E.02.07-D10-TESA-D0.9-Final Project Report

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Abstract

The final report of the TESA project provides a publishable summary of the results. In addition it lists all deliverables, dissemination activities, eligible costs, deviations, bills and lessons learned.

Authoring & Approval

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This deliverable consists of SJU foreground.

Table of Contents

List of tables

Publishable Summary

Due to the rapid increase in air travel, there is an urgent need to increase enroute-to-enroute airspace capacity and improve safety without negatively impacting the environment. The current tactical approach to Air Traffic Management (ATM) is unable to meet future capacity, safety and environmental demands. A new strategic, collaborative and automated approach to ATM is required worldwide. A key aspect of collaboration and automation is the need to guarantee common situational awareness between all stakeholders as a function of time, extrapolated into the future. The aim of TESA (Trajectory prediction and conflict resolution for Enroute-to-enroute Seamless Air Traffic management) was to develop reliable Trajectory Prediction (TP) and Conflict Detection and Resolution (CDR) capabilities, with the specific objectives to address the sources of error (uncertainty) in TP and to use the improved TP to optimise CDR (thereby enhancing safety). The TP and CDR models were to be validated with real operational aircraft data and sensitivity analysis undertaken to characterise performance.

The objectives were to be achieved through the execution of the specific tasks to:

- develop a detailed understanding of the SESAR Concept of Operations (ConOps) and the corresponding requirements for Decision Support Tools (DSTs) with a specific focus on Trajectory Prediction (TP) and Conflict Detection and Resolution (CDR);
- develop a TP tool with optimal performance enabling the simulation of gate-to-gate trajectories in advance of aircraft operation, including complex manoeuvres and airport surface movement.
- develop the capability to simulate the impact of the uncertainties in the drivers of TP performance on TP uncertainties.
- carry out a sensitivity analysis on the principal sources of TP uncertainties and model these uncertainties, leading to the development of the capability to predict TP uncertainties.
- evaluate TP performance against real data.
- use the TP tool to develop a Conflict Detection (CD) tool and test it with real data.
- develop optimised Conflict Resolution (CR) capabilities on the basis of the new TP and CD tools and test them with relevant data.

During the course of the project most of the effort was allocated to the development of the TP tool. Development of the CD tool was done with much lower effort and testing involved limited simulated data only. CR research comprised a high-level study of conflict resolution methodologies based on the new TP and CD models.

In line with the refined scope and objectives of the TESA, the following achievements and innovations have been realised:

- The various elements of the SESAR concept that require the support of TP and CDR were determined. The functionalities of the tools for each of the concept elements were identified, and a framework developed for the derivation of the requirements for each of the elements. From the mapping of the requirements to the state-of-the-art, it was determined that many of the SESAR concept elements cannot be supported fully by current state-of-the-art TP and CDR tools. The main limitations are the complexity of the contextual constraints, uncertainties in the environmental parameters and aircraft performance, as well the computational resources required for real-time processing (for the elements that require real-time updates).
- Based on the findings above, instead of targeting a specific performance, TESA developed the best possible TP capable of predicting trajectories gate-to-gate in advance of the operation. This was achieved by extending Imperial College London's enroute TP capabilities to the TMA and taxiing over time horizons of any duration under ideal conditions. The main innovations here were new models to reduce ambiguity and complexity of aircraft intent representation for complex manoeuvres, and accounting for aircraft dynamics and operational limitations (e.g. performance limits) as well as the wind impacts during such procedures. For taxiing, a simple model of surface friction was developed. All models were developed on the basis of real data from flight-data records. Under ideal conditions, the enhanced tool (HIPER-TP) achieved maximum absolute errors with respect to a real trajectory of 2nm (along-track), 36 seconds (along-track), 0.32 nm (cross-track) and 575ft (altitude) over a look-ahead time of approximately two hours.
- In order to account for the various sources of uncertainty in trajectory prediction, TESA developed the capability to simulate TP uncertainties and carried out a sensitivity analysis on the principal sources to

determine those that require further modelling. The uncertainties considered were: initial position, wind, temperature, pressure, initial mass, and fuel-flow rate. The results from the sensitivity analysis showed that the largest sources are the uncertainties in the initial mass, as well as the along-track and cross-track components of wind. The impact of the control uncertainties was found to be most significant during the TMA phase of flight due to the significantly more complex manoeuvres.

- The simulated uncertainties were used to develop a predictive TP uncertainty model distinguishing between two primary error sources: model and input data. TP model errors were developed on the basis of real Flight-Data-Record (FDR) data as a function of aircraft operational state. Input data errors were taken from relevant data sources were available and, in the absence of relevant documentation, assumptions were made on the remaining input data errors. TESA developed a strategy for combining these two error sources to obtain a conservative estimate of predictive TP uncertainties.

- TESA developed a performance evaluation strategy for HIPER-TP, including its uncertainty modules. The evaluation strategy focussed on both short- and long-term predictions, with look-ahead times covering the entire duration of a flight. An important finding was that the accuracy of the TP 4D state-parameters is not sufficient to guarantee a representative aircraft configuration: the same trajectory can be achieved with different aircraft configurations. TESA thus iteratively optimised the TP model by minimising 4D position errors as well as aircraft control parameter errors (e.g. thrust and drag), speed and mass errors. While the 4D state parameters (longitude, latitude, height and time) are the primary parameters of TP accuracy performance, the prediction performance of the remaining parameters (referred to as secondary parameters) is also important. These secondary parameters are a direct reflection of the level of realism with which the trajectory has been simulated. Another key performance metric assessed by TESA is TP integrity, a measure of the level of confidence that can be placed in the tool. The performance was evaluated using real FDR data, comparing the predicted parameters under ideal and error-conditions from the TP engine with the observed parameters from the FDR data. The results show that the currently proposed accuracy performance targets for Time-Of-Overfly over a given point (set at 30 seconds – 95% – for the en-route phase of flight [ED75 - Addendum]) can be met. However, the target of 10 seconds (95%) for the TMA phase of flight is unlikely to be met.

- On the basis of HIPER-TP, TESA developed a sophisticated Conflict Detection (CD) model that takes into consideration the uncertainties associated with TP, which are predicted ahead of time. This enables not only short-term conflict detection, but also the detection of conflicts over much larger volumes and time-horizons, thereby adding a holistic dimension to conflict detection. Current CD approaches typically assume a constant conservative uncertainty volume surrounding each aircraft, which mostly overestimates, but at times underestimates the collision risk. Such approaches therefore are likely to generate false alerts and occasionally missed detections. TESA's approach predicts the instantaneous uncertainty volume at each point in space and time, ahead of time, accounting for the predicted TP uncertainties separately in each dimension. This volume is dynamic in all dimensions and representative of the predicted contextual conditions prevailing at the time at which the aircraft is predicted to pass the given point. It thereby enables a realistic and optimal detection of conflict risk, improving not only accuracy but also reliability and robustness. Furthermore, by predicting TP uncertainties ahead of time over the duration of an entire flight, the CD tool is able to provide a holistic assessment of conflicts, thereby enabling a more strategic approach to the generation of optimised conflict-free trajectories. As a result, TESA's HIPER-CD tool should generate less false alerts and missed detections and thereby better determine the instantaneous existence of a conflict. Given the lack of FDR data, the evaluation of the performance of HIPER-CD was based on simulations only. The tool was successfully tested using a number of selected simulated encounter scenarios, representative of potential actual scenarios. The scenarios tested included level crossing conflicts, vertical conflicts, longitudinal conflicts and no-conflict scenarios.

- Building upon HIPER-TP and HIPER-CD, TESA developed a high-level strategy for conflict resolution, with the goal to take into account stakeholder preferences and maximise the safety and minimise environmental impacts of trajectory based operations from a holistic perspective. Key novelties enabled by the TESA developments are: improved prioritisation logic on the basis of actual collision risk during conflict resolution in the presence of multiple conflicts and improved resolution trajectories due to the more accurate trajectory uncertainty constraints.

TESA has made significant contributions to the development of new Trajectory Prediction (TP) and Conflict Detection (CD) tools, and formulation of high level resolution strategies to improve automation systems for future air traffic management. TESA's work has produced 7 deliverables and 4 peer-reviewed journal papers, 2 conference papers, and contributed to RTCA/EUROCAE standardisation as part of RTCA SC227 and EUROCAE WG85. TESA has already provided key inputs to several second call SESAR WP-E projects, including FLITE and iMET, thereby ensuring continued relevance.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and in progress). Where appropriate, provide feedback from presentations. Describe exploitation plans.
- Provide a complete overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies).
- Analyse the lessons learnt at project level.

Note on project re-scoping. During the course of the project it was agreed that the original objectives proposed in the tender were over-ambitious. In particular a comprehensive conflict resolution model would be highly demanding and would divert effort from completing the high quality TP. The proposal was discussed and agreed during the mid-project gate meeting (see report) and was captured in a new plan followed by a formal change request.

1.2 Intended readership

This document is intended for developers of ATM tools, ANSPs, and regulatory bodies focussed on increasing capacity and safety and on minimising environmental impacts of aircraft operations. In addition it is relevant to the activities of standardisation bodies.

1.3 Inputs from other projects

N/A

1.4 Glossary of terms

Term	Definition
3D	Three-dimensional
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
CD	Conflict Detection
CDR	Conflict Detection and Resolution
CPLX	ComPLeX
CR	Conflict Resolution
DST	Decision Support Tool
ENV	ENVironmental
FCR	Fuel Consumption Rate

Term	Definition
FMS	Flight Management System
FPA	Flight Path Angle
FPL	Flight Plan
HIPER	High PERformance
ICAO	International Civil Aviation Organisation
ICL	Imperial College London
ROCD	Rate Of Climb-Descent
RTCA	Radio Technical Commission for Aviation
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
TESA	Trajectory prediction and conflict resolution for Enroute-to-enroute Seamless Air Traffic management
TMA	Terminal Manoeuvring Area
TP	Trajectory Prediction

2 Technical Project Deliverables

Management deliverables such as progress reports, gate report or this final report need not be included.

Number	Title	Short Description	Approval status
D0.0	Project Plan	Project Plan including dissemination strategy.	Approved
D1.1	Operational Concepts Definition	Review of the SESAR ConOps elements that require the support of trajectory prediction and conflict detection and resolution tools; identification of functionalities and development of framework for derivation of requirements.	Approved
D1.2	Trajectory Prediction Algorithms	Description of the elements of ICL's Trajectory Prediction (TP) tool that were developed to enable complex manoeuvres in the TMA and to enable basic airport surface movement.	Approved
D1.3	Trajectory Prediction Evaluation Strategy	Description of the performance evaluation strategy of ICL's Trajectory Prediction (TP) tool.	Approved
D1.4	Trajectory Prediction Algorithms – Ideal and Uncertainty Conditions	Review of the new elements of TP developed within TESA and description of the TP uncertainty model	Approved
D2.1	Conflict Detection Algorithms and Evaluation Strategy	Description of the developed algorithms and performance evaluation strategy	Approved
D3.1	Trajectory Prediction Validation Results	Description of the performance evaluation of ICL's Trajectory Prediction (TP) tool.	Approved
D3.2	Conflict Resolution – High-level Methodology	This document addresses conflict resolution for future Air Traffic Management. It builds upon TESA Deliverables D1.4 and D2.1 to develop a high-level methodology for conflict resolution, with the goal to maximise the safety of trajectory based operations based on stakeholder preferences.	Approved

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

1. Paper at the SESAR Innovation Days, Toulouse (2011): Trajectory prediction and conflict resolution for Enroute-to-enroute Seamless Air traffic management – TESA. The paper addresses the objectives of TESA and the proposed methodology to address these objectives.
2. Poster at the SESAR Innovation Days, Braunschweig (2012): Addressing Uncertainty in Future Decision Support Tools – TESA. The poster provides an overview of the sensitivity analysis of input data errors on TP uncertainties.
3. Journal Paper in the Journal of Air Transport Management (2013): Performance Requirements of Future Trajectory Prediction and Conflict Detection and Resolution Tools within SESAR and NextGen: Framework for the Derivation and Discussion. The paper reviews the key functions of the TP and CDR elements of DSTs in relation to the SESAR ConOps applications. It discusses the key performance drivers, derives performance metrics and develops a framework for the derivation of TP and CDR performance requirements, to support industry and standardisation bodies in the harmonisation process. A mapping exercise is undertaken to identify which of the functionalities are supported by state-of-the-art TP and CDR tools (in the public domain) and establishes those that require further research and development, highlighting some of the key challenges. (In Press).
4. Journal Paper in the Aeronautical Journal (2013): Gate-to-gate advanced trajectory prediction for future Air Traffic Management. The paper describes the novel techniques developed within TESA to predict aircraft trajectories for the ground-phase and for the transitions between the ground- and enroute-phases of operation, thereby enabling gate-to-gate (or enroute-to-enroute) Trajectory Prediction (TP). Performance results are described. (Under review).
5. Journal Paper, to be submitted to ATC Quarterly (2013): Uncertainties in future trajectory predictors – sensitivity analysis. This paper develops novel techniques to assess trajectory predictor uncertainties. The error sources associated with trajectory prediction are assessed and a sensitivity analysis of select parameters is carried out. (In preparation).
6. Journal Paper, to be submitted (2014). Conflict Detection and Resolution - Identification of Issues under SESAR. This paper will describe the conflict detection and resolution methodology developed within TESA. (In preparation).

3.2 Presentations/publications at other conferences/journals

N/A

3.3 Demonstrations

Presentation of the TP tool to Eurocontrol, Maastricht (2011): High-Performance Trajectory Prediction Tool.

3.4 Exploitation plans

- The tool developed within TESA will form a key element for the WP-E FLITE project.
- The research carried out within TESA has provided key inputs into standardisation bodies: RTCA SC227 and EUROCAE WG85.
- TESA is expected to provide key inputs to the WP-E iMET project.
- TESA forms the basis for wider research on the efficiency, capacity, safety and environmental impacts of gate-to-gate operations. This includes research at Imperial into Collaborative Airport Approaches (CAOs) and localised environmental impacts.

4 Total Eligible Costs

This section is based on the Project Costs Breakdown Forms of the eligible costs incurred by project participants.

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
20-Dec-2011	D0.0 + D0.1 + D1.1	29,221.97	2,172.67(Overheads);544.23(Travel)	*Paid*
24-May-2012	D0.0 + D0.1 + D1.1		1,271(Travel)	*Paid*
28-Nov-2012	D0.3+D1.2+D1.3	58,976.64	4,261.82(Overheads);1,906.40(Travel)	*Paid*
25-Nov-2013	D0.4+D0.5+D0.6+D0.7+D0.8+D0.8+D0.9+D2.1+D2.2+D3.1+D3.2	170,142.49	12,201.61(Overheads);3,459.41(Travel;,706.79(Other)	*Billed*
GRAND TOTAL	All deliverables combined	258,341.10	18,636.10(Overheads);7,181.04(Travel);706.79(Other)	

Table 2 Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
Imperial College London	570	1091	258,341.10	258,341.10	Significant additional human resource required.
GRAND TOTAL					

Table 3 Overview of Effort and Costs per project participant

5 Project Lessons Learnt

What worked well?
Project coordination was excellent
Review and approval of deliverables was good and timely
What should be improved?
Unable to complete full analysis of conflict resolution due to lack of time: the project duration of 30 months is much too short and should be increased.
Lack of links with other SESAR projects.
Administrative procedures are too complex.
Better access to relevant data (within SESAR) is needed.

Table 4 - Project Lessons Learnt