Final Project Report WP-E

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Abstract

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

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This deliverable consists of SJU foreground.

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Publishable Summary

Introduction and problem statement

Early 2015 headlines in newspapers and aviation journals touted: accident rates in commercial aviation are the lowest ever. This achievement is due to a continuing improvement effort. Accident rates in general aviation have stagnated however in the past decade. There is a significant gap in safety performance in commercial aviation and general aviation, with respective (estimated) accident rates of 6 and 100 accidents per 10 million flight hours. A specific occurrence category where commercial aviation is far outperforming general aviation is “mid-air collision”. In EASA Member States there are about 30 mid-air collisions involving a General Aviation (GA) aircraft for every mid-air collision involving a commercial aircraft. The ProGA study aimed to improve performance in this area by enabling better traffic awareness for GA pilots and alleviating their workload.

Initially SESAR had a clear focus on commercial aviation, especially the light GA integration into SESAR was taken into account to a far lesser extent. Although this is changing (see e.g. the SESAR Large Scale Demonstration project EVA - Electronic Visibility via ADS-B), the opportunities to use SESAR rationales for GA benefit are not yet fully utilized. SESAR’s idea behind 4D trajectories is to reduce uncertainty and thereby increase safety. ProGA took up the challenge to reduce uncertainty about the future position of surrounding - and possibly conflicting - traffic without the need for any pre-agreed trajectory. Such pre-agreed trajectory would be unacceptable for the GA community who wishes to maintain freedom of flight. Instead ProGA is able to estimate the future position of surrounding traffic based on information on typical behaviour of GA pilots and the intent of the flight.

The ProGA concept

Figure 1 summarises the ProGA prediction concept. GNSS traces of flown flight paths are acquired and processed to acquire a statistical characterisation of typical GA behaviour - ‘GA recurring patterns’. During the in-flight phase, the system element responsible for casting state-based predictions takes care of continually estimating the aircraft position and ground speed by filtering a signal-in of GNSS type. This state-based prediction is compared to the recurring patterns and shared flight intent, if available, to cast a longer-term intent-based prediction.

An operational implementation of the ProGA concept can provide three distinct functionalities:

- The presentation of areas with a significant probability of high traffic density during the intended flight, for use during the planning of that flight. These areas are derived from the statistical characterisation of GA recurring patterns, and, if available, declared flight intents of flights that will take place in the same time window as the flight that is being planned. The recurring patterns can also be used directly by a pilot to get acquainted with commonly used flight paths, especially around airfields.

- The cockpit display of areas with a significant probability of high traffic density and the cockpit display of GA recurring patterns for use during flight execution.

- The cockpit display of traffic, including their predicted future positions. These predictions will be shown as flight corridors.

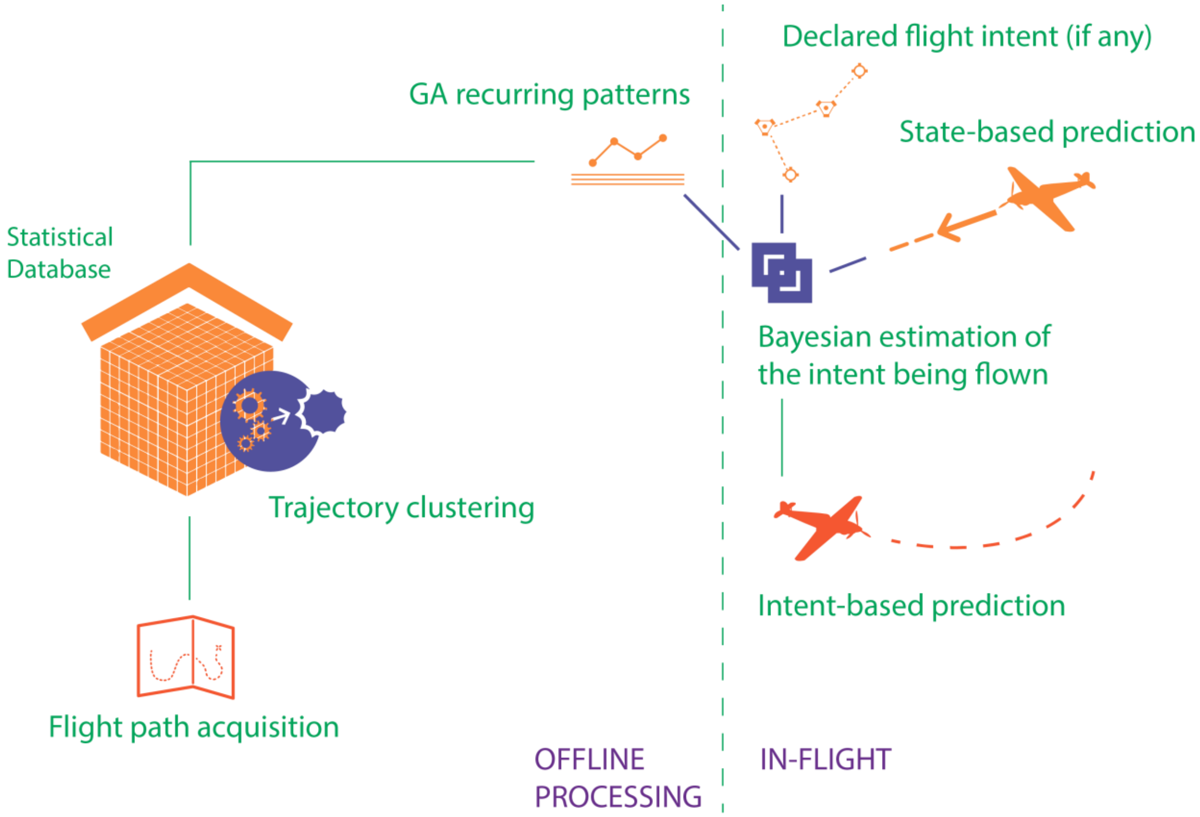

Figure 1 - Outline of the ProGA prediction concept

The study approach

One of the key elements of the ProGA concept is the derivation of GA recurring patterns. The first step in the project was therefore to analyse traffic data and develop definitions of typical GA flight patterns. To this end recorded flight paths from flights in France and the Netherlands were studied. The output of this analysis was used for the development of an algorithm that is able to translate GNSS traces into GA recurring pattern information. Additionally an algorithm was developed that used the GA recurring pattern information - together with shared flight intent - to estimate the flight corridor of an aircraft of which position and ground speed are known. A Human Machine Interface (HMI) was developed to present this information to a pilot using a tablet.

Parallel to the algorithm and HMI development a safety benefit analysis has been performed. The hypothesis of this analysis was that the ProGA concept should improve the situational awareness of a pilot and thereby reduce the probability that a GA aircraft comes in conflict with another conflict, with as ultimate outcome a mid-air collision. The safety benefit analysis studied both the beneficial and the detrimental effect of the concept. For the former a barrier diagram was developed to analyse on which barriers and precursors of a mid-air collision scenario ProGA could have an impact. For the latter a functional hazard analysis was carried out.

Preliminary validation of the concept was carried out by hosting a GA pilot workshop and by a real-time simulation session. In the workshop the ProGA concept was explained to acquire a synthesis of opinions on foreseen safety benefits and likely detrimental effects. For the real-time simulation a mock-up cockpit was made using Microsoft Flight Simulator for visuals and aircraft dynamics. GA pilots were asked to fly the aircraft and avoid conflicting traffic. Scenarios were performed with and without the use of ProGA. In the latter case conflicting traffic including their predicted flight corridor were display to the pilot using a tablet application. The Real Time Simulations were used to test the HMI and elicit opinions on foreseen safety benefits and likely detrimental effects.

Key results and future steps

In the project a prototype implementation of the ProGA concept is developed. The prototype consists of a flight simulator (cockpit and flight envelope simulation software, pilot commands, 3D scenery rendering), a ProGA central unit able to collect, elaborate and share data (traffic, flight intents, GA recurring patterns, actually flown flight paths) and to generate predictions, and a tablet application able to provide the pilot with flight corridor predictions of surrounding traffic. Figure 2 shows the main component of ProGA's user-interface: a moving map on which the own-ship (black arrow) and the surrounding traffic (yellow arrows) are displayed. When touching a yellow arrow a prediction can be requested. The predicted flight corridor (the collection of red lines) is then displayed on the map.

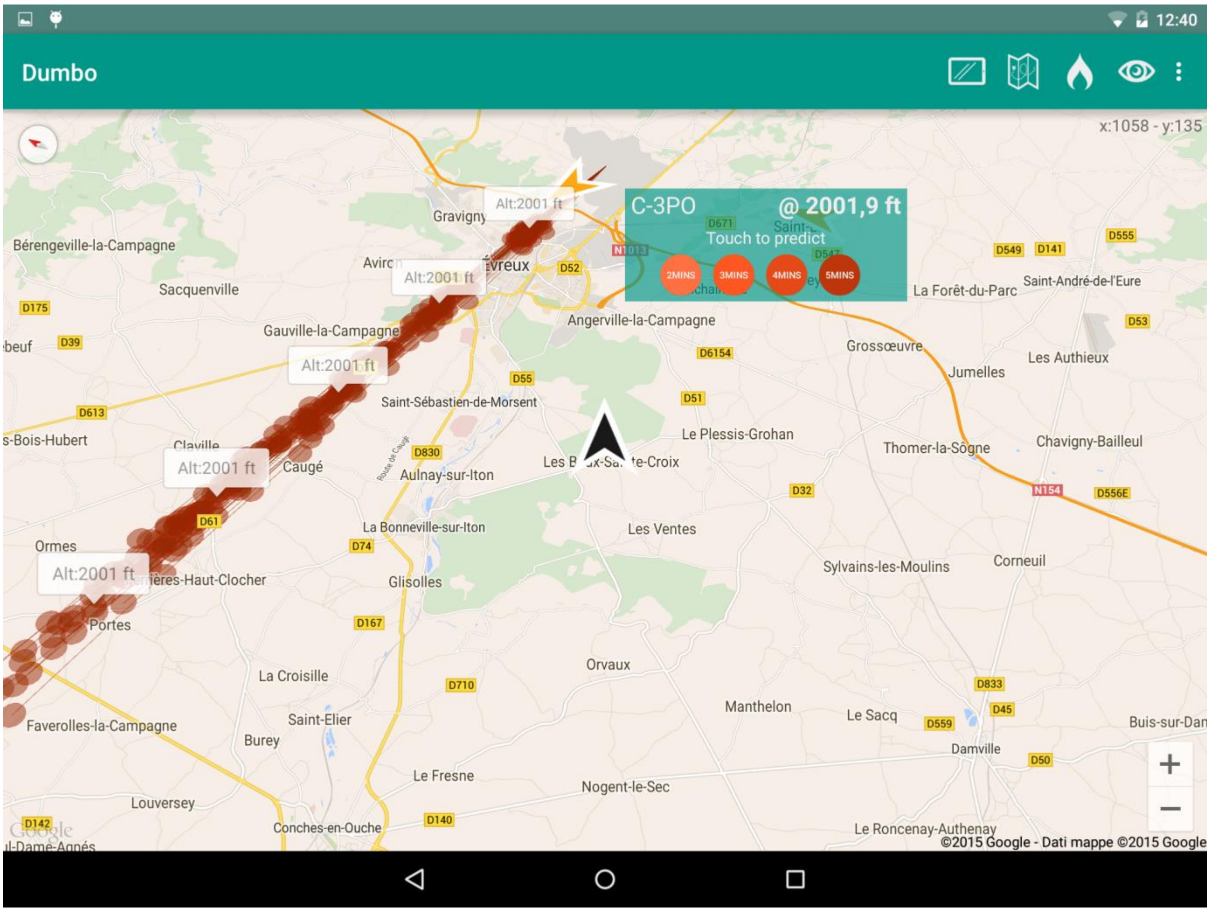

Figure 2 - Prototype human-machine interface for ProGA, including a predicted flight corridor

The key objective of the ProGA project was to study the feasibility of the ProGA concept. The concept evolves around the idea of estimating the near-future location of GA traffic. In the course of the project no definitive showstoppers are found. Introduction of ProGA functionalities gives a pilot tools to assure improved strategic conflict management, enhanced situational awareness, and an increased conflict horizon to resolve conflicts in. These attributes are likely to reduce mid-air collision rates.

The innovative idea of ProGA was researched in a time-frame of two years, so a fully functional system is not yet developed. However, the idea of providing GA pilots with advanced traffic information is thought to have benefits that warrant further investigation. The end outcome of such an investigation should be a thorough cost-benefit analysis. This analysis should weigh the quality of predictions needed for ProGA to be embraced by the pilots and the costs associated with that quality. Additional topics that require further study are: the essentiality of flight intents, the time it takes to collect sufficient GNSS traces to assure the development of useable GA recurring patterns, pilot acceptance of the concept, the human-machine interface and liability issues of the provision of safety sensitive information to the pilot that is difficult to validate.

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.

1.2 Intended readership

The intended readership of this deliverable is Eurocontrol and SJU.

1.3 Inputs from other projects

For this deliverable no input from other project is used.

1.4 Glossary of terms

Term	Definition
ATC	Air Traffic Control
GA	General Aviation
MAC	Mid-air collision
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D1.1	General aviation aircraft operation and related safety issues.	This deliverable describes the operations of light GA aircraft in the current air traffic management context and identifies the air traffic management safety issues faced by general aviation and by other traffic flying in close proximity of GA aircraft. The information provided in this report has been gathered through a field survey about the current GA community practices, real flight data are described and analysed. This data is used to set the grounds for the definition of the light GA aircraft monitoring concept and overall system architecture description that will be detailed in WP1.2. Recommendations are made to define a system making possible future safe and compatible light GA aircraft operations and SESAR compliant aircraft operations.	Approved
D1.2	GA aircraft monitoring concept and overall system architecture descriptions	This deliverable describes the ProGA monitoring concept and the associated overall system architecture enabling the integration of the operations of light GA aircraft in the future SESAR air traffic management context. Several system options are anticipated, starting with a system based only on real time observations and historical statistical flight path data up to a system in which pilots and ATC would add to the system real time data before and during the flight through various means. The analysis of the current situation in aircraft equipage and existing ground networks capabilities shows that the ProGA project objectives appear to be reachable.	Approved (not made public)
D1.3	Analysis of the total benefit brought by ProGA to the SESAR aviation system	This deliverable gives the final overview of the proposed ProGA concept: the functionalities, system needs and optional system architectures. It gives an overview of net safety benefits that can be achieved - taking into account possible detrimental effect - and costs associated to the concept.	Submitted
D2.1	Algorithm description and performance tests report	This deliverable describes how the approach to the prediction of light General Aviation flights has been designed and implemented, and provides some preliminary experimental evidences of its capabilities. These experiments demonstrate that the approach adopted by ProGA is promising and worthy of being further developed.	Approved
D2.2	Proof of concept description and Human Factors	This deliverable describes the Proof of Concept of the project. Within Work Package 2 an interactive prototype has been developed to investigate whether, to what extent and under which circumstances ProGA functionalities are able to address the needs of light	Submitted, review comments received and processed, re-

	assessment report	General Aviation pilots. The outcomes of an evaluation by means of both expert judgment and Real Time Simulations involving pilots are also presented in the document.	submitted
D3.1	Safety scoping, change assessment and safety criteria derivation	In deliverable safety criteria are derived. The accident type impacted by the change brought forth by ProGA is Mid-air Collision (MAC). The proposed ProGA applications aim to increase the time horizon in which an airborne conflict (a precursor to a MAC) can be solved. The overall safety criterion is to achieve a reduction in mid-air collision rate. From this overall criterion more detailed safety criteria are defined.	Approved
D3.2	Safety objectives and safety requirements derivation	This deliverable documents the derivation of safety objectives and safety requirements that need to be met to enable a reduction in mid-air collision risk. 8 safety objectives have been defined that describe what is needed to reduce pre-existing risks. 12 safety objectives have been defined that describe what is needed to minimize newly generated hazards. 27 safety requirements have been defined that describe how the objectives can be met. ProGA will enable a reduction in mid-air collision rate in case all safety objectives are achieved by meeting all safety requirements.	Submitted, review comments received and processed, re-submitted

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

SESAR Innovation Days - 26-28 November 2013 - Stockholm - poster presentation

A poster was presented to introduce the project, see Figure 3.

Figure 3 - Poster as presented at the 2013 SESAR innovation days

ICRAT - May 2014 - Istanbul - paper presentation

<u>Paper title</u>: Prediction the future location of a General Aviation aircraft [1]

Abstract: To date, scheduled, business and military aviation are well represented in the SESAR Concept. Low-end light GA is currently taken into account and integrated into SESAR to a far lesser extent. SESAR WP-E project ProGA aims to bridge this gap and has as objective to study the feasibility of a system that can continually and automatically predict the future GA aircraft's flight corridor or its volume of operation. This paper describes the foreseen system's input, the approach to the prediction process and to the way the system can interact with air traffic management. An important input for the prediction process is a statistic of historical flight paths acquired by the system. The compiled flight path information can be used to describe standard GA behaviour and to predict the likely future flight corridor or volume of operation. This information can be used by ATC as it gives additional data about aircraft approaching controlled airspace and it triggers an alert in case of risks of airspace infringements.

Feedback: The paper won a best paper award.

SESAR Innovation Days - 25-27 November 2014 - Madrid - paper presentation

Paper title: Traffic predictions supporting General Aviation [2]

Abstract: General Aviation (GA) pilots are responsible to stay well-clear of other traffic and avoid conflicts. This paper outlines a research that is aimed to enlarge the time horizon over which a GA pilot can solve a conflict. This is done by moving beyond state-based predictions to intent-based predictions of flight paths. The idea is to use a stochastic filter with a dynamical model that embeds a notion of flight intent. This flight intent can either be estimated by comparison to a statistic of recurring GA flight patterns or by using intents that are shared prior to flight. A preliminary assessment of the prediction concept showed promising results: the algorithm is capable of producing realistic longer-term predictions, also in the presence of turns and sudden changes of the pilot's flight intent.

USA/Europe Seminar on ATM R&D - 23-26 June 2015 - Lisbon - paper (not accepted)

Paper title**:** The benefits of intent-based flight path predictions for conflict management in general aviation [3]

Abstract: In Europe there are about 30 mid-air collisions involving a general aviation (GA) aircraft for every mid-air collision involving a commercial aircraft. GA performance in this area can be improved by enabling better traffic awareness for GA pilots. In airspace classes where no separation services are provided by ATC, GA pilots are responsible to stay well-clear of other traffic and avoid conflicts. This paper outlines potential safety benefits enabled by an innovative concept that enlarges the time horizon over which a GA pilot can solve a conflict. This is done by moving beyond short-term state-based predictions to longer-term intent-based predictions of future flight paths. State-based predictions assume a fixed direction of flight, while intent-based predictions include knowledge on future turns or altitude changes. A preliminary assessment of the prediction concept showed promising results: the developed algorithm is capable of producing realistic longer-term predictions, also in the presence of turns and sudden changes of the pilot's flight intent. The concept encompasses three main functions: (a) the presentation of areas of potential high traffic-density for use during flight planning (b) the cockpit display of areas with a significant probability of high traffic density for use during flight execution, and (c) the cockpit display of traffic in the surrounding, including their predicted future flight paths. The first two options enable improved strategic conflict management; a pilot can choose to avoid busy areas. The last option enables improved tactical conflict management; a pilot's time horizon to identify future conflicts is increased and traffic awareness is improved.

Feedback: The paper was not accepted. The following feedback was received: "The paper was reviewed by 3 members of the progam committee. It is well written, and organized. The paper presents the ProGA concept and project. The objective of the project is to provide General Aviation Pilots with tools that can help them dealing with the encountered traffic. The idea is to give pilots the trajectory intents of the surrounding aircraft. The step of introducing intents for improving trajectory planning is valid and covered in various research activities. However, uncertainty boundaries of building intent from statistical analysis of recurrent patterns appear as being quite big. No mention is made of the potential risks of giving to pilots wrong information on intents. No experimental validation is proposed, the paper only refers to pilots interviews. As the authors say, "the concept is expected to introduce safety benefits". A lot of pilot conjecture is included. The idea lacks validation to be published. The authors refer to a previous paper which seems to deal with most of the technical aspects of the problem. No reference is made to many existing machine learning techniques applied to trajectory prediction.

3.2 Presentations/publications at other conferences/journals

Presentation at EGAST meeting - 25 November 2014

ProGA was presented at a meeting of the European General Aviation Safety Team (EGAST) in November 2014. Although it is a rather practical platform (not so much research oriented) there was positive feedback, especially the idea of determining and presenting hot-spots was found interesting.

3.3 Web presence

Project website: http://proga.nlr.nl/

The website contains a description of the project (background, objectives, work packages), contact details and a list of publications.

3.4 Demonstrations

No demonstrations were given, besides simulation sessions at Deep Blue premises to validate HMI design choices and hypothesized safety benefits (results documented in Deliverable D2.2).

3.5 Exploitation plans

NLR was responsible for WP3: the safety benefit analysis. This has increased the experience and knowledge in applying the SESAR safety assessment methodology for innovative technologies that do not yet have a clear concept of operation. This knowledge will be used in future SESAR projects.

ONERA was responsible for WP1 (Requirements and concept validation) and was enthusiastic in starting the ProGA project in its original version, in anticipation to bringing high benefit in safety to GA aircraft (being cooperative and having in consequence a better situational awareness) and improving also safety of commercial traffic through an easier identification of airspace infringement risks (detection of aircraft having a behavior that does not meet statistical standard behavior of other aircraft). However, to meet SJU wishes, a redirection of the project has been made toward a system that brings benefit to GA pilots only at a cost that may make it difficult to implement. In parallel, since the proposal of the ProGA project was made, the development of a ground network named Open Glider Network, utilizing FLARM, comparable to the one proposed in the original ProGA project, has grown in Europe at an incredible pace; several hundreds of receivers are already active in 2015 all over Europe, from 0 in 2012. FLARM is used to lower the risk of collision whereas the ground network is used for surveillance and post-crash search and rescue purposes. ONERA continues to work on this concept, hoping that a conflict, identified on OGN and FlightRadar 24 (they are interconnected) but not on conventional radars and ADS-B equipment, does not end in a catastrophic event.

Deep Blue was responsible for WP2 (Proof of Concept) and has gained a considerable experience by the analysis of needs for light General Aviation pilots. The development of an HMI prototype for GA and its validation through Real Time Simulations has been an opportunity to further extend company's know-how about usability and aviation domain suitability for innovative mobile technologies. Research about innovative Trajectory Prediction algorithms establishes a strong grounding for future R&D projects within SESAR and H2020 framework.

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
2 July 2014	D0.1, D0.2, D1.1, D1.2	€104,236.82	€4,229.16 (travel)	Paid
3 December 2014	D0.3, D0.4, D0.5, D2.1, D3.1	€152,211.49	€3,873.57 (travel)	Paid
Invoice 3*	D0.6, D0.7, D2.2, D3.2	€152,717 ex. VAT	€7,500 (equipment) + travel (tbd)	Due
Invoice 4*	D0.8, D0.9, D1.3	€104,307 ex. VAT	travel (tbd)	Due
GRAND TOTAL		=< €503,230 ex VAT (including other costs)		
* Invoices due. 'Contribution for Effort' based on payment schedule (November 2014)				

Table 2 - Overview of Billing

Company	Planned man-days*	Actual man-days	Total Cost*	Total Contribution*	Reason for Deviation
NLR	280	300 (estimate)	€277,261	€207,946	Larger 'actual man-days' than 'planned man-days' will not result in a total contribution higher than €207,946.
Deep Blue	365	368 (estimate)	€150,512	€112,884	
ONERA	250	155 (end of May)	€211,601	€158,701	Lower 'actual man-days' than 'planned man-days' due to the redirection of the project objectives.
GRAND TOTAL	895	825 (estimate)	€639,374	€479,531	
* Based on 12-120610 i-AF32-AO annex I_ProGA, actual contribution might vary					

Table 3 - Overview of Effort and Costs per project participant

5 Project Lessons Learnt

What worked well?
There is good support from the Project Officer, especially in his role as liaison between the project and SJU. This allowed the project to continue work after SJU posed concerns regarding the project direction.
The SESAR Innovation Days provide a good platform for sharing results and experiences from WPE research.
The subject matter experts from AOPA, SJU and Eurocontrol provide good support and valuable feedback. This allowed us to improve our work.
WPE offers the possibility to work on innovative ideas. WPE works as a funnel to assure the most promising research areas can be studied further towards actual implementation.
The good cooperation between consortium partners. The different expertise helped in achieving well-balanced project results.
What should be improved?
Agree on project approach with SJU as early as possible. A SJU representative should be present at the kick-off meeting.
The availability of flight path data should have been checked earlier in the project, preferably in the proposal phase.
Cooperation with the other GA-related project 'AGATHA' never really materialized.
Difficult to acquire 'opinion' of GA community since it is such a diverse field.
Deliverable review should take less time.

Table 4 - Project Lessons Learnt

6 References

[1] Claude Le Tallec, Damiano Taurino, Carlo Lancia and Joram Verstraeten, Predicting the future location of a General Aviation aircraft, ICRAT 2014

[2] Carlo Lancia, Damiano Taurino, Giuseppe Frau, Joram Verstraeten and Claude Le Tallec, Traffic predictions supporting General Aviation, SID 2014

[3] Joram Verstraeten, Carlo Lancia, Damiano Taurino, Giuseppe Frau, Claude Le Tallec, The benefits of intent-based flight path predictions for conflict management in general aviation, 11th USA/Europe Air Traffic Management Research and Development Seminar, ATM2015, *not accepted*