INNOVATIVE FUTURE AIR TRANSPORT SYSTEM

SIXTH FRAMEWORK PROGRAMME

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Title: PUBLISHABLE FINAL ACTIVITY REPORT

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INTRODUCTION

The perspective that is considered in the Innovative Future Air Transport System (IFATS) project opens new ways not only for the management of the air traffic (ATM), but also for the management of the overall air transport system (ATSM).

In this project, the IFATS consortium decided to use a methodology providing a large and open thinking space in order to imagine and propose new far term solutions to pioneer the air transport of the future.

The basic feature of the IFATS concept is to go as far as possible in the automation of the ATS. The approach that has been taken is purely technical: thus, the concept that has been defined is a "technically possible" extremely automated system and not necessarily a "likely to happen" system.

The project started with identifying and analysing the technical issues of the automation of the ATS functions, and then it came to the validation of the resulting innovative ATS itself through safety analysis, simulations and debates organised in two workshops.

This procedure has enabled the consortium to think "out of the box" and to introduce a cornerstone feature of the IFATS concept: 4D contracts in a 4D airspace.

The 4D trajectory concept (being at a given geographical position at a given time) is already existing and widely studied, but its main drawback is that the compliance of the real 4D aircraft trajectory with the planned one has to be constantly monitored. Indeed, the 4D trajectory may vary due to meteorological conditions, for example. Additionally, whoever is in charge of trying to keep the aircraft on the planned 4D trajectory, the pilot or the controller, the task is hard to achieve.

The aircraft automation brings a part of the solution with the 4D FMS. Then, the question of who will be in charge of maintaining separation has to be answered.

The IFATS concept is straight forward on this issue. First, the ground segment of the system (the Air Transport Management System), which is also automated, is in charge of the generation of conflict-free 4D trajectories according to the demand and to the airspace capacity. Then, aircraft are given 4D contracts**;** they are in charge of monitoring their own compliance with the contract, which means staying inside their assigned 4D volume, or to ask for a new one if they cannot. In doing so, they have the guarantee to fly conflict-free trajectories.

Of course, the main difficulty lies in the generation of those conflict-free trajectories. To ease this generation, the four dimensions of the airspace are fully used without the current constraints linked to procedures, navigation waypoints, ATC sectors and airways: 4D contracts are created and have to be respected in the very large four dimensions airspace.

The IFATS project main goal has been to develop, as far as possible, the definition of this concept and to validate through simulations some of its components.

This document summarizes the actions that have been pursued until the end of the first phase of the project in June 2007 and gives the major findings.

A second phase of the project, aiming at a detailed simulation and evolution of the concept, has been proposed at the first call of the FP7.

PROJECT MOTIVATIONS

“I feel guilty when I travel by air”. This is a rather unexpected statement in the current thinking process to shape the future of the Air Transport System (ATS). It has been published in March 2007 in a French weekly magazine (Ref. 1). The paper was about flying from Paris to China for holidays and stated that the consequence of such a trip was an emission of more than 7 tons of CO_2 per passenger.

What is the basis for such a view?

An explanation can be given, grossly exaggerating the issue, when considering this emission of CO_2 and the quantity of fuel burned during a single flight.

Is there a possibility, a risk, to be charged with a crime against humanity in 40 or 50 years time, if you have contributed to burn large quantities of fuel and to emit huge volume of CO_2, only for you own comfort, flying to long distance locations, for your holidays?

The answer could be yes, if, at a point in time in the future, the population of the earth will be lacking energy and fresh air, just to sustain its existence…

This iconoclast statement should not been seen as provocative. Its goal is to initiate a debate leading towards an investigation and a definition of a highly efficient future air transport system. The air traffic evolution depends on many parameters and, as such, it may not be as predictive as stated today; growth potential could be different from what is expected nowadays!

In this perspective, the IFATS project looked at disruptive options of the future ATS, i.e. concepts of ATS where pilot-less transport aircraft would be operating with a high degree of automation providing autonomy, controlled and monitored by ground operators through a network-centric architecture communication system.

The benefits that are expected from the IFATS concept are numerous; the most important ones are a better safety, a higher capacity, a low dependency on traffic evolution parameters and a radical improvement of the environmental issues by optimizing the aircraft trajectories. These topics are comprehensively described in the various sections of this report.

PART 1 - IFATS PROJECT EXECUTION

1. SCIENTIFIC OBJECTIVES OF IFATS

The IFATS project proposes to study a revolutionary concept for a future air transportation system (ATS) by adding as much onboard automation and autonomy to the aircraft as necessary to fulfil the overall requirements of improved efficiency and safety of air transportation.

- All the various air and ground components of the system communicate with one another through a network-centric architecture;
- Aircraft fly autonomously pre-programmed flight plans using sophisticated onboard computing and sensor systems. Ground operators are responsible for the overall situation, whereabouts of aircraft and tracking of their intentions.

Functionalities of the system are flexibly distributed between the ground and aircraft, relying on intensive data communication capabilities between aircraft, and between aircraft and the network of ground stations.

Current pilots and controllers tasks are deeply modified as the elements of the system communicate digitally: pilots can be removed from the cockpit and controllers work is transformed into system monitoring actions. Additional features are added like direct assistance from the aircraft manufacturer for in flight aircraft diagnosis and remote maintenance.

The central goals of this project are:

- to define a technically viable concept of an air transportation system where aircraft would be operating with a high degree of automation providing autonomy controlled and monitored by ground operators through a network-centric architecture;
- to define autonomous operation procedures and optimise tasks sharing between the operators, the automated ground control system, the autonomous onboard computing systems and to identify any need for an onboard engineer;
- to determine the minimum requirements and functionalities of the onboard system, to ensure safe operation in the case of communication loss with the ground control system;
- to perform a safety analysis of the concept and to provide guidelines to certification issues;
- to identify the difficulties to overcome to build such an Air Transport System, in both the technical and cultural aspects;
- to find out an adequate level of automation for a future acceptable system;
- to analyse a procedure to migrate from the present situation to this future system.

Driven by the assumption of an aircraft with a sophisticated level of autonomy, the necessary functionalities of the ground and onboard components of a future air transportation system can be isolated and analysed on their conceptual maturity.

This includes normal operations as well as critical flight situations or emergency cases.

Comparing the IFATS approach with the planned evolutionary improvements of the existing air transportation system will determine the main differences, advantages and weaknesses of IFATS vs. the existing system.

The comparison results could be used in one of the two directions:

- the IFATS approach could be adopted as the long-term air transportation concept;
- or IFATS ideas could be used to improve the current air traffic systems in the mid term perspective while using IFATS validated concepts.

2. IFATS CONSORTIUM

IFATS project involves 11 contractors. The team for the project was carefully selected having in mind the skills and experiences required to analyse the essential needs of a future air transport system, to investigate and verify the various requirements on the flight and ground segments and their interrelationship.

The consortium represents the different elements for the development of the IFATS in both the application / implementation aspects and the research / development aspects which are required for a successful RTD project.

In detail the consortium consists of:

- 4 large aviation companies representing the different aspects for ground and flight segments;
- 1 project management oriented SME;
- 4 national research institutes on aeronautics;
- 2 leading high educational institutes on aeronautics.

Partners are coming from France, Germany, Italy, Greece and Israel.

Office National d'Etudes et de Recherches Aérospatiales (ONERA)

A public, scientific and technical establishment with both industrial and commercial responsibilities, Onera reports to the French Ministry of Defense and enjoys financial independence.

The expertise of Onera covers all the scientific disciplines involved in aircraft, spacecraft and missile design. It makes Onera an essential partner in the French and European aeronautics and space community.

The activity covers a wide spectrum of topics from Basic Research to Flight Testing. Through the teamwork of its scientists recognized internationally in their respective fields and its engineers with a systems approach, Onera promotes ongoing dialog between basic and applied research, medium and long range approach, areas of special expertise and an optimized overall approach. Mathematical models, numerical simulation, laboratory and wind tunnel experiments and flight testing combine to give a better understanding of the physical phenomena encountered and enable to validate aircraft, spacecraft and missile performance predictions.

Onera conducts research in the disciplines and techniques involved in design of an aircraft or spacecraft: aerodynamics, flight dynamics, energetics, structural strength, materials, optics and laser, acoustics, radar and electromagnetism, electronics, systems, robotics, information processing. The research is focused on federating themes and programmes, such as fluid mechanics and information processing.

Onera activity in the safety and security field spans from software integrity to flight control robustness in degraded conditions. Moreover, an ongoing co-operation with NASA is focusing on aviation safety incident reports.

Cost reduction in system design becomes an important objective, computer tools have been developed to help system design from requirements to conceptual definition while low cost sensor techniques are investigated.

Concerning Air Traffic Management, a federative project has been carried on resulting in a comprehensive analysis tool for air traffic from the approach flight phase to the departure flight path.

Onera is also a gateway between scientific research and industry, cooperating with CNRS (National Scientific Research Centre) and the most prestigious universities. Since its creation in 1946, it has worked on all the major French and European aeronautical and space programmes, including Mirage, Concorde, Airbus, Ariane, Rafale, etc.

EADS Defence and Security Systems SA, France

EADS Defence and Security Systems SA (EADS DS SA) is a subsidiary of the EADS group, and is part of the Business Unit Defence and Communications Systems (DCS), which has revenues in 2003 around 1.2 Billion euros, with 5800 employees.

The DCS Business Unit is the EADS Systems House and is an integrated part of the EADS Defence and Security Systems Division.

DS, with revenues of about € 5.2 billion in 2003 and roughly 24,000 employees across nine nations, forms the defence pole within EADS. It offers integrated systems solutions to the new challenges confronting armed forces and homeland security units. It is active in the areas of military aircraft, missile systems, Intelligence, Surveillance and Reconnaissance (ISR) systems with manned and unmanned aerial vehicles (UAVs), battlefield management systems, defence electronics, sensors and avionics, and related services.

EADS is a global leader in aerospace, defence and related services. In 2003, the Group generated revenues of over € 30 billion and employed a workforce of more than 109,000.

Israel Aircraft Industries, Israel

Israel Aircraft Industries is globally recognized as a leader in developing military and commercial aerospace technology. This distinction is the result of nearly a half-century of designing, engineering and manufacturing, for customers throughout the world.

From a relatively small operation to become an industry leader, a company must be versatile and highly motivated, innovative and competitive. IAI was built around these qualities, and has improved upon them with its years of acquired experience. Israel Aircraft Industries has operated for decades according to the laws, regulations and internationally accepted norms in the business world. As the Company endeavors to conform to the international atmosphere which dictates a close adherence to ethical standards, the Company has produced a special document The Business Behavior Code, which, together with existing standards and the commitment to providing high quality products and services, will ensure the continued strength and development of Israel Aircraft Industries. The Company's ambition is to continue to initiate and achieve technological breakthroughs that characterize the best in the industry.

Israel Aircraft Industries is Israel's main aerospace corporation. IAI employs approximately 14,500 people. A few of the many projects currently in progress at IAI are:

- design, integration and manufacturing of a family of business jets; including the latest Galaxy (G200), and the current new design of Astra SPX wide body (G150) program;
- conversion of Boeing 747 from passenger to cargo configuration;
- jet engine nacelles;
- military aircraft upgrade programs;
- development and manufacturing of unmanned airborne vehicles (UAV's) for military and civil applications, etc.

IAI Headquarters includes five operating units: Commercial Aircraft Group (CAG); Bedek Aviation Group; Systems Missile and Space Group, Elta Systems Group and Military Aircraft Group (MAG).

The CAG's Engineering Division is a single site aerospace engineering centre. It's expertise encompasses every required aircraft development discipline and task - from concept definition to prototype flight-testing and certification.

Development and production of state-of-the-art executive jets is the CAG's flagship activity. Following the success of the Astra SP and the Astra SPX, the CAG has developed the GALAXY new generation executive jet and currently is developing the new G150 aircraft (Astra SPX wide body).

The Flight Control Systems department was responsible for the design and approval of all the digital FBW systems, for manned and unmanned aerial vehicles, that were developed under the military as well as under the commercial aircraft group.

The incentives of the Engineering Division and the FCS department in this project are to exploit the possibilities of improving the safety of flight, and exploring new automated systems.

Thales Communications SA, France

Thales Communications SA is a subsidiary of the Thales group and is part of its Communications Business Group. The revenue of BGCOM is around 1.5 billion euros, with 9000 employees in 14 countries. It operates through its subsidiaries in Belgium, Canada, France, Germany, Italy, Malaysia, Netherlands, Norway, Spain, Switzerland, and United Kingdom.

Thales Communications SA is a world leader in its domain of activity covering communications networks, satellite communications, mobile radiocommunications, naval & infrastructure communication systems, airborne communication, navigation and identification systems both for civil and military aircrafts, command information systems, radiosurveillance systems and radio spectrum monitoring.

Thales Communications SA is basing its leading position on constant and significant efforts in research and development for all the technologies involved in the ground, naval and airborne communication, identification and navigation fields both for military and civil applications, for which security and safety aspects are key.

Alenia Aeronautica S.p.A, Italy

Alenia Aeronautica S.p.A., a company of Finmeccanica S.p.A which is one of the Italy's major high tech companies, is among Europe's leading manufacturers of aircraft systems.

The company is dedicated to a full range of activities, from design and production to modification and product support for both military and civil aircraft. The majority of these activities entails collaborations with the world's most important aerospace industries.

In the military aircraft field the company designs and manufactures, directly or through international collaborations, combat and transport aircraft such as the Eurofighter/Typhoon, the ultimate European advanced combat aircraft, the AMX tactical aircraft, a joint program with Embraer of Brazil and Aermacchi of Italy, the tri-national Tornado multi-role combat aircraft, the C-27J Spartan tactical transport airlifter jointly developed with Lockheed Martin, the ATR42MP Surveyon in cooperation with EADS, a maritime patrol version of the ATR42 commuter aircraft.

Alenia Aeronautica plays a main role in the commercial aircraft sector.

Through its collaboration with EADS it has jointly developed the turbo-prop aircraft family for regional transport, ATR, which is now the most successful commuter program, with more than 600 units.

The technological capabilities shown by Alenia Aeronautica in the field of aerostructures have been widely credited, since the company has supported the world's major manufacturers in the construction of some of today's best-known commercial aircraft.

The company has long been co-operating with Boeing and participate in the manufacturing of B767, B777, B717, B757 with the supply of structural parts. Alenia Aeronautica also cooperates with Airbus consortium by manufacturing aerostructures for A321. In cooperation with EADS, it supplies structural parts for the A300/310 and the A340-500/600. Through BAE Systems, Alenia supplies machined parts for A319/320/321 and A340.

Alenia Aeronautica is also involved (with a 4% share) in the new A380 programme, the 550-seat civil aircraft which will be the most relevant strategic investment of Airbus in the next twenty years.

The company's research and development activities are focused on developing its different business lines, improving existing products, developing new European civil and military aircraft and increasing competitiveness through the enhancement of industrial processes.

Alenia Aeronautica research and development activities aim at developing its capabilities within the partnerships and collaborations in which it participates and focus on specific aeronautical technologies, material technologies and their production processes, on-board and mission systems and functional integration as well as feasibility and definition studies for new projects.

Employing a staff of more than 7452 people, it reached 2001 revenues of 1,140 million Euro, 80% of which from the export and with a Research & Development expenditure of more than 134 million Euro.

Erdyn consultants, France

Erdyn is a technology and services company. Incorporated in 1984, independent, it cumulates a strong expertise. It specializes in scientific and technical consultancy, aimed at industrial innovation. It is a "société anonyme " with a working capital of 100 000 €.

Erdyn services are organized as two business lines :

- consulting: R&D program audit, organization, management; market surveys, competitive intelligence, industrial property ; partners search, technology transfer.
- R&D: contract research, new products and processes; feasibility studies, computer modelling; expertise and diagnostic.

The expertise erdyn has built up is based on its knowledge and practice of the engineering sciences, including: thermodynamics, mechanics, material sciences, solid state physics, electricity and electronics, applied mathematics, computer sciences, environmental sciences, metrology, optics, chemistry…

This expertise has been applied to a wide variety of sectors such as energy production and distribution, raw materials and metal working, the environment, building and civil engineering, automobile and transportation, telecommunications, aeronautics and space, chemical engineering, sensors, control and command, to name but a few.

With large industry groups as well as with small and medium-size companies or public sector (research agencies, administrations), erdyn builds up long-lasting partnerships, based on its science and technology awareness, industrial experience and methodical exactness. With all clients, erdyn is engaged through confidentiality agreements.

Erdyn owns the OPQCM “technology” label (quality control) ; its clients may benefit from the “Crédit d’Impôt Recherche”.

Deutsches Zentrum für Luft und Raumfahrt e.V, Germany

DLR is the national German research establishment, responsible for research activities in aerospace, energy technology, and transport, as well as the national space agency. DLR operates 30 institutes, test and operational facilities, with the majority located at eight main research centres, with a total number of about 4.500 employees. Research activities are focused to serve the scientific, economical and social purposes. DLR sees its role to close the gap between university and industry. Long term experience exists in international project management and has been proven in projects on the European or international level.

The main relevant experience relates to systems design, performance analysis using ground and airborne simulators, sensor simulation and application, and data-link verification. In particular, DLR brings in its considerable expertise on intelligent systems for autonomous aircraft guidance and control and its air traffic management simulation tools. DLR is strongly committing the improvement of safety of the whole air transport system.

Direction des Services de la Navigation Aérienne (DSNA/DTI/SDER), France

DSNA/SDER ("Sous-Direction des Etudes et de la Recherche appliquée"), the French air navigation study centre, is responsible for promoting and designing advanced concepts required for the development of the future air traffic control system within the European context.

DSNA/SDER undertakes studies, research and experimentation in the following areas :

- air traffic and air space management;
- telecommunications;
- aircraft surveillance;
- airborne aircraft separation systems;
- human computer interaction techniques;
- everything else which contributes to the performance of ATC/ ATM.

All these studies are supported by the use of significant and powerful computer resources spread and interlinked between different sites to perform experiments and simulations needed for concept validation.

Centro Italiano Ricerche Aerospaziali ScpA, Italy

CIRA, the Italian Aerospace Research Centre, is a limited consortium company founded in July 1984. The Italian government has entrusted CIRA to manage the PRORA (Italian Aerospace Research Program).

CIRA institutional aim is :

- to carry out the PRORA by realising Excellence Centres, which shall integrate Research Capabilities with the Large Fluid dynamic Facilities and Technological Laboratories in several main technologies areas;
- to be the National focal point in Aerospace Research and Technology;
- to contribute to the Competitive and Sustainable Growth of the Italian Aerospace Sector;
- to identify Scientific Objectives and develop Basic Research in synergy with the National and International Scientific Community;

- to support the Industry in Applied Research both in the development phase and in the technology validation phase;
- to act as a partner of the Scientific Community and Industry;
- to facilitate technology transfer from the aerospace field to other sectors ;
- to provide technical assistance to public Authorities for qualification and regulations.

As a member of EREA, CIRA works in close co-operation with European Aerospace Research Establishments.

CIRA participates to the project with the Flight System Department (SISV) which has a large experience in the fields of Flight Mechanics, Flight Control and Automation, due to the participation in both international and national research activities and in supporting Italian aviation manufacturers. The activities carried out cover the whole development cycle of advanced flight control technologies starting from the theoretical study until the validation by means of real-time HW in the loop simulations and experimental flight tests by using small scale flying demonstrator.

In particular the department has direct expertise in the following fields :

- Development and validation of flight mechanics models for performance/stability evaluation and assessment;
- Design of flight control laws to improve the bare aircraft/rotorcraft behaviour;
- Vehicle Trajectory optimisation and Control;
- Automatic Take Off and Landing for UAV;
- Control System Rapid Prototyping;
- Real-Time HW in the loop simulations.

University of Patras, Greece

The University of Patras is one of the largest academic institutions in Greece, including schools on the basic sciences, engineering, economics, social sciences and humanities, health sciences, as well as arts and architecture. It currently has 700 faculty members, 1,600 employees, and about 18,000 undergraduates and 2,000 graduate students. The School of Engineering covers all main disciplines, including Mechanical & Aeronautics, Electrical, Civil, Chemical, and Computer Engineering.

The Department of Mechanical and Aeronautical Engineering has facilities housed in two ample buildings and includes modern laboratories covering applied mechanics, design and manufacturing, thermal and fluid sciences, aeronautics and automation. It involves 45 faculty members, 900 undergraduate students, and over 100 Ph.D. students. The department is very active in innovative teaching and research, and participates in numerous national, European, and international educational and research programs.

The Stochastic Mechanical Systems (SMS) Group of the Department specializes in innovative stochastic methods for estimation, identification, prediction, fault diagnosis and controls in various types of mechanical and aeronautical systems. The Group is led by Professor Fassois, and involves post docs, several Ph.D. students, M.Sc. students, and a technical assistant. The Group runs two modern laboratory facilities for teaching and research: a Mechanical Systems facility and a Structural Identification and Control facility.

Technion – Israel Institute of Technology, Israel

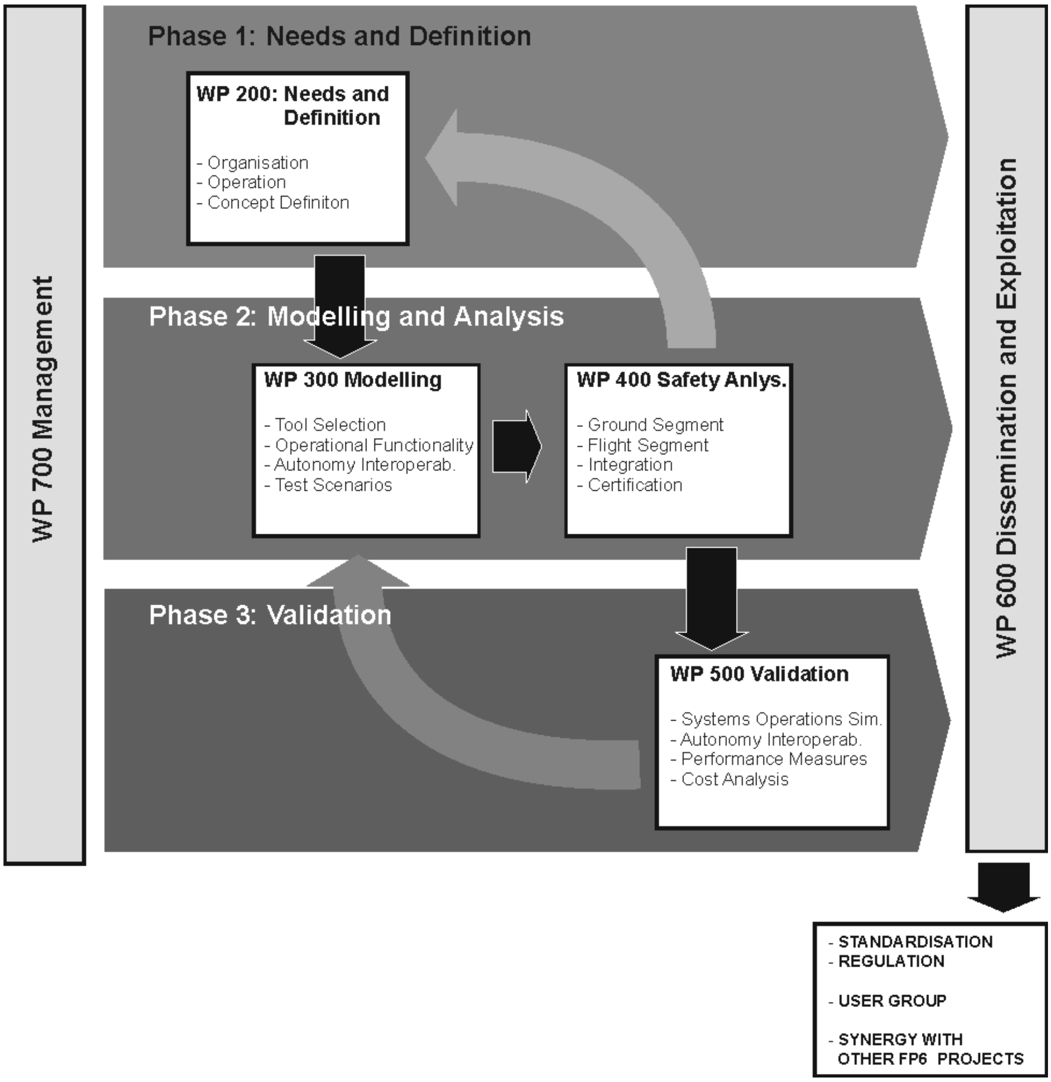
The Technion - Israel Institute of Technology is Israel's oldest university, founded in 1924, and is the only institute of higher learning devoted to the education of engineers, scientists, and physicians. Of the total enrollment of 12,800 students, 9,200 are undergraduates and 3,600 are graduates, studying at one of its 20 Faculties.

The Technion is an independent university directed by a Board of Governors. The executive power is exercised by the President. The supreme academic authority is the Senate, which consists of the President, the Vice Presidents, all full professors, Faculty Deans and elected representatives of the 20 Faculties.

The Faculty of Aerospace Engineering was founded in 1954. It is the only Faculty in Israel to offer academic degrees in Aerospace Engineering. About 400 undergraduates and 120 graduate students are currently studying in the faculty. Since founded, it graduated more than 1600 aeronautical and aerospace engineers. Research activities at the Faculty cover most of the areas of Aerospace sciences.

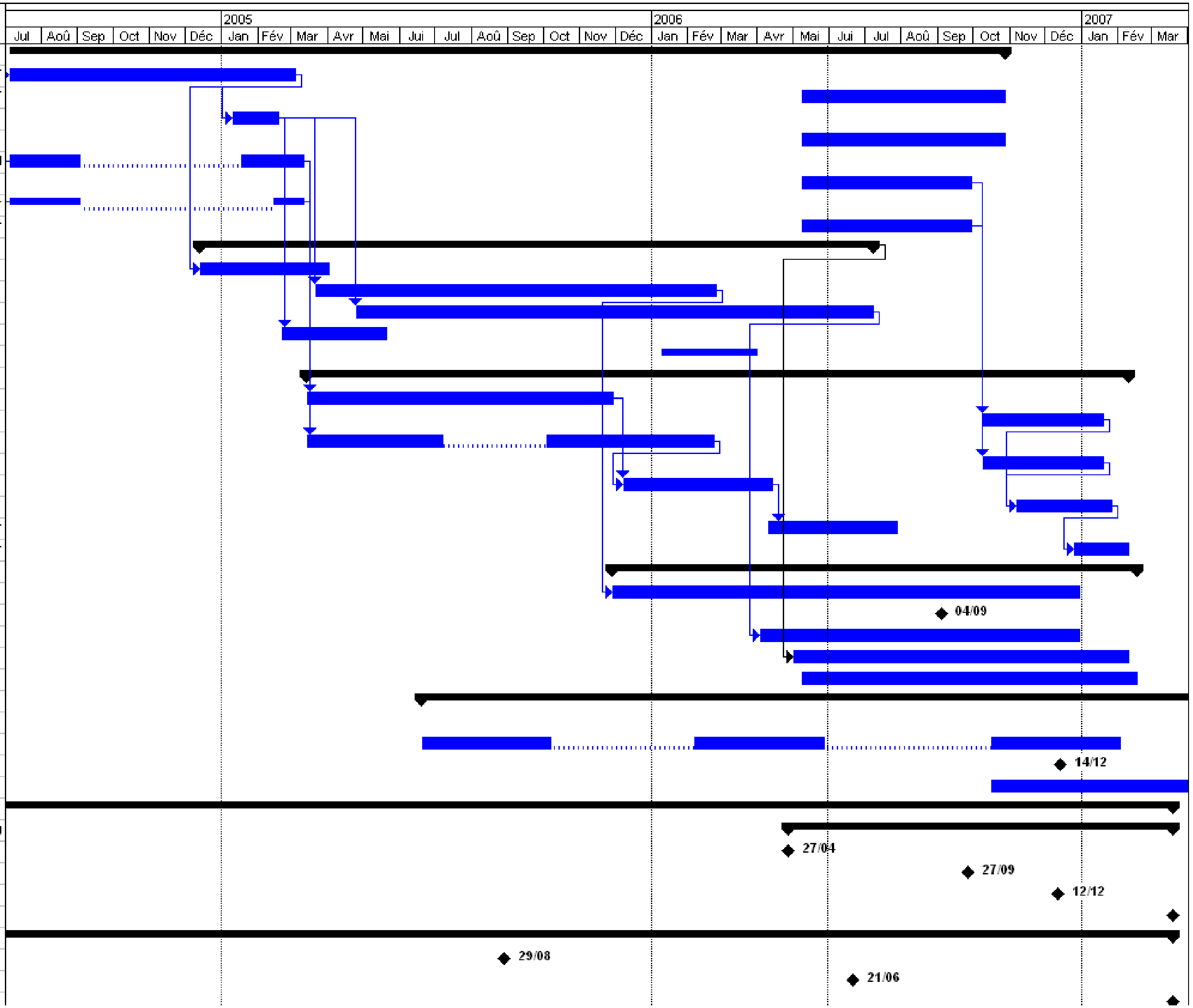
3. ORGANIZATION OF THE WORK INSIDE IFATS PROJECT

The IFATS project has adopted the following logical approach to achieve its objectives. All activities within IFATS have been partitioned into work-packages with information flow and interdependencies as shown in the figure hereunder.

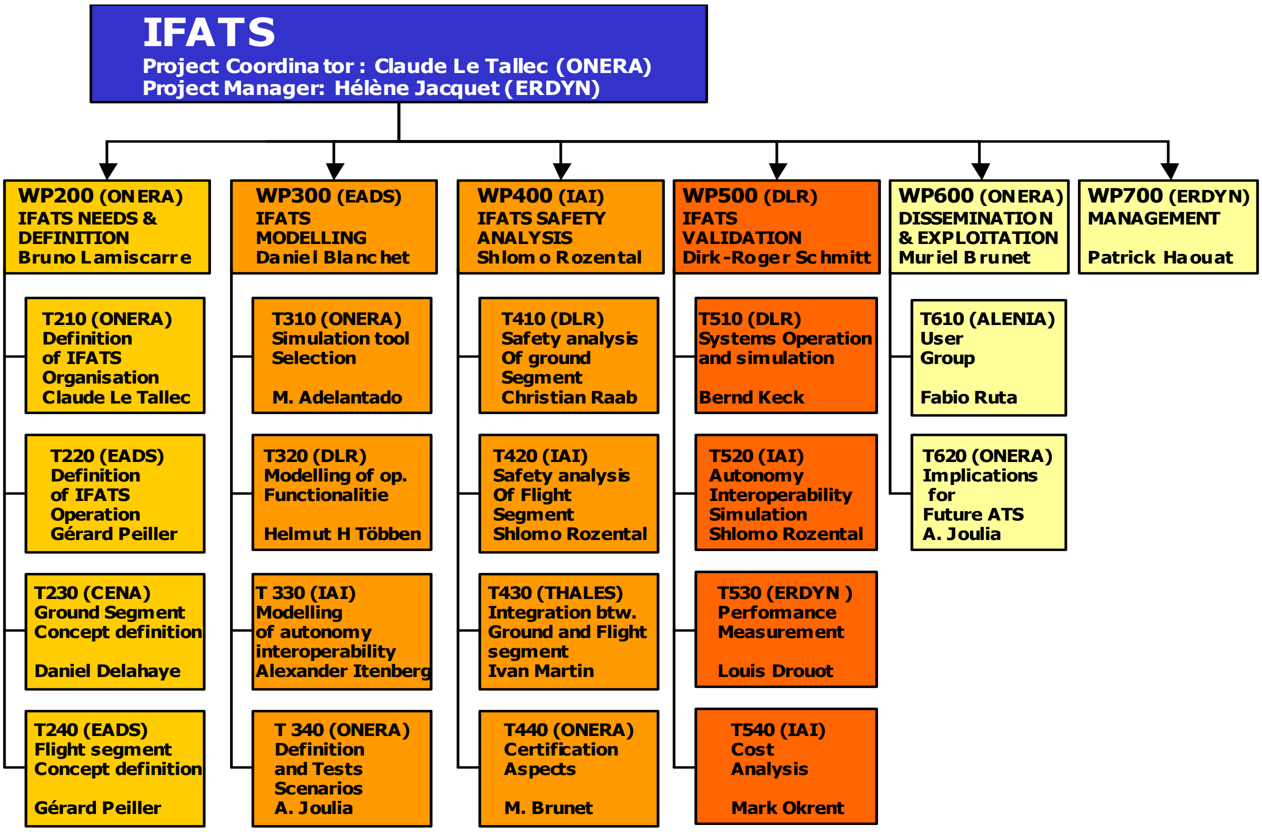


The total duration of the project to carry out these three phases has been 36 months: the Gantt chart of the project is shown next page.

N°	Nom de la tâche
1	**WP 200 IFATS DEFINITION**
2	Task 210.1 Definition and Organisation of the IFAT
3	Task 210.2 Definition and Organisation of the IFAT
4	Task 220.1 Definition of the IFATS Operations - Ite
5	Task 220.2 Definition of the IFATS Operations - Ite
6	Task 230.1 Ground Segment Concept Definition - I
7	
8	Task 240.1 Flight Segment Concept Definition - Iter
9	Task 240.1 Flight Segment Concept Definition - Iter
10	**WP 300 IFATS MODELLING**
11	Task 310 Simulation Tools and Scope
12	Task 320 Modelling of Operational Functionality
13	Task 330 Modelling of Autonomy Interoperability
14	Task 340.1 Definition of Test Scenarios - Iteration
15	Task 340.2 Definition of Test Scenarios - Iteration
16	**WP 400 IFATS SAFETY ANALYSIS**
17	Task 410.1 Safety Analysis of Ground Segment -
18	Task 410.2 Safety Analysis of Ground Segment -
19	Task 420.1 Safety Analysis of Flight Segment - Ite
20	Task 420.2 Safety Analysis of Flight Segment - Ite
21	Task 430.1 Integration Between Ground and Air S
22	Task 430.2 Integration Between Ground and Air S
23	Task 440.1 Certification Aspects of the IFATS Cor
24	Task 440.2 Certification Aspects of the IFATS Cor
25	**WP 500 VALIDATION**
26	Task 510 System Operations Simulation
27	Special meeting for integration
28	Task 520 Autonomy Interoperability Simulation
29	Task 530 Performance Measurements
30	Task 540 Cost Analysis
31	**WP 600 DISSEMINATION AND EXPLOITATION**
32	**Task 610 User Group**
33	User feed-back
34	WORKSHOP
35	Task 620 Implication to Future...
36	**WP 700 MANAGEMENT**
37	**Technical and management review meeting**
38	TRM 8
39	TRM 9/ PMM5
40	TRM 10
41	TRM 11
42	**Formal meetings**
43	Project Mid-Term Review (month 18)
44	Project year 2 review meeting
45	Project Final meeting (33 months)



Responsibilities of each partner inside the project are summarized thanks to the work break down structure presented here under.



Responsibilities of each partner inside the consortium

PART 2 - IFATS FINDINGS AND CONCLUSIONS

4. DEFINITION OF THE IFATS CONCEPT

The basic feature of the IFATS concept is to go as far as possible in the ATS automation. Thus the first topic to be discussed is "what is possible?".

Several answers can be given; they are very dependent on the consulted people. Controllers will have their own view, based on their current work, knowledge and career perspective; the same applies for pilots (Ref. 2).

Dealing with public opinion is far more complicated. This opinion is made from the knowledge it has about the ATS automation, this knowledge is built from the information that can be provided on this type of concept, but this type of concept is not fully defined yet…

Instead of being stuck by this hen and egg problem, the approach that has been taken in the IFATS project is purely technical: thus, the concept that has been defined is a "technically possible" extremely automated system and not necessarily a "likely to happen" system.

In order to build the IFATSystem, several constraints have been taken into account. These constraints can be divided into three main categories: technical, cultural and social.

Considering the IFATS methodology, which is to study a fully automated system in order to derive an acceptable future one, only the technical constraints have been considered. Indeed, cultural constraints (passengers to accept to fly a pilot-free aircraft) and social constraints (pilot and controller jobs not existing any more) bring to much show-stoppers for the IFATS methodology and have no real impact on the high level technical definition of such a system that has been pursued in the project.

The main technical constraints are:

- For the ground segment: to be able to automatically manage the traffic planning, taking into account the airlines wishes as well as the various uncertainties of the flights. The emergency situations have also to be managed, possibly with the man in the loop;
- For the air segment (the aircraft): to be able to fully automate the flight, i.e. the capability of the aircraft to manage all the flight phases and all the pre-planned emergency situations (see this notion later);
- At a more global level, the safety and security of the system has to be ensured whatever the situation could be. This is achieved through secured data links and adequate communication protocols.

Taking into account the identified main constraints, the functional analysis of the IFATSystem has been performed. This analysis started by the definition of the function sharing between the air and ground segments.

To summarise, the ground segment is in charge of the system management that includes the 4D contracts generation (strategic and tactical planning, on ground and airborne). We will explain later what is this major IFATS key notion, the 4D contracts updates, the management or emergency situations for which no recovery strategy has been implemented in the aircraft, the system monitoring, the aircraft maintenance and the interface with the manned piloted traffic (general and military aviation).

The air segment is in charge of respecting the 4D contract given by the ground segment, of the trajectory monitoring and of new 4D contract requests (if needed). Other capabilities have also to be implemented on board, such as health monitoring functions, emergency situations management; update of the ATS database (especially for the current weather as any aircraft is a sensor of the system).

Based on the previous function sharing definition and on the observation of the current ATS functionalities, the IFATS concept has been defined. This definition started with the identification of the IFATS actors (Figure 1).

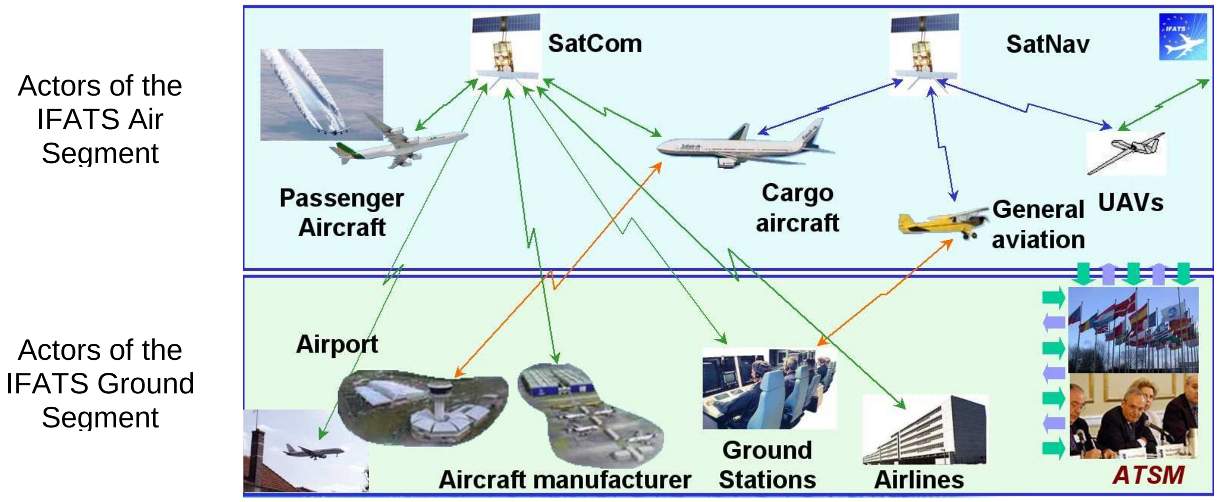


Figure 1 - IFATS actors

Most of these actors already exist today, but would require some adaptations to the IFATSystem.

The specific IFATS actors are:

- The ATSM (Air Transport System Management) which is in charge of the management of the overall system, especially the 4D contracts management (computations for original flight planning and real-time update);
- The ground stations, which are the physical parts of the ground segment in charge of the air traffic monitoring function.

The IFATS concept is based on three “key notions”:

1. The 4D contracts: each aircraft is given a contract before its flight and it has the responsibility to respect it all along the flight. If it is not possible for any reason, it has to ask the ATSM for a new 4D contract or, at least, broadcast this information in the vicinity of its current flight zone; this will be detailed later in this report.

   These contracts are generated by the centralised ATSM to be made of conflict-free flight paths. So, as long as all the aircraft are respecting their contracts, no conflict can occur (Figure 2).

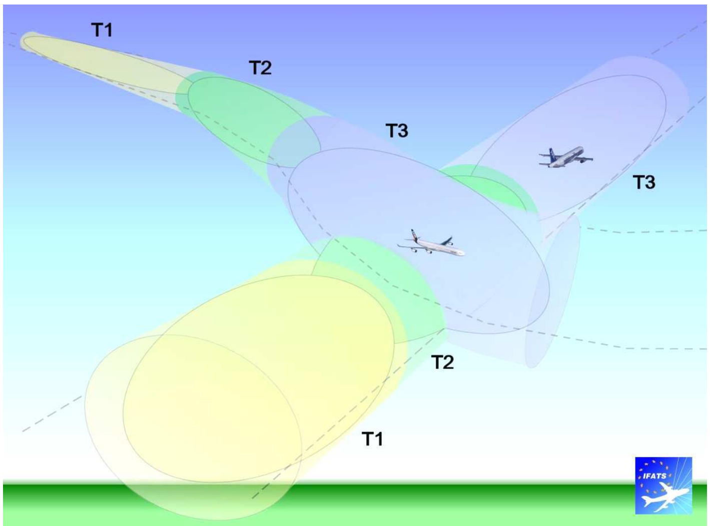


Figure 2 - Contractual 4D trajectories

2. The 4D contracts are given to the aircraft with some margins (e.g. in order to be able to manage small differences between the predicted weather and the real one).

   These margins are called “bubbles” and are of two types: freedom bubble, in which the aircraft can freely fly (small modifications from the original trajectory are allowed) and safety bubble, larger, in order to ensure that no collision is possible between two aircraft flying on the edge of their respective freedom bubbles (Figure 3).

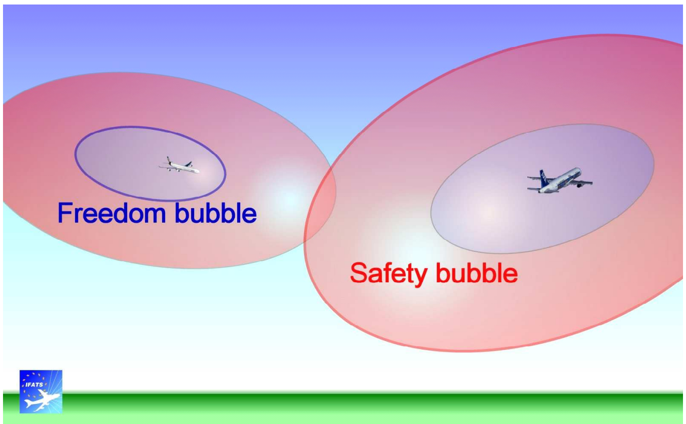


Figure 3 - Freedom in a fully constrained airspace

3. The 4D airspace: the four dimensions of the airspace are considered (x, y, z, t). Conflict-free flight paths are calculated taking into account these four degrees of freedom. The notions of waypoints, ATC sector and airways, which are essential to make a human air traffic control possible, can be abandoned.

5. IFATS CONCEPT OF OPERATION

The story starts with the 4D contracts generation (strategic planning, several months before the flights). These contracts are computed by the ATSM, taking into account the various constraints issued from the other ground actors (Figure 4).

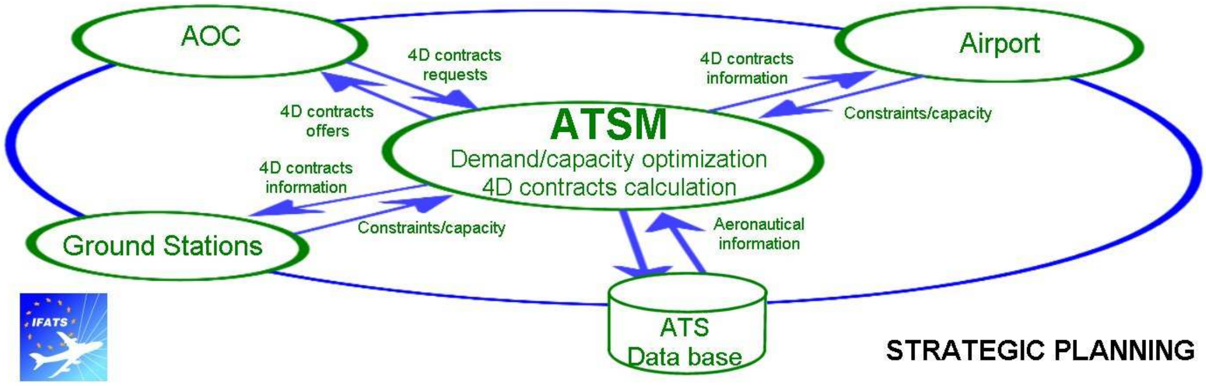


Figure 4 - The ATSM creates and manages the strategic planning

These contracts are updated just before the flight in order to take into account the latest weather report and forecast.

En route, in nominal conditions, the aircraft follow their 4D contracts, and if this is not possible, they ask the ATSM for a new one.

A fundamental enabler of the IFATS system is the data communication network. It is based on a network-centric architecture that is illustrated Figure 5.

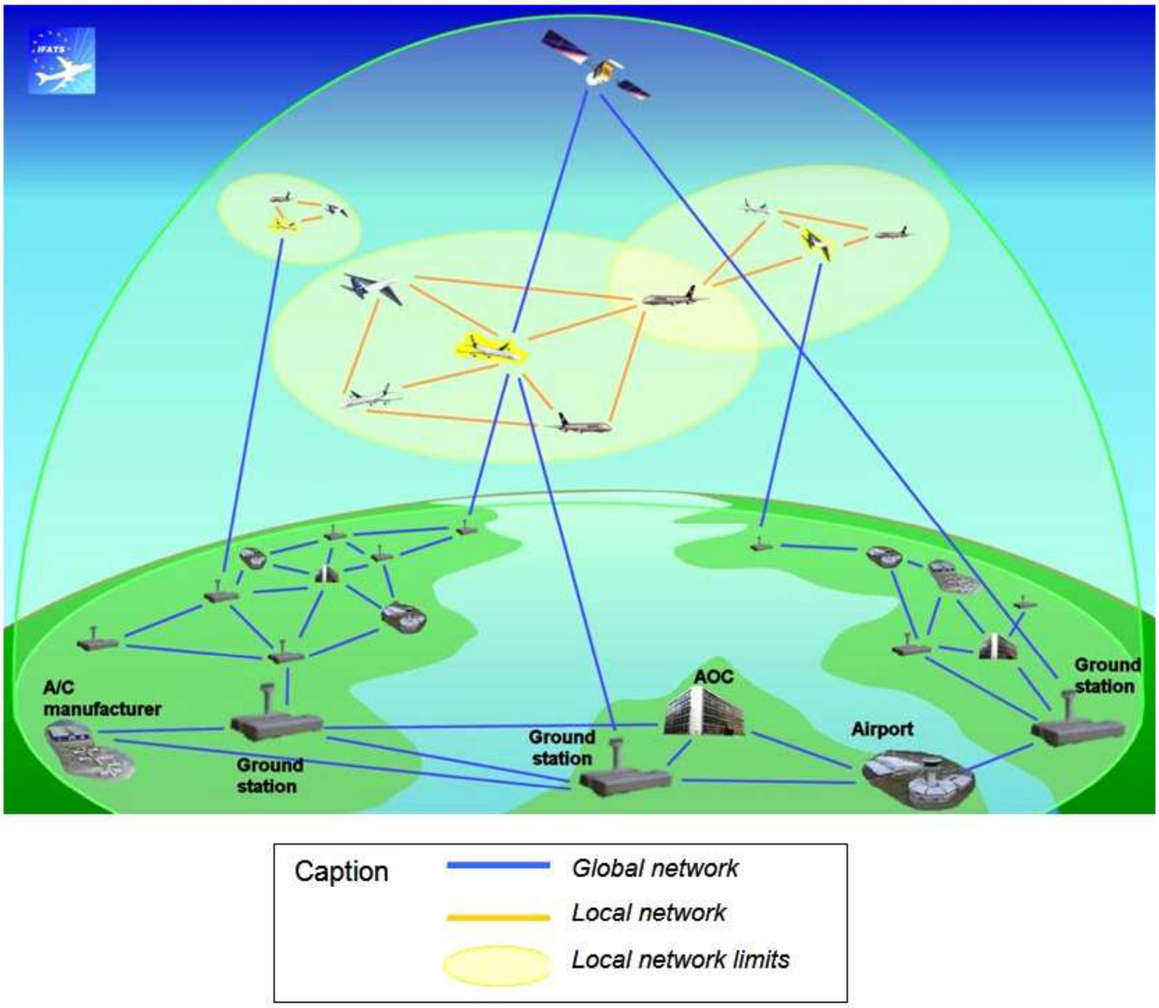


Figure 5 - General view of the overall architecture

To be more precise, this global architecture consists of two types of network:

- The global network figured in blue colour in Figure 5 and Figure 6: this large spatial extension network links all the ground segment sub-systems and all the aircraft. This network is used in nominal conditions for all the communications;
- The local network figured in yellow colour in Figure 5 and Figure 6, links aircraft which are close to each other in a given area. This network is mainly used for emergency situations autonomous management, when there is no time to send a request to the ATSM to get a new contract.

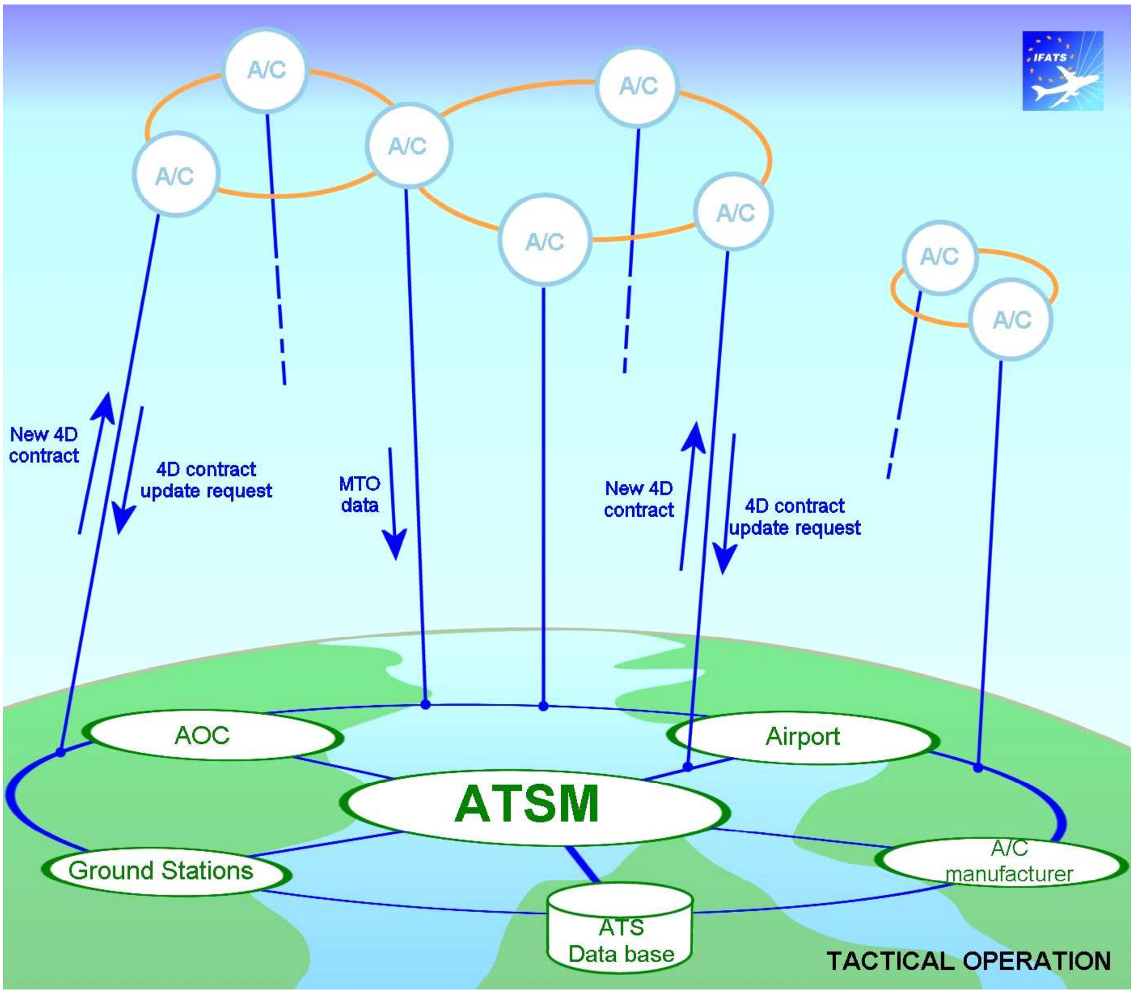


Figure 6 - View of the two types of network

6. IFATS EMERGENCY MANAGEMENT

The emergency/failure management is, of course, included in the IFATS concept definition. A comprehensive analysis of all the possible cases has been performed in the project. Generally speaking, if a failure for which a recovery strategy has been implemented occurs, this pre-planned recovery strategy is directly applied.

If a failure for which no recovery strategy has been implemented occurs, the aircraft status is downloaded to a team of experts sitting at the manufacturer of the concerned aircraft place on the ground. Using high capability computing resources and their knowledge of the aircraft, these experts can define a recovery strategy that is immediately uploaded to the aircraft.

Figure 7 illustrates one of the cases that have been analysed. The small circles represent aircraft, the blue ones are healthy aircraft complying with their contract, and the red one represents an aircraft facing an emergency situation which makes impossible the compliance to its 4D contract. The yellow circle represents the local data communication network whereas the arrows show the overall communication network use.

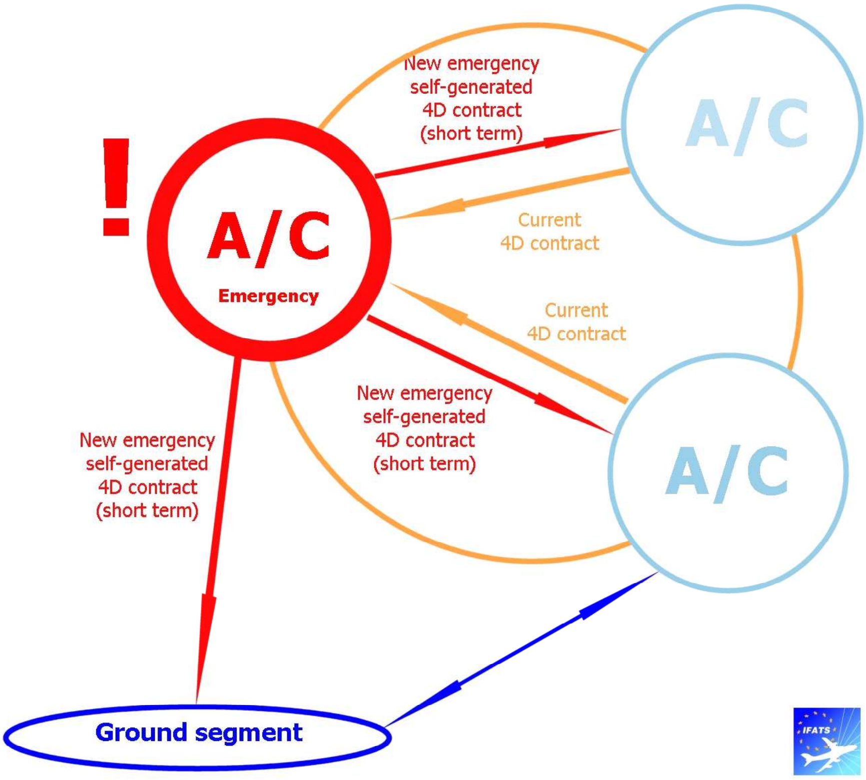


Figure 7 - Emergency situation management

In Figure 7, the aircraft facing the emergency (red circle) self generates a short term 4D contract from its local situational awareness gained thanks to the local network. This change in the local planning is disseminated to all the aircraft flying in the vicinity of the aircraft in difficulties and to the ground segment. When time permits, new 4D contracts are given to all the aircraft that have been affected by the considered emergency.

7. IFATS PERFORMANCE

The performance assessment of the IFATS concept has been performed by many of the project consortium partners. This report summarizes the work that has been performed until the end of the project. Additional information is included in the detailed reports that have been published all along the project.

7.1. Weather forecast accuracy

The IFATS concept and its expected capabilities depend on many factors; the weather forecast accuracy is a major one.

This is due to the fact that the strategic planning is developed from the long term weather forecast whereas the tactical planning has to face the real time weather encountered by the fleet of the airborne aircraft.

To help analyzing the sensitivity of the IFATS concept to this problem, a conceptual flight simulation has been developed, incorporating actual and predicted weather data and possible flight strategies.

This simulation goal is to set a rational basis for deciding on the IFATS concept implementation. The specific goals are:

- assess the accuracy of weather forecast;
- assess the expected flight path/time deviations form a pre-planned trajectory due to differences between the forecast and the actual weather;
- analyze the effect of the 'bubble' size on the number of trajectory re-plans en-route;
- estimate the effect of airspeed corrections on the above, by applying velocity control in order to decrease deviations in time/position.

Some basic assessments have been made to set the parameters of the simulation. As an example, actual weather is not considered to be known instantaneously, but with an approximately one hour data processing delay.

The main objective of the simulation has been to obtain statistics of time differences between the pre-planned and the actual aircraft trajectories. To this end, different routes, departure times, and days of the year have been systematically analyzed over a part of Europe. To reduce complexity, the flights were performed along the grid, at constant altitude and Mach, covering both north/south and east/west headings.

Each line of the grid has been used to specify the 3D flight-paths, for a total of 125 east/west and 221 north/south possible flight paths, see Figure 8.

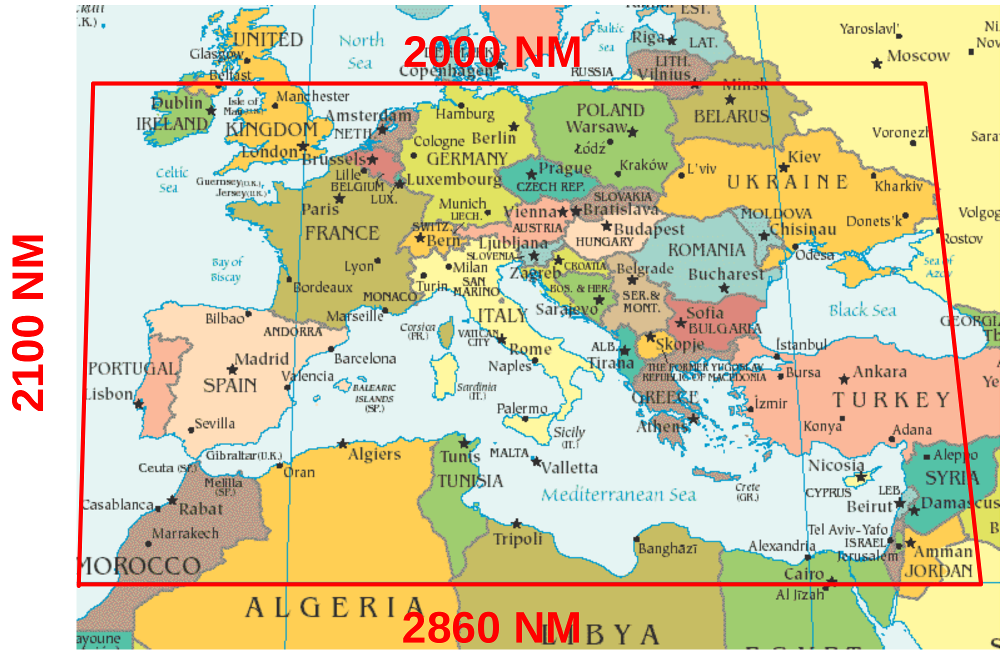


Figure 8 - Zone considered for the meteorological analysis

For each flight, a pre-planned 4D trajectory contract has been issued based on the most recent available weather forecast. In particular, estimated time of arrival to each grid point along the trajectory has been computed. Next, using actual weather, the actual time of arrival to each point along the trajectory has been computed, assuming the aircraft follow exactly the prescribed 3D flight path. The differences in the arrival time have been translated into position errors using ground-speed. Since the aim of the simulation was to gather statistics on time/position errors, it did not address conflicts. Hence all trajectories dealt with were assumed to be conflict free.

Regarding the meteorological data used, they were purchased from Meteo-France:

- Actual and forecast weather: wind and temperature in Europe, year 2004
- Weather data at 00:00, 06:00, 12:00, 18:00
- 6, 12 hours forecast
- Data area 15°W-40°E, 30°N-61°N, resolution of 0.25°

Most of the simulations were carried out with a 'bubble', defining the allowable aircraft position variations around the nominal 4D trajectory. Since the aircraft were restricted to follow the 3D paths exactly, only deviations along the flight path were evaluated. In those simulations, when the trajectory position error exceeded the bubble size (an event referred to as a 'bubble exit' in the sequel), a new 4D contract with updated times along the grid was issued instantaneously. This trajectory, initiated at the current aircraft position and time, was generated along the original 3D flight path using the most recent weather forecast and, as before, was assumed to be conflict free with other traffic.

The simulation includes optional velocity control logic to reduce the aircraft 4D trajectory position errors, or, equivalently, to control the aircraft so as to remain within the prescribed trajectory error bubble. In the currently implemented logic, at each grid point, the velocity control algorithm was designed to minimize the time deviation from the pre-planned trajectory at the next grid point. It was assumed that the airspeed (or Mach) can be changed instantaneously. The airspeed corrections have been saturated by maximum and minimum values (e.g. plus or minus 0.02 Mach) defined by the user.

Only en-route simulations were carried out in this study. In all cases, nominally, the aircraft were assumed to fly at a constant Mach number of 0.8 and flight level 340. It was assumed that this Mach number was the optimal Mach number for cruise. Flights departed along all the grid lines every hour at 1, 2, 3, 4 and 5 pm. At this stage only east/west flights were analyzed. An array of about 125 aircraft, departing at the same time along the respective east/west grid lines will be referred to hereafter as a 'wave'. The simulations covered one month (30 days) of April 2004.

Let's consider the simulation case that is the closer to the expected capabilities of the aircraft and of the weather forecast accuracy in 2040:

- Flight with velocity control of ±0.02M, bubbles of 1.5, 2, 3 and 5NM

Weather forecast was accessed by examining the difference between actual winds at altitude of 34 kft and their 6-hour forecast. It was observed that the mean and standard deviations of the forecast errors are practically the same during the whole period examined both for south-north and west-east winds components.

The mean and standard deviations are 0 and 3 knots, respectively. The maximum forecast errors vary between 8 to 15 knots for most of the period, peaking to over 40 knots (0.065 Mach at this altitude) on April 15. These deviations are beyond the aircraft airspeed change capabilities.

Thus, with such deviations the aircraft would not be able to comply with its 4D trajectory and a new contract would need to be generated by the ground segment.

Figure 9 shows a contour map of these differences over the simulation area for mid-day of April 15, 2004.

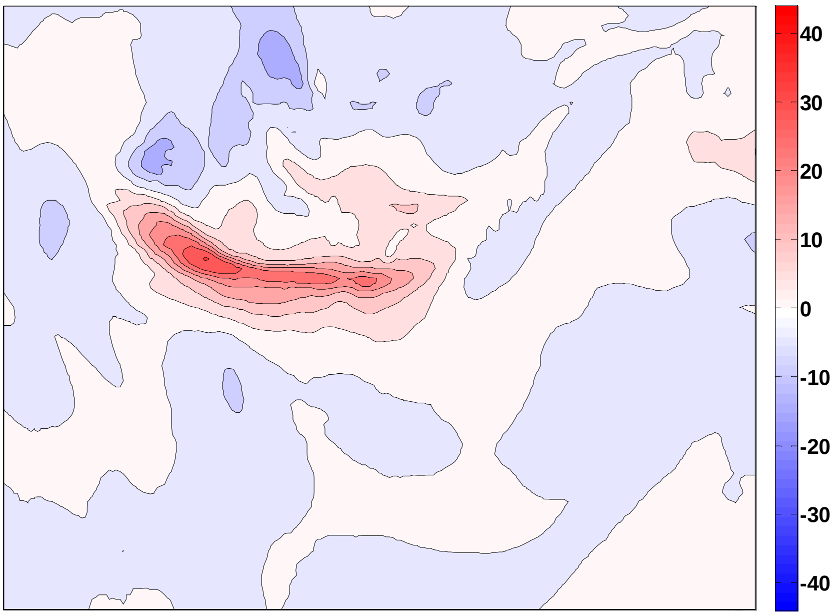


Figure 9 - Weather 6 hour prediction accuracy, April, 2004, 18:00 winds West-East

The inaccuracies in the weather forecast lead to time/position deviations from the pre-planned trajectory. Both maximal and standard deviations from the pre-planned trajectories increase with the flight time and weather forecast time interval from the most recent weather update to departure.

In order to estimate the trajectory re-planning rate, the notion of bubble-exits per hour per aircraft in the air was introduced. This quantity can be interpreted as the probability density function of a currently flying aircraft to exit a bubble, i.e. having to negotiate a new 4D contract.

For 6000 aircraft simultaneously in the air, with velocity control of ±0.02M and the smallest 1.5NM analyzed bubble size, the maximum expected re-plan rate would be 2.5 re-plans a minute. Maintaining the velocity variations at ±0.02M and increasing the bubble size to 5NM reduces the number of re-plans to 0.002 per aircraft per hour maximum. That would require 1 re-plan every 5 minutes for the entire 6000 aircraft fleet.

The major conclusion of this study concerns the weather forecast accuracy. It is evident that time/position deviations and therefore the amount of required trajectory re-plans increases with time. For long flights the accuracy of the forecast is insufficient and hence trajectory re-plans are unavoidable.

However, it has been observed that, taking into account a velocity control of ±0.02M for all individual aircraft and reasonable expected weather accuracy for the time frame of a potential implementation of an IFATS concept, the anticipated number of contract re-negotiations appears to be within the limits of the computer capabilities at this same 2040 horizon.

7.2. Communication network structure and management

The IFATS global network is based on a centralized TDMA (Time Division Multiple Access) with ground stations (see Figure 6). At a any time, any aircraft is communicating with several ground stations as shown on Figure 10.

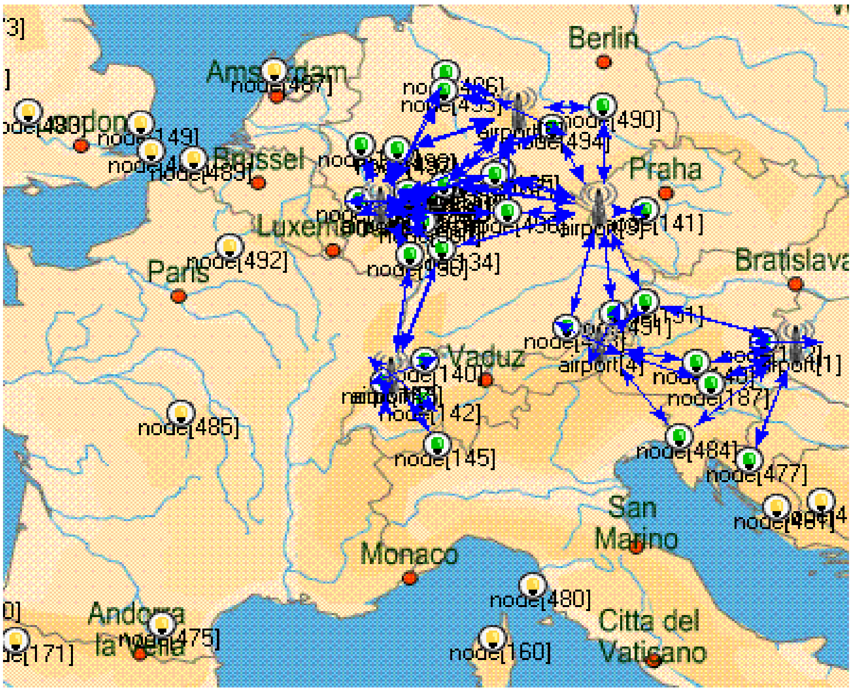


Figure 10 - Global communication network

A Quality of Service (QoS) policy depending on the priority of the message to be transmitted has been developed. The services that could be needed for an IFATS aircraft are numerous, the most important ones are:

- 4D contract re-planning;
- Weather transmission;
- Immediate Support request;
- Maintenance purpose;
- Communication with AOC.

Since bandwidth is scarce and will stay scarce in the future, the innovative proposed solution for the IFATSystem is to share the bandwidth between different services and to set priorities between them.

Obviously, when an IFATS aircraft needs a 4D contract update or an immediate support, the communication priority level must be high whereas weather transmission and maintenance support may have a lower one.

In order to design the data link, the simulation tool enables to measure the required bandwidth and latency. The Quality of service concept, which is quite innovative in such a system, allows to share the bandwidth and to give access to the radio layer to the one that really needs it.

Regarding security, each message is secured by a cyclic redundancy check (CRC) and an encryption key in order to avoid corruption of information and intrusion.

Whatever the number of needed ground stations can be, the required bandwidth has been estimated by the simulation to 2MBit/s per ground stations which can fit into 2 MHz for one Ground stations.

Considering that 21 frequencies are required for the whole world, it means that IFATS need about 42 MHz for its ground to air communications.

The IFATS local network (see Figure 6) is based on a distributed STDMA (Self-organizing Time Division Multiple Access) scheme (not centralized) locally linking aircraft in the vicinity of the same location (Figure 11 and Figure 12).

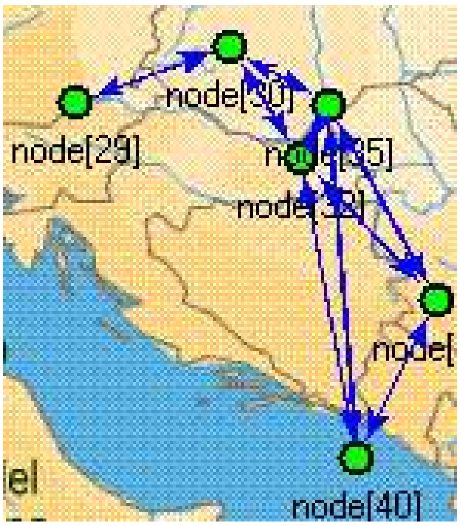


Figure 11 - Local network without critical situation

Figure 12 - Local network with critical situation (aircraft with a red circle)

For this network, a distance based QoS policy has been defined: if two aircraft are close from each other, messages are sent at a higher rate (local network, Figure 12). Otherwise, aircraft are sharing the remaining bandwidth.

The proposed data link layer is self-Organizing TDMA (Time division Multiple Access). Each plane will send its position, intention and will reserve slots for the next frames. Some optional field will be sent:

1) Weather information
2) Acknowledgement

If the conditions require sending weather or turbulence information, an ADS-B message will be completed by weather information.

With the current traffic, one 50 kHz channel is enough, according to the simulations. In order to accept more aircraft, two channels (100 kHz) will be needed: one for en-route and one for TMA. This bandwidth can fit into one VHF channel.

On these two channels, there will be several qualities of service:

1) Conventional situation and weather awareness (at a tentative rate of 1 message per 5 seconds);
2) Situation and weather awareness with good quality of service (at a tentative rate of 10 per second);
3) Relay (on available slots).

This quality of service enables to share the bandwidth to the situation that needs it.

7.3. Aircraft health monitoring

Since no pilot is present in an IFATS autonomous aircraft, its health monitoring should be based exclusively on purposely designed devices (hardware) and methodologies (software). Both solutions should contribute to the increase of the autonomous decision-making capabilities of the aircraft.

One should always expect that the introduction of extra autonomy in the pilot–less IFATS aircraft would lead to an even more complex system, which should be monitored even more accurately than by the past. Introducing even more sensors (hardware) for health monitoring purposes seems unavoidable. However, their number must be kept as low as possible, in order to maintain (if not improve) the failure probability rates, following the complexity increase due to the new sensors.

The approach considered in the IFATS project is faithful to the above mentioned principle. The health monitoring scheme of the IFATS aircraft has been designed to rely on available data from existing devices, which are processed via novel advanced algorithms and methodologies to deliver reliable health information about the monitored aircraft subsystems. Hence, the scheme may be used either as a stand alone application or as a complementary device which cross-checks some existing health monitoring information, thus augmenting the analytical redundancy present onboard.

The scheme is based on supervising the interactions between subsystems of the aircraft. These interactions are always valid for an aircraft operating in healthy (that is fault-free) state. When one or more faults affect the aircraft, these interactions change significantly. Hence, a health monitoring scheme is designed to check the behaviour of the previously mentioned interactions and deliver Fault Detection and Isolation (FDI) results. In practice, the scheme is designed as follows:

A. According to the monitored component, the interaction between two groups of available recorded signals is considered. The first group contains the “input” signals and the second the “output” ones. Their dependency (or interaction) may be modeled via advanced mathematical pooled nonlinear representations, which are generally well-suited for describing the considered dynamics under a multitude of aircraft operating conditions (turbulence, cross-winds and so on) and flight envelope points. Hence, these representations are superior to physical-principle based ones (when these are available), which may often be only locally valid. The modeled interactions correspond to an aircraft operating in healthy state under varying external conditions and flight envelope positions.

B. When a typical "healthy-state" nonlinear representation is identified, it is used onboard an aircraft in unknown health state, to evaluate the interaction of the previously-defined groups of signals at each time instant. If the current interaction is statistically found to differ with respect to the typical "healthy-state" one, then fault occurrence is deduced. Furthermore, using advanced hypothesis tests, the scheme is also capable of isolating the occurred fault(s) as potentially belonging to some predefined fault classes.

Two main aircraft systems are monitored, namely the control surfaces (elevator and ailerons) and the engines.

The control surfaces health monitoring is based on the Multiple Input Single Output (MISO) relationship (interaction) of four signals:

- Three taken as inputs (angle-of-attack, lateral and vertical accelerations) ;
- one as output (pitch rate).

The interaction is modelled for a healthy aircraft via a Constant Coefficient Pooled- Nonlinear AutoRegressive with eXogenous excitation (CCP-NARX) representation. The changes on this interaction for an aircraft operating in unknown health state are checked and evaluated through purposely built statistical hypothesis tests (see *UPatras D.330-2 Design and Demonstration of Fault Detection and Identification Autonomous Decision Making Algorithms* report) to deliver FDI results.

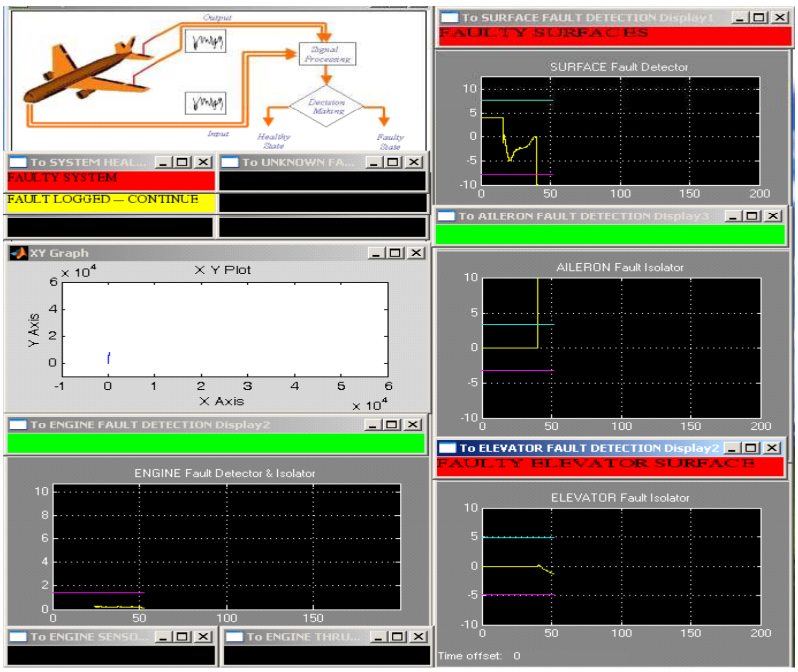


Figure 13 - Simulation Interface for onboard FDI results: The aircraft experiences a faulty elevator, detected in the upper RHS monitor and isolated in the lower RHS one

The health monitor interface (built in SIMULINK™ v. 7.1) as tested in the simulation campaign in December 2006 in Braunschweig, Germany is presented in Figure 13. The aircraft trajectory is presented on the XY-plot monitor (left column, in the middle), the potential control surfaces faults are detected in the upper RHS monitor and isolated in the remaining two RHS ones (faulty aileron and faulty elevator from top to bottom, respectively). Engine faults are detected and isolated in the lower LHS monitor.

Fault detection and isolation is accompanied by a color change (from green to red) of the corresponding monitor tag, as shown in Figure 13, for the detection and isolation of a faulty elevator.

The engine health monitoring is based on the Single Input Single Output (SISO) relationship (interaction) between the throttle and the thrust signals (see *D 520-3 Demonstration of IFATS Aircraft System Fault Detection and Identification Software* report).

The interaction is modelled for a healthy aircraft via a Constant Coefficient Pooled- Nonlinear AutoRegressive with eXogenous excitation (CCP-NARX) representation.

The changes on this interaction for an aircraft operating in unknown health state are checked and evaluated through purposely built statistical hypothesis tests (see *UPatras D.330-2 Design and Demonstration of Fault Detection and Identification Autonomous Decision Making Algorithms* report) to deliver FDI results.

Note that in this document a simpler version of the engine health monitoring scheme (based on modelling of the single thrust signal via CCP-NAR representations) had been proposed. However, the version tested in the simulation campaign used the better performing solution based on the CCP-NARX representation. A typical example of its operation may be seen in Figure 14.

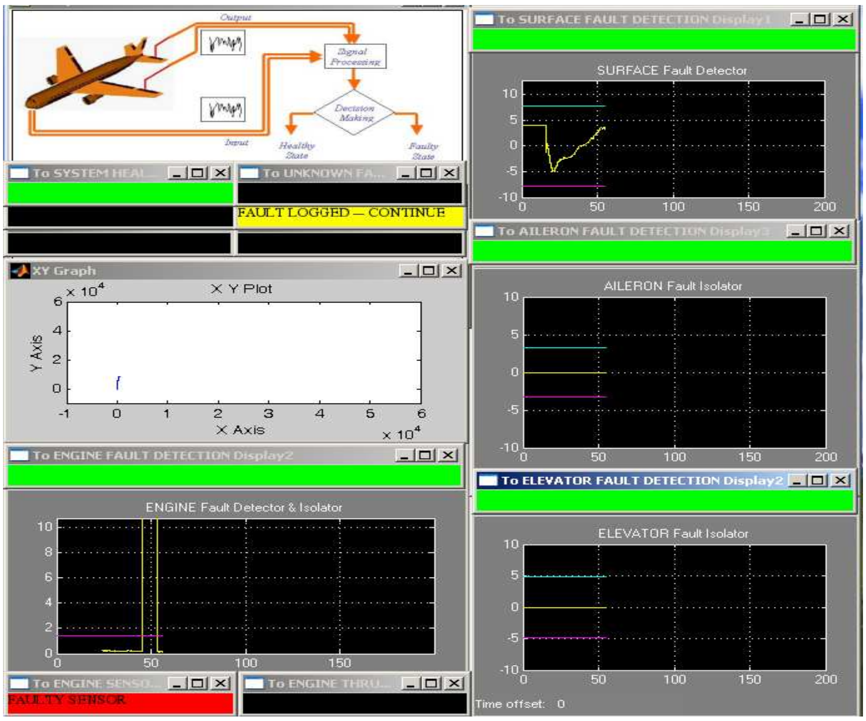


Figure 14 - Simulation Interface for onboard FDI results: The aircraft experiences a faulty engine sensor, detected and isolated in the lower LHS monitor

According to the validation tests (see *UPatras D.330-2 Design and Demonstration of Fault Detection and Identification Autonomous Decision Making Algorithms* report), the fault detection and isolation rates of the FDI scheme were very good in the majority of cases. Detection rates were always higher than 93%, while isolation rates exceeded 95% in most cases. Note that, during the validation process several hundreds of test flights (conducted under varying turbulence conditions with light or intense maneuvering) were used to obtain the aforementioned rates.

The simulation campaign, held in December 2006 in Braunschweig, Germany, highlighted the effectiveness of the FDI scheme, since this was additionally tested with an aircraft affected by sequential faults (initial elevator followed some seconds later by an unknown sensor fault, see *D 520-3 Demonstration of IFATS Aircraft System Fault Detection and Identification Software* report) with equally good results.

A special comment has to be made on the sensor technology needed for the successful operation of the health monitoring scheme. In all cases considered, the scheme's design allows for sensors already present in conventional aircrafts, to be used with good results. This also points out, that the use of improved performance sensors could further enhance the detection and isolation capabilities of the FDI scheme. Since no further sensors are needed for the scheme's operation, it is expected that the system complexity would be kept at the same level as before the scheme's integration to the aircraft. Hence, the failure probability rates should not deteriorate.

It is also expected that the extra computational burden, resulting from the signal processing and the statistical hypothesis tests which is carried out onboard the monitored aircraft, will not be a major drawback for two reasons:

The CCP-NARX representations utilized are quite compact and they may operate in almost real time, if a powerful PC and a dedicated modelling environment (instead of a general purpose tool like SIMULINK™) are used.

The hypothesis tests, which statistically evaluate the CCP-NARX-provided information to deliver health monitoring results, are instantaneous.

Finally, the exact numbers of fault classes which can be detected and potentially isolated have yet to be defined. The fault classes considered in this project (control surface and engine faults) are quite significant, but more research is needed in order to make an accurate estimation of the faults which can be reliably diagnosed out of each I/O relationship. It may however be asserted, that practically most of the *high level checks* (control surface basic operations, engine response to throttle, landing gear operation and so on) may be reliably undertaken via the use of many similar FDI schemes, operating in parallel and monitoring many I/O relationships through existing recorded signals.

7.4. Autonomous separation provision and collision avoidance

The IFATS concept is based on the fact that in all the airspace covered by the system, all IFATS aircraft are cooperative: they broadcast their position and speed via data-link. There are not any more conflicts as the Ground Segment generates conflict free contracts. The non-cooperative aircraft have to fly in specific areas, known by the system.

Since aircraft are fully automated, they have to be as autonomous as technically possible during the whole flight. In case of failure of the Ground Segment or complete data-link loss (emergency condition), IFATS aircraft must be able to generate autonomously temporary conflict free trajectories. Moreover, they must be able to detect non-cooperative aircraft which can be lost out of their reserved areas.

Hence, in for the IFATS flight segment, two functionalities – both *Autonomous* and *Airborne* – need to be considered:

- *Separation Assurance* – This functionality is activated when air-to-ground data-link is lost but air-to-air data-link is working. Thanks to the air-to-air data-link each aircraft can detect and resolve conflicts (by generating new short-term 4D contracts) autonomously. Moreover, air-to-air data-link allows conflicts to be detected and resolved at relatively long ranges (100-140 n mi) so to guarantee the Separation Assurance. Manoeuvres are cooperative and the short-term 4D-contract generation algorithm of each aircraft has to compute a new conflict-free 4D contract which it has to follow.

- *Collision Avoidance* – This functionality is activated when both air-to-air and air-to-ground data-link is lost (total data-link loss). In this case the last resource to detect conflicts is represented by onboard sensors, which have a restricted field of view (at present the range of onboard radar is 3-6 n mi). For this functionality, avoidance manoeuvres have to be considered non-cooperative. Instead of short-term 4D contract generation, one has to talk about "Collision Avoidance" manoeuvres: they are adjusted time by time (with a proper update rate) in order to take into account all unexpected trajectory changes of other aircraft.

The onboard Autonomous Separation Assurance and Collision Avoidance System (ASACAS) provides backup to a similar function existing in ATSM. ATSM provides separation at a relatively long range, whereas airborne ASACAS is engaged autonomously, at a mid/long range when separation has failed and caused a collision situation.

The ASACAS can compute autonomously, through the detection of potential collision situations, a short term 4D trajectory that performs the right separation and/or collision free flight path. ASACAS is completely different from current ASAS and TCAS equipments, since ASACAS generates full 4D trajectories, can perform both cooperative and non-cooperative collision avoidance manoeuvres (whereas TCAS works only in cooperative way) and performs optimal avoidance manoeuvres, i.e. the deviation from the nominal trajectory is minimized.

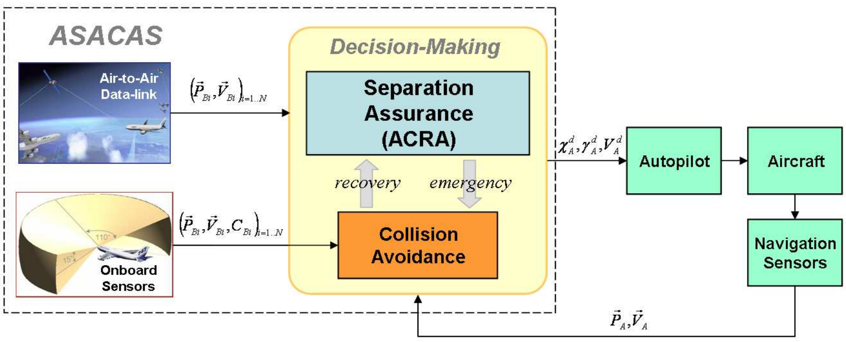


Figure 15 - Functional architecture of ASACAS

The core of the functional architecture of ASACAS (cf. Figure 15) is represented by a decision-making algorithm which receives speed and position vectors of the own aircraft together with speed, position vectors and intents of surrounding aircraft. On the basis of this information, the decision-making algorithm computes the right reference signals for the autopilot, in terms of speed module, track and slope demands.

As for the Collision Avoidance module, the design of the ASACAS has been performed by considering as a starting point a geometric approach used in planar mobile robotics; then a novel algorithm for the 3D case has been derived, where the deviation from the nominal trajectory is minimized (optimal conflict free flight path generation).

As to the Separation Assurance module, an Automated Conflict Resolution Algorithm (ACRA) can provide autonomous aircraft separation assurance: after a conflict arising with one or more aircraft has been detected, ACRA can produce a safe conflict resolution trajectory to maintain separation with other traffic. ACRA has been conceived as an autonomous system, to be installed onboard aircraft and generate commands directly to the autopilot. ACRA is not rule-based but uses an efficient computational approach, thus resulting suitable for real-time applications. An important characteristic built into the ACRA strategy for generating the conflict resolution manoeuvre is the principle of minimizing deviation from the original trajectory. The decision-making logic implemented into ACRA foresees two control strategies properly combined: Speed Control Strategy and 3D-Directional Control Strategy.

While the Collision Avoidance module has been developed and tested at a detailed level, for the Separation Assurance module it has been carried out a conceptual design with a preliminary validation via simulation.

In order to prove the effectiveness of the proposed algorithms, families of conflict resolution solutions were constructed by ACRA, via Monte Carlo simulations, according to a realistic conflict scenario. General properties of efficient conflict resolution manoeuvres have been determined, based on the observation about the structure of this solution family. Simulation results showed that all conflicts can be solved. Numerical simulations by using a more challenging scenario have also been carried out. In particular, realistic aircraft models (with proper dynamic limitations) have been taken into account, in order to remove the simplified hypothesis of instantaneous speed vector change.

Figure 16 shows an example of the self-organizing capacity of 16 conflicting aircraft equipped with ASACAS.

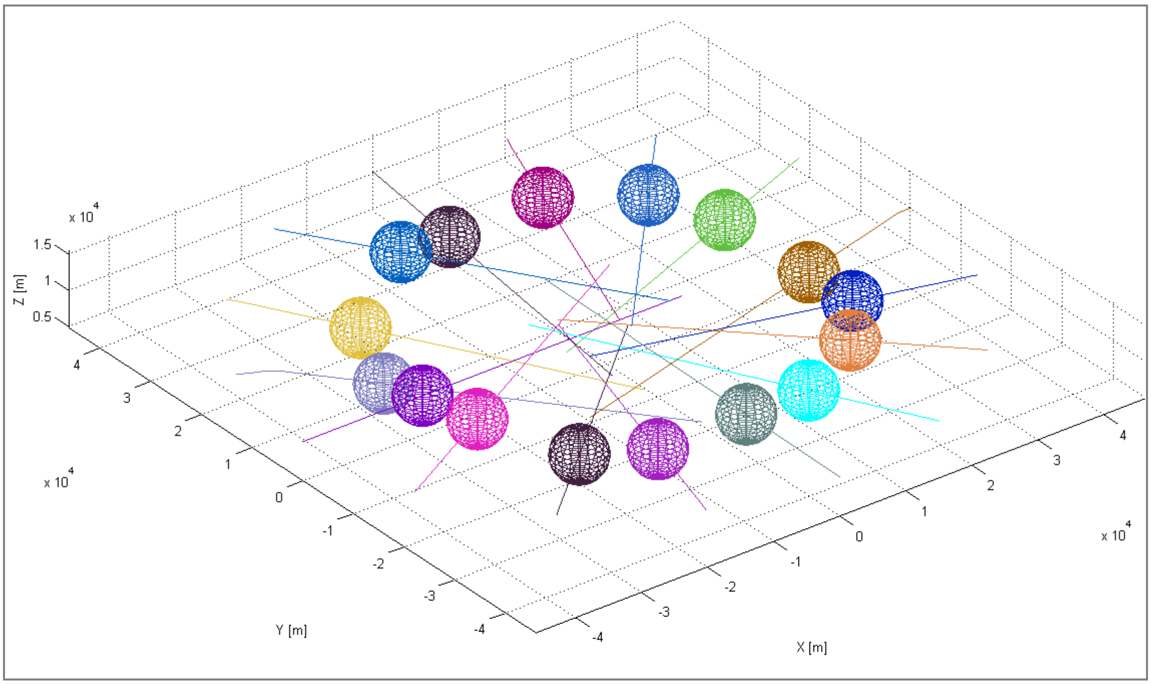


Figure 16 - Conflict resolution 4D trajectories of 16 conflicting A/Cs equipped with ASACAS

As case study, consider the following realistic scenario around Frankfurt airport analyzed during Simulation Campaign at the Braunschweig DLR site in Germany, as illustrated on Figure 17.

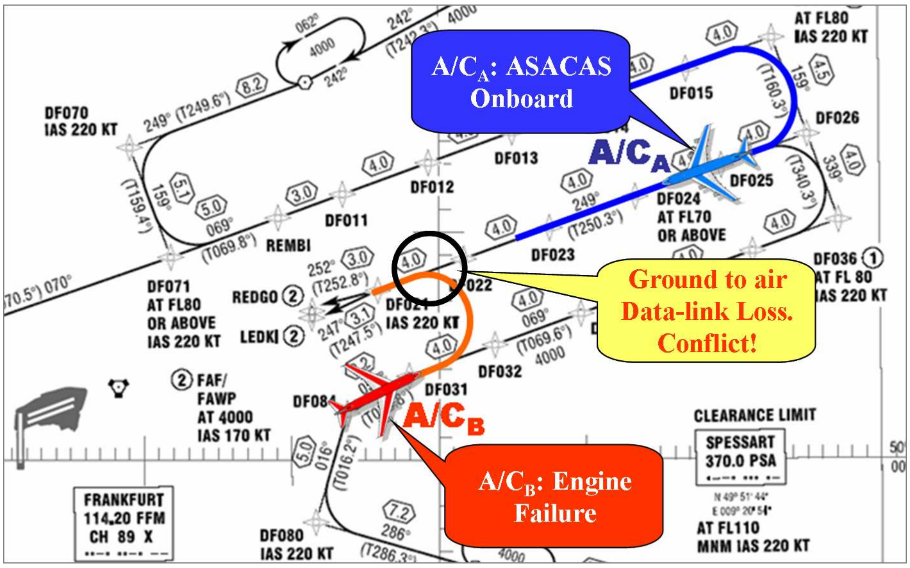


Figure 17 - Case study conflict scenario around Frankfurt airport

Two aircraft are approaching the runway: the red A/C has an engine failure and must land with priority. Ground Segment assigns to the red A/C a new 4D contract for emergency landing and to the blue A/C a new 4D contract to avoid a conflict which could arise with red A/C.

At the same time, blue A/C experiences an air-to-ground data link loss. Hence, blue A/C is not able to receive its new 4D contract: it has to generate autonomously its own temporary conflict free contract from its knowledge of the local situation.

Blue A/C, thanks to this local situational awareness and thanks to the ASACAS decision-making algorithm, can generate its temporary contract compatible with the current red A/C behaviour (speed, track and slope are changed simultaneously) maintaining separation with or avoiding the red A/C, leaving it to pass for the emergency landing (Figure 18).

The performed manoeuvre is “optimal” in the sense that deviation from the nominal trajectory is proved to be minimized, thus avoiding that blue aircraft becomes an intruder for other aircraft.

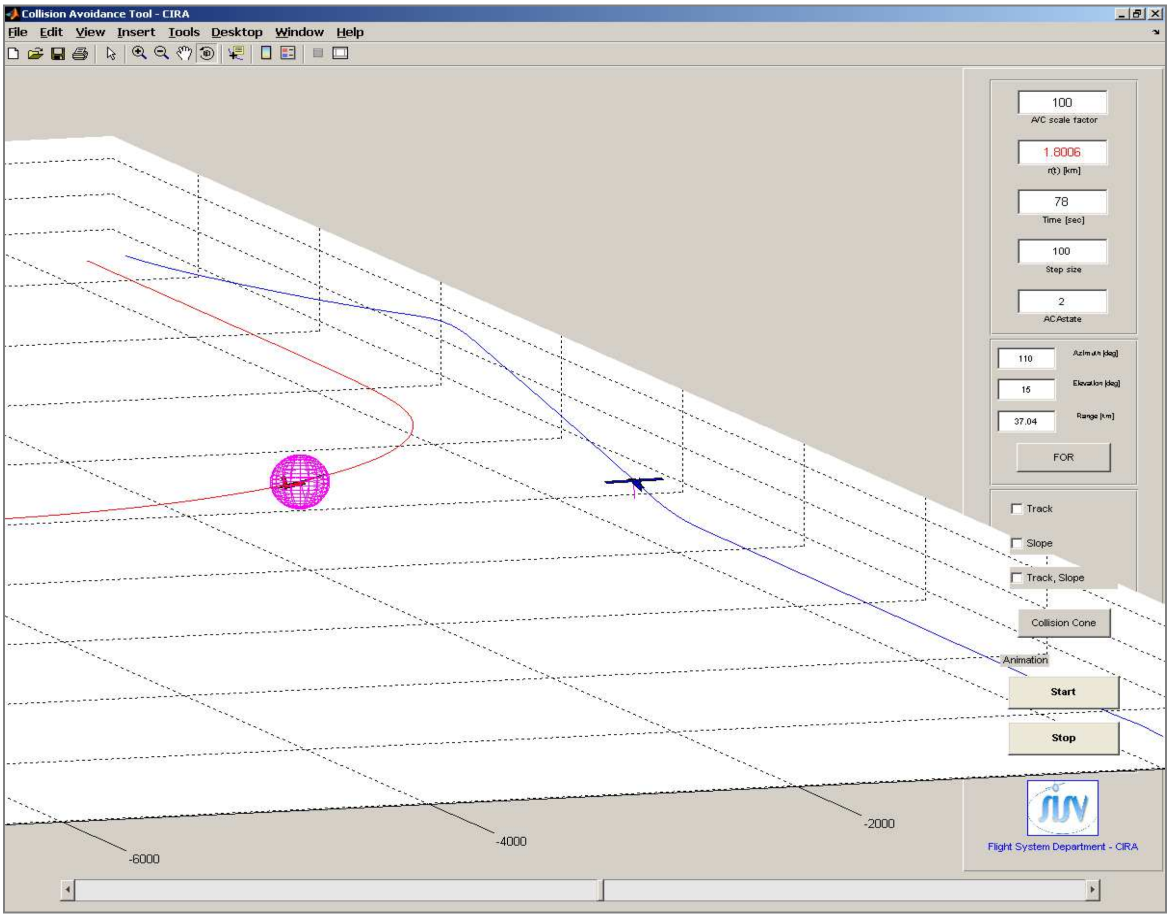


Figure 18 - Temporary autonomous 4D contract generation: a 3D collision avoidance manoeuvre

7.5. Safety analysis

The new concept of IFATS dictates naturally new air and ground architectures (no pilot onboard, no ATC), innovative technologies (communication, sensors, computation, infra-structure etc.) and new concept of operation. These leads of course to new requirements in safety: more redundancies, higher reliabilities, lower probabilities for failures and finally, new airworthiness and operation rules adjusted to the new concept.

The safety analysis in this project was conducted in order to identify the most critical hazards in the IFATS ground and air system, to propose mitigation factors in order to reduce worst severities (to values lower than I and II) and in overall to find the solution and the means that will enable us to increase safety by at least one magnitude of order compared to present requirements.

General description of the IFATS ground and air segments are presented in Figure 19 and Figure 20.

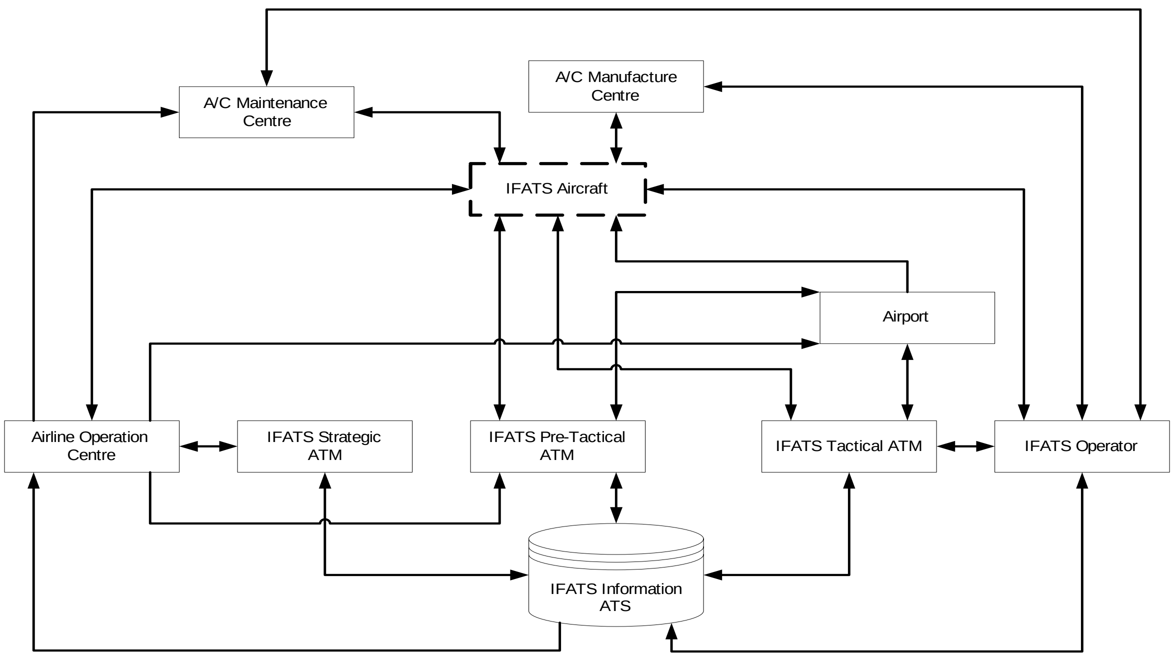


Figure 19 - IFATS Ground Segment

The major conclusions of the safety analysis showed clearly and obviously that loss of data or data corruption without situation awareness is one of the major drivers for the occurrence of hazard state with a severity class I and II impact. However, many hazardous concerning the loss of element functionality can be mitigated by back-up systems.

The key elements identified for the ground system were the tactical ATM and the information ATS database. Major drivers for ground segment safety were the data link safety; distributed computation; system redundancy and data base safety. Specific findings related to the ground segment were:

– Information should flow freely and be protected from corruption or outside access;
– Measures have to be established to prevent a corruption of data that is transferred;
– Encryption and check-sum technology (already available) can be used.

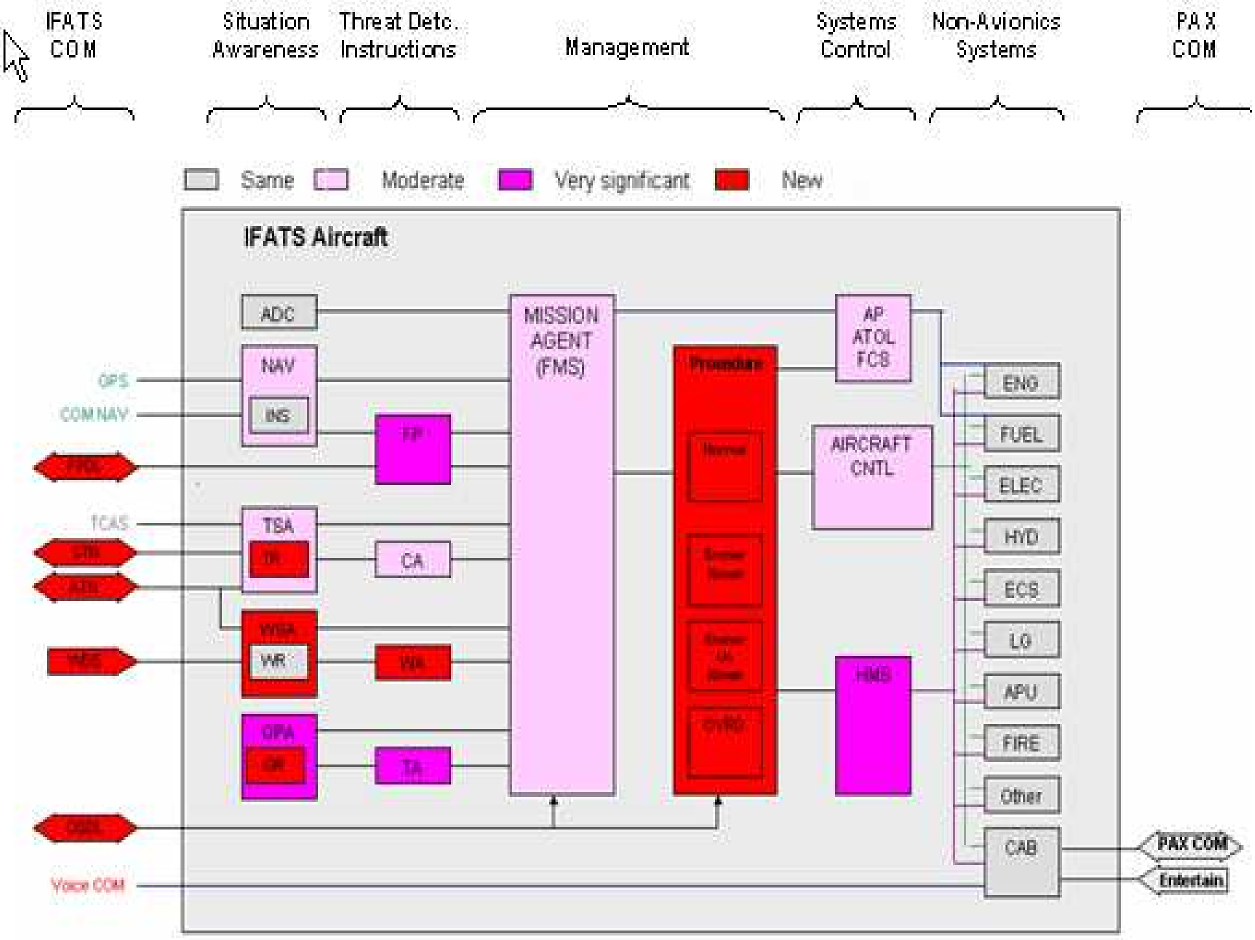


Figure 20 - IFATS Air Segment - Main functions

Specific findings related to the air segment were:

Identification should be based on cross checking of information from several sources and the solution should be based on independent redundancies: systems and measurements onboard; other aircraft; ground means (ATM, ATC, NAV-Stations).

Absence of pilot eyes in IFATS aircraft is one of the main issues in this analysis. Thus, the optional recommended risk mitigation is compensation by additional sensors and means: airborne radar, bird detection radar etc; image processing: change detection, move detection, super resolution etc.

7.6. Certification

The main findings on certification issues for IFATS concern the study of the following question: can we use the existing certification standards in the certification process of IFATS?

At a general level, it is interesting to note that the high level objective of ICAO SARPS, that are the baseline for current regulations of manned aircraft, is still valid for an IFATS aircraft: “protection of 3rd parties and property, plus cabin safety requirements aimed specifically at assuring adequate protection for passengers and crew “.

Moreover, as far as the ground air traffic management is concerned, the high level objectives of the ESARRs, dealing with the development and implementation of safety regulatory requirements in Europe, are applicable to an innovative ATM concept.

In order to investigate the possible tailoring of current regulations in the certification process of IFATS, the main regulations relative to the aircraft and to the ATM have been reviewed and practically tailored within the tailoring methodology recommended by the EASA[1].

7.6.1. The aircraft

The main adaptations of CS-25 concern, as it can be expected, the pilot tasks. Some tasks relative to cabin and passengers can be executed by the senior cabin crew member. The most critical tasks relative to the monitoring, the control and the management of abnormal situation are managed by the “brain” of the IFATS aircraft called the “air Manager”. The requirements of the Air Manager, in charge of monitoring and controlling the aircraft, managing and executing all procedures of the aircraft, have to be written.

On top of that, there are three critical items to be added in the airworthiness code of IFATS. Firstly, there are new on-board equipments (the Air Manager, the automatic take-off and landing system, emergency recovery capabilities. On the ground, requirements have to be written with regard to the central database, which is the heart of the information network of IFATS, display of the ground operator has to be defined, and the possibility of handover of an aircraft by the ground segment is a critical point to be specified.

The main adaptations of JAR-OPS 1 concern crew responsibilities, airline tasks and pilots’ tasks regarding meteorological conditions management, the execution of emergency procedures and the low visibility operations.

Interestingly, the adaptations of these requirements have an impact on both air and ground segments. For example, the management of meteo conditions is not only becoming a requirement of the air segment with regard to the corresponding Air Manager task and the role of the aircraft of an atmospheric sensor, but also a requirement relative to the central database of the ground segment.

A critical adaptation deals with the expert team on the ground, which shall be available in case of unknown failure detected by the Air Manager without any predefined recovery procedure.

[1] ***EASA A-NPA 16/2005 « Policy for UAV certification »***

New operational items concern the detection of non-cooperative traffic, the no-visibility procedures for departure, arrival and taxiing, and the responsibilities and role of the ground operator.

The quantitative results of the tailoring of the CS-25 and the JAR-OPS 1 indicate that the number of fully, partially and "intended" paragraphs represents roughly 90% of the paragraphs. Of course, critical items have to be added but this first tailoring shows that current regulations relative to transport aircraft can be used as a baseline for the certification process of IFATS aircraft.

	Percentage of requirements	
Tailoring code	**CS-25**	**JAR-OPS 1**
Fully applicable	**64%**	**62%**
Intent applicable	**17%**	**14%**
Partially applicable	**13%**	**10%**
Not applicable	3%	9%
Alternative criteria required	3%	5%

Table 1 - Tailoring quantitative results on aircraft current regulations

7.6.2. The ATM

Main adaptations of the ESARRs concern the airspace organization (like airspace structure and "functional airspace blocks"), state responsibility, severity classes definitions based on ATC workload, air traffic controllers competencies.

State responsibility is becoming a multinational supervisory authority responsibility.

Concerning severity classes, impact on crew or ATC control or workload shall be replaced by impact on aircraft functional capability

The main additional items deal with the ground-to-ground communication and the ground central database integrity.

The quantitative results of the tailoring of the ESARRs indicate that the number of fully, partially or "intended" paragraphs represents roughly 90% of the paragraphs. Again, critical items have to be added but this first tailoring shows that current regulations relative to the ATM can be used as a baseline for the certification process of the IFATS ground segment.

Tailoring code	ESARRs Percentage of requirements
Fully applicable	**83%**
Intent applicable	**6%**
Partially applicable	**5%**
Not applicable	~0 %
Alternative criteria required	6 %

Table 2 - Tailoring quantitative results on ATM current regulations

7.6.3. Conclusion on current regulations tailoring

A preliminary tailoring of the current regulations relative to the air transport (aircraft and ATM) shows that, although many critical new items need to be specified, they can used as a baseline for the certification process of IFATS.

Moreover, the tailoring study shows that in such an innovative concept, requirements relative to air and ground segments are strongly mutually dependent. Consequently, the certification process of IFATS calls for on one hand more correlation between airworthiness and operational certification of the aircraft and on the other hand, an harmonization of aircraft and ATM requirements. As this process will take a long time, it is urgent to start it now.

7.7. Automatic and autonomous behaviour of the aircraft

A tool capable of simulating a fully automatic and autonomous aircraft has been developed in the project to simulate all the flight phases, taxi, takeoff, navigation and landing.

Thanks to this tool (Figure 21), the capabilities of an automated aircraft to handle various failures and emergencies have been analyzed.

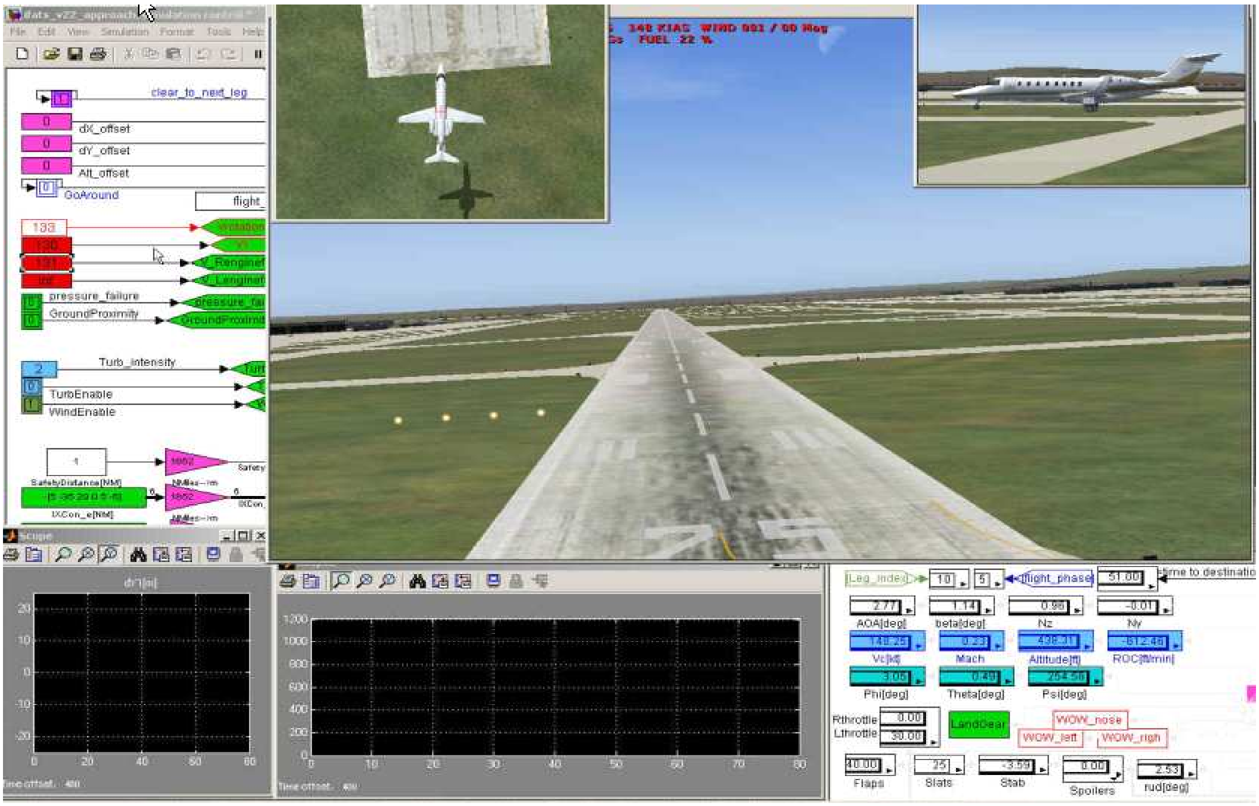


Figure 21 - Simulation tool interface

Unsurprisingly, this analysis did not raise crucial unsolvable technical problems. As demonstrated by the current operational unmanned aircraft systems (UAS), the technology is not far from being fully mature today, in 2007. The IFATS time horizon is such that technical problem should not be seen as show stoppers.

However, regulations have to be defined to enable the step change involved by the integration of pilot-less aircraft in the airspace.

The UAS community is currently dealing with these problems that can be classified into three main categories:

- Certification (ICAO Art. 31);
- Flight crew licensing and training (ICAO Art. 32);
- Operational requirements (ICAO Art.12).

Hopefully for this UAS community, these problems will be solved by the time a possible automated air transport system would be developed.

7.8. IFATS air traffic simulations

In December 2006, at the Braunschweig DLR site in Germany, Air Traffic simulations were conducted with “real” AT/C and pseudo-pilots and in fully automatic IFATS mode. Figure 22 shows the room of the simulations facilities where experts are sitting to run their individual simulation tools in order to analyse the various subsystems performance and behaviour of the overall system.

Figure 22 - Main distributed simulation room

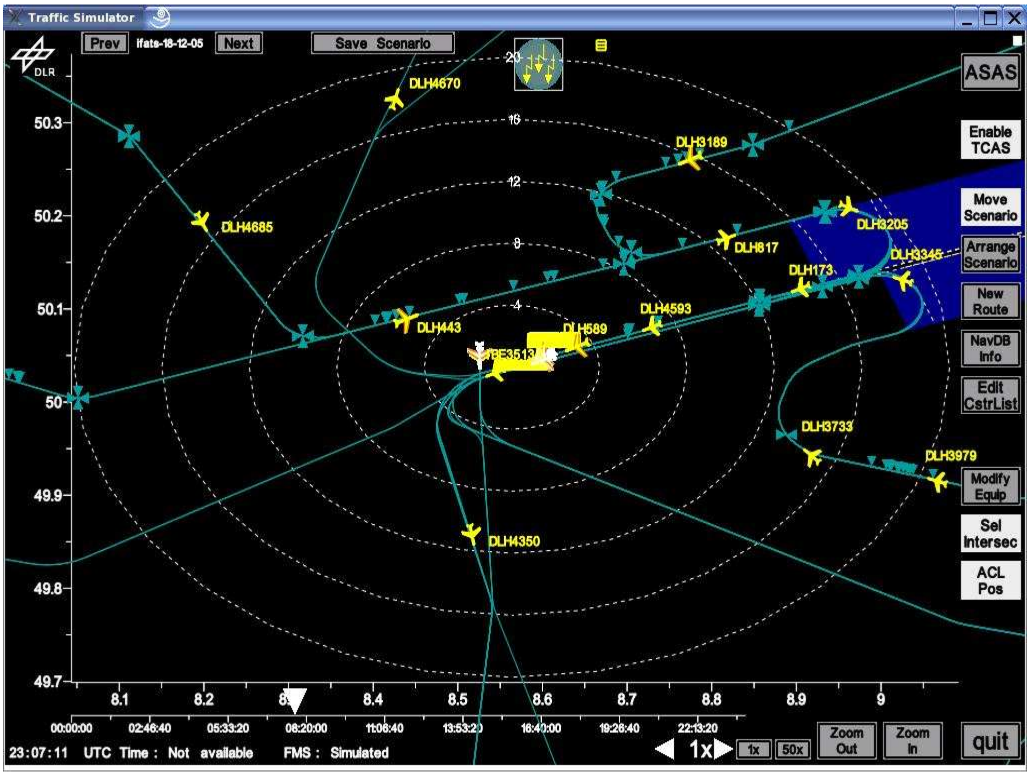


Figure 23 - Frankfurt airport area on the simulation screen with 4-D contract

As shown in Figure 23, the main DLR tool simulates the aircraft flying their 4D contracts arriving in the vicinity of the Frankfurt airport and taking-off or landing there. Normal situations were demonstrated together with disturbances such as thunderstorm (aircraft has to avoid thunderstorm area, this induces a re-planning action), degraded performance aircraft and aircraft facing an emergency.

The table in Figure 24 shows some of the results that were obtained during one simulations campaign.

Run	Type	Duration	Human Controller	IFATS
2	*normal*	01h:31m (91 min)	19h:46m (56 a/c)	18h:16m (54 a/c)
4	*normal*	01h:32m (92 min)	22h:19m (57 a/c)	18h:16m (54 a/c)
5	Emergency DLH419. MLD863	01h:33m (93 min)	22h:46m (57 a/c)	18h:40m (55 a/c)
6	Emergency DLH419. MLD863	01h:33m (93 min)	22h:49m (55 a/c)	18h:41m (55 a/c)
7	Emergency DLH1EM. DLH75A	01h:33m (93 min)	20h:52m (59 a/c)	18h:40m (55 a/c)
8	Emergency DLH1EM. DLH75A	01h:30m (90 min)	23h:35m (58 a/c)	18h:00m (53 a/c)

Figure 24 - Comparison between current ATC and IFATS concept

The “Duration” column shows the simulation run duration.

The fourth one gives the total duration of the flights of the aircraft between entering the TMA and landing at Frankfurt. The number of aircraft is the total landed aircraft

This first set of results shows that the IFATSystem lowers the duration of the flight optimizing the landing sequences whereas the controllers, asked by the simulations team to land as much aircraft as they could, gave some shortcuts to a number of aircraft to optimize this score while the automated system just followed the planned procedures…

This early stage simulations show the learning curve that has to be followed when defining and developing an automatism. Experience has to be gained patiently to raise the automatism at an acceptable level!

7.9. Airport traffic management

A ground planner simulation tool has been developed in order to simulate the management of the aircraft ground movements of the Frankfurt airport.

It allows the simulation of the ground movements planning and execution for two types of contracts: from gate to runway for the departing flights, and from runway to gate for the arriving flights.

The Figure 25 is a screenshot from the graphical interface. The background is a map of the Frankfurt airport. On this background, aircraft are moving.

The colour of each aircraft indicates its status:

- Yellow for landing and taking-off aircraft;
- Green for taxiing aircraft;
- Red for stopped aircraft;
- Dark blue for aircraft disembarking passengers;
- Purple for idle aircraft;
- Light blue for aircraft embarking passengers.

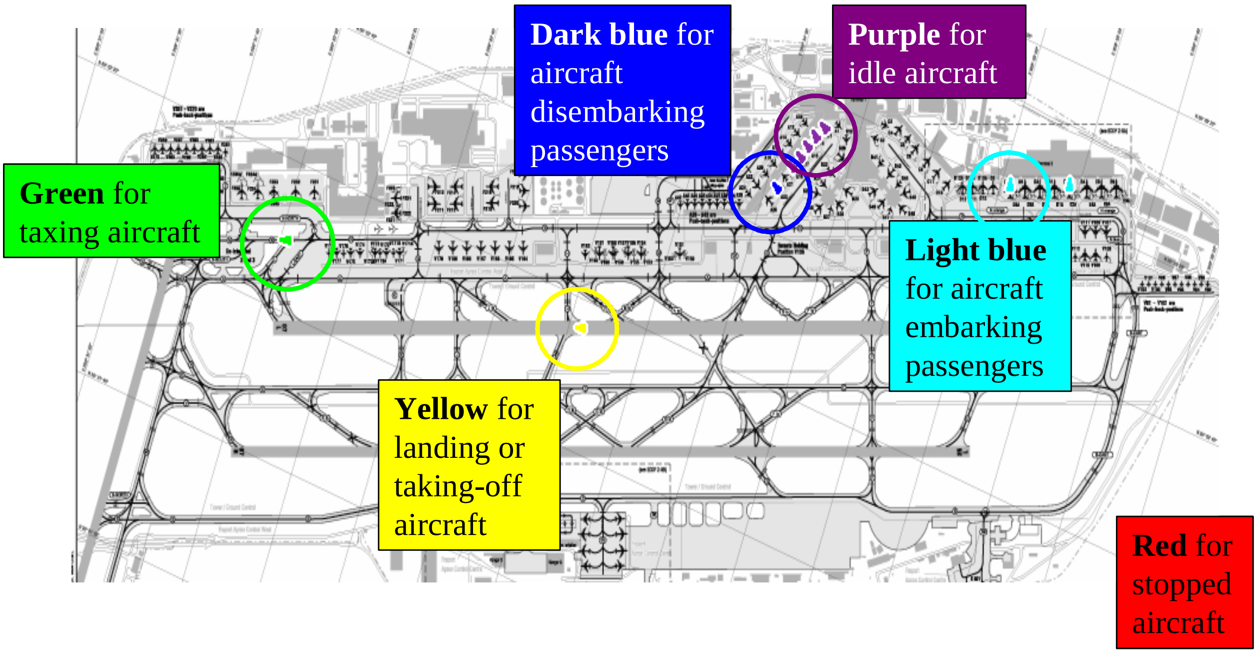


Figure 25 - Ground planner simulation tool graphical interface

The planning of the ground movements of the aircraft is made by the ground segment of the system. To this end, it has to compute the contracts and to send them to the aircraft.

These contracts are based on a graph of taxiway network. They are sent to the air segment as a sequence of time interval stamped waypoints.

These contracts are computed including minimum & maximum arrival time at each node of the trajectory using an algorithm that memorises all already planned contracts in order to get conflict free contracts.

The computation of a new contract is based on an adaptation of a A* tree search algorithm.

The search for departing flights aims at finding a conflict-free path at nominal speed. If this is not possible, the flight is delayed at gate. For arrival flights, the algorithm has the same aim.

But in case of impossibility, the aircraft can be stopped upstream the first intersection before the potential conflict.

This simulation has demonstrated that the automation enables a smooth organisation of the ground movements eliminating most of the queues before taking off and after landing.

This improvement is due to the possibility to have:

- a comprehensive, real time, centralised situational awareness of the state of the elements of the system;
- a very low reaction time of the actors through a direct control of aircraft by the ground system.

8. IFATS PERFORMANCE ASSESSMENT METHODOLOGY

The methodological approach used considers IFATS as the global Air Traffic System (ATS), and not only the current ATM...

ATS performance is defined through ICAO's Key Performance Areas (KPA) and indicators (KPI). Five KPAs which appear to be most relevant with respect to the IFATS concept were considered: capacity, efficiency, flexibility, predictability, safety.

A review of accidentology data has also been made. Historical data analysis stresses implication of human factors in the vast majority of incidents and accidents, i.e. between 50% and 75% of all causes (Ref. 7). This is one of the main "drivers" behind the IFATS rationale, with a new "man in the loop" concept.

The Air Traffic simulations mentioned in section C demonstrated the potential positive impact of IFATS on flight efficiency (KPA n°4) and predict ability (KPA n°9). A survey of participating controllers was conducted during the simulations. It indicates that IFATS simulation scenarios will have to be more complex to be more realistic, with capacity to "expect the unexpected". It also indicates that IFATS development would benefit from a closer implication of controllers and pilots in the analysis process.

Nevertheless, regarding the performance analysis, the major finding has been that a full and comprehensive assessment of the system was not possible through independent simulations analysing punctually one of the various aspects to be studied.

The project work has been efficient to define and developed a concept, using the simulations to fine tuning the definition of the various functions that have to be implemented in such a system. But a comprehensive performance assessment will need further work based on a modelling of the overall ATS and the simulation of its operation mode for various circumstances such has the weather forecast accuracy, the communication network quality of service, etc.

To this end, the IFATS consortium members are proposing a follow up phase of the IFATS project in the new European research Framework Program.

9. USER GROUP OUTPUTS

In the framework of IFATS project the Consortium identified the strong need to ask for a free and unbiased evaluation of the concept through an "User Group" composed of qualified persons in the field of air transport. The 'Users Group includes all persons who will be involved in the definition, management and use of the IFATS finished product, i.e. Pilots, ATC controllers, Airlines, National Aviation Authorities, Manufacturers, International Organisations.

An User Group composed of 15 highly qualified experts has then been created to review and advise on IFATS outcomes; their involvement has been a key point with regard to the soundness and credibility of the project outcomes.

Their activity, which has been carried out all along the project, has produced analysis and recommendations which focuses on three important aspects addressed by the project:

- IFATS definition;
- IFATS safety/certification aspects;
- IFATS validation.

In order to involve the Users and gather their assessment a questionnaire has been prepared to be used as the unifying thread during the interviews performed throughout Europe. Two dedicated meetings were also organised.

Questions have been conceived to collect users' comments and recommendations with respect to the project achievements.

Before answering the questionnaire the User Group has been requested to evaluate IFATS outcomes through the review of the project deliverables as they were made available.

In the following the most significant inputs in terms of statement and recommendations gathered during the interviews are reported.

- Almost all Users agree that the foreseen integration of manned and unmanned aircraft integration is technically feasible. Highlighted that the integration represents a challenge and that, to be achieved, it needs to be examined also from a regulatory point of view
- A transition plan from the current system to IFATS would be needed. In general such transition should be phased and involve both air and ground segments. The definition of segregated portions of airspace (to be progressively enlarged) where phased improvements can be experienced is suggested.
- Highlighted the opportunity to further analyse and consider the operational aspects. End Users should be more involved in the future IFATS.
- Highlighted the need to refer clearly in the project of international laws: this is considered a lack. Military presence in the airspace should be addressed in the next IFATS.

- The major obstacles related to safety of IFATS, according to the User Group members, includes: Data base errors, Security and terrorist activity related attacks, New threats associated to the technological concepts tied to IFATS, Exceptional weather conditions, Duality of traffic (automated, not automated),
- IFATS current safety analysis is that it is a good first step that needs to be further detailed and refined. Appropriate guidelines for development of subsequent safety studies should be identified and adopted.
- The Key Performance Areas that should be investigated in priority for the performance measurement of IFATS are: Safety, Capacity, Efficiency, Cost effectiveness, Security.
- Cost analysis should be performed with a phased approach: first starting with qualitative assessment and then adopting quantitative methods as the overall system is defined in detail.

10. IFATS SOCIAL ACCEPTABILITY

This section of the paper relates to the non-technical but important issue that is the societal acceptability of a fully automated system as proposed by IFATS. This point has not been answered yet by the project, but the issue has been raised and somewhat qualified as far as the project was progressing.

It is important to deal with the societal acceptability as early as possible: indeed, for such a project based on a disruptive approach, the risk of failure due to a rejection of the solution by the affected parties is high. Considering that IFATS - or future projects related to the development of enabling technologies - will propose the best technological answers, this is not yet enough to guarantee the acceptance of the solution by the affected parties.

The first question we should consider is « Who is affected?»: generally, and when building a long term strategic research agenda is concerned, it is commonly agreed that all the stakeholders should be involved in the process. But it is less common to involve as well the users (simple citizens) or the actors of the system (pilots, controllers, crew members). Indeed, only the question of knowing how to involve citizens (for example) in the definition of research orientations is pretty hard to answer.

However, there are numerous reasons why the users would be inclined to reject the idea of IFATS, or of a fully automated ATS.

The first that comes to mind is of course the “fear of not having a pilot” to count on in cases of any difficulty during a flight. Reasons driving the ATS/ATM actors to reject the idea may be more connected to their view of their own situation than a more global perspective.... Their position can be derived from the statement “As you know, for many the fear of the future is often based on an over-glorified perception of the past” (Ref. 1).

Thus, dealing with societal acceptability has a lot to stake with building confidence with affected parties: the starting point for building this confidence is to understand the points of view: who is affected, why, who is under the influence of whom. To do so, it might also be a good start to look at what has been done in areas that are more advanced that the air transport as far as automation is concerned: train for example, and ground transportation in general.

Second step towards the instauration of this virtuous circle that is necessary to build confidence, we need to educate and convince people about the advantages of a fully automated ATS. To some extent, we need to "make" public opinion while developing the concept: we need to influence. For that, it is necessary to have a clear view of what could be such a future ATS. How it will operate, what will be the transition phase, what are the main outcomes of this technical progress. We need to be convincing on the risks, and the solutions necessary to reduce these risks. This information is not available yet at this stage of the project.

Finally, and it may be the most difficult task, we need to involve the affected parties directly into the process of defining R&D orientations, so they can influence the development process and drives researchers, engineers and stakeholders towards a better acceptability of the solution they would come with. The question here is to know how to have people from various origins (technical, social, nationality…), participating to the definition of research orientations for subjects that are complex and technically difficult.

Social sciences researchers have addressed this question in the past decades. Several approaches have been defined, from the collective panel, to the participative democracy: after an overview of all these techniques, we found that the one called "Interactive Technology Assessment Method", developed in the Netherlands, was the most suitable to our needs. Basic principles of this methodology have been adapted to the issue of assessing the Integration of Pilot-free Aircraft in the Single European Sky by several partners of IFATS.

The core of the approach we developed relies on the organisation of several working groups putting together representatives of affected parties that have been trained prior any debate and discussions using IFATS results and scenarios.

Finally, and because the main purpose is to define R&D orientations, this working group is supervised by a steering committee composed by ATS specialists in charge of exploiting outputs of the working groups and of defining realistic R&D orientations. A limited experiment at the regional level will be organized and financed by the « Conseil Régional d'Ile de France » late in 2007. It will only consist in apprehending the acceptability from the user's point of view.

11. FUTURE ATS ROADMAP

11.1. Introduction

Figure 26 shows the project workflow regarding the definition of the future ATS roadmap.

The IFATS project team has developed a definition of a highly automated Air transports system as it has been detailed in this report.

Through the Braunschweig workshop, the Châtillon round table and the outputs of the project users group, feedback has been generated and taken into account to refine the final IFATS elements definition and system organisation.

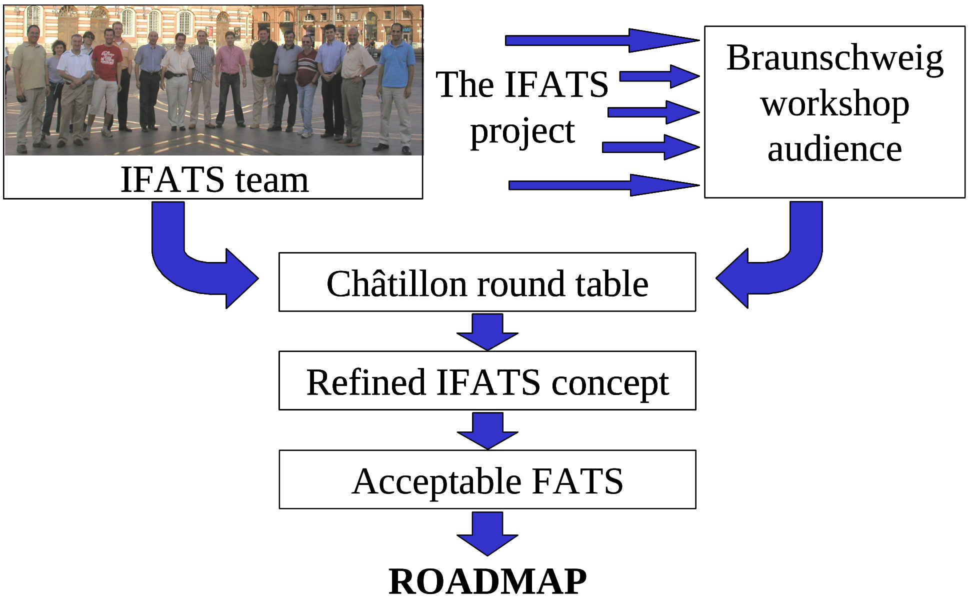


Figure 26 - Project work flow towards the future ATS roadmap definition

Regarding what can be expected in the future, preliminary thoughts can be expressed after this three year long definition and evaluation effort.

Nevertheless, they have to be considered as temporary as this IFATS-1 project did not consider a detailed definition of the overall system concept that has been proposed and evaluated. Moreover, due to the high level description of the defined system, investigations were not as wide and deep as in other projects dealing with more conservative ideas and often focus on one single aspect of the overall ATS.

The current achievement of the work makes possible the following assessments.

11.2. Technical feasibility of the air segment

Technically speaking, the distance that separates today's aircraft from IFATS aircraft is not so large. Of course, pilots are still onboard but a very limited number of flight phases are still manually operated.

Thus, a fully automatic transport aircraft seems to be technically feasible as it is demonstrated through the already flying large UAVs like the Global Hawk.

New airframes without cockpit have to be designed with a complete new arrangement of the electrical / hydraulic internal layout.

An addition of adequate sensors to monitor the aircraft status (smoke detectors, vibration sensors, etc.) is required and associated systems (hardware and software) have to be implemented together with a significant upgrade of the communication means (air-to-air and air-to-ground) are required. All this seems to be technically achievable in the mid term.

The second phase of the IFATS project that has been proposed for the first call of the FP7 aims at detailing the definition of a fully automated aircraft in order to better determine the functional characteristics to be implemented to get the same level of safety and security as the current one.

11.3. Technical feasibility of the ground segment

The actors that already exist such as airports infrastructure (excluding ATC), aircraft manufacturers and airlines only require adaptations.

Regarding the new actors, such as ground stations that do not exist at all, new infrastructures have to be created from scratch.

Technology is already there but a considerable work has to be done to make the system efficient, safe and secure.

The ATSM may be the most difficult part of the system to design. It requires the creation of a planetary-scale traffic planner within a multinational organization.

Hardware and software have to be developed together with a totally new concept of operation. This will require time and money, a competitive position of Europe is this field has to be encouraged as soon as possible to keep, or gain, a leadership role in the far term ATS evolution (that includes the ATM, of course).

11.4. Technical feasibility of the communication networks

Some current aircraft are already equipped with "ADS-B out" whereas the ASAS function will require "ADS-B in". This short term situation is not so far from a preliminary form of the so-called local network defined in the IFATS project.

The communication topic is made complex due to the frequency availability & "productivity" problem.

Nevertheless, the lower number of **voice** messages that is one of the main advantages of the IFATS concepts (machines "speaking" to machines instead of machines informing men speaking to other men giving data to machines) simplifies the data flow and lower the needs for frequencies.

Radio navigation frequencies will also be made available and digital message processing will lower the duration of all the data exchanges between the various actors of the overall system.

Of course, the vital need for an « extreme » security of the data exchanges will require a major effort on efficient and secure communication protocols and hardware designs.

11.5. Role of the human

The role of the human in the system has been discussed all along the project with passion and lucidity.

For sure, the future air transport system will not be an unmanned system!

Humans will still be in the system but not at the same place and nor for the same functions.

One of the statements made in the SESAR initiative is as follows:

Irrespective of any future vision the human will remain the most flexible and creative element to direct the performance of the overall ATM System including the management of threats, errors and unpredictable events.

The equivalent statement that has been made in the IFATS perspective is as follows:

The human will remain the most flexible and creative element to direct the performance of the overall ATSystem, designing an automated system in which he will keep a role where his performance level is the highest.

In IFATS, the human being is seen as extremely efficient when and where the functions he has to perform are not too much closely interfaced with automation.

Another aspect of the human's role concerns the responsibility that will be placed on the various people involved in the air transport system management. This topic will have to be addressed taking into account many parameters, from the design of the aircraft to the operation of the airlines. However, with the increase of the automated function in new generation aircraft, similar problems have already to be addressed nowadays.

11.6. What will happen? When and where?

"What will happen?" is a difficult question and no clear answer can be given yet. Deeper analyses have to be performed to get a more clear view of what types of changes can be expected in the ATS.

Although the case of the automatic metro is far from the air transport system, let's see the situation faced by the engineers in charge of the development of this automated metro Line 14 in Paris.

They had two questions in mind while designing the new line:

What will the passengers think of the changes?

Will they dare to board a métro without a pilot on board?

When starting the operation of line 14, no rejection reaction was observed from the passengers… they were just enjoying the former driver's view!

And now, Paris Line 14 use is constantly increasing…

May be a good summary of the situation may be taken from the editorial of the magazine "The Controller" (Ref. 2) : *"Whether the automation of the future will be as advanced as the IFATS vision of Onera is debatable. But their assumption is a correct one: if you want to totally automate ATC, there will be also no pilots anymore, as only computers can interface with computers".*

And of course, the same comment applies symmetrically about the automation of the aircraft that cannot be achieved if the ATC is still operated by controllers.

"When and where?" is not simpler to answer.

May be China will take the lead for their domestic air transport network: they have a dramatic demand for air travel to satisfy and have difficulties to get well trained and experienced pilots.

It may be more difficult for them to educate pilots than to create a local automated ATS!

12. CONCLUSION

Pioneering the air transport of the future is not a simple issue. Nowadays, a few years after the first flight centennial celebration, the ATS is far from being optimally structured and fully developed to meet the user's needs and comply with the more and more stringent environmental constraints.

Ambitious objectives have been stated in the ACARE Vision 2020 in Europe (Ref. 5 and Ref. 6), and metrics have been defined to assess their level of achievement: the future ATS will definitely have to be more time efficient and highly customer oriented, keeping costs low while being environment friendly and secure; this has to be valid and proven whatever the evolution of the traffic will be.

Choosing the means to reach these objectives is not so obvious. The ATS is a complex system, which integrates multiple interacting subsystems designed to provide its core functions, i.e. transporting passengers and goods. Huge technical and technological progress has been achieved at the subsystem level, centred on a human controller or operator. Placing the man as the major front-line actor brings intelligence into the overall system, but it also brings limitations and weaknesses.

In the near to mid term future, i.e. 2020-2030 time frame, no major ATS changes can be expected: in the coming years the ATS will necessarily be not very different from what it is today for evident reasons of continuity.

Looking in the more distant horizon, to really pioneer the future, gives more freedom and flexibility, but also brings some uncertainty. In this perspective, thinking “out of the box” is welcome, and should even be seen as a required methodology.

Indeed, preparing this far future of the ATS is an unchallenged opportunity to promote excellence in scientific and technological research, development and demonstration. Moreover, the international nature of the ATS calls for trans-national research and industrial cooperation to take up many of the current European efforts in this field.

For this 2050 vision, the IFATS FP6 STREP has started to pave the way through a rather radical and non-conventional methodology. Instead of analysing how to evolve smoothly from the current ATS to a potential future one, the IFATS consortium has elected to study what could be an extreme far term solution: a fully automated ATS where pilots and ground controllers would be replaced by operators in charge of numerous monitoring functions.

The qualitative results that have been obtained up to the end of the first phase of the project (June 2007) are promising. With such a system, capacity, efficiency, safety and environmental friendliness are improved. Nevertheless, quantitative assessments need further in-depth investigation whereas the analysis of some issues, such as security, has to be detailed and extended.

At the end of the IFATS project, high level simulations prove that this extremely automated ATS where aircraft would be operating automatically, monitored by an automatic control supervised by ground operators, is a credible option.

But further investigation is needed to identify what could be a transition phase between the current ATS and such a disruptive concept.

"UAV airliners will happen. It is a question of when, not if" was the conclusion of the Flight International editorial paper relating the IFATS Braunschweig workshop in December 2006 (Ref. 3).

This is also the strong belief of the IFATS consortium members!

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Ref. 1 - Anne-Sophie Bellalche, "Le bout du monde, grande tendance du week-end", *Challenges*, n°70, 8 mars 2007, pp. 100-101.

Ref. 2 - Ph. Domogala, Editor, "Should we fear automation?", *The Controller, Journal of Air Traffic Control*, 2/2005, 3rd quarter 2006, September 2006, pp. 5.

Ref. 3 - Peter La Franchi, "Researchers reveal pilotless vision" *Flight International*, 19 December 2006- 1 January 2007, pp. 3, 6.

Ref. 4 - Hervé Tilloy, "Le système de transport aérien au crible de l'automatisation" *Air et Cosmos*, n° 2005,1 December 2006, pp. 35.

Ref. 5 - Advisory Council for Aeronautics Research in Europe (ACARE) Strategic Research Agenda SRA-1, Volume 1 and 2, October 2002

Ref. 6 - Advisory Council for Aeronautics Research in Europe (ACARE) Strategic Research Agenda SRA-2, Volume 1 and 2, October 2004

Ref. 7 - Boeing, 2005 Statistical summary of commercial jet Airplane Accidents, May 2006

PART 3 – PUBLISHABLE RESULTS

SCIENTIFIC PAPERS PUBLISHED BY IFATS

- "IFATS autonomous aircraft", Shlomo Rozental, 47th ISRAEL annual conference on aerospace sciences.
- "A Novel 3D Geometric Algorithm for Aircraft Autonomous Collision Avoidance", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, 45th IEEE Conference on Decision and Control (CDC'06), December 13-15, 2006, San Diego, California USA.
- "Decision-Making Algorithms for Aircraft Autonomous Collision Avoidance", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, 5th EUROCONTROL Innovative Research Workshop & Exhibition, December 5-7, 2006, Bretigny-sur-Orge, France.
- "Autonomous Aircraft Separation Assurance and Collision Avoidance Algorithm", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, 7th ATM Seminar, 2007, Barcelona, Spain.
- "Aircraft Collision Avoidance: An Optimal 3D Analytical Solution for Real-time Applications", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, submitted to 46th IEEE Conference on Decision and Control (CDC'07), 2007, New Orleans, USA.
- "FDI for Aircraft Systems Using Stochastic Pooled NARMAX Representations: Design and Assessment", D.G. Dimogianopoulos, J.D. Hios and S.D. Fassois to appear in the IEEE Transactions on Control Systems Technology, 2007.
- "Integral Minimum Variance-Like Control for Pooled Nonlinear Representations with Application to an Aircraft System ", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois to appear in the International Journal of Control, 2007.
- "On-board Statistical Detection and Compensation of Anomalous Pilot Aircraft Interactions", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois to appear in the IEEE Transactions on Aerospace and Electronic Systems, 2007.
- "On-board Statistical Detection and Control of Anomalous Pilot Aircraft Interactions", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois,16th IFAC World Congress, July 4-8, 2005, Prague, Czech Republic.
- "Nonlinear Integral Minimum Variance-Like Control with Application to an Aircraft System", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois, 14th Mediterranean Conference on Control Automation, June 28-30, 2006, Ancona, Italy.
- "Fault Detection and Isolation in Aircraft Systems Using Stochastic Nonlinear Modelling of Flight Data Dependencies", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois, 14th Mediterranean Conference on Control Automation, June 28-30, 2006, Ancona, Italy.
- "Statistical Fault Detection and Identification in Aircraft Systems via Functionally Pooled Nonlinear Modelling of Flight Data Dependencies", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois, 25th International Congress of the Aeronautical Sciences (ICAS), September 3-8, 2006, Hamburg, Germany.
- "On-Board Engine FDI in Autonomous Aircrafts Using Compact Stochastic Nonlinear Modelling of Flight Signal Dependencies", D.G. Dimogianopoulos, J.D. Hios and S.D. Fassois to appear in the Proceedings of the European Control Conference (ECC) 2007, July 2-5, 2007, Kos, Greece.

- "2D Trajectory Re-planning and Optimization in the Presence of Stationary Obstacles", Lior Ben-Yshai, Moshe Idan, IACAS 47, Feb. 22, 2007, Haifa, Israel.

LARGE AUDIENCE DOCUMENTS PRESENTING IFATS CONCEPT AND RESULTS

All the following documents are available on the website of IFATS Project

www.ifats-project.org

- Full high level description of IFATS Project Slides presenting the project as it has been defined, roles of the partners, anticipated results (copyright IFATS Consortium 2004).
- IFATS concept - presentation paper: this paper (and associated presentation) has been presented at the Eurocontrol Innovative Workshop held in Bretigny (France) on December 06-08 of 2005.
- IFATS concept illustrated video describing the main components and concepts of IFATS approach (copyright IFATS consortium 2006).
- IFATS concept explained: several presentations together with their comments (some are missing) are explaining parts of IFATS concepts. This material is publicly available. (Copyright IFATS consortium 2006).
- General Presentation of IFATS
  - The influence of weather forecast accuracy on trajectories replanning;
  - The autonomous take off and landing;
  - IFATS communications needs and architecture;
  - Aircraft health monitoring, fault detection;
  - Aircraft separation and collision avoidance;
  - IFATS concept safety analysis;
  - IFATS concept certification aspects;
  - IFATS Aircraft cost estimation;
  - Air traffic simulation in the area of Frankfurt airport;
  - Evaluation of IFATS concept;
  - Simulation of the ground operations in the airport zone;
  - IFATS societal acceptance;
  - Roadmap to future ATS;
  - Comments from the user groups and participants to workshop.

EVENTS WHERE IFATS PROJECT HAS BEEN PRESENTED

- 01/06 Special IFATS session at SAFEE technical meeting, ONERA
- 02/06 ONERA's Asia-Pacific aerospace R&T workshop, ONERA
- 03/06 Invited paper to EqIMG/EU Workshop on Reduced Crew operation, ONERA
- 05/06 ONERA's UAV activity presentation workshop, ONERA
- 06/06 Invited paper Aeronautics Days 2006, ONERA
- 12/06 IFATS simulation workshop, IFATS consortium
- 02/07 Paper – "2D Trajectory Re-Planning and Optimization in the Presence of Stationary Obstacles" 47th Israel Annual Conference on Aerospace Sciences - 2007 Israel, 30 people, Technion
- 03/07 IFATS final meeting, IFATS consortium
- 05/07 Presentation of IFATS during the AIAA conference: Infotech@Aerospace, Rohnert Park, USA, ONERA

INNOVATIVE FUTURE AIR TRANSPORT SYSTEM

SIXTH FRAMEWORK PROGRAMME

Reference: IFATS/ONERA/07/D700.9-PSR	Date: 30/07/2007
Contractor(s)	: CoDo
Author(s)	: CLT, AJ, HJ et al.
WP/ Task : 700	Type (1,2,3): 1
Confidentiality	: 2-Unclassified
Distribution	: All
See also	: All the individual deliverables produced by IFATS

Title: PUBLISHABLE FINAL ACTIVITY REPORT

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INTRODUCTION

The perspective that is considered in the Innovative Future Air Transport System (IFATS) project opens new ways not only for the management of the air traffic (ATM), but also for the management of the overall air transport system (ATSM).

In this project, the IFATS consortium decided to use a methodology providing a large and open thinking space in order to imagine and propose new far term solutions to pioneer the air transport of the future.

The basic feature of the IFATS concept is to go as far as possible in the automation of the ATS. The approach that has been taken is purely technical: thus, the concept that has been defined is a "technically possible" extremely automated system and not necessarily a "likely to happen" system.

The project started with identifying and analysing the technical issues of the automation of the ATS functions, and then it came to the validation of the resulting innovative ATS itself through safety analysis, simulations and debates organised in two workshops.

This procedure has enabled the consortium to think "out of the box" and to introduce a cornerstone feature of the IFATS concept: 4D contracts in a 4D airspace.

The 4D trajectory concept (being at a given geographical position at a given time) is already existing and widely studied, but its main drawback is that the compliance of the real 4D aircraft trajectory with the planned one has to be constantly monitored. Indeed, the 4D trajectory may vary due to meteorological conditions, for example. Additionally, whoever is in charge of trying to keep the aircraft on the planned 4D trajectory, the pilot or the controller, the task is hard to achieve.

The aircraft automation brings a part of the solution with the 4D FMS. Then, the question of who will be in charge of maintaining separation has to be answered.

The IFATS concept is straight forward on this issue. First, the ground segment of the system (the Air Transport Management System), which is also automated, is in charge of the generation of conflict-free 4D trajectories according to the demand and to the airspace capacity. Then, aircraft are given 4D contracts**;** they are in charge of monitoring their own compliance with the contract, which means staying inside their assigned 4D volume, or to ask for a new one if they cannot. In doing so, they have the guarantee to fly conflict-free trajectories.

Of course, the main difficulty lies in the generation of those conflict-free trajectories. To ease this generation, the four dimensions of the airspace are fully used without the current constraints linked to procedures, navigation waypoints, ATC sectors and airways: 4D contracts are created and have to be respected in the very large four dimensions airspace.

The IFATS project main goal has been to develop, as far as possible, the definition of this concept and to validate through simulations some of its components.

This document summarizes the actions that have been pursued until the end of the first phase of the project in June 2007 and gives the major findings.

A second phase of the project, aiming at a detailed simulation and evolution of the concept, has been proposed at the first call of the FP7.

PROJECT MOTIVATIONS

"I feel guilty when I travel by air". This is a rather unexpected statement in the current thinking process to shape the future of the Air Transport System (ATS). It has been published in March 2007 in a French weekly magazine (Ref. 1). The paper was about flying from Paris to China for holidays and stated that the consequence of such a trip was an emission of more than 7 tons of CO_2 per passenger.

What is the basis for such a view?

An explanation can be given, grossly exaggerating the issue, when considering this emission of CO_2 and the quantity of fuel burned during a single flight.

Is there a possibility, a risk, to be charged with a crime against humanity in 40 or 50 years time, if you have contributed to burn large quantities of fuel and to emit huge volume of CO_2, only for you own comfort, flying to long distance locations, for your holidays?

The answer could be yes, if, at a point in time in the future, the population of the earth will be lacking energy and fresh air, just to sustain its existence…

This iconoclast statement should not been seen as provocative. Its goal is to initiate a debate leading towards an investigation and a definition of a highly efficient future air transport system. The air traffic evolution depends on many parameters and, as such, it may not be as predictive as stated today; growth potential could be different from what is expected nowadays!

In this perspective, the IFATS project looked at disruptive options of the future ATS, i.e. concepts of ATS where pilot-less transport aircraft would be operating with a high degree of automation providing autonomy, controlled and monitored by ground operators through a network-centric architecture communication system.

The benefits that are expected from the IFATS concept are numerous; the most important ones are a better safety, a higher capacity, a low dependency on traffic evolution parameters and a radical improvement of the environmental issues by optimizing the aircraft trajectories. These topics are comprehensively described in the various sections of this report.

PART 1 - IFATS PROJECT EXECUTION

1. SCIENTIFIC OBJECTIVES OF IFATS

The IFATS project proposes to study a revolutionary concept for a future air transportation system (ATS) by adding as much onboard automation and autonomy to the aircraft as necessary to fulfil the overall requirements of improved efficiency and safety of air transportation.

- All the various air and ground components of the system communicate with one another through a network-centric architecture;
- Aircraft fly autonomously pre-programmed flight plans using sophisticated onboard computing and sensor systems. Ground operators are responsible for the overall situation, whereabouts of aircraft and tracking of their intentions.

Functionalities of the system are flexibly distributed between the ground and aircraft, relying on intensive data communication capabilities between aircraft, and between aircraft and the network of ground stations.

Current pilots and controllers tasks are deeply modified as the elements of the system communicate digitally: pilots can be removed from the cockpit and controllers work is transformed into system monitoring actions. Additional features are added like direct assistance from the aircraft manufacturer for in flight aircraft diagnosis and remote maintenance.

The central goals of this project are:

- to define a technically viable concept of an air transportation system where aircraft would be operating with a high degree of automation providing autonomy controlled and monitored by ground operators through a network-centric architecture;
- to define autonomous operation procedures and optimise tasks sharing between the operators, the automated ground control system, the autonomous onboard computing systems and to identify any need for an onboard engineer;
- to determine the minimum requirements and functionalities of the onboard system, to ensure safe operation in the case of communication loss with the ground control system;
- to perform a safety analysis of the concept and to provide guidelines to certification issues;
- to identify the difficulties to overcome to build such an Air Transport System, in both the technical and cultural aspects;
- to find out an adequate level of automation for a future acceptable system;
- to analyse a procedure to migrate from the present situation to this future system.

Driven by the assumption of an aircraft with a sophisticated level of autonomy, the necessary functionalities of the ground and onboard components of a future air transportation system can be isolated and analysed on their conceptual maturity.

This includes normal operations as well as critical flight situations or emergency cases.

Comparing the IFATS approach with the planned evolutionary improvements of the existing air transportation system will determine the main differences, advantages and weaknesses of IFATS vs. the existing system.

The comparison results could be used in one of the two directions:

- the IFATS approach could be adopted as the long-term air transportation concept;
- or IFATS ideas could be used to improve the current air traffic systems in the mid term perspective while using IFATS validated concepts.

2. IFATS CONSORTIUM

IFATS project involves 11 contractors. The team for the project was carefully selected having in mind the skills and experiences required to analyse the essential needs of a future air transport system, to investigate and verify the various requirements on the flight and ground segments and their interrelationship.

The consortium represents the different elements for the development of the IFATS in both the application / implementation aspects and the research / development aspects which are required for a successful RTD project.

In detail the consortium consists of:

- 4 large aviation companies representing the different aspects for ground and flight segments;
- 1 project management oriented SME;
- 4 national research institutes on aeronautics;
- 2 leading high educational institutes on aeronautics.

Partners are coming from France, Germany, Italy, Greece and Israel.

Office National d'Etudes et de Recherches Aérospatiales (ONERA)

A public, scientific and technical establishment with both industrial and commercial responsibilities, Onera reports to the French Ministry of Defense and enjoys financial independence.

The expertise of Onera covers all the scientific disciplines involved in aircraft, spacecraft and missile design. It makes Onera an essential partner in the French and European aeronautics and space community.

The activity covers a wide spectrum of topics from Basic Research to Flight Testing. Through the teamwork of its scientists recognized internationally in their respective fields and its engineers with a systems approach, Onera promotes ongoing dialog between basic and applied research, medium and long range approach, areas of special expertise and an optimized overall approach. Mathematical models, numerical simulation, laboratory and wind tunnel experiments and flight testing combine to give a better understanding of the physical phenomena encountered and enable to validate aircraft, spacecraft and missile performance predictions.

Onera conducts research in the disciplines and techniques involved in design of an aircraft or spacecraft: aerodynamics, flight dynamics, energetics, structural strength, materials, optics and laser, acoustics, radar and electromagnetism, electronics, systems, robotics, information processing. The research is focused on federating themes and programmes, such as fluid mechanics and information processing.

Onera activity in the safety and security field spans from software integrity to flight control robustness in degraded conditions. Moreover, an ongoing co-operation with NASA is focusing on aviation safety incident reports.

Cost reduction in system design becomes an important objective, computer tools have been developed to help system design from requirements to conceptual definition while low cost sensor techniques are investigated.

Concerning Air Traffic Management, a federative project has been carried on resulting in a comprehensive analysis tool for air traffic from the approach flight phase to the departure flight path.

Onera is also a gateway between scientific research and industry, cooperating with CNRS (National Scientific Research Centre) and the most prestigious universities. Since its creation in 1946, it has worked on all the major French and European aeronautical and space programmes, including Mirage, Concorde, Airbus, Ariane, Rafale, etc.

EADS Defence and Security Systems SA, France

EADS Defence and Security Systems SA (EADS DS SA) is a subsidiary of the EADS group, and is part of the Business Unit Defence and Communications Systems (DCS), which has revenues in 2003 around 1.2 Billion euros, with 5800 employees.

The DCS Business Unit is the EADS Systems House and is an integrated part of the EADS Defence and Security Systems Division.

DS, with revenues of about € 5.2 billion in 2003 and roughly 24,000 employees across nine nations, forms the defence pole within EADS. It offers integrated systems solutions to the new challenges confronting armed forces and homeland security units. It is active in the areas of military aircraft, missile systems, Intelligence, Surveillance and Reconnaissance (ISR) systems with manned and unmanned aerial vehicles (UAVs), battlefield management systems, defence electronics, sensors and avionics, and related services.

EADS is a global leader in aerospace, defence and related services. In 2003, the Group generated revenues of over € 30 billion and employed a workforce of more than 109,000.

Israel Aircraft Industries, Israel

Israel Aircraft Industries is globally recognized as a leader in developing military and commercial aerospace technology. This distinction is the result of nearly a half-century of designing, engineering and manufacturing, for customers throughout the world.

From a relatively small operation to become an industry leader, a company must be versatile and highly motivated, innovative and competitive. IAI was built around these qualities, and has improved upon them with its years of acquired experience. Israel Aircraft Industries has operated for decades according to the laws, regulations and internationally accepted norms in the business world. As the Company endeavors to conform to the international atmosphere which dictates a close adherence to ethical standards, the Company has produced a special document The Business Behavior Code, which, together with existing standards and the commitment to providing high quality products and services, will ensure the continued strength and development of Israel Aircraft Industries. The Company's ambition is to continue to initiate and achieve technological breakthroughs that characterize the best in the industry.

Israel Aircraft Industries is Israel's main aerospace corporation. IAI employs approximately 14,500 people. A few of the many projects currently in progress at IAI are:

- design, integration and manufacturing of a family of business jets; including the latest Galaxy (G200), and the current new design of Astra SPX wide body (G150) program;
- conversion of Boeing 747 from passenger to cargo configuration;
- jet engine nacelles;
- military aircraft upgrade programs;
- development and manufacturing of unmanned airborne vehicles (UAV's) for military and civil applications, etc.

IAI Headquarters includes five operating units: Commercial Aircraft Group (CAG); Bedek Aviation Group; Systems Missile and Space Group, Elta Systems Group and Military Aircraft Group (MAG).

The CAG's Engineering Division is a single site aerospace engineering centre. It's expertise encompasses every required aircraft development discipline and task - from concept definition to prototype flight-testing and certification.

Development and production of state-of-the-art executive jets is the CAG's flagship activity. Following the success of the Astra SP and the Astra SPX, the CAG has developed the GALAXY new generation executive jet and currently is developing the new G150 aircraft (Astra SPX wide body).

The Flight Control Systems department was responsible for the design and approval of all the digital FBW systems, for manned and unmanned aerial vehicles, that were developed under the military as well as under the commercial aircraft group.

The incentives of the Engineering Division and the FCS department in this project are to exploit the possibilities of improving the safety of flight, and exploring new automated systems.

Thales Communications SA, France

Thales Communications SA is a subsidiary of the Thales group and is part of its Communications Business Group. The revenue of BGCOM is around 1.5 billion euros, with 9000 employees in 14 countries. It operates through its subsidiaries in Belgium, Canada, France, Germany, Italy, Malaysia, Netherlands, Norway, Spain, Switzerland, and United Kingdom.

Thales Communications SA is a world leader in its domain of activity covering communications networks, satellite communications, mobile radiocommunications, naval & infrastructure communication systems, airborne communication, navigation and identification systems both for civil and military aircrafts, command information systems, radiosurveillance systems and radio spectrum monitoring.

Thales Communications SA is basing its leading position on constant and significant efforts in research and development for all the technologies involved in the ground, naval and airborne communication, identification and navigation fields both for military and civil applications, for which security and safety aspects are key.

Alenia Aeronautica S.p.A, Italy

Alenia Aeronautica S.p.A., a company of Finmeccanica S.p.A which is one of the Italy's major high tech companies, is among Europe's leading manufacturers of aircraft systems.

The company is dedicated to a full range of activities, from design and production to modification and product support for both military and civil aircraft. The majority of these activities entails collaborations with the world's most important aerospace industries.

In the military aircraft field the company designs and manufactures, directly or through international collaborations, combat and transport aircraft such as the Eurofighter/Typhoon, the ultimate European advanced combat aircraft, the AMX tactical aircraft, a joint program with Embraer of Brazil and Aermacchi of Italy, the tri-national Tornado multi-role combat aircraft, the C-27J Spartan tactical transport airlifter jointly developed with Lockheed Martin, the ATR42MP Surveyon in cooperation with EADS, a maritime patrol version of the ATR42 commuter aircraft.

Alenia Aeronautica plays a main role in the commercial aircraft sector.

Through its collaboration with EADS it has jointly developed the turbo-prop aircraft family for regional transport, ATR, which is now the most successful commuter program, with more than 600 units.

The technological capabilities shown by Alenia Aeronautica in the field of aerostructures have been widely credited, since the company has supported the world's major manufacturers in the construction of some of today's best-known commercial aircraft.

The company has long been co-operating with Boeing and participate in the manufacturing of B767, B777, B717, B757 with the supply of structural parts. Alenia Aeronautica also cooperates with Airbus consortium by manufacturing aerostructures for A321. In cooperation with EADS, it supplies structural parts for the A300/310 and the A340-500/600. Through BAE Systems, Alenia supplies machined parts for A319/320/321 and A340.

Alenia Aeronautica is also involved (with a 4% share) in the new A380 programme, the 550-seat civil aircraft which will be the most relevant strategic investment of Airbus in the next twenty years.

The company's research and development activities are focused on developing its different business lines, improving existing products, developing new European civil and military aircraft and increasing competitiveness through the enhancement of industrial processes.

Alenia Aeronautica research and development activities aim at developing its capabilities within the partnerships and collaborations in which it participates and focus on specific aeronautical technologies, material technologies and their production processes, on-board and mission systems and functional integration as well as feasibility and definition studies for new projects.

Employing a staff of more than 7452 people, it reached 2001 revenues of 1,140 million Euro, 80% of which from the export and with a Research & Development expenditure of more than 134 million Euro.

Erdyn consultants, France

Erdyn is a technology and services company. Incorporated in 1984, independent, it cumulates a strong expertise. It specializes in scientific and technical consultancy, aimed at industrial innovation. It is a "société anonyme " with a working capital of 100 000 €.

Erdyn services are organized as two business lines :

- consulting: R&D program audit, organization, management; market surveys, competitive intelligence, industrial property ; partners search, technology transfer.
- R&D: contract research, new products and processes; feasibility studies, computer modelling; expertise and diagnostic.

The expertise erdyn has built up is based on its knowledge and practice of the engineering sciences, including: thermodynamics, mechanics, material sciences, solid state physics, electricity and electronics, applied mathematics, computer sciences, environmental sciences, metrology, optics, chemistry…

This expertise has been applied to a wide variety of sectors such as energy production and distribution, raw materials and metal working, the environment, building and civil engineering, automobile and transportation, telecommunications, aeronautics and space, chemical engineering, sensors, control and command, to name but a few.

With large industry groups as well as with small and medium-size companies or public sector (research agencies, administrations), erdyn builds up long-lasting partnerships, based on its science and technology awareness, industrial experience and methodical exactness. With all clients, erdyn is engaged through confidentiality agreements.

Erdyn owns the OPQCM “technology” label (quality control) ; its clients may benefit from the “Crédit d’Impôt Recherche”.

Deutsches Zentrum für Luft und Raumfahrt e.V, Germany

DLR is the national German research establishment, responsible for research activities in aerospace, energy technology, and transport, as well as the national space agency. DLR operates 30 institutes, test and operational facilities, with the majority located at eight main research centres, with a total number of about 4.500 employees. Research activities are focused to serve the scientific, economical and social purposes. DLR sees its role to close the gap between university and industry. Long term experience exists in international project management and has been proven in projects on the European or international level.

The main relevant experience relates to systems design, performance analysis using ground and airborne simulators, sensor simulation and application, and data-link verification. In particular, DLR brings in its considerable expertise on intelligent systems for autonomous aircraft guidance and control and its air traffic management simulation tools. DLR is strongly committing the improvement of safety of the whole air transport system.

Direction des Services de la Navigation Aérienne (DSNA/DTI/SDER), France

DSNA/SDER ("Sous-Direction des Etudes et de la Recherche appliquée"), the French air navigation study centre, is responsible for promoting and designing advanced concepts required for the development of the future air traffic control system within the European context.

DSNA/SDER undertakes studies, research and experimentation in the following areas :

- air traffic and air space management;
- telecommunications;
- aircraft surveillance;
- airborne aircraft separation systems;
- human computer interaction techniques;
- everything else which contributes to the performance of ATC/ ATM.

All these studies are supported by the use of significant and powerful computer resources spread and interlinked between different sites to perform experiments and simulations needed for concept validation.

Centro Italiano Ricerche Aerospaziali ScpA, Italy

CIRA, the Italian Aerospace Research Centre, is a limited consortium company founded in July 1984. The Italian government has entrusted CIRA to manage the PRORA (Italian Aerospace Research Program).

CIRA institutional aim is :

- to carry out the PRORA by realising Excellence Centres, which shall integrate Research Capabilities with the Large Fluid dynamic Facilities and Technological Laboratories in several main technologies areas;
- to be the National focal point in Aerospace Research and Technology;
- to contribute to the Competitive and Sustainable Growth of the Italian Aerospace Sector;
- to identify Scientific Objectives and develop Basic Research in synergy with the National and International Scientific Community;

- to support the Industry in Applied Research both in the development phase and in the technology validation phase;
- to act as a partner of the Scientific Community and Industry;
- to facilitate technology transfer from the aerospace field to other sectors ;
- to provide technical assistance to public Authorities for qualification and regulations.

As a member of EREA, CIRA works in close co-operation with European Aerospace Research Establishments.

CIRA participates to the project with the Flight System Department (SISV) which has a large experience in the fields of Flight Mechanics, Flight Control and Automation, due to the participation in both international and national research activities and in supporting Italian aviation manufacturers. The activities carried out cover the whole development cycle of advanced flight control technologies starting from the theoretical study until the validation by means of real-time HW in the loop simulations and experimental flight tests by using small scale flying demonstrator.

In particular the department has direct expertise in the following fields :

- Development and validation of flight mechanics models for performance/stability evaluation and assessment;
- Design of flight control laws to improve the bare aircraft/rotorcraft behaviour;
- Vehicle Trajectory optimisation and Control;
- Automatic Take Off and Landing for UAV;
- Control System Rapid Prototyping;
- Real-Time HW in the loop simulations.

University of Patras, Greece

The University of Patras is one of the largest academic institutions in Greece, including schools on the basic sciences, engineering, economics, social sciences and humanities, health sciences, as well as arts and architecture. It currently has 700 faculty members, 1,600 employees, and about 18,000 undergraduates and 2,000 graduate students. The School of Engineering covers all main disciplines, including Mechanical & Aeronautics, Electrical, Civil, Chemical, and Computer Engineering.

The Department of Mechanical and Aeronautical Engineering has facilities housed in two ample buildings and includes modern laboratories covering applied mechanics, design and manufacturing, thermal and fluid sciences, aeronautics and automation. It involves 45 faculty members, 900 undergraduate students, and over 100 Ph.D. students. The department is very active in innovative teaching and research, and participates in numerous national, European, and international educational and research programs.

The Stochastic Mechanical Systems (SMS) Group of the Department specializes in innovative stochastic methods for estimation, identification, prediction, fault diagnosis and controls in various types of mechanical and aeronautical systems. The Group is led by Professor Fassois, and involves post docs, several Ph.D. students, M.Sc. students, and a technical assistant. The Group runs two modern laboratory facilities for teaching and research: a Mechanical Systems facility and a Structural Identification and Control facility.

Technion – Israel Institute of Technology, Israel

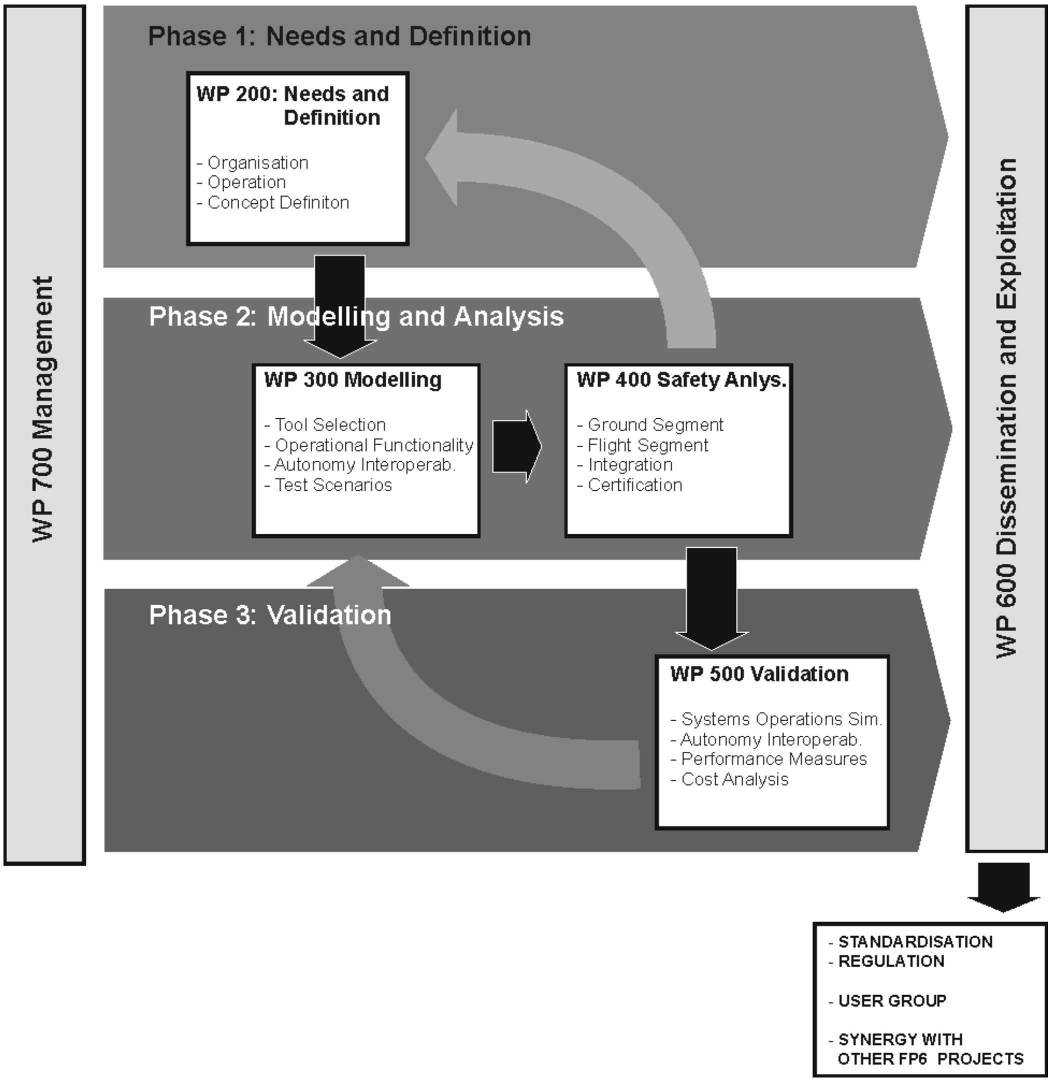
The Technion - Israel Institute of Technology is Israel's oldest university, founded in 1924, and is the only institute of higher learning devoted to the education of engineers, scientists, and physicians. Of the total enrollment of 12,800 students, 9,200 are undergraduates and 3,600 are graduates, studying at one of its 20 Faculties.

The Technion is an independent university directed by a Board of Governors. The executive power is exercised by the President. The supreme academic authority is the Senate, which consists of the President, the Vice Presidents, all full professors, Faculty Deans and elected representatives of the 20 Faculties.

The Faculty of Aerospace Engineering was founded in 1954. It is the only Faculty in Israel to offer academic degrees in Aerospace Engineering. About 400 undergraduates and 120 graduate students are currently studying in the faculty. Since founded, it graduated more than 1600 aeronautical and aerospace engineers. Research activities at the Faculty cover most of the areas of Aerospace sciences.

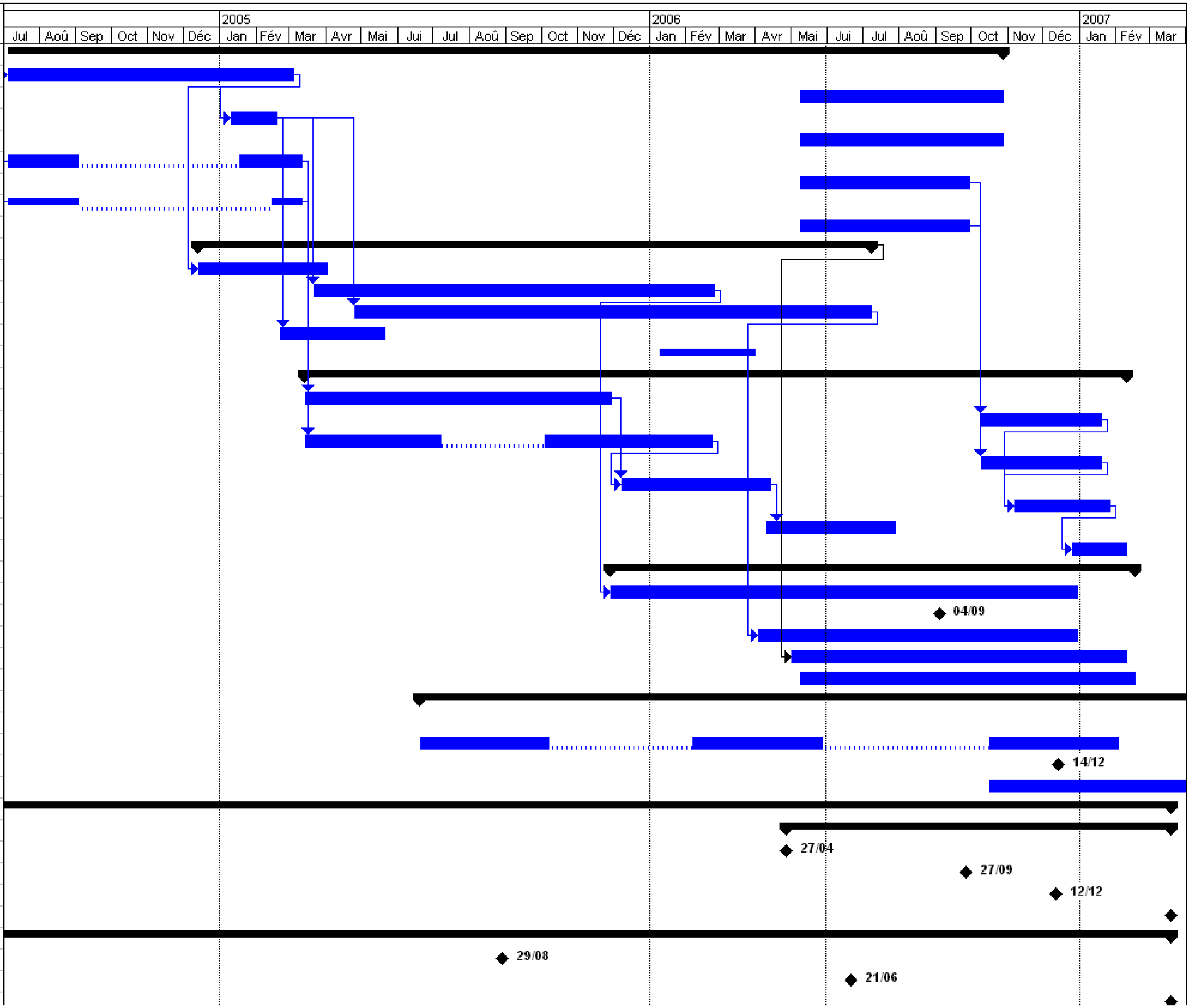
3. ORGANIZATION OF THE WORK INSIDE IFATS PROJECT

The IFATS project has adopted the following logical approach to achieve its objectives. All activities within IFATS have been partitioned into work-packages with information flow and interdependencies as shown in the figure hereunder.

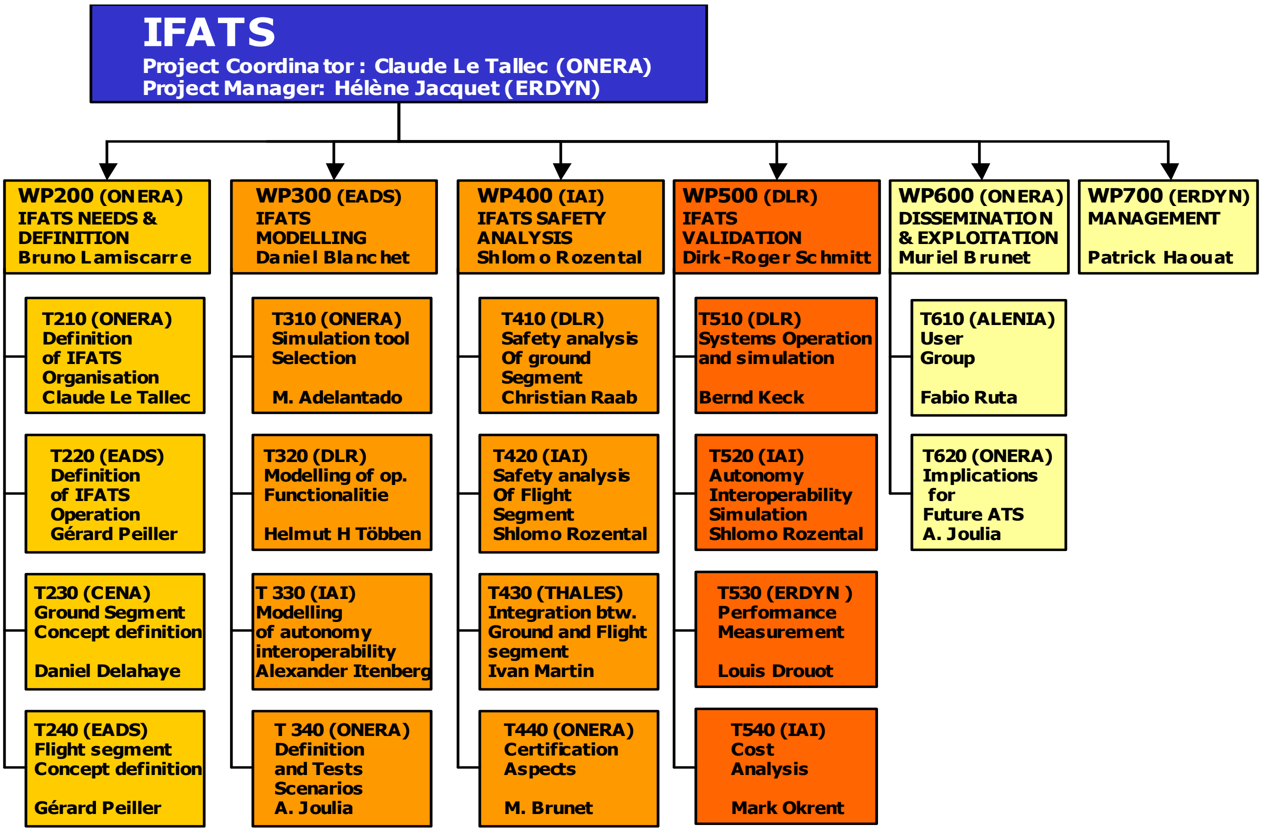


The total duration of the project to carry out these three phases has been 36 months: the Gantt chart of the project is shown next page.

N°	Nom de la tâche
1	**WP 200 IFATS DEFINITION**
2	Task 210.1 Definition and Organisation of the IFAT
3	Task 210.2 Definition and Organisation of the IFAT
4	Task 220.1 Definition of the IFATS Operations - Ite
5	Task 220.2 Definition of the IFATS Operations - Ite
6	Task 230.1 Ground Segment Concept Definition - I
7	
8	Task 240.1 Flight Segment Concept Definition - Iter
9	Task 240.1 Flight Segment Concept Definition - Iter
10	**WP 300 IFATS MODELLING**
11	Task 310 Simulation Tools and Scope
12	Task 320 Modelling of Operational Functionality
13	Task 330 Modelling of Autonomy Interoperability
14	Task 340.1 Definition of Test Scenarios - Iteration
15	Task 340.2 Definition of Test Scenarios - Iteration
16	**WP 400 IFATS SAFETY ANALYSIS**
17	Task 410.1 Safety Analysis of Ground Segment -
18	Task 410.2 Safety Analysis of Ground Segment -
19	Task 420.1 Safety Analysis of Flight Segment - Ite
20	Task 420.2 Safety Analysis of Flight Segment - Ite
21	Task 430.1 Integration Between Ground and Air S
22	Task 430.2 Integration Between Ground and Air S
23	Task 440.1 Certification Aspects of the IFATS Cor
24	Task 440.2 Certification Aspects of the IFATS Cor
25	**WP 500 VALIDATION**
26	Task 510 System Operations Simulation
27	Special meeting for integration
28	Task 520 Autonomy Interoperability Simulation
29	Task 530 Performance Measurements
30	Task 540 Cost Analysis
31	**WP 600 DISSEMINATION AND EXPLOITATION**
32	**Task 610 User Group**
33	User feed-back
34	WORKSHOP
35	Task 620 Implication to Future...
36	**WP 700 MANAGEMENT**
37	**Technical and management review meeting**
38	TRM 8
39	TRM 9/ PMM5
40	TRM 10
41	TRM 11
42	**Formal meetings**
43	Project Mid-Term Review (month 18)
44	Project year 2 review meeting
45	Project Final meeting (33 months)



Responsibilities of each partner inside the project are summarized thanks to the work break down structure presented here under.



Responsibilities of each partner inside the consortium

PART 2 - IFATS FINDINGS AND CONCLUSIONS

4. DEFINITION OF THE IFATS CONCEPT

The basic feature of the IFATS concept is to go as far as possible in the ATS automation. Thus the first topic to be discussed is "what is possible?".

Several answers can be given; they are very dependent on the consulted people. Controllers will have their own view, based on their current work, knowledge and career perspective; the same applies for pilots (Ref. 2).

Dealing with public opinion is far more complicated. This opinion is made from the knowledge it has about the ATS automation, this knowledge is built from the information that can be provided on this type of concept, but this type of concept is not fully defined yet…

Instead of being stuck by this hen and egg problem, the approach that has been taken in the IFATS project is purely technical: thus, the concept that has been defined is a "technically possible" extremely automated system and not necessarily a "likely to happen" system.

In order to build the IFATSystem, several constraints have been taken into account. These constraints can be divided into three main categories: technical, cultural and social.

Considering the IFATS methodology, which is to study a fully automated system in order to derive an acceptable future one, only the technical constraints have been considered. Indeed, cultural constraints (passengers to accept to fly a pilot-free aircraft) and social constraints (pilot and controller jobs not existing any more) bring to much show-stoppers for the IFATS methodology and have no real impact on the high level technical definition of such a system that has been pursued in the project.

The main technical constraints are:

- For the ground segment: to be able to automatically manage the traffic planning, taking into account the airlines wishes as well as the various uncertainties of the flights. The emergency situations have also to be managed, possibly with the man in the loop;
- For the air segment (the aircraft): to be able to fully automate the flight, i.e. the capability of the aircraft to manage all the flight phases and all the pre-planned emergency situations (see this notion later);
- At a more global level, the safety and security of the system has to be ensured whatever the situation could be. This is achieved through secured data links and adequate communication protocols.

Taking into account the identified main constraints, the functional analysis of the IFATSystem has been performed. This analysis started by the definition of the function sharing between the air and ground segments.

To summarise, the ground segment is in charge of the system management that includes the 4D contracts generation (strategic and tactical planning, on ground and airborne). We will explain later what is this major IFATS key notion, the 4D contracts updates, the management or emergency situations for which no recovery strategy has been implemented in the aircraft, the system monitoring, the aircraft maintenance and the interface with the manned piloted traffic (general and military aviation).

The air segment is in charge of respecting the 4D contract given by the ground segment, of the trajectory monitoring and of new 4D contract requests (if needed). Other capabilities have also to be implemented on board, such as health monitoring functions, emergency situations management; update of the ATS database (especially for the current weather as any aircraft is a sensor of the system).

Based on the previous function sharing definition and on the observation of the current ATS functionalities, the IFATS concept has been defined. This definition started with the identification of the IFATS actors (Figure 1).

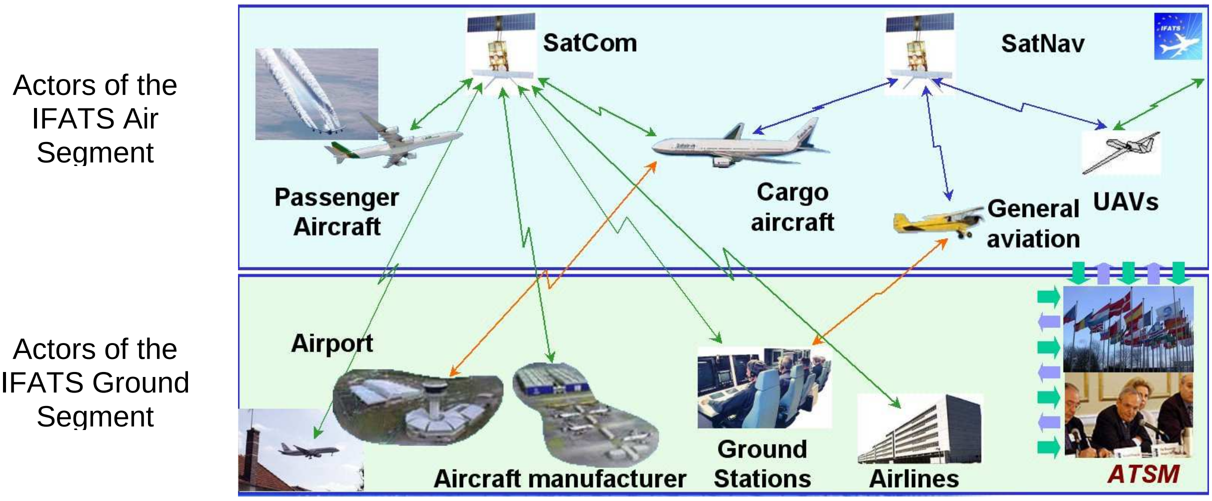


Figure 1 - IFATS actors

Most of these actors already exist today, but would require some adaptations to the IFATSystem.

The specific IFATS actors are:

- The ATSM (Air Transport System Management) which is in charge of the management of the overall system, especially the 4D contracts management (computations for original flight planning and real-time update);
- The ground stations, which are the physical parts of the ground segment in charge of the air traffic monitoring function.

The IFATS concept is based on three "key notions":

1. The 4D contracts: each aircraft is given a contract before its flight and it has the responsibility to respect it all along the flight. If it is not possible for any reason, it has to ask the ATSM for a new 4D contract or, at least, broadcast this information in the vicinity of its current flight zone; this will be detailed later in this report.

These contracts are generated by the centralised ATSM to be made of conflict-free flight paths. So, as long as all the aircraft are respecting their contracts, no conflict can occur (Figure 2).

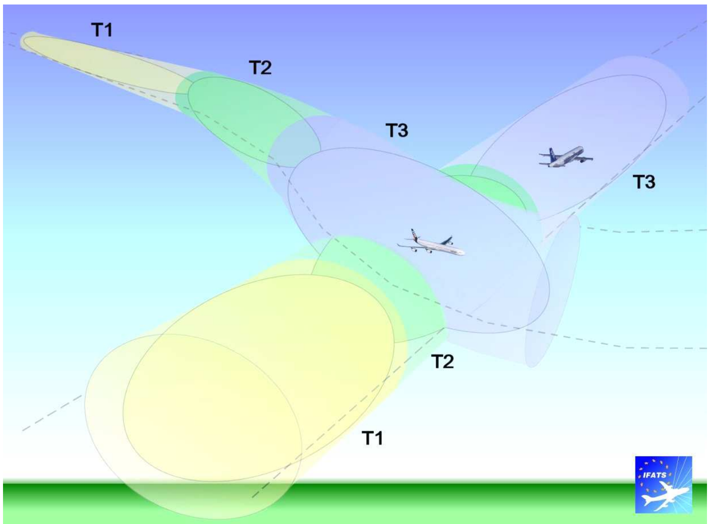


Figure 2 - Contractual 4D trajectories

2. The 4D contracts are given to the aircraft with some margins (e.g. in order to be able to manage small differences between the predicted weather and the real one).

These margins are called "bubbles" and are of two types: freedom bubble, in which the aircraft can freely fly (small modifications from the original trajectory are allowed) and safety bubble, larger, in order to ensure that no collision is possible between two aircraft flying on the edge of their respective freedom bubbles (Figure 3).

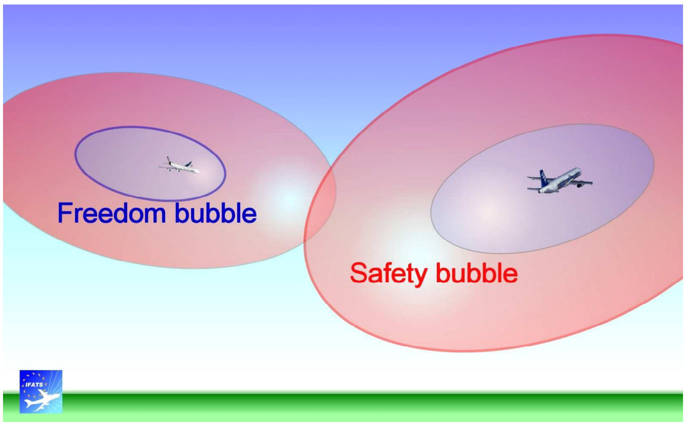


Figure 3 - Freedom in a fully constrained airspace

3. The 4D airspace: the four dimensions of the airspace are considered (x, y, z, t). Conflict-free flight paths are calculated taking into account these four degrees of freedom. The notions of waypoints, ATC sector and airways, which are essential to make a human air traffic control possible, can be abandoned.

5. IFATS CONCEPT OF OPERATION

The story starts with the 4D contracts generation (strategic planning, several months before the flights). These contracts are computed by the ATSM, taking into account the various constraints issued from the other ground actors (Figure 4).

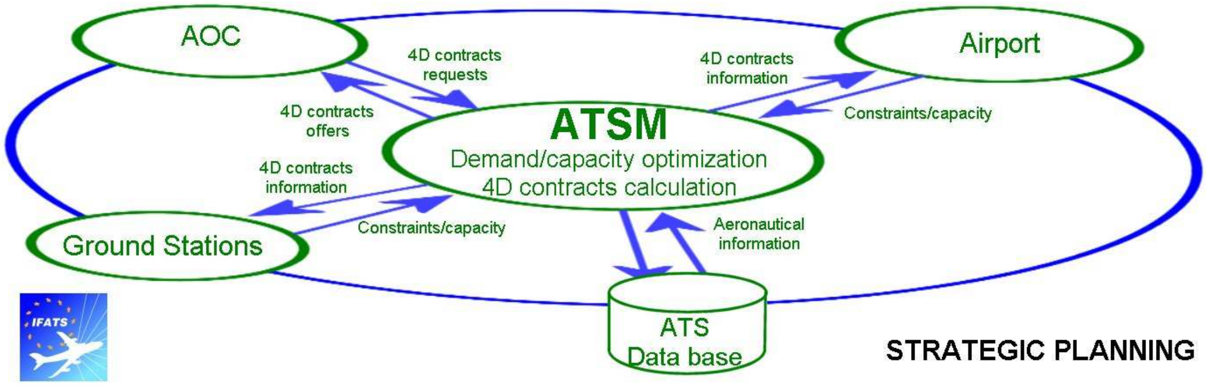


Figure 4 - The ATSM creates and manages the strategic planning

These contracts are updated just before the flight in order to take into account the latest weather report and forecast.

En route, in nominal conditions, the aircraft follow their 4D contracts, and if this is not possible, they ask the ATSM for a new one.

A fundamental enabler of the IFATS system is the data communication network. It is based on a network-centric architecture that is illustrated Figure 5.

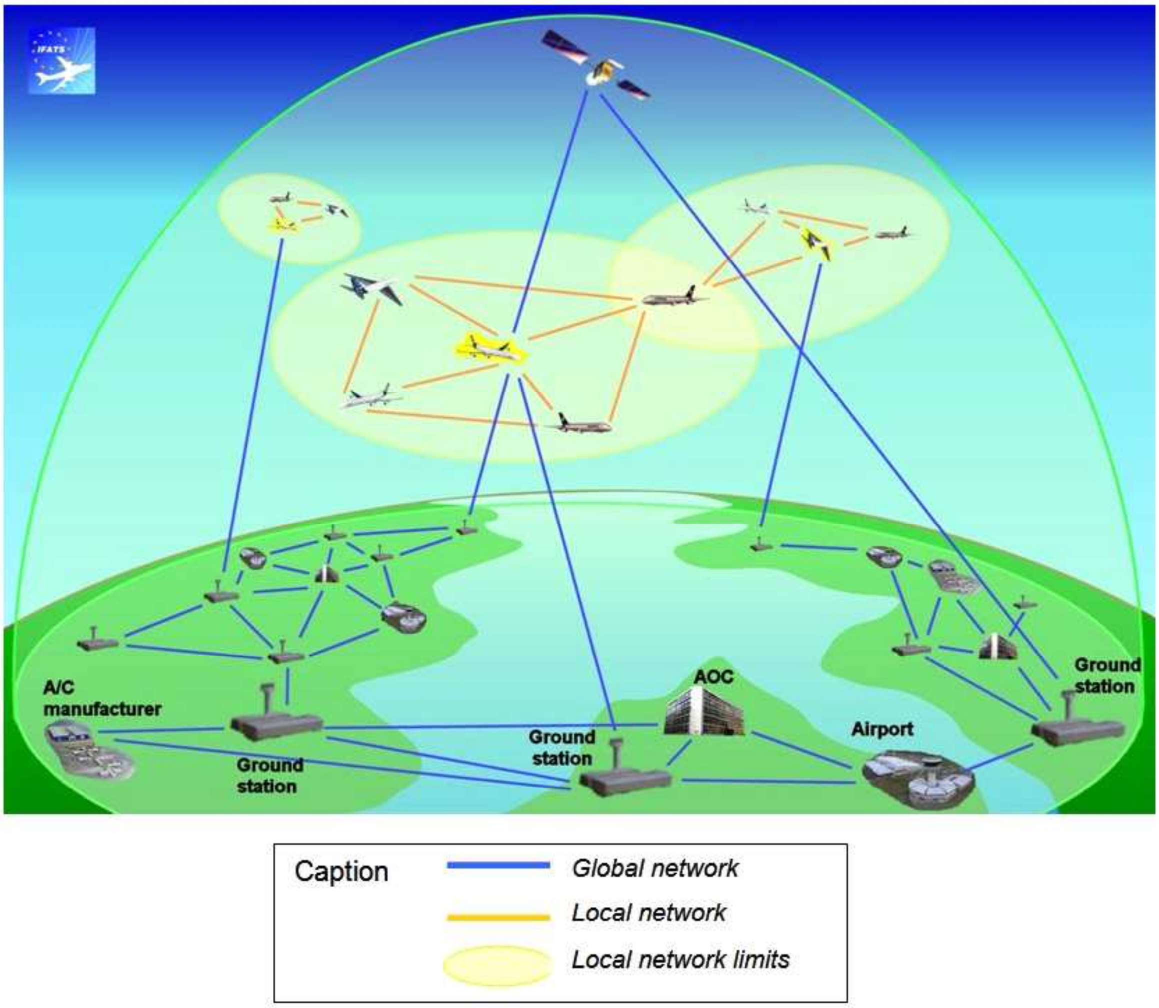


Figure 5 - General view of the overall architecture

To be more precise, this global architecture consists of two types of network:

- The global network figured in blue colour in Figure 5 and Figure 6: this large spatial extension network links all the ground segment sub-systems and all the aircraft. This network is used in nominal conditions for all the communications;
- The local network figured in yellow colour in Figure 5 and Figure 6, links aircraft which are close to each other in a given area. This network is mainly used for emergency situations autonomous management, when there is no time to send a request to the ATSM to get a new contract.

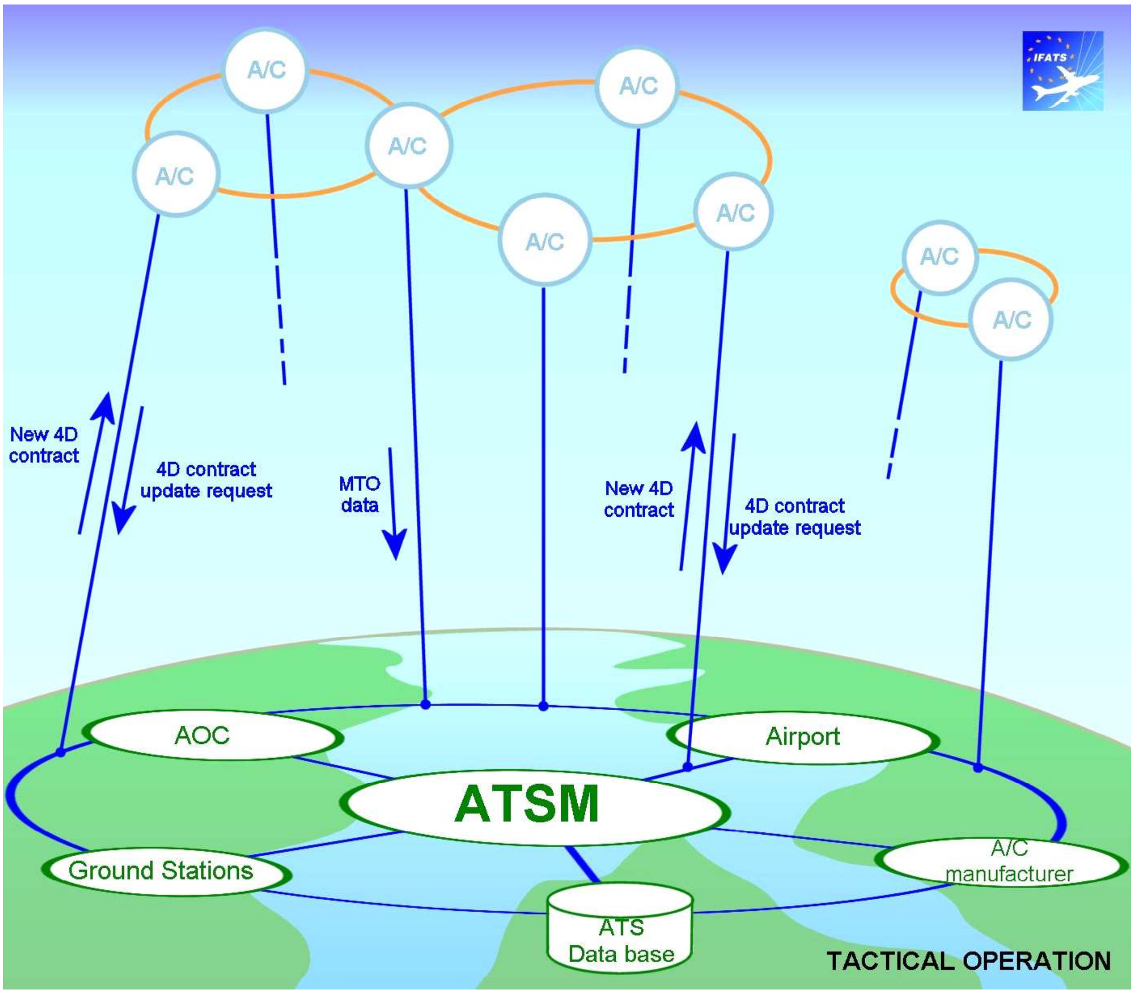


Figure 6 - View of the two types of network

6. IFATS EMERGENCY MANAGEMENT

The emergency/failure management is, of course, included in the IFATS concept definition. A comprehensive analysis of all the possible cases has been performed in the project. Generally speaking, if a failure for which a recovery strategy has been implemented occurs, this pre-planned recovery strategy is directly applied.

If a failure for which no recovery strategy has been implemented occurs, the aircraft status is downloaded to a team of experts sitting at the manufacturer of the concerned aircraft place on the ground. Using high capability computing resources and their knowledge of the aircraft, these experts can define a recovery strategy that is immediately uploaded to the aircraft.

Figure 7 illustrates one of the cases that have been analysed. The small circles represent aircraft, the blue ones are healthy aircraft complying with their contract, and the red one represents an aircraft facing an emergency situation which makes impossible the compliance to its 4D contract. The yellow circle represents the local data communication network whereas the arrows show the overall communication network use.

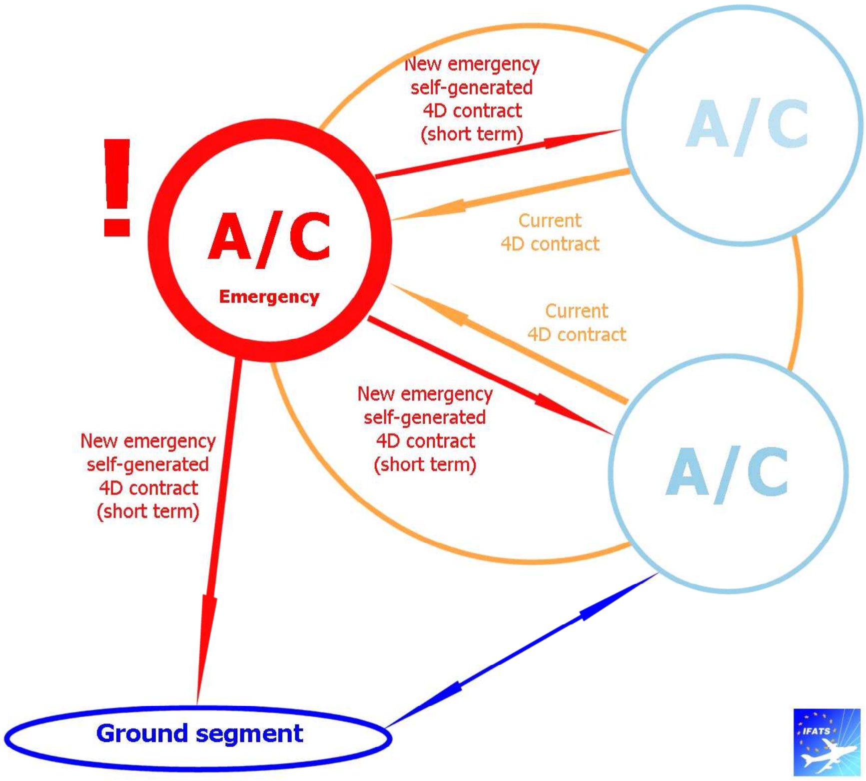


Figure 7 - Emergency situation management

In Figure 7, the aircraft facing the emergency (red circle) self generates a short term 4D contract from its local situational awareness gained thanks to the local network. This change in the local planning is disseminated to all the aircraft flying in the vicinity of the aircraft in difficulties and to the ground segment. When time permits, new 4D contracts are given to all the aircraft that have been affected by the considered emergency.

7. IFATS PERFORMANCE

The performance assessment of the IFATS concept has been performed by many of the project consortium partners. This report summarizes the work that has been performed until the end of the project. Additional information is included in the detailed reports that have been published all along the project.

7.1. Weather forecast accuracy

The IFATS concept and its expected capabilities depend on many factors; the weather forecast accuracy is a major one.

This is due to the fact that the strategic planning is developed from the long term weather forecast whereas the tactical planning has to face the real time weather encountered by the fleet of the airborne aircraft.

To help analyzing the sensitivity of the IFATS concept to this problem, a conceptual flight simulation has been developed, incorporating actual and predicted weather data and possible flight strategies.

This simulation goal is to set a rational basis for deciding on the IFATS concept implementation. The specific goals are:

- assess the accuracy of weather forecast;
- assess the expected flight path/time deviations form a pre-planned trajectory due to differences between the forecast and the actual weather;
- analyze the effect of the 'bubble' size on the number of trajectory re-plans en-route;
- estimate the effect of airspeed corrections on the above, by applying velocity control in order to decrease deviations in time/position.

Some basic assessments have been made to set the parameters of the simulation. As an example, actual weather is not considered to be known instantaneously, but with an approximately one hour data processing delay.

The main objective of the simulation has been to obtain statistics of time differences between the pre-planned and the actual aircraft trajectories. To this end, different routes, departure times, and days of the year have been systematically analyzed over a part of Europe. To reduce complexity, the flights were performed along the grid, at constant altitude and Mach, covering both north/south and east/west headings.

Each line of the grid has been used to specify the 3D flight-paths, for a total of 125 east/west and 221 north/south possible flight paths, see Figure 8.

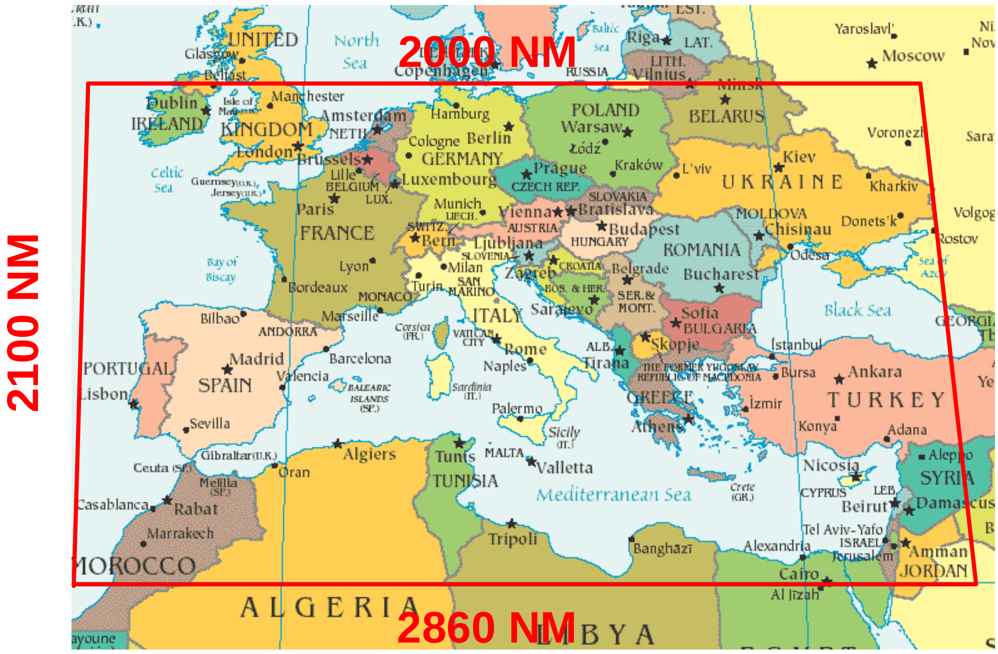


Figure 8 - Zone considered for the meteorological analysis

For each flight, a pre-planned 4D trajectory contract has been issued based on the most recent available weather forecast. In particular, estimated time of arrival to each grid point along the trajectory has been computed. Next, using actual weather, the actual time of arrival to each point along the trajectory has been computed, assuming the aircraft follow exactly the prescribed 3D flight path. The differences in the arrival time have been translated into position errors using ground-speed. Since the aim of the simulation was to gather statistics on time/position errors, it did not address conflicts. Hence all trajectories dealt with were assumed to be conflict free.

Regarding the meteorological data used, they were purchased from Meteo-France:

- Actual and forecast weather: wind and temperature in Europe, year 2004
- Weather data at 00:00, 06:00, 12:00, 18:00
- 6, 12 hours forecast
- Data area 15°W-40°E, 30°N-61°N, resolution of 0.25°

Most of the simulations were carried out with a 'bubble', defining the allowable aircraft position variations around the nominal 4D trajectory. Since the aircraft were restricted to follow the 3D paths exactly, only deviations along the flight path were evaluated. In those simulations, when the trajectory position error exceeded the bubble size (an event referred to as a 'bubble exit' in the sequel), a new 4D contract with updated times along the grid was issued instantaneously. This trajectory, initiated at the current aircraft position and time, was generated along the original 3D flight path using the most recent weather forecast and, as before, was assumed to be conflict free with other traffic.

The simulation includes optional velocity control logic to reduce the aircraft 4D trajectory position errors, or, equivalently, to control the aircraft so as to remain within the prescribed trajectory error bubble. In the currently implemented logic, at each grid point, the velocity control algorithm was designed to minimize the time deviation from the pre-planned trajectory at the next grid point. It was assumed that the airspeed (or Mach) can be changed instantaneously. The airspeed corrections have been saturated by maximum and minimum values (e.g. plus or minus 0.02 Mach) defined by the user.

Only en-route simulations were carried out in this study. In all cases, nominally, the aircraft were assumed to fly at a constant Mach number of 0.8 and flight level 340. It was assumed that this Mach number was the optimal Mach number for cruise. Flights departed along all the grid lines every hour at 1, 2, 3, 4 and 5 pm. At this stage only east/west flights were analyzed. An array of about 125 aircraft, departing at the same time along the respective east/west grid lines will be referred to hereafter as a 'wave'. The simulations covered one month (30 days) of April 2004.

Let's consider the simulation case that is the closer to the expected capabilities of the aircraft and of the weather forecast accuracy in 2040:

- Flight with velocity control of ±0.02M, bubbles of 1.5, 2, 3 and 5NM

Weather forecast was accessed by examining the difference between actual winds at altitude of 34 kft and their 6-hour forecast. It was observed that the mean and standard deviations of the forecast errors are practically the same during the whole period examined both for south-north and west-east winds components.

The mean and standard deviations are 0 and 3 knots, respectively. The maximum forecast errors vary between 8 to 15 knots for most of the period, peaking to over 40 knots (0.065 Mach at this altitude) on April 15. These deviations are beyond the aircraft airspeed change capabilities.

Thus, with such deviations the aircraft would not be able to comply with its 4D trajectory and a new contract would need to be generated by the ground segment.

Figure 9 shows a contour map of these differences over the simulation area for mid-day of April 15, 2004.

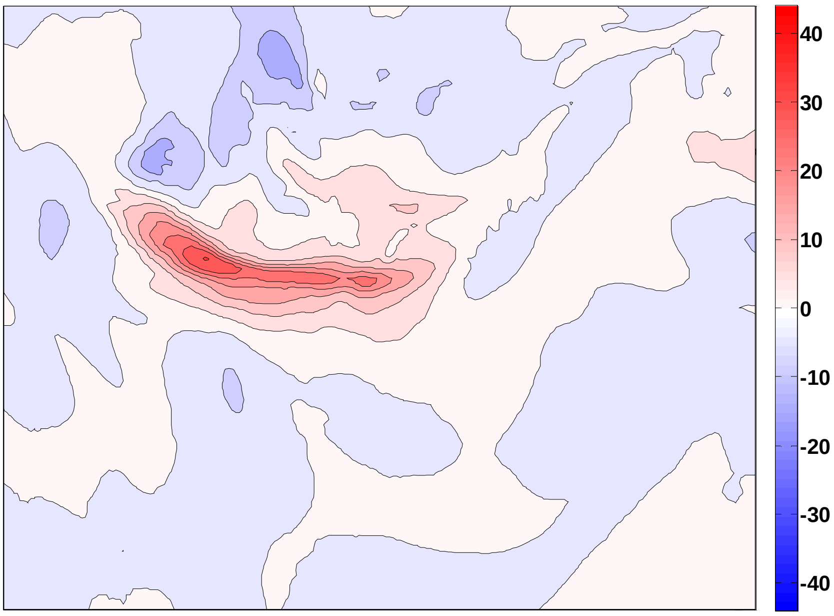


Figure 9 - Weather 6 hour prediction accuracy, April, 2004, 18:00 winds West-East

The inaccuracies in the weather forecast lead to time/position deviations from the pre-planned trajectory. Both maximal and standard deviations from the pre-planned trajectories increase with the flight time and weather forecast time interval from the most recent weather update to departure.

In order to estimate the trajectory re-planning rate, the notion of bubble-exits per hour per aircraft in the air was introduced. This quantity can be interpreted as the probability density function of a currently flying aircraft to exit a bubble, i.e. having to negotiate a new 4D contract.

For 6000 aircraft simultaneously in the air, with velocity control of ±0.02M and the smallest 1.5NM analyzed bubble size, the maximum expected re-plan rate would be 2.5 re-plans a minute. Maintaining the velocity variations at ±0.02M and increasing the bubble size to 5NM reduces the number of re-plans to 0.002 per aircraft per hour maximum. That would require 1 re-plan every 5 minutes for the entire 6000 aircraft fleet.

The major conclusion of this study concerns the weather forecast accuracy. It is evident that time/position deviations and therefore the amount of required trajectory re-plans increases with time. For long flights the accuracy of the forecast is insufficient and hence trajectory re-plans are unavoidable.

However, it has been observed that, taking into account a velocity control of ±0.02M for all individual aircraft and reasonable expected weather accuracy for the time frame of a potential implementation of an IFATS concept, the anticipated number of contract re-negotiations appears to be within the limits of the computer capabilities at this same 2040 horizon.

7.2. Communication network structure and management

The IFATS global network is based on a centralized TDMA (Time Division Multiple Access) with ground stations (see Figure 6). At a any time, any aircraft is communicating with several ground stations as shown on Figure 10.

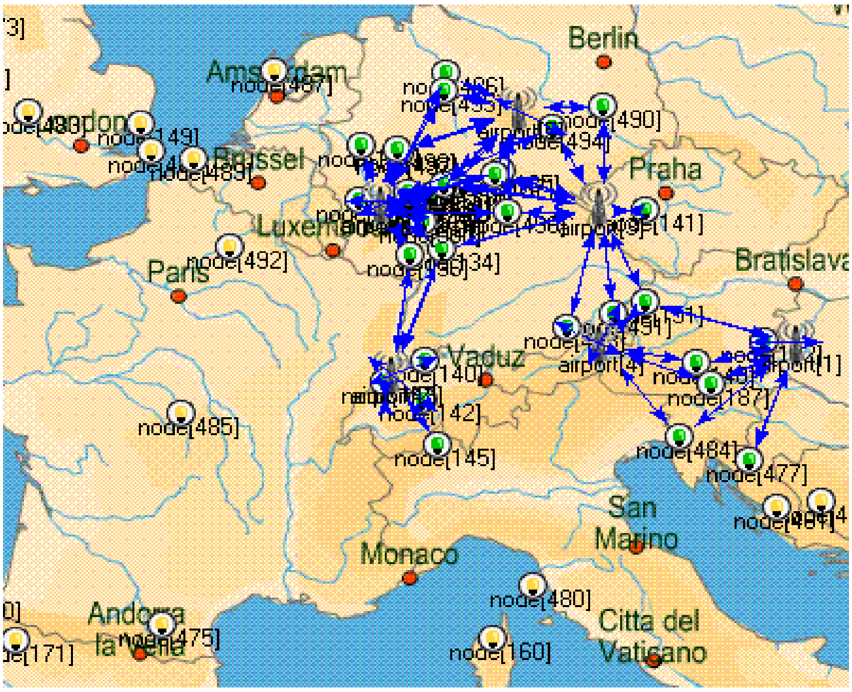


Figure 10 - Global communication network

A Quality of Service (QoS) policy depending on the priority of the message to be transmitted has been developed. The services that could be needed for an IFATS aircraft are numerous, the most important ones are:

- 4D contract re-planning;
- Weather transmission;
- Immediate Support request;
- Maintenance purpose;
- Communication with AOC.

Since bandwidth is scarce and will stay scarce in the future, the innovative proposed solution for the IFATSystem is to share the bandwidth between different services and to set priorities between them.

Obviously, when an IFATS aircraft needs a 4D contract update or an immediate support, the communication priority level must be high whereas weather transmission and maintenance support may have a lower one.

In order to design the data link, the simulation tool enables to measure the required bandwidth and latency. The Quality of service concept, which is quite innovative in such a system, allows to share the bandwidth and to give access to the radio layer to the one that really needs it.

Regarding security, each message is secured by a cyclic redundancy check (CRC) and an encryption key in order to avoid corruption of information and intrusion.

Whatever the number of needed ground stations can be, the required bandwidth has been estimated by the simulation to 2MBit/s per ground stations which can fit into 2 MHz for one Ground stations.

Considering that 21 frequencies are required for the whole world, it means that IFATS need about 42 MHz for its ground to air communications.

The IFATS local network (see Figure 6) is based on a distributed STDMA (Self-organizing Time Division Multiple Access) scheme (not centralized) locally linking aircraft in the vicinity of the same location (Figure 11 and Figure 12).

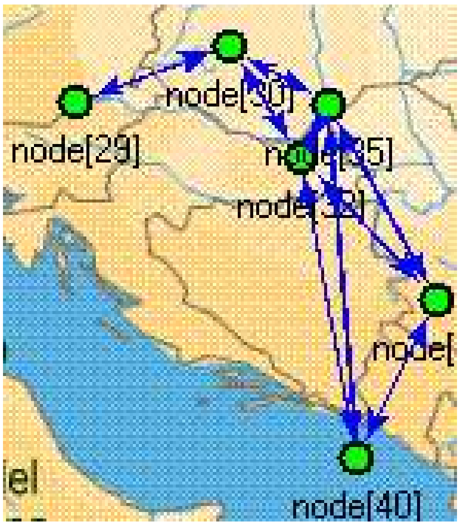


Figure 11 - Local network without critical situation

Figure 12 - Local network with critical situation (aircraft with a red circle)

For this network, a distance based QoS policy has been defined: if two aircraft are close from each other, messages are sent at a higher rate (local network, Figure 12). Otherwise, aircraft are sharing the remaining bandwidth.

The proposed data link layer is self-Organizing TDMA (Time division Multiple Access). Each plane will send its position, intention and will reserve slots for the next frames. Some optional field will be sent:

1) Weather information
2) Acknowledgement

If the conditions require sending weather or turbulence information, an ADS-B message will be completed by weather information.

With the current traffic, one 50 kHz channel is enough, according to the simulations. In order to accept more aircraft, two channels (100 kHz) will be needed: one for en-route and one for TMA. This bandwidth can fit into one VHF channel.

On these two channels, there will be several qualities of service:

1) Conventional situation and weather awareness (at a tentative rate of 1 message per 5 seconds);
2) Situation and weather awareness with good quality of service (at a tentative rate of 10 per second);
3) Relay (on available slots).

This quality of service enables to share the bandwidth to the situation that needs it.

7.3. Aircraft health monitoring

Since no pilot is present in an IFATS autonomous aircraft, its health monitoring should be based exclusively on purposely designed devices (hardware) and methodologies (software). Both solutions should contribute to the increase of the autonomous decision-making capabilities of the aircraft.

One should always expect that the introduction of extra autonomy in the pilot–less IFATS aircraft would lead to an even more complex system, which should be monitored even more accurately than by the past. Introducing even more sensors (hardware) for health monitoring purposes seems unavoidable. However, their number must be kept as low as possible, in order to maintain (if not improve) the failure probability rates, following the complexity increase due to the new sensors.

The approach considered in the IFATS project is faithful to the above mentioned principle. The health monitoring scheme of the IFATS aircraft has been designed to rely on available data from existing devices, which are processed via novel advanced algorithms and methodologies to deliver reliable health information about the monitored aircraft subsystems. Hence, the scheme may be used either as a stand alone application or as a complementary device which cross-checks some existing health monitoring information, thus augmenting the analytical redundancy present onboard.

The scheme is based on supervising the interactions between subsystems of the aircraft. These interactions are always valid for an aircraft operating in healthy (that is fault-free) state. When one or more faults affect the aircraft, these interactions change significantly. Hence, a health monitoring scheme is designed to check the behaviour of the previously mentioned interactions and deliver Fault Detection and Isolation (FDI) results. In practice, the scheme is designed as follows:

A. According to the monitored component, the interaction between two groups of available recorded signals is considered. The first group contains the “input” signals and the second the “output” ones. Their dependency (or interaction) may be modeled via advanced mathematical pooled nonlinear representations, which are generally well-suited for describing the considered dynamics under a multitude of aircraft operating conditions (turbulence, cross-winds and so on) and flight envelope points. Hence, these representations are superior to physical-principle based ones (when these are available), which may often be only locally valid. The modeled interactions correspond to an aircraft operating in healthy state under varying external conditions and flight envelope positions.

B. When a typical “healthy-state” nonlinear representation is identified, it is used onboard an aircraft in unknown health state, to evaluate the interaction of the previously-defined groups of signals at each time instant. If the current interaction is statistically found to differ with respect to the typical “healthy-state” one, then fault occurrence is deduced. Furthermore, using advanced hypothesis tests, the scheme is also capable of isolating the occurred fault(s) as potentially belonging to some predefined fault classes.

Two main aircraft systems are monitored, namely the control surfaces (elevator and ailerons) and the engines.

The control surfaces health monitoring is based on the Multiple Input Single Output (MISO) relationship (interaction) of four signals:

- Three taken as inputs (angle-of-attack, lateral and vertical accelerations) ;
- one as output (pitch rate).

The interaction is modelled for a healthy aircraft via a Constant Coefficient Pooled- Nonlinear AutoRegressive with eXogenous excitation (CCP-NARX) representation. The changes on this interaction for an aircraft operating in unknown health state are checked and evaluated through purposely built statistical hypothesis tests (see *UPatras D.330-2 Design and Demonstration of Fault Detection and Identification Autonomous Decision Making Algorithms* report) to deliver FDI results.

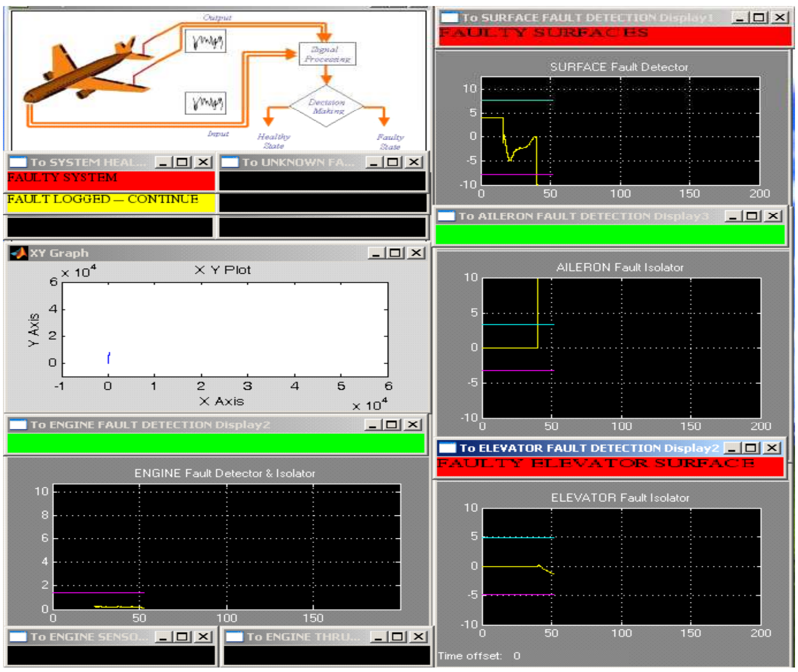


Figure 13 - Simulation Interface for onboard FDI results: The aircraft experiences a faulty elevator, detected in the upper RHS monitor and isolated in the lower RHS one

The health monitor interface (built in SIMULINK™ v. 7.1) as tested in the simulation campaign in December 2006 in Braunschweig, Germany is presented in Figure 13. The aircraft trajectory is presented on the XY-plot monitor (left column, in the middle), the potential control surfaces faults are detected in the upper RHS monitor and isolated in the remaining two RHS ones (faulty aileron and faulty elevator from top to bottom, respectively). Engine faults are detected and isolated in the lower LHS monitor.

Fault detection and isolation is accompanied by a color change (from green to red) of the corresponding monitor tag, as shown in Figure 13, for the detection and isolation of a faulty elevator.

The engine health monitoring is based on the Single Input Single Output (SISO) relationship (interaction) between the throttle and the thrust signals (see *D 520-3 Demonstration of IFATS Aircraft System Fault Detection and Identification Software* report).

The interaction is modelled for a healthy aircraft via a Constant Coefficient Pooled- Nonlinear AutoRegressive with eXogenous excitation (CCP-NARX) representation.

The changes on this interaction for an aircraft operating in unknown health state are checked and evaluated through purposely built statistical hypothesis tests (see *UPatras D.330-2 Design and Demonstration of Fault Detection and Identification Autonomous Decision Making Algorithms* report) to deliver FDI results.

Note that in this document a simpler version of the engine health monitoring scheme (based on modelling of the single thrust signal via CCP-NAR representations) had been proposed. However, the version tested in the simulation campaign used the better performing solution based on the CCP-NARX representation. A typical example of its operation may be seen in Figure 14.

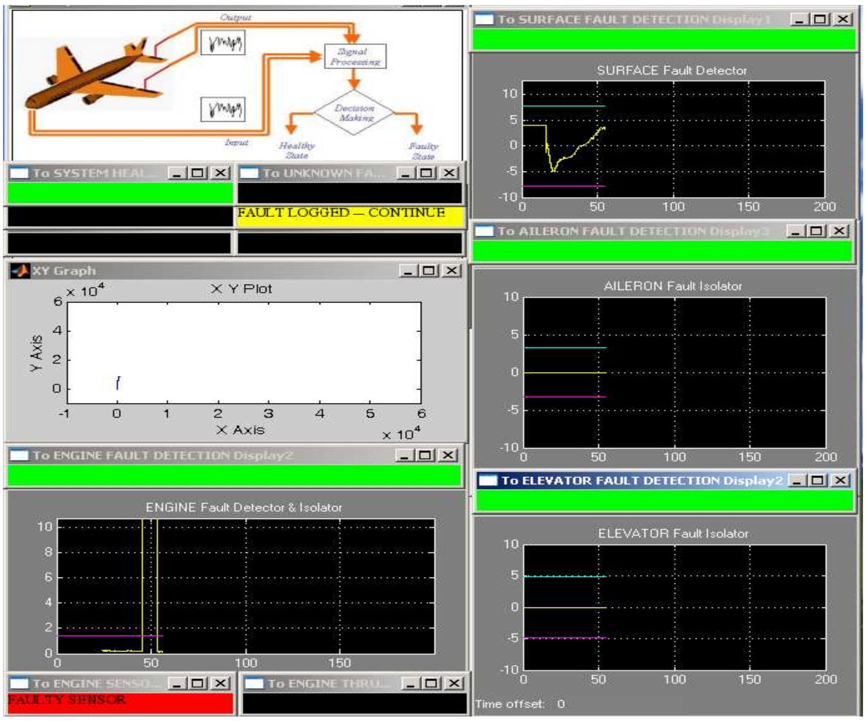


Figure 14 - Simulation Interface for onboard FDI results: The aircraft experiences a faulty engine sensor, detected and isolated in the lower LHS monitor

According to the validation tests (see *UPatras D.330-2 Design and Demonstration of Fault Detection and Identification Autonomous Decision Making Algorithms* report), the fault detection and isolation rates of the FDI scheme were very good in the majority of cases. Detection rates were always higher than 93%, while isolation rates exceeded 95% in most cases. Note that, during the validation process several hundreds of test flights (conducted under varying turbulence conditions with light or intense maneuvering) were used to obtain the aforementioned rates.

The simulation campaign, held in December 2006 in Braunschweig, Germany, highlighted the effectiveness of the FDI scheme, since this was additionally tested with an aircraft affected by sequential faults (initial elevator followed some seconds later by an unknown sensor fault, see *D 520-3 Demonstration of IFATS Aircraft System Fault Detection and Identification Software* report) with equally good results.

A special comment has to be made on the sensor technology needed for the successful operation of the health monitoring scheme. In all cases considered, the scheme's design allows for sensors already present in conventional aircrafts, to be used with good results. This also points out, that the use of improved performance sensors could further enhance the detection and isolation capabilities of the FDI scheme. Since no further sensors are needed for the scheme's operation, it is expected that the system complexity would be kept at the same level as before the scheme's integration to the aircraft. Hence, the failure probability rates should not deteriorate.

It is also expected that the extra computational burden, resulting from the signal processing and the statistical hypothesis tests which is carried out onboard the monitored aircraft, will not be a major drawback for two reasons:

The CCP-NARX representations utilized are quite compact and they may operate in almost real time, if a powerful PC and a dedicated modelling environment (instead of a general purpose tool like SIMULINK™) are used.

The hypothesis tests, which statistically evaluate the CCP-NARX-provided information to deliver health monitoring results, are instantaneous.

Finally, the exact numbers of fault classes which can be detected and potentially isolated have yet to be defined. The fault classes considered in this project (control surface and engine faults) are quite significant, but more research is needed in order to make an accurate estimation of the faults which can be reliably diagnosed out of each I/O relationship. It may however be asserted, that practically most of the *high level checks* (control surface basic operations, engine response to throttle, landing gear operation and so on) may be reliably undertaken via the use of many similar FDI schemes, operating in parallel and monitoring many I/O relationships through existing recorded signals.

7.4. Autonomous separation provision and collision avoidance

The IFATS concept is based on the fact that in all the airspace covered by the system, all IFATS aircraft are cooperative: they broadcast their position and speed via data-link. There are not any more conflicts as the Ground Segment generates conflict free contracts. The non-cooperative aircraft have to fly in specific areas, known by the system.

Since aircraft are fully automated, they have to be as autonomous as technically possible during the whole flight. In case of failure of the Ground Segment or complete data-link loss (emergency condition), IFATS aircraft must be able to generate autonomously temporary conflict free trajectories. Moreover, they must be able to detect non-cooperative aircraft which can be lost out of their reserved areas.

Hence, in for the IFATS flight segment, two functionalities – both *Autonomous* and *Airborne* – need to be considered:

- *Separation Assurance* – This functionality is activated when air-to-ground data-link is lost but air-to-air data-link is working. Thanks to the air-to-air data-link each aircraft can detect and resolve conflicts (by generating new short-term 4D contracts) autonomously. Moreover, air-to-air data-link allows conflicts to be detected and resolved at relatively long ranges (100-140 n mi) so to guarantee the Separation Assurance. Manoeuvres are cooperative and the short-term 4D-contract generation algorithm of each aircraft has to compute a new conflict-free 4D contract which it has to follow.

- *Collision Avoidance* – This functionality is activated when both air-to-air and air-to-ground data-link is lost (total data-link loss). In this case the last resource to detect conflicts is represented by onboard sensors, which have a restricted field of view (at present the range of onboard radar is 3-6 n mi). For this functionality, avoidance manoeuvres have to be considered non-cooperative. Instead of short-term 4D contract generation, one has to talk about "Collision Avoidance" manoeuvres: they are adjusted time by time (with a proper update rate) in order to take into account all unexpected trajectory changes of other aircraft.

The onboard Autonomous Separation Assurance and Collision Avoidance System (ASACAS) provides backup to a similar function existing in ATSM. ATSM provides separation at a relatively long range, whereas airborne ASACAS is engaged autonomously, at a mid/long range when separation has failed and caused a collision situation.

The ASACAS can compute autonomously, through the detection of potential collision situations, a short term 4D trajectory that performs the right separation and/or collision free flight path. ASACAS is completely different from current ASAS and TCAS equipments, since ASACAS generates full 4D trajectories, can perform both cooperative and non-cooperative collision avoidance manoeuvres (whereas TCAS works only in cooperative way) and performs optimal avoidance manoeuvres, i.e. the deviation from the nominal trajectory is minimized.

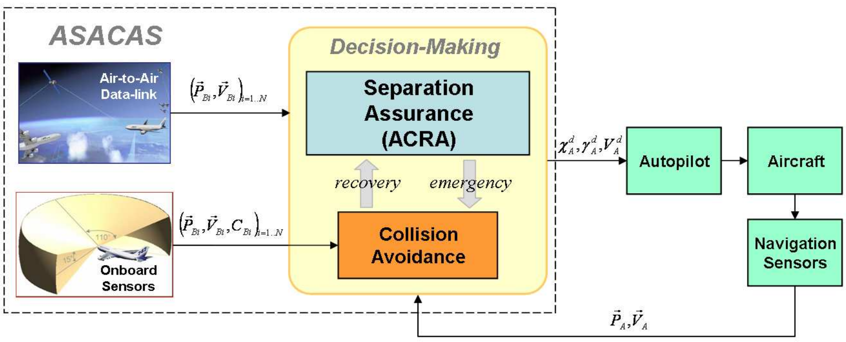


Figure 15 - Functional architecture of ASACAS

The core of the functional architecture of ASACAS (cf. Figure 15) is represented by a decision-making algorithm which receives speed and position vectors of the own aircraft together with speed, position vectors and intents of surrounding aircraft. On the basis of this information, the decision-making algorithm computes the right reference signals for the autopilot, in terms of speed module, track and slope demands.

As for the Collision Avoidance module, the design of the ASACAS has been performed by considering as a starting point a geometric approach used in planar mobile robotics; then a novel algorithm for the 3D case has been derived, where the deviation from the nominal trajectory is minimized (optimal conflict free flight path generation).

As to the Separation Assurance module, an Automated Conflict Resolution Algorithm (ACRA) can provide autonomous aircraft separation assurance: after a conflict arising with one or more aircraft has been detected, ACRA can produce a safe conflict resolution trajectory to maintain separation with other traffic. ACRA has been conceived as an autonomous system, to be installed onboard aircraft and generate commands directly to the autopilot. ACRA is not rule-based but uses an efficient computational approach, thus resulting suitable for real-time applications. An important characteristic built into the ACRA strategy for generating the conflict resolution manoeuvre is the principle of minimizing deviation from the original trajectory. The decision-making logic implemented into ACRA foresees two control strategies properly combined: Speed Control Strategy and 3D-Directional Control Strategy.

While the Collision Avoidance module has been developed and tested at a detailed level, for the Separation Assurance module it has been carried out a conceptual design with a preliminary validation via simulation.

In order to prove the effectiveness of the proposed algorithms, families of conflict resolution solutions were constructed by ACRA, via Monte Carlo simulations, according to a realistic conflict scenario. General properties of efficient conflict resolution manoeuvres have been determined, based on the observation about the structure of this solution family. Simulation results showed that all conflicts can be solved. Numerical simulations by using a more challenging scenario have also been carried out. In particular, realistic aircraft models (with proper dynamic limitations) have been taken into account, in order to remove the simplified hypothesis of instantaneous speed vector change.

Figure 16 shows an example of the self-organizing capacity of 16 conflicting aircraft equipped with ASACAS.

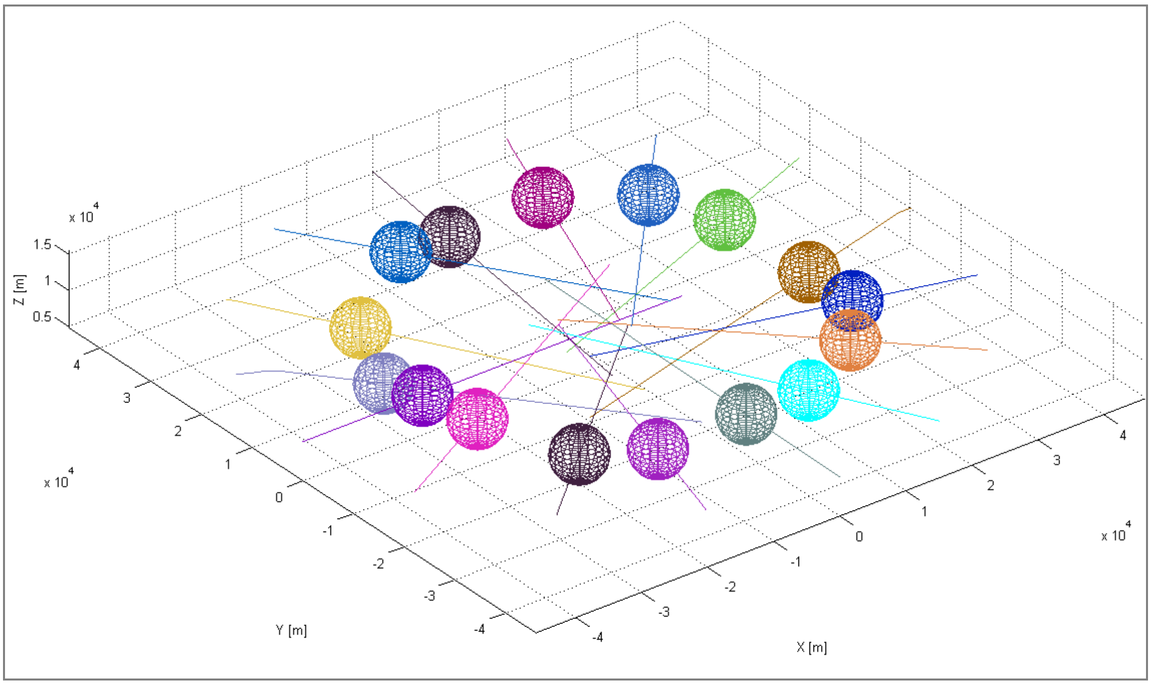


Figure 16 - Conflict resolution 4D trajectories of 16 conflicting A/Cs equipped with ASACAS

As case study, consider the following realistic scenario around Frankfurt airport analyzed during Simulation Campaign at the Braunschweig DLR site in Germany, as illustrated on Figure 17.

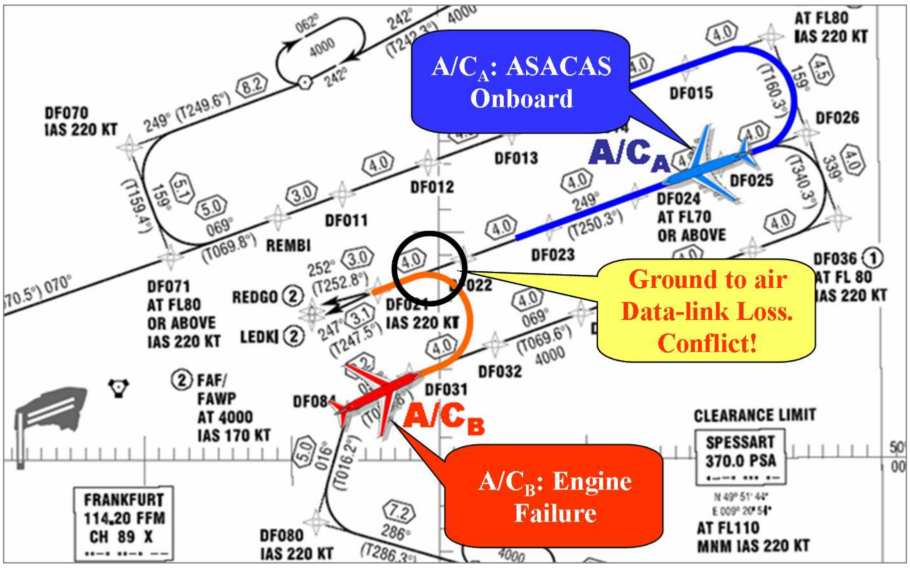


Figure 17 - Case study conflict scenario around Frankfurt airport

Two aircraft are approaching the runway: the red A/C has an engine failure and must land with priority. Ground Segment assigns to the red A/C a new 4D contract for emergency landing and to the blue A/C a new 4D contract to avoid a conflict which could arise with red A/C.

At the same time, blue A/C experiences an air-to-ground data link loss. Hence, blue A/C is not able to receive its new 4D contract: it has to generate autonomously its own temporary conflict free contract from its knowledge of the local situation.

Blue A/C, thanks to this local situational awareness and thanks to the ASACAS decision-making algorithm, can generate its temporary contract compatible with the current red A/C behaviour (speed, track and slope are changed simultaneously) maintaining separation with or avoiding the red A/C, leaving it to pass for the emergency landing (Figure 18).

The performed manoeuvre is “optimal” in the sense that deviation from the nominal trajectory is proved to be minimized, thus avoiding that blue aircraft becomes an intruder for other aircraft.

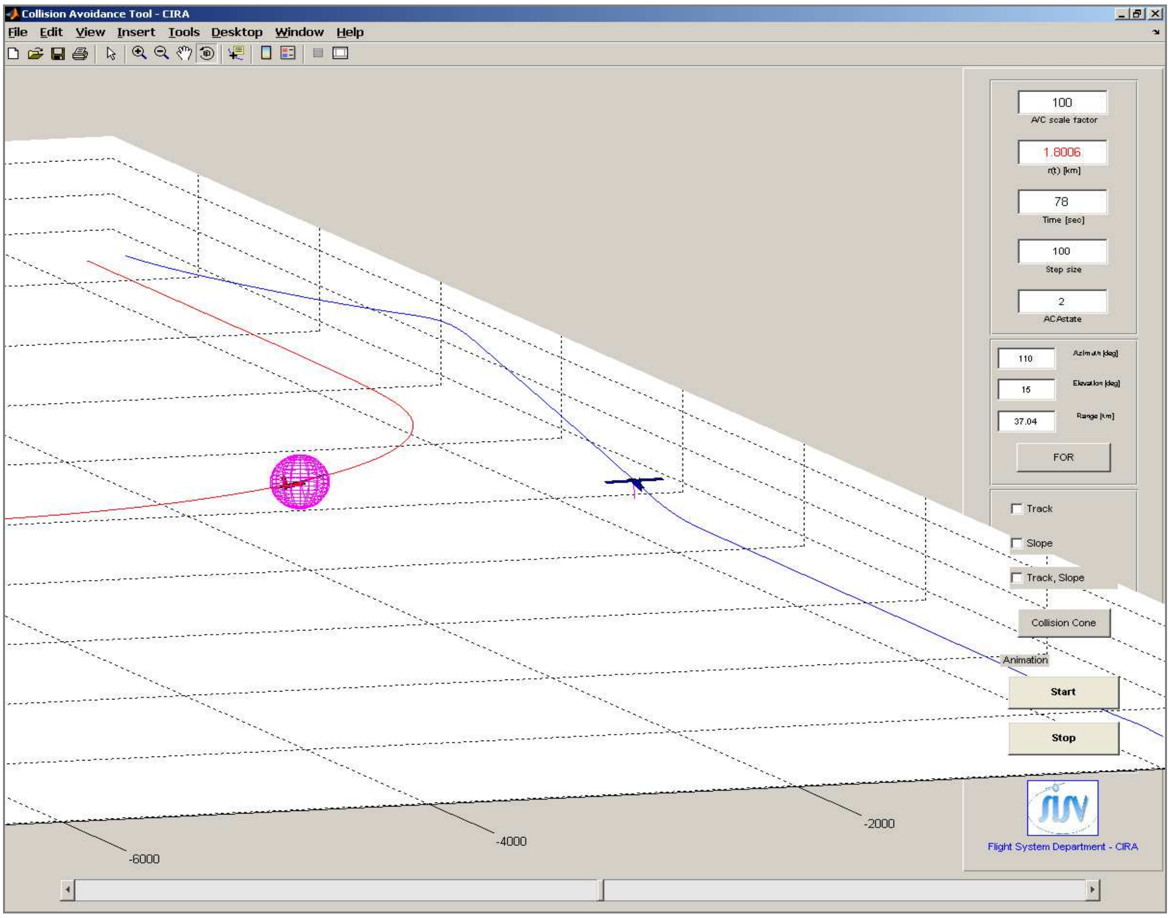


Figure 18 - Temporary autonomous 4D contract generation: a 3D collision avoidance manoeuvre

7.5. Safety analysis

The new concept of IFATS dictates naturally new air and ground architectures (no pilot onboard, no ATC), innovative technologies (communication, sensors, computation, infra-structure etc.) and new concept of operation. These leads of course to new requirements in safety: more redundancies, higher reliabilities, lower probabilities for failures and finally, new airworthiness and operation rules adjusted to the new concept.

The safety analysis in this project was conducted in order to identify the most critical hazards in the IFATS ground and air system, to propose mitigation factors in order to reduce worst severities (to values lower than I and II) and in overall to find the solution and the means that will enable us to increase safety by at least one magnitude of order compared to present requirements.

General description of the IFATS ground and air segments are presented in Figure 19 and Figure 20.

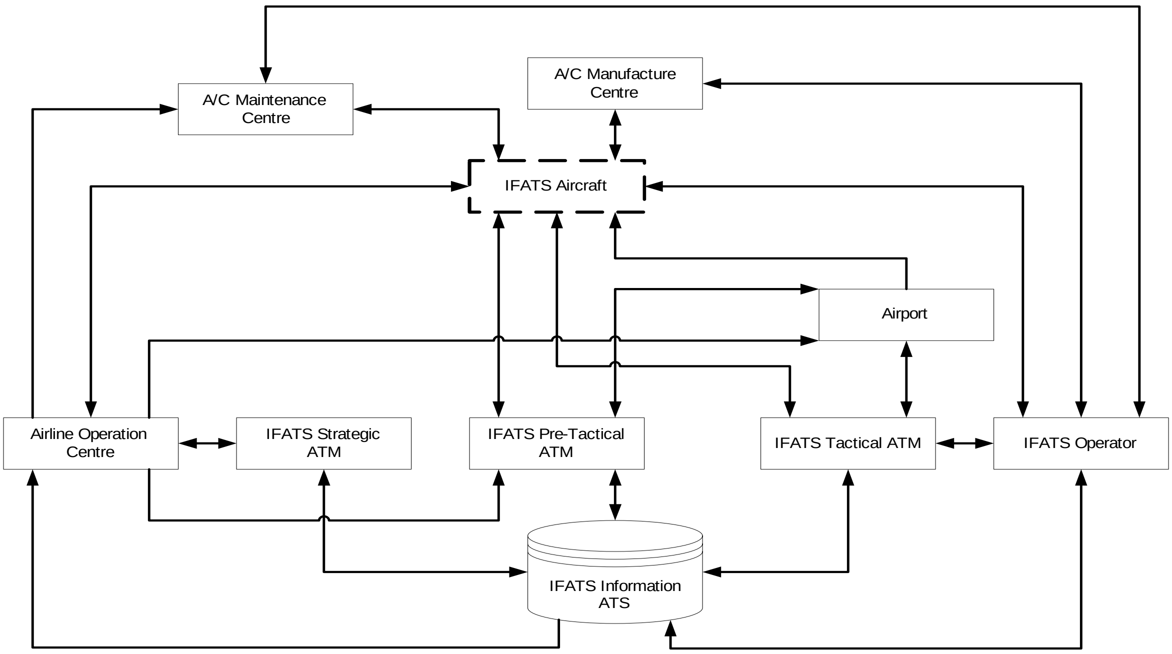


Figure 19 - IFATS Ground Segment

The major conclusions of the safety analysis showed clearly and obviously that loss of data or data corruption without situation awareness is one of the major drivers for the occurrence of hazard state with a severity class I and II impact. However, many hazardous concerning the loss of element functionality can be mitigated by back-up systems.

The key elements identified for the ground system were the tactical ATM and the information ATS database. Major drivers for ground segment safety were the data link safety; distributed computation; system redundancy and data base safety. Specific findings related to the ground segment were:

- Information should flow freely and be protected from corruption or outside access;
- Measures have to be established to prevent a corruption of data that is transferred;
- Encryption and check-sum technology (already available) can be used.

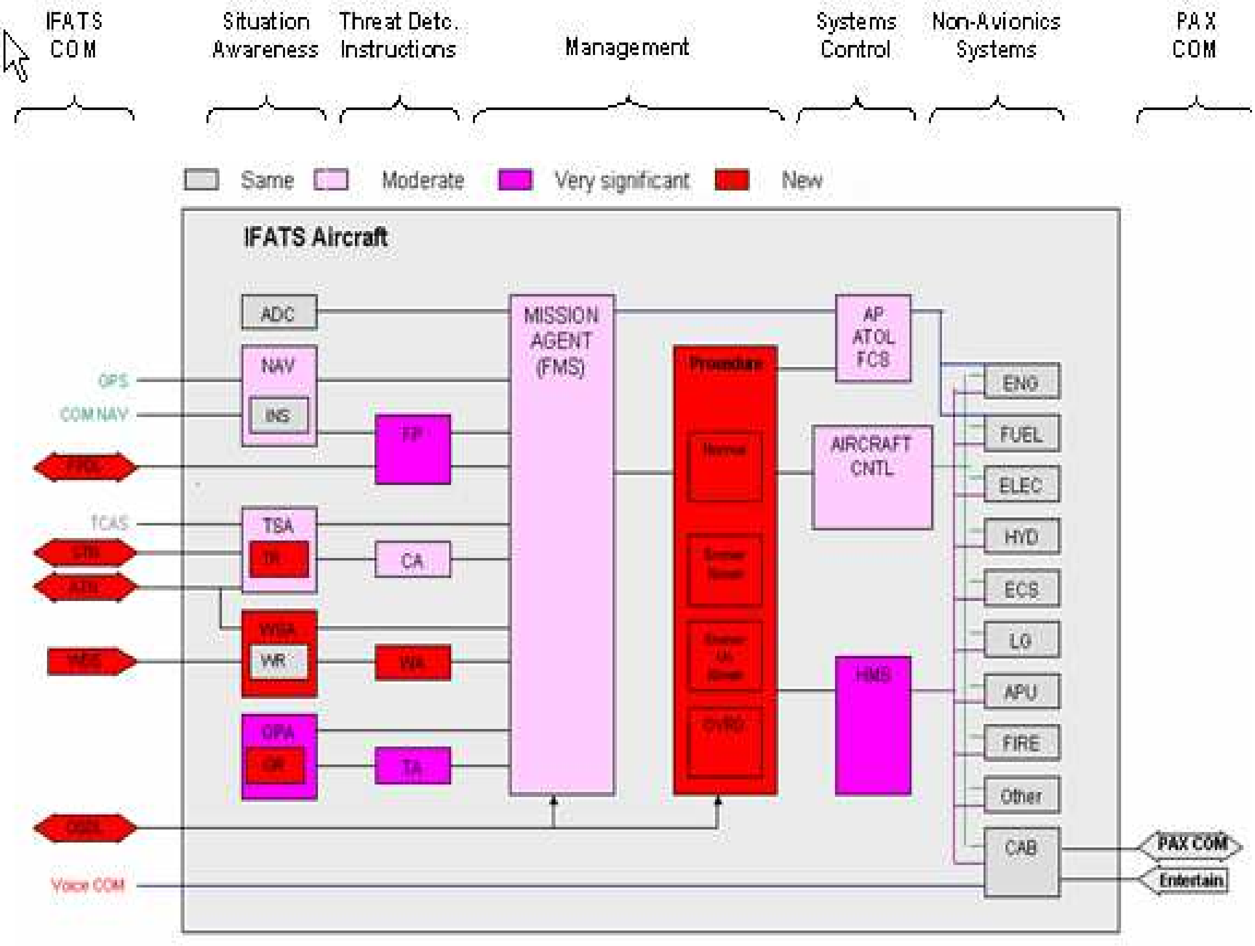


Figure 20 - IFATS Air Segment - Main functions

Specific findings related to the air segment were:

Identification should be based on cross checking of information from several sources and the solution should be based on independent redundancies: systems and measurements onboard; other aircraft; ground means (ATM, ATC, NAV-Stations).

Absence of pilot eyes in IFATS aircraft is one of the main issues in this analysis. Thus, the optional recommended risk mitigation is compensation by additional sensors and means: airborne radar, bird detection radar etc; image processing: change detection, move detection, super resolution etc.

7.6. Certification

The main findings on certification issues for IFATS concern the study of the following question: can we use the existing certification standards in the certification process of IFATS?

At a general level, it is interesting to note that the high level objective of ICAO SARPS, that are the baseline for current regulations of manned aircraft, is still valid for an IFATS aircraft: “protection of 3rd parties and property, plus cabin safety requirements aimed specifically at assuring adequate protection for passengers and crew “.

Moreover, as far as the ground air traffic management is concerned, the high level objectives of the ESARRs, dealing with the development and implementation of safety regulatory requirements in Europe, are applicable to an innovative ATM concept.

In order to investigate the possible tailoring of current regulations in the certification process of IFATS, the main regulations relative to the aircraft and to the ATM have been reviewed and practically tailored within the tailoring methodology recommended by the EASA[1].

7.6.1. The aircraft

The main adaptations of CS-25 concern, as it can be expected, the pilot tasks. Some tasks relative to cabin and passengers can be executed by the senior cabin crew member. The most critical tasks relative to the monitoring, the control and the management of abnormal situation are managed by the “brain” of the IFATS aircraft called the “air Manager”. The requirements of the Air Manager, in charge of monitoring and controlling the aircraft, managing and executing all procedures of the aircraft, have to be written.

On top of that, there are three critical items to be added in the airworthiness code of IFATS. Firstly, there are new on-board equipments (the Air Manager, the automatic take-off and landing system, emergency recovery capabilities. On the ground, requirements have to be written with regard to the central database, which is the heart of the information network of IFATS, display of the ground operator has to be defined, and the possibility of handover of an aircraft by the ground segment is a critical point to be specified.

The main adaptations of JAR-OPS 1 concern crew responsibilities, airline tasks and pilots’ tasks regarding meteorological conditions management, the execution of emergency procedures and the low visibility operations.

Interestingly, the adaptations of these requirements have an impact on both air and ground segments. For example, the management of meteo conditions is not only becoming a requirement of the air segment with regard to the corresponding Air Manager task and the role of the aircraft of an atmospheric sensor, but also a requirement relative to the central database of the ground segment.

A critical adaptation deals with the expert team on the ground, which shall be available in case of unknown failure detected by the Air Manager without any predefined recovery procedure.

[1] ***EASA A-NPA 16/2005 « Policy for UAV certification »***

New operational items concern the detection of non-cooperative traffic, the no-visibility procedures for departure, arrival and taxiing, and the responsibilities and role of the ground operator.

The quantitative results of the tailoring of the CS-25 and the JAR-OPS 1 indicate that the number of fully, partially and "intended" paragraphs represents roughly 90% of the paragraphs. Of course, critical items have to be added but this first tailoring shows that current regulations relative to transport aircraft can be used as a baseline for the certification process of IFATS aircraft.

	Percentage of requirements	
Tailoring code	**CS-25**	**JAR-OPS 1**
Fully applicable	**64%**	**62%**
Intent applicable	**17%**	**14%**
Partially applicable	**13%**	**10%**
Not applicable	3%	9%
Alternative criteria required	3%	5%

Table 1 - Tailoring quantitative results on aircraft current regulations

7.6.2. The ATM

Main adaptations of the ESARRs concern the airspace organization (like airspace structure and "functional airspace blocks"), state responsibility, severity classes definitions based on ATC workload, air traffic controllers competencies.

State responsibility is becoming a multinational supervisory authority responsibility.

Concerning severity classes, impact on crew or ATC control or workload shall be replaced by impact on aircraft functional capability

The main additional items deal with the ground-to-ground communication and the ground central database integrity.

The quantitative results of the tailoring of the ESARRs indicate that the number of fully, partially or "intended" paragraphs represents roughly 90% of the paragraphs. Again, critical items have to be added but this first tailoring shows that current regulations relative to the ATM can be used as a baseline for the certification process of the IFATS ground segment.

Tailoring code	ESARRs Percentage of requirements
Fully applicable	**83%**
Intent applicable	**6%**
Partially applicable	**5%**
Not applicable	~0 %
Alternative criteria required	6 %

Table 2 - Tailoring quantitative results on ATM current regulations

7.6.3. Conclusion on current regulations tailoring

A preliminary tailoring of the current regulations relative to the air transport (aircraft and ATM) shows that, although many critical new items need to be specified, they can used as a baseline for the certification process of IFATS.

Moreover, the tailoring study shows that in such an innovative concept, requirements relative to air and ground segments are strongly mutually dependent. Consequently, the certification process of IFATS calls for on one hand more correlation between airworthiness and operational certification of the aircraft and on the other hand, an harmonization of aircraft and ATM requirements. As this process will take a long time, it is urgent to start it now.

7.7. Automatic and autonomous behaviour of the aircraft

A tool capable of simulating a fully automatic and autonomous aircraft has been developed in the project to simulate all the flight phases, taxi, takeoff, navigation and landing.

Thanks to this tool (Figure 21), the capabilities of an automated aircraft to handle various failures and emergencies have been analyzed.

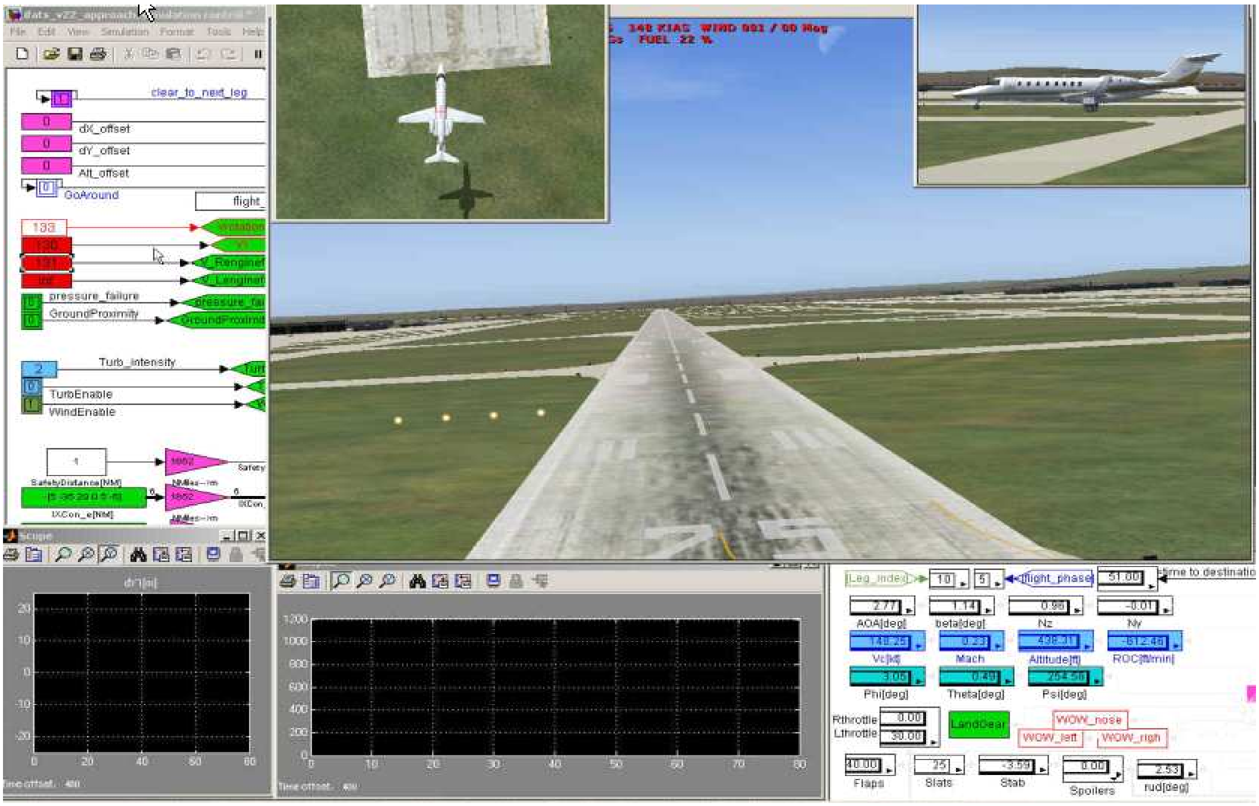


Figure 21 - Simulation tool interface

Unsurprisingly, this analysis did not raise crucial unsolvable technical problems. As demonstrated by the current operational unmanned aircraft systems (UAS), the technology is not far from being fully mature today, in 2007. The IFATS time horizon is such that technical problem should not be seen as show stoppers.

However, regulations have to be defined to enable the step change involved by the integration of pilot-less aircraft in the airspace.

The UAS community is currently dealing with these problems that can be classified into three main categories:

- Certification (ICAO Art. 31);
- Flight crew licensing and training (ICAO Art. 32);
- Operational requirements (ICAO Art.12).

Hopefully for this UAS community, these problems will be solved by the time a possible automated air transport system would be developed.

7.8. IFATS air traffic simulations

In December 2006, at the Braunschweig DLR site in Germany, Air Traffic simulations were conducted with “real” AT/C and pseudo-pilots and in fully automatic IFATS mode. Figure 22 shows the room of the simulations facilities where experts are sitting to run their individual simulation tools in order to analyse the various subsystems performance and behaviour of the overall system.

Figure 22 - Main distributed simulation room

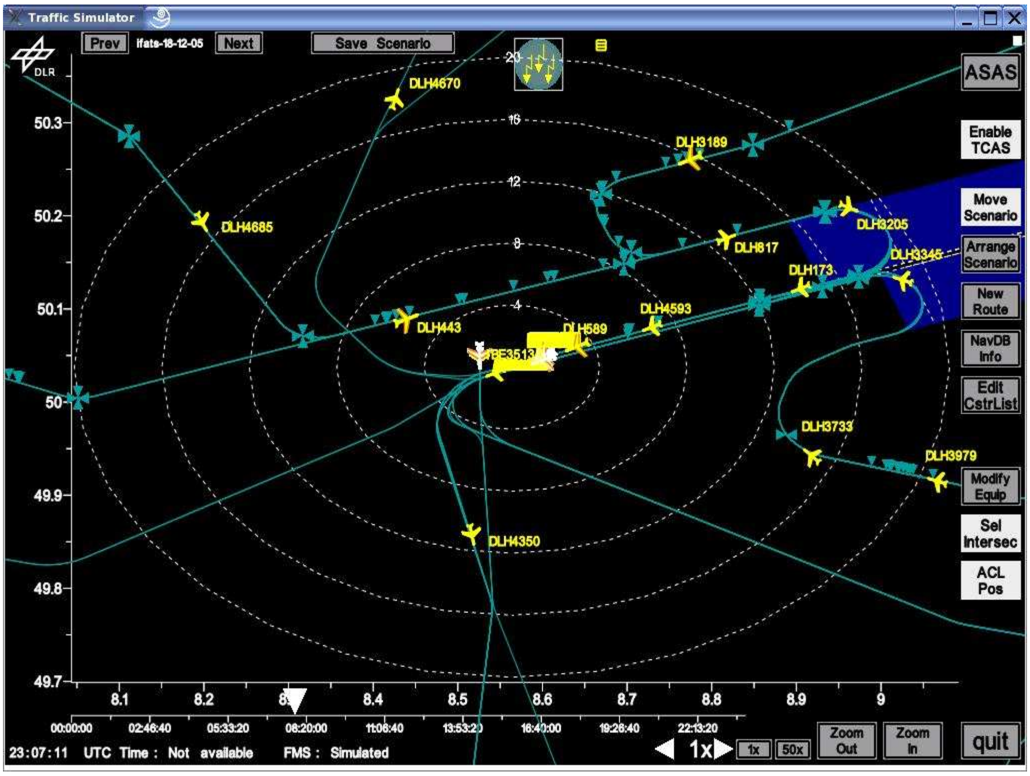


Figure 23 - Frankfurt airport area on the simulation screen with 4-D contract

As shown in Figure 23, the main DLR tool simulates the aircraft flying their 4D contracts arriving in the vicinity of the Frankfurt airport and taking-off or landing there. Normal situations were demonstrated together with disturbances such as thunderstorm (aircraft has to avoid thunderstorm area, this induces a re-planning action), degraded performance aircraft and aircraft facing an emergency.

The table in Figure 24 shows some of the results that were obtained during one simulations campaign.

Run	Type	Duration	Human Controller	IFATS
2	*normal*	01h:31m (91 min)	19h:46m (56 a/c)	18h:16m (54 a/c)
4	*normal*	01h:32m (92 min)	22h:19m (57 a/c)	18h:16m (54 a/c)
5	Emergency DLH419. MLD863	01h:33m (93 min)	22h:46m (57 a/c)	18h:40m (55 a/c)
6	Emergency DLH419. MLD863	01h:33m (93 min)	22h:49m (55 a/c)	18h:41m (55 a/c)
7	Emergency DLH1EM. DLH75A	01h:33m (93 min)	20h:52m (59 a/c)	18h:40m (55 a/c)
8	Emergency DLH1EM. DLH75A	01h:30m (90 min)	23h:35m (58 a/c)	18h:00m (53 a/c)

Figure 24 - Comparison between current ATC and IFATS concept

The "Duration" column shows the simulation run duration.

The fourth one gives the total duration of the flights of the aircraft between entering the TMA and landing at Frankfurt. The number of aircraft is the total landed aircraft

This first set of results shows that the IFATSystem lowers the duration of the flight optimizing the landing sequences whereas the controllers, asked by the simulations team to land as much aircraft as they could, gave some shortcuts to a number of aircraft to optimize this score while the automated system just followed the planned procedures…

This early stage simulations show the learning curve that has to be followed when defining and developing an automatism. Experience has to be gained patiently to raise the automatism at an acceptable level!

7.9. Airport traffic management

A ground planner simulation tool has been developed in order to simulate the management of the aircraft ground movements of the Frankfurt airport.

It allows the simulation of the ground movements planning and execution for two types of contracts: from gate to runway for the departing flights, and from runway to gate for the arriving flights.

The Figure 25 is a screenshot from the graphical interface. The background is a map of the Frankfurt airport. On this background, aircraft are moving.

The colour of each aircraft indicates its status:

- Yellow for landing and taking-off aircraft;
- Green for taxiing aircraft;
- Red for stopped aircraft;
- Dark blue for aircraft disembarking passengers;
- Purple for idle aircraft;
- Light blue for aircraft embarking passengers.

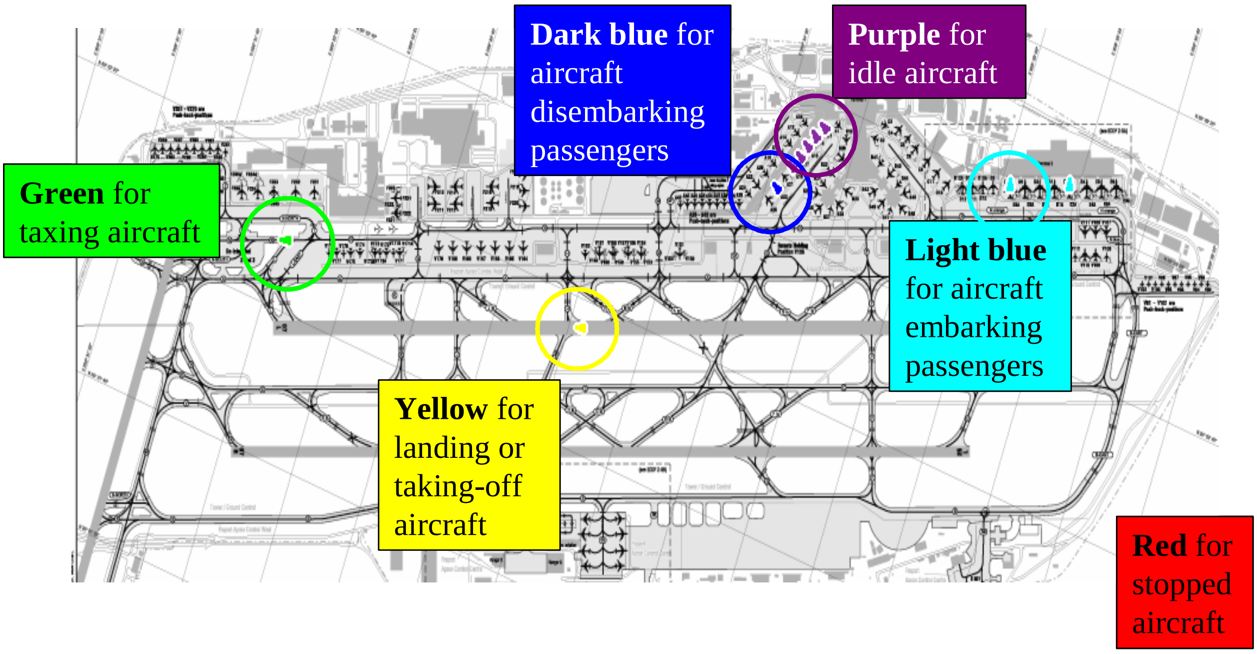


Figure 25 - Ground planner simulation tool graphical interface

The planning of the ground movements of the aircraft is made by the ground segment of the system. To this end, it has to compute the contracts and to send them to the aircraft.

These contracts are based on a graph of taxiway network. They are sent to the air segment as a sequence of time interval stamped waypoints.

These contracts are computed including minimum & maximum arrival time at each node of the trajectory using an algorithm that memorises all already planned contracts in order to get conflict free contracts.

The computation of a new contract is based on an adaptation of a A* tree search algorithm.

The search for departing flights aims at finding a conflict-free path at nominal speed. If this is not possible, the flight is delayed at gate. For arrival flights, the algorithm has the same aim.

But in case of impossibility, the aircraft can be stopped upstream the first intersection before the potential conflict.

This simulation has demonstrated that the automation enables a smooth organisation of the ground movements eliminating most of the queues before taking off and after landing.

This improvement is due to the possibility to have:

- a comprehensive, real time, centralised situational awareness of the state of the elements of the system;
- a very low reaction time of the actors through a direct control of aircraft by the ground system.

8. IFATS PERFORMANCE ASSESSMENT METHODOLOGY

The methodological approach used considers IFATS as the global Air Traffic System (ATS), and not only the current ATM...

ATS performance is defined through ICAO's Key Performance Areas (KPA) and indicators (KPI). Five KPAs which appear to be most relevant with respect to the IFATS concept were considered: capacity, efficiency, flexibility, predictability, safety.

A review of accidentology data has also been made. Historical data analysis stresses implication of human factors in the vast majority of incidents and accidents, i.e. between 50% and 75% of all causes (Ref. 7). This is one of the main “drivers” behind the IFATS rationale, with a new “man in the loop” concept.

The Air Traffic simulations mentioned in section C demonstrated the potential positive impact of IFATS on flight efficiency (KPA n°4) and predict ability (KPA n°9). A survey of participating controllers was conducted during the simulations. It indicates that IFATS simulation scenarios will have to be more complex to be more realistic, with capacity to “expect the unexpected”. It also indicates that IFATS development would benefit from a closer implication of controllers and pilots in the analysis process.

Nevertheless, regarding the performance analysis, the major finding has been that a full and comprehensive assessment of the system was not possible through independent simulations analysing punctually one of the various aspects to be studied.

The project work has been efficient to define and developed a concept, using the simulations to fine tuning the definition of the various functions that have to be implemented in such a system. But a comprehensive performance assessment will need further work based on a modelling of the overall ATS and the simulation of its operation mode for various circumstances such has the weather forecast accuracy, the communication network quality of service, etc.

To this end, the IFATS consortium members are proposing a follow up phase of the IFATS project in the new European research Framework Program.

9. USER GROUP OUTPUTS

In the framework of IFATS project the Consortium identified the strong need to ask for a free and unbiased evaluation of the concept through an “User Group” composed of qualified persons in the field of air transport. The ‘Users Group includes all persons who will be involved in the definition, management and use of the IFATS finished product, i.e. Pilots, ATC controllers, Airlines, National Aviation Authorities, Manufacturers, International Organisations.

An User Group composed of 15 highly qualified experts has then been created to review and advise on IFATS outcomes; their involvement has been a key point with regard to the soundness and credibility of the project outcomes.

Their activity, which has been carried out all along the project, has produced analysis and recommendations which focuses on three important aspects addressed by the project:

- IFATS definition;
- IFATS safety/certification aspects;
- IFATS validation.

In order to involve the Users and gather their assessment a questionnaire has been prepared to be used as the unifying thread during the interviews performed throughout Europe. Two dedicated meetings were also organised.

Questions have been conceived to collect users’ comments and recommendations with respect to the project achievements.

Before answering the questionnaire the User Group has been requested to evaluate IFATS outcomes through the review of the project deliverables as they were made available.

In the following the most significant inputs in terms of statement and recommendations gathered during the interviews are reported.

- Almost all Users agree that the foreseen integration of manned and unmanned aircraft integration is technically feasible. Highlighted that the integration represents a challenge and that, to be achieved, it needs to be examined also from a regulatory point of view
- A transition plan from the current system to IFATS would be needed. In general such transition should be phased and involve both air and ground segments. The definition of segregated portions of airspace (to be progressively enlarged) where phased improvements can be experienced is suggested.
- Highlighted the opportunity to further analyse and consider the operational aspects. End Users should be more involved in the future IFATS.
- Highlighted the need to refer clearly in the project of international laws: this is considered a lack. Military presence in the airspace should be addressed in the next IFATS.

- The major obstacles related to safety of IFATS, according to the User Group members, includes: Data base errors, Security and terrorist activity related attacks, New threats associated to the technological concepts tied to IFATS, Exceptional weather conditions, Duality of traffic (automated, not automated),

- IFATS current safety analysis is that it is a good first step that needs to be further detailed and refined. Appropriate guidelines for development of subsequent safety studies should be identified and adopted.

- The Key Performance Areas that should be investigated in priority for the performance measurement of IFATS are: Safety, Capacity, Efficiency, Cost effectiveness, Security.

- Cost analysis should be performed with a phased approach: first starting with qualitative assessment and then adopting quantitative methods as the overall system is defined in detail.

10. IFATS SOCIAL ACCEPTABILITY

This section of the paper relates to the non-technical but important issue that is the societal acceptability of a fully automated system as proposed by IFATS. This point has not been answered yet by the project, but the issue has been raised and somewhat qualified as far as the project was progressing.

It is important to deal with the societal acceptability as early as possible: indeed, for such a project based on a disruptive approach, the risk of failure due to a rejection of the solution by the affected parties is high. Considering that IFATS - or future projects related to the development of enabling technologies - will propose the best technological answers, this is not yet enough to guarantee the acceptance of the solution by the affected parties.

The first question we should consider is « Who is affected?»: generally, and when building a long term strategic research agenda is concerned, it is commonly agreed that all the stakeholders should be involved in the process. But it is less common to involve as well the users (simple citizens) or the actors of the system (pilots, controllers, crew members). Indeed, only the question of knowing how to involve citizens (for example) in the definition of research orientations is pretty hard to answer.

However, there are numerous reasons why the users would be inclined to reject the idea of IFATS, or of a fully automated ATS.

The first that comes to mind is of course the “fear of not having a pilot” to count on in cases of any difficulty during a flight. Reasons driving the ATS/ATM actors to reject the idea may be more connected to their view of their own situation than a more global perspective.... Their position can be derived from the statement “As you know, for many the fear of the future is often based on an over-glorified perception of the past” (Ref. 1).

Thus, dealing with societal acceptability has a lot to stake with building confidence with affected parties: the starting point for building this confidence is to understand the points of view: who is affected, why, who is under the influence of whom. To do so, it might also be a good start to look at what has been done in areas that are more advanced that the air transport as far as automation is concerned: train for example, and ground transportation in general.

Second step towards the instauration of this virtuous circle that is necessary to build confidence, we need to educate and convince people about the advantages of a fully automated ATS. To some extent, we need to “make” public opinion while developing the concept: we need to influence. For that, it is necessary to have a clear view of what could be such a future ATS. How it will operate, what will be the transition phase, what are the main outcomes of this technical progress. We need to be convincing on the risks, and the solutions necessary to reduce these risks. This information is not available yet at this stage of the project.

Finally, and it may be the most difficult task, we need to involve the affected parties directly into the process of defining R&D orientations, so they can influence the development process and drives researchers, engineers and stakeholders towards a better acceptability of the solution they would come with. The question here is to know how to have people from various origins (technical, social, nationality…), participating to the definition of research orientations for subjects that are complex and technically difficult.

Social sciences researchers have addressed this question in the past decades. Several approaches have been defined, from the collective panel, to the participative democracy: after an overview of all these techniques, we found that the one called “Interactive Technology Assessment Method”, developed in the Netherlands, was the most suitable to our needs. Basic principles of this methodology have been adapted to the issue of assessing the Integration of Pilot-free Aircraft in the Single European Sky by several partners of IFATS.

The core of the approach we developed relies on the organisation of several working groups putting together representatives of affected parties that have been trained prior any debate and discussions using IFATS results and scenarios.

Finally, and because the main purpose is to define R&D orientations, this working group is supervised by a steering committee composed by ATS specialists in charge of exploiting outputs of the working groups and of defining realistic R&D orientations. A limited experiment at the regional level will be organized and financed by the « Conseil Régional d’Ile de France » late in 2007. It will only consist in apprehending the acceptability from the user’s point of view.

11. FUTURE ATS ROADMAP

11.1. Introduction

Figure 26 shows the project workflow regarding the definition of the future ATS roadmap.

The IFATS project team has developed a definition of a highly automated Air transports system as it has been detailed in this report.

Through the Braunschweig workshop, the Châtillon round table and the outputs of the project users group, feedback has been generated and taken into account to refine the final IFATS elements definition and system organisation.

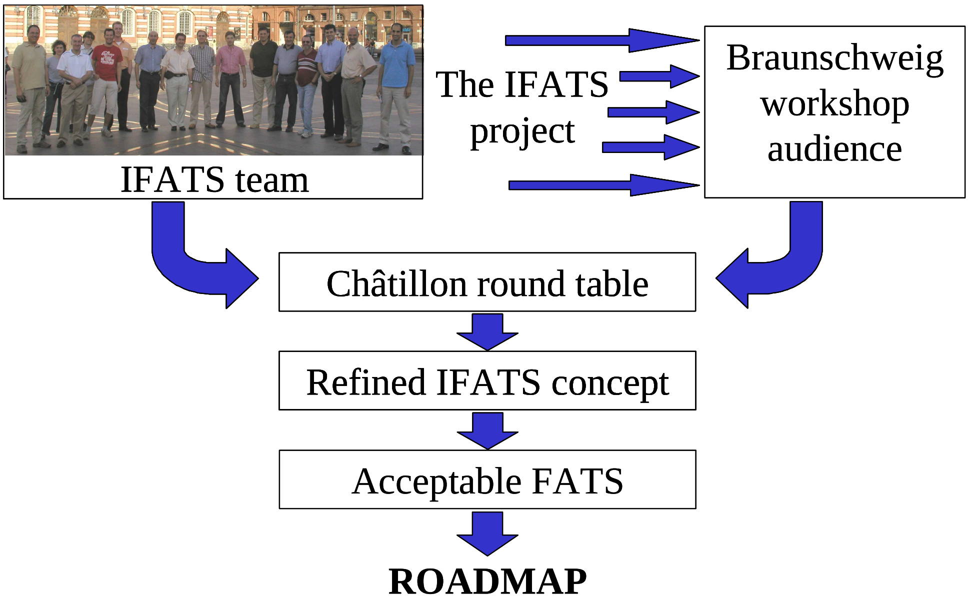


Figure 26 - Project work flow towards the future ATS roadmap definition

Regarding what can be expected in the future, preliminary thoughts can be expressed after this three year long definition and evaluation effort.

Nevertheless, they have to be considered as temporary as this IFATS-1 project did not consider a detailed definition of the overall system concept that has been proposed and evaluated. Moreover, due to the high level description of the defined system, investigations were not as wide and deep as in other projects dealing with more conservative ideas and often focus on one single aspect of the overall ATS.

The current achievement of the work makes possible the following assessments.

11.2. Technical feasibility of the air segment

Technically speaking, the distance that separates today's aircraft from IFATS aircraft is not so large. Of course, pilots are still onboard but a very limited number of flight phases are still manually operated.

Thus, a fully automatic transport aircraft seems to be technically feasible as it is demonstrated through the already flying large UAVs like the Global Hawk.

New airframes without cockpit have to be designed with a complete new arrangement of the electrical / hydraulic internal layout.

An addition of adequate sensors to monitor the aircraft status (smoke detectors, vibration sensors, etc.) is required and associated systems (hardware and software) have to be implemented together with a significant upgrade of the communication means (air-to-air and air-to-ground) are required. All this seems to be technically achievable in the mid term.

The second phase of the IFATS project that has been proposed for the first call of the FP7 aims at detailing the definition of a fully automated aircraft in order to better determine the functional characteristics to be implemented to get the same level of safety and security as the current one.

11.3. Technical feasibility of the ground segment

The actors that already exist such as airports infrastructure (excluding ATC), aircraft manufacturers and airlines only require adaptations.

Regarding the new actors, such as ground stations that do not exist at all, new infrastructures have to be created from scratch.

Technology is already there but a considerable work has to be done to make the system efficient, safe and secure.

The ATSM may be the most difficult part of the system to design. It requires the creation of a planetary-scale traffic planner within a multinational organization.

Hardware and software have to be developed together with a totally new concept of operation. This will require time and money, a competitive position of Europe is this field has to be encouraged as soon as possible to keep, or gain, a leadership role in the far term ATS evolution (that includes the ATM, of course).

11.4. Technical feasibility of the communication networks

Some current aircraft are already equipped with “ADS-B out” whereas the ASAS function will require “ADS-B in”. This short term situation is not so far from a preliminary form of the so-called local network defined in the IFATS project.

The communication topic is made complex due to the frequency availability & “productivity” problem.

Nevertheless, the lower number of **voice** messages that is one of the main advantages of the IFATS concepts (machines "speaking" to machines instead of machines informing men speaking to other men giving data to machines) simplifies the data flow and lower the needs for frequencies.

Radio navigation frequencies will also be made available and digital message processing will lower the duration of all the data exchanges between the various actors of the overall system.

Of course, the vital need for an « extreme » security of the data exchanges will require a major effort on efficient and secure communication protocols and hardware designs.

11.5. Role of the human

The role of the human in the system has been discussed all along the project with passion and lucidity.

For sure, the future air transport system will not be an unmanned system!

Humans will still be in the system but not at the same place and nor for the same functions.

One of the statements made in the SESAR initiative is as follows:

Irrespective of any future vision the human will remain the most flexible and creative element to direct the performance of the overall ATM System including the management of threats, errors and unpredictable events.

The equivalent statement that has been made in the IFATS perspective is as follows:

The human will remain the most flexible and creative element to direct the performance of the overall ATSystem, designing an automated system in which he will keep a role where his performance level is the highest.

In IFATS, the human being is seen as extremely efficient when and where the functions he has to perform are not too much closely interfaced with automation.

Another aspect of the human's role concerns the responsibility that will be placed on the various people involved in the air transport system management. This topic will have to be addressed taking into account many parameters, from the design of the aircraft to the operation of the airlines. However, with the increase of the automated function in new generation aircraft, similar problems have already to be addressed nowadays.

11.6. What will happen? When and where?

"What will happen?" is a difficult question and no clear answer can be given yet. Deeper analyses have to be performed to get a more clear view of what types of changes can be expected in the ATS.

Although the case of the automatic metro is far from the air transport system, let's see the situation faced by the engineers in charge of the development of this automated metro Line 14 in Paris.

They had two questions in mind while designing the new line:

What will the passengers think of the changes?

Will they dare to board a métro without a pilot on board?

When starting the operation of line 14, no rejection reaction was observed from the passengers… they were just enjoying the former driver's view!

And now, Paris Line 14 use is constantly increasing…

May be a good summary of the situation may be taken from the editorial of the magazine "The Controller" (Ref. 2) : *"Whether the automation of the future will be as advanced as the IFATS vision of Onera is debatable. But their assumption is a correct one: if you want to totally automate ATC, there will be also no pilots anymore, as only computers can interface with computers".*

And of course, the same comment applies symmetrically about the automation of the aircraft that cannot be achieved if the ATC is still operated by controllers.

"When and where?" is not simpler to answer.

May be China will take the lead for their domestic air transport network: they have a dramatic demand for air travel to satisfy and have difficulties to get well trained and experienced pilots.

It may be more difficult for them to educate pilots than to create a local automated ATS!

12. CONCLUSION

Pioneering the air transport of the future is not a simple issue. Nowadays, a few years after the first flight centennial celebration, the ATS is far from being optimally structured and fully developed to meet the user's needs and comply with the more and more stringent environmental constraints.

Ambitious objectives have been stated in the ACARE Vision 2020 in Europe (Ref. 5 and Ref. 6), and metrics have been defined to assess their level of achievement: the future ATS will definitely have to be more time efficient and highly customer oriented, keeping costs low while being environment friendly and secure; this has to be valid and proven whatever the evolution of the traffic will be.

Choosing the means to reach these objectives is not so obvious. The ATS is a complex system, which integrates multiple interacting subsystems designed to provide its core functions, i.e. transporting passengers and goods. Huge technical and technological progress has been achieved at the subsystem level, centred on a human controller or operator. Placing the man as the major front-line actor brings intelligence into the overall system, but it also brings limitations and weaknesses.

In the near to mid term future, i.e. 2020-2030 time frame, no major ATS changes can be expected: in the coming years the ATS will necessarily be not very different from what it is today for evident reasons of continuity.

Looking in the more distant horizon, to really pioneer the future, gives more freedom and flexibility, but also brings some uncertainty. In this perspective, thinking “out of the box” is welcome, and should even be seen as a required methodology.

Indeed, preparing this far future of the ATS is an unchallenged opportunity to promote excellence in scientific and technological research, development and demonstration. Moreover, the international nature of the ATS calls for trans-national research and industrial cooperation to take up many of the current European efforts in this field.

For this 2050 vision, the IFATS FP6 STREP has started to pave the way through a rather radical and non-conventional methodology. Instead of analysing how to evolve smoothly from the current ATS to a potential future one, the IFATS consortium has elected to study what could be an extreme far term solution: a fully automated ATS where pilots and ground controllers would be replaced by operators in charge of numerous monitoring functions.

The qualitative results that have been obtained up to the end of the first phase of the project (June 2007) are promising. With such a system, capacity, efficiency, safety and environmental friendliness are improved. Nevertheless, quantitative assessments need further in-depth investigation whereas the analysis of some issues, such as security, has to be detailed and extended.

At the end of the IFATS project, high level simulations prove that this extremely automated ATS where aircraft would be operating automatically, monitored by an automatic control supervised by ground operators, is a credible option.

But further investigation is needed to identify what could be a transition phase between the current ATS and such a disruptive concept.

"UAV airliners will happen. It is a question of when, not if" was the conclusion of the Flight International editorial paper relating the IFATS Braunschweig workshop in December 2006 (Ref. 3).

This is also the strong belief of the IFATS consortium members!

13. REFERENCES

Ref. 1 - Anne-Sophie Bellalche, “Le bout du monde, grande tendance du week-end”, *Challenges*, n°70, 8 mars 2007, pp. 100-101.

Ref. 2 - Ph. Domogala, Editor, “Should we fear automation?”, *The Controller, Journal of Air Traffic Control*, 2/2005, 3rd quarter 2006, September 2006, pp. 5.

Ref. 3 - Peter La Franchi, “Researchers reveal pilotless vision” *Flight International*, 19 December 2006- 1 January 2007, pp. 3, 6.

Ref. 4 - Hervé Tilloy, “Le système de transport aérien au crible de l’automatisation” *Air et Cosmos*, n°2005,1 December 2006, pp. 35.

Ref. 5 - Advisory Council for Aeronautics Research in Europe (ACARE) Strategic Research Agenda SRA-1, Volume 1 and 2, October 2002

Ref. 6 - Advisory Council for Aeronautics Research in Europe (ACARE) Strategic Research Agenda SRA-2, Volume 1 and 2, October 2004

Ref. 7 - Boeing, 2005 Statistical summary of commercial jet Airplane Accidents, May 2006

PART 3 – PUBLISHABLE RESULTS

SCIENTIFIC PAPERS PUBLISHED BY IFATS

- "IFATS autonomous aircraft", Shlomo Rozental, 47th ISRAEL annual conference on aerospace sciences.
- "A Novel 3D Geometric Algorithm for Aircraft Autonomous Collision Avoidance", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, 45th IEEE Conference on Decision and Control (CDC'06), December 13-15, 2006, San Diego, California USA.
- "Decision-Making Algorithms for Aircraft Autonomous Collision Avoidance", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, 5th EUROCONTROL Innovative Research Workshop & Exhibition, December 5-7, 2006, Bretigny-sur-Orge, France.
- "Autonomous Aircraft Separation Assurance and Collision Avoidance Algorithm", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, 7th ATM Seminar, 2007, Barcelona, Spain.
- "Aircraft Collision Avoidance: An Optimal 3D Analytical Solution for Real-time Applications", C. Carbone, U. Ciniglio, F. Corraro, S. Luongo, submitted to 46th IEEE Conference on Decision and Control (CDC'07), 2007, New Orleans, USA.
- "FDI for Aircraft Systems Using Stochastic Pooled NARMAX Representations: Design and Assessment", D.G. Dimogianopoulos, J.D. Hios and S.D. Fassois to appear in the IEEE Transactions on Control Systems Technology, 2007.
- "Integral Minimum Variance-Like Control for Pooled Nonlinear Representations with Application to an Aircraft System ", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois to appear in the International Journal of Control, 2007.
- "On-board Statistical Detection and Compensation of Anomalous Pilot Aircraft Interactions", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois to appear in the IEEE Transactions on Aerospace and Electronic Systems, 2007.
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- "Nonlinear Integral Minimum Variance-Like Control with Application to an Aircraft System", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois, 14th Mediterranean Conference on Control Automation, June 28-30, 2006, Ancona, Italy.
- "Fault Detection and Isolation in Aircraft Systems Using Stochastic Nonlinear Modelling of Flight Data Dependencies", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois, 14th Mediterranean Conference on Control Automation, June 28-30, 2006, Ancona, Italy.
- "Statistical Fault Detection and Identification in Aircraft Systems via Functionally Pooled Nonlinear Modelling of Flight Data Dependencies", D.G Dimogianopoulos, J.D. Hios and S. D. Fassois, 25th International Congress of the Aeronautical Sciences (ICAS), September 3-8, 2006, Hamburg, Germany.
- "On-Board Engine FDI in Autonomous Aircrafts Using Compact Stochastic Nonlinear Modelling of Flight Signal Dependencies", D.G. Dimogianopoulos, J.D. Hios and S.D. Fassois to appear in the Proceedings of the European Control Conference (ECC) 2007, July 2-5, 2007, Kos, Greece.

- "2D Trajectory Re-planning and Optimization in the Presence of Stationary Obstacles", Lior Ben-Yshai, Moshe Idan, IACAS 47, Feb. 22, 2007, Haifa, Israel.

LARGE AUDIENCE DOCUMENTS PRESENTING IFATS CONCEPT AND RESULTS

All the following documents are available on the website of IFATS Project

www.ifats-project.org

- Full high level description of IFATS Project Slides presenting the project as it has been defined, roles of the partners, anticipated results (copyright IFATS Consortium 2004).
- IFATS concept - presentation paper: this paper (and associated presentation) has been presented at the Eurocontrol Innovative Workshop held in Bretigny (France) on December 06-08 of 2005.
- IFATS concept illustrated video describing the main components and concepts of IFATS approach (copyright IFATS consortium 2006).
- IFATS concept explained: several presentations together with their comments (some are missing) are explaining parts of IFATS concepts. This material is publicly available. (Copyright IFATS consortium 2006).
- General Presentation of IFATS
    - The influence of weather forecast accuracy on trajectories replanning;
    - The autonomous take off and landing;
    - IFATS communications needs and architecture;
    - Aircraft health monitoring, fault detection;
    - Aircraft separation and collision avoidance;
    - IFATS concept safety analysis;
    - IFATS concept certification aspects;
    - IFATS Aircraft cost estimation;
    - Air traffic simulation in the area of Frankfurt airport;
    - Evaluation of IFATS concept;
    - Simulation of the ground operations in the airport zone;
    - IFATS societal acceptance;
    - Roadmap to future ATS;
    - Comments from the user groups and participants to workshop.

EVENTS WHERE IFATS PROJECT HAS BEEN PRESENTED

- 01/06 Special IFATS session at SAFEE technical meeting, ONERA
- 02/06 ONERA's Asia-Pacific aerospace R&T workshop, ONERA
- 03/06 Invited paper to EqIMG/EU Workshop on Reduced Crew operation, ONERA
- 05/06 ONERA's UAV activity presentation workshop, ONERA
- 06/06 Invited paper Aeronautics Days 2006, ONERA
- 12/06 IFATS simulation workshop, IFATS consortium
- 02/07 Paper – "2D Trajectory Re-Planning and Optimization in the Presence of Stationary Obstacles" 47th Israel Annual Conference on Aerospace Sciences - 2007 Israel, 30 people, Technion
- 03/07 IFATS final meeting, IFATS consortium
- 05/07 Presentation of IFATS during the AIAA conference: Infotech@Aerospace, Rohnert Park, USA, ONERA