FLYSAFE – WP 6.7.3

D6.7-3 Public - Final Publishable Report

Abstract:

This document is the final publishable report of the FP6 FLYSAFE project. It describes the work performed during the project and the main deliverables produced. The main achievements of FLYSAFE are also detailed, with a view of the validation process performed and an overview of the main results. Finally, recommendations for future projects are submitted, to carry on FLYSAFE results.

Contract Number:	**AIP4-CT-2005-516167**	**Proposal Number:**	**FP6 - 516167**
Project Acronym:	**FLYSAFE**		
Project Co-ordinator:	**THALES AVIONICS**		

Document Title:	Final Publishable Report			**Deliverable:**	D6.7-3 PUB
Document Id N°:	FLY_673THA_PUB_A	**Version:**	A	**Date:**	25/05/2010
Status:	Version A for delivery				

Filename:	FLY_673THA_Final Publishable Report.doc

Project Classification:	Public

Approval Status		
Document Manager	**Verification Authority**	**Project Approval**
THALES Avionics	THALES Avionics	PMC
Marc Fabreguettes	Catherine Le Bris	PMC members
Project Manager	Project Controller	

This page is intentionally left blank.

Revision Table

Version	Date	Modified Pages	Modified Sections	Comments
A01	18/03/09			First draft
A02	15/06/09			Complements from other partners
A03	30/11/09			With results from MTE and Flight tests
A04	15/01/10			PMC Approval
A05	25/05/10			Approved with comments
A	14/07/10			Delivered to the EC

This page intentionally left blank.

Table of Contents

Executive Summary

This document is the final publishable report of the FP6 FLYSAFE Project.

It is divided in four main parts:

- Presentation of the project, with a reminder of the objectives and their motivations. (section 1)
- Administrative aspects (sections 2 to 4)
- Main achievements (section 5)
- Conclusion, recommendations for future research (section 6)

1. FLYSAFE PRESENTATION

1.1. SCOPE AND OBJECTIVES OF FLYSAFE

1.1.1. Background

Air traffic is expected to triple world-wide within the next 20 years. With the existing onboard and on-ground systems, this would lead to an increase of aircraft accidents, in the same, or a higher proportion. Despite the fact that accidents are rare, this increase is perceived as unacceptable by society and new systems and solutions must be found to maintain the number of accidents at its current low level. As safety of flight depends to a large extent on flight crew actions it is essential that crewmembers are supplied with reliable information that can be used at all times. FLYSAFE has contributed to this goal in developing the required new systems allowing the crew to make the right decision to avoid conflicts caused by weather, traffic and terrain."

1.1.2. Project Objectives

FLYSAFE has been the first decisive big step towards the "VISION 2020" produced by the ACARE, for safety in flight operations. It has designed, developd, implemented, tested and validated a complete Next Generation Integrated Surveillance System (NG ISS), going a decisive step further than the emerging integrated safety systems.

FLYSAFE focused particularly on the areas identified as the main types of accidents around the world: loss of control, controlled flight into terrain, and approach and landing accidents. It has addressed three types of threats: adverse weather conditions, traffic hazards and terrain hazards. For each of them it has developed new systems and functions, notably: improved situation awareness, advance warning, alert prioritisation, and enhanced human-machine interface.

FLYSAFE has also developed solutions to enable aircraft to retrieve timely, dedicated, improved weather information, by means of a set of Weather Information Management Systems (WIMS). These WIMS are able to gather, format and send to the aircraft all essential atmospheric data, as relevant for the safety and efficiency of their flight. This uplinked data has been be presented in an innovative and consistent way to the crew. Innovative prediction capabilities have been deployed, both on board of the aircraft and on the ground, to provide warnings which are optimised with respect to the simultaneous constraints of safety and airspace capacity.

1.1.3. Description of the work

The project started with a review of the results of past and on-going investigation of accidents and incidents, the identification of contributing causes, and the definition of ways to address them.

The results of this analysis was then used to set up new, high level functional requirements and feed the pilot evaluation tasks with scenarios that were used to assess new versus state-of-the-art technologies.

The three main types of hazards sources for aviation: adverse atmospheric conditions, traffic and terrain, have led to the creation of three project branches, with a fourth branch dedicated to the development of the Next Generation Integrated Surveillance System itself with the integration of the design solutions.

- "Atmospheric hazards" developed means to increase the awareness and fidelity onboard aircraft with regard to all major sources of atmospheric hazards (wake vortex, windshear, clear air turbulence, icing, and thunderstorm).
- "Traffic hazards" developed means to increase the crew traffic situation awareness and provide them with early information on potential traffic hazards along the flight path.
- "Terrain information management" developed means to increase the crew terrain and obstacle situation awareness and provide them with the terrain and obstacle hazards along the flight path and functionalities that enable the crew to avoid conflict with terrain and obstacles.

As part of the NG ISS, innovative system functions were developed, notably:

- Strategic data consolidation to anticipate any identified strategic risks related to atmospheric phenomena, traffic and terrain, along the planned flight path of the aircraft. This function is to reduce the number of tactical alerts generated inside the cockpit by anticipating those threats and advising the crew where a replanning is required.
- Tactical alert management to help the crew to manage all alerts generated by the "safety net" functions, such as TCAS, TAWS, and windshear, i.e. for those situations where an immediate response is required.
- Intelligent Crew Support to provide support for the crew in the event that they may make an error or a mistake caused by high workload, fatigue, anxiety, etc, by monitoring flight phase, environment and crew actions.

Standardisation activities were undertaken for the introduction and promotion of future products, thus reducing the time to market. The certification aspects of these new concepts was taken into account from project start onwards, to at least reveal the areas of certification issues.

Finally, the validation of the complete system, and proof of concept, with both ground and onboard components, was performed through a set of simulator and flight tests, involving a representative group of pilots.

1.1.4. Results

The project culminated with the production of a complete safety-related integrated system (NG ISS), embodying all the innovations, connected to a test bed allowing us to activate it, run simulations and to evaluate the safety gains obtainable by future marketable systems based on those features.
The Weather Information Management Systems (WIMS) were a key outcome from the project. They have been validated in the project in support of the NG ISS. They might be used to enhance both the safety and efficiency of air transport through their use for provision of services to other stake-holders in the air transport sector (ATC, airport operators and airlines).
Flight test results were used to validate the complete chain of weather information processing (aircraft atmospheric data, downlink, WIMS and routine data, uplink, weather data fusion) and to populate a weather database to be used during the full simulation evaluation.
All these results contributed to achieving the ACARE goal of reducing the rate of accidents by 80% within 20 years.

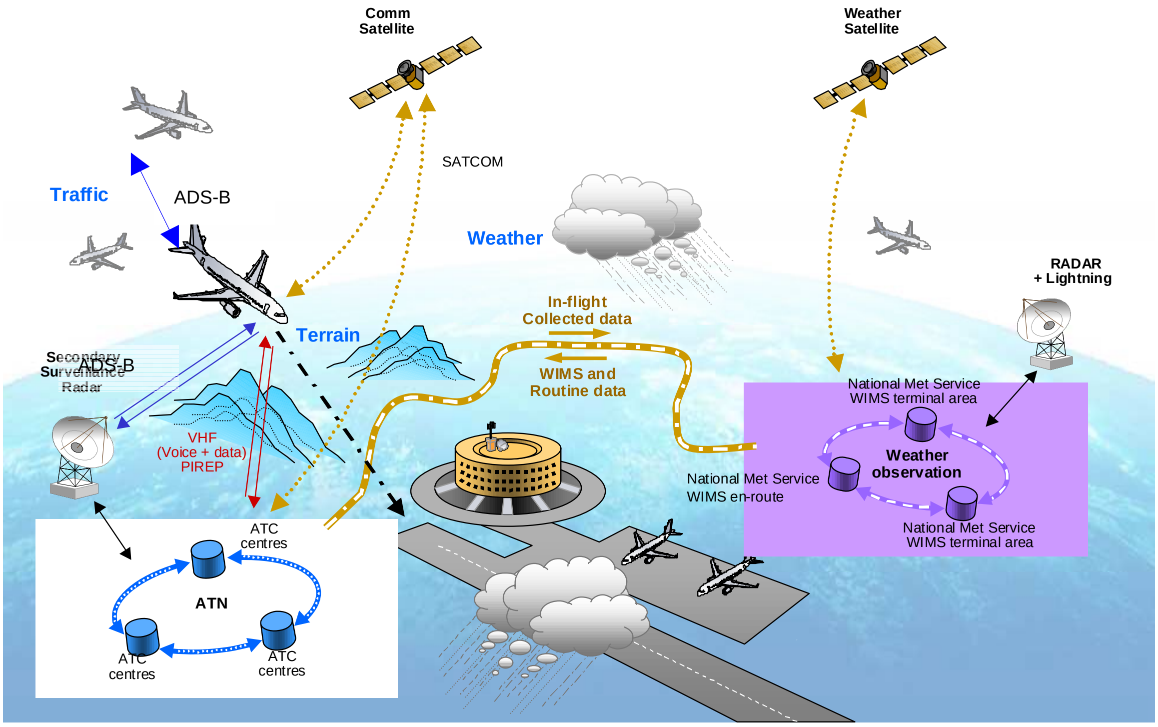


Figure 1: FLYSAFE overall concept

2. LIST OF PARTNERS

Participants				
Role*	**Number**	**Name**	**Three letter code**	**Country**
CO	1	Thales Avionics	THA	FR
CR	2	AIRBUS France	A-F	FR
CR	3	BAE SYSTEMS	BAE	UK
CR	4	Diehl Aerospace GmbH	DAV	DE
CR	5	NLR	NLR	NL
CR	6	Met Office	UKM	UK
CR	7	University of Hanover	UNI	DE
CR	8	AIRBUS Deutschland	A-D	DE
CR	9	Adria Airways	ADR	SI
CR	10	Air Malta	AMC	MT
CR	11	AustroControl	ACG	AT
CR	12	Avitronics Research	AVI	GR
CR	13	AVTECH	AVT	SE
CR	14	CNRS	CNR	FR
CR	15	Deep Blue	DPB	IT
CR	16	DLR (Oberpfaffenhoffen)	DLR	DE
CR	17	Eurocopter Deutschland	ECD	DE
CR	18	Euro-telematik AG	ETG	DE
CR	19	Galileo Avionica	GAL	IT
CR	20	GTD Sistemas de Informacion	GTD	ES
CR	21	Hellenic Aircraft Industries	HAI	GR
CR	22	Hovemere	HVM	UK
CR	23	Jeppesen GmbH	JEP	DE
CR	24	Meteo France	FME	FR
CR	25	ONERA	ONE	FR
CR	26	Rockwell Collins France	RCF	FR
CR	27	Skysoft Portugal	SKY	PT
CR	28	Thales Air Defence	TAD	FR
CR	29	Thales Laser	TAL	FR
CR	30	TsAGI	TSA	RU
CR	31	Université Catholique de Louvain	UCL	BE
CR	32	Technische Universitaet Darmstadt	TUD	DE
CR	33	Cranfield University	CFD	UK
CR	34	University of Malta	UOM	MT
CR	35	USE2ACES	U2A	NL
CR	36	Dassault Aviation	DAS	FR

- List of participants

Note:
*CO = Coordinator
CR = Contractor

3. LIST OF WORKPACKAGES

WP No	Work package title	Leader
1	Operational Assessment	THA
1.1	Collection of data, constraints and definition of requirements	NLR
1.1.1	Aircraft accidents & incidents analysis & definition of reqs.	NLR
1.1.2	Market acceptability pre-assessment	THA
1.2	Specifications	THA
1.2.1	Overall system specification and integration process definition	THA
1.2.2	Atmospheric awareness specification	UKM
1.2.3	Traffic awareness specification	BAE
1.2.4	Terrain awareness specification	THA
1.2.5	Information fusion & HMI specification	TUD
1.3	Certification basis analysis	NLR
1.3.1	Certification issues review	NLR
1.3.2	Overall system risk assessment	THA
1.4	Definition of standards-related activities	DAV
2	Atmospheric hazards	UKM
2.1	Weather Impact Studies	UNI
2.1.1	In-depth safety and risk analysis	UNI
2.1.2	Delay studies	UNI
2.2	Aviation weather provision	DLR
2.2.1	Internal specification of WIMS	DLR
2.2.2	Wake vortex WIMS	DLR
2.2.3	CAT WIMS	UKM
2.2.4	ICE WIMS	UNI
2.2.5	CB WIMS	DLR
2.2.6	Routine weather parameters and products	FME
2.2.7	Ground weather processors and communication means	UKM
2.2.8	Internal evaluation and assessment	FME
2.3	Onboard weather management	THA
2.3.1	Onboard wake prediction and alert	THA
2.3.2	CAT detection	THA
2.3.3	Weather radar enhanced modes	RCF
2.3.4	Airborne atmospheric probes	THA
2.3.5	Onboard weather data link management	RCF
2.3.6	Weather data fusion	RCF
3	Traffic Hazards	BAE
3.1	Analysis and Specification	BAE
3.1.1	Specification of operational situations, goals, behaviours	BAE
3.1.2	Functional Specification	BAE
3.1.3	Definition of HMI alternatives	TUD
3.1.4	Definition of procedure alternatives	BAE
3.1.5	Study impact of ASAS package 1 on safety	TUD
3.2	Customisation and Validation	BAE
3.2.1	Identification of critical design issues for HMI	BAE
3.2.2	Modification of software	BAE
3.2.3	Evaluation Plan for Traffic PTE	TUD
3.2.4	Performance of PTE	TUD
3.2.5	Analysis of PTE results	BAE
4	Terrain Hazards	THA
4.1	Terrain situation awareness	THA
4.1.1	Terrain situation awareness specification	THA
4.1.2	Terrain situation awareness development	THA
4.1.3	Terrain situation awareness IV&V	THA
4.2	Obstacle situation awareness	THA

WP No	Work package title	Leader
4.2.1	Obstacle situation awareness specification	THA
4.2.2	Obstacle situation awareness development	THA
4.2.3	Obstacle situation awareness IV&V	THA
4.3	Database and WXR correlation	RCF
4.3.1	WXR ground mapping techniques and technology	RCF
4.3.2	Correlation mechanisms, database improvement and business case	RCF
5	Next Generation Integrated Surveillance System	DAV
5.1	NG ISS architecture and I/O configuration	THA
5.1.1	NG ISS architecture study	NLR
5.1.2	Specification of NG ISS mock-up	THA
5.1.3	NG ISS mock-up development	THA
5.1.4	NG ISS mock-up Integration, Verification & Validation	THA
5.2	Tactical alert management	GAL
5.2.1	Tactical alert management specification	SKY
5.2.2	Tactical alert management development	SKY
5.2.3	Tactical alert management Integration, Verification & Validation	SKY
5.3	Intelligent Crew Support - Int-CS	BAE
5.3.1	Int-CS Support Scenarios	BAE
5.3.2	Int-CS Development and Programming	BAE
5.3.3	Int-CS PTE IV&V	BAE
5.4	Strategic data consolidation	GTD
5.4.1	Strategic data consolidation specification	GTD
5.4.2	Strategic data consolidation development	GTD
5.4.3	Strategic data consolidation Integration, Verification & Validation	GTD
5.5	Display & audio management	THA
5.5.1	Display and audio management specification	THA
5.5.2	Display and audio management development	THA
5.5.3	Display and audio management Integration, Verification & Validation	THA
5.6	Database server implementation	DAV
5.6.1	Database server implementation specification	DAV
5.6.2	Database server implementation development	DAV
5.6.3	Database server implementation Integration, Verification & Validation	DAV
5.7	Test Bed implementation	THA
5.7.1	Test Bed Architecture specification	THA
5.7.2	Test Bed Architecture development	THA
5.7.3	Test Bed Architecture Integration, Verification & Validation	THA
5.7.4	Test Bed integration of components and validation	THA
6	Evaluation and Results Assessment	NLR
6.1	Operational Scenario Specification & Flight Test RFP	THA
6.1.1	Operational Scenario Specification (OSS)	THA
6.1.2	Flight Test RFP	FME
6.1.3	Preliminary Test plan	NLR
6.2	Project and ISS safety goals assessment	ONE
6.2.1	Project goals assessment	AVI
6.2.2	Qualitative safety assessment	DPB
6.2.3	Risk assessment modelling	ONE
6.2.4	Quantitative safety assessment	ONE
6.2.5	Validation of the safety assessment	DPB
6.2.6	PGAT tool support	DPB
6.3	Test bed specification	NLR
6.3.1	ATC simulator environment specification	NLR
6.3.2	FFS environment specification	NLR
6.3.3	ATC tower simulator environment specification	NLR
6.3.4	Weather simulator server specification	NLR
6.3.5	Flight tests specification	FME
6.4	Test bed customisation	NLR
6.4.1	ATC simulator customisation	NLR

WP No	Work package title	Leader
6.4.2	FFS customisation	NLR
6.4.3	ATC tower simulator customisation	NLR
6.4.4	Weather simulator server customisation	NLR
6.4.5	Flight tests aircraft customisation	FME
6.5	Integration, Verification & Validation	NLR
6.5.1	Integration support to WP 5.7.4	NLR
6.5.2	Integration and Verification of NG ISS on FFS	NLR
6.5.3	Validation of NG ISS on FFS	NLR
6.6	Training of Users	A-F
6.7	Evaluation and Result Assessment	NLR
6.7.1	FFS evaluations	NLR
6.7.2	FT evaluations	FME
6.7.3	Data and result assessment	NLR
7	Exploitation, Standards and Dissemination	DAV
7.1	Exploitation	DAV
7.2	Interaction with international standards	DAV
7.3	Dissemination activities	DAV

- Work package leadership allocation – third level

4. OVERVIEW OF GENERAL PROJECT ACHIEVEMENTS

Maintaining the highest level of safety in air transportation is essential to ensure its on-going success all around the world. To remain the safest means of transport, it must adapt to the major changes occurring in the aviation system, notably the tripling of traffic within the next 20 years.

This is why both FAA, through CAST, and JAA, through JSSI, have launched initiatives on US and European sides, in recent years, whose "aim is the continuous improvement of the safety system leading to further reductions in the annual number of accidents and the annual number of fatalities irrespective of the growth in air traffic" .

They have identified seven areas, among which four represent 80% of the overall accidents / incidents: Weather (80% of which is turbulence related), Traffic (occurring both in the air and on the ground), Terrain (Controlled Flight Into Terrain) and Loss of Control.

Solutions have to be found among all stakeholders with coordinated actions at their level, to reduce accident risks in all these areas.

One most important action at European level has of course been the work of the *Advisory Council for Aeronautics Research in Europe* (ACARE), through the definition of the Vision 2020 and the following *Strategic Research Agenda* (SRA), that both address the air transport safety challenge.

The FLYSAFE project has been initiated, elaborated and finalised to address the air transport safety challenge identified by ACARE in the SRA, from a pilot's perspective, i.e. in defining, developing and testing new functions and systems able to reduce the risks of accidents in providing the cockpit crew with a better knowledge and information, on its environment. This is illustrated in the picture presented in Figure 1, in the Publishable Executive Summary.

The first objective of FLYSAFE was to design, develop and validate with the most relevant skills in Europe, new solutions able to be integrated on-board aircraft in approx. 2010-2013. It has concentrated on implementing and evaluating an on-board system for all phases of flight, and more specifically on the surveillance aspect of the CNS/ATM concept. It has integrated the solutions against all weather phenomena hazards, traffic hazards, terrain hazards and loss of control hazards into innovative fusion functions to be validated on an embedded platform (Next Generation Integrated Surveillance System) interfaced with the other aircraft systems. FLYSAFE has been the core European project on on-board safety systems, involving all categories of stakeholders through its extensive consortium and its External Expert Advisory Group (EEAG).

FLYSAFE also launched research activities on ground based Weather Information Management System (WIMS) as it constitutes a major, nevertheless lacking, stakeholder for safety data relative to weather phenomena. Although the solutions proposed by the WIMS targeted the on-board safety requirements of the crew, their applicability has also extended to the Flight Management System (FMS) and ATM.

The world-wide acceptance of the solutions designed for both on-board and ground system needed to be supported by internationally agreed standards. One very important objective of FLYSAFE was consequently to make sure that this standardisation effort is made, as a European initiative.

FLYSAFE was mainly concentrating on large transport aeroplanes operated in commercial air transport. However, some solutions have the potential to address the commuter and helicopter market, and possibilities of applications to these sectors have been studied in the Project.

From the FLYSAFE general objectives, the FLYSAFE team has selected a set of specific scientific and technological objectives, each of them based on innovations that can be go one step further that the current state-of-the-art.

These major scientific and technological innovations deal with atmospheric hazard management, traffic functions, terrain / obstacle functions and fusion functions to be integrated and validated on a Next Generation Integrated Surveillance System (NG ISS).

Due to the very innovative nature of the new system, the target is for new aircraft.

However, specific attention has been given to the applicability of the results to existing aircraft whenever it is feasible and affordable.

The primary innovation in FLYSAFE was to address the complex hierarchy of scales and terms of weather information needed on-board an aircraft in the different phases of flight in an integrated approach illustrated in the figure below. The ground system lies at the bottom, while the aircraft is represented at the top. Communication links are of two kinds. "Broadcast" refers to information uniformly distributed, while "dedicated processed products" refers to a protocol in which the information is differently and specifically processed toward each client.

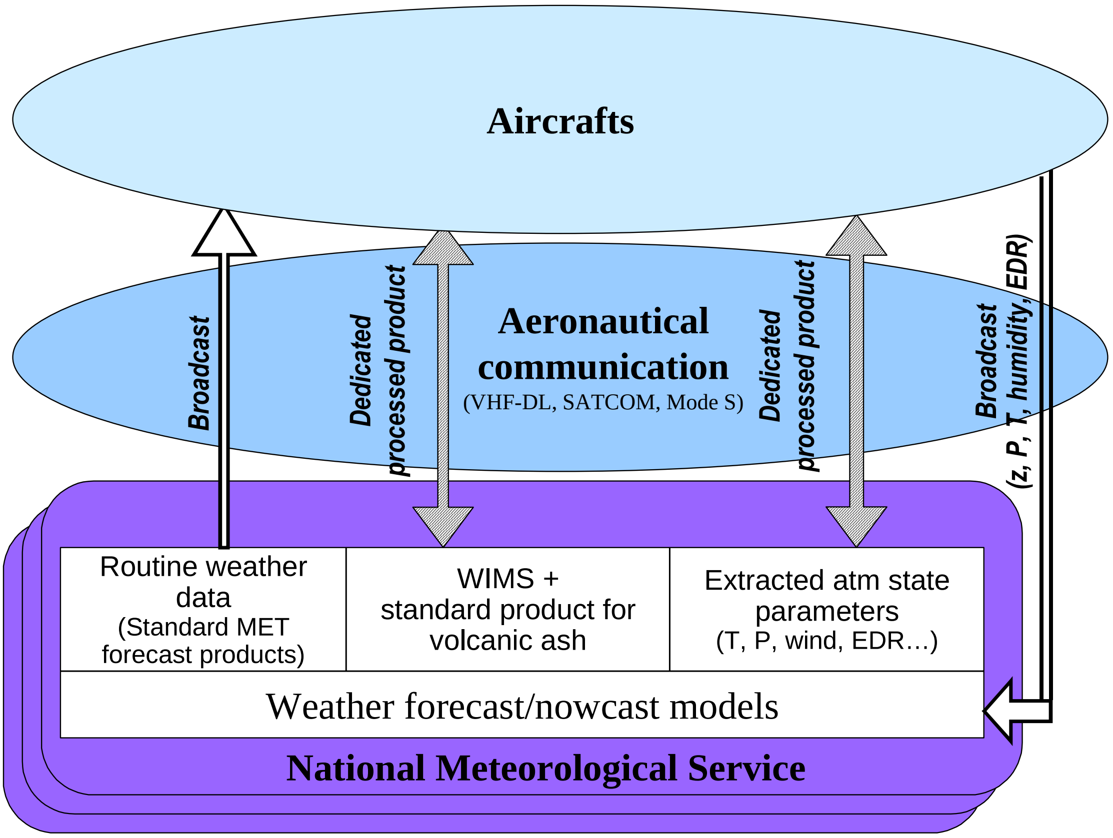


Figure 2 On-ground weather processing architecture

The ground system will distribute standard forecast products to all aircraft on a broadcast mode, and short term diagnostics of atmospheric hazards on a dedicated processed mode. Such a configuration significantly reduces the amount of data to be transmitted and the work load of the on-board computer by pre-processing and sending only relevant and timely data to the aircraft.

For the very short term, diagnostics will rely on in-situ measurements and remote sensing on-board the aircraft.

Additional information about atmospheric state parameters that are needed for on-board diagnostics, and which cannot be measured on-board will also be transmitted to the aircraft from the ground on a dedicated processed mode. The figure also indicates that such atmospheric parameters (especially wind mapping) will efficiently support the Flight Management System. Finally, on-board measured parameters that may significantly improve ground weather predictions will be broadcasted by the aircraft to the ground.

On-board, medium term forecast that is less critical will be displayed on a separate awareness screen. In contrast, ground short term and on-board very short-term diagnostics will be fused by the Integrated Surveillance System.

FLYSAFE has progressed towards an onboard weather information management system by

- improving the current capability of the existing onboard weather radar,
- completing the validation of a LiDAR-based atmospheric hazard detector to progress towards a product for wake and CAT.
- Assessing current and under-development airborne atmospheric sensors (water vapour, icing, lightning…), to select the most promising ones that would provide valuable data down-linked to the ground weather prediction centres
- develop weather data fusion algorithms allowing onboard evaluation or consolidation of weather hazards that could be encountered ahead or along the flight path

Regarding the traffic hazards, FLYSAFE has implemented the ASAS Package 1 functions and runway incursion avoidance and taxi collision avoidance functions. It integrated these functions into the NG ISS context by formatting the outputs for integration into the tactical alert management and strategic data consolidation functions of the NG ISS.

Regarding terrain, FLYSAFE innovated by evaluating terrain display to enhance the terrain awareness of the crew. The structure of the NG ISS and the use of high bandwidth bus with enhanced protocols (ARINC 661) allow the definition of new display to be presented on the cockpit. Three types of terrain presentation have been studied:

- cartographic,
- 2D ½ also known as 2D with shading (see Figure on the side) and
- 3D exocentric Navigation Display.

The advantage of each solution has been compared to the state-of-the-art during the evaluation phase using scenarios covering all phases of flight. Solutions have been proposed for future design according to the evaluations results. The new terrain display will draw new requirements on terrain database. Thus, it has been planned, within FLYSAFE, to actively participate to the definition of standards considering the on-board terrain database specifications.

Regarding the obstacles, FLYSAFE performed an analysis of the requirements in order to determine, which obstacles are an issue for aircraft safety, how they shall be detected and avoided and when they shall be presented to the crew in order to maintain the highest degree of safety. The work needed to be performed at several levels: the obstacle database design and consistency, the detection and the avoidance algorithm and the display presentation.

One remarkable achievement of FLYSAFE is the definition of fusion functions, collecting and managing together all information available on-board on flight hazards (terrain, traffic and atmospheric related). All innovative functions have been integrated on the Next Generation Integrated Surveillance System for validation and proof of their applicability in solving the safety issue.

Validation means

- FLYSAFE platform including the NG ISS.

System innovations

- Centralised database server
- Enhanced display system (Display Management Module) adapted to NG ISS requirements
- Open architecture to allow for the addition of new sensors, alerts and functions.

Function innovations

- Fusion of atmospheric, traffic and terrain data on a single coherent presentation
- Intelligent Crew Support to help the crew in aircraft management
- Anticipation of hazardous situation relative to atmospheric phenomena, traffic and terrain, along the flight path
- Enhanced human machine interface (crew interaction with surveillance system, crew monitoring)
- Display presentation of atmospheric, traffic and terrain information on Navigation Display and Vertical Situation Display (Cartographic, 2D½ and exocentric 3D ND)
- Side Display (SD) for flight operations support (navigation charts, map hosting, weather routine data)
- Taxi Display to support current standard flight operations during take-off and landing.

This system will increase the crew capabilities to anticipate all hazards – terrain, traffic, and atmospheric related- along its flight path and take appropriate actions

Another major achievement of FLYSAFE is the definition of an enhanced cockpit display system with larger screens and useful area (8"x12") to be able to display the surveillance information, an improved HMI with windowing and on-screen interaction capabilities, a management of non specific input device, such as the Crew Control Devices and Keyboard, in order to constitute an open HMI.

FLYSAFE's intention was to leap one step further as compared to existing products and to anticipate and respond to the needs of the next generation of such equipment up to a mock-up stage integrated in a representative environment.

5. MAIN ACHIEVEMENTS

As FLYSAFE is aimed at designing, implementing, validating and testing an integrated system, the approach taken has been to structure the project as for a system development project, with the following phases:

- Definition of requirements
- Definition of the overall system specifications
- Parallel development of the different sub-systems and the Integrated System itself
- Integration, verification & validation
- Evaluation

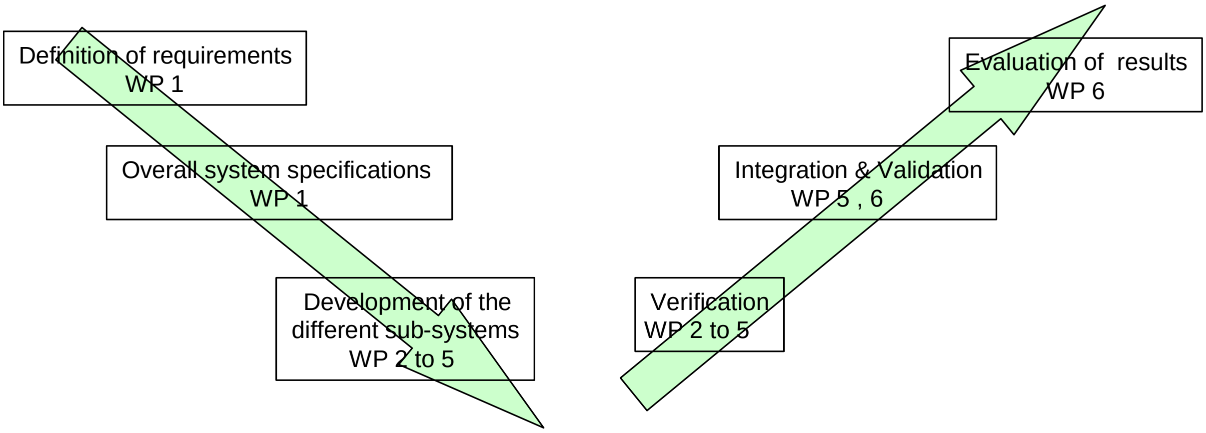


Figure 3: Project WBS process

On the top of this, exploitation and dissemination tasks have been grouped in WP 7, and consortium management tasks have all been grouped within WP 0.

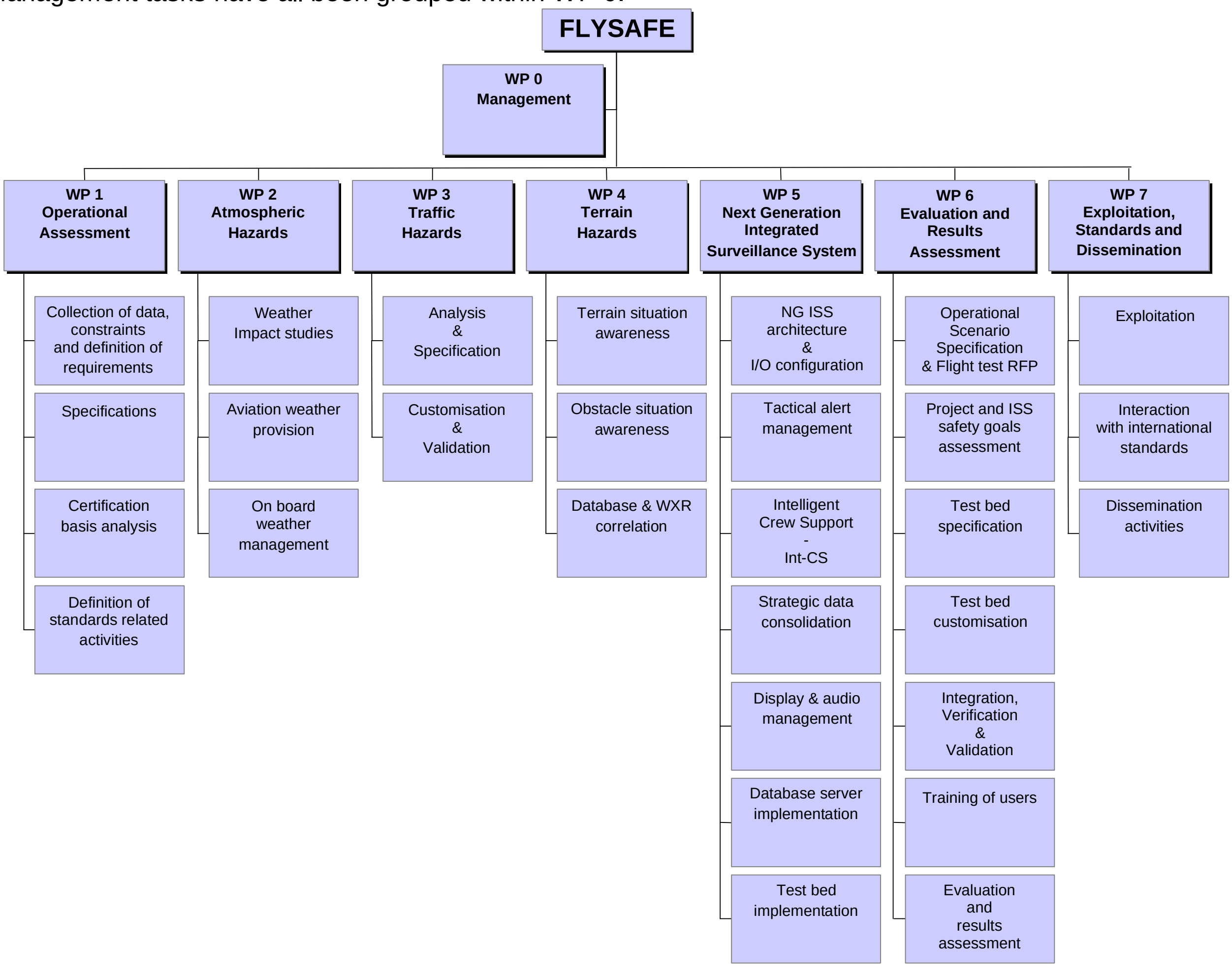


Figure 4: WBS second level

5.1.1. WP1 Operationnal Assessment

WP 1 aimed at setting the ground of the overall project, and is broken down in four parts, listed below:

- WP 1.1 Collection of data, constraints and definition of requirements
- WP 1.2 Specifications
- WP 1.3 Certification basis analysis
- WP 1.4 Definition of standards-related activities

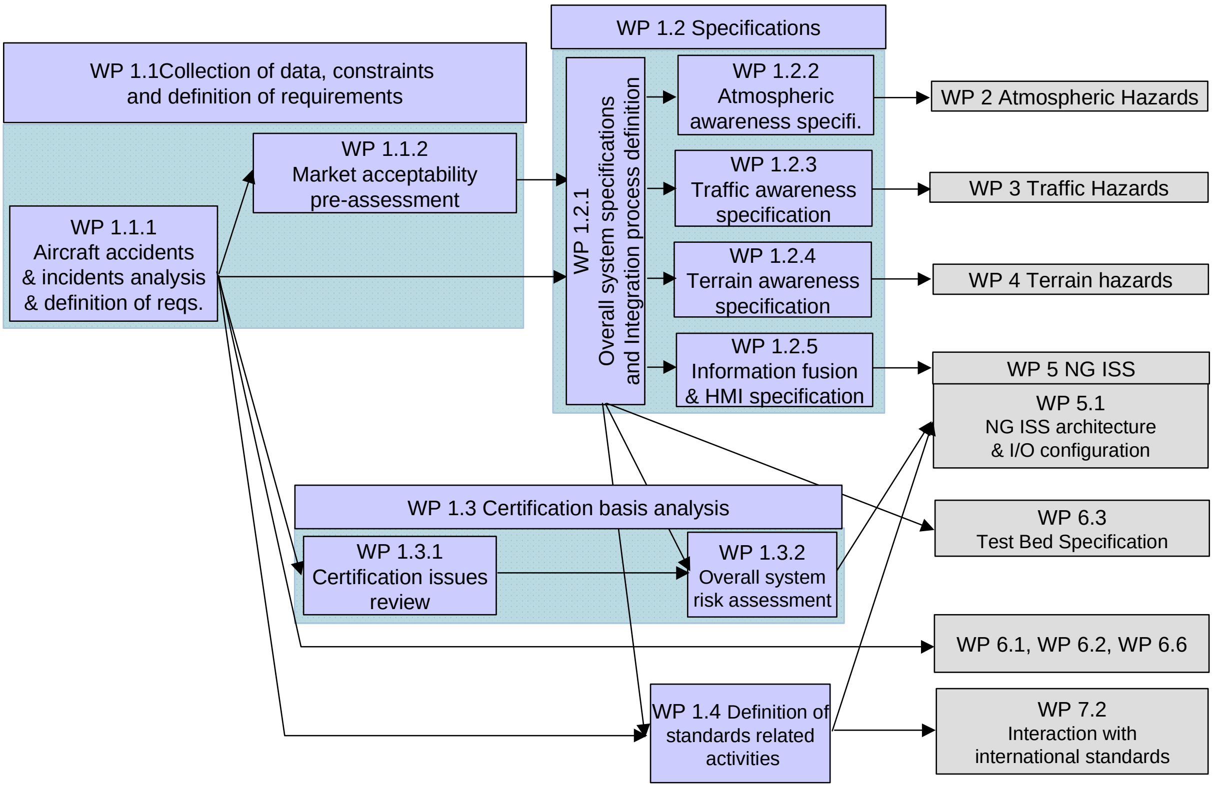


Figure 5: WP 1 data flow

5.1.2. WP 1.1 Collection of data, constraints and definition of requirements

5.1.3. WP 1.1 Results

The first task was to identify a list of hazards (or more precisely the causal and contributing factors that may have led to an incident or accident) relevant to the FLYSAFE system. For this study the following main categories chosen were: Flight Crew, Ground Crew, Air Traffic System/ATC, Airport operations, Airlines/Operators, Aircraft Equipment/Manufacturers, Weather Services, Aviation Community. Turbulence, Charting Authority and Non-categorised Hazards. Furthermore five specially defined FLYSAFE-related sub-categories: Weather, Traffic, Terrain, Integrated, and Other. Together these formed a matrix in which the causal and contributing factors were given from all safety studies performed (which generally provided data classified into ICAO categories) and which have been mapped on the foreseen main NG-ISS functions of FLYSAFE. Partners looked into various databases and safety sources to identify relevant cases and to define these causal and contributing factors. Also looked at was the study of JAA’s FAST (Future Air System Safety Team) into foreseen changes inside the future air transport system (including ATC matters) and the CAST (Civil Aviation Safety Team) study performed by an international safety team. The various obtained partner results were coupled via a master excel file and hence provided the insight in which hazards categories were most pronounced available in the ICAO / FLYSAFE matrix. Subsequently the identified hazards were coupled to a potential FLYSAFE solution and as such led to an operational need and NG-ISS requirement input.

Initially the second task was to analyse aviation (aircraft incident/accident) safety databases with respect to the identified hazards. A wide set of reports and surveys already existed at that time (and still exist) on aircraft accidents and incidents: from national authorities (CAST, JAA Safety Strategic Initiatives, FAST), Transport Safety Boards (NTSB, BEA), Airlines and airlines associations, Pilot associations, National & International Safety associations (NTSB, EASA, etc). Many of these reports and existing incident/accident data base statistics have been explored intensively, using data till end of 2004, to analyse the 'current' practice situation of that moment. However, the available database statistics were generally not directly usable to judge frequency of occurrence and/or severity of the consequences of hazards in relation to new aircraft systems and operations. For this purpose, a dedicated FLYSAFE system/operation specific aviation safety data base analysis was executed. Still the results found were not easy transferable to the FLYSAFE operational definition context. Hence this task was finally transformed into a prioritisation task of the hazard list, hence a prioritisation of the outcome of the first task.

The results of the above two tasks led to the overview and definition on safety aspects inside the OCD (Deliverable D 1.1.1), more precisely to section 4.3.2 and to the Appendices E and F. The resulting list of hazards relevant for FLYSAFE and the NG-ISS was also used as input for the qualitative safety analysis of the proposed new FLYSAFE system and operational concept (in WP 6.2). Furthermore, based on the analysis of these reports, the FLYSAFE team, supported by the External Expert Advisory Group (EEAG), selected the most relevant means to cope with causal factors in the chain of events that might lead to incidents and/or accidents to address within the NG-ISS concept.
The third task was to define the new NG-ISS operational concept and novel working procedures (for pilots and possibly air traffic controllers). This comprised the definition of the main novel aspects of the Next Generation Integrated Surveillance System (NG-ISS) to be set up under FLYSAFE from an operational need and operational perspective. Hence the Operational Concept Definition (OCD) had to take into account operational matters, but also addressed:

- enhancing cockpit functions and information displays (e.g. situation awareness),
- creating new HMI features,
- introducing new sensors and detection algorithms,
- integration of sensors, systems and algorithms into flight procedures.

An important issue was to make clear the differences between the current operational environment and the proposed FLYSAFE operational concept. The OCD was to be used as input for the system specification in WP1.2, certification basis analysis WP 1.3 and the scenario definition in WP6.1.

All three tasks were worked on an resulted into the Operational Concept Description (OCD) report:

- D 1.1.1 Final Operational Concept Description (Version A)
-

It was found important to ensure that the envisaged NG-ISS functions and systems would be accepted by the market. The market was defined in FLYSAFE as being the commercial air transport and related sectors such as service providers.

Two tasks were executed under a "Market acceptability investigation"

- "Questionnaire to pilots and airlines", made on the basis of the distribution of a questionnaire to airlines and pilots and collection of the feedback
- "Market acceptability of WIMS" which was produced by UNI on the basis of their extensive set of previous studies performed

However, while performing the work, it was revealed that it would not be reasonably achievable to achieve a quantitative study, with a reliable assessment of the costs on one side, and the value for user on the other side. This was due to two major difficulties:

Firstly, on the customer side, it is neither in the airlines' nor in the airframers' habits to give values for new services or functions that one can propose to them. They have rather request for proposals from systems suppliers and make up their mind once they have several offers in hand. So the "value to customer" of the functions / systems can not be obtained by questionnaires or interviews. So practically seen no realisms existed to get this information from them. As an alternative, the only process reasonably achievable was to estimate the benefits and gains that the airlines could make through the service rendered. But at the stage the project was in one could only make rough estimates of the gains to any operators through a better knowledge of the atmospheric adverse conditions.

Secondly, on the supplier's side, it was generally not possible to estimate the cost at which a new system / function could be marketed at this stage of the project where the function was of course not developed, and even not specified in detail. This was true for the on-board systems, but also for the ground systems, the WIMS, delivering the atmospheric data to the aircraft.

Consequently, it was agreed on that the quantitative study for the on-board systems and functions was re-directed into an estimate, by UNI, of the potential operational gains that could be obtained through the knowledge and proper use by the pilots of the atmospheric adverse conditions. The experience and know-how available at UNI who had already conducted a wide set of extensive studies in that area, allowed them to provide inputs for FLYSAFE without having to question airlines and end-users separately on this topic.

Finally, despite it was envisaged to distribute a questionnaire to ATC and airport authorities, in the frame of the WIMS acceptability assessment, UNI expressed that they had already all information needed at their disposal and that they would not gain more through a new questionnaire. This was accepted, and lead to a change in the approach proposed. Whilst designing the questionnaire for pilots and airlines, the WP112 team realised that they could get, through the responses to the questionnaire, more than the economical results. This WP will allow indeed making a pre-assessment of the various expectations of pilots and airlines with regard to on-board safety means. Hence the scope of the questionnaire was extended.

A web-based questionnaire was set up, and distributed. Actions were taken by several partners to get the web site questionnaire filled by relevant stakeholder, like helicopter pilots, business jets pilots as well as air transport pilots, ATC and airport authorities. Answers received were analysed and especially AMC took all data received on the web site to produce all the statistical charts. The report on the study contains information on the expectations regarding the NG-ISS and its specific functions. Assessment of acceptance by fixed wing pilots (of air transport aircraft and business jets), rotorcraft pilots, and at airlines level is proved. Furthermore a dedicated study is made to the acceptance of the new weather products (WIMS), by airport authorities, airports and pilots.

The first study was made through a questionnaire distributed on a public web site. For the preparation of this version A of D 1.1.2, 84 responses have been received. They came from the 5 continents and mostly from pilots with a strong experience. The second version consolidates the results and analysis of the first one. And even a version C was set up to make the report public
The results were unambiguous, the trends in acceptability were frank, so the questionnaire was relevant and the questioned population behaved homogenously. Nearly all pilots met regularly hazardous situations (more than once a year), with regard to the traffic (90%), and adverse atmospheric conditions (87%). 35% of pilots met hazardous situations, with regard to the terrain (and obstacles). Focusing on atmospheric conditions: 85% of pilots met at least once a year hazardous icing conditions, 88% of pilots met CAT events, 80% met wake vortex turbulence, and 14% met volcanic ash (which is far from negligible).
The analysis of these responses showed strong expectations from the pilots to get more accurate and reliable information on all types of hazards. This is particularly true for the various atmospheric hazards: 70% wanted more accurate and reliable information on atmospheric conditions. For traffic information, they were 65%, and 52% for terrain and obstacle information. A strong majority of pilots wished to have new or at least improvements on man-machine interface features, for situational awareness, alert management and hazard anticipation. Pilots' expectations were very strong both for "tactical" data and for strategic or alert information. Pilots looked forward to innovative functions for each of the four atmospheric hazard treated in FLYSAFE. In the airport environment pilots said that they also needed to have a better tactical view particularly with regard to runway incursion and taxi collision with obstacle, and strongly expected new on-board functions, which FLYSAF addressed later on. Pilots stressed that all improvement have to be such that the information is presented clearly and in a way that it does not increase the workload.
Among the 12 criteria proposed to the airlines for the selection of new functions and systems, the most important were: the improvement of safety, the pilots' acceptance, the integration capability in other avionics packages, and the upgradeability.

The second investigation was conducted by the University of Hannover and was made on the basis of the existing studies in the US and in Europe. These studies converge in demonstrating the high economic and social interest of WIMS that could provide aircraft and ATC with reliable atmospheric data:
Some main results found were:

- USA: the annual estimated weather-related costs for accident damage, injuries, delays and unexpected operating costs are estimated to be $3 billion
- The estimated potential annual economic benefit from integrated weather forecast systems for test bed installations, deployed at Memphis, Orlando and Dallas-Fort-Worth, was $235 million

Hence there is a big economical gain to be expected when weather delays can be reduced significantly.

The outcome of the work was documented inside three following report versions:

- D 1.1.2 Market acceptability pre-assessment (Versions A, B and C)

5.1.4. WP 1.2 Results

The domain specifications from WP1.2.2, 1.2.3, 1.2.4 and 1.2.5 are documented in internal FLYSAFE deliverables (one for each domain) and summarized in the following overall deliverables

- D 1.2.1-1 “Overall System Specification – High Level”

This document describes the overall functional architecture of the proposed FLYSAFE systems, including the ground and the airborne segments; for each main function in the architecture, the foreseen capability is explained and interfaces listed.

The ground segment is described as combining information from the Weather Information Management Systems, routine weather data and volcanic ash into the ground-based weather processors which then are defined in terms of coverage in a local and a global processor. The ground-based weather processors are interconnected with the air traffic management. Finally the weather information from the processors can be transmitted to the airborne segment with datalink.

Onboard the aircraft, the airborne segment is composed of the systems and functions hosted on the aircraft either functionally inside the perimeter of the FLYSAFE Next Generation Integrated Surveillance System or outside. The functions external to the NG-ISS include aircraft sensors, controls, weather information services, database server, navigation function, flight deck displays and the detection of non collaborative targets. The NG-ISS hosts the weather, traffic and terrain surveillance functions, the fusion functions for weather, traffic and terrain hazards, the alert prioritisation function for tactical operations, the consolidation of weather, traffic and terrain data with a filter to detect conflict for strategic operations, the dataloading, configuration management, maintenance, Intelligent Crew Support and audio/display management system.

- D 1.2.1-2 “Overall System Specification – FLYSAFE platform and test bed”

This document is a companion to the previous one and describes the overall functional architecture of the proposed FLYSAFE systems **as they will be developed during the project**, i.e. amendments are providing to the high level functionality descriptions for the target product so that the FLYSAFE evalution objectives can be met . It also describes the methods of evaluation to be applied (stepped approach using Part Task and Main Task Evaluations).

In short, most of the ground segment aspects are developed for the FLYSAFE Flight Tests, such that only interesting WIMS output data is provided to the Full Flight Simulation. Most of the terrain and traffic aspects are developed for the Full Flight Simulation, whereas the core of airborne weather surveillance is geared towards the Flight Tests. Nevertheless, a simulation will allow to have the airborne weather radar related functionalities to be combined with traffic and terrain awareness. Finally, no development of the helicopter specifics is foreseen within FLYSAFE.

- D 1.2 “Specification of the FLYSAFE System Functions”

This report describes, in more details than in D 1.2.1-1 and D 1.2.1-2, the overall functional architecture of the proposed FLYSAFE systems for the target product **and** as they will be developed during the project. The main functions of the FLYSAFE systems are described, amendments for the project evaluations are added and the functional requirements are listed, including the ones already derived in the FLYSAFE Operational Concept Document.

In short, this document concentrates on the high-level functional elements (architecture, description, requirements and interfaces) necessary to start the detailed specification in the work packages 2-3-4 and 5. Compliance tables provide a synthetic view of how it is foreseen in FLYSAFE to include each requirement and is being reviewed as a preliminary to the IVV of the NG-ISS within WP5.7.

Besides the specifications, architectures and interfaces descriptions, this WP produced the integration process document in which high-level guidelines and requirements for integration within WP 5.7 and WP6 are listed. This report will be used as input to the Software and Hardware development plans within WP5.

5.1.5. WP 1.3 Results

The NG-ISS should improve the overall safety of aircraft operations by providing long term (strategic) and short term information (tactical) to improve situational awareness and immediate response capabilities for the majority of the conceivable operational hazards. These include weather, terrain and traffic hazards that are taken care of in the NG-ISS by providing an integrated flight warning and information management system.

Under the task of identifying certification issues, an extensive review was performed of the surveillance related regulatory documents. The result, the FLYSAFE NG-ISS certification basis analysis (CBA) provides a baseline of all consolidated airworthiness, certification requirements and standards applicable to the NG-ISS. It should be regarded as an initial guideline for the certification of the NG-ISS based on the definition of the system and overall system specifications available at the moment of the review. This means that, ones new developments have occurred or new functions are defined throughout the evolution of the system, the structure of this CBA may be utilised further to improve or extend the certification basis where necessary.

The FLYSAFE NG-ISS certification basis has been established in two phases in order to provide a complete certification guideline in one report volume. In the first phase, the baseline for the existing requirements has been established following the certification analysis results of the EU funded FP 5 ISAWARE-II project. ISAWARE II can be considered as a forerunner of the more improved and complex NG-ISS. Review of the ISAWARE-II certification basis concluded that it provides a sound baseline for the establishment of a CBA for FLYSAFE. Where necessary, these requirements were extended and/or updated based on changes within the (European) certification requirements.

The second phase established an NG-ISS specific certification policy based on an overview of all identified new NG-ISS innovations.

The NG-ISS certification compliance database, developed as part of the FLYSAFE certification basis, provides a quick reference for NG-ISS certification by correlating the NG-ISS functionalities with the established certification basis.

Certification of a final product is out of scope for FLYSAFE. However, the FLYSAFE certification basis can be used as a proposal document for certification requirements negotiations with the authorities in a possible later phase.

The achievements have been issued jointly with an excel file

- D 1.3.1 Certification Basis Analysis (Version A)
- CBA compliance database (excel file) (Version A)

Within the FLYSAFE preliminary Functional Hazard Assessment (FHA), the Next Generation Integrated Surveillance System (NG-ISS) main functions were assessed in terms of conceivable hazards that can be identified with respect to failure condition scenarios at aircraft level. Operational experts (pilots) within the consortium participated in this assessment of the potential hazards of which a few were already identified in WP 1.3.1.

The preliminary FHA, as performed within the FLYSAFE work package 1.3.2, was used as an input to the final system FHA within the project in WP 5.1.1 .The preliminary FHA is not an evaluation of design adequacy but rather an identification of functional hazards that shall be considered during development of an NG-ISS. It was furthermore based on the NG-ISS functionalities as defined in the project. The results of both preliminary FHA and subsequent system FHA shall be used in the determination of System Software and Hardware Design Assurance levels, when pursuing a real product development.

The NG-ISS objective is to enhance flight crew awareness of “external” traffic, weather and terrain hazards. The purpose of the FLYSAFE preliminary FHA was to check that the installation of such a system onboard an aircraft does not introduce new “internal” hazards.

Most significant hazards that could be potentially introduced by such a system were mainly related to the few cases where the flight crew could be potentially misled by erroneous or conflicting indications or false alerts provided by the NG-ISS.

The NG-ISS aimed to incorporate Data Fusion and Conflict Detection functions within each surveillance domain (traffic, weather or terrain). Data Consolidation was performed possibly across those domains. At the time of this preliminary FHA, the definition of those functions was not mature enough to allow for a detailed assessment, particularly for the Data Consolidation function.

In addition, few assumptions were made on the NG-ISS functions that would be implemented. In particular, the Airborne Separation Assurance System (ASAS) applications such as the Enhanced Traffic Situational Awareness on the airport Surface (ATSA-SURF) and Airborne Spacing Application - Sequencing & Merging (ASPA-S&M) were retained among the seven potential ASAS Package 1 airborne applications proposed for implementation. The NG-ISS detailed definition confirmed those assumptions. However, only those two applications were assessed, being the most mature ones with relevant to descriptive material available.

The Intelligent Crew Support (ICS) function was also left out from this preliminary FHA as a definition of this system was not available at the time. The system FHA, as follow-on of the preliminary FHA, checked this function in more details, given the preliminary NG-ISS architectural design. It was anticipated that no critical hazards would be introduced by this new function.

The results have been reported in

- D 1.3.2 Preliminary Functional Hazard Assessment (PFHA) (Version A)

5.1.6. WP 1.4 Results

For the definition of the standardization working groups we defined a process in the frame of WP1.4 that is illustrated in the figure below. The basis for this work was a competence table that contained all known standards and a mapping between standards and WP1.4 partners.

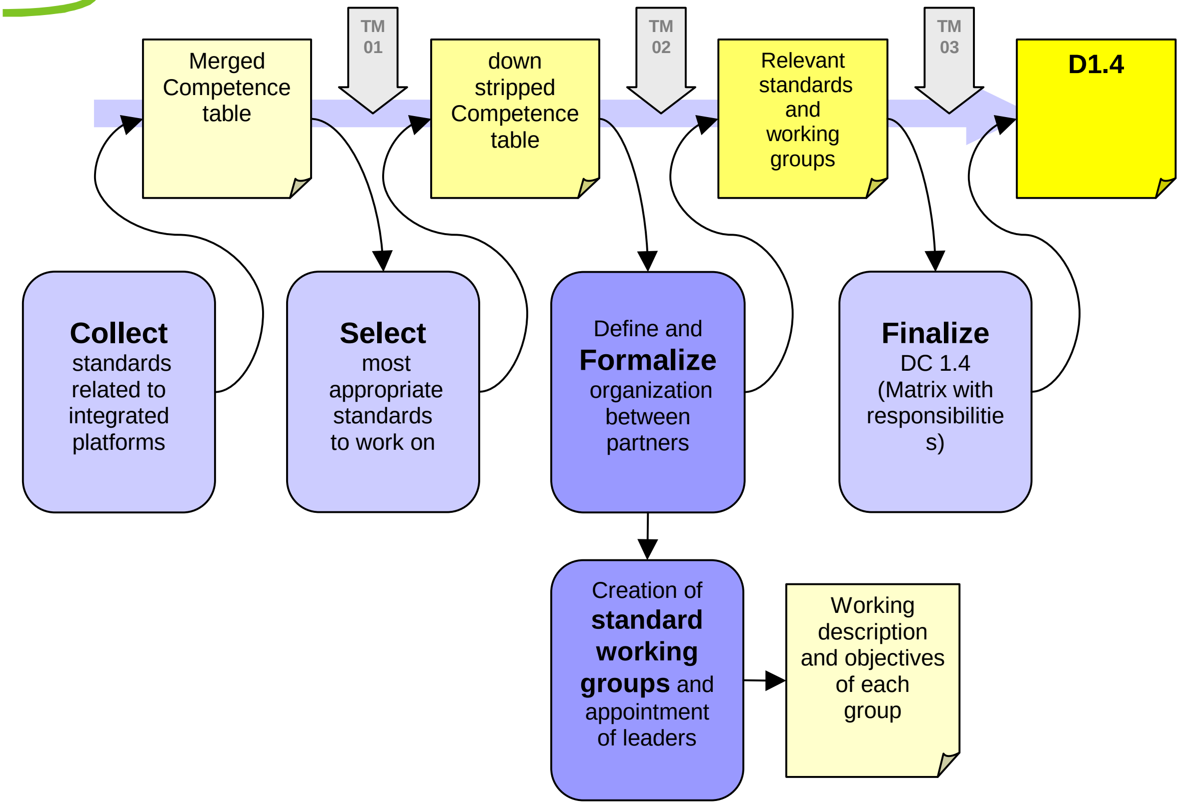


Figure 6: Connection of tasks in WP1.4

The FLYSAFE partners reviewed various standard definition activities linked to the integrated platform. They selected the most appropriate standards to work on. The FLYSAFE partners defined and formalised the organisation between themselves to interact with these international bodies: creation of 5 FLYSAFE standard working groups with appointment of leaders:

- Weather sensors and services
  - This group is dealing mainly with the standards related to weather and identified as relevant for FLYSAFE in the frame of WP 1.4.
- Surveillance- and alerting systems
  - This group is dealing with standards related to integrated surveillance systems like the FLYSAFE NG-ISS itself. It has to make sure, that all the developments of FLYSAFE are reflected in the standards and if necessary amend the corresponding documents.
- Traffic and ASAS applications
  - This working group deals with Traffic and ASAS (Airborne Separation Assurance System) related applications. The working group is concerned with the *operational concepts*, *definitions*, *requirements* and *analysis* developed within standardization organizations.
- Datalink and associated applications
  - The working group scope is mainly based upon the participation to the Joint RTCA Special Committee 206 / EUROCAE Working Group 44/53

- Databases and Database Management
  - o This working group is dealing with all standards related to format specifications, data exchange, data query interfaces and database management technologies.

Each of these groups was described in detail by elaborating the exact scope of the group, the objectives of the group, the participating partners and the official standardization bodies involved. Then each partner involved in WP1.4 and WP7.2 had to choose in which group he wants to participate.

	WP14 and WP72 partners								WP14-only		WP72-only						
	AVI	DAS	DAV	ETG	FME	RCF	THA	UKM	A-F	ECD	ACG	BAE	JEP	TUD	CFD	UNI	UOM
Weather sensors and services				X	X	X	X	X			X					X	
Surveillance- and alerting systems	X						X								X		X
Traffic and ASAS applications				X								X		X	X		X
Datalink and associated applications		X	X	X		X	X							X			
Databases and Database Management			X	X	X		X						X	X			
Preliminary leaders are marked with a dark gray background.																	

Figure 7: Matrix, mapping each partner to at least one standard working group.

The results of WP 1.4 will be used in WP 7.2 to follow the recommended standardisation working group.

More details about the groups can be found in D1.4 – Matrix mapping the responsible partner to the relevant standard activity.

5.2. WP2 ATMOSPHERIC HAZARDS

5.2.1. WP 2.1 Results

WP 2.1.1 was mainly focused on the following questions:

1. Determine the role of weather in aviation accidents.
2. Analyse the weather impact compared to other causes.

3. Find out which weather contributes to accidents most frequently.
4. Investigate which weather phenomena are the most dangerous.
5. Determine aircraft-specific threats
6. Enable to determine FLYSAFE's success

The objectives listed above were successfully met by using two basic types of data sets: Aviation accident databases and climatologies of many relevant weather threats. Additionally, TSA conducted a sophisticated simulation of possible in-flight wake vortex encounters based on real air traffic data kindly provided by Eurocontrol.

The first part of the WP 2.1.1 work dealt with the weather risks. After an extensive literature study, a number of potentially hazardous atmospheric phenomena was identified and described in detail including their possible adverse effect on aircraft operation. These phenomena were thunderstorms (CB), lightning, hail, microbursts/downbursts, (heavy) precipitation, icing, turbulence, low visibility, and volcanic ash. For most of these it was also possible to provide climatologies which enable to identify areas and times of maximum occurrence.

TSA developed a state-of-the-art wake vortex simulation model, which can be adapted to any aircraft. They used Eurocontrol CFMU air traffic data from different days in 2005 and 2006 which contained information on the position and type of aircraft. For these days each aircraft was tracked and checked whether or not it came close to another aircraft. Following that, the possible encounter of one of these aircraft with the wake vortex of the other a/c was calculated. If one such case was detected the type of encounter was determined. As wake vortexes of a large aircraft potentially have a severe effect on smaller aircraft that is not the case the other way around. For simplicity, three different mass groups were introduced (heavy (3), medium (2) and light (1)) to group the potentially hazardous encounters (3-2, 3-1 and 2-1). The severity of the wake vortex encounter not only depends on the size of the different aircraft, but, also on the geometry of the flight paths and vortexes and their vortexes age.

It was found that wake vortex encounters potentially take place several times a day over Europe and that the greatest probability of encounter occurs during the cruise stage of a flight.

The largest part of work within WP 2.1.1 covered the aviation accident analysis. A large range of databases was searched for accidents where weather was at least a contributing factor. The ICAO (worldwide) and NTSB (US) databases provided most valuable. The data were analysed with respect of three different types of air transport: commercial passenger transport (including bizjet), general aviation and helicopters.

One of the key findings of the study of weather related commercial aviation accidents is that in those accidents, within the 1995-2007 period, more than 2200 passengers and crew were fatally injured. This is equivalent to about 170 per year. Another 680 persons were seriously injured while more than 1500 sustained minor injuries. Most of these accidents could have been prevented had the crew received up-to-date or more detailed weather information or timely warnings in flight.

These numbers are lower limits only (!), as the ICAO database is far from complete due to the slow process of reporting of the accident reports by the member states. Another factor which leads to an underestimation is the selection process used for the analysis. It is based on the information available in the reports. However, the reports in the database are often incomplete and then do not allow the attribution of an accident to weather related factors. Such accidents are excluded from the analysis.

Compared with the total number of commercial aviation accidents contained in the ICAO database weather contributed to 16% of fatal accidents, 32% of nonfatal accidents but only 11% of accidents without injuries.

Also, a strong mass group and flight phase dependence was found. Of all weather related commercial aviation accidents, >55% happen during en-route for large aircraft (above 27 tonnes). These are mostly due to turbulence encounters and the subsequent injury of passengers or crew members who had not fasted their seat belts. Events with serious injuries are always rated as accidents according to the ICAO rules. For small aircraft most weather accidents happen during the approach and landing phase.

There is also great differences between large and small aircraft with respect of the weather phenomena which are factors in the accidents during different flight phases. As already mentioned above, during en-route, most of the weather accidents of large aircraft are due to turbulence encounters. But, for small aircraft low visibility and icing are the prime factors.

The different weather phenomena also have different degrees of severity with respect of the injury level. While turbulence is responsible for 60% of the minor and 40% of the serious injuries in weather accidents, low visibility was a factor in 40% of the serious injuries and almost 70% of the fatal injuries.

Low visibility and also icing, even though the latter is responsible for only 18% of the fatal injuries, are the

This document is produced under the EC contract AIP4-CT-2005-516167.
It is the property of the FLYSAFE consortium

most deadly weather factors in commercial aviation. In such accidents, about 40% of passengers and crew received fatal injuries.

It was also investigated which weather phenomena are involved in the different accident types. In 93% of the weather related CFIT accidents, low visibility was a factor. Weather related LOC-I is mostly due to icing (35%) and wind effects (32%). Abnormal runway contact is usually caused by wind effects (53%), low visibility (28%) and icing (18%). Runway excursion is also often due to wind effects (34%) and a slippery runway (water, snow and ice, 36%).

The accidents analysis of general aviation accidents shows that those numbers are very similar to small aircraft in commercial aviation.

The analysis which focused on helicopters mirrored many of the findings of the commercial and general aviation weather accidents. Such accidents are typically caused by a chain of events and not a single event, with a large fraction due to the pilots' decision making and not malfunctioning of the helicopter. From all human factors errors the misjudgement of weather situations leads to the greatest number of fatal accidents. The biggest weather hazard is the loss of visual reference, typically caused by flying a VFR flight into IMC. This is also the "the single largest killer". Extreme weather phenomena like thunderstorms etc. itself aren't obviously such a big threat probably because their existence is well known. Loss of visual reference then often results in CFIT or obstacle related accidents.

WP 212 focused on the impact of weather on flight delays. Delay causing factors are generally investigated in several existing studies. However, most of these studies refer to the U.S. On the European side, only a limited number of studies and reports exists, as e.g. EuroControl (2005)[1], EuroControl (2006)[2], EuroControl[3], Rehm (2003)[4], Rehm and Klawonn (2005)[5], Solf (2005)[6] and Spehr and Hauf (2003)[7].

Whereas most of the investigations on weather induced flight delays are based on the analysis of delay codes, independent methods (as in Rehm (2003)4 and Rehm and Klawonn (2005)5) should be used within WP 212 in order to assess and quantify the weather impact on flight delays. Other delay causing factors were not part of the investigations within WP 212. However, they were partly included for completeness in order to obtain good overall model results.

The main task within WP 212 was the development of a punctuality model for airports. This model was calibrated and tested on data from Frankfurt Airport and good results were obtained. The model allows for a discrimination of the impact of certain weather parameters on flight delays respectively airport punctuality. Additionally, the model allows for a forecast of daily airport punctuality, based on forecast weather and traffic. This option is of high value for airports with regard to staff and material planning.

The results obtained in WP 212 using robust methods and focussing on a detailed and meteorologically

[1] EuroControl, 2005: Report on Punctuality Drivers at Major European Airports, prepared by the Performance Review Unit, May 2005

[2] EuroControl, 2006: Performance Review Report 2005, An assessment of air traffic management in Europe during the calendar year 2005, Performance Review Commission, April 2006

[3] EuroControl: eCODA, CODA Reports, Available from internet: <URL: https://extranet.eurocontrol.int/http://prisme-web.hq.corp.eurocontrol.int/ecoda/coda/public/standard_page/public_application.html>

[4] Rehm, F., 2003: Data Mining Methoden zur Bestimmung des Einflusses von Wetterfaktoren auf die Anflugverspätungen an Flughäfen, Master Thesis, Fakultät für Informatik der Otto-von-Guericke-Universität Magdeburg

[5] Rehm, F. and F. Klawonn, 2005: Learning methods for Air Traffic Management, Symbolic and Quantitative Approaches to Reasoning with Uncertainty, Volume 3571/2005, ISBN 978-3-540-27326-4, 992-1001, Springer Berlin/Heidelberg

[6] Solf, M., 2005: Einflüsse auf die Variabilität von Anflugzeiten bei Verkehrsflugzeugen, Diplomarbeit, Technische Universität Braunschweig, Institut für Flugführung, Deutsches Zentrum für Luft- und Raumfahrt, Institut für Flugführung

[7] Spehr, U. and T. Hauf, 2003: Analyse des Wettereinflusses auf die Pünktlichkeit im Flugverkehr, Diplomarbeit im Fach Meterologie, Universität Hannover, Institut für Meteorologie und Klimatologie

meaningful specification of weather parameters confirm the large impact of weather on flight delays/punctuality. The punctuality analysis and forecast tool developed is a big step towards an operational punctuality forecast system used by airport service providers.

Besides the modelling of punctuality, three questionnaires were set up in WP 212, dedicated to helicopter operations, business jet operations and ATC/ATM/airport operators, in order to learn more about how weather in detail impacts efficiency in daily operations and to find out about the needs regarding meteorological products to increase efficiency. These questionnaires gave valuable feedback also with regard to WIMS-developments within FLYSAFE. In summary, the WIMS meet exactly several of the requirements named (for more detailed information, please refer to D 2.1-2).

It is well known that weather impacts safety and efficiency. The general strategy to reduce that impact is hazard recognition and avoidance, which means the optimization for a minimum impacted 4d-trajectory. WIMS are, within FLYSAFE, integrated in the cockpit to increase the pilot's hazard awareness. A thinkable future application is the adaptation to and integration into ATC / ATM and airport planning. U.S. studies estimated avoidable weather related delays through pro-active adverse weather management to be between 10 and 40 %. As the same method is applied to reduce delays and increase safety, any future reduction of delays through WIMS and WIMS-like technologies will simultaneously increase safety. In that heuristic sense, delays can be used as a rough measure for safety - objections and limitations are well-known - and constitute a contribution to a safety metric.

5.2.2. WP 2.2 Results

The global objective is the development of a capability to provide on-time and tailored weather information from ground to the cockpit to support safe and efficient operations. This requires the development of Weather Information Management Systems (WIMSs), which provide highly specialised information addressing the hazards "wake vortex" (WV), "clear-air turbulence" (CAT), in-flight icing (ICE), and thunderstorms (CB) that prove to be a particular challenge. In addition, there are objectives to ensure consistent support to the onboard detection capabilities and to perform internal validation of the performance of the WIMSs.

The end product of this work package is software, which can be run in a number of different modes, to support the operation of the NG-ISS in the FLYSAFE evaluation.

It is based on the output from WPs 1.1, 1.2 and 2.1, which defines the type and nature of information on meteorological hazards that is expected by the pilots. The WIMS will provide their data to a Ground Weather Processor (GWP) where the pre-processed and compacted meteorological information will be collected. The GWP will operate in two modes: for en-route support, the data will be stored in a centralised weather processor (CWP) . The second mode is adapted to the airport terminal area and operated by a local weather processor (LWP) on a limited domain, with finer-scale local observations and short-term predictions. The GWP provides all weather data for a particular flight and broadcasts the required information to the aircraft at the gate (during flight preparation). When the aircraft is in-flight, updates of the hazardous weather situations are transmitted by the GWP to the aircraft upon request where it is combined with airborne collected data, see WP 2.3.

The figure below illustrates the flow of information between the forecast and/or observed hazards, through the WIMS, the GWP and finally the link to the aircraft. This figure illustrates the basic idea of WP 2.2. Atmospheric phenomena and weather hazards (first, bottom row) that affect the aircraft (fifth, top row) are monitored by observation systems (second row). Data from the latter will be processed by each WIMS (third row), using forecasting models, and the optimum information about type, location and strength of the respective weather hazard will be evaluated and formatted as object-oriented data. The latter will be sent to the aircraft via the Ground Weather Processors (fourth row), which will tailor the information to the aircraft's systems and communications capability. Data will be fused onboard with diagnostics from onboard sensors.

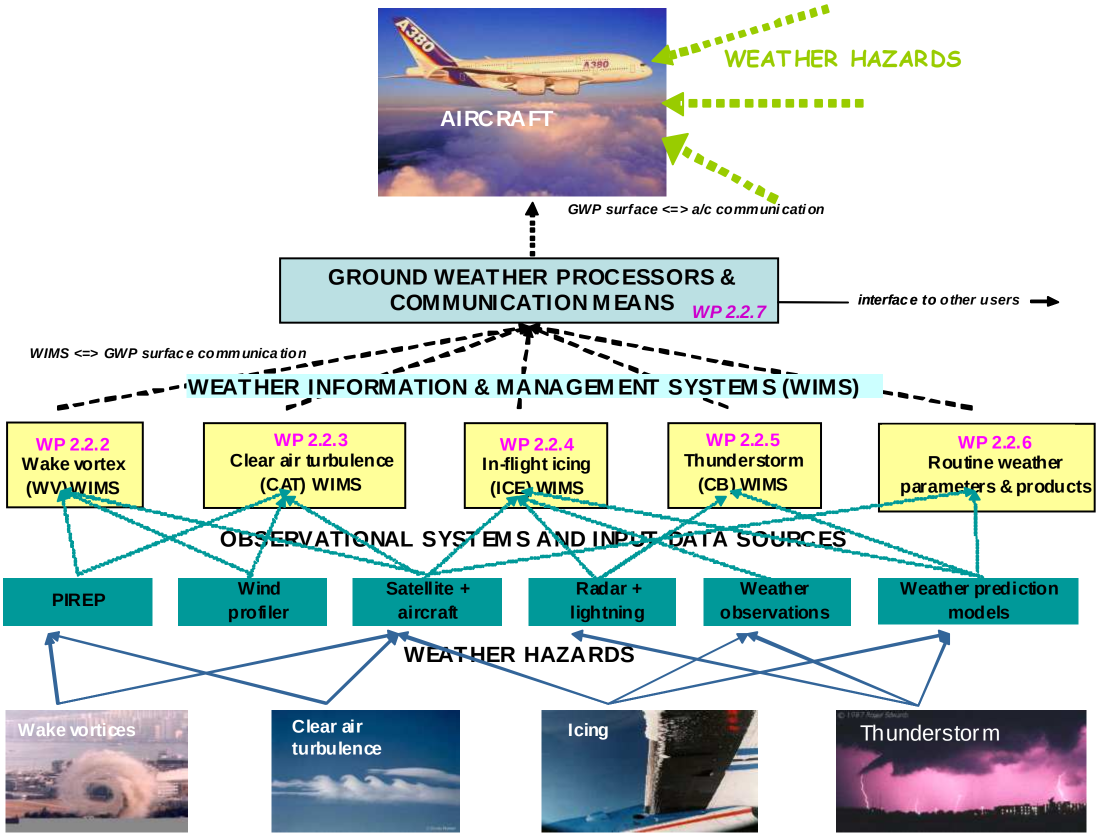


Figure 8: Weather Information Management System Organisation

The WIMS provide information at regular time intervals. The required information is tailored and up-linked by the GWP to the aircraft upon request. Institutional issues have been addressed to make up operational solutions for the operations of the GWP and its coordination with the distributed network of airport GWPs. The GWP is designed as to also be exploitable by air traffic control, airport operators, airline operating centres, and other users, as well as by weather consultants in the national weather services. In the final stage, weather information systems will be operated at distributed weather or research centres.

WP 2.2 is broken down into eight work packages. The figure below structures the work and tasks to be performed and their link to other packages of FLYSAFE.

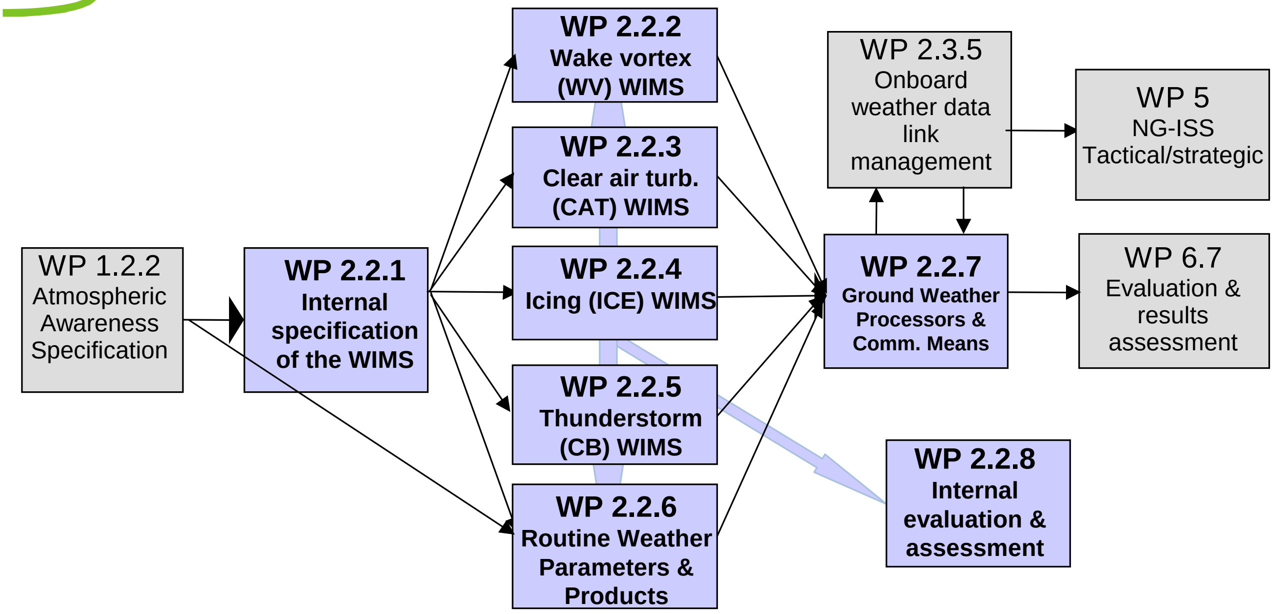


Figure 9: WP 2.2 work-package structure

The results are documented in the Deliverable FLY_221DLR_DEL_D221_A. It describes and specifies

- the WIMS wake vortex (WV), clear air turbulence (CAT), in-flight icing (ICE), and thunderstorm (CB),
- the routine weather parameters and products (RWPP),
- the ground weather processor (GWP), including data communication, fusion and consolidation.

D 2.2.1 concretises all respective function interfaces and outlines the evaluation strategy for the FLYSAFE platform and target products (to be detailed and specified in WP 2.2.8).

The document continues and builds on the respective specification work and documents from WP 1. It reviews and completes the descriptions of the weather related functions from the ground and the interface control document.

The deliverable D 2.2.1 functioned as the reference document for the development of the WIMS (in WPs 2.2.2 to 2.2.5), the routine weather parameters and products (WP 2.2.6), the ground weather processor and the communication means from WIMS to GWP and from GWP to the cockpit and to other potential users as ATM, AOC and airports (WP 2.2.7, 2.3.5, 2.3.6).

The document further enabled other partners in the project (in particular from WP 5 and 6) to understand the functionality of the WIMS, RWPP and GWP and to perform their work in building up the tools, software, interfaces, data fusion and link realisations, HMI, etc in the NG-ISS.

The results are documented in the Deliverable FLY_222DLR_DEL_D222_A. It describes the final design and functionality of the Weather Information and Management System for Wake Vortices (WV WIMS) as part of the ground segment of FLYSAFE. WV WIMS aims at the FLYSAFE Target Product. It is being designed and developed for the EN-ROUTE airspace (ENR mode) and for the TMA airspace (TMA mode)

The WV WIMS *receives*

(i) meteorological data provided by the UK Met Office (for ENR) and the German Weather Service, DWD (for TMA),
(ii) local meteorological measurements from equipment installed at the airport (for TMA),
(iii) and ground-based WV monitoring data (for TMA).

For the FLYSAFE Target Product, the WV WIMS in mode ENR *delivers* to the CWP

- meteorological parameters forecast by the UK Met Office; these data can be used by the on-board Wake Encounter Prevention System (WEPS) under development in WP 2.3.1 for aircraft flying en-route.

For the FLYSAFE Target Product, the WV WIMS in mode TMA *delivers* to the LWP

- meteorological parameters forecast by the German Weather Service; these data can be used by the on-board Wake Encounter Prevention System (WEPS) under development in WP 2.3.1 for aircraft flying in the TMA;
- minimum safe separations in time for ATC considering classes of aircraft between the Final Approach Fix and the Runway Threshold or – for departures – between take-off and end of initial climb phase. These separations are deduced from WV trajectories, circulation and safety areas as forecast by DLR's wake vortex advisory system.

The functionality of the WV WIMS (mode TMA) has been demonstrated during 66 days of the FRA2006/07 campaign at Frankfurt Airport from 18 Dec 2006 until 28 Feb 2007. The system covered the glide paths of runways 25L and R from the final approach fix to the threshold (11 NM) and combined measured & forecasted meteorological data for wake prediction. The time horizon for weather predictions was 12 hours with a 10 minute increment and an update every 12 hours. For the target product of the TMA mode it is envisaged to reduce the weather forecast horizon to 2 hours, with a 10 minute increment and an update each hour. The time horizon for the WV predictions and minimum separation times for final approach is 60 minutes; updates are available every 10 minutes. From the 66 days of performance test at Frankfurt we found that

- the system ran stable - no forecast breakdowns occurred,
- aircraft separations could have been reduced in 75 % of the time compared to ICAO wake vortex separation standards,
- the predictions were correct: at least for about 1100 landings observed during 16 days no warnings of false and potentially hazardous forecasts occurred.

Fast-time simulations, which took into account the real traffic mix and operational constraints in the period of one month, revealed that with such a system at Frankfurt Airport the capacity for landing aircraft could *strategically* be increased by 3% (roughly 1 – 1.5 aircraft per hour) when accepting an average delay of 4 minutes per flight. On the other hand and thinking in *tactical* terms, the system could be used to reduce the average delay of 4 minutes by almost 50% when keeping the arrival rate constant. This approach would result in a very substantial saving of fuel and CO_2 emissions.

The components of the TMA mode system also allow for prediction of wakes from departing aircraft.

The ENR mode of WV WIMS consists mainly of output data routinely produced by the UK Met Office weather forecast models and, as such, needs no further evaluation. These data represent the meteorological conditions in the en-route airspace (i.e. basically everything outside the TMA) and serve as input to the onboard Wake Encounter Prevention System (WEPS) under development in WP 2.3.1. The time horizon for weather predictions is 12 hours with a 3 hour increment and an update every 6 hours for the ENR mode.

The achievements of WP 224 can be summarised as follwos:

- Definition of the three-scale ICE WIMS structure using UKMet's UM to represent the global scale, UNI/DWD's ADWICE to represent the regional/continental scale and FME's SIGMA to represent the local/TMA scale.
- Development of an algorithm (grid2object) that can convert the gridded icing forecast products into polygonal object representation and output them in GML code to the Ground Weather Processor
- Integration of the three scale subsystems and the grid2object algorithm into a "baseline" mockup to demonstrate the workability of the approach
- Definition and realisation of an "advanced" specification for further integration of the subsystems and improved information usage
- Realisation of a working, largely automated, real-time ICE WIMS in support of the flight tests

The incentive to organise ICE WIMS operation using the three scales arose from two different facts. Firstly, the three partner organisations (UKMet, UNI, FME) happened to have previously developed systems that had these three distinct characteristic spatial and temporal resolutions, so it was a natural fit. Secondly, but no less importantly, icing is a phenomenon that can exhibit a high spatial variability, especially in the vertical dimension. Therefore, areas with denser air traffic need to be covered with more detailed and more frequent forecasts.

For FLYSAFE, it was decided to demonstrate an integrated approach using the Unified Model's global coverage as a basis for long-range pre/re-planning. The higher horizontal and vertical resolution of ADWICE over Europe is intended to facilitate flight route planning in a high traffic environment with small margins. The French SIGMA system, which in its operational form covers all of France, was adapted to cover an area of roughly 200nm around Paris Charles de Gaulle airport. This area is also called the terminal manoeuvring area (TMA) and is covered at very high spatial resolution with updates every 15min. This is specifically intended to allow icing-aware planning of flight operation around the airport. Movements such as holdings also occur at lower and therefore more icing-prone altitudes. The actual logic which determines where the three scale products overlap, with smaller-scale data overriding the higher-scale data, is implemented in the GWP (WP227).

The first milestone of WP224 is the Baseline Specification documented in DI224-1 which outlines the organisation structure described above. This formed the basis for the baseline mockup, which was the first realisation of a system of data exchange between the three scale subsystems and a central database that was to become the GWP.

The major achievement of the baseline ICE WIMS was the creation of a common icing data format that was compatible with the GML specification set for data exchange within FLYSAFE WIMS systems. Generally, forecasts of atmospheric conditions are produced as gridded data, because they are produced by grid-based forecasting models. Such gridded data has advantages for scientific applications but is usually very data-intensive, since every single grid point is represented with a value even if the majority are zero. The planned data-link between the FLYSAFE ground segment and the aircraft is very limited in bandwidth, though.

Therefore, an algorithm called grid2obj (grid to object) was developed to identify areas of icing in these gridded fields and represent them simply by their outline, defined with a (small) number of points. By this method, large areas of icing can be represented as a polygon objects with much fewer points than the equivalent gridded representation, thus saving data size. These objects represent areas of icing potential identified by the icing forecast and are output in the form of a list of geographic coordinates describing the vertex locations of each of these objects. This list is annotated in GML and is associated with metadata describing such things as time of creation, which scale this product represents, etc.

The Advanced ICE WIMS specification (DI 224-3) and mockup built upon this foundation to create a functioning system that is able to be run in continuous operations and was employed in support of the flight tests in 2008. There were a few changes in the GML specifications for the advanced system that implemented some compatibility improvements and enables the implementation of further data sources, even though this is not planned for FLYSAFE. The underlying icing forecast subsystems also underwent some development, notably FME's SIGMA with many upgrades to its numerical weather model.

WP224 successfully demonstrated the feasibility of using three disparate forecast systems in an overlapping arrangement to use higher resolution forecasts where available and needed. The complete ICE WIMS structure as a chain of connected subsystems was successfully implemented and operated over an extended period in support of the flight tests in 2008. These flight tests also demonstrated the successfully operation of the digital data link from the GWP and of the flight data corridor concept. The evaluation effort including the ground demonstrations also revealed that there is some potential for improvement by the HMI designers in the integration of icing forecast data into the cockpit interface, specifically the integrated navigation display.

The results are documented in the Deliverable FLY_225DLR_DEL_D225_A. It describes the final design and functionality of the Weather Information and Management System for thunderstorms (CB WIMS) as part of the ground segment of FLYSAFE.

The CB WIMS has been developed in two development stages: a baseline version and an advanced version and it provides thunderstorm forecasts on three scales:

(i) Local (TMA) scale, derived from systems developed at Météo France and DLR
(ii) Regional (continental) scale, derived from systems developed at Météo France and DLR
(iii) Global scale, provided by output from UKMet Office' Unified Model

These scale products differ in terms of area covered, spatial resolution and time between updates. Moving from global via continental to local scale, they provide increasingly more high-resolution forecasts and at a faster rate, while reducing the area covered. The resolution of the data bases used to generate the CB WIMS products increases in the same way. According to their designation, the global product covers (nearly) the whole earth surface, the continental product covers an area such as that of Europe in this case, while the local(TMA) product is limited to roughly 100km around an airport (Paris CDG in this case). These products are produced independently and delivered to the Ground-Weather-Processor (GWP) as thunderstorm bottom and top volumes which are designated with one of two severities: moderate and severe. These volumes which represent hazard spaces to aircraft when approaching thunderstorms at low or high levels (lower and upper troposphere) are provided as objects in the form of polygonal areas with bottom and top, with a number of attributes. In case of a request by an aircraft the GWP selects the product with the finest resolution and uploads relevant data for the flight corridor of the aircraft.

The functionality of the CB WIMS has been demonstrated during the FLYSAFE demonstration effort, which includes a full flight simulator (FFS) running at NLR and operating, among other functions, a simplified WIMS test-bed. Furthermore, real conditions have been assessed during a two-phase flight test program taking part in winter 2007/2008 and summer 2008 respectively. Although the first flight test campaign aimed at performing flights in icing conditions to test the ICE WIMS products, CB WIMS took part too in order to assess the operational data delivery to the GWP. The second flight test had then a fully operational data-link and tested real-time provision of WIMS data to the GWP, real-time tailoring, upload, fusion, and display on the aircraft.

Additional task evaluations have been performed and documented as part of WP228, WP644 and WP 673.

A prioritised list of the various weather products which have to be provided to the aircraft in addition to the WIMS products was established after consultation of the External Experts Advisory Group (EEAG). Details can be found in D 2.2.6-1.

Most of the time, the format used for these products is very difficult to interpret for crew members with respect to their intended flight path and the possible alternative routings, thus along with the design of the Flysafe exchange format a reflection was conducted in order to improve the usability of the products.

Two versions of FLYSAFE's Weather Object format have been developed using the OGC (Open Geospatial Consortium) Geospatial Markup Language (GML).

A first version, FLYSAFE's baseline Weather Object format has been designed for the Full Flight Simulator Experiment and was delivered at the beginning of 2007. This format is fully documented in the ICN "Definition of the GML format for WIMS and routine weather data exchange, DRAFT V4".

The first uses of the baseline Weather Object format have conducted to the design of the FLYSAFE's advanced Weather Object format which was delivered at the end of 2007. This format has been used during the Flight Test experiment 5 and is fully documented in the ICN "Definition of the GML format for WIMS exchange advanced version V5".

FLYSAFE's weather community consider it is highly desirable that users have the opportunity to experience the full richness of the WIMS that is not necessarily confined to an oversimplified version on the Navigation Display.

Moreover, a display showing all innovative weather products including WIMS and routine weather products would be of great value as a demonstrator for what could be developed to fulfil the requirements of ATM/ATC operators, especially within the context of SESAR and NEXTGEN and to show a more functional and integrated display.

The intent of the NG-ISS is to change current working practices, as a consequence a pathway is needed between current working practices to the new working practices of the future. The availability of a weather side-display mock-up will help users to express their preferences, as well as explore HMI related issues.

To fulfil these needs, a non-interactive mock-up has been designed. The functional overview of this mock-up is described in D 2.2.6-1. The only purpose of this mock-up is to show what kind of weather side display could be developed.

This mock-up was demonstrated at the second WIMS science meeting held in Geneva, July 2007 as well as at the final FLYSAFE Forum, March 2009.

The development of the Ground Weather Processor (GWP) occurred in two stages, which proceeded reasonably as planned; with completion of stage 1, the baseline version, in February 2007 and stage 2, the advanced version, in November 2007. The differences between what was implemented and what was planned were due either to a technical issue that proved to be more complex than envisaged or due to the availability of resources to enable features to be properly evaluated. In this section only a summary of the main achievements against the planned objectives are considered. Details are provided according to the high level breakdown of the work package plan

Sub-system 1: communications

The development of sub-system 1, data communications, was not wholly completed within WP2.2.7. The solution required elements from other work packages, including software and hardware components. The ground communications was implemented since this used existing internet technologies. However, the aeronautical datalink proved trickier since this required additional equipment and a telecoms service agreement. The final solution for the aeronautical datalink was delivered as part of WP6 Flight Trials.

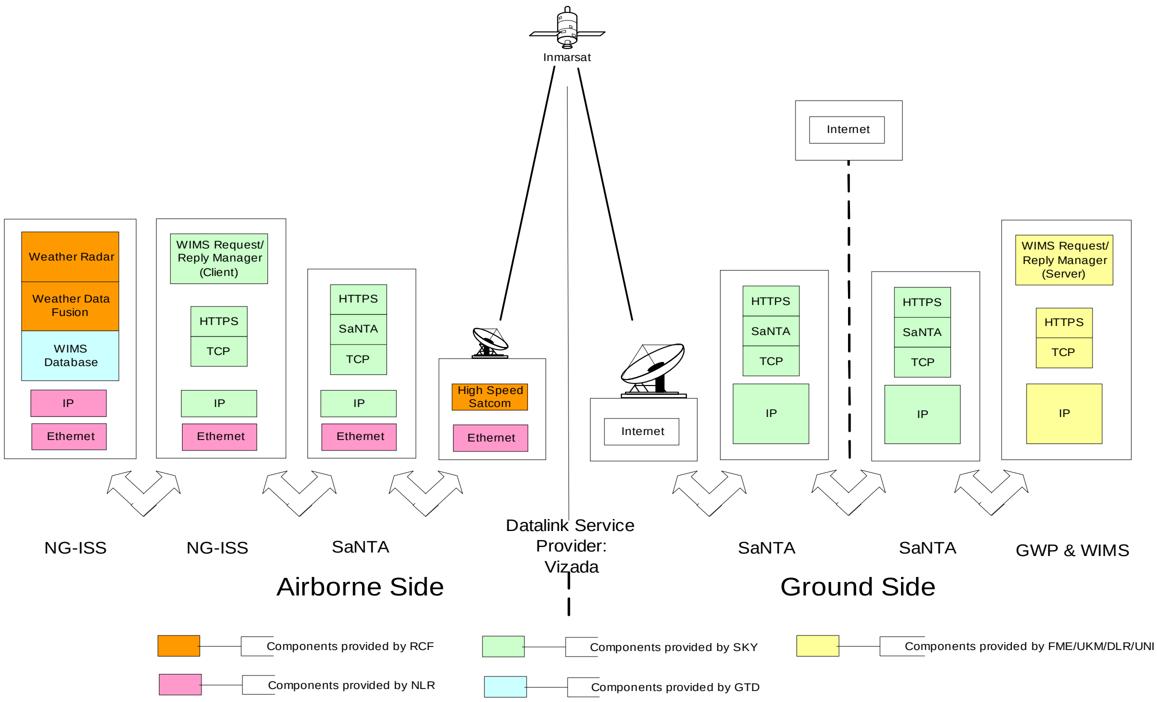


Figure 10: Datalink solution.

The data link between the WIMS and GWP used standard internet protocols, TCP/IP. The data link connection between the ground and airborne components was established using a communication service provider (CSP) for Inmarsat. To enable a seamless connection using the HTTPS internet protocol between the NG-ISS and the GWP across a satellite data link, SaNTA network components were installed at key points on the end-to-end path. SaNTA implements a new protocol stack, mainly replacing TCP with a proprietary transport protocol suited for the satellite link, which claims to speed up SATCOM transmission. A client-side request/reply manager was installed as part of the on-board solution, and was used to access the GWP. A corresponding server-side request/reply manager was installed as part of the GWP solution at Meteo France.

Sub-system 2: Weather Data Processing

During the initial design and specification of the baseline version it became clear that a more generic solution for the Ground Weather Processor was possible, as it was noted that the only distinction between the local and central weather processor were their roles and data content. Therefore a generic architecture was developed; this afforded some efficiency in the development of the Ground Weather Processor. A mechanism to submit requests and return replies was developed as no standard existed at the time (although such standards are now under development). In addition software was developed to compress the data to be transmitted whilst retaining its information content.

- GWP Architecture

The baseline GWP was built using open source components and was also used to demonstrate the proof of concept that meaningful weather information could be exchanged; and that routine production of the range of data could be performed by different suppliers, at all spatial and temporal scales (as described for the WIMS). This development also included a novel technique to convert gridded numerical weather prediction data into weather objects, expressed using GML. All data was stored within a geo-spatial database. The advanced GWP involved the reconfiguration of the baseline GWP to incorporate standards complaint open source components more suited to the project's requirements – namely OGC web feature services.

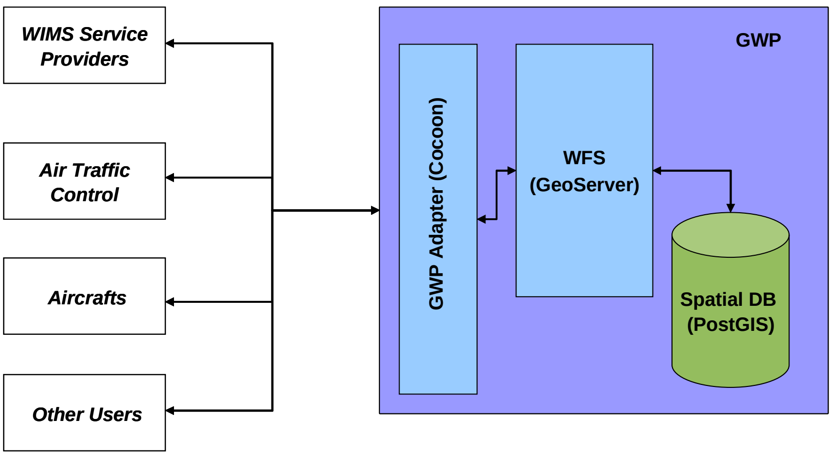


Figure 11: WP 2.2.7 Architecture overview for Advanced GWP.

The web feature service architecture used for the advanced GWP was based on OGC specifications:

- Web Feature Services (OGC WFS v1.1.0)
  - supporting database functions for feature (objects) insertion, update and delete operations for (geographic) using the http protocol
- Use of GML version 3.1
  - FLYSAFE objects are compliant with this standard, a revised and re-factored meteorological data model was developed using the latest released version of GML,
- Data discovery
  - enables data extraction by feature attributes and to constrain data extraction spatially and temporally

- Object data stored using a relational geospatial database – PostGIS – that was coupled to the OGC WFS

- Meteorological Data Model.

A data model was developed using the Unified Modelling Language (UML). Various tools (Enterprise Architect, XML Spy, Hollow-World GML Schema and Shapechange) were then used to translate this data model into form compliant with the Geospatial Mark-up Language (GML). The data model was in two parts. The first part covers the request and reply process and the second part the weather objects.

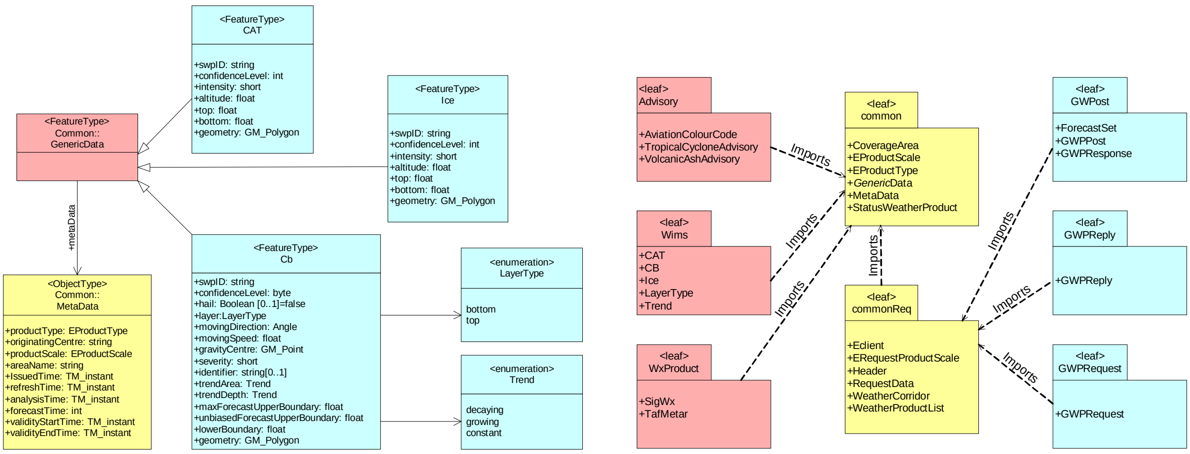


Figure 12: Data models for request/reply (left) and weather objects (right).

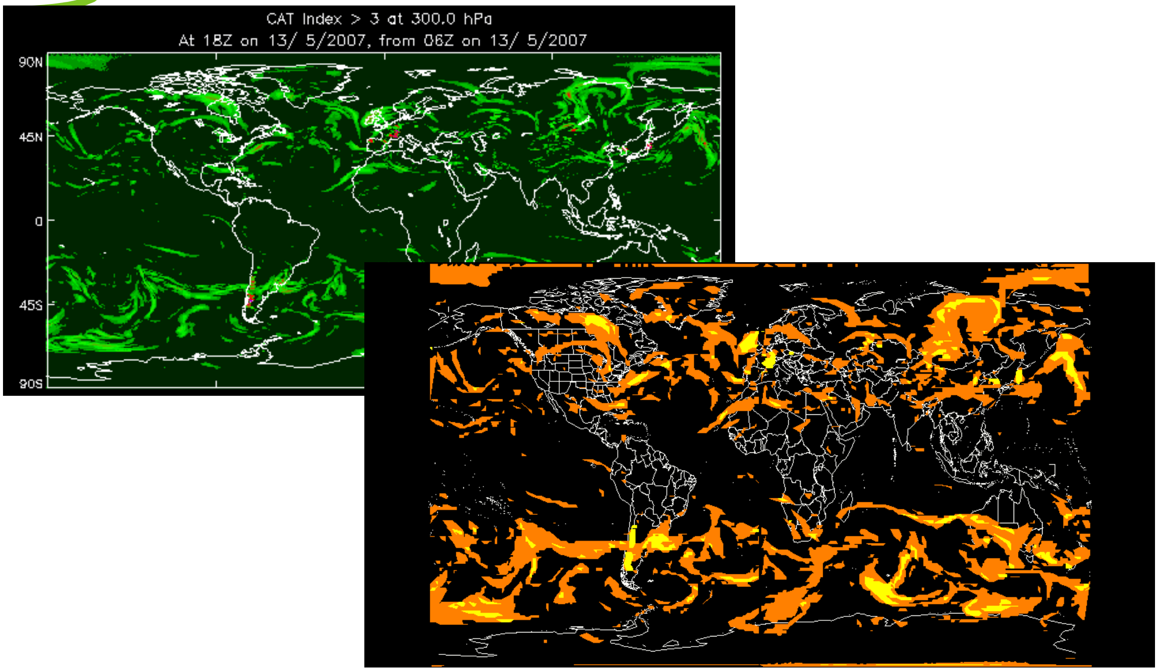


Figure 13: Comparison of CAT field (green) with CAT Objects (orange & yellow).

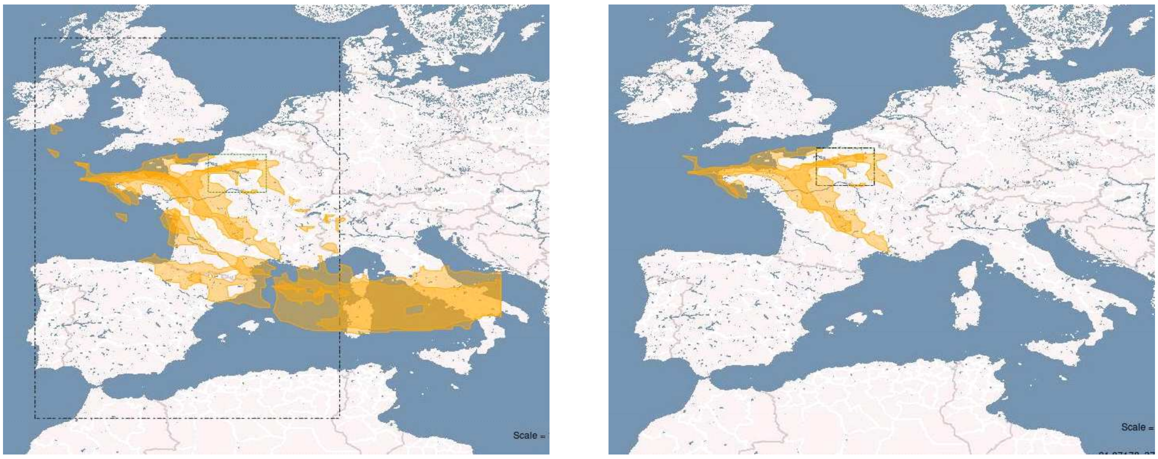


Figure 14: WP 2.2.7 Spatial and Temporal selection and display of weather data from the GWP.

To conclude, an operational GWP node was developed and implemented along with associated communications infrastructure to permit data exchange between ground and airborne users. The GWP would accept routine production data from its data suppliers, the WIMS, and which were stored in a geospatial database. The GWP accepted requests from its data consumers, on demand for any spatial and temporal configuration. All data exchange took place using standard internet protocols with all data expressed using the GML format. The solutions implemented were demonstrated in an operational context during the flight trials conducted as part of WP 6.7.3 and WP 6.7.4.

Conclusion

To conclude, an operational GWP node was developed and implemented along with an associated communications infrastructure to permit data exchange between ground and airborne users. A data model was developed to realise the concept of the weather object. A novel method was devised to convert routine output from the data suppliers into meaningful weather objects for the consumer.

The GWP would accept routine production of weather objects from its data suppliers, the WIMS, and which were stored in a geospatial database. The GWP accepted requests from its data consumers, on demand for any spatial and temporal configuration. All data exchange took place using standard internet protocols with all data expressed using the GML format. The solutions implemented were demonstrated in an operational context during the flight trials conducted as part of WP 6.7.3 and WP 6.7.4.

Evaluations results are detailed in the section corresponding to each specific WIMS.

A general overview of the PTEs and MTEs performed is given in the corresponding sections.

5.2.3. WP 2.3 results

Based on the requirements defined in WP 1.2.2, this work package aimed at specifying, developing and validating the onboard weather management system, dealing with the onboard weather data collection, processing and fusion.

There were two main research areas:

1) Development of onboard systems:
   - Onboard wake prediction and alert (WP 2.3.1)
   - Sensor technology and detection strategy for clear air turbulence (WP 2.3.2)
   - Enhanced and new weather radar modes (WP 2.3.3)
   - Airborne atmospheric probes for enhanced weather forecasting models (WP 2.3.4)
2) Weather information processing in relation to Central Weather Processor inputs
   - Weather data link management for uplinked weather data processing (WP 2.3.5)
   - Weather data fusion onboard the aircraft (WP 2.3.6)

The last two work packages transcend the boundaries between specific weather hazards: WP 2.3.5 (weather data link) is the onboard counterpart of WP 2.2.7 (Ground weather processors and communication means). The outputs of the WIMSs, processed through WP 2.2.7, are consolidated in the ground weather processors (GWP) and the flow of information between the GWP and the aircraft is handled in WP 2.3.5. Onboard data fusion is handled by WP 2.3.6 which generates global weather data sets to be provided to the Next Generation Integrated Surveillance System (NG-ISS) merging function in WP 5.4. The final result consist of presenting to the aircrew the atmospheric situation on a graphic display.

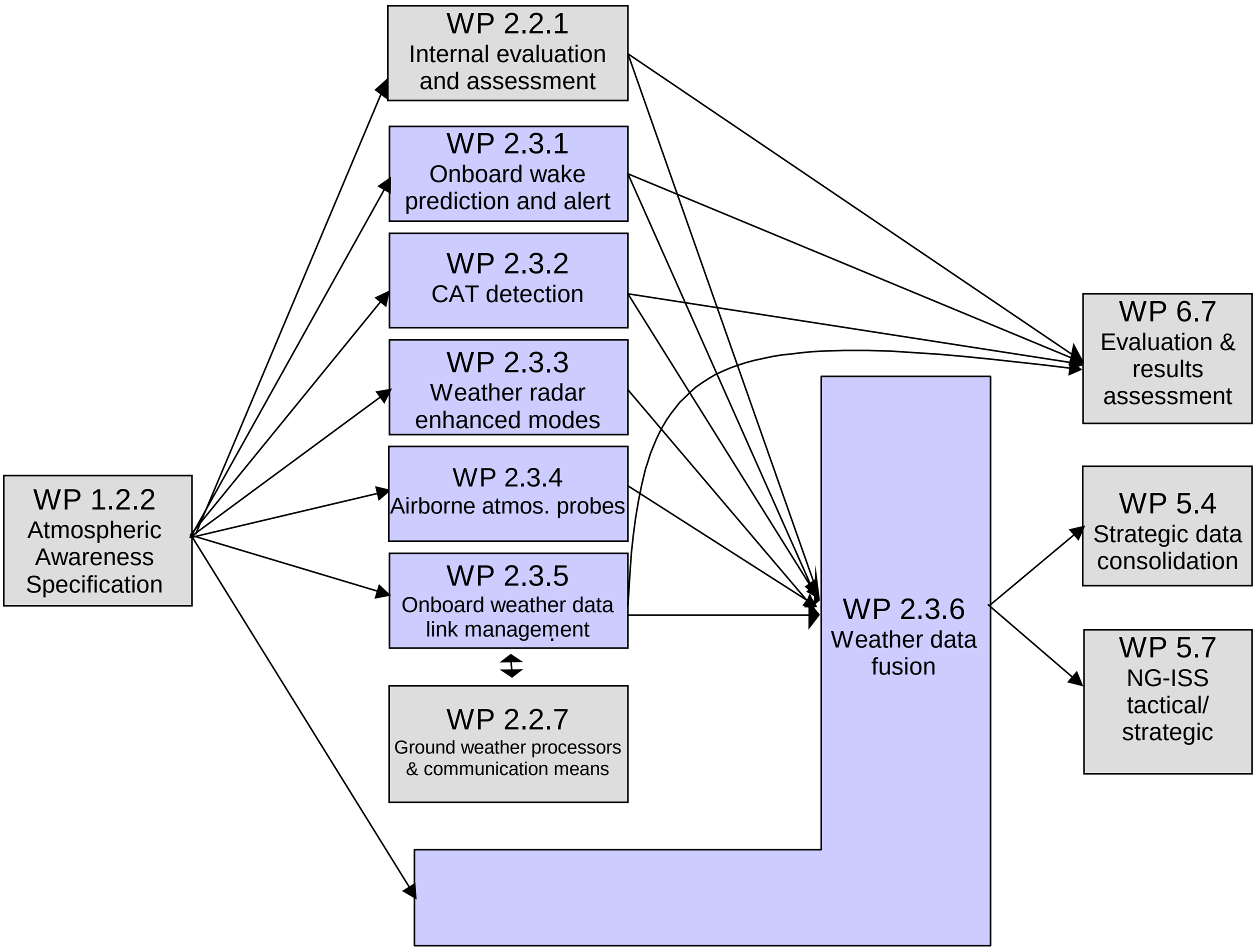


Figure 15: WP 2.3 data process

Within FLYSAFE WP231 an airborne WEPS (Wake Encounter Prevention System) has been developed and evaluated.

The document D231-1, 1st deliverable of WP231, presented the functional description of the Wake Encounter Prevention System. Starting from the WEPS description in D231-1, a detailed specification of the Part Task Evaluation was derived in internal deliverable DI231-1.

Based on the architecture defined in DI231-1, the following functions have been developed:

- Wake predictors, based on existing P-VFS and P2P models, extended to cruise flight altitudes (see internal deliverable DI231-2)
- Conflict detection (see internal deliverable DI231-3)
- Severity estimation (see internal deliverable DI231-3)
- Alerting logic (see internal deliverable DI231-4)

Those functions, with the corresponding HMI, were implemented on AIRBUS THOR flight simulator (see internal deliverable DI231-4).

The WEPS concept was tested and evaluated by test pilots using the THOR flight simulator in December, 2007 (see internal deliverable DI231-5). All participating evaluation pilots have been generally satisfied with the WEPS prototype installation.

The work performed in the context of WP231 has specifically shown that:

- The existing wake prediction models, which have originally been designed for low altitude, apply to all flight phases, including cruise, with minor modifications. The models have furthermore been adapted to allow for dynamically varying input uncertainties.
- The computational requirements by both probabilistic wake predictors – using different methods for probabilisation – are significant but still allow their direct use in a real-time, on-board wake alerting system.
- Both predictors produce slightly different results for identical inputs. Since no data for validation is available their quality cannot finally be assessed. A merging algorithm to fuse both predictors' results has been created yielding probably the best overall estimate of wake location and characteristics.
- Based on best estimates of typical input data uncertainties for the cruise flight phase the sizes of the predicted volumes of probable wake location are not as large as to prevent their sole use for advance wake alerting.
- Operationally relevant wake encounter alerting algorithms can be based on probabilistic wake prediction in combination with 4D conflict detection and dynamic severity estimation.
- Given the small spatial extend of typical wake vortices and the approximate predictability of their location allow for short-term avoidance manoeuvres requiring vertical flight path deviations of potentially not more than 400 feet or lateral flight path deviations of potentially not more than 0.5 NM.
- Advance alerting (up to 3 minutes) is feasible and allows – given the approximate size of the predicted wake volumes – avoidance of severe wake encounters with benign avoidance manoeuvres that can be flown smoothly without disturbing passengers.

The diverse evaluations performed have furthermore revealed some remaining challenges and potentials for improvement, e.g.:

- Accurate wake prediction is significantly influenced by the gross weight and wingspan of the wake generating aircraft as well as the wind direction and speed at the wake generating aircraft. These quantities are currently not part of general available airborne data broadcasts (e.g. ADS-B). For WEPS-like applications the future inclusion of such data in airborne broadcast protocols is encouraged. If bandwidth limits apply an update rate of about 2 - 6 seconds may be sufficient.
- The complexity to spatial-temporally estimate relevant meteorological input quantities and especially their uncertainty from distributed sources (individual aircraft as well as up-linked meteorological data with large grid sizes and low update rates for the cruise flight regime) has been underestimated. Given the lack of corresponding measurements an input data fusion function could not be developed.
- Wake avoidance manoeuvres other than strategic right lateral offsets are currently not permitted. But depending on the situation short-term vertical or lateral avoidance manoeuvres seem to be the optimum manoeuvre. The safety of such manoeuvres needed to be verified by other surveillance functions (e.g. within the NG-ISS), requiring additional interfaces.
- Short-term avoidance manoeuvres should not be solely procedural but be accompanied by dedicated flight guidance and pilot interfaces.

Overall, WP231 has shown the feasibility of airborne wake encounter prevention up to cruise flight altitudes and based on wake prediction alone. For this the broadcasting of an aircraft's gross weight, its wingspan and the measured wind characteristics are important. Tactical, short-term vertical and lateral flight path deviations – depending on the relative geometry between wake and aircraft – seem most appropriate for avoidance but require deeper integration with other surveillance functions within the NG-ISS.

The WEPS concept seems feasible and operationally relevant. In order to create an operational system additional research is needed. The following items are suggested for future evaluation:

- Wake prediction models need to be validated with wake vortex measurements under varying atmospheric conditions and from different aircraft at cruise flight levels.
- The spatial-temporal variability of meteorological data at the range of wake forecasting should be studied and corresponding estimation/fusion filters need to be developed.
- The WEPS prototype should be further developed to seamlessly cater for all flight phases and to include coupling of wake detection and prediction.

Turbulence is a major hazard for aviation. Despite the continuous avionics technology progress (including the weather radar), the number of turbulence accidents has increased by a factor of 5 since 1980. Part of this is due to the increase of traffic, but the rate of accident per million flight departures has also increased by a factor of 2 since 1980. For the aviation transportation industry as a whole, the total cost is estimated over 100 M$ per year.

A whole class of turbulence, representing 40% of turbulence accidents, and designated as Clear Air Turbulence, cannot be detected by any existing airborne equipment, including state-of-the-art weather radar. This kind of turbulence is linked to large amplitude gravity waves (caused by wind flow over mountains for example) or to strong vertical shear of horizontal wind (Kelvin-Helmholtz instabilities).

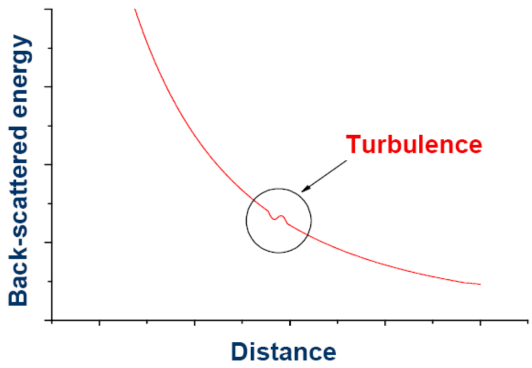
3 operational concepts for turbulence protection have been identified, each corresponding to a given range of action of the equipment. The characteristics of those concepts are presented in the following chart.

RANGE	CONCEPT	REQUIRED DATA	DISTANCE TIME	SAFETY CRITICAL FUNCTION
LONG RANGE	Avoidance of turbulence encounter	- Severity, position and dimension of turbulent area - Short term evolution of turbulent area and severity	> 2 minutes > 30 km	NO
MEDIUM RANGE	Protection of passengers and crew by seat belts fasten	Turbulence detection (for a severity threshold) and time to encounter	30 s to 2 minutes 8 km to 30 km	NO
SHORT RANGE	Protection of aircraft and passengers by mitigation of the turbulence effect with Flight Controls	3 axis air speed ahead of the aircraft	0.2 s to 1 s 50 m to 300 m	YES

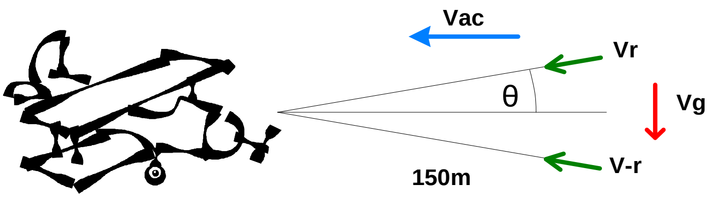
The long-range application cannot be fulfilled by any detection equipment, given the current technology status and expected mid-term evolution. Possible solutions could be provided by ground predictions such as provided by the CAT WIMS studied in FLYSAFE WP2.2.3.

However, the UV direct detection Rayleigh LIDAR is a good candidate for medium range and short-range operations.

- The medium-range CAT detection is based on air density fluctuations measured through backscattered energy fluctuations of the LIDAR signal



- The short-range operation is based on 3-axis wind velocity measurement ahead of the aircraft, obtained by spectral analysis of the Doppler shift of backscattered LIDAR signal



The analysis of LIDAR technologies, regarding the main components (laser source and detection device), taking into account the requirements of aircraft installation (size, power and environment issues) give the results indicated in the following chart. 2 different maturity steps are considered, the 1^{st} one corresponding to state of the art of industrial development, available within 5 years for airborne applications, the 2^{nd} corresponds to laboratory developments, commercially available within 10 years.

PARAMETER		1ST STEP (5 YEARS)	2ND STEP (10 YEARS)
LASER SOURCE	Power Efficiency	1%	5%
	Optical Power (200 W electrical power available)	2 W	10 W
	Technology	Diode pump Nd:YAG	Diode pump Nd:YAG Yb:YAG $Nd:YVO_4$
DETECTION	Quantum efficiency	40%	80%
	Technology	Photon counting APD array	EM CCD

The following chart summarizes the calculated LIDAR performance for both short range and medium range applications, for both 1^{st} and 2^{nd} steps of technology maturity level.

<table>
<tr><th rowspan="2">APPLICATION</th><th rowspan="2">PARAMETER</th><th colspan="2">TECHNOLOGY MATURITY</th></tr>
<tr><th>1ST STEP
(5 YEARS)</th><th>2ND STEP
(10 YEARS)</th></tr>
<tr><td>SHORT RANGE</td><td>RMS Error on vertical air velocity</td><td>2.7 m/s with no aerosol
1 m/s with aerosols</td><td>0.9 m/s with no aerosol (a)
0.3 m/s with aerosols (a)</td></tr>
<tr><td rowspan="2">MEDIUM RANGE</td><td rowspan="2">FAR and MAR for a given detection range</td><td rowspan="2">At detection range = 15 km:
- FAR = 10^{-3} per 5 km
- MAR = 40%</td><td>At detection range = 15 km:
- FAR = 10^{-4} per 5 km
- MAR = 10%</td></tr>
<tr><td>At detection range = 30 km:
- FAR = 10^{-3} per 5 km
- MAR = 40% (b)</td></tr>
</table>

(a): Extrapolated from 1st step with square root evolution law (improvement by $10^{1/2} \cong 3$)
(b): Extrapolated from 1st step with cubic root evolution law (improvement by $10^{1/3} \cong 2$)

- Short-range performance with the first technology step may not be sufficient in regard of requirements for coupling the equipment to the aircraft flight control.

  The second technology step will allow a large improvement of the measurement performance, making them suitable for an airborne application.

- The medium-range performance is interesting even at the first step, allowing a 1-minute before encounter warning, with 10^{-3} per 5 km False Alarm Rate (FAR) (1 false alarm in a transatlantic flight) and more than half of turbulence detected.

  The second technology step will improve the situation, by providing whether a longer warning time (up to 2 minutes) or a lower FAR (10^{-4} per 5 km) and Missed Alarm Rate (MAR) (<10%) for a 1-minute before encounter warning.

The performance calculation was done by analytical study, based on hypothesis regarding the turbulence and atmosphere physics. These hypotheses will need to be addressed and confirmed in further projects, including experimental aspects and taking into account experimental data that are not available within the FLYSAFE project. The identified hypotheses are:

- For Short-Range operation, the influence of the homogeneity of the wind speed in the measurement volume

- For Medium-Range operation, the hypotheses are the turbulence model, the knowledge of N value, and the influence of aerosols

In both Medium and Short Range application, the validation of the equipment should include flight tests, first on a research aircraft to perform functional validation (Technology Readiness Level (TRL) 4/5) then in commercial transport aircraft, as passenger in shadow mode for prototype validation (TRL 7).

For the functional validation of medium range operation, flight tests should be performed with a large support from meteorological services in order to maximise the CAT encounter events.

The results are fully documented in FLYSAFE deliverable D2.3.3-2 “Enhanced airborne weather radar sub-system detailed description”.

In a first task an assessment of which on-board weather radar features, functions or modes can be enhanced and which additional weather awareness capability would be improved by these new radar performances has been conducted.

The following modes, which don't require a deep modification of the current antenna technology, have been considered:

- Storm characterization mode: This mode uses a specific scanning strategy – 3D: horizontal & vertical - in order to sample a CB cell in an optimized way. Then standard radar processing is performed on the data collected. Refined information is deduced from the analysis of the volumetric structure (reflectivity, Doppler) of the cell and from correlation of the radar data with atmospheric parameters. The refined information obtained is the prediction of the storm turbulent top and the measurement of the storm growth and maturity.

- Addition of lightning information obtained from an onboard sensor in order to refine the hazard information linked to a weather cell and to better measure the storm growth and maturity.

- A study of state of the art airborne lightning sensors performances has been conducted,

- High level requirements for suitable airborne lightning sensors were assessed.

In a second task, experimental algorithms for Storm characterisation and hail discrimination modes were developed. These algorithms efficiency were evaluated by analysis of a set of simulation based on real weather event recorded data emulating an airborne Doppler weather radar simulator.

- Storm characterization mode: Simulations globally give correct assessment of vertical extent of the weather cell. This assessment is repeatable when the cell is observed from various angles of view and various ranges – up to a maximum range estimated at 60NM. At higher ranges, due to the increase of the radar bin volume, the storm top determination accuracy degrades progressively and is no longer valid for ranges higher than 80NM. The weather radar simulator does not take into account the attenuation caused by intervening rain, hence the results obtained are a best case only achievable if this attenuation is compensated by the radar using dual polarization techniques or others.

- Hydrometeor identification (rain, snow, hail) mode: A classification method based on fuzzy logic has been developed and evaluated, this method was based only on ZH, ZDR and LDR parameters because of simulator limitations. The analysis of the simulation sets gives the following conclusions:

  - For a given range ring, it appears that the size of the range bin has not a significant impact on the performances of the classification algorithm.

  - For a given WxR configuration (i.e. range bin size), as expected, it appears that the performances decreases with range.

  - From the results that have been obtained – and considering the limitations that are reminded below – it seems that the classification of hydrometeors could be done efficiently at ranges below 30 km (18,5 nm). At further ranges, the rates of correct classification are below 75% in the simulations which suggest they will be even lower in a practical implementation.

  - The principal limitation comes from the beam aperture in the dimension across the scan direction (e.g. elevation aperture if the scan is horizontal). The integration of several radials during the scan allows reducing the angular width of the radar bin in the scan plane. However, as this integration is made only in the scan direction, the angular width in the across direction remains very important (aperture of the beam is around 3°). As a consequen ce, a lot of hydrometeors are contained in this vertical extent and this has a strong impact on the computed reflectivity, and so on the computed polarimetric variables and finally on the classification result.

  - The melting layer (an app. 500 m thick layer beneath the 0°C isotherm) will have a great influence on the data. Radar signals can even be contaminated through the side lobes of the antenna.

  Nevertheless the simulation results are subject to several limitations:

  - On one hand, the path attenuation has not been considered in the simulation when generating PPI's of polarimetric variables (ZH, ZDR and LDR). The input data of the classification algorithm should then be seen as “perfectly corrected” data. As in a practical implementation the signals will be attenuated and the correction will not be perfect, the classification performances will decrease.

- On the other hand, the weather radar simulator in its current version has limited the classification algorithm to the uses of only three polarimetric variables (ZH, ZDR and LDR). The phase information especially could not have been used, which prevented to consider KDP and rhoHV as inputs.

- Finally, the possibility of defining another scanning strategy - in both horizontal and vertical directions, during a scan - should be considered as a potential enhancement.

In a first task, the existing services provided by the aviation to the meteorological community, and the sensors and associated atmospherics parameters that are covered by those existing services, have been described

In a second task, the additional needs of the meteorological community, regarding atmospheric parameters not covered by existing systems or products, have been identified.

In a third task, potential sensors, at different development steps, have been identified, that could be used for those additional needs, and aircraft installation for such sensors has been discussed discussed.

Finally, the benefits of those different sensors have been evaluated.

ATMOSPHERIC PARAMETER	MEASUREMENT DEVICE	MATURITY STATUS	COMMENT
PRESSURE	Static pressure sensor	On board commercial aircrafts	Required by aircraft operation
TEMPERATURE	Total temperature probe	On board commercial aircrafts	Required by aircraft operation
	Radiometer (remote sensing)	Mature for research applications	Suitable only for research applications
HUMIDITY	TAMDAR sensor	Validated in operational conditions	For medium altitude aircrafts (commuters)
	WVSS-II sensor	Under validation in operational conditions	For commercial jet airplanes
	LIDAR (remote detection)	Laboratory experiment	Requires extensive optical processing
WIND SPEED & DIRECTION	ADIRS : pressure & temperature sensors + accelerometers and gyrometers + GNSS	On board commercial aircrafts	Required by aircraft operation
TURBULENCE	Accelerometers (in situ measurement)	On board commercial aircrafts	Required by aircraft operation
	Lidar (remote detection)	Mock up / Prototype	Long or short range detection
ICING CONDITIONS	Deicing system (ON / OFF)	On board commercial aircrafts	Very limited performances
	TAMDAR sensor	Validated in operational conditions	For medium altitude aircrafts (commuters)
	Icing certification instruments	Validated in operational conditions	Economic interest to be analysed
	LIDAR (remote detection)	Laboratory experiment	Requires extensive optical processing
LIGHTNING	STORMSCOPE	Commercialy available	Remote lightning detection
	ALISDAR	Prototype	Detects in-situ lightning strikes & remote lightning
VOLCANIC HASH	LIDAR (remote detection)	Laboratory experiment	Requires extensive optical processing
VISIBILITY	LIDAR (remote detection)	Laboratory experiment	Simple back-scatter Lidar

AMDAR Sensors

- Definition of weather data link characteristics:

The available data link technologies have been identified, as well as emerging data links and those of next decade. Correlation of theoretical available bandwidth of these data links and estimated size/refresh rate/ latency of weather data to uplink according to potential airborne applications needs (weather data fusion and WIMS display) has been made.

- Definition of Weather Data link Management (WDM):

The Weather Data link Management has been defined to upload weather forecasts (WIMS) onboard the aircraft according to aircraft needs (weather data fusion and weather display applications): it was based on WIMS products uplink on request from aircraft for the area of interest (weather corridor computed on aircraft 3D position and heading). Based on estimated WIMS data size and given data link speed rate at application level, a WIMS Request / Reply Manager process has been defined: periodic requests were sent to the Ground Weather Processor (hosting the WIMS database on ground) to get WIMS products in the area of interest, thanks to spatial and temporal selection capability of the Ground Weather Processor.

- Documents:

An overview of "state-of-the-art" data link technologies has been presented in the D2.3.5-1 document. Due to very large amounts of data (weather forecasts) to uplink onboard and induced required bandwidth, the best-fitted onboard weather data link system is a satellite link with high speed data rate. Other data link means (VHF with VDL Mode 2, Mode 4…) do not offer sufficient bandwidth to uplink WIMS products with their current size. Bandwidth is a major constraint for onboard use of WIMS products.

The D2.3.5-2 document has been written as the system specification of the mock-up developed for flight trials (WIMS Request / Reply management according to aircraft needs and area of interest).

- Flight tests mock-up:

According to the D2.3.5-2 document, a data link mock-up (prototype) has been developed and evaluated with flight trials of summer 2008. The retained data link solution for the flight tests was a High Speed SATCOM (Swift 64 Mobile Packet Data Service) which was used to manage point-to-point communications. A specific component (SANTA) acted as an IP protocol enhancer that speeded up data exchanges. The point-to-point capability with the Ground Weather Processor has been demonstrated. However, latency of weather data dispatching from observations used as inputs of ground predictive models to air users (through the ground network and the data link) is disrupting a real-time dissemination of weather forecasts.

The size of uplinked WIMS products (even once compressed) is larger than expected and huge amounts of data are uplinked onboard the aircraft (WIMS ICE, CAT and CB products in the area of interest). It has been highlighted by the weather community that, since the number of WIMS products was increasing with increasing adverse weather situation, it was difficult to provide an overall estimation of maximum size of data to uplink for the area of interest. Passing large amounts of weather data requires a broad data "pipe". Bandwidth is and will always be a major constraint, even with new satellite technologies that should emerge in the coming decade.

Several options could be envisaged to reduce the amount of uplinked WIMS data:

- Moving from XML-type to BUFR-type format would increase the complexity of WIMS production (the need for intermediate coding will become necessary) and would decrease the data size. This increase in complexity may be the price to be paid to minimize the bandwidth constraint.

- Decrease the details level of some WIMS products (smoothing polygons which show at present fine details which are not necessary for pilots): WIMS ICE Regional products with their multiple layers for example are not required with so many details for navigation purpose.

- Use of a more reactive and secured degraded mode for Weather Datalink Management could help to reduce the temporal depth of the Weather Corridor (and the amount of uplinked WIMS).

Communication cost is also a major constraint for airlines that would be interested in uplinking weather forecasts onboard. Weather forecasts data size and communication cost figures from the flight tests have been presented to RTCA/EUROCAE Working Group 76: the immediate feedback from airlines representatives was that they would be reluctant of the costs caused when uploading so large amounts of data. Further work should be done on weather data size optimization (format, compression, reduction of polygon points without loosing information content…) to reduce weather data flow for data link purpose.

The flight tests summer campaign has been done in simple conditions (isolated CB conditions and a single aircraft equipped with WIMS products uplink system). Flying through embedded thunderstorms and with a fleet of aircrafts equipped with WIMS products uplink system in the same region would degrade the system performances from a communication point of view (the bandwidth is shared by all the users/ embedded thunderstorms would increase size of uplinked data). Swift 64 service would not be sufficient to support a large deployment of NG-ISS on several aircrafts with current size of WIMS products.

Swift 64 Mobile Packet Data Service is an affordable solution for modest amounts of data to transfer (which is not the case for WIMS products), as it is billed by the kilobyte and not by the connection time. The overall communication cost could be reduced if Swift Broadband service is used (not available for the flight tests summer campaign). INMARSAT hinted that the cost of accessing the Internet over the new Swift Broadband network will be less than users pay now with Swift 64 (Swift Broadband is also a mean to boost effective data rate). Regional satellite operators - Africa or Asia - may also offer competitive solutions (although none of these operators offers a global coverage).

Further work is required for a well-balanced Weather Data link Management solution with reduced and optimized weather data size, better effective data transfer rate and competitive communication costs.

- Review of Weather Data Fusion related specifications and definition of WIMS format:

Support on WIMS products format definition has been provided for Baseline and Advanced versions to take into account aeronautical constraints. A Confidence Level has been defined for WIMS products.

- Definition of Weather Data Fusion:

Additional weather information / overlays in the cockpit will overload the pilots' cognitive capabilities. Pilots will have difficulties correlating information when paging through various weather products. The Weather Data Fusion aims at combining different sources of weather information to offer a complete and enhanced weather picture to the flight crew.

Based on WIMS format and on airborne radar data format (ARINC 453 format or similar format for Full Flight Simulator), the Weather Data Fusion process has been defined to combine convective weather data (CB) from different sources and to provide a consolidated area of weather hazards (spatial association) and fused parameters. In addition to the polygon outlining the consolidated area of danger (horizontal extent), the Fused CB data included severity, vertical extent, maturity (vertical and horizontal trend), presence of hail, speed, direction,…

- Specification of Weather Data Fusion:

Weather Data Fusion principles have been described in the D2.3.6-2 document. The detailed Weather Data Fusion specification for flight tests has been described in the D2.3.6-3 document.

- Full Flight Simulation and Flight tests mock-up:

Weather Data Fusion algorithms have been developed and tested on the Full Flight Simulator. Fused Data were transmitted to the "Strategic weather conflict detection" function and displayed on the HMI.

According to D2.3.6-3 document (detailed specification), a mock-up (prototype) has been developed and evaluated with flight trials during summer 2008.

For the flight trials, the onboard weather sensors were:

- A Fully Automatic Weather radar (Multiscan), with Ground Clutter Suppression and Automatic Tilt Management functions, that provides a clutter-free display of weather hazards at extended range (320 Nm),
- A lightning detector that displays the location of lightning discharges.

The uplinked weather forecasts were WIMS CB, CAT and ICE products. Only horizontal extent of the weather hazards was displayed on the basic HMI of the Weather Display for situational awareness: there was no possible reuse of the HMI developed for the Full Flight Simulator due to the used platform.

Through combination of airborne radar observations and uplinked weather forecasts, regions of weather hazards have been delineated on a basic HMI. WIMS CB Bottom products were mainly used for weather data fusion; relatively few WIMS CB Top products were uplinked during the flight trials, since the flights were not enough convective to present CBs that reached up high altitudes (thunderstorms were not deeply developed vertically). Weather conditions encountered during the Experiment 5 were less convective than the ones of Experiment 1and 2 and present scattered CBs at development stage, rather than embedded CBs.

Observations from ground radar and its derived WIMS CB Bottom products, when compared to observations from the airborne radar, are different due to different used technologies (polarisation, resolution, wavelength and intrinsic characteristics) and to vertical dispersion of reflectivity: cell maturity is a large factor in how the reflectivity decreases as a function of height (colder temperatures). Combining both of these information is a challenge, which was partially achieved with data fusion. Superimposition of both WIMS CB Bottom polygons and airborne radar cells when quite different raises HMI issues: it could lead to crew misinterpretation (human factors).

Use of weather forecasts onboard is dependent upon spatial accuracy of these forecasts, which depends itself on their timely dissemination - from observations used by predictive models to the Ground Weather Processor and then to the final user (aircraft): for short range hazards, spatial accuracy is a critical constraint whereas it is less stringent for long range hazards. Onboard sensors provide instantaneous observations with rapid refresh rate compared to weather forecasts. One hurdle to use weather forecasts on board is their real-time availability on board: the overall transmission delay from WIMS producers to the final air user is important in the context of Experiment 5 and it shows it is a limiting factor for operational aspects, if not properly addressed. The greater the forecast range (forecasts at 5, 10, 15, 20 minutes …) is, the less reliable the forecast is.

Local WIMS CB products, when related to mature CBs, offer adequate precision for Weather Data Fusion purpose on TMA area, even with the latency generated by the experimental ground weather segment used for the flight tests. Regional WIMS CB products - especially CB Top products in their current version - present a latency of up to 15 minutes which, combined with the de-synchronization delay induced by aircraft periodic queries, can lead to use WIMS forecasts product beyond 30 minutes. This penalizes their use for airborne applications requiring high position accuracy. The overall transmission delay exacerbates Regional WIMS / airborne radar data discrepancies for scattered CBs at development stage. Improvement of the data latency at ground segment should enhance cases of developing CBs.

- As regards to Regional WIMS CB Top products, too few cases have occurred in the Experiment 5 to come to a final conclusion. The overall transmission delay of Regional CB Top products could be reduced if a more rapid satellite scan were used as input of the ground predictive model. The METEOSAT Rapid Scanning service generates image data at 5 minutes intervals (instead of 15 minutes intervals) that could be used for that purpose. The Rapid Scanning service scans reduced area (latitude range from approximately 15°to 70°) .
- The overall transmission delay of Regional CB Bottom products could be also reduced, considering that radar composite are available over large parts of Europe at 5 minutes refresh rate, and taking into account that the upcoming European radar compositing centre could accommodate such a rate.

The Weather Data Fusion provides a consolidated view of different combined data sources suitable for mid and long-range weather hazards. Each source has its own position error, timing error and limit… The main interest is to use strengths of each source to have consolidated weather data in the cockpit.

Two different graphical representations of Fused CB polygons have been proposed to display the area of weather hazards on the HMI:

Method #1: polygons of 6 points based on interpolated WIMS CB polygon. This representation (used during the flight tests) seems too coarse for range smaller than 80 Nm. Accurate information from on board sensors (instantaneous observations at flight levels with rapid refresh rate) is required to avoid or pass through short-range weather hazards, especially for CB cells that are growing and developing.

- Method #2: polygons of maximum 22 points based on union of radar cell and WIMS CB polygon with concavities attenuation. This additional proposed representation (used for data fusion replay as an off-airplane process) is better for short-range weather hazards. It does clearly show the benefits of using more points to represent the fused polygons. However, pilots' feedback is that they would like to have even more detailed Fused CB polygons to feel comfortable to navigate with and to be able to pass through short-range CBs. The number of points used to describe the hazardous area (Fused CB polygon) could be increased to closer match to real contour of cells of reflectivity. Pilots want to visually check by outside looking what is displayed on the HMI in terms of weather hazards: providing a rough/simplified contour for Fused CB objects is disturbing for the pilots because they do not recognize the stylized contour of Fused CB objects when looking out of the window.

- An alternative solution could be to present on the HMI the outline contour of union of both cell of reflectivity of the airborne radar and WIMS CB polygon: this would allow keeping the maximum of details of both sources.

The severity of a thunderstorm is identified as an important parameter to be able to fly through CBs: however, as the observed reflectivity is different at flight level and at ground level for developing/growing CBs observed during the Experiment 5, it is challenging to fuse the severity information, even if using the vertical extent and trend of WIMS CB products. If the cell is growing, then the hazard exists above the radar and visual cloud top. Conversely, if the cell is decaying, the altitude of the hazard is below the cell visual top. Severity really depends upon the growth versus decay of the cell and how fast it is evolving. At the present moment, the severity parameter of Fused CB objects is based on the one provided by WIMS CB objects.

The experience gained from the flight tests and from pilots' feedback quoted above also suggests reconsidering one of the assumptions of the data fusion process, i.e. the assumption that data fusion outputs should represent the hazardous area with symbolic/simplified polygons for short range weather hazards. It also suggests including additional elements for gauging the weighting factor of both sources: the range of weather hazards, the Confidence Level of WIMS products and the attenuation of the airborne radar signal by cells of high reflectivity with same azimuth (when the limit of Path Attenuation Compensation function - implemented through automatic gain addition - is reached).

A possible way forward for HMI issues is to present either the outline of union of airborne radar cell in raw mode and WIMS CB polygon or the superimposition of airborne radar cell in raw mode and WIMS CB polygon, while giving through the HMI more visual impact to the airborne radar at short range and less at long range. It has to be considered that, because most of the value brought by WIMS CB products lies in the strategic horizon (growing/decaying trend, severity parameters…), HMI issues are then a bit less stringent for long range weather hazards. By contrast, the added value of WIMS CB products (vertical extent, presence of hail…) at short ranges, i.e. for the tactical horizon, should only be carried to the pilot in the way of enhancing the airborne weather radar raw data representation in some graphical way.

5.3. WP3 TRAFFIC HAZARDS

Air traffic hazards have been addressed in other projects, such as the FP 6 IP "C-ATM". Consequently, FLYSAFE has not developed new functions or systems in this field, but rather used the outputs of C-ATM and other previous projects and integrated them into the Next Generation Integrated Surveillance System (NG-ISS). Regarding the data link technologies for traffic surveillance, FLYSAFE has also used the results from other studies, and has selected 1090ES ADS-B as the model technology for simulator evaluations.

Ground traffic hazards have been addressed in the FP 6 IP "EMMA". FLYSAFE initially requested authority from the EMMA project Sub-Package 2 (SP2) leader to reuse relevant EMMA onboard technology, but due to project policies and restrictions, EMMA information and technology was only able to be re-used in FLYSAFE to a limited extent.

The FLYSAFE Traffic project-team re-used existing models of sensors for TCAS, ADS-B and Mode S, and customised the following functions, taking into account the outputs of WP 1.2.3:

- ASPA-S&M function available from previous projects and BAE Systems internal development.
- Runway incursion alerting function available from previous projects, with development by CFD and UOM during FLYSAFE.

- Taxi collision-avoidance function based on TUD's involvement in previous projects (e.g. ISAWARE II, EMMA).
- Anticipation of future traffic hazards function from ISAWARE II, providing the crew with advisory information of potential conflict ahead of current position anticipated beyond the TCAS alert. Note that specification of this function was performed by WP 3, but development was performed as part of the NG-ISS Strategic Conflict Detection and Resolution function, in WP 5).

These functions were provided with improved HMI capabilities, intended to be compatible with the display of weather and terrain information on a multifunction display. Traffic hazard-detection functions were integrated into the NG ISS context by (a) providing short-term hazard alert outputs for integration into the Tactical Alert Management (TAM) function of the NG-ISS, and (b) strategic traffic hazard alerting functionality was built into the Strategic Data Consolidation function of the NG ISS.

The work package was divided into two sub work packages:

- **WP 3.1 "Analysis and Specification"** analysed the needs of a traffic situation awareness system and specified the requirements for a solution based on on-board equipment.
- **WP 3.2 "Customisation and Validation"** customised the selected traffic situation awareness solutions, developed new functionality where necessary, and validated them for integration in the FLYSAFE platform by means of the Traffic Part Task Evaluation (PTE).

The resulting Traffic software components were integrated into the NG ISS platform in WP 5.7.

Work Package 3.1 included a review of the work done by previous and on-going projects in the areas of air traffic and ground traffic situation awareness. The software / functional specifications developed by these projects were analysed and compared with the results of WP 1.2.3 "Traffic Awareness Specification", and a consolidated detailed Traffic specification was produced for the FLYSAFE platform.

The WP also studied the impact of the different systems on the presentation of traffic information together with terrain and weather phenomena. This analysis allowed the definition of Traffic HMI design alternatives and the associated procedure alternatives, as well as the specification of the interfaces necessary for the Traffic functions to operate in the context of the NG-ISS.

Some of the detailed Traffic definition and design activities were performed by the traffic partners working in three defined "Strand" sub-teams, as follows:

Strand 1: "**Airborne**" – Tactical airborne traffic conflict detection (e.g. TCAS), and the ASAS Package 1 ASPA-S&M Application;

Strand 2: "**Runway**" - runway incursion avoidance (take-off and landing);

Strand 3: "**Taxi**" - taxi collision prevention.

These three strands are shown in the following figure, together with the two "columns" of shared Traffic functionality – Traffic Data Fusion (traFUS) (which fuses traffic information from all available sensors) and Traffic flight deck situation awareness and alerting. The strand structure was adopted to allow each of the three sub-teams involved to develop their own technology independent of each other prior to the Traffic PTE. Whilst all Traffic partners were involved in function specification, the "strand" approach for technology development was adopted in order to:

a) prevent the development of one strand being impacted by delays in another

b) allow Traffic functions to be delivered for integration at the Traffic PTE site as early as possible

The specific roles and responsibilities of partners working in the three identified strands were defined in the corresponding third level work package definitions.

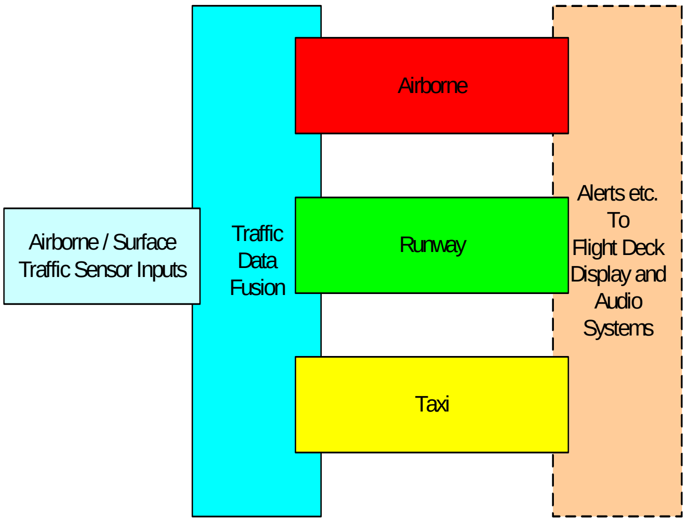


Figure 16:Traffic Functional Groupings

5.3.1. WP 3.1 Results

The results of this WP are fully documented in FLYSAFE Report D 3.1.1, the “Specification of Operational Situations, Goals and Behaviours for the Traffic segment of the NG-ISS”, version A, September 2006. Specifications are provided for several Traffic subsystems with response-times ranging from immediate reaction (safety net functions such as ACAS), through tactical alerting systems (e.g. airport surface movement alerting) to inputs for strategic traffic decision and planning aids. The report provides a short review of the inputs used for the work, and:

- Defines the required behaviour of the full scope of Traffic functionality to be developed during the FLYSAFE project,
- Identifies a set of function-verification tests to be used to prove that the supplied functionality complies with its behavioural requirements
- Lists an initial definition of tests to be used during the man-in-the-loop Traffic Part-Task Evaluation (PTE) conducted at the Technical University of Darmstadt (TUD).

The results of this WP are fully documented in FLYSAFE Report D 3.1.2, the “Specification of Functional Requirements for Evaluation” for the Traffic segment of the NG-ISS. The report:

- Defines the functional and performance requirements for the full scope of Traffic functionality to be developed during the FLYSAFE project.
- Identifies the complete set of Traffic interfaces, in terms of:
    - o External Traffic interfaces (i.e. interfaces between Traffic functions and other parts of the NG-ISS or the operating environment)
    - o Intra-Traffic interfaces (i.e. interfaces between functions within the Traffic segment), and
    - o Internal function interfaces (i.e. interfaces within the function being described), which forms part of the function design description.
- Describes the set of test harnesses necessary to prepare the Traffic functions for the man-in-the-loop Traffic Part Task Evaluations (PTE) to be undertaken at the Technical University of Darmstadt (TUD).

The results of this WP are fully documented in FLYSAFE Internal Report DI 3.1.3, the "Definition of HMI Alternatives", version A, November 2006. This document describes Human Machine Interface (HMI) concepts for Traffic functionality of the NG-ISS, based on the requirements developed within the "Traffic Awareness Specification" work package (WP 1.2.3) and the "Information Fusion and HMI specification" work package (WP 1.2.5). The report identifies the requirements applicable to the scope of the Traffic work package and provides a full set of requirements - along with HMI alternatives - to the Traffic software development within work package 3.2.2. The Traffic HMI alternatives presented in this report are directed towards a homogenized concept which addresses the threat partitions identified for the traffic work package, namely airborne traffic concepts (ASAS S&M) and surface movement traffic conflicts. An "HMI requirements matrix" is used to ensure that the HMI concepts selected for implementation comply with all the applicable requirements. A second matrix, the "HMI Threat Table" is adapted from an output of WP 1.2.5, with the intention of documenting potential issues that might emerge during Traffic development and integration.

The results of this WP are fully documented in FLYSAFE Report D 3.1.4, "Operational Procedures for NG-ISS Traffic", version A, dated May 2007, which documents all of the procedures specific to the Traffic segment of the Next Generation Integrated Surveillance System (NG-ISS). The procedures described take into account applicable conclusions/recommendations produced by the Traffic HMI and Procedures Focus Group, in order to ensure consistency of operation across the entire NG-ISS – and (as far as possible) consistency with current aircraft operations. The areas of Traffic functionality covered in this document are ASPA Sequencing and Merging (Traffic "Airborne" strand), the Runway Collision Avoidance Function, RCAF ("Runway" strand) and the Surface Movement Awareness and Alerting System SMAAS, ("Taxi" strand).

The results of this WP are fully documented in FLYSAFE Report D 3.1.5 "Safety Implications of ASAS Package 1 Applications", version A dated June 2007. Since the FLYSAFE NG-ISS is intended to comply with a circa 2020 operational environment, the use of ADS-B data is assumed throughout Traffic functionality and selected ASAS Package 1 applications are expressly included in the Traffic functionality. However, the scope of WP 3.1.5 is wider than just those functions implemented for the NG-ISS and includes all Package 1 applications. The report:

- Identifies a set of ASAS (Package 1) potential safety issues;
- Analyses this information to identify trends & patterns;
- Performs a more detailed analysis for selected ASAS applications (see below);
- Reviews the potential safety impact of each issue in terms of its likelihood and severity;
- Documents safety implications and trends identified during the analysis.

All ASAS Package 1 applications are included in the survey, but a subset was selected for more detailed analysis. These are:

- The Airborne Spacing Application – Sequencing and Merging (**ASPA-S&M**),
- Airborne Traffic Situation Awareness - In-Trail Procedure (**ATSA-ITP**)
- Airborne Traffic Situation Awareness on the airport SURFace (**ATSA-SURF**)

The review of safety assessments has shown that the Airborne Traffic Situation Awareness (ATSA) applications share a set of safety issues in common, even though individual applications are intended to be used in different phase of flight. Further studies are required in order to mitigate key hazards and to specify the impact of ATSA on the ground ATC. On the other hand, no blocking issues have been identified, mainly because all of the different ATSA applications aim at providing incremental improvement to existing procedures.

In ASAS spacing (e.g. ASPA-S&M), four mutual "major" or "hazardous" hazards have been found through the cross-check of safety assessments carried out by the ASAS Requirements Focus Group (RFG) and the Large Scale European ADS pre-implementation Programme (SEAP). The following operational hazards have the most severe consequences if they occur and are undetected:

- Error in flight parameter adjustment by pilot to control the airborne separation,
- Unexpected manoeuvre of the crossed / target aircraft during the execution,

- Erroneous pilot checking of separation after a manoeuvre

In the case of other ASAS applications (ASPA-C&P, ATSA-ITP), the analysis showed that some of the ASPA-S&M hazards are applicable to, or have counterparts with, the hazards found in ATSA-ITP and ASPA-C&P. For example: loss of ADS-B capability or undetected non-execution of the relevant manoeuvre. With regard to ADS-B applications, safety analyses are still ongoing and some of the applications are immature; no solid safety recommendations are currently available other than for the ADS-B-NRA application. It is worth noting that, in the case of ASPA-S&M, some of the identified failure modes (for example, incorrect flight parameter adjustment by the aircrew) are alleviated in the FLYSAFE context by automatic execution of the manoeuvre.

The objectives of the work package have been achieved with the review of available safety study results and the identification of the most significant hazards for Package 1 applications, with a particular focus on those applications directly relevant to the NG-ISS, i.e. ASPA-S&M and ATSA-SURF.

5.3.2. WP 3.2 Results

The results of the WP 3.2.x activities are fully documented in a set of reports as follows:

WP 3.2.1: FLYSAFE Report D 3.2.1, "Critical HMI Design Issues for Traffic HMI", version A, May 2007.

WP 3.2.3: FLYSAFE Report D 3.2.3, "Evaluation Plan for Traffic PTE", version A, November 2007.

WP 3.2.4: Minutes of the Traffic Presentation Day, January 2008.

WP 3.2.5: FLYSAFE Report D 3.2.5, "Traffic PTE Results Report", version A, May 2008.

(Note that WP 3.2.2 resulted in a set of internal documents.)

In summary, the Traffic PTE Report outlines the simulator environment used during the Traffic Part Task Evaluations, summarises the evaluation methodology used and describes the results obtained. The specific functions included in the Traffic PTE are:

- Airborne Spacing Application – Sequencing and Merging (ASPA-S&M), from the Traffic "Airborne" strand,
- The Runway Collision Avoidance Function (RCAF), generically referred to as the Traffic "Runway" strand, and
- The Surface Movement Awareness and Alerting System (SMAAS) and airport moving map functions of the Traffic "Taxi" strand.

For each of these functions, prototype software was verified at the individual contributing Partners' sites prior to being transferred to the Technical University of Darmstadt (TUD) for integration. Contributed Traffic functions were integrated onto the TUD fixed-base flight deck simulator system and previously agreed acceptance tests (defined in WP 3.2.3) were used to confirm that the function was operating as intended. The PTE scenarios and procedures (also defined in WP 3.2.3) were divided into two main classes: (a) airborne scenarios used for the ASPA-S&M function and general traffic situation awareness evaluations and (b) airport surface-movement scenarios used for the SMAAS, RCAF and Taxi Map functions.

The principal objective of the Traffic PTE was to establish the operational usability of each of the new Traffic functions, in a realistic simulation environment. Two series of PTE sessions were conducted; ten evaluations of the SMAAS (with three "pre-test" sessions) and six evaluations of each of the RCAF and ASPA-S&M functions. Report D 3.2.5 records detailed results from these evaluations, together with identified human factors issues with the current implementations and recommendations for future development of the functions. It was concluded that each of these functions was sufficiently mature to be taken forward into NG-ISS integration (WP 5.7); selected HMI and behavioural improvements identified in the Traffic PTE were implemented as part of this activity.

5.4. WP4 TERRAIN HAZARDS

WP 4 is broken down in three parts, listed below:

- WP4.1 Terrain situation awareness
- WP4.2 Obstacle situation awareness
- WP4.3 Database and WXR correlation

Although Terrain and obstacles use distinct databases, the design philosophy of the obstacle alerting function is that of the terrain alerting function. The distinction that FLYSAFE has applied in the proposal phase has been removed in the specification, development and IVV phases, while for administrative reasons the work-package numbering has been kept separate. Moreover, the real distinction within WP4.1 and WP4 was between the tasks related to the development of TAWS enhanced terrain and obstacle and the white paper study on the helicopter needs for enhanced terrain and obstacle awareness.

Finally, note that the functional perimeter of the terrain and obstacle functions do not include the representation aspects which shall be dealt with in WP5.5. As one of the requirements, the developed terrain and obstacle functions shall provide the necessary output parameters to support the associated representation functions described in the D 1.2.1-2 "Overall System Specification – FLYSAFE platform and test-bed".

5.4.1. WP 4.1 & WP 4.2 Results

The results are fully documented in FLYSAFE deliverable D 4.1.1 “Terrain and Obstacle Awareness Specification” for the specifications of the terrain and obstacle awareness functions to be developed within the TAWS platform and the D 4.1.3 “Terrain and Obstacle IVV report” for the developments, integration, verification and validation of the terrain/obstacle functions.

The reports provide

- A brief overview of existing certified capabilities for a TAWS system
- The new set of requirements addressing the terrain/obstacle functions including constraints initiated from avionics (e.g. architecture), detection capability and algorithms, alerting including prioritization, failure modes and nuisance reduction potential.
- The definition of tests to be conducted to pass the integration of the new modules within the TAWS baseline product and the results, as well as the definition of the external interfaces between the enhanced TAWS and the NG-ISS
- The definition of tests to be conducted to pass the verification of the new modules and the results including the compliance matrix and non-regression
- The definition of scenarios for the validation that was conducted as the Terrain PTE and the operational feedback received.

The results are fully documented in the FLYSAFE WP 4 internal report “Helicopter Terrain and Obstacle Situation Awareness”. This report provides

- A summary of incidents and accidents reports regarding helicopter crashes due to terrain and/or obstacle hazards, highlighting the hazardousness of linear obstacles such as cables,
- A survey of terrain and/or obstacle information requirements as existing in current national and international standards to point out their inadequacy with respect to helicopter operations,

- A summary of terrain and obstacle data availability to the helicopter operator and/or the database provider showing that completeness is a major issue and recommending multiple data-providing sources dynamically completed with in-situ observations,

- A proposal of display solution for terrain and obstacle information supporting 3D or SVS cockpit displays and going beyond the standardised obstacle pictograms.

5.4.2. WP 4.3 Results

The final product of this Work Package is an assessment of mechanisms, detection techniques and weather radar technologies involved in terrain database improvement, hence requirements for future commercial airborne weather radars.

The results of WP4.3.1 study are fully documented in FLYSAFE deliverable D4.3.1 “Ground mapping function of WXR definition”. Within this deliverable, benefits expected from correlation are detailed and discussed. Based on these expected benefits, key radar performances are specified. Advanced airborne Radar Ground mapping, obstacle detection techniques and technologies enabling the WXR mapping / Terrain database correlation are identified and assessed. An iterative process is implemented to find the balance between radar achievable resolution, resolution needed by correlation algorithms and cost impacts.

The results of WP4.3.2 study are fully documented in FLYSAFE deliverable D4.3.2 “Terrain database and WXR correlation concepts and algorithms definition”.

This deliverable assesses the state of the art of terrain and obstacle databases comprising:

- The acquisition and representation of terrain and obstacle data as well as the most common attributes for this data, including Geo-referencing.

- Existing aeronautical information database systems.

- State of the art of geo-registration.

This deliverable also describes the correlation process comprising:

- The definition of the inputs i.e. the WxR ground mapping data and the Terrain and obstacle databases, the different steps of the correlation mechanisms and of the outputs that are used for database improvement.

- Practical considerations such as possible limitations and orders of magnitude to keep in mind when evaluating this function.

This deliverable also considers the potential impacts on the Database management. These impacts are divided into two main aspects. The first one is the qualitative improvement that can be expected from the use of correlated data as compared to the use of databases singly. This should be understood in the sense of an increase in value. The second one is the quantitative aspect that is to say how the databases organisation and management could optimally take the correlation process into account.

This deliverable also includes a preliminary business case study which concludes on the potential interest of further investigating and developing the Correlation for Terrain surveillance, considering the main impacts of this correlation on WXR and DB.

5.5. WP5 NEXT GENERATION INTEGRATED SURVEILLANCE SYSTEM

The main workpackage purpose was to develop and validate hardware and software components specific to the FLYSAFE PLATFORM and to integrate these components together with the components developed in WP 2.3, WP 3 and WP 4 into the FLYSAFE PLATFORM. Once validated, the FLYSAFE PLATFORM was integrated in the Full Flight Simulator at NLR for final evaluation (WP 6).

The Next Generation Integrated Surveillance System main work package was divided into seven work packages:

- **WP 5.1 "NG ISS architecture and I/O configuration"** identified the most suitable architecture for the NG ISS and defined the communication interface that consolidates input data coming from external systems. The architecture and interface were analysed and requirements were identified for a possible integration into a family of legacy aircraft. It also pursued the work started in WP 1.3, by providing a preliminary system safety assessment for the proposed NG ISS architecture.
- **WP 5.2 "Tactical alert management"** gathers and rationalises alerts coming from the "safety net" functions. Furthermore it collects information about potential hazardous areas from the other NG ISS subsystems to recommend an appropriate counter action to the flight crew with the aim to avoid subsequent alerts.
- **WP 5.3 “Intelligent Crew Support”** monitors the flight phase, environment and crew actions to provide early warning of inappropriate crew responses before they lead to serious consequences.
- **WP 5.4 "Strategic data consolidation"** merges terrain, traffic and weather data into a comprehensive set of surveillance data, providing anticipation functions to reduce the occurrence of alerts.
- **WP 5.5 "Display and audio management"** provides display and audio outputs to the display system to present the results of the surveillance function.
- **WP 5.6 "Database server implementation"** aims at solving the constraints linked to the use of several databases (terrain, obstacle, weather, aircraft performance, etc) by a central means of distribution and configuration management.
- **WP 5.7 "Test Bed implementation"** specifies and develops the integration test bed integrating the various pieces of software developed during the project.

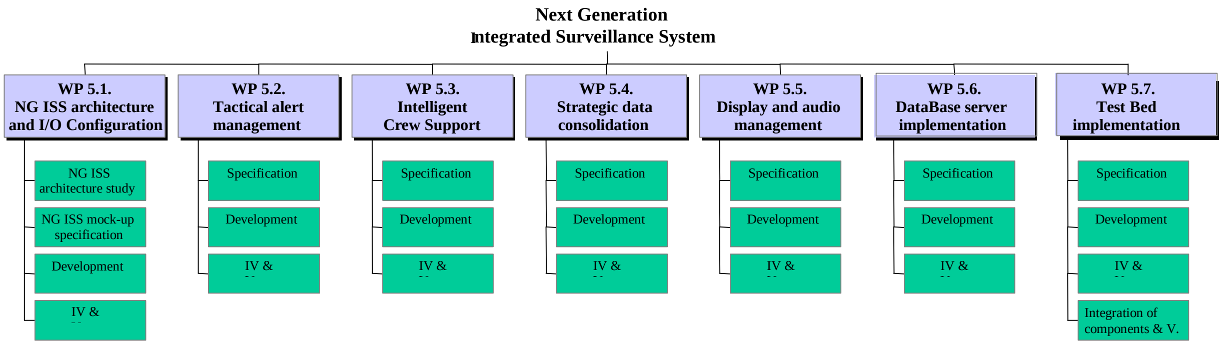


Figure 17: WP 5 sub-workpackages

New software was developed in, **WP 5.2**, **WP 5.3**, **WP 5.4, WP 5.5** and **WP 5.6** based on the results of 5th FP ISAWARE II project. **WP 5.1** and **WP 5.7** led to the delivery of the experimental FLYSAFE platform which was then integrated in the WP 6.5.

This central Work Package addressed two main aspects:

- The system functions
- The hardware architecture and implementation

The **system functions** are at the heart of the Next Generation Integrated Surveillance System. They:

- Fuse the data provided by the previously described sub-systems concerning traffic, terrain and weather information.
- Present in the best way the most useful set of information at the right time allowing the crew to build their situation awareness.

These system functions also assist the crew in their usual tasks by providing them with information on standard procedures. The Intelligent Crew Support (ICS) monitors the aircraft state and certain crew actions (and inaction) and compare those observations with a plan with the expected activities for the given phase of flight. The system alerts the crew to missing or inappropriate actions, thus improving flight safety by early trapping of pilot errors.

These functions deal with either tactical or strategic information management.

The former are related to attention needed or actions to be taken in a short term (i.e. Caution and Warning).

The latter are related to longer term information:

- potential hazard along the predicted flight path,
- Situation awareness presentation.

The **architecture and implementation** tasks dealt with the integration of these functions in a mock-up that were later on connected to the NLR FFS to build an enabling platform for future surveillance system capabilities. All development was done according to a Software and Hardware Development Plan.

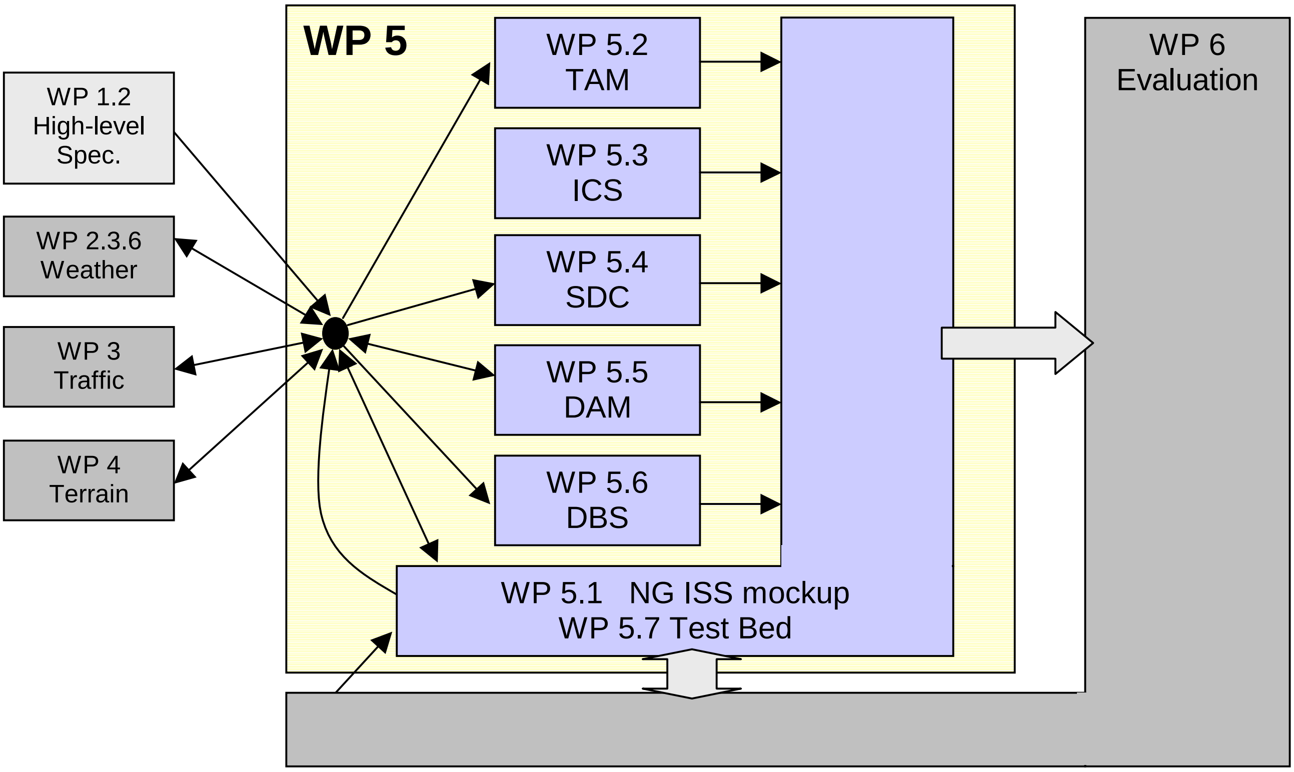


Figure 18: WP 5 work flow

One benefit of the NG ISS architecture is to significantly simplify aircraft installations and reduce life cycle costs through integration, as well as providing meaningful operational benefits.

The enabling platform is designed so as to be adaptable to future devices such as Clear Air Turbulence sensor, Wake Vortex sensor and future ASAS functions.

st-bed Specification". The report contains the specifications of different types of functions: functions that are imported from the NLR evaluation test-bed, functions that are specific to the THALES test-bed and finally, elements common to both test-beds from the THALES standpoint.

The results of WP 5.7.2 and 5.7.3 consist in the development of the NG-ISS testbed such that the integration, verification and validation of the NG-ISS components developed in WP2-3-4-5 can be achieved. The development was compliant to the above specifications and stated ready for the next phase of the project: the NG-ISS IVV.

The results of the NG-ISS IVV conducted within WP 5.7.4 are documented in D 5.7.3 "NG-ISS IVV report". This document outlines the results obtained during the integration, the verification and the validation of the NG-ISS that was held at THALES Toulouse. In particular, it includes

- The IVV methodology, the means and the results for each module and the NG-ISS as a whole. Note that each individual module was provided to the integration platform with its own IVV report that was the basis for the integration and the verification. The validation tests were either excerpted from the validation scenarios proposed in PTE (whenever applicable) or defined for this task.
- The feedback on the modification requests gathered after the WP4 Terrain Surveillance PTE,
- The HMI PTE held at THALES Bordeaux,
- The IVV plan for the ICS PTE held at BAE Rochester at the end of the WP5.7.4 and which results will be part of the WP6 achievements,
- The report of the Graphics Generator IVV performed at Diehl Aerospace Frankfurt.

The report concluded with the list of recommendations issued by operationals during the NG-ISS IVV and the planning for the transfer of the NG-ISS mock-up to the NLR.

5.6. WP6 EVALUATION AND RESULTS

5.6.1. WP 6.1 Results

The work package 6.1 consists of three 3rd Level WPs:

- WP 6.1.1 Operational Scenario Specification (OSS)
- WP 6.1.2 Flight Tests RFP
- WP 6.1.3 Preliminary Test plan definition
-

In the first project year the document D 6.1-2 was created. This document constituted the Request For Proposal (RFP) information package for the flight test to be executed inside the project. It described the overall flight tests to be performed (objectives and the expected flight test conditions required instrumentation, etc.), the structure of the offer, the review and selection process and the foreseen contractual aspects.
On 30/11/05 the full RFP package (Version A) was send to the CEC for a formal review and approval. Approval was implicitly obtained on 28/02/06, allowing opening the RFP process. However, on the 16/03/06, so during the second project year, the EC informed the project management that it was not acceptable, from their legal perspective, to open simultaneously a call for tender internal of the project and externally. Consequently, the consortium had to make a decision and decided to keep the RFP internal. The open call procedure was cancelled. However, the same process and time schedule was maintained for the internal selection. The call for RFP remained open until 12th of May 2006. To adapt the RFP to this new situation, report D 6.1-2 Version B (that had to be corrected into version C) was created and issued at 13/03/06. Subsequently a flight test process and guidance document (DI 6.1.2) was set up and a review committee was

established.
Two formal bid responses were received on this RFP. One from SAFIRE (a FME consortium) and another by NLR. Both bids passed the technical review held during a meeting at 17th of July 2006..The selection of the proposal for submission to the FLYSAFE Steering Committee (SC) and the EC was made by an unanimous proposal of the review committee to the Project Management Committee and by the PMC to the SC, on the basis of its critical analysis of the offers. At the 3rd SC-meeting (held at 12th of Oct'06) final approval was given to these two partners and to the foreseen flight test budget and funding aspects. As a result, SAFIRE would execute the sub-experiments 1 to 3 using their ATR-42 aircraft, and NLR would execute sub-experiment 5 and include a part of sub-experiment 4, making use of their Metro Swearingen II aircraft. The SAFIRE consortium would execute two test campaigns, while for NLR the initially foreseen two test campaigns were integrated into a single flight test campaign, the so-called Summer campaign. Program management adapted the work programme to include and detail the flight tests inside the work programme (under WP6.3.5, WP6.4.5 and WP6.7.2) via the yearly DIP process and updated the EC contract accordingly.

Based on the OCD [D-111] set up under WP1.1.1 and the OSC [D-612] produced under WP 6.1.1, it was foreseen to produce a Preliminary Test Plan (PTP) for the MTE of WP 6.7.1.

Various efforts were made to draft the PTP-document and various initial experimental (scenario) ideas were launched. The PTP focus was on human factors aspects, like situation awareness, work load, flight safety and usability, etc. But the main difficulty encountered was to have the proper insight in the novel cockpit technologies and impact on crew HMI (display and controls) to be able to create a preliminary experiment matrix with associated experimental objectives, scenarios and required data gathering. The NG-ISS developments and associated discussions remained too much at the software technical level, which was not very suitable and not detailed enough for the preparation of an operational assessment. Hence it turned out to be too complicated to have the required level of essential experimental details present for creating a proper and experiment plan having a suitable quality levels. There just remained too many uncertainties. For example, it took very long to establish whether or not the NG-ISS related weather aspects could be actually used in the MTE. Down-linking of a flight plan resolution for a potential (weather) conflict would form part of the actual MTE, but only in a very limited way, not allowing a real comparison type of evaluations. Also the actual base line set up, so to which and how some new NG-ISS functions were going to be compared could not be frozen. And finally, the important aspect of procedures for the air traffic controllers at ATC radar and tower simulator and for involved pseudo-pilots remained unclear hence undefined to shortly before the actual MTE took place. All these matters depended largely on the integration, validation and verification process of the NG-ISS developments. The uncertainty in progression of these developments directly fed the uncertainty in the PTP. As such the internal PTP was not turned into a rounded-off document anymore.

5.6.2. WP 6.2 Results

WP6.2.2 initiated the safety assessment process by performing the Qualitative Safety. This work-package has gathered to a large extent the information necessary to identify the most relevant situations in which FLYSAFE is expected to provide a safety benefit with respect to the safety ensured by current aircraft equipments. More specifically the study has identified the hazards that can be eliminated or mitigated by reducing the risk associated to them in terms of severity and frequency.

The hazards identified are 28 in total

A majority of them (24) pertain to one of the three strands of FLYSAFE, i.e. Weather, Traffic and Terrain. While the remainder of hazards combine threats pertaining to at least two different strands. The combinations are Weather and Traffic, Weather and Terrain and Traffic and Terrain.

WEATHER HAZARDS
WEA/1 – Extreme icing conditions during flight. WEA/2 – Severe wind conditions at low altitudes WEA/3 – Wake vortex at low altitudes WEA/4 – Severe turbulence during flight
TRAFFIC HAZARDS
TRA/1 – Ownship in conflict with another equipped aircraft/vehicle during taxi TRA/2 – Ownship in conflict with parked aircraft during taxiing TRA/3 – Ownship in taxi causes conflict with aircraft lined-up for take-off TRA/4 – Ownship landing in conflict with vehicle/aircraft entering the runway (or already on runway) TRA/5 – Conflict with other aircraft or vehicle during pushback manoeuvre TRA/6 – Traffic conflict during take-off TRA/7 – Attempt to take-off while not on the cleared runway TRA/8 – ATC instructions inconsistent with TCAS RAs in the imminence of a conflict with other aircraft in flight TRA/9 – Conflict with other aircraft in flight TRA/10 – Inability of the ownship to follow TCAS RA
TERRAIN HAZARDS
TER/1 – Failure of flight crew to correctly identify aircraft height above ground (Vertical SA) TER/2 – Failure of flight crew to correctly identify aircraft position over ground (Horizontal SA) TER/3 – Altimeter setting error in climb TER/4 – Altimeter setting error in descent TER/5 – Conflict with fix obstacles whilst manoeuvring on the ground TER/6 – Insufficient understanding of airport layout to correctly perform surface operations TER/7 – Altitude inadvertently selected below MSA/MRVA TER/8 –Too high energy at landing TER/9 – Emergency descent following A/C depressurisation TER/10 – Degraded aircraft performance during take-off
COMBINED WEATHER AND TRAFFIC HAZARDS
WEA-TRA/1 – Runway Incursion in reduced visibility
COMBINED WEATHER AND TERRAIN HAZARDS
WEA-TER/1 – Severe weather activity over high terrain
COMBINED TRAFFIC AND TERRAIN HAZARDS
TRA-TER/1 – One Engine Failure in high density of traffic and high terrain TRA-TER/2 – Combined Activation of Traffic and Terrain Safety Nets

Figure 19: List of hazards of the qualitative safety assessment

Due to its qualitative methodology, the study included only a first assessment of the severity and frequency of each hazard, based on the consultation of technical, operational and safety experts and on analysis of accident databases. Thus, the study results were not expressed in terms of safety measures and no specific safety requirements were identified. However the identification of a large number of hazards and of the role played by specific FLYSAFE functions (with a special attention to NG-ISS functions) paved the way for a more accurate estimation of the safety benefits provided by the FLYSAFE concept in the frame of the following work-packages inside WP6.2.

Coming after the qualitative safety assessment, WP6.2.3 has provided a risk assessment methodology for the NG-ISS. Two different modelling techniques, Fault Tree Analysis (FTA) and AltaRica were tested. Indeed, Fault tree is a well-know approach. Nevertheless, the fault-tree approach can generate a huge and time-consuming work when the safety analysis implies to analyse individually a great amount of hazards as it is the case here since [WP 622 DI] has defined 28 hazards to be analysed. Therefore, in that context of numerous hazards, we proposed to investigate as a complementary approach the AltaRica modelling methodology. This methodology, extensively used in the safety analysis of aircraft systems and sub-systems models, enables to build one model that can handle a group of several feared events, like for example one model for each set of hazards (traffic, weather, terrain).

As a starting point, some samples of the hazards analysed in WP6.2.2 were used in order to apply both techniques and to evaluate their outcomes. The proposed methodlogy is the following: FTA analyses are performed first. Human factors aspects and their potential responsibilities are considered inside each hazard. Then, the fault trees are used as inputs to build the AltaRica models.

From the risk assessment methodology defined previously, WP6.2.4 carried out the quantitative safety analysis. The Fault Tree Analysis was applied to the 28 hazardous events identified in the context of the Qualitative Safety Assessment (DI 622).

The Quantitative Safety Assessment based on FTA consists in comparing the frequency of occurrence of a set of identified hazards in the baseline condition and in the experimental condition. The baseline condition takes as a reference the state-of-the-art cockpit of an Airbus A320. The experimental conditions consider the same equipment plus the new functions introduced by the NG-ISS.

In essence each identified hazard is modelled with two different FTs: a baseline tree and an NG-ISS mitigated one. The difference between the frequency of occurrence of the top events in the two FTs, if any, gives a measure of the expected safety benefit gathered by the Flysafe NG-ISS

The following table summarises the final outcomes, i.e. the probability of the top event for the baseline FTs and for the mitigated ones.

Hazard Code	Probability Top Event without NG-ISS	Probability Top Event with NG-ISS
Weather		
S-WEA/1	1.828744E-007	4.388986E-008
S-WEA/2A	6.017095E-008	6.017097E-009
S-WEA/2B	1.873840E-008	4.109350E-009
S-WEA/3	6.006000E-009 (5,5 years)	1.601600E-009 (20,8 years)
S-WEA/4	6.119999E-009	1.440000E-010
N-WEA/5	3.143992E-009	3.143994E-010
Traffic		
TRA/1	6.209834E-005 (4,7 hours)	2.450017E-005 (11,9 hours)
TRA/3	2.481948E-005	2.697961E-006
TRA/4	3.329957E-005	4.476233E-006
S-TRA/5	1.530004E-006 (7,9 days)	1.530004E-006 (7,9 days)
TRA/6	1.242861E-005	1.146581E-006
Terrain		
S-TER/1	1.127869E-007	4.878142E-008
S-TER/2	3.024998E-007 (40,3 days)	1.451999E-007 (83,87 days)
S-TER/3	3.048893E-007	4.268968E-008
S-TER/4	7.803940E-007	2.081332E-008
S-TER/7	2.531183E-007	1.948797E-008
S-TER/8	4.560471E-008	4.564702E-009
S-TER/9	1.607040E-009	3.283200E-010
S-TER/10	2.210857E-007	2.067986E-008

Figure 20: final outcomes

To be totally successful, FLYSAFE must not only achieve its technological objectives, but also prove that these objectives are met. The good achievements of all goals and objectives must be displayed with methods and means “as objective as possible”, during the validation and the evaluation phases of the project. This is why FLYSAFE paid a specific attention to the definition of clearly achievable and quantifiable objectives devoting two specific work packages for this purpose, i.e. WP 6.2.1 and WP 6.2.6.

The Annex I “Description of Work” clearly specified a set of three high level objectives, also called first level objectives (FLOs):

FLO1: “To develop, validate and test an innovative, efficient and competitive on-board integrated surveillance system, based on European resources, and prove that it increases safety”.

FLO2: “To develop, validate and test ground weather means (WIMS) to provide aircraft with weather safety related information and prove that they increase safety”.

FLO3: “To develop international standards to support the definition of the two systems (on-board and on-ground) above”.

For monitoring the high level project objectives a method was set up in WP6.2.1 comparable to the one used within the VICTORIA project. The basic principle of this method was to start from the Project top-level objectives, to capture all them, to subdivide them into sub-objectives, up to a level where it becomes possible to quantify the status of their achievements. A compromise was reached between the level of details which allows an accurate assessment and the number of lower-level objectives, which increases the work needed to get the result. The FLYSAFE team agreed that the appropriate compromise is reached with a breakdown of objectives up to the third level.

The decomposition of the high level objectives into objectives of third level was followed by the identification of the suitable work packages able for the assessment of them. The full list of the sub-objectives and respective work packages in charge of assessing their achievement was created during the WP 6.2.1 activities and subsequently maintained, updated during the lifespan of WP 6.2.6.

The actual achievement reached by an objective was evaluated from a quantitative point of view allocating a dedicated score. For instance, considering the project goals related to flight safety or situation awareness (SA) improvements, when it was:

- 0% ÷ 25%, a 0.25 score of the overall SA objective was given.
- 25% ÷ 50%, a 0.50 score of the overall SA objective was given.
- 50% ÷ 75%, a 0.75 score of the overall SA objective was given.
- 75% ÷ 100%, a 1.0 score of the overall SA objective was given.

By averaging all the new HMI functions (N), the overall relative SA achievement was given by:

SA_achieved = (SA_function1 + SA_function2+……+SA_functionN) / N

The score evaluation of the project objectives was automated adopting a tool able to support the assessment. Within the frame of WP 6.2.1, several tools available in the market of from other projects were investigated but none of the candidate tools fitted precisely with the specific needs of FLYSAFE. This has let to the decision to create a specific tool for FLYSAFE able to fit precisely with the needs of the project. This tool was named Project Goal Assessment Tool (PGAT). PGAT is software implemented by MS Excel 2003. It provides simple functionalities to support and automate the assessment of the actual achievement of each project objective. PGAT adopts a structured tree-calculation approach. Once tests upon the criteria of achievements of sub-objectives are made, the corresponding sub-objective achievement values are entered in the tool, allowing an assessment of the achievement status of the overall objectives.

The work of PGAT tool and on the actual progress of the project objectives kept on WP 6.2.6. The role of the WP 6.2.6 was to:

- Revise the objectives and sub-objectives that may evolve during the project lifecycle as required by project management.
- Ensure the management and maintenance of PGAT. The activity performed for (a) the data gathering of the low level scores and (b) the consequent populating of PGAT consisted in delivering standard questionnaires - also called *PGAT Templates* – to the work package leader responsible for the achievement assessment.
- Support as relevant the use of the tool by all concerned FLYSAFE partners in particular the concerned work package leaders.

Support the project management in extracting information about project objective achievements during the whole duration of the project.

The results regarding WP 6.2.1 are fully documented in the report D-621 “Project Goals Assessment Tool”, version A, September 2005.

The activities related to WP 6.2.1 were positively closed the first year of the project. The main results obtained by this work package were:

(a) decomposition of the top-level objectives in lower level, quantifiable objectives;
(b) consolidation of the planned breakdown of the objectives;
(c) investigation on the market of the suitable tool able to automate the computation of the scores of the high level objectives starting from the third level objectives;
(d) creation of a dedicated tool for the computation, i.e. the PGAT tool.

The activities performed in WP 6.2.6 mainly dealt with the maintenance of PGAT and the evaluation of scores achieved by the project objectives. Three documents were produced during the lifespan of the work package. The philosophy and the functioning description of the PGAT tool were documented in the FLYSAFE internal report DI-626 “PGAT User Guide”, version A, July 2007. The actual scores achieved by the project objectives were fully reported in the MS Excel 2003 document, version A05, July 2008. The evaluation of the achieved scores according to different perspectives was documented in the final report DI-626_B “PGAT Results”, version A, July 2009.

The results coming from the WP 6.2.6 were positive. The PGAT demonstrated to be a useful tool, able to support the evaluation and the assessment of the project objectives. The populating process was conducted in a fast way, without troubles or mistakes. The tree structure of the PGAT let to immediately evaluate the final scores associated to the high level objectives that represent the focus of the WP 6.2.6 activity.

The procedure adopted for the populating of the PGAT, i.e. the delivery of standard templates, was very clear for the people interviewed. This procedure revealed oneself of having a twofold benefit: (a) it allowed to automate the PGAT populating process with positive effects in terms of effort and time spent, (b) it let to regularly update - according to the actual progress in the project - the association between low level objectives and responsible work packages and the real purpose of the concerned objectives.

Regarding the scores achieved by the project objectives, the overall trend was very positive. The first and second level objectives both reached a high figure.

The lowest value was obtained by the second project level objective and its final score was equal to 0.83. However this figure represents a positive fulfilment of the planned purpose, i.e. *to develop, validate and test **ground weather means** (WIMS) to provide aircraft with weather safety related information and prove that they increase safety.* The highest value was reached by the objective related to the **standardisation and the dissemination activities**, i.e. the third objective. Its final score was equal to 1.0. The intermediate objective, in terms of achieved value, was represented by the first objective: *to develop, validate and test an innovative, efficient and competitive **on-board integrated surveillance system**, based on European resources, and prove that it increases safety.* The final score was equal to 0.92.

If we look at the results from an NG-ISS strand perspective (Traffic, Terrain and Weather) then the results are as follow.

Results in the Traffic strand

The project objectives of third level belonging to the traffic strand were related to the development, the integration and the safety assessment of the traffic collision avoidance functions.

The following figure shows all the objectives involved, their achieved scores and the overall trend obtained in this particular strand. The mean achieved value was equal to **0.92**. This value means that the 92% of the planned purposes regarding traffic was met.

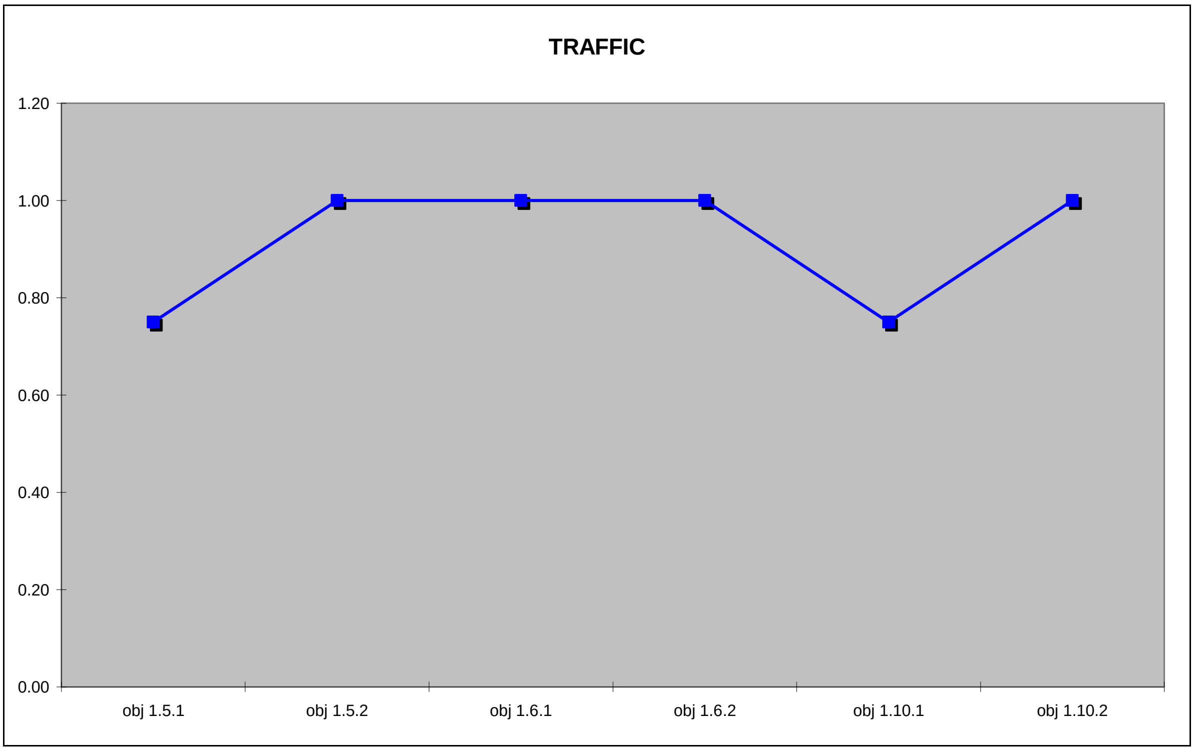


Figure 21: Scores in the Traffic strand

It is easily visible that the general trend consisted to the full achievement of the planned purposes. Only in two cases (i.e. objectives 1.5.1 and 1.10.1) the full value was not obtained.

In case of objective 1.5.1 the selected score 0.75 was based on the actual result of the integration phase. As reported in the dedicated sheet of PGAT, the ACAS was integrated but had to be bypassed in the end as the TCAS output were not pushed through properly. In addition, the strategic traffic conflict detection worked in limited case (90° crossing same altitude) and as a consequence the traffic strategic conflict resolution could not be shown.

The same trend can be observed looking the objective 1.10.1. The objective did not achieve the full score because the terrain conflict detection was not directly integrated in the SDC, but relied on an external component.

Results in the Terrain strand

The overall figure obtained in the terrain strand was equal to **0.94**. The terrain strand achieved a good score as the traffic one. The 94% of the planned purposes was covered.

The following figure shows all the objectives involved, their achieved scores and the overall trend obtained in this strand.

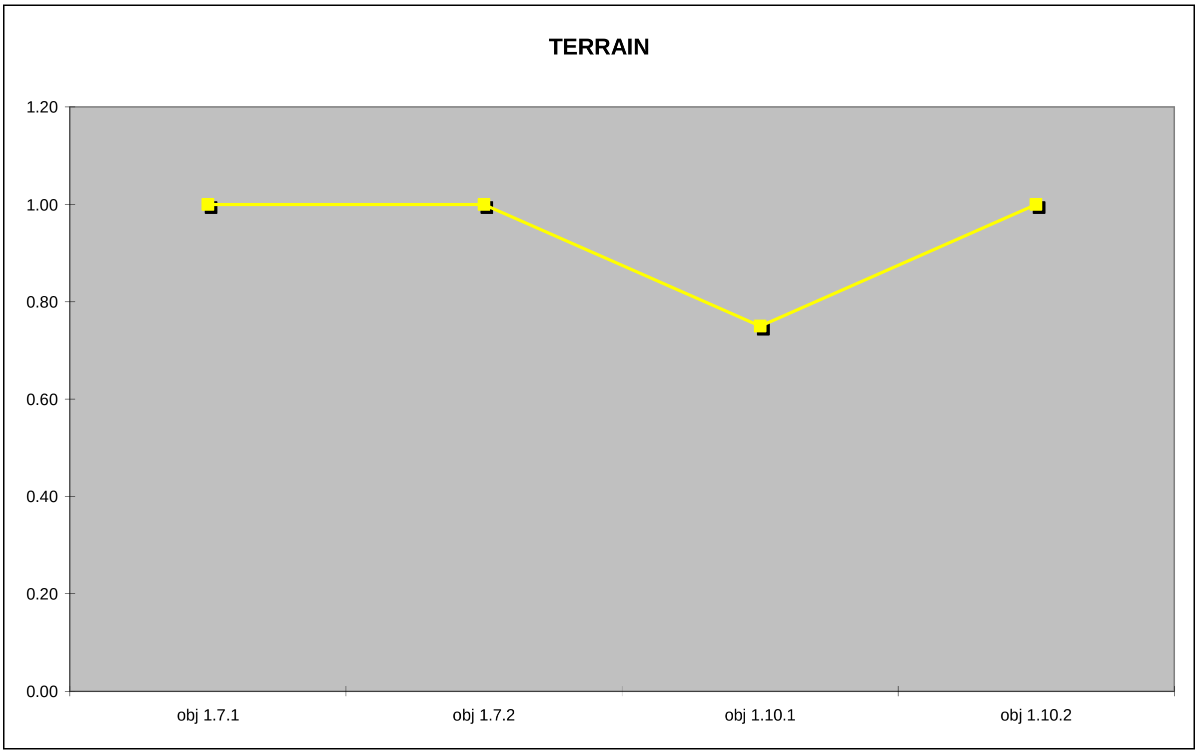


Figure 22: Scores in the Terrain strand

Looking the figure the tendency achieved in the terrain strand is easily observable. A soft deflection with respect to the full overall achievement is present and it is caused by the objective 1.10.1. The reason of this score was explained in the previous section regarding the traffic strand.

Results in the Weather strand

The weather strand was the group with the higher number of related objectives. They were equal to 32. The reason of this high number can be found in the purposes of the objectives. Some of them were linked to the ground means and others to the airborne functions. So, the weather strand was highly populated because it covered both the ground and the air side, too.

The following figure shows all the third level objectives related to the weather strand and their partial scores. The overall figure achieved in the weather group was equal to **0.89**.

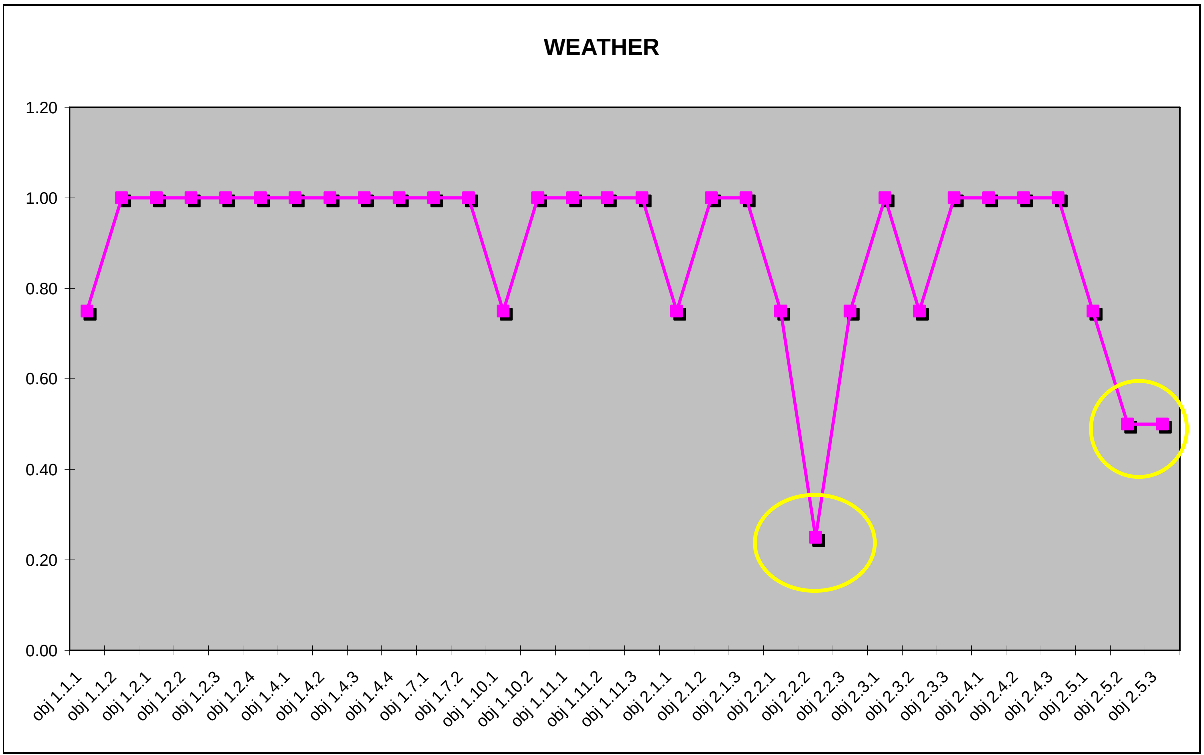


Figure 23: Scores in the Weather strand

Actually, the line shows some deflections. In most of the cases the deflection is soft; the height is equal to 0.75. In three cases the score is quite low (see the yellow circles). The score is respectively equal to 0.25 in case of the objective 2.2.2 (to validate innovative clear air turbulence information management system for transmission to and use by the crew) and equal to 0.50 in case of the objective 2.5.2 (to validate innovative routine weather data functions and objective) and objective 2.5.3 (to test innovative routine weather data functions).

The low score achieved by objective 2.2.2 reflects the limitations and the assumptions applied in performing the validation of the clear air turbulence information management system. As reported by the work package responsible for the validation activity, the related validation objectives were assessed only plotting the CAT objects on the screen and checking that they look reasonable.

With respect to the validation (linked to objective 2.5.2), the related activity was focussed only to the exchange format of the routine products. The meteorological content of the products was not validated because - as its development – not foreseen in the framework of FLYSAFE. With respect to the testing (linked to objective 2.5.3), three principle limitations appeared at the end of the work:

(a) The real output of the testing did not completely match the planned ones. It had been expected to be able to implement standard routine weather information onto the EFB inside the FFS as well.
(b) All the relevant operating conditions were not considered because the routine weather data were directly stored in the EFB and were not refreshed using the Ground Weather Processor.
(c) Routine weather data were not implemented in the GWP nor tested during the flight tests, as their display in the cockpit during the flight tests was planned.

In summary, the final scores achieved by the PGAT populating were positive as they were all higher than 0.83. Even when the second level objective reached the lowest value because of a set of limitations and assumptions that affected some related low level objectives, the global score obtained a successful value of 0.92.

This final value, close to one, clearly indicates that the FLYSAFE project goals were achieved.

PGAT has been proven a very useful and easy to use instrument. It can be refined and further improved in future projects.

5.6.3. WP 6.3 Results

According to the work programme "ATC simulation within FLYSAFE should be realistic." Hence, the main task was to identify the project relevant aspects for the ATC simulator environment creating relevant requirements for all the ATC developments to be performed, by using documents from inside and outside the project. The full ATC simulator consisted of radar and tower facilities, allowing this requirement generation work to be done jointly for both simulators.

Internal brainstorms were held to define the minimum level of ATC aspects needed within the project and an explorative session was held with project partner U2A. This led to first insight into the minimum number of aircraft needed to give a pilot the feeling of a realistic operational environment. Furthermore initial ideas were developed in how realistic this other traffic should behave: either by using automatic control (via scripting) or more manually via (pseudo) pilots controlling these other aircraft. Also first suggestions were provided about how the pilot would communicate with ATCO: via R/T and/or CPDLC. The various phases of flight: from gate/startup, pushback/taxi out, take-off, initial climb (<FL100), Enroute Climb & Cruise, Descent, Approach and Landing to Taxi –in, were all explored in more detail. For each flight phase the number of ATC positions required and the minimum number of aircraft needed to create the "realism" feeling was identified. In addition a base line ATC configuration was set up against a foreseen 2020 ATC situation to reveal the expected near future technology steps.

Subsequently the airports of interest were more closely analyzed. This even let to a visit to the Tower of Innsbruck Airport to assess the real life day-to-day operations of ATC and the local meteo office. Furthermore detailed airport and operational information was gathered on the ATC aspects of Paris Charles de Gaulle Airport (for clearance delivery, startup control, ground control, runway control, tower and approach control). This also let to more insight on the minimum required amount of ATCO positions. Based on all this information some technical and operational decisions were made. Full gate-to-gate operations from Paris Charles de Gaulle to Innsbruck (or vice versa); as well as ASAS operations inside the TMA, the use of helicopters, and the application of CPDLC-B were excluded from the project scope. Also, as the status of SMGCS in the near future time frame was found too unclear, the aspects of Taxi Conflict Monitoring by ATC, as well as AMAN, DMAN and on ground Runway Incursion and Alerting System (RIAS) systems availability were addressed. On Paris Charles de Gaulle only a single RIAS for the "active runway" was foreseen but no TCM, AMAN or DMAN. Also a very limited SMGCS and CPDLC set was chosen. On Innsbruck Airport no CPDLC and no SMGCS would be available. Flight plan down-linking and ASAS S&M related CPDLC would be possible in the Paris CdG enroute sectors, but not inside the TMA. Some FLYSAFE NG-ISS new foreseen aspects were retained for the time being, like RA-down-linking. However RA-down-linking and also the RIAS on Paris Charles de Gaulle were both excluded in a later stage.

In addition the current ATC simulator facilities of NLR were described and using all the gathered new ATC aspects to be developed, like new sectors, new ATCO working positions for Innsbruck and Paris Charles de Gaulle Approach and tower, new ATCO HMI for taxi route inputs, ASAS S&M CPLDC, etc, new requirements were generated for these, both in terms of hardware and software, as to suit the FLYSAFE project best. Also some very specific ATC development aspects were identified, like for the airport visual system database of the tower simulator and a project risk assessment was made on having it developed.

Finally the first conceptual steps were made in the identification and description of ATC procedures belonging to the full new ATC setup. For instance new ATC procedures belonging to the ASAS Sequence & Merging process were set up.

The set of ATC requirements were documented and formed part of the full requirements deliverable D 6.3.1:

- D 6.3-1 Specification of Simulation Environments (Version A)

The first step performed was to analyse the FLYSAFE Operational Concept Definition document and the NG-ISS detailed specifications. Based on these inputs the new elements needed by the GRACE full motion flight simulator where inventoried, both in terms of new hardware as well as for software aspects.

The requirements have been reported in:

- D 6.3-1 Specification of Simulation Environments (Version A)

The NARSIM Tower simulator environment requirements were setup jointly with those for the NARSIM Radar simulator environment. The same results as indicated under WP 6.3.1 were achieved.

The tower related requirements have been reported in

- D 6.3-1 Specification of Simulation Environments (Version A)

Initially it was foreseen to use the weather simulator server to be the interface between the Meteo offices/network and the flight simulation facilities. This server then would be the collector of the real life, streaming weather data, or alternatively be the collector of recorded, but remotely played weather cases. However this all turned out to be too complicated to set up for an experiment (MTE) that needs controllability and repeatability. So the use of streaming real life weather data was replaced by the use of recorded weather data to be played locally at the flight simulator facility. Also the need for special experiment aspects would require the use of dedicated weather data coming out of engineering cases.

Inputs document (like OCD and NG-ISS specifications) were studied and requirements were set up.
The following aspects were drafted in the weather specification part:

- Source(s) of weather data, means to connect to (external) weather source
- Controllability of weather (e.g. select a particular weather)
- Requirements of flight simulator, ATC and tower simulator
- Type of weather data provided, dynamics of the data (time dependency of weather), distribution of weather information to all facilities
- What type and how many computers are needed to run the various s/w applications, testing tools to be set up.
- define sets of 4D grids in a format suitable for the NLR's onboard weather radar simulator
-

The following subtasks were performed:

- Creation of the flight test board and definition of authority and responsibilities
- Creation of the Flight Test (FT) specifications (D 6.3-2 & D6.3-3):
    - detailed definition and description of FT test/compliance requirements
    - detailed definition and description of required equipment on-board test aircraft an in ground station
- After production of D. 6.3-2 & D.6.3-3 Flight Test Plans (FTP) were defined and written, one per flight test aircraft operator separately.

The flight test plans consist of :

- Preparation of FT: definition of organization, responsibilities, objectives/required results, aircraft instrumentation, modification, data acquisition, scheduling
- Execution of FT: Location, scheduling, operational conditions/restrictions, test support, go/no-go, briefings and test techniques. procedures.
- Safety: safety assessment, FT related emergency procedures, crew training, safety

After the flight test aircraft providers were selected, technical teams were created for the various flight test campaigns that were foreseen. These teams worked independently but were overall steered by one partner (Meteo France).

The teams set up and structured the process of all required activities to prepare and execute the flight test programmes. Requirements and test plans were created for the flight tests: one for the experiments performed by SAFIRE's ATR-42 aircraft and the other one for the experiment performed by NLR's Metro-Swearingen II aircraft. Also a Flight Test Board was established, that would seek for consensus solutions in case of severe technical or programmatic difficulties. This board never had to meet due to the great commitment and excellent way of working of all involved.

Three fixed wing flight test campaigns were foreseen, while later on during the project a helicopter flight test, to be organised and executed by ECD, was added:

- SAFIRE Winter Campaign (Flight Tests 1, 2 and 3)
- SAFIRE Summer Campaign (Flight Tests 1, 2 and 3)
- NLR Summer Campaign (Flight Test 5)
- Helicopter Flight Test

Per flight test a/c operator the work executed existed of:

- detailed definition and description of FT test/compliance with requirements.
- identification of the required a/c modifications and certification for the test aircraft.
- definition of campaign participants, technical objectives, aircraft instrumentation matters, data logging(including video registrations), flight plans and the overall planning of the activities.
- risks identification, mitigation and back up planning.

Flight Test Plans were used as running documents that were updated when new technical information became available, or when major technical issues were resolved.

Figure 24:ATR-42 aircraft (operated by SAFIRE/FME)

Figure 25 Metro Swearingen II aircraft operated by NLR

Planned fixed wing Flight Tests

The flight tests within FLYSAFE related to a large extend to the testing of aspects of the Weather Information Management System (WIMS).

Flight Test Experiment 1 was about the WIMS evaluations in the Local Weather Processor Area (LWPA).

Flight Test Experiment 2 was about the WIMS evaluations in the Central Weather Processor Area (CWPA).

The difference between the LWPA and CWPA area solutions is in the accuracy that can be attained in the weather predictions. For instance the LWPA solutions make use of ground based radars to have a more accurate weather prediction inside an area covering as small as the TMA by using very high grid sizes in numerical computations. The LWPA produces weather predictions over a far bigger area, say over countries or even the whole of Europe, hence the grid sizes used for those predictions have to be larger. This affects the accuracy of the WIMS products directly.

So during Flight Tests experiments 1 and 2 the objective was to evaluate through in-situ atmospheric measurements the WIMS predictions. Weather data describing the state of the atmosphere, acquired by the on-board equipment of the research aircraft, were gathered to test and improve the atmospheric ground system predictions (WIMS) developed in FLYSAFE. More specifically these data was used for:

- direct comparison wherever possible with the WIMS products like CAT-WIMS, ICE-WIMS and CB-WIMS (
i.e. via turbulence measurements, Ice probe, on-board weather radar measurements),
- evaluation of the WIMS (See D.2.2.8-1).
- WIMS future developments, improvement of the WIMS calculation algorithms (i.e. cloud microphysics, atmospheric state parameters)

Flight Test Experiment 3 was about novel onboard sensors, (except for an improved radar mode which formed part of experiment 5). The objective was to experiment with in situ atmospheric measurements the behaviour of the following two on board sensors: a) a LiDAR as a new means for CAT detection and b) a novel in-flight icing sensor. However in a late stage of the project the novel icing sensor had to be dropped and standard in-flight icing measurements took place. In addition recording of weather radar data was facilitated.

Flight Test experiment 4 was partly moved into experiment 5 and partly not rewarded (in WP 6.1.1).

Flight Test experiment 5 was to evaluate an innovative “weather chain”: a real time upload of the ICE-, CB- and/or CAT-WIMS products from the ground (via the GWP) via data link to the aircraft. Onboard the aircraft a new weather radar system with a few new modes was installed to test a novel way of CB-detection and also to test the new derived fusion logic of the CB-WIMS with the output of this novel weather radar detection system.

The first campaign (Winter campaign) was planned for experiments 1, 2 and 3. There was a main focus on icing conditions and the experiments aimed at evaluating the ICE-WIMS off-line:

- The (ICE-) WIMS output were not sent to the aircraft
- The (ICE-) WIMS were not performed in real time, but a-priory determined and loaded on board.

The second campaign (Summer campaign) was planned for experiments 1, 2, 3 and 5 and aimed at evaluating the WIMS in real time:

- The ICE- and CB-WIMS were derived in real time and compared with in-situ measurements.
- Also, recordings of the airborne weather radar outputs (CB-information) were performed to be able to asses these airborne data with data of on ground radars.

These fixed wing flight tests were executed following 2 different flight areas: TMA and European flight plans. The TMA scale is linked to the LWPA's and the European scale is linked to the CWPA's.

The flight test areas were defined to be:

a) TMA flights around Paris Charles de Gaulle and

b) European flights

The TMA flights were mainly related to Flight Test (experiment) 1 and also foreseen and used for Flight Test

5.

The TMA flights were planned and performed in the area of Paris, France. The area of action was about 300 km diameter, centred on Paris. The aircraft had to follow preliminary defined legs and adjusted altitudes in real time following the weather situation and the ATC agreements.

Special ATC procedures would be needed for these TMA flights. A few meetings were held with Paris ATC and an agreement was established and with the air traffic controllers. The test area was agreed on and the final flight plan was planned to look like the following route:

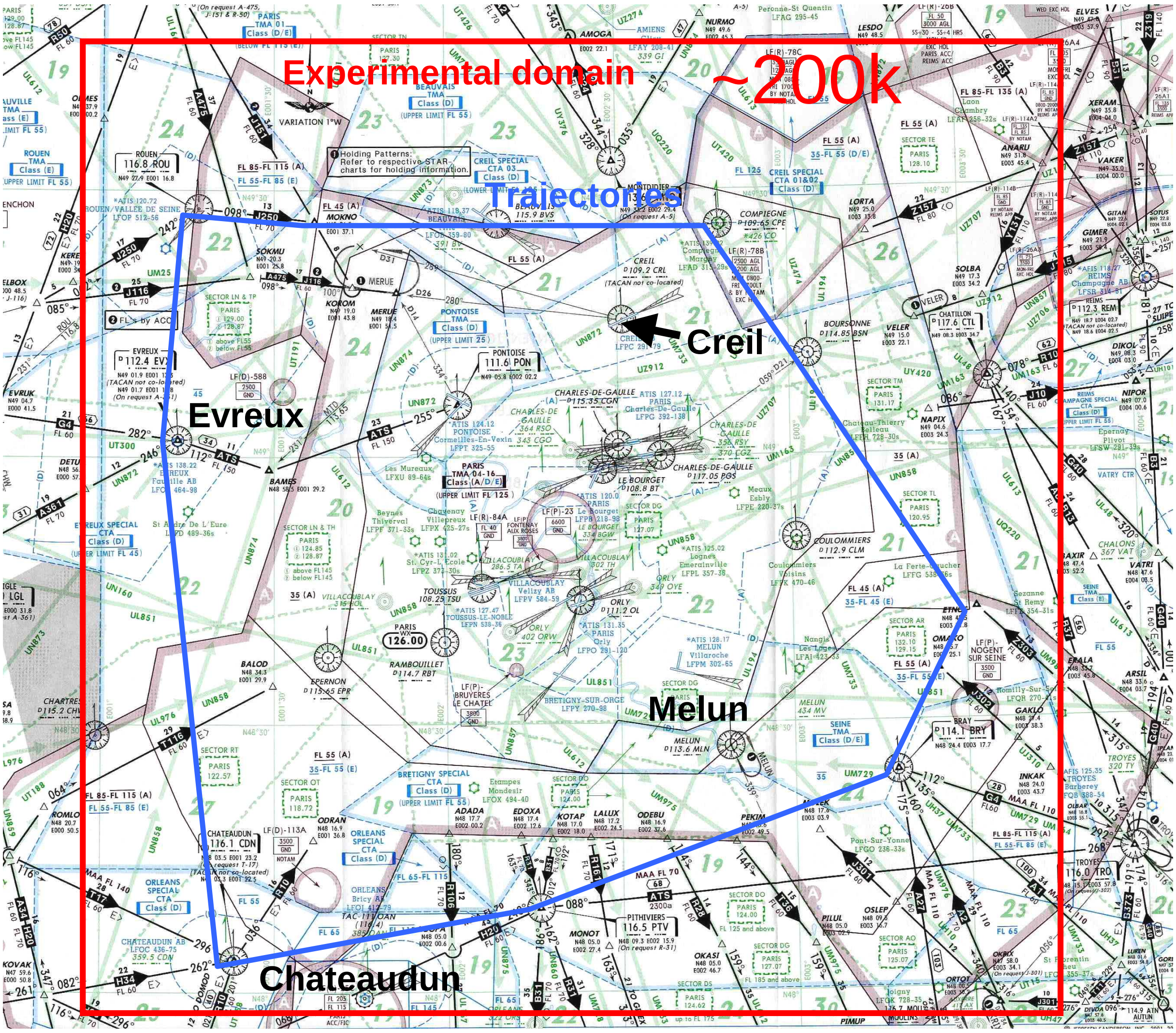


Figure 26 Flight test area around Paris Charles de Gaulle.

Starting point:

The aircraft would start from an airport close to the survey area that meant, close to Paris.

In reality the flight plans executed differed somewhat form this initially planned set up.

The European flights were dedicated to perform experiment 2 (CWPA). The aircraft would perform a transit flight to a European destination and would return the same day. (Example of such a flight: Creil-Amsterdam). The aircraft test flight could start from any airport: the TMA flight starting point as well as the aircraft home-base near Toulouse (Francazal).

The Winter and Summer Campaign were planned for a maximum of 80 flight hours in total and FT5 for a maximum of 60 flight hours (in one campaign).

Planned helicopter flight test

The helicopter flight test was introduced later on in the programme, after closure of this WP, and effectively specified under WP645. ECD would fly the tests with their

Apart from creating internal documents, specifications of the fixed wing flight tests were formally reported in:

- D 6.3-2 Flight Test detailed specification (SAFIRE part)
- D.6.3-2 Flight Test detailed specification (NLR part)

5.6.4. WP 6.4 Results

Based on the simulation development requirements set up (D 6.3-1) and special specifications created for the controller HMI's to perform the new FLYSAFE functions, (like ASAS S&M and the Taxi route planner), the ATC simulator was adapted. These modifications consisted only of software modifications.

- The Innsbruck visual system database (for the Tower simulator) was created including data elements delivered by JEP. This database development and its use were shared between the Tower simulator and the GRACE (FFS).

- Interface definitions were adapted to include ADS-B, TIS-B and CPDLC aspects at a more detailed level. Subsequently these were integrated into the NARSIM interface software.

- An interface was implemented to support push-to-talk events as well as frequency switches to connect the cockpit voice system at all times to the appropriate ATC position.

- The controller working positions required to support ground-, runway-, tower and approach control at Paris Charles de Gaulle and Innsbruck airport were developed, for instance with a new 'radar map'.

- The enroute controller working positions required to support parts of flights between Paris and Innsbruck were integrated with the appropriate airspace (sectors, waypoints, procedures) covering a large part of Western Europe into NARSIM.

- The new FLYSAFE CPDLC message sets were integrated in NARSIM

- For the enroute controllers to deal with ASAS S&M data link messages, a specific input means through interactive menus on the radar screen was implemented to support the different ASAS S&M manoeuvres.

- For the controllers to deal with CPDLC messages, taxi route generation; new (software) input means, like a numeric keypad, were created as well as a stop bar control panel for the airports of interest.

- Initial traffic samples were set up to facilitate development testing. As such correlation between the Air Traffic Server of NARSIM, which generated the other aircraft during the MTE and presentation of this other traffic inside the visual databases of Innsbruck and Paris CDG was successfully tested.

- The pseudo-pilot positions, to control the other traffic, were enhanced to allow the use of data link.

- A coupling between the central weather server and the NARSIM Meteo server was aimed to be established but just did not reach the stage for actual use inside the MTE. Due to project time pressures this development had to be abandoned.

All developments were locally tested, while the specific sets of new interface data, like CPDLC message sets generated by NARSIM were also tested in combination with NLR's fixed based and moving base flight simulators (i.e. APERO and GRACE).

The final state of the NARSIM simulators was achieved on time to perform the full integration testing at an adequate supporting level to allow "realistic" ATC although certain very specific developments had to be continued during the integration and verification phase of the project (see WP6.5). When customisation had been achieved, readiness was issues via a formal management statement. This statement was considered to be deliverable:

- D 6.4-1 Customisation of simulation environments

Based on the specification (D 6.3-1), the various GRACE hardware and software adaptations were performed. The hardware modifications consisted of:

- GRACE was set up in the Airbus cockpit look and feel (side stick, control loading)
- A LCD housing structure support development
- Installation and connection of four (UXGA) LCD screens
- LCD wiring
- Side displays were installed and a moving front displays
- The installation of the KCCU's. This also required the housing of the cockpit centre console to be adapted
- 1 Gbyte network switch installation

A computer network was designed and set up including a customer network for relevant partner computers. New equipment (switches and PCs) were ordered and installed.

From a software perspective, various models were enhanced or modified:

- The various interfaces required were set up and implemented. These consisted of the bse-protocol for the partner applications and the DIS-protocol for the coupling of data between the GRACE and the NARSIM simulators.

- The Research FMS was adapted to all kinds of needs. Firstly for ASAS S&M heading and speed control inputs. But also with data link functions (to & from ATC) allowing crew-interaction with the SDC for the conflict resolution mode. A conflict resolution was presented in the secondary flight plan. And by using a touch screen DCDU to transfer ASAS control messages, to request a taxi-clearance, etc.

- The traffic manager application that could generate other traffic, in addition of the NARSIM Traffic server, was adapted on various points. For instance the airport data of Paris Charles de Gaulle and Innsbruck were incorporated, including stop bars (and its controls). Also a limited set of local CPDLC messages (or commands) were generated and could be activated using this tool. This allowed local testing of CPDLC functions of the NG-ISS (i.e. SMAAS, ICS, RCAF, etc) without having to use a full NARSIM (ATC) simulator environment. And traffic samples and (standalone) scenarios were generated to support integration testing. The traffic manager also formed the master 'gate-way' to the NARSIM facilities when running a GRACE-NARSIM coupled simulation, hence was coupled to the DIS protocol.

- The onboard weather radar model was adapted to the new created weather cases (allowing the 4D-time domain) as hosted by the central weather server.

- Visual system databases were created for Paris Charles de Gaulle and (with help of partner Jeppesen) also for Innsbruck airport. This was a joint creation with the NARSIM Tower simulator development. The visual was further enhanced with new models, for instance for CB-clouds presentation. These CB-clouds were coupled (in time and position) to the central weather server.

- The Flight Warning Computer and the sound system were enhanced with the FLYSAFE specific NG-ISS aspects (new warnings, prioritisation and inhibit logic, and alerting sounds).

- The R/T system was enhanced and coupled to ATC frequencies to allow direct voice contact with ATC using the NARSIM simulation.

- The automatic questionnaire tools were prepared for the experiment.

- The EFB Class-1 software of Jeppesen was installed and presented on the fold-away front displays.

The final state of the GRACE simulator was achieved on time to perform the MTE integration testing at an adequate supporting level, although certain very specific developments had to be continued during the integration and verification phase of the project (see WP6.5). Customisation development readiness was issued by the formal statement that customisation was achieved, via the deliverable:

- D 6.4-1 Customisation of simulation environments

The development work on the NARSIM Tower simulator was executed jointly with the developments on NARSIM Radar, hence the technical achievements are the same as described under WP6.4.1

The final state of the NARSIM simulators were achieved on time to perform the full integration testing at an adequate supporting level to allow “realistic” ATC. This was issued by the formal statement (a deliverable) that customisation was achieved:

- D 6.4-1 Customisation of simulation environments

Based on the specification set up under WP 6.3 (D 6.3-1), a central weather server was established to facilitate the weather-related simulation aspects for all simulators involved. No special hardware set up was required. Initially it was foreseen to also use this central weather server during the pre-integration testing at THA, but this could not be achieved on time. The coupling aspects between the central weather server and the GRACE flight simulator were established. A weather editor was created to handle large amounts of weather data files and to have a coupling with the outside visual of GRACE to allow visibility to be directly influenced by the severity and intensity of the weather Also the initial weather coupling aspects with the NARSIM Meteo server simulator were set up, but these development could not be finalised (under WP6.5) due to the time pressures and technical complexity.
In order to provide ATC correct and enough information about the weather situation during simulations, weather radar charts were presented on ATC displays as part of the controller working position. The same information was provided to the pseudo pilots for controlling other traffic. For each scenario the weather radar charts, corresponding to the weather situation in GRACE, were prepared and were made available to the ATC simulation as static pictures.
Knowing the weather situation gave ATC and pseudo pilots the opportunity to control all traffic in a realistic manner.

The weather cases used consisted of weather data files (sets of 4D-grids) in a format suitable for the NLR's onboard weather radar simulator and host simulation. At first so-called numerical weather prediction model simulations with Meteo-France's mesoscale (Méso-NH) model were performed. These numerical simulations provided a particular weather scenario with thunderstorms and icing in the area of the Innsbruck airport.

For Weather + Terrain investigation purposes: Innsbruck weather case
The Innsbruck weather scenario occurred during the Intense Observing Period (IOP) 2b (19 and 20 September 1999) of the Mesoscale Alpine Program, with one of the scientific objectives was to study the influence of orography on heavy precipitation distribution. During IOP2b, pre-frontal and frontal precipitations

happen over the Southern Alps slopes, fed by warm and moist flows from Mediterranean and Adriatic seas. The precipitation occurred around the Innsbruck region on the 20th of September, in the pre-frontal phase. Cells are of convective type: reflectivity values more than 50 dBZ and vertical velocities of 10 m/s are simulated. They are organized in north-south oriented bands, spreading over more than 50 km. Precipitating bands crossed the Innsbruck region from west to east between 11 and 16 UTC.
This particular weather case was used inside the MTE.
For Weather + Traffic investigation purposes: Paris CDG as recorded on 23/06/2005.
The Paris CDG storms of the 23rd of June were warm storms reinforced by the altitude circulation: at the synoptic scale, this situation is characterized by a low in altitude over the northern half of France, above extremely dry and warm layers near the ground. These conditions are particularly favourable to convection occurrence. The first convective developments appear in the morning and precipitation happen in the mid-day. Between 12 and 16H UTC, stormy cells develop continuously in several locations around Paris region, within a large-scale cyclonic structure. Their life time is 1 to 2 hours. Strong updrafts are simulated with vertical velocities of 11 m/s. Situation is critic over Paris at about 16h UTC: road traffic is disturbed, underground is flooded and airports are paralysed for a few hours.
Later during the project it turned out that this Paris CDG weather case could not be used inside the MTE. Some new more or less 'enroute-related' (4D) weather cases were developed by FME, ONERA, DLR, GTD and NLR. FME provided the 2D ground weather radar data and the WIMS CB bottom data.
For this they selected the cases from a database containing real life radar data (recordings) of the European domain. DLR generated the associated CB-top data using its CB-TRAM algorithm. NLR combined all three to generate 3D weather grids, hence filled the weather parts between the CB-top and CB-bottom with reflectivity and some other weather characteristics. Also ASCII was transformed into XML/GML format. GTD generated all the required full WIMS objects. The fourth dimension (time) was obtained by having the grids coupled to a certain UTC time. Thus each weather case covered a 2 hours time-interval, using 3D-grids in steps of 15 minutes. The selected radar data were (severe) CB-cases from:

- 17-08-2008 from 15:00 UTC to 19:00 UTC
- 31-08-2008 from 13:00 UTC to 20:00 UTC
- 02-09-2008 from 16:00 UTC to 21:00 UTC
- 03-09-2009 from 16:15 UTC to 18:15 UTC

While for testing two other data cases were setup by FME:
- 20-09-1999 from 13:30 UTC to 16:00 UTC
- 23-06-2005 from 16:30 UTC to 18:00 UTC

The simulated ground-based weather radar observations fed the algorithms in charge of producing the WIMS data in the simulations. Four WIMS products were foreseen in FLYSAFE:
- Wake Vortex -WIMS
- Clear Air Turbulence-WIMS
- Thunderstorms (CB)-WIMS
- In-flight icing (ICE)-WIMS

Only the latter two were actually implemented and applied inside the MTE.

For the weather data fusion, uplinked data from emulated WIMS were merged with the simulated WXR data. However, since both sets stemmed from the same Méso-NH 4D weather situation, this made some of the weather fusion technical issues (e.g. coherence) less relevant.

Routine weather data sets, (like METAR, SIGMET, etc) were planned to be extracted from the Méso-NH simulation outputs as well, but eventually this was not further pursued. Similarly, the developments related to Clear Air Turbulence (CAT)-WIMS were started but eventually could not be used inside the MTE due to priority given to solve other technical difficulties on NG-ISS logic.

The final state of the central weather server simulator was achieved on time to perform the full integration testing at an adequate supporting level to allow weather generation and presentation in the GRACE visual, for use in the airborne weather radar detection and for use in the weather fusion logic. Also the NG-ISS related strategic weather function of the SDC could be tested with these weather cases. This readiness was issued by the formal statement (that customisation was achieved via the following deliverable:

- D 6.4-1 Customisation of simulation environments

Based on the specification set up under WP 6.3.5, the modifications to the aircraft (SAFIRE for experiments 1, 2, and 3, NLR for experiment 5) that was used for the FT were implemented.
This involved both hardware and/or software aspects.
The implemented system/ functions were tested and validated, first on ground and in the air (shake test and calibration flights).

SAFIRE's ATR 42 was ready to perform the winter flight trials on February 2nd 2008.
SAFIRE's ATR 42 was ready to perform the summer flight trials on August 4th 2008.
NLR's Metro II swearingen was ready to perform flight test experiment 5 on August 6th 2008.

Flight tests1, 2 and 3 Winter Campaign

The Winter Campaign required the installation of an experimental LiDAR. There were several structural modifications made to the ATR-42 aircraft cabin to be able to install and use the LiDAR equipment, like a reinforced window. This window modification required a dedicated cabin pressurisation test which was performed successfully.
The LiDAR device itself was calibrated on ground in Francazal (first in the hanger, then in the apron), and finally during a one hour flight dedicated to the LiDAR calibration. This made the LiDAR ready for the flights. The LiDAR had a line – of sight through this window by looking perpendicular to the aircraft's flight trajectory (flight speed) and recorded the so-called atmospheric backscattered signal.
The aircraft was furthermore prepared for ice detection to allow ICE-WIMS predictions to be verified.
Hence recording of a backscattered signal all along the flights (no turbulence required), as well as "context" recording and an off line data analysis was foreseen and facilitated.

Flight Tests 1, 2 and 3 Summer Campaign

This campaign required the installation of a new weather radar output recording device, as well as the installation of the LiDAR system. Furthermore, various instruments were available on board the aircraft to measure meteorological parameters. One of these was a King Probe which measured the heat released when water was vaporized. Another instrument used in cloud physics was the PVM-100 (Gerber Probe) which determined the cloud droplet size distribution. All these systems were checked and calibrated when needed.

Figure 27: On board LiDAR equipment

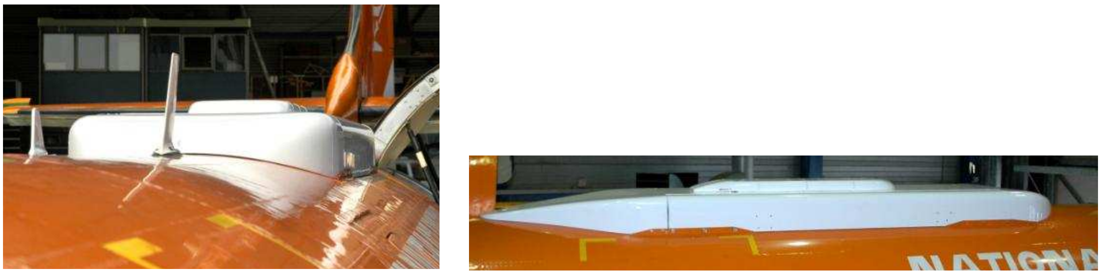
Flight Test 5 Summer Campaign

The FT5 required various new onboard instrumentations:
- weather radar system and control/display unit
- SATCOM units (incl. transceiver, antenna and related equipment)
- Antenna box modification (to accommodate SATCOM antenna)
- experimental displays
- partner computers
- equipment housing racks
- new cables, connectors and convertors
- Storm scope (lightning data for project as well as safety device)

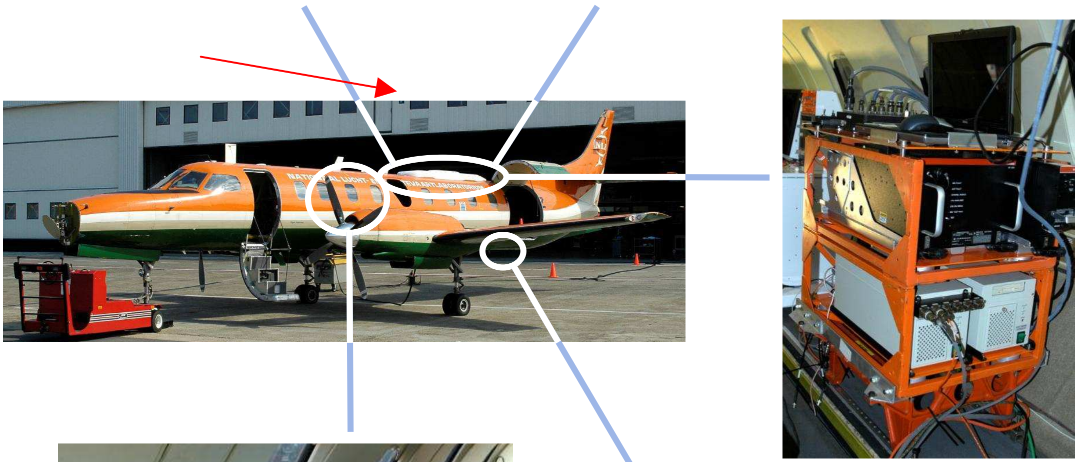
See figure below.

Various meetings with involved partners were needed to establish the equipment details, interface and installation aspects and to discuss the equipment documentation. For instance, after an intense analysis process it was decided and approved by project management to use SATCOM instead of a multi-mode receiver, since VDL-mode 2 was considered to have a too low bandwidth. After this choice was made SATCOM equipment had to be arranged and a dedicated contract was set up with a SATCOM provider for the customisation and flight test period of interest. Also a full system functional design was made and a plan of housing all the equipment in the aircraft cabin. Subsequently all system connectors, cables and cable provisions were agreed on, produced installed and tested.

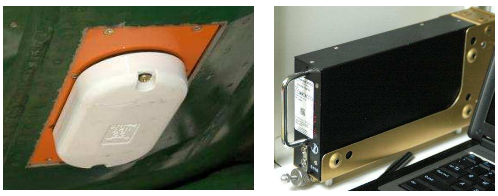
The housing of computers and displays was developed, tested on in-flight loads and installed inside the test aircraft. Partners worked on the hardware units to be installed, like a Radar Display and Control Panel, Weather radar and WIMS display, Signal Processing unit (SPU) and the software needed in all units,. Especially the new Multi-scan weather radar (antenna) system Of RCF and the SATCOM aspects like SANTA router/server (an IP address accelerator of SKY) as well as the weather radar fusion software integration aspects (of RCF and GTD) were worked on. Here fusion means the onboard fusion of the real weather radar signal with the CB-WIMS objects that via SATCOM were retrieved from a database inside the Ground Weather Processor (GWP). Also ICE-WIMS and CAT-WIMS objects could be uploaded to the aircraft and presented on a special display, but no onboard fusion was foreseen for those weather matters.



SATCOM datalink antenna and units from Rockwell Collins



Workstations at operator console



Stormscope antenna and processing unit from L3

Figure 28: Flight Test 5 equipment and customisation aspects

The customisation and integration testing was performed on site at the NLR hangar of the Metro-Swearingen II a/c at Schiphol Airport Amsterdam The SATCOM antenna was installed on top of the antenna box on the aircraft's roof. Together with the SANTA equipment (an ether IP protocol and data link enhancer) and the SATCOM high speed Swift 64 data link equipment, intensive testing on equipment and software was performed. During the equipment installation period, a blue label unit of the weather radar antenna was received from RCF-USA and used to check on the mechanical connections and all relevant installation matters. This was followed by a delivery of the real (red label) Multi-scan weather radar antenna unit to be used in the experiment, which nicely fitted. After installation in the aircraft's nose an on ground weather radar axis alignment testing was executed. Associated antenna (control) software was received and full integration testing was performed using all relevant system components. To allow system testing using SATCOM inputs\connections in combination with the new weather radar antenna, for instance for checking the weather data fusion logic, the aircraft generally had to be outside the hangar. This also prevented interference of surrounding buildings and personnel being fried by an active weather radar in use. The customisation period transitioned into a validation period when the first fully integrated check-out, named a shake down flight was held at 6th August 2008.This flight was used as an in flight weather radar calibration flight. After some re-calibration of the new weather radar unit, a second shake down flight was successfully held at 13th of August 2008.

Helicopter Flight Test

An EC145 research helicopter flight test was specified and prepared. The aim of this test was to assess the reception of WIMS data on board of the helicopter. A high speed SWIFT64 SATCOM antenna was installed and checked out. This check consisted of:

- Tracking SATCOM antenna
- Antenna preamplifier
- SWIFT Modem/Receiver

Use would be made of a predefined set of weather (WIMS) data created by the FLYSAFE meteo community and locally stored on computers.

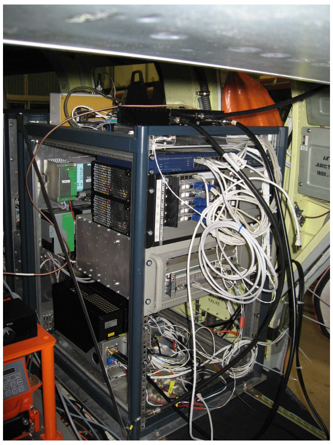


Figure 29: EC 145 helicopter customisation aspects: Antenna and ground plate mounted on the helicopter tail boom (left). SATCOM receiver and antenna control unit inside the experimental equipment rack (right).

A shake down flight was performed to check the installation of the SATCOM antenna that was mounted on the tail boom. This consisted of a HIGE, HOGE (Hover in / out of ground effect) manoeuvres and level flights at 60 kts, 100 kts with side slips left and right, and of 306 degrees level turns with 30 degrees of bank. Furthermore the antenna vibration levels were measured and checked in three orthogonal (x, y, and z) directions.

After an intensive integration testing and customisation period and when the final state of the customisation was achieved to perform the full flight test evaluations a readiness reporting was done This readiness was issued by the following formal statements (as a deliverable) that customisation was achieved:

- D 6.4-2 Flight Testbed customised for FLYSAFE (SAFIRE-Winter campaign)
- D 6.4-3 Flight Testbed customised for FLYSAFE (SAFIRE-Summer campaign
- D 6.4-4 Flight Testbed customised for FLYSAFE (NLR-Summer campaign)
- D 6.4-5 Flight Testbed customised for FLYSAFE (Helicopter Flight Test)

5.6.5. WP 6.5 Results

This WP was purposely planned overlapping with WP 5.7.4, to allow the Integration phase of the NG ISS to be harmonized between the THA-Toulouse and NLR-Amsterdam simulator facilities. Some s/w developments actually were taking place under WP6.4.2 but this way could be carried over to suit the WP 5.7.4 integrations. For instance the bse-interfaces and tools, like the Airborne Doppler Weather Radar (ADWR) unit, the TCAS model and the traffic generation tool (winTMX) were adapted for use and delivered to the THALES test bed, including some test displays and a software flight mode control panel. Furthermore alignment discussion on LCD h/w and resolution requirements formed part of this work The 5.7.4 IVV process and the final WP 5.7.4 reporting were supported from within this WP by some WP6 partners not directly a partner inside WP 5.7.4. Finally, the first preparatory steps to transfer the NG-ISS from THALES to NLR were supported.

There was no other, formal WP 6.5.1 report deliverable.

Before the arrival of all the NG-ISS software and hardware, NLR had installed a 1 GB network with APERO and added 8 standard PC's to the existing APERO computer environment. This standard environment contained 11 computers: 2 display PC's (named AIRSIM at NLR) and 9 other PC's for using the host software, the FMS, the traffic simulation (TMX), sound and visual simulation, etc. Also 3 partner laptops were integrated with a so-called "customer-network" connected to this environment.

After the NG ISS test bed was validated by pilots in WP 5.7, the test bed was send to the FFS at NLR Amsterdam for integration and verification. So originally 2 tasks were planned:

1- Integration of NG-ISS into the FFS environment
2- Verification of the NG-ISS on the FFS

Furthermore a task-3 addressing all new developments required to make the NG-ISS an operational system in the GRACE was added:

FMS + SDC coupling aspects
Traffic functions +CPDLC coupling aspects
New functional improvements of existing applications, based on WP3 and WP5 PTE's outcome (D325 / D574)
New dataset generation traffic, weather cases, etc.
Conversion to newest BSE--conversion

However due to the unavailability of GRACE in the July until October 2008 period, the Integration and Verification activities of the NG-ISS had to be divided between two facilities, i.e. between APERO and GRACE.

The software was arriving from mid July 2008 onwards. With the help of the latest IVV reports and user-guides of all NG-ISS applications NLR began the installation.

When the GRACE simulator became available the full NG-ISS set up was transferred into a new computer network environment. It had a total of at least 36 computers (of which 32 PC's) including three partner laptops inside. After a first re-check period the application testing was continued on GRACE. But a clear verification process, where results from APERO could be checked against results on GRACE was only possible at a high software level and not at a very detailed application outcome level.

Apart from testing functions separately, running the NG-ISS with all applications active also needed special attention, as this would be the way it had to run during the MTE. A concern was in the network load expectations, an issue that was at debate long before the integrations started, but could not be estimated beforehand very well. It was found out by running the full NG-ISS software system setup.

For the sake of preventing data overloads (i.e. saturation) a 1GB network switch was put into the network next to a 100 Mb switch and peak loads were recorded. Comparing the recorded maxima with the theoretical limit values showed that the network load on the 1Gb-switch was only about 1.6%, while for the 100Mb-switch it was about 33% (=360.2/1080). From this it can cautiously be concluded that the need for the 1 Gb switch was far less than a-priori assumed. However it prevented an overload on the 100 Mb switch

Also a computer network connection with the ATC simulator (NARSIM) was established and tested as well as an R/T connection with controllers from this ATC simulator. The connections were tested and some aspects of scenario effects and technical matters were addressed.

The verification task became the natural continuation of the integration testing on GRACE. The number of issues to be resolved and the complexity of developing and testing in parallel new software functions like data link, CPDLC, DCDU, FMS and ASAS or SDC-couplings, newly required HMI matters, the development of new weather cases (as needed by the SDC-function)under WP6.4.4, were all reasons why the two tasks became intermixed.

Other than in previous PTEs of FLYSAFE, ATC simulations had to be involved and a pilot-ATC interaction through the FMS should be developed. Those interactions also implied some new pilot and ATCO HMI. This was the case for:

- SDC conflict resolution through the secondary flight plan in the FMS and downlink of it to ATC
- Receiving an uplink message to confirm the down linked flight plan
- Traffic functions ASAS and SMAAS with CPDLC interface.

For GRACE a solution was chosen to use extra FMS-CDU's as Data link Control Display Units (DCDU). Those were software-wise incorporated on the Side displays in GRACE. More work went into the data link coupling aspects with NARSIM and subsequently within the SDC, traASA and the Surface Movement Awareness and Alerting System (SMAAS) applications as the communication protocol had to be clarified first and extended as well on CPDLC message set matters.

Apart from the interfacing aspects with ATC (NARSIM) also an update of the BSE interface version v.3.0.07, as needed by GRACE was executed by all NG-ISS related partner applications.

Further additional developments were related to the experimental set-up for the MTE, such as:

- Experimental matters, this relates to progressive scenario development (for crew training on GRACE) versus experiment scenarios, and required datasets
- First measurement aspects (how, what, when)

- Baseline versus enhanced system set up selection
- New datasets (traffic samples, weather grids\aspects and other circumstances)
- ICS functions with the Charles de Gaulle airport, correlation with the visual system database

With respect to new datasets used, it was discovered that the maximum number of other traffic was set for several applications at a) different numbers and b) too low for the scenarios in mind. To prevent some difficulty for particular NG-ISS applications, a compromise of a maximum of 72 aircraft was used. For this increase of allowable other traffic quite a few modifications had to be performed in the interfaces and applications of both the traffic chain of the NG-ISS logic and in the chain of the display (ND) software; as well as a filtering function for declutter purposes being necessary.

Another impact on additional developments was caused by the limitations of the scenario space in which the current weather cases did not trigger all NG-ISS functions. Therefore it was concluded to have additional weather cases that were located about mid-way between Paris and Innsbruck. The process to install these weather cases both as WIMS-Data in the NG-ISS database as well as in the onboard WXR-database was quite different than how the already available weather cases at Paris and at Innsbruck were processed. This was mainly due to a migration of interfaces to newer interface standards on WIMS data over the years. WIMS data available from the flight test had to be converted to an older format that was in use for the simulations, whilst for the WXR data it had to be improvised from ground-radar pictures (in digital format) for the bottom-part of the CB's, and the top-part had to be reshaped according the WIMS data. Many partners had a role in reshaping the weather data cases and its software environment, like for example FME / DLR /GTD / UKM / RCF /SKY and NLR.

During this integration and verification testing phase, several partners came over to assist in resolving s/w issues with their software. Several integration sessions were planned for this. Also many testing took place with the project pilots of NLR and U2A flying on the flight simulator.

5.6.6. WP 6.6 Results

Firstly a training needs analysis was performed in which the trainee groups and other stakeholders were indentified. This need analysis was documented. Subsequently plans for the training approach and training development were created by analysing available NG-ISS specifications and operational context documents. Based on these inputs the training content was gathered and a technical implementation plan was set up. It was decided to set up a flight crew Computer Based Training (CBT) and introductory CBT using Microsoft© Power Point. The CBT technical content implementation started first for the Traffic strand of the NG-ISS. The Weather- and Terrain strands were added later-on. A first full CBT version was delivered (in version A) for review and the "Training Means" and "Training Design" reporting aspects were combined into one single internal document: "Training Means and Design Report". This A-version of the CBT training materials was applied in the piloted evaluations (PTE) at THA (and a few other PTE's) and this led to a list of modifications for both CBT's. An updated Introductory and User Training CBTs was produced (Version B) and to the latter also an audio commentary was added.
After training analysis and development the third task was to perform a training delivery. The ATC people involved in the final MTE were asked to be trained on the NG-ISS aspects using these CBT's. It was found out that those formed important tools for them to understand the role and behaviour of the new functions of the NG-ISS. Also feedback of comments of ATC persons to the user CBT formed an important improvement aspect for the training materials. Combined with the latest NG-ISS functional modifications introduced during the IVV process (WP6.5), new or updated content (materials) were gathered and these were all included into a final delivered version (-C) of the training materials.

Finally, these CBT's were really applied in the MTE and subjectively assessed afterwards. One of the major results and conclusions of that review was that both CBT's were very much appreciated by the participating crews. They were considered to be of industrial quality level. The development aspects were only reported project-internally. The MTE review results are part of WP671 (gathering of review results) and WP673 (analysis of results).

The CBT's were specifically delivered as:

- D 6.6 Training Materials (Versions A, B and C)

5.6.7. WP 6.7 Results

After the verifications and validations were performed, airline crews were invited to participate to the Main Task Evaluation (MTE). A total of 9 crews participated to this MTE, of which one crew only could execute a part of the full program; hence we refer to 8+1 crews. These crews were selected partly from airlines within the consortium (ADR, AMC) and partly from other airlines and other project partners (like DAS). They executed an intense four day programme, in which also the training materials, set up and delivered by WP 6.6 were used. The whole MTE lasted until the 23rd of April 2009.

Each crew consisted of a captain and a first officer, apart from one crew when two captains participated. This constituted a total of 18 experiment subjects. Both crew members acted alternating in the role of Pilot Flying (and Pilot Taxiing) and Pilot Non Flying. Crews participated for 4 full days. They performed a crew training on the first day and scenarios during the following days. The initial experiment schedule to do all training on the first day could not be met. So after the first two crews participated, the training on Innsbruck approaches and SDC-matters was done in later days.

A typical crew's MTE-day schedule is shown in the table below.

MTE	Aspects addressed
1st day	Crew Briefing, Familiarisation and training on aircraft basics, GRACE cockpit and NG-ISS functions and displays aspects (like the new PFD, new ND, the AMM, ICS, RCAF, ASAS S&M and the data link and DCDU). Potentially first crew training on Innsbruck approaches.
2nd day	Evaluation session on Taxiing-out and take-offs on Paris Charles de Gaulle, Approaches, landings and taxiing-in. Head / Eye tracking system used. Crew training on Innsbruck approaches.
3rd day	Evaluation session on ASAS S&M (in the morning). Evaluation session on Innsbruck terrain & WIMS & weather approaches, including one RCAF run in the afternoon. Head / Eye-tracking system used. Training on SDC matters.
4th day	Evaluation session on SDC-traffic and weather in the morning. Final Debriefing (questionnaires) in the afternoon.

Figure 30 : MTE global crew schedule

The table below shows when the crews participated

CREWS	MTE-dates	Subject
0	16 - 18 February 2009	P1 & P2

CREWS	MTE-dates	Subject
1	23 - 26 February 2009	P3 & P4
2	02 - 05 March 2009	P5 & P6
3	09 – 12 March 2009	P7 & P8
4	16 – 19 March 2009	P9 & P10
5	March 30 – 02 April 2009	P11 & P12
6	06 – 09 April 2009	P13 & P14
7	14 -17 April 2009	P15 & P16
8	20 – 23 April 2009	P17 & P18

Figure 31 Participating crew dates

All subjects acted in a crew concept. Subtracting the briefing, training, familiarisation and debriefing parts, both about half a day, this provided a total of 27 (=9x3) measurement days in which about 207.2 net flight simulator hours were performed on GRACE, hence an average of about 7.7 hours on GRACE a day. This can be considered intense because crews generally are used to simulator training sessions having a 4 hours maximum a day. NARSIM was not always coupled to GRACE leading to less simulation hours for that facility.

A total of 295 MTE runs were performed. This gives an average of 33 runs per crew. About 43% (128 runs) were used for familiarisation and crew training, while 57% (167 runs) were devoted to the real assessment. So it almost took as much runs to train crews as to do the actual exercise due to the high number of novel aspects in the overall MTE set up.

It is noted that less crews participated than originally planned for. This was due to the project's remaining budget after the extended WP 6.5's IVV period and the remaining project time and simulators availability time. Given the overall MTE setup, the influence on the final results assessment was estimated not to have a big impact. However, it has definitely led to some less (statistically) significant results in the data obtained, as the statistical power of the results decreased.

All crews were very enthusiastic about the MTE programme and the NG-ISS concept, despite the long days and intense simulator and questionnaire sessions.

Winter Campaign (Flight Tests 1, 2 and 3)

During this campaign the Flight Test 1, 2 and 3, as described under WP6.3.5 were executed. Its focus was on in-flight icing aspects. In this campaign only the instrumented ATR-42 test aircraft of SAFIRE' was involved.

Depending on the weather conditions, flights operated either from Toulouse or from Creil.

Starting from Creil, experiments 1 and 3 were performed inside the Paris TMA, see figure below, hence the WIMS were linked to LWPA. The protocol of operation was approved by Paris ATC and executed as planned. The blue trajectory gives an example, where the aircraft flew during day time with about 180 knots at a chosen Flight Level and for some parts of this flight about 1000ft above and 1000 ft below.

Flight tests 2 and 3 were devoted to the testing of the ICE-WIMS on an European scale by using the CWPA, and having the LiDAR on board always. Those flights sometimes took 4 hrs. Daily briefings were held with WIMS scientists, the SAFIRE crew and specialised aviation meteorology forecasters to decide on the go/no-go decisions, depending on weather conditions, actual position of the aircraft (Toulouse our Creil), planned flights for the aircraft, the ATC related TMA protocol (which require lead time of 2 days).

The campaign was optimally planned in the winter period to have the best likelihood to encounter severe icing conditions. During this flight test campaign a 10 days high temperature situation occurred over the European

flight area of interest, and very unfortunately was blocking, or at least heavily reducing, the possible chances of encountering these conditions. As always the weather does not allow itself to be “pre-planned”.
A total of eleven flights were performed using about 40 flight hours: two engineering flight to perform a LiDAR calibration and nine experimental flights were performed of which one TMA flight and eight European flights. The first (European) flight started at 4th of Feb’08 (when light icing was encountered) and the last flight held was held at 2nd of March.
During this campaign only light to moderate in-flight icing conditions were encountered; and moderate turbulence for two flights. In experiment 3 about 39 hrs of (LiDAR) data was successfully collected for further analysis and the LiDAR system itself worked very well during the campaign. The single TMA flight executed was found very useful to validate the ATC TMA operational protocol aspects also needed in the Summer Campaign.

Summer Campaign
This campaign was planned during the Summer period (July-Sept’08) inside the Paris TMA based on the likelihood of encountering severe CB’s at that location and period in time. Hence it primarily aimed at validation oft the CB-WIMS (see further explanation inside WP 6.3.5). In this campaign two instrumented test aircraft were involved independently: SAFIRE’s ATR-42 and NLR’s Metro-Swearingen II. As a safety precaution, the latter aircraft would only fly under isolated CB conditions because the aircraft operated an uncertified weather radar system, while the other aircraft also flew under conditions of enclose CB’s (having a certified WXR system on board). A full meteo team of involved partners prepared the weather briefing information early every morning. So flight test dedicated weather forecasts were generated every day with variable prediction horizons assess the likelihood of encountering CB somewhere in Europe, and more specifically inside the Paris TMA. These WIMS weather prediction charts were made available via a special website Preflight briefings were held almost every morning, sometimes even during the weekend, between 09.00 and 10.00 hrs (apart from days that clearly would not fit to fly) involving WIMS scientists, flights crews of SAFIRE and NLR, specialists in weather forecasts. As the Paris TMA flights required the ATC (approval) protocol to be adhered to advance planning was crucial but also reduced the short term flying options. But in an overall sense the decision process laid out worked very well.

Flight Tests 1, 2 and 3
Flight Tests 1 and 2 consisted of 11 flights from 4th of August till 3rd of September accumulating in total about 40 hrs of flight. Again eleven flights were executed, of which two were inside the TMA and nine in the European domain. When these tests were combined with Flight Test experiment 3, which occurred in total five times, about 22 hours of LiDAR data was collected in parallel.

Flight Test 5
The flight test objectives were three-fold:
– To uplink weather forecasts
– To fuse weather data on-board
– To display weather information

In the period from August 6th through September 10th 2008, over 40 hours of flight testing has been accumulated in 21 flights performed. The first two flights were shakedown flights in order to check the full new installed installation in flight (like for the weather radar alignment checks and in flight SATCOM data reception and weather fusion logic). Another three flights were ferry flights to position the aircraft for the required weather. The remaining sixteen flights were test flights of which one was held inside the Paris TMA and the other fifteen were considered to flights testing the WIMS on an European scale.

Given the characteristic of the Local WIMS products inside the TMA, test flights inside the Paris TMA were the main interest of the project. The LWPA characteristics would have more data points per unit area, i.e. smaller data grid, and faster refresh rate based on high quality ground radar data), local WIMS. But due to the However, due to the weather situation in the summer of 2008, only one Local WIMS test flight could be flown in the Paris TMA. The fifteen remaining flights were Regional WIMS flights. During one of these Regional flights, the Paris TMA could still be approached and scanned with the on-board weather radar.
Convective weather has been found over following countries: The Netherlands, Germany, France and Spain.

Figure 32 : Overview the cabin of the ATR42 during the winter flight trials

Figure 33 : Overview of the cabin of the Metro II during the summer flight trials

Helicopter flight tests

The helicopter specific NG ISS was realized and tested. Firstly in simulation and secondly in a flight test. For this, Eurocopter (ECD) contributed with both a research helicopter with free programmable FMS and display system with a 3D Synthetic Vision System (SVS) and 2.5 D map (NMD). In both displays there was a presentation of Terrain, Weather, Air traffic, Obstacles and Airspaces. The main focus of the assessment was given to:
- Weather (WIMS) data presentation including a weather chain from ground to helicopter via SATCOM
- Traffic presentation

During a helicopter simulator session in Ottobrunn on the 9th of December 2009 an HMI evaluation took place for Weather and Traffic treats.

And a successful helicopter flight was held on the 18th of February 2009 In Donauwörth. On that particular flight an evaluation was made of the SATCOM data link for WIMS data uplink and for the system aspects including the presentation of WIMS data in the cockpit. The crew set-up in the helicopter existed of 4 persons in total: 1 pilot and 1 flight test engineer in the cockpit, 1 operator behind the operator station and 1 observer. The quality of the SATCOM data link was assessed in:

- Straight and level flights at 60 kts and 100kts
- Straight and level flights in North, East, South and West directions with 100 kts
- 360degrees level turns with 30 deg bank, left & right, 100 kts

Data rates were measured and checked for interruptions

Furthermore the weather data chain onto the cockpit displays were tested. Checks were performed regarding the data reception on requests from the operator station, and the WIMS weather data overlay on the NMD and SVS were checked out.

Figure 34 : Eurocopter's research helicopter EC 145 during FLYSAFE flight tests.

Results for the MTE-Full Flight Simulator

The main results of the flight simulator trials performed in the February – April 2009 period are provided. The experiment was held on the full flight simulator GRACE (Generic Research Aircraft Cockpit Environment) facility of NLR coupled with NLR's ATC simulator (NARSIM).The FFS experiment looked into various human factor aspects of the FLYSAFE Next Generation Integrated Surveillance System (NG-ISS), like crew workload, Situation Awareness (SA) and flight safety.

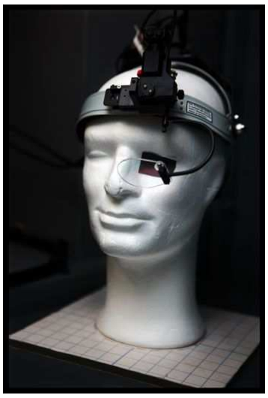


Figure 35 : Head/Eye-tracker device.

A lot of MTE (FFS) experiment data was gathered. From the audio tracks of most recorded video data a transcript was created per crew of all run debriefings performed. Per experiment topic these were collected over crews and analyzed in conjunction with the transcript of the final debriefing held at the end of the MTE and with the final debriefing questionnaire. Furthermore the subjective (pilot comment) data of the various run- and session questionnaires were collected, analyzed and reported. Objective data was looked at for the NG-ISS on ground functions only, e.g. pilot's eye tracking data, aircraft taxi routes and groundspeeds. The following sub-sections will present some main results and conclusions.

4.1.24.2.1 Pilot Computer Based Training (CBT)

The goal of the WP6.6's Introductory Computer Based Training, the User CBT and the Simulator training was to prepare all participating crews for the FLYSAFE MTE. Figure 8 shows an example of the resuls. When combining all answers from the pilot questionnaires that were used inside the MTE assessment it can be stated that the training as a whole was successful in enabling all crews to work with and understand the FLYSAFE NG-ISS system components and functions that were evaluated. This shows that a good mix of training media, self-study and interactive scenarios add up to a successful method when mastering new cockpit systems.

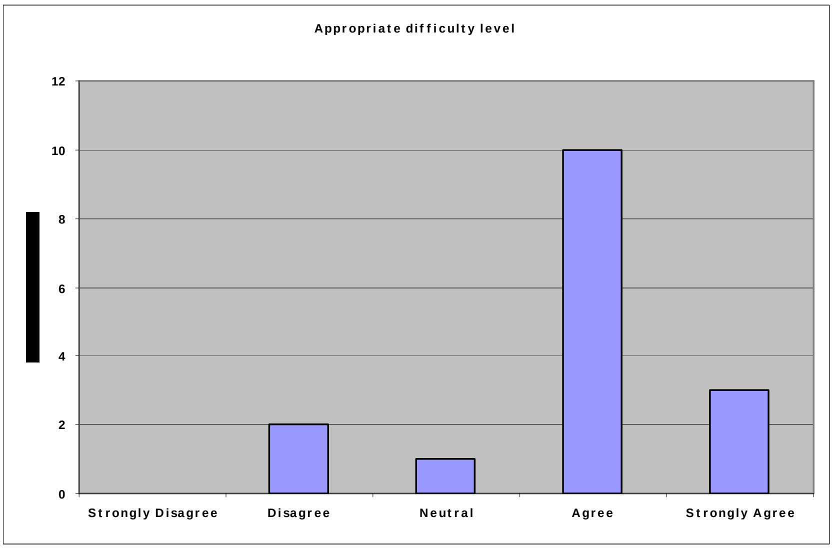


Figure 36 CBT appropriate difficulty level.

4.1.24.2.2 NG-ISS on ground functions (Airport Moving Map, SMAAS, Traffic Conflict Avoidance, Runway Incursions prevention, ICS and RCAF)

Figure 37: FLYSAFE cockpit setup of NG-ISS inside FFS (GRACE).

An overview of FLYSAFE cockpit aspects of the NG-ISS can be found in figure above: four large LCD screens for left and right PFDs and NDs, two Datalink Control and Display Units (DCDUs) and two Front Displays for use of a class 1 type of electronic flight bag software. Control of the NG-ISS display software was performed via the NG-ISS Control Panel window using the Key Control Cursor unit (KCCU). Also some ASAS, Flight Plan Checking (FPC) and Vertical Situation Display (VSD) aspects were controlled via this window, see Figure 10.

Figure 38: NG-ISS Control Panel.

Pilots' overall impression regarding the on ground functions of the NG-ISS, both for creation of improved situation awareness and for traffic conflict avoidance was very positive. They appreciated this system part very much because it increased their situation awareness, and improved perceived safety. The ground traffic presentation concepts were deemed quite mature. Pilots showed a high interest on those functions and they considered them giving the support they missed with current systems. More than one pilot made statements like "I want to have it on my aircraft, yesterday".

Results of other Work Packages

Finally, the main results of WP2 to WP5 were collected and described inside this final Technical Report under the respective individual WP's. The contributions to the project's overall achievements formed part of the WP6.2 (PGAT) assessment.

The results of the MTE and flight tests performed have been reported in more detail inside:

- D 6.7-1 Flight Simulation Evaluation Report (Version A)
- D 6.7-2 Flight Test Evaluation Report (Version A)

D 6.7-3 Final Technical Report (Version A), this report.

5.7. WP7 EXPLOITATION, STANDARDS AND DISSEMINATION

This main work package was divided into three work packages:

- WP 7.1 "Exploitation" aimed at developing an Exploitation strategy towards the industrialisation, marketing and full exploitation of FLYSAFE IP results for future:
    - Onboard surveillance system,
    - On ground weather information management system,
    - Onboard safety functions,
- WP 7.2 "Interaction with international standards" aimed at providing an organisation to enable efficient and productive actions on international standardisation working groups.
- WP 7.3 "Dissemination activities" aimed at enabling the proper dissemination of the project scope, status and results all along its development.

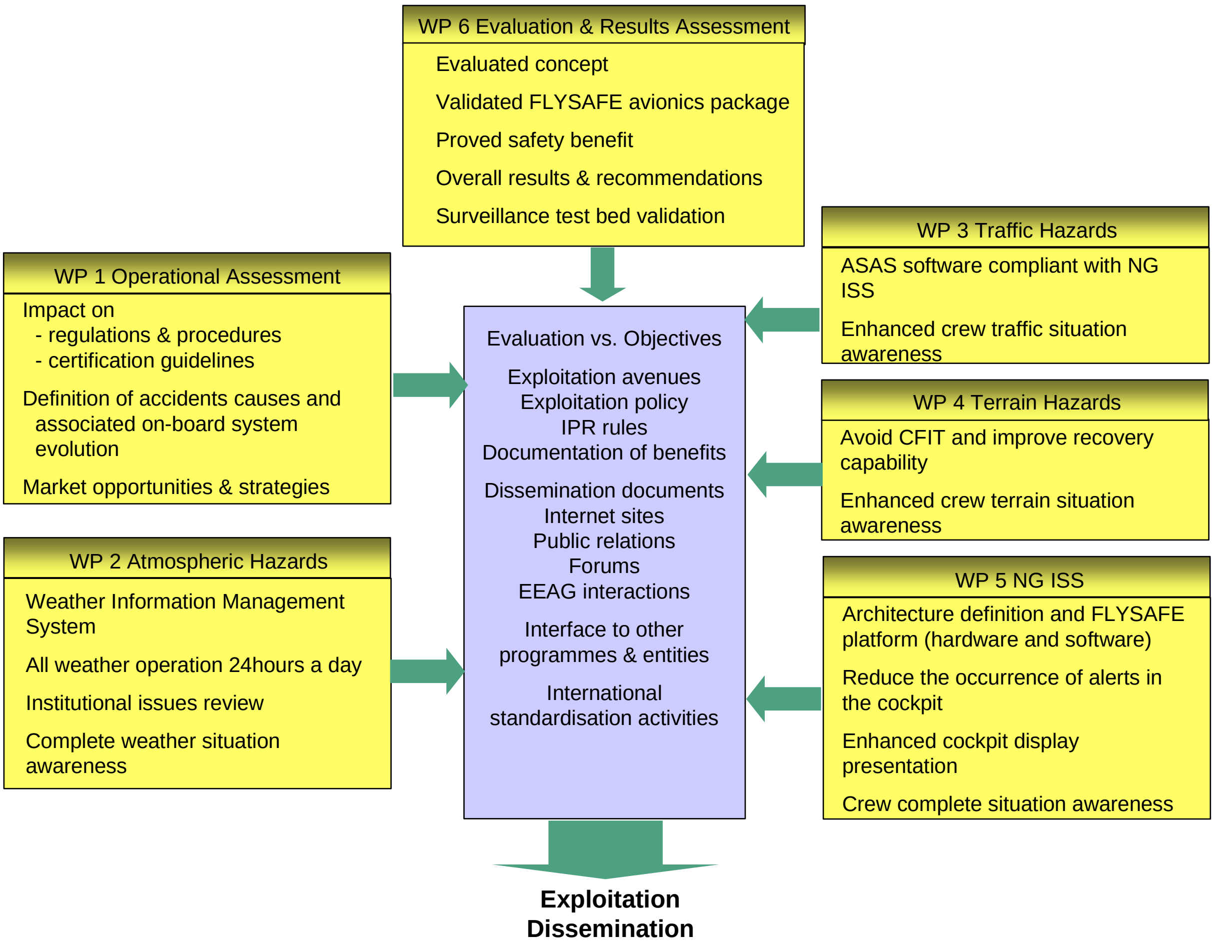


Figure 39: Exploitation & Dissemination process

5.7.1. WP 7.1 Results

A detailed exploitation strategy was defined and implemented. This included the identification of applicable exploitation domains and a exploitation risk analysis. Details are provided in the deliverable "FLY_710DAV_DEL_D7.1-1_A.pdf" Based on the exploitation risk analysis areas were identified which had to be given more focus. Furthermore a list of exploitable items was created which includes all functions, concepts and systems developed in the FLYSAFE project. This list also reflects knowledge gained in specific domains.

Each exploitable item comes with small overview and a description of responsible partners and roles as well as technological, economic and market considerations. A TRL (Technology Readiness Level) assessment was performed per exploitable item, taking into account the different needs of airborne and ground systems. Therefore the original definition of TRLs from NASA was adapted especially by modification of transition criteria that define if a certain TRL is reached or not.

A market analysis was performed giving an overview about the potential use of the FLYSAFE innovations. Details are given in the Final Activity Report.

WP 7.1 as well encouraged the process of filling new patent applications with a special focus on the case when patents have to be shared between several partners. It turned out that this was not necessary in the frame of FLYSAFE. Other patents or patent applications are reported in the Final Activity Report.

5.7.2. WP 7.2 Results

The FLYSAFE partners reviewed various standard definition activities linked to the integrated platform. They selected the most appropriate standards to work on. It was planned to open new standardisation working groups when no standardisation activity exists in a given field of activity, however this was not necessary. The WP 7.2 partners defined and formalised the organisation between them to interact with these international bodies by the creation of FLYSAFE standard working groups with appointed leaders.

An index was generated of all the international groups that should be involved in clarifying the institutional issues concerning the operation of the WIMS.

Due to the international nature of these standards committee, it was necessary to participate to meetings outside the European Union. Provisions were made in the project for this by the concerned partners.

All partners participated in their field of activity (avionics, meteorology, HMI). To feature this five internal standardisation working groups were formed which worked on:

- Weather Sensors and Services
- Surveillance and Alerting Systems
- Traffic and ASAS Applications
- Datalink and Associated Applications
- Database and Database Management

Members of those working groups followed the standardisation work in their specific domain and participated to international standardisation meetings. For each of those meetings a meeting report sheet was filled and made available to the FLYSAFE consortium. The meeting report sheets summarised the meeting results and identified as well the impact on FLYSAFE.

The diagram below shows the attended international standardisation meetings per FLYSAFE working group. This gives an impression of FLYSAFE standardisation activities. It helps to identify fields of activities to which FLYSAFE information was conveyed and where required information from other international standardisation working groups were collected.

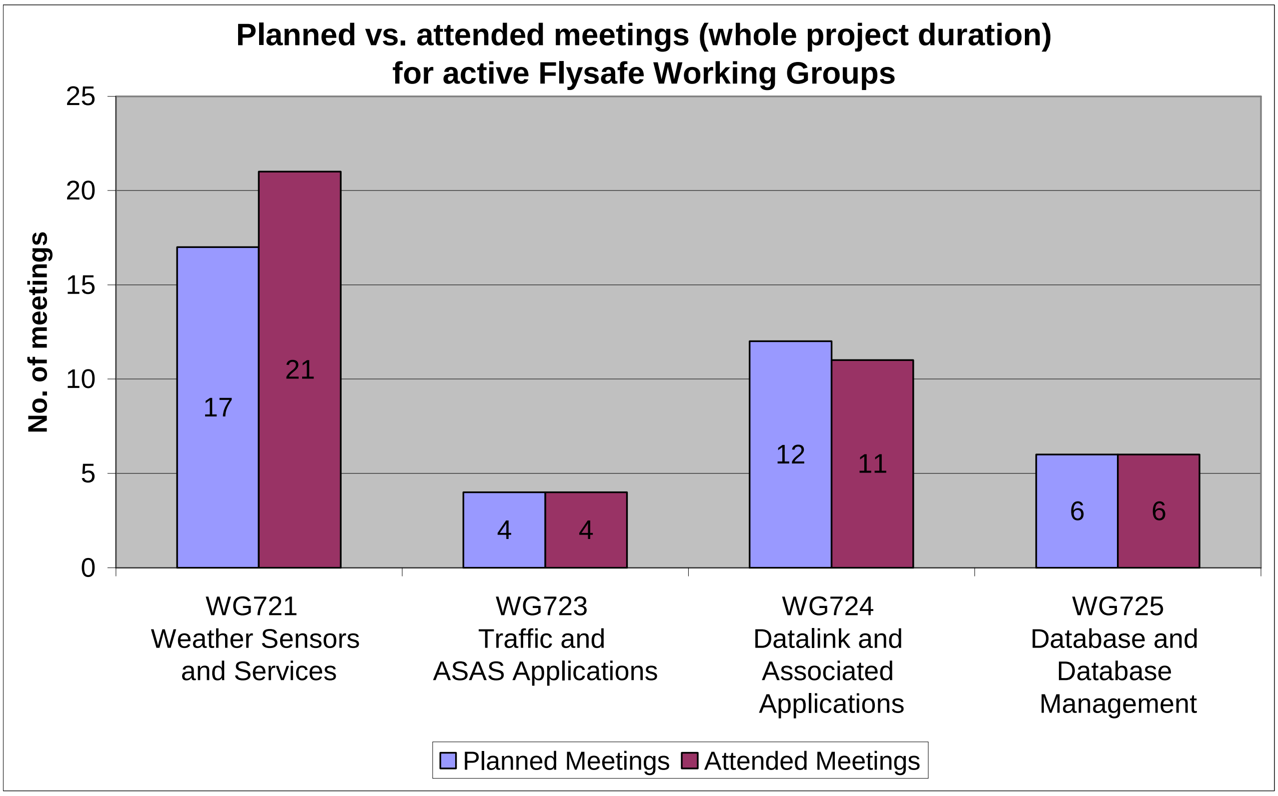


Figure 40: Standardization Meetings with FLYSAFE participation

WG 722 was closed in 2006 because the ISS Working Group reached consensus on ARINC Project Paper 768 for ISS (Integrated Surveillance System) in 2005. The decision was made to keep the FLYSAFE WG 722 existing in case the FLYSAFE developments would create the need to reopen the ARINC 768 working group, which did not happen. So there were no meetings of the WG 722 during WP 7.2

The interaction with international standards was essential to the FLYSAFE consortium in two ways. The first aim was to get access to latest knowledge about international standardisation activities and results. The second objective was to disseminate FLYSAFE results and to incorporate them into international standards. By doing that the future usage of FLYSAFE concepts and functions is prepared which as well conveys the exploitation of FLYSAFE results.

The FLYSAFE partners will continue to promote their achievements after the projects end. That ensures proper exploitation of the FLYSAFE results. Some activities will be continued in other research projects. As one example the data compression for XML weather data exchange model shall be named which will continue to be a topic in SESAR.

5.7.3. WP 7.3 Results

In the frame of FLYSAFE numerous and varied different dissemination activities were performed. These activities can be grouped in two different ways: a) the type of dissemination activities (presentations, articles…) and b) the scope. In this document all items are grouped according to their type, the change of scope during the project lifetime is described briefly.

In the beginning of FLYSAFE the main objective was to make the project known to the external world. As in the beginning no results were available, the main focus was on communicating what the expected results will be and by that increasing the interest of external bodies in FLYSAFE. The first phase of FLYSAFE was also used to get as many inputs from external bodies and future stakeholders as possible. The EEAG (External Experts Advisory Group) is just one example to get external involvement by a group that regularly meets once a year to steer the project into the right direction. In addition, online questionnaires were used to get more information from airlines and pilots as the end users of the FLYSAFE results.

During the specification and development of the FLYSAFE functions the focus of dissemination was on the coordination with other projects. This prevents duplicated work but also makes sure that relevant aspects of the work are covered. One example of this kind of activity is the second forum which was held together with the ASAS TN2 Network to maximize the exchange between both projects.

In the final phase of FLYSAFE the focus was on disseminating the results. Several presentations and press articles were published to tell relevant research communities, standardization bodies, authorities and end users about the FLYSAFE flight tests and main task evaluations. In France and in the Netherlands several TV programmes broadcasted on national TV channels about the FLYSAFE project. During the final forum, TV coverage was provided starting with the early morning news and during every news show until the late evening news on the primary national TV channel.

Planning and realization of the different kinds of dissemination means are described in the deliverable " FLY_730DAV_DEL_D7.3-5_A.pdf" which is the final report on Dissemination Activities.

The objectives were met with one deviation. Instead of 4 dissemination forums three forums were held. In addition to the initial plan several short videos were produced.

In a project of the size of FLYSAFE it is essential to coordinate dissemination activities carefully to present a consistent picture to the outside world. Therefore careful planning was done at project start-up to select the right dissemination means at the right time – such as Forums, the External Experts Advisory Group, presentations and stands at international fairs and congresses, several videos and press releases. Furthermore we insisted on the principle of announcing dissemination activities well in advance. All dissemination material was reviewed to ensure consistency. In summary the dissemination activities were planned carefully and resulted in high quality material.

It is not possible to measure the effect of dissemination quantitatively because the result of a specific action occurs months or even years after, so it is very difficult to say if a single dissemination activity was successful or not. However, it is clear that the total sum of dissemination activities in the early years of FLYSAFE had a big effect in the end phase. That can for example be seen from the high number of guests at the final dissemination forum, from the high ranking of FLYSAFE in the list of most relevant projects to SESAR and from CleanSky's high interest of in FLYSAFE.

Seeing that the high quality and good planning of dissemination material was maintained throughout the project lifetime we can expect that the project results will be used widely after the projects end and that the positions of the FLYSAFE partners in their respective fields of activity in the global market are strengthened.

6. RECOMMENDATIONS FOR FUTURE RESEARCH

6.1. WP1 OPERATIONAL ASSESSMENT

Designing and integrating a complex and coherent system, with 36 partners of very different backgrounds is not an easy task !. From WP 1 activities we can pinpoint the following lessons learned :

- If parallelism during the specification of each sub-system is inevitable, room should be kept at the end for the consolidation at the system level (HMI, …)

- Exchange information within the groups / WPs / users is a very important activity:
  - ◊ Internally it should be organized within “transversal groups” to be able to address subjects involving more than one WP. Brainstorming between operational experts and “engineers” should be organize regularly to check system usability (through slidesware, early prototyping, …).
  - ◊ Externally, the EEAG (External Expert Advisory Group) has proven is efficiency to collect external expertise from parties not involved in the consortium.

- Integration and evaluation activities should be prepared as early as possible :
  - ◊ Evaluation constraints should be identified (simulated data needed, …).
  - ◊ The evaluation platform(s) detailed architecture should be initialised as soon as possible, in order to identified the full list of the components (what) and which partners will provide it (who).
  - ◊ The integration process (how the components will be integrated), should be defined early and shared with the partners, as it will define rules to be followed by each components provider (delivery format, user guide, acceptance tests, …).
  - ◊ The internal dependencies between WPs/tasks should be identified carefully.

- A formal description methodology should be used to describe the high level architecture (Functional architecture, Components behaviour and interfaces):
  - ◊ To define the interfaces between subsystems very early (allowing partners to work on their independent subsystem and ensuring the global consistency).
  - ◊ To guarantee a common understanding of what the system should do (user’s requirement) and how it will do it (system specification). This should be initiated at the beginning of the specification, even during operational concept requirements, as « A consistent set of drawings is worth 1 000 000 words ».
  - ◊ When selecting a methodology and its associated tools, all the constraints should be taken into account : cost of the tools & the training, design team availability through all the project duration (as data should be kept consistent), ...

6.2. WP2 ATMOSPHERIC HAZARDS

6.2.1. WIMS product chain should be improved in terms of data processing

1. Improve Cb WIMS refresh rate by a number of means, including the use of METEOSAT rapid scan data, use of European 5 minute radar composite
2. Improve air/ground synchronisation so that a request from the aircraft is coordinated with availability of updated data at Ground Weather Processor (GWP). Another possibility would be for the GWP to promulgate data to aircraft when it (the GWP) receive the data (between the first request from the aircraft and a request by the aircraft to cease sending data).
3. WIMS object sizes should be reduced, by a number of independent technologies.
4. Visual representation of Fused Cb objects (on board) should be improved, including refining the shape (e.g. by increasing the number of points) and providing indications of severity

6.2.2. Further flight trials should be conducted

Further, carefully planned flight trials should be conducted. The purpose of the flight trials is to document differences between ground based and airborne radar returns from developing and mature Cbs. This in turn will give rise to improved understanding of the strengths and weaknesses of ground based and airborne radars. The airborne radar should ideally be of the type considered early in the FLYSAFE project but which was later considered too large to be accommodated in any of the available aircraft. The radar should have full digital recording capability. The radar should be fully certificated so that there are no unusual constraints on where the aircraft carrying the radar can fly. The experiments should take place in an area where there is excellent, 3D ground based radar coverage but minimal ATM constraints, i.e. not Paris. It should include flight levels relevant to TMA activity, in cases with embedded Cbs showing complex organisation in space. The proposed further flight trials over lap in purpose with a proposed detailed simulation study of Cbs, which follows in this list of recommendations.

6.2.3. A detailed simulation study of Cbs should be undertaken

The purpose here is to gain improved understanding of the strengths and weaknesses of ground based and airborne radars (this was a purpose of the proposed further flight trials, which preceded in this list of recommendations). The intention would be to generate realistic simulations of Cbs and then generate simulated returns for simulated ground based and airborne radar, including the simulation of signal averaging across the radar beam width, and signal extinction by precipitation. The data would be used to address questions such as the capabilities of automatic tilt management for compensating for attenuation.

6.2.4. A cost benefit study should be undertaken

Although reducing WIMS object sizes is desirable when it can be achieved with no discernible loss of quality (e.g. through use of binary XML), at some point data volumes could be reduced through removing some data (e.g. detail, information about severity) which is of potential value to the pilot. Although quantifying benefits where safety is concerned is very difficult, it is clear that the additional information from WIMS (e.g. information about particular hazards such as hail) could be very valuable to the pilot. If at all possible the study should address all costs of providing the data, including the costs of providing sensors on large numbers of aircraft.

6.2.5. The WIMS product chain should be improved in terms of science

Improvements should be made to numerical weather prediction which will improve forecast quality and smooth the transition from nowcast to forecast time horizons.
Improvements in the ground-based observation systems (as e.g. generalized polarization and 3D data on radars and improved space-time resolution and available channels on geostationary satellites) and in their processing should add even more value for on-board use, and with respect to on-board data. Better use should be made of lightning data.

The assignment of probability values should be refined and made consistent across WIMS products. Work should be undertaken to reduce or if possible eliminate inconsistencies between the WIMS products on different scales.

6.2.6. The CAT WIMS should be improved, and on-board detection of CAT should be developed

It is necessary to recognise all three causes of CAT, i.e. shear, mountain waves and convection. A CAT prediction system using artificial intelligence would be of value. New algorithms for predicting CAT (e.g. Knox, McCann and Williams, 2008) should be developed. Methods of ingesting measurements of turbulence into short range forecasting packages such as WAFTAGE should be developed. Concepts in on-board detection e.g. DELICAT should be pursued.

6.2.7. Further developments in the prediction of icing

It is highly desirable to develop a two stage process for predicting icing intensity. In stage 1, meteorological parameters would be predicted and promulgated to the aircraft (these parameters would include supercooled liquid water content and dropsize information). In stage 2, these data would be processed on board the aircraft and converted into an aircraft-specific threat. However, at this stage algorithms for predicting the effects on aircraft are not generally available.

A method for indicating patchy icing areas should be developed. An icing product for Air Traffic Management (ATM) needs to be developed.

6.2.8. Further developments in on-board wake prediction and alert

Wake predictors should be validated for a range of altitudes, aircraft and meteorological conditions. The meteorological data should be enhanced through the development of estimation and fusion filters. Wake detection and prediction should be coupled.

6.3. WP3 TRAFFIC HAZARDS

A range of topics for further investigation, development or improvement were identified after both the Traffic PTE and the Main Task Evaluations. The following subsections summarise these recommendations, which have arisen primarily from the Traffic PTE.

6.3.1. Taxi Operations (SMAAS)

- Development of refined display symbology rules for the presentation of traffic and other relevant features during taxi operations whilst avoiding visual clutter on the displays.
- Improvement in the location and visual prioritisation of taxiway designators to avoid them being obscured by other display features.
- Inclusion of audible alerting for situations when the own aircraft deviates from its cleared taxi route.
- Development of new procedures and CRM roles to ensure that (a) both aircrew are fully aware of all hazards and (b) all necessary avoiding actions are correctly distributed between the PF and the PM.
- Detailed investigation of the display of traffic information for aircrew situation-awareness while there is only partial traffic coverage. This issue is a potential safety hazard (for example, if the aircrew place too much confidence in a partially-populated traffic display) and is especially important currently / in the near future, when Traffic data coverage is likely to be incomplete.

6.3.2. Runway Operations

“Own-Aircraft” Incursions (SMAAS)

- Development of Incursion alerts (visual and audible) that make it clear what form of incursion is about to take place (e.g. the difference between an un-cleared entry to a runway vs. an entry to a closed runway).
- Investigation of the possibility of automatic control of the Taxi Map scale so as to show the entire runway

length in the event of an incursion alert (would ensure that the incursion event is visible whatever scale / location had been selected, but is associated with various adverse implications).

- Presentation of all relevant traffic in the event of an incursion alert.

"Other Aircraft" Incursions (RCAF)

- Alerting philosophy and procedures have to be developed to (a) transfer incursion information to the aircrew as effectively as possible and (b) ensure that both the PF and PM take the necessary action in the limited time available. In order to maintain aircrew confidence in the system, this may have to include indication that an incursion has been detected, but that it is safe to continue.
- Further investigation of the effectiveness of the distance call-out during the STOP TRAFFIC alert situation.
- Further development of the audio alerting and alert suppression thresholds in the vicinity of V1.
- Enhancement of the alerting logic to prevent the generation of spurious alerts when visual separations are being maintained in VMC.
- Further integration of RCAF alerting with existing take-off and landing procedures and display formats.

6.3.3. Airborne Sequencing & Merging Manoeuvres (ASPA-S&M)

- Development of improved system mode status information, so that the crew are aware when a significant change has occurred. This awareness issue affects both changes internal to the application (e.g. reaching the "turn direct" point in a Vector manoeuvre)and "external" changes, such as the termination of a manoruvre caused by unexpected behaviour of the target aircraft.
- Presentation of more complete and more detailed spacing status information, so that the aircrew are better aware of the evolving situation during all phases of a spacing manoeuvre.
- Improved information to assist the aircrew in deciding whether a manoeuvre instruction is feasible or not. The original concept was that the system performs this check autonomously, but evaluators felt that they needed more involvement / awareness at this stage of the manoeuvre, so that they were "in the loop" about the future conduct of their flight.

6.4. WP4 TERRAIN HAZARDS

6.4.1. Recommendations regarding Terrain Awareness and Warning System

FLYSAFE has supported the main elements than enhanced the terrain and obstacle situation awareness, i.e:

- A vertical situation function to complement the horizontal view of terrain and obstacle in the navigation display,
- A safety altitude function following ISAWAREII's recommendations and adding more operational feedback to the design,

- A flight path check function to anticipate potential conflicts with terrain and/or obstacle(s) on the aircraft intended flight path.

Future research to extend the crew awareness with respect to terrain and obstacle(s) would be geared towards specific aircraft operations or extend the elements already covered, for example

- Vertical awareness of the terrain is implemented by the Terrain Hazard Display, however awareness of the lateral margins with respect to terrain is not provided. Although lateral safety is ensured by Required Navigation Precision, crew awareness of lateral closeness to the terrain could support approaches to high altitude airports (e.g. Andeans, Tibetans) or mountainous airports (e.g. Calvi, Chambery, Queenstown). Lateral awareness is also paramount for the special operations close to terrain that require the voluntary disabling of the TAWS (airborne fire-fighting, water scooping).

- Although obstacles are less of a hazard to Air Transport aircraft than to helicopters (see subsection 6.4.3), extension from point obstacle awareness to linear obstacle awareness should be recommended.

FLYSAFE has supported the development of new alerts, i.e:

- Point obstacle alerting following the design philosophy of the terrain alerting predictive mode and adapted to the specificities like a dedicated database and dedicated processing for high-density obstacle areas (e.g. metropolitan areas),

- Flight path conflicts identification to trigger the crew to check and correct trajectory, whether to avoid terrain or obstacle(s) and verify the situation when the conflict pertains to safety altitude(s).

Future research would allow to climb in the value chain and move beyond mere alerting. It would encompass decision aiding, possibly up to automation, for example

- Decision aid (guidance) for manual escape in the case of TAWS utmost critical alert “avoid terrain” and/or “avoid obstacle”. Note that this research would be different than that already carried out within EC-funded projects such as SAFEE (FP5) or SOFIA (FP7) in which the specific security context allow to have more anticipation on the recovery initiative, in this case the crew is assumed able and willing until the moment the system warns that a pull-up manoeuvre will not be sufficient to clear the hazard,

- Extension of the decision aid to full automation of the escape manoeuvre. The automated part would after the tactical escape segment ensure that the ownship can rejoin the “normal” traffic or at least coordinate with ATC that the escape does a minimal disruption to other traffic in the area. This could be tested in obstacle-dense metropolitan areas for example,

- The flight path checking function is the antechamber to re-planning. Re-planning proposal was developed during FLYSAFE for weather and traffic, while terrain re-planning would need further research. Terrain and obstacle re-planning alternatives could be investigated as a bridge function between surveillance and flight management in such a way that trajectory constraints could be integrated within the solution, which was not the case in FLYSAFE developments, and ATC be more involved in the process, which was set ad-hoc for FLYSAFE MTE.

Finally, regarding the supporting databases, future research could address

- Ensuring higher reliability amongst data provider so that the database information is more accurate and more complete (this need is also common for the helicopter platform),

- Investigate the feasibility and how to harmonise design procedures between the ground and the board for the Navigation database (from which the TAWS but not only extract data); harmonisation could also be applied to the performance database which is used for various purposes by different actors (e.g. flight management, auto-pilot, surveillance) and which design varies according to the aircraft manufacturer,

- As more than one application often use the same database information, and assuming the avionics architecture does not include a database server (e.g. for criticality/safety reasons), how to promote coherence between these users is a topic to be studied,

- Continuing on the standardisation work for AIS and MET datalink services, research should be carried out to implement the ground architecture including data repository and onboard avionics including data storage, handling and distribution to end-users (systems and crew),

6.4.2. Recommendations regarding DB/Weather radar correlation function

FLYSAFE has allowed the white paper to identify operational benefits for the function, as well as requirements on both the radar and the terrain database, and list a few candidate algorithms and design philosophy. Future research would be geared toward increasing the Technology Maturity Level (TRL) of the function via proper specification, development and validation. This activity would include

- Based on the operational benefit report, the selection of an operational context and test scenario (including the pertinence of flight tests versus simulated environment, the use of off-line weather radar images or simulated weather radar images,…),

- Based on the requirement report and state-of-the-art candidate database and weather radar (simulated or real), the specification of the component, its functional behaviour and interfaces (external and internal),

- Based on a selection of potential candidate algorithms (further the trade-off process that was started within FLYSAFE), the implementation of a solution and possibly more following the selection results,

- The Integration, verification and validation of such developed solution, including operational feedback, quantification of said operational benefit and recommendation.

- The investigation of this function's impact on existing standard (e.g. request re-opening or orient), the identification of the need for new standard (make recommendation to standardisation bodies) and the consequences on certification (e.g. can incremental certification be envisaged, how to certify the new function,…)

6.4.3. Recommendations regarding Terrain and Obstacle Awareness and Alerting for helicopters

The helicopter white paper has shown that

- Helicopter specific operations require dedicated consideration when it comes to terrain/obstacle awareness and alerting and not simply a mere transfer of air transport devised solutions.

- In terms of data, helicopter needs are not answered. The need for completeness pushes for multiple sources of information, while accuracy requirements are to be considered but not as priority number one. As part of completeness, the importance of linear obstacle has also been highlighted.

- To provide safe coverage during helicopter operations, database should be complemented with in-situ detection. Going further, the results could be dynamically enriching the database.

- Technical feasibility for off-line rendered terrain presentation was shown. The advantage of this solution is, that it adds only little workload to the onboard hardware and the quality of the rendering can be more sophisticated than what would be achievable with a run time rendering process.

As the conclusions were issued from a white paper supported with quick-prototyping and questionnaire, future research would consist in further proving the above conclusions:

- The operational context could be set for helicopter identified operations like Search and Rescue in mountainous terrain. This would set the framework for the local enhancement of the database,

- Investigate the increase in completeness of the obstacle database from existing data providers (static part of the database), setting wherever possible data consolidation and merging techniques. Data content should include linear obstacles, in particular cables,

- The dynamic enhancement of the database would consist in consolidating with in-situ observed obstacle from an onboard sensor. Existing technology such as lidar could be used as the onboard data source. Process to enhance the database as well as algorithms to correlate would also be part of the research,

- Then, specification of the enhanced terrain and obstacle awareness and alerting function could be prototyped based on the enhanced database above and helicopter specific logic. The steps are classical ones: specification of the component/system, its functional behaviour and interfaces (external and internal), implementation of a solution, and finally Integration, verification and validation of developed solution, including operational feedback,

- The investigation of this function's impact on existing standard (e.g. request re-opening or orient), the identification of the need for new standard (make recommendation to standardisation bodies) and the consequences on certification (e.g. can incremental certification be envisaged, how to certify the new function,…).

6.5. WP5 NEXT GENERATION INTEGRATED SURVEILLANCE SYSTEM

- In addition to the ICD and specific peer reviews, **the early development of stubs** was really useful for the verification of the interfaces and for mitigate the integration risks. As sooner the interface incompatibility is detected as lower would be the development impact and cost.
- Improve the weather awareness algorithm by better taking into account the confidence level of the WIMS data. In some WIMS data like icing, this value was always set to the same value.
- Evaluate how to better share the strategic conflict and resolution information between A/C and ATC.
- Evaluate the impact of the conflict resolution system on the ATM operation and workload.

6.6. WP6 EVALUATION AND RESULTS ASSESSMENT

- The NG ISS safety assessment proved to be challenging since new functions had to be assessed but these functions lacked supportive safety data. The Safety Model Analysis was found useful in relative comparisons and about a factor 10 in probability occurrence improvement is expected for some new safety functions. Still the definition of a proper baseline supported by suitable safety data should be improved in future programs.

- Challenging flight test programmes were executed successfully, on time, within budget and with very good results. For future research it is recommended to look in more detail into the improved data link solutions, or multi-mode receivers, i.e. faster transfer of bigger data packages (volumes) and with a higher bandwidth. FLYSAFE performed first steps in research on in-flight detection of icing and on weather fusion of CB weather products. This can be further stepped up both in terms of new on-board sensors and (fusion) techniques as well as gathering validation data for the ground products (WIMS) in flight. Also research dedicated to Clear Air Turbulence (CAT) detection is promoted.

Flight Test 5 Related-

o

- o Draw functional diagrams of applicable instrumentation and interfaces early in the project. Technical review meetings essential to detail all ins and outs
- o Peer reviews prevented wiring/cabling implementation and space problems for FT5
- o Perform full end-to-end system integration testing in a lab-environment first before installing systems inside the a/c. Reduces a/c system integration time considerably
- o Flight plan co-ordination with Paris TMA / ATC was smooth, but start FT organising discussions with ATC authorities timely.
- o Meteo briefings held worked very well
- o Avoid too many constraints in weather-related flight tests, when possible.
- o

- Project goals assessment tool PGAT worked well, but intermediate status less easy to derive.

- o Most new Weather, Traffic, Terrain and NG-ISS functions can be re-used and further enhanced in future EU-projects, in CleanSky and SESAR. See WP 2 till WP 5 for more details
- o Novel Airport Moving Map and VSD aspects to enter new-build aircraft rapidly now
- o MTE Final Results to be presented and brought to human factors groups, aviation congresses, and Safety / Certification organisations
- o For FT1-3 (see WP 2). FT5 results are available for further research on uplinked WIMS, fused CB HMI and datalink aspects like compression techniques. 3D representation of CBs and Fused CBs to be further studied
- o Multiscan WXR / small antenna already planned to be installed on business aircraft
- o Developments for FLYSAFE GRACE and NARSIM set ups to be further enhanced and used in CleanSky (and potentially SESAR) as validation platforms, e.g. 4D-trajectory management
- o PGAT process potentially transferable to other projects