full managed mode and no modification to the original flight plan should be applied by the crew.

Note: Some limitations regarding ATSU and FM behaviour correspond to the current prototype standard. Refer to § 4.2.1

6.4.7.2 EPP and TP

This section provides the results of the TPs accuracy comparison assessments that have been done by Indra, EUROCONTROL (MUAC), NATS, Skyguide and Thales.

For a given route and constraints/restrictions, the accuracy of any TP can be determined by checking how good the TP anticipates the way in which the Aircraft will close the remaining degrees of freedom and compute a trajectory compliant with flight route and restrictions.

The remaining degrees of freedom can be classified into three groups:

- 2D path: Even if there are exceptions (especially in approach phases), in most cases the expanded route and procedures do not contain information on how the turns are to be performed. This way, each TP needs to close this degree of freedom by choosing an approach which can be a standardized approach (same in all turns) or by deciding on a case-by-case basis.
- Altitude profile: In a similar way, in most cases the altitude constraints are just providing the maximum and minimum altitudes in some points, but it is not specified the detailed way in which those restrictions should be fulfilled (Rate of Climb or Descent, point where manoeuvres will be started/completed, etc).
- Speed profile: Similarly, the departure & arrival/approach procedures sometimes include some limitations, and there is a general limitation to IAS 250 bellow FL100. But apart from that, there is no constraint or restriction on the speeds neither on how the acceleration/deceleration manoeuvres should be executed.

In particular, and for altitude and speed profile, it must be noted that the way in which the degrees of freedom can be closed is limited by the aircraft performances. In fact, one of the most recommendable strategies to close degrees of freedom in the altitude and speed profiles are based on managing the Throttle rating (either maximum or IDLE) and to let the aircraft to gain/loss energy (speed and/or altitude) according to the physical characteristics of the aircraft.

Since the new ADS-C reports are not containing information about FMS internal performance models, the ground TPs will need to maintain their current models (BADA being the most typical one in Europe). Nevertheless, and for those strategies based on setting maximum/minimum throttle settings, it must be noted that the overall aircraft performance depends on the following factors:

- First: the flight status characteristics, such as the speed, the altitude and the current mass, for which the new ADS-C reports are providing quite detailed information, and so, the uncertainties around those parameters are minimized thanks to the usage of ADS-C reports in ground TPs.
- Second: the physical engine & aerodynamic parameters, which are not covered by the ADS-C reports. So, will remain as uncertainty in the TPs.
    - This could include also the aerodynamic configuration policy.
- Third: the meteo data, such as the temperature, density, pressure, wind, etc, which are not covered by ADS-C report. Nevertheless, other SESAR solutions are working on the alignment of meteo data across all stakeholders, and so the uncertainties will be minimized in the future (but not in this particular study).

This way, it is expected that the usage of ADS-C reports in ground TPs will improve the TPs through the provision of information about:

- The aircraft preferred strategy to close degrees of freedom between each pair of route points/restrictions.

    - Not directly provided in most cases, but can be deduced from the predicted trajectory in most cases.
- Precise information about some of the parameters on which the ground TP aircraft performances formulas are depending (first bullet of the above list).
    - Note that some of those parameters are general preferences that the ground TP should also take into account when computing what-if trajectories (or in general, any trajectory for a non-aligned flight intent).

It is very important to highlight that the above is just a subset of the overall ADS-C benefits. In fact, there are other benefits that could justify the deployment on their own, but are not part of this study:

- The EPPs will improve safety thanks to a better awareness in ground about the aircraft known route and constraints. Conformance monitoring can be anticipated.
- The EPP raw prediction could be useful to be directly considered as one of the trajectory sources for (e.g.) conflict detection.

6.4.7.2.1 Indra approach: Increased accuracy of the ground Trajectory Predictor. (see description TAB KPI)

Indra has focused on the improvements on the Altitude and Speed profiles.

It must be noted that, in general terms, the speed profile of the aircrafts is reasonably simple: to fly at its preferred climbing/cruise/descending speed unless any existing restriction forces the aircraft to fly at different speed. The speed change manoeuvres are reasonably short in time, and uncertainties (and so impact) on their duration are reasonably low. This way, knowledge of the preferred climb/cruise/descent speed minimizes the most of the speed profile uncertainty.

Nevertheless, no quantitative KPI is provided regarding the speed profile. The reason is twofold:

- Once the same speed is set on both TPs, the remaining uncertainty is almost zero, and located on the acceleration/deceleration manoeuvres, with a small global impact on the trajectory uncertainty.
- The speed itself is not part of the 4D trajectory, even if it influences the trajectory in the following way:
    - The turn manoeuvres (lateral profile is left out of this study).
    - The lift/drag computation, which influences the altitude profile (rate of climb/descent), and so is analysed as part of the altitude profile analysis.
    - The distance covered (per time unit), which has been removed from Indra analysis due to the uncertainties on wind information to be used (explained in following sections), and the significant impact those uncertainties have on the covered distance.

This way, Indra analysis mainly focuses on the reduction of the uncertainty on the altitude profile.

More particularly, Indra has developed a TP prototype which is able to use the ADS-C reports to:

- Replace the BADA standardized speed schedule (this is: detecting aircraft strategy to close the speed uncertainty, and using it to compute better trajectories).
- Use the EPP reported mass as initial mass of the trajectory.

Nevertheless, it must be noted that the detection (and usage) of the aircraft preferred strategy to close the degrees of freedom in the vertical profile has been left out of this study. The Indra TP prototype maintains BADA proposed default strategy on the vertical profile, which is based on setting the maximum/minimum Throttle setting and let the aircraft to evolve according to its physical characteristics. The rationale is as follows:

- First: the development effort & time to implement other altitude strategies exceeds the available time and resources for this study.
- Second: further clarifications would be needed from Airborne partners to learn about how to deduce properly, from the EPP, the applied strategies.
- Third: the default BADA strategy is the preferred FMS strategy in most cases. So, we have lots of data from PEGASE flights to compare against.

This way, this section provides KPIs on the reduction of the uncertainty of the altitude profile, and those KPIs are provided separately depending on the strategy followed by the FMS. Nevertheless, the most interesting KPIs are those for the BADA-strategy manoeuvres, where the reduction of uncertainty will be possible thanks to the knowledge of the preferred speed strategy and actual mass.

For the other manoeuvres, (where the TP and the FMS model a different manoeuvre), some KPIs are also provided, but they should not be considered as final results on EPP usage due to the limitations of the current prototype with regards to the implementation of those strategies. When implemented, the uncertainty should be significantly minimized. This will be better explained in following sections.

6.4.7.2.1.1 Altitude profile reference trajectory

The first step to measure any TP improvement is to define the reference trajectory to compare against.

The current state of the art on trajectory prediction analysis is to compare the computed predictions against the actual navigated trajectory. Nevertheless, this approximation brings a problem when performing this TP assessment and this led us to take a different approach.

One of the key objectives of SESAR is to reach (in some years from now), the point where the aircrafts are allowed to fly their desired profile, minimizing as much as possible the ground imposed restrictions to such profile. This is: to fly the Airspace User perception of the optimal trajectory (the FMS trajectory), which is computed taking into account his known restrictions and conditions, with a minimum influence of the ground ATC segment, which should be produced only in case this optimal trajectory has any conflict with other surrounding aircrafts (encounters, sequencing, complexity, etc).

Unfortunately, PEGASE flights were controlled using today's systems and following today's procedures. This means that PEGASE flights were subject to several tactical decisions not allowing the aircraft to fly its optimal previous profile, but a different one.

The most obvious example is the identification of the Top Of Descent. The FMS computed Top Of Descent is the point where the aircraft prefers to start descending to ensure the most beneficial trajectory. Nevertheless, the actual (navigated) Top Of Descent was significantly anticipated in most PEGASE flights because:

Either the ATCO provided an immediate (anticipated) descent clearance (to avoid a conflict, to have some extra margin, or due to the lack of knowledge on the preferred TOD position).

Or the ATCO allowed the crew to initiate the manoeuvre at their preferred position, but the pilot chose to start the manoeuvre in anticipation (for whatever reason).

Even worse: a tactical clearance to anticipate a descent will not only impact the point where such manoeuvre starts, but also has a significant impact on the Rate Of Descent of such manoeuvre (it is necessary to set a lower Rate Of Descent to compensate).

So, which is the most appropriate reference TOD to compare against? Which is the TOD that should be predicted by ground TPs? The FMS computed one or the actual one?

Following the SESAR target concept, ground TPs should be able to properly identify the optimal TOD position thanks to the EPP information, and so controllers can let the aircraft to start descending there. Only in the case there is a conflict, the ATCO should modify the RBT (ideally by adding a new strategic constraint, instead of implementing a tactical action), and so the FMS would compute (and provide) an updated TOD.

In other words: the FMS TOD is (in general terms) a good TOD prediction even if this does not necessary mean that is a good TOD plan. The ATCOs need good predictions to be able to properly identify conflicts (in order to solve them in anticipation). We should not confuse a bad plan with a bad prediction.

The 2D orders can also have a big impact on the 3D profile. A shortened arrival and/or approach path (after a direct order, for example) would imply changes on the descending profile (for example, anticipating the optimal Top Of Descent point).

There are some examples in section 6.4.7.2.1.7out scenarios where the aircraft followed the profile and where the aircraft followed a different profile, to understand the complexity of comparing predictions against real flown tracks.

This way, the approach followed is to compare both Test Bench trajectories (one using ADS-C data and one not using ADS-C data) versus the EPP trajectory itself, since this trajectory is fully representative on the airline preferences over its known set of restrictions.

6.4.7.2.1.2 Selecting and reproducing the most significant EPPs for each flight

Each PEGASE flight has produced tens of EPPs. Since the EPPs will be the reference trajectory for our analysis, this means having tens of references for each flight, and so, the analysis could be done for each one of them.

Nevertheless, in most cases one new EPP is not providing substantial added value against the previous one. This is: some EPPs are just providing minor updates compared to the previous one, and so, the KPIs measured for one EPP are representative of several consecutive EPPs (when there are no significant changes).

This way, an effort was invested to select the most appropriate EPPs for each flight. This is: the EPPs which are providing a more significant added value for the analysis. Since the analysis is focusing on the vertical profile, the focus was to search for significant changes on climbing and descending profiles, which lead to the following typical EPPs chosen for each flight:

- For climbing trajectories
    - The first (usable) EPP report, which includes the FMS prediction for the whole climb.
        - The ADS-C reports are providing actual position and mass, but not actual speed. During the acceleration phases (typically bellow 5.000 ft and between 10.000 and 12.000 ft), there is an uncertainty on the initial speed which compromises the KPIs. For that reason, in some cases, we discarded some EPPs where we considered there was a significant uncertainty on the initial speed.

    - For some flights, the ADS-C contracts were established when the aircraft was already high (let's say above FL250), and so we had not good EPPs for the climb (just some of them containing a small portion of the climb, close to RFL).
  - Any intermediate EPP report in case there are significant changes on:
    - Either the climbing speed schedule.
    - Or the Rate Of Climb until the Top Of Climb.
- For descending trajectories:
  - The first EPP report including a descent to the ADES.
    - Normally, when the flight is still at climbing phase (and also during the initial part of the cruise phase), the STAR is typically not yet available, and the EPP shows a descent to the airport (to the ARP).
  - The first EPP report where the STAR/approach procedures have been inserted.
  - Any additional trajectory in case there are changes on the STAR/approach procedures, or in the descending scheduled speed.
  - The first EPP report just after the descent phase starts (this is: the aircraft starts descending from its RFL and no point in the EPP is flagged as being the TOD).
    - Once we analyse the first EPP in descent phase, we do not continue analysing EPPs since the pending EPPs will not provide a significant added value for the analysis.

Once the EPPs are selected, a flight plan is created by copying the flight intent as perceived by the FMS (this is: starting from ADS-C reported position, following FMS route and having the same restrictions). Nevertheless, in some cases, and due to the limitations of the FMS/ATSU prototype, the last EPP points (end of descending profile) are placed in the same 2D position, but with different altitudes and ETOs. In those cases, the flight was reproduced only up to the first of those points.

With regards to the Meteo data, and since the target trajectory is the FMS one, the appropriate meteo data would be the FMS perceived meteo data. Unfortunately, it has not been possible to use this data for any flight due to the complexity of accessing FMS managed weather forecast (and also due to the complexity of managing a complex meteo model in the Test Bench). This way, the flights were reproduced using zero wind, and checking the historical temperature data for the corresponding aerodrome (departure for climbing trajectories, and arrival for descending trajectories).

The usage of the actual temperature measured at the airport could introduce some uncertainty, but we assume that the error is not too big (let's say around 5 degrees), and so the impact should be low.

Nevertheless, the unavailability of FMS wind data, has significant impact on any distance-based KPI:

- Distance vs time (this is: expected ETOs on points).
- Distance vs altitude (this is: 3D profile of the climb/descent).

However, in the BADA model, the Rate Of Climb or Descent does not depend on the wind, and is fully representative of BADA aircraft performance model. This way, if we demonstrate good results on the reduction of the Rate Of Climb/Descent uncertainty, we can deduce good results in other graphs (since we are flying at the same speed), even if this is not directly demonstrated. Any additional unexpected difference on the other KPIs would be derived from the wind uncertainty.

6.4.7.2.1.3 Selected KPIs

Due to the above reasons, the KPI that will be produced by this study is the reduction on the uncertainty on the Rate Of Climb/Descent along the climb/descent phases.

In order to provide this KPI, the Rate Of Climb/Descent error will be measured both as absolute error (difference in ft/m) and as relative error (percentage over a reference ft/m), and also for both computed trajectories: without ADS-C data and with ADS-C data.

Note that, the EPP point information does not include any instantaneous value for the Rate Of Climb/Descent at each point, but provides a predicted altitude and ETO for that point. So, the mean ROCD between two consecutive points on the EPP can be easily obtained and compared with an equivalent computation in the ground.

See bellow an example:

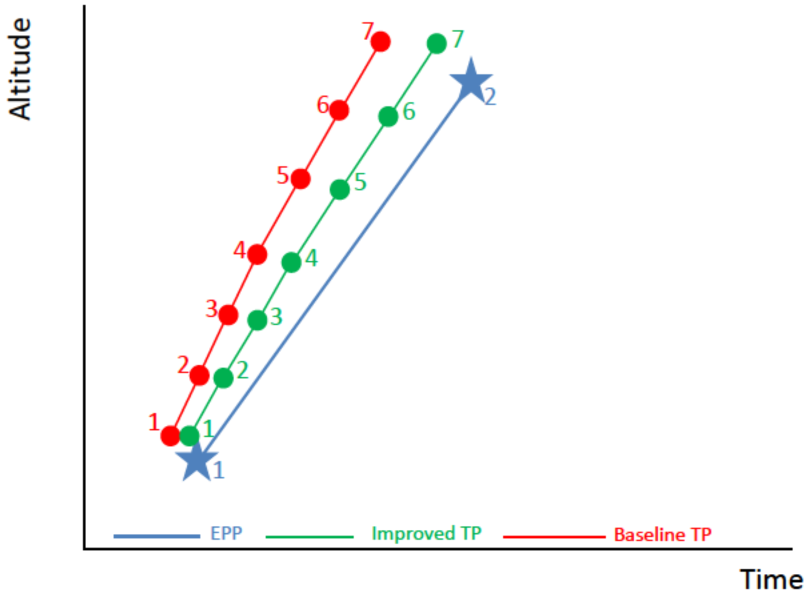


Figure 68 Example for Indra TP computation of ROCD improvement KPI

The mean ROCD between two points is to be obtained as the difference in altitudes divided by the difference in time for those points:

- The reference ROCD will be the mean ROCD between EPP points 1 and 2 (consecutive).
- The baseline ROCD will be the mean ROCD between Baseline TP points 1 and 7, since those points are the closest points (in altitude) to the EPP points (for which we define the reference ROCD).
- Similarly, the improved ROCD will be the mean ROCD between Improved TP points 1 and 7.

Once we know the ROCD values, we can compute the ROCD error on both TP trajectories, and so, the improvements.

Obviously, an EPP typically contains more than two points, and the ROCD error identified for each EPP segment (between consecutive points) is different. In order to consolidate the mean ROCD error for that EPP, the approach was to compute a weighted mean of the ROCD error on each EPP segment (weighted by the delta altitude covered within this segment). In this way, a big error in a short segment weights less than a medium error on a long segment.

A similar approach was followed to get the mean error for a single flight, for which several EPPs are analysed, and also to consolidate results among several flights.

6.4.7.2.1.4 Classifying EPP segments by altitude profile strategy

As previously explained, the FMS uses different strategies to close the degrees of freedom in the altitude profile.

In absence of altitude restrictions, the standard approach for the FMS is to implement a BADA-like strategy, where the throttle is set to the maximum (or minimum), the speed is set to a fixed value and the altitude evolves freely (with short acceleration/deceleration manoeuvres when a speed restriction starts/ends).

Nevertheless, there are also other circumstances where the FMS chooses different strategies, and this has a big impact on the altitude profile. Since those strategies are not implemented by the current ground TP prototype, the TP results are bad (whatever using or not the current mass and speed strategy information).

This way, when computing the KPIs, and for each of the EPPs analysed, the EPP climbing and descending segments have been classified into the three following groups (expert judgement):

- BADA-strategy manoeuvre: When the manoeuvre implemented in this segment seems to be a manoeuvre aligned with BADA default strategy. This is: based on max/min throttle setting. They are normally called "unrestricted climb/descent" by Airborne partners.
- Other strategies: When the manoeuvre implemented seems to follow a different strategy, not based on setting a particular Throttle rating, but based on following a target altitude profile.
- Unclear manoeuvres: When some relevant information is missing to properly classify this segment into the previous 2 groups.

In the following subsections, examples of the manoeuvres from second and third group are given.

6.4.7.2.1.4.1 Other strategies (non BADA)

Within the EPPs, we have found two types of manoeuvres where the control rule is not based on a particular Throttle rating, but based on following a particular altitude profile:

- Procedural & Geometric manoeuvres during arrival & approach.
- Low (or sometimes High) Rate Of Descent to catch-up optimal descent profile from current position.

Procedural & Geometric manoeuvres

The arrival and approach procedures are including some restrictions that the aircraft shall follow, and in some cases, these restrictions force a particular altitude profile to be followed. The most typical one is the 3 degrees final approach glide path, but this is not the only one. Any STAR / Approach procedure includes restrictions (sometimes a fixed altitude value, and sometimes a range between two altitude values).

In most cases, an IDLE throttle rating manoeuvre would imply descending too shallow or too steep between consecutive restrictions, and so, the restrictions would not be fulfilled. So, a different strategy is needed, and the one chosen by the FMS differs from the ground TP one:

- The ground TP only descends with an IDLE strategy. So:
  - If the resulting Rate Of Descent was too high, levelled segments are inserted.
  - If the resulting Rate Of Descent was too low and the altitude restriction is not reached at the corresponding position, it does not make any correction, and just provides a trajectory which does not achieve this restriction (in PEGASE flights, this typically happened during the approach phase, including ILS glide path)
- On the other hand, the FMS follows a different strategy. When the IDLE throttle strategy does not fulfil a restriction, it changes this manoeuvre and implements a geometric manoeuvre to the closest restriction range limit. This way, a geometric path is forced, and the necessary throttle value is computed by the FMS to follow such forced profile.
  - For those cases where a higher Rate of Descent would be needed, it is still unclear how is this managed by the FMS, but most likely the FMS foresees a different aerodynamic configuration which increases the Drag, such as using spoilers.

In Figure 20, a clear example is provided for the previous cases:

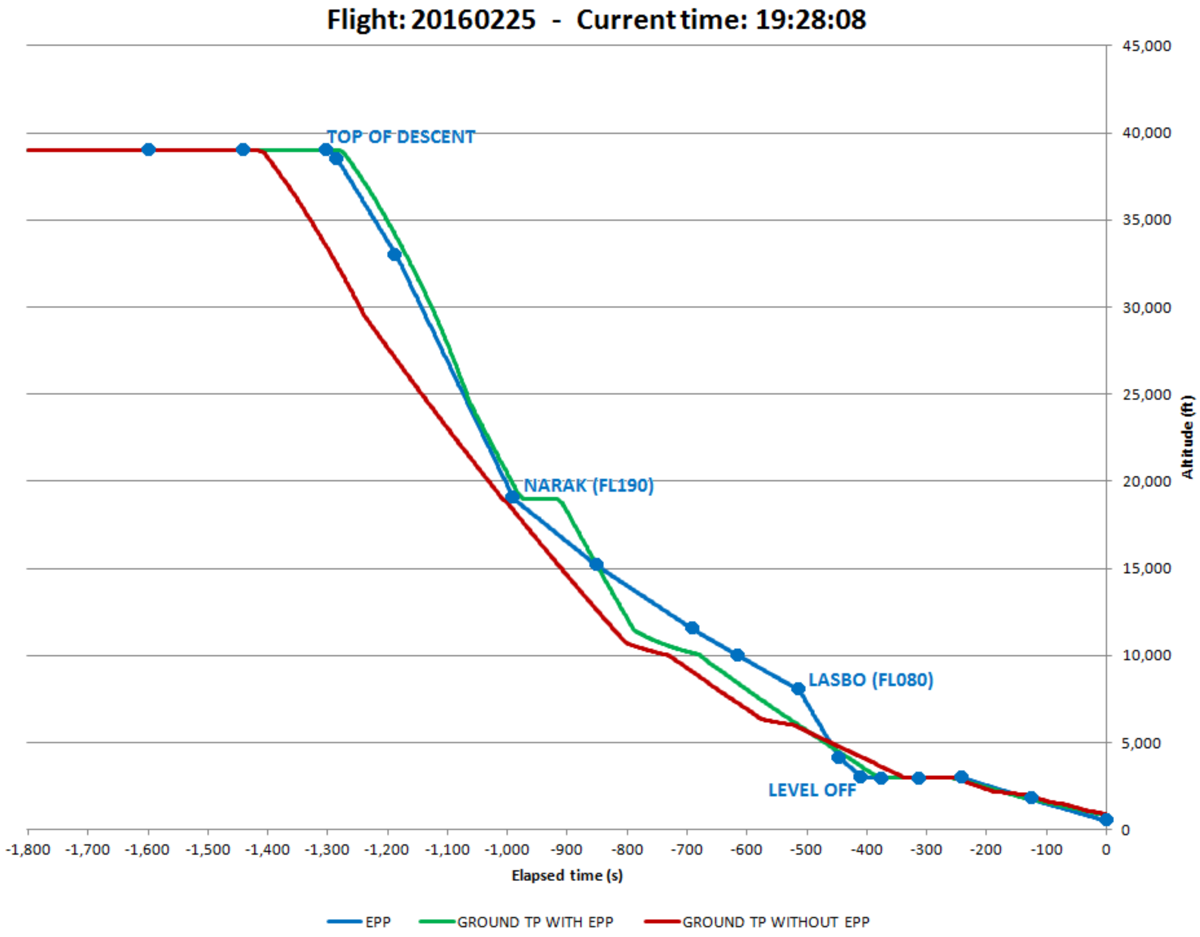


Figure 69 Example for Geometrical & Procedure manoeuvres on EPPs

In the previous figure, we can see:

- Between the Top Of Descent and NARAK, there is a BADA-standard manoeuvre (based on IDLE throttle), and we can see significant improvements on the Rate Of Descent predicted by the TP when using EPP data.
- Between NARAK and LASBO, the EPP shows a geometric manoeuvre allowing to achieve both restrictions, with a reasonably constant Rate Of Descent. On the other hand, the ground TP implements an IDLE throttle manoeuvre which leads into a globally higher Rate Of Descent, and so needs to add the levelled segment just after NARAK. During the descent, we can see three different Rate Of Descent values in the ground TP:
  - The highest one, close to NARAK, where the speed is constant: IAS 340.
  - The lowest one, close to FL100, where the deceleration to IAS 250 takes place.
  - The final one, close to LASBO, where the speed is constant: IAS 250.
- Between LASBO and the LEVEL OFF point, the FMS forces a high Rate Of Descent, probably using spoilers. In fact, the Rate Of Descent here is almost as big as the one above NARAK, where the speed (and so the Drag) is significantly higher. On the other hand, the ground TP is just unable to compute a trajectory which achieves LASBO restriction.

It must be highlighted that not all FMSs would behave in the same way, especially legacy FMSs. This functionality is linked to a general FMS support to continuous descent approach which might not be supported by some currently existing FMSs.

Low (or sometimes high) Rate Of Descent to catch-up optimal profile from current position

As it was explained in section 6.4.6.2.1.2, the aircrafts normally start descending far from their optimal TOD, and this can be due to different reasons (conflicts, safety margin, etc). PEGASE flights are not an exception.

In fact, in almost all PEGASE flights, the start of the descent phase happened several miles before the predicted optimal TOD point. In such scenario, the flight has more distance until the landing at the airport runway, but the altitude change is the same one. So, the Rate Of Descent needs to be lower.

In this scenarios, the FMS computes a constant Rate Of Descent manoeuvre from aircraft current position (normally 1.000 ft/m) until it crosses the optimal descent profile (which is based on IDLE Throttle rating).

On the other hand, the ground TP uses its standardized IDLE descent from its current position until the cleared altitude, where it inserts a levelled segment until it crosses the same optimal profile.

In the Figure 21, a good example of the previous can be seen:

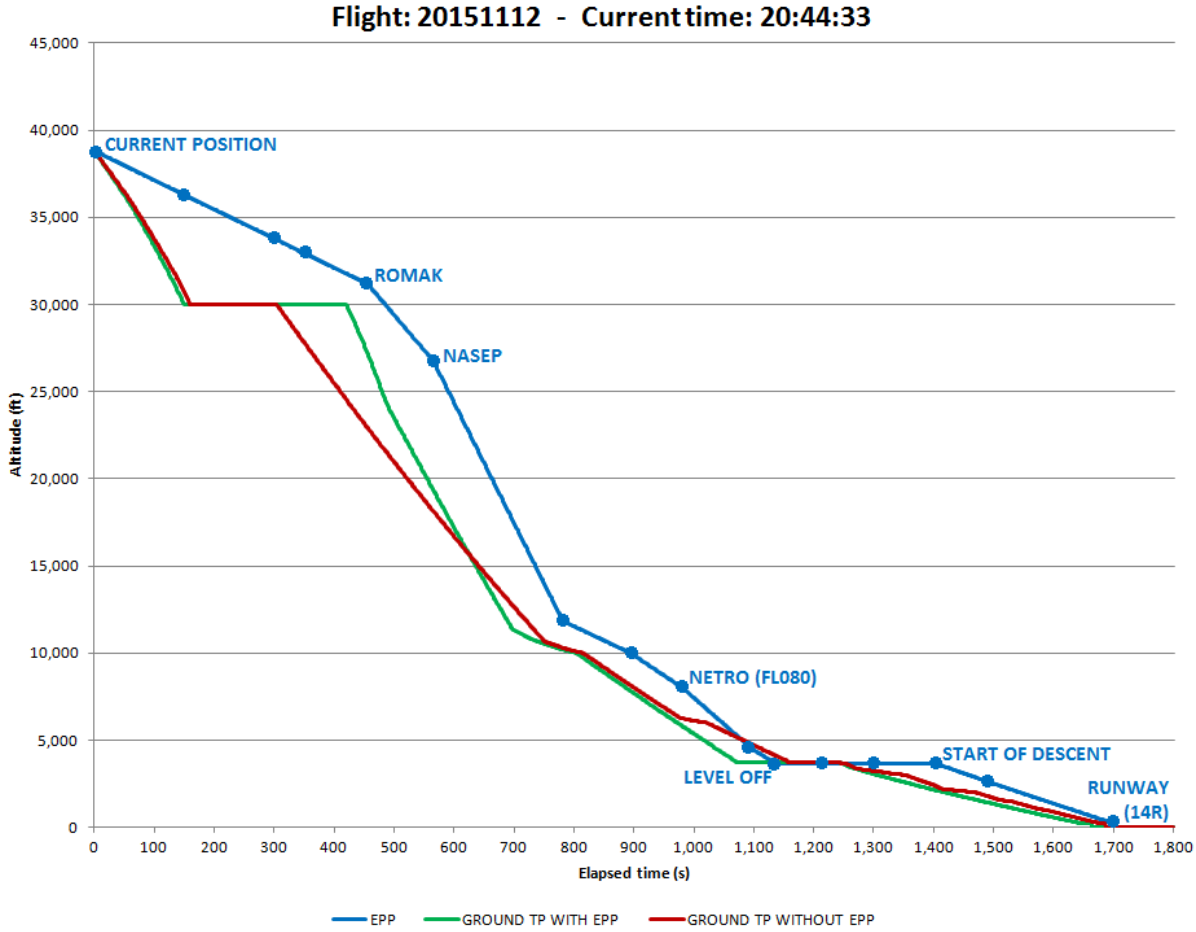


Figure 70: Example for low Rate Of Descent manoeuvres to catch-up optimal profile on EPPs

In the previous figure, we can see:

- Between current position and ROMAK: A shallow descent (1000 ft/m) until ROMAK. As it can be seen, the ground TP descents steeper (IDLE descent) and then levels.
- Between ROMAK & NASEP: One of the doubts, which are explained in following section (the same example will be referred).
- Between NASEP & NETRO: A BADA-standard manoeuvre (IDLE thrust rating), where the improvements are clearly demonstrated.
- Between NETRO and LEVEL OFF: A geometric manoeuvre, like the ones explained in previous example (but in this case, the difference compared to an IDLE descent was small).
- Between START OF DESCENT and RUNWAY 14R: A geometric manoeuvre (3 degrees glide path) which cannot be followed by the ground TP (either with or without using EPP info), and so the TP was not able to achieve the existing Start Of Descent constraint (TBN79).

Note that, in very few cases, the opposite scenario was found: the aircraft position was above the optimal descent path. In such cases, instead of using a constant (and low) Rate Of Descent manoeuvre, the FMS implements an IDLE manoeuvre with spoilers, with the same objective: to catch-up the optimal descent profile.

Note also that these are the manoeuvres for which the TP error is higher, since the mean Rate Of Descent at those RFL-like altitudes (for the ground TP) is often above 3.000 ft/m, while the EPP Rate Of Descent there is close to 1.000 ft/m.

Finally, note also that, similarly to the previous case, not all FMSs behave in the same way, and some FMSs (especially old ones) would behave more similarly to the ground TP approach.

6.4.7.2.1.4.2 Unclear manoeuvres

There are some manoeuvres which are difficult to classify in the previous two groups (this is: being or not a BADA strategy manoeuvre, based on setting max/min throttle rating).

Two types of doubts have been found:

- Doubts derived from missing points in the EPPs.
- Doubts derived from unknown speed strategy at the end of climb phase.
- Doubts related with an unexpectedly low Rate Of Descent close to the RFL.

Doubts derived from missing point

The FMS/ATSU prototype includes a logic to determine, from the fine grain & detailed FMS trajectory which are the points that shall be included in the EPP message. While it seems obvious to include some EPP points (such as route points, or the Top Of Descent point), it is not so obvious to include other FMS-calculated points.

In the PEGASE flights, for anticipated descent (see previous section), the ATSU rules are not including the point where the smooth descent (1,000 ft/m) manoeuvre catches up the optimal descent profile (normally based on IDLE throttle rating). This is the case for the segment between ROMAK & NASEP, in figure 67, where it seems this segment could be decomposed into a constant ROCD segment (just after ROMAK) and an IDLE throttle segment (just before NASEP).

So, this segment includes two manoeuvres, and each of them would be naturally classified into a different group (BADA strategy vs other strategy). So, the whole segment cannot be considered as belonging to one concrete group and so is classified into the current group (Unclear Manoeuvre).

Doubts derived from unknown speed strategy at the end of climb phase

During the climb phase, some aircrafts are cleared to an intermediate climbing level around FL310. When reaching this altitude, the aircraft levels.

Some aircrafts in this situation produce some EPPs showing a strange altitude/speed profile. Even if, at that altitude, the aircraft should typically climb at constant MACH, the EPP shows IAS speed for each point, and this IAS speed decreases with the altitude

For example, for the flight 20160330, at 15:14:27, the following points are published:

EPP point number (and name)	Altitude	Speed
1 (ABAME)	32410 ft	296 IAS
2 (ABSOG)	34600 ft	282 IAS
3 (BOMBI)	37330 ft	264 IAS
4 (GIGET)	38570 ft	257 IAS
5 (topOfClimb)	39000 ft	254 IAS
6 (ABUKA)	39000 ft	0.8 (MACH)
...		

Table 28 Example for unknown climb speed strategy close to RFL on EPPs

Was the aircraft following a constant speed strategy? Was it a constant MACH?

Possibly, the aircraft received some ATCO speed clearance. Or maybe it was performing some in-flight tests. Something similar happened for a few flights (5 of them)

Anyway, it is clear that there are big uncertainties on the speed strategy in this segment, and the ground TP was not able to properly clone the speed strategy. Since the impact of the speed strategy on the altitude profile is very significant, the segments like the above one were classified as an unclear manoeuvre.

Doubts related with an unexpectedly low Rate Of Descent close to the RFL

For some PEGASE flights, the Rate of Descent predicted by the FMS close to the RFL is unexpectedly low. An example is provided in Figure 71:

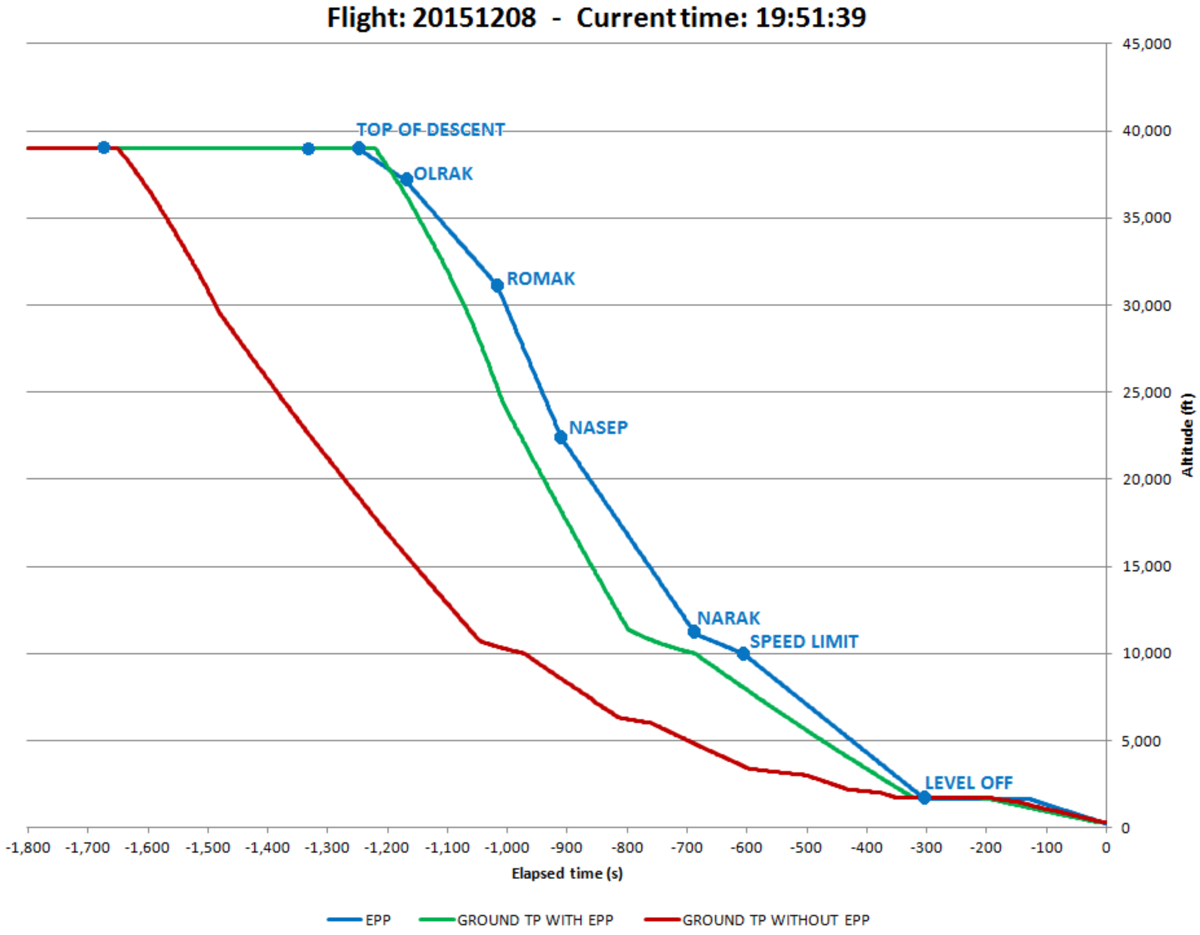


Figure 71 Example for unexpectedly low Rate Of Descent close to the RFL on EPPs (1)

In this EPP profile, the segment between the Top Of Descent and ROMAK has a very low ROCD. The difference is so big that it is very unlikely that the FMS was selecting an IDLE Throttle rating strategy. Nevertheless, this needs to be still confirmed by Airborne Industry, and by now, it is considered as a doubt.

Note that, for the same aircraft, sometime after, another descent profile is published:

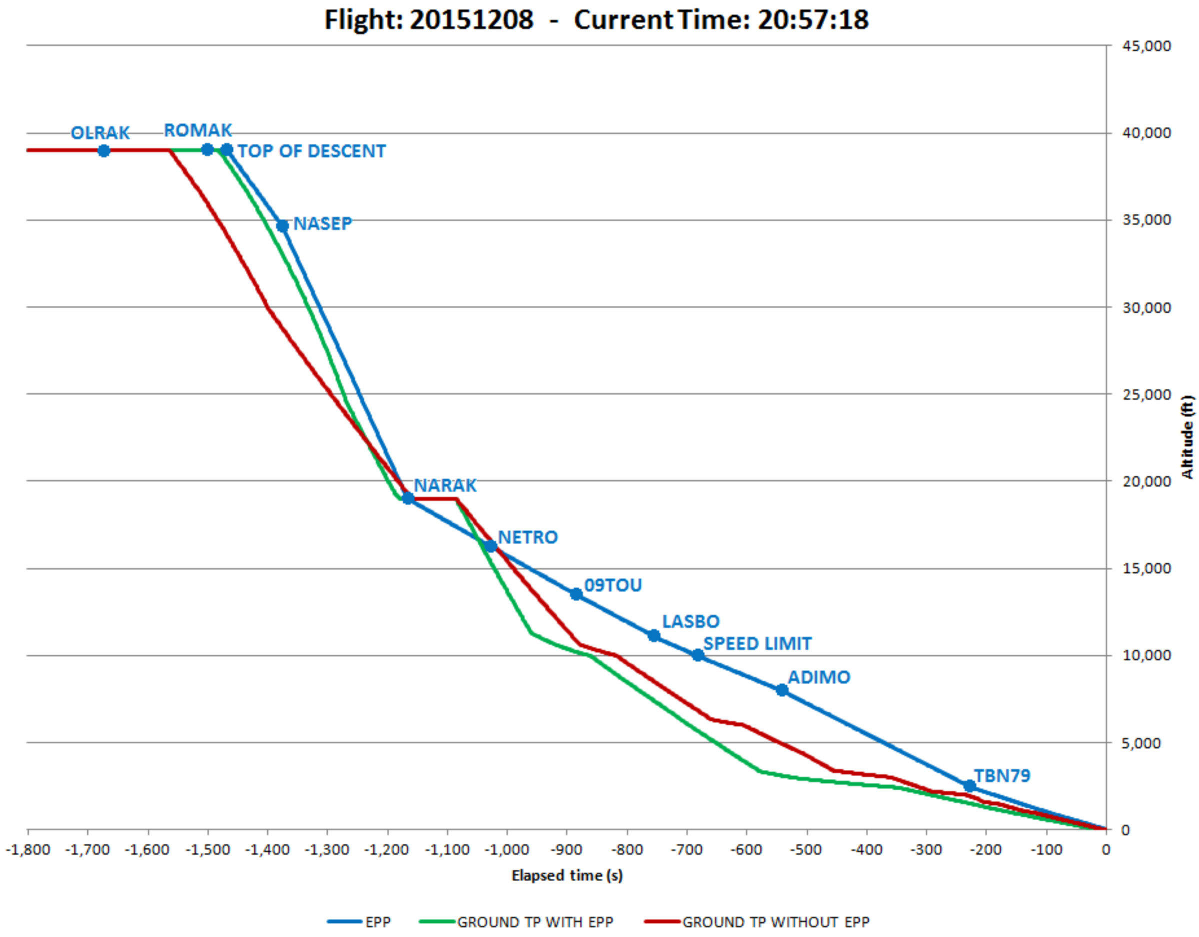


Figure 72 Example for unexpectedly low Rate Of Descent close to the RFL on EPPs (2)

In this latest profile, the STAR and approach procedures have been inserted, and so there are several geometric manoeuvres bellow NARAK. Nevertheless, the important segment here is the beginning of the descent. In this example, the unexpectedly shallow descent profile that was foreseen close to the RFL in the previous prediction cannot be found, and the overall descending profile (above NARAK) is clearly an IDLE throttle strategy.

There are other flights in which something similar happens, and the beginning of the descent phase is unexpectedly shallow, and there is no clear explanation yet on why this happens. This way, those segments have been classified as doubt segments until further explanation can be given by Airborne Industry.

6.4.7.2.1.5 TP improvement results

In this section, the results of the analysis are provided.

It must be noted that the results are focusing on the improvements of the ROCD prediction. Nevertheless, as explained in section 0, there is another significant improvement, which is the longitudinal accuracy of the trajectory (ETOs on points). This is an obvious secondary effect of computing a trajectory at the same speed. Nevertheless, since the FMS wind data was not available during the analysis, the EPP and the ground TPs cannot be compared to produce a KPI.

So, and focusing on the ROCD, the results are provided for each of the groups of manoeuvres (BADA-strategy manoeuvres, other strategies and unclear manoeuvres).

6.4.7.2.1.5.1 Results for BADA-strategy manoeuvres

The weighted arithmetic mean of the TP results for the analysed climbing profiles (for the BADA-strategy manoeuvres) is as follows:

Climbing profiles – BADA strategy manoeuvres					
Initial ROCD uncertainty		Final ROCD uncertainty		Improvement	
Absolute	Relative	Absolute	Relative	Absolute	Relative
274.53	14.74%	143.93	7.65%	47.57%	48.10%

Table 29 TP results on Climbing profiles – BADA strategy manoeuvres

On the other hand, the weighted arithmetic mean of the TP results for the analysed descending profiles (for the BADA-strategy manoeuvres) is as follows:

Descending profiles – BADA strategy manoeuvres					
Initial ROCD uncertainty		Final ROCD uncertainty		Improvement	
Absolute	Relative	Absolute	Relative	Absolute	Relative
646.06	21.46%	220.92	8.72%	65.80%	59.37%

Table 30 TP results on Descending profiles – BADA strategy manoeuvres

As it can be seen, for those climbing segments which are following a BADA-like strategy (maximum throttle rating), there are substantial improvements on the BADA ROCD prediction when setting the correct speed strategy and the correct mass.

6.4.7.2.1.5.2 Results for other strategies

In the climbing profiles, all manoeuvres have been considered as BADA-strategy ones, except a few exceptions that have been considered unclear manoeuvres (results in following section).

On the other hand, the weighted arithmetic mean of the TP results for the analysed descending profiles is as follows:

Descending profiles – Other strategies					
Initial ROCD uncertainty		Final ROCD uncertainty		Improvement	
Absolute	Relative	Absolute	Relative	Absolute	Relative
1063.71	84.40%	1250.71	101.99%	-17.58%	-20.84%

Table 31 TP results on Climbing profiles – Other strategies

As it can be seen, the TP results are bad, whatever using or not the EPP data (around 1.000 ft/m of uncertainty).

This is because the ground TP is always implementing the same descending strategy (IDLE throttle) while the FMS is using a different strategy in these segments. So, the results are bad.

This way, these results are highlighting the importance of improving the ground TP to detect, from the EPP, the preferred strategy for the vertical profile, and then implement the same strategy. This way, the EPP will help to significantly improve the trajectory here also in those manoeuvres. Nevertheless, this improvement was not done in the ground TP prototype (as explained in section 6.4.6.2.1.1) and is left for future improvements (probably during SESAR 2020 PJ18-06).

Additionally to the previous, it is also interesting to analyse why the results are worse. This is: it is clear that the results will be always bad (whatever using or not the EPP data) if the TP is modelling a different strategy, but why the results are worse when using the EPP data?

In almost all cases, the implementation of a different vertical profile strategy (different from IDLE throttle strategy) means setting a lower Rate Of Descent. For example: when the aircraft is cleared to descent in anticipation, the FMS sets a constant Rate Of Descent manoeuvre typically equal to 1.000 ft/m, while the IDLE-rating Rate Of Descent would be typically around 3.000 or 4.000 ft/m. Additionally, the geometric manoeuvres are typically applied during arrival/approach procedures, and those procedures are designed to be flown by several aircraft models in several meteorological conditions. So, they are designed to be shallow enough.

On the other hand, the PEGASE flights have the following typical characteristics:

- The actual weight of the aircraft is quite low, since the payload is almost zero (no passengers).
- The actual preferred descent speed is IAS 340 in most cases, which is higher than the BADA standard preferred speed for an A320 (IAS 310).

The effect of computing an IDLE descent with a lower mass and higher speed is an increase of the Rate Of Descent (as shown in the example figures in previous sections).

This way, and for PEGASE flights, the usage of EPP data for IDLE descend manoeuvres means increasing the Rate Of Descent in the ground TP, while the reference trajectory (EPP one) is implementing a different strategy based on lowering the Rate Of Descent. This is why the results are worse when using EPP data in those manoeuvres.

Nevertheless, if we also had EPP data for other flights (heavier & slower flights), the effect of using EPP data would be the opposite (a lower Rate Of Descent). In this scenario, we would see that the results are better, but would remain being bad results. So, the conclusion would be the same one: the usage of EPP data to improve ground trajectories should include the detection of those manoeuvres and their implementation in the ground trajectory. This is the only way to have good results in these manoeuvres.

6.4.7.2.1.5.3 Results for unclear manoeuvres

In climbing profile, there were a few examples of unclear manoeuvres, mostly derived from an unclear speed strategy (as explained in section 6.4.7.2.1.4.2). The weighted arithmetic mean of the TP results for those unclear climbing profiles is as follows:

Climbing profiles – Unclear manoeuvres					
Initial ROCD uncertainty		Final ROCD uncertainty		Improvement	
Absolute	Relative	Absolute	Relative	Absolute	Relative
444.57	157,84 %	539.24	165.26%	**-21.29%**	**-4.70%**

Table 32 TP results on Climbing profiles – Unclear manoeuvres

Since the speed strategy was confusing on those few climbing manoeuvres, it is difficult to extract any conclusion. Anyway, it must be highlighted that, in those manoeuvres, the EPP Rate of Climb was very low, and it is not fully clear why.

On the other hand, and for unclear manoeuvres on descent profiles, the result is as follows:

Descending profiles – Unclear manoeuvres					
Initial ROCD uncertainty		Final ROCD uncertainty		Improvement	
Absolute	Relative	Absolute	Relative	Absolute	Relative
662.41	28.04%	997.11	43.05%	**-50.53%**	**-53.50%**

Table 33 TP results on Descending profiles – Unclear manoeuvres

Anyway, as shown in section 6.4.7.2.1.4.2, the unclear manoeuvres imply a reduced Rate Of Descent. So, the rationale for having bad results (not only bad, but worse) are the same ones as the ones provided in the previous section.

6.4.7.2.1.5.4 Results summary

The results presented are demonstrating a significant reduction of the uncertainty on the computation of the Rate of Climb and Descent in unrestricted manoeuvres (this is: based on Maximum or IDLE Throttle rating) on the ground planner trajectory when the TP is provided with the aircraft high level speed strategy and the actual mass.

The results that have been obtained are better in descending manoeuvres than in climbing manoeuvres. This is because:

- In climbing manoeuvres, the speed strategy followed was typically slightly higher than the BADA standard speed. This means lowering the ROCD. Nevertheless, this was sometimes compensated by an increase of ROCD derived from the very low actual mass. This way, the final improvement is not so big.
- On the other hand, preferred IAS descending speed in most cases was significantly higher than BADA standard approach. This means increasing the ROCD (steeper descent). And this effect was amplified by having a very low mass. So, the baseline uncertainty for those descending manoeuvres was quite big, and the improvement is big.

Obviously, as long as the actual mass and preferred speed provided through the EPP is similar to the ground estimated mass and standard BADA speed schedule, the effect on the ground trajectory will not be significant. This way, the EPP will obviously be more useful for those flights for which the actual mass and preferred speed differs significantly from baseline ground TP estimation.

Additionally, and even if not formally demonstrated, the alignment on the aircraft high level speed strategy will obviously provide benefits on the longitudinal profile (ETOs on points). This was left out from the analysis since it is also significantly impacted by the wind, and there was no information about the wind which was forecasted in our reference trajectory (the EPP, and so, the FMS wind model).

Nevertheless, it has been also demonstrated that the FMSs are modelling other manoeuvres, which are not based on a particular Throttle rating, and so the ground TPs need to be improved. This would include the formulas to compute those kinds of manoeuvre, but also the logic to decide when each manoeuvre shall be applied.

It must be noted that, from the EPP trajectory, it should be possible to deduce the type of manoeuvres that are currently planned by the FMS. If this is done, and so the same manoeuvre is implemented in ground TPs, significant improvements would be expected for all the manoeuvres (not limited to the Maximum / IDLE throttle rating manoeuvres). Even more: in those manoeuvres, the results would be even better, since those manoeuvres are not so dependent on the aircraft physical performance model (those manoeuvres are based on following a particular altitude profile, and so, if they are implemented, there would not be any further uncertainty on the aircraft intent).

Finally, it must be noted that, while the detection of some frequent manoeuvres (such as constant Rate Of Descent manoeuvres or geometric manoeuvres) seem feasible, further conversations with airborne industry would be necessary in order to properly understand pending doubts, as well as differences between FMSs and/or aircraft models. This would be necessary in order to maximize the information about manoeuvres that could be extracted from the EPP trajectory.

6.4.7.2.1.6 Detailed results per flight (only for BADA strategy manoeuvres)

The following tables contain the results per flight that have been obtained during the analysis. The focus is set only on BADA-strategy manoeuvres, since they are the relevant ones of this study.

Note in new tables, the "Delta Altitude" attribute means the biggest vertical manoeuvre range that has been analysed for the concerned flight. Note that, it is not possible in most flights to analyse the whole climb/descent manoeuvre, either because there were different manoeuvres (other strategies, unclear manoeuvres) or either because not enough data was collected. In general, the bigger this number is, the more relevant the result is.

Climbing manoeuvres results:

Date	Callsign	Climbing						
		Initial ROCD uncertainty		Final ROCD uncertainty		Delta altitude	Improvement	
		Absolute	Relative	Absolute	Relative		Absolute	Relative
05/06/2015	AIB02DM	563.35	24.46%	247.90	12.10%	39,000	55.99%	50.54%
17/06/2015	AIB02BM	297.92	14.64%	211.50	10.95%	39,000	29.01%	25.21%
28/10/2015	AIB02IN	0.23	0.02%	59.87	5.20%	10,550	-25,760.87%	-25,760.87%
10/11/2015	AIB02IE	340.23	28.92%	155.19	13.19%	4,000	54.39%	54.39%
18/11/2015	AIB02BU	188.94	11.30%	61.28	3.87%	22,470	67.56%	65.79%
30/11/2015	AIB0214A	412.31	27.26%	64.13	4.51%	26,599	84.45%	83.47%
30/11/2015	AIB0214B	343.61	22.85%	133.52	8.76%	34,096	61.14%	61.65%
30/11/2015	AIB0214C	185.13	8.16%	188.30	8.67%	32,497	-1.71%	-6.29%
30/11/2015	AIB0214D	221.59	12.00%	182.36	9.63%	14,371	17.70%	19.76%

30/11/2015	AIB0214E	932.91	27.92%	493.31	14.28%	4,248	47.12%	48.87%
02/12/2015	AIB02BI	141.24	7.45%	182.43	10.58%	15,886	-29.16%	-42.07%
08/12/2015	AIB02IT	129.00	11.02%	46.18	3.89%	7,000	64.20%	64.67%
11/12/2015	AIB0214F	318.85	20.93%	77.34	3.16%	26,950	75.74%	84.92%
11/12/2015	AIB0214G	262.49	20.69%	175.31	8.88%	24,090	33.21%	57.09%
11/12/2015	AIB0214I	212.37	18.57%	94.01	8.44%	4,896	55.73%	54.53%
21/12/2016	AIB03DO	128.88	8.15%	111.22	6.49%	25,566	13.70%	20.39%
13/01/2016	AIB02DF	117.36	8.52%	124.66	9.76%	24,100	-6.22%	-14.50%
15/01/2016	AIB04IH	227.38	10.98%	173.46	8.95%	31,770	23.71%	18.50%
29/01/2016	AIB02DR	188.75	14.44%	82.28	6.24%	14,670	56.41%	56.78%
01/02/2016	AIB02DT	25.75	1.58%	124.05	7.63%	15,180	-381.84%	-381.84%
09/02/2016	AIB02BO	205.22	11.14%	151.83	7.19%	15,770	26.02%	35.52%
16/02/2016	AIB02BD	177.83	12.32%	124.55	8.04%	21,660	29.96%	34.73%
24/02/2016	AIB02IA	49.04	5.66%	173.28	18.43%	7,100	-253.32%	-225.41%
25/02/2016	AIB02IE	134.22	11.02%	40.92	3.74%	8,000	69.51%	66.03%
26/02/2016	AIB03IR	421.84	29.41%	194.32	13.26%	8,000	53.94%	54.92%
02/03/2016	AIB03DX	527.48	37.94%	358.23	24.37%	2,000	32.09%	35.75%
04/03/2016	AIB02BQ	446.75	25.81%	52.18	3.50%	21,560	88.32%	86.45%
11/03/2016	AIB02BX	404.18	21.03%	72.62	4.04%	24,340	82.03%	80.78%
18/03/2016	AIB02DH	106.90	5.49%	98.78	4.85%	30,200	7.59%	11.68%
30/03/2016	AIB02IC	188.25	12.12%	186.52	11.42%	25,580	0.92%	5.80%
04/04/2016	AIB04DU	196.52	9.32%	128.45	5.61%	38,980	34.64%	39.78%
05/04/2016	AIB02DA	825.68	26.39%	433.74	14.22%	30,740	47.47%	46.12%
19/04/2016	AIB03IS	248.16	11.51%	67.79	2.79%	18,460	72.68%	75.77%
22/04/2016	AIB02IK	330.73	12.04%	164.47	6.19%	27,150	50.27%	48.55%
25/04/2016	AIB02DR	261.59	15.04%	116.11	5.96%	23,970	55.61%	60.39%
29/04/2016	AIB02BH	135.66	12.50%	239.65	22.08%	7,000	-76.66%	-76.66%
03/05/2016	AIB02IO	110.62	6.31%	101.91	5.76%	29,360	7.87%	8.78%
04/05/2016	AIB02BY	417.94	21.14%	158.19	9.22%	25,563	62.15%	56.41%
01/06/2016	AIB04IM	218.20	16.76%	71.14	5.05%	8,000	67.40%	69.87%
30/06/2016	AIB03DM	132.66	7.49%	82.26	3.96%	29,780	37.99%	47.10%
15/07/2016	AIB04IZ	319.25	21.21%	31.70	2.11%	15,380	90.07%	90.07%
22/07/2016	AIB02IS	265.01	16.76%	97.18	6.50%	9,550	63.33%	61.21%

Table 34 TP results on Climbing profiles per flight – BADA strategy manoeuvres

Note that, even for the non-improved flights, the final uncertainty value is nice, and aligned with the results of the other flights.

Descending manoeuvres results:

Date	Callsign	Descending						
		Initial ROCD uncertainty		Final ROCD uncertainty		Delta altitude	Improvement	
		Absolute	Relative	Absolute	Relative		Absolute	Relative
05/06/2015	AIB02DM	607.05	24.03%	108.01	4.59%	36,989	82.21%	80.91%
17/06/2015	AIB02BM	817.23	22.66%	178.49	6.60%	31,000	78.16%	70.89%
28/09/2015	AIB02DN	530.55	20.00%	151.24	7.02%	33,392	71.49%	64.90%
28/10/2015	AIB02IN	425.24	15.22%	170.43	7.63%	36,000	59.92%	49.90%
10/11/2015	AIB02IE	970.18	25.07%	128.84	4.59%	20,000	86.72%	81.70%
12/11/2015	AIB02DJ	960.76	26.97%	202.16	6.39%	37,183	78.96%	76.31%
18/11/2015	AIB02BU	784.86	23.56%	119.77	4.28%	37,010	84.74%	81.82%
30/11/2015	AIB0214A	353.47	30.50%	193.32	11.99%	24,418	45.31%	60.70%
30/11/2015	AIB0214B	143.60	9.48%	153.09	8.32%	37,894	-6.61%	12.27%
30/11/2015	AIB0214C	367.44	15.26%	191.51	8.14%	32,508	47.88%	46.65%
30/11/2015	AIB0214D	168.45	10.93%	196.75	10.79%	23,540	-16.80%	1.23%
30/11/2015	AIB0214E	411.21	27.15%	217.37	14.59%	17,181	47.14%	46.24%
02/12/2015	AIB02BI	834.37	23.90%	236.47	7.24%	31,000	71.66%	69.70%
08/12/2015	AIB02IT	1,128.40	30.15%	233.66	8.06%	29,435	79.29%	73.26%
11/12/2015	AIB0214F	362.65	20.03%	226.61	11.81%	28,580	37.51%	41.04%
11/12/2015	AIB0214G	359.61	16.88%	315.08	14.06%	35,000	12.38%	16.67%

11/12/2015	AIB0214I	301.03	12.16%	277.99	10.78%	36,000	7.66%	11.36%
21/12/2016	AIB03DO	386.56	13.65%	127.94	5.32%	22,360	66.90%	61.02%
13/01/2016	AIB02DF	768.08	20.64%	162.68	5.39%	31,000	78.82%	73.87%
15/01/2016	AIB04IH	901.41	23.78%	161.31	5.44%	31,540	82.11%	77.12%
29/01/2016	AIB02DR	723.29	23.59%	177.03	6.64%	36,967	75.52%	71.84%
01/02/2016	AIB02DT	1,451.69	33.25%	3.65	0.08%	13,900	99.75%	99.75%
09/02/2016	AIB02BO	799.93	26.52%	251.77	9.39%	32,963	68.53%	64.61%
16/02/2016	AIB02BD	446.13	12.38%	461.92	14.02%	20,000	-3.54%	-13.28%
24/02/2016	AIB02IA	643.08	20.62%	280.36	10.68%	21,000	56.40%	48.24%
25/02/2016	AIB02IE	796.94	26.65%	282.58	17.13%	37,190	64.54%	35.72%
26/02/2016	AIB03IR	390.98	14.51%	215.29	8.14%	36,988	44.94%	43.94%
02/03/2016	AIB03DX	1,218.51	29.13%	318.95	8.70%	20,000	73.82%	70.15%
04/03/2016	AIB02BQ	1,072.02	33.37%	188.61	5.43%	31,037	82.41%	83.73%
11/03/2016	AIB02BX	570.72	20.25%	445.56	14.57%	36,956	21.93%	28.03%
11/03/2016	AIB02DS	488.76	13.89%	467.65	13.29%	20,000	4.32%	4.32%
18/03/2016	AIB02DH	651.59	25.93%	326.19	14.35%	36,050	49.94%	44.66%
30/03/2016	AIB02IC	855.43	24.13%	291.99	9.32%	29,000	65.87%	61.40%
05/04/2016	AIB02DA	500.56	25.66%	192.14	10.88%	36,097	61.61%	57.59%
19/04/2016	AIB03IS	600.18	21.07%	247.15	8.98%	36,450	58.82%	57.37%
22/04/2016	AIB02IK	680.92	20.03%	179.23	6.50%	29,000	73.68%	67.54%
25/04/2016	AIB02DR	593.17	25.52%	108.46	4.87%	20,000	81.72%	80.93%
29/04/2016	AIB02BH	1,017.82	24.17%	147.23	4.58%	18,000	85.53%	81.06%
03/05/2016	AIB02IO	829.52	21.83%	319.74	8.88%	20,010	61.45%	59.33%
04/05/2016	AIB02BY	334.34	14.99%	291.48	11.30%	31,000	12.82%	24.58%
12/05/2016	AIB02DL	731.14	22.64%	257.62	10.16%	28,250	64.76%	55.11%
01/06/2016	AIB04IM	571.80	15.77%	123.33	4.34%	20,000	78.43%	72.45%
30/06/2016	AIB03DM	986.52	24.03%	156.92	4.63%	29,000	84.09%	80.72%
15/07/2016	AIB04IZ	414.83	19.27%	217.38	9.74%	29,000	47.60%	49.45%
22/07/2016	AIB02IS	852.11	22.63%	189.36	6.60%	26,940	77.78%	70.82%

Table 35 TP results on Descending profiles per flight – BADA strategy manoeuvres

6.4.7.2.1.6.1 Mean and standard deviation

Another general KPI that can be also obtained is the mean and standard deviation of the initial and final uncertainty. Note that this computation does not take into account the "Delta Altitude" as a ponderation attribute, and so the uncertainty figures are slightly different from the ones in section 6.4.7.2.1.5.1

Note also that the computation is done only for the absolute ROCD uncertainty value (in feet/minute).

	Climbing manoeuvres		Descending manoeuvres	
	Initial Uncertainty	Final Uncertainty	Initial Uncertainty	Final Uncertainty
Mean value	270.52	146.05	662.31	219.87
Std. Deviation	186.37	97.61	283.23	93.13

Table 36 TP results (mean and standard deviation) – BADA strategy manoeuvres

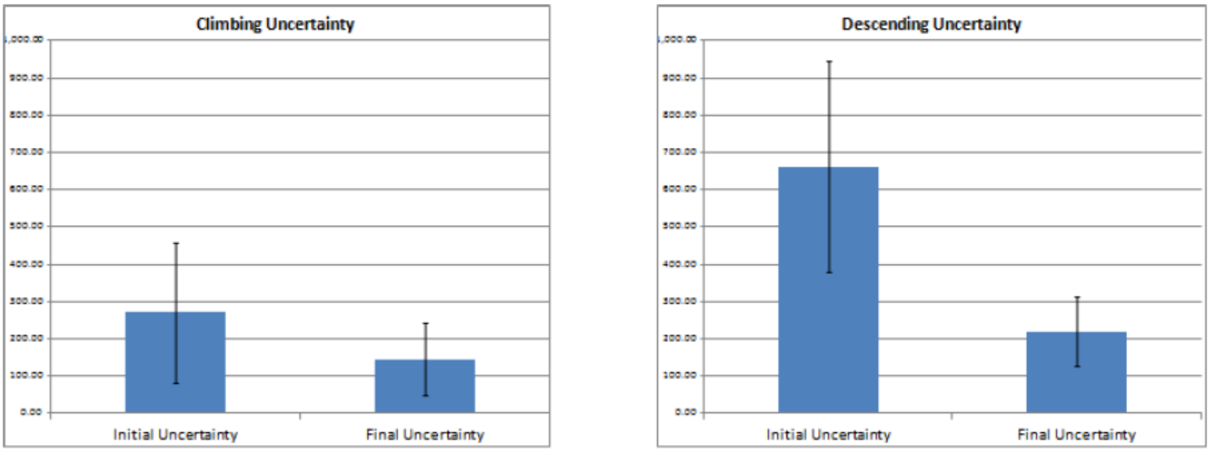


Figure 73 TP results (mean and standard deviation) – BADA strategy manoeuvres

6.4.7.2.1.7 Comparison against surveillance tracks

As it has been explained in section 6.4.7.2.1.1, the reference profile for the analysis has been the EPP itself, since the aircraft is usually not allowed to fly its preferred profile (there are a lot of tactical actions during a descent profile).

Nevertheless, there are a few cases where the analysed flights were allowed to fly according to their preferred profile, and the pilot followed it.

Without the intention to perform a detailed analysis on the improvements versus the surveillance tracks, a couple of examples are given in Figure 74 and Figure 75, where the potential improvements on the ground planned trajectory to predict the flown trajectory is observed.

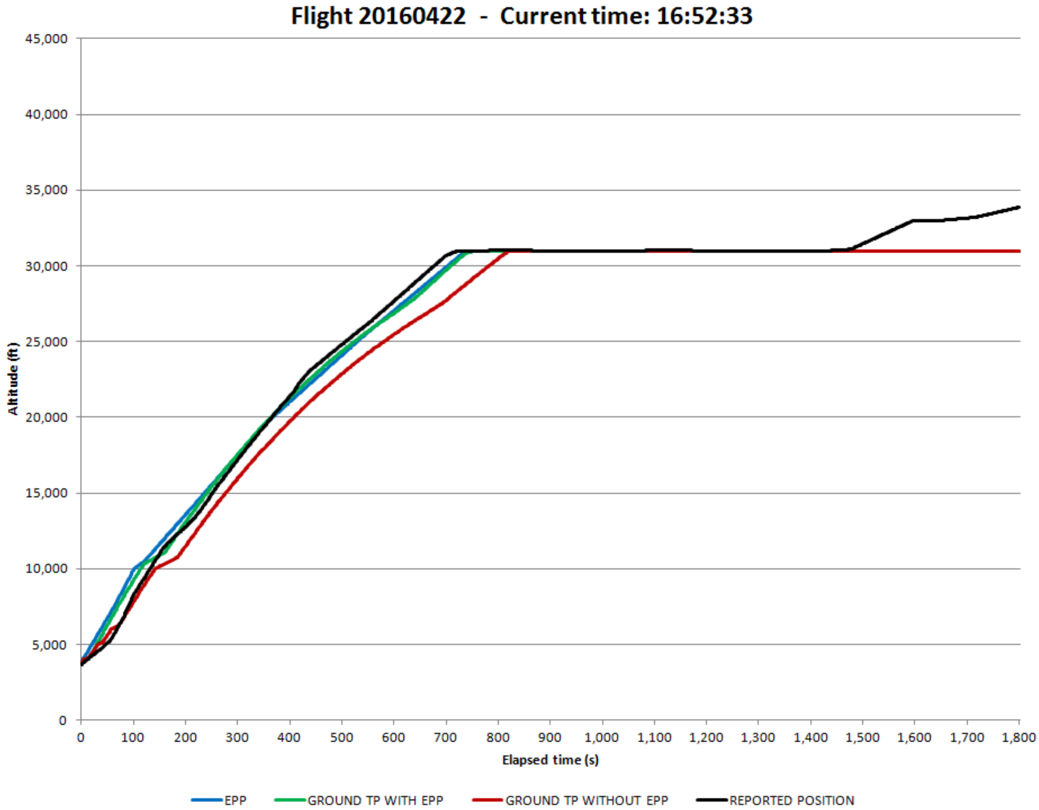


Figure 74 Example for improvements on climbing profile (vs ADS-C reported positions)

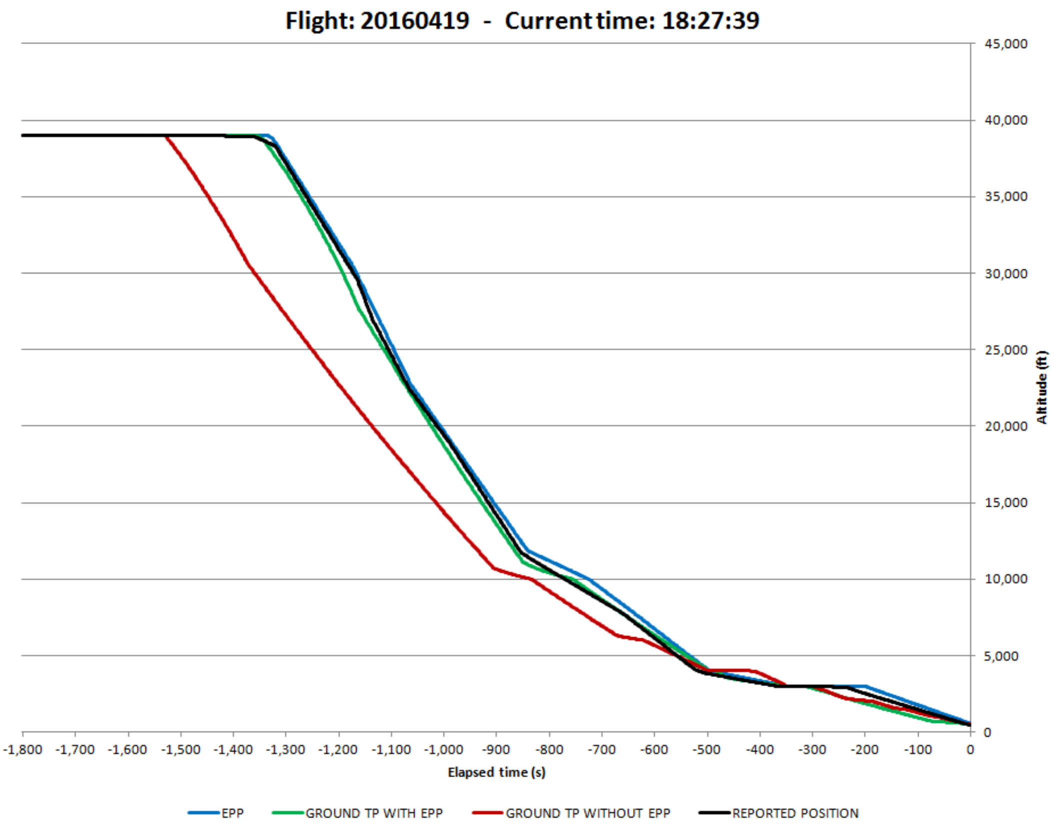


Figure 75 Example for improvements on descending profile (vs ADS-C reported positions)

On the other hand, in Figure 76, two examples are provided about flights where the actual flown trajectories do not match any of the existing predictions (neither the EPP, nor the ground TP).

Note that this does not mean that the prediction is bad, but just that some tactical actions were performed and this invalidated the plan.

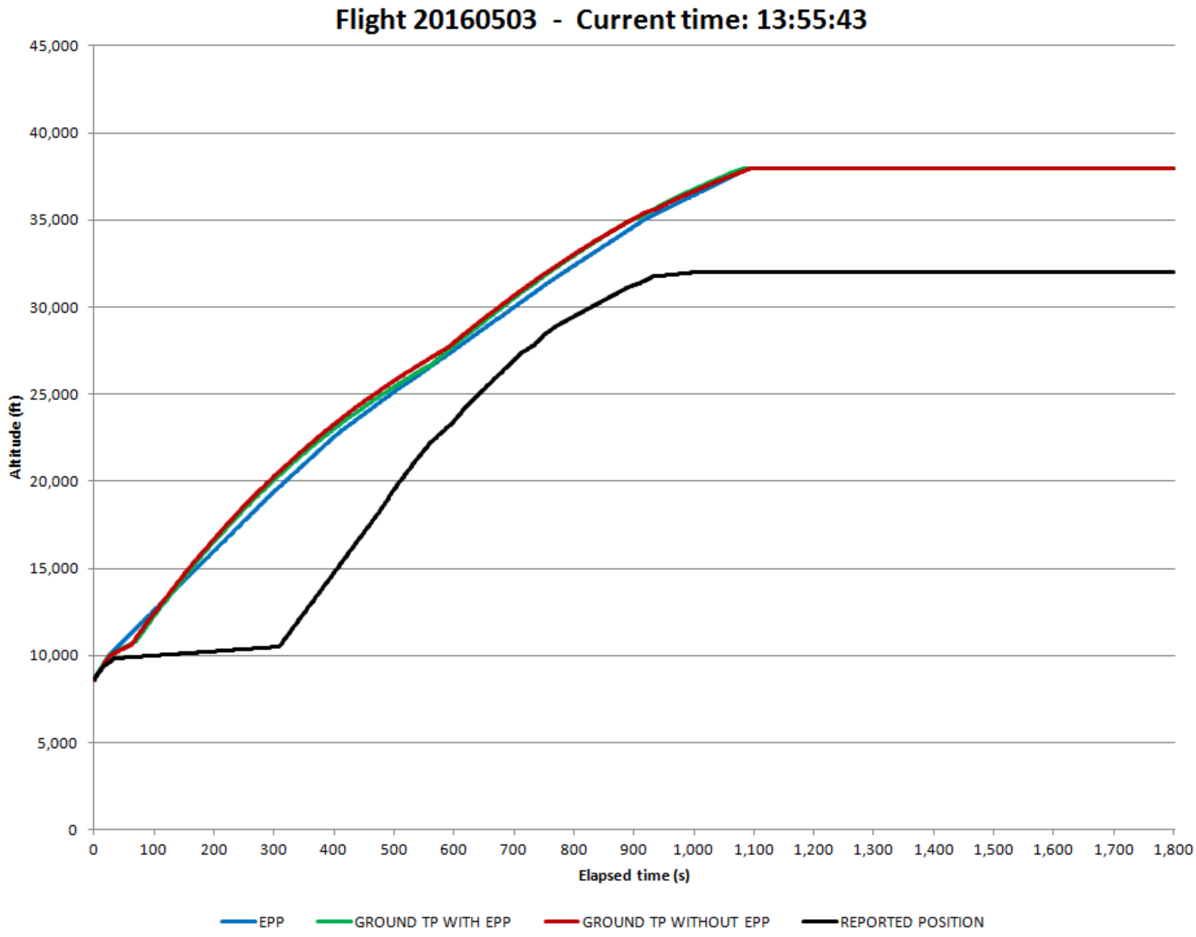


Figure 76 Climbing profile not properly predicted

In Figure 76 Climbing profile not properly predicted above, the aircraft levelled at FL100. When resuming the climb, the big ROCD is derived from a significant lower actual climbing speed (lower than the climbing FMS preferred speed, which was IAS 324).

It seems that the pilot entered a selected speed equal to IAS 219, as it can be checked in the EPP published when the aircraft was at FL 105. Nevertheless, the lack of ground information on speed clearances does not allow understanding if the pilot set this speed just for aircraft testing (being a production aircraft) or if this was derived from an ATC clearance)

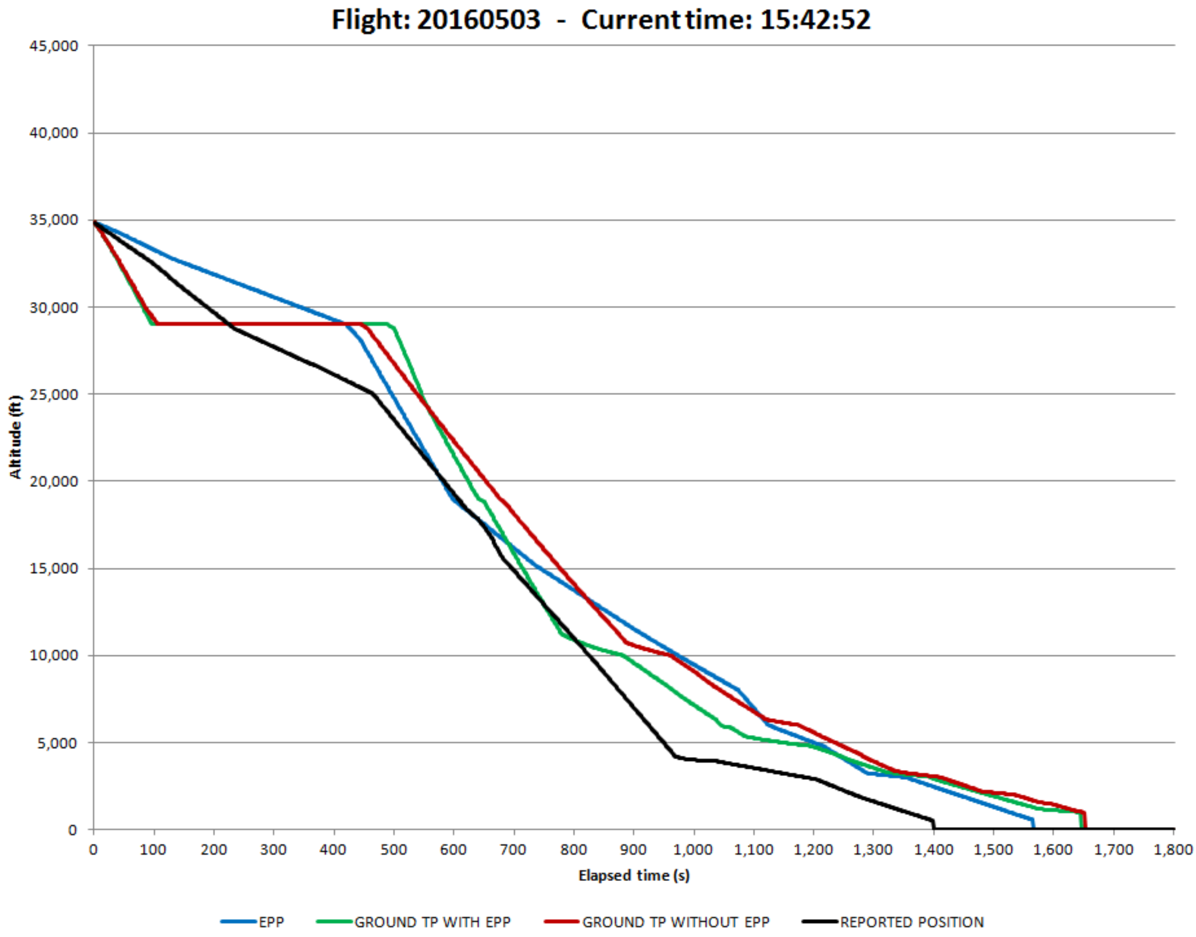


Figure 77 Descending profile not properly predicted

In Figure 77 Descending profile not properly predicted above, we can see that the flown trajectory was not properly predicted (or better said: the plan was not followed). The following bullets explain the aircraft behaviour:

- The aircraft is cleared to descend. Current altitude is FL350. The FMS (EPP) predicts the classical 1.000 ft/m to catch-up the optimal profile around FL290.
- Nevertheless, the aircraft starts descending in selected mode, with a Rate Of Descent equal to 1.500 ft/m (ATCO clearance? Pilot preference? Not fully clear)
- Approximately at FL290, the pilot changes to managed mode, and then the aircraft follows the new FMS profile (not shown in the graph):
  - First, low Rate Of Descent until FL250
  - Then, IDLE-throttle descent until FL190 approx (NARAK)
- Once at FL190 (NARAK) the aircraft is instructed a direct. This shortens the distance to the airport. The geometric procedure to LASBO is no longer necessary, and instead, the aircraft needs to descend steeper to be able to land. This is done in selected mode.
- Once the aircraft reaches approx. 4.000 ft, it just follows the Final Approach procedure.

As said, there is an IDLE-throttle manoeuvre between FL250 and FL190, but this is not exact. In fact, there were no reported positions between FL250 and FL190 (no ADS-C reports received). Our understanding is that the aircraft maintained the 1.000 ft/m Rate

Of Descent a little bit longer (up to FL245 approx.) and then changed to the IDLE-throttle, with a Rate Of Descent similar to the EPP one (instead of being slightly lower). Nevertheless, this cannot be demonstrated without detailed surveillance data.

Other examples of climbing trajectories are proposed below:

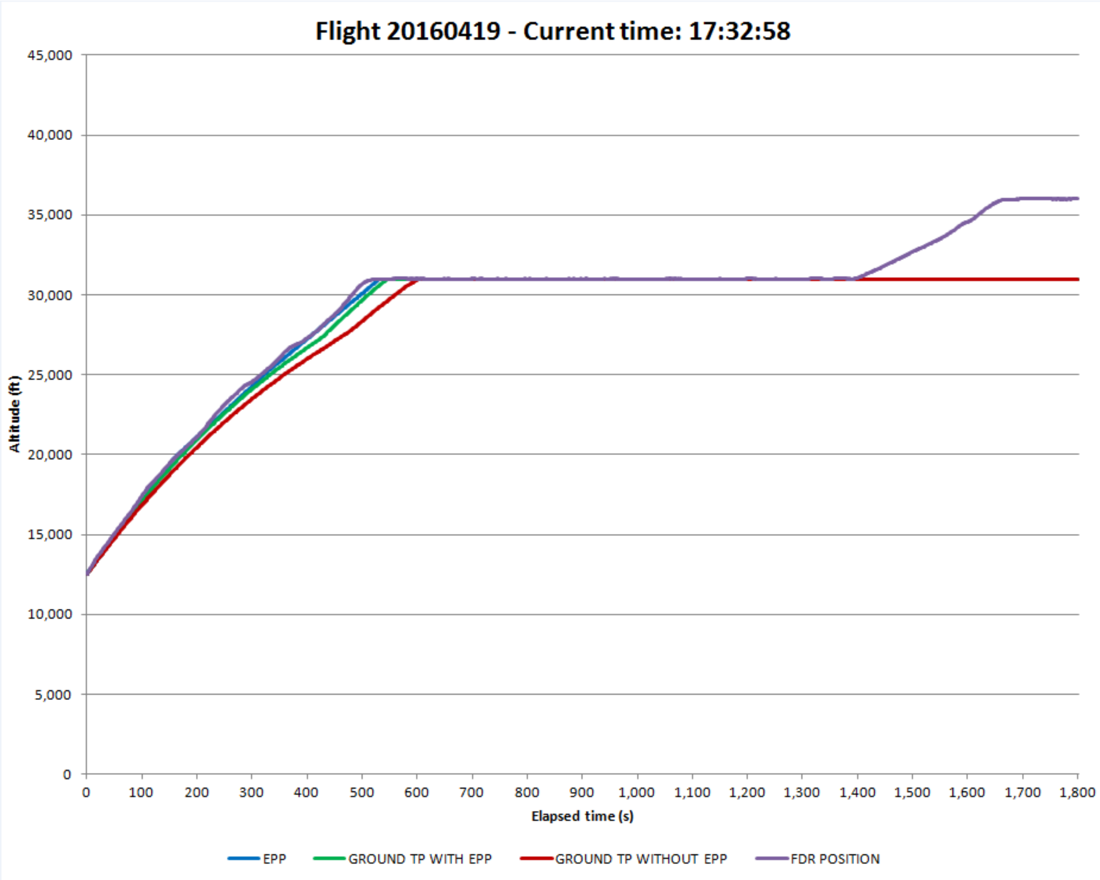


Figure 78 : Flight 20160419

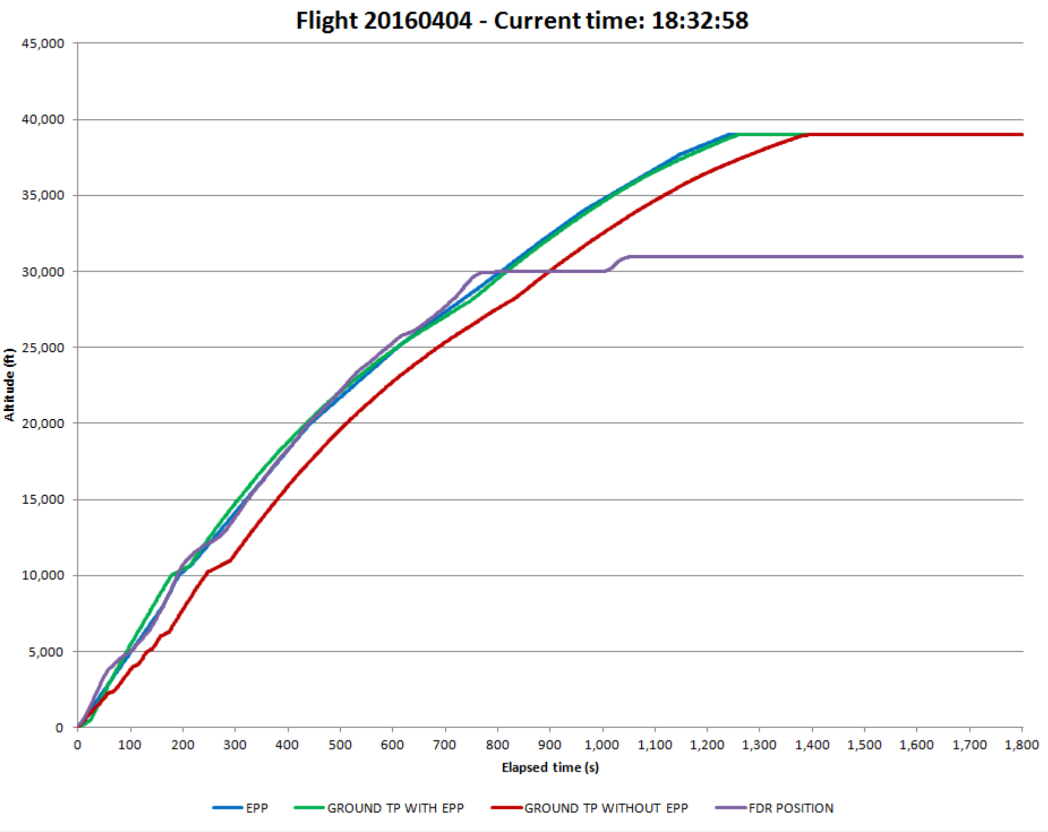


Figure 79 : Flight 20160404

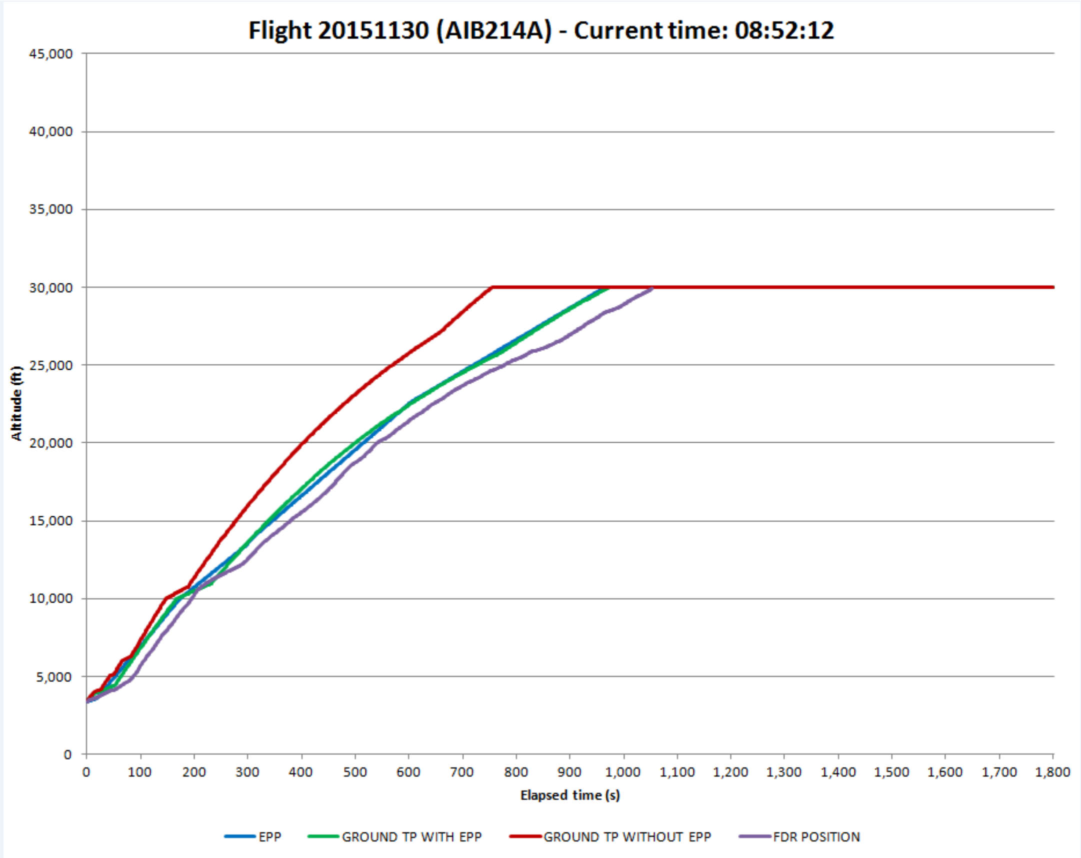


Figure 80 : Flight 20151130

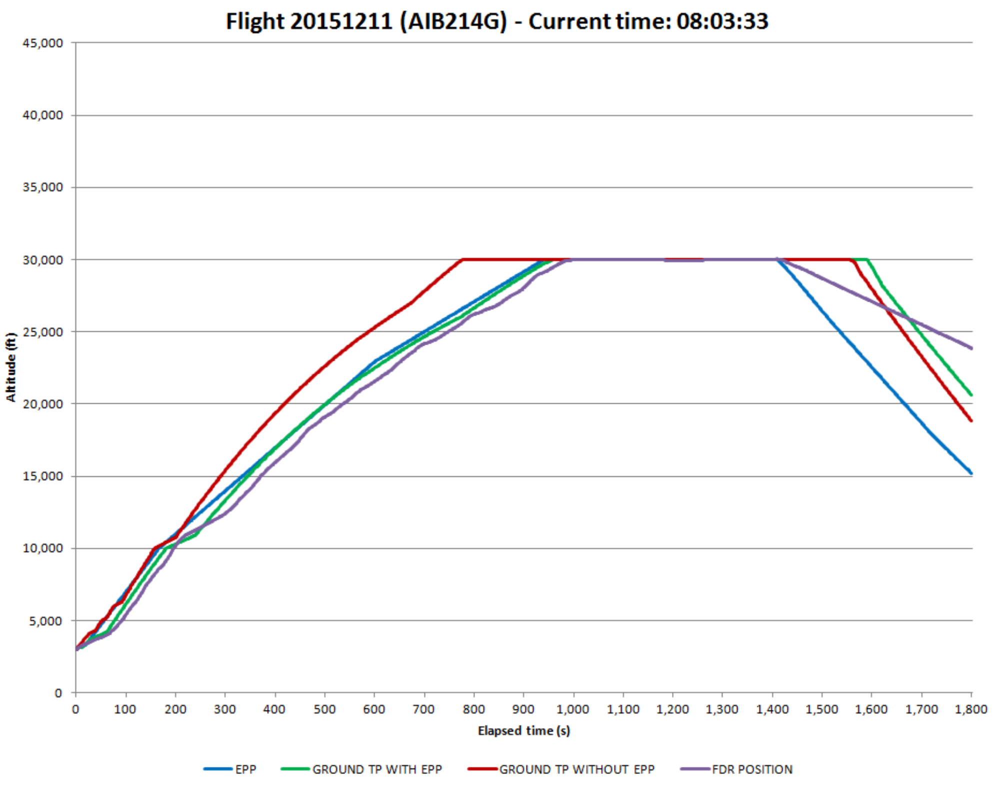


Figure 81 : Flight 20151211

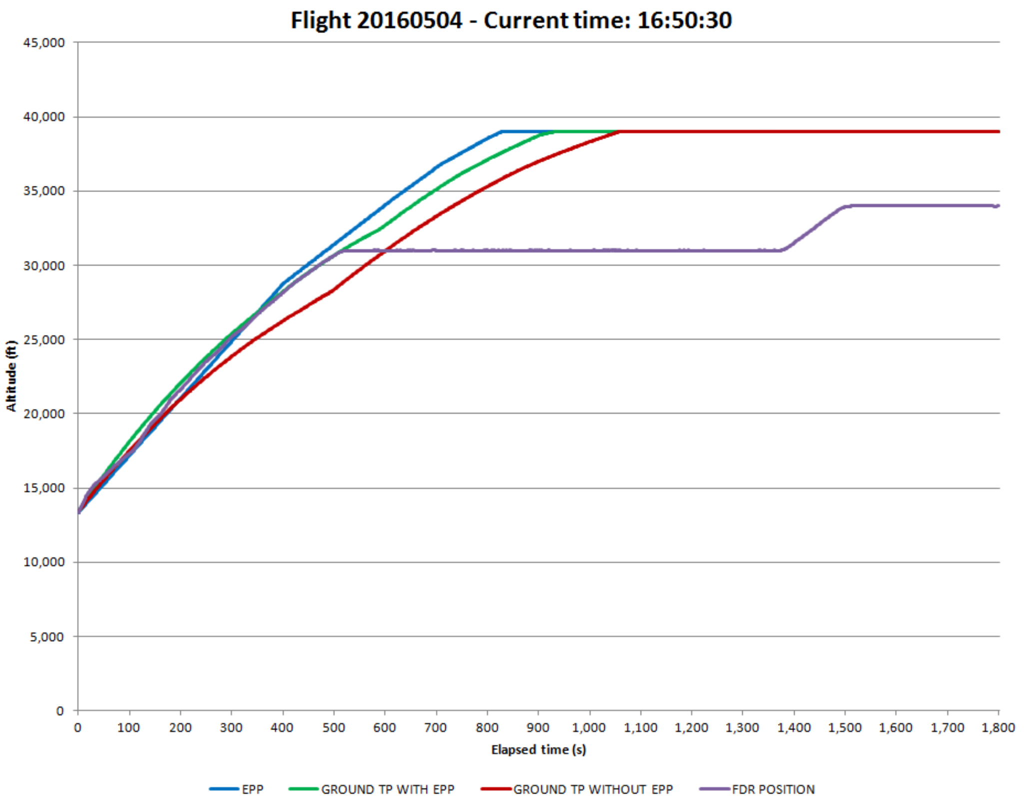


Figure 82 : Flight 20160504

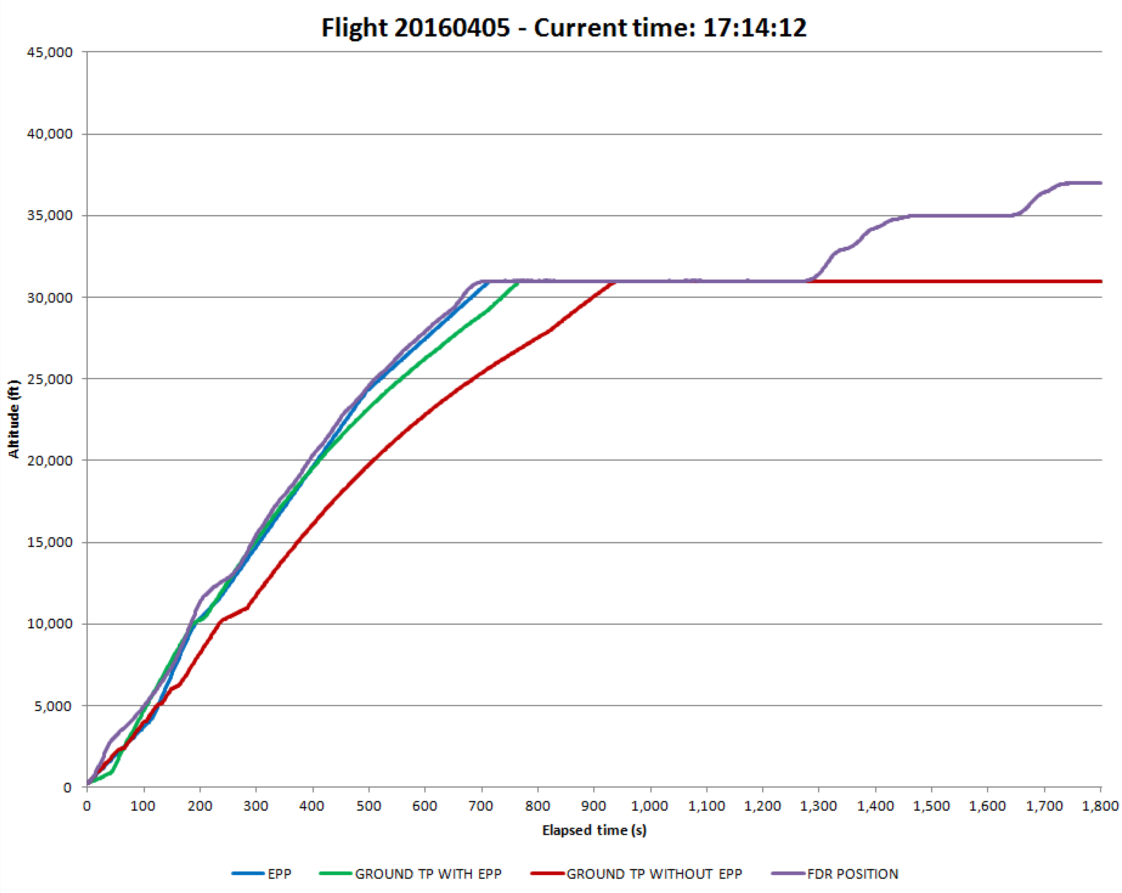


Figure 83 : Flight 20160405

6.4.7.2.2 Skyguide approach: Increased accuracy of the ground Trajectory Predictor.

For each eligible PEGASE flight, EPP data has been collected via the Eurocontrol web service (Yellow profile).

Depending of the route flown by the participating PEGASE flight (East or Center), the analysis focuses on different exit navpoints (COP: Coordination Point) of skyguide's FIRs (Flight Information Region).

The Swiss airspace contains 2 FIRs: Geneva and Zurich FIR.

East PEGASE flight route crosses both Swiss FIRs. Therefore for these flights, the Trajectory Prediction comparison was performed on two waypoints:

- BENOT as the exit navpoint of Zurich FIR and COP between Zurich ACC and Geneva ACC
- NINTU as the exit navpoint of Geneva FIR and COP between Geneva ACC and Aix ACC.

Centre PEGASE flight route crosses only Geneva FIR. The Trajectory Prediction comparison was performed on one waypoint:

- NINTU as the exit navpoint of Geneva FIR and COP between Geneva ACC and Aix ACC.

As West PEGASE flight route does not cross any of Swiss FIRs, no analysis has been performed on the West route PEGASE flight.

The "activation event" of the flight within Zurich ACC (East route) or within Geneva ACC (Center route) is the trigger for the start of trajectory prediction data comparison.

The "activation" is an ATC event occurring when estimated time over the COP between two ACC (e.g. Karlsruhe ACC and Zurich ACC for East PEGASE flights) is electronically sent by the upstream ACC (e.g. Karlsruhe ACC) to the downstream ACC (e.g. Zurich ACC). This event generally occurs 10 minutes prior to the time the aircraft is expected to fly over the COP. This event is triggered by an OLDI message referenced as "ACT message".

- All Transit PEGASE flights (trail flights from Hamburg to Toulouse) are then activated when ACT message sent by the neighbouring adjacent centre (Germany (Karlsruhe ACC) or France (Reims) depending of the flight) is received by Zurich or Geneva ACC.
- Flights flying from Geneva to Hamburg are activated at take-off.

The trajectory comparison ends when the flight overflies the exit COP.

6.4.7.2.2.1 AIB02IA

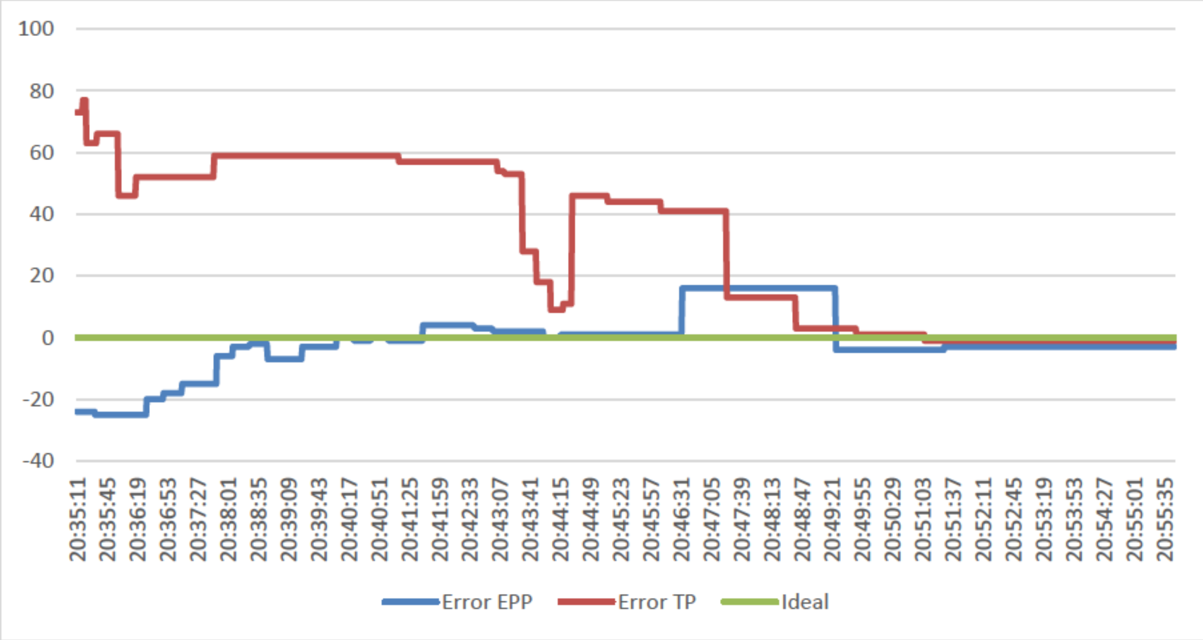
This flight occurred on the 24th February 2016. It was an East flight. The COP between Zurich FIR and Geneva FIR is BENOT. This analysis focuses on the time computed on that point.

After having collected the EPP data, all estimated times on BENOT waypoint (COP) were extracted.

Then the estimated times on BENOT provided by the ground TP were extracted too.

From the radar tracks, it was possible to compute the real time over the COP. As flights almost never overflow the COP, the time was taken on the point of the flown trajectory, closest to the COP.

With these three values (EPP estimated times, TP estimated times and overflown time), time error from EPP and ground TP computation can be shown on the graphic below.



In this case, the EPP estimated times are much better than the ones computed by the ground TP. Even if it is obvious in the graphic to see that EPP had a better accuracy than ground TP, a mathematical method has been applied to determine this result:

- Each line of the following table represents a change of the computed time on BENOT either from the EPP or from the ground TP.
- The delta Time column is the difference between the time of the current line and the next line.
- The Weight column values are obtained by multiplying the delta time by the error.

  *Weight Error EPP = delta time_ * Error EPP*

  *Weight Error TP = delta time_ * Error TP*

- The Weight column represents square area between the computed time (Estim EPP or Estim TP) and the overflown time.
- At the bottom of the table, a sum of all weights is computed.
- The best computation engine (EPP or Ground TP) is the one having the minimum total sum of weights (minimum square area).

Time	Estim EPP	Estim TP	Waypoint overflown time	delta Time_	Error EPP	Weight error EPP	Error TP	Weight error TP
20:35:11	20:55:24	20:57:01	20:55:48	7	-24	168	73	511
20:35:18	20:55:24	20:57:05	20:55:48	4	-24	96	77	308
20:35:22	20:55:24	20:56:51	20:55:48	10	-24	240	63	630
20:35:32	20:55:23	20:56:51	20:55:48	2	-25	50	63	126
20:35:34	20:55:23	20:56:54	20:55:48	24	-25	600	66	1584
20:35:58	20:55:23	20:56:34	20:55:48	20	-25	500	46	920
20:36:18	20:55:23	20:56:40	20:55:48	12	-25	300	52	624
20:36:30	20:55:28	20:56:40	20:55:48	19	-20	380	52	988
20:36:49	20:55:30	20:56:40	20:55:48	21	-18	378	52	1092

20:37:10	20:55:33	20:56:40	20:55:48	36	-15	540	52	1872
20:37:46	20:55:33	20:56:47	20:55:48	3	-15	45	59	177
20:37:49	20:55:42	20:56:47	20:55:48	18	-6	108	59	1062
20:38:07	20:55:45	20:56:47	20:55:48	19	-3	57	59	1121
20:38:26	20:55:46	20:56:47	20:55:48	20	-2	40	59	1180
20:38:46	20:55:41	20:56:47	20:55:48	39	-7	273	59	2301
20:39:25	20:55:45	20:56:47	20:55:48	39	-3	117	59	2301
20:40:04	20:55:48	20:56:47	20:55:48	19	0	0	59	1121
20:40:23	20:55:47	20:56:47	20:55:48	20	-1	20	59	1180
20:40:43	20:55:48	20:56:47	20:55:48	19	0	0	59	1121
20:41:02	20:55:47	20:56:47	20:55:48	12	-1	12	59	708
20:41:14	20:55:47	20:56:45	20:55:48	27	-1	27	57	1539
20:41:41	20:55:52	20:56:45	20:55:48	58	4	232	57	3306
20:42:39	20:55:51	20:56:45	20:55:48	21	3	63	57	1197
20:43:00	20:55:50	20:56:45	20:55:48	5	2	10	57	285
20:43:05	20:55:50	20:56:42	20:55:48	8	2	16	54	432
20:43:13	20:55:50	20:56:41	20:55:48	20	2	40	53	1060
20:43:33	20:55:50	20:56:16	20:55:48	16	2	32	28	448
20:43:49	20:55:50	20:56:06	20:55:48	8	2	16	18	144
20:43:57	20:55:48	20:56:06	20:55:48	8	0	0	18	144
20:44:05	20:55:48	20:55:57	20:55:48	11	0	0	9	99
20:44:16	20:55:49	20:55:57	20:55:48	3	1	3	9	27
20:44:19	20:55:49	20:55:59	20:55:48	10	1	10	11	110
20:44:29	20:55:49	20:56:34	20:55:48	40	1	40	46	1840
20:45:09	20:55:49	20:56:32	20:55:48	60	1	60	44	2640
20:46:09	20:55:49	20:56:29	20:55:48	24	1	24	41	984
20:46:33	20:56:04	20:56:29	20:55:48	50	16	800	41	2050
20:47:23	20:56:04	20:56:01	20:55:48	78	16	1248	13	1014
20:48:41	20:56:04	20:55:51	20:55:48	45	16	720	3	135
20:49:26	20:55:44	20:55:51	20:55:48	23	-4	92	3	69
20:49:49	20:55:44	20:55:49	20:55:48	77	-4	308	1	77
20:51:06	20:55:44	20:55:47	20:55:48	22	-4	88	-1	22
20:51:28	20:55:45	20:55:47	20:55:48	260	-3	780	-1	260
Total						8533		38809

6.4.7.2.2.2 AIB02DL

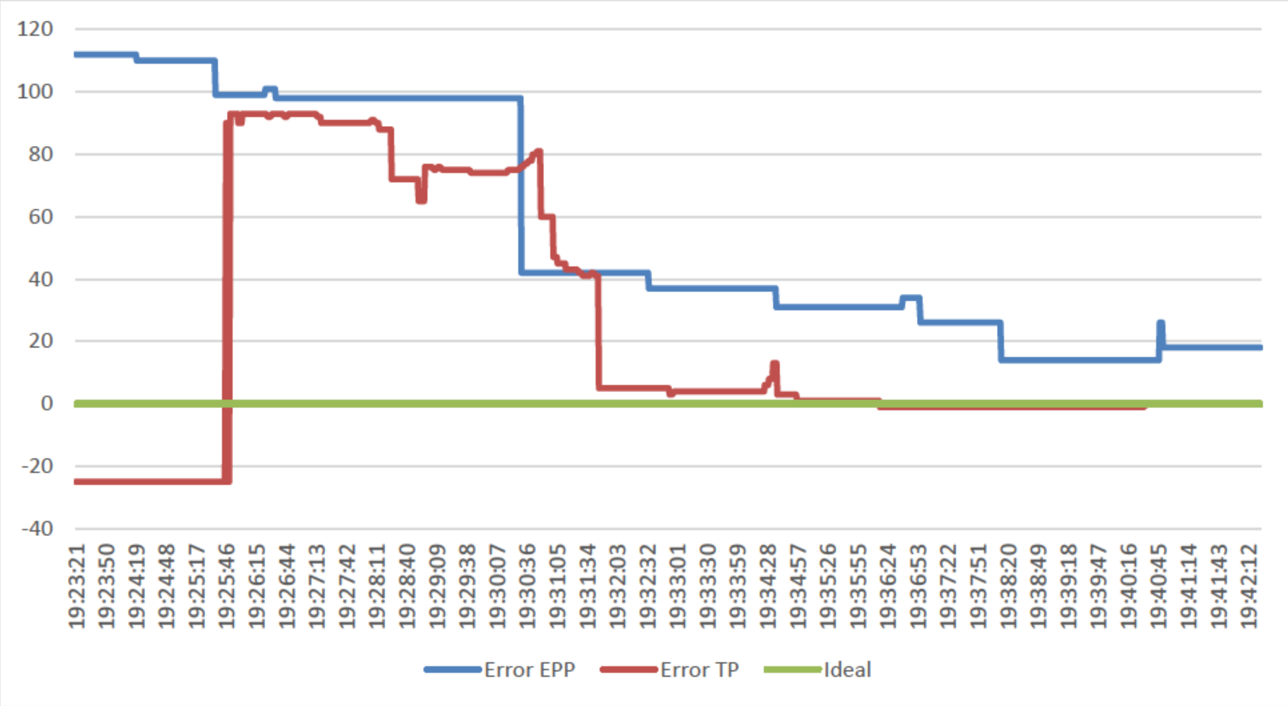
This second example shows a case where the ground TP prediction is better than the EPP prediction.

This flight occurred on the 12th May 2016. It was a Centre flight. The exit COP of the Geneva FIR is NINTU. This analysis focuses on the time computed on that point.

Until 19h25:46, the time estimates over NINTU was computed by the FDP with a very simple algorithm which always computes the same estimate depending of the trajectory of the flight. This is why, for several minutes, the estimate time is constant at 19h42:00.

Then at 19h25:46, the ATCO takes AOC (Assume Of Control) of the flight. From that time, the ground TP computes estimates.

Between 19h26:34 and 19h30:31, 3 EPPs were emitted without any time estimates nor levels. It contained only 2D trajectory. The EPP received at 19h30:31 contained a new level (390 instead of 370) and a new cruise speed (0.8 instead of 0.78). The fact that we didn't receive correct EPP during 4 minutes and that in the meantime, the level and the speed changed explains that the EPP estimates suddenly jumps for 1 minute. If the EPP would have contained 4D trajectory, the graph would have probably been more linear.



Time	Estim EPP	Estim TP	Waypoint overflown time	Time_delta	Error EPP	Weight error EPP	Error TP	Weight error TP
19:23:21	19:44:17	19:42:00	19:42:25	59	112	6608	-25	1475
19:24:20	19:44:15	19:42:00	19:42:25	76	110	8360	-25	1900
19:25:36	19:44:04	19:42:00	19:42:25	10	99	990	-25	250
19:25:46	19:44:04	19:43:55	19:42:25	1	99	99	90	90
19:25:47	19:44:04	19:42:00	19:42:25	3	99	297	-25	75
19:25:50	19:44:04	19:43:58	19:42:25	8	99	792	93	744
19:25:58	19:44:04	19:43:55	19:42:25	4	99	396	90	360
19:26:02	19:44:04	19:43:58	19:42:25	22	99	2178	93	2046
19:26:24	19:44:06	19:43:58	19:42:25	2	101	202	93	186
19:26:26	19:44:06	19:43:57	19:42:25	4	101	404	92	368
19:26:30	19:44:06	19:43:58	19:42:25	4	101	404	93	372
19:26:34	19:44:03	19:43:58	19:42:25	8	98	784	93	744
19:26:42	19:44:03	19:43:57	19:42:25	4	98	392	92	368
19:26:46	19:44:03	19:43:58	19:42:25	28	98	2744	93	2604
19:27:14	19:44:03	19:43:57	19:42:25	4	98	392	92	368
19:27:18	19:44:03	19:43:55	19:42:25	48	98	4704	90	4320
19:28:06	19:44:03	19:43:56	19:42:25	4	98	392	91	364
19:28:10	19:44:03	19:43:55	19:42:25	4	98	392	90	360

19:28:14	19:44:03	19:43:53	19:42:25	12	98	1176	88	1056
19:28:26	19:44:03	19:43:37	19:42:25	26	98	2548	72	1872
19:28:52	19:44:03	19:43:30	19:42:25	6	98	588	65	390
19:28:58	19:44:03	19:43:41	19:42:25	8	98	784	76	608
19:29:06	19:44:03	19:43:40	19:42:25	4	98	392	75	300
19:29:10	19:44:03	19:43:41	19:42:25	4	98	392	76	304
19:29:14	19:44:03	19:43:40	19:42:25	28	98	2744	75	2100
19:29:42	19:44:03	19:43:39	19:42:25	36	98	3528	74	2664
19:30:18	19:44:03	19:43:40	19:42:25	12	98	1176	75	900
19:30:30	19:44:03	19:43:41	19:42:25	1	98	98	76	76
19:30:31	19:43:07	19:43:41	19:42:25	3	42	126	76	228
19:30:34	19:43:07	19:43:42	19:42:25	4	42	168	77	308
19:30:38	19:43:07	19:43:43	19:42:25	4	42	168	78	312
19:30:42	19:43:07	19:43:45	19:42:25	4	42	168	80	320
19:30:46	19:43:07	19:43:46	19:42:25	4	42	168	81	324
19:30:50	19:43:07	19:43:25	19:42:25	12	42	504	60	720
19:31:02	19:43:07	19:43:12	19:42:25	4	42	168	47	188
19:31:06	19:43:07	19:43:10	19:42:25	8	42	336	45	360
19:31:14	19:43:07	19:43:08	19:42:25	12	42	504	43	516
19:31:26	19:43:07	19:43:07	19:42:25	4	42	168	42	168
19:31:30	19:43:07	19:43:06	19:42:25	8	42	336	41	328
19:31:38	19:43:07	19:43:07	19:42:25	4	42	168	42	168
19:31:42	19:43:07	19:43:06	19:42:25	4	42	168	41	164
19:31:46	19:43:07	19:42:30	19:42:25	48	42	2016	5	240
19:32:34	19:43:02	19:42:30	19:42:25	20	37	740	5	100
19:32:54	19:43:02	19:42:28	19:42:25	4	37	148	3	12
19:32:58	19:43:02	19:42:29	19:42:25	88	37	3256	4	352
19:34:26	19:43:02	19:42:31	19:42:25	4	37	148	6	24
19:34:30	19:43:02	19:42:33	19:42:25	4	37	148	8	32
19:34:34	19:43:02	19:42:38	19:42:25	3	37	111	13	39
19:34:37	19:42:56	19:42:38	19:42:25	1	31	31	13	13
19:34:38	19:42:56	19:42:28	19:42:25	19	31	589	3	57
19:34:57	19:42:56	19:42:26	19:42:25	80	31	2480	1	80
19:36:17	19:42:56	19:42:24	19:42:25	22	31	682	-1	22
19:36:39	19:42:59	19:42:24	19:42:25	17	34	578	-1	17
19:36:56	19:42:51	19:42:24	19:42:25	78	26	2028	-1	78
19:38:14	19:42:39	19:42:24	19:42:25	139	14	1946	-1	139
19:40:33	19:42:39	19:42:25	19:42:25	14	14	196	0	0
19:40:47	19:42:51	19:42:25	19:42:25	3	26	78	0	0
19:40:50	19:42:43	19:42:25	19:42:25	95	18	1710	0	0
Total						63991		32573

6.4.7.3 Comparison between EPP and ground TP

The aim of this part is to compare the EPP precision with skyguide ground TP precision in order to know if EPP can be used in the future to improve computed trajectory times.

The ground TP uses the O4D trajectory engine delivered by Harris. This engine is embedded in skyguide's equipment and is configured with BADA 3.12

The O4D module calculates planned exit point for OLDI transmission and all tactical point projections to be used for HST/DST (Horizontal Scanning Tool/Dynamic Scanning Tool). It includes climb/descent estimates to CFL. The aircraft performance, the wind situation are used for the calculation of the trajectory projection.

Analysis starts when the flight is activated:

- Transit flights (trial flights from Hamburg to Toulouse) are activated when skyguide receives an ACT message from the neighbouring adjacent centre (Germany or France depending of the flight). This is generally around 10 minutes before the flight enters the Swiss airspace.
- Flights that fly from Geneva to Hamburg are activated at take-off.

Analysis is stopped when the flight overflies the exit COP. Except when DCT

24 times, our TP has a better time prediction than the EPPs.

21 times, EPPs had better time prediction than our TP

The result of the analysis shows that there is no significant improvement from the EPP over skyguide ground TP. In order to avoid degrading the current ground TP, a smart algorithm shall be implemented to use the EPP when it has a better accuracy than the ground TP.

The following table summarises the comparison analysis.

The first column is the identification of the flight: airbus identification, aircraft registration and callsign.

The second column is the COP on which we compared data. Depending of the trajectory of the flight, the COP can be BENOT, NINTU or VEDOK. LSGG is not a COP but the Geneva airport. There were two dedicated flights with Go Around at Geneva.

The third column indicates which source computed the best times for the COP.

Identification	COP	Best results
AIB02BM	BENOT	TP
AIB02BM	NINTU	TP
AIB02DN	NINTU	TP
AIB02IE	NINTU	TP
AIB02DJ	NINTU	TP
AIB214A	LSGG	TP
AIB214A	VEDOK	TP
AIB02BI	BENOT	TP
AIB02BI	NINTU	TP
AIB04IT	BENOT	TP
AIB04IT	NINTU	EPP

AIB214	LSGG	EPP
AIB214	VEDOK	EPP
AIB04IH	BENOT	EPP
AIB04IH	NINTU	TP
AIB02DR	NINTU	TP
AIB02DT	NINTU	EPP
AIB02BD	BENOT	EPP
AIB02BD	NINTU	EPP
AIB02IA	BENOT	EPP
AIB02IA	NINTU	TP
AIB02IE	BENOT	EPP
AIB02IE	NINTU	EPP
AIB03IR	BENOT	TP
AIB03IR	NINTU	EPP
AIB03DX	BENOT	EPP
AIB03DX	NINTU	EPP
AIB02BQ	NINTU	TP
AIB02BX	BENOT	EPP
AIB02BX	NINTU	EPP
AIB02DH	NINTU	EPP
AIB02IC	BENOT	EPP
AIB02IC	NINTU	TP
AIB04DU	BENOT	EPP
AIB04DU	NINTU	EPP
AIB04DA	BENOT	TP
AIB04DA	NINTU	TP
AIB03IS	BENOT	TP
AIB03IS	NINTU	EPP
AIB02IK	BENOT	TP
AIB02IK	NINTU	EPP
AIB02DR	NINTU	TP
AIB02BY	BENOT	TP
AIB02BY	NINTU	TP
AIB02DL	NINTU	TP
Total		TP

No systematic check of the managed modes or correct route in the FMS has occurred; hence possible reasons some flights show better or worse TP behaviour have not been identified.

6.4.7.3.1 NATS approach: Increased accuracy of the ground Trajectory Predictor.

The following sections describe the analysis method used to measure the accuracy of ground trajectory prediction algorithms; and present the results from comparing the accuracy of a baseline TP implementation with those of an enhanced TP using EPP parameters.

6.4.7.3.1.1 Analysis Method

- This analysis investigated the potential improvements to ground TP systems that could be realised by incorporating EPP data downlinked from the aircraft.
- The analysis has been carried out using the NATS iFACTS TP algorithm software which utilises the BADA aircraft performance model version 3.10.1. (see [6]).
- The TP analysis conducted for PEGASE used the same methods as previous NATS' TP analysis carried out for SESAR VP771 (see [5]). VP771 examined the improvements to TP accuracy from incorporating EPP parameters using simulated flights. The same analysis has been repeated for the PEGASE flight-trials to investigate whether the same benefits can be achieved for real flights.
- The analysis involved the following steps:
- The parameters chosen for incorporation in TP are the EPP latest aircraft mass and the EPP speed-schedule.
- The same TP algorithm software used for SESAR VP771 has been used for PEGASE. The TP algorithms have been modified to read in the EPP reports and to extract the EPP mass and speed-schedule parameters. These parameters are then used in the TP algorithm in place of the BADA model mass and speed-schedule values. The TP algorithm software includes configuration settings to enable or disable the EPP parameters.
- The ground TP uses the most recent EPP report at the time of prediction. The most recent EPP report overrides previous EPP reports.
- The TP was then run for each flight; firstly in baseline configuration (using the BADA model mass and speed-schedule), and then repeated in EPP configuration using the EPP mass and speed-schedule parameters. The resulting trajectory predictions for each flight are stored in a relational database. As such the effect of the EPP parameters can be compared with the baseline ground TP configuration.
- Ground TPs generated along the extent of each radar track were stored in a database. Schemes to compare the predicted trajectories with the recorded radar track position data were executed and analysis techniques were developed to measure the ground TP error in each configuration.
- The accuracy measurement results were then exported into an excel spreadsheet to generate averages for each configuration, and to produce tabulated data and graphical plots for incorporation into this report.

Selection of flights and valid TP measurement conditions

It was not possible to perform TP analysis tests using the full set of PEGASE flights. A number of restrictions have to be applied in order for valid TP accuracy measurements to be made. This reduced the number of flights that could be used for the analysis:

- The flight must have radar track data for the full duration of the measurement. A number of PEGASE flights do not have recorded radar data available for portions of flight. This was especially true of the descent phase, where radar data was not available for the majority of the flights.
- The flight must have EPP data available at the time the TP prediction is run. For a number of flights, EPP data was not available during the initial climb phase, and a number of flights experienced drop-out of EPP data during flight.
- The flight must be operating in speed-managed mode at the time the TP prediction is run, in order for the EPP speed-schedule parameters to be used in TP. A number

of flights were observed to operate in speed selected mode for significant periods of flight.

- The TP accuracy measurements were restricted to levels above 15,000ft. The reason for this is that flights operate with a fixed speed of 250 knots below 10,000ft, and it was observed that a number of flights conducted test manoeuvres at levels below 15,000ft.
- In order for valid TP accuracy measurements to be made, the flight must be in a continuous climb/descent vertical manoeuvre, with no intermediate level-offs interrupting the climb or descent. The TP measurements were restricted to continuous climb or descent portions of flight.
- In order for valid TP accuracy measurements to be made, the lateral flight-path of the radar track was compared for conformance with the lateral path of the predicted trajectory. Any lateral deviations greater than 10NM were excluded from the analysis. These lateral deviations were caused by ATC navigation clearances such as vectoring or direct route instructions, which were made after the TP prediction time, but which occurred during the TP prediction look-ahead period.

For each flight which met these conditions, the valid periods of continuous climb or descent suitable for TP accuracy measurement were identified. This was done by manual inspection of the radar track data to identify the start time of the longest duration continuous climb or descent for each flight. The TP run setup parameters were then set accordingly for each flight to ensure the maximum available range of continuous climb or descent levels was used for the trajectory prediction.

The following list of PEGASE flights were identified as meeting these conditions for TP analysis.

- 20 flights provided suitable continuous climb manoeuvres
- 4 flights provided suitable continuous descent manoeuvres

Callsign	Continuous Climb	Continuous Descent
AIB02BH	✓	
AIB02BI	✓	
AIB02BM	✓	
AIB02BU	✓	
AIB02BX	✓	
AIB02BY	✓	
AIB02DF	✓	
AIB02DH	✓	
AIB02DM	✓	
AIB02DR	✓	
AIB02DT	✓	
AIB02IC	✓	
AIB02IK	✓	
AIB03DO	✓	
AIB03IS	✓	
AIB214B	✓	✓
AIB214C	✓	✓
AIB214D	✓	
AIB214F		✓
AIB214G	✓	✓
AIB214I	✓	

Table 37 Flights selected for TP analysis

Availability of meteorological data

A limitation of the TP analysis has been the lack of meteorological data for the PEGASE flights. The TP algorithms use forecast temperature and wind velocity data. However, for most of the climb and descent manoeuvres analysed, meteorological forecast data was not available, and default values have been used (zero wind velocity and ISA standard temperature). Suitable meteorological forecast data for the NATS TP analysis was only available for flights AIB214C and AIB214D which conducted climb/descent manoeuvres in UK airspace.

Measurement of TP error

TP error is measured by comparing the TP predicted positions and times, with the actual flight positions and times as reported by the radar track data.

These comparison measurements were achieved by establishing reference points along the radar track spaced at 10 second intervals. These 10 second spaced reference points were determined by interpolation between the recorded radar track data points.

For each reference radar point, a corresponding TP measurement point is determined. These TP measurement points are positioned perpendicularly abeam each reference radar point. Again, this is achieved by interpolation of the TP points.

This scheme of reference radar points and their corresponding (abeam) TP measurement points is illustrated in the following diagram:

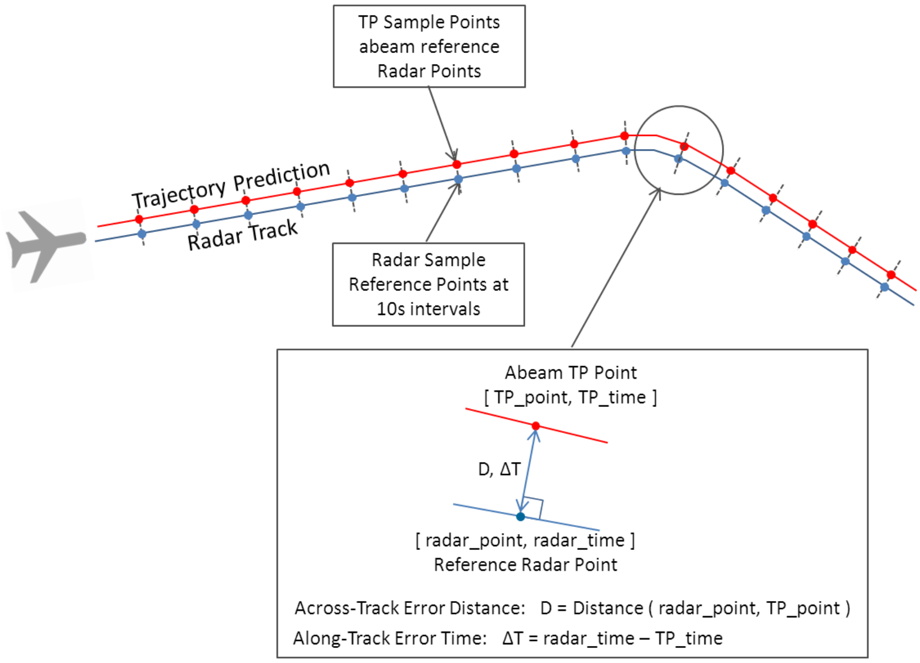


Figure 84 Method of comparing TP measurement points with radar reference points

The TP error is measured at each reference point in three dimensions: along-track error, across-track error and vertical error.

- **Vertical Error**: A measure of the difference between the TP predicted level and the recorded radar level at each reference point. The vertical error provides a measure of how well the TP models the rate-of-change of altitude.

  The vertical error at each reference point is calculated as the difference between the rate-of-change of the radar altitude, and the rate-of-change of the TP altitude, during the TP look-ahead time. The vertical error is measured as a positive magnitude value in the units of feet per minute.

$$vertical\_error\ (ft/min) = \frac{|radar\_altitude - TP\_altitude|}{(TP\_look\_ahead\_time/60)}$$

- **Along-track error**: A measure of the difference between the TP predicted time at a reference point, and the actual time that the recorded radar track passed the reference point. The along-track error provides a measure of how well TP predicts the aircraft speed.
- The along-track error at each reference point is calculated as the difference between the radar point time and the predicted trajectory point time. It is calculated as a proportion of the TP look-ahead time at the measurement point. The along-track error is measured as a positive magnitude value in units of seconds per minute.

$$along\_track\_error\ (sec/min) = \frac{|radar\_time - TP\_time|}{(TP\_look\_ahead\_time/60)}$$

- **Across-track error**: A measure of the perpendicular distance between the TP predicted flight-path and the actual recorded radar flight-path at each reference point. The across-track error provides a measure of how well the TP models the lateral path of flight (e.g. accuracy of modelling turns at waypoints). The across-track error is measured as a positive absolute value in units of NM.

$$across\_track\_error\ (NM) = distance(radar\_point\ - TP\_point)$$

Averaging of TP error measurements

The TP error measurements are calculated for each reference point along the trajectory. In order to produce an overall measure of the trajectory error, an average value is calculated.

In order to calculate the overall average error measurement for the full set of flight trajectories, a weighted average is determined taking into account the number of measurements in each trajectory.

$$average\_error = \frac{\sum E_{T1} + \sum E_{T2} + \sum E_{T3} + \cdots}{N_{T1} + N_{T2} + N_{T3} + \cdots}$$

Where E represents the individual error measurements at each reference point on each trajectory; and N represents the number of error measurements for each trajectory.

TP run configurations

As described above two TP configurations were used, and the analysis has compared the TP error measurements for these two configurations:

TP Configuration	Description
1. BADA	TP Baseline configuration; the BADA model only is used to calculate aircraft performance
2. EPP M S	TP uses a combination of EPP Mass and EPP speed-schedule parameters to calculate aircraft performance

Table 38 TP run configurations

6.4.7.3.1.2 TP accuracy analysis results

This section presents the results of the TP accuracy measurements comparing the baseline TP with the enhanced TP using EPP data.

TP vertical error measurement results

The following figures show the overall average TP vertical error results for the 20 climb trajectories and the 4 descent trajectories. The results are shown separately for climb.

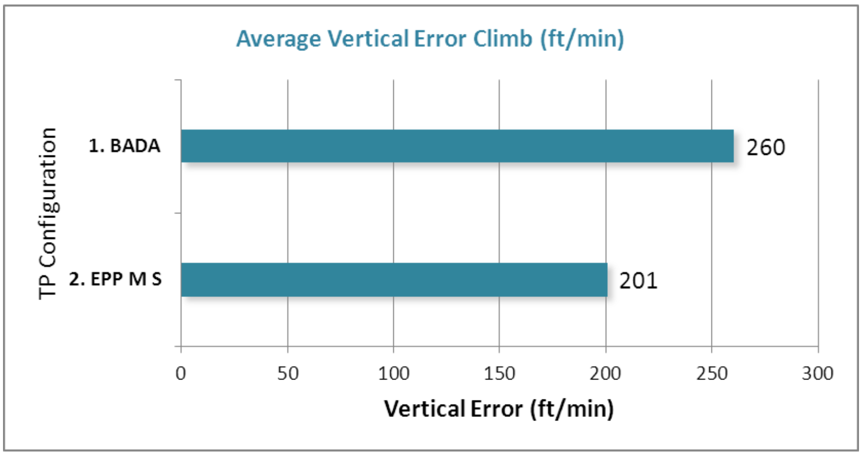


Figure 85 TP average vertical error measurements for climb

The vertical error measurement results for the climb trajectories show a noticeable reduction in error from using EPP mass and speed-schedule parameters in TP.

However, for the descent trajectories, with the small sample size of only 4 descent trajectories it was not possible to draw any valid conclusions from the descent measurements.

As an illustration of the potential benefits of the use of EPP data in TP, the following figures show a typical example of one of the PEGASE flights, showing the improvement in the TP climb profile achieved by using EPP mass and speed-schedule parameters.

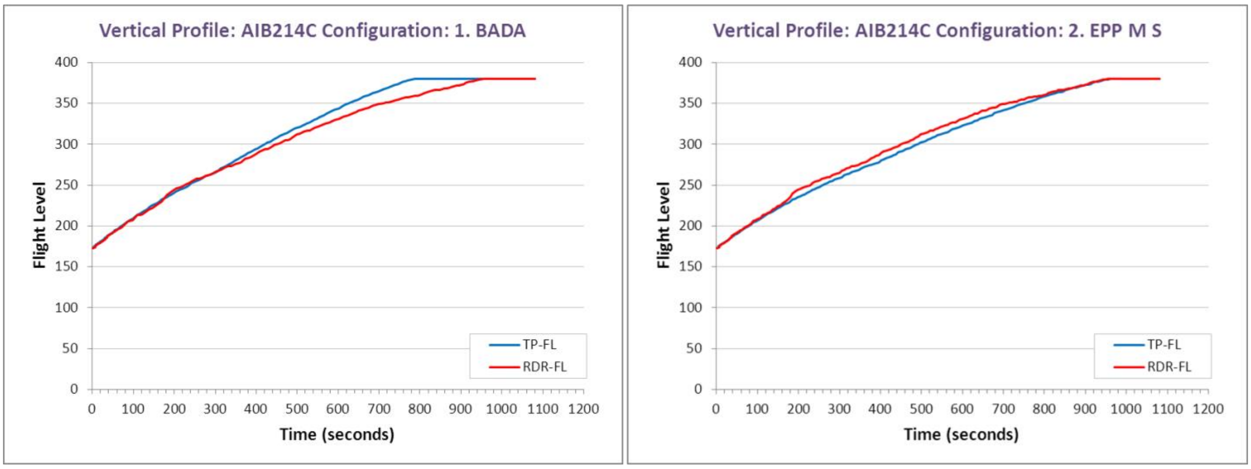


Figure 86 TP vertical profile predictions for flight AIB214C

The figure above shows the TP vertical profile predictions for PEGASE flight AIB214C on 30th November 2015 flying from EDHI-EGNR. The figure shows the predicted vertical profiles for the two TP configurations. The figures plot the vertical flight level versus time; the TP predicted profile is plotted in blue, and the actual vertical profile flown as reported by radar is plotted in red. The figure on the left shows the baseline TP (BADA) vertical profile, and the figure on the right shows the enhanced TP (EPP mass and speed-schedule) vertical profile.

It can be seen that the TP configuration using EPP mass and speed-schedule parameters provides a much more accurate prediction of the actual vertical profile flown, with a very close match between the predicted profile and the actual profile, and a much more accurate prediction of the top-of-climb time.

In this example, the use of EPP mass provides an improved TP climb profile. The mass value used in the iFACTS TP algorithm derived from the BADA model for an A320 is 54200kg. However, the actual mass value reported in the EPP data for this flight is 59940kg, which is 5740kg heavier than the modelled value. By using the more accurate EPP mass value, the TP is able to compute a more accurate climb profile.

TP along-track error analysis

The along-track error analysis was unable to provide a valid result. Investigation of the EPP data for the selected flights identified that the majority of the flights were operated in speed selected mode for significant periods during flight. The analysis applied a filter to select only periods operating in speed- managed mode, but this resulted in too few measurements to produce a valid assessment of the differences in along-track errors.

TP across-track error measurement results

The use of EPP mass and speed-schedule data in TP is not expected to have any effect on the across-track errors in TP. Therefore no analysis was conducted on the across-track errors.

6.4.7.3.1.3 TP accuracy analysis conclusions

The TP accuracy analysis has investigated the effects of using EPP mass and speed-schedule parameters in the NATS iFACTS trajectory predictor algorithms, compared to a baseline TP configuration using the BADA model mass and speed-schedule values.

The TP accuracy has been assessed by measuring the differences between the TP predicted trajectories, compared to the actual trajectories flown by the aircraft, as reported in the recorded radar data. The TP error differences have been measured in three dimensions; vertical error, along-track error and across-track error.

The TP analysis was conducted using a subset of the PEGASE flights. The flights selected were those which provided sufficient recorded data, and which met the conditions necessary to enable a valid comparison of the predicted trajectory with the recorded radar track.

A limitation of the analysis has been the lack of availability of meteorological forecast data for the trajectory predictions. Meteorological forecast data was only available for two of the analysed flights.

The results of the TP analysis have proved inconclusive. The TP vertical error measurements show a noticeable improvement in the TP climb predictions through using EPP mass and speed-schedule parameters. This improvement is due to the more accurate mass data available from EPP.

However it was not possible to provide an assessment of the along-track TP error performance. It was found that there were too few measurements of flight in speed managed mode, so that it was not possible to provide valid along-track error results.

6.4.7.3.2 ADS-C vs. EFD comparison

Many ANSP currently use EFD, "Electronic Flight Data" to estimate the arrival time of aircraft in their area of interest. EFD are end-to-end trajectories for flights and are sent by EUROCONTROL Network Manager periodically or when any trajectory changes sufficiently. EUROCONTROL builds these trajectories from the flight plan plus updates such as "First System Activation" (FSA) and "Correlated Position Report" (CPR) the latter being derived from radar data. In order to limit the computational and communication load associated with these updates there is a certain tolerance that has to be exceeded before a position report will trigger a trajectory recalculation and hence EFD emission. Because of these tolerances it is generally accepted that the EFD are not perfect. More on EFD as well as FSA and CPR can be found in references [7][8][9].

ANSP would like to have good predictions of flight arrival time in order to estimate and if necessary react to the controller workload foreseen in the near future; workload can be estimated from the predicted traffic which is the combination of all the flights.

This study tried to compare using ADS-C with EFD to predict the time over the coordination point (COP) at which a flight entered the area of interest of skyguide. For each flight the actual time over the coordination point could be found from skyguide's radar recordings. The study was limited to the flights for which the appropriate data was available as the study was made. Note this is all of such flights, no selection has been made.

ARCID	FSA	Route	COP	Radar Time	Distance to COP in NM	Elapsed	Remark
AIB02BM	14:30:03	East	NATOR	15:16:54	0.05	2811	
AIB02DN	16:05:54	Center	MOROK	16:59:56	3.84	3242	
AIB02IE	19:49:33	East	NATOR	20:34:05	20.58	2672	
AIB02DJ	19:14:36	Center	MOROK	20:16:40	0.79	3724	
AIB214A	08:44:32	LFBO-LSGG	BELUS	09:23:15	0.18	2323	
AIB214B	09:42:45	LSGG-EDHI	KORED	09:54:48	0.15	723	COP is exit point
AIB02BI	18:25:54	East	NATOR	19:13:45	0.20	2871	
AIB04IT	19:30:00	East	NATOR	20:19:13	0.27	2953	
AIB214F	07:53:40	LFBO-LSGG	BELUS	08:36:23	0.21	2563	
AIB214G	08:59:12	LSGG-EDHI	KORED	09:13:32	0.05	860	COP is exit point
AIB02DF	16:32:30	Center	MOROK	17:34:28	13.80	3718	COP not overflown
AIB04IH	17:13:51	East	NATOR	18:00:05	0.16	2774	
AIB02DR	16:23:44	Center	MOROK	17:23:20	1.06	3576	
AIB02DT	17:15:44	Center	MOROK	18:18:24	0.97	3760	
AIB02BD	19:18:25	East	NATOR	20:00:05	18.82	2500	COP not overflown
AIB02IA	19:56:54	East	NATOR	20:45:09	13.89	2895	COP not overflown
AIB02IE	18:11:29	East	NATOR	18:56:41	0.21	2712	

ARCID	FSA	Route	COP	Radar Time	Distance to COP in NM	Elapsed	Remark
AIB03IR	16:08:11	East	NATOR	17:00:17	13.82	3126	COP not overflown
AIB03DX	16:34:02	East	NATOR	17:24:13	5.95	3011	
AIB02BQ	15:39:27	Center	MOROK	16:46:53	5.26	4046	
AIB02BX	17:00:20	East	NATOR	17:47:25	16.31	2825	COP not overflown
AIB02DH	15:50:19	Center	MOROK	16:43:49	1.48	3210	EPP Problem case 1
AIB02IC	14:46:20	East	NATOR	15:39:24	11.64	3184	COP not overflown
AIB04DU	18:44:26	East	NATOR	19:36:34	3.27	3128	
AIB02DA	17:29:10	East	NATOR	18:20:22	0.18	3072	
AIB03IS	17:28:16	East	NATOR	18:12:26	0.24	2650	
AIB02IK	16:51:22	East	NATOR	17:38:44	0.16	2842	
AIB02DR	18:48:15	Center	MOROK	19:45:11	22.10	3416	COP not overflown EPP Problem case 2
AIB02BH	15:18:52	Center	MOROK	16:19:23	1.27	3631	
AIB02BY	16:46:19	East	NATOR	17:26:02	16.86	2383	COP not overflown
AIB02DL	18:30:21	Center	MOROK	19:31:14	4.41	3653	
AIB04IM	17:50:53	East	NATOR	18:37:31	0.57	2798	

Table 39 Flights for which EPP and EFD were compared

The Aircraft Identifier (ARCID, also called Call-sign) is not unique. Where this might cause confusion the FSA time is also mentioned.

FSA is the time associated with the First System Activation message received by EUROCONTROL NM for this flight. This is taken to be the take-off time of the flight.

The Radar time is the time at the closest point of approach to the COP (Coordination point). The closest distance at which the flight came to the COP is given; The FMS will consider the point overflown if that distance is less than 7 Nautical Miles. In the cases above where the COP is not overflown the aircraft is generally flying directly to some point beyond the COP. In this case the air crew often remove the intermediate points from the FMS' plan, and hence the COP is no longer mentioned in the EPP report; in the graphics below this is visible when the EPP predictions stop long before closest point of approach.

For convenience the number of seconds elapsed between the FSA and the Radar time is shown in the elapsed column. This unit is used in the graphics that follow. Note that in most cases EPP were not received until sometime after FSA.

A typical "East" flight has a path as shown in Figure 79 below. The flight was coordinated with the previous control centre at the point NINTU. After NINTU, a flight like this flight becomes visible on the Swiss controller's display and effectively contributes to that controller's workload.

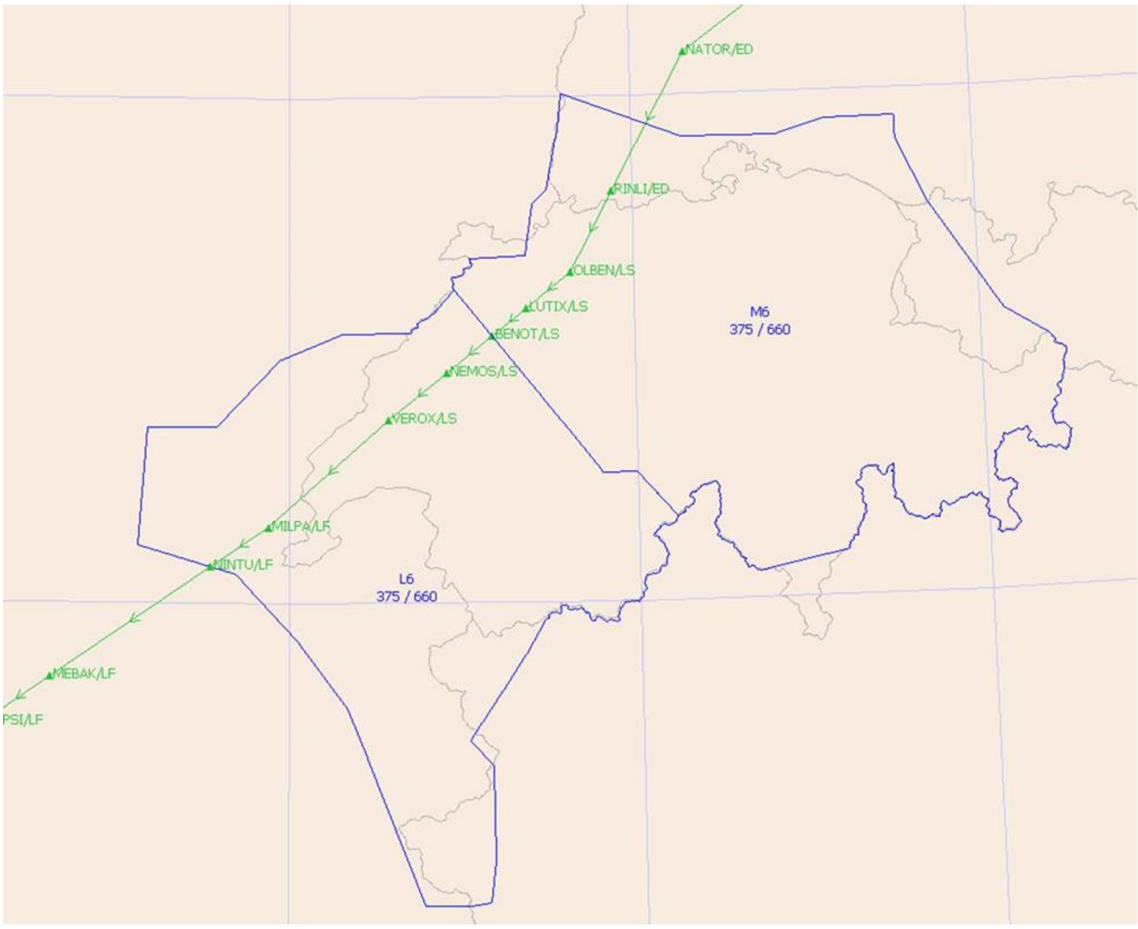


Figure 87 a typical "east" flight passing over Switzerland

The graphs that follow discuss the "prediction error." The Radar time above is taken to be the actual time over the point. The predicted time in either the EPP or the EFD is subtracted from the Radar time and the result converted to seconds. A negative number shows the prediction was after the actual, the flight arrived earlier than predicted. A positive number shows the prediction was before the actual, the flight arrived later than predicted.

In all cases, only predictions made at or after FSA are considered as take-off time is such a large source of uncertainty in trajectory prediction. EPP collected in the PEGASE project before take-off show elapsed times over points. EFD usually exhibit significant changes in the predictions when the flight takes off.

Two problem cases are mentioned in Table 39 and these are discussed below.

First an overall presentation of the EPP and EFD prediction error for all the cases mentioned in Table 39 is shown in Figure 88. The vertical and horizontal scales are in seconds. The vertical scale runs from predicted times 20 minutes after the actual to 10 minutes before, that is -1200 seconds to +600 seconds. Perfection is zero. The horizontal axis gives the time in advance the prediction was made and the scale extends to 70 minutes or 4200 seconds. There are few cases for which EPP data was available more than 50 minutes ahead of time over COP

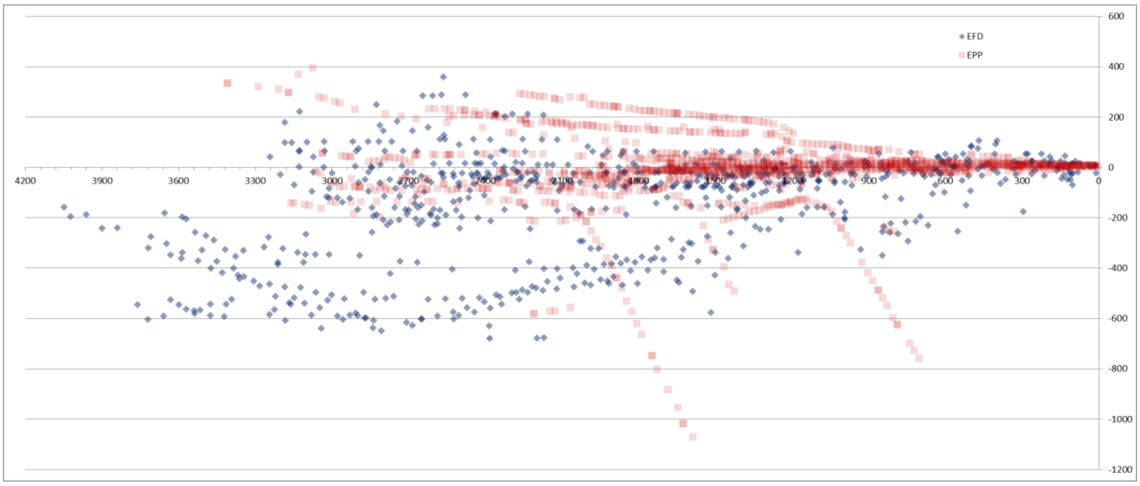


Figure 88 cumulative EFD (blue) and EPP (red) prediction error

The “negative” half of the graph is dominated by two sets of EPP data. These are the EPP problem cases mentioned in Table 39 and explained below. Reducing the range of the vertical axis allow the majority of the data to be seen more clearly in Figure 89, below.

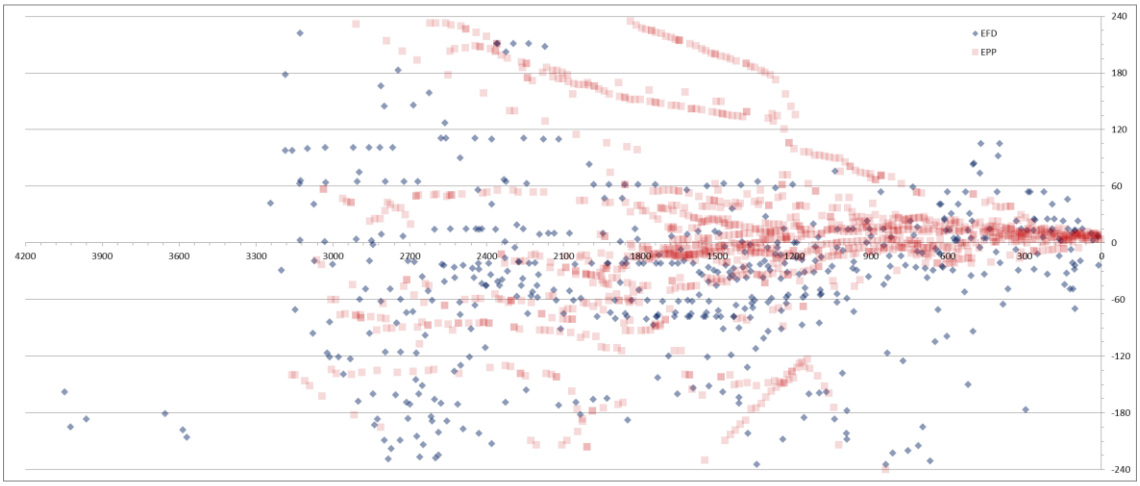


Figure 89 cumulative EFD (blue) and EPP (red) prediction error on a limited scale

In both Figure 88 and Figure 89 the dots representing each data point have been rendered in a partly transparent way (sometimes referred to as non-zero-Alpha). As there are many more EPP data points than EFD, the EPP dots are shown “more transparently”.

As there are such a large number of data points, presentations which identify specific flights and also show all flights and also show EPP and EFD are unfeasibly hard to read. The following, Figure 90 is thus a presentation of only the EFD prediction errors, identifying each flight. Figure 91 follows showing EPP prediction errors on the same vertical scale. Note carefully that the lines drawn between the points are only to help the reader identify the predictions for one flight and are **not** indicative of values in between the data points. In practice each prediction will be the only known value until a new prediction is received and at that time the new prediction replaces the previous one; a timeline of prediction error would be a series of steps.

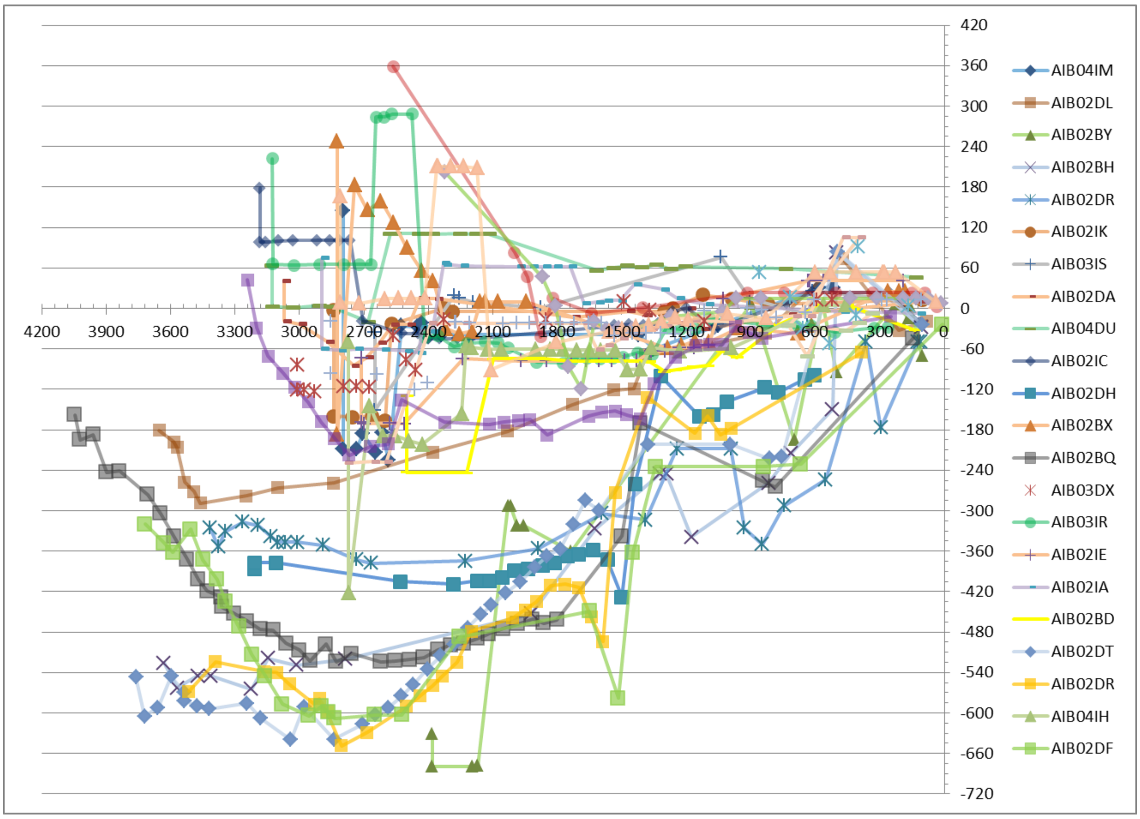


Figure 90 EFD prediction errors for all flights

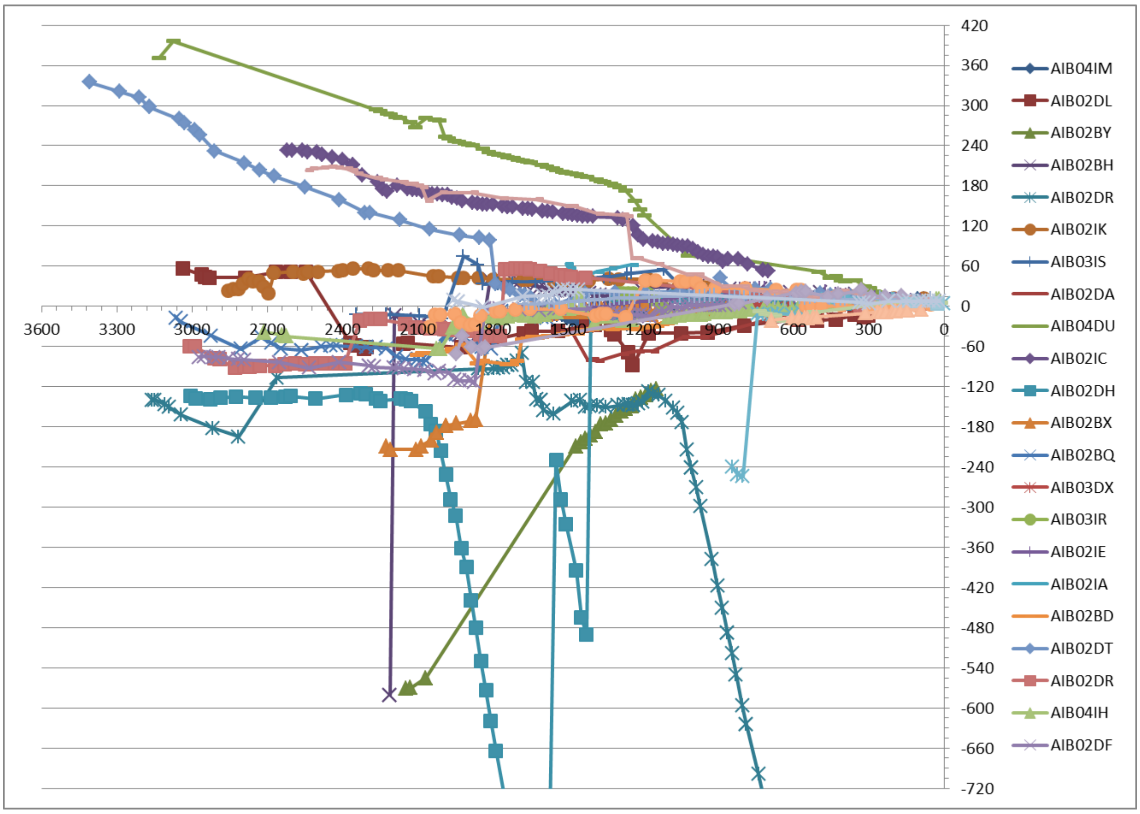


Figure 91 EPP prediction errors for all flights

Note figures Figure 90and Figure 91use the same scale on their vertical axis.
The two problem flights, AIB02DH and AIB02DR suffer from the same issue. The prediction errors for AIB02DH are shown in below.

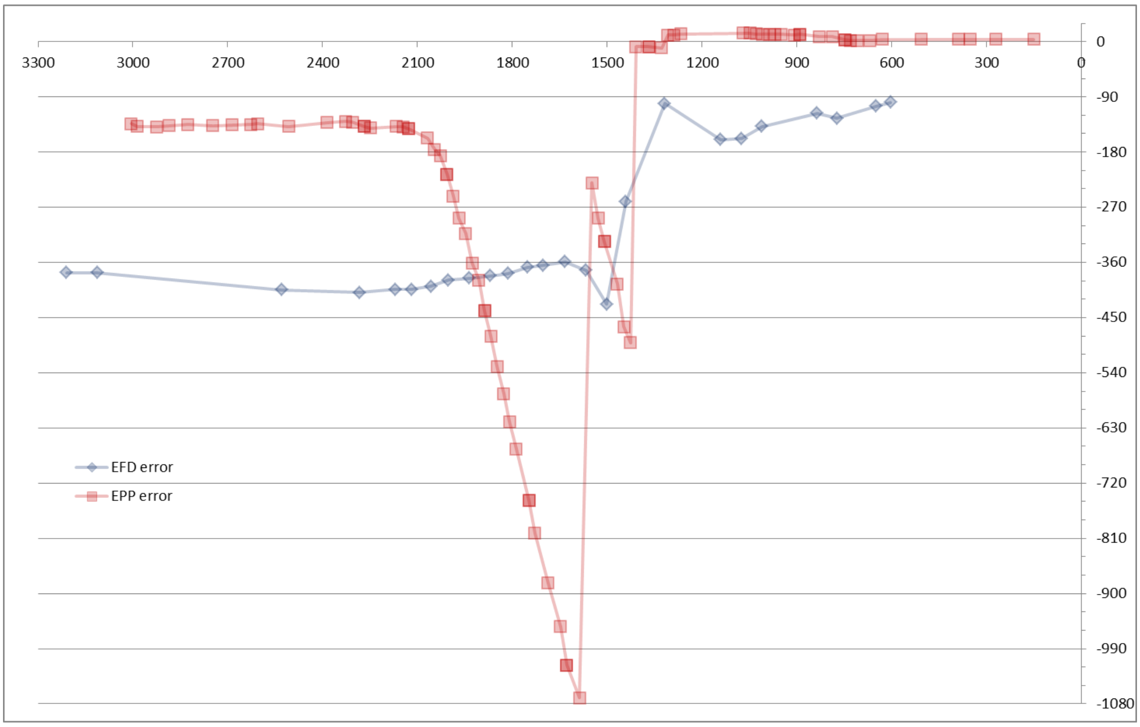


Figure 92 EPP and EFD prediction error for AIB02DH

There are two sections of the EPP graph where the prediction error is becoming negative – meaning the predicted time over the COP (in this case MOROK) is after the actual time. In each case the same thing has happened: the next point in the planned sequence has not been overflown, but bypassed. In the leftmost and largest "trough" in Figure 92, the predicted point sequence was as given in Table 40

Point name	Estimated time over at 16:05:23	Estimated time over at 16:18:01
OSN	passed	
DOMEG	16:09:54	removed
ABAMI	16:12:22	removed
BAM	16:13:15	removed
NOR	16:17:31	16:19:23

Table 40 times over points in EPP for AIB02DH

Table 40 shows that until the EPP computed at 16:08:01, the FMS's expected next point was DOMEG. DOMEG had been bypassed but not overflown as the aircraft was following a direct path to NOR. Hence DOMEG was an increasing distance behind the aircraft and the FMS calculated a trajectory that would go back to visit DOMEG. Thus later points have times over that include a round trip backwards, giving estimates for arrival at the COP that get further in the future at twice the rate at which time is passing. Immediately before the EPP computed at 16:08:01 the air crew have updated the point sequence. But at the time they did so the flight seems to have been abeam NOR and the same situation occurred for the next few points until at 16:22:01 a EPP was calculated with the next point SUTAL which, at last, was ahead of the aircraft. In the graph Figure 92, that update corresponds to the red line going up to the horizontal axis at about 1400 seconds.

There are other reasons the EPP does not perfectly predict arrival at the point. In terms of their effect, largest to smallest, these include (but are not limited to)

1. The COP is not overflown. Thus the EPP prediction for a time over is being compared with time over something else; a nearest point of approach.
2. On the way to the COP the flight did not follow the plan but flew direct. This occurs a lot but the size of the effect depends on the amount of short-cut achieved.
3. The flight was not executed as the FMS would have predicted. PEGASE flights are test flights and when the crew make tests, the flight might be different from the FMS' prediction, particularly in terms of speed or flight level.

Other causes can be imagined but these three are most often seen in PEGASE flights.

A flight which seems to be mostly free of such problems is AIB02BH. This flight followed the Centre route. FSA was 15:18:52 and MOROK was overflown at 16:19:23. As in many PEGASE flights, the first EPP was received at 15:42:45 when the aircraft was at FL300. The first two reports contain a loop in the sequence of points the FMS expects to visit, which disappears in the third report. This behaviour is typically indicative of EPP sent by the prototype equipment while the air crew are updating the list of points. This loop corresponds to the large negative error (meaning predicted time is after actual time) in the first point on the EPP graph, Figure 93 below. After that the flight included a series of direct segments, each seen as a sudden vertical change in the prediction, but none seems to have a big impact on the prediction.

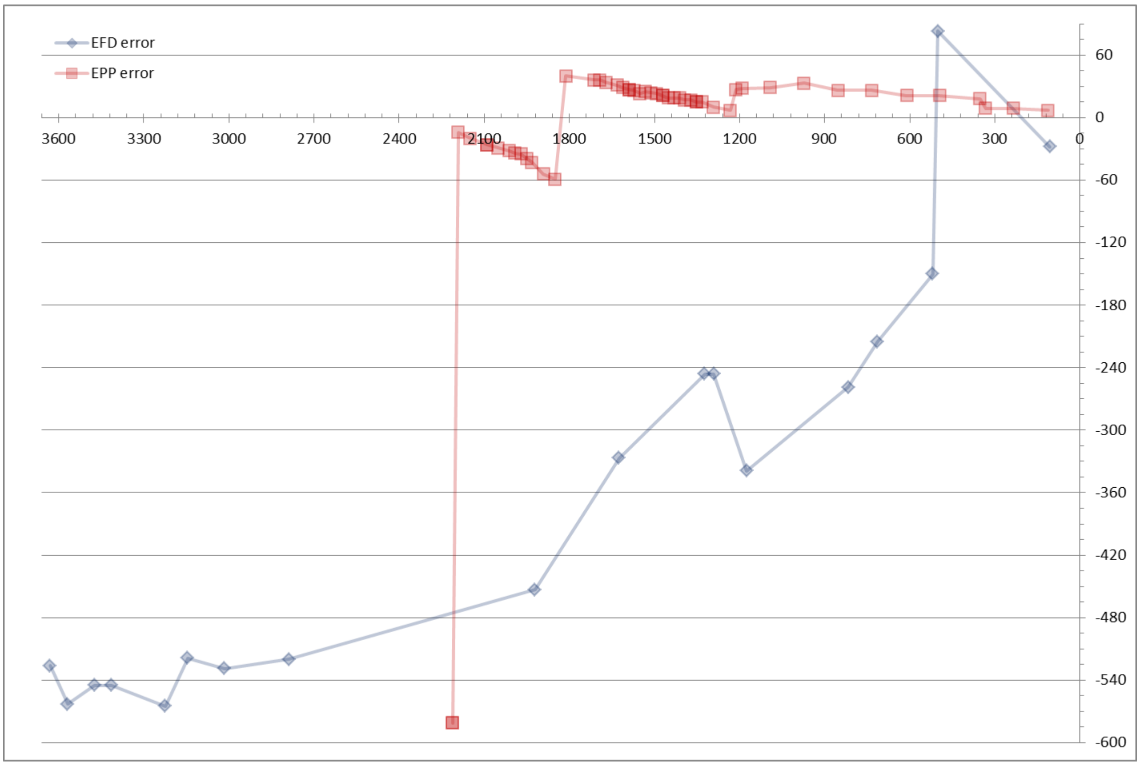


Figure 93 EPP vs EFD prediction error for AIB02BH crossing MOROK

In Figure 93 the EPP gives a prediction accurate to within a minute from 15:42:51 until the COP is crossed at 16:19:23, that is 2192 seconds, or more than 36 minutes ahead, a precision not matched by the EFD until one minute before.

If the ten flights for which the COP is not overflown or which have the "point in the sequence but already passed" problem are removed, then Figure 91, above is transformed into Figure 94, below. The same scales are used for both. In Figure 94, all predictions are within 1 minute accuracy ten minutes before.

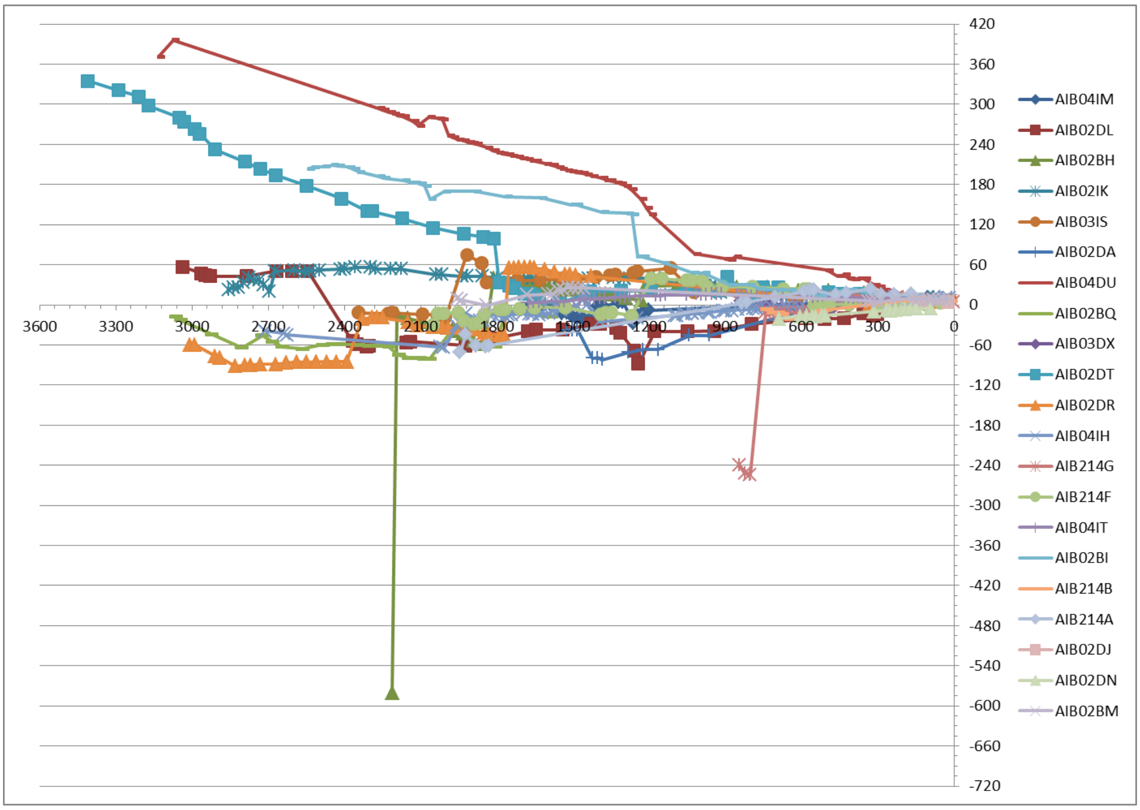


Figure 94 EPP prediction error for COP actually overflown when unsequenced point problems are removed

To compare EFD and EPP, the following two graphs, Figure 95 and Figure 96, consider all flights in the manner of Figure 88 and show the mean and standard deviation of the EPP and EFD prediction errors at 5 minute intervals. These "buckets" are labelled 1,2,3,etc corresponding to [0..300), [300..600), [600..900) seconds respectively.

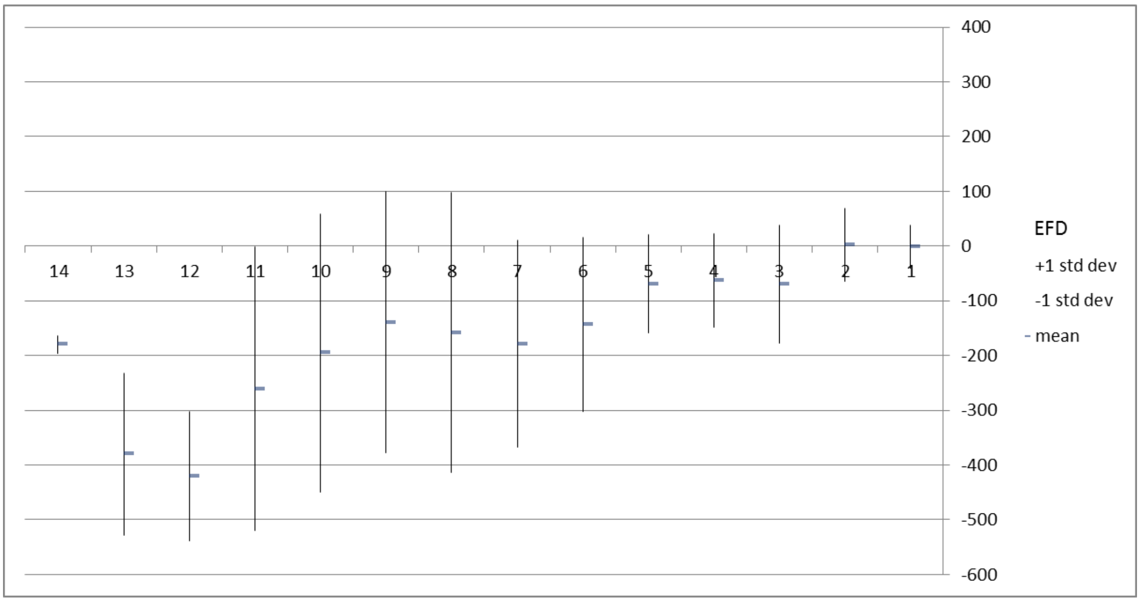


Figure 95 mean and standard deviation of EFD prediction error in 300 second buckets

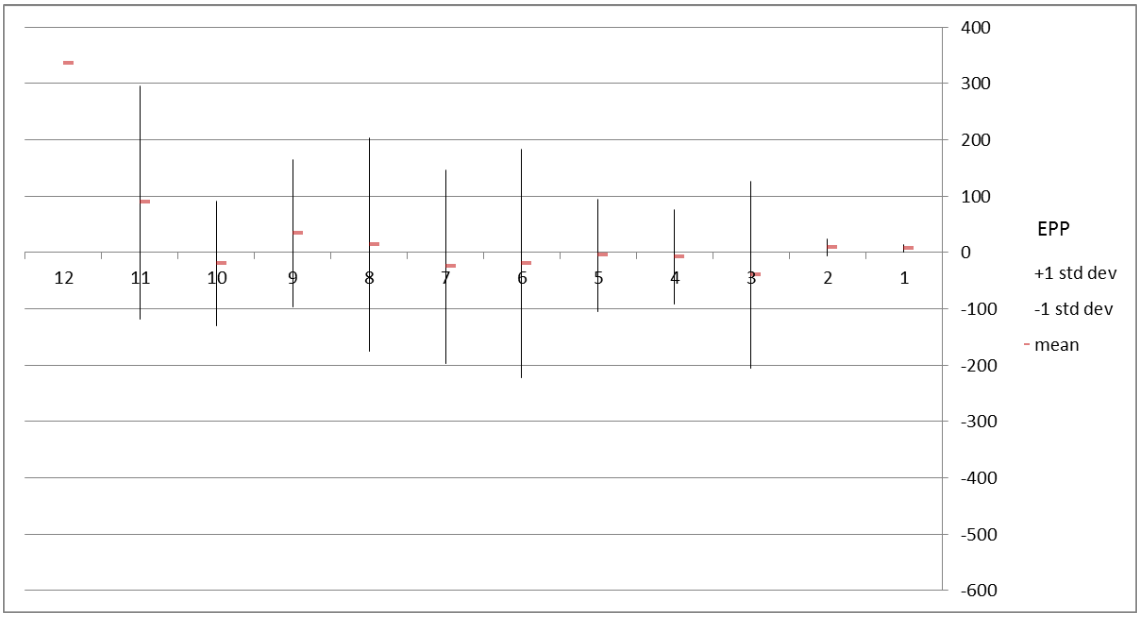


Figure 96 mean and standard deviation of EPP prediction error in 300 second buckets

Hence in the cases studied, the EPP seems to offer a better prediction of time over COP than EFD.

6.4.7.3.3 MUAC Approach: Measure the impact of the mass parameter variation on dynamic TP computations (feed the TP with mass variations all along a flight plan cycle).

6.4.7.3.3.1 Technical Context for MUAC analysis

For this exercise, MUAC FDPS was enhanced with the possibility to inject the gross mass dynamically during the flight plan lifecycle using the MAGERIT tool provided by Indra.

Each PEGASE flight can be replayed on MUAC IBP using this tool, fed by the gross mass received in the EPP during the real flight data collection.

For each iteration, a "screenshot" of the ground Trajectory Prediction is performed, enabling to compare the effect of the gross mass injection compared to the initial Trajectory Prediction computed by MUAC FDPS without the EPP data. The "screenshot" is composed of the FDPS progression log files, being the output of the Trajectory Prediction computation.

The context for this analysis is summarised by the following items:

- ADS-C latitude, longitude, level and time were used as track update
- Recorded track data updates were not used
- EPP mass was injected at each ADS-C report

- MUAC adaptation data was used (including airspace and constraints)
- ICAO Standard Atmosphere was used
- Controller inputs that were actually performed during the flight were not reproduced
- Wind data was injected for 2 flights only

6.4.7.3.3.2 Method details for MUAC analysis

The initial flight plans (as received from the CFMU on the online system) had to be reworked to enable the comparison with the flown trajectory. The following items had to be modified:

- The 2D routes were modified when necessary to stay within lateral conformance

  (2D modifications only, necessary when the flight received route or direct clearances)
- EOBD and EOBT were shifted to allow simultaneous replay of multiple flights

The ADS-C reports were modified to allow simultaneous replay of multiple flights (the times were shifted)

The vertical accuracy with/without EPP mass was measured against ADS-C position:

- With different look-ahead values
- For unrestricted climb only (the comparison is less reliable after a CFL input has been processed by the aircraft)
- The output was analysed using percentile statistics for vertical error of TP over look-ahead time

6.4.7.3.3.3 Quantity of data available for MUAC analysis

For this exercise, the data available for MUAC analysis is a subset of the PEGASE flights. Both EEC and MUAC had ADS-C contracts running for this exercise, with different types of issues:

- The ADS-C connection was sometimes failing for one but not for the other.
- EEC sometimes reconnected manually when a contract subscription failed while MUAC did not.

  Although MUAC implemented a script to reconnect automatically in case of communication issue, and MUAC had the possibility to manually reconnect, it was decided not to force the connection in case of failure, to give priority to EEC connection in case multiple connections could induce side-effects.
- MUAC had different ADS-C contract parameters setup

  (Triggering less EPPs than for EEC contract setup)
- MUAC can only replay the flights for the portions that are crossing MUAC AOI.
- Sometimes, the flight diverted too much due to ATC clearances and could not be used for replay.

For all these reasons, the number of PEGASE flights eligible to MUAC analysis is limited to 14 flights:

- 13 departing from EDHI – climbing in EDYY AOI
- 1 arriving to EDHI – descending in EDYY AOI

The following diagram represents the flights segments available in MUAC AOI until the cruise level is reached or CFL input is executed:

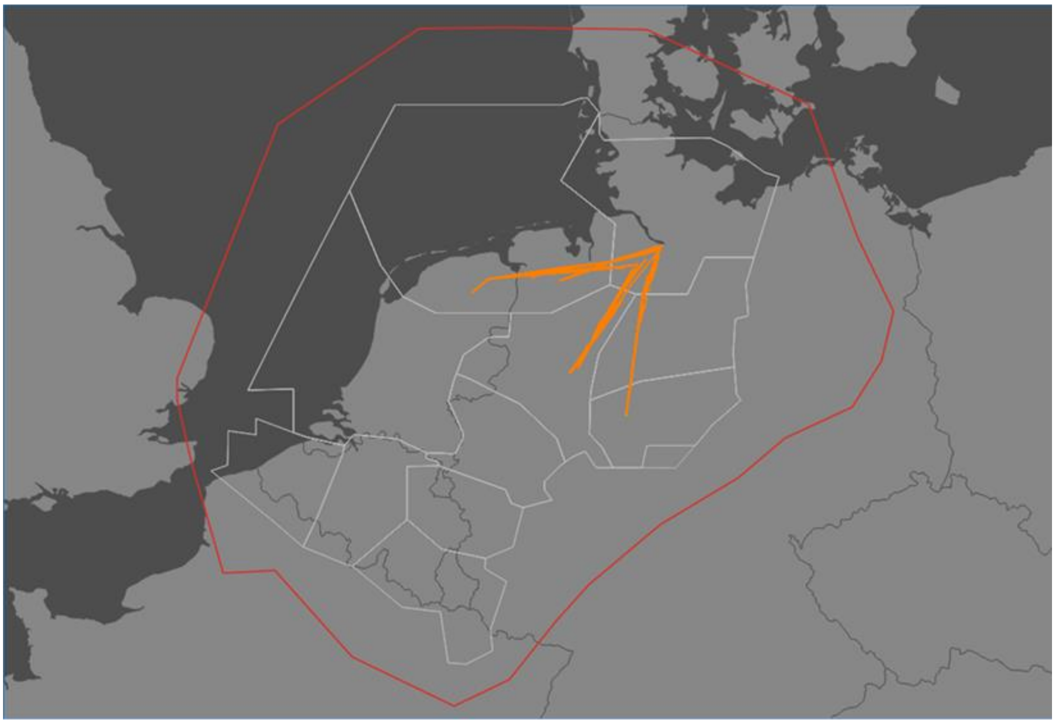


Figure 97 Climb segments in MUAC AOI

In this picture:

- The climb segments are represented in orange.
- MUAC AOR is composed of the sectors delimited in white.
- MUAC AOI is represented by the red line

This graph makes it clear that the PEGASE flights followed three different routes as far as MUAC is concerned (East, Central and West), with very little variance, as expected. This is in a way good for the analysis because it enables a comparison between several flights to assess MUAC results variance. On another hand, this shows that the sample representativeness is limited, and that the results should be taken from a distance until a more diverse traffic is used for a similar study.

6.4.7.3.3.4 Generation of the raw data for the analysis

6.4.7.3.3.4.1 Trajectory prediction output for climbing flights

6.4.7.3.3.4.1.1 Example of a simulation output:

The following graphs show a comparison between the initial ground trajectory prediction output and the one using the EPP mass. The position of the aircraft stated in the successive ADS-C reports is also displayed.

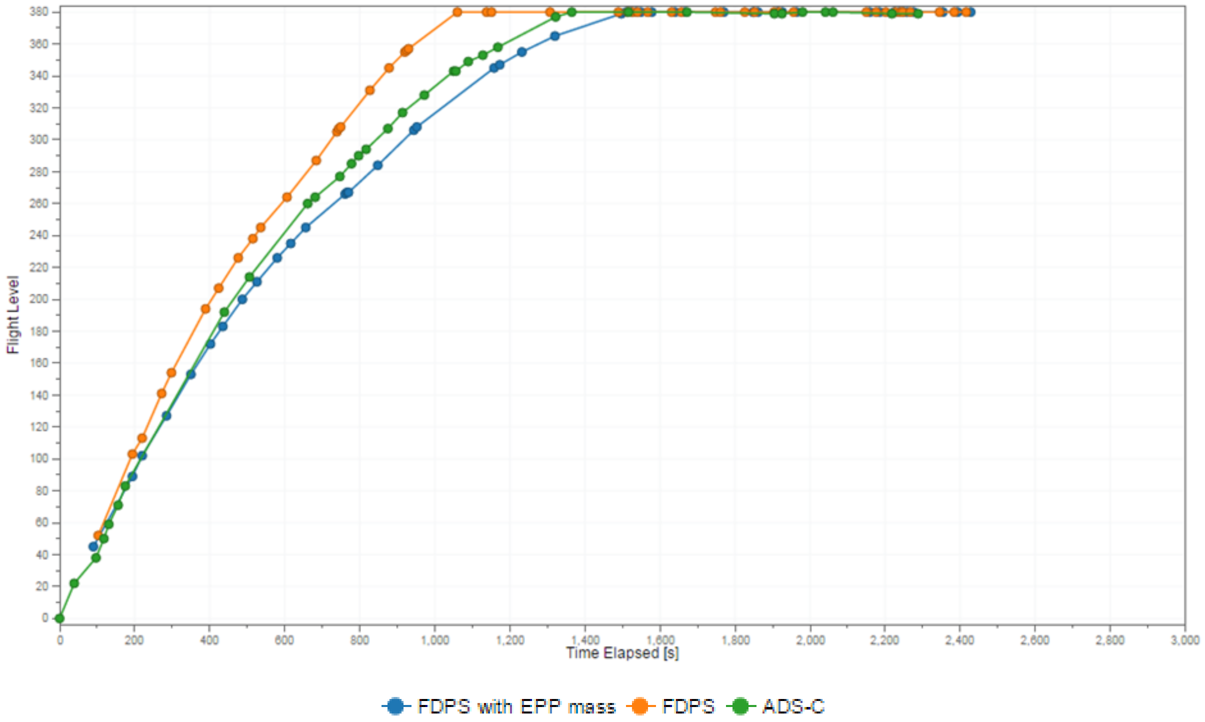


Figure 98 EPP Mass influence on TP – AIB0124

In this case, the ground trajectory prediction using the EPP mass injection (in blue) is closer than the trajectory actually flown by the aircraft (in green), when comparing to the initial ground trajectory prediction (in orange). The enhancement of using the EPP mass is even more obvious in the first phase of the flight (up to 500 seconds); then the trajectory prediction diverges from the flown trajectory, although it is closer than the initial trajectory prediction.

6.4.7.3.3.4.1.2 Limitations due to unplanned level constraints during the climb phase:

The example from the previous section is one of the few examples for which the climb is unconstrained; most of the flights show a level constraint at some point (i.e. the ADS-C report levels off while the ground TP predicts a flight climbing to a higher level). This is because of a controller clearance set on the real flight, which cannot be reproduced in the simulation environment. It also happens that LOAs are not executed, so the ground trajectory prediction plans constraints that are not followed by the aircraft.

Because of this, the analysis has to be limited to the segment before the flight levels-off.

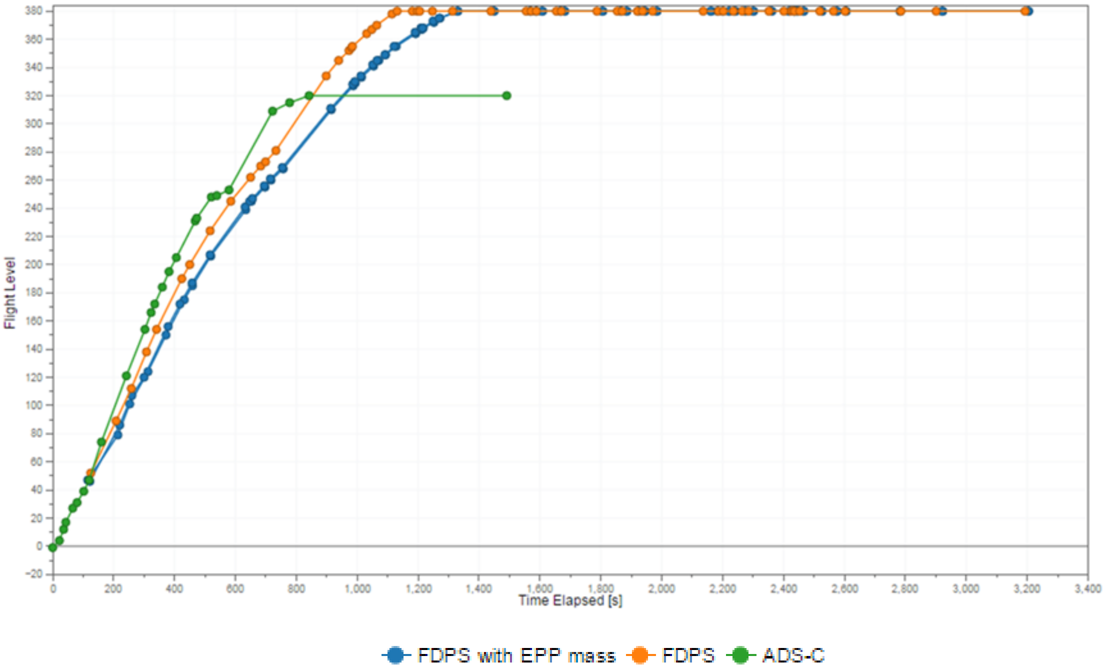


Figure 99 EPP Mass influence on TP – AIB02DM

In the diagram above, the analysis can only be performed in the climb phase before the level off (approximately before 700 seconds elapses).

In this case, the usage of the EPP mass has a negative impact on the trajectory prediction (the orange line is closer to the green one than the blue line.

6.4.7.3.3.4.1.3 Examples of positive influence of the EPP mass usage on the trajectory prediction:

For some flights, the EPP mass influence on the ground trajectory prediction has a positive impact: the ground trajectory prediction using the EPP mass is closer to the trajectory actually flown by the aircraft:

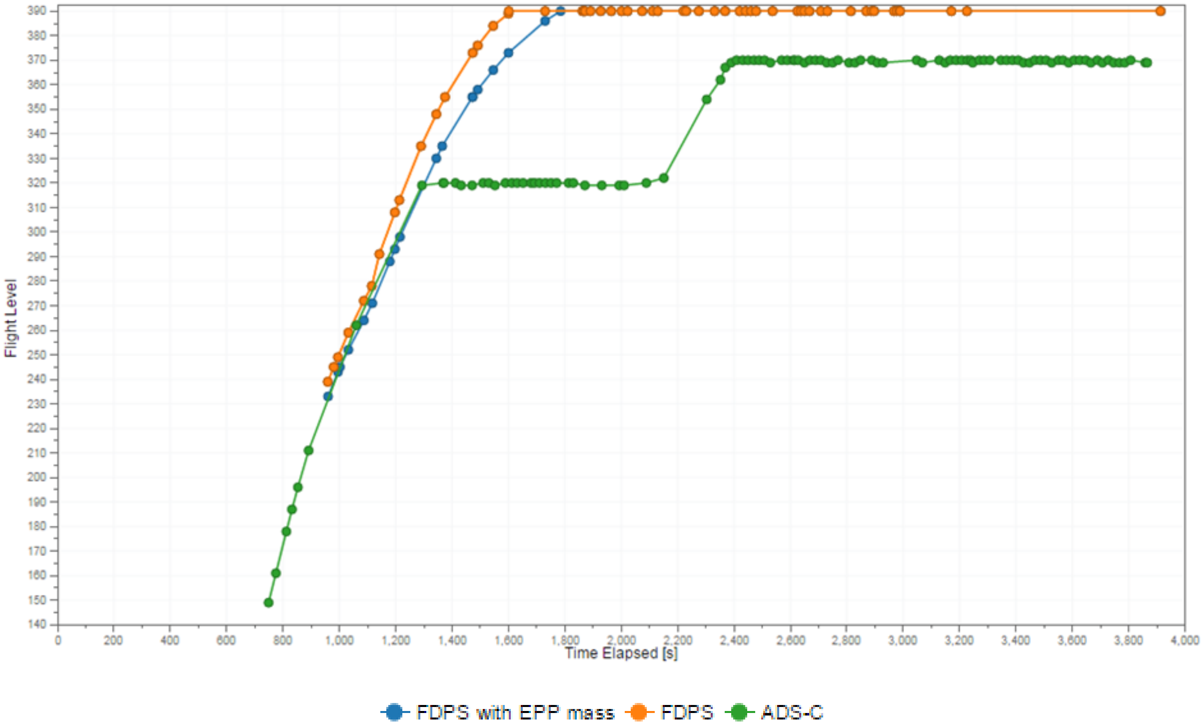


Figure 100 Positive EPP Mass influence on TP – AIB02DF

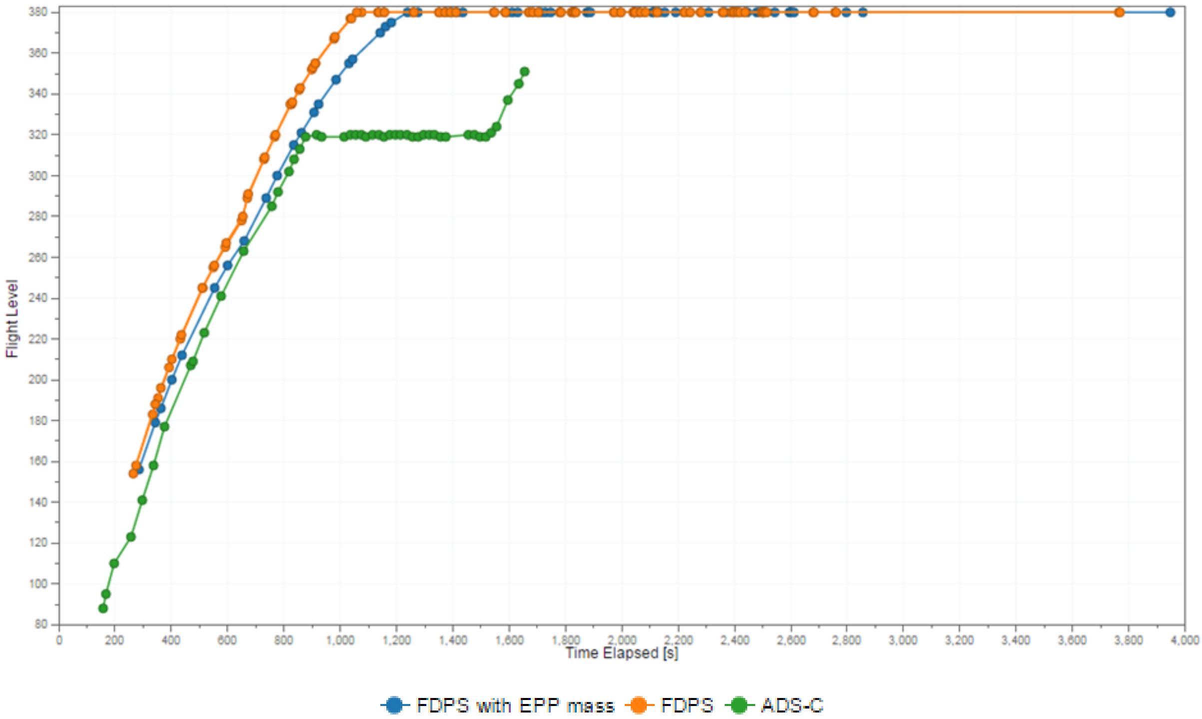


Figure 101 Positive EPP Mass influence on TP – AIB02DH

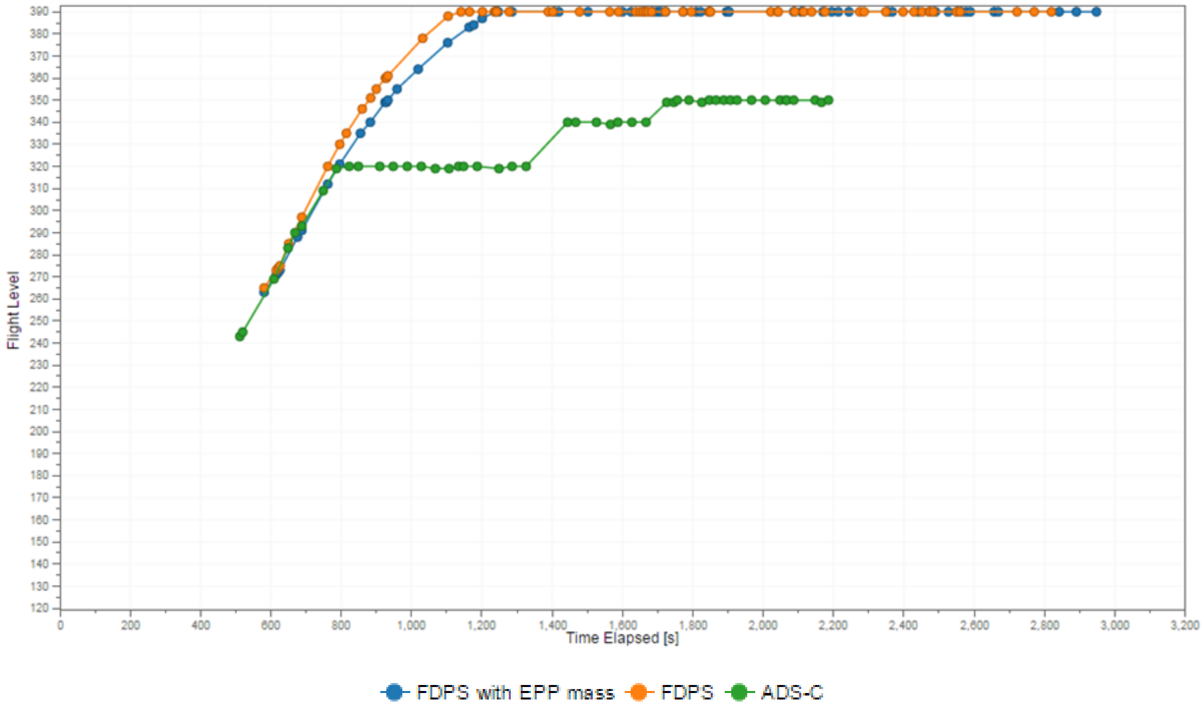


Figure 102 Positive EPP Mass influence on TP – AIB02DT

6.4.7.3.3.4.1.4 Examples of negative influence of the EPP mass usage on the trajectory prediction:

For some flights, the EPP mass influence on the ground trajectory prediction has a negative impact:

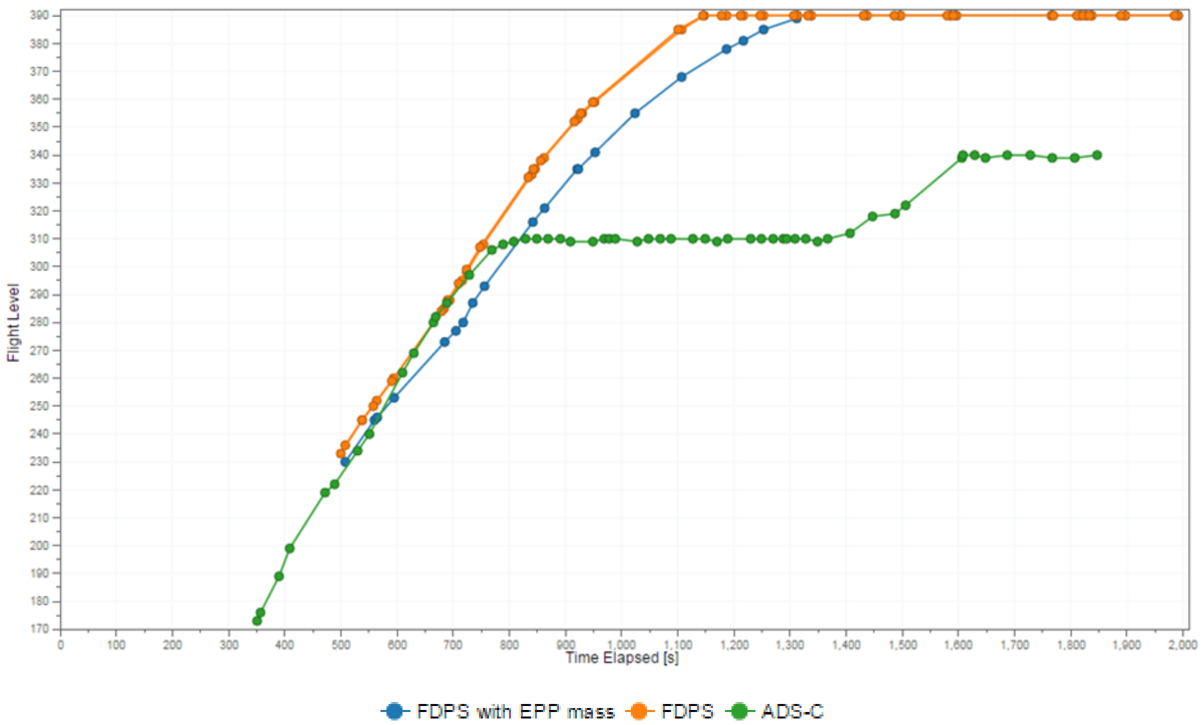


Figure 103 Negative EPP Mass influence on TP – AIB02BD

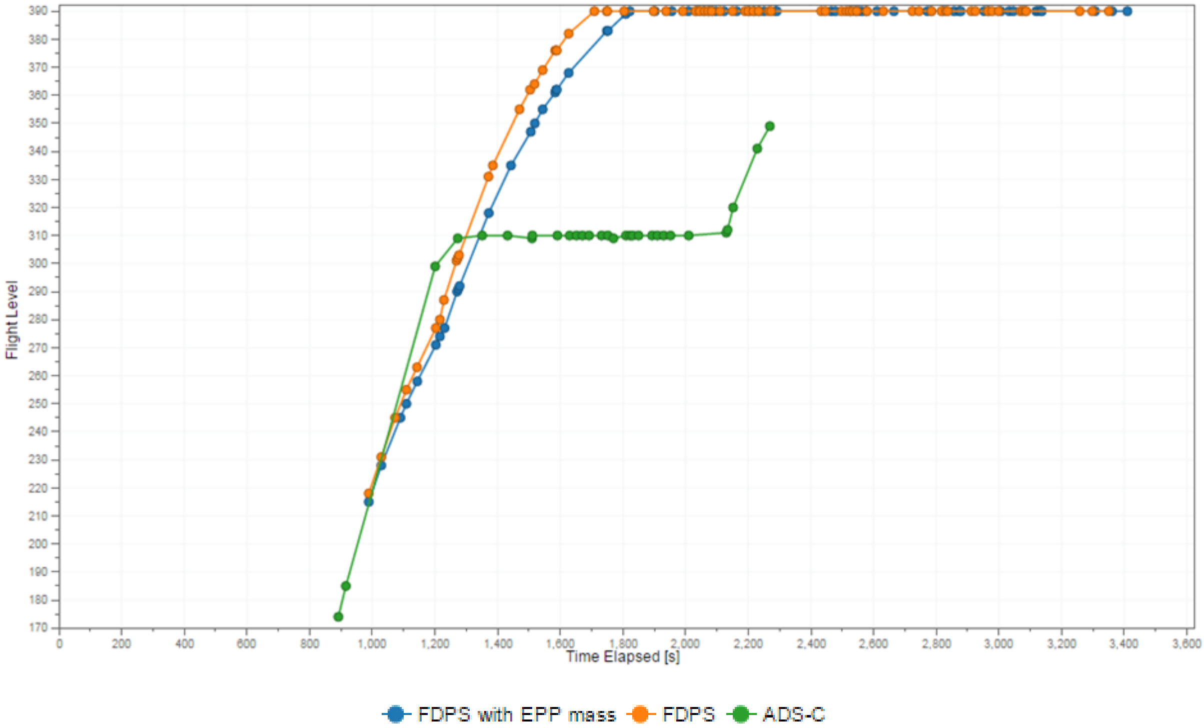


Figure 104 Negative EPP Mass influence on TP – AIB02BQ

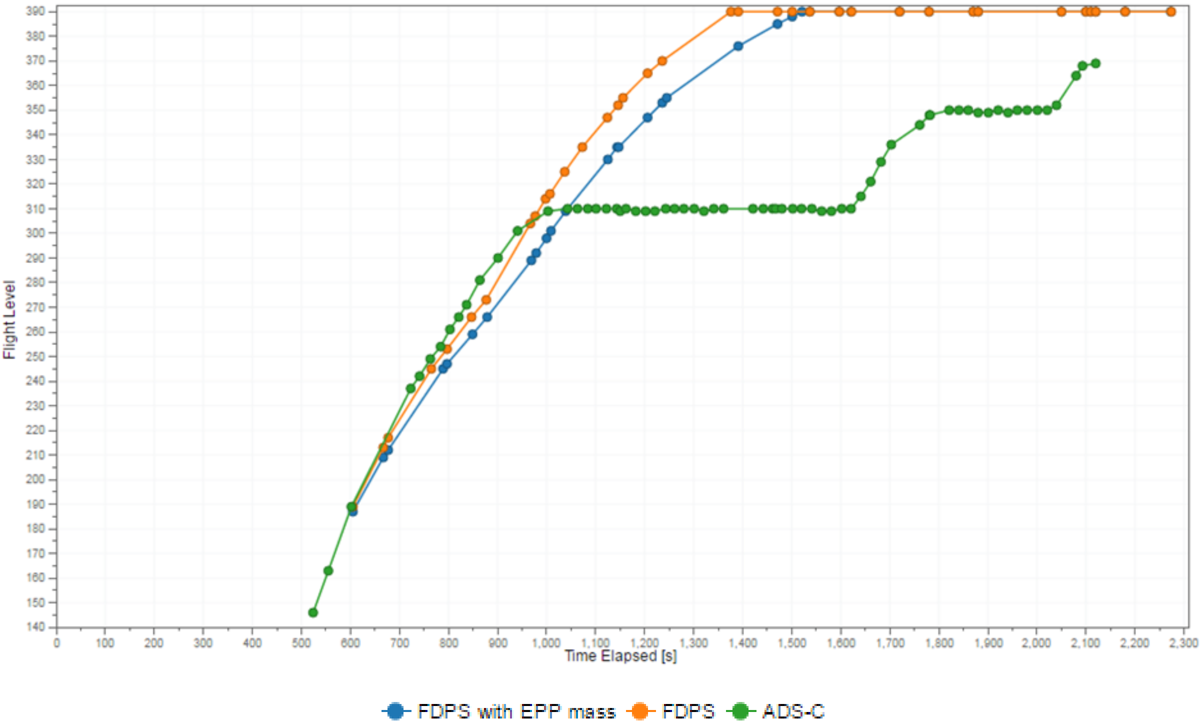


Figure 105 Negative EPP Mass influence on TP – AIB02BX

6.4.7.3.3.4.1.5 Outcome of the analysis:

The graphs presented above are only examples. More data is available, not only because there are more flights, but also because this kind of computation is performed multiple times along the flight lifecycle, as the flight moves forward, with each ADS-C report reception. Sometimes, assessing the result of the EPP mass usage is not so simple, because a part of the trajectory is improved, and another part is degraded for the same computation, as shown in the following example:

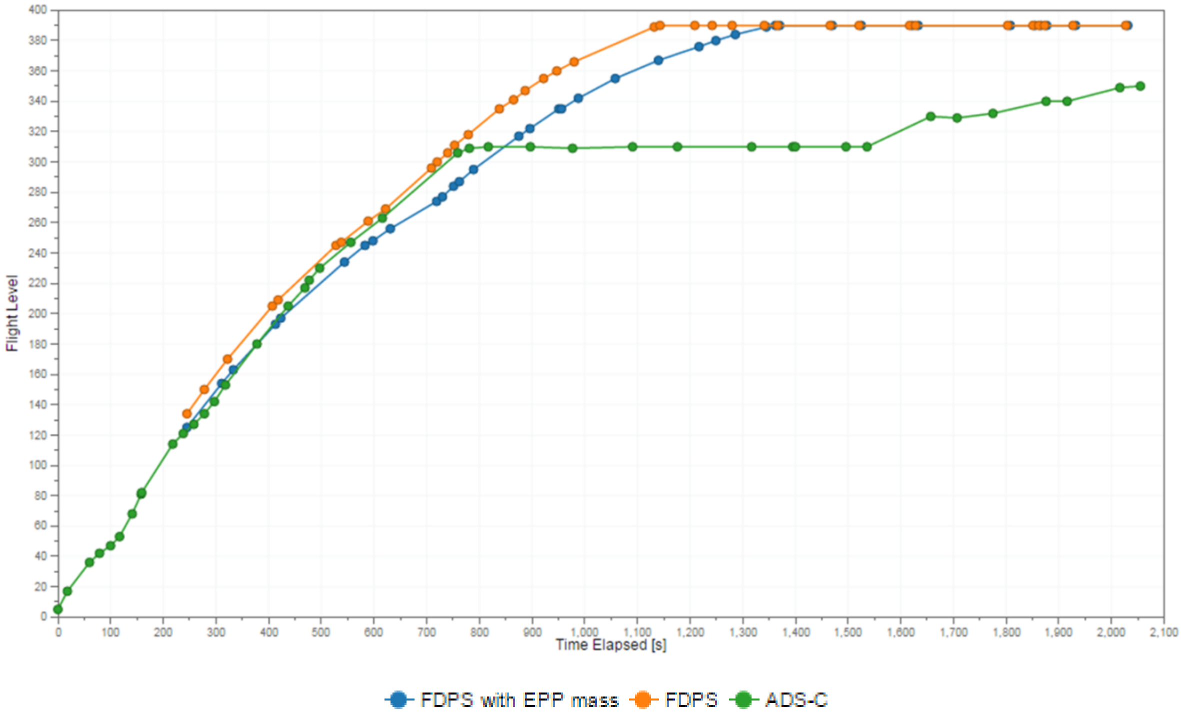


Figure 106 Negative EPP Mass influence on TP – AIB02BX

In the example above, the trajectory prediction is improved in the early climb (up to 450 seconds), and then degraded.

A more refined analysis is performed in section 6.4.7.3.3.5, using the percentile method to assess a statistical pattern.

6.4.7.3.3.4.2 Trajectory prediction output for descending flights

Only one flight was available with a descent phase within MUAC AOI. The following graph represents the influence of the EPP mass usage on the ground trajectory prediction:

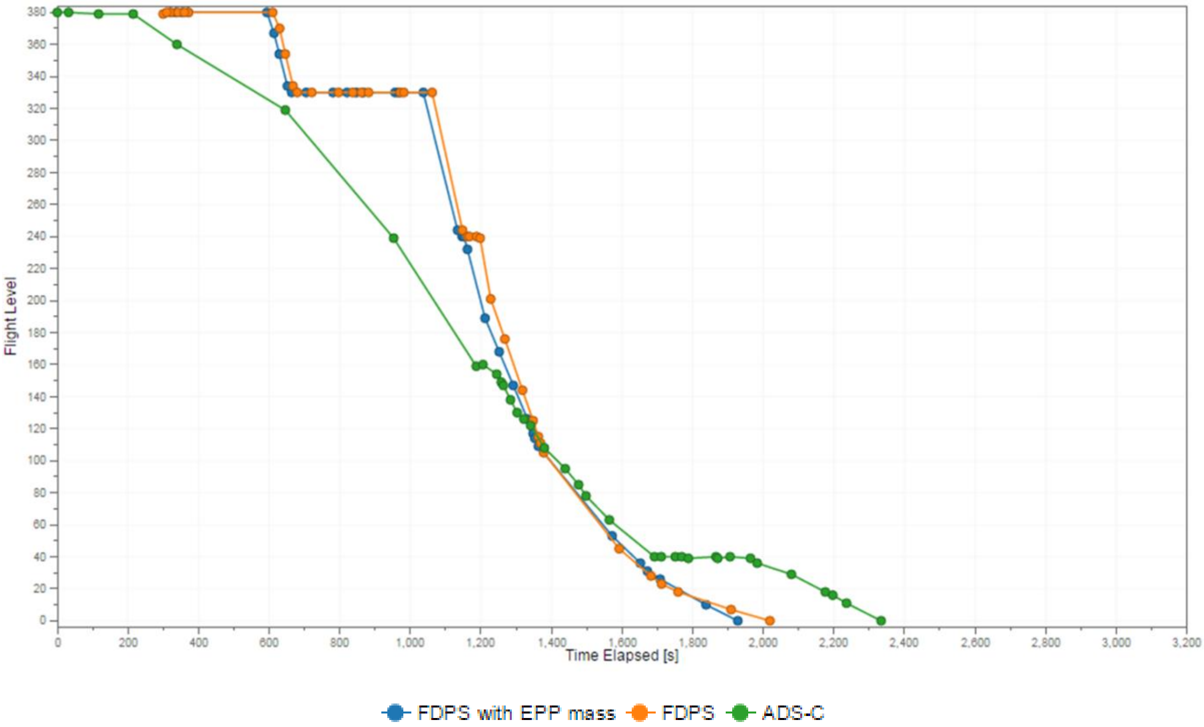


Figure 107 EPP Mass influence on TP for a descending flight – AIB214

This graph shows that the descent flown by the aircraft is quite different than the planned one. This can be due to an early descent clearance from the controller, or a "when ready" descent clearance, leaving it up to the pilot to decide when he will actually start the descent.

The ground trajectory prediction shows two steps corresponding to level constraints that are not known by the airborne systems. This phenomenon is due to the usage of situation lines within MUAC environment. Situation lines are level constraints defined offline depending on route conditions for the flight (ADEP, ADES, route points ….). These constraints are commonly used "work arounds" and are used to set a fixed sector sequence in MUAC, not depending on what the flight will actually fly. This is a way to ensure that MUAC operational sequence is respected and that the controller responsible to manage the exit with the next unit will be the correct one according to MUAC operational bilateral agreements.

This kind of system design reduces the possible positive effects of trajectory prediction improvements based on aircraft data. If controller input had been possible the level off would still have been present but overwritten as each ATCO clearance modified to the FDPS descent. A development of the investigation tools should be considered.

6.4.7.3.3.4.3 Influence of the wind data

Most of the analysis has been performed without wind data. The effect of injecting the wind data in MUAC FDPS has been studied for two flights: one in climb, one in descent.

Note; the temperature is not used by MUAC FDS, only the wind is used.

6.4.7.3.3.4.3.1 Wind influence for a climbing flight:

The following graph shows the analysis output for a climbing flight and without the injection of wind data:

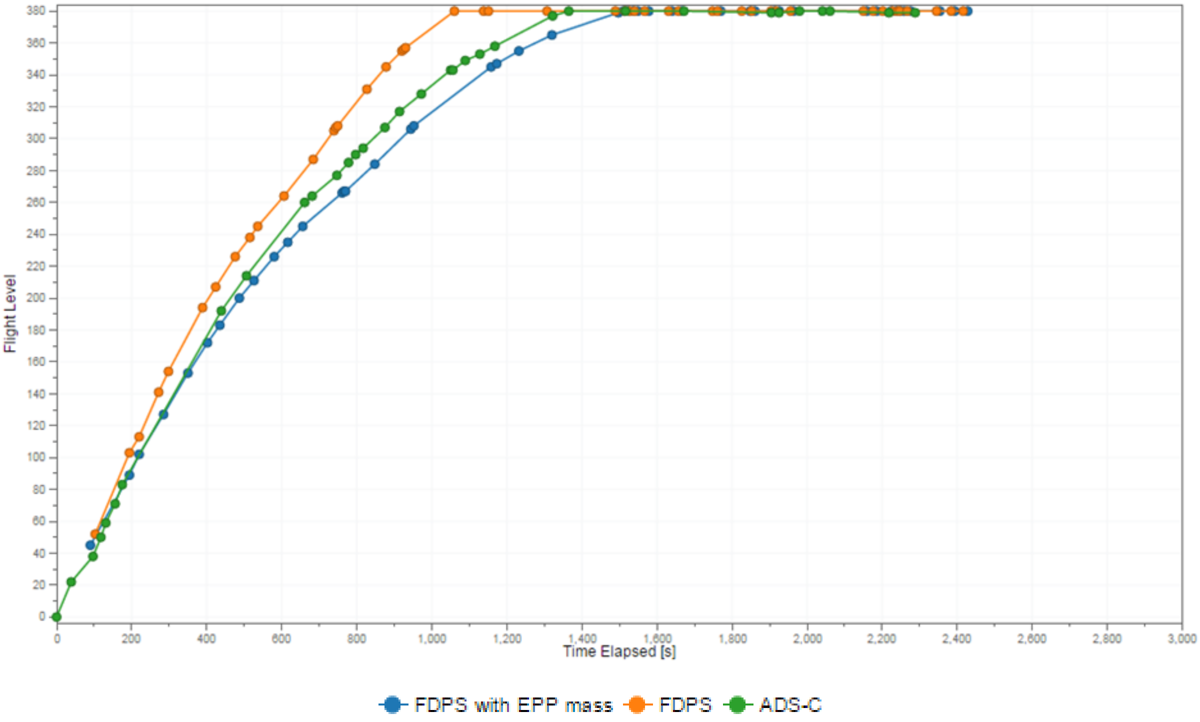


Figure 108 EPP Mass influence on TP – AIB0124 with no wind data

The following graph shows the analysis output for the same flight, with the injection of wind data:

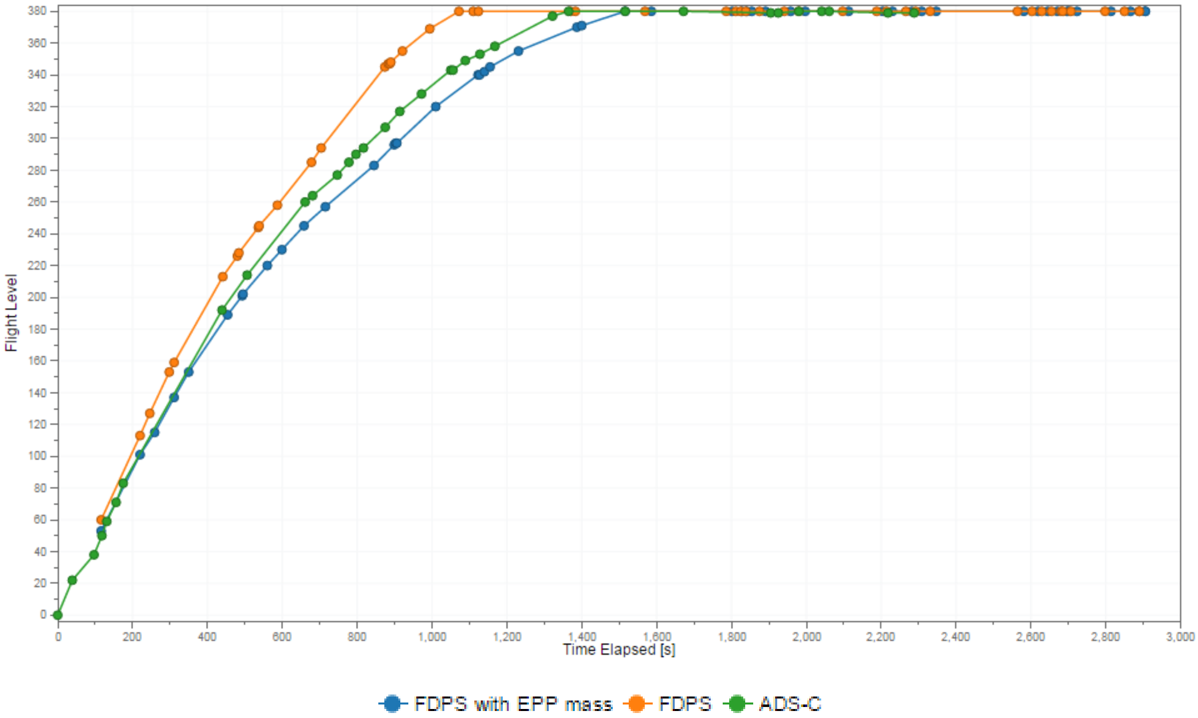


Figure 109 EPP Mass influence on TP – AIB0124 with wind data injection

The wind data has almost no influence on the ground trajectory prediction. At first this was a surprise to the validation team because this flight was heading West in to the wind.

After some analysis, it is understood that this is a normal behaviour because the rate of climb/descent does not depend on the winds, only the distance overflown does (This graph represents the vertical profile against the time elapsed so the rate of climb/descent is addressed here).

6.4.7.3.3.4.3.2 Wind influence for a descending flight:

The following graph shows the analysis output for a descending flight and without the injection of wind data:

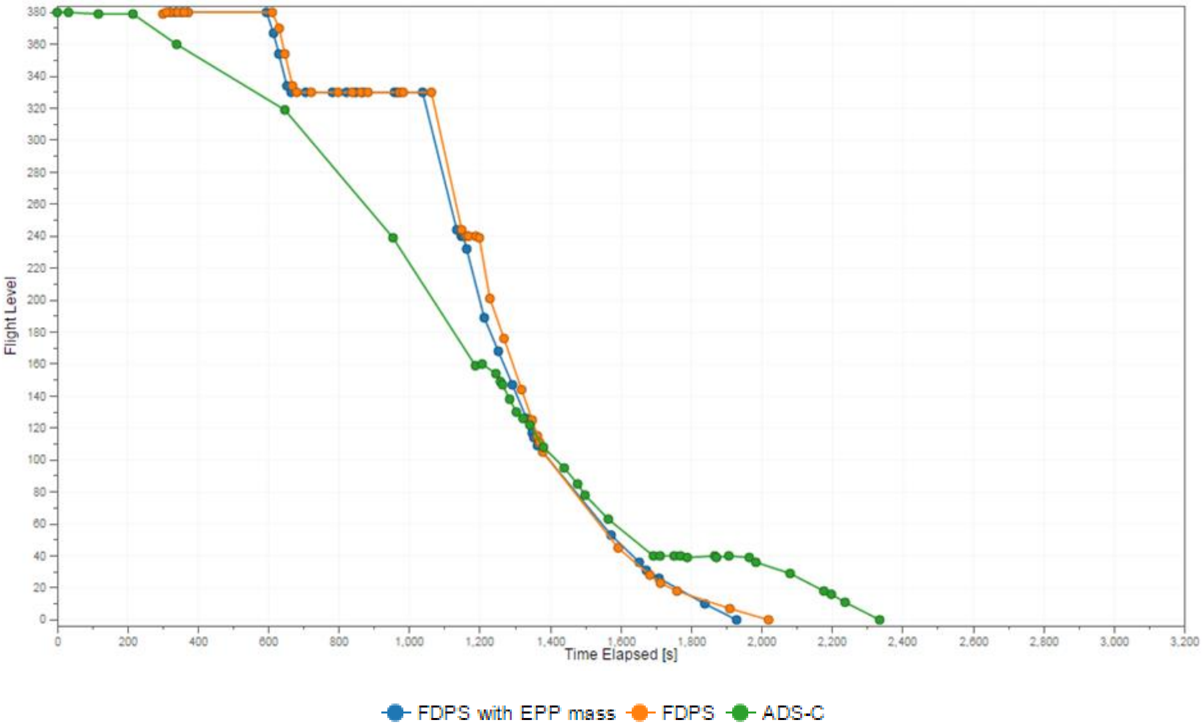


Figure 110 EPP Mass influence on TP – AIB214 with no wind data

The following graph shows the analysis output for the same flight, with the injection of wind data:

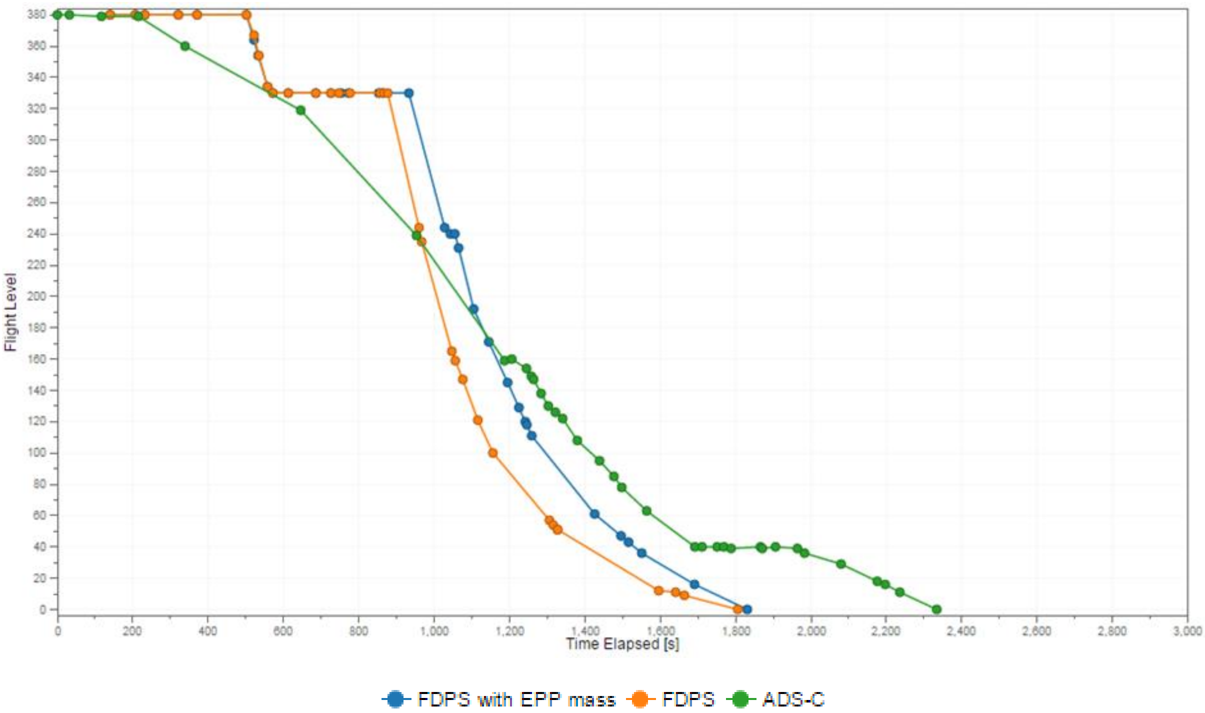


Figure 111 EPP Mass influence on TP – AIB214 with wind data injection

The wind data has a significant influence on the ground trajectory prediction. At first this was a surprise to the validation team because this flight was heading North-East, with a lateral wind only.

As explained in the previous section, the rate of climb/descent is considered with this type of graph, and it does not depend on the winds. With this in mind, we can observe that:

- The trajectories are shifted. This is because the total duration of the flight changes and the descending manoeuvre is the last thing performed. This way, if the descent manoeuvre duration is X (this is constant, for any winds), but the total duration of the flight is Y (and this is NOT constant, depends on the wind), the descent manoeuvre will start at Y-X, which will not be constant.
- In the orange trajectory, a steady segment at FL240 disappears. Considering a backward computation, in both cases, the orange trajectory takes 835 seconds to "climb" up to FL240. In one case, this level is reached before the constraint line position, and in the other, this level is reached after since the wind impacts the distance covered.
- The wind shifts orange trajectory more than blue one. Since the altitude profile is different in both trajectories, they do not face exactly the same wind, which could explain the difference. For example, the orange trajectory will stay longer at lower altitudes. If there is a small head wind there, this will have a bigger impact on the orange trajectory.

6.4.7.3.3.4.3.3 Wind influence analysis

The impact of wind data on the trajectory prediction enhancement seems to be different in the climbing and descending phases. A larger variety of data (with flights departing/arriving from/to different airports, with different routes) would be needed to draw conclusions this topic.

6.4.7.3.3.4.4 Impact of the ferry flight nature

One limitation of this exercise is that ferry flights are used. These flights have a proper set of test to perform outside of the PEGASE domain, sometimes involving a different behaviour or flight course than what a revenue flight would do.

Sometimes, the specific ferry flight behaviour can be noticed by MUAC analysis team, and the flight data can be set aside of the analysis. Sometimes, the specific behaviour can go undetected and it is a possible bias of this study.

Below is an example of a specific behaviour which was detected by the analysis team and led to the flight data to be discarded.

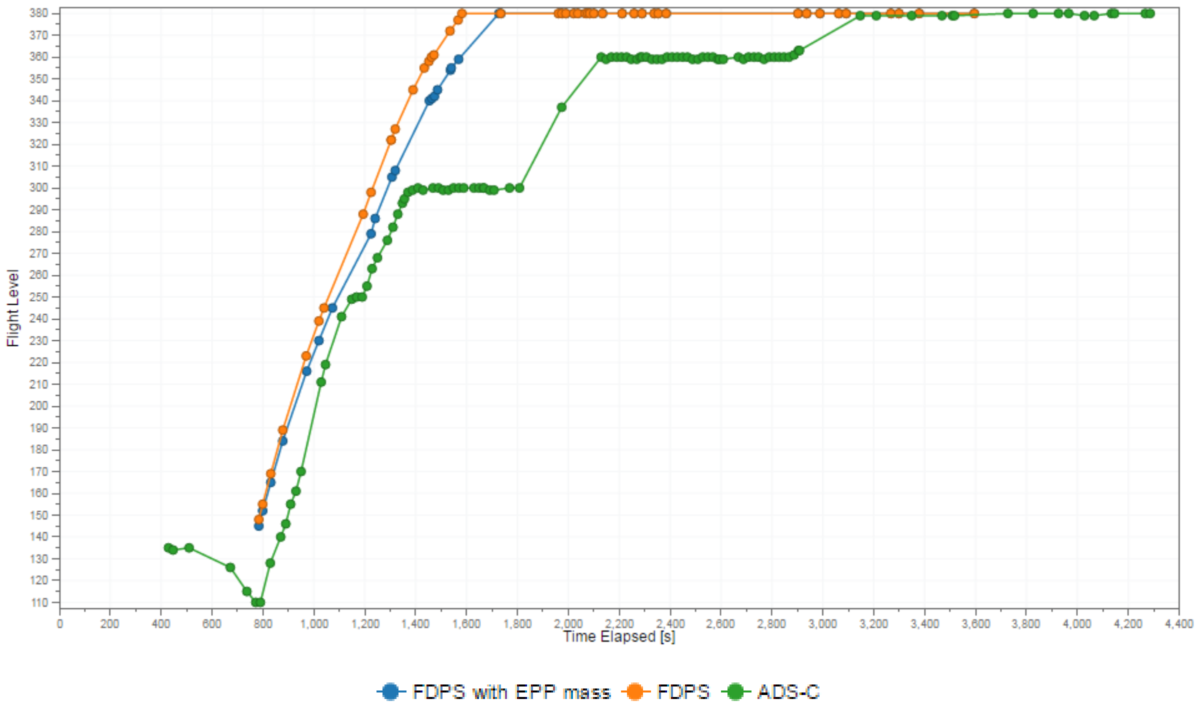


Figure 112 Unusual intermediate descent phase – AIB02BU

In this example, an usual descent phase is performed by the aircraft during the climb phase (as from 500 Seconds). It is highly probable that a specific test was performed for this flight.

6.4.7.3.3.5 Percentile approach for the analysis

6.4.7.3.3.5.1 Percentile approach description

The data generated as described in section 6.4.7.3.3.4 has been processed statistically to provide an overview of the impact of using the EPP mass in the ground system trajectory prediction.

The data treated for the analysis is a comparison between the vertical accuracy of the ground trajectory prediction with the ADS report flight level (DeltaFL). This comparison is done for the initial ground TP and the improved ground TP using the EPP mass injection:

- Delta FL = FDPS TP FL - ADS-C FL
- Delta FL = FDPS TP with EPP mass FL - ADS-C FL

DeltaFL is calculated in FL units – for example: 5 FL = 500 feet.

The following parameters are used for the statistical treatment:

- Ground trajectory prediction computed after each EPP injection.

  This means that if 15 EPPs were received for a flight, 15 trajectory predictions will be available for the statistical treatment.

  For each trajectory prediction, the data is available from the current position to the first stepped climb (limitation described in section 6.4.7.3.3.4.1).
- In the frame of available data, the DeltaFL is sampled every 15 seconds.
- The result is presented in the form of box and whisker plots showing DeltaFL percentiles over the look ahead:
  - The point in the box represents the median of the DeltaFL: half of the trajectory predictions for this flight are above this value.
  - 50% of the trajectory predictions for this flight show a DeltaFL between the bottom and the top of the box for the specific look ahead.
  - 25% of the trajectory predictions for this flight show a DeltaFL above the top of the box.
  - 25% of the trajectory predictions for this flight show a DeltaFL below the bottom of the box.
  - 20% of the trajectory predictions for this flight show a DeltaFL between the top of the box and the top whisker (horizontal thin line).
  - 20% of the trajectory predictions for this flight show a DeltaFL between the bottom of the box and the bottom whisker.
  - 5% of the trajectory predictions for this flight show a DeltaFL above the top of the top whisker.
  - 5% of the trajectory predictions for this flight show a DeltaFL below the bottom of the bottom whisker.

  Note: the vertical accuracy was analysed in relative value (i.e. +/- FL).

The following graph gives an example of percentile analysis for one flight:

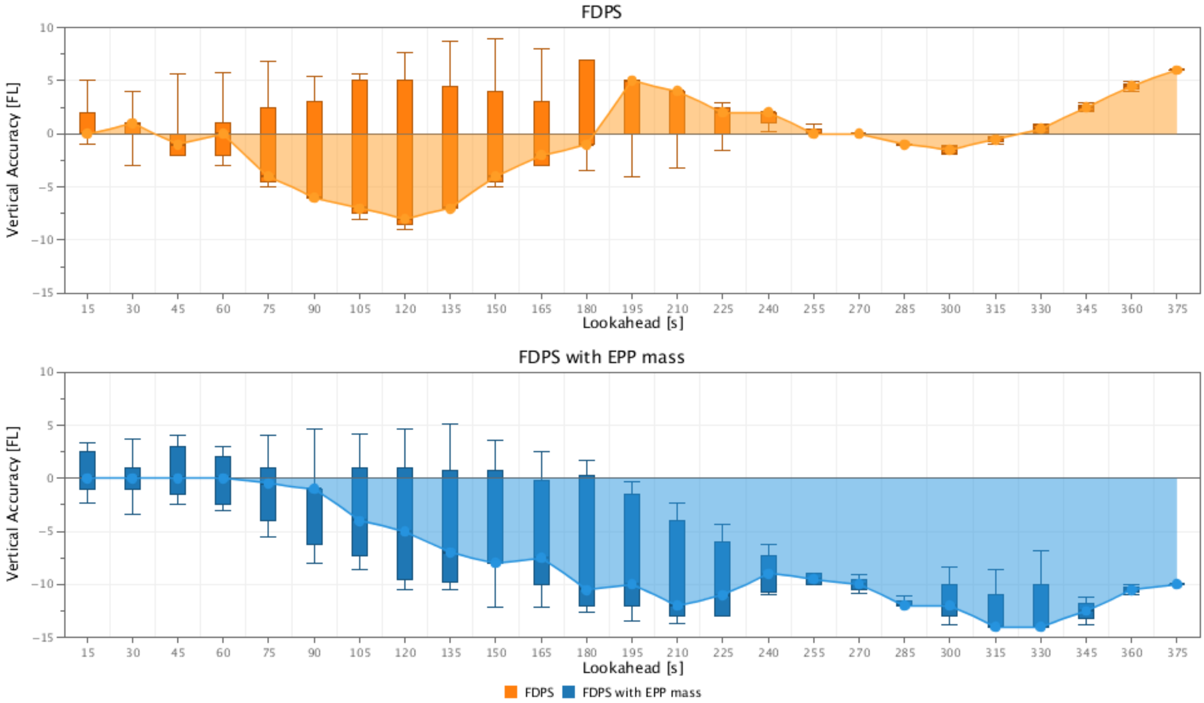


Figure 113 Percentile approach example – AIB02BD

For this example, and for a look-ahead of 75 seconds:

- For the initial trajectory prediction,
  - Half of the trajectory predictions for this flight are above a -4 FL vertical accuracy.
  - 50% of the trajectory predictions for this flight have a vertical accuracy between -4.5 and 2.5 FL.
  - 20% of the trajectory predictions for this flight have a vertical accuracy between 2.5 and 6.8 FL.
  - 20% of the trajectory predictions for this flight have a vertical accuracy between -4 and -5 FL.
  - 5% of the trajectory predictions have a vertical accuracy higher than 6.8 FL.
  - 5% of the trajectory predictions have a vertical accuracy lower than -5 FL.
- For the trajectory prediction injecting the EPP mass,
  - Half of the trajectory predictions for this flight are above a -0.5 FL vertical accuracy.
  - 50% of the trajectory predictions for this flight have a vertical accuracy between -4 and 1 FL.
  - 20% of the trajectory predictions for this flight have a vertical accuracy between 1 and 4.5 FL.
  - 20% of the trajectory predictions for this flight have a vertical accuracy between -4 and -5.55 FL.
  - 5% of the trajectory predictions have a vertical accuracy higher than 4 FL.

- 5% of the trajectory predictions have a vertical accuracy lower than -5.55 FL.

For this specific look ahead and this specific flight, it can be said that the injection of the mass improves the ground trajectory prediction for this flight.

6.4.7.3.3.5.2 Detailed results for the percentile approach

The detailed results per flight are presented in Appendix A.

6.4.7.3.3.5.2.1 Vertical accuracy per look ahead:

The following graph represents the vertical accuracy per look ahead for all flights combined:

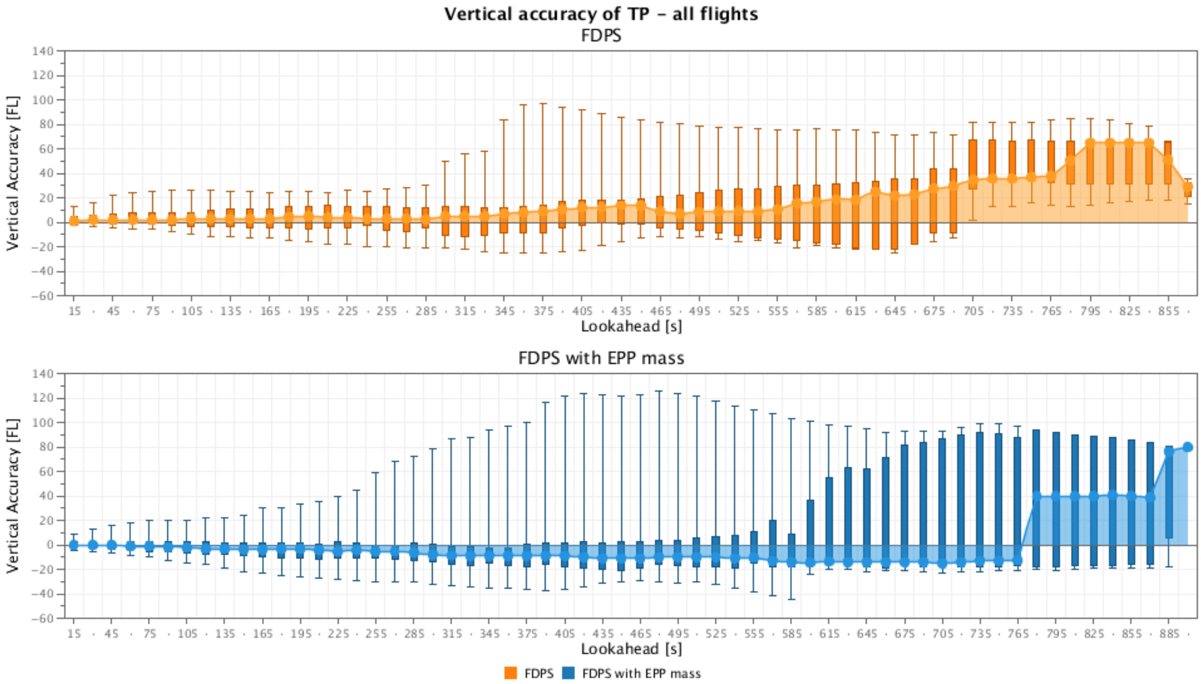


Figure 114 Percentile approach results (all flights)

This graph shows that:

- The vertical accuracy is globally reduced when the look ahead increases, which is as expected.
- The vertical accuracy median is similar in absolute value for the initial trajectory prediction and the one using the EPP mass injection.
- The vertical accuracy absolute value is different for the initial trajectory prediction and the one using the EPP mass injection: the trajectory prediction using the EPP mass injection has a tendency to be below the trajectory flown by the aircraft, while the initial trajectory prediction has a tendency to be above. This is mostly caused by underestimated initial mass predictions from FDPS.

6.4.7.3.3.5.2.2 Vertical accuracy per flight:

The following graph represents the vertical accuracy per flight for all look-ahead combined:

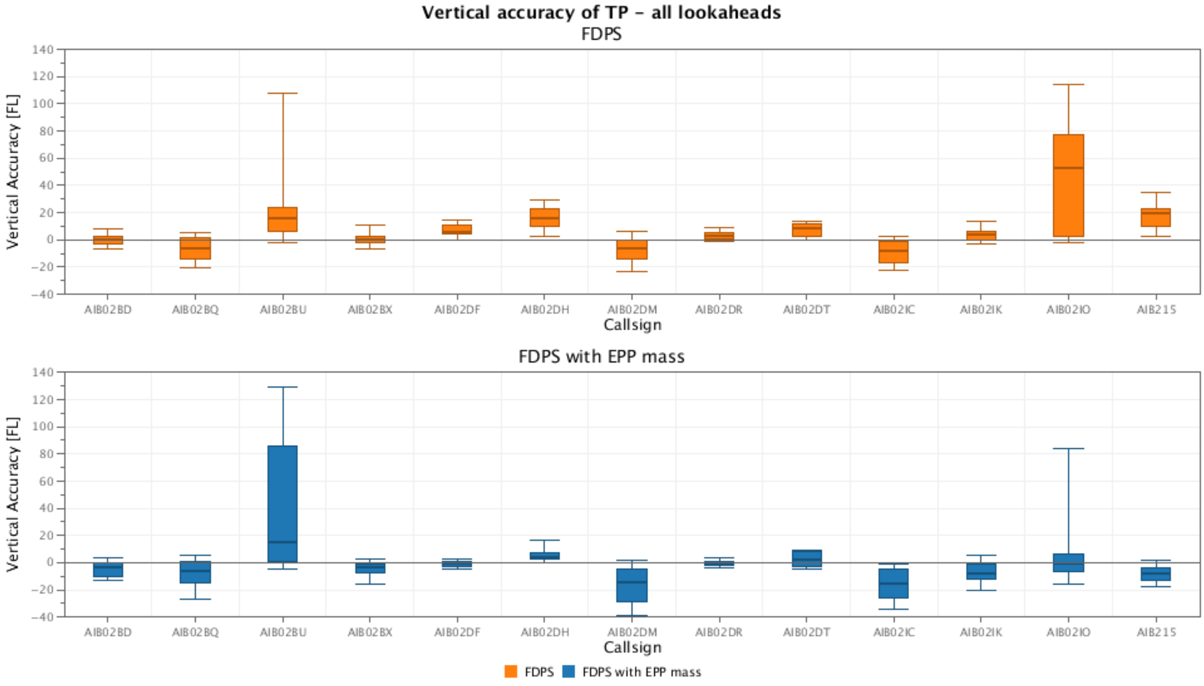


Figure 115 Percentile approach results (all look ahead)

This graph shows that the injection of the EPP mass in the ground trajectory prediction is sometimes beneficial, but not always.

When considering the median vertical accuracy, only 8 flights out of 14 show better results using the EPP mass injection (AIB02BQ, AIB02BU, AIB02DF, AIB02DH, AIB02DR, AIB02DT, AIB02IO, AIB215).

For one of these 8 flights, the median is improved, but there is also more variance, so the overall improvement is not that obvious (AIB02BU AIB02BU is the flight with unusual intermediate descent phase – refer to Figure 112).

The same type of graph was issued, limiting the look-ahead range at 10 minutes to perform a short-term improvement assessment:

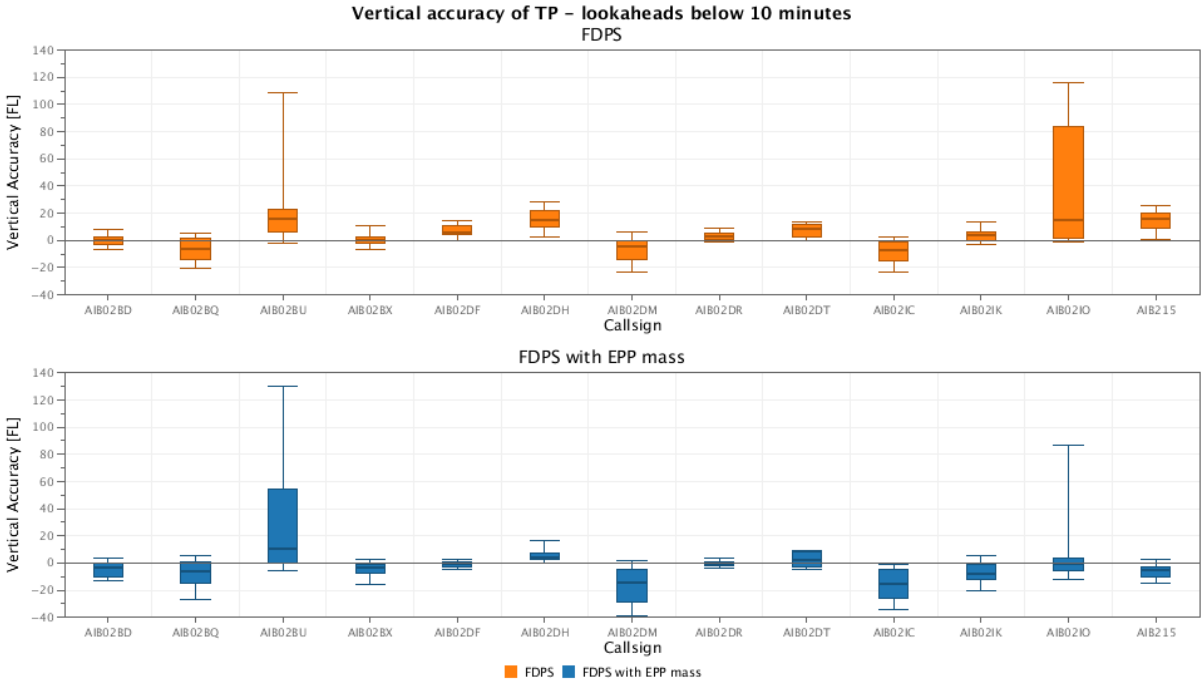


Figure 116 Percentile approach results (Look ahead up to 10 minutes combined)

We can observe that the results do not depend on the look-ahead range:

- The median vertical accuracy is very similar than for all look ahead combined.
- The variance is slightly reduced but not significantly, apart for AIB02BU (which had a very important variance to begin with, due to intermediate unexpected descent phase – refer to Figure 112).

6.4.7.3.3.5.2.3 Vertical accuracy for all flights, all look ahead:

The following graph represents the vertical accuracy for all flights and look ahead combined:

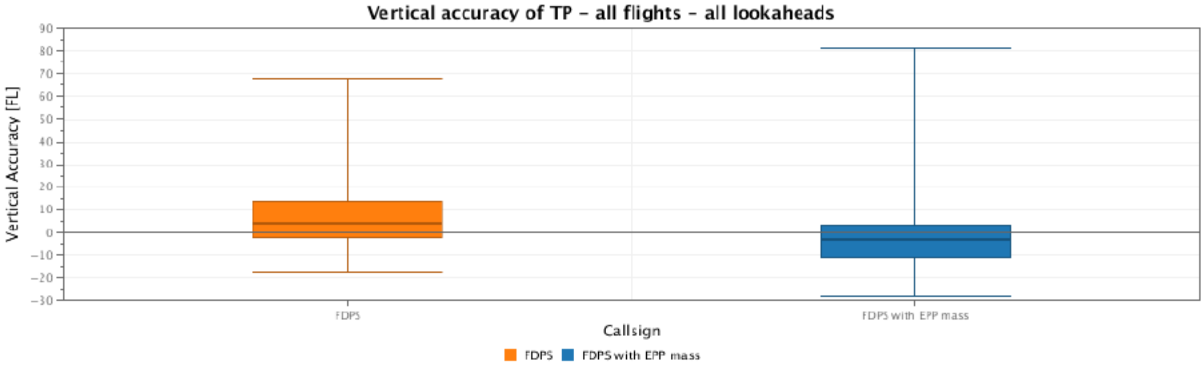


Figure 117 Percentile approach results (all flights, all look ahead)

The result echoes the observations for all flights, with different look ahead: the gain of using the EPP mass is not obvious:

- The absolute vertical accuracy is similar
- The impact is more on the relative value:

  The trajectory prediction using the EPP mass injection has a tendency to be below the trajectory flown by the aircraft, while the initial trajectory prediction has a tendency to be above.

6.4.7.3.3.5.2.4 Vertical accuracy depending on the route:

Because no clear tendency emerges from the analysis above, the analysis team thought it could be interesting to sort the results depending on the route flown by the aircraft. As a reminder, three main routes have been used by PEGASE flights: East, West and Central. For each type of route, a similar 2D path was flown by the successive aircrafts, as mentioned in section 6.4.7.3.3.3

The following tables show the vertical accuracy for the initial trajectory prediction and for the one using the EPP mass injection. Each table correspond to a specific route type.

Note: in the tables below, all flights departed from EDHI with destination LFBO. The only exception is AIB215, departing EDHI with destination EGNR.

Callsign	**AIB02BU**	**AIB02DM**	**AIB02IO**	**AIB215 (ADES=EGNR)**
Vertical accuracy of the initial TP (Median Delta FL)	16	-6	53	19
Vertical accuracy of the TP with EPP mass injection (Median Delta FL)	15	-15	-1	-8

Vertical accuracy gain of the EPP mass injection (FL)	1	-9	13	11

Table 41: Vertical accuracy for the flights flying the western route

For the western route flight, the vertical accuracy is significantly increased, apart for one flight.

Callsign	AIB02BQ	AIB02DF	AIB02DH	AIB02DR	AIB02DT
Vertical accuracy of the initial TP (Median Delta FL)	-6	6	16	3	8
Vertical accuracy of the TP with EPP mass injection (Median Delta FL)	-6.5	-1	4	-1	2
Vertical accuracy gain of the EPP mass injection (FL)	-0.5	5	12	2	6

Table 42: Vertical accuracy for the flights flying the central route

For the western route flight, the vertical accuracy is increased, apart for one flight for which it is slightly degraded.

Callsign	AIB02BD	AIB02BX	AIB02IC	AIB02IK
Vertical accuracy of the initial TP (Median Delta FL)	0	0	-8	4
Vertical accuracy of the TP with EPP mass injection (Median Delta FL)	-4	-4	-16	-8.5
Vertical accuracy gain of the EPP mass injection (FL)	-4	-4	-8	-4.5

Table 43: Vertical accuracy for the flights flying the eastern route

For the western route flight, the vertical accuracy is degraded for all flights.

This study indicates that the route structure flown by the aircraft has an influence on the gain brought by the EPP mass injection in the ground trajectory prediction.

This conclusion should be taken from a distance since there is only a small amount of sample available to confirm a clear pattern. Also, the problem detected with the wind processing in MUAC system could have an influence on this study (refer to section 6.4.7.3.3.4.3.3)

6.4.7.3.3.6 Maastricht's overall conclusion

Although we learnt a lot it has become clear that with the limited number of flights and the limited "mass oriented" analyses done up till now, it is too early to draw any firm conclusion. Further work is justified on the mass investigation and studies need to be performed to integrate more ADS-C information such as the speed profiles and ToC/ToD, using live flights, using temperature data...

Maastricht persists in their belief that from a Maastricht UAC perspective that the availability of the consistency check is already largely justifying an implementation in the MUAC OPS Room, bringing safety benefits in the lateral path in a similar fashion to the vertical check provided by Mode S Enhanced Surveillance Selected Altitude.

Note: the previous topic was not studied specifically in the frame of PEGASE but is a conclusion from the i4D studies performed in the frame of SESAR and concluded by the Step C with the exercises VP-472 & VP-463 refer to [3].

Maastricht expects to continue in SESAR2020 PJ31 with the "remaining" ferry flights and in particular with the revenue flights as expected as from mid-2018.

6.4.7.3.3.7 Maastricht's recommendations

The following recommendations were derived from the MUAC conclusions and analysis process during this exercise:

- More studies about the wind data influence on the trajectory predictions should be performed.
- Investigations should be performed on the reason causing MUAC trajectory prediction to underestimate the aircraft mass, while the PEGASE aircraft mass are supposed to be low already.
- Propose to enhance INDRA's MAGERIT tool with automated inclusion of controller inputs, weather data and the possibility to run fast time simulations to increase the accuracy and efficiency of the analysis process.
- The Ground trajectory prediction contains internal system constraints to derive the controller sequence even if not actually adhered to in the execution of the flight. This highlights the importance of synchronising the intended profile between air and ground to build the future path using the same vertical, lateral and for the future longitudinal expectations
- PEGASE investigations are constrained by the limited number of flights available to be analysed, for the future:
  - more flights are needed
  - more diverse flight plans, including more arrival flights
  - flights which behave more as a standard passenger flight (less "test" flights)
  - better insight in aircraft parameters on flights, to also look for more differentiation, e.g. cost index

6.4.7.3.4 Thales analysis on EPP vs TP ETO accuracy time horizon

From the FDR data provided by Airbus, Thales have been in a position to:

- retrieve the complete 3D trajectory flown by the aircraft,
- infer ATC clearances (mainly CFL and DIRTO) that impacted the profile and the flown route.

Along with the relevant GRIB forecast (wind and temperature), this data has been used to stimulate an operational Thales TopSky-ATC Trajectory Prediction (TP), on a single virtual FIR covering the full "PEGASE airspace".

ATCOs have performed real-time simulation sessions with flight plans, surveillance tracks, met forecast and ATC clearances that were as close as possible to the real PEGASE flights conditions.

Predictions computed by the ground TP have then been compared against the EPPs that were originally received for the flights, for those periods of time during which EPPs were actually sent by the aircraft, in order to get comparable data.

The comparison has been focused on the evolution of the precision and stability of the predicted ETO on overflown route waypoints (measured by time difference between ATO and ETO along Y-axis) according to the time horizon (Time To Go along X-axis) to these waypoints.

Even when they were overflown, waypoints located within the STAR (except the first one which is the last route point – typically NARAK for most of the PEGASE flights) and approach procedures have been discarded because of the outstanding ATO-ETO differences retrieved from the EPP on these points when the procedure is loaded in the FMS.

A set of 17 PEGASE flights has been selected for simulation because required simulation data was fully retrieved so far: AIB02BU, AIB02DF, AIB04IH, AIB02DR on 29/01/2016, AIB02DT, AIB02BO, AIB02BD on 16/02/2016, AIB03DX, AIB02IA, AIB02IE on 25/02/2016, AIB03IR, AIB02BQ, AIB02BX, AIB02DH on 18/03/2016, AIB02IC, AIB02IO and AIB02BY. The 3 main used routes (East, Centre and West) were thus addressed.

The first synthesis obtained is reflected in the figure below:

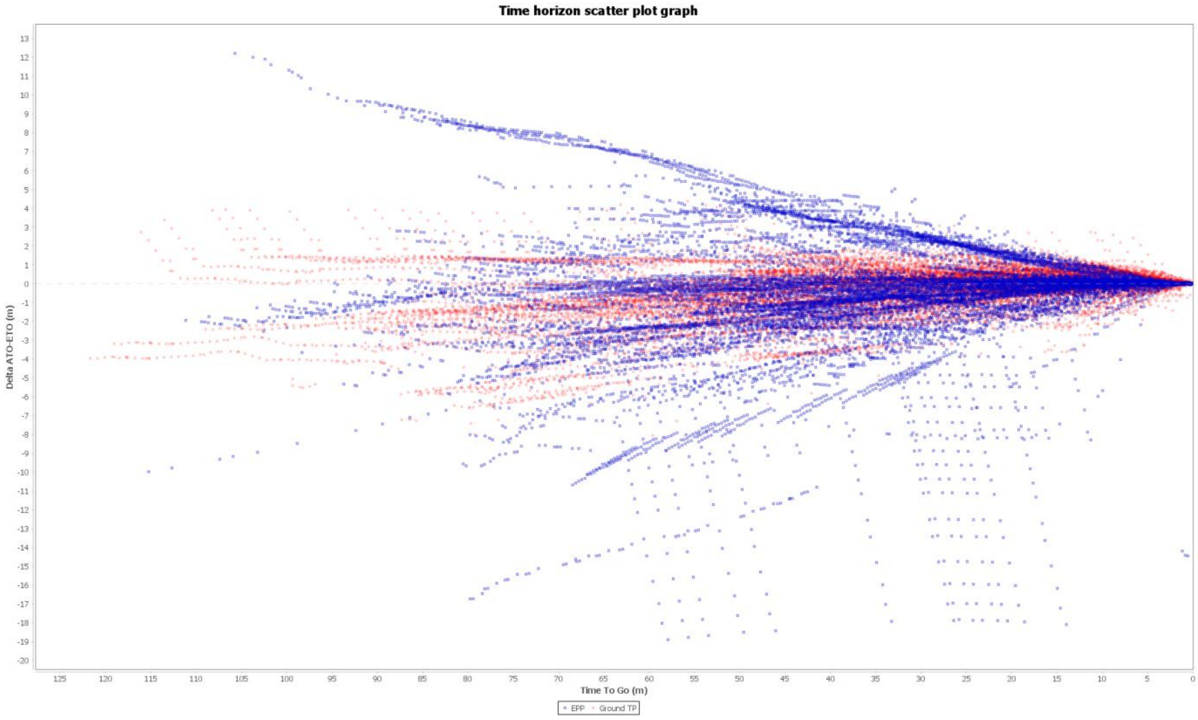


Figure 118 : EPP vs. TP ETOs when flying in any mode

Given the wide dispersion of EPP points, it was necessary to keep only the EPP points when the ADS-C report state a full-managed mode for lateral, speed and vertical modes.

This excluded 7 simulated flights from the analysis:

- AIB02DT, AIB02DR on 29/01/2016, AIB02IA, AIB03IR and AIB02DH on 18/03/2016 for which none of the EPPs indicates a full-managed mode
- AIB03DX and AIB02BQ for which some EPPs indicated a full-managed mode but none of them includes an overflown waypoint.

When showing only the EPPs that were in full-managed mode, the time horizon synthesis obtained is reflected on the figure below:

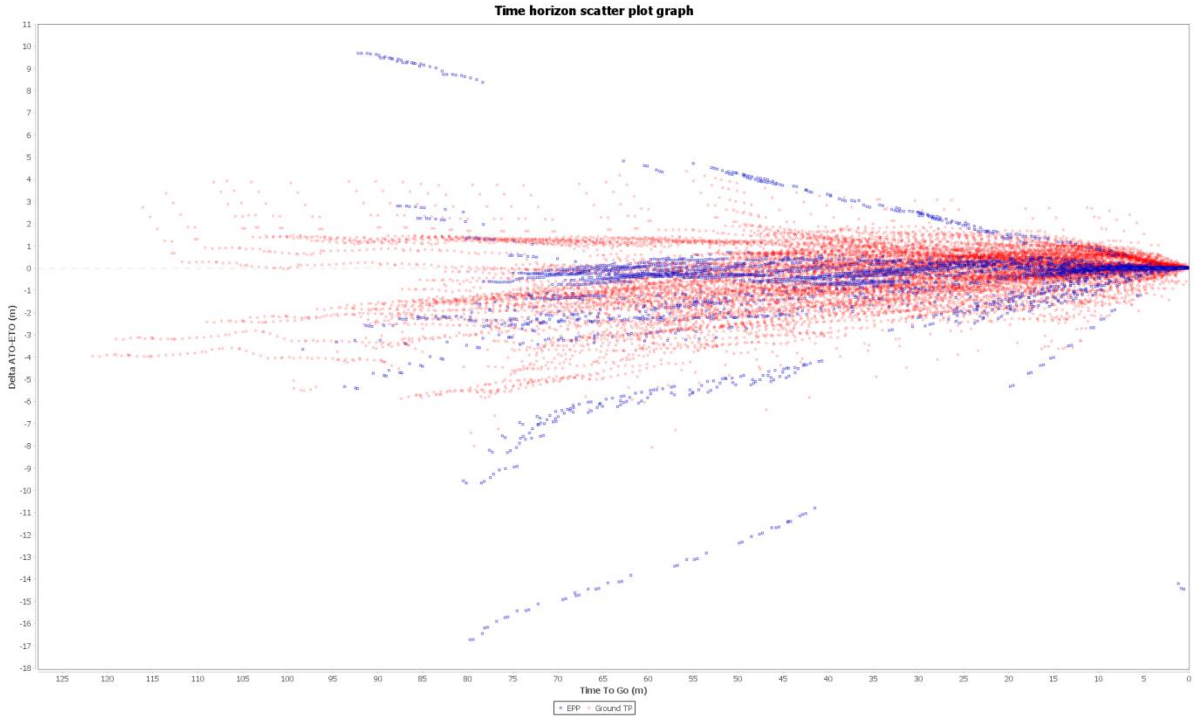


Figure 119: EPP vs. TP ETOs when flying in full-managed mode

The graph shows that:

- At more than 20 minutes from the waypoints, the EPP (blue squares) has more dispersion than the ground TP (red bullets). This should require a complementary analysis on the exact cause because there is no obvious reason to get such a difference. It is currently suspected that met forecast was not loaded on board for some of the PEGASE flights.
- Between 20 and 10 minutes from the waypoints, the EPP and ground TP roughly get an equivalent dispersion for ATO-ETO delta (≈ ± 2 minutes).
- At less than 10 minutes from the waypoints, the EPP is generally more accurate than the ground TP (except, as stated above, for the STAR and APP points that have been filtered out from the graph due to the ETO glitches they apparently have when the procedure is loaded on board). The graph shows an exception that should be analysed on NARAK for AIB02BU where the EPP has an ATO-ETO delta absolute value of more than 14 minutes when being at less than 1 minute from the point.

6.4.8 Exercise Recommendations and Potential Improvements for EPP contract

Data analysis is not yet finished. Depending of the time needed the results could be provided in an additional document.

Nevertheless the key items that could be used to proposed recommendation about contract definition are:

- At least one EPP should be sent while the A/C is on the ground as soon as the A/C is able to provide it
- Periodic contract, with limited set of data to check if contract and EPP are still "alive". The frequency has to be defined
- A route change with a deviation less than 5° up to 7 NM could have a limited impact (refer to Figure 120). Event trigger could be greater than these parameters. – This needs to be validated.

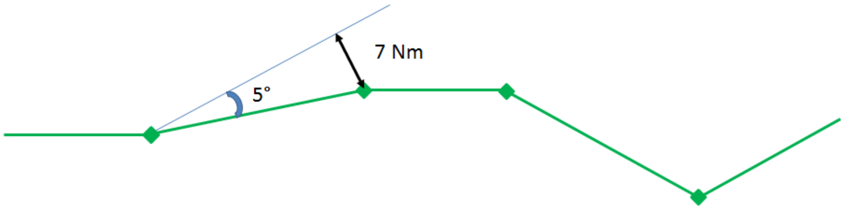


Figure 120 : Route change deviation proposal

6.4.8.1 OBJ-0106-003 Provide recommendation…

During the PEGASE demonstration, the content of the ADS-C contracts established from EUROCONTROL EEC facility were crafted to collect as much data as possible: e.g. for periodic contract, the shortest acceptable period was selected, or, for all contracts, the maximum number of waypoints were requested.

These contract definitions are obviously not operationally realistic. However, the aim was to have highest possible data flow so it could be analyzed to determine the real information flow (in term of report-to-report changes).

This study was planned during PEGASE but, unfortunately, could not be carried. So at this stage no new recommendation can be provided concerning contract definitions.

6.4.8.2 OBJ-0106-004 Operationally useful improvement

Operational benefits were demonstrated by the use of EPP data within ground systems.

The EPP enhanced TP will be evaluated against the current TP and its potential improvement The EPP data was used to compare operational tools used in the realistic scenarii to demonstrate the potential benefits expected.

6.4.8.2.1 Indra

The current operational concept relies on a planned trajectory prediction, for many functions, such as flow management tools, calculations and management of the sector crossing sequence, and obviously also MTCD and traffic sequencing tools (such as AMAN).

Nevertheless, and being the focus of this demonstration exercise, today's planned trajectories are not perfect. Their accuracy is limited by the lack of information about airspace user's preferences or meteorological data. This limited accuracy implies an uncertainty on future aircraft position which is obviously bigger for longer look-ahead horizons.

For conflict detection, the need is to manage this uncertainty which introduces nuisance alerts, which increases for longer look-ahead horizon, and for higher density/complexity traffic. In today's European highest density/complexity airspaces, MTCD tools (look-ahead horizon around 20 to 30 minutes) are not considered useful. This is different for lower density airspaces, where MTCD has proved useful even if nuisance alerts are still a limitation for full acceptability.

The uncertainty also limits the confidence of the planner controller on the mid-term predicted aircraft position. This way, during the planner controller task to de-conflict traffic, the planner controller follows conservative strategies, mainly based on negotiating entry/exit conditions and planned level within the sector. These strategies are constituting a human-oriented process to consider some margin around the mid-term prediction. While those strategies allow to (almost) completely de-conflict traffic in lower density/complexity airspaces, the high complexity/density of other airspaces makes impossible to design, in 30 minutes look-ahead horizon, a conflict free ground plan. The planner will make his best to reduce the number of conflicts, but some of them will need to be solved by executive controllers in shorter look-ahead horizon, where the uncertainty around predicted aircraft position (around 5 to 10 minutes) is lower and detailed solutions (with smaller uncertainty margins) can be implemented. Unfortunately, solving a conflict in tactical phase typically implies a change on the flight trajectory (usually with open-loop clearances) which invalidates the former mid-term plan (and so contributes to increase the mid-term uncertainty)

Additionally, and now focusing on flight efficiency, neither a conservative planner controller restriction nor a tactical action constitutes an optimal solution to a conflict, and so implies a negative impact on Airspace Users objectives.

In a future scenario, where the TP is enhanced with EPP data (among other new/improved data), the uncertainty on a 30 minute look-ahead horizon will be reduced. This should allow reducing the extra safety margins which are managed by the system tools (implying a reduction of the nuisance alerts) and should also increase the planner controller confidence in the prediction. Together with improved mid-term trajectory management tools and procedures, this should allow the planner controller to better de-conflict traffic by following strategies based on a more precise management of the flight trajectory within the sector in a mid-term horizon, minimizing:

- The deviation with respect to the previous plan needed to solve any conflict,
- The conflicts left for tactical management and
- The negative impact on Airspace User objectives

Last, but not least, it is very important to highlight that the objective is not to "copy" the EPP trajectory in the ground TP. Instead, the objective is to have accurate trajectories in ground for whatever flight intent. It must be noted that, even in a scenario where all stakeholders are able to align their view on the flight route and restrictions, the ground ATC tools will always need to compute alternative trajectories during conflict resolution processes. Several what-if trajectories would need to be tested in ground to decide which is the most appropriate one to solve any detected conflict or issue. Once the best solution has been selected, the RBT revision mechanisms would be used to communicate the change to the crew.

In order to ensure that those alternative (what-if) trajectories are also accurate, those trajectories should also take benefit from the ADS-C reports, including the EPP trajectory.

This way, in order to improve the ground TPs, it is necessary to extract (from the ADS-C / EPP) high level preferences that can be applied to whatever flight intent, such as the preferred speed schedule (which should be reasonably stable as long as there is not a big re-routing or cost-index change). Then, the ground TP would apply those preferences in its algorithm. Once the selected change is communicated to the crew and a new EPP is received, this EPP must be checked to confirm if the high level preferences for the manoeuvres are maintained (and obviously also to confirm if the crew properly understood (and coded in the FMS) the instruction, but this is out of the scope of this analysis).

So, when talking about how to improve ground predicted trajectories, it is very important to follow a strategy based on deducing high level stable preferences, even if detailed prediction on particular points coming from the EPP could also be useful as extra information, possibly to estimate the uncertainty of the current predictions or as a direct input for some ATCO tools in certain scenarios.

6.4.8.2.2 NATS

- **Analysis of EPP characteristics**

- The analysis from the PEGASE flight trials indicates that there can be situations where the EPP predicted trajectory does not accurately represent the aircraft behaviour, and therefore there will need to be integrity checks, and conformance checks applied before the EPP data may be incorporated into the ground-based trajectory management systems.

- There will also need to be improved processes to ensure that the flight-plan information loaded into aircraft and any data entered by the flight crew exactly matches the flight-plan/business trajectory information in ground systems. It will be necessary to ensure that the flight-plan information loaded into the aircraft precisely represents the planned profile of flight, including any changes to cruise level during the flight.

- The analysis has observed that there can be periods of time where aircraft EPP data may be unavailable or incomplete, and periods of time where the integrity and conformance checks will indicate that elements of the EPP data cannot be used. Ground based trajectory management functions will need to be designed to cater for these situations.
- Once these functions are in place ensuring greater consistency between the aircraft and ground systems, then the analysis from the PEGASE flight trials indicates that the downlinked EPP data has the potential to provide accurate information to enhance these ground system functions.

EPP Waypoint ETO data

A number of ATM processes require estimates of a flight's time of arrival over a given waypoint, to inform their planning. These processes cover a spectrum of look-ahead time, from the short term (tactical and planner controller tasks), through Arrival and Flow Management functions, to longer term processes such as demand and capacity balancing at a regional level.

The results of the waypoint ETO analysis indicate that accuracy improves with reducing prediction horizon, and these results show potential benefits of using EPP ETOs to support AMAN sequence building.

Further work is required to isolate factors that may influence the ETO performance which may enable further accuracy to be derived from the EPP ETOs. Addressing these factors may require some changes to flight-deck and ATC procedures, the impact of which will need to be investigated.

EPP top-of-descent

This initial study supports the conclusion that EPP-derived predictions of ToD location have the *potential* to support planner and tactical controller tasks. However, the current results set has a negative bias, and a wide spread of errors that would currently prevent use of the data in this manner. Current common operational practises lead to frequent manually-initiated early descents which induce these negative errors. It should be recognised that the EPP-reported ToD position is the *optimum* ToD point for the aircraft, which rarely corresponds to the ToD point flown, and should be treated as such.

EPP speed-schedule data

The results of the EPP speed-schedule accuracy measurements indicate that the speed-schedule parameters are accurate to within ± 2% compared with the observed IAS and Mach speeds flown by the aircraft, across all phases of flight. These results indicate that the speed-schedule parameters represent an accurate source of information to support ground based trajectory prediction.

The use of EPP speed-schedule data to improve the accuracy of IAS and Mach speeds and the IAS-Mach crossover level in TP will bring benefits to ATC operations. Controllers will have increased confidence in the controller tools; the improved accuracy of speed predictions will provide better support for streaming traffic, with the potential to reduce the number of ATC speed instructions that must be issued.

TP analysis of the use of EPP mass and speed-schedule

The results of the TP analysis have proved inconclusive. The TP vertical error measurements show a noticeable improvement through using EPP mass and speed-schedule parameters. This improvement is due to the more accurate mass data available from EPP.

However it was not possible to provide an assessment of the along-track TP error performance. It was found that there were too few measurements of flight in speed managed mode, so that it was not possible to provide valid along-track error results.

6.4.8.2.3 Skyguide

EFD vs EPP comparison shows that prediction can be improved by integrating EPP estimates on top of EFD estimates. Using EPP would improve the tactical traffic load predictions across the airspace and sectors.

Concerning the ground TP improvement, the analysis shows that it is difficult to assess improvement of the EPP for operational usage. The ground TP is precise enough on the en-route part. On the inbound part, it seems that EPP could improve the prediction but there was only 2 flights landing at Geneva so it is not possible to conclude on that part.

Another possible area of usage of the EPP would be having the capability to display the “EPP planned trajectory” specified from the EPP at the ATCO CWP on request. The ATCO would then be able to check that ATC instructions are correctly followed by the aircraft (DCT, CFL). ATC instructions are introduced in the ground system. It would be possible to raise an alert to the ATCO CWP few seconds later if the next received EPP shows that the last ATC instructions are not followed.

6.4.8.2.4 Thales

Given the known limitations of current SESAR prototypes, especially the uncertainty of FMS mode stated in the EPP, a definitive recommendation would require additional experimentations after having fixed the issues. Along with connectivity issues it was not possible to have a significant set of complete (gate-to-gate) samples.

However, PEGASE experimentation confirms the recommendations that were previously highlighted during i4D exercises previously performed in the context of SESAR program:

- Only use the EPP when the aircraft is in full lateral, vertical and speed managed mode, (assuming the status reflected in the EPP is corrected)
- Only use the EPP when there is a conformance between the lateral profiles of the EPP and the ground TP (consistent airborne and ground flight plans)
- Only use the EPP when the position accuracy reported in the figure of merit of the ADS report is at least 6 – this was actually the case of every EPPs received during PEGASE flights: values were either 6 (under 0.25 NM) or 7 (under 0.05 NM).

Additional analysis might be required regarding the EPP computation age to determine if a confidence threshold shall be applied.

In any case, even trusting the lateral, vertical and speed modes reflected in the EPPs, it appears that the number of ATC clearances received during PEGASE flights, especially on Center and East routes have significantly challenged the EPP. With non-Continuous Climb Operation and various DIRTO or vectoring instructions, there are significant periods of time when the aircraft needs to be in either lateral selected mode of vertical selected mode. The time some DIRTOs have taken to be reflected in the EPP should highlight a recommendation to the pilots to try to stay as much as possible in managed mode in order to maximise the usability of the EPPs on ground.

6.4.9 Results impacting regulation and standardisation initiatives

Regulation and standardisation were not included in the PEGASE project scope.

6.4.10 Unexpected Behaviours/Results

6.4.10.1 % of provider aborts: Number of flight affected by provider abort due to unknown issue

6.4.10.1.1 Provider Aborts

64% of the flights were (when a flight consisted of different legs they are aggregated hereafter) affected by provider aborts of any type.
Provider aborts can be caused by malfunction of the onboard systems or the ground systems or air-ground communication issues. They are a known issue in VDL2 environments and are being investigated in the context of ELSA project.
In the context of PEGASE, two main reasons codes coming with an ADS-Provider-Abort indication on the ground ADS-C Tool were observed:

1) Reason=timer-expiry: which only occurs when an ADS-C Contract is in the establishment phase; i.e. the received PA indication is as an 'answer ' to the ADS-Contract request resulting from ADS-C ATN local stack timers expiry. These

timers are ADS-C SARPs timers, t-EC-1(event request), t-PC-1(periodic request) set to 6 minutes raised when the ADS request is sent.
The PA in such a case reveals no answer from the aircraft, likely due to COM issues (also could be equipment switched off).

2) Reason=communications-service-failure: which can occur when an ADS-C Contract is in the establishment phase or in transfer phase.
-In transfer Phase typically reveals a COM issue or ATSU reset. The PA is notified after inactivity timer period at TP4 layer or exceeded retransmissions count at TP4, the inactivity period at TP4 layer is 6 minutes – be careful not the same as the ADS timers above explained.
-In establishment Phase, if there is a COM issue, we will have timer-expiry as the reason for the PA because ADS timers and TP4 inactivity timers are equal and ADS timers triggered first.
In the context of PEGASE communications-service-failure in establishment phase typically revealed that the ATSU was unable to answer positively to ADS-C connection requests (for example in case of a failed integrity check).. The ATSU answers to the TP4 connect request at TP4 layer with a TP4 Disconnect.
The answer from the aircraft in such a case comes very quickly.

Most of the provider aborts encountered were of reason/type "communications-service-failure": they affected 58% of the flights. 36% of the flights did not experience any provider aborts.

Figure 121shows the number of provider aborts per flight.

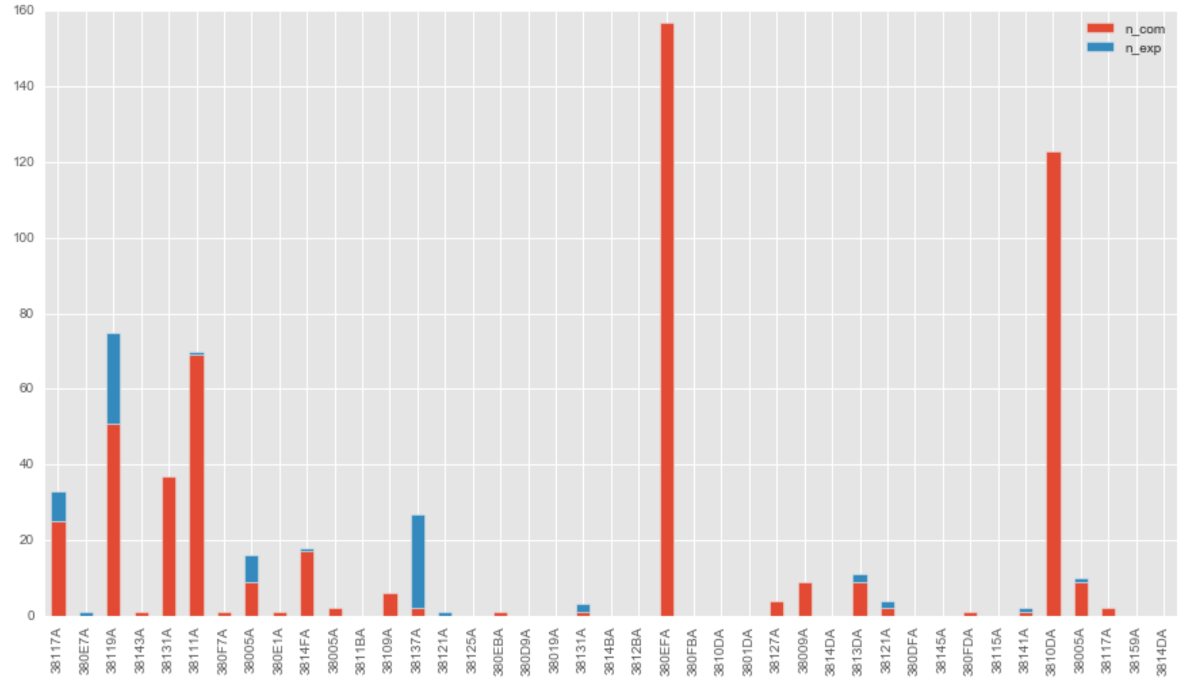


Figure 121: Provider Aborts per flight

The general statistics of the number of PAs per flight are reported in the following table. Note that the data for the flights consisting of several legs (AIB214 flights on the 30/11/2015 and 11/12/2015) are aggregated in the table. The 'Comms' line reports the PAs caused by 'communications-service-failure' PAs while the 'Timer' line reports the PAs caused by 'timer-expiry'.

	n	Mean	Std	Min	25%	50%	75%	Max
Total	41	15	34	0	0	1	10	157
Comms	41	13	33	0	0	1	9	157
Timer	41	2	5	0	0	0	1	25

It appears that the Provider Aborts caused by communications-service-failure, were much more frequent than PAs caused by the timer-expiry: in a ratio of about 5-to-1. The variability of the number of PAs is great with a few flights accounting for much of the variability (75% of the flights experiencing less than 10 PAs).
For the flights with a high number of PAs most of them are of reason "communication-service-failure" caused by an ATSU malfunction and could be solved in most of the case by a reset of the ATSU.

PAs statistics not considering the flights with a number of PAs greater than the 3 percentile are:

	n	Mean	Std	Min	25%	50%	75%	Max
Total	37	5	9	0	0	1	4	37
Comms	37	4	8	0	0	1	2	37
Timer	37	1	4	0	0	0	1	25

Here are the details of flights that experienced the highest numbers of PAs:

Date	Flight	# PAs	# Comms	# Timer	Details
04/03/2016	AIB02BQ	157	157	0	Connection lost
08/06/2016	AIB02DH	123	123	0	Connection lost
28/09/2015	AIB02DN	75	51	24	Connection lost
12/11/2015	AIB02DJ	70	69	1	Connection lost

The following flights have been affected by the highest number of PAs caused by 'timer-expiry'.

Date	Flight	# PAs	# Comms	# Timer	Details
15/01/2016	AIB04IH	27	2	25	timer-expiry
28/09/2015	AIB02DN	75	51	24	timer-expiry

6.4.10.1.2 ATN route changes and durations

In order to be able to establish End to End connectivity with the A/C at application layer (CM Logon/Contact, ADS-C contracts requests and ADS-C reports reception), ATN Air/Ground connectivity and ATN routing information (ATN routes or prefixes) to the aircraft have to be setup and maintained with Air/Ground communication service providers all along a flight.

During a flight ATN Air/Ground connectivity and ATN routes to the aircraft may unexpectedly become unavailable due to ATN communications issues. For each flight The ATN routing information transitions (ATN routes available or not available) have been captured at the EEC'.

ATN Air/Ground connectivity can be established either with SITA or ARINC Air/Ground communication service provider.

	n	Mean	Std	Min	25%	50%	75%	Max
# Routes	33	4	2	2	3	4	5	10
# Providers	33	1	0	1	1	1	1	2

94% of the 143 ATN routes used during the 33 PEGASE flights where this data is currently available were established through SITA. The average route "life" is 1 hour, 20 minutes and 19 seconds (01:20:19). The route life distribution is shown in Figure 122. The figure shows a quite high number of routes with a short up time between 44 sec (the minimum) and 10 minutes. The average is pushed to right by a few long route up times (when the equipment was kept switched on after landing). The median is located around 37 minutes which is consistent with the average flight duration and the average number of route per flight.

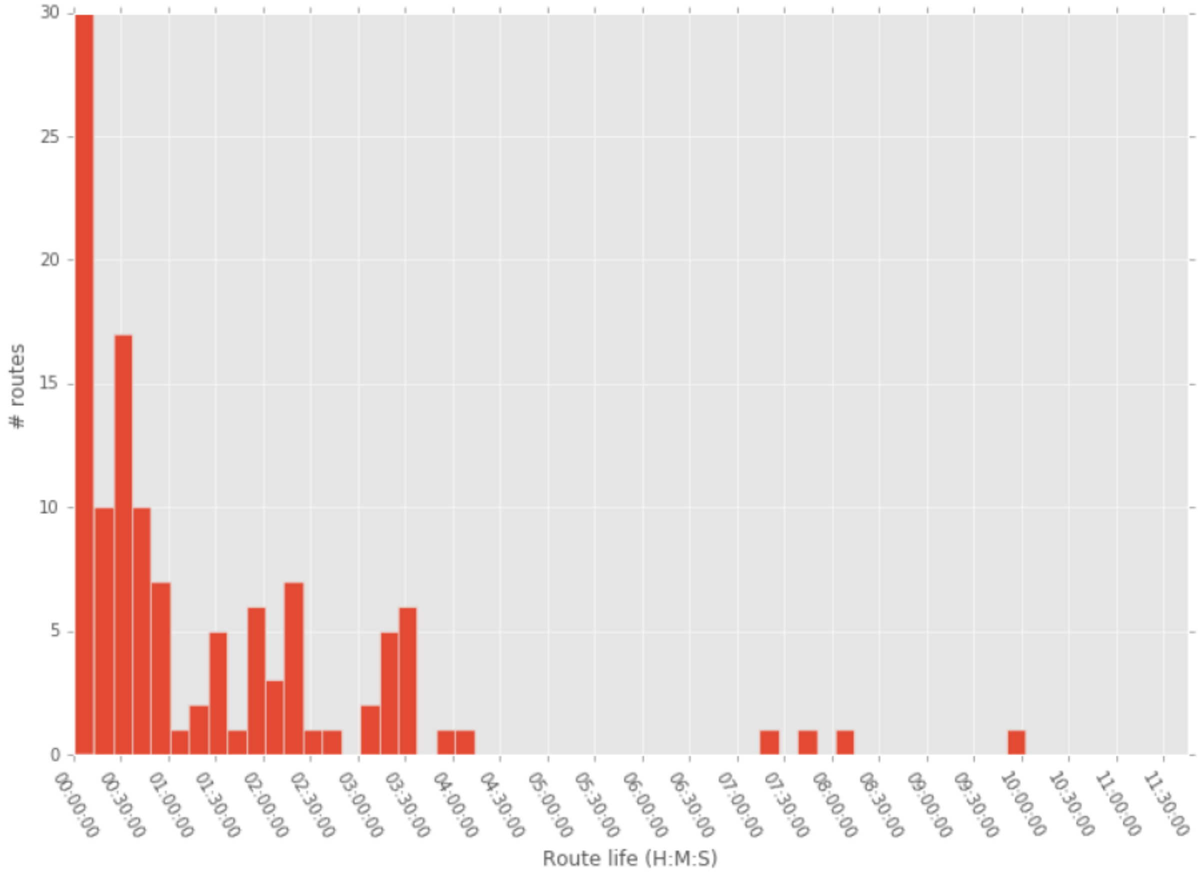


Figure 122: Route life distribution

6.4.10.1.3 Report transit times

When an ADS-C report has been computed by the ATSU, it is handed over to the ATN network layers for transmission. The time at which the report is sent is recorded in it while the report reception time is available from the datalink tools logs. The difference between these two times is the report transit time. For some flights and during some periods, significant increases in transit times have been observed.

At this stage, however, the cause of these high transit times has not been definitively identified. In general, they cannot be related only to ATN route transitions nor to a loss of communication.

As an example, the following figure displays the transit times observed during flight AIB04DU on the 04/04/2016:

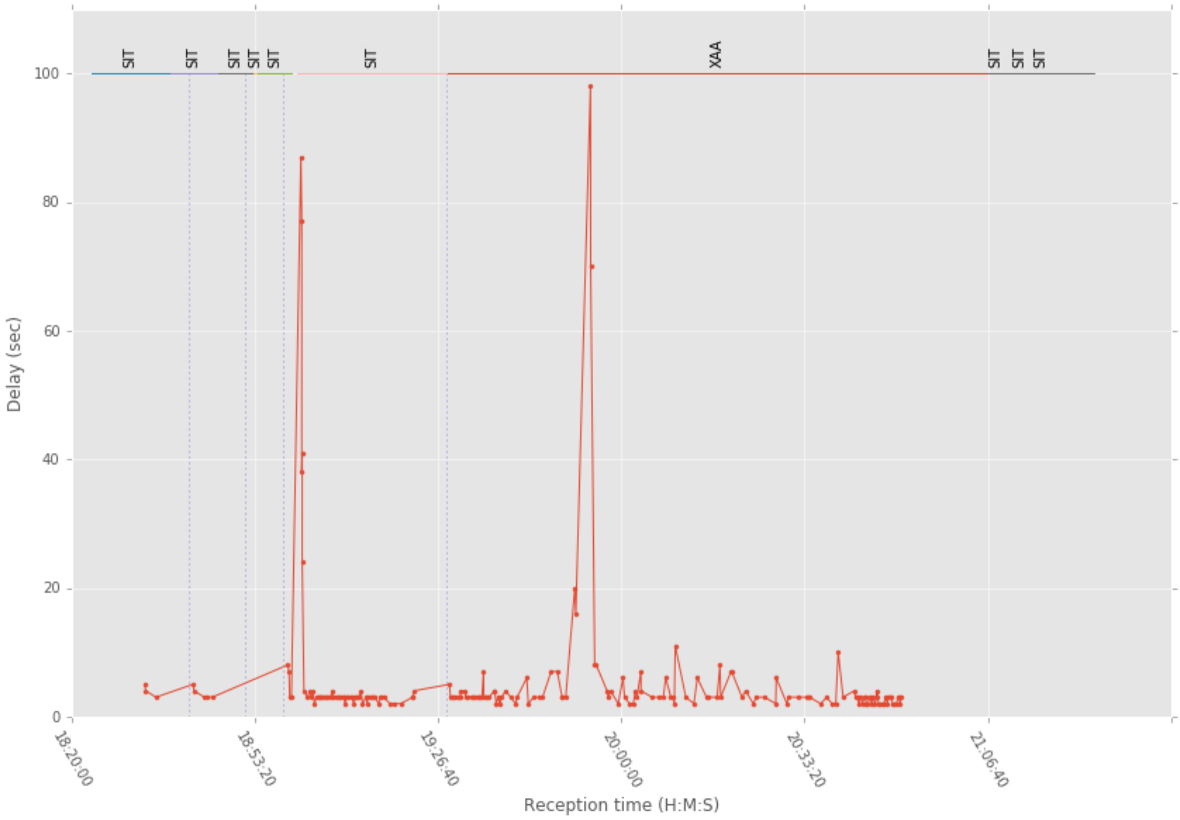


Figure 123: Transit times/delays for flight AIB04DU

The horizontal lines at the top of the figure indicate the route transitions: Each of the coloured lines represent an established route with the A/C. The name of the provider is displayed above the routes (SIT for SITA, XAA for ARINC). At the beginning if the flight, several routes were established with SITA. The dotted vertical lines represent the reception on the ground of a Provider Abort (communications-service-failure). These PAs may result from an ATSU reset (configuration or following the Flight Test Request). Just after this series of route transitions (around 19:15), high transit time are observed. The transit times stay low till a fourth provider abort. The ATN route was then established through ARINC for the rest of the flight while important transit times are nonetheless observed just before 20:00. This increase does not seem to be linked to a route transition nor resulted in a Provider Abort. After landing the network equipment was apparently kept on and re-established some routes with SITA.

The following table provides the basic statistics of the transit time (see also Figure 124).

	n	Mean	Std	Min	25%	50%	75%	Max
Xmit time	7712	9.00	25.61	0.00	2.00	3.00	4.00	376.00

Most of the transmission times are of the order of a few seconds (the 3rd quartile is 4 sec). However a few very high transit times (the maximum transit time is 376 seconds: more than 6 minutes) force artificial increases of both the average and the standard deviation.

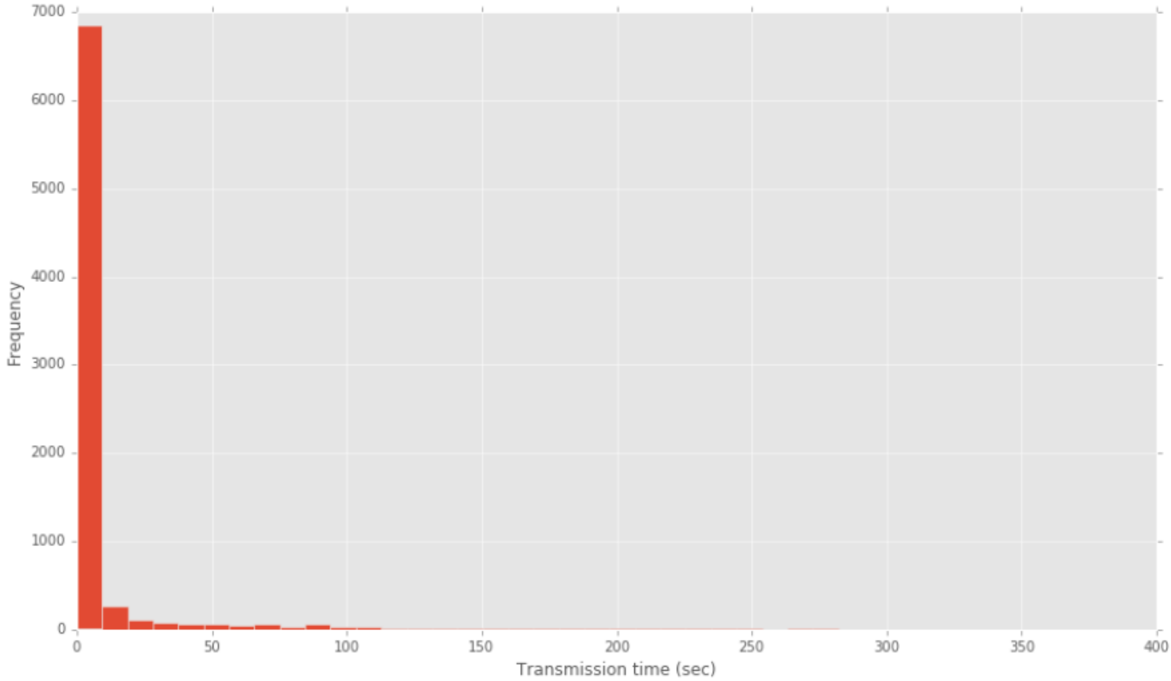


Figure 124: Transit time distribution

6.4.10.1.4 CPDLC round trip times

During flight AIB14 on the 10/06/2016, a CPDLC connection was established with the Aircraft to collect round trip times. The test consisted in sending from the ground CPDLC messages (in this case, UM1 Standby messages) with incorrect message references (0). These messages triggered immediate ATSU replies with DM62 (Error Unrecognized Msg Reference Number). No crew involvement was required.

The connection was maintained during 36 minutes and 66 exchanges (uplink message sent and downlinked reply received) could take place. The round trip times were computed as the difference (in seconds) between the time the uplink message was sent and the error reply was received.

The round trip time statistics are summarized in the following table:

	n	Mean	Std	Min	25%	50%	75%	Max
Round trip	66	3.14	4.88	1.00	1.00	2.00	2.00	30.00

For three quarter of the exchanges (3rd quartile/75%), the round trip times were less than two seconds. However, This is confirmed by the round trip time distribution show in the Figure 125: the majority of round trip times are below 5 seconds while a few outliers show round trip times up to 30 seconds.

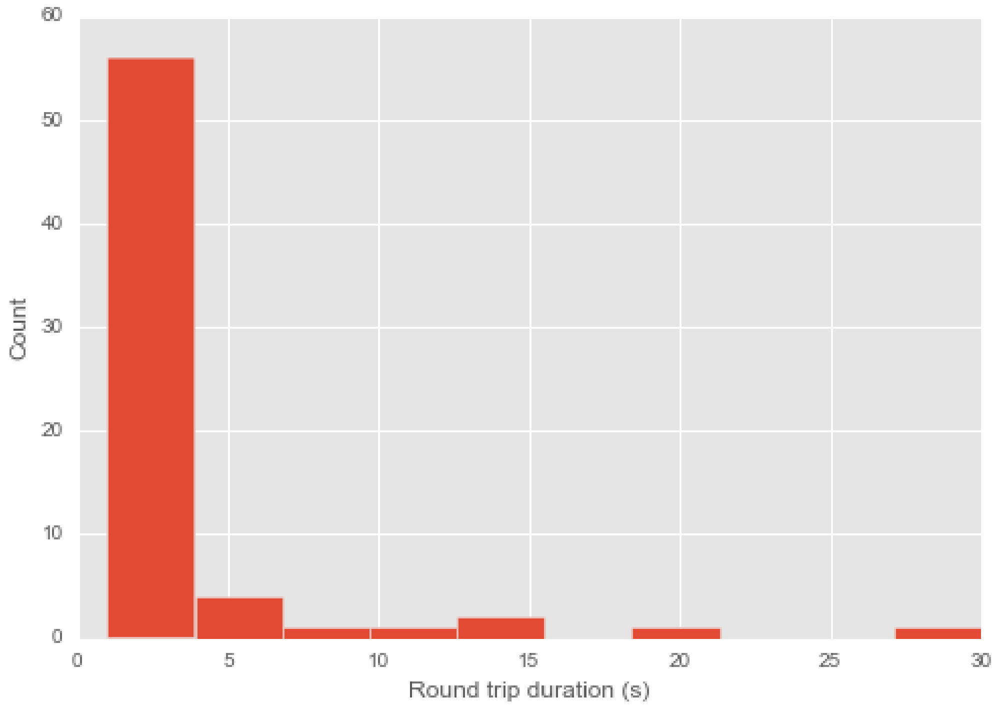


Figure 125: CPDLC round trip times distribution

Looking at the evolution of the round trip times during the flights (Figure 126) the high roundtrip times appear during the first half of the test period probably reflecting the characteristics of the communication infrastructure at that time (busy area, overloaded channel, …).

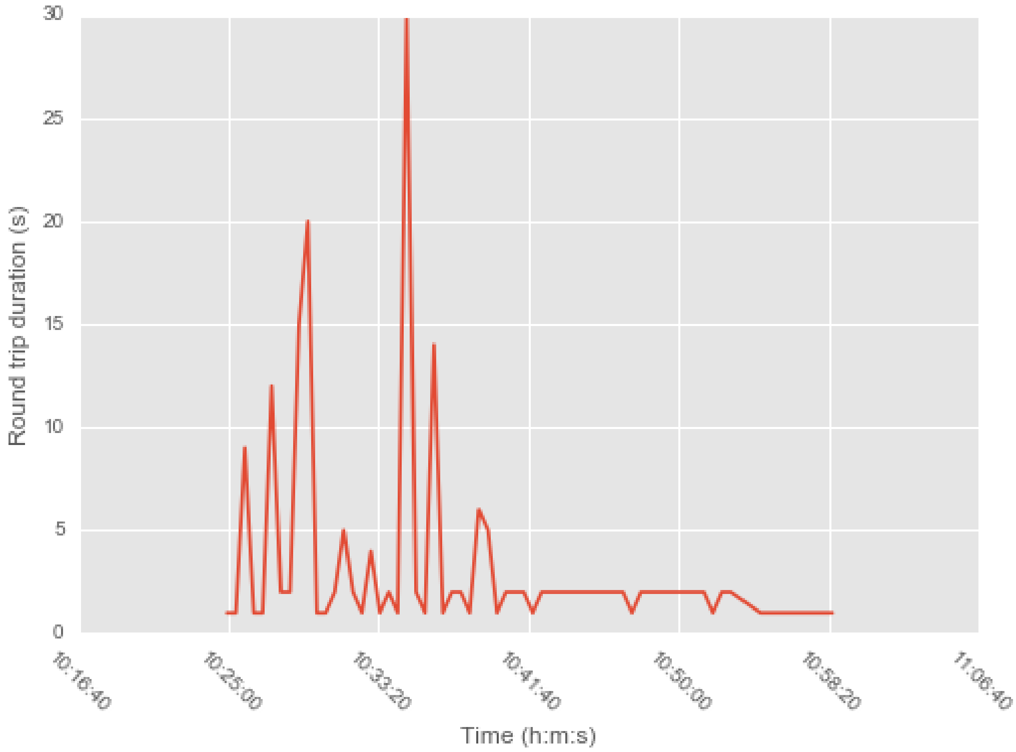


Figure 126: CPDLC Round trip times evolution

6.4.10.2 Identify & classify technical show-stoppers i.e. concurrent connexion, A/C position in HBG

Root causes analysis about flight not performed or performed without data recoded are:

- Flights not performed: 67 flights cancelled for logistic issues mainly because:
  - Equipment not ready
  - Equipment not send to Hamburg
  - 1 Equipment damage (FMS HWL / CFM) with reparation needed
  - 1 Equipment FMS failure (FMS HWL) with reparation needed

- Flights performed but no EPP data recorded: 6 flights with no EPP data recorded mainly because:
  - 1 flight due to Eurocontrol tool
  - 5 flights due to A/C not responding to EPP contracts (mainly provider abort).

To mitigate the risk on non A/C response a new procedure has been put in place. This new process was to perform an ATSU reset during the climb phase.

6.4.10.3 Intrinsic ADS-C characteristics: The FMS Operations/Assumptions (e.g. FMS modes, discontinuities…), Description of the "Anomalies Limitations" (e.g. no alt/t, 0 lat-lon…), Statistics about the respective frequencies

Problems to list and detail here

- Latitude/longitude anomaly
- ATSU freeze in case of concurrent connections
- ATSU reset after ICAO address configuration
- One FMS indicating vertical managed mode as engaged

6.4.10.3.1 EPP Specific characteristics

During the PEGASE flights, EPP with specific characteristics were observed. The following table describes these different characteristics:

Characteristic Identifier	Description	Explanation
noAltT	The points in the EPP do not have altitude and time attached to them	i4D explanation: There is no altitude nor time when the FMS is re-computing a 2D route after a significant route change (when the ATSU needs to send an EPP because of event or periodic and the data is not yet available to the ATSU).
frozen	The EPP is not updated and the prediction starts at the time earlier than the current time	
xshaped	The EPP 2D profile is crossing itself (see Figure 127).	This happens when the crew is updating the FMS Flight Plan. The FMS is aware of the “discontinuity” but this information is not conveyed in the reports (in Version H)
zero_ll	One or more points in the EPP have zero latitude and longitude.	
beforeTO	The EPP is computed before the A/C has taken-off. As the T/O is not known, the times attached to the EPP points are relative (T/O time = 0).	
empty	The EPP contains no point.	
Altitude discontinuity		

Figure 127: Example of "xshaped" EPP

The statistics regarding the number of EPPs affected by these specific characteristics for the PEGASE flights are the following:

	n	Mean	Std	Min	25%	50%	75%	Max
noAltT	46	3	6	0	0	0	2	36
frozen	46	18	18	0	9	12	19	83
xshaped	46	4	11	0	0	0	2	59
zero_ll	46	0	0	0	0	0	0	2
beforeTO	46	1	4	0	0	0	0	18
empty	46	3	2	0	0	4	5	7

The corresponding boxplot giving an indication of their respective distributions is given in Figure 128.

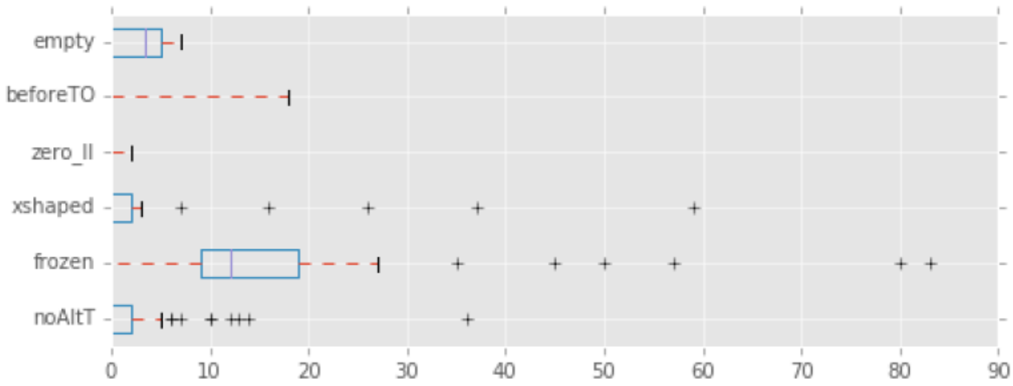


Figure 128: Boxplot of the EPP special characteristics

The following table gives the incidence of these different characteristics by indicating the number of PEGASE flights affected by at least one EPP showing the corresponding characteristic:

Characteristic	# flight affected	%
beforeTO	9	19.1
empty	33	70.2
frozen	43	91.5
noAltT	19	40.4
xshaped	20	42.6
zero ll	5	10.6

6.4.11 Quality of Demonstration Results

There are a number of aspects of the PEGASE project which affect the representativeness of the demonstration results.

- All the analysis has been carried out for only a single aircraft type; the Airbus A320
- The analysis covers FMS systems from two manufacturers; Thales and Honeywell. The FMS and ATSU systems used for the project are prototype implementations with some known anomalies.
- The analysis covers only a few different airspace routes, and only a few airports.
- The flights involved were ferry-flights rather than commercial airline flights and there may be differences in the way that the aircraft were flown, and the range of aircraft masses covered.
- The data-collection for the project was not able to achieve full coverage for all of the flights. Full radar data coverage was not available, full meteorological data was not available, and not all ATC instructions were available, and this reduced the capability to analyse all the phases of flight.

6.4.12 Significance of Demonstration Results

The previous section of this report lists the factors which limit the quality of the demonstration results. These factors limit how representative the flight trials were and this in turn affects the statistical and operational significance of the analysis results.

However, the analysis carried out for the project has covered 42 live flight-trials and this represents a significant step forward from previous studies that involved much smaller number of flights, or simulated flights. The data that has been collected, and the analysis that has been conducted, provides a large bank of information that will support the future development of EPP capabilities.

6.5 Conclusions and recommendations

6.5.1 Conclusions

Refer to §8.1

6.5.2 Recommendations

Refer to § 8.2

From ADS-C operational usage, we should draw attention to the possible prioritisation of periodic reports transmission over event reports at ADS-C user level in case of an 'overflow on transmission queue' issue on board the aircraft.

7 Summary of the Communication Activities

As define in the PEGASE demonstration reports the communication activities that have been performed are:

- Participation and presentation of PEGASE project during the SESAR Demonstration Activities Workshop (28-29 October 2014, Toulouse):

  In addition an interview has been performed (video)

  Agenda in appendix D:

  SJUDemoWorkshopAgenda_FINAL.pdf

  PEGASE presentation

  PEGASE Pres part Final.pdf

- Participation and dedicated PEGASE stand during SESAR Showcase - A Conference & Exhibition of SESAR 1 Results (14 – 16 June 2016 Amsterdam).

  For this event a PEGASE poster has been presented with a video and flyers.

  Agenda:

  SESAR_showcase_agenda.pdf

  Note: A second version of this video is under study to add some results and partners testimonies;

- Internal and external communication have been done.

8 Next Steps

PEGASE project has been launched in the scope of SESAR 1 un order to perform flight trials with a more real environment based on Airbus flights and analysed by ANSP and ATM ground manufacturer.

Based on PEGASE elements, the next steps, in the scope of SESAR 2020, will be to increase the full representativeness of EPP usage.

The VLD (Very Large Demonstration) will now involve:

-In a first step call Wave 1 the ANSP in order to included EPP treatment in their ATM tools.

-In a second step call Wave 2 the airlines with A/C EPP equipped during revenue flights.

Then these 2 waves will open the door to deployment covered by the pilot common project "PCP AF6" (see figure below):

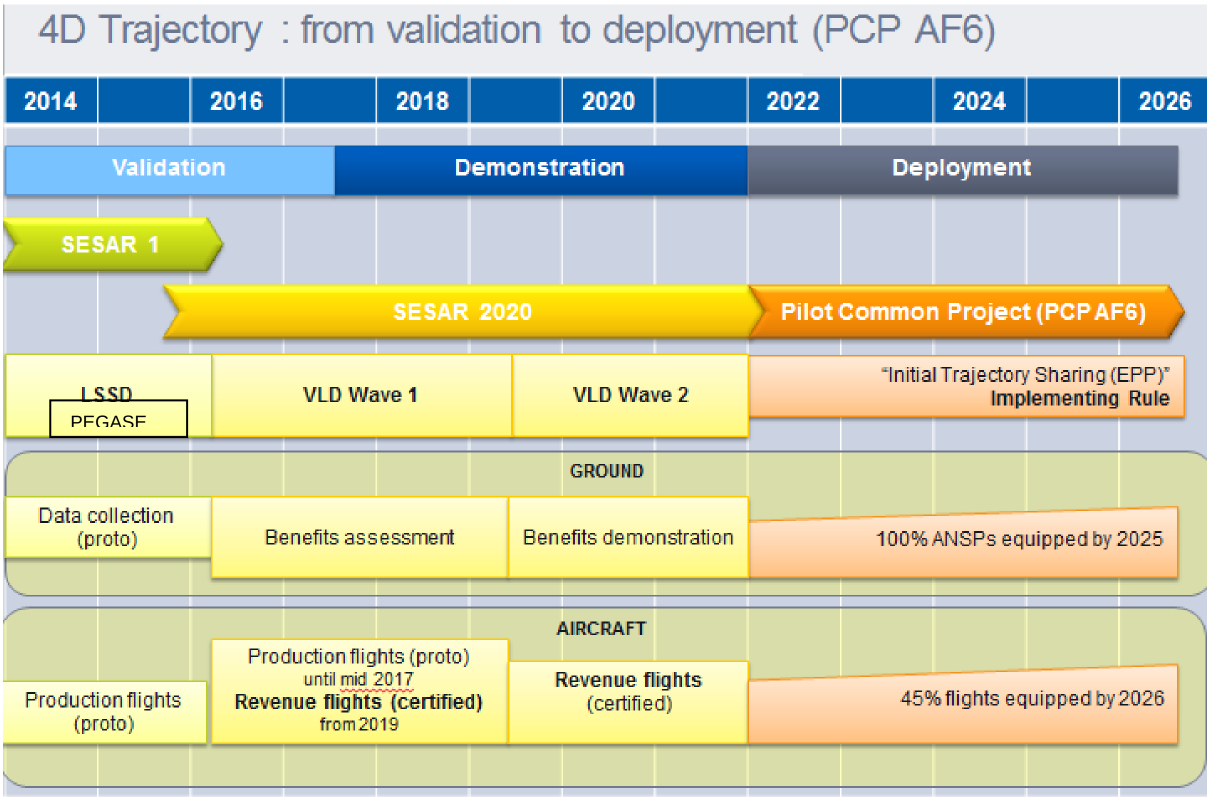


Figure 129: 4D trajectory from validation to deployment

Initial Trajectory Information Sharing (i4D), part of PCP AF6, consists of the improved use of target times and trajectory information, including the use of on-board 4D trajectory data by the ground ATC system, implying fewer tactical interventions and improved de-confliction situation.

PCP - AF6 includes part of the Step 1 Essential Operational Change for the "Moving from Airspace to 4D Trajectory Management" Key Feature as defined in the Master Plan (version 2012) as well as indirectly supporting other Key Features addressed by the other AFs through the use of shared trajectory information. In particular, it is expected that in a short to medium term horizon :

In the SESAR 2020 scope the activities covering the 4D trajectory will be PJ 01 and 10, PJ18 and PJ31 (see schema below).

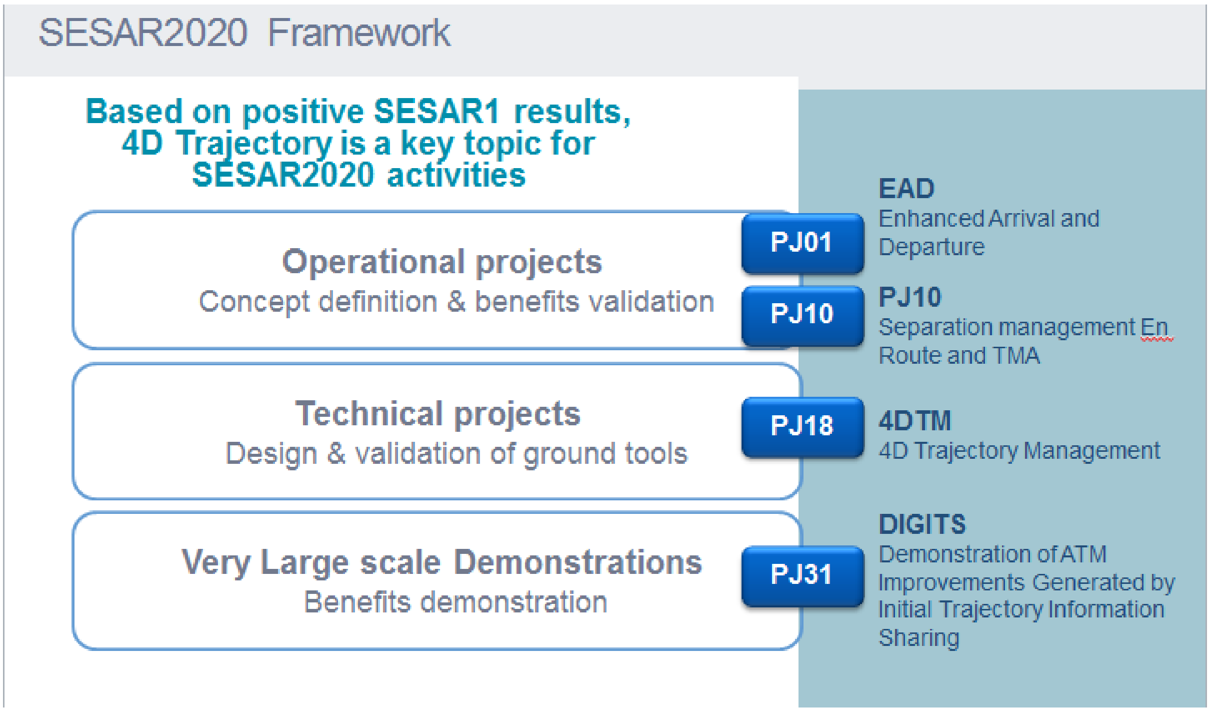


Figure 130: SESAR 2020 framework

The AF6 will be linked with:

- The down-linked aircraft trajectory may be used to enhance the AMAN functionality described in **AF1**
- Downlink trajectory information may be integrated into the Enhanced Short Term ATFCM Measures calculation and the Automated Support for Traffic Complexity Assessment as specified in **AF3**
- Downlink trajectory information may be integrated into the Network Operations Plan as specified in **AF4**

8.1 Conclusions

8.1.1 Data collection

Thanks to the 59 flights supported by radar, ADS-B, EFD, DFDR, controller inputs, weather data, pre-flight and post-flight reports, crew debrief (including DCT / vectoring) information. the data collection has been successful.

8.1.1.1 What has been done

Data collection requirements have been met.

The limitations of the prototype airborne equipment (see 4.2.1) have constrained the PEGASE work. For an unknown reason, the ATSU has had to be reset during climb to ensure reliable response to the ADS-C contract request. This problem has not been studied in the scope of PEGASE but worked around. The problem should be studied.

8.1.1.2 Operational Impact

Despite a few limitation mentioned above, the PEGASE data has been used and analysed, and will be available for additional research.

8.1.1.3 Potential Benefit

See paragraphs below

8.1.1.4 To do next

Check that in the latest standards for ATSU and VDL mode 2 transmission these issues have been solved (in particular multi-frequency benefit for VDL).

Communication coverage limitation has not allowed the PEGASE exercise to record data in all locations it planned (lower altitude, specific area). Communication coverage over most of Europe should be investigated.

PEGASE data analysis has benefited greatly from having DFDR, pre-flight and post-flight reports, crew debrief (including DCT / vectoring). Collection of such data is recommended in any similar, future exercise.

8.1.2 Data distribution

Data distribution requirements have been met.

8.1.2.1 What has been done

The ADS-C data is distributed on the ground as described earlier and is summarised in the image above, Figure 16

For 91.4% for the PEGASE flights, all the downlinked reports were successfully distributed on the ground through the Web Service Notification service.

For the remaining 8.6% of the flights (4 flights) not all downlinked reports could be distributed online.

The online distribution service was compliant with SWIM yellow profile.

8.1.2.2 Operational Impact

PEGASE data has been successfully and efficiently distributed online. This method can be re-used again.

8.1.2.3 Potential Benefit

Ground redistribution should save bandwidth and reduce A/C contract connections (that are limited to 5).

Ground redistribution allows a huge number of ground stations to receive ADS-C data from anyone A/C.

8.1.2.4 To do next

For simultaneous flights online distribution service should be able to handle more than one flight at the time.

The online distribution service should ensure the 24 bit address is present along with any ADS-C report.

8.1.3 EPP Contracts

8.1.3.1 What has been done

8.1.3.2 Operational Impact

The full benefit of EPP will come when most aircraft are able to provide them. The experience of the Mode S project showed that the 2 biggest aircraft companies were well equipped but other companies took years before providing an acceptable level of equipage. Methods to encourage equipage should be investigated.

8.1.3.3 Potential Benefit

See paragraphs below

8.1.3.4 To do next

PEGASE data analysis has benefited greatly from having DFDR, pre-flight and post-flight reports, crew debrief (including DCT / vectoring). Collection of such data is recommended in any similar, future exercise.

Periodic reports have a value as an indication that a connection remains. In this regard we can envisage that the ground system may rely on the periodic reports. In this case it is recommended that the priorities of periodic and event reports should be investigated.

In the PEGASE project, periodic reports have been collected at the fastest frequency possible. The effect of increasing the period could be investigating by selecting reports from existing logs.

The aim of recommending specific ADS-C contracts has not been met (Event contract has to be improved to reduce high rate of reporting). This should be addresses in any future projects, or by re-analysing PEGASE data.

8.1.4 EPP Accuracy

8.1.4.1 What has been done

This demonstration showed that the EPP prediction is reliable when:

1. The Aircraft FMS is in full Managed mode
2. The FMS flight plan is what will be flown. Synchronisation of Intent
3. The wind and temperature models entered in the FMS are updated with the latest current values and updated during the flight if they evolve significantly.

The EPP is a planned trajectory and it includes the known constraints, However it does not reflect the aircraft behaviour in response to tactical clearances and instructions issued from the ground.

The analysis described in this report presents the accuracy of the EPP prediction before a Way Point. It shows that the closer the aircraft is from the waypoint the more precise is the prediction. This evolution is globally continuous inducing that the ratio (delta prediction / time before Way point) is quite constant. The analysis shows that this ratio, called error percentage prediction, has an average value between 1 and 3 until one hour before the Waypoint. An error percentage below 3% is the indicator of an accurate prediction signal.

The demonstration also shows that the EPP predictions of a fixed point are really more precise that those of a movable point (pseudo WayPoint) due to the fact that the position of the movable point evolves during then flight.

For the analysed moveable points, it has been observed that the position predictions at the Way Point time were located in a range of ± 6 NM to the real Way Point although the uncertainty range without EPP was 110 NM (cf Figure 66 : Uncertainties position on fixed points).

This demonstration also showed that most of the time, the EPP are more precise than EFD.

For a small number of the trial flights, EFD predictions were better but EPP estimates were not so far from the real trajectory; however in these cases the fly intent was not synchronized between the air and the ground.

8.1.4.2 Operational Impact

Compared to the predictions provided by current ground TP, these EPP predictions are better for moveable points in particular the ToC, ToD.

So EPP-derived predicted top of descent position has the potential to usefully inform controllers of a flight's optimum ToD position. The value of this information to the controller is high in particular when the aim is to favour Continuous Descent Operations; a result already identified in earlier SESAR i4D exercises.

The use of EPP data to complement or improve the prediction made by the Network Manager and distributed in the EFD messages impacts ATC planning.

8.1.4.3 Potential Benefits

The ADS-C reports and the EPP contain valuable data that, when conveyed to the controller, would help him to take better and informed decisions.

In ATC planning, by using the EPP, the prediction available in the EFD message can be improved bringing potential benefits in tools such as extended horizon AMAN or DCB processes when the flight is still beyond the area of interest of the ANSP.

Complementing EFD data with EPP data could improve tactical load predictions tools especially when the intent information can be kept synchronized.

8.1.4.4 To do next

This demonstration confirmed that airborne prediction accuracy is highly dependent, on one hand, on the synchronisation of data (intent and meteo) between the air and the ground and, on the other hand, on the ability of the A/C to flight its trajectory in managed mode. As this is central to the SESAR concept and a pre-requisite for Trajectory-Based Operations, research should continue on the operational and technical means to achieve the best possible air-ground synchronization and to keep tactical interventions to the minimum.

Another interesting area of further research is to determine if and how the Network Manager could leverage the airborne information downlinked in the ADS-C reports to improve the planning trajectory shared on the ground using the EFD messages.

8.1.5 Ground Trajectory Prediction

8.1.5.1 What has been done

In order for the EPP to bring value to the ground trajectory prediction, the intended trajectory has to be shared (including with the FMS) and the flight should be in managed mode. In the PEGASE project, we can only conclude on TP improvement for those flights where this was true.

Twenty six flights have been observed with climbs that meet these conditions and in these cases the improvement of the ground TP for the climb by using the EPP is clear.

On the other hand, Descents during the PEGASE flights were mostly not in managed mode, and/or including manoeuvres still not modelled by ground TPs. The lack of comparable descent manoeuvres does not allow to confirm improvements, but some potential has been shown during equivalent (idle) manoeuvres.

With regards to cruise ground TP is currently considered acceptable. Uncertainty is mainly derived from wind models and unpredictable route changes (directs), and the EPP data does not provide information to minimize the uncertainty there.

8.1.5.2 Operational Impact

In High Density/Complexity environments, the currently existing uncertainty on climb & descent preferred manoeuvres forces the ATCOs to follow conservative procedures based on setting several climb & descent restrictions for all aircrafts. Those restrictions are designed to minimize the uncertainty, but also to facilitate conflict detection & resolution processes: typical crossing points between traffic flows are known and there are validated procedures to manage them.

When the traffic density/complexity decreases (such as during the night), it is considered feasible and safe to stop applying the restrictions, and to let the aircrafts to follow their business optimal profile. The uncertainty on the profile remains being the same, but any potential short-term detected conflict can then be managed with ad-hoc tactical clearances.

In a future environment the new ADS-C reports will minimize the uncertainty around the business optimal profile. This could enable to design new tools and procedures for high density/complexity situations in order to better assess the need to strictly apply or to relax the restrictions for each flight.

Nevertheless, this implies a change mainly in ATCO procedures that has not been validated yet in an R&D environment, and so was not considered during PEGASE flights. Instead, the focus was set on demonstrating the technical enabler.

8.1.5.3 Potential Benefit

The application of any of the currently existing operational restrictions imply less flexibility for the aircraft to follow its business-optimal profile.

Once the ADS-C reports enable a more accurate trajectory and the above described improvement in the ATCO operations, the relaxed application (or even the removal) of some of those restrictions for properly equipped aircrafts will enable them to fly a profile closer to their optimal one.

Nevertheless, as explained before, this still needs to be validated since PEGASE flights were controlled using today's tools & ATCO procedures.

8.1.5.4 To do next

The PEGASE demonstration was limited to one aircraft type. The good technical results should also be confirmed in a more varied exercise.

Additionally, further R&D activities are needed in order to define in detail new ATCO procedures taking full benefit of existing & future ATCO tools, allowing to validate the foreseen improvements in the operations and in the air navigation services.

8.1.6 EPP Standard

8.1.6.1 What has been done

The PEGASE project has been realised with the following standard:

- ATSU: preliminary version of ED229 : Draft I (February 2012)
- ADS-C B2: ED-228 Rev.A (March 2016)

8.1.6.2 Operational Impact

Not Applicable

8.1.6.3 Potential Benefit

Not Applicable

8.1.6.4 To do next

These prototypes, used during PEGASE project, have known limitations that for some of them are already corrected and are planned to be removed in the next production standard : ED229 Revision 1 (April 2016).

8.2 Recommendations

From the results and conclusions of this report, the following recommendations should be considered:

8.2.1 Data collection

R1) The full benefit of EPP will come when most aircraft are able to provide them. The experience of the Mode S project showed that the 2 biggest aircraft companies were well equipped but other companies took years before providing an acceptable level of equipage. It is recommended that methods to encourage aircraft EPP equipage should be investigated.

R2) Communication coverage limitation has not allowed the PEGASE exercise to record data in all locations it planned. It is recommended that communication coverage over most of Europe should be investigated.

R3) PEGASE data analysis has benefited greatly from having DFDR, pre-flight and post-flight reports, crew debrief (including DCT / vectoring). Collection of such data is recommended in any similar, future exercise.

R4) The absence of ATCo clearances recording didn't allow to efficiently analyse some aircraft behaviour and related EPP content. It is recommended to record every ATCo clearances during any similar future exercise.

8.2.2 Data distribution

R5) The ground distribution service should ensures the 24 bit address is present along with any ADS-C report.

R6) The ground redistribution of ADS-C reports seems to have saved bandwidth in the Air-Ground link. It is recommended that the benefit of this is quantified and that in future ground distribution is envisaged to the maximum extent.

8.2.3 EPP Contracts

R7) Some reports have been "omitted" at times, seemingly in the processes on board the aircraft. It is recommended that investigation of this phenomenon is carried out.

R8) Periodic reports have a value as an indication that a connection remains. In this regard we can envisage that the ground system may rely on the periodic reports. In this case it is recommended that the priorities of periodic and event reports should be investigated.

R9) In the PEGASE project, periodic reports have been collected at the fastest frequency possible. It is recommended that the effect of increasing the period be investigated by selecting reports from existing logs.

R10) There have been periods in which there have been very many Event reports resulting from certain crew behaviour. It is recommended that a method of reducing this need be investigated.

R11) During the PEGASE demonstration, the content of the ADS-C contracts established from EUROCONTROL EEC facility were crafted to collect as much data as possible: e.g. for periodic contract, the shortest acceptable period was selected, or, for all contracts, the maximum number of waypoints were requested.

These contract definitions are obviously not operationally realistic. However, the aim was to have highest possible data flow so it could be analyzed to determine the real information flow (in term of report-to-report changes).

This study was planned during PEGASE but, unfortunately, could not be carried. So at this stage no new recommendation can be provided concerning contract definitions.

It is thus recommended that the ADS-C reports collected during the PEGASE flights are further analyzed to determine not only the optimal content but also the right balance between the different contract types and the required frequency of the periodic reports.

8.2.4 EPP Accuracy

The main issue that decreases the value of the EPP as a 4D trajectory prediction that has been identified in this report is the difference between the intent (planning) that generates the Aircraft's prediction which is seen in the EPP, and the intent which eventually directs the aircraft to move. Hence the following recommendations mostly relate to intent sharing.

R12) It is recommended that an Investigation is made into the effect of providing anticipated vertical planning constraints to the flight-deck, e.g. step climbs, as these may improve the accuracy of EPP-derived predictions.

R13) Further investigation of the effect on EPP-derived predictions of approach-phase behaviours is recommended, e.g. ATC vectoring, and point-merge procedures.

R14) Further work is recommended to understand the impact of operational behaviours on EPP data, both on the flight-deck and in ATC. To achieve this, a flight campaign should be carried out including a number of operators (refer to §8).

R15) It is recommended that the data integrity-checking required to enable the use of EPP data in different ATM processes is investigated further.

8.2.5 Ground potential usage

Ground Trajectory Predictions are always needed to support ground based systems. All ground trajectories can benefit from EPP data, even when evaluating trajectories (what-if trajectories, etc) that follow a different plan from the one reflected by the EPP. Supporting this requires preferences to be extracted from the EPP, such as speed schedule that can be applied in other trajectory calculations.

Especially when modeling descents, Ground TP would benefit from being able to model different aircraft control laws and apply them appropriately. The EPP that meet the criteria mentioned in 8.1.2 can be used to confirm initial guesses of the preferred control laws.

The improved trajectory algorithms should be considered an enabler for a new operational procedure that still needs to be defined. This new procedure might rely on further technical enablers, such as new what-if tools managing the current business-optimal profile, and helping the ATCOs to assess which restrictions must be applied and which could be skipped.

R16) It is recommended that further technical analysis is carried out into the use of EPP data to enhance ground TP. This should include investigation into potential methods for modeling the different control laws that can be applied by aircraft.

R17) It is recommended that a demonstration analysis on a wider range of trajectories is conducted to further assess the benefits from the EPP, additionally the range of airlines and aircraft types should be enlarged, as should the number of equipped aircraft simultaneously in the area being studied.

R18) It is recommended that EPP is used to enhance EFD. There are two different ways to apply this recommendation:

1. This can be done by ANSPs who can aggregate the two sources in their tactical load predictions tool.

2. This can be done by EUROCONTROL who is providing EFD data to ANSPs. EFD are triggered by different event. EPP can be added as another event type.

R19) It is recommended to define and validate new operational procedures (specially for ATCOs), relying on the improved trajectory computation algorithms and also on new tools, focusing on facilitating Airspace Users optimal business profiles (when possible) in higher density/complexity environments.

R20) It is recommended that a CBA (Cost Benefits Analysis) should be carried out to support a decision about the usage of the EPP in the ground trajectory.

8.2.6 EPP standard

R21) To take into account the last correction, it is recommended for the next exercises to work with the new production standard : ED229 Revision 1 (April 2016). References

9 References

9.1 Applicable Documents

[1] EUROCONTROL ATM Lexicon
https://extranet.eurocontrol.int/http://atmlexicon.eurocontrol.int/en/index.php/SESAR

9.2 Reference Documents

The following documents provide input/guidance/further information/other:

[1] ATM Master Plan
https://www.atmmasterplan.eu

[2] Pegase demonstration plan: https://extranet.sesarju.eu -lssd-pegase (DO2):

SESAR Joint Undertaking Programme > Large Scale Demonstration > LSD.01.04 Pegase > Project Execution > D01 Demonstration plan

[3] 04.03-D64-i4D+CTA Validation Report- Step C, Edition 00.02.01, Dated 04/06/2014

[4] 05 06 01-D082-EXE-05 06 01-VP-478 Validation Report, Edition 00.01.01, Dated 26/09/2014

[5] P04.05 D820 EXE-04.05-VP-771 Validation report (4.5 deliverable) 01.00.00

[6] USER MANUAL FOR THE BASE OF AIRCRAFT DATA (BADA) REVISION 3.10: EEC Technical/Scientific Report No. 12/04/10-45

[7] EFD presentation:
https://www.eurocontrol.int/sites/default/files/article/content/documents/nm/network-operations/b-2-etfms-data-redistribution-20130116-koo.ppt

[8] EFD FAQ: https://www.eurocontrol.int/faqs/triggers-and-content-efd

[9] EUROCONTROL NM's ATFCM user Manual:
http://www.eurocontrol.int/sites/default/files/content/documents/nm/network-operations/HANDBOOK/atfcm-users-manual-current.pdf

[10] P05.05.02 D04 Final Project Report on the concept and benefits for improving TP using AOC data, Edition 00.01.03

[11] P05.06.04 D35 Consolidated OSED 02.00.00

[12] VLD.01.04 **PEGASE Demonstration Report** 01.00.00

Appendix A Detailed results per flight for MUAC percentile approach analysis

The following graphs show the detailed results of the percentile approach for each flight.

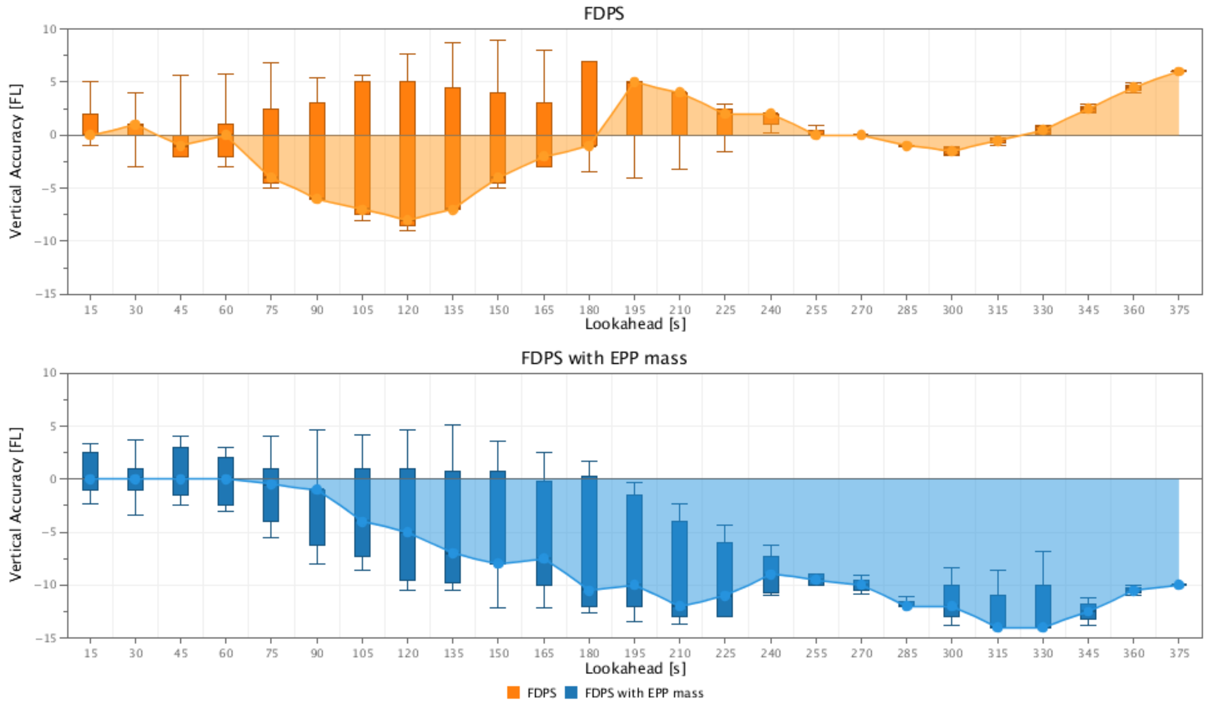


Figure 131 Percentile approach result– AIB02BD

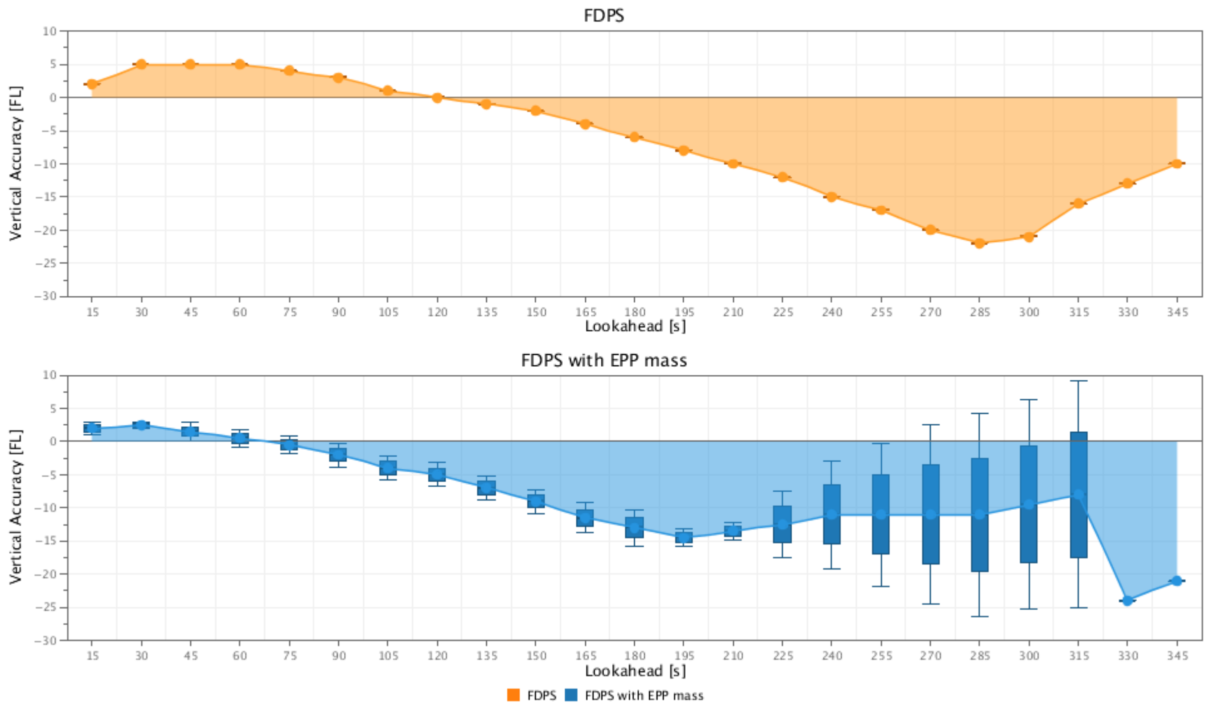


Figure 132 Percentile approach result– AIB02BQ

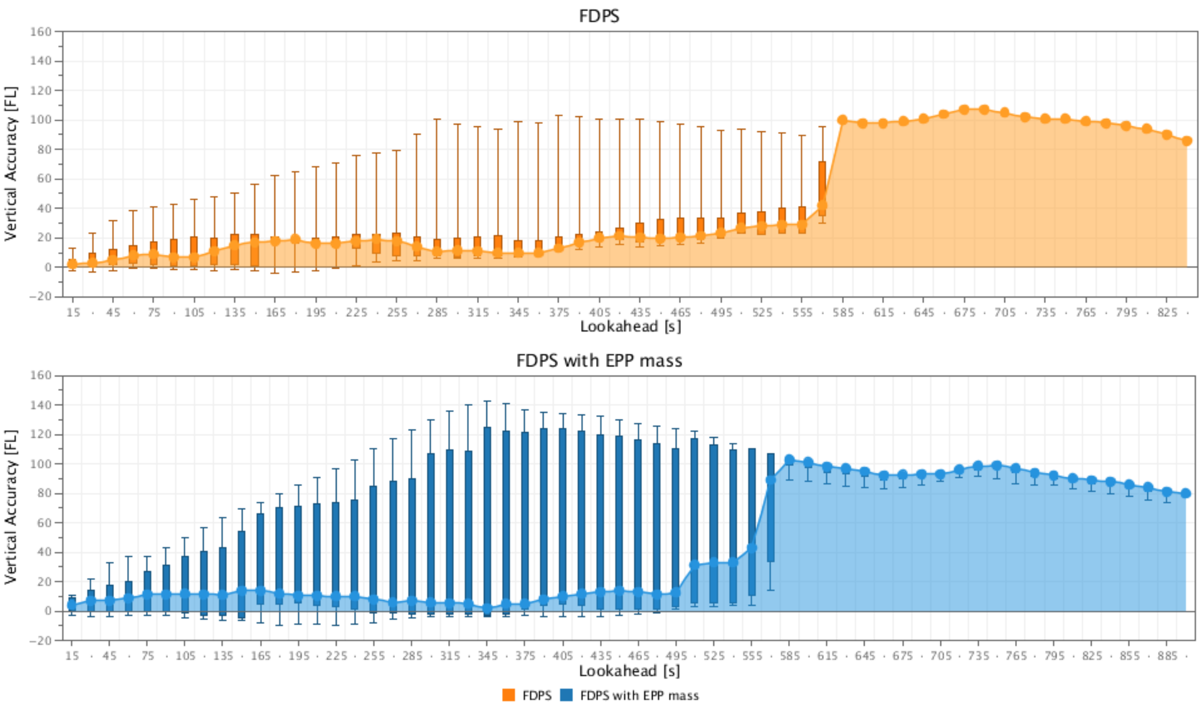


Figure 133 Percentile approach result– AIB02BU

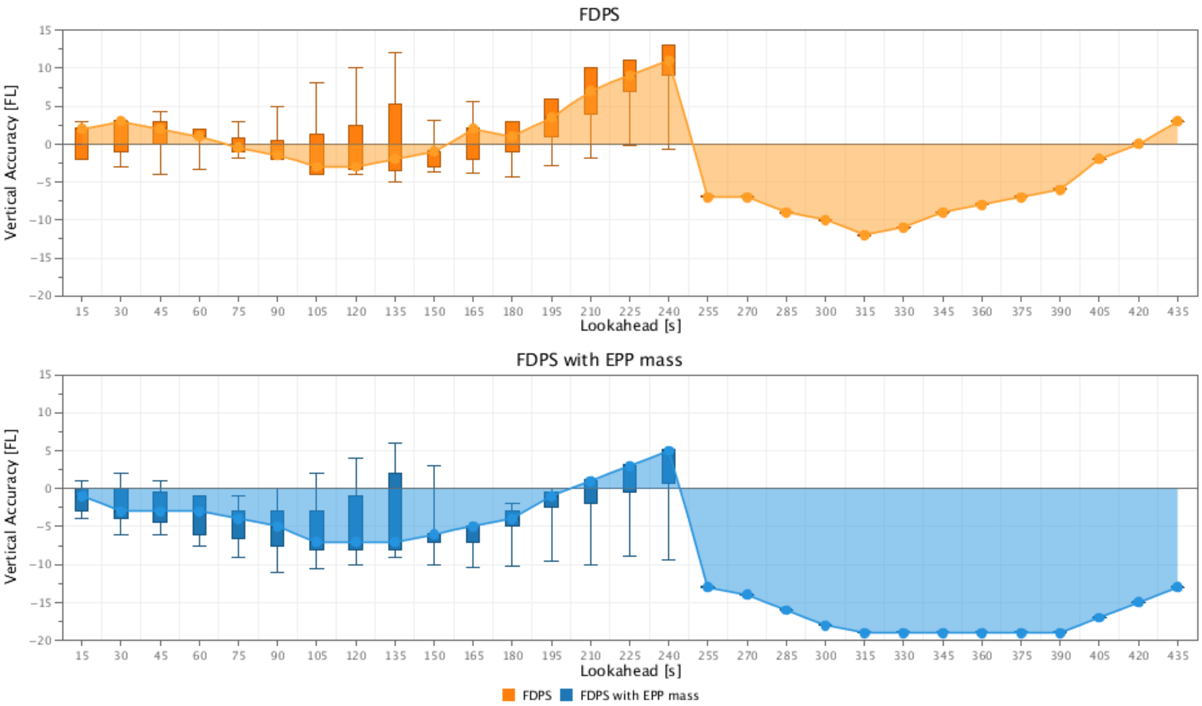


Figure 134 Percentile approach result– AIB02BX

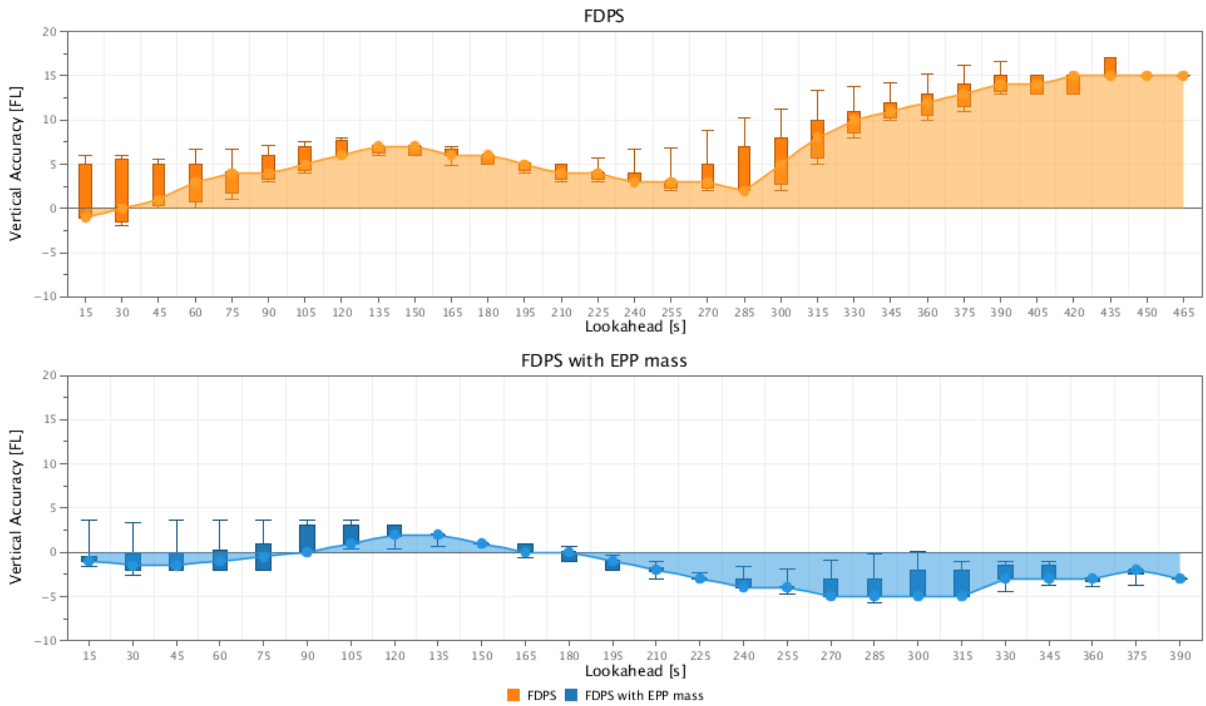


Figure 135 Percentile approach result– AIB02DF

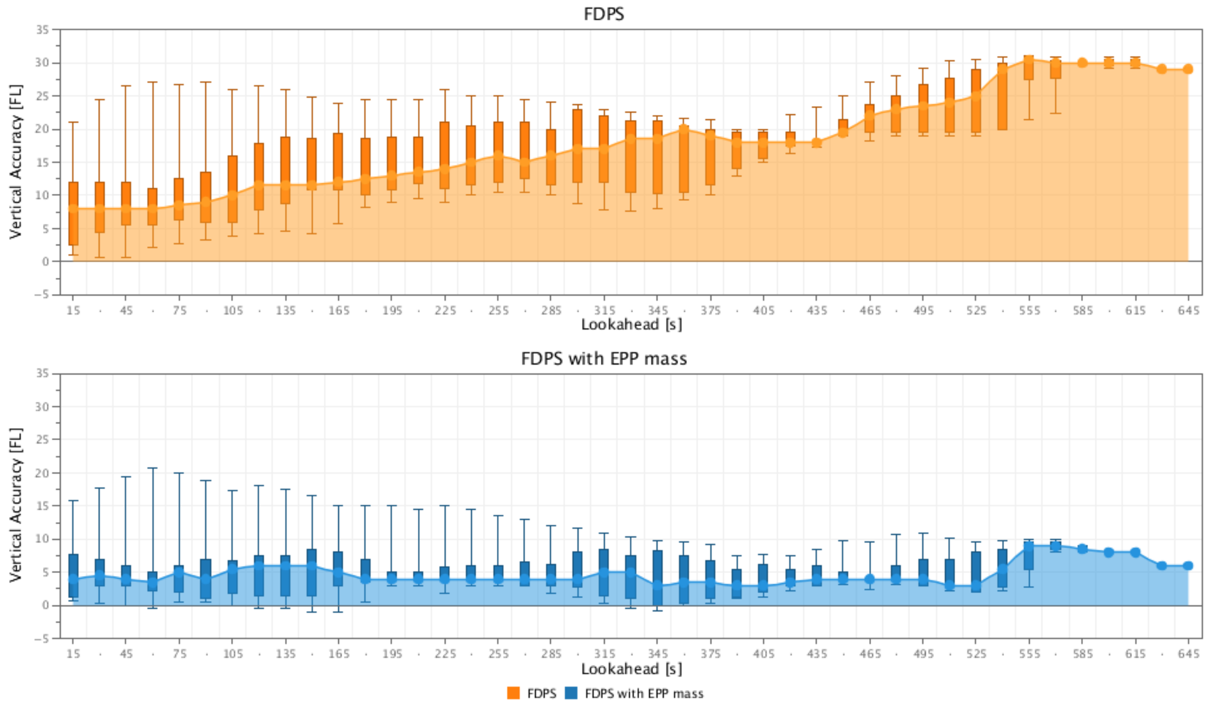


Figure 136 Percentile approach result– AIB02DH

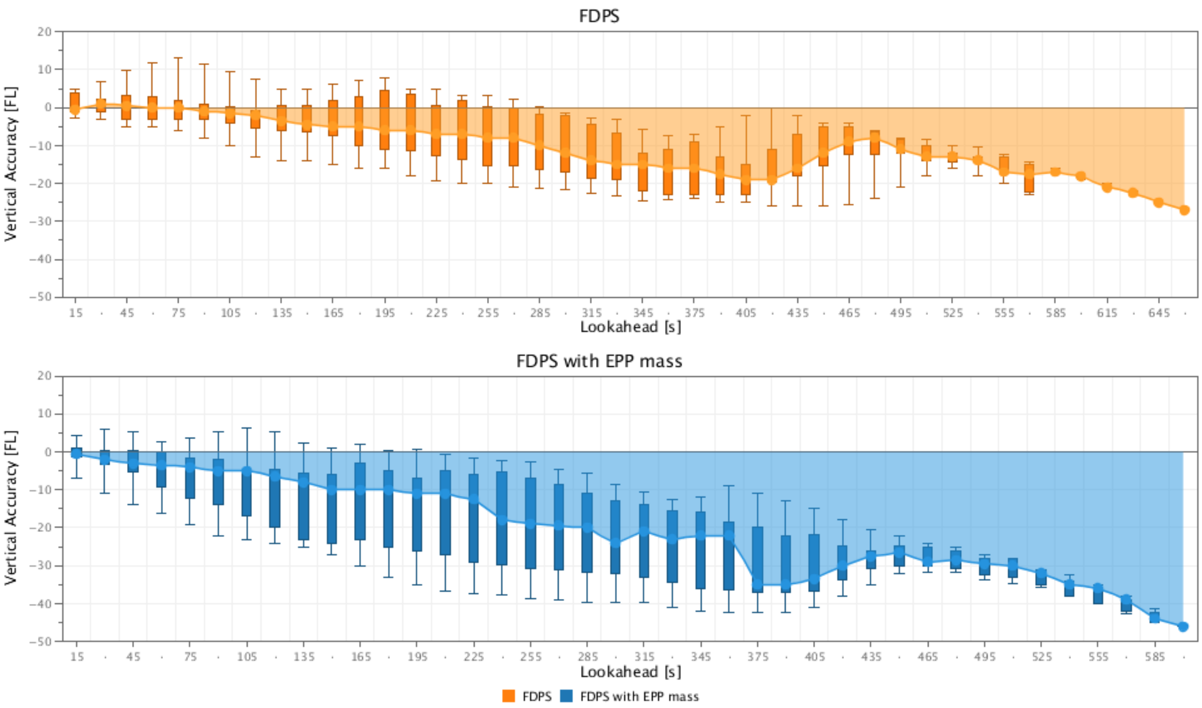


Figure 137 Percentile approach result– AIB02DM

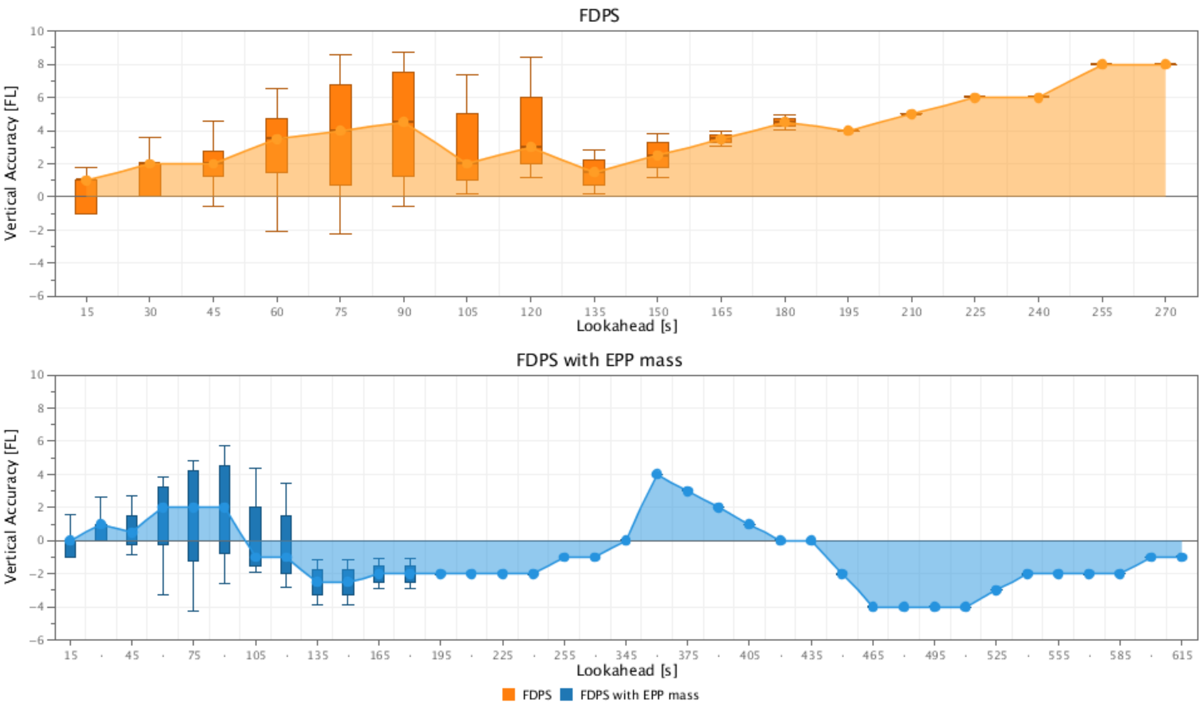


Figure 138 Percentile approach result– AIB02DR

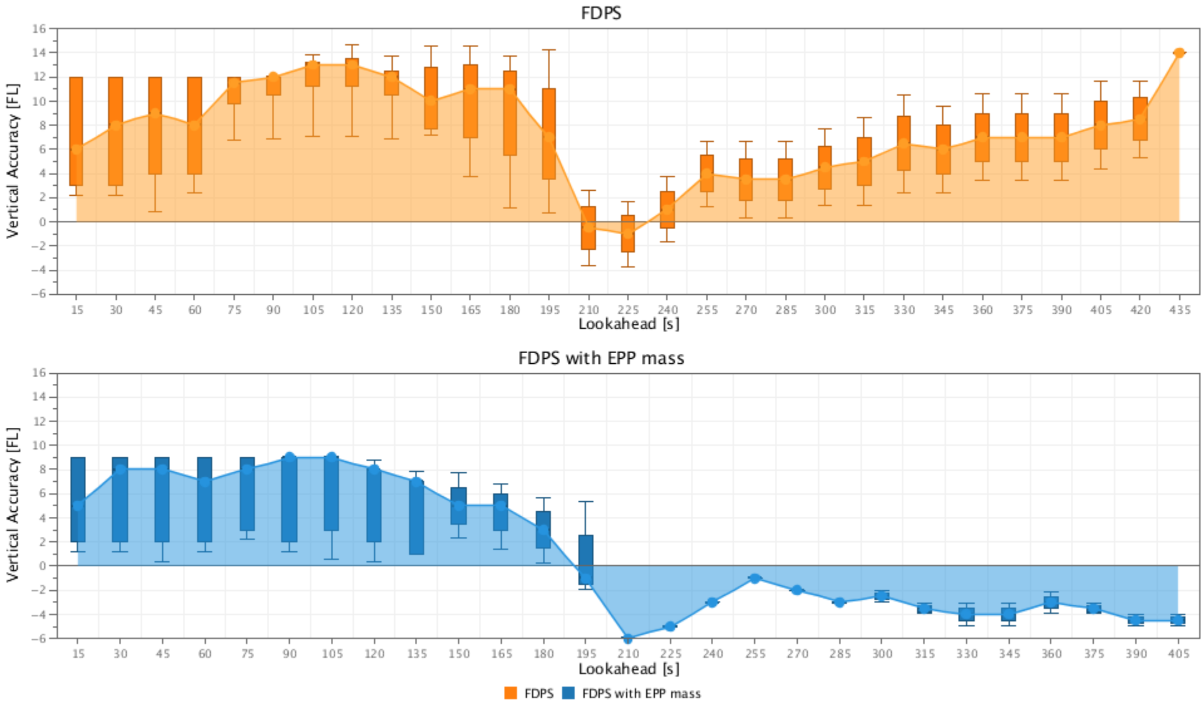


Figure 139 Percentile approach result– AIB02DT

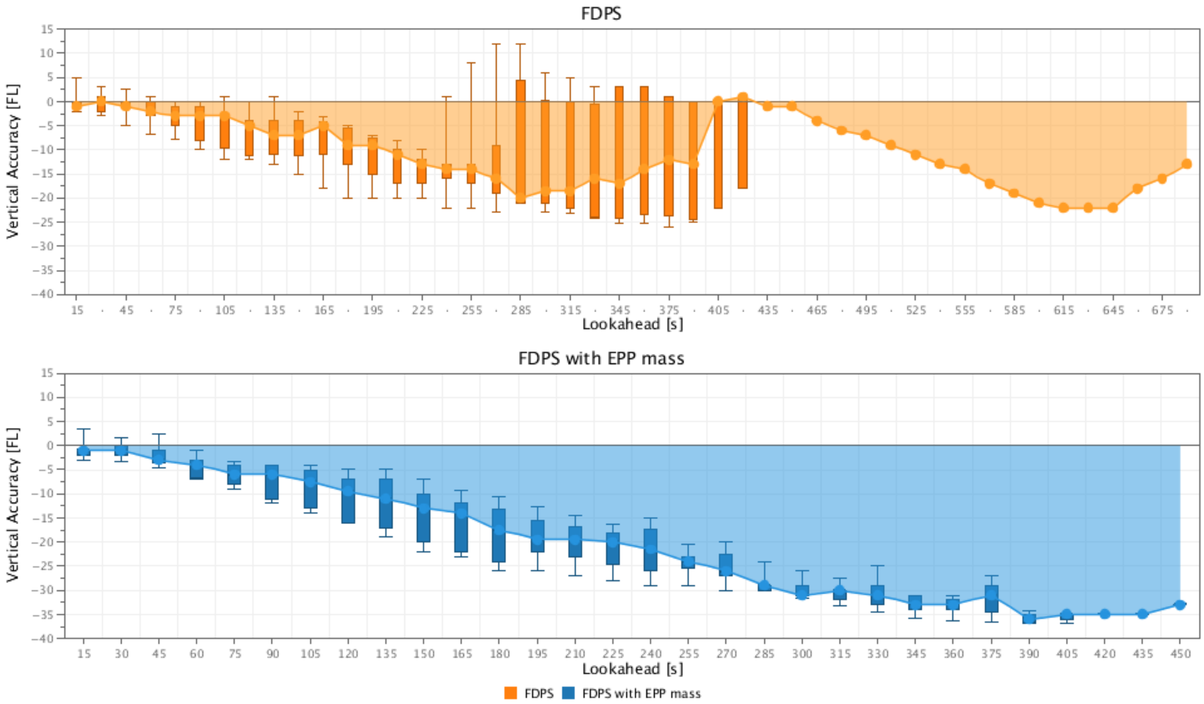


Figure 140 Percentile approach result– AIB02IC

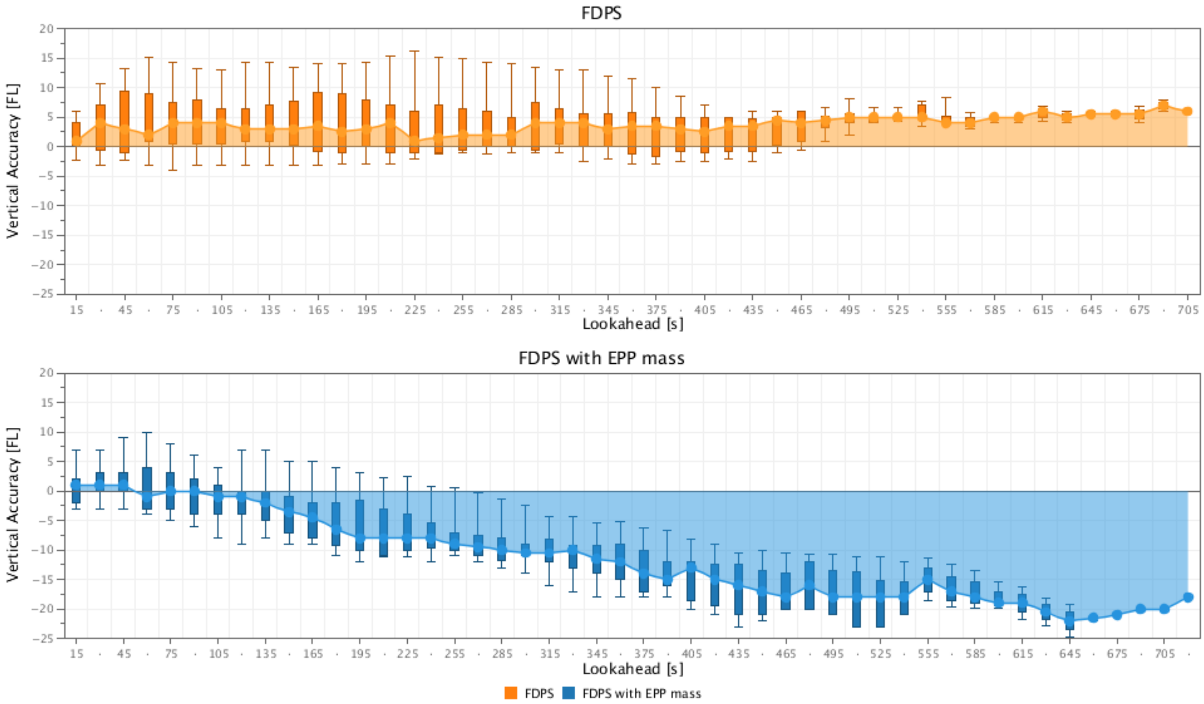


Figure 141 Percentile approach result– AIB02IK

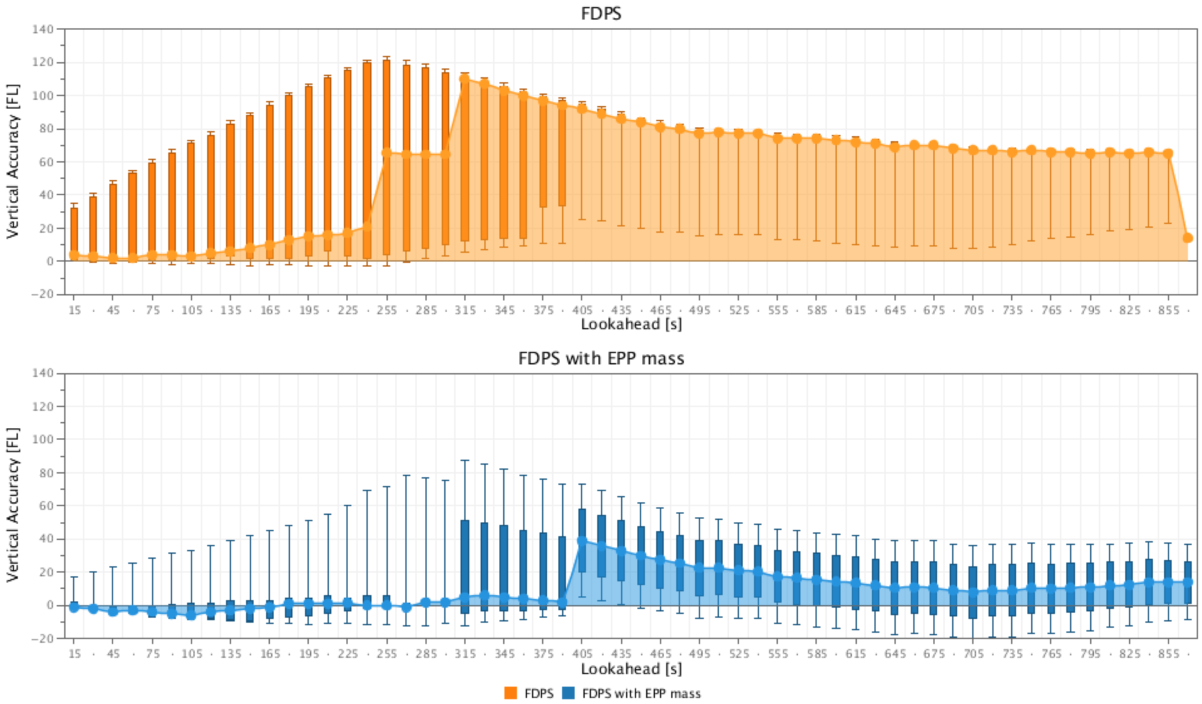


Figure 142 Percentile approach result– AIB02IO

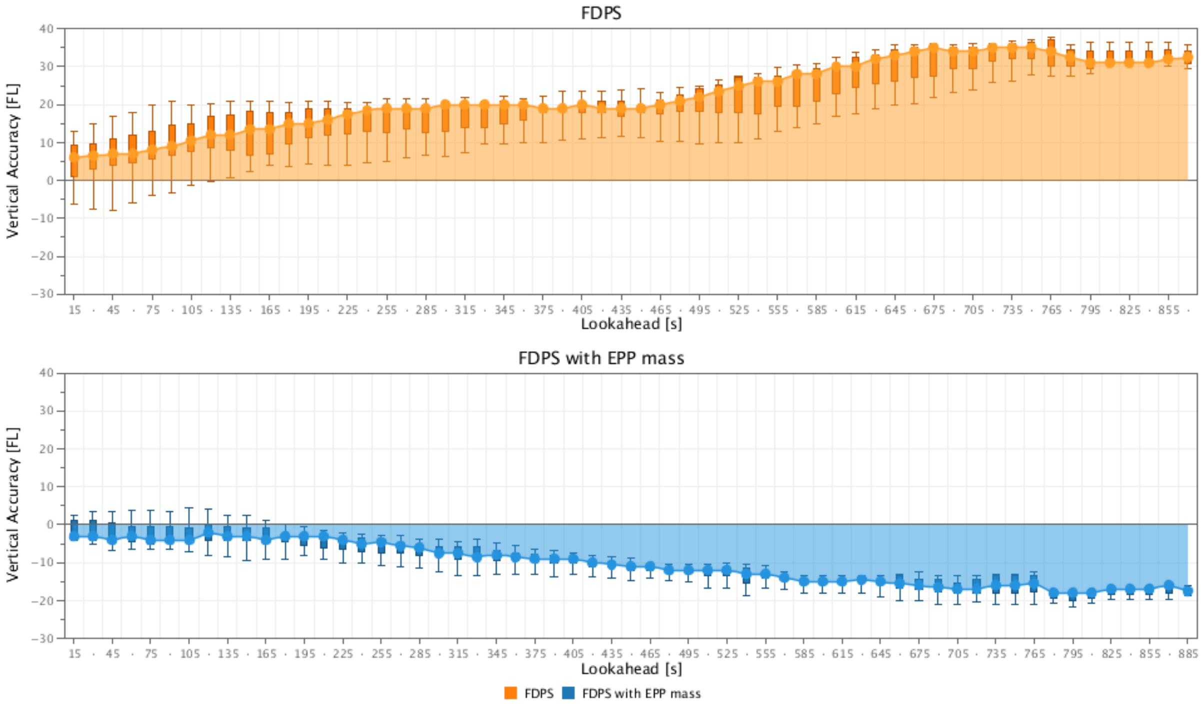


Figure 143 Percentile approach result– AIB0214 + wind injection

Appendix B A/C positions: ADS-B/C vs. Radar data

In several analyses carried out for this report, the actual A/C positions used were the one reported by the A/C (through ADS-B or ADS-C) instead of radar data as this former data was more widely available and easier to use.

To justify and validate this approach, the following analysis has been made on a sample of 19 PEGASE flights for which both radar data and ABS-B/C data was available. It compares the positions reported in ADS-B and C messages against the radar positions.

For each of the flights in this analysis, the differences between ADS-B/C and radar positions have been collected and their minimum, maximum, mean and median values computed.

These values are reported in the following tables and figures.

A.1 Mean differences

	n	Mean	Std	Min	25%	50%	75%	Max
Diff (nm)	19	0.47	0.79	0.13	0.13	0.18	0.25	3.38

For three quarters of the flights in the sample, the mean position differences stay below 0.25 nm. The distribution of the mean differences (Figure 144) shows that the all the means are below 0.5 nm except for three flights (see below, max differences)

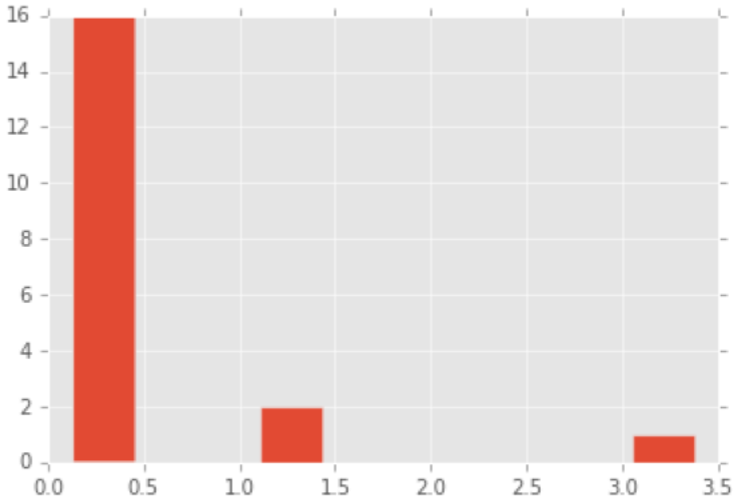


Figure 144: Distribution of the mean differences

A.2 Median differences

	n	Mean	Std	Min	25%	50%	75%	Max
Diff (nm)	19	0.13	0.03	0.09	0.11	0.12	0.13	0.24

The median values not being "influenced" by extreme values, it shows that for all flights at least 50% of the position differences were lower than 0.24 nm.

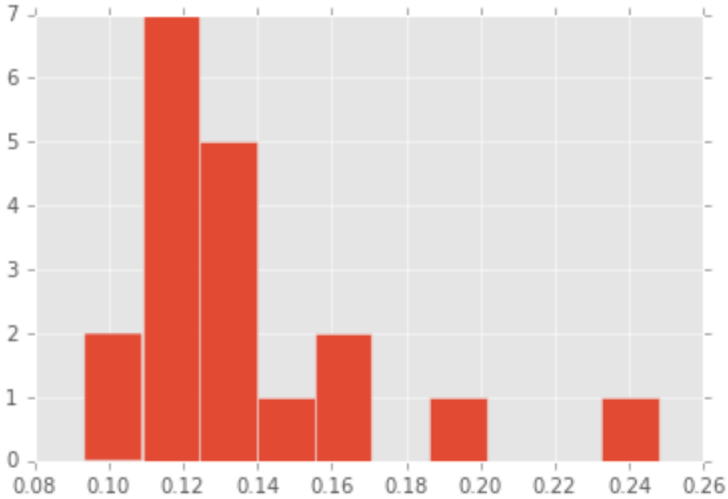


Figure 145: Distribution of the median differences

A.3 Max differences

	n	Mean	Std	Min	25%	50%	75%	Max
Diff (nm)	19	6.76	8.08	2.24	4.08	4.74	5.32	39.18

The median (50%) of the maximum differences stays below 5 nm. For three quarters of the flight, the maximum difference is less or equal to 5.32 nm.

The distribution shows that values above 5 nm are only observed for three flights.

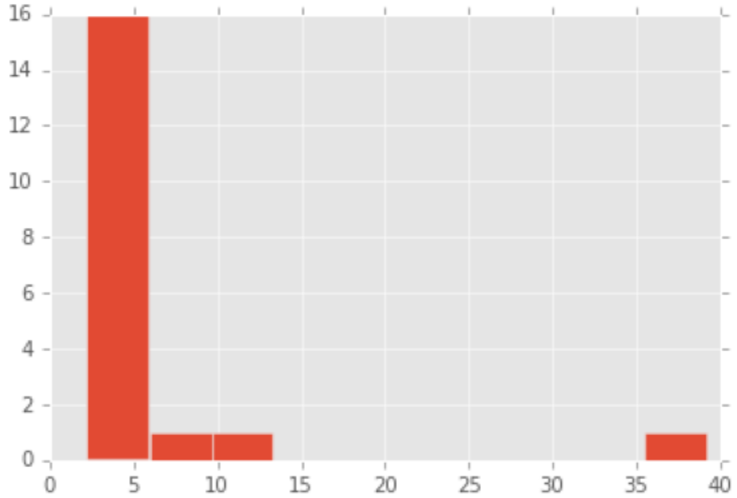


Figure 146: Distribution of the maximum differences

A.4 Conclusion

From this analysis it appears that the mean and especially median difference values stay small. In rare cases (3 occurrences in this sample), the maximum differences were greater than 5 nm.

The use of ADS-B/C appears to be a valid alternative to the radar data in the frame of PEGASE.

Appendix C Top Of Descent Prediction

The Prediction of the Top of Descent is based on the optimize position suggested by the FMS. This position may be different if the TOD provided by the FMS is modified due to the pilots choose or ATC request to start the descent at a different moment (before or after the suggested Top of Descent).

The examples below present two cases during which the pilots respected the Top Of Descent as suggested by the FMS, and one case where the FMS Top Of Descent was not respected.

<u>Example 1 : Top Of Descent respected</u>

The graph below represents in red the altitude profile of the analysed flight (in feet) and in blue the delta prediction value of the TOD time (in seconds).

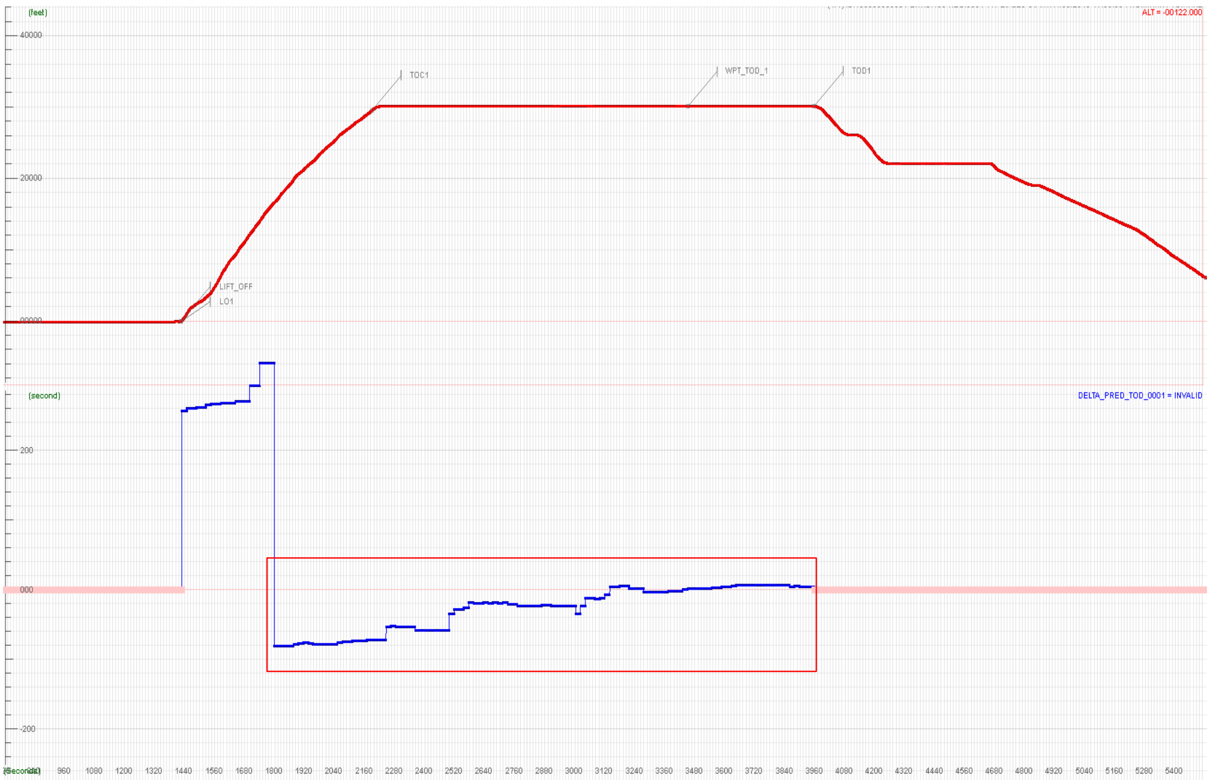


Figure 147: Example 1: FMS TOD respected

On this example where the FMS TOD has been respected, the evolution of the delta prediction shows that the EPP precision is below 90 seconds 40 minutes before the TOD.

The next figure is a zoom of this delta prediction during the last 40 minutes.

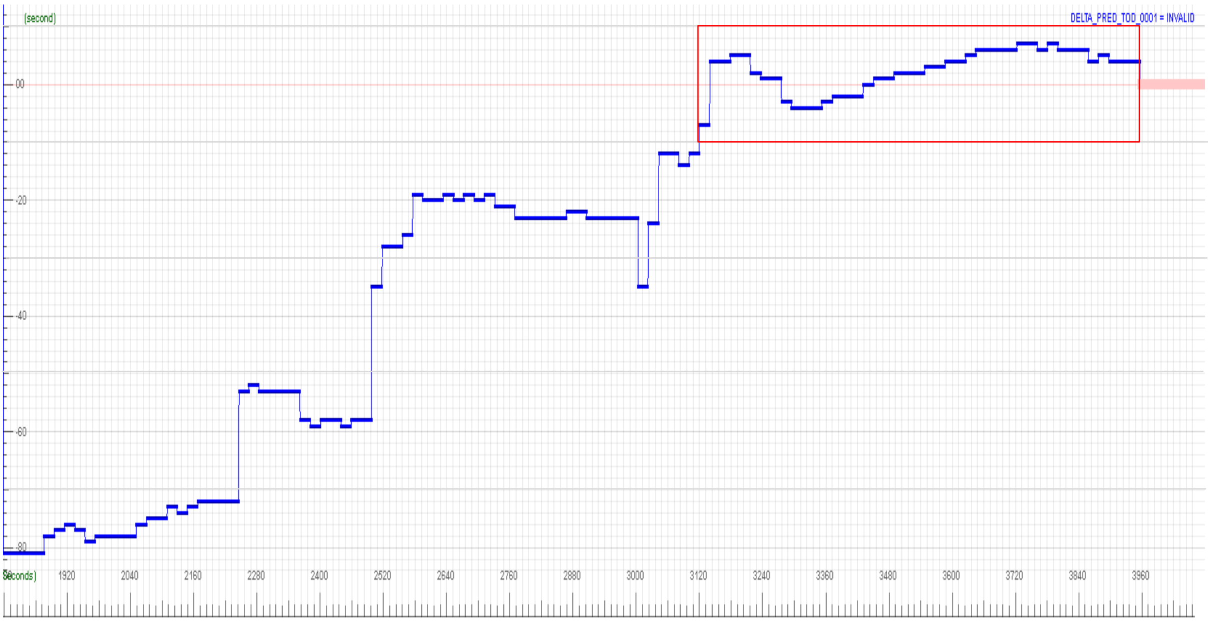


Figure 148: Example 1 Delta time prediction zoom

This zoom on the delta prediction shows that the EPP precision is below 10 seconds 14 minutes before the TOD

The graph below represent the distance (in nautical miles) between the real TOD Position and the predicted TOP Descent position during the last 35 minutes before the TOD

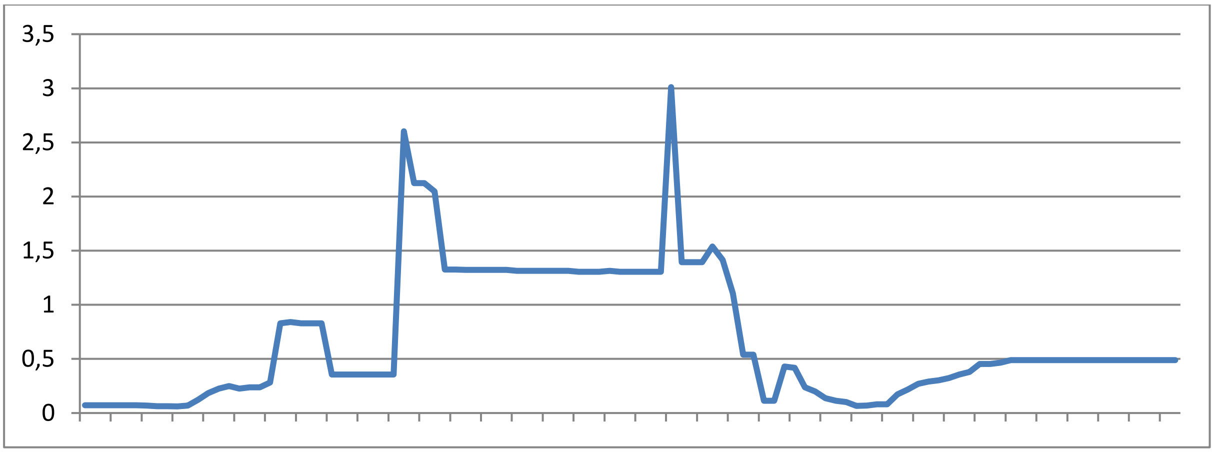


Figure 149: Example 1 Distance to TOD predicted position

It shows that the maximum detected distance is 3 nautical miles and that the predicted TOD position is fixed 5 minutes before TOD (~40 nm before) with an error of 0.5 nm.

The Percentage of predicted position error = 0.48/40 = 1.2%

Example 2 : Top Of Descent respected

The graph below represents in red the altitude profile of the analysed flight (in feet) and in blue the delta prediction value of the TOD time (in seconds).

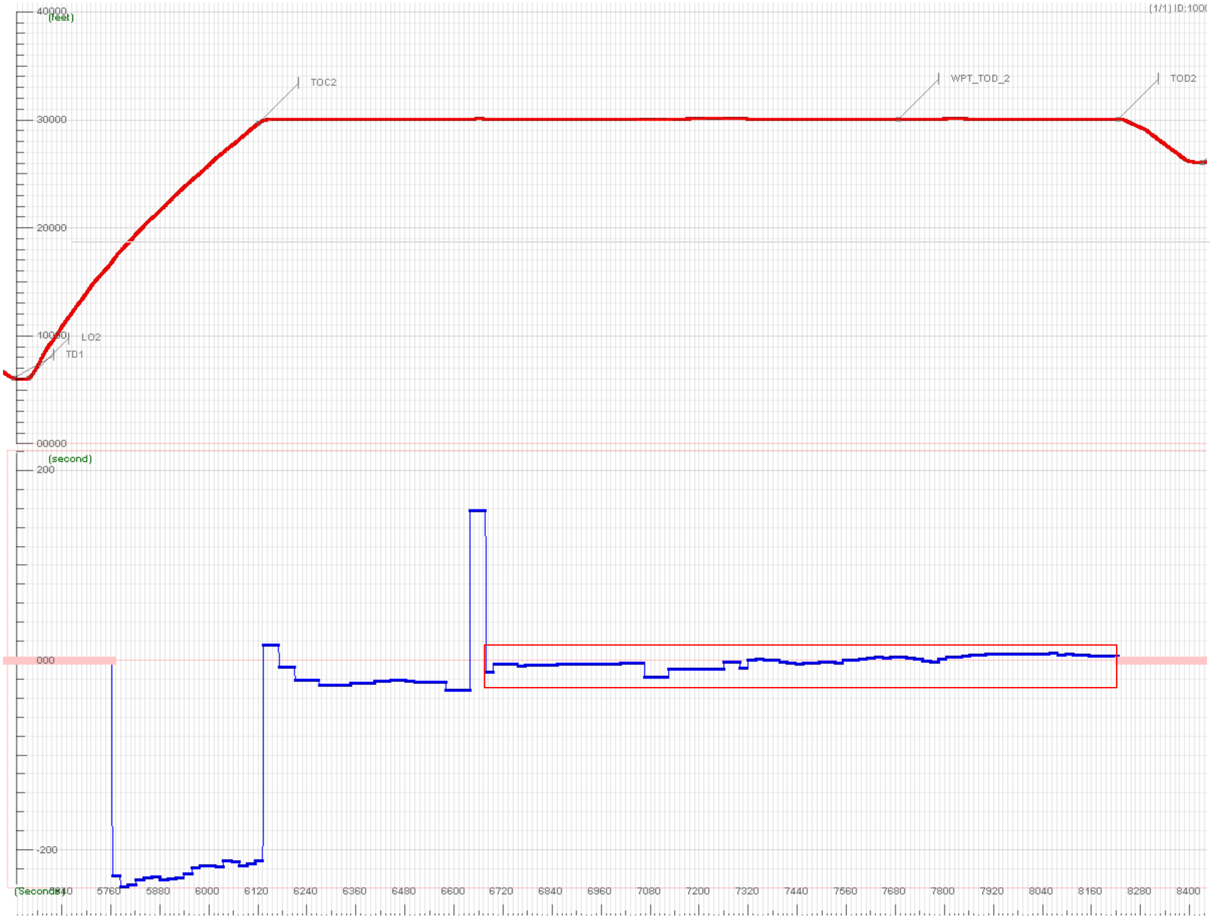


Figure 150: Example 2: FMS TOD respected

On this second example where the FMS TOD has been respected, the evolution of the delta prediction shows that the EPP precision is below 20 seconds 25 minutes before the TOD. The next figure is a zoom of this delta prediction during this last 25 minutes.

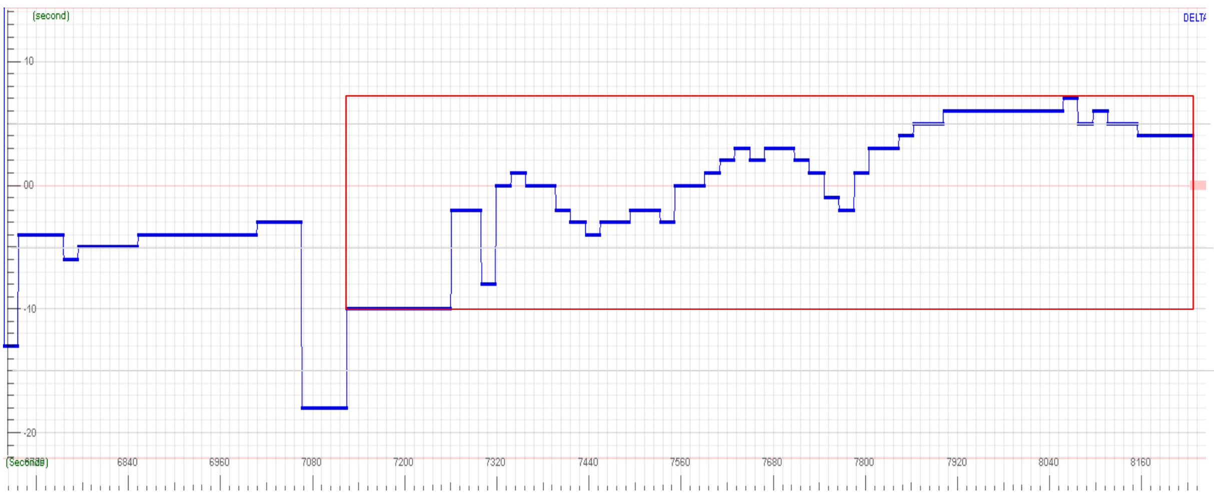


Figure 151: Example 2 Delta time prediction zoom

This zoom on the delta prediction shows that the EPP precision is below 10 seconds 18 minutes before the TOD

The graph below represent the distance (in nautical miles) between the real TOD Position and the predicted TOP Descent position during the last 40 minutes before the TOD

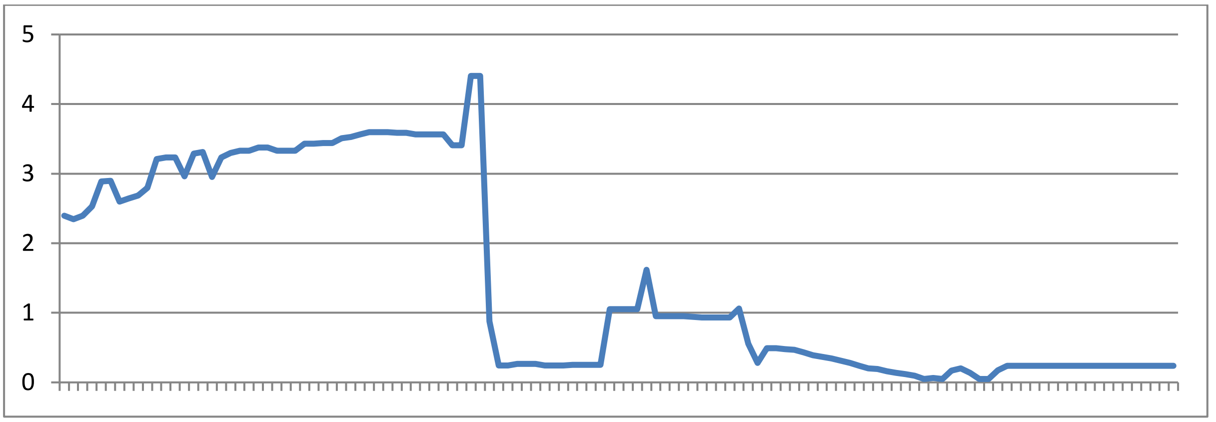


Figure 152: Example 2 Distance to TOD predicted position

A maximum distance value of 4.5 NM is detected 25 min before TOD. Afterwards the distance is always below 1.5 NM. As the previous example the predicted TOD position is fixed 5 minutes before TOD (~40 nm before) with an error of 0.23 nm.

- ⇨ The Percentage of predicted position error = 0.23/40 = 0.57%

Example 3 : Top Of Descent not respected

The graph below represents in red the altitude profile of the analysed flight (in feet) and in blue the delta prediction value of the TOD time (in seconds).

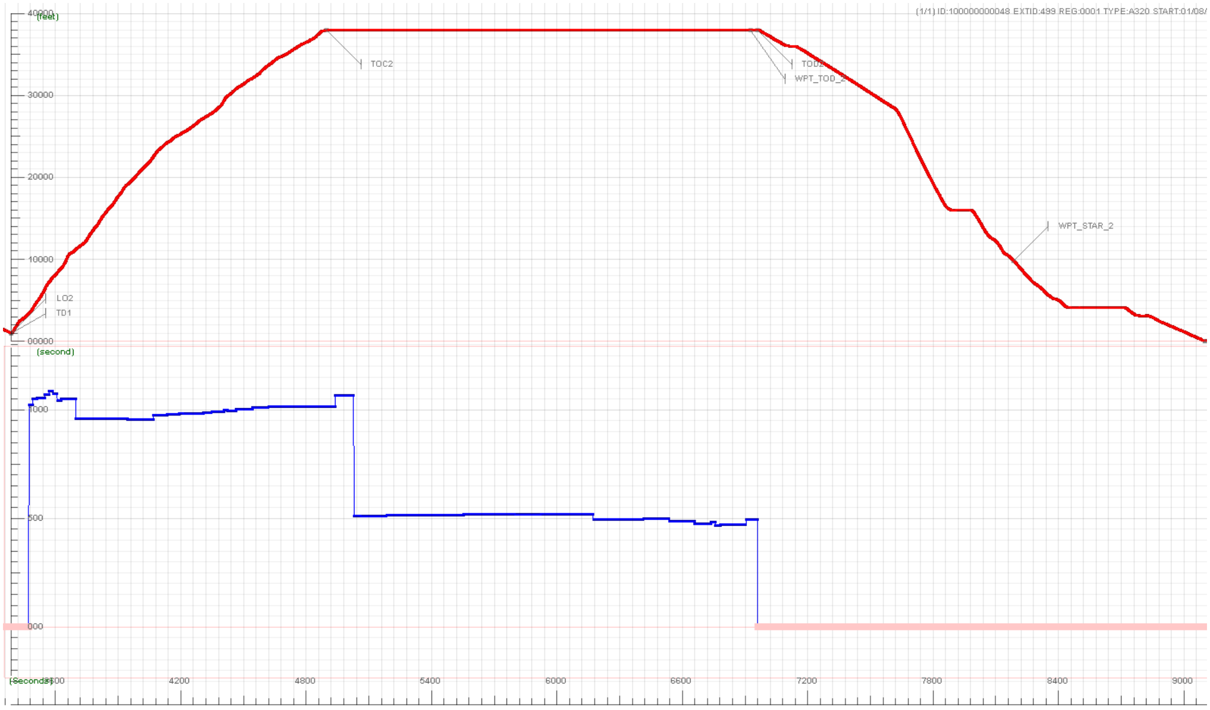


Figure 153: Example 3: FMS TOD not respected

On this example where the FMS TOD has not been respected, the delta prediction time is always very high and still at a value of 500 seconds at the descent start. This mean that according to the FMS the TOD should have been realised 500 second later.

This example demonstrate that the EPP prediction is relevant if the crew has well respected the FMS TOD.

Conclusion

This analysis demonstrated that the EPP TOD prediction could be very accurate when the FMS TOD has been respected by the crew:

- Time prediction:
  - Delta time prediction < 1 minute, 25 minutes before TOD
  - Delta time prediction < 10 seconds, 10 minutes before TOD
- Position prediction:
  - Delta distance prediction < 3 NM 25 minutes before TOD
  - Position prediction fixed 40 NM before TOD (~5 minutes before)

To conserve this good accuracy the crew and or the ATC should try to respect the suggested FMS TOD. It is important to sensitize all ATC contributors to the importance to respect the FMS recommendation and to the benefit it can bring them.

Appendix D Communication data

- SESAR Showcase - A Conference & Exhibition of SESAR 1 Results (14 – 16 June 2016 Amsterdam).

  Agenda:

DAY 1: 14 JUNE 2016

11:00 – 12:30 REGISTRATION AND NETWORKING LUNCH

12:45 – 13:00 **Welcome**

Florian Guillermet, Executive Director, SESAR JU

13:00 – 13:15 **Keynote speech**

Marian-Jean Marinescu, Member of the European Parliament

13:15 – 14:15 **Opening remarks**

- Maurizio Castelletti, Head of Unit Single European Sky, DG MOVE, European Commission
- Frank Brenner, Director General, Eurocontrol and Vice-Chairman of the SESAR JU Administrative Board
- Martin Rolfe, CEO, NATS, and Vice-Chairman of CANSO Europe
- Simon McNamara, Director General, ERA

14:15 – 15:15 **Plenary ONE: Improving network management and flight planning**

Moderated by Michael Standar, Chief Strategy and External Relations, SESAR JU

- Franck Goldnadel, Chief Airport Operations Officer & Paris Charles de Gaulle Airport Managing Director, Paris Aéroport (Groupe ADP)
- Joe Sultana, Director Network Manager, Eurocontrol
- Rafael Schvartzman, Regional Senior Vice President for Europe, IATA
- Todd Donovan, Vice President, Strategy & Marketing - Air Traffic Management, Thales
- Donald Ward, Head of NextGen International Office, FAA

15:15 – 15:45 COFFEE BREAK

15:45 – 16:45

Improving network management and flight planning *Moderated by Peter Alty, SESAR JU* Theatre, floor 2	More efficient airport operations *Moderated by Robin Garrity, SESAR JU* Auditorium, floor 2	Efficient flight operations and air navigation service provision *Moderated by Olivia Nunez, SESAR JU* Panorama hall, floor 5
A1	**C1**	**B1**
A1.1 Airspace users reducing delay costs with the user-driven prioritisation process, UDPP, *Nadine Pilon, Eurocontrol & Olaf Belzer, SABRE* A1.2 Departure flexibility (DLFEX) at Paris Charles de Gaulle (SESAR Demonstration Project), *Melanie Grandmaire, Air France & Kamal Amri, Paris Aéroport (Groupe ADP)*	C1.1 Precision approaches using GBAS Cat II/III, *José Manuel Rísquez Fernández, ENAIRE & George Papageorgiou, Honeywell* C1.2 Time-based separation, *Robert Graham, Eurocontrol & Mark Watson, NATS*	B1.1 Conflict detection and resolution aid to controllers, *Jean-Louis Garcia, DSNA* B1.2 Advanced separation management tools and new controller organisation schemas, *Leticia González Mota, Indra* B1.3 Conflict detection and resolution aid to planner controllers, *Roberta Pigliacampo, Leonardo-Finmeccanica*

16:45 – 17:00 SHORT BREAK

17:00 – 18:00 **Long-term and innovative research (WPE): Lessons learned**

Introduced by Keir Fitch, Head of Unit, Research and Innovative Transport Systems, DG MOVE

- *Introducing SESAR WPE, Colin Meckiff, Head of Long Term and Innovative Research, Eurocontrol*
- WPE example: SATURN, Lorenzo Castelli, University of Trieste
- WPE example: ERAINT, Enric Pastor, Universitat Politècnica de Catalunya
- Lessons learned and concluding remarks: David Bowen, Chief ATM, SESAR JU

18:00 – 18:15 **Official opening of the SESAR Showcase Exhibition**

18:00 – 19:30 NETWORKING COCKTAIL, EXHIBITION HALL

2 @SESAR_JU #SESAR

DAY 2: 15 JUNE 2016

08:30 - 09:00 WELCOME COFFEE & REGISTRATION

09:00 - 09:15 **Keynote address**
Matej Zakonjšek, Head of Cabinet, European Commissioner for Transport

09:15 - 10:00 **Introductory remarks**
- Jeff Poole, Director General, CANSO
- Jan Pie, Secretary General, ASD Europe
- Prof. Klaus-Dieter Scheurle, A6 Chairman, and CEO of DFS Deutsche Flugsicherung GmbH

10:00 - 11:00 **Plenary TWO: Efficient flight operations and air navigation service provision**
Moderated by David Bowen, Chief ATM, SESAR JU
- Michael Hickey, COO, Ryanair
- Pascal Lhoest, Director of Flight Operations, NetJets
- Neil Planzer, Vice President of Air Traffic Management Strategy, Boeing
- Koos Noordeloos, Deputy Director Corporate Development, Schiphol Airport
- Maurice Georges, CEO, DSNA

11:00 - 11:30 COFFEE BREAK

11:30 - 12:30	**Efficient flight operations and air navigation service provision** *Moderated by Olivia Nunez, SESAR JU* Panorama hall, floor 5	**Enabling infrastructure and systems capabilities enablers** *Moderated by Marouan Chida, SESAR JU* Auditorium, floor 2	**More efficient airport operations** *Moderated by Robin Garrity, SESAR JU* Theatre, floor 2
	B2	**D1**	**C2**
	B2.1 Extended AMAN, *Gerald Regniaud, DSNA & Paul Nicholls, NATS*	D1.1 Electronic visibility via ADS-B for small aircraft (SESAR Demonstration Project: EVA), *John Koma, NATS*	C2.1 Integrated surface management, *Hervé Drevillon, DSNA*
	B2.2 CTA including i4D, *Peder Id, NORACON*	D.1.2 Trajectory exchange using SATCOM Iris Precursor, *Patrick Lelievre, Airbus*	C2.2 Airport safety support tools for pilots, vehicle drivers and controllers, *Nicolas Leon, DSNA*

12:30 - 13:30 LUNCH

13:30 - 14:30 **Plenary THREE: More efficient airport operations**
Moderated by Bo Redeborn, Former Principle Director ATM, Eurocontrol
- Michael Nachtigaller, Lufthansa Programme Manager SESAR
- Fredrik Lindblom, Product Manager - Collaborative Decision Making & Efficiency Solutions, SAAB
- Mark Watson, Head of Research and Development, NATS
- Thorsten Astheimer, Air Traffic Solutions Manager, Fraport, representing SEAC
- Rowland Hayler, Program Leader, Gatwick Airport

14:30 - 14:45 SHORT BREAK

@SESAR_JU #SESAR 3

DAY 2: 15 JUNE 2016

14:45 - 15:45	**More efficient airport operations** *Moderated by Robin Garrity SESAR JU* Auditorium, floor 2	**Improving network management and flight planning** *Moderated by Peter Alty, SESAR JU* Panorama hall, floor 5	**Enabling infrastructure and systems capabilities enablers** *Moderated by Marouan Chida, SESAR JU* Theatre, floor 2
	C3	**A2**	**D2**
	C3.1 Airport operations management, *Mark Burgess, Heathrow*	A2.1 Advanced flexible use of airspace (AFUA), *Kris Delcourte, Eurocontrol & Davide Bardelli, Lufthansa Systems*	D2.1 System-wide information management (SWIM), *Peder Blomqvist, LFV & Xavier Jourdain, Thales Group*
	C3.2 Integration of AOP-NOP and target time management- Step1, *Gonzalo Quiles, Indra*	A2.2 Free routing and direct routing, *Florence Serdot-Omer, DSNA & Luigi Brucculeri, ENAV*	D2.2 Enabling future weather information for european aviation, *Rosalind Lapsley, EUMETNET & Daniel Muller, Thales*
	C3.3 Remote tower services, *Marcus Filipp, LFV & Rainer Kaufhold, DFS Deutsche Flugsicherung GmbH*		

15:45 - 16:15 COFFEE BREAK

16.15 - 17.15 **Plenary FOUR: Enabling infrastructure and systems capabilities enablers**
Moderated by Pierre Bachelier, Independent ATM Expert and Former Head of ATM Programme, Airbus
- Rolf Henke, Chairman, ACARE
- Captain Sven Kutschera, Lufthansa Group
- Bruno Darboux, Vice President, Systems Programmes & Strategy Airbus
- Ramon Tarrech, Director, Indra
- Iacopo Prissinotti, Head of International Strategies, ENAV

17:15 - 17:30 SHORT BREAK

17.30 - 18.30	**Enabling infrastructure and systems capabilities enablers** *Moderated by Marouan Chida, SESAR JU* Auditorium, floor 2	**Improving network management and flight planning** *Moderated by Peter Alty, SESAR JU* Panorama hall, floor 5	**Efficient flight operations and air navigation service provision** *Moderated by Robin Garrity, SESAR JU* Theatre, floor 2
	D3	**A3**	**B3**
	D3.1 Improving traffic predictions and aligning trajectories with the extended flight plan, *Gérard Mavoian, Eurocontrol & Urban Weisshaar, Lufthansa Systems*	A3.1 Demand capacity balancing in a dynamic fashion, *Soenke Mahlich, Eurocontrol*	B3.1 SESAR Virtual Centres, *Benoit Reder, DSNA & Richard Beaulieu, Thales*
	D3.2 Improving civil-military ATM performance with integrated flight plan and airspace management tools, *Edgar Reuber, Eurocontrol & Klaus Dieter Hermann, Airbus Defence & Space*	A3.2 Complexity management in en-route, *Pablo Sánchez Escalonilla, ENAIRE*	B3.2 Integrating RPAS into the Civil Aviation System (SESAR RPAS Demonstration Project: CLAIRE), *Mark Watson, NATS & Neil Watson, Thales*

19:30 - 23:00 NETWORKING EVENT - HERMITAGE (by invitation only)

4 @SESAR_JU #SESAR

DAY 3: 16 JUNE 2016

08:30 - 09:00	WELCOME COFFEE & REGISTRATION
09:00 - 09:45	**Introductory remarks** • Catalin Radu, Deputy Director Aviation Safety, ICAO • Thomas Reynaert, Managing Director, A4E • Roland Van Reybroeck, Director for Cooperation Planning & Support, European Defence Agency
09:45 - 10:00	**SESAR : A performance driven approach** José Miguel de Pablo, Director of CRIDA, ENAIRE
10:00 - 11:00	**SESAR achievements** *Moderated by Philip Butterworth-Hayes, journalist* • Morten Dambaek, CEO, Naviair • Patrick Peters, President and CEO, IFATCA • Olivier Jankovec, Director General, ACI Europe • Michael Holzbauer, Director European ATM Programmes, Frequentis • Stefano Porfiri, Head of SESAR Programme, Leonardo-Finmeccanica • Patrick Schuster, Head of MPP & ATM Engineering, Airbus
11:00 - 11:30	COFFEE BREAK
11:30 - 12:30	**SESAR: What's on the horizon?** *Moderated by Florian Guillermet, Executive Director, SESAR JU* • **Performance perspective: converting SESAR achievements into performance gains and cost savings** Peter Griffiths, PRB Chair • **SESAR Deployment** Massimo Garbini, Managing Director, SESAR Deployment Manager • **Research and Innovation towards 2020 and beyond** Ralf Bertsch, Director Planning & Innovation, DFS Deutsche Flugsicherung GmbH
12:30 - 13:00	**SESAR 2020: ATM challenges for the near future** *Closing remarks by Florian Guillermet, Executive Director, SESAR JU* • Sharon Dijksma, State Secretary for Infrastructure and the Environment, Dutch Ministry • Henrik Hololei, Director General, DG MOVE, European Commission, and Chairman of the Administrative Board of the SESAR JU
13:00 - 14:00	LUNCH
14:00	END

@SESAR_JU #SESAR 5

- SESAR DemonstrationActivities Workshop (28-29 October 2014, Toulouse):
  - Agenda

SESAR Demonstration Activities Workshop

28-29 October 2014, Toulouse

Agenda

SESAR JOINT UNDERTAKING

Day 1 - Final project results (activities completed)

08:30	Welcome coffee	
09:30	Welcome and practical information	Pierre Bachelier and Tom Maier, Airbus
09:45	Setting the scene	Alain Siebert, SJU
10:15	SWIM (Oceanic, Flight Object exchange)	ICATS
11:00	Traffic Synchronisation (Oceanic, RBT, E-AMAN)	TOPFLIGHT
11:45	Group picture and lunch break	
13:00	Moving from Airspace to 4D Trajectory Management (En-Route Continental, Free Route)	FRAMAK
13:45	Moving from Airspace to 4D Trajectory Management (En-Route Continental, Free Route)	AFD
14:30	Moving from Airspace to 4D Trajectory Management (En-Route Continental, MET Services)	TOPMET
15:15	Coffee break	
15:45	Airport Integration & Throughput (CTOT>TTA)	FAIR STREAM
16:30	Airport Integration & Throughput (CDM, UDPP)	DFLEX
17:00	Airport Integration & Throughput (GA)	NASCIO
17:30	Wrap-up of the day	Alain Siebert, SJU
18:30 - 19:30	Visit of A380 Final Assembly Line for interested participants	

Hosted by:

AIRBUS

SESAR Demonstration Activities Workshop

28-29 October 2014, Toulouse

Agenda

Day 2 - New project plans

08:00	Networking coffee	
09:00	Airport Integration & Throughput (NOP, TTA, A-CDM, GBAS/SBAS Advanced procedures, SVGS advanced procedures, EFVS Advanced procedures)	iStream, E-CRA, AAL (Joint presentation coordinated by SJU)
10:30	Coffee Break	
11:00	Airport Integration & Throughput (Remote towers)	RACOON, Remote Towers, RTO (Joint presentation coordinated by SJU)
12:15	Moving from Airspace to 4D Trajectory Management (Free Route)	PEGASE, Free Solutions
12:45	Lunch break	
13:45	Traffic Synchronisation (CDO, RNP)	ODP, Budapest 2.0, RISE (joint presentation coordinated by SJU)
14:45	Low cost CNS equipment and solutions for General Aviation/Rotorcraft)	EVA, PROUD
15:45	Coffee Break	
16:15	SWIM (ADS-C EPP, MET and AIM)	TOPLINK 1&2 (Joint presentation coordinated by SJU)
17:30	Conclusions	Alain Siebert, SJU
18:00	End of workshop	

Hosted by: AIRBUS

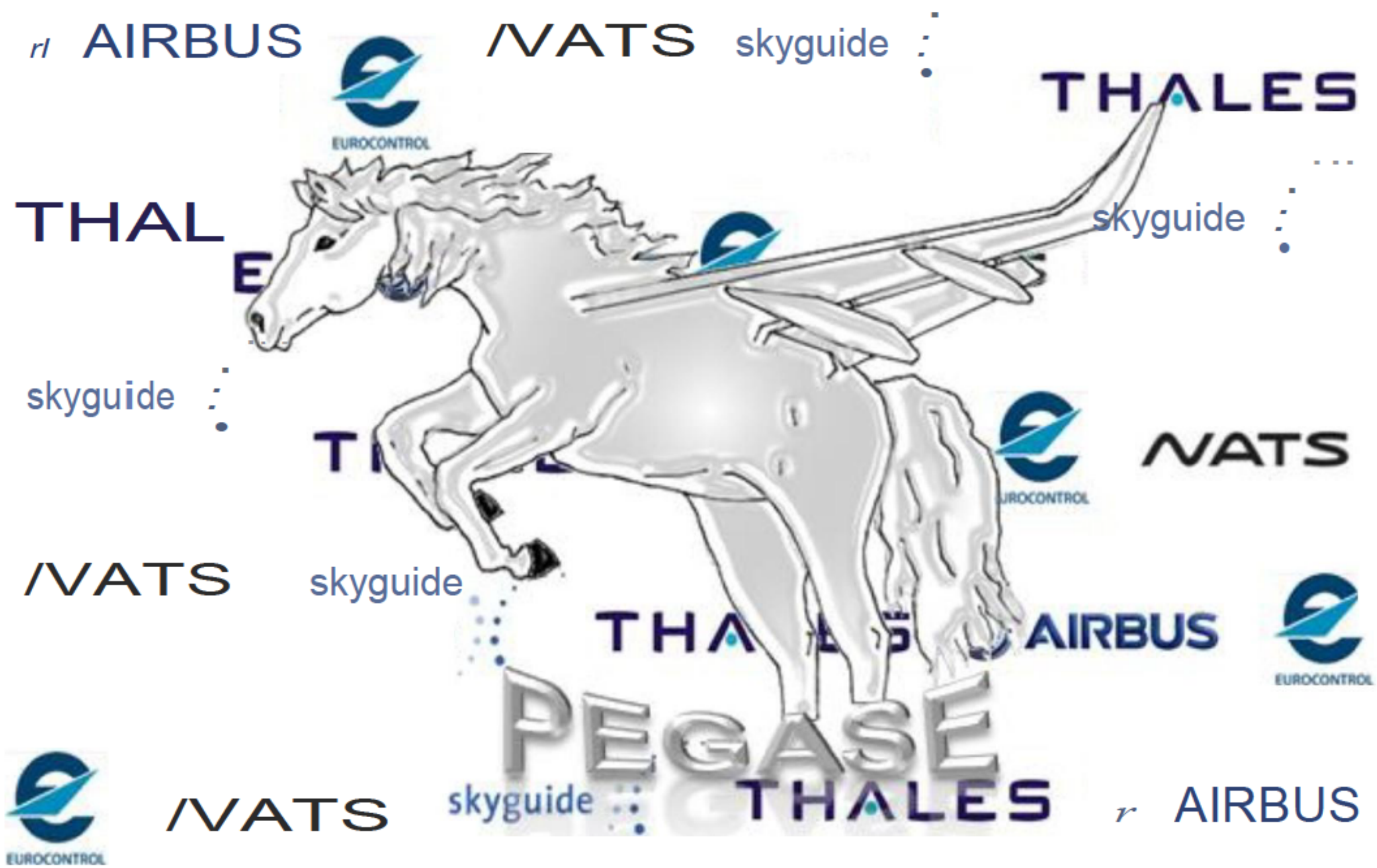
- PEGASE presentation

FROM INNOVATION TO SOLUTION

SESAR ANNUAL DEMO WORKSHOP

Toulouse, 28-29 October 2014

Day 2: New Project Plans

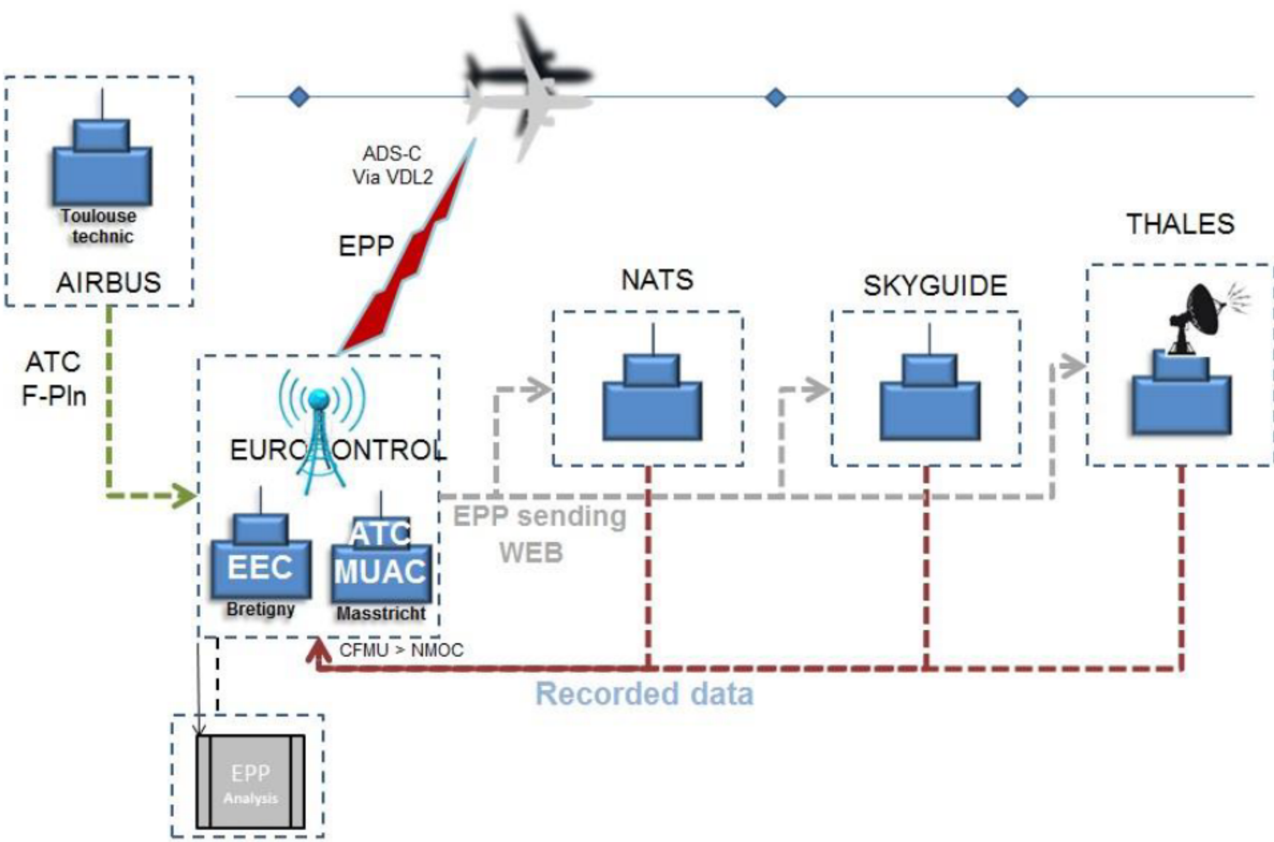

PEGASE

PEGASE: Project Description

PEGASE: **P**roviding **E**ffective **G**round & **A**ir data **S**haring via **E**PP.

- **PEGASE supports SESAR Priority Strategic Business Needs moving from Airspace to 4D Trajectory**

- **PEGASE will provide EPP information on projected aircraft trajectory calculated with the aircraft's systems.**



- **EPP information will be shared with ANSPs, and ground manufacturer systems, for operational use.**

- **Off-line analysis will be performed for statistics on EPP performance and reliability.**

FROM INNOVATION TO SOLUTION

EPP: Extended Project Profile

PEGASE: Project Objectives

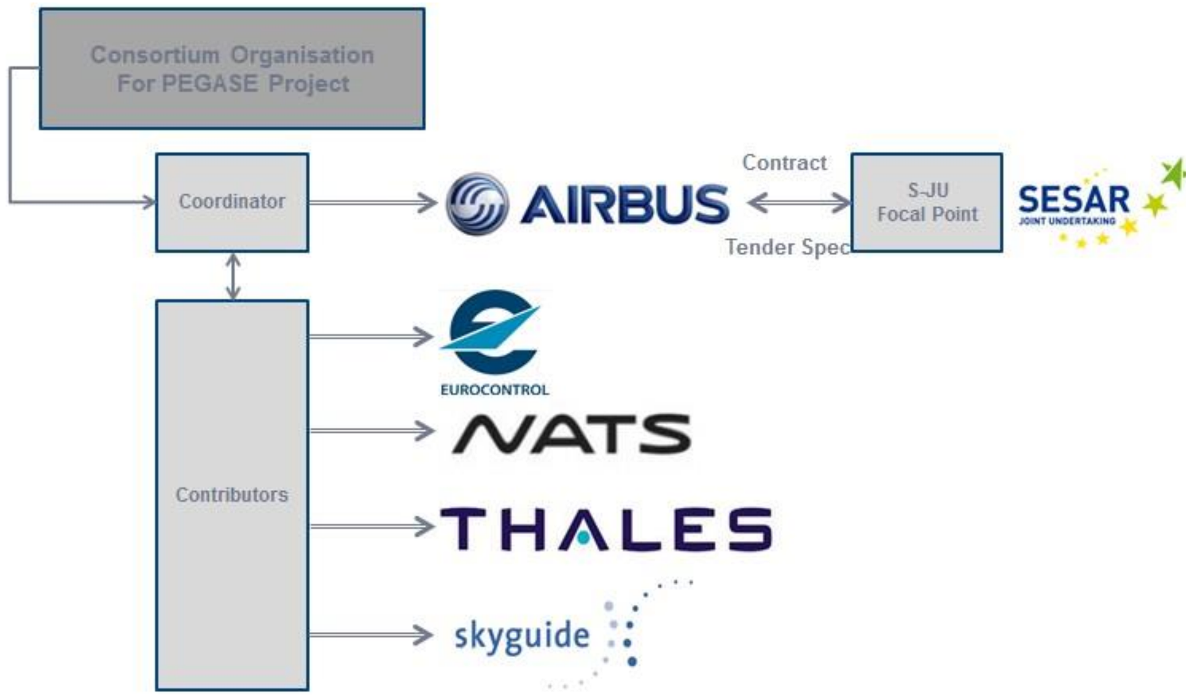
- Building on previous SESAR exercises and SESAR i4D flight trials
- Aligned with PCP* AF**#6 (Initial Trajectory Information Sharing)
- Designed to illustrate that EPP provides accurate and reliable info:
  - 100 flights in busy European airspace
  - 3 ANSPs and one ground manufacturer + the Network Manager
- Designed to demonstrate that EPP incorporated in ATC ground systems enables:
  - A reduction of spurious conflict and traffic alerts
  - A better management of separations and complex traffic flows
  - Lesser need for Radio Telephony communications
  - More predictable climb / descent
- Paving the way to SESAR 2020 Very Large Demonstrations

* PCP: Pilot Common Project, ** AF: ATM Functionalities

FROM INNOVATION TO SOLUTION

PEGASE: Consortium Description

- The PEGASE Consortium includes the following partners:
  - AIRBUS
  - EUROCONTROL
  - NATS
  - skyguide
  - THALES



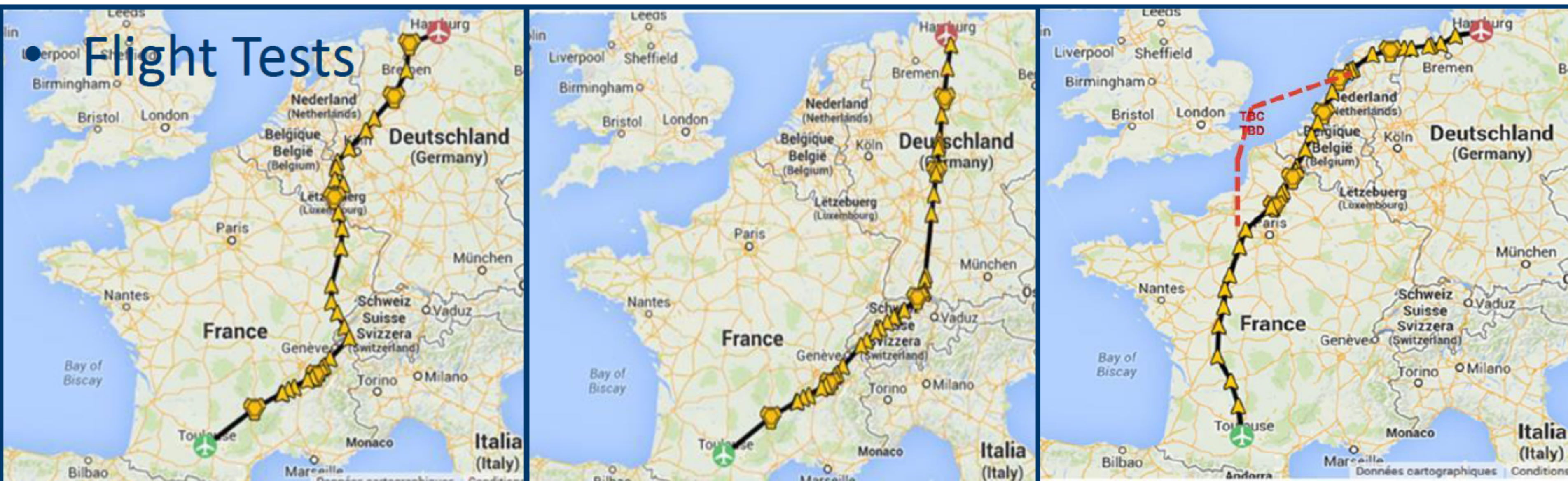
And… is supported by Honeywell & SITA

FROM INNOVATION TO SOLUTION

PEGASE: Project Content

- Simulator Validation

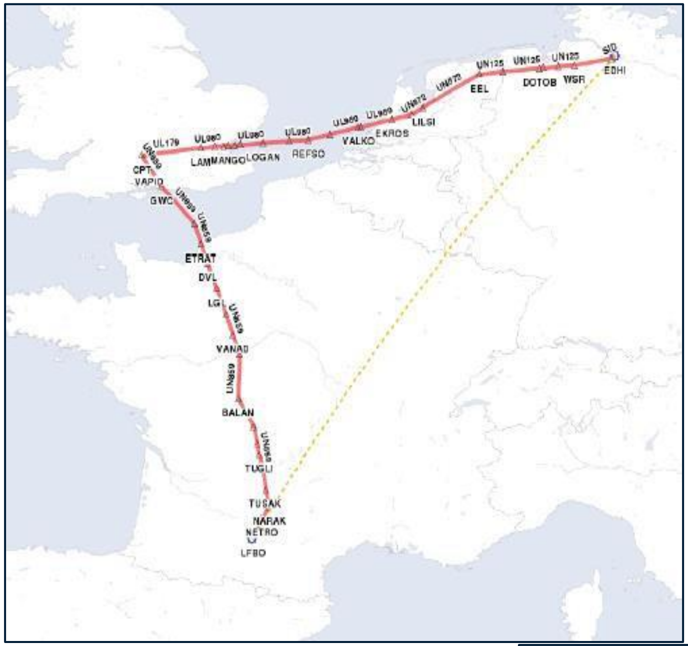
- Flight Tests

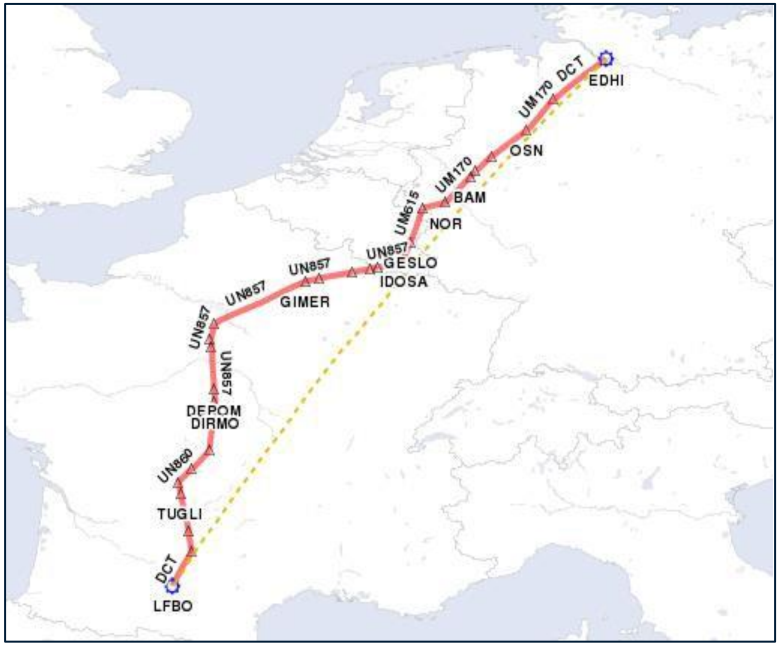


- EPP Performance Analysis

- End-User Feedback on EPP Operational Usage

PEGASE Flight Plans





FROM INNOVATION TO SOLUTION

FTR

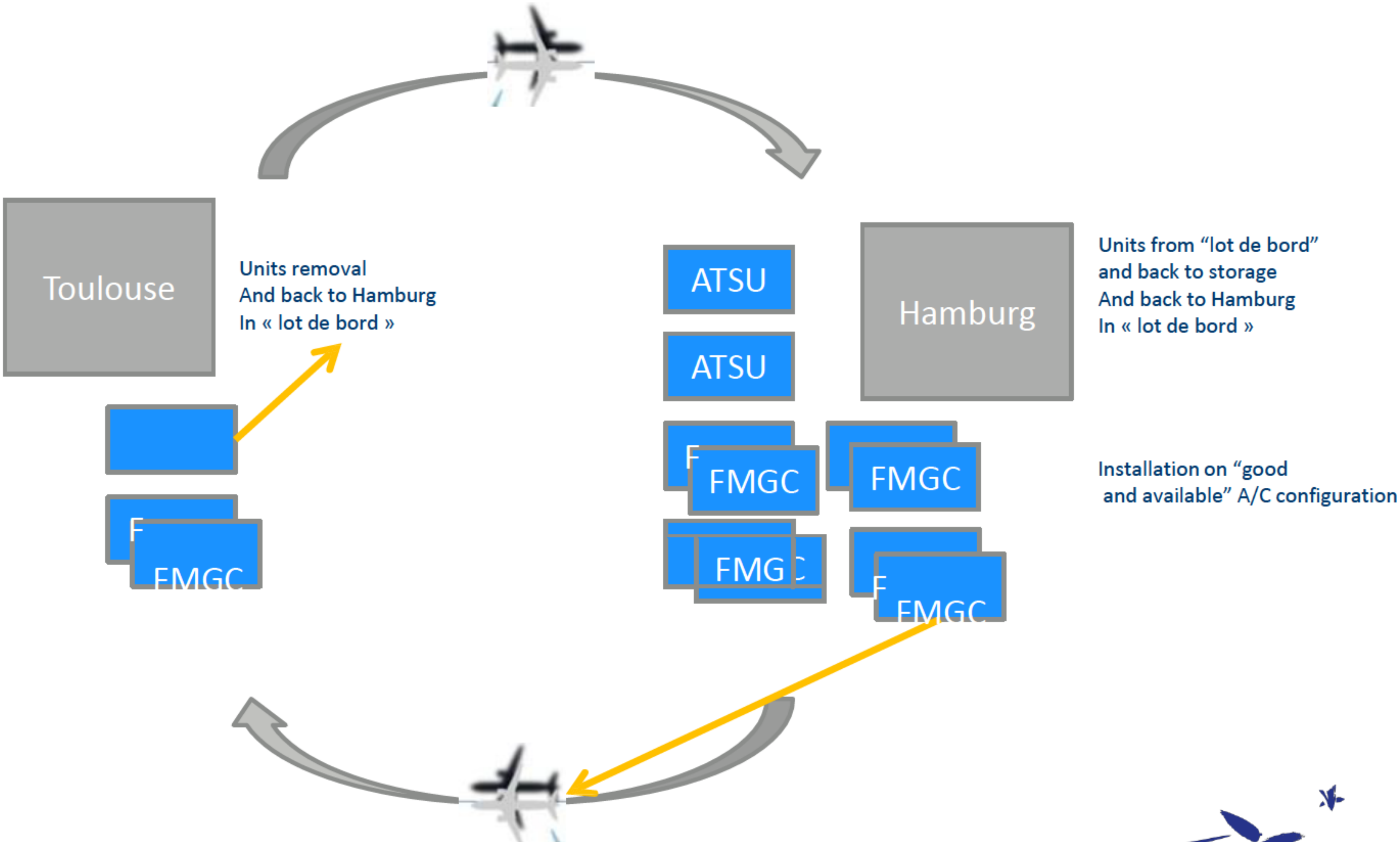
- FTR activities:
  - Check A/C configuration to valid the configuration (specific ATSU and FMS based on i4D)
  - Performed the log-on with ATC center:
    - Today 2or3 log-on (Maastricht, Bretigny and Toulouse tech (TBC)).
    - Tomorrow could be with NATS/THALES/SKYGUIDE.

    (4 log-on max)

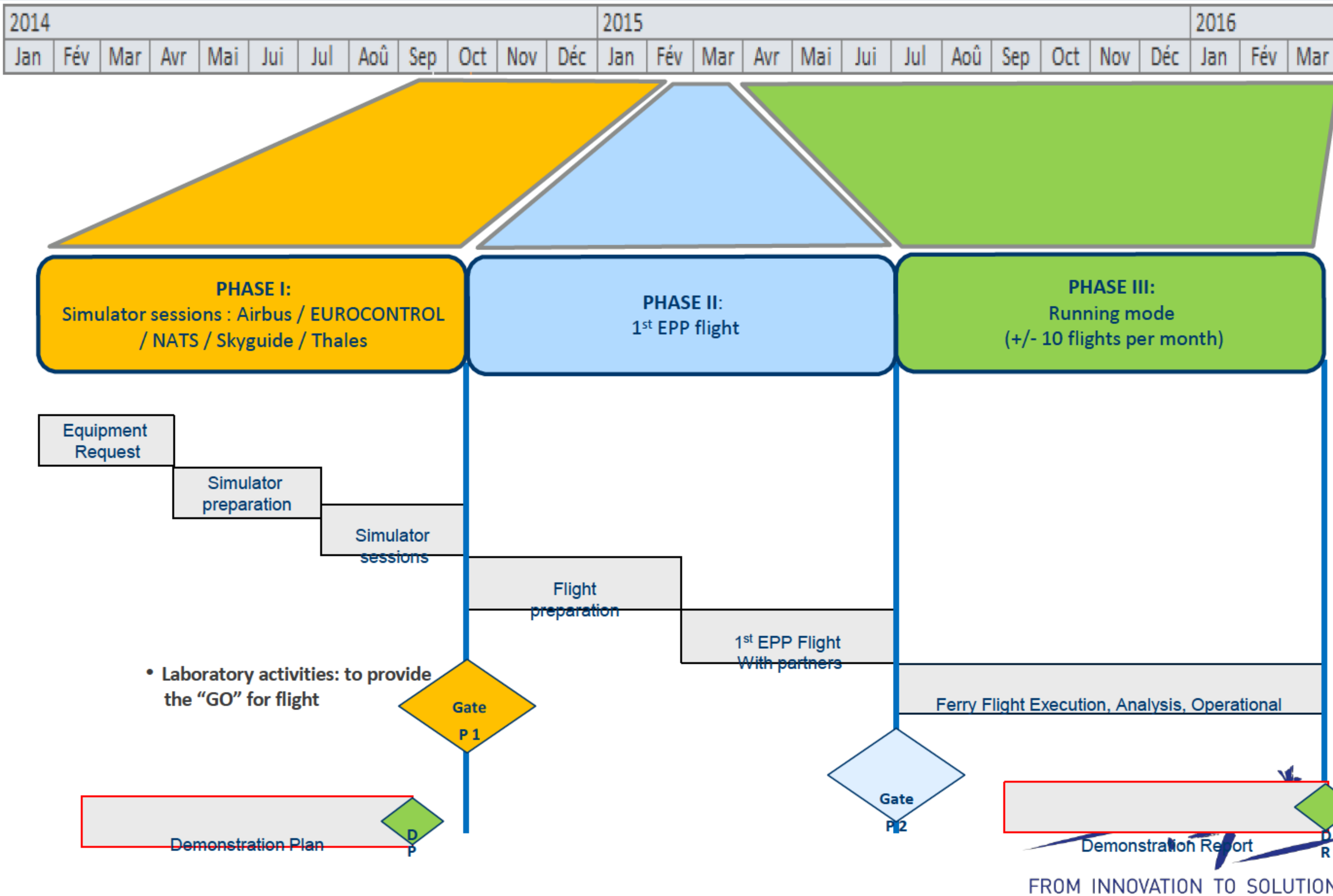
  - Record the ATC center F-Plan modification
  - Winds loading (manually or automatic TBC).

FROM INNOVATION TO SOLUTION

Logistic Aspects



FROM INNOVATION TO SOLUTION


2014
2015
2016
Jan Fév Mar Avr Mai Jui Jul Aoû Sep Oct Nov Déc Jan Fév Mar Avr Mai Jui Jul Aoû Sep Oct Nov Déc Jan Fév Mar
PHASE I:
Simulator sessions : Airbus / EUROCONTROL / NATS / Skyguide / Thales
PHASE II:
1st EPP flight
PHASE III:
Running mode
(+/- 10 flights per month)
Equipment Request
Simulator preparation
Simulator sessions
Flight preparation
1st EPP Flight With partners
Ferry Flight Execution, Analysis, Operational
• Laboratory activities: to provide the "GO" for flight
Gate P 1
Gate P 2
Demonstration Plan
D P
Demonstration Report
D R
FROM INNOVATION TO SOLUTION

- Illustrate EPP reliability, to foster ANSPs confidence on data usage.

- Confirm expectations for the efficiency of future ATC tools based on improved 4D accuracy:
  - Conformance Monitoring
  - Conflict Detection
  - Enhanced Arrival Management
  - ...

Specifically, with regards to benefits on:

  - Safety
  - Flight Predictability & flexibility
  - Airspace and Airport Capacity.

FROM INNOVATION TO SOLUTION

Thank You ..

Appendix E PEGASE Contract definition

EEC periodic

```
ADSRequestContract {
  periodic-contract {
    contract_number = 1
    reporting_rate {
      reporting-time-minutes-scale = 2
    }
    extended_projected_profile_modulus {
      modulus = 1
      extended_projected_profile_extent {
        number-of-way-points = 128
      }
    }
  }
}
```

EEC event

```
ADSRequestContract {
  event-contract {
    contract_number = 2
    extended_projected_profile_change {
      epp_reporting_window {
        number-of-way-points = 128
      }
      epp_event_type_trigger = { 7, 1111011x }
      epp_event_type_tolerance_trigger {
        continuous {
          epp_monitoring_window {
            number-of-way-points = 128
          }
          epp_tolerance_values {
            latitudelongitude_TOL1 = 5900
            level_TOL2 = 20
            time_TOL3 = 10
            time_percentage_TOL4 = 100
            air_speed_TOL5 {
              ias_TOL5 = 100
              mach_number_TOL5 = 100
            }
          }
        }
      }
    }
  }
}
```

MUAC periodic

```
ADSRequestContract {
  periodic_contract {
    contract_number = 0
```

```
    reporting_rate {
      reporting_time_minutes_scale = 5
    }
    extended_projected_profile_modulus {
      modulus = 1
      extended_projected_profile_extent {
        number_of_way_points = 40
      }
    }
  }
}
```

MUAC event

```
ADSRequestContract {
  event_contract {
    contract_number = 1
    extended_projected_profile_change {
      epp_reporting_window {
        number_of_way_points = 40
      }
      epp_event_type_trigger = { 7, 1111000x }
      epp_event_type_tolerance_trigger {
        continuous {
          epp_monitoring_window {
            number_of_way_points = 25
          }
          epp_tolerance_values {
            latitudelongitude_TOL1 = 5900
           level_TOL2 = 10
            time_TOL3 = 300
            time_percentage_TOL4 = 100
            air_speed_TOL5 {
              ias_TOL5 = 100
              mach_number_TOL5 = 100
            }
          }
        }
      }
    }
  }
}
```

Appendix F Data dictionary

Data provider	Data prefix	Name	Details	Content Originator	Original format	Processed	Distribution format	Formal format	Availability	Distributor	Media	Timing	Frequency	Comment
Airbus	A01	Flight plan and winds	Flight plan & winds dowloaded in FMS	Airbus	Flight plan format		Message Outlook.		Yes	Airbus	File	online	per flight	
Airbus	A02	A/C info	Date of flight, A/C configuration (FM, engine, DCDU installed, VDR), Immat, ICAO code & Flight ID.	Airbus	Excel File		Excel File		Yes	Airbus	File	online	per flight	
Airbus	A03	Flight Deck Information	Information/inputs from Flight Deck. Tactical instructions outside partners airspace	AIRBUS	A/C log, Hand writing and scan.	Partial	Scan and included in excel file	Yes	Partial	Airbus	File	offline	per flight	
Airbus	A04	AOC Data	AOC data - original planned take off mass, speed schedule, flight plan	AIRBUS	PFR and A/C log.	Partial	Scan and included in excel file	Yes	Partial	Airbus	File	offline	per flight	
ECTL	E01	Online ADS-C Report distribution		AIRBUS	DL Tool logs	Extraction	XER and PER as payload of SOAP Messages	Yes	Yes	ECTL	WSN	online	per flight	
ECTL	E02	Online Corrected ADS-C Report distribution		AIRBUS	DL Tool logs	Extraction + Correction	XER and PER as payload of SOAP Messages	Yes	Yes	ECTL	WSN	online	per flight	
ECTL	E03	ADS-C Reports (EEC)	Logged version of on-line distribution	AIRBUS	DL Tool logs	Extraction	Archive containing the PDUs in XER/PER	Yes	Yes	ECTL	File	offline	per flight	Several flights/days could be distributed at once. To be agreed
ECTL	E04	Corrected ADS-C Reports (EEC)	Logged version of on-line distribution	AIRBUS	DL Tool logs	Extraction + Correction	Archive containing the PDUs in XER/PER	Yes	Yes	ECTL	File	offline	per flight	Several flights/days could be distributed at

														once. To be agreed
ECTL	E05	DL Tools logs	Full Tool logs in EEC, includes 'human readable' interpretation of ADS-C reports	ECTL	DL Tool logs	No	Zipped logs	Sort of	To be confirmed	ECTL	File	offline	per day	Several flights/days could be distributed at once. To be agreed
ECTL	E06	ADS-C Reports (MUAC)		AIRBUS	DLFEP Logs	Extraction	Archive containing the PDUs in XER/PER	Yes	Yes	ECTL	File	offline	per flight	Several flights/days could be distributed at once. To be agreed
ECTL	E07	DLFEP logs	Full DL logs from MUAC	ECTL	DLFEP Logs	No	Zipped logs	Sort of	To be confirmed	ECTL	File	offline	per day	Several flights/days could be distributed at once. To be agreed
ECTL	E08	MUAC Radar Data		ECTL	Asterix	Extraction	An archive containing the CAT 62 messages per day	Yes (CAT62)	Yes	ECTL	File	offline	per day	The CAT 62 messages could be decoded
ECTL	E09	MUAC TP Data	Trajectory (4D) as presented to the ATCO.	ECTL	FPCO asn1	Yes	An archive containing the computed trajectories as list of points as presented to the ATCO.	XML format	Yes	ECTL	File	offline	per flight	
ECTL	E10	MUAC Controller inputs	Clearances/Instructions input by the controllers	ECTL	Odsinput asn1	Yes	An archive containing the received inputs by the MUAC FDPS from the ATCO's HMI.	XML format	Yes	ECTL	File	offline	per flight	

ECTL	E11	ECTL NM EFDs	Loggged version of an evolving prediction of the flight, starting with FPL and predicted wind data, augmented with activation data and position reports (various), each modification incidating its cause.	ECTL	ETFMS EFD oplog	Yes	An archive containing the computed trajectories as list of points.	To be provided (csv-like)	Yes	ECTL	File	offline	per flight
ECTL	E12	ECTL NM ENV data	List of point names and positions mentioned in the FPL and EFD, valid at the moment the FPL was flown. Explanantion of airways as lists of points for those airways mentioned in the FPL.	ECTL	geo-env CAC-D	Extraction	CSV files	csv for points: name, lat, long and separate csv for airways: name, pt, pt, pt, pt, pt, ...	Yes	ECTL	File	offline	per flight
ECTL	E13	Upper Wind & Temperature information	Provides upper wind & temperature information, as used by MUAC TP, for FL 050, 100, 180, 240, 300, 320, 340, 360, 390 & 530 spread over an horizontal grid.	WAFC London is provider (received via Brussels MET Office)	MWW	Yes	MWW	XML format	Yes	ECTL	File	offline	per day
ECTL	E14	ADS-B data	Flight Aware data	Flight aware	json	Yes	Zip	Original data + csv	Yes	ECTL	File	offline	per flight
NATS	N01	NATS Radar Data	Recorded radar track data within NATS radar coverage region.	NATS	NATS ARDAT format	Yes	CSV files	To be provided (csv)	Yes	NATS	File	offline	per flight
NATS	N02	NATS Flight Data	Recorded Flight Plan Data	NATS	CSV	Yes	CSV files	To be provided (csv)	Yes	NATS	File	offline	per flight
NATS	N03	NATS Tactical Instructions Data	Recorded NATS ATC tactical instructions.	NATS	CSV	Yes	CSV files	To be provided (csv)	Yes	NATS	File	offline	per flight

NATS	N04	ADS-B data	Provided by Flight Aware (subject to contract details)	Flight aware	CSV (TBC)	yes	CSV files (tbc)	To be provided (csv)	TBC	NATS	file	offline	per flight subject to ADS-B capability	
Skyguide	S01	FDP logs	Logs concerning the SFPL from the FDP system	Skyguide	FDP log	Extraction	Zipped logs	Sort of	To be confirmed We need the agreement of the Safety team	Skyguide	File	offline	per flight	Before sharing any data, the Skyguide's safety team shall agree on it
Skyguide	S02	Skyguide Radar Data	Radar traks concerning the SFPL.	Skyguide	Asterix	Extraction	An archive containing the flight CAT 62 messages	Yes (CAT62)	To be confirmed We need the agreement of the Safety team	Skyguide	File	offline	per flight	Before sharing any data, the Skyguide's safety team shall agree on it
Skyguide	S03	4D logs	4D logs concerning the SFPL.	Skyguide	4D log	Extraction	Zipped logs	Sort of	To be confirmed We need the agreement of the Safety team	Skyguide	File	offline	per flight	Before sharing any data, the Skyguide's safety team shall agree on it
Thales	T01	Raw sensor data	ASTERIX frames for PEGASE flights	Thales	ASTERIX	Extraction	Binary	Yes	If sensors are up	Thales	File	offline	per flight	When flight is within sensor coverage
Thales	T02	ADS-B data	Human readable ADS-B information for PEGASE flights	Thales	CSV	Extraction	CSV file	No	If sensors are up	Thales	File	offline	per flight	When flight is within sensor coverage
Thales	T03	Online reception	Timestamped datalink messages as received over G/G SWIM distribution	ECTL	CSV	Extraction	CSV file	No	If G/G distribution active	Thales	File	offline	per flight	

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