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DESIGN AND INTEGRATION OF FLEXI BIRD – A LOW COST SUB-SCALE RESEARCH AIRCRAFT FOR SAFETY AND ENVIRONMENTAL ISSUES

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Abstract

This paper is focused on aircraft design, systems and systems integration. The main goal of this activity is to prove that IEP (Innovative Evaluation Platform) - called also Flexi_Bird - can be successfully used in research of environmental issues and safety of passenger airplane flight. Aircraft design philosophy, structure, on-board systems and preparation to free flight experiments will be presented in details. Flexi-Bird is outfitted with high-quality instrumentation and prepared to register the control input, and to measure the aircraft output including hazardous states of flight (simulation of emergency) and response to brutal control. An array of microphones is planed to be set-up on ground to measure the noise coming from different aircraft components. Flight data will be fully stored on-board and partly transmitted to the ground control station for analysis. Most of systems were customized, tailored to Flexi-Bird structure and research tasks to be performed, including the autopilot widely tested with Matlab/ Simulink software. Extensive testing of all on-board systems was performed in Stuttgart University using the so-called "Iron Bird" and presented in a global overview.

1 Nomenclature

ADP	Air Data Probe
AoA	Angle of Attack
AoS	Angle of Sideslip
BWB	Blended Wing Body
CAN	Controller Area Network
CS	Control Surface
FSM	Flying Scaled Model
HIB	Human Interface Board
IAS	Indicated Airspeed
IEP	Innovative Evaluation Platform
IMU	Inertial Measurement Unit
IoA	Institute of Aviation
FMCS	Flight Management and Control System
GCU	Gear Control Unit
LCU	Link Control Unit
MTOW	Maximum Take of Weight
NACRE	New Aircraft Concept Research
PW	Warsaw University of Technology
RX	Receiver
TAS	True Airspeed
TCU	Tail Control Unit
TLM	Telemetry
TX	Transmitter
WCU	Wing Control Unit
UST	University of Stuttgart

2 Preface

Key challenges of aircraft industry are environmental issues and performance requirements. To meet current needs the research interest of the aircraft industry shifts towards unconventional approaches in many areas. The European Research Project NACRE proposes therefore the development of a new test facility defined as Innovative Evaluation Platform (IEP) to enable investigations especially for aeronautical disciplines and also for complete aircraft configurations.

Since the IEP has a character of a generic evaluation and measurement platform (comparable to other methods like wind tunnel or computational methods) it must be designed in a highly modular way (Fig. 1) to enable a multidisciplinary use of it. The modular approach was consequently followed in the complete design process starting from aerodynamic, structure up to avionic system, payload and measurement system. Additionally the system design fulfils requirements of an efficient and quick test process including the change of test configuration and conditions. Therefore the system is also optimized for rapid reconfiguration of hardware and software between different tests. Finally the system meets requirements generated by safety, operational aspects and authorities (legal aspects). The IEP consists of a flying part equipped with high qualitative data acquisition, measurement and processing system, autopilot and communication devices, as well as the ground segment consisting of data monitoring, control and navigation devices.

3 Introduction

In recent times the aircraft industry has permanently enhanced aircraft systems, aerodynamics, and flight behaviour and advanced the global aircraft performance to a high performance level. Aircraft have become larger, faster and more efficient. At the same time the aircraft industry is confronted with limits in terms of material, structures, environmental issues, availability of resources and also with political constraints. It can be observed that the aircraft industry is starting to open up the perspective in the direction of unconventional approaches in many areas of interest. A quick look at the latest innovations discloses many significant changes in aircraft design and concepts e.g. use of composite materials, change of aircraft configuration (BWB research activities), alternative fuel, environment-friendly design and low noise emission concepts to give only a short list. All these items also require new methods during the preliminary design process for computation, analysis and tests [1-9]. Especially the change of the aerodynamic shape of aircraft creates a new need for a measurement and analysis tools. A potential tool in form of a flying scale model was analysed in the frame of the European Research Project NACRE [10-13].

4 Flexi Bird as a new research tool, complementary to CFD, Wind Tunnel and others

To-day aircraft designers and manufacturers working on new projects widely use traditional engineering methods (for example data sheets), numerical simulations (for example CFD methods) and experimental test facilities (for example wind tunnels, catapults as ONERA B20 facility), simulators, and full scale (prototype) flight tests. However, when studying a new aircraft concept (if one does not possess a wide experience with similar configurations), a complementary solution could be employed using for example a FSM, playing a role of an IEP. In the original FP6 NACRE proposal the FSM was expected to be used in many research areas, including the research of High-Lift Devices, Laminar Flow Research, Wake Vortex Encounters, and others. However, following the detail analysis the flying test program was limited to Flight dynamics, Recovery from Hazardous Flight Conditions and Noise Assessment. Several (25) conceptual design projects (called further configurations) of FSM were prepared at PW and 2 of them (IEP-15 and IEP-21) were selected for further elaboration and preparation of detailed projects. Both configurations resemble a typical current passenger airplane, but they are not a scaled version of any existing aircraft. The main goal of the flying test experiment to be performed using this IEP is to demonstrate the advantages of this method for the design team in a very early stage of design, i.e. during the conceptual or preliminary design. Aircraft structure is done of carbon-epoxy composite using the wet lay up technique, and the LPC process (Low Pressure Curing). External shells of wing, tail-beams and most of ribs were laminated in negative moulds, being prepared using CNC (Computer Numerical Control) machine. Moulds were done of PROLAB-65, partly in ONERA, partly in PW. Smaller moulds were milled at one plate. Moulds of the container were prepared in two phases: in the first phase a number of plates were CNC-machined and then joined to obtain a positive model of the container, next in the second phase a negative mould for container was manufactured using the wet lay up technique. PROLAB-65 is a non-porous material of very good dimensional stability, easy for milling and has a very good surface quality (smoothness) after finishing the milled surfaces. Its density is equal to 0,65 g/cm^3, hardness equal to 63 Shore D (according ISO-868-85).

Flying Scaled Models were used several times in the past to help understand some physical phenomena encountered by full scale aircraft. A number of such research programmes are reviewed in [1-9].

5 IEP - Innovative Evaluation Platform

Since the outcome of the initial evaluation phase of the project was that the main potential is expected in three aeronautical disciplines:

- Flight dynamics,
- Noise assessment and
- Recovery from hazardous flight conditions.

There was a decision to build such measurement platform during the second phase of the project.

The three fields of interest were identified during the evaluation phase and identified as fields with a) high potential to benefit from free flight tests with sub scale models in an early design phase; b) areas which are confronted in other analysis methods with constraints which can be opened up using free flight tests (e.g. analysis of recovery manoeuvres in wind tunnel is limited; in free flight - full scale test is possible but risky and normally not performed; in free flight - sub scale test with unmanned test vehicles is *possible, cost effective and without risk of human life*).

The test bed is a twin engine (jet turbine), 145kg MTOW, generic, highly modular, unmanned airplane for multidisciplinary use for research purpose. The design is optimized for tests in the three areas but additionally open for a wider field of test. The IEP is a test vehicle which can be reconfigured by reorganising complete hardware groups. This enables a usage for testing in various disciplines as required.

6 System Design Objectives

The IEP was designed as an aircraft with the purpose of multidisciplinary use. Consequently the system design must follow the same design principles which created a number of unconventional requirements [11].

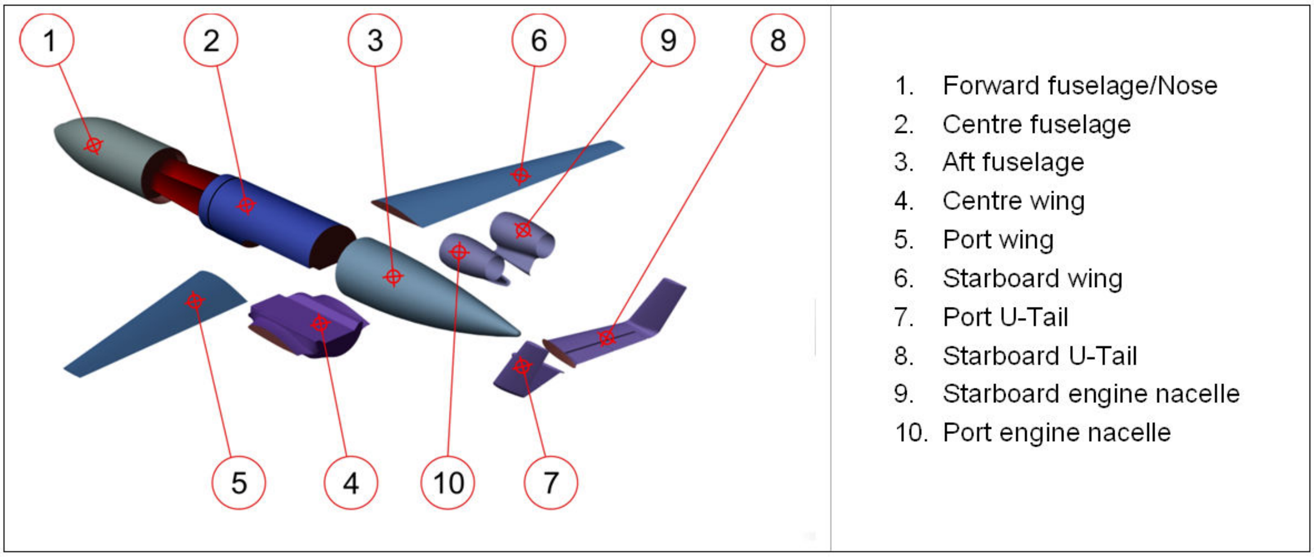

Fig. 1 Modular concept of the IEP

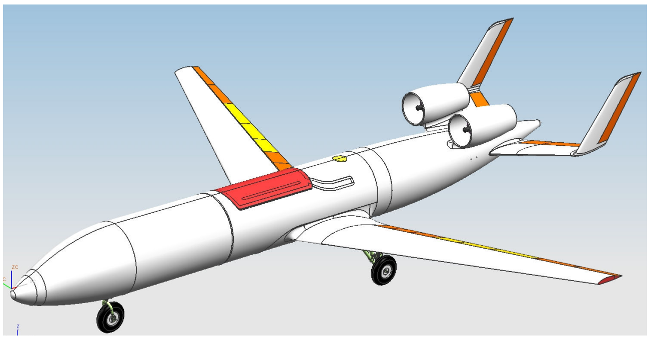

Fig. 2 Flying test model - version - 15

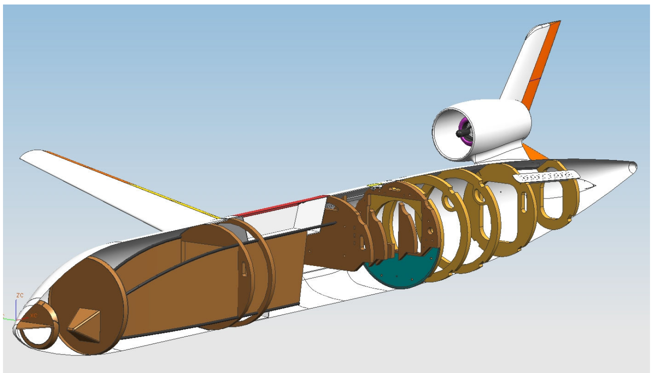

Fig. 3 Internal structure of IEP-15

The IEP should be usable in different fields of interest which leads to a system which must provide corresponding sensor equipment, data acquisition systems and interfaces to be used for flight measurements in several research areas.

The system must also be operable for potential future use which might bring different requirements. Therefore the electronic hardware was set up in a modular way to achieve the possibility to exchange systems according to state of the art needs or technical developments.

One of the biggest impacts on system design has created the structural modularity of flying hardware. The IEP can be reconfigured (plug and play like) to different aircraft configurations. All parts of the aircraft can be replaced, reassembled or exchanged in a way that different types of tail versions, wing configurations or different fuselage dimensions can be tested with the same hardware. This is one of the most powerful features of the IEP. Using it, e.g. noise analysis with different tail types (T-Tail, U-Tail or other like V Tail) can be done in a very short time frame. The whole aircraft design philosophy follows this modular design principle. Wings can be mounted in a forward swept or standard configuration using adapters. The fuselage can be extended and the position of wing root can be changed using spacers. In the time frame of NACRE two different tail versions were realized to show the operational benefit of that concept.

The system must provide several features to meet the requirements generated through the modular concept.

- *The avionic system must support the possibility to disassemble the aircraft into segments preferable even during the flight test campaigns.*
- *The system must support a quick reconfiguration of the aircraft.*
- *The system must be flexible for changing hardware modules (like U- and T-Tail), to attach different type and numbers of actuators, different control strategies (actuator command mixing), different sensor equipments or other specific hardware and software settings.*
- *The interfaces must provide possibility to connect different modules and must be generic and flexible to fit selected modules which might be designed in the future.*

Some aspects listed above influence the system design and are derived from the special requirement of modularity. Additionally there are other aspects which have been considered during the design process which are shortly mentioned bellow:

- *Safety aspects (self monitoring and recovery system)*
- *Redundancy aspects*
- Repeatability of test (automatic flight control system)

7 Avionics Concept and Architecture

The IEP System consists of several parts, generally divided into onboard and ground systems, Fig.4. The experimental hardware can normally be found on both sides. For flight experiments the aircraft is equipped with specialized hardware. For noise measurement the aircraft has noise generators and microphones on board and a microphone array has been installed on ground. An overview of the noise instrumentation is given in [11, 13]. In the ground control station the control devices have been implemented to manage and control the experiment equipment onboard. The system communicates via different up - and downlink channels with frequency diversity and frequency hopping systems. For manual flight phases a pilot on ground controls the aircraft via RC link while the autopilot onboard commands the aircraft during automatic flight phases. The ground control station is separated into different screens which can be configured according to the needs of the flight tests. Some standard displays like moving map, internal state monitor, and system control screen are always in use. The experiment control screen is optional and can be adapted to the flight mission equipment.

The core of the onboard system is the flight management and control system (FMCS). It is a computer system which controls all flight threads like autopilot, navigation but also data acquisition, data post processing and management, data storage, communication with other modules, communication with ground control station and much more. The FMCS is connected by CAN Bus system with several sub units which fulfil specialized tasks.

The electronic sub units are located in each aircraft module which can be disassembled. In each wing an electronic device (WCU) is located. Such a device is also in the tail modules (TCU) and in the central part of the aircraft (GCU). The task of these sub modules is to communicate with the main computer to get data for connected actuators and to deliver the

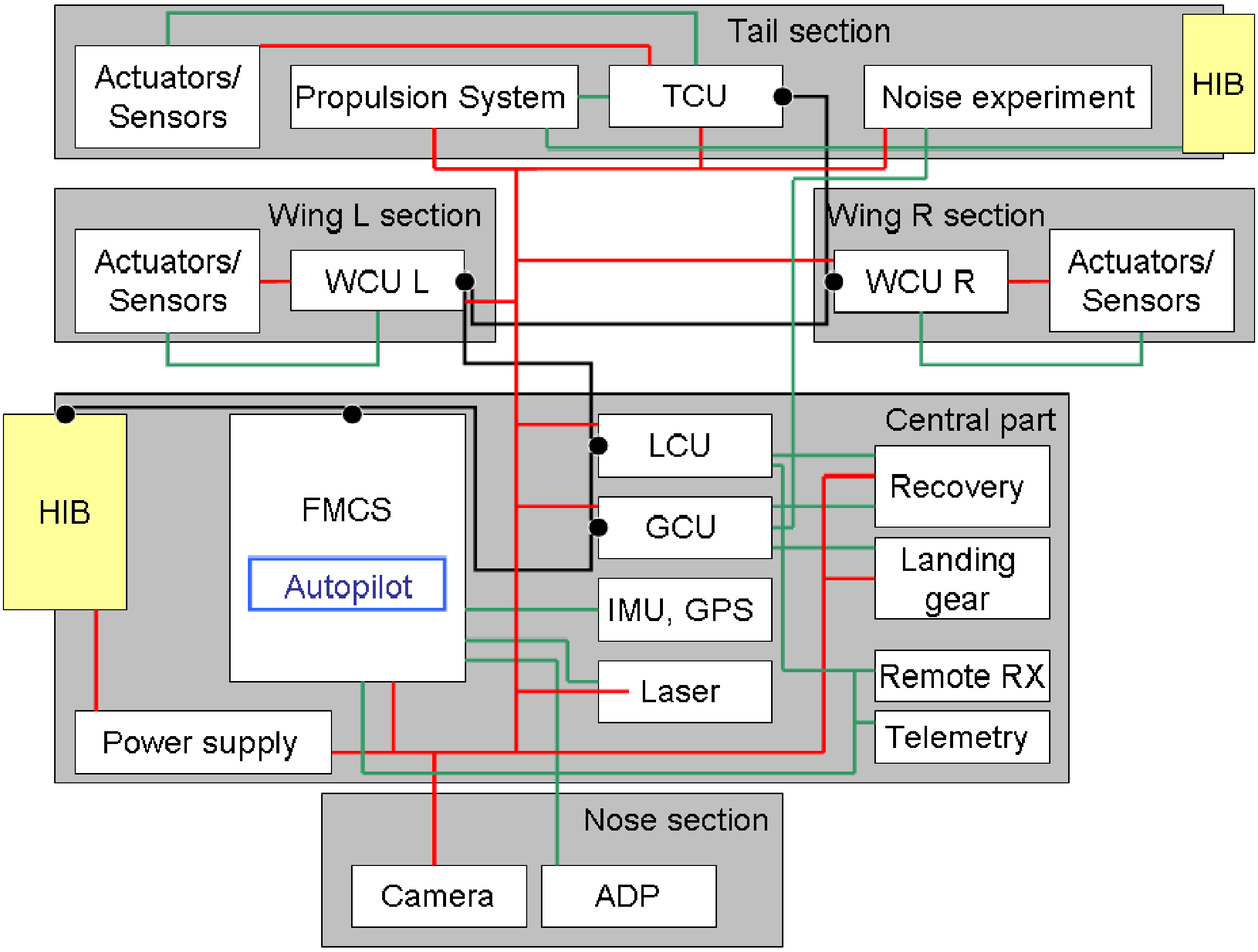

Fig. 4 High level architecture of the IEP

sensor information. Additionally, the modules manage to translate the generic information of the FMCS to specified commands for the actuators. The FMCS gives e.g. rudder commands to the TCU where the signal is translated into a specific number of electrical commands depending on whether the T Tail (3 rudder control surfaces) or the U Tail (4 rudder control surfaces) is applied. The modules also harmonize the movement of all control surfaces which correspond to the same function, see chapter 8.1. The FMCS also communicates with several sensors like IMU, GPS and laser altitude sensor which are located in the same aircraft module. Sensors which are placed somewhere else in the aircraft are processed by the corresponding unit. Such a concept avoids large wiring harnesses and is flexible concerning the replacement, exchange or upgrade of sensors. In case of changes the wiring needn't be changed in the whole aircraft but only inside the corresponding hardware module. Interfaces of the modules are also not impacted by such changes due to data transmission by the CAN bus system. Only CAN bus messages must be reconfigured. Sensors attached to the system in that way are: ADP – located in the nose, control surface deflection and force measurement (located in each module) and noise sensors (located in the tail).

For safety reason a recovery system (parachute) is installed. The recovery system should make it possible to stop the flight at any time if required. It is not designed as a landing device so damage on the structure is possible if the system is activated. The communication between man and machine is performed on different ways (telemetry, serial connection, CAN bus interface or Ethernet). Each interface is designated for special purposes such as hardware in the loop simulation, internal state monitoring, in flight monitoring or software updates. The interfaces are located on Human Interface Boards (HIB) which also provide system state information by LEDs, access to data log and various switches to drive the system.

7.1 Modularity

As described the modularity of the overall system is one of the key features of that flying test bed. The avionic architecture supports the modular design principles. Structural modules are equipped with interface panels to route power supply as well as communication connections from the FMCS system inside the specific IEP modules. The communication is performed by CAN bus system. Due to the fact that in each IEP module there is an electronic data processing unit such CAN bus messages can be decoded close to the designated actuator or sensor and translated into electrical signals. Changes in the modules (e.g. if a new wing with special sensor equipment should be flown) does not impact the interfaces but only the CAN bus messages and the software.

The power supply of the modules is on the one hand redundant and on the other hand side split into sub circuits separating electrical systems, actuators and sensors.

7.2 Safety and Redundancy

The IEP was designed to be used in closed and restricted areas. That decision had a big impact on the design of the avionic system. In many countries the legal aspects of UAV operation is not yet fully solved. Therefore the NACRE team decided to use a restricted area for the flight tests. To get a permission to fly in restricted areas it must be shown that the vehicle will never leave the designated airspace. For the IEP a flight abort system was developed, which provides a guaranty that the flight can be stopped under any conditions. Therefore a parachute with a double redundant actuators, power supply and control electronic, was developed. The ejection of that system can be activated by the backup pilot, from the ground control station or automatically, if the onboard system detects a total loss of data link for a certain time. The transmission of the manual flight abort signal from ground to airborne system is realized via three different frequencies and two different types of transmission techniques (two times 2.4 GHz frequency hopping (diversity) system and 869 MHz

Telemetry system). The signal is transmitted on ground via three antennas and received onboard via five HF modules with five antennas with orientation diversity. The recovery system represents one of the systems with the highest redundancy level in the IEP avionic.

In order to also increase the reliability of the system, redundancies have also been implemented in the power supply system, wiring harness, control surface actuators, propulsion system and fuel system.

7.3 System complexity

The system of the IEP was designed and manufactured under the usage of a combination of COTS products and self developed components. Sensors and actuators are COTS components, while the complete FMCS is self-designed by UST. The electronic system was produced in the framework of the project as well as the software code for the onboard system and the ground control station. The goal was to use as much COTS products as necessary and to focus only on advanced development of items where shelf products do not achieve the required performances. The result is a system which provides 72 actuator output ports, 168 analog and digital input ports with up to 16 bit accuracy for the sensors. The datalog contains sets of more than 600 values which are stored with 100 Hz frequency. Compared to small autopilot systems of different suppliers the FMCS is several times faster and much more powerful. Additionally it provides interfaces for CAN bus, RS232 and I2C bus on each module, what enables installation of payload systems anywhere in the aircraft.

8 Avionics Design

In the following paragraphs some detailed information about selected system groups will be given.

8.1 Power supply

The power supply system consists of eight independent circuits which are driven each by redundant battery systems. The batteries of five main circuits are connected to power management boards which protect the system from shortcuts, voltage drop of batteries and overloads and which manage the use of four times redundant battery packs. The system was tested successfully under maximum load conditions (with a two times reserve) and under long endurance conditions.

The circuits provide power independently to the logical units, two times to actuators, to the LCU (redundant electronic for flight abort system, link monitoring and FMCS monitoring), to the propulsion system, the camera, the laser and the payload (noise measurement equipment).

8.2 Actuators

The aircraft is equipped with 36 actuators and two jet engines. All movable flaps (elevator, aileron, rudder, high lift devices) are split into several mechanically independent parts. This solution offers a redundancy, important when an actuator fails or is blocked. The contiguous CS are not impacted in such situation. Additionally, the force is evently distributed to several actuators which enables the usage of smaller actuators that fit mechanically inside the airfoil dimensions. Due to that fact the wings are stand-alone modules with integrated actuator systems. The high number of CS at trailing edge of Horizontal Tail Plane (4), Vertical Tail Plane (4) and wings (2x 8) additionally offers the possibility to change the control strategy by software and to test unconventional control methods (e.g. butterfly).

The aircraft is additionally equipped with a retractable, steerable landing gear (including disc brakes). Actuator forces have been measured during the wind tunnel tests.

8.3 Recovery system

The recovery parachute system was designed for an ejection speed of more than 80 m/s. This system in its final stage of development was tested in the gust wind tunnel (6,3 m) to validate a proper ejection under critical conditions (low speed and high angle of sideslip). The redundant ejection hardware was developed at UST. It is linked to an internal state monitoring system which observes the FMCS system and the link condition of the aircraft. If the FMCS is inoperable due to failures or all data links are unavailable, the flight abort system activates the parachute after a certain time. Additionally the parachute can be ejected at any time from ground by the back up pilot or the ground control station crew, if required. In case of activation also other systems reacts: engine shut off and landing gear extraction starts.

8.4 Sensor System

The aircraft is equipped with several sensors.

- a high precision laser altitude sensor,
- IMU (3DMG Microstrain) driven with an advanced data processing algorithm developed by Fraunhofer Institute Stuttgart,
- ADP (IAS, TAS, AoA, AoS, Temperature),
- GPS,
- CS- deflection sensors,
- CS force measurement system.

Additionally, there are several sensors for the internal state monitoring of the recovery system, landing gear retraction position etc.

8.5 Autopilot

The autopilot system was developed and tested with Matlab/ Simulink. It is a combination of several controllers which provide the following features: stabilization in all axes, level flight (altitude hold), waypoint navigation, climb and sink maneuvers, speed control, handling of failure cases (like “one engine off” condition), wind compensation, 3D path control. The system is developed at UST. It contains an advanced algorithm for waypoint navigation.

A simulation environment was also developed for optimization of control strategies, controller gains and to test the overall flight campaign. The simulation is connected to a “Hardware in the Loop” simulation so the autopilot code could be also tested running on the target system. The physical model was taken from a flight simulator (X-Plane) fed by wind tunnel test data of PW. The Autopilot was validated in flight using a small UAV.

9 System Verification and Validation

To enable a safe operation of the flying test bed an extensive test program was developed to proof that all system components are working together properly. The test conditions were set-up as close as possible to the real flight conditions. Additionally, test conditions were set to selective critical conditions which include safety margins. The team of researchers used the test results as a basis to achieve a decision whether the flight program of the IEP can be started or not.

9.1 Methods

To achieve a complete picture of the performance of the system, different evaluation, verification and validation methods were used.

Single system tests: Before installing of all the systems in the IEP, various single system tests in form of high load conditions or long endurance tests were performed especially for actuators, power supply, parachute, fuel system and sensors.

Iron Bird: The complete system was installed on an Iron Bird (Fig. 5). Thus all components could be tested under simulated flight conditions. The Iron Bird offered the possibility to check system components, system groups and the overall system and to analyze also the influences in between.

Wind tunnel tests: Since the size of that UAV allows using large wind tunnels, the team took the opportunity to verify the computational results analyzing the whole aircraft in the T3 wind tunnel (5m) of the IoA. The recovery system was tested in the gust wind tunnel (6,3m) in UST to verify proper ejection and deployment of the parachute system even in critical conditions.

Flutter analysis and ground vibration test: Once the system was completely installed, the IEP team performed a vibration test to identify critical speeds and flutter modes.

Flight tests: Several components and system groups were also tested in flight before installing them on the IEP. The Laser Altitude Sensor and ADP were checked under flight conditions with an ultra light aircraft to verify the performance. ADP was tested in terms of the accuracy, tendency for wind vane oscillation and mechanical strength under high speed. For the laser sensor different ground surfaces (snow, ice, grass, concrete and forest) were tested to validate the performance under real flight conditions.

In an additional flight test the complete computer system of the IEP was installed on a 2.4 m UAV to test the onboard hardware and software performance under real flight conditions. At this occasion also the autopilot was in action for the first time. All in flight tests were performed in UST. The range of the telemetry system and RC control were also tested during a flight test in an ultra light aircraft. The range could be tested that way without ground effects and under real flight conditions.

9.2 Iron Bird

To test all hardware components and onboard software, an Iron Bird was designed. On the Iron Bird all systems (actuators, sensors, wiring harness, flight computer, recovery system, propulsion system…) were installed in the full scale. The Iron Bird can be connected with the ground control station and a flight simulator. The pilot is able to fly the model using a beamer with a simulated view (ground based viewpoint towards the aircraft). Such installation was used for pilot training, adjustment of the systems, calibration of the control surfaces and adjustment of the autopilot.

Additionally, there were systematic tests of critical conditions like voltage drop in the system, loss of control surfaces, one-engine-off condition, loss of flight relevant sensor signals, loss of data link, loss of RC link, total loss of link and more. The Iron Bird was a powerful tool for the complete development and test process of the IEP. The Iron Bird is still active and can be used for further developments of the IEP.

Fig. 5 Iron Bird

9.3 Wind tunnel tests

IEP15 and IEP21 were tested in the IoA 5M Low–Speed Wind Tunnel to determine the longitudinal and lateral characteristics, (Fig. 7). The test was performed at Mach number of 0.07 to 0.13 and Reynolds number of 0.8×10^6 to 1.44×10^6. The aerodynamic characteristics were measured using a strain gauges internal balance at the angle of attack range from -9^o to $+29^o$ and the sideslip angles from -5° to +15°.

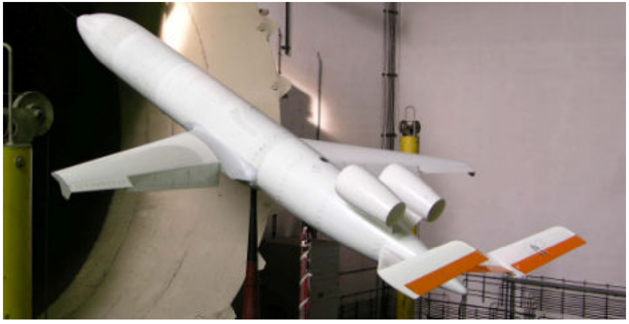

Fig. 6 IEP 15 Model in Wind Tunnel T3, IoA

The longitudinal and lateral static stability, the effectiveness of a tail of “U” and “T” type and drag characteristics of the NACRE IEP model baseline configuration were obtained. The NACRE IEP model breakdown data and drag build–up characteristic were determined. Approximately 104 runs were performed for combination of one fuselage, one wing planform, horizontal and vertical tail "U" and "T" configurations and ADP location. The goals of tests were: (1) to determine effects of tail configuration on measured aerodynamic characteristics of the IEP model; (2) to obtain accurate stability, control effectiveness and drag data of chosen baseline configuration for angles of attack from –9° to + 29° and sideslip angles from -5° to +15° and (3) to optimise pitching moment using wing fences (because pitch-up phenomenon was discovered in Wind tunnel).

9.4 Trim and stability analysis

Stability analysis was preceded by finding the trim conditions, computed by use of STB software, solving nonlinear equations of equilibrium. Nonlinearity usually comes from nonlinear aerodynamic characteristics, nonlinear coupling between forces acting on main wing and flaps, rudders (for example alpha influences on normal force via CL and also on drag force via CL^2), thrust inclination factor and many other reasons. Thrust required for steady level flight, angle of attack and elevator deflections versus flight speed were computed. Initial results of stability analysis showed that the phugoid mode is partly unstable at low speeds; however its time to double is long enough to be acceptable. Some modes are also very sensitive to the travel of the centre gravity, especially the phugoid. The stability analysis shows that IEP-15 and 21 configurations mostly fulfil stability requirements and that the stability correction to be done by FMCS will be marginal.

9.5 Flutter analysis based on ground vibration tests

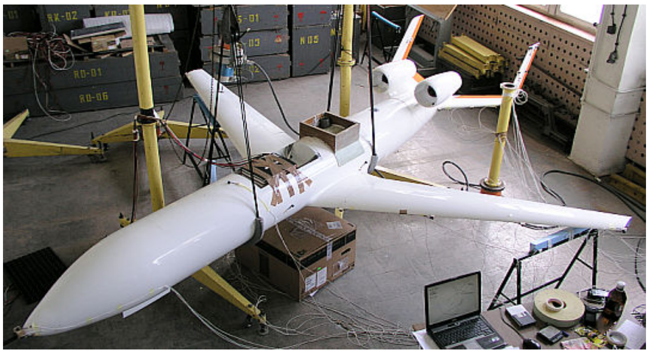

Fig. 7 Ground Vibration Tests carried out in the IoA

Symmetrical and anti-symmetrical mode shapes were measured in laboratory of IoA, (Fig. 8). Critical flutter speed for many cases (different aircraft weight, CG position, stiffness in Flight Control System (FCS), actuators connected and disconnected, and many others) were computed using NASTRAN software. Results of this analysis can be summarised as follows:

- Critical flutter speed [110 m/s] for standard stiffness at FCS is beyond of the practical range of speeds [27 ÷ 92 m/s];
- If flexibility of FCS is reduced from standard value of 89 [Hz] to 32 [Hz], then the critical flutter speed is reduced to 58 m/s. It means that stiffness at FCS must be carefully monitored between successive flights;
- If any actuator (especially mounted on outer ailerons or on the higher rudders) is disconnected (i.e. if any control surface is free to rotate) the critical flutter speed could be really very low (32 m/s for outer aileron);
- Weight of the airplane practically does not influence on Critical Flutter Speed (because the weight change follows refuelling only – fuel tank is located at central part of fuselage and does not change the moments of inertia).

9.6 Simulation

The simulation which was used to develop the autopilot was a code based on MATLAB/ Simulink. UST developed a tool chain for code generation, test and validation. The autopilot software modules were generated in Simulink. Connected to a flight simulator these modules could be optimized and the controller architecture could be validated. The Simulink models were compiled with the real time workshop for the target, microcontroller based, onboard system. The flight simulator was fed with a physical model of the IEP based on geometrical data, wind tunnel test results and computational results. The flight simulator also provided a visual feedback of the airplane behaviour which was useful for pilot and ground crew training. The simulation environment could be combined with the Hardware in the Loop simulation on the Iron Bird. In that state the complete flight missions including running original hardware and software, working actuators, simulated sensor data and a pilot in the loop could be performed. This set up was used to train complete flights including take off phase, transition legs, automatic flight control (hand over to autopilot), measurement legs and landing procedures, (Fig. 6) The ground control station was also online connected which enabled ground crew training.

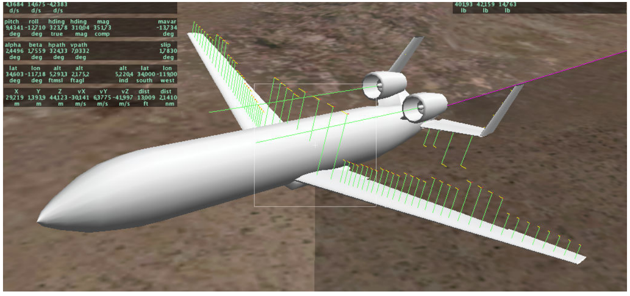

Fig. 8 Visualization of flight of IEP 15

9.7 Engine and fuel system test

One of the most important tests was focused on the validation of expected thrust of the two P200 JetCAT engines, (Fig. 9). These engines are not standard JetCAT engines but optimized versions in terms of electromagnetic compatibility and higher thrust. Using a balance the thrust of the engines was measured separately and then jointly at maximum rounds per minute (112 krpm).

Fig. 9 Engine full throttle test and thrust measurement (440N) (performed in UST)

An additional point was to figure out if influences of the advanced active bubble protection in the fuel system could be measured. The hopper tanks of the IEP are equipped with an active air removing system which enables a bubble free fuel flow, even during the requested high dynamic flight maneuvers. The complete fuel system was also tested before installation on the Iron Bird with several fueling, draining and high load simulation tests.

9.8 Flight Tests

Once the onboard system was completely developed and tested on ground, UST performed a flight test of that system using a 2.4 m UAV. The complete onboard system including all relevant sensors and the recovery system electronics were installed on that UAV. A generic flight program for the autopilot was uploaded and the ground control station was also installed. The test pilot started the UAV manually from a concrete runway. At a safe altitude the pilot handed over the airplane to the FMCS. The UAV engaged the desired track and flew several rounds on the predefined pattern. After the landing a datalog (>100Mb) could be downloaded from the internal data storage for the further flight data post processing. The datalog contains data sets of about 600 values which are stored with 100Hz frequency. The autopilot clearly demonstrated its high performance.

This test did not only validate the performance of the complete onboard system but also verified the development tool chain. All control parameters for the test UAV were determined with the same process as it was made for the IEP. The selection of autopilot parameters (tuned only by simulation) resulted in a stable behaviour of the aircraft. Waypoint navigation was possible already during the first flight of the whole system. The good results of the flight test with the small UAV carrier gave to the project team the high confidence about the parameter for the IEP which were generated with the same method. To prepare the flight tests of the IEP, Taxi tests of IEP were performed partly in Stuttgart and partly in Modlin, Jan.-Feb.2010, (Fig. 10.)

10 Conclusions

The IEP represents a flight ready generic measurement platform developed by a team of European partners (NLR, ONERA, PW and UST). The aircraft is about 145 kg and has a wingspan of 4,16 m. It is ready to support the researchers of future projects with flight test data. The concept of the aircraft allows covering a wide range of test areas. The modular concept allows quick changes of aircraft configurations and instrumentation. Particularly the questions concerning environmental issues (low noise emissions, efficiency) and new propulsion concepts (open rotor) are some of potential areas for future research by Flexi-Bird.

Fig. 10 IEP during taxi test February 2010; T-Tail version

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