Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Upgrading a multi-mission research aircraft

Problem area
National Aerospace Laboratory NLR and Delft University of Technology, Faculty of Aerospace Engineering together operate a special aircraft for research purposes. Unlike other Special Purpose Aircraft, PH-LAB is truly a multi-mission aircraft, engaged in a wide variety of R&D in-flight research projects and often specially modified for each project. For this aircraft a significant upgrade of the aircraft avionics and data acquisition suite was designed, certified and implemented.

Description of work
The paper describes the mission spectrum of PH-LAB and the cockpit upgrade that was designed to support its operational role.

Results and conclusions
Operating a SPA can be done using different business models. NLR/TUD have chosen to adapt a modus operandus where the aircraft serves as a Multi Mission SPA. As a consequence the aircraft is modified frequently, changing the configuration of the aircraft on a regular basis. For this aircraft and its specific role it was possible to develop a business case for the development of a new flight deck and data acquisition system based on an integrated design.

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This report is based on a paper presented at the Air Transport and Operations Symposium 2012, June 18-20, Delft, The Netherlands.

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Contents

Nomenclature

SPA = Special Purpose Aircraft
STC = Supplemental Type Certificate

I. Introduction

SPECIAL Purpose Aircraft (SPA) are flying platforms with applications in addition to commercial air transport. When related to SPA in R&D environments, examples of SPA can be found in several fields, such as remote sensing, atmospheric research, avionics development, micro-gravity research, and the application of the SPA as flying classroom for instructional purposes.

For some R&D applications the SPA is the carrying vehicle of specific sensors: the aircraft in itself is not the research objective. These sensors need to be developed and maintained. Integration of these sensors will typically involve changes to the type certificate of the aircraft through a Supplemental Type Certificate (STC) or other means.

Operating a SPA is a demanding task in an economically challenging environment for several reasons. All expenses related to owning and operating an aircraft apply: not only direct operating costs such as fuel and landing fees, but also depreciation, insurance, maintenance, flight crew and administrative costs related to the continued airworthiness of the aircraft. Operators of a SPA will normally have a very small fleet of one or a few aircraft, so these recurring costs must be carried by a few airframes. In addition, these aircraft will normally not fly the number of hours that a passenger-carrying aircraft will make, increasing the break-even hourly rate further.

An operator of a SPA can be a small business with a very low cost structure, working with long-term contracts for a few large customers. For example in aerial survey and flight inspection of navigation aids such companies can be found. Another possibility is that a SPA is operated as a flight division inside a larger commercial company such as an avionics manufacturer, or as part of a semi-governmental institute, such as a national Meteorological Office.

Since the early Nineties the Dutch National Aerospace Laboratory NLR and Delft University of Technology Faculty of Aerospace Engineering have been operating a SPA using yet another business model by adapting a Cessna Citation II to serve as a *Multi Mission* SPA. This aircraft, call-sign PH-LAB is engaged in a wide variety of R&D in-flight research projects and often specially modified for each project. Although this means that the aircraft is often modified and adapted, the dependency on one or two larger contracts is not an Achilles' heel in the economic viability of such an operation. Examples of earlier deployments of the aircraft span a wide range of special missions, including Remote Sensing missions, operation as a Flying Classroom, measurement of take-off performance on contaminated runways, Sense- & Avoid technology development missions, wake vortex encounter measurements, Flight Inspection flights, implementation of a Fly-By-Wire system, volcanic ash measurement flights, and many more.

As with every research facility, the operator faced an assessment if this aircraft still meets the requirements for continued operation in its present role, or perhaps a mid-life upgrade or even a replacement was required. A business case was developed, based on the very broad and versatile mission spectrum, for the continued use of the aircraft until 2020 and beyond. Based on this business case a significant upgrade of the aircraft avionics and data acquisition suite was designed, certified and implemented in 2011.

The paper will elaborate on the modification capability applied in designing and implementing aircraft modifications in support of its multi-mission role. A broad range of missions that this SPA is involved in, as well as on some mission-specific modifications that were designed for this aircraft, will be discussed. Furthermore, the development of the Business Case for the mid-life upgrade will be explained, as well as a description of the implemented improvements to the aircraft avionics and data acquisition system.

II. Operations and Design and implementation of aircraft modifications

As a *multi-mission* SPA, the aircraft is deployed on various missions during the year, often requiring multiple modifications over the period of a number of weeks. Due to this need for frequent modifications, NLR and TUD have an agreement with the Dutch Civil Aviation Authorities (CAA-NL) where limited authority is delegated to NLR-employed approved inspectors to certify smaller modifications. When a new project requires modification or instrumentation of the aircraft, the request for this modification is forwarded to the Research Aircraft Design Organisation (RADO), a department of NLR that is capable of designing the modification. Here a judgement is made on the scope of the modification and whether it should be judged as a major, minor change. Minor changes can be approved and certified by the RADO, after which the NLR Part-145 organisation can perform the modification on the aircraft. Major changes will follow the route of a Supplemental Type Certificate (STC) via the CAA-NL. All the examples treated in this paper were designed in-house.

For every project, the flight test operations department is involved in a very early phase, even before the design of the modification starts. Generally one of the research test pilots is dedicated to the project as project pilot. He then becomes responsible for drafting the flight test schedule and functions as a consultant to the project engineers.

III. Examples of PH-LAB Special Missions

A. Integration of optical sensors

Within the framework of the European DANIELA and NESLIE research projects PH-LAB was modified to accommodate an innovative optical air data system. This system applies a LiDAR to measure the air speed vector of the aircraft. This system was evaluated during flight tests in polar, moderate and tropical regions[1].

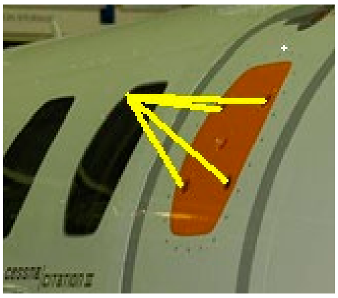

Figure 1. Alignment of four LiDAR beams for air data measurements.

Measuring airspeed, α and β using and optical technique works by using four laser beams, focused on a very small volume just outside the aircraft fuselage (See Figure 1). Part of the emitted laser energy is backscattered to the system's receiver by particles in the airflow, like aerosols, water and ice particles. The shifted frequency (Doppler shift) in these four returned signals is a measure for the air speeds along each of the four axes. With three out of the four axes, the aircraft's air speed vector (magnitude and direction) can be determined. A fourth axis is used to determine a consistency parameter.

To install this system the location of the existing emergency escape hatch was chosen as pass-through for the laser beams. The existing window was replaced with a aluminum plate housing four optical grade glasses. The plate was manufactured and certified at NLR and included provisions for additional stiffness as well as a system for anti-icing and defogging of the windows.

Avionics boxes for the optical system and data recording were developed and attached to the existing seat tracks in the cabin.

For this configuration the classification of the emergency hatch and cabin modifications were such that certification of it was performed internally by NLR's approved inspectors.

An extended version of this set-up was required for research into forward looking LiDAR applications, such as wake vortex or Clear Air Turbulence (CAT) detection. Within the IWAKE and DELICAT EU programs an outward protruding extension was developed to house a mirror assembly that enables the laser beam to point in the direction of flight.

As can be seen in figure 2, this extension could potentially influence the air flow into the engine and could affect aircraft handling and performance. A more extensive certification path was required that included CFD analysis and flight tests, leading to a STC for this configuration.

Figure 2. External mirror assembly for forward-looking LiDAR applications.

B. Flight Inspection

A common application of SPA is flight inspection activities for the calibration of radio navigation aids according to ICAO guidelines. NLR/TUD is responsible for flight checking all ILS, VOR, DME and TACAN facilities for Air Traffic Control The Netherlands (LVNL) and the Royal Dutch Airforce (RNLAF).

For this purpose the aircraft is equipped with an Aerodata Flight Inspection System (FIS), with specially calibrated antennas for the reception of radio signals, using a Differential GPS system as a reference. Inside the cabin a Flight Inspection console is fitted as the working position of the Flight Inspector.

Flight Inspection is a recurring activity for NLR/TUD, often performed ad-hoc or in-between research programs. For this reason the aircraft configuration is changed regularly to a flight inspection configuration and back.

Figure 3. Flight Inspector console fitted in the cabin.

C. Take-off and landing performance on contaminated runways

Following a review of accidents involving commercial jets during take-off and landing, aviation authorities in the early 1990s identified the need to update existing regulations and flight manuals. The aim of the CONTAMRUNWAY study[4] was to support legislation in reviewing the validity of the existing requirements for operation on runways contaminated by rain/snow/ice for small and commuter aircraft. This was done by measuring contaminated runway drag and the aquaplanning speed of wheels free to roll (no braking), identifying the most important parameters acting on the total drag and assess the validity of AMJ 25.1591 "Supplementary Performance information for take-off from wet runways and for operation on runways contaminated by standing water, slush, loose snow, compacted snow or ice". To do this, the aircraft was instrumented with accelerometers and wheel speed sensors and a number of take-offs, landings and ground runs were performed in standing water, dry snow and on compacted snow. Flight trials were performed at Cranfield (UK) and Skavska (Sweden).

This project demonstrated that flight test activities are not restricted to the carriage of sensors, but the aircraft itself can be the object of research. It also shows that Medium and High risk flight testing is part of the activities. For this purpose, NLR/TUD apply a Flight Test Operating Manual[5], providing a regime for the preparation and execution of flight tests, including a rigorous safety assessment as part or the preparation phase.

Figure 4. Take-off and landing trials on wet and contaminated runways.

D. Flying Classroom

Delft University has a long history of incorporating test flights in the aerospace engineering curriculum. When TU Delft and NLR acquired PH-LAB, one of the first projects was the development of the flying classroom. A central data-acquisition system was built that logs data from various sources and distributes this data via an on-board Ethernet. Touch-screen displays were installed in the seat head rests with the seats in a forward facing commuter configuration, so that six student observers can view the displays and interact with the system. A coordinator station was installed behind the cockpit divider to control the system. All bachelor students make one or two test flights during the curriculum and perform measurements on performance and flying qualities of the aircraft.

E. Fly-By-Wire testbed

In 2006, TU Delft research on developing a method to objectively and quantifiably asses the extent to which a flight simulator supports real-flight pilot behavior reached the stage where in-flight measurements became necessary. An essential part of this research was to obtain a database of multimodal, i.e., visual-vestibular pilot models in real flight.

A fly-by-wire control system including a sidestick was designed, built and certified that made it possible to fly automatic flight maneuvers and fly the aircraft with computer generated flight control signals. By introducing this fly-by-wire control system it was possible to set the conditions to properly estimate these pilot models.

Figure 5. FBW controls (below glareshield), side-stick and experimental display.

To limit the time and expense involved with certifying FBW-control actuators, use was made of the existing autopilot control actuators. The experimental system breaks in on the existing autopilot channels. This way, it was possible to certify the experimental FBW system, without the actuators. The system can be connected to the onboard experimental computer, which allows for a very flexible setup, where different control laws can be selected during flight. Different controllers can be connected to the experimental computers, such as the side stick depicted in Figure 5.

IV. Aircraft upgrade

A. The need for a mid-life upgrade

In the previous section it was demonstrated that the business model for this SPA is based on multi-mission engagements, with the aircraft frequently undergoing (major) modifications. Approaching 20 years in service, several avionics components, such as CRT tubes, analog symbol generators and electro-mechanical instruments, were approaching the Mean Time To Repair (MTTR). In addition, new CNS requirements for the operation in European airspace were being published by Eurocontrol and others, for example the requirement for the carriage of ModeS transponders with Extended Squitter, the introduction of Performance Based Navigation and the upcoming introduction of CPDLC. Meeting these requirements meant that the existing avionics needed to be replaced to continue operations in the longer term.

Also, NLR has been selected as Associate Partner for SESAR. To be able to support future ATM related research its flying testbed should ideally be equipped with state-of-the-art avionics.

Based on these considerations and through a market analysis a Business Case was developed where it was demonstrated that the investment in a major avionics upgrade made economical sense[2].

B. Design of the new flight deck avionics and data acquisition system

Rather than simply replacing the existing avionics, a more extensive program was developed that also increased the aircraft capabilities, preparing the aircraft for a future role of ATM testbed. The following elements were incorporated in the design:

1. Replacement of the existing CRTs and electro-mechanical instruments by LCD displays. The option is created to replace the cockpit displays with experimental displays fed by workstations in the cabin;
2. Replacement of the FMS with a new UNS 1Fw SBAS enabled FMS with a Multi Mission Management System (MMMS), an ARINC-739 compliant MCDU and new ModeS transponders. This meant that the aircraft is now compliant with all present and foreseen CNS requirements;
3. Introduction of a server platform for non-essential applications, such as paperless cockpit applications, synthetic vision, ASAS and datalink applications;
4. An Integrated Avionics Processor System (IAPS) provides single-point access to all parameters on the ARINC-429 databus. This means a significant simplification of the data acquisition system.

5. Replacement of attitude gyros by a dual Attitude Heading Reference System (AHRS). For many flight tests an Inertial Navigation System (INS) is fitted in the cabin as reference for attitude information. These instrument grade INSes are expensive to maintain and are approaching their end-of-life cycle. When required, accurate attitude information can now be derived from the AHRS.

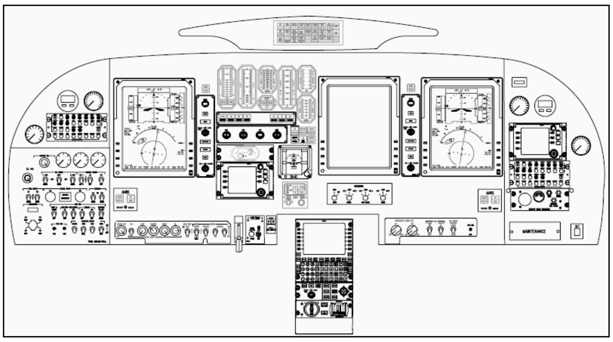

Figure 5. Schematic overview of modified flight deck.

6. Replacement of existing communication and navigation equipment, Radio Control Units, Weather Radar, TAWS, TCAS, Air Data Computers, CVR and Standby Instruments.

One special point of attention had to be given to the requirement to prepare the aircraft for possible research projects with experimental displays fitted in the aircraft. The design was chosen to accommodate possible experimental displays on the right hand side of the aircraft, replacing the number 2 and 3 screens. To meet dispatch requirements an Integrated Standby Instrument System (ISIS) was added to the design, and a third independent attitude indicator was retained. This enables the aircraft to be dispatched with only the pilot flight display. Because it was envisaged that external (test)pilots will be invited for the evaluation of such displays this meant that possibly a non-typerated pilot must be accomodated. As the C550 is certified as a two-pilot aircraft, a Single Pilot waiver was sought for possible test flights with an external pilot occupying the right seat.

C. Certification

For the modification use was made of an existing Transport Canada STC. This STC was then subsequently changed to meet NLR/TUD requirements, such as the Single Pilot requirement and a change in flight deck instruments lay-out. This STC was submitted to EASA for transfer.

In addition, a second STC was developed as PH-LAB is not a standard C550. Several minor structural and wiring differences existed that were addressed in a separate STC that was submitted to CAA-NL.

For both the transfer of the existing STC as for the national STC a certification program was required that included ground- and flight tests. Also, for the operational approval for Single Pilot operations a flight test schedule was performed.

The certification effort was initiated well in advance of the actual modification and spanned almost one calendar year, the total downtime of the aircraft was approximately 3 months.

V. Conclusion

Operating a SPA can be done using different business models. NLR/TUD have chosen to adapt a modus operandus where the aircraft serves as a Multi Mission SPA. As a consequence the aircraft is modified frequently, changing the configuration of the aircraft on a regular basis. These modifications can be limited to changes in the instrumentation, but can also require obtaining an STC for the modified configuration and thus requiring a substantial certification effort. To support the aircraft in this multi-mission role, an operational, maintenance, continued airworthiness and design organisation is required.

For this aircraft and its specific role it was possible to develop a business case for the development of a new flight deck and data acquisition system based on an integrated design. Preparing the aircraft for future ATM research was a focal point of the design. Almost all avionics were replaced and the aircraft was prepared for Single Pilot operations with experimental displays. A bundle of EASA and national STCs, together with additional Operational Approvals, was required to continue operating this aircraft in its role as Multi Mission SPA.

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