An innovative evaluation platform for new aircraft concepts

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ABSTRACT

Within the European project NACRE (New Aircraft Concept REsearch), a team of research centres and universities focuses on the assessment of a test facility in the form of a flying platform. The goal of this Innovative Evaluation Platform (IEP) is to offer engineers a new tool to investigate areas of interest during the early design phases of advanced aeronautical systems.

After an initial phase during which the potential benefits of such a platform have been demonstrated, the go-ahead for the IEP design and manufacturing has been given. In this second phase, a lot of attention has been brought to the system specifications since the platform has to meet the requirements of both an aerial vehicle and a test facility. The subsequent design process followed a stringent course of actions to achieve the design of a competitive test facility. The consortium aims for a final integration and flight trials in fall 2009.

1.0 INTRODUCTION

Over the past 60 years, aircraft companies continuously optimised the classic commercial aircraft configuration in order to meet the demand of airline companies in terms of passenger capabilities, mission performance and appealing return on investment values. Today, the margins for improvement of this configuration are limited and future objectives regarding perceived noise and air pollution are becoming more and more stringent. Manufacturers are then forced to explore unconventional concepts for next generation aircraft. Since these designs often present a real shift from historical trends, current tools and methods, based on a large historical database of numerical simulations, experiments and flight tests are now reaching the boundaries of their utilisation envelope with no option for extrapolations without a large amount of uncertainty.

For these reasons, the European project NACRE — a project regrouping thirty-six partners managed by Airbus and half financed by the European Commission — initiated the study of a flying test bed to help the exploration of revolutionary solutions during the initial design stages. Defined as Innovative Evaluation Platform (IEP), this system should enable investigations in six areas of interest: high-lift devices, flight dynamics, recovery from Hazardous Flight Conditions (HFC), noise assessment, wake vortices and laminar flow. The proposed roadmap to complete the project (Task T1.4) divides the research into three subtasks: first, T1.4.1 concentrates on the assessment and feasibility of an IEP to evaluate the potential benefits of such a new method. Following positive conclusions, the project enters T1.4.2 during which the flying test bed is designed and manufactured. Finally, flight tests, associated data

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analysis and assessment of the IEP as a test facility are scheduled in T1.4.3.

Written at the end of the T1.4.2, the goal of this paper is to present the rationale behind the design of the IEP. In particular, focus is brought on the assessment and feasibility phase demonstrating the system benefits, the objectives definition and the requirement analysis. This document is completed by a description of design phases and an overview of the flying platform final design with its key features.

2.0 DESIGN PROCESS

With the objective of being a new tool to investigate certain disciplines, the IEP can be considered as a test facility. Simultaneously, the research is based around the idea of a flying test bed. The IEP is then both a flying platform and a test facility. Because of complex interactions between these characteristics, the consortium sets up a thorough design process to define a system of systems meeting stringent specifications.

As illustrated in Fig. 1, the design process explores at first the needs of the aeronautical community and the possible solutions for such an innovative test facility based on a flying platform. This assessment and feasibility step feeds then the design phases of a complex system of systems. The next paragraphs detail the different phases of this roadmap.

3.0 ASSESSMENT AND FEASIBILITY

Carried out in T1.4.1, the assessment and feasibility phase searches the potential benefits of a flying platform to investigate several areas of interest using standard test techniques as reference for comparison. These benefits could concern technical capabilities, costs reduction and operational flexibility. The output of the subtask is then a multi-perspective evaluation of the IEP based on four distinct steps[1]:

- Assessment of the existing techniques;
- Assessment of the IEP;
- IEP concepts and proposals;
- Comparison matrices,

3.1 Assessment of the existing test techniques

To initiate the assessment, the consortium decided to gather all details about the existing test techniques currently used in the investigation of the disciplines. The considered methods are divided into three categories:

- Numerical tools (computational fluid dynamics, computational aero acoustics, systems simulation);
- Fixed models (wind tunnels, towing tanks, anechoic wind tunnel);
- Free models (flight laboratory, vertical wind tunnel, SACSO[2], full scale aircraft and/or modified full scale aircraft).

For all these methods, the completed analysis includes the review of technical capabilities, costs, schedules and risk. With the completion of this phase, the research team generates a database including specific strengths and weaknesses of each existing test techniques to be used as a reference to evaluate the IEP.

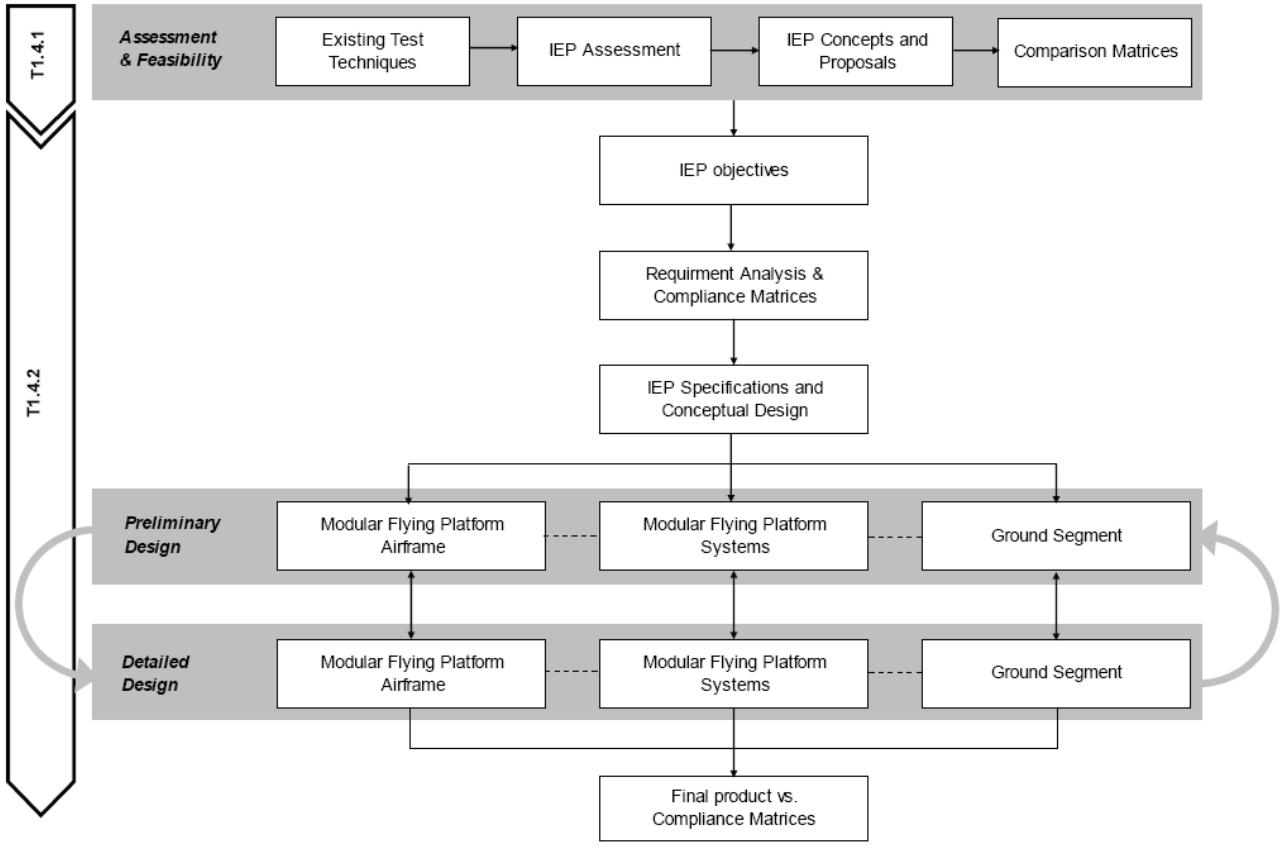


Figure 1. IEP design process.

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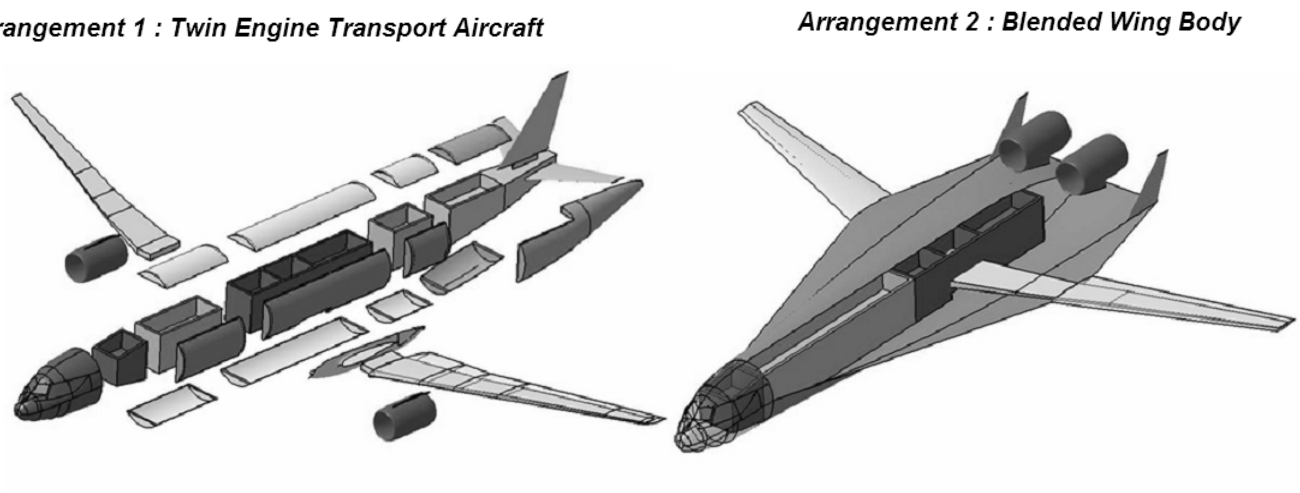


Figure 2. Modular flying platform concept (Onera / DERM).

3.2 Assessment of the innovative evaluation platform

The following step focused on the IEP evaluation, first from a technical point of view and later from an economical prospective. A thorough analysis for each discipline is then carried out to emphasise the scientific aspects related to an IEP. The covered topics were the following:

- Current capabilities in the discipline (i.e. flight dynamics) investigation;
- Limitations and needs of the IEP;
- Assets of an IEP;
- IEP requirements and constraints analysis;
- IEP preliminary definition;
- Flight test program main steps;
- Specific instrumentation;
- Data identification;
- Data accuracy identification.

Based on these various investigations completed by experts, an important conclusion is that an IEP under the form of a flying test bed is an answer in each discipline to both the limitations of the current test facilities and the need for new test approaches. However, with the objective of competing with proven facilities in terms of accuracy and reliability of the measurements, the IEP must meet a series of stringent scientific requirements[1,3].

Nowadays, customers select a test facility not only according to its technical capabilities but also because of its operational and economical aspects. These characteristics are thus appraised for the IEP to complete the overall evaluation. Costs are estimated through a subsystem breakdown in which items to be designed and manufactured have been identified as well as commercial-off-the-shelf (COTS) systems. The fine resolution of this decomposition enables the team to estimate the design and manufacturing costs for low cost and high end products. In parallel, studies on airworthiness and regulations, flight test ranges, test session costs and scheduling issues provide the research group with details concerning the operational side of the IEP.

3.3 IEP Concepts and proposals

Following the previous analyses, the research team defines three IEP proposals to be built according to the NACRE budget and schedule respectively focusing on:

- Flight dynamics;
- Noise assessment;
- Recovery procedures from hazardous flight conditions.

It is important to note that the severe requirements impacting the MFP design in order to carry out research in the area of high-lift devices, laminar flow and wake vortices are not compatible with the available budget and timetable of NACRE[4]. The initial objective of investigating six areas of interest is then reduced and the project concentrates on the remaining three domains.

All these proposals are based on a flying platform controlled from a specifically designed ground station. Concerning the platform, the concept of a Modular Flying Platform (MFP) is integrated within the various IEP proposals. This concept is based on the design of a modular structure that can be rearranged according to aircraft configuration. Around these structural parts, external shapes are obtained through the manufacturing of fairings that do not have to support structural efforts. Figure 2 illustrates how the MFP enables the test team to build two radically different airframes around the same common modular structure.

Such modularity enables the testing various aircraft configurations at minimum costs since the structure and the principal on-board systems are constantly reused[1]. Further technical discussions around the airframe design enabled the design team to define a ‘combined proposal’. This proposal revolves around the design of a unique platform enabling the investigation of all three areas of interest. This particular design strictly follows the requirements imposed by each discipline. The resulting solution presents undeniable assets and it leads to the system to be built in T1.4.2.

3.4 Comparison between the existing test techniques and the IEP

The fourth and final step of the subtask was an assessment of the proposals against the existing test techniques. Based on a grading system, this step enabled the appreciation of the differences between the test methods based on the following five criteria:

- Technical capability;
- Acquisition costs;
- Maintenance costs;
- Session costs;
- Operability.

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The assessment by experts for all three areas of interest (flight dynamics investigation, recovery from hazardous flight condition research and noise assessment) started with the completion of comparison matrices based on the available information at an early design stage. The data have been subsequently represented on radar plots to emphasise important trends[1]:

- The IEP offers lower acquisition costs;
- The IEP requires lower maintenance,
- The IEP has higher session costs than conventional facilities but still lower than full scale aircraft tests;
- The IEP operability is more complex than standard test techniques but still better than a full scale aircraft ;
- The IEP offers some gain on the scientific aspects such as the study of full trajectories in real atmosphere.

All steps of the assessment and feasibility task are detailed in the first deliverable of the project[1]. Conclusions indicated that an IEP based around a modular flying platform offers technical gain and some economical profitability in comparison to today's experimental facilities under the condition of meeting stringent requirements. Given this positive outcome of T1.4.1, the consortium decided to design, manufacture and test an IEP. Through these flight tests and the analysis of the recorded data, it will be possible to confirm or not this first IEP assessment.

4.0 IEP OBJECTIVES

With additional studies carried out at the beginning of T1.4.2 and additional information to upgrade the proposals made during T1.4.1, the team converged toward a unique IEP proposal described by the following definition[5] and the associated test procedure:

"The IEP must be a competitive test facility under the form of an Unmanned Flying Platform to be designed and manufactured within NACRE T1.4.2 enabling:

- the identification of stability and control parameters;
- the noise assessment;
- the analysis of different recovery procedures in the case of HFC

at a conceptual design level for different aircraft concepts to be tested in T1.4.3."

Regarding the IEP associated test procedure, it is based on performing specific automated missions with flight conditions monitored from a ground station. The data recorded during the flight are then analysed by the domain specialist to investigate phenomenon related to a discipline. According to the scheduled tests, the flight test engineer plans a mission through a set of waypoints[6]. These points enable the definition of assessment legs during which the actual measurements will take place. Figure 3 illustrates an example of an IEP mission.

The flight management system allows the automated navigation and control of the platform to the different 3D coordinates with the desired flight parameters. On the ground, a control station includes a series of monitors where the flight path and all parameters of interest are shown in real time. These data include flight mechanics related values as well as internal states variables of the IEP subsystems. In this manner, the flight test engineers are continuously aware of the state of the mission and of the subsystems. It is important to note that, if necessary, the mission can be modified at any time by the ground team.

As emphasised in the IEP definition, the missions to be performed by the flying platform are clearly oriented toward specific flight measurements. Precise flight test procedures are thus defined by the different experts in the disciplines[5]. These associated flight test procedures and the IEP definition reported earlier detailing technical and management aspects have been subsequently used as references to complete the requirement analysis.

5.0 REQUIREMENTS ANALYSIS

Task T1.4.1 emphasised the necessity for specialists to have a new tool to study certain aspects of technical disciplines. At this point, the design team derives a series of requirements to be met by the flying test bed in order to answer this need. By focusing on the complete IEP definition, it is clear that some notions are directly linked to the system of systems aspects while others are related to the test procedures. It is then decided to use different methods to identify the requirement according to their type:

5.1 System requirements

The method to derive the system requirements is based on a top-down approach. Through brainstorming sessions and several iterations, top level requirements identified within the definition are broken down into lower level requirements. The high level concepts considered during this analysis are:

- The IEP must be designed and manufactured within T1.4.2 of the NACRE project and tested in T1.4.3;
- The IEP is based on the utilisation on an Unmanned Flying Platform;
- The IEP must be a competitive test facility;
- The investigations for the different disciplines must be carried out for different aircraft concepts.

This method allows the design team to define 32 system requirements directly impacting the design of the IEP.

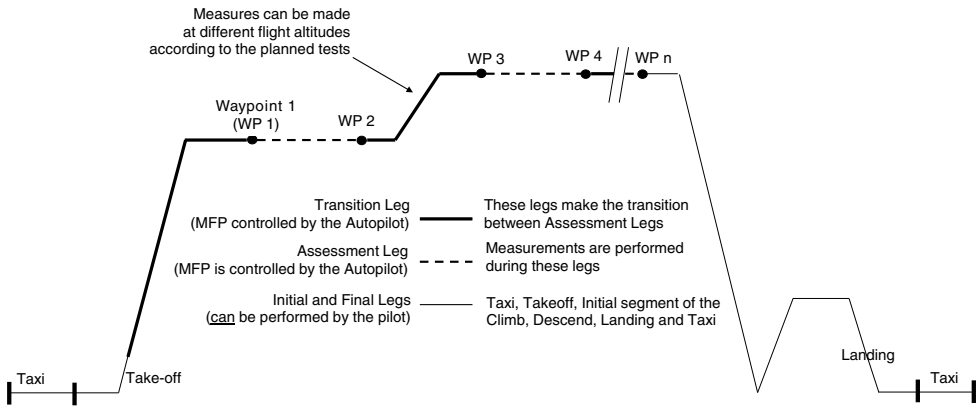


Figure 3. Typical IEP mission profile.

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5.2 Test procedure requirements

As a test facility, the IEP has to provide experimental results that can be applied to the real aircraft. In the case of a flying platform simulating the dynamics of a full scale aircraft concept, valid extrapolations are possible when the following primary requirements are met[1,2]:

- The flying platform must be designed meeting the Froude Similarity with the full scale concept under study;
- The lifting surfaces of the flying platform flying at low Reynolds numbers must be modified in order to have the same aerodynamics characteristics as the full scale concept flying at higher Reynolds numbers.

The IEP definition insists on the measurement capabilities of the system. It is then important to capture the requirements implied by the different test procedures. Since the flight test main steps have been detailed earlier during the IEP objective definition, the design team concentrates on each one of them to derive supplementary requirements. With additional test procedure requirements provided by noise specialists to ensure a thorough discipline investigation, the consortium defined a total of 36 test procedure requirements.

Presented under the form of two distinct compliance matrices, these referenced system requirements and test procedure requirements drive the entire design process.

6.0 DESIGN PROCESSES

Although the nature of the IEP led to an unconventional requirement analysis, the design processes follows a common process. Following the requirement identification, the consortium initiates the conceptual design. As an initial step, the design team began by analysing the studies associated with the modularity requirement. A modular airframe involves indeed a structural analysis as well as a stability and control assessment for all possible configurations. This long and complex design loop is even more complex in the case of Blended Wing Body arrangement. Because of the schedule and budget constraints of the NACRE project, the design team decides to aim a reduced modularity enabling the study of advanced evolution of the current transport aircraft. NACRE references in this case for the configuration are the Simple Flying Bus and the Pro Green Aircraft (PGA). Since a key feature of this latest concept is its low noise characteristics and the IEP targets to investigate noise aspects, the design team decides to base the reference configuration of the IEP on the PGA. The modularity is validated by offering the possibility to test a different empennage solution on the same aircraft. Always in order to limit the complexity (and thus costs) of the internal systems, it is decided that the second aircraft arrangement must also have the engines in an aft position. After a qualitative assessment of the possible alternatives, a T-Tail solution is chosen. The selected configurations labeled IEP-15 and IEP-21 are illustrated in the next figure (Fig. 4).

The flight test to be performed with the platform will thus enable the comparison of aircraft concepts with different empennage in terms of flight dynamics, noise and recovery from HFC. It is important to note that during these conceptual developments, it has been necessary to conserve a same cabin length for the fuselage in order to compare aircraft with the same payload capabilities. This constraint forced the design team to make adjustments on the tail to keep the same volume coefficient. After these considerations at the conceptual level for the airframe, specifications on the necessary data to be measured during the flight are issued. These data are separated in Standard Aircraft Parameters to be always recorded during flight and Specific Parameters to be measured during the noise assessment tests. The specifications include the required sampling rate, the accuracy and the units of the measured values. Following the conceptual design, the preliminary and the detailed design processes of the IEP are carried out. The developments are performed according to a breakdown that divides the IEP into three main subsystems: the modular flying platform airframe, the modular flying platform systems and the ground segment.

For the Modular Flying Platform (MFP) Airframe, the preliminary design starts with the sizing of the vehicle. The most important aspect in forof this topic is the necessity to obtain the Froude similarity between the full scale concept and the IEP airframe. However, specific operational aspects of the IEP and the available engines on the market limit the design space. Considering all these constraints, the team defines in the end an airframe that has a maximum take-off gross weight of 100kg and a span of 4·16m with two engines delivering each one a maximum thrust of about 200N at sea level. Subsequently, the lifting surfaces airfoils are selected in order to have similar aerodynamics between the full scale aircraft flying at high Reynolds numbers and the MFP flying at lower speeds and altitude. The preliminary design of the airframe is completed by the sizing of the control surfaces based on a reference database. With this preliminary design information, the detailed design concentrates on the analysis of aerodynamics, stability and control as well and structural integrity with high-fidelity tools to validate and/or redesign the elements of the airframe.

The systems to be integrated within the MFP are the following: propulsion system, fuel system, inertia control system, landing gear, flight control system, data link, recovery system, mission equipment and on-board power supply. Concerning their development, some are derived from existing systems available on the market while others necessitate a complete new design following specific requirements. During the preliminary design phase, the design team assessed the different possible options and selects selected the best design meeting the technical and economical constraints. These solutions are reviewed and validated afterward at the detailed design stage with refined methods to analyse the technical points[5].The following Fig. 5 shows the final design of the MFP airframe and its integrated systems:

During flight tests, the IEP will be operated in a closed flight test range. The associated specific airworthiness requirements imply to

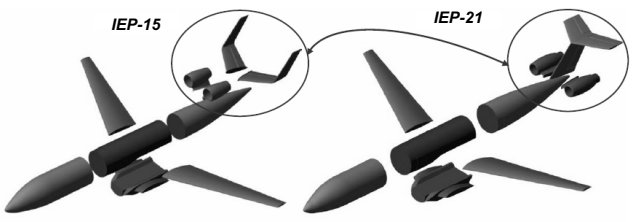


Figure 4. Conceptual 3D models of the Modular Flying Platform.

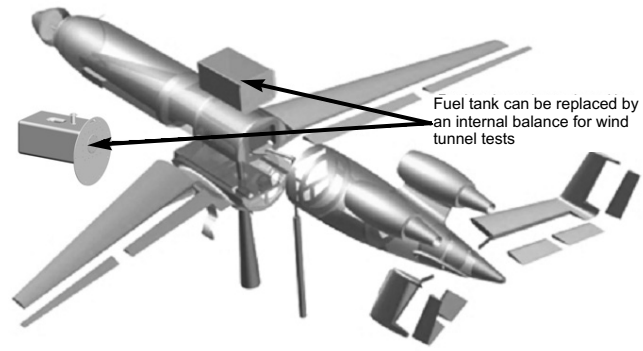


Figure 5. Digital mock-up of the Modular Flying Platform.

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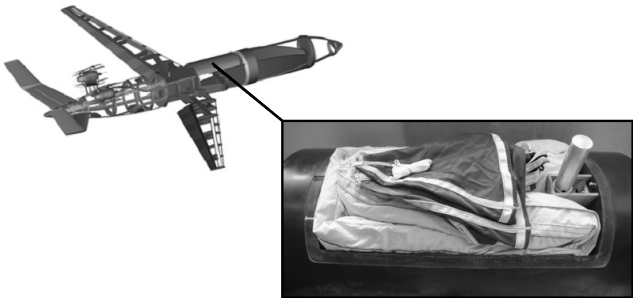


Figure 6. Recovery system.

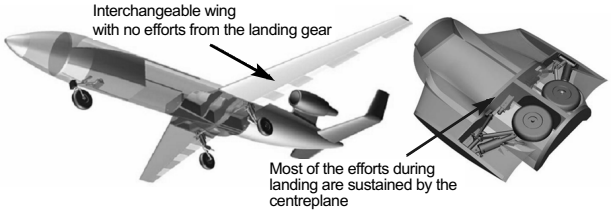


Figure 7. Landing gear solution.

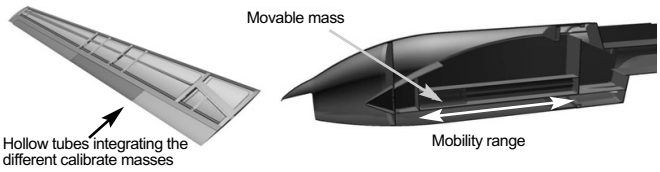


Figure 8. Inertial properties control.

terminate the flight as soon as the boundaries of the test zones are reached. The IEP includes then a flight termination system based on a parachute installed in the central part of the fuselage. This parachute can also be used to recover the airframe in case of a critical component failure (Fig. 6).

Because of its particular requirements, the airframe offers interesting key features that are presented in this section. Since the system requirements indicate the necessity to easily change the wings, the design team integrates the landing gear in the central element below the fuselage where the wings are fixed (called centre plane). In this manner, the structural efforts applied on the wings wings do not have to withstand structural efforts during landing are limited. This simplifies the design of future wings and enables rapid configuration changes on the flight test site.

The design team also integrated different systems to set up the inertial properties of the flying platform. First, hollow tubes are integrated within the wing in order to install different calibrated masses. In this manner, the flight test engineers can set the moment of inertia of the airframe according to the flight test objective before a flight. Second, a movable mass is installed within the fuselage to enable the control of the centre of gravity of the aerial vehicle. Such an attribute clearly increases the productivity of the IEP since several CG positions can be verified during a single flight.

The diverse developments associated with the Ground Segment lead the definition of a ground station based on a computer network associated with a modem. Each computer has its function such as mission planning, flight parameters surveillance, measurement data visualisation and on-board systems status monitoring. The ground station is completed by a control console that enables a remote control of the platform by the human pilot. More details on the Ground Segment are available in the NACRE report[5].

7.0 CONCLUSIONS

Within the European project NACRE, an important research has been carried out with the prospective of designing an Innovative Evaluation Platform under the form of a flying test bed. This IEP aims at helping the investigation of different disciplines during the early design phases of new aircraft concepts. The initial assessment and feasibility phase demonstrated that such a solution offers potential benefits in terms of technical capabilities and economic viability over the existing test facility for the identification of stability and control parameters, the noise assessment and the analysis of different recovery procedures in the case of hazardous flight conditions. However, this flying test facility is subject to stringent requirements that drive the design.

This is why the subsequent design phases largely relied on the objectives and requirements definition. During the conceptual design phase, the key element for the selection of the configuration has been risk minimisation. Since the IEP is a first step towards a European test facility based on free-flights, the idea was to reduce the number of technical challenges. For this reason, the platform is under the form of rather conventional architecture. During the preliminary and detailed design, the international team optimised the collaboration between the different research entities according their specialties.

This organisation led to innovative systems regarding the airframe and the ground segment. In the end, the consortium managed the design of an IEP based on a Modular Flying Platform meeting the severe requirements implied by the complex nature of the system. The following next step is then to both complete the manufacturing process and initiate the flight trials of this test facility prototype.

In the future, further developments of the IEP should enhance its competitiveness and enable tests with more radical aircraft configurations such as blended wing bodies or flying wings.

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