Lessons Learned on the T-38 Avionics Upgrade Program

Brian A. Kish
445th Flight Test Squadron
187 North Flightline Road
Edwards AFB, CA 93524
brian.kish@edwards.af.mil

John Deems
john.deems@edwards.af.mil

Dawn Dunlop
dawn.dunlop@edwards.af.mil

Eric Fitz
eric.fitz@edwards.af.mil

Abstract – Avionics testing is a major portion of all current aircraft flight-test programs. Lessons learned from the T-38 Avionics Upgrade Program are given. While the details are unique to the T-38 Avionics Upgrade Program, the lessons apply to all flight-test programs. Since no formal technical report was done for this program, this paper also serves as a written account of the program's evolution. Four problem areas are listed which lead to the following lessons learned: Don't let flying get ahead of data analysis. If the software doesn't work in software-in-the-loop facilities, it won't work in the airplane. However, software that works in software-in-the-loop facilities may *not* work in the airplane. Properly instrument the test aircraft based on its mission. Apply common sense logic when using existing drawings. If something doesn't look right, the drawing could actually be wrong. Incorporate operationally representative maneuvers in development test and evaluation. Test things one-by-one in development test and evaluation (i.e. use the scientific method of isolating one variable).

TABLE OF CONTENTS

1. INTRODUCTION

Avionics testing includes weapons, electronic countermeasures, communications, navigation, egress, environmental control, flight controls, fire control systems, engine, instrument and crew station analysis, plus support and test equipment for these systems. The magnitude, complexity and importance of avionics testing quickly becomes apparent. Avionics testing not only includes evaluation of the individual aircraft systems, but the integration of these systems into the airframe with each other to maximize operational effectiveness. Avionics testing is a major portion of all current aircraft flight-test programs.

One constant in avionics testing is that new systems have improvements in technology for which "standard" test methods or techniques may not exist. Most test teams start with a test approach based on how it was done on similar systems or simply test against contract specifications, which is getting more difficult in today's streamlined acquisition. With acquisition reform, contracts contain more operational specifications and less detailed specifications [1]. Regardless, the following question must be answered: "What are the goals of the system and how well does the system meet these goals?" The expected goals for any system should include goals for operational suitability, reliability & maintainability, systems integration, in addition to measuring how well a given system meets its technical specifications.

Avionics testing places the greatest demands on the technical competence, ingenuity, aggressiveness, and managerial skills of the test pilot and flight-test engineer. A test team must become experts on the "nuts and bolts" of that system's operation as well as the operation of similar systems. The impact of any aircraft system on other aircraft systems (systems integration) must be closely monitored. The importance of avionics testing is clearly spelled out in the United States Air Force Test Pilot School's syllabus. "Because the majority of all flight testing is directly related to systems test, graduates of the United States Air Force Test Pilot School should expect to spend the majority of their flight test careers in this area and should endeavor to develop the strongest foundation possible in order to contribute to this portion of the test environment." [2]

To save time and money, final test results were briefed to the system program office in lieu of writing a formal technical report. Since no formal technical report was required, this paper will document the evolution of the T-38 Avionics Upgrade Program. Source selection, avionics systems description, objectives, and evaluation criteria will be covered. Four challenge areas will be presented which led to several lessons learned. Finally, conclusions and recommendations will be given.

The intent of this paper is NOT to point fingers at any members of the test team or contractor. The purpose is to present common "traps" the T-38 Avionics Upgrade Program fell into that could plague any flight test program. Program management is the art of balancing cost, schedule, and performance. Often programmatic pressures and the desire to succeed can cloud one's judgement. Reviewing lessons learned from other programs prior to beginning a new test program should reduce the chance and frequency of costly mistakes.

2. Program Description

The T-38 has been used for pilot training for about 40 years. As avionics systems on modern aircraft become more and more advanced, a gap is growing between what is learned at Undergraduate Pilot Training and what is needed to operate these new avionics systems. Rather than retire the T-38 and develop a new trainer aircraft, a decision was made to upgrade the T-38 with new avionics. The goal was to extend the useful life of the T-38 another 40 years. The state-of-art digital cockpit will introduce students to digital technology, similar to what they will encounter when they receive their wings and begin flying in front-line units the world over.

The T-38 Avionics Upgrade Program (AUP) invoked acquisition streamlining and reform. Use of non-developmental items (NDI) was emphasized. The United States Air Force considered a wide variety of proposals – from full NDI to full development. Source selection was based on a "best value"-criteria consisting of utility, technical quality, management, risk, and price. The Boeing Company proposed teaming with Israel Aircraft Industries who upgraded the avionics of the F-5 (similar to the T-38) for the Chilean Air Force. Boeing proposed use of commercially available avionics and maximum software reuse. Their proposal was selected as the "best value" to the government by the source selection agency.

The purpose of the T-38 AUP is to provide realistic advanced training for future United States Air Force (USAF) fighter/bomber pilots (use of head-up display, glass cockpit, and hands-on-throttle-and-stick). The upgrade will also improve the reliability factor (from the current 15 flight hours mean time between failure, to a projected 60 flight hours). National airspace requirements for Global Positioning Systems and Traffic Collision Avoidance System are being imposed on all aircraft, and the T-38 AUP will meet or exceed current requirements and be capable of evolving with new requirements.

Over 500 USAF T-38 aircraft will be upgraded to the digital cockpit. The upgrade will be installed at Williams Gateway Airport, Mesa, Arizona. Aircrew training will be conducted in 36 Aircrew Training Devices (simulators). A contractor support package will be provided to support the T-38 aircraft avionics and the simulators at Moody Air Force Base (AFB), Columbus AFB, Vance AFB, Randolph AFB, Laughlin AFB, and Sheppard AFB. Initial operational capability is scheduled for the end of 2000. The T-38 AUP consisted of the following new components:

- Head-Up Display (HUD)
- Up Front Control Panel (UFCP)
- Global Positioning System (GPS)
- Inertial Navigation System (INS)
- Radar Altimeter
- Stability Augmentation System
- Mission Display Processor (MDP)
- Multi-Function Display (MFD)
- Electronic Engine Display (EED)
- Terrain & Collision Avoidance System (TCAS)
- UHF/VHF Radios
- Hands-on-Throttle-and-Stick (HOTAS)
- Air Data Computer
- Data Transfer Set
- Video Tape Recorder
- No-Drop Bombing System

These upgrades will allow students to practice, under controlled situations, the demanding cockpit management tasks they will be required to perform while operating their advanced aircraft. Figure 1 shows the overall program schedule. Figure 2 shows the cockpit layout of the T-38 AUP. Figure 3 shows the cockpit layout of the current T-38A for comparison. The T-38 AUP uses a "glass cockpit" with a HUD and up front control panel, while the T-38A uses "steam gauges" and lacks a HUD or central control panel. All of the components listed above were considered NDI or commercial off the shelf (COTS). With Boeing's proposal of maximum software reuse, 40 development test and evaluation (DT&E) sorties (plus 12 sorties for training operational test pilots) seemed reasonable. Israeli Aircraft Industries' experience with Chili's F-5 Plus Avionics Upgrade Program projected confidence these 40 test sorties could be flown over a 12-week timeframe. Allowing for unknowns, three software builds were planned prior to production. Specific objectives and evaluation criteria for DT&E are listed in Table 1. All in all, the plan seemed feasible. Program execution was another story.

Year	1998				1999				2000			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4
Development	■											
SIL testing		■										
DT&E			■									
OT training				■								
OT&E				■								
Production						■	■	■	■	■	■	■
IOC									■			

■ planned ☐ actual

Figure 1 Overall Program Schedule

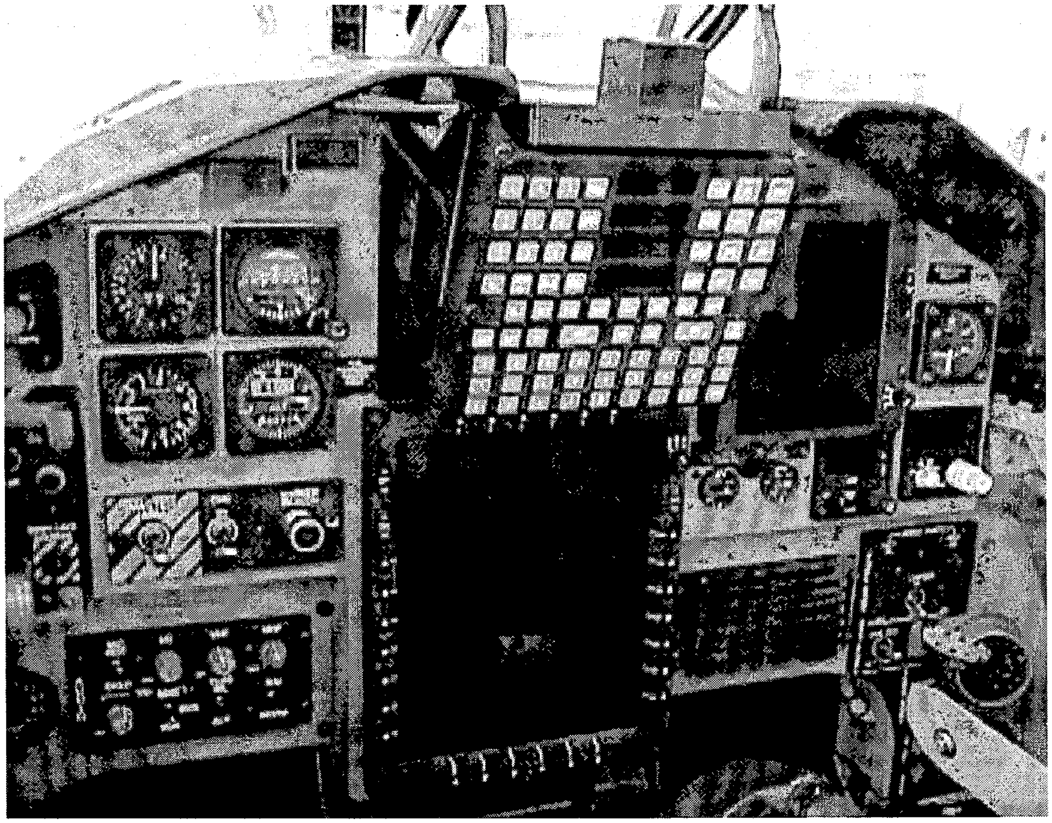

Figure 2 T-38 Avionics Upgrade Program Front Cockpit Layout

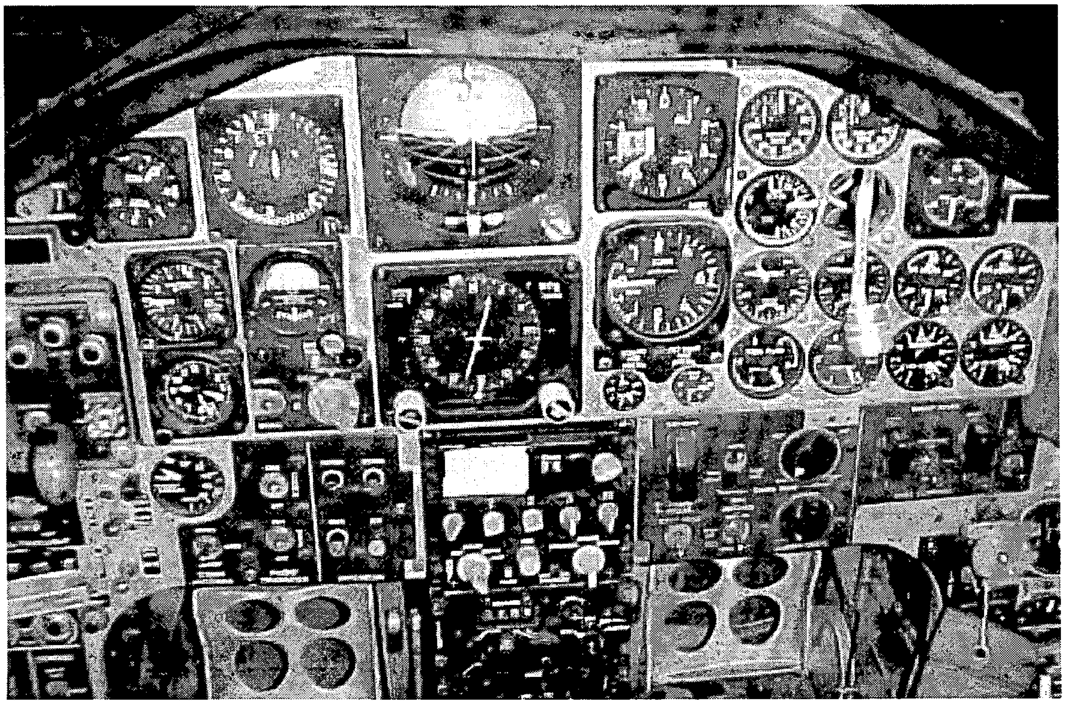

Figure 3 Current T-38A Front Cockpit Layout

Table 1 T-38 AUP Objectives and Evaluation Criteria

OBJECTIVE	EVALUATION CRITERIA
1. Demonstrate data transfer to and from the aircraft.	Mission planning data is correctly transferred to the MDP from the mission planning system. Maintenance and debriefing data can be extracted. All unclassified data, including Operational Flight Program are transferred via a single interface in the front crew station
2. Demonstrate HUD operation	Flight reference and general symbols are displayed properly in navigation mode. Attack and flight reference symbols are displayed as designed in air-to-air and air-to-ground modes.
3. Demonstrate the UFCP functions.	The specified data and commands can be input through the UFCP.
4. Demonstrate the MFD display formats and operation.	The MFD functions as the primary head-down flight reference, and as an avionics control and data manipulation tool. The view from the color television system can be displayed with synthetic overlaid flight reference data.
5. Demonstrate the HOTAS functions.	The specified control functions are provided on the throttles and stick.
6. Demonstrate the electronic engine displays, including fuel quantity indication.	Engine parameters and fuel quantity are indicated with the specified accuracy.
7. Demonstrate the operation of the stand-by instruments.	The standby instruments indicate airspeed, altitude, vertical velocity, attitude and magnetic heading with the specified accuracy.
8. Demonstrate the operation of the TCAS.	The system meets the Federal Aviation Administration (FAA) requirements for TCAS level II equipment.
9. Demonstrate the clock function.	The MFD clock can be set via the UFCP and displays the GPS or MDP time, and includes an elapsed time function.
10. Demonstrate cockpit lighting and readability of the displays in day, night and twilight conditions.	Cockpit lighting is adequate and the displays are readable in the specified conditions.
11. Demonstrate the performance of the navigation system using GPS, INS, VHF Omni-directional Range (VOR) / Instrument Landing System (ILS), and a blended solution.	The navigation system meets the requirements detailed in the performance specification.
12. Demonstrate the design function of the radio and intercom communication systems.	UHF, VHF and inter-cockpit communication systems operate as designed. The aircraft transponder meets FAA requirements.
13. Demonstrate the simulated stores management system.	The system adequately simulates bomb releases, computes scores and, displays and stores the data. Simulated A/A gun and Short Range Missile (SRM) are also provided.
14. Test the operation and accuracy of the radar altimeter.	The radar altimeter operates within the design parameters and accuracy.
15. Demonstrate the video and audio recording capability.	Displays and can be recorded automatically and manually with event markers.
16. Analyze the operating environment of the avionics system in normal and extreme conditions.	The vibration and thermal environment in the avionics bays and cockpit will be measured throughout the test program. No environmentally induced system anomalies occur.
17. Analyze the electromagnetic compatibility of the avionics system with itself and the operational environment.	The requirements of MIL-E-6051D are met.
18. Test the air data computer and verify the air data calibration.	The air data calibration is shown to meet the performance specification.
19. Demonstrate the new Stability Augmentation System.	Directional damping and control is adequate to perform the required missions.
20. Collect Reliability and Maintainability (R&M) data for analysis under the R&M test plan.	Maintenance and mission data is provided to the Joint Reliability and Maintainability Evaluation Team.

Testing in the Software Integration Lab (SIL) finished in Jun 98. While errors appeared in the SIL, they were believed to be unique to the SIL. The first DT&E flight occurred three weeks ahead of schedule on 8 Jul 98. Initial DT&E finished over one year later after 152 sorties (61 considered DT&E) and took 11 software builds. The other 91 sorties consisted of pilot proficiency, familiarization, guest, and training sorties. Figure 4 shows planned sorties over time, actual sorties flown over time, and software drops.

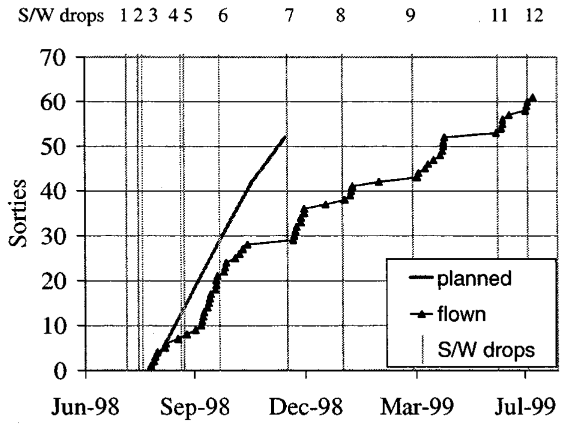

Figure 4 Planned versus Actual Sorties

Forecasts include two major software builds with more DT&E continuing through Aug 2000. Various cockpit-working groups have occurred where operational pilots have given valuable input into cockpit layout and software/hardware functionality. Programmatically, some schedule and cost was sacrificed to meet performance requirements. The final product should meet user needs. The next section gives lessons learned in four areas of the program.

3. Lessons Learned

Every flight test program has unknown challenges to overcome. Program managers rely on philosophies, processes, procedures, etc to minimize the occurrence and impact of unknowns. Four challenge areas are presented here which led to several lessons learned. While the details are unique to the T-38 Avionics Upgrade Program, the lessons apply to all flight test programs.

Example 1: Pitot-static calibration error

Pitot-static calibration is required at the beginning of a flight test program. For the T-38 AUP, decisions were made to fly a series of pitot-static sorties and analyze the data at a later date. A sign error was discovered in the air data computer's software. The series of pitot-static sorties had to be re-flown.

Lesson learned: Don't let flying get ahead of data analysis.

Example 2: Errors found in Software Integration Lab (SIL)

Prior to first flight, the SIL was used to wring out the system. Errors were found in the SIL, but engineers claimed the errors were SIL unique. Those same errors appeared in flight. In addition, errors not seem in the SIL appeared in flight.

Lessons learned: If the software doesn't work in the SIL, it won't work in the airplane. Software that does work in the SIL may not work in the airplane.

Example 3: Noisy normal load factor (g)

For cost reasons, decisions were made to leave out certain parameters for flight test instrumentation. This occurs on all programs. For the T-38 AUP, normal load factor (critical for the T-38's mission) was left off. Operational pilots were trained by the development test pilots during DT&E. The difference occurred in the profile. Operationally representative maneuvers (heat-to-guns, break turns, guns jinks) were flown during this training. Vibration of the embedded GPS/INS (which calculated g forces) led to unusable displayed g and tripped the maximum g sensor prematurely. Two problems needed solving. First, the noisy data had to be filtered. Second, the filtered solution had to be verified. Figure 5 shows how raw data from the embedded GPS/INS (EGI) was filtered.

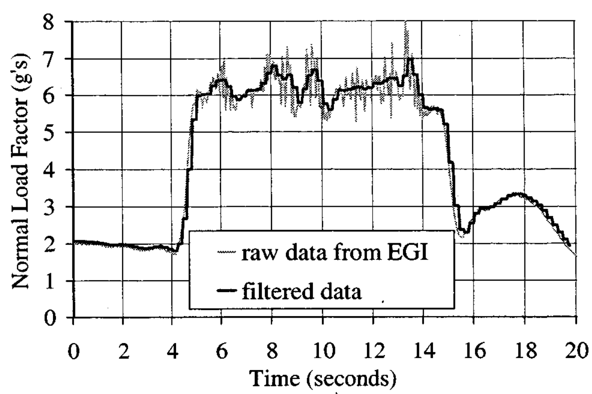

Figure 5 Normal Load Factor from the EGI

To verify the filtered solution, normal load factor had to be instrumented on the aircraft (truth source). To speed up the instrumentation process, drawings from existing T-38A test aircraft were used. Using existing drawings of similar instrumentation is a common practice. The 20-year old drawing was titled "accelerometer installation at the center of gravity". The technician installed the accelerometer according to the drawing. A crew chief looked at the location and said, "that's not the center of gravity". The location was near the engine inlet. The center of gravity is normally along the wing cord, which was another five feet aft. Rumors quickly spread that the T-38 Avionics Upgrade Program caused the T-38's center of gravity to move five feet. This, of course, was nonsense.

The drawing was mislabeled. The location near the engine inlet was easier to access than the center of gravity. One can translate data post flight back to the center of gravity. Some questions come up: Have people been correcting for this difference for the past 20 years when using data from these T-38's? If not, is all the data gathered from T-38 testing from the last 20 years invalid? Figure 6 shows how the filtered solution compared to the truth source.

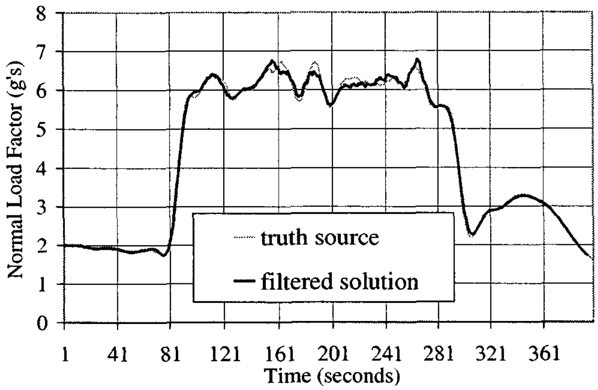

Figure 6 Filtered Solution Compared to Truth

Lessons learned: Properly instrument the test aircraft based on its mission. Apply commonsense logic when using existing drawings. If something doesn't look right, the drawing could actually be wrong. Incorporate operationally representative maneuvers in DT&E.

Example 4: Fuel quantity errors

In the middle of testing software, a decision to change some hardware was made. The electronic engine display (EED) was modified to [ironically] eliminate electromagnetic interference. The new EED was put in the test aircraft along with other modified hardware. Shortly after takeoff, the pilot noted fuel quantity seemed about 500 pounds low. This 500-pound discrepancy remained constant throughout the flight. The pilot erred on the cautious side and landed with 1000 pounds on the display. When the pitot-heat switch was turned off during taxi, the display read 1500 pounds. There was an electromagnetic compatibility problem between the EED and the pitot-heat switch.

People become optimistic, especially when things have been going well. Temptations to skip steps in the process sometimes win, as was the case in this example. Instead of testing each new hardware component one-by-one, a series of hardware changes were tested at one time. Luckily, the pilot found a clue during taxi. He simply paused and observed cockpit gauges after each step in the after-landing checklist (the scientific method of isolating one variable).

Lesson learned: Test things one-by-one in development test and evaluation (i.e. use the scientific method of isolating one variable).

4. CONCLUSION

Avionics testing continues to be a major portion of all current aircraft flight-test programs. Lessons learned from the T-38 Avionics Upgrade Program were given. While the details were unique to the T-38 Avionics Upgrade Program, the lessons apply to all flight-test programs. Four problem areas were listed which led to the following lessons learned: Don't let flying get ahead of data analysis. If the software doesn't work in software-in-the-loop facilities, it won't work in the airplane. However, software that works in software-in-the-loop facilities may *not* work in the airplane. Properly instrument the test aircraft based on its mission. Apply commonsense logic when using existing drawings. If something doesn't look right, the drawing could actually be wrong. Incorporate operationally representative maneuvers in development test and evaluation. Test things one-by-one in development test and evaluation (i.e. use the scientific method of isolating one variable).

REFERENCES

[1] DoD Directive 5000.1, 15 March 1996

[2] Systems Phase Planning Guide, USAF Test Pilot School, January 1995

AUTHOR'S BIOGRAPHY

Captain Brian Kish has been with the United States Air Force for over 8 years. He has a Bachelor of Science degree in Aerospace Engineering from Illinois Institute of Technology and a Master of Science degree in Aeronautical Engineering from the Air Force Institute of Technology. Captain Kish is also a graduate of the United States Air Force Test Pilot School. He has performed research and analysis on vehicle dynamics, human operator dynamics, and aircraft handling qualities, for fixed-wing aircraft. He has authored two technical reports and four technical articles and papers. He is a member of the American Institute of Aeronautics and Astronautics, Society of Flight Test Engineers, Air Force Association, and Soaring Society of America.