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Flight Management System 4DT Flight Demonstration Test Report

For the Shadow GCS as Part of UFIT CRDA

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16. Abstract

GE Aviation Systems and AAI Corporation have signed Cooperative Research and Development Agreements (CRDA) with the Federal Aviation Administration (FAA) to support four dimensional trajectory (4DT) based operations within the National Airspace System (NAS), using the GE Aviation Flight Management System (FMS) and AAI Shadow Unmanned Aircraft System (UAS) as an evaluation platform. This report details the results of flight test demonstrations conducted in December 2009 and the associated analysis.

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1. INTRODUCTION

GE Aviation Systems and AAI Corporation have signed Cooperative Research and Development Agreements (CRDA) with the Federal Aviation Administration (FAA) to support four dimensional trajectory (4DT) based operations within the National Airspace System (NAS) using the GE Aviation Flight Management System (FMS) and the AAI RQ-7B Shadow Unmanned Aircraft System (UAS) as an evaluation platform.

The figure below outlines the basic architecture approach for the 4DT FMS Shadow platform. The simulation and flight demonstration architectures differ slightly between the FMS interface and the UAS Ground Control Station (GCS) and avionics.

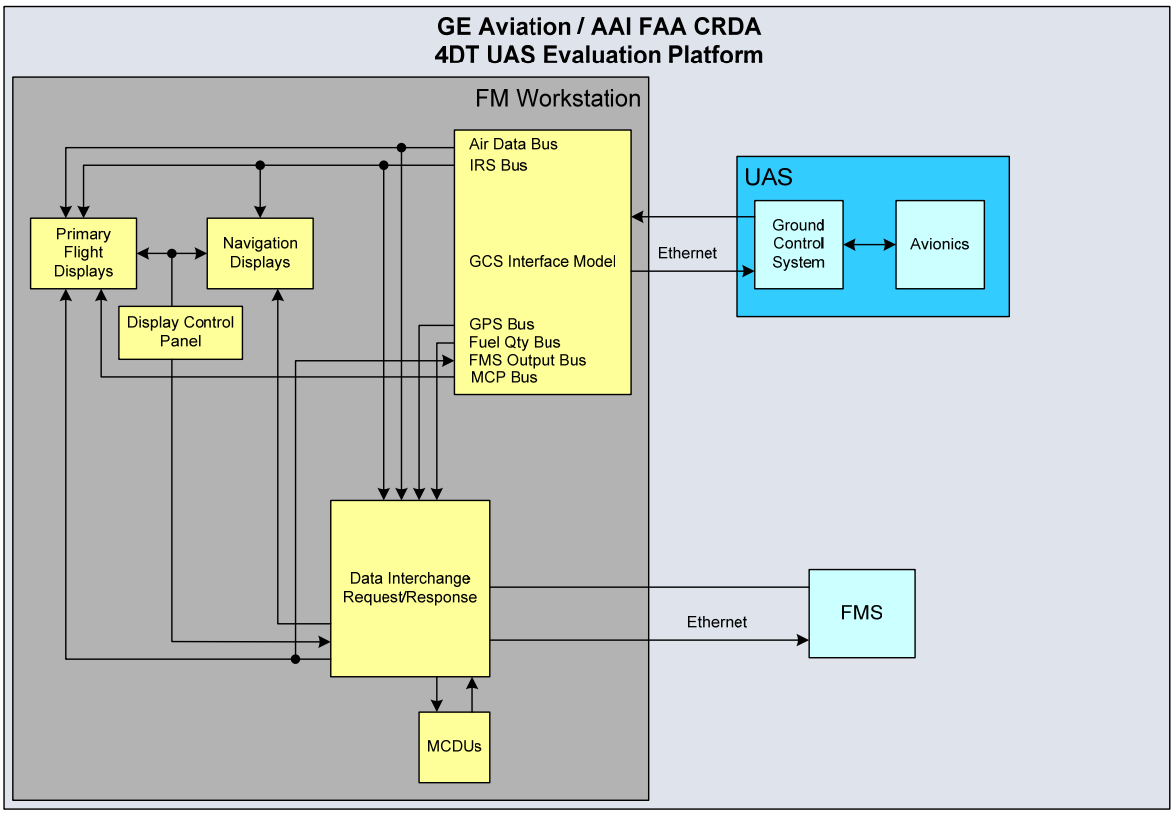

Figure 1-1 - 4DT UAS Evaluation Platform

The 4DT UAS Evaluation Platform is the first stage in a 2-stage approach to an eventual integration of a commercially certifiable 4DT FMS with a UAS. The first stage is an initial 'coupling' of the simulated FMS (sFMS) which utilizes actual flight hardware and software modified for the specific UAS platform. The term 'coupling' refers to interfacing the sFMS with the GCS, utilizing several key parameters in the simulation environment to control the UAS with limited sensor input and flight model changes. Further modifications are built upon this coupled architecture to support the required levels of integrity for actual flight demonstration. The coupled architecture provides a framework of understanding and development for the second stage, the development of an Integrated UAS/FMS Architecture. As a core component of the UAS, the Integrated

UAS/FMS Architecture is a more stringent, robustly linked 4DT FMS furthering NAS operations.

This document outlines the first stage coupling of GE Aviation Systems' sFMS with AAI's GCS.

2. OVERVIEW

The development approach used for the FMS 4DT Flight Demonstration Test was to modify a fielded Tactical Unmanned Aerial Vehicle (TUAV) GCS to interface to the FMS system and to the RQ-7B Shadow UAS. For the first flight demonstration, this modification required no changes to the aircraft nor Ground Data Terminal (GDT). The only required changes were to the Vehicle Control Station (VCS) software residing in the GCS and to the FMS 4DT Software. The FMS 4DT system, monitored by the pilot, could command the aircraft to fly to locations and arrive at a requested time. The pilot had the capability to override FMS 4DT control of the aircraft at any time.

Flight tests were conducted to verify the operation of the modified VCS Software (SW) in the GCS both for its normal functionality and the added FMS 4DT functionality. Typical patterns and altitudes were flown using the FMS 4DT and data was collected. Performance was compared to the currently fielded Shadow TUAV GCS and to the expected FMS 4DT performance.

2.1 LOCATION AND SETUP

The FMS GCS (FGCS) was located at the Redstone Arsenal Flight line within the AAI GCS Lab Trailer. No special test equipment was used during this flight test. The FMS 4DT system was located inside of the Lab Trailer and connected to the trailer using an Ethernet cable to connect to the Tac LAN. A simplified block diagram is shown in Figure 2-1.

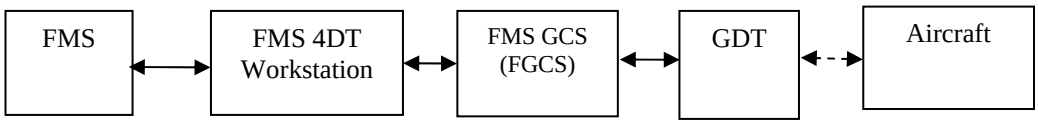

Figure 2-1 – Simplified Block Diagram

3. FLIGHT DEMONSTRATION TEST

3.1 FLIGHT DEMONSTRATION COMPONENTS

1. 4DT Based FGCS
   a) GCS
   b) VCS Software
2. Portable GCS
3. Ground Data Terminal
4. 4DT Based FMS
5. TUAV
   a) Aircraft
   b) Software

3.2 TEST METHOD

The flight test was performed as described in the FGCS Detailed Test Plan. FAA, GE Aviation, and AAI personnel were present and conducted the flight test. The flight test validated the operation of both the GE-supplied FMS 4DT system and the AAI-supplied FGCS software.

3.3 TEST CRITERIA

The purpose of the FMS 4DT Laboratory/System Integration Tests was to verify that the modified VCS software functioned properly with a fielded TUAV System and with the FMS 4DT system. This test incorporated changes to the GCS only. Results of the ground portion of the tests were used in preparing the Airworthiness Release required to transition to flight testing.

The FGCS testing at Redstone was conducted in two separate stages to verify:

1. FGCS TUAV Shadow ground and flight
2. FGCS/FMS 4DT testing

3.4 TEST PERFORMED

The purpose of the first stage of testing was to demonstrate that the modified VCS software properly controlled a fielded TUAV Shadow. The only modification to the VCS SW was an update to allow FMS 4DT control of a new flight mode.

The purpose of the second stage of testing was to verify the new FMS 4DT functionality added to the GCS. This new functionality allows the GCS to interface with the FMS 4DT system. FMS 4DT was used to:

- Request the aircraft to fly to an FMS route
- Request the aircraft to fly to an approach path

The pilot has the option to allow FMS 4DT to take control of these functions and take back control of the aircraft at any time.

3.5 TESTING OVERVIEW

3.5.1 Day 1 – Wednesday, Dec. 2, 2009

It rained and was overcast all day so no flights were possible. Testing was done using the simulation mode in the GCS. There was some difficulty getting the Ethernet connection between the FMS Workstation and GCS working, so a few software changes were made in the FMS Workstation to provide better visibility of the connection status. After AAI made some adjustments to the sub-net addresses on the GCS side, the connection was established and worked smoothly thereafter.

3.5.2 Day 2 – Thursday, Dec. 3, 2009

Although the rain stopped, the ceiling was only 2000 feet so flights were limited to the restricted airspace C-EAST, a ½ nm wide strip about 3 nm long just west of the runway. The team was able to evaluate capture and tracking of a straight-line segment and tested the ability for the pilot to take back control in both the “Knobs” and “Control Stick” modes. In all cases, lateral capture and control was excellent. No issues were observed during transfer of control. Total flight time was 32 minutes, with 10 minutes coupled to the FMS. Transfer of control to the FMS occurred 6 times.

3.5.3 Day 3 – Friday, Dec 4, 2009

Good visibility to 6000 feet allowed operation within restricted areas C-EAST, C-NORTH, C-SOUTH, and part of A-WEST for a total operating area of 2 nm by 5 nm. Evaluations included lateral control on curves, speed up/speed down, and climb/descent with small altitude changes, all of which were satisfactory. An idle descent was made from 6000 feet but aborted at about 3400 feet when a low RPM indication on the aircraft prevented continuing idle thrust. Evaluation of the descent segment flown showed that the aircraft descended about 300 feet less than the FMS model predicted over the 2600 foot descent. We attempted glide path control from 2040 feet to 1685 feet (a 3-degree path terminating at 1000 feet above the runway) but the aircraft unexpectedly climbed when engaged in the “Throttles” mode. A second attempt along a path in area C-EAST resulted in similar behavior so no more attempts were made. A couple of legs were flown in the Required Time of Arrival (RTA) mode, with proper operation noted for speeding up and slowing down as the RTA time was varied. However, because the Global Position

System (GPS) did not output time, absolute measurements of time error were not made. Total flight time was 3 hours, with 1½ hours coupled to the FMS.

3.6 FLIGHT DEMONSTRATION OBSERVATIONS

1. The testing on Day 2 (back and forth in area C-EAST) required the pilot to control the aircraft using the "Stick Control" mode because he can command up to a 30 degree bank angle where the Flight Management Computer (FMC) control is limited to 20 degrees. Because the restricted area is only ½ nm wide, the pilot is required to take the aircraft to the edge of one border and immediately start a 30 degree bank angle turn to keep the aircraft within the restricted area on the other edge of the border.
2. Predicted turns built by the FMC have much too large radii, especially for non-active legs. This causes discontinuities to unnecessarily be inserted when waypoints are closely spaced. See Figure 3-1, where the subsequent loops around the path have large radius turns. The turns are reduced to a more reasonable size when the leg is active.
3. An Estimated Time of Arrival (ETA) jump of around 1 minute was seen on a leg where the time to go was around 2 minutes with no change to the target speed. This was observed when the RTA mode was engaged.
4. During the ground test, the EXT KNOBS mode was selected on the GCS to check that LNAV and VNAV commands were being received. Both LNAV and VNAV indicated valid until selected. As soon as VNAV was engaged, it registered invalid and disconnected because altitude was not sufficient to allow VNAV control. Since the selection remained on, VNAV again engaged. The result was that VNAV cycled on and off continuously. This was expected because there is no "ARM" state in the GCS.
5. At the computed top of descent, the FMC altitude was automatically set to the next lower altitude, causing the aircraft to start to descend. Because the aircraft was flown adjacent to the destination airport, a predicted path to the destination airport at the end of the entered waypoints caused T/D to be inadvertently passed and the aircraft started descending. Although the system operated as intended, it became somewhat of a nuisance for flight testing in such a constrained area.

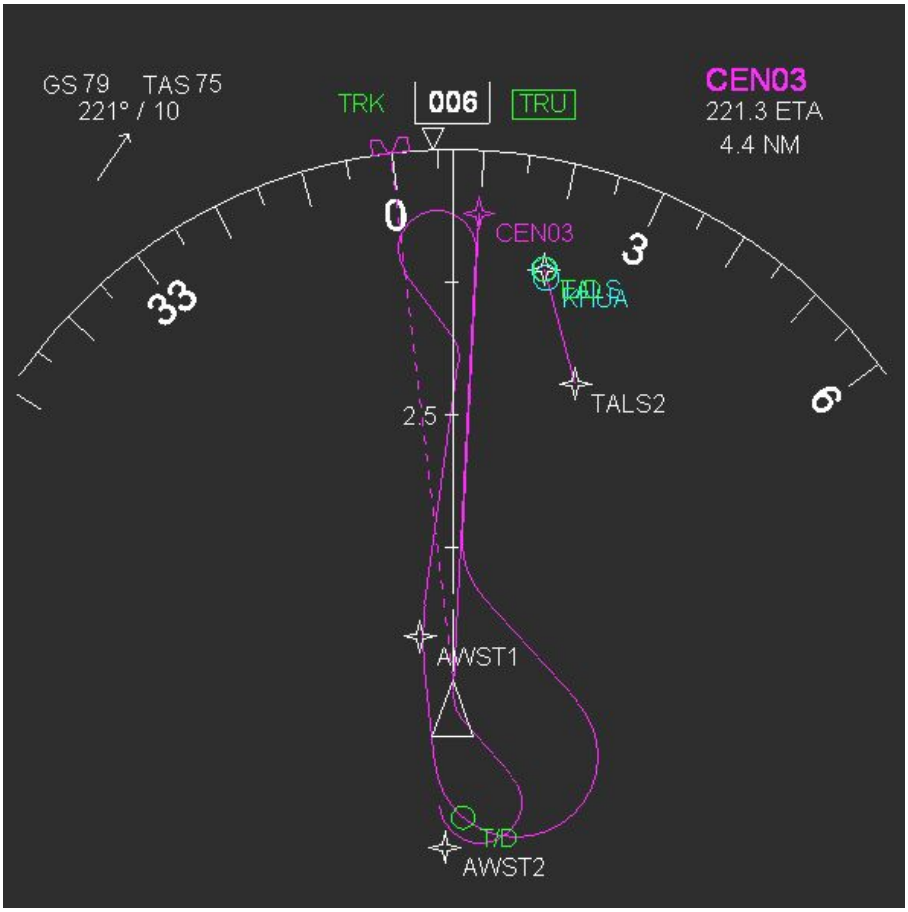

Figure 3-1 – Day 3 Route Showing Predicted Turns

6. Idle descent seemed to be slightly off the FMC performance model. The vertical profile in Figure 3-2 shows that the aircraft descent rate was less than that predicted by the FMC model. This may be caused by the assumed Zero Fuel Weight entered in the FMC (since the actual weight of the aircraft was unknown). The predicted descent rate varies with the aircraft weight.
7. Vertical path control for a specified flight path angle on approach was unacceptable. When initially engaged in "Throttle" or PATH mode, the airspeed error was a little high (caused by starting descent slightly late), causing the aircraft to pitch up to chase the speed because the autopilot uses speed on elevator when in the Throttle mode. Even though the throttle was commanded near idle, the altitude increased more than 400 feet above path, causing the FMC to revert back to SPEED mode, putting the aircraft back into the KNOBS mode. (Note: Because the gradient path was manually built, the FMC does not consider this an approach phase of flight. If it were an actual approach procedure, reversion to SPEED would have been inhibited). When the aircraft is in the KNOBS mode, the throttle command from the FMC is synchronized to the actual aircraft vertical speed, so that the starting point for the throttle command is quite high when the aircraft is climbing and the "Throttle" mode is re-activated, thus making vertical

8. Vertical path control was also observed when initially descending from 6000 feet, where the aircraft speed was very close to the target. In this case, the vertical path control behaved properly.

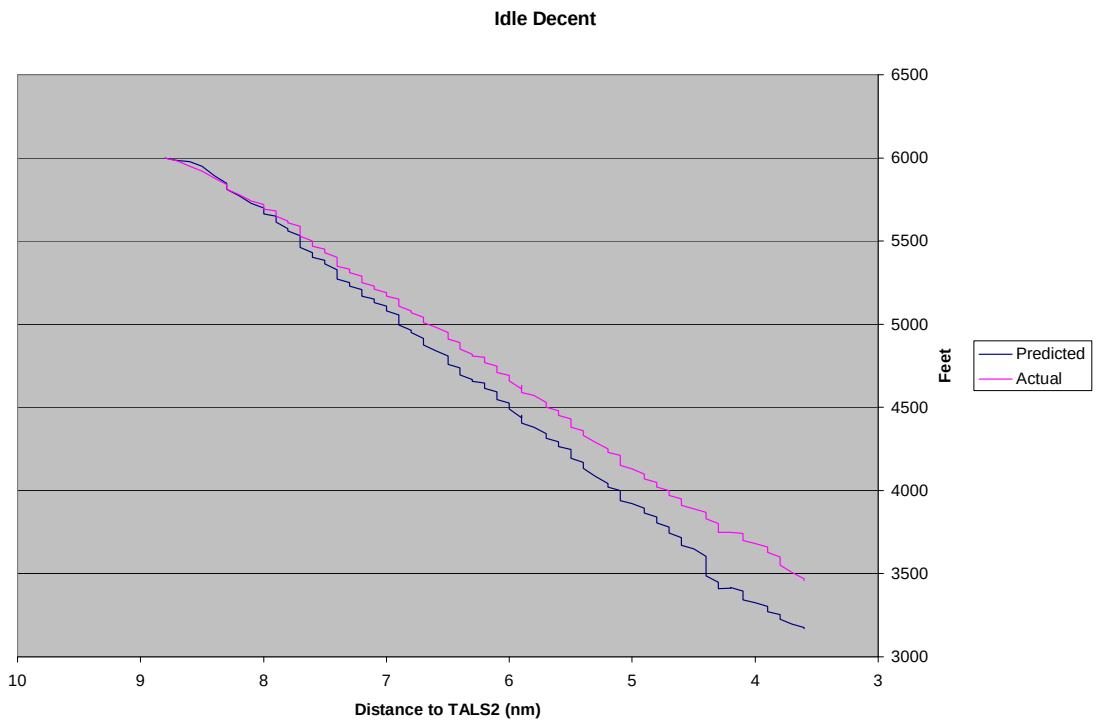

Figure 3-2 – Idle Descent Altitude Profile

3.7 CONCLUSIONS

The FMS 4DT GCS VCS SW performed as expected. There were no failures noted during the test flight and all objectives were tested and passed.

The FMS 4DT performed as expected for the route portion of the testing but the approach portion of the FMS 4DT did not work entirely as expected. Very restricted airspace availability made it difficult to observe normal descent procedures, especially with a simulated approach glide slope ending at 1000 ft above the runway (restriction imposed for safety purposes). However, it was shown that vertical control using throttle command for a specified flight path angle caused undesirable responses (as outlined in Section 3.6 #8).

3.8 RECOMMENDATIONS

As a result of the flight test, the following changes are recommended to the FMS and GCS software to improve their operation:

1. FMS – Change the predicted speed for Shadow operating speed, remove the ground speed limit, further evaluate ETA computations, and replace throttle command control with a more suitable control such as vertical speed
2. GCS – Add vertical speed control, and output for GPS time and accuracy information for FMS.

4. ACRONYMS

4DT	Four Dimensional Trajectory
CRDA	Cooperative Research and Development Agreement
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FGCS	FMS GCS
GCS	Ground Control Station
GDT	Ground Data Terminal
FMC	Flight Management Computer
FMS	Flight Management System
GCS	Ground Control Station
GPS	Global Position System
NAS	National Airspace System
RTA	Required Time of Arrival
sFMS	Simulated FMS
SW	Software
TUAV	Tactical Unmanned Aerial Vehicle
UAS	Unmanned Aircraft System
VCS	Vehicle Control Station