Abstract

Commercial and General Aviation has benefited over the years through the efforts of Research and Development (R&D). Some of these efforts are pursued by the aerospace industry, partnerships with academic institutions, and most frequently by aviation-related government agencies. The Federal Aviation Administration (FAA) has participated and contributed significantly to R&D efforts at the William J. Hughes Technical Center in Egg Harbor Township, New Jersey. Certification of new avionic systems, flight control devices and computer communication functions have increased aircraft dependability, reliability and improved aircraft safety. The longevity of aircraft used in Commercial and General Aviation has increased because of the combined efforts by industry, academia, and the government.

Aircraft Engineering and Modification methodologies will be discussed and analyzed. Each of the modifications required changes to an FAA aircraft, classified in the standard category, for Flight Test and Performance purposes. The equipment was mounted and hard fastened on a rack at the Technical Center. Each aircraft modified for the project underwent structural, mechanical and electrical study and analysis to meet the Flight Test standards prescribed by the FAA. A sincere attempt will be made to demonstrate some origins of aviation progress, highlight the benefits from the versatile open systems work effort, and present an economic feasibility of this supported organizational effort with a view towards the future.

The Aircraft Engineering and Modification Concept

Improvements in civilian aviation have evolved from the combined efforts of the aerospace industry, research and development institutions and the military. The aerospace industry has introduced many changes in aerodynamic thinking. These changes have inspired new design techniques, tools, and fabrication methods using new materials, metals, and technology. Research and development institutions have received grants to explore and study new technologies while working with various government agencies and the aerospace industry. The airline industry has invested capital and human resources over time to promote the success of new technologies.

The state of aviation technology is sometimes advanced after the success of each space program. Aerospace companies involved in certain aspects of each space program have contributed some of their resources toward improving the state of modern aviation. These companies to advance aviation using aircraft modification have created collaborations, agreements and long-term research programs. These modification efforts are sometimes long range. In one instance, the modification to the aircraft is only part of a larger effort. At other times, an airplane will undergo a modification solely for the installation of new equipment. A certification process is then involved. The modification process is similar in each case since a set of rules prescribed by the FAA Code of Federal Regulations are followed.

Partnerships within the aviation community have created a productive, trustful and ambitious atmosphere. Graduate Schools of Engineering have competed for various research grants from

1 This paper was written as a result of the experiences gained from the study, design and implementation of Aircraft Project Modifications for Research and Development purposes. No new concepts or proprietary information is discussed except to provide the reader with technical reasons for the benefits of this technology.

2 In Aircraft Engineering and Modification when certification issues are involved the Code of Federal Regulations under the FAA Title 14 for Aeronautics and Space, Parts 1 to 199 are used. System alterations, design changes and enhancements must be justified in accordance with these regulations.

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government agencies and the aerospace industries. These agencies and industries have then gathered these research results and implemented new technologies wherever possible. Commercial, general aviation and the airline industry have usually benefited over the years because of these relationships.

Government agencies involved in aviation and aerospace-related activities have expanded their roles beyond the regulatory mission associated with them. The National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the FAA and certain parts of the Department of Defense (DOD) have initiated agreements and beneficial arrangements with aerospace companies and the airline industry. The goals of which have been to further research efforts in aviation using aircraft modification as a tool to reach these goals.

Commercial Aircraft Engineering and Modification Services

A modification to an aircraft can be complex or basic. This usually depends on the purpose and goals of the modification. For desired changes in aircraft structure, avionic system enhancements or other internal and external reconfigurations requirements are established. Table 1 below lists the kinds of modification or the reasons for the modification. Demands for these desired changes have increased the number of companies that provide specialized services in aircraft engineering and modification. Special aerospace projects that involve the government, aerospace companies and academic researchers often employ a modification service company when necessary.

### Table 1. Different Kinds of Aircraft Modification

<table>
<thead>
<tr>
<th>Reason for Aircraft Modification</th>
<th>FAA Classification of Aircraft During Flight Test</th>
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<tbody>
<tr>
<td>(1) Experimental for (R&amp;D) Purposes</td>
<td>Standard or Experimental</td>
</tr>
<tr>
<td>(2) Certification of Avionics or Aircraft System Function</td>
<td>Standard or Experimental</td>
</tr>
<tr>
<td>(3) Enhancement of Commercial or Transport Aircraft</td>
<td>Standard</td>
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Aircraft Engineering & Installation (AEI) Services is a Florida-based corporation serving the air transport, regional airline, and heavy corporate jet markets. The company designs, manufactures, and supervises the installation of aircraft avionic systems on different types of commercial airframes. Company personnel possess a number of specialized certifications, ratings and licenses to compete in the market. The company is an FAA Production Approval Holder (PAH)

3 This defines a company which is the holder of a Type Certificate (TC), Production Certificate (PC), Parts Manufacturer Approval (PMA), or Technical Standard Order Authorized (TSOA) with respect to a particular product or part thereof.

Parts Manufacturer Approval (PMA) on numerous avionics installation products for many major transport category aircraft. [1]

Orion Technologies is an aerospace design and engineering firm located in Snohomish, Washington. The company is similar to the service capabilities rendered by AEI. The range of these services includes changes to experimental aircraft and model development where most of the design and change modifications are for non-mainstream organizations. Orion provides design, engineering and fabrication support to aviation projects where

4 This is an approval issued by the FAA to produce a modification or replacement part for sale and installation on a type certified product.

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market oriented aesthetics, optimized performance and structural integrity are important parameters. The customer list includes private individuals, smaller companies and mainstream organizations. The orion experience encompasses all aspects of aircraft development including design, fabrication, assembly and flight test. Due to the company’s experience with marine technology, they have explored a number of hull-borne and wing-in-ground-effect (WIG) product options. These “boat” concepts blend aircraft technology and utility with the marine vehicle. [2]

Aircraft Technical Service (ATS) in Van Nuys, California is a professional modification service that handles complex modification programs. ATS has recently upgraded its suite of design tools. The application Pro/Engineer enables the designer more flexibility in routing systems such as ducting, piping and wiring harnesses. Their engineering capabilities are structural and electrical. Their abilities include equipment mounting racks and consoles, upgrades for video projectors, screens and sound systems. The company has successfully engineered programs for the DC-10 Flying Test bed, for the Boeing 720 Flying Test bed, for the DC-9, Saber liner, King Air and Boeing 707. [3]

The ATS modification of the DC-10 was a complex task. The interior was completely reconfigured to install over eighteen 6' tall equipment racks, twelve operator workstations, and a customer presentation area in the rear cabin. The aircraft Environmental Control System was modified to provide forced air-cooling for electronic equipment and repositioned passenger load. The aircraft electrical power distribution and control system was redesigned increasing generator capacity by 33%. Changes in generator control units and feeder cables were necessary to complete this task. [3]

Dependent on the type of modification and desired functionalities in-depth studies are performed using a staff of scientists and consulting engineers. Aerocon (Aerospace Consulting) Engineering delivers a full range of engineering support and FAA interface services for small and large transport aircraft. Designated Engineering Representatives (DERs)5 and Designative Airworthiness Representatives (DARs)6 are appointed by the FAA and are on site. A staff of scientists specializing in structural analysis, aerodynamics, thermodynamics, and physics and materials research supports them. Installations of avionic and electronic systems, inertial navigation systems, weather radar packages and Satellite Communication (SATCOM) systems are part of the company’s experience. Design, analysis and installation interface for propulsion and fuel system analysis is another service provided by Aerocon. [4]

The demand for large and small aircraft repairs has created a specialized and specific new marketplace. There are customers who instead of test bed configurations, market-oriented aesthetics, or avionic enhancements require repair services. Associated Air Center is located in Dallas, Texas and employs virtually every discipline in aviation. Repairs and modifications to aircraft structures, and various aircraft, electrical and avionic systems, are supervised. The on-site DER representatives meet all applicable FAA regulations as in other aircraft modification companies. The company’s engineers have dictated the type of certification that is needed for each modification or repair. In addition, there is a standardized review process for each system that is modified or repaired. During this process, all functionalities are examined for the intended purpose. [5]

Data acquisition equipment that depends on remote monitoring and remote monitoring techniques has relied on the unique placement of sensors and sensor installation. An aircraft, which is a flying test bed, has a successful mission only if the proper data is collected during the flight test. Some aircraft modification services recognize the need for special remote monitoring devices and the necessary sensor installation configurations. This specialty would be in addition to the usually aircraft modification services offered by other companies.

5 A Designated Engineering Representative (DER) is a private person designated by FAA Administrator to act as its representative for examining inspecting and testing aircraft and related data. A DER may recommend approval or approve data within the limitations of his or her certificate of authority.
6 A Designated Airworthiness Representative (DAR) is a private individual designated by the FAA Administrator to perform the examinations, testing and inspections to determine compliance with applicable airworthiness standards.
General Dynamic Advanced Information Systems (AIS) Sensor Flight Test Center has been dedicated to the installation and integration of remote sensing equipment onto aircraft. [6] The Sensor Flight Test Center has performed required engineering, aircraft modifications, sensor installation, and flight test of various airborne sensor configurations, airborne remote sensing data collection and Convair 580 flight training. [6]

The General Dynamics AIS facility is located at Willow Run Airport near Detroit. Their engineering groups have offered customers a complete end-to-end solution for designing building and flight-testing airborne remote sensing systems. The company has operated two turbo-prop Convair 580 aircraft that have been modified to serve as test beds for experimental radar, multispectral scanners and other electronic equipment. [6]

Interior reconfigurations when necessary can be considered an important aspect of a modification when commercial airlines or aircraft leasing companies are the customers. Northwest Aerospace Technologies (NAT) is an aerospace engineering and manufacturing services company specializing in commercial aircraft modification programs requiring FAA and foreign regulatory agency approval. Typical services that NAT has offered include interior reconfigurations, Intermediate Frequency Equipment (IFE) system installations, structural, and flight control and avionics system modifications. The company has experience with all Airbus and Boeing aircraft models, various regional jets and the FAA and Joint Aviation Authority (JAA) certification processes. [7]

The commercial airline industry, the government sector, the aviation-manufacturing world and other customers have expressed a need for specialized aircraft modification services. New service-rendering companies have surfaced to respond to this need and meet the requirements of the changing aircraft modification environment.

**Partnerships with Academic Institutions**

Universities and research learning centers receive grants each year from aerospace companies and government agencies involved in aviation-related activities. Aerospace companies usually have economic motives for their financial investments, while government agencies seek adherence to rules and regulations. Recently both parties have discovered mutual interests, goals and milestones. This has created an aviation community that has benefited the aviation industry, the airlines and the state of technical advances.

The Avionics Engineering Center (AEC) at Ohio University demonstrates the partnership between academic institutions and the government. The Center was established in 1963 to support a unique combination of theoreticians and technical specialists to address navigation issues encountered in air transportation and furnish timely practical solutions. [8] In one instance NASA awarded a contract to the Center in June 2001 for the Second Generation Reusable Launch Vehicle (2G RLV) Program. This work was accomplished to develop an Integrated Guidance and Control (IG&C) system that supports all RLV architecture concepts. After this Program was transitioned to the Orbital Space Plane (OSP), AEC was subcontracted by Lockheed Martin to develop a fault-tolerant flight control system for its’ OSP. When NASA terminated the OSP Program early in 2005 and the new Exploration Program was initiated, AEC was invited to participate in a Boeing proposal for developing an autonomous planetary landing vehicle. The role of the Center in this project was to develop the fault adaptive flight executive based on previously learned technology. These research activities are continuing under the sponsorship of the Boeing proposal. They are experiencing moderate success since the technology and knowledge base has been recycled from program to program. [8]

An additional advantage to the university is that the AEC has become a repository for current and historical avionics-related documents. The center’s reference library includes extensive documentation of FAA, NASA, military and industrial projects undertaken by the Center and others. This collection serves as a valuable source of references to those investigating avionics issues. [8]

The University of Washington School of Aeronautics and Astronautics is another premier facility known for pursuing groundbreaking research. The investment of government agencies
is well represented. The Aerospace and Engineering Building was completely funded by NASA and the Redmond Plasma Physics Laboratory was built with support from the Department of Energy. Receiving financial assistance and participating in programs funded by these government agencies creates an invaluable opportunity for intellectual and professional growth. They have numerous research areas. These areas range from aerodynamics and fluid mechanics that pace developments in the aerospace related industries to air breathing propulsion and the development of a competitive aircraft gas turbine engine. [9]

The faculties of the Georgia Institute of Technology have many professors involved in aeronautical and aerodynamic research. Cooperation and investments in scholarship have been beneficial for the Air Force of Scientific Research, the Defense Advanced Research Projects Agency (DARPA), the Army Research Office, and NASA, the National Science Foundation (NSF), U.S. Army & Aviation Missiles Command (AMCOM) and private industry. [10]

Consortiums and associations of educational institutions have evolved for the express purpose of contributing to government agencies. The Universities Space Research Association is a private nonprofit corporation founded in 1969. Comprised of 95 members, USRA provides a mechanism for colleges to effectively cooperate with each other and the government to further space science and technology. Most of USRA activities are funded by grants and contracts from NASA. [11]

Only three academic institutions have been discussed. Throughout the country, many other colleges and universities have participated in cooperative efforts with government agencies and aerospace companies. These mutual agreements of contributing to education facilitate solutions to unanswered questions and accelerate the progress in aviation.

Aerospace-Related Government Agencies

Certain government agencies have always been involved in aviation and aerospace, however for a long time they have worked independently supporting their own mission needs. Recently this has changed to the extent that interagency cooperation has been seen and demonstrated. Resources, ideas, and research have been shared among numerous government agencies. Letters of Agreements (LOAs), Memorandums of Understandings (MOU), and interagency investments have created a trustful spirit in terms of advancing technology in aviation and aerospace.

Aerospace companies have started new business relationships and continued old ones with many aerospace-related government agencies. NASA to provide maintenance awarded a contract to DynCorp Technical Services LLC, which is a Computer Sciences Corporation in Fort Worth, and modification services for part of NASA’S aircraft fleet. The contract includes support for Johnson Space Center (JSC) operations at Ellington Field in Houston and at facilities in El Paso, Texas; Edwards Air Force Base, Calif.; Langley Research Center (LaRC), Hampton, Va.; and other domestic and foreign remote sites where services are required. [12]

One important project for NASA, which required a major aircraft modification, was the creation of the Stratospheric Observatory for Infrared Astronomy (SOFIA). This was to be the largest observatory in the world. L-3 Communications Integrated Systems provided design engineering, airframe structural modification, telescope design integration and flight test activities to deliver an FAA-certified SOFIA Observatory. All telescopic subsystems on the Boeing 747-SP were integrated for the first time. Evergreen airlines have assumed responsibility for maintenance and flight operations of the aircraft. [13]

There are international aviation authorities that U.S. government agencies have recognized as leaders in the aviation community. These authorities have contributed to establishing international standards in aviation. The FAA has cooperated and participated in international forums so mutual agreements can be met in aviation standards and regulations.

One representative international body is the Joint Aviation Authorities (JAA), which is part of the European Civil Aviation Conference (ECAC). A number of European states have their own civil aviation regulatory authorities, but they have agreed
to develop and implement common safety standards and regulations. Since 1987 the JAA has extended their interest to operations, maintenance, licensing and certification / design standards for all classes of aircraft. The JAA has placed much emphasis on equating their regulations with those of the FAA.

[14]

Aircraft Engineering and Flight Test

The Preparations and Management of the Modification Process

Each aircraft modification will vary according to the type of modification, reason for modification and aircraft requirements. The required documentation that needs to be prepared and processed will vary also dependent on the methods of the modification. There are similarities in all modification procedures; however, the documentation for these procedures can only be completed when the purpose and requirements of the modification are understood.

There are formalities involved with every modification. Prior to modifying an aircraft, familiarity is required with the existing structural and systems characteristics so compatibility problems can be avoided. Knowledge of the certification requirements would also be necessary. The effects of the turbine engine(s) on payload, mass distribution induced flutter changes, and structural margins should be determined. If an automatic pilot system is installed it should be compatible with the aircraft turbine / engine installation which would be verified by a flight test. A turbine conversion necessitates a flight test program. The tests performed May or may not include handling qualities, performance flutter, spins, hot fuel climb, engine cooling, engine operating characteristics and autopilot. [15] Each company that renders a modification service consults and communicates with the regional FAA Aircraft Certification Office (ACO)

7. The FAA Aircraft Certification Office (ACO) determines aircraft airworthiness following a major or minor modification. There are regional offices throughout the country and they are contacted early in the modification process. A DER is an employee of the company but represents the interests of the regional FAA ACO in matters of aircraft airworthiness and certification. Safety concerns are of paramount importance to the ACO.

The company performing the modification expects to propose an overall certification plan. This plan should include the essential steps or actions and the anticipated sequence of events for submitting drawings, process specifications, reports, analyses, tests, and other documentation to obtain installation approval. Dependent on the type of modification certain documents are prepared.

A Supplemental Type Certificate is a document issued by the FAA approving a product modification. The STC defines the change in the product design, states how the modification affects the existing type design and identifies the serial effectively. If an STC is required, it usually suggests a major modification to an aircraft. If a repair is completed on an aircraft, which is a type of modification FAA Form 337 must be completed. All repair work is clearly identified on this form. An FAA Order 8110.3 is a Statement of Compliance with the Federal Aviation Regulations. The company who performed the modification completes this form. It then becomes part of the data package and forwarded to the regional ACO. The data package contains all drawings, engineering reports, and all relevant information explaining the modification work effort. The work is defended to the regional ACO with justification language so the airworthiness characteristics of the airplane are not compromised.

Each company that provides a modification service is obliged to employ the professionals with the necessary skill-set requirements. It is essential for these skilled specialists to possess a number of FAA Certified Ratings and licenses. Some of these certified professionals include:

- FAA DERs in different type of specializations, (i.e. systems, structures, compliance inspections)

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• FAA Designated Manufacturing Inspection Representative (DMIR)
• Avionics Modification / Installation Specialists.
• Specialists with FCC Radiotelephone and RADAR endorsements
• Inspection Authorization Personnel
• FAA Certified Airframe & Power plant Technicians

The ACO usually grants permission to the aircraft category and flight classification after it receives the data package. Safety considerations are always an important parameter in determining aircraft category and flight classification. Identifying all pertinent FARs under Parts 23 and 25 that are affected by the modification is paramount for safety under Parts 23 and 25. In the safety, engineering areas Failure Modes and Effects Analysis (FMEA) and Fault Tree Analysis are used.

In the technique known as FMEA the safety engineer starts with a block diagram of a system. The engineer then considers what happens if each block of the diagram fails. The engineer then draws up a table in which failures are paired with their effects and an evaluation of the effects. The design of the system is then corrected, and the table adjusted accordingly until the system is known to not have any unacceptable problems. Usually several engineers’ review this analysis repeatedly until a certain confidence level is reached. [16]

The FAA William J. Hughes Technical Center has an operation similar to an aircraft modification service company. Modifications are performed on a number of aircraft in the Technical Center’s Fleet for R&D purposes. The same specialists and professionals with the essential skill-sets necessary are located in Egg Harbor Township.

Each aircraft in the fleet is specially configured for power considerations. Project installations receive power from separate project power access points, strategically fastened junction boxes and galley power on the Convair 580s. Temporary and sometimes-permanent wiring, connections and harnessing to specially designed and installed project racks are created for each project. Reuse of the installation equipment is occasionally a viable option when there are similar requests for different airplanes. Resources are conserved, productivity is increased and efficiency is gained during the modification when these decisions are made.

Flight Test Management and Operations

The Flight Test Management process and operations is determined before the completion of the modification. Aircraft airworthiness, Type Certification (TC), STCs or other required FAA documentation is usually obtained during and sometimes prior to the aircraft modification effort.

Each company, airline, or government-sponsored agency that has completed a modification to an aircraft has similar procedures for the management of flight test operations. Dependent on the kind of modification the flight test may vary. The flight test is scheduled after a major aircraft repair on a standard transport category aircraft would be different from a flight test for an R&D aircraft or a flying laboratory. Aircraft preparation, certification and the availability of qualified flight engineers, navigators and test pilot personnel have always been important elements in determining the readiness for a flight test operation. However, aircraft modification companies have competed for the attention of general and commercial aviation customers. So additional efforts have been undertaken to capture the aircraft modification business and improve the flight test operations part of the service. As an example, the company AEROCON has added a large transport category aircraft to its inventory of engineering and test equipment. This configured aircraft is designed to facilitate the quick installation and removal of flight test equipment and personnel support systems providing an ideal platform for flight-testing and observation. [4] The company’s use of small twin-engine aircraft has been better suited to a variety of smaller scale flight test programs.

Zenith Aviation in Tuscon, Arizona has accommodated two customers by assisting the FAA and the JAA with certification flight-testing. [17]
The FAA William J. Hughes Technical Center has managed its flight test program and operations in a very efficient manner. Upon the completion of the project installation, the request is handled and scheduled by the Flight Test Group. All scheduled flight tests are coordinated with the flight operations of the facility and approved by the management of the office. In this manner, all required flight test personnel are available when necessary.

Aircraft Engineering Methodologies and Project Installations

Three aircraft modifications are discussed that were conducted at the FAA William J. Hughes Technical Center. The design specifications for the Empennage Strain Gage Survey Equipment with Data Acquisition, the TCAS II Installation and the Inertial Reference System Installation were created by the engineering department and implemented by the modification shop. The modification techniques adopted were useful and necessary in order to connect the data collection equipment. These techniques enabled the FAA to obtain data on stress loads for the Beechcraft King Air 200 aircraft. In addition, vital TCAS II navigation data for ATC purposes was acquired. Each aircraft acted as a flying laboratory during the flight test operation. After the flight test operation the data information collected was studied, analyzed and evaluated. Based on the retrieved data and aircraft flight, behavior existing maintenance requirements were improved and aircraft longevity was increased. For the TCAS II installation the data obtained was able to assist air traffic control on the ground and enhance the benefits of navigation systems.

The Empennage Strain Gage Survey Equipment with Data Acquisition System

Specialty Measurements Incorporated (SMI) designed the Empennage Strain Gage Survey equipment. Validyne Engineering Corporation provided the Data Acquisition System, which accompanied the equipment package. The aircraft used for this effort was the Beechcraft King Air 200, N-35 located at the FAA William J. Hughes Technical Center (See Figure 1). The objective of the installation was to measure the flight loads imposed on the tail of an executive/commuter aircraft under real flight conditions. A matrix of strain gages were placed symmetrically on the inboard section of the forward and aft spars of the fin. No strain gages were mounted on the elevators or rudder of the aircraft. The output of these strain gages routes to two signal-conditioning boxes located in the electrical equipment bay of the airplane. The wiring continues from the bay to where the signals are received at the Data Acquisition System mounted in the cabin of the aircraft. The Data Acquisition System is intended to monitor and record the strain gage data along with a number of other aircraft parameters. Due to the nature of flight operations and demands on the aircraft, the entire installation was completed in two periods. [18]

The placement of the equipment included the signal conditioning in the aft electrical equipment compartment, two 3-axis accelerometer packages (one at the base of the empennage and the other at the center of gravity) and the Data Acquisition system.

The thirty-four strain gages placed in the vertical and horizontal stabilizers are chosen as control points. These points are monitored because they represent potentially critical areas and contribute to significant flight loads, whose failure could result in a catastrophic failure of the aircraft. Each channel is wired into a full Wheatstone bridge arrangement with two active arms for temperature compensation. The strain gages are installed using a coating suitable for the expected test conditions. The shear stresses are calculated from the output of a rectangular rosette consisting of three (3) strain gages measuring strain at 0, 45 and 90 degrees. They are located in an area where localized buckling or very high bending is believed to occur. Each channel will be installed with a terminal where the lead wire will be attached. Lead wires from the strain gages are routed to the location of signal conditioning. A lead wire is attached to the terminal strip and then the necessary protective coating is installed. [18]

The strain gages are routed to two signal-conditioning boxes that contain power, filters and amplifiers. The amplifier gains are set for +5VDC output at full design stress levels. These 34 channels are further routed from the signal
conditioning boxes and wired through the cabin safety outflow valve port located at station 348. The wires bundles terminate at the interface bracket of the Data Collection Acquisition rack.

Figure 1. The Beechcraft King Air 200 Was Used for the Empennage Strain Gage Survey Installation

An AC & DC Power Distribution box is designed and built to channel 115VAC and 28VDC to the Data Acquisition Collection equipment. At the project Navigation rack located across the Data Acquisition rack in the cabin, 115VAC and 28 VDC project power is accessed from Hubble connectors. The Power Distribution Box and Project Navigation Rack provide circuit protection and isolation. [18]

Data on structural integrity is recorded and analyzed to determine the continuing fatigue failure of the aircraft. There are existing analyses such as “Wing Fatigue Analysis for FAA Flight Inspection Aircraft Model 300” that can be used to the maximum extent possible as a baseline. Fatigue analysis can also be performed to update the baseline fatigue lives. An appropriate scatter factor can then be applied to obtain the safe-life of each major component. This process with experience and judgment can be the basis for contractor recommendations for possible FAA action. Some of these actions would involve replacement timer for parts, special periodic inspections and/or possible usage changes required to assure the continued structural integrity of the FAA Beech King Air 200 flight instruction aircraft. [18]

Twenty related Federal Aviation Regulations (FARs) were addressed in the substantiation of this installation and reported to the regional ACO. Some of those involved, flight and navigation instruments, miscellaneous equipment and systems and installations. Others commented on were factor of safety, materials and workmanship and accessibility in defending this installation. When the installation was completed, there was sufficient evidence to believe airworthiness would not be compromised.

The Traffic Collision Avoidance System (TCAS) II

The Traffic Collision Avoidance System (TCAS) Computer Unit is the central unit of the Traffic Alert and Collision Avoidance System (TCAS) II. This unit was installed as an R&D modification to a Convair 580 aircraft, N-91 located at the Technical Center (See Figure 2).
Circuits for transmitting, receiving, signal processing, computing and interfacing input/output signals are incorporated into the unit. The transmitter circuit of the unit is composed of pulse and Differential Phase-Shift Keying (DPSK) modulators, power amplification stages, a high power precision step attenuator (whisper shout), output filters and Built-in-Test-Equipment (BITE) power detection circuitry. The high power applied to a whisper/shout attenuator, controls the transmitted power applied to the antennas. The receiver section Bering Electronics Unit (BEU) consists of four identical channels, which provide very accurate bearing information. One receiver channel has a single conversion receiver, high quality log amp, and a high resolution A to D converter. [19]

The TCAS II directional antenna is a four element vertically polarized, monopole array capable of transmitting in four selectable directions at 1030 MHz. The antenna is capable of receiving replies from all directions simultaneously with bearing information at 1090 MHz using the amplitude-ratio monopulse techniques. The upper directional antenna is mounted at a station located on top and on the bottom; a lower directional antenna is mounted.

The Mode S transponder is mounted on the TCAS equipment rack. The transponder interrogations are received on 1030 MHz, and transmitter replies are on 1090 MHz, which are the same frequencies as the Air Traffic Control RADAR Beacon System (ATCRBS) Transponder. The Mode S transponder, however, was developed for Mode S operation and can function alone in Mode S or in conjunction with TCAS. [19]

If the replying aircraft transmits a Mode S signal, that information is processed by the TCAS computer to coordinate avoidance-maneuver information between the two aircraft. The TCAS Computer develops and outputs Mode S data to the associated system Mode S transponder for transmission back to the other aircraft. The computer generates the resolution and traffic-advisory signals for output to the associated indicators, which is displayed to the flight crew.
The signal processor and computer (CPU) circuits provides the control and data analysis necessary for transmitter-receiver operation. It contains the program for analyzing data developed because of signals from other transponders, and generates the traffic and resolution advisories for the cockpit displays. The CPU is software controlled and communicates with the signal processor and the input/output interface through a system interface bus.

The input/output interface circuits handle the A/D, D/A, ARINC, synchro, discrete and analog signal conversion required for communication with external TCAS equipment. The interface has its own computer circuits to control internal operation.

The input/output data, controlled by the local processor and interconnected via a bus to the CPU, provides the interface between the transmitter-receiver and all external equipment except for RF signal paths, such as, TCAS data to the data recorder, audio output messages to the cockpit-audio system and discrete outputs to the external warning lamps and tone generators. The transmitter-receiver outputs an L-band RF suppression pulse which is tied to the aircraft’s suppression bus. [19]

The data recorder is mounted on the TCAS II equipment rack. The recorder is an IBM-PC compatible computer, containing a microprocessor-based recorder controller, a hard disk drive, a real time clock, and an ARINC 429 interface receiving data from the TCAS processor. TCAS data is recorded on tape cartridges, which can be removed after processing.

The Honeywell TCAS II equipment rack, which was fabricated for a Boeing 727, N-40 flight demonstration, was re-used for the purpose of this Bendix System installation and flight test demonstration. The equipment rack was assembled by the aircraft modification shop under the guidance of the engineering department. Figure 3 illustrates the Cockpit Console Suite of a Typical Convair 580. (There was no interference with the existing aircraft avionics suite during the flight test. Also project power was used for this project modification) The major components on the rack are a TCAS II data recorder mounted on the bottom shelf that is manufactured by Advanced Logical Solutions (ALS), the TCAS Computer Unit, the TCAS ATC/Mode S transponder on the middle shelf, and a TCAS traffic display unit on the top shelf. The middle shelf also carries two connector panels, a switch panel, and a power distribution box, which are lightweight. They are mounted on the shelf with 2 or more #10 screws. The mounting provisions for the connector panels, switch panels and the power distribution box are considered adequate. [19]

Figure 3. The Cockpit Console Suite of a Typical Convair 580

About twenty related FARs were addressed in the substantiation of this equipment installation, which was reported to the regional ACO. Some of those involved included, Regulations in the General Category (circuit breaker and circuit protection devices). Others covered included electrical systems and equipment. Most of the regulations concerned were in Part 25, Airworthiness Standards for Transport Category Airplanes. Since this was an installation with equipment on a rack receiving project power only those FARs concerning that equipment and affecting the aircraft were addressed. Structural rules and regulations for the racks were cited where necessary.

After the modification was completed, an Electromagnetic Interference (EMI) test was done in accordance with recommended procedures by the vendor. The diversity tests for the Mode S transponder, upper and lower antennas was performed with an HP 8566B/85662A Spectrum Analyzer and recorded. A flight test for the aircraft was then scheduled. Since there was sufficient evidence to believe airworthiness would not be
compromised, the aircraft was able to fly in the standard category.

**The Inertial Reference System (IRS)**

The Inertial Reference Unit (IRU) of the Inertial Reference System (IRS) will provide attitude and heading information in true and magnetic north reference with velocities and present position. This information is used and required to support TCAS research and development activities. The aircraft used for this effort was the Boeing 727, N-40, which is another member of the Technical Center fleet (See Figure 4).

![The Boeing 727 Was Used for the Inertial Reference System Installation](image)

**Figure 4. The Boeing 727 Was Used for the Inertial Reference System Installation**

The YG1854 LASEREF Special Reference Mission Inertial Reference System consists of the IRU, the IRU Blower Motor, the Mode Selector Unit (MSU), and the Battery Unit AMPS-2000. The project rack mounted components include the above along with a project computer used as an Inertial Sensor Display Unit (ISDU) equivalent. [20]

For alignment, a system performance test is performed on the position the pilot enters. The IRU then conducts a reasonable test on latitude and longitude immediately after each entry. The unit compares the entered latitude and longitude with that stored at the last power down. If the entered position does not agree within a given limit of the stored position, the entered latitude and longitude fails the test and the MSU ALIGN annunciator flashes. If the entered position does agree, the MSU ALIGN annunciator goes steady. Alignment is completed when the entered latitude passes a system performance test. This requires the latitude entered by the pilot be within a given limit of the latitude computed by the IRU. All data and information exchanged is in digital format. [20]

The YG1854 LASEREF IRS is mounted at the top shelf of a rack at station location 630 on the right side. The IRU is wired to the MSU and ISDU equivalent on the rack on one side along with the fan, relay and battery unit on the other side. Two interface brackets are also on the pallet, one between the IRU and the ISDU equivalent and the other between the IRU and the connector on the Project Junction Box. When supporting TCAS the Sperry Air Data Computer (ADC) located in the electrical equipment bay sends 575 digital bus information via the Project Junction Box to the IRS.

The IRU then sends 429 data information through the same connector to a 61-pin connector in Project Junction Box 100. A TCAS II 61-pin mating connector interface is then used to collect the 429 data information. This data information encapsulates the required heading and attitude data for TCAS R&D flight test purposes. [20]

Twenty-one related FARs were addressed in substantiation of this modification installation. This was reported to the regional ACO. Since the Boeing 727 is a transport category aircraft, many of the

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FARs used in the Convair 580 installation applied again. Some of these involved Regulations in the General Category (circuit breaker and circuit protection devices). Others covered electrical systems and equipment. All of the regulations cited were in Part 25, Airworthiness Standards for Transport Category Aircraft. Structural rules and regulations pertaining to the racks were also cited where necessary. Since this was, an installation with equipment on a rack receiving project power an electrical load analysis was not necessary. (This was the case in the Convair 580 project modification).

After the modification was completed, an EMI test was performed in accordance with the established EMI procedure for project installations. Following the completed installation, a flight test was scheduled and performed to observe the functional and operational performance of the YG1854 LASEREF IRS in support of the TCAS Program. (Figure 5 illustrates the appearance of a typical project installation, which requires two racks on the Boeing 727). Note the racks shown illustrate another installation and not the IRS.

Figure 5. A Typical Project Installation on The Boeing 727 Shows Racks with Each Shelf Fully Mounted

The Economic Feasibility and Beneficial Necessity

Cost Analysis of a Managed Project Modification

The analytical means to measure the cost benefits of a well-managed project modification are practiced by each company, government service organization and airline. Recently new aircraft modification companies have emerged and entered the marketplace for the express purpose of competing with older companies. Established aircraft modification services have tried to create investment opportunities by expanding there base. The new collaborations with government agencies and the academic world and the airline industry have created a beneficial environment for the aviation community.

Each well-managed project modification can reduce the future costs of industrial engineering, aircraft part development and experimentation associated with R&D. Some methods used to accomplish these goals are cost estimating. On a small scale, reusing racks, wiring harnesses and project-related equipment whenever possible can reduce the costs of project installations. For larger modifications, state-of-the-art customers should use cost models and economic analysis tools with accurate planning, budgeting and funding estimates. The modification service will use computer-aided modeling to validate requirements and visualize production designs. The cost structures of these companies will improve when efficient applications and devices are used. [21]

Cost Effectiveness of a Managed Project Modification

Cost effectiveness can sometimes be measured in terms derived benefits for the aviation community, safety measures that can be applied to commercial aviation quickly and profits margins that can improved.

The investment of funds and resources by the airlines, government service agencies and private companies are always aimed at the desired result. When these results surface in a timely fashion, the investment can be considered cost effective. Some benefits evident in general and commercial
aviation are extending the life of older aircraft, bringing airline aircraft into compliance with FAA operational requirements and reducing downtime maintenance operations. [21]

Safety measures studied, evaluated and applied in the proper manner is another cost effective product derived from a flight test event. Currently aircraft designers using flying test beds are searching for ways to save weight while maintaining safety. The sensitivity of safety to design changes is being linked to cost at some research centers. [22] Also new ways to measure safety are sometimes discovered during the course of a managed project modification.

Profit margins can be considered a sensitive issue when discussing cost effectiveness. This is true since there is competition among companies that provide modification services. However since the marketplace is large with different customers and demands most companies providing a modification service will survive because of the large customer base.

**Conclusion**

The aerospace industry, government agencies, the academic community and the airlines have discovered adopting approaches of partnership and collaboration benefit the aviation community as a whole. Technology exchanges and investment of resources have rewarded commercial and general aviation. The academic community has benefited also by receiving grants from the government and industry to continue aerospace research. These new relationships have extended into the areas of aircraft design and modification.

Aircraft modification services have started to satisfy the various demands regarding aircraft engineering. Dependent on the type of modification and desired requirements a specialized modification service can meet the tailored needs of the industry or government customer. Universities and research institutions have competed for grants and contributed to aircraft design and modification efforts.

The preparations and management process prior to an aircraft modification will vary according to the type of modification needs. The on-site FAA representative usually forwards the FAA documentation required to the regional ACO in a timely manner. The documentation will differ for experimental modifications and aircraft flown as flying laboratories. However, the same certified professionals employed by an aircraft modification service will be employed by a government service organization. In addition, the same safety precautions, rules, and regulations will be followed.

The FAA William J. Hughes Technical Center in New Jersey has an operation similar to an aircraft modification service. Project installation modifications are performed in a manner consistent with FAA rules and regulations. The goals of certification of new avionics, navigation and computer communication equipment are often realized after a successful flight test. The data information collected during the flight test is usually studied, examined and evaluated before a decision is made on the technology tested.

Project installation and aircraft modification demonstrates a versatility as an open system architecture since the knowledge gained can be used throughout the aviation community. The advantages and benefits from an aircraft modification have not been clearly measured. In the end, only with the proper incentives and increased cooperation by all members of the aviation community can advances in all aspects of aviation occur.

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