THE UNIVERSITY OF TENNESSEE
SPACE INSTITUTE

Aviation Systems & Flight Research

ENGINEERING WORK INSTRUCTION

REV 1

AVIATION SYSTEM PROGRAM
UNIVERSITY OF TENNESSEE SPACE INSTITUTE
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1.0 Purpose

The purpose of this work instruction is to detail the process necessary to integrate flight research systems (airborne science and flight test instrumentation and test articles) onto University of Tennessee Space Institute (UTSI) aircraft.

2.0 Applicability

This Engineering Work Instruction is to be followed by Engineering, Maintenance, and Flight Operations personnel at UTSI as well as experimenters from other institutions.

3.0 Overview

UTSI flies many different types of flight research systems onboard its aircraft in support of educational and research objectives. Flight research systems include airborne science instrumentation and test articles as well as test instrumentation and test articles used to understand the performance and characteristics of aircraft in flight. Flight research systems consist of those systems which are both unique to the research aircraft and that have a specific application in supporting engineering or science applications. Flight research systems may be installed for research or for educational purposes. There are four governing directives which define the processes for design, installation, safety and testing of flight research systems in UTSI aircraft. They are:

a. *The Engineering Work Instruction* – This instruction provides the engineering and work flow process for turning user requirements into hardware and software. Instructions are given for integrating experiments, instrumentation, and test articles onto UTSI aircraft. This process also supports the airworthiness and safety process and supports the generation of test plans, test cards and flight procedures.

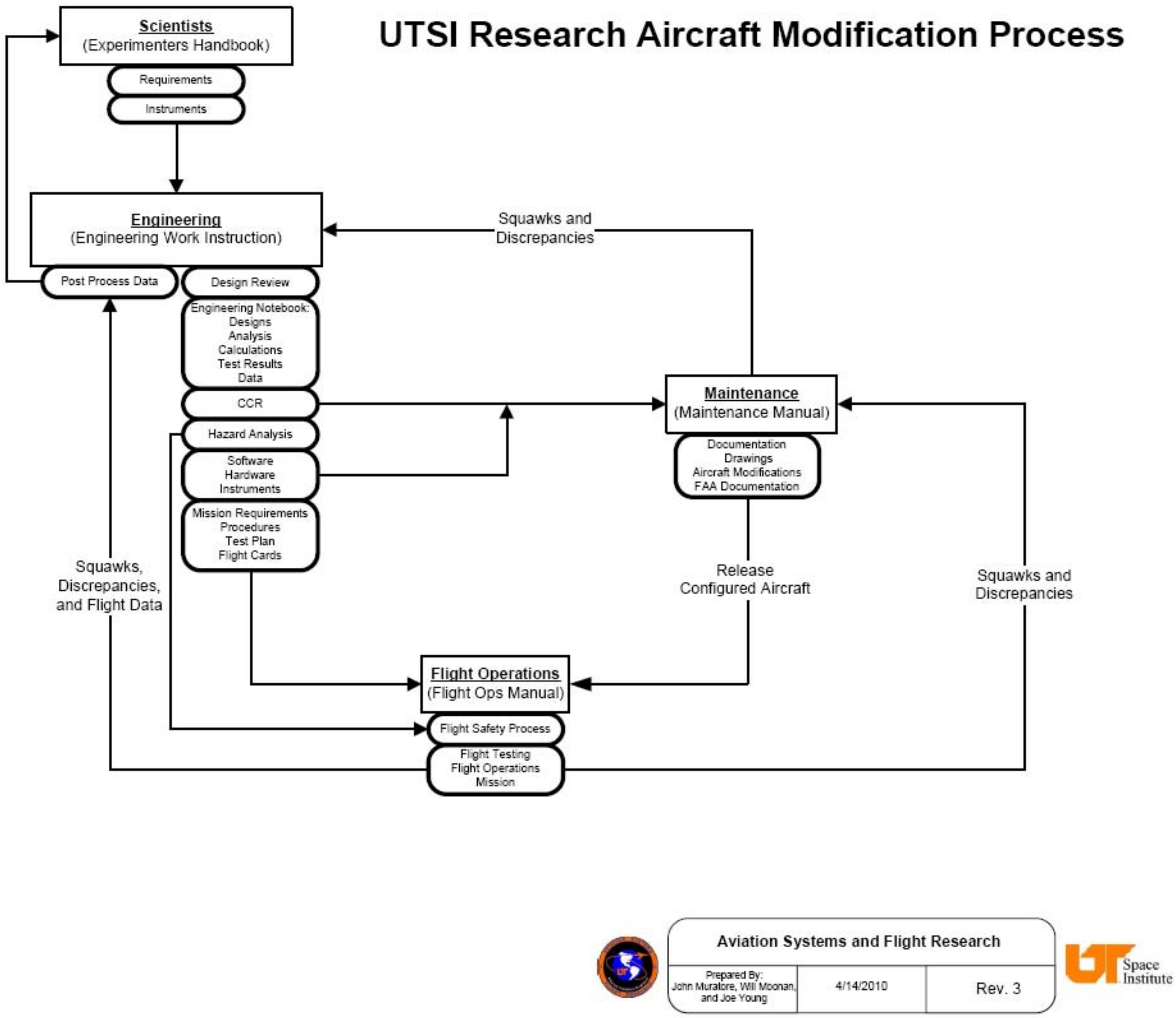
b. *The Aircraft Maintenance Manual* – This manual defines the policy, procedures, guidelines, instructions and responsibilities for aircraft maintenance at UTSI. The maintenance manual also establishes acceptable practices and documentation requirements for integrating experiments, instrumentation, and test articles onto UTSI aircraft.

c. *The Flight Operations Manual* – This manual provides policy, procedures, guidelines, instructions and responsibilities for the safe and efficient operation of UTSI aircraft. This manual also defines the qualifications and the preparation and training required for pilots and all other flight crew members.

d. *The Flight Operations Airworthiness and Safety Manual* – This manual defines the process for hazard identification and mitigation of risks associated with UTSI flight operations. The process includes procedures for conducting a comparative risk assessment and defines the documentation and approval requirements that must be satisfied in order to conduct flight operations.

Figure 1 provides the general work flow for integrating flight research systems with a UTSI aircraft. It also shows how the various entities such as engineering, operations and maintenance are coordinated during this process.

Figure 1 – UTSI Research Aircraft Modification Process



The process begins with a request by a Customer to perform a research investigation using a UTSI aircraft. Once a project is started, Engineering will take the customer request and generate the necessary preliminary designs and analyses. A Configuration Control Request or CCR is then written, which baselines a design and initiates the fabrication of hardware or data system equipment. If a design change is required as it evolves, a new CCR is written to supersede the original document. Using information supplied by Engineering and the Customer, Maintenance begins planning for any required hardware or equipment fabrications and installations, and Flight Operations begins preliminary mission planning. Engineering conducts rig and laboratory testing and performs various analyses to support risk mitigation throughout the airworthiness and safety process. All three entities, Engineering, Maintenance, and Flight Operations are then coordinated for the necessary airworthiness and safety reviews. When flight testing is approved and conducted, the results are fed back into the design if necessary to address aircraft or system performance problems and amend flight permits and aircraft limitations if required.

Principal Investigators/Customers provide two key inputs to the Engineering process. First they provide requirements upon which the vehicle modifications and the mission design are based. Second, they provide most of the research equipment that is flown on the UTSI aircraft. UTSI for the most part does not design new airborne science instruments and primarily supports airborne science experimenters in integrating their instruments onboard UTSI aircraft. Often experimenters specify off-the-shelf instruments for UTSI to procure and integrate. These are usually not the primary scientific instruments on the mission although they can be. When UTSI determines that the instruments will be of use to more than one set of experimenters, UTSI will integrate the instruments into part of the permanent complement of hardware flown on the UTSI aircraft as standard research equipment. Standard research equipment remains on the aircraft for all missions versus mission specific research equipment that is only flown for one set of investigations. UTSI will determine that research equipment that is flown on the aircraft whether delivered or specified by the investigator, does not pose any hazards to the operation of the aircraft or to critical flight systems when the research equipment is integrated to the airframe.

The Engineering process is controlled by this Engineering Work Instruction. UTSI is capable of integrating complex instrumentation, sensors and systems into its fleet of primarily general aviation research aircraft. Although UTSI is a relatively small organization, it can provide engineering support for this integration in the required disciplines including aerodynamics, stability and control, structures, mechanical design, instrumentation and systems. UTSI often conducts Design Reviews using a structured design walkthrough process. Structured design walkthroughs are a recognized best practice in engineering design for conducting design reviews in small group settings. Design walkthroughs usually occur after regularly scheduled Monday Project Meetings. Participation by all affected disciplines is mandatory for a structured design walkthrough. In the structured design walkthrough, the designer presents designs as well as supporting calculations, analysis, and test results. Follow-up on actions or issues identified in these walkthroughs are the responsibility of the presenting design engineer. The details presented in this review are normally placed into the Engineering Notebook. Engineering Notebooks exist for the Structure, Systems, Software, Airborne Sensors and Aerosciences/ Flight Mechanics disciplines. For larger or more complex projects a full formal Design Review is scheduled. Design reviews are scheduled in advance with design documentation distributed ahead of the review, mandatory participation by affected parties, formal presentations and formal tracking of action items. Independent reviewers may be added to design reviews depending on complexity of design and the need for outside expertise.

Design Information that must be baselined for use by the maintenance team in the Maintenance Process to integrate equipment onto the aircraft (such as wiring interface details) is accomplished through a configuration control process utilizing a Configuration Control Request (CCR). The CCR documents the information that is to be baselined and the review and approval by the appropriate disciplines. Baseline configuration management is maintained by requiring communication of changes through another CCR which informs the entire team of the change.

Hazard Analysis is also a key product of the Engineering Process. The engineering detail necessary to complete a hazard analysis worksheet is produced through the engineering process; the actual discussion and acceptance/mitigation of risk is accomplished through the Flight Safety process.

The Engineering Process also produces the hardware, software and instruments to complete the mission planning in the Flight Operations Process. Furthermore, the Engineering process produces additional mission requirements, procedures, flight test cards, and plans necessary as inputs to the flight operations process.

Finally, the Engineering Process analyzes the data produced in test missions and assesses the anomalies (“squawks”) that may occur on flights. The Engineering Process is followed to correct these as required with changes to the flight hardware, software, and procedures to resolve discrepancies and anomalies prior to the next flight.

At the overview level, the primary goal of the Maintenance Process is to produce a fully configuration controlled and documented aircraft that is released for flight operations. Anomalies identified by this process either in the preflight phase during integration or during the postflight inspections are passed to the Engineering Process for resolution.

At the overview level, the primary purpose of the Flight Operations Process is to produce successful flight operations with the desired flight data. The Flight Operations process in this diagram includes the Flight Safety Process. The Flight Operations Process takes input from Engineering to prepare actual mission plans, executes the missions, provides flight data and identified anomalies (“squawks”) to Engineering for resolution.

4.0 Detailed Engineering Process Flows Overview

There are two process flows for integrating research systems onto UTSI aircraft. The first process flow (Figure 2) is for instrumentation or test articles that do not alter the aircraft’s outer moldline and do not require external attachment. This is the case for many of the experiments on UTSI aircraft. These types of instruments do not affect the aircraft’s aerodynamics nor do they have to survive significant aerodynamic loads. Small protrusions of the outer moldline from instruments also are included in this process flow; this includes cases where integration is performed on small optics or antennae. The only effects of these types of devices on the aircrafts flying qualities are through effects on weight and balance (center of gravity). Calculation of weight and balance and ensuring that the aircraft is within weight and balance limits is ensured through the Maintenance and Flight Operations processes.

The second process flow is for instrumentation or test articles that significantly affect the outer moldline or those which are strongly affected by flight loads. This process flow (Figure 3) includes evaluation of the aerodynamics of instruments and their attachments, the effects of aerodynamic changes on aircraft flight controls and stability, vibration and flutter and an assessment of aerodynamic and inertial loads on instruments and their attachments, including finite element analysis of stress when applicable.

Figure 2 – Process for Integrating Airborne Science Instrumentation and Test Articles that are not Externally Attached

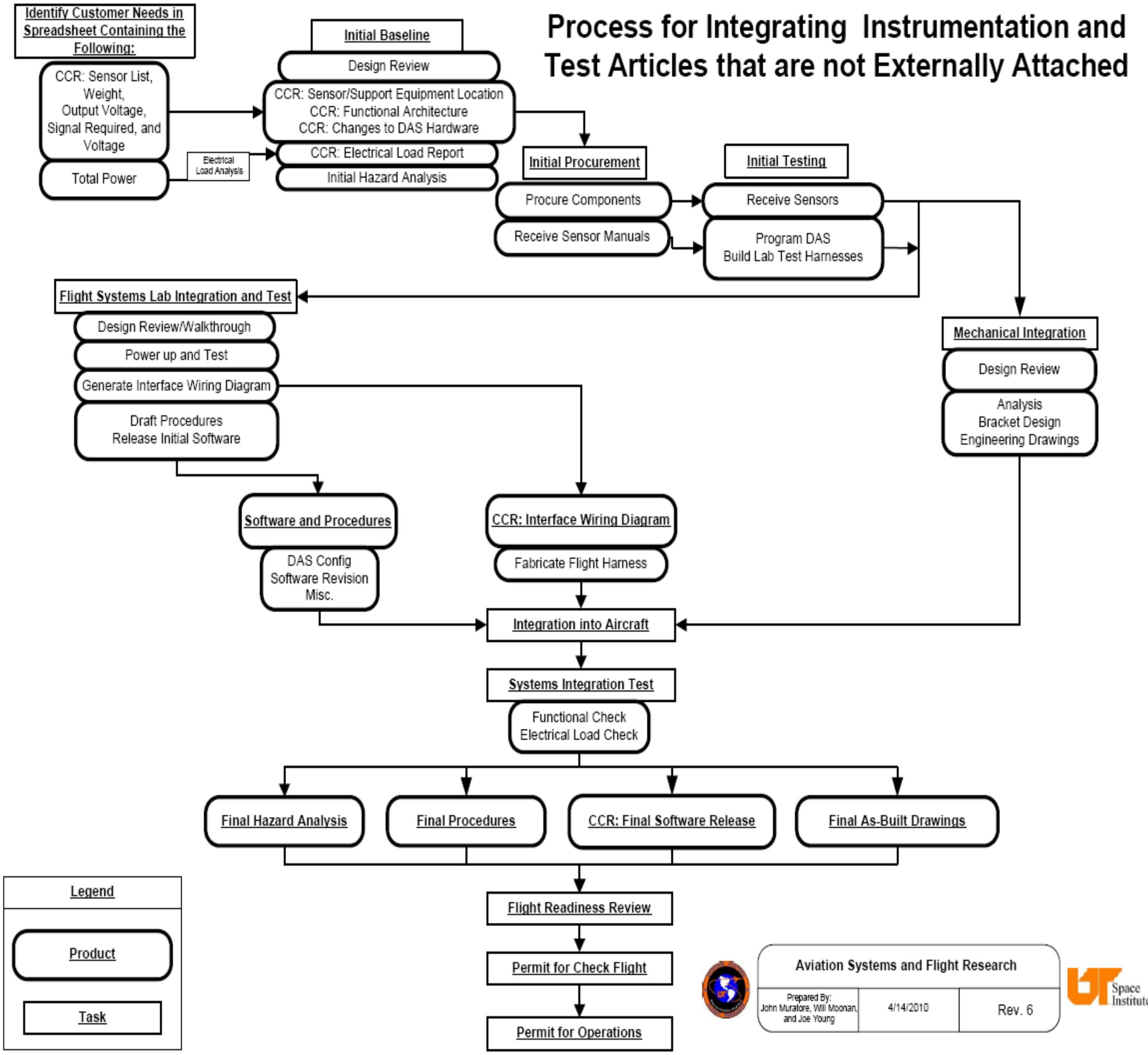
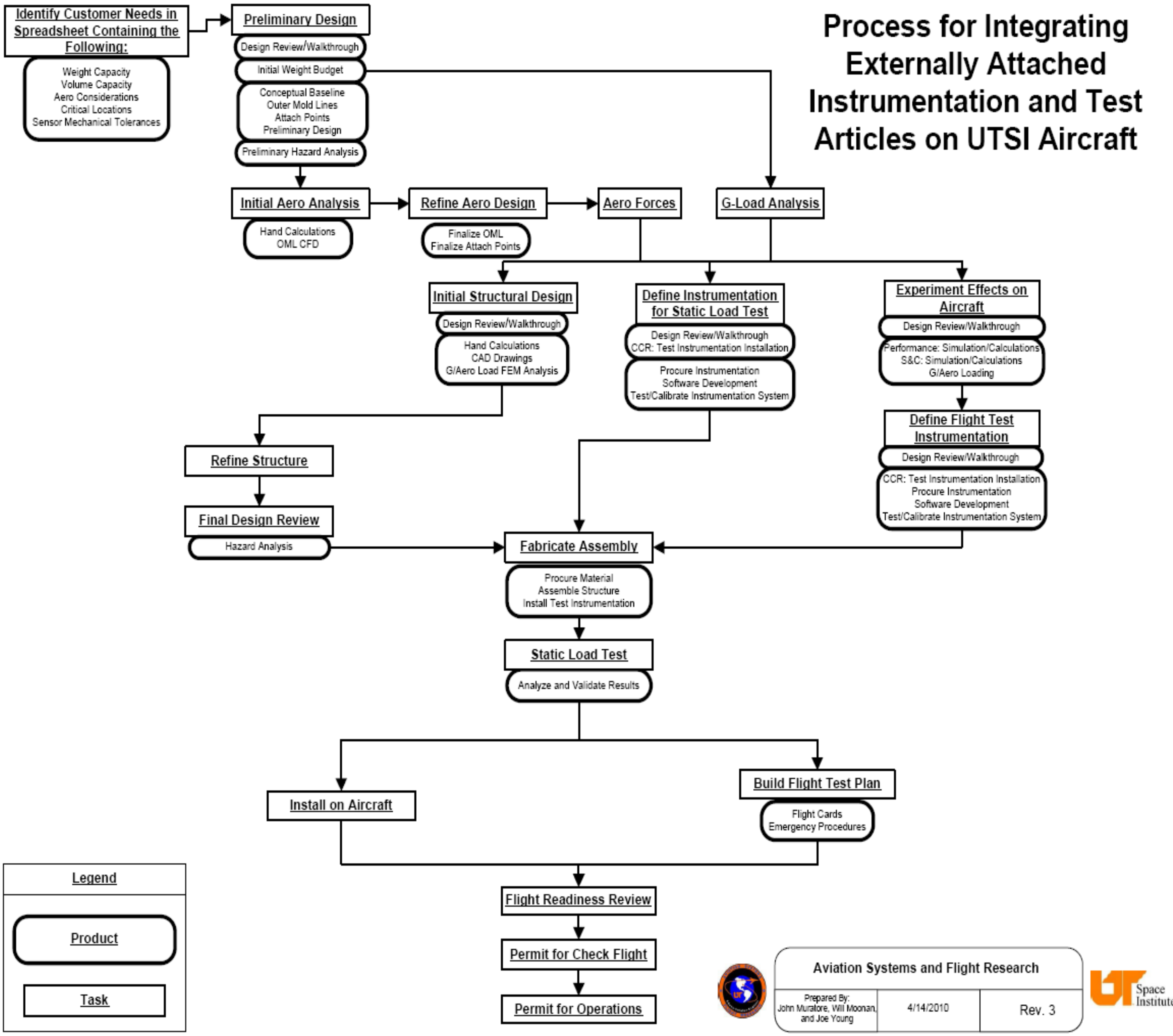


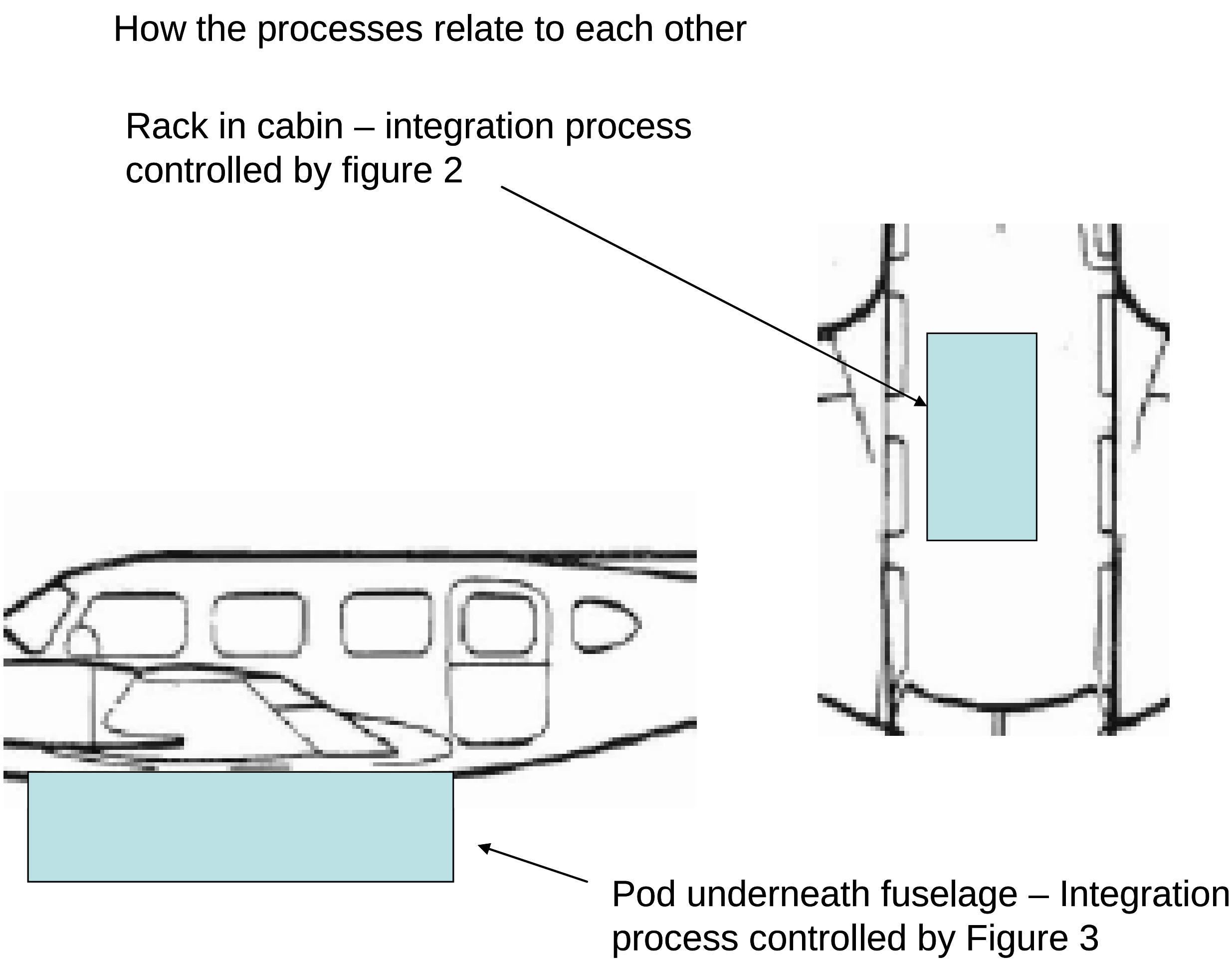
Figure 3 – Process for Integrating Externally Attached Instrumentation and Test Articles



5.0 Details of Process for Integrating Airborne Science Instrumentation and Test Articles that are not externally attached

This section describes the process for integrating experiment instruments and test articles that are not externally attached; this includes complete experiments or parts of an experiment that are not externally attached. For example, an instrument may include a rack of equipment and an externally attached instrument. In this case the process for integrating the rack and interfacing wiring is controlled by this process (documented in Figure 2) and the process for integrating the pod is controlled by the process for externally mounted equipment (Figure 3). Figure 4 illustrates this breakdown.

Figure 4 - How the Processes Relate to Each Other



The process for integrating Airborne Science instrumentation and test articles that are not externally attached starts with identifying customer needs. This is normally documented in a spreadsheet that identifies all of the instrumentation and equipment that needs to be integrated. This spreadsheet describes the volume, weight, electrical power needs, and data acquisition channels for each piece of equipment. An example of the spreadsheet is shown below in Figure 5.

Figure 5 – Example Instrumentation Spreadsheet

NOAA Mercury Mission Sensors

Measurement Requirement	MC or TD*	Item	Vendor	Model	Cost	Mounting Location	Weight	Dimensions	Power	Instrumentation
Airborne ozone	MC	Airborne ozone detector				Window plate	30 lbs	H 5.25 in x W 17 in x D 20 in, fits into 19-inch rack, 22.5 in with Al cylinder protruding from back	100 W, 112 Vac	Two analog 0-10 VDC signals
Airborne SO2	MC	SO2 detector	GFE		"Miniaturization" required by NOAA	Window plate	33		112 Vac	Four analog 0-10 VDC signals and serial port
Airborne Hg	mc	tekran					51		112V ac	serial port on tekran, serial port of mass flow controller, analog on mass controller, mass controller needs power 24v
Air sampling	MC	Denuder in cabin	GFE				22			pumps must be powered, analog on pressure controller, pressure controller needs power - 24v
Humidity	MC	Optisonde chilled mirror Dew Point hygrometer	Buck Research Instruments Boulder Colo	1011C	$25,000	probe mounted on outside of fuselage	Sensor wt 1.5 lbs, Control Unit Weight 1.25 lbs, Power Unit 3.25 lbs	Sensing Unit 2.5 in diameter by 4.25 in long, Control/Indicator Unit 3.26 in by 3.26 in by 5.88 in, Power Unit 6.38 by 6.06 by 12 inches	24 VDC, 2.5 Amps	analog 0-10Vdc and serial rs-232
Total particle measurement	MC	Water based TSI condensation nuclei counter	TSI, Shoreview, MN	3760			12 lbs	12 by 6 by 11 in	112VAC , 1.2 Amps	one pulse train - must count pulses - pump must be powered, flowmeter one analog signal, flowmeter must be powered 24vdc

* MC = Mission Critical, item must be flown, TD = Technically Desirable, item will be flown if space, weight, power, integration, etc. is available

This spreadsheet is baselined through CCR. This information is used to generate a preliminary electrical load analysis to determine if the equipment will work with the existing aircraft electrical system or whether modifications will be required. When the electrical loads are clearly within our experience, the electrical load analysis may not be initially developed and the final installed electrical load may be determined through test. The baselining of the instrumentation spreadsheet allows preliminary design to begin. This includes development of CCRs which show the instrument location (figure 6), the total system architecture (figure 7), and the location of modules in the data acquisition system (figure 8).

Once these items have been baselined, procurement of equipment can proceed. Each procurement request is prepared by the responsible engineer and then approved by the project manager. As soon as equipment is selected, UTSI requests the instrument or equipment providers to provide a user's manual for the equipment or instrument. This user manual provides an early start and basis for determining interface wiring requirements and for developing interfacing LabVIEW software for the data acquisition system. The user manual also provides initial details on weight and mounting locations for determining how the instrument is to be mounted in the aircraft.

Once the instrumentation or equipment arrives it goes to the Flight Systems Laboratory (Figure 9) at UTSI for initial testing. The Flight Systems Laboratory contains data acquisition hardware and software identical to that in the Navajo aircraft; this is used to develop the hardware and software interfaces for equipment and instruments. Power supplies and other equipment simulate the remaining interfaces of the aircraft to the science instrumentation. The purpose of the Flight Systems Laboratory testing is to determine the operating characteristics of the equipment as well as to validate the software that will operate the equipment in the aircraft. To do this, test harnesses are built from the information in the equipment user's manual. Once these harnesses have been tested successfully in the Flight Systems Lab, the requirements for the interfacing wiring harness for the aircraft are baselined in a CCR (Figure 10). The Flight Systems Laboratory can also be interfaced to flight simulations to allow the interfacing software to be exercised through complete mission profiles.

Figure 6 – Instrument Location Example

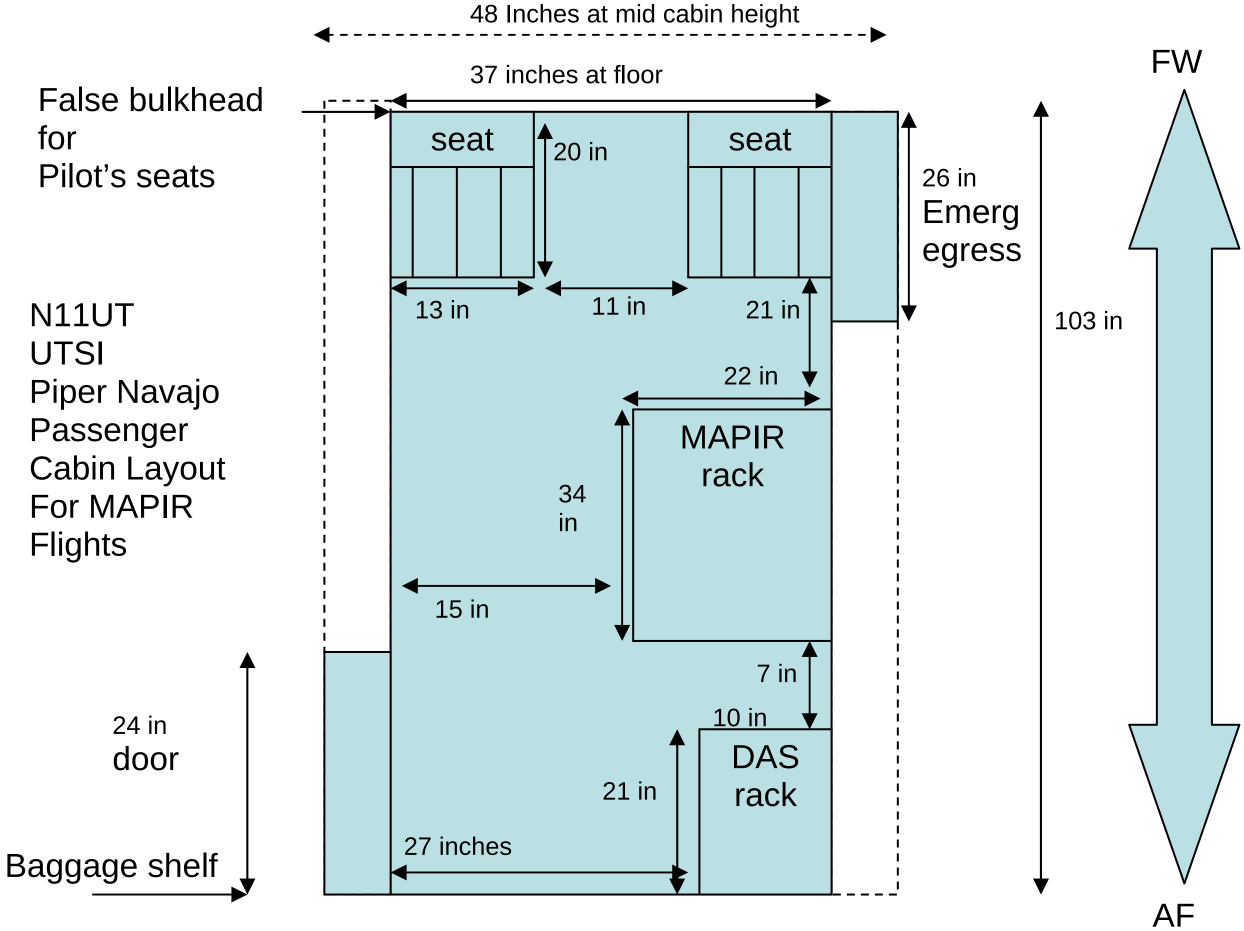


Figure 7 – Architecture Example

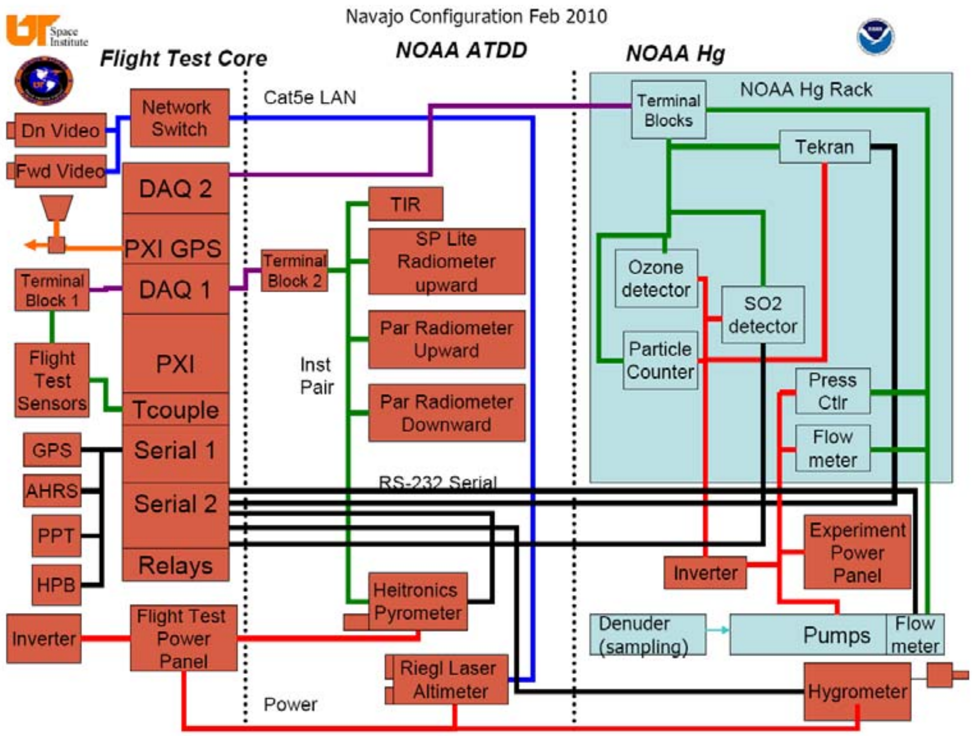


Figure 8 – Location of Modules in DAQ system

Date: 3/17/2009

	SL1	SL2	SL3	SL4	SL5	SL6	SL7	SL8	
	8104 Controller	NI-6682 GPS	NI-6224 DAQ	NI-6224 DAQ	NI-8430 4 CH Serial	NI-8430 4 CH Serial	NI-4351 TC Mod	NI-4110 Programmable Power Supply	

Figure 9 – Breadboard in Flight Systems Laboratory at UTSI

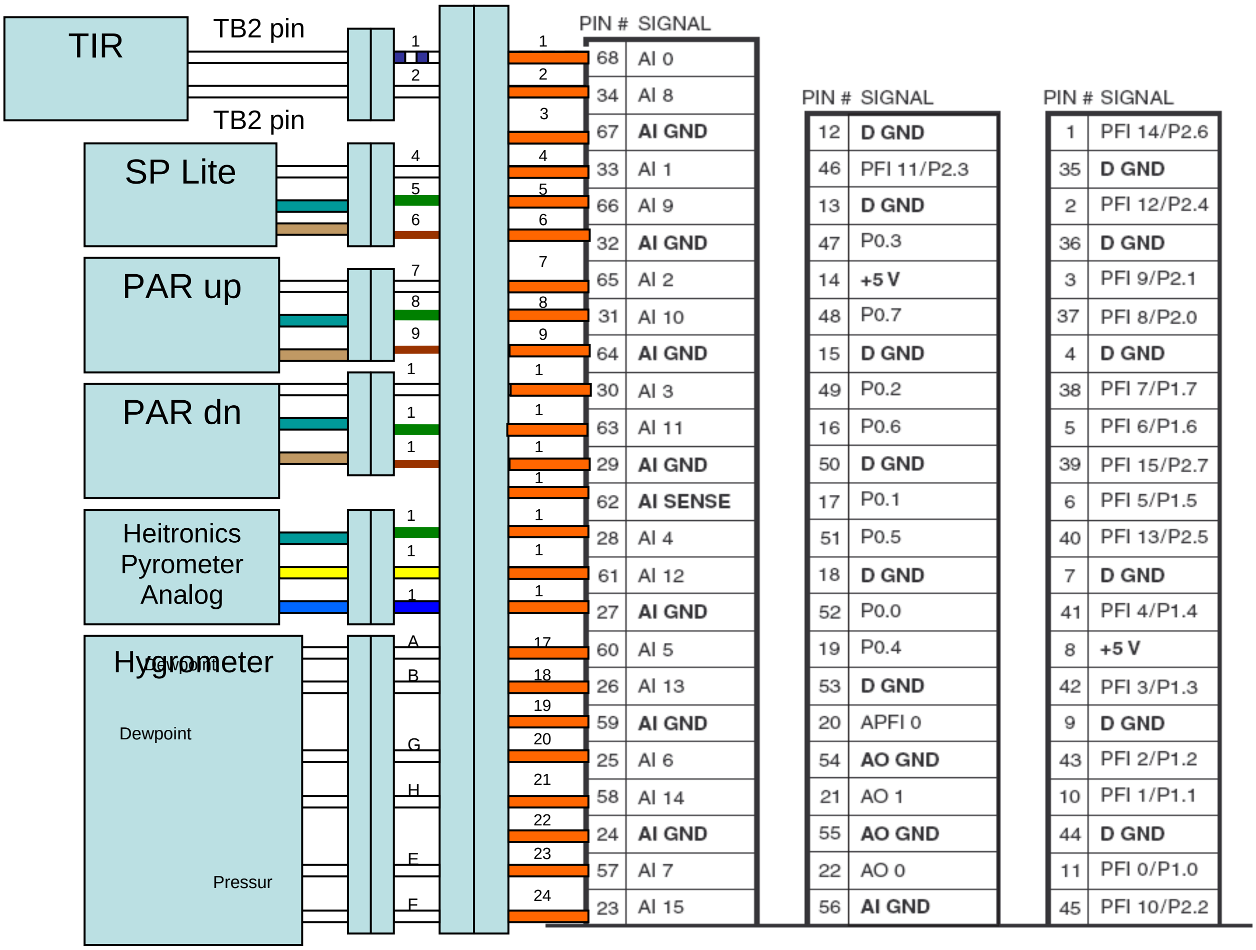
The Flight Systems Laboratory is critical to integrating new instruments into the aircraft in a timely manner. The Flight Systems Laboratory is responsible for producing the software, initial operating procedures, and wiring interface drawings necessary to integrate the equipment to the aircraft.

Once the new hardware and equipment has been exercised in the Flight Systems Laboratory it is released to the hangar for mechanical integration in the aircraft. Equipment may be directly interfaced to the aircraft or installed in a rack which is mounted in the aircraft. Design of the brackets or rack to mount the equipment occurs in parallel with the Flight Systems Laboratory integration. UTSI has a standard rack configuration which was tested and analyzed for the MAPIR mission. New hardware sets are evaluated and if they are less mass and put lower loads into the rack than the previously analyzed and tested rack, additional tests are not required. Initial rack testing for the MAPIR was to FAA crashworthiness standards (9 g longitudinal, 2 g vertical and 1.5g lateral).

Once wiring harness, mechanical, and software integration is complete, a systems integration test is performed. The purpose of the systems integration test is to

a. Confirm function of the new hardware and software
b. Determine the actual electrical load
c. Determine that no electromagnetic interference exists between flight systems and experiment systems

Figure 10 – Example of Interface Wiring Definition



Upon completion of the Systems Integration Test, the Hazard Analysis is finalized, the flight procedures are finalized, and the Maintenance community completes final as-installed documentation per the Maintenance Manual. This material is brought together for the Flight Readiness Review. The Flight Safety Review (which may be conducted as part of the readiness review) and the Flight Readiness Review lead to approval to fly check flights of the specified configuration. Successful completion of the check flights releases the aircraft for use in airborne science or flight test experiment flights.

6.0 Details of Process for Integrating Airborne Science Instrumentation and Test Articles that are externally attached or that affect the outer moldline

When UTSI is mounting externally attached hardware or hardware that protrudes or changes the outer moldline, the first step is to baseline the nature of the modification. This includes the physical shape and the conditions of flight that are required. An example of this for the MAPIR pod is Figure 11

Figure 11 – Example of Requirements Baseline

Finalized Fairing Dimensions and Analysis Conditions

- Dimensions
  - Total Height = 14 inches
  - Total Width = 40.12 in + 1 in = 41.12 in
  - Total Length = 7.5 ft
    - Nose length = 14 inches
    - Afterbody length = 35.88 inches
- Analysis Freestream Conditions
  - 236 kts (272 mph) @ sea level
  - Angle-of-attack and sideslip (α, β)
    - (0°, 0°), (+10°, 0°), (0°, +20°), (+10°, +20°), (-10°, +20°)
- Configurations
  - Front Fairing + MAPIR "box" + Aft Fairing
  - MAPIR "box" only

Baselining the initial outer moldline allows preliminary structural design to start (Figure 12). Following the preliminary design, initial aerodynamics calculations can be made with simple area/velocity engineering techniques as well as initial Computational Fluid Dynamics (CFD) techniques (Figure 13). These are documented in the Structures Engineering Notebook. Following initial definition of the aerodynamic and inertial loads, three activities are started. The first is detailed structural design. The second is design of the ground static load test. This includes design of the load test fixture as well as the instrumentation. Finally computations are made to estimate the effects of the structural modification on flying properties of the aircraft. The results of the CFD are used in manual computations as well as computer simulations (Figure 14) to evaluate the effects of the external modification to critical aircraft performance parameters. These are documented in the Aerosciences and Flight Mechanics Engineering Notebook.

Figure 12 – Preliminary Mechanical Dimensions

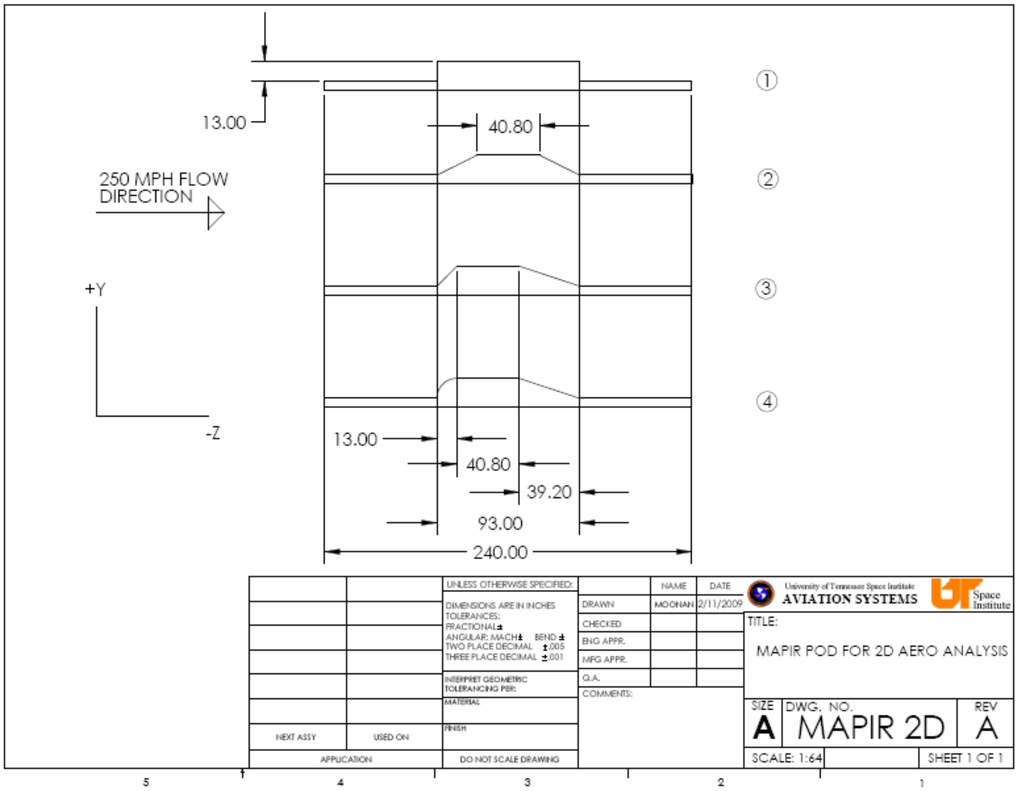


Figure 13 – Example of Initial CFD Calculations

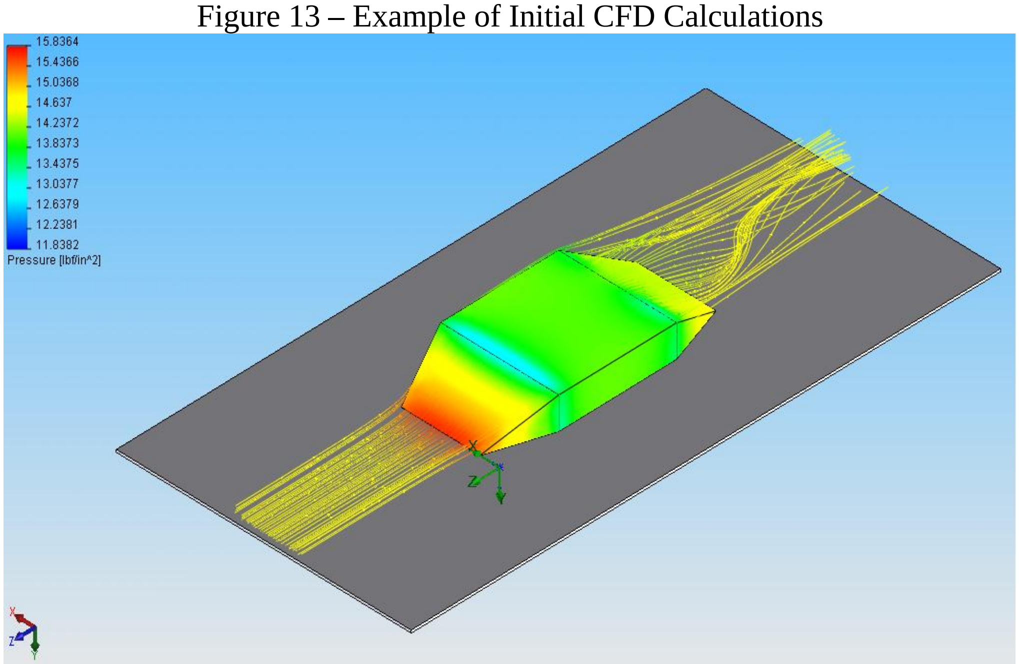


Figure 14 – Example Computer Simulation

As the initial computer simulations of handling are performed, definition of required flight test instrumentation (strain gages, accelerometers, etc.) can be performed. These are documented by CCR.

As the structural design proceeds, a final design walkthrough/review can be performed. This leads to authority to proceed with structural fabrication and assembly. When the structural modifications are fabricated and assembled, they proceed to static structural ground test. Static test may occur on the structures both before and after they are attached to the aircraft. Once the structural modifications have been installed on the aircraft and tested, the results of this work are passed to the flight readiness review process.

7.0 Conclusion

A disciplined and rigorous process has been developed to integrate airborne science and flight test equipment onboard UTSI aircraft. This process encompasses the best known design and analysis practices and utilizes current and available technology to the maximum extent possible. Rapid prototyping of installations is made possible by the use of analysis, test rigs, bread-boarding and flight simulation as required. As a result, UTSI flight operations can effectively integrate research equipment into its aircraft to support engineering and scientific investigations practices of larger programs while operating in the smaller environment of UTSI