NASA/CR-2017-219595

NASA ATD-1 Avionics Phase 2: Flight Test Plan

John A. Brown
Boeing, Seattle, Washington

March 2017

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question to help@sti.nasa.gov

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/CR-2017-219595

NASA ATD-1 Avionics Phase 2: Flight Test Plan

John A. Brown
Boeing, Seattle, Washington

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Contract NNL13AA03B, NNL15AB46T

March 2017

Available from:

NASA STI Program / Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500

NASA ATD-1 Avionics Phase 2

Flight Test Plan

Deliverable 4.22

DOCUMENT NUMBER	RELEASE/REVISION:	RELEASE/REVISION DATE:
D780-10411-1	**B**	**8 March 2017**

CONTENT OWNER:

Boeing (Airspace Operational Efficiency)

All revisions to this document must be approved by the content owner before release.

Document Information

Original Release Date	Contract or CDRL Number (if required)
June 29, 2016	NNL13AA03B-NNL15AB46T
Limitations	

Authorization for Release

AUTHOR:	Signature on File	9M-PW-ERCS	29 June 2016
	John A. Brown	Org. Number	Date
APPROVAL:	Signature on File	9M-PW-ERCS	29 June 2016
	Karl J. Rein-Weston	Org. Number	Date
DOCUMENT RELEASE:	Signature on File	9M-PW-ERCS	29 June 2016
	Barbara L. Withers	Org. Number	Date

Table of Contents

List of Figures

1. Purpose and Objectives

The purpose of this flight test plan is to describe procedures for conducting FIM operations with the FIM Avionics Systems installed in two test aircraft.

The objectives of this flight test plan are as follows:

- To provide a description of the FIM Avionics System
- To define procedures and processes to be conducted prior to each aircraft's departure and the processes to be adopted after departure from Boeing Field but prior to initiation of the flight test processes
- To describe the coordination with affected ATC facilities that has already been achieved, and remaining required coordination immediately prior to and during the flights, and during the flight test procedures.
- To define flight crew resources, including pilots, flight test engineers and flight test directors to be made available by Honeywell, United Airlines, and The Boeing Company
- To describe the target aircraft and FIM-equipped aircraft that will conduct the flight tests
- To define training requirements for pilots, flight test engineers, flight test directors and airborne and ground observers along with materials required to support this training
- To define flight test requirements in terms of planned test conditions and show how associated requirements from contract documentation are met
- To define details of the flights and associated criteria
- To describe each individual flight test scenario
- To define data collection capabilities in all three aircraft and show how associated requirements from contract documentation are met
- To describe requirements for participation by observers in the aircraft and in the ATC facilities, and define any associated constraints
- To provide a guide to flight crews and flight test directors for pre-flight functional testing and for execution of the test procedures
- Provide a list of contacts relevant to the flight test process

2. Introduction and Flight Summary

Boeing is prime contractor in NASA Langley's Air Traffic Management Technology Demonstration 1 (ATD-1), Phase 2 contract that will culminate in flight testing of ADS-B-based flight deck interval management early in 2017. Honeywell and United Airlines are sub-contractors to Boeing, and it is they who will provide the aircraft, equipment and operating crews. Honeywell will operate a suitably equipped Falcon 900 or similar business jet as the lead or 'target' aircraft, as well as a suitably equipped flight test 757 to execute interval management procedures. United will operate a suitably equipped 737 of some description that will also execute the procedures. The 757 and 737 will operate with Experimental certificates obtained by the operators, and flights will be conducted under a combination of VFR and IFR within the normal operating envelopes of all the aircraft. The operations unique to the FIM procedures are not safety critical; they simply require FAA-approved custom arrivals (STAR "Specials') to be flown to published instrument approaches at Moses Lake. Prototype flight deck equipment will provide speed guidance that will result in achievement and/or maintenance of predefined longitudinal spacing goals. The values of the spacing goals will be chosen to provide a suitable buffer distance in excess of separation minima to allow air traffic controllers to be comfortable with the procedures and to provide normal ATC services. This is a follow-on from the NASA ATD-1 Phase 1 testing carried out using the Boeing 787 ecoDemonstrator with a T-38 target, but this time no 'formation' or chase flying is required.

The purpose of the flight test program is fivefold:

Demonstrate the functionality of the newly developed prototype FIM Avionics System.

Measure the FIM performance achieved in the course of flying the set of test procedures by a single pair of airplanes (target and FIM airplane) or a string of three airplanes (target and two FIM airplanes) as operationally appropriate.

Gather data that will allow analysis of the effects of variables and of real-world perturbations across chains.

Assess the overall benefits of the FIM operations.

Assess the acceptability of the procedures and flight deck implementation to operational personnel, principally pilots.

The flight tests defined in Annex A of this document will be conducted by two or three aircraft operating from some combination of Boeing Field (KBFI), SEATAC International (KSEA) and Paine Field (KPAE).

The flights will be accomplished by a combination of the following aircraft:

Honeywell flight test Boeing 757 equipped with ADS-B Out and FIM Avionics System

Honeywell business jet (Falcon or business jet with similar performance and capabilities) equipped with certified ADS-B Out equipment

United Airlines Boeing 737 equipped with ADS-B Out and FIM Avionics System

Testing will be carried out to demonstrate prototype FIM Avionics System performance in executing the following four of the five defined and standardized Flight deck Interval Management Spacing (FIM-S) clearance types described in RTCA documents:

Achieve-by then maintain

Capture then maintain

Maintain current spacing

Final approach spacing

Testing will be carried out in a high level, en route cruise condition, during descents from high and medium levels over a set of custom Standard Terminal Arrival Routes (STARs) to published Instrument Approach Procedures at Moses Lake (KMWH) airport, and in the airport instrument pattern to achieve final approach spacing. The test conditions will include the following:

Early merges between aircraft flying en route transitions to the first common point on a single STAR.

Early and later achievement of spacing in a single stream of three aircraft on a common arrival.

Late merges between aircraft flying STARs and IAPs at a common point on IAPs.

Arrival direction diversity provided by the defined routes to allow assessment of the effects of different wind vectors on the vertical performance of the test aircraft and on the trajectory prediction capabilities of the FIM Avionics Systems.

Route definitions that allow for initiation of FIM procedures at both high altitude (FL350) and medium altitude (FL230), providing procedural diversity and economy of flight hours. Starting points for each aircraft will be defined for each test condition.

A total of 38 different test conditions has been defined and each may be carried out to either end of KMWH runway 14L/32R to allow testing to be carried out almost regardless of airport configuration. All test conditions will be conducted by all three aircraft, except those for Final Approach Spacing which will employ only two aircraft. For the Final Approach Spacing conditions, to maximize data gathering capability, the Boeing 737 and 757 aircraft will be used.

The Boeing team plans to carry out the required flight tests over a period of not more than 18 non-contiguous flight test days for the Honeywell aircraft. The United Airlines aircraft is committed to not more than 82 block hours (chock to chock). Both values include a 10% contingency to allow for unacceptable weather conditions and aircraft or system unserviceability.

3. FIM Avionics System Description / Configuration

Detail of all aspects of the prototype FIM Avionics System's design is or will be provided in the following deliverables:

- FIM Avionics Technical Reference Manual (Deliverable 4.16)
- FIM Avionics Operations Manual (Deliverable 4.17)
- Software Design Description (Deliverable 4.4)
- Test Aircraft Installation Plan (Deliverable 4.23)

The FIM-S system developed and installed for the ATD-1 Avionics Phase 2 flight test consists of a FIM-S application that uses NASA's ASTAR algorithm as a reference base implemented in dual, Class 3 EFBs that are mounted as side displays on the flight decks of Boeing 737-900 and Boeing 757-200 aircraft. In addition, two prototype Configurable Graphics Displays (CGD) that provide speed advisories and other FIM situational awareness information to the pilots are installed in their primary fields of view. A Honeywell DO-317A-compliant TCAS Traffic Processing Unit (TPU) provides the ADS-B In track processing capability, and this feeds the FIM-S application running in the EFBs. The EFBs provide the following capabilities:

- FIM-S application
- Touchscreen data entry and application control functions
- Display of FIM-S application entered and processed data
- Traffic situational awareness through a Traffic Display
- Output of speed guidance and situational information to the CGD.

On FIM system initialization, one of the EFBs will be designated as the Master, and will use received and input data to perform the computations resulting in the provision of speed guidance and FIM situational awareness information. The Master EFB feeds both CGDs. Should this EFB fail, the slave EFB must be restarted to allow it to be assigned the Master role and to provide information to the CGDs. Both Master and Slave EFB can be used simultaneously for data entry and display selections are independent. Crew procedures will be defined to ensure that a single data-entry field is not being addressed simultaneously by both pilots.

Provision has been made for the display, once sufficient data have been made available, of either current Measured Spacing Interval or Predicted Spacing Interval, depending on the type of operation planned, so that a suitable assigned spacing goal can be entered for use in the test condition.

Figure 1 below shows the components of the FIM system (dark blue) and the existing avionics that provide data to the FIM system (light blue). These data are partly FIM aircraft data and partly data from the target received via ADS-B. The TPU is largely production standard; most importantly, the TCAS function that resides in the TPU is fully production standard, and regression testing has been carried out to ensure that TCAS capabilities are unimpaired.

No data from the prototype system flow back to the certified avionics. Data identifying the designated aircraft are fed back from the EFB's Aircraft Interface Device (AID) to the TPU to ensure that the target aircraft data are always available to the Traffic Display regardless of how many ADS-B equipped aircraft are providing data that are being processed by the TPU.

The FIM Avionics Operations Manual (Deliverable 4.17) provides details of use of the system.

The laptop connected to the AID is part of the data-gathering system in both the FIM aircraft.

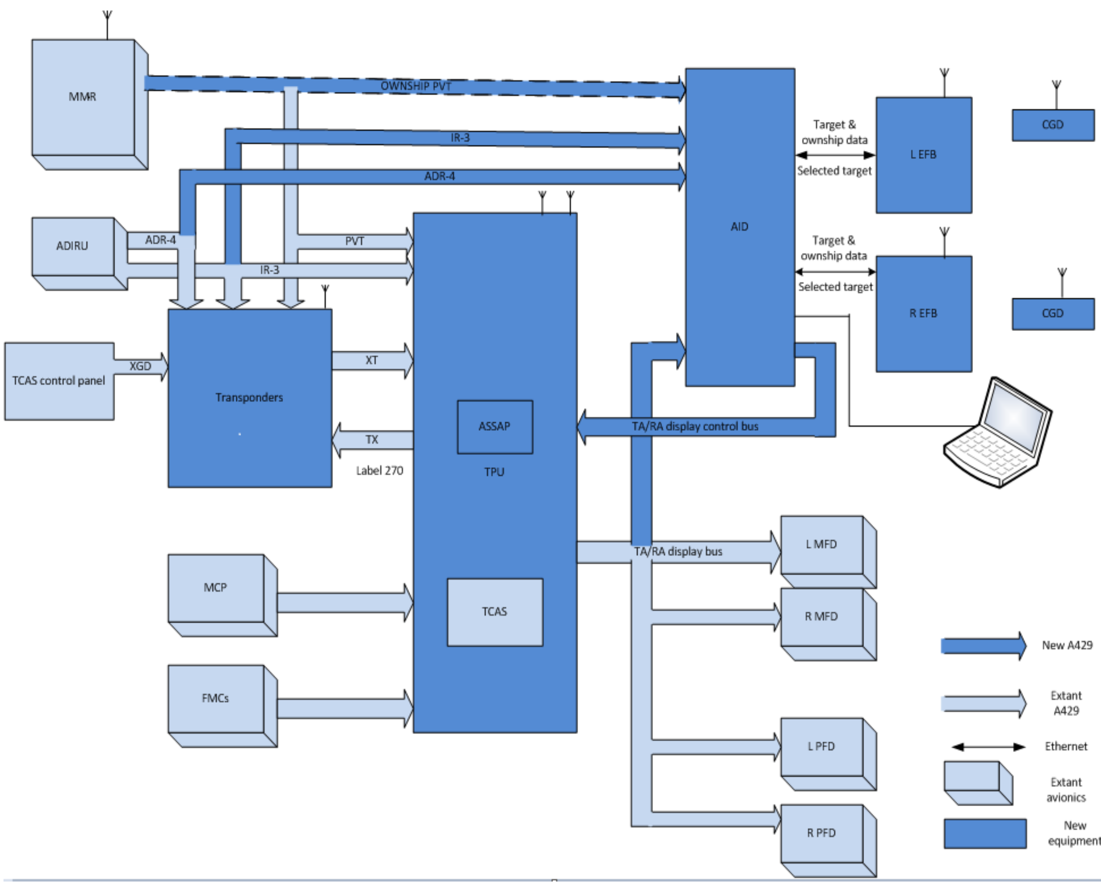


Figure 1 - FIM System Hardware/Software Configuration

4. Pre-Departure

4.1 Pre-Flight Requirements

Pre-flight Briefing. The Flight Test Director will conduct face-to-face briefings at or close to Boeing Field. The briefing items include the items listed in this section, to include the Flight Test Director's making the decision to launch or not.

Test Schedule for the day. The sequence of test conditions will be developed through coordination primarily between NASA and the Flight Test Director, but with input from all stakeholders. The sequence will be defined based on test condition priorities and preceding achievements, available aircraft/crew, weather conditions, flight crew input, and ATC input.

Test Cards. Test cards will be developed for each flight test condition and availability of a set suitable for the day's planned operation will be assured during the pre-flight briefing. Any procedure planned for a flight must be briefed and test cards must be available. For each condition, one test card will be available for each runway end, since arrival and approach procedures differ. In addition, to allow for a change in roles should the target aircraft become unavailable, each FIM aircraft must also carry a set of target aircraft test cards for the day, and a set of test cards for the other FIM aircraft. See Annex D for examples.

There will be no absolute time element in determining when each test procedure will start. Test procedures will include start positions for each aircraft based on the needs of the specific test condition to be executed. These positions will have been defined taking into account minimum spacing requirements, varying procedure leg lengths, the type of procedure to be executed, and some conservatism to compensate for wind vector variability in those procedures in which more than one procedure is flown. A minimum PSI or MSI, depending on the test condition, will be included in each test card. In addition, for all test conditions in which both aircraft in a pair (ie non-FIM and FIM1 or FIM1 and FIM2) are flying the same route, minimum along-track distances will be provided in the test card.

During data entry, when PSI or MSI is displayed on the CDTI, crews must confirm that the value is greater than the minimum stated in the test card for the specific run. If the value is greater, the most important criterion for initiation of the procedure has been satisfied. The other important criteria are as follows:

- Assigned Spacing Goal based on MSI or PSI has been entered.
- The aircraft is in lateral conformance (<3 NM displacement) with the cruise route or arrival procedure, or proceeding direct to the first waypoint in the arrival procedure.
- The commanded speed provided by the FIM system once armed must be acceptable to the crew.

If the displayed value of PSI or MSI is lower than the minimum value stated in the specific test card, the crew will notify the Flight Test Director, who will then consult with the NASA Technical Lead to determine what course of action to take.

The Flight Test Director will monitor aircraft relative positions on a traffic display and offer instructions as needed. Crews should report distance/time variation maneuvers of all kinds to the Flight Test Director on the dedicated test frequency, though the Flight Test Director will also listen out on the ATC frequency in use. Crews should also report 'Ready' to the Flight Test Director once all initiation criteria have been satisfied. The test procedure must not be executed until instructed by the Flight Test Director.

Flight Documentation. Availability of all required flight documentation (arrival and approach procedure charts, flight plan, release, etc.) will be confirmed.

Aircraft/Crew Availability. Availability of aircraft and qualified, current, FIM-trained crewmembers will be confirmed. In addition, availability of essential flight test personnel (Flight Test Directors, Flight Test Engineers, observers, etc.) will be determined. Qualification and approval of all non-aircraft personnel to be aboard, and with access to the SEATAC flight line ramp for United aircraft personnel, will be determined.

Minimum Equipment List.

Beyond flight safety, flight test requirements will determine the minimum set of equipment required to proceed from launch or to continue a flight; requirements for FIM and data-gathering functionality will be defined. All aircraft will be operated in accordance with the requirements of their individual Minimum Equipment Lists (MEL). However, the approved MEL may allow the aircraft to depart with equipment unserviceabilities that would prevent normal operation of the prototype FIM system. Therefore, flight test MELs will be developed that identify all equipment unserviceabilities that would be acceptable under the standard MEL, but would preclude use of the FIM system. In addition, the prototype system and the various data gathering capabilities must be included as essentially serviceable items prior to launch. This minimum equipment list (MEL) unique to conducting FIM operations and RNP AR arrivals is shown in Annex E to assist each Captain to determine whether the aircraft is ready for flight or not.

Contingencies. Contingency procedures (see Section 15.5) for all foreseeable failures relating to flight test and data gathering functionality will be briefed. These procedures will include attempts to reset equipment functions including the prototype FIM system as well as reallocation of aircraft roles in the event that one becomes unserviceable in flight. The Flight Test Director in consultation with NASA will determine a reversionary plan in the event of unforeseen circumstances.

Meteorological Data. Actual and forecast data for the operating area and associated airports will be briefed and a decision made as to the suitability for flight in general and for the flight test. Where necessary, diversion airports will be defined and test schedules amended to be accommodated in available flight test time. Wind data for the initial en route flight test and for at least the initial arrival flight test will be available. Methods of obtaining updates and synchronizing the use of same data sets will be established.

Launch Decision. Based on the preceding, the Flight Test Director will make the launch decision with the concurrence of the briefing participants.

Post-flight Arrangements. The post-flight briefings will be conducted at Boeing, and the time set by the Flight Test Director during the aircraft's return to the Seattle area.

4.3 Initialization and Set-Up Requirements

Pre-flight checks. All normal pre-flight checklists for the specific aircraft will be carried out. In addition, flight crews will be provided with supplementary checklists for the FIM Avionics System to guide the crews through power-up and subsequent functional checks. The checklist will include the need to acquire a stationary or moving ADS-B target where possible to confirm ADS-B In and a measure of FIM-S system functionality. ADS-B Out functionality must also be ensured. The checklist will allow the crew to confirm, as far as is possible while the aircraft is on the ground, that the FIM Avionics System is fully functional.

Although the Falcon aircraft will not be equipped with a FIM Avionics System, availability of its ADS-B Out function is essential to the three-ship tests, and so the function's serviceability must be established before the two FIM aircraft take off. In addition, the Falcon will be equipped with ADS-B In to allow the Flight Test Director to monitor and potentially guide the test activities. This capability may also provide a means of checking ADS-B Out serviceability of the two FIM-equipped aircraft.

Data recording. Ensure that all non-FIM data recording equipment is ready to record prior to taxi. This includes bus intercepts on the 757 and FDR recording on the 737, as well as TPU Compact Flash recording in both aircraft. Ensure all video/audio recording is available and ready if in use. Ensure FIM data recording system is available and ready to receive data from the FIM system.

FIM System Data Entry. Since almost all information for the first test condition will be available prior to departure, crews will be able to complete much of the data entry task before takeoff. Items unique to the particular version of FIM software used in the flight test include:

1) The Target aircraft must be at a constant altitude for a time period of at least three minutes before the pilots arm the IM equipment in order for the Target aircraft's cruise information to be properly estimated. If this is not done, the IM equipment will assume that the Target aircraft is in a descent when building its trajectory, potentially resulting in erroneous speed commands.
2) For time-based Capture and Maintain operations, IM must be activated after the Ownship reaches an along-patch position where the Target aircraft had valid time-history data (i.e., the Target aircraft should have been on path and at a stable speed when it was at the Ownship's location).
3) For the cases where the aircraft start at FL230, IM should not be activated if there are downstream waypoints with altitude constraints that would violate the FL230 cruise altitude (i.e., an AT constraint with an altitude greater than FL230 or a window constraint where the lower altitude is above FL230). If this is not done, the waypoints with the violating altitude constraints will be deleted from the Ownship and/or Target aircraft's Trajectory.

5. Target & FIM Aircraft Departure Requirements

5.1 Departures from the Seattle Area

The test aircraft will depart from Boeing Field and/or Paine Field and/or SEATAC airport at the beginning of each test day. Intervals between aircraft departures will be set each test day to minimize airborne delay in initiation of the first test point. If this first test is to be an en route cruise test, departures will result in the aircraft being approximately 2 minutes apart once they are in a stream on a common route.

The departure route from the Puget Sound area will initially be as directed by ATC; the planned route to the en route cruise test condition location and to the arrival procedure initiation locations is intended to minimize conflicts with Seattle inbound traffic by routing via waypoints ZADON, ZELAK, ZIRAN, AND BARYN; see the flight plan table chart extract and below. The route also uses waypoints placed to assure suitable separation from the Okanogan and Roosevelt Military Operating Areas to the north and flight crews should be aware of the need to remain clear of this airspace. The latter part of the route has been optimized to provide sufficient flight time to allow full evaluation of the en route spacing clearance type under test, and also to economize on recovery to the beginning of the first arrival test condition.

Once crew workload has diminished to an acceptable degree, data entry for the first test condition will be accomplished/completed.

Waypoint	Altitude	Distance to next WPT (NM)	Cumulative distance from KBFI (NM)
KBFI	Climb	23	
ZADON	Climb	8	23
ZELAK	Climb	46	31
ZIRAN	FL350	13	77
BARYN	FL350	51	90
SINGG	FL350	41	141
JELVO	FL350	17	182
MAHTA	FL350	15	199
RIINO	FL350		214

Figure 2 - Departure and En Route Test Condition Route

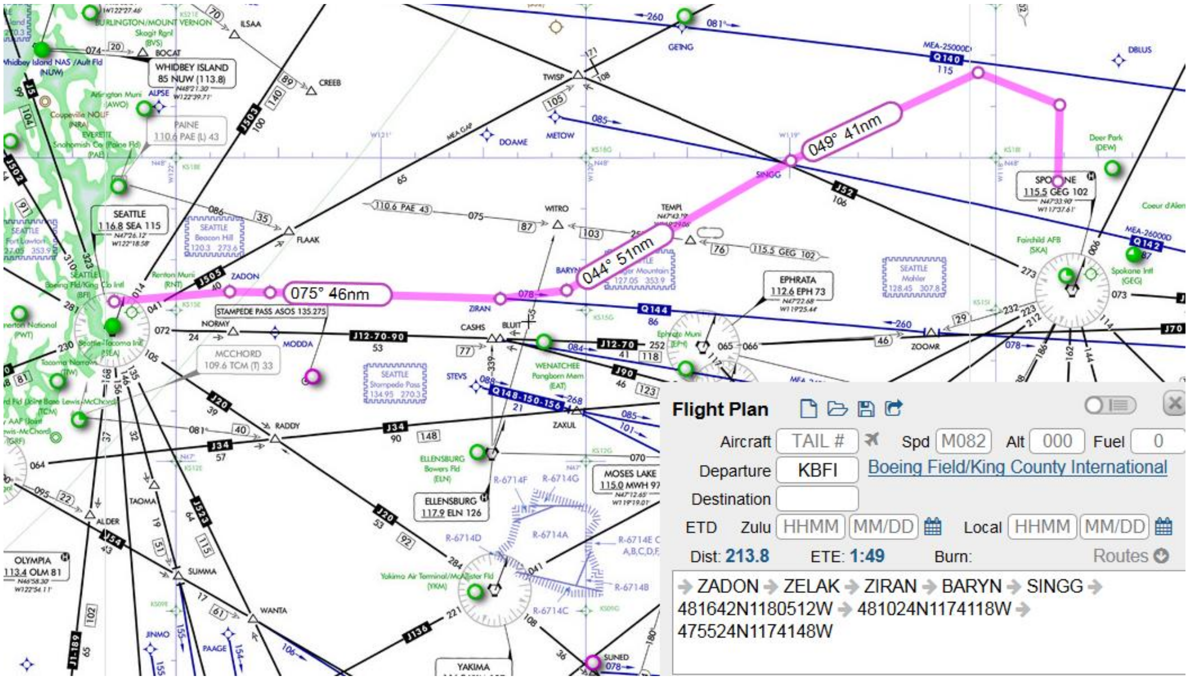


Figure 3 - Departure and En Route Test Condition Route Chart

5.2 Departures from Moses Lake

The departure routes from Moses Lake airport will be dictated by the circumstances of the departure and by the intent of the departing aircraft. The circumstances are as follows:

- A test condition has been completed and all/both aircraft execute a missed approach.
- Expect Missed Approach Instructions to include “Fly Runway Heading Maintain 10 thousand”
- The aircraft has/have been on the ground to refuel or for some contingency, and are departing the airport in the normal way.

The various intentions of the aircraft are as follows and each may be coupled to either of the circumstances above:

- Climb to FL350 to set up for high altitude initiation of a test condition at the waypoint or the point prior to or after a waypoint specified in the daily test plan

- Climb to FL230 to set up for medium altitude initiation of a test condition at the waypoint or the point prior to or after a waypoint specified in the daily test plan
- Climb to approximately 6,000 ft and enter instrument pattern to conduct a Final Approach Spacing test condition
- Climb to cleared altitude for recovery to Boeing Field and/or Paine Field and/or SEATAC airport.

In all combinations of circumstance and intent, flight crews should expect initial heading vectors and sequential climb clearances followed by clearance direct to the appropriate waypoint or mid-procedure location. Moses Lake TRACON will hand the aircraft off to Seattle Center. FL230 has been chosen as a medium altitude initiation level to minimize frequency changes and thus coordination with Seattle Center.

6. ATC Coordination

6.1 ATC Facilities

Managers and controllers at Seattle Center and Moses Lake ATC facilities have been involved in the team's custom route planning process and have agreed that the Special STARs, their connections to the published, public instrument approach procedures, and the planned general use of the airspace are acceptable. They will tell us, during more detailed coordination, the minimum distance they wish to see between aircraft engaged in the flight test if intervention is to be avoided. Experimental Test Cards were developed and validated during simulation at Langley. The test cards were developed to improve the consistency of the experiments while allowing the accuracy of the algorithm is stressed. While operating in the National Airspace System (NAS) standard separation will be provided by Air Traffic Facilitates. Early flights will use spacing that results in 7 NM minimum distance in Seattle Center's airspace and 5 NM on final approach. This value may be reduced as controllers (and pilots) gain confidence in the FIM functions. While understanding that traffic conflicts must be avoided or resolved, the importance of allowing the procedures to progress undisturbed has been stressed.

6.2 Custom Arrival Procedure Approval

Because it is necessary to guarantee that the custom STARs can be utilized under Instrument Flight Rules, it has become necessary to obtain formal approval of the STARs as 'Specials'.

Jeppesen interaction with FAA Flight Standards AFS460 indicated a need for further approval. Part of this further process is a letter of acceptance of the procedures and their intended short-term use from the ATC facilities.

Interaction with NW Mountain All Weather Operations group who in turn will interact with the Regional Approach Procedure Team and with the FAA Principal Operations Inspector who deals with Boeing flight operations. The latter is necessary owing to Boeing's accepting the role of Proponent for the published Special STARs. Following approval by the NW Regional organization, the data defining the procedures were sent for Environmental Impact Assessment. Once that hurdle is cleared the application package will be submitted to FAA Flight Standards for approval. Letters of No Technical Objection to the procedures from Seattle Center and Moses Lake TRACON, essential parts of the submission package, have been received from the facilities.

Jeppesen has developed the custom arrival procedures and initiated publication as Special STARs. Each of the two STARs connects to RNAV (RNP) Z instrument approach procedures for KMWH runways 32R and 14L through points that are common to STAR and IAP. The instrument approach procedures are published public procedures with no changes.

The NALTE and SUBDY STARs each have two en route transitions. There is major commonality between the STARs connecting to the two runway ends. Vertical and speed constraints have been included in the STARs to make them similar to STARs used in major terminal areas, and to provide the information that the FIM Avionics System needs for trajectory generation.

A full set of arrival and approach charts and summary tables appears at Annex B.

7. Flight Crew Resources

7.1 Honeywell

Boeing 757. Four pilots qualified to fly the Boeing 757, and trained in the use of FIM-S and in the flight test processes will be available. All pilots will be trained and certified to fly AR instrument approaches.

Falcon target aircraft. One or two pilots qualified to fly the Falcon 900, and familiar through training with the FIM-S operation and in the flight test processes will be available. If only one pilot is trained, a second pilot qualified to fly the Falcon and briefed on FIM-S and the flight test requirements will also be available. All pilots will be trained and certified to fly AR instrument approaches. If the Falcon is replaced by an equivalent business jet in the course of the flight test program, operating crews will be similarly qualified and trained.

7.2 United Airlines

Boeing 737. Four pilots qualified to fly the Boeing 737, and trained in the use of FIM-S and in the flight test processes will be available. All pilots will be trained and certified to fly AR instrument approaches. The intent is that each operating crew will consist of a 737-qualified experimental test pilot as captain and a line first officer.

7.3 Flight Test Director

The primary flight test director will be provided by Boeing Research & Technology. The primary flight test director will normally fly on the B757.

Boeing Research & Technology will also provide a back-up Flight Test Director to cater for non-availability of the primary and, because some testing may be accomplished should one of the aircraft become unserviceable in the course of a test flight, the back-up will fly in a different aircraft from the primary.

United will have an experimental test pilot flying in the 737 and acting as a flight test coordinator.

8. Aircraft Descriptions

8.1 FIM-Equipped Aircraft

One of the FIM-equipped aircraft will be a Honeywell Boeing 757 test aircraft, equipped with ADS-B In technology and the FIM Avionics System. As a test airplane, it is suitably equipped to meet data-gathering requirements.

The second FIM-equipped aircraft will be a United Airlines Boeing 737-900ER, also equipped with ADS-B In technology and the FIM Avionics System. As an in-service aircraft, its data gathering capabilities will be limited to the FIM Avionics System itself, and to existing systems like the Flight Data Recorder.

Both aircraft will operate with an Experimental certificate acquired by its operator, and will meet the following requirements stated in SOW Task 3.6.1.1:

- Commercial transport category airplane (i.e., a 757 and a 737).
- Equipped with an ARINC 735B (DO-185B–compliant) TPU.
- Equipped with transponders providing ADS-B In and Out functionality compliant with DO-260B requirements.
- Equipped with GNSS.
- Equipped with an FMS and other avionics capable of sourcing all data required for the FIM application.
- LNAV/VNAV capable or equivalent.
- Capable of speed intervention through the MCP or equivalent.
- ‘Authorization Required’ instrument approach procedure capable.

8.2 Target Aircraft

The designated target airplane will have the following characteristics meeting contract requirements:

- Aircraft with comparable performance to a commercial transport category airplane. A Dassault Falcon 900 or an equivalent business jet will be provided by Honeywell. It will have limited data-gathering capability.
- Equipped with transponders providing ADS-B Out functionality compliant with DO-260B requirements.
- Equipped with GNSS.
- LNAV/VNAV capable including RF legs.
- ‘Authorization Required’ instrument approach procedure capable.

9. Training Materials and Requirements

9.1 Honeywell

Honeywell and Boeing will provide crews with an overview of FIM-S, and will walk through the prototype system's HMI functionality. Basically, they will train on the avionics. United crews may join this training either face-to-face or virtually.

9.2 United Airlines

United will provide the theory of FIM partly with materials provided by Boeing. The pilots are already involved in approval processes, so they are technically knowledgeable.

9.3 Computer-Based Training

NASA Langley is developing web-based computer-based training that will be provided prior to the simulator training sessions to ensure that all involved are familiar with the FIM system usage and the operational tasks. This training will cover IM theory, pilot inputs, clearance types, settings, test area airspace constraints (eg MOAs) etc.

9.4 Common Simulator Training

NASA Langley will provide simulator training to a cadre of the flight test and line pilots who will be involved in the flight test. Training will cover both test condition execution and transition from the end of one condition to the beginning of the next. Each training week will start with classroom familiarization that will supplement the computer-based training. Simulator sessions will start simple – system familiarization and individual test condition execution. Then the two cabs will be connected and some scenarios will include a pseudo-target to create a 3-ship scenario. All en route test conditions, all arrival/approach test conditions and all Final Approach Spacing will be experienced. Culmination will be a full test day without simulator freeze.

9.5 FIM Avionics Operations Manual

Honeywell is leading development of the FIM Avionics Operations Manual (Deliverable 4.17). This document will provide descriptions and illustrations of the operational use of the FIM equipment, and this will provide a basis for pilot knowledge and training development.

10. Flight Details for Target and FIM Aircraft

10.1 Flight Test Requirements

The driver for the definition of test conditions is SOW Task 3.6.5, as follows. Text in italics is explanatory addition.

The flight test plan shall include, but is not be limited to scenarios that address the following route and flight parameters:

In-trail from same en route transition and arrival procedure

Merges from different en-route transitions but on the same arrival procedure

Merges from different arrival procedures (e.g., different STARS)

Test conditions in which two of the aircraft merge from different en route transitions to the same arrival procedure and then merge with the third aircraft on the other arrival procedure have also been included.

Closed routes (arrival and approach procedures connected)

Custom-developed arrival routes have been designed to link to approach transitions to RNAV (RNP) Z instrument approach procedures to runways 32R and 14L at Moses Lake. Each approach includes RF legs.

String geometry

Aircraft 1/2/3 in-trail

Aircraft 1/3 in-trail w/aircraft 2 on merge

Aircraft 1/2 in trail w/aircraft 3 on merge

Test conditions include aircraft 1 and 2 merging from different en route transitions and then 3 merging into the stream when the two arrivals reach a common point. The conditions also include 1 and 3 merging from different en route transitions and then 2 merging into the stream when the two arrivals reach a common point. NASA's preference is that the 757 will generally be the second aircraft in the stream to take advantage of potentially superior data-gathering capabilities.

Initial Spacing Error – defined by the test matrix (Figure 4) for each scenario

Target aircraft delay - (high, medium, low) determined by NASA.

Note: In all of these cases the delay shall not require vectoring.

Further consideration by NASA has amended these requirements for initial spacing error values, eliminated one requirement for target aircraft delay, and set the remaining two at percentage values. The values will be transformed into speed requirements for the target aircraft test cards.

Each test shall consist of 1 string of 1 ADS-B Out Target aircraft followed by two ADS-B in/Out FIM aircraft

Test conditions for the Final Approach Spacing clearance type are planned to include only two aircraft. Any aircraft of the three can act as target while only the 757 or the 737 can execute the procedure. In order to take full advantage of the data-gathering capabilities of the two FIM-equipped aircraft, wherever possible, the Final Approach Spacing test conditions will be executed by the 737 (target) and 757.

For each flight, the aircraft shall continue to the Planned Termination Point but preferably descend at the appropriate speed to the Decision Altitude

NASA has agreed that the added time and risk of landing from each approach is not justified. Test conditions will continue to the Termination Point at least, and approaches can be continued to a missed approach to overfly the runway threshold to measure spacing at that point following transition, by each FIM aircraft, from FIM speed guidance to Final Approach Speed. In effect therefore, given the importance of understanding the effects of spacing compression once FIM guidance is no longer followed, test conditions will continue to decision altitude unless operational needs require the run be terminated earlier.

10.2 Sequence Details

The Falcon jet will always lead a stream of three aircraft for en route and arrival procedures. 757 and 737 will be allocated to second and third in stream at longitudinal spacing distances based on wake separation needs. If aircraft characteristics or non-availability of the target aircraft dictate a need to place the 737 ahead of the 757, test cards will be available prior to flight with amended spacing requirements to accommodate the configuration of the traffic stream.

In the only two-ship test conditions considered (Final Approach Spacing), any aircraft can act as lead and either FIM aircraft will execute the FIM procedure. The same will apply if circumstances result in unavailability of one aircraft and it is determined that a two-ship flight test other than Final Approach spacing will be flown.

10.3 Departure, Climb and Landing Details

The departure sequence and inter-departure spacing will be as consistent as possible with the needs of the upcoming test condition. The 737 will, at the beginning of each test flight, be departing from SEATAC airport while the other two aircraft will depart from Boeing Field. The flight test director will coordinate with SEATAC TRACON to facilitate the passage of departure information for the 737 so that departures from Boeing Field can be achieved in a way that minimizes in-flight delay.

All participating aircraft will climb to make good the start altitude for the upcoming test condition. Where necessary any aircraft will hold at its designated start point for the upcoming test condition as needed to make good the start altitude. Such holding will also allow adjustment of inter-aircraft spacing if required.

If necessary and by arrangement with service providers, any aircraft may land at Moses Lake to refuel. Final landings of each test day will be at Boeing Field and SEATAC.

10.4 Flight Time

The proposal included only 33 flight test conditions which met and exceeded the requirements laid out in the RFP, and it was on this basis that the following estimates were made.

Based on the proposed number of different flight test conditions and on the desire to conduct each test condition twice, it has been estimated that 82 block hours (off-chocks to on-chocks), including a 10% contingency, will be required. This estimate has driven the contractual arrangement with United Airlines.

It is also estimated, based on practical sortie length (fuel consumption, crew fatigue, crew duty time including pre-flight briefings) that the 66 flight test conditions could be executed in 18 flying days, including a 10% contingency. This estimate has driven the contractual arrangement with Honeywell.

NASA has redefined the composition of the set of test conditions resulting in 38 test conditions. Because many of the arrival conditions will be initiated at medium altitude, it is likely that more test conditions can be executed within the flight hour and day constraints. NASA has prioritized the test conditions and determined numbers of condition iterations for each priority level to ensure that essential requirements will be satisfied first and, potentially, some low priority test conditions abandoned if it becomes necessary.

10.5 Number of Test Condition Iterations

The number of iterations of each of the 38 test conditions has been determined and prioritized. Within the flight days and flight time limitations, NASA may stipulate more or fewer iterations based on observed behavior of the FIM Avionics System.

10.6 Meteorological Criteria for Flight Test

The meteorological criteria that will be used to determine if flight test operations on any given day should be initiated or continued will be consistent with operators' criteria and procedures. In addition, the flight test director, in negotiation with the NASA flight test point-of-contact may decide that the effects of certain meteorological conditions make those conditions unsuitable for data collection.

The tests can be carried out in IFR, but the aircraft and FIM procedure performance effects of use of anti-icing and limiting target or FIM aircraft speeds to turbulence penetration speeds must be considered.

Some meteorological conditions may call for significant diversion fuel to be reserved, and this may limit the length of associated test days. If it is considered likely that it will not be possible to land at the Puget Sound airports (i.e. aircraft are likely to divert to other airports), the resulting disruption to the schedule may affect the desirability of initiating a day's operations.

Operators will obtain initial and updated sets of wind and temperature data from their own flight operations departments to cover all requirements including those of the cruise test conditions and descents in the Moses Lake area.

10.7 Problem Reporting

All events or circumstances that flight crews, flight test directors and observers see as problems in the course of flight testing must be recorded and reported. The report should include aircraft, time, position, altitude, calibrated airspeed, test condition, and nature of the event or circumstance. The dual objectives are to facilitate safety incident reporting and to register occurrences that affect the performance of the FIM function.

If any problems that threaten aircraft or operation safety are encountered, flight crews should follow associated processes and procedures while abandoning the FIM procedure and informing ATC.

Events or circumstances that may influence the performance of the FIM system include, but are not limited to the following:

ATC intervention resulting in deviation from procedure lateral path or preventing conformance to speed guidance and thus resulting in suspension of FIM operations.

ATC intervention preventing continuous descent but allowing continuation of FIM procedures

Use of anti-icing that affects engine idle setting

Non-conformance to FIM speed guidance due to operational necessity (e.g. flying at turbulence penetration speed, FIM speed change requiring inappropriate configuration change, FIM speed change that would make achieving an altitude constraint unlikely, etc.)

Equipment unserviceability precluding or otherwise affecting the FIM operation or the recording of FIM data necessary to measure its performance.

11. Scenario Description

Airport. Cruise condition tests will be conducted following departure from Boeing Field and SeaTac airport, and will be terminated prior to commencement of an arrival procedure at Moses Lake. All arrival and final approach spacing test conditions included in the flight test condition matrix will be carried out at Moses Lake.

Custom arrival procedures have been designed to connect to RNAV (RNP) Z instrument approach procedures to runways 32R and 14L at KMWH without any discontinuities. These arrivals will be published as 'Special' procedures and, as such, will be flown under Instrument Flight Rules.

Phraseology script. ATC will provide clearances to individual test aircraft to clear them to fly the arrival and instrument approach procedures. The speed constraints included in the arrival procedures will be respected by the target aircraft, though some test conditions call for speeds up to 10% less than the speed constraints to be flown. Such intent will be made clear to the ATC facilities. The FIM aircraft speeds will not be limited to the arrival procedure speed constraints; the FIM system will provide speed guidance values within ±15% of the speed constraints. A FIM clearance will provide relief from adherence to speed constraints when FIM becomes an operational procedure. However, all speed restrictions (250 kt below 10,000 ft; 210 kt maximum for RF legs in the instrument approach procedures) will be respected by all aircraft.

All information that will be provided using the phraseology in industry standards for FIM clearances will be included in each individual test card.

Additional test elements. Once sufficient data have been gathered to satisfy data analysis requirements for all required test conditions, if flight test time remains, NASA may request that an additional iteration of a non-critical test condition be executed with the inclusion of a suspend and resume process. This process will be described in a supplementary test card, and the description will include constraints associated with the initiation of the sub-procedure. However, no specific flight test condition will be defined to accommodate this activity.

During recovery from the flight test airspace to the Seattle area, flight crews may choose to execute additional FIM procedures against targets of opportunity, including one of the flight test aircraft. In order to minimize disruption and the risk of uncertainty's being induced in other crews unfamiliar with the test, it may be necessary to base target IFPI on information gathered over RT of clearances provided to these aircraft rather than requesting the information from ATC. Selected spacing values must be consistent with assurance of provision of a spacing buffer over safe separation minima. Flight crews must request ATC clearance to change speed commensurate with the FIM speed guidance, and the procedures must be terminated prior to entry into Seattle TRACON's airspace.

12. Data Collection

Annex C contains the full Data Collection and Analysis Plan.

Data will be gathered to satisfy the requirements defined in the System Requirements Definition Document and contract SOW. The majority of data gathering will be accomplished automatically, under the control of flight test personnel, in on-board systems. There are four categories of data being collected for every condition:

- FIM data: Data collected by the FIM system (EFB), mostly consisting of data necessary to evaluate FIM performance. It will also collect pilot entry data and system state evolution
- TPU data: Data recorded in the TPU directly from ownship data and ADS/B reports for aircraft in range. This data will only be used to troubleshoot FIM system operation in cases where it has been determined necessary. All other TPU data produced for the FIM system is recorded upon entry into the FIM system at the local end (EFB)
- Other aircraft data: This category includes data identified as required for evaluation of other FIM performance and/or aircraft performance data. This includes but is not limited to FMS computed path vertical and lateral deviation, MCP speed, and fuel flow, from which Flight Technical Error, Fuel Burn, and latency metrics will be extracted.
- Video/Audio: This category includes the raw video (including audio) captured by the video/audio recording system on the Honeywell 757 aircraft only.

Only the Honeywell Falcon 900 (F900) will have some amount of data recording for aircraft data.

Manual recording will include mostly administrative data entered on flight test cards, including those for the non-FIM aircraft. They will include essential data entry fields for manual entry either in electronic form in a tablet computer, or more conventionally. The flight test cards themselves will provide the data to which the FIM system and flight crews have responded. Deviations from the defined test condition in the form of crew-initiated cancellation or suspension, ATC intervention of any kind, and system unserviceability will be recorded and the information managed as part of the flight test data. Target final approach speed is a parameter that will be included.

Data gathering requirements derive from the desire to provide the following post-analysis products:

- Spacing performance
  - Spacing performance statistics at achieve-by point or planned termination point

  - Distribution of results
  - Measures of central tendency
  - Regression to wind conditions
- Spacing prediction evolution
  - (Time histories of MSI/PSI
  - Time histories of actual spacing from aircraft state for same route only)
- Trajectory Generator performance
  - Altitude/speed vs distance-to-go plots comparing trajectory generator output to flight management system guidance at specified time points or events
  - Lateral plots (latitude/longitude) comparing trajectory generator output to flight management system guidance
- Flight Technical Error performance
  - Altitude/speed vs distance-to-go plots comparing actual state to trajectory generator and/or flight management system guidance
  - Lateral plots (latitude/longitude) comparing actual state to TG output to trajectory generator and/or flight management system guidance
  - Superimpose monitoring events if any
- Fuel burn performance
  - Fuel burned from IM start to achieve-by point or planned termination point
    - » Distribution of results
    - » Measures of central tendency
    - » Regression to wind conditions

Note: Baseline for fuel burn performance will be those test conditions in which the target aircraft is not subject to delay.

A full description of data gathering and analysis is in Annex C.

13. Flight Test Director

The primary purpose of tools to be provided for the Flight Test Director (e.g. laptop-based workstation) is to ensure that the procedure to be executed is safe, and secondarily to maximize the probability that the set-up will achieve the desired test matrix conditions for that scenario. The primary tool to provide the awareness to the FTD is PLANET (http://www.atmosphere.aero/products-services/planet/), a suite of software tools that will display the special STARs, special use airspace to the north of the area, airfields, and the current forecast wind. The PLANET software also provides a chat dialogue functionality for any registered user. This display will allow visualization of the progress of the aircraft to their defined test condition start points and throughout the execution of each condition.

The Flight Test Director must also direct recovery from unplanned events like perturbations caused by ATC intervention, and support real-time ‘tweaks’ for test efficiency

Boeing obtained the use of a discrete VHF voice communications frequency that will allow aircraft-to-aircraft communication for test coordination. Additional communications is also available via the internet using the WiFi systems onboard the three flight test aircraft.

The Flight Test Director and backup will be provided with complete sets of arrival charts, instrument approach plates, test cards for the planned flight test conditions and for fallback options resulting from unavailability of one of the aircraft, descriptions of linking activities that will provide expectations of aircraft flight paths from the end of one flight test procedure to the beginning of the next, and

The Flight Test Director is responsible for ensuring that a research minimum equipment list (MEL) is made available for each aircraft to be used as part of a Go / No-Go (or Continue/ Discontinue) decision support matrix. Aircraft operators will develop the research MELs through consultation with the development engineers and installers. The Flight Test Director will develop backup plans to modify the test matrix in order to accommodate potential unavailability of one of the aircraft.

14. Observer Requirements and Constraints

14.1 Guidance to Boeing Personnel and Direct Contractors

For an in-service flight test on aircraft which are not owned and operated by Boeing, only the Boeing employees and contractors are required to have Flight Clearances. The owners of the aircraft take responsibility for the employees of the owner. To initiate the Flight Clearance process, go to http://fteapp.web.boeing.com/flightclearance/CreateRequest.aspx. 'Flight Clearance for Personnel—Commercial Programs' Document Number D6-83006-4 refers.

14.2 Observer Processes, Requirements and Constraints

Honeywell 757 and Falcon/business jet; Honeywell will need to brief observers on safety and other crewmember information prior to their participating in a flight. Everyone must attend the pre-flight briefing. The entire process can be completed just prior to the flights.

United Airlines 737; a signed release of liability will be required by United Airlines. Badging for those wishing to fly in the 737 will be provided by United. Separate lists of personnel planning to fly frequently and those planning to fly or visit only once must be provided. Separate badging will be required for access to the operational ramp area through observer interaction with King County.

NASA employees, contractors, and guests will require boarding authorization from NASA. The NASA Langley Research Center forms and process will be used to accomplish this.'

Seattle Center; processes for gaining access to the center's operational floor have been defined and disseminated to would-be observers.

Moses Lake TRACON; processes for gaining access to the control room have been defined and disseminated to would-be observers.

15. Procedures Specification

15.1 Setting Up a Flight Test Condition

The first test condition of most or all flight test sorties will be conducted in the en route domain. The planned route is described and depicted in the Departure Requirements section above and the set-up requirements will be defined in the individual test card for the condition. Departure times from SeaTac and Boeing Field will be adjusted, as much as possible, to ensure that aircraft arrive on the test portion of the route in the right order with suitable longitudinal spacing. The Flight Test Director will monitor progress using the PLANET traffic display and requesting estimated times of arrival for the aircraft at a point on the route. The value of longitudinal spacing at initiation is not critical to the flight test. However, to assure separation, the goal will be to achieve no less than 7 NM between aircraft at the same altitude throughout the test condition. Since all en route test conditions requiring adjustment of spacing begin with a positive spacing error (spacing must be increased), achieving as little as 7 NM spacing prior to execution is acceptable. If departure delays result in inadequate or excessive spacing, speed adjustment, doglegs or holding may be used to achieve more acceptable spacing. Starting conditions will be FL350 and 0.78M.

Starting conditions for each of the arrival test conditions will be defined in individual test cards for the condition. Distances to the runway threshold will be used to position each aircraft on the appropriate arrival procedure. The distances will provide a reasonable longitudinal spacing interval in either time of distance. Allowance will be made for headwind component effects and for planned initial spacing errors. Start points will be defined as distances along the procedure paths before a named waypoint. Test cards will recognize when an aircraft might arrive at a start point and provide expectation of the need to adjust arrival timing through speed modulation, doglegs or holding. For high altitude start points, starting conditions will be FL350 and 0.78M; for medium level start points, starting conditions will be FL230 and 280 KCAS. Both lateral and vertical separation will be used to deconflict aircraft when delaying at their respective location.

The Flight Test Director will monitor each aircraft's progress toward the initiation point of each test condition. Environmental conditions and/or ATC influence may result in the need to intercede to achieve simultaneously acceptable flight state for each of the aircraft.

Only three of the four FIM operations will be executed in the en route and arrival domains. All will be executed by two FIM aircraft and a target aircraft:

- Achieve-by then Maintain
- Capture then Maintain
- Maintain Current Spacing

The final FIM operation, Final Approach Spacing, will be executed in the instrument pattern. Only two aircraft will execute these procedures; the intent is that both FIM-equipped aircraft participate to provide greater operational flexibility, improved target data acquisition capability, and possibly additional crew exposure to the procedure.

For the en route operations, all aircraft will follow filed flight plan routes except as instructed or cleared by ATC. ATC should be made aware that the aircraft, including the target in many of the test conditions, will change speed without specific clearance once the test commences.

For arrival operations, each aircraft will be cleared for the arrival/approach combination, including descent, by ATC, but will receive no instructions regarding the specifics of the FIM operation itself.

For Final Approach Spacing operations, Moses Lake Tower/TRACON will direct the aircraft onto a downwind leg approximately 5 NM laterally displaced from the final approach path. Test conditions will dictate whether one aircraft must be on an intercepting path and, in those cases whether it be target or FIM aircraft.

15.2 FIM Data Entry

The detail of operation of the FIM system is provided in the FIM Avionics Operations Manual (Deliverable 4.17) and it is assumed that flight test crews will have become familiar with the system's use through the operators' familiarization processes and during computer-based and simulator training provided by NASA Langley.

Four different types of FIM operation are planned, and the following provides data input requirements in the order dictated by FIM system operation. All information for each test condition will be provided in the correct order on each test card. Since there is no dependency on ATC for provision of the information, flight test crews can enter the data for the next flight test condition at a time most convenient to the underlying aircraft operation. Since the Flight Test Director will be dependent on entered target and FIM aircraft route data in monitoring and refining the set-up process, crews should enter data for the upcoming test condition at the earliest opportunity.

For all operations, planned route (string of named waypoints for en route test condition; arrival transition and approach procedures from the navigation database for arrival/approach conditions; instrument approach procedures only for the Final Approach Spacing conditions) should first be entered into the FMS to facilitate test condition set-up. Additional place/ bearing/distance waypoints may be provided in the test cards prior to the first point in the arrival procedures for arrival test conditions. Test or transit cards will provide along-track waypoints at distances before or after named waypoints to allow refinement of test condition set-ups.

For all cruise and arrival flight test conditions. From the Home page, OWNSHIP & WINDS, enter the following:

Destination airport (KMWH)

Planned runway (not needed for en route test conditions) from ATIS. If ATIS does not offer 32R or 14L, negotiate with ATC to use one or the other.

Flight Path (waypoint string for en route test conditions; list of procedures based on airport and runway for arrivals; runway or instrument approach procedure for Final Approach Spacing) from the test card

Select VIEW AS WAYPOINTS and confirm that FMS and FIM system agree

If aircraft is not already on the selected route, select DIRECT TO and enter first downstream waypoint available

Wind data (CRUISE FORECAST WINDS for each en route waypoint; DESCENT FCST WINDS for arrivals) Forecast wind data for cruise and descent, will have been provided at the pre-flight briefing along with required altitudes for the descents. The Flight Test Director will copy surface wind from ATIS and instruct both FIM-equipped aircraft to enter the same value. All aircraft will use an identical set. Identical data should also be entered into the FMS.

Achieve-by then Maintain. From the Home Page, IM CLEARANCE, enter the following:

Select CROSS

SPACING GOAL 111 sec or 11 NM depending on spacing type in test condition (this will not be the value used; it is entered to provide the system with enough data to allow either Measured or Predicted Spacing Interval to be displayed so that the SPACING GOAL can be selected based on safety requirements and on initial spacing error requirements.)

TARGET ID from the test card

TARGET ROUTE (waypoint string for en route test conditions; list of procedures based on airport and runway for arrivals; runway or instrument approach procedure for Final Approach Spacing) from the test card

ACHIEVE BY (waypoint name included in the waypoint list for both target and FIM aircraft) from the test card. Always use ACHIEVE BY WPT option.

TERMINATE AT (waypoint name included in the waypoint list for both target and FIM aircraft) from the test card. Always use TERMINATE AT WPT option.

ARM and confirm that ownship and target waypoint strings are consistent with entered routes (ie the same/different waypoint strings; ABP and PTP as selected

Note PSI displayed next to spacing goal indication. CANCEL IM and enter SPACING GOAL value as PSI displayed plus or minus initial spacing error from the test card

ARM

EXECUTE when initiation criteria met

Capture then Maintain. From the Home Page, IM CLEARANCE, enter the following:

Select CAPTURE

SPACING GOAL 111 sec or 11 NM depending on spacing type in test condition (this will not be the value used; it is entered to provide the system with enough data to allow either Measured or Predicted Spacing Interval to be displayed so that the SPACING GOAL can be selected based on safety requirements and on initial spacing error requirements.)

TARGET ID from the test card

TARGET ROUTE confirm displayed information same as ownship

TERMINATE AT (waypoint name included in the waypoint list for both target and FIM aircraft) from the test card. Always use TERMINATE AT WPT option.

ARM and confirm that ownship and target waypoint strings are the same; PTP as selected

Note MSI displayed next to spacing goal indication. CANCEL IM and enter SPACING GOAL value as MSI displayed plus or minus initial spacing error from the test card

ARM

EXECUTE when initiation criteria met

Maintain Current Spacing. From the Home Page, IM CLEARANCE, enter the following:

Select MAINTAIN

CURRENT SPACING select appropriate units from test card

TARGET ID from the test card

TARGET ROUTE confirm displayed information same as ownship

TERMINATE AT (waypoint name included in the waypoint list for both target and FIM aircraft) from the test card. Always use TERMINATE AT WPT option.

ARM and confirm that ownship and target waypoint strings are the same; PTP as selected. Confirm MSI is greater than minimum from test card.

EXECUTE when initiation criteria met

Final Approach Spacing. From the Home Page, IM CLEARANCE, enter the following:

Select SPACING

SPACING GOAL 111 sec or 11 NM depending on spacing type in test condition (this will not be the value used; it is entered to provide the system with enough data to allow either Measured or Predicted Spacing Interval to be displayed so that the SPACING GOAL can be selected based on safety requirements and on initial spacing error requirements.)

TARGET ID from the test card

TARGET ROUTE confirm displayed information same as executing FIM aircraft.

ARM THE FIM SYSTEM ONLY AFTER ATC HAS TURNED ANY APPROACH-INTERCEPTING AIRCRAFT (TARGET OR OWNSHIP) ONTO A VECTOR THAT IS 30° OR LESS DISPLACED FROM THE APPROACH CENTERLINE. The ARM function will not be available until the intercepting aircraft is within 45° of the approach centerline.

The FIM aircraft crew will ascertain when they are on the intercept vector (within the 30° requirements) when they are flying the intercept to final.

When the target is flying the intercept and the FIM aircraft is already on final, it may be necessary for the FIM aircraft crew to make multiple attempts to ARM. The target aircraft crew will be instructed to announce when the target is on the intercept over the flight test frequency.

ARM and confirm that FIM aircraft and target waypoint strings are the same; PTP is DEFAULT/6.25.

Note MSI displayed next to spacing goal indication. CANCEL IM and enter SPACING GOAL value as MSI displayed plus or minus initial spacing error from the test card.

EXECUTE when initiation criteria met (target or FIM aircraft [as and if applicable] on intercept heading 30° or less displaced from the final approach path).

Initiation criteria. As stated in the input lists above, the FIM function should not be executed until initiation criteria are met. The FIM system will not allow initiation unless all required data are entered and the data monitored for quality meet associated requirements. The following criteria should be assessed by the flight crew prior to execution.

'Execute' function available.

FIM speed guidance value acceptable to the flight crew. If not, inform the Flight Test Director.

Target aircraft flying direct to the first waypoint or already between waypoints in the en route test segment or in the arrival procedure. For Final Approach Spacing, target should either be on final approach or on an intercept vector 30° or less displaced from the initial approach track.

Distance to target no less than the value in the test card.

Aircraft on speed and altitude defined in the test card. Target and FIM aircraft may already be in descent at initiation.

If all criteria are met, to include the ASG with within the goal shown on the test card, the flight crew report the ASG to the Flight Test Director. If the PSI and ASG is outside the desired range shown on the test card, the flight crew report the PSI to the Flight Test Director. The Flight Test Director will consult with the NASA Technical Lead to determine what course of action to take.

15.3 Execution of a FIM Flight Test Condition

All aircraft. Be responsive to all ATC instructions even if it means that the test condition must be abandoned.

Target aircraft. With the exception of speed reduction to simulate ATC delay, en route, arrival and approach operations are standard for the target aircraft.

Utilize LNAV and VNAV for all en route and arrival test conditions. The instrument approach procedures to be used (RNAV (RNP) Z) in arrival test conditions are Authorization Required procedures requiring RNP 0.3.

For arrival test conditions, attempt to get ATC descent clearance in time to begin descent at FMS TOD. If required by ATC to descend prematurely or delay descent, note along-track parameter (time or distance) relative to FMS TOD.

Some arrival test conditions emulate target delay by requiring a percentage reduction in Mach Number and calibrated airspeed relative to the planned descent speed profile, the procedure speed constraints, and the airspace/procedure speed restrictions. The resultant speeds will be included in the test cards for these test conditions. Crews of target aircraft are at liberty to achieve these reduced speeds in whatever way they wish, either through manual entry or through constraint and restriction amendment.

Regardless of how the aircraft is flown, crews should attempt to remain within 400 ft vertically of the FMS-defined vertical path using thrust or drag modulation to achieve the defined combination of vertical path and speed.

Aircraft executing FIM. Utilize LNAV and VNAV for all en route and arrival test conditions. RNAV 1 is the minimum assumed performance for FIM operations. The instrument approach procedures to be used (RNAV (RNP) Z) in arrival test conditions are Authorization Required procedures requiring RNP 0.3.

For arrival test conditions, attempt to get ATC descent clearance in time to begin descent at FMS TOD. Descent clearances will routinely be issued as “Descend at Pilots Discretion”. If required by ATC to descend prematurely or delay descent, note along-track parameter (time or distance) relative to FMS TOD.

Moses Lake Approach Control has agreed to provide radar vectors to position aircraft to intercept the final approach course outside the 20 mile gate on the extended centerline of the runway. For Final Approach Spacing test conditions, use SEL HDG for positioning and intercept leg. Note heading on intercept leg. Select appropriate automation mode to allow capture of ILS (runway 32R) or RNAV (GPS) Y (runway 14L). `In both cases, since a final approach of at least 20 NM is required, it will be necessary to build a final approach path from the threshold (for ILS) or from the IAF (for RNAV Y) to provide a path to intercept.

Set FIM guidance speed displayed in CGD into MCP speed window as soon as a change occurs/is noticed. Timeliness of speed selection is an important parameter for FIM operational performance. Lag in selection and slow speed change following selection can each result in speed conformance alerts.

For en route and high altitude start arrivals, use Mach Number or Calibrated Airspeed inputs as presented by the FIM system. The FIM system crossover altitude may not be the same as the FMS’s.

Do not select speeds outside the normal envelope or the aircraft (upper, bottom end of barber pole; lower, top of amber band or equivalents).

If FIM guidance provides speeds higher than V_{MO}/M_{MO}, note guidance value, select highest speed with which flight crew is comfortable and note value.

If FIM guidance provides speed lower than top of the amber band, reconfigure the aircraft to accommodate if possible. If subsequent speed guidance exceeds the achieved flap limit speed, leave flaps as selected, select highest speed with which flight crew is comfortable and note value.

If there is a need to limit speed to turbulence penetration speed, utilize that limit and note the value.

Do not limit selected CAS to arrival procedure speed constraints. For FIM operations, variance above and below speed constraint values has been coordinated with ATC. The maximum variation should be 15% greater than or less than the published speed constraint.

However, do not exceed 250 kt below 10,000 ft. FIM guidance <u>should</u> respect this restriction.

Do not exceed 210 kt for the RNAV (RNP) Z instrument approach procedures; these speeds allow conformance to RF leg paths. FIM guidance <u>should</u> respect this restriction.

If MCP speed entry results in VNAV SPD mode, allow aircraft to deviate from the vertical path.

However, respect ALL vertical constraints using speedbrake or level flight segments as required.

Configure aircraft consistent with FIM guidance speed values. Guidance speed will no longer be displayed once the FIM aircraft reaches the Planned Termination Point; the flight crew can then adjust speed to allow for a stabilized approach at the final approach speed appropriate to the gross weight of the aircraft as adjusted for wind/gust factor. **If the crew feels that speed must be reduced to allow a stabilized approach to be achieved while FIM speed guidance is being provided, adherence to FIM speed guidance can be abandoned at any time. If, in achieving a stabilized approach, FIM speed guidance is not followed, note the parameters on the post-run survey.**

For arrival/approach test conditions, continue the instrument approach to decision altitude, then make a missed approach and continue on runway heading, climbing as cleared by ATC, for 10 NM. Although this is not the missed approach procedure for the instrument approaches, the procedure will have been coordinated with Moses Lake ATC.

15.4 Transit to Next Test Condition Start Point

Following completion of a test condition, all aircraft will proceed to the start point for the next test condition, or will transit back to the Seattle operating bases. For all sorties, test cards will be interleaved with transit cards that will provide expectations for the process, though ATC requirements may overcome any specific plan since transits will be the least critical parts of the flight plans.

From en route test conditions.

The general intent is that, on completion of an en route test condition, aircraft will reposition to the start of an arrival-to-approach from a high altitude start point. Every effort will be made to make this process as efficient as possible by sequencing test conditions appropriately. Transit cards will provide routing including, where necessary, place/bearing/distance or along-track waypoints related to waypoints in the procedures to be followed for the next test condition. Aircraft with shorter distances to the defined initial point may be directed to enter holding; inbound track and turn direction will be provided.

From arrival-to-approach test condition.

Following a missed approach from an arrival-to-approach test condition, aircraft will reposition either to the start of an arrival-to-approach from a medium altitude start point, or will seek ATC clearance to enter a closed instrument approach pattern for a Final Approach Spacing test condition. Rarely, if insufficient high altitude start data for arrival-to-approach test conditions has been gathered, transit may be back to a high altitude start point; such a requirement will be included in the pre-flight briefing and transit and test cards will reflect the process.

From Final Approach Spacing test condition.

Final Approach Spacing test conditions will terminate at decision altitude in a missed approach, which will routinely be followed by a second Final Approach Spacing Test. Generally the second test condition sequence will conclude scenarios for the day.. All flight test conditions will have a corresponding flight plan on file with the air traffic facility. If the test sequence for the day calls for additional runs, the transit would be as described above for additional arrival-to-approach test conditions.

15.5 Contingency Procedures:

Pre-departure:

FIM System or Data Gathering system unserviceability:

- Aircraft crew and Honeywell/Boeing support team will provide an estimate on time to rectify.
- Flight Test Director, in consultation with NASA Flight Test POC and flight crews will determine if later launch remains practical.
    - Latest launch time set.
- If determined that launch will not be achieved that day, Flight Test Director, in consultation with NASA Flight Test POC and flight crews will determine if a two-ship test should be conducted.

Aircraft system unserviceability:

- Aircraft crew and Honeywell or UAL support team will provide an estimate on time to rectify.
- Flight Test Director, in consultation with NASA Flight Test POC and flight crews will determine if later launch remains practical.
    - Latest launch time set.
- If determined that launch will not be achieved that day, Flight Test Director, in consultation with NASA Flight Test POC and flight crews will determine if a two-ship test should be conducted.

ATC stop:

- Flight Test Director will liaise with ATC to determine earliest launch time.
- Flight Test Director, in consultation with NASA Flight Test POC and flight crews will determine if later launch remains practical.
    - Latest launch time set.

Weather:

- Honeywell and UAL flight crews will determine if departure, test area and arrival weather are acceptable for flight. If not, is improvement expected?
    - Latest launch time set.

After two aircraft depart:

Remaining aircraft fails to launch as a result of FIM System or Data Gathering system unserviceability or aircraft system unserviceability:

- Aircraft crew and/or Honeywell, UAL and/or Boeing support team will provide an estimate on time to rectify.
  - Latest launch time set.
- Based on all available information, Flight Test Director, in consultation with NASA Flight Test POC, regardless of whether they are already airborne or still on the ground, will determine the disposition of the airborne aircraft:
  - Position in test area and conduct two-ship tests
  - Position in test area and loiter awaiting arrival of third aircraft
  - Recover to departure airports at earliest opportunity

ATC stop:

- Responsible manager in flight test 'war room' or Flight Test Director will liaise with ATC to determine earliest launch time.
- Responsible manager in flight test 'war room' or Flight Test Director, in consultation with NASA Flight Test POC and flight crews will determine if later launch remains practical.
  - Latest launch time set.
- Based on all available information, responsible manager in flight test 'war room' or Flight Test Director, in consultation with NASA Flight Test POC or other available NASA person, will determine the disposition of the airborne aircraft:
  - Position in test area and conduct two-ship tests
  - Position in test area and loiter awaiting arrival of third aircraft
  - Recover to departure airports at earliest opportunity

After one aircraft departs:

Simultaneous failures in two aircraft are not considered:

ATC stop:

- Responsible manager in flight test 'war room' or Flight Test Director will liaise with ATC to determine earliest launch time.
- Responsible manager in flight test 'war room' or Flight Test Director, in consultation with NASA Flight Test POC and flight crews will determine if later launch remains practical.
  - Latest launch time set.
- Based on all available information, responsible manager in flight test 'war room' or Flight Test Director, in consultation with NASA Flight Test POC or other available NASA person, will determine the disposition of the airborne aircraft:
  - Position in test area and loiter awaiting arrival of other aircraft
  - Recover to departure airport at earliest opportunity

After all aircraft airborne:

FIM System or Data Gathering system unserviceability:

Aircraft system unserviceability:

- Flight crew deals with emergency or unserviceability using operator/manufacturer procedures.
  - Aircraft diverts if necessary.
  - If FIM2 aircraft, target and FIM1 continue procedure for completion then recover to start points for next procedure and loiter awaiting decision.
  - If target aircraft, FIM1 and FIM2 continue procedure for completion then recover to start points for next procedure and loiter awaiting decision.
  - If FIM1 aircraft, target and FIM2 aircraft break off FIM procedure and recover to start points for next procedure with ATC approval, and loiter awaiting decision.
- Flight crew determines if testing can continue.
  - If so, Flight Test Director, in consultation with NASA Flight Test POC and flight crew will determine if any associated degradation in aircraft capability/performance will preclude further testing.
  - If testing can continue, aircraft recovers to start point for next procedure, with ATC approval.
  - If testing with unserviceable aircraft cannot continue, Flight Test Director, in consultation with NASA Flight Test POC, determines whether two-ship testing should be carried out.
    - If not, all aircraft recover to departure airports.
    - If so, Flight Test Director, in consultation with NASA Flight Test POC, determines which test condition(s) will be executed.

ATC denies use of airspace for the test (other aircraft emergency, ATC system issue, etc.):

- Flight Test Director will liaise with ATC to determine earliest time for recommencement.
- Flight Test Director, in consultation with NASA Flight Test POC and flight crews, will determine if recommencement remains practical.
  - Latest recommencement time set.
- If recommencement impractical, aircraft recover to departure airports.

Weather:

- If weather in the cruise airspace, the arrival airspace or in the instrument pattern proves to be unsuitable for operations
  - Flight crew(s) express their unwillingness to continue
  - All aircraft recover to departure airports.

Other eventualities:

ATC intervention resulting in deviation from procedure lateral path, thus resulting in suspension of FIM operations:

Note that such an event affecting either the non-FIM target or FIM1 in its role as target will also affect succeeding aircraft.

- Report interruption to Flight Test Director.
- If target aircraft, recover to procedure when permitted by ATC and note the interruption.
- Affected FIM flight crew(s) select 'SUSPEND' (regardless of whether target or ownship is and report issue to Flight Test Director.
- When cleared to continue by ATC, flight crew(s) determine whether target and ownship are in lateral conformance and whether speed guidance, once provided , is an acceptable speed.
- If acceptable, continue the procedure and note the interruption
- Flight Test Director monitors and, in consultation with NASA Flight Test POC, determines if run should continue.
    - If not, instruct flight crews to discontinue and negotiate recovery to start of the same (if medium level start point) or subsequent (if high level start point) test conditions in the day's schedule.

ATC intervention preventing conformance to speed guidance:

- Report interruption to Flight Test Director and note interruption.
- Continue procedure at cleared speed ignoring FIM speed guidance.
- Flight Test Director monitors and, in consultation with NASA Flight Test POC, determines if run should continue.
    - If not, instruct flight crews to discontinue and negotiate recovery to start of the same (if medium level start point) or subsequent (if high level start point) test conditions in the day's schedule.
- When cleared to continue at FIM speed by ATC, flight crew(s) determine whether speed guidance is an acceptable speed.
    - If not, report fact to Flight Test Director.

ATC intervention preventing continuous descent but allowing continuation of FIM procedures:

- Report interruption to Flight Test Director and note interruption.
- Continue procedure, conforming to ATC vertical clearance.
- Flight Test Director monitors and, in consultation with NASA Flight Test POC, determines if run should continue.
    - If not, instruct flight crews to discontinue and negotiate recovery to start of the same (if medium level start point) or subsequent (if high level start point) test conditions in the day's schedule.

Use of anti-icing that affects engine idle setting:

- Report incidence to Flight Test Director and note. Report continuing procedure.
- Continue procedure, modulating thrust/drag as necessary to stay within 500 ft of FMS vertical path.

Non-conformance to FIM speed guidance due to operational necessity (e.g. flying at turbulence penetration speed, FIM speed change requiring inappropriate configuration change, FIM speed change that would make achieving an altitude constraint unlikely, etc.):

- Report incidence to Flight Test Director and note. Report continuing procedure, or that aborting if considered unsafe to continue.
- Flight Test Director monitors and, in consultation with NASA Flight Test POC, determines if run should continue.
    - If not, instruct flight crews to discontinue and negotiate recovery to start of the same (if medium level start point) or subsequent (if high level start point) test conditions in the day’s schedule.

Annex A: Flight Test Conditions

The content of the table in Figure 4 describes flight test conditions that will satisfy the various requirements for the flight test as set out in the Statement of Work. The types of FIM clearance that will generate the test conditions are as follows:

- Achieve by then maintain (CROSS in system functionality)
- Capture then maintain (CAPTURE)
- Maintain current spacing (MAINTAIN)
- Final approach spacing (SPACE)

As far as possible, the test conditions allow variables that affect the operation and its performance to be isolated so that their effects can be assessed individually. However, it is understood that it is impossible to control some of the variables (eg effects of wind vector, latency in crew response to speed guidance) and, because there are many independent variables, total isolation will not be achieved. However, the distribution of combinations of variables will allow close examination of the following effects:

- Target delay
- Type of algorithm (trajectory-based or constant-time delay)
- Early and late Achieve By Point placement

The test conditions will be executed in three different operating environments:

- En route at FL350 and normal cruise speed
- During RNAV arrivals and instrument approaches including merging flows within STARs and on final approach (some initiated at high altitude (FL350) while most will be initiated at medium altitude (FL230) to reduce test condition cycle time)
- Tactical use between aircraft performing or intercepting an instrument approach procedure

Each three-aircraft test procedure generates two separate FIM procedures. FIM1 aircraft will follow a target that is performing a standard arrival/approach or is delayed (speed reduction) in the course performing a standard arrival/approach. FIM2 aircraft will follow FIM1 and must therefore compensate for the speed changes executed by FIM1 in achieving its FIM goal. In the majority of cases, FIM2 will be reacting to a different FIM clearance type than FIM1.

Test conditions have been prioritized to ensure that the most important conditions and combinations are encountered first. Where a test condition is executed more than once, every effort will be made to duplicate the first test by ensuring that the aircraft assigned to FIM1 and FIM2 positions are the same aircraft.

Scenario	Tgt Route	Tgt Delay (see TgtRts)	FIM1 Clnc Type	FIM1 T/D	FIM1 Route	FIM1 SpErr	FIM1 ABP	FIM1 PTP	FIM2 Clnc Type	FIM2 T/D	FIM2 Route	FIM2 SpErr	FIM2 ABP	FIM2 PTP
A1	en route	0 (.78M)	CROSS	Time	en route	+20 sec	JELVO	MAHTA	CROSS	Time	en route	-15 sec	JELVO	MAHTA
A2	en route	0 (.78M)	CROSS	Distance	en route	+3 NM	JELVO	MAHTA	CROSS	Distance	en route	-2 NM	JELVO	MAHTA
A3	en route	0 (.78M)	CAPTURE	Time	en route	+20 sec	na	JELVO	CAPTURE	Time	en route	-15 sec	na	JELVO
A4	en route	0 (.78M)	CAPTURE	Distance	en route	+3 NM	na	JELVO	CAPTURE	Distance	en route	-2 NM	na	JELVO
A5	en route	0 (.78M)	MAINTAIN	Time	en route	na	na	JELVO	MAINTAIN	Time	en route	na	na	JELVO
A6	en route	0 (.78M)	MAINTAIN	Distance	en route	na	na	JELVO	MAINTAIN	Distance	en route	na	na	JELVO
B1	JELVO.SUBDY	No Delay	CROSS	Time	ZIRAN.SUBDY	-20	NALTE	FAF	CAPTURE	Time	ZIRAN.SUBDY	+30	na	FAF
B2	ZIRAN.SUBDY	No Delay	CROSS	Time	JELVO.SUBDY	0	PTP	FAF	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF
B3	ZIRAN.SUBDY	No Delay	CROSS	Time	JELVO.SUBDY	+60	PTP	FAF	CROSS	Time	TRAKX.UPBOB	+30	PTP	FAF
B4	JELVO.SUBDY	No Delay	CAPTURE	Time	JELVO.SUBDY	-60	na	FAF	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF
B5	JELVO.SUBDY	No Delay	CAPTURE	Time	JELVO.SUBDY	+60	na	FAF	CROSS	Time	TRAKX.UPBOB	+30	PTP	FAF
B6	JELVO.SUBDY	No Delay	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF	CROSS	Time	ZIRAN.SUBDY	+15	NALTE	FAF
B7	JELVO.SUBDY	Med Delay	CROSS	Time	ZIRAN.SUBDY	-20	NALTE	FAF	CAPTURE	Time	ZIRAN.SUBDY	+30	na	FAF
B8	ZIRAN.SUBDY	Med Delay	CROSS	Time	JELVO.SUBDY	0	PTP	FAF	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF
B9	ZIRAN.SUBDY	Med Delay	CROSS	Time	JELVO.SUBDY	+60	PTP	FAF	CROSS	Time	TRAKX.UPBOB	+30	PTP	FAF
B10	JELVO.SUBDY	Med Delay	CAPTURE	Time	JELVO.SUBDY	-60	na	FAF	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF
B11	JELVO.SUBDY	Med Delay	CAPTURE	Time	JELVO.SUBDY	+60	na	FAF	CROSS	Time	TRAKX.UPBOB	+30	PTP	FAF
B12	JELVO.SUBDY	Med Delay	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF	CROSS	Time	ZIRAN.SUBDY	+15	NALTE	FAF
B13	JELVO.SUBDY	High Delay	CROSS	Time	ZIRAN.SUBDY	-20	NALTE	FAF	CAPTURE	Time	ZIRAN.SUBDY	+30	na	FAF
B14	ZIRAN.SUBDY	High Delay	CROSS	Time	JELVO.SUBDY	0	PTP	FAF	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF
B15	ZIRAN.SUBDY	High Delay	CROSS	Time	JELVO.SUBDY	+60	PTP	FAF	CROSS	Time	TRAKX.UPBOB	+30	PTP	FAF
B16	JELVO.SUBDY	High Delay	CAPTURE	Time	JELVO.SUBDY	-60	na	FAF	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF
B17	JELVO.SUBDY	High Delay	CAPTURE	Time	JELVO.SUBDY	+60	na	FAF	CROSS	Time	TRAKX.UPBOB	+30	PTP	FAF
B18	JELVO.SUBDY	High Delay	MAINTAIN	Time	JELVO.SUBDY	na	na	FAF	CROSS	Time	ZIRAN.SUBDY	+15	NALTE	FAF
B19	ZIRAN.SUBDY	No Delay	CROSS	Time	JELVO.SUBDY	+20	NALTE	FAF	CROSS	Time	ZIRAN.SUBDY	+15	NALTE	FAF
B20	ZIRAN.SUBDY	Med Delay	CROSS	Time	JELVO.SUBDY	+20	NALTE	FAF	CROSS	Time	ZIRAN.SUBDY	+15	NALTE	FAF
B21	ZIRAN.SUBDY	High Delay	CROSS	Time	JELVO.SUBDY	+20	NALTE	FAF	CROSS	Time	ZIRAN.SUBDY	+15	NALTE	FAF
B22	ZIRAN.SUBDY	No Delay	CROSS	Distance	JELVO.SUBDY	+2 nm	PTP	FAF	CROSS	Distance	ZIRAN.SUBDY	+1 nm	PTP	FAF
B23	ZIRAN.SUBDY	Med Delay	CROSS	Distance	JELVO.SUBDY	+2 nm	PTP	FAF	CROSS	Distance	ZIRAN.SUBDY	+1 nm	PTP	FAF
B24	ZIRAN.SUBDY	High Delay	CROSS	Distance	JELVO.SUBDY	+2 nm	PTP	FAF	CROSS	Distance	ZIRAN.SUBDY	+1 nm	PTP	FAF
C1	Str-in	No Delay	FINAL	Time	Str-in	+15 sec	PTP	6.25						
C2	Str-in	No Delay	FINAL	Distance	Str-in	+1 NM	PTP	6.25						
C3	Str-in	No Delay	FINAL	Time	Turn	+15 sec	PTP	6.25						
C4	Str-in	No Delay	FINAL	Distance	Turn	+1 NM	PTP	6.25						
C5	Turn	No Delay	FINAL	Time	Str-in	+15 sec	PTP	6.25						
C6	Turn	No Delay	FINAL	Distance	Str-in	+1 NM	PTP	6.25						
C7	Str-in	High Delay	FINAL	Distance	Turn	+1 NM	PTP	6.25						
C8	Turn	High Delay	FINAL	Distance	Str-in	+1 NM	PTP	6.25						

Figure 4. Flight Test Matrix

Annex B: Arrival and Approach Procedures

The arrival procedures depicted on the following pages have been developed by the NASA ATD-1 Phase 2 team. The procedures have many of the features found in recently implemented arrival procedures at busy airports in the USA in that they have speed and/or altitude constraints at a number of the defining waypoints. The FIM system requires these constraints to define the vertical and speed profiles for both target and executing aircraft. Because the flight tests will be carried out under Instrument Flight Rules, the procedures have been subjected to normal development and approval processes, and will be published as Special procedures for use only by Honeywell and United Airlines

The SUBDY RNAV STAR has en route transitions (ZIRAN and JELVO start points) converging from west and east and thus providing arrival direction diversity allowing examination of the differing effects of wind components. The transitions merge at waypoint NALTE at 17,000 ft msl, providing opportunity for a merge between traffic streams part-way down the descent, but with control space to allow correction of initial spacing error from both high altitude initiations (FL350) and medium altitude initiations (FL230). The STAR terminates at SUBDY, which is also a transition waypoint to the RNAV (RNP) Z AR approach to Moses Lake runway 32R.

The NALTE RNAV STAR is similar to the SUBDY STAR in form and function. The STAR terminates at NALTE, a common initial point with an approach transition to the RNAV (RNP) Z AR instrument approach to Moses Lake runway 14L. (Note: only the STARs and IAPs to runway 32 were flown during the flight test.)

The UPBOB RNAV STAR provides more arrival direction diversity by bringing the user to Moses Lake from the southeast. The STAR terminates at UPBOB, a common initial point with approach transitions to the RNAV (RNP) Z AR instrument approaches to Moses Lake runways 32R and 14L.

All STARs, therefore, provide simple linking between arrival and approach procedures as needed by FIM system functioning. When selecting the procedures in the FMS per flight test card instructions, see Annex D for more detail, flight crews will close any discontinuities ensuring that all procedure points remain.

The instrument approach procedures depicted in the approach plates are for public published procedures to runways 32R and 14L at Moses Lake. RNAV (RNP) Z Authorization Required approaches have been selected because they contain RF legs which will satisfy testing requirements of the FIM system algorithm.

Flight crews will be provided with current charts for STARs and will obtain plates for the approach procedures. STARs and IAPs will be included in flight test navigation data bases in both the FMS and the FIM system.

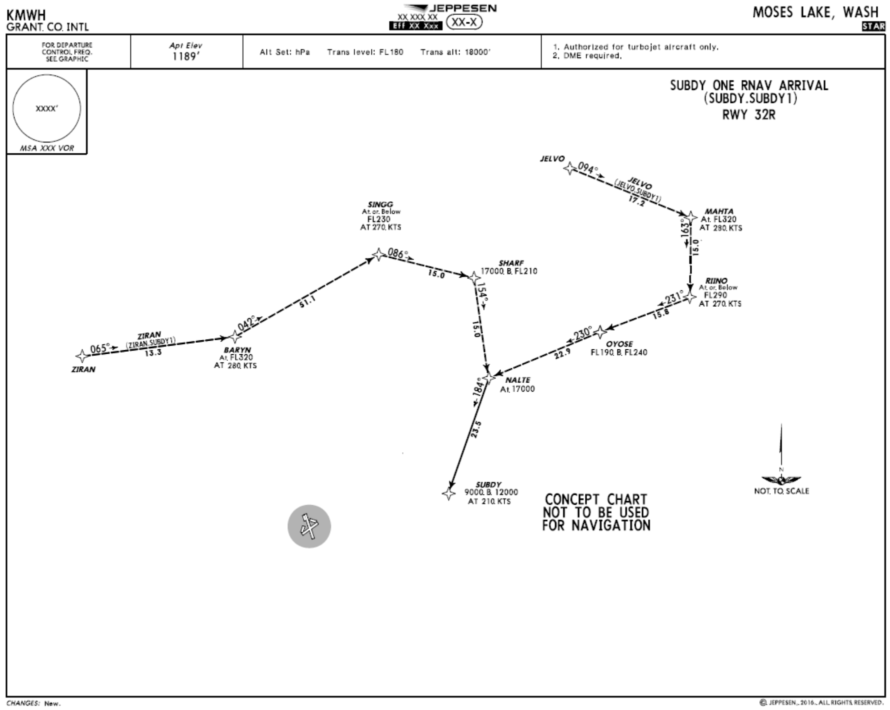


Figure 5. SUBDY1 RNAV Arrival

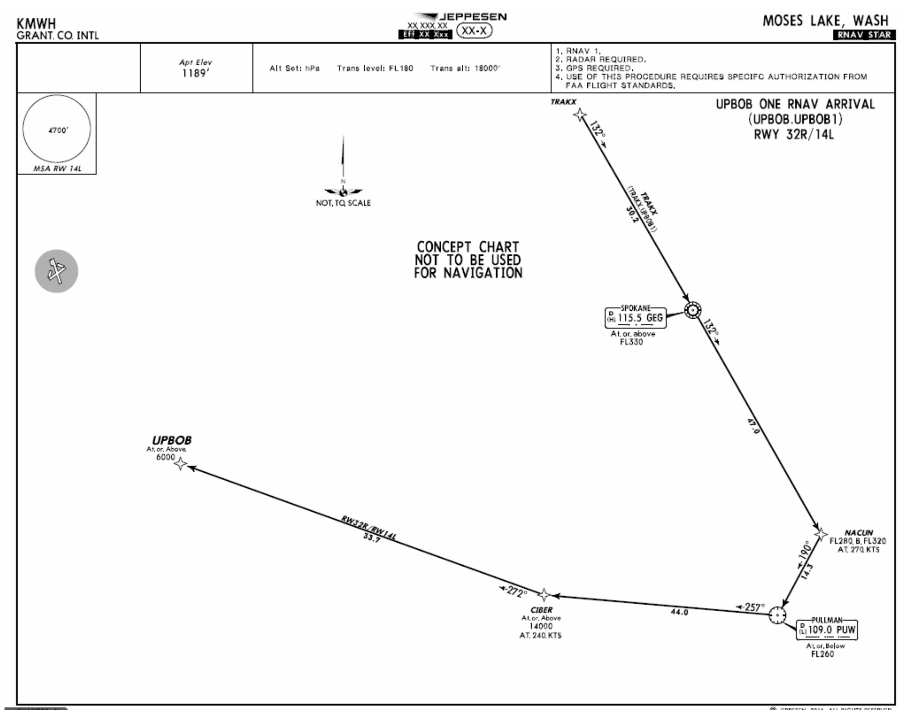


Figure 6, UPBOB1 RNAV Arrival

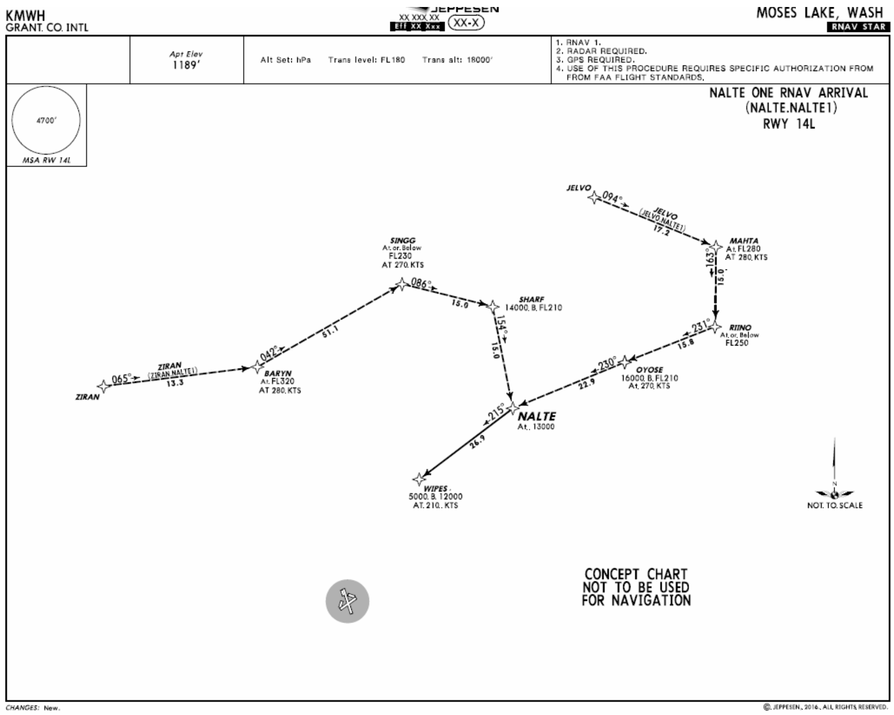


Figure 7. NALTE1 RNAV Arrival

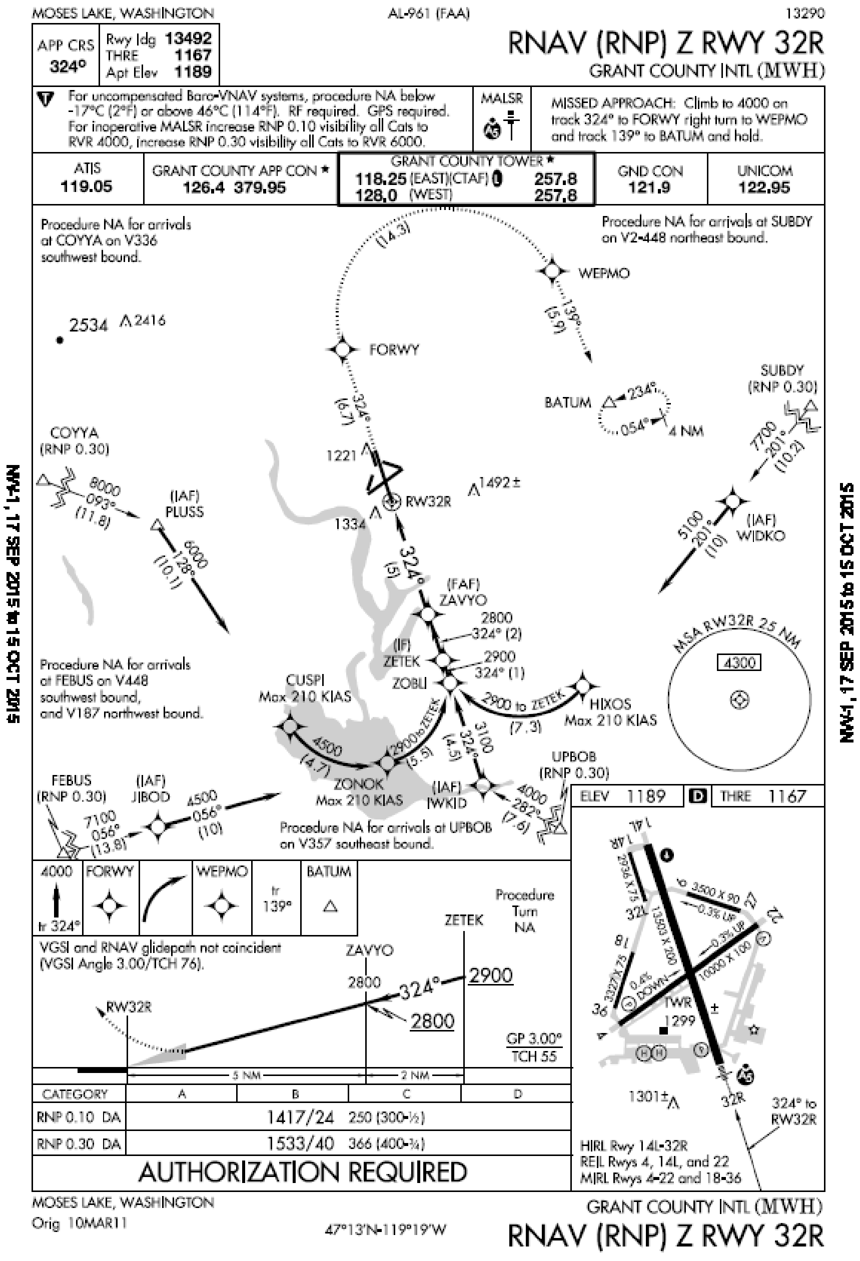


Figure 8. RNAV (RNP) Z AR to runway 32R (KMWH)

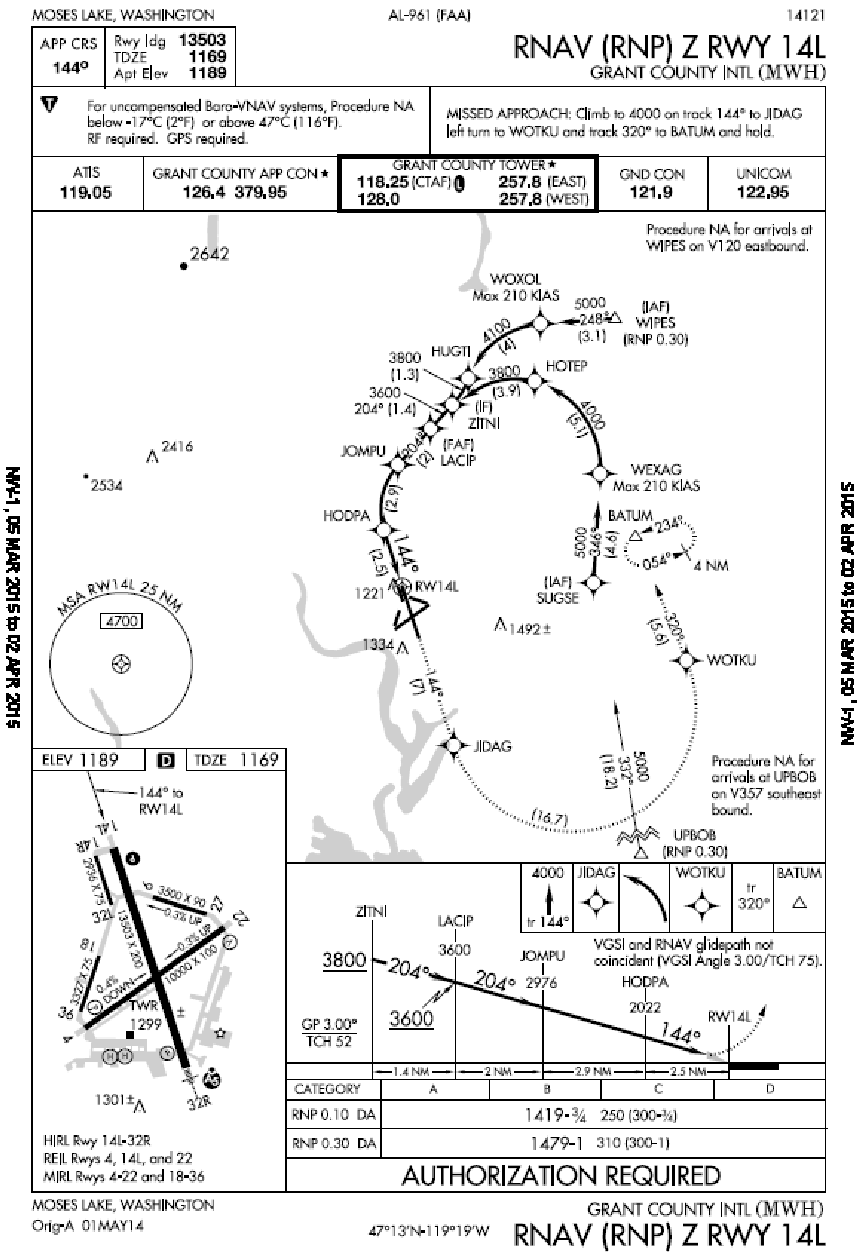


Figure 9. RNAV (RNP) AR to runway 14L (KMWH)

Annex C: Data Gathering and Analysis Plan

This annex describes what and how data will be collected during the Flight Test, and how that data serves the analysis requirements for the Flight Test. This annex has gone through several updates as the plan matured, and as data and analysis products became available. This version is the third and final iteration of the document.

REQUIREMENTS BASIS

Data recording requirements are tied to three fundamental sources:

Contract SOW

Section 3.6.5 – Flight Test Plan covering Data Collection (this annex of the document)

Section 3.6.18 – Flight Test Data delivery (Deliverable 4.24), including "ADS-B log data" (3.6.18.3), "FIM system log data" (3.6.18.4) and "FMS data" (3.6.18.5).

Section 3.6.19 – Post Flight Data Analysis Report (Deliverable 4.26), naming ATD-1 Measures of Performance (MOP) as found in *GFI 5.11*, including:

- Spacing Error (along path and final delivery accuracy at the ABP)
- Fuel Consumed (along path and at the ABP)
- Flight Technical Error (lateral and vertical)
- IFPI Path Definition Error (lateral, vertical, speed profiles)
- Latency between speed command displayed and flight crew initiation of speed change
- For each MOP in GFI 5.11, regression analysis to
  - Wind conditions
  - Final approach speed

Section 3.6.22 – Tech POC to determine parameters necessary to evaluate FIM performance and delivery of Flight Test IM Performance Data (Deliverable 4.25)

NASA submitted a data request list on 06/14/16 that constitutes the set of data to be recorded and delivered under Deliverables 4.24 (Flight Test Data) and 4.25 (IM Performance Data), subject to the coordination language in SOW 3.6.22. This NASA document has become the basis for documenting data recording requirements and traceability to recording systems, procedures and data artifacts, and is presented herein. Some data items in the list will not be provided on all platforms due to technical constraints. Rationale and mitigations are presented in this document iteration as well. The NASA document has been translated into a spreadsheet and is referred throughout this document by the moniker *Data Collection Details Spreadsheet*, or *Data Collection Spreadsheet*. The spreadsheet can be found on the Boeing Sharepoint site and is considered an accompanying document to this text. The current version of the spreadsheet is version 4.3 and is described in details in the next section.

NASA System Requirement Document (GFI 5.13 - SRD) and the Boeing-derived System Requirements Definition Document (SRDD)

Section 4.6 and all subsections of the SRD and corresponding SRDD requirements (R-BOE-SRDD-2219 to R-BOE-SRDD-2373) describing all data to be recorded from the FIM System.

Internally generated system requirements

These are requirements for data collection to support system integration testing, expected to be a superset to the data collection requirements of Section 4.6 of the NASA SRD and associated SRDD requirements.

DATA COLLECTION SPREADSHEET WALK-THROUGH

This section presents the Data Collection spreadsheet derived from the NASA Data request document. The current version of the spreadsheet is version 4.3 and can be found on the Boeing ATD1 program SharePoint site within the "Documents in Rework" folder, under the Flight Test Plan document folder, with name "NASA ATD1 Data Recording details_v4-3.xlsx".

The spreadsheet includes an Overall tab describing the requested data items and traces each to a recording system on each of four airplane platforms participating in the flight test. The five other tabs describe in more detail how each recording system traces each data item to a location within the system, in some cases to a file name and location.

At this point the spreadsheet is meant primarily to document coverage of the requested data items to recording systems. Form and format of the data is discussed further in this document and may be updated in further releases.

Overall Tab

Column A in the Overall tab includes each of the data parameters found in the NASA data request list, in each of seven data categories (Administrative, Aircraft State, FMS and Guidance, FIM TG, FIM function, FIM HMI and Video/Audio).

NOTE: The survey data (flight crew and ATC) has been removed from the SOW and thus is no longer considered data required for submission under Deliverables 4.24 and 4.25 and is thus absent from the spreadsheet and this Annex.

Column B includes the description provided by NASA and additional clarification edited by Boeing following discussions held in the Data Collection Working Group (DCWG) for each item in Column A.

Column C includes Boeing comments on the data item.

Columns D and E trace back to requirements in the SRD, SRDD and SOW. Some requested data does not have clear traceability or its traceability is subject to interpretation and is noted as such for reference. Column F is a comment section on the requirement traceability.

Columns G-J each correspond to an aircraft participating in the flight test. Column G is for the Honeywell 757; column H for the United 737; column I for the Honeywell engineering Falcon 900 aircraft (non-FIM aircraft); and column I for a Honeywell commercial transport aircraft (non-FIM aircraft). The last two are the aircraft types Honeywell will provide for the role of non-FIM aircraft (not concurrently). The exact attribution of each to individual test runs in the Flight Test Matrix is not yet known and will be subject to aircraft availability. Only the Falcon 900 contains a recording system, owning to its engineering flight test category; the other aircraft type (column J) will not have any local recording capability, but some of its data will be sent over ADS/B and will be recorded by other flight test aircraft within range or ATC and the spreadsheet is annotated as such.

Each cell in columns G-J is color coded according to the following convention:

Green – Data item is recordable within one or more local recording system or is derivable from data produced by the recording system. Its recording is traceable to a requirement and/or had been considered within the program cost basis at program start.

Red – Data item is not found on any available recording system within the aircraft and no surrogate can be found without changes to the underlying aircraft hardware/software.

Blue – Data item can be recorded on an available recording system, or requires a surrogate, and its recording was not envisioned within the program cost basis at program start. These items will require additional scrutiny and likely will require a CCB event to commit to recording.

Additionally, each green and blue cell in columns G-J list the recording system(s) providing the data item and links to the equivalent cell in other spreadsheet tabs further documenting parameter name, form etc. within the particular recording system. When multiple recording systems are identified for a data item, the first system is considered the primary system and is guarantee to record the data. The secondary and further systems may record the data in duplicate, and may only be used when troubleshooting individual flight test issues.

Identified gaps in data recording from the NASA request (red and blue cells): rationale and mitigation

Aircraft State Data Category:

The only available Aircraft State Data available on the Transport category Honeywell non-FIM aircraft (column J) is what is sent by the transponder over ADS/B. Local recording in the form of portable GPS unit has been considered, but would only provide a smaller subset of the ADS/B data. When in range, either of the two FIM aircraft will have the ADS/B data recorded in their TPU upon receipt. When not in range, ATC may have recordings of ADS/B data as Washington Center is outfitted with ADS/B, but that would require coordination with ATC for data collection and retrieval. Alternatively similar data is available publically via web services such as Flight Aware and may be retrieved post-flight.

Speed Brake parameter on the 757 is traced to Label 203 on the FADEC bus, and is available for GE and P&W engines. However, the Honeywell 757 has Rolls Royce engines and the corresponding parameter cannot be found on the same bus. Throttle lever angle on the 757 has been traced to label 134 on the FADEC bus, again not available for Rolls Royce engines on this aircraft. Gear setting on the Honeywell 757 has also not been traced to available digital data.

Honeywell has traced the inputs to the FDR as a way to capture the missing data, and at present has determined this solution is not feasible for capture. Continued exploration for the capture of these parameters will continue until start of flight test. Any changes to wiring or data collection configuration on the 757 will be amended if that occurs.

Mitigation strategies involve using the video of a general cockpit view to determine manual throttle, speed brake and gear activity by the pilots. Pilots or observers can be asked to note when speed brakes are deployed. The engine pressure ratio (EPR) is thought to be a potential surrogate for throttle lever angle, but the actual EPR value is also not available on this aircraft. However, the selected EPR value should correspond to autothrottle targets and thus would indicate throttle targets corresponding to MCP selected speed values (or FMS values when the MCP window is closed). That has been traced to label 021 on the FMC EFIS bus, but would not necessarily indicate overriding manual throttle activity on the part of the pilot. That would need annotation by the pilots or observers either live or post-facto via video observation.

The MCP Speed Window Flag may not be available directly in the form NASA is describing. On the 737 FDR, there is a discrete variable named MCP SPEED (word 158, label 270) which may indicate if the aircraft is commanded to the MCP speed (as opposed to the FMS), indicating the MCP window must be open. Alternatively, the presence of a value in the SELECTED AIRSPEED (or SELECTED MACH), may indicate the window is open. Determining whether positive confirmation of the MCP window being closed via an existing variable will require inspection of sample files for the default (no entry) value in the SELECTED AIRSPEED (or SELECTED MACH) data in a controlled environment. This is planned to occur with data collected during aircraft ferry flight from the installation location to the Seattle area. In general, crew procedures will dictate the aircraft starts with the window closed (aircraft flying VNAV PATH), until the FIM system displays a commanded speed, at which point the pilot will dial the speed in the MCP and the window opens. During suspend operations, the pilot will be instructed to keep the last commanded speed (or other safe speed) in the MCP, and thus keep the window open. Thus procedurally, the MCP window should only be closed prior to FIM operation start, and open thereafter.

Horizontal Velocity Accuracy, also known as NACv, is set to a static value on Boeing airplanes based on the certification level and related equipment. It is expected to always show a value of 1.0 in the non-degraded case, and the transponder sets the value for broadcast of the ADS/B message. The Honeywell TPU consumes this value and performs functional checks and reporting in degraded cases. See AC 20-165B B.4.14 for reference. Several special cases tests have been added to the Honeywell TPU for use in non-rule compliant aircraft. NACv = 1 should be assumed unless the system reports a system fault (in which case the FIM application will be inhibited). The TPU does not locally record the NACv value and thus the parameter cannot be recorded locally on each FIM aircraft. However the value will be available in ADS/B reports when collected by other aircraft in range.

Vertical Position Accuracy, also known as VFOM, is output by the GPS, but is only consumed by the TPU if a special geometric option is enabled, which is not available within this version of the TPU system. A value sufficient for ADS-B applications is ensured by 14 CFR 91.217. Several means of compliance are available, generally by installation of an altimeter that meets one or more TSO qualifications. See AC 20-165B 3.4., which are expected to be on the FIM aircraft in use.

FMS and Guidance Data Category:

FMS Vertical and Horizontal Trajectory data is not typically output on any bus on commercial transport aircraft. SRD review noted the difficulty in recording this type of data out of commercial FMS. The United 737 and the transport Honeywell non-FIM aircraft will thus not have the ability to record the FMS trajectory. However, the lateral and vertical deviations will be recordable at 1Hz and thus at least the vertical and horizontal guidance path can be instantaneously constructed at 1Hz from the state and the deviation values. However, this is not fully equivalent to a forward-looking horizontal and vertical trajectory since the reconstructed version only reflects the instantaneous guidance and thus changes to the trajectory may not be visible.

The Honeywell 757 is expected to fly a black label, Pegasus FMS, which does not include the ability to record the full trajectory locally. The FIDO subsystem could enable the recording of it, but would require a FMS software change. Boeing does not recommend performing the test program with a red-label FMS solely for satisfying logging requirements as it may add risk and uncertainty.

The F900 aircraft ASCB system has identified labels for the FMS trajectory, but the extent of it is tied to display selections in the cockpit and the frequency of recording is not clear. Time and effort would be required to determine how much of the trajectory data could be recorded, under what display conditions, and verify the process. Boeing and Honeywell did not estimate such effort at program start and thus pursuing this effort will likely be subject to CCB.

Honeywell determined that according its 757 airplane documentation, the needed labels for the FMS guidance modes (lateral, vertical, longitudinal) are available on the FM bus which is already wired to the patch panel. At the time of this writing we are waiting for the 757 to be available to physically confirm.

FIM HMI Data Category:

The FIM system will record HMI entries and displayed elements, but will not be capable of recording display and navigation state. Thus particular HMI navigation and display state elements, such as page changes, color and flashing states (e.g. rows 132 and 144) will not be recordable. Display state (e.g. color and flashing) will be tied to FIM function, which has state recorded. For example, a flashing IM Commanded Speed value occurs when the Speed Conformance Monitor determines the aircraft speed to be out of conformance with the commanded speed, which is a recorded event. Thus the display state can be inferred from the functional state in many cases. Verification of the linkage will occur at system test. HMI navigation state (e.g. page changes) will be recorded on video on the 757 platform.

When HMI entry is recorded, it will be recorded on the master EFB. Given the functional nature of the master/slave interaction, the master will always reflect the latest entry. Thus the logged entry on the master will reflect changes on the slave, but the logged value will not differentiate where the entry last occurred (master or slave). If that is required in troubleshoot cases, the video captured will be synchronized with the logged data and can be correlated.

CGD data will not be recorded locally on the CGD platform and functionally always mirrors the equivalent state on the master EFB, which is being recorded. Verification of the linkage will occur at system test by visual inspection.

Temperature forecast will not be entered by the pilot, as was determined and documented in the SRD version 3.1 update. Temperature forecast is based on the computation of a delta temperature from the standard ISA model temperature and the sensed ownship temperature for its altitude, which is then applied forward at all downstream TCPs. The FIM TG logs will include forecast temperature corresponding to this forecast for each TCP.

Data Recording Systems and associated spreadsheet tabs

Seven separate data recording systems will be used to capture the green cells shown in the Data Collection Spreadsheet.

1. monEFB recording system polling the Master EFB (737 and 757 aircraft)
2. monTPA recording system polling the TPU (737 and 757 aircraft)
3. Flight Data Recorder (FDR) on the United 737
4. ARINC 429 bus intercepts on the Honeywell 757
5. ASCB system intercepts on the Honeywell F900
6. Video and audio recording system on the Honeywell 757
7. Microsoft Excel based Administrative data recording on all platforms

The data recording system architecture for the first two items in the list above is shown in Figure C.1 below. CGD data will not be recorded separately, as all its data comes from the master EFB and no separately derived data occurs on the CGD itself.

EFB Recording System:

EFB Data collection occurs physically on a Boeing laptop (Dell Precision) via a data broker program called monEFB developed by Honeywell under this program. The portable computer will be physically connected to the AID via Ethernet and run the monEFB program, which leverages recording modules within the FIM software hosted on the master EFB. The monEFB program configures connection to the EFB and manages the recording of data (start/stop, file naming, etc.) in binary form (*.dat file) on the laptop internal and external storage (solid state hard drive over USB).

The monEFB system is designed to record all identified parameters in the monEFB tab of the Data Collection spreadsheet, and additional data items identified to support integrated system functional testing pre-SAR and for SAR. The monEFB system supports some amount of live data view, mostly in ASCII/text form displayed on the screen of the data recording laptop. This type of live data view should be sufficient to determine FIM system correct operation and data recording health status prior to and during each identified Flight Test condition on board the aircraft.

Upon return to base, or in some cases requiring troubleshooting while in flight, a program named XCRIBE (developed by Honeywell) will produce ASCII based CSV files that are human readable based on the binary monEFB DAT file and DEF (definition files) specifying individual logs and their content. The format and structure of these logs (and thus the associated DEF files) is documented in the Data Collection spreadsheet and other artifacts. Sample CSV files for as many as 30 individual CSV logs have been supplied to NASA, as well as the corresponding single DAT file, the XCRIBE program, and associated documentation to assist NASA in defining different data form and format if it so chooses.

A single SSD of 500GB size will be used and removed from the aircraft after every flight. Tests to date in the lab with the current data definitions indicate the DAT file size to be approximately 18MB per flight hour. XCRIBE expands this into 29 CSV logs (to date) totaling 44MB per flight hour. The largest item in the log is the Traffic File, containing all ADS/B traffic (DTIF), and is likely larger in flight test due to real surrounding traffic. Assuming a 8x multiplier on the traffic data alone, we arrive at a total of ~60MB per flight hour for the EFB CSV logs, and 35MB per flight hour for the DAT file. This averages to ~100MB per flight test hour for the totality of the EFB data, although technically only the DAT files need be recorded live on the aircraft (CSV files can be produced off-board).

The Boeing developed analysis platform will read the CSV files produced by XCRIBE using the Honeywell created DEF files also supplied to NASA. The monEFB tab of the Data Collection Spreadsheet traces each data item recorded by the EFB to both a data structure and parameter name as found in the DAT file, as well as individual CSV log file and column name. Currently the monEFB recordings cover more data than NASA has asked for in the Data Request document, primarily to support system testing efforts occurring in the laboratory.

TPU Recording System:

A similar program to monEFB will record TPU data via the same laptop (monTPA) as shown in Figure C.1. The TPU is also capable of writing the same data (DAT files) within the unit on a CompactFlash card and can be used as backup in cases where monTPA does conflict with monEFB during flight test, a condition never observed in the laboratory environment. The same data will be produced in either case. The monTPA software allows live view capability, whereas local TPU recording will not. Also, the monTPA software will allow creating new files for each test condition, whereas local TPU recording will not (unattended recording).

Since most data produced by the TPU for the EFB is being recorded within the EFB via monEFB, the TPU data will likely only be used in troubleshooting situations associated with TPU function when the need arises.

Only five parameters in the Data Collection Spreadsheet have been identified as recordable only by the TPU, all other parameters are also recorded on the EFB:

- Horizontal Position Accuracy
- Horizontal Position Integrity

These parameters are used by the TPU to declare eligibility of ownship and target state data for participating in FIM application. The eligibility is reported to the EFB, which logs it. In cases where eligibility is source of issues identified on a particular run, this TPU data will be mined to identify cause. It is not expected to occur frequently.

- Geometric Vertical Position
- Geometric Vertical Rate

Only barometric altitude is sent to the EFB and all TG computations are based on barometric values.

- Horizontal Velocity Vector

The Horizontal Velocity Vector (N/S and E/W velocity components) are being passed to the EFB, which logs it as ground speed and true track.

The TPU tab of the Data Collection Spreadsheet traces each data item recorded by the TPU to both a data structure and parameter name as found in its DAT file (recorded either on local CompactFlash, or via monTPA), as well as individual CSV log file and column name. Individual CSV log formats and content has been documented and shared with NASA and contains more data than identified in the spreadsheet. Sample file audits reveal that the TPU DAT file take up about 20MB per flight test hour.

Thus, assuming worst case scenario (5 flight test hours per day), a SSD of 500GB will have ample room to store all the data produced by FIM system via monEFB and monTPA, even while keeping all of the CSV generated files in flight.

Summary of FIM data size estimates:

EFB DAT file: 35MB per flight test hour

EFB CSV files: 60MB per flight test hour

TPU DAT file: 20MB per flight test hour

TPU CSV files: 40MB per flight test hour

TOTAL DAT file sizes: 55MB per flight test hour

TOTAL CSV file sizes: 100MB per flight test hour

Worst case flight test hour per day: 5

Worst case minimum size (DAT files only): 275MB per day

Worst case total size (DAT + all CSV): 700MB per day

United 737 FDR Data Recording System:

United 737 airplane data will be recorded by the Flight Data Recorder (FDR). The FDR tab of the Data Collection spreadsheet documents which data items are recorded by this system, and their location and representation within the FDR system. This type of data recording will not have live view capability and will be off-boarded upon return to base. Many of the parameters it will record are duplicates of the data recorded in monEFB. The data that is found solely in the FDR is airplane data such as fuel and configuration related controls (flaps, spoilers, thrust and gear).

The FDR data is extractable using United maintenance tools while the aircraft in on the ground and is provided to Boeing in FDR binary format. This format must be converted to other formats by Boeing to be usable, including a CSV representation of the totality of the data. A sample FDR file has been provided by United to Boeing and processing into CSV format has occurred; NASA has received the sample file. Splitting data content into individual flight conditions will occur from the CSV files, based on time markers recorded in the Administrative Excel spreadsheet kept by the Flight Test Director.

True airspeed is not recorded directly in the FDR but will be derived by post-processing CAS. Totalizer Fuel will be computed by integrating fuel flow, per engine, subtracted from an initial value for fuel in tanks (left, center, main) obtained from a stable period (no accelerating level flight) at the beginning of every flight test condition.

The sample file reveals the size of the data captured and provided in CSV form will approximate 2MB per flight hour.

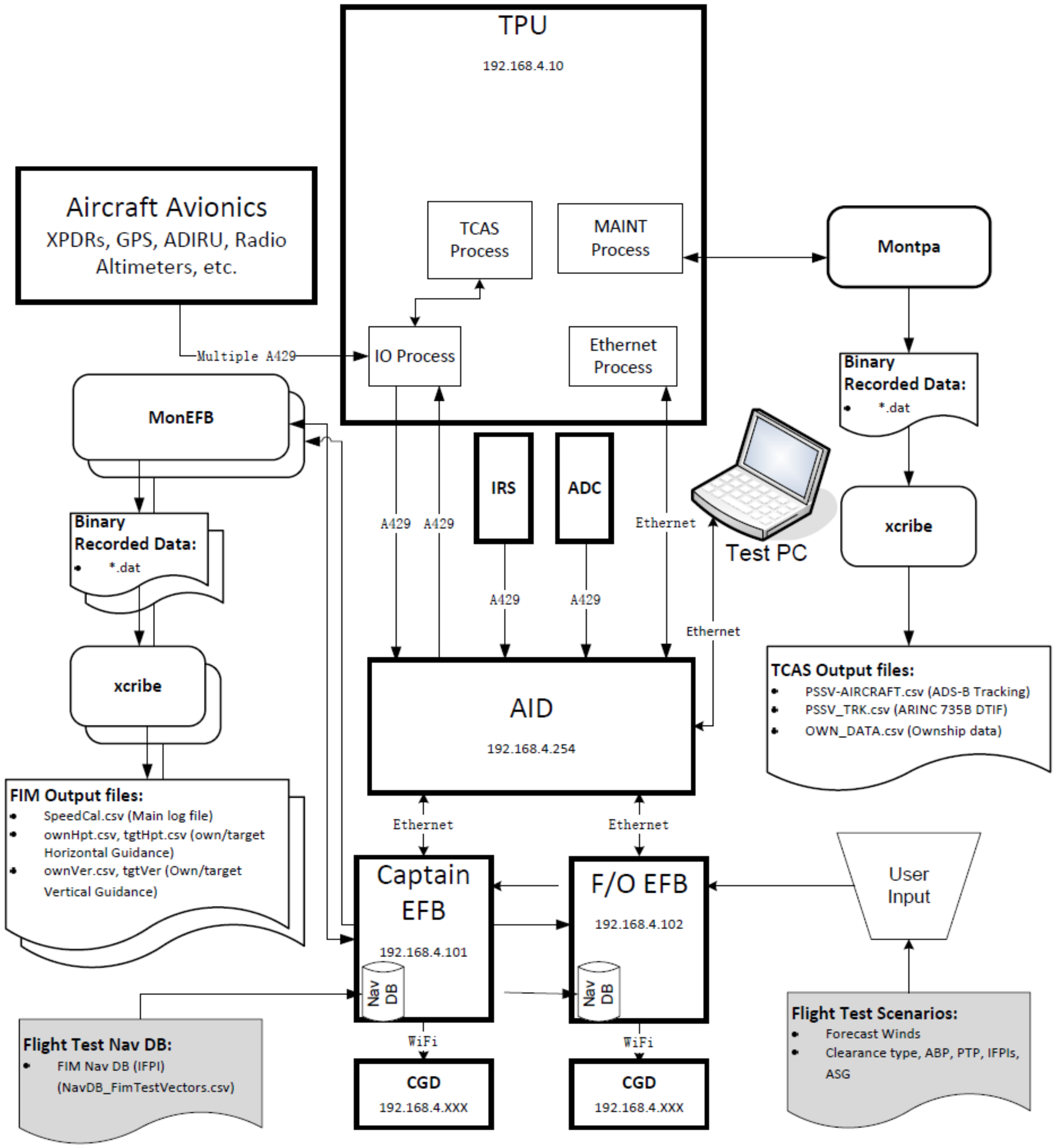


Figure 10. FIM Data Collection System Architecture

Honeywell 757 Bus Intercept Data Recording System:

The Honeywell 757, being an instrumented flight test aircraft, has the ability to intercept bus data for a variety of busses on the aircraft connected to a patch panel. The 757 non-FIM data tab of the Data Collection Spreadsheet traces each data item attributed to this aircraft to an available bus and label. All recording hardware is already present on the Honeywell 757. A bus intercept software suite will be used by a flight test engineer on the flight to setup and record specific intercepts on the identified buses to produce one or more data files stored on-board. Per standard Honeywell flight test procedures, the test engineer will cycle the bus intercept data into new files for each flight test condition. All data will be copied onto a removable storage SSD while back at the base, prior to exiting the aircraft. The data will also be stored on Honeywell servers and backed-up per Honeywell flight testing procedures. A sample files for the 757 obtained while it was on the ground has been shared with NASA. This data file reveals the anticipated size of the data will approximate 90MB per flight test hour.

Honeywell Falcon 900 Recording System:

The Honeywell Falcon 900 (non-FIM aircraft) has some level of instrumentation available. The F900 non-FIM data tab of the Data Collection Spreadsheet traces each data item attributed to this aircraft to the ACSB system providing the recording, including data representation (units). A sample CSV file has been shared with NASA. At this time it is not expected to record separate files per flight test condition and thus a single file will be provided to Boeing by Honeywell for each flight test day within a 24 hour flow time. The sample file provided reveals the anticipated size of the data will approximate 90MB per flight hour.

Video/Audio Recording System:

On 3/23/2016 Boeing received a request from NASA to record audio and video of the flight deck operation of the FIM system. NASA interprets video and audio recording to be required under SOW 3.6.22 as exemplified within its Data Request Document. Honeywell will provide a video/audio recording system for its 757 aircraft, but United has not agreed to such recording on their 737 aircraft due to its pilot union limitations.

The 757 video and audio recording system includes two cameras mounted in such a way as to afford full view of both EFBs, with mixed-in audio corresponding to the audio control/tuning panel selections made by the pilot. This allows audio mix-in capturing pilot to pilot interactions via their headset microphones, pilot to ATC communications occurring over VHF radio, and pilot to Flight Director occurring over VHF radio. The video cameras will interface with a Network Time Protocol (NTP) server over Ethernet available on the aircraft, which will be used to time stamp all recorded video with UTC date/time for later correlation with other data correlated to the same time. The cameras are controllable over the network and will store video files on external storage via a separate laptop. A NASA provided 500GB external SSD will be used to record the data and Honeywell will deliver the data directly to NASA (not a contract deliverable). NASA requests the video format to be MP4 in H.264 encoding, which at HD resolution (1920x1080) assuming a standard 30 frames per second averages at worst 25GB per hour. For a 5 hour recording duration, this would correspond to a total necessary size on disk of exactly 250GB (2 cameras).

Administrative Data Collection System:

On the 757 and 737, a Flight Test Engineer (or the Flight Test Director), will take notes for each test condition that will identify test condition number, aircraft, date, start time, start location (approximate, or relative to the active waypoint), and end time. The notes should also include time stamps for events recorded during the flight test, for example covering conditions that were not expected, or would warrant data inspection post flight. Those notes will either be manually written on a pre-formatted form and transcribed into a spreadsheet at debrief, or directly entered in a spreadsheet on the FIM data recording laptop. On the non-FIM aircraft, the crew will take simplified notes on their test card, which will be transcribed into a spreadsheet at debrief.

Time Correlation

Data alignment across multiple recording systems is paramount to the analysis tasks at hand. The alignment will be done by use of a common time representation from a common time source. UTC time from GPS source will be the correlating time element across all recording systems and will be present in each system's captured data file at 1Hz along with the other data. In cases when a single file is produced for the flight test day (e.g. FDR data, TPU data when recorded on CompactFlash), it can be separated into chunks corresponding to each flight test condition by annotating the test condition start and stop times using the same time representation and source.

DATA RECORDING PROCEDURES

This section documents the procedures used to record each type of data on each recording system, including media handling and off-boarding procedures. At the time of this writing, these are still considered draft procedures. The next iteration of the document will flesh out more details and integrate within the rest of the flight test procedures identified elsewhere in this document.

FIM Data Recording Procedures (EFB and TPU)

A flight test engineer will operate the FIM system recording laptop on each FIM aircraft participating in a given flight test condition. Prior to the start of the flight test condition, the flight test engineer will determine and relate to the flight test director, proper functioning of the laptop and software recording system (monEFB and monTPA), and will start a new DAT file recording for each system, of the appropriate name, based on a file naming scheme that allows determination of the day, time, aircraft and flight test condition. Similarly, the engineer will log on a spreadsheet on the same laptop, administrative information about the test condition.

Recording will start 10 minutes prior to the execution of the flight test condition if feasible, and verification of valid recording, both from the live view and file content inspection, will be a required step for execution of the flight test condition on all participating FIM aircraft. Recording will continue until the Decision Altitude (DA) is achieved, which is past the Planned Termination Point (PTP). Upon return to base, each monEFB and monTPA DAT file recorded by the flight test engineer on the laptop will be off-boarded onto the flight test data repository. This involves physically taking the SSD drive off the aircraft, plugging it into a Boeing networked computing asset, and moving the files onto the Boeing network.

XSCRIBE will be used to generate CSV logs and a cursory inspection of each file will be performed to determine the quality of the recorded data and its ability to produce the required analysis for each identified flight condition. NASA will be given a copy of each file (DAT and CSV) nightly at or shortly after debrief and may review contents with Boeing subject to staff availability. Based on the CSV file content, Boeing will produce visual artifacts (graphs, MOPs) to determine success of the flight test day and feed forward any issues for the next planned test day if time permits.

In summary, the FIM data recording procedure will follow the identified steps:

- Pre-departure after aircraft power-on: Verify laptop is properly connected, has SSD storage attached, sufficient recording space exists for the daily test conditions, and the laptop can connect to the EFB/TPU system.
- Per condition, before start of test:
  - Start recording under a new file name, following the file naming convention
  - Enter test administrative data in the scenario spreadsheet
  - Using live-view, verify recording is occurring and data presented corresponds to expected FIM system state
  - Inspect the local file to determine proper name, timestamp and file size growth
  - Report recording system status to Flight Test Director
- Per condition, at end of test:
  - Verify recording occurred by inspection of file size and timestamp
  - Verify sufficient storage remains for the next condition. If necessary, attach a different external SSD, or switch to recording on the laptop hard-disk.
- Post-departure:
  - Off-board laptop and external SSDs used and copy all files to the flight test data repository.
  - Produce CSV logs using XSCRIBE for each test case directly on the flight test data repository.
  - Duplicate each CSV file and share with NASA in a directory structure as follows:

- Test condition
  - 737 Aircraft
    - All CSV files for this aircraft and flight test condition
  - 757 Aircraft
    - All CSV files for this aircraft and flight test condition

  This may happen via physical media (thumb drive), or access to a network file share.

- – Inspect CSV files for proper content (cursory analysis) and produce visual artifacts and some MOPs to assess success of each run using analysis scripts on the Analysis Platform.
- – Return laptop to initial state, including erasing day-of data recording

757 aircraft Data Recording Procedures

Aircraft bus data recording will be set up pre-departure according to standard Honeywell flight test procedures. The recording system has the ability to record each condition into separate files and the procedures will include steps for cycling the recording to a new file, and recording the cycle number as well as matching it to each individual flight test condition in the administrative test record. The data will be recorded on on-board media and archived into Honeywell flight test data repositories upon conclusion of the flight. The data will be duplicated and moved to the Boeing SSDs in the aircraft at the conclusion of each flight for off-board storage into the ATD Flight Test Data repository.

In summary, the 757 data recording procedure will follow the identified steps:

- Pre-departure: Set up and verify recording for non-FIM data
- During test: Record test condition start/stop times in UTC time from GPS source
- After aircraft power off:
  - – Copy local bus data (for each condition) onto Boeing SSD
  - – Transfer SSD contents into ATD flight test data repository
  - – Inspect file for proper content (cursory analysis only)

United aircraft

The United aircraft will utilize the FDR (Flight Data Recorder) system to record airplane data. The FDR system will not have the ability to record each condition into separate files; thus there will be a need to split the recording into individual chunks corresponding to each flight test condition by correlation to UTC time stamps for each condition start/stop.

Raw FDR data recorded on-board the aircraft must be off-loaded using a maintenance portable computer by United, is typically not human readable, and must be processed. United will retrieve the FDR file upon return to base and deliver it on portable media to Boeing. Boeing will convert the FDR file to CSV format, a process estimated to take 1-3 business days and performed by personnel not associated with the program. Thus FDR data will not be used to determine success of the current flight day.

In summary, the 737 data recording procedure will follow the identified steps:

- Pre-departure: Verify FDR system is ready and operational
- During test: Record test condition start/stop times in UTC time from GPS source and document in Administrative data spreadsheet.
- After arrival:
    - Retrieve data from aircraft (United)
    - Process data into usable form (Boeing)
    - Copy content into flight test data repository
    - Separate file content into individual flight test condition per the test condition time stamps (start/stop)

Video/Audio Recording Procedures

Video and audio will be captured on the Honeywell 757 platform through the use of the two onboard camera systems.

In summary the 757 audio/video recording procedure will follow the identified steps:

- Pre-departure: Verify audio/video system is installed properly and set up to record the desired views
- During test: Record test condition start/stop times in UTC time from GPS source
- After arrival:
    - Rename file to follow naming template, including day/time/flight test day #
    - Document each flight test condition start/stop times
    - Copy audio/video data onto NASA SSD

– Deliver media and test condition start/stop times to NASA

FLIGHT TEST DATA DELIVERY (Deliverable 4.24): TIMING, FORM AND FORMAT

NASA requests all the flight test data be delivered in a single file in common format, for each aircraft and for each test condition at the conclusion of the flight test program. This will require re-packaging all the data collected from multiple sources in multiple forms, a task not strictly necessary to support Boeing's analysis and data delivery sections of the SOW. Boeing will deliver to NASA, upon conclusion of the flight test program, and possibly in some increments during the flight test program to be negotiated, all the individual files produced by the various systems on each platform for each condition. Although not in common format, this delivery will be structured to clearly relate all data files to the test condition and aircraft as follows.

Top Level	Day Directory	Run Directory	Airplane Directory	System Directory	Contents
	Day1-2017-0115				
		Run1-Condition1			
			737		
				EFB	*.dat, *.csv
				TPU	*.dat, *.csv
				Non-FIMdata	FDR.csv
			757		
				EFB	*.dat, *.csv
				TPU	*.dat, *.csv
				Non-FIMdata	BUSdata.csv
			F900		
				Non-FIMdata	ASCB.csv
		Run2-Condition2			
		RunX-ConditionY			
		…			
	Day2-2017-0116				
	…				

Within the last level directory (system directory), the type, date, run number, condition number and aircraft type will included in the file name.

For example, a EFB DAT file for Day3, Run 3, Condition 1, from the 757 may have the name "Day3-Run3-Condition1-757-EFB.dat" and be found in the corresponding directory.

The entirety of the data content, in the structure described above will be delivered to NASA on physical media or via SharePoint and will constitute Deliverable 4.24 by the date of delivery stated in the Work Plan.

Daily FIM system data (EFB data) will be delivered to NASA and inspected jointly for determination of experiment success. Criteria and tools for determining daily experiment success are being developed and will be finalized prior to flight test program commencement.

Data Flow Summary

The data flow for the flight test program is depicted graphically in Figure 11 below:

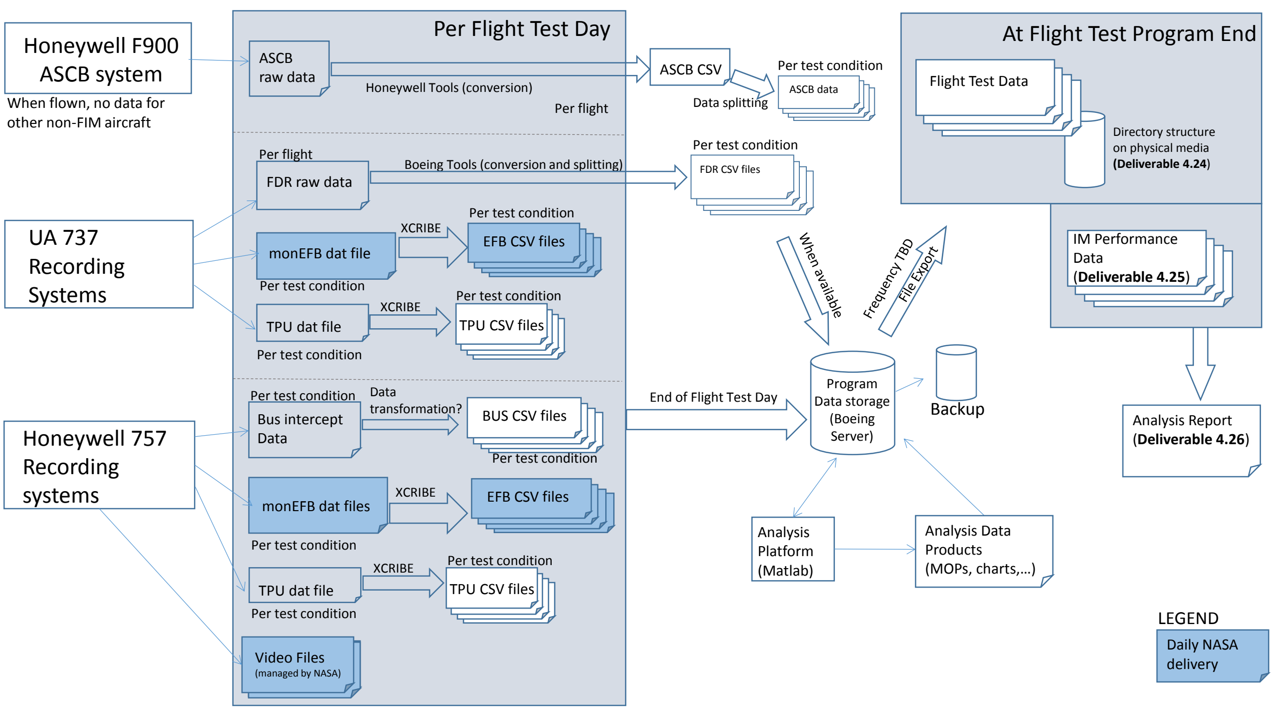


Figure 11. Data Flow

EFB, TPU and 757 non-FIM data will be available per test condition at the conclusion of each flight test day. All other data (except for video and audio) will need to be processed and split into individual chunks based on each test condition start/stop times recorded in each Administrative Spreadsheet and this may take longer than is available at the conclusion of the flight test day.

The EFB and TPU DAT and CSV files labeled according to a common scheme that includes flight test day, date, aircraft (757 or 737), and flight test condition (experiment number), will be cursorily inspected shortly following the conclusion of each flight test day and shared with NASA. Inspection and analysis may be done jointly during or shortly after the flight debrief. NASA may use its own tools, and

Boeing will leverage its analysis platform on this data to produce MOPS and graphical artifacts that will help in determining the success of the run, or identify issues requiring further review. The latter may need inspection of other data that may only become available later, depending on the processing flow time and available resources in the intervening hours.

Video and audio files will be handed to NASA directly on NASA media by Honeywell in the aircraft upon return to base.

All flight test data (both raw form and processed, except for video/audio), with proper naming based on the appropriate convention, will be placed in the flight test data repository (a Boeing server) when it becomes available. The Analysis Platform will be used on this data to create MOP and other analysis products at least at the end of the flight test program, but likely sooner and at some frequency, depending on available resources and need to inspect data in cases requiring problem identification.

DATA ARCHIVING/POST-PROCESSING SYSTEM

Flight Test Data Repository

All data obtained through flight testing (except video) will be loaded onto a networked data repository that the analysis system will have access to. A shared folder on a Boeing file server is envisioned to serve this role. Boeing file servers are typically backed up nightly and are access controlled.

Data size estimates:

FIM system (per FIM aircraft [2], per flight test hour): 155 MB

FDR system (737 only, per flight hour): 2MB

757 system (757 only, per flight test hour): 90MB

ASCB system (F900 only, per flight hour): 90MB

Flight test hours: 18days, 5 hours each = 90 hours

Total flight hours (including flight time to/from test condition and test transition): 90 hours

Total FIM data recorded: 155MB/hr * 2 * 90 hr = 28 GB

Total non-FIM data recorded: (2MB/hr+90MB/hr+90MB/hr) * 90 hours = 17GB

Total data recorded: 45 GB

Thus, even considering for duplication of data and a factor of 2.0 for conservatism, a 500GB medium should hold all the flight test data comfortably.

Analysis Platform

The analysis platform will be a Boeing computing asset running Matlab and executing Matlab code directly on the data, or a copy of the data. The analysis data derived from analysis will be kept in a separate, but correlated, location on the flight test data repository for each flight test condition. Aggregated analysis data, such as MOPs for a variety of flight conditions will be kept at a higher level.

Matlab as a platform is capable of interfacing directly with network share data, and the analysis code can be version controlled. For large data manipulations, Boeing has the ability to utilize a computing cluster for parallelization. Analysis code will be shared with NASA prior to flight test to validate the method and content of analysis data and artifacts produced.

ANALYSIS PRODUCTS AND PROCEDURES

Analysis requirements are tied to SOW 3.6.19 and the documented MOPs as found in *GFI 5.11*. A review of the MOPs definition and corroboration with NASA occurred through correspondence and at CDR. The following data will be derived to support the type of analyses called for in the SOW.

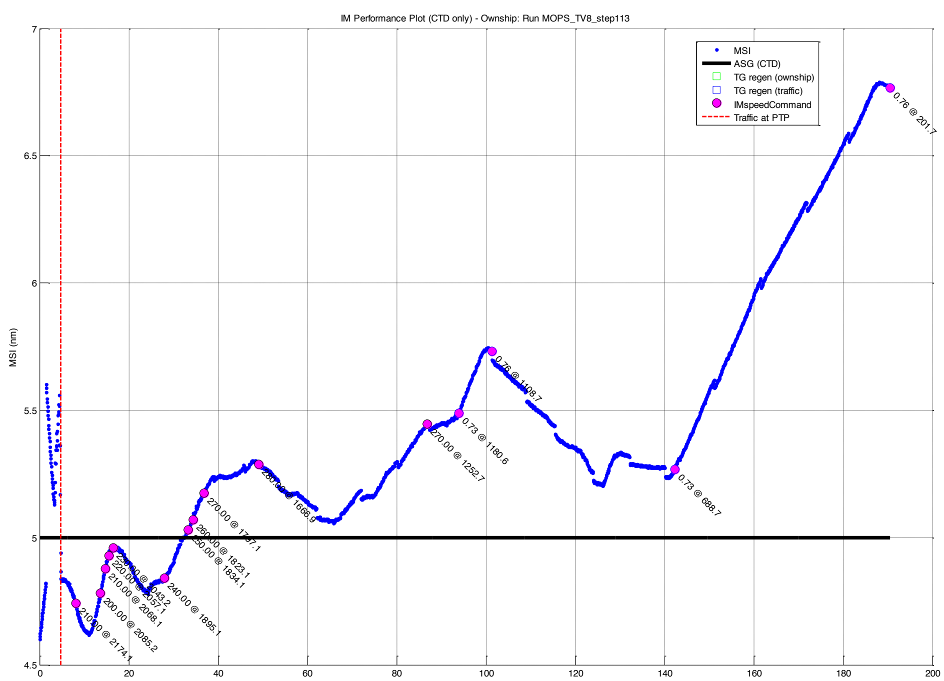
Spacing Error (Performance) MOP

When available, MSI (in time or distance) will be the measure of the actual spacing, logged at 1Hz starting when the system entered the ARMED state. The FIM control operates on the difference between the spacing interval (measured or predicted) and the assigned spacing goal. In capture, maintain, and in the maintain phase of achieve operations, the spacing interval will be MSI, computed on-board the FIM system based on both aircraft state and IFPI. The actual MSI can be computed post-facto against the aircraft recorded state using the same method, but no difference is expected as the source of error for such computation is solely rooted in the error of the input (IFPI and state), for which no error-free sources exist. Thus the MSI reported by the FIM system can be taken to be the actual MSI. In regions of flight when the FIM system does not produce MSI (e.g. prior to ARM state, during the achieve stage of achieve and maintain operations on a coincident segment, or after PTP), the MSI value will be computed from the aircraft state history using the same methodology. Thus actual spacing, and spacing error (MSE), can be reported in corresponding geometries at all points in the flight profile for all times from start of test condition to the end of it.

Typical ways to report such data are in the form of line plots of MSI and/or MSE against distance to go to a common point (PTP or beyond). For maintain operations, the aggregate spacing performance MOP reported for an operation (1 or 2 FIM operations per test condition) will include three categories:

- The initial spacing error at system EXECUTE state transition
- Descriptive statistics of the predicted spacing error (PSE) during the achieve segment including
  a. Mean
  b. Standard Deviation
- Descriptive statistics of the spacing error (MSE) during the maintain segment including
  a. Mean
  b. Standard Deviation
- The achieved spacing error at the PTP

An example of such plots produced by the Matlab analysis platform on sample data taken during system development is shown below:



The plot depicts MSI against Distance to Go (DTG) superimposed with FIM commands and critical time points between the system reaching the EXECUTE state, and the ownship passing the PTP. For this example, the following metrics are recorded:

Initial error at EXECUTE: 1.7677 nm

Achieved error at PTP: -0.1664nm

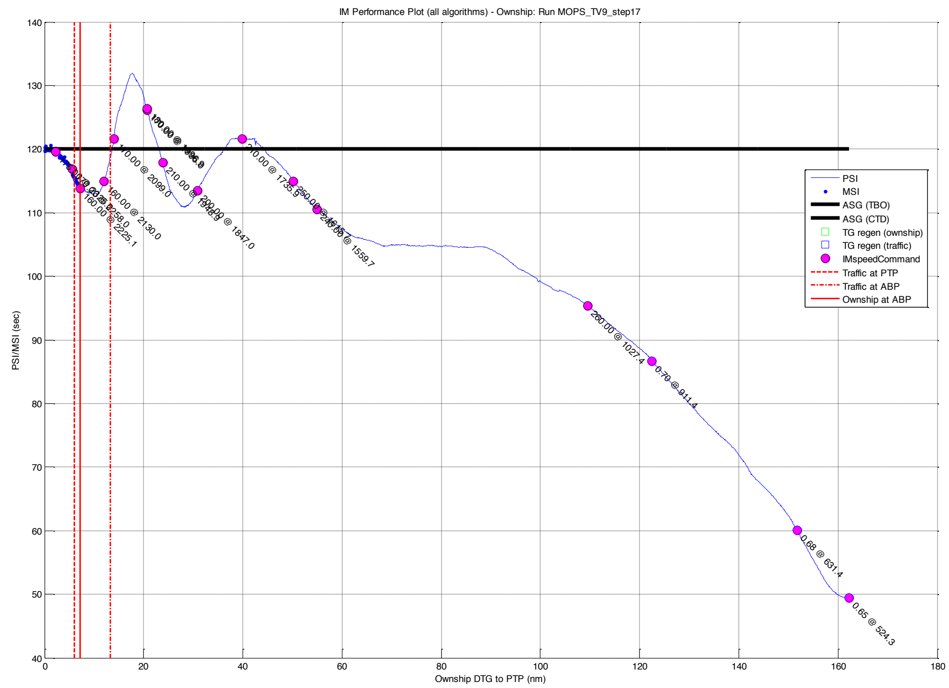
Mean absolute error throughout operation: 0.4744 nm

STD absolute error throughout operation: 0.4360 nm

For achieve operations, PSI (in time or distance) is computed by the FIM system and can be reported against distance to go (DTG). In geometries where the merge point occurs prior to the ABP, MSI can be computed for the common segment using state data. On those common segments, MSI can be compared to PSI as a surrogate measure of prediction performance. For achieve operations, the aggregate spacing performance reported for an operation (1 or 2 FIM operations per test condition) will likely include five categories:

- The initial predicted spacing error at system EXECUTE state transition
- The initial spacing error (from MSI) at the beginning of the common segment (if any)
- The achieved spacing error (MSI) at the ABP
- Descriptive statistics of the spacing error (MSE) during the maintain segment including
    a. Mean
    b. Standard Deviation
- The achieved spacing error (MSI) at the PTP

An example of MSI plot for achieve-by operation is shown below. It is very similar to the plot for capture/maintain operations, except PSI is shown instead of MSI.



Initial error at EXECUTE: -70.5188 s

Achieved error at ABP: -5.46s

Achieved error at PTP: 0.47s

Mean absolute error achieve segment (to ABP): 20.91s

STD absolute error achieve segment (to ABP): 19.1233s

Mean absolute error maintain segment (ABP to PTP): 2.07s

STD absolute error achieve segment (ABP to PTP): 1.91s

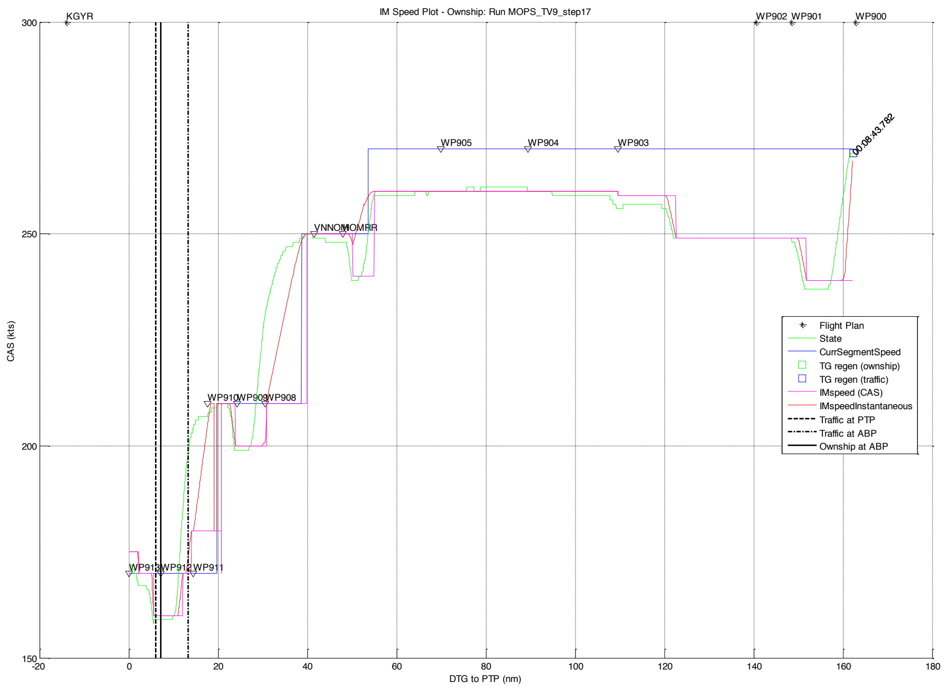
Aggregate statistics for each of these Spacing performance MOP will be computed and reported for comparable conditions in the flight test matrix. Measures of central tendency will be computed and reported either as discrete numbers or as box plots for each comparable conditions. The Spacing Performance MOP as defined in GFI 5.11 will be reported for comparable conditions based on that data.

<u>Control/Capture Performance</u>

Measures of performance of the control go beyond the observed quality of the achieved control. The number, timing and size of each control action also needs to be analyzed and correlated to the achieved performance. For each test condition, the following data will be computed as measures of control performance:

- Time and value of each FIM speed advisory (IM commanded speed) issued by the FIM system
- Time and value of the corresponding speed entered in the MCP by the pilot (actual commanded speed)
- Control action delay, computed as the difference in time between 1 and 2 above for each control action
  - If the pilot decides to not implement the FIM speed for any reason, he will be asked to annotate the time/value and reason on the test card.
- Control margin, computed as the difference between the nominal speed and the maximum/minimum speed for each flight segment. Control margin remaining can be computed similarly against the issued FIM speed.
- Control status, indicating whether the control was subject to any speed limiting, indicating the nature of the limit.
- Capture time, computed as the time taken for the aircraft state to reach the control after MCP entry.
- Control monitoring events, in the form of number and timing of control conformance events issued by the FIM system.

Graphical representation of the above data will be created in a DTG vs Airspeed plot for each FIM aircraft. For example of such plots see the plots shown under the Spacing Performance section above. Each command is shown at its appropriate DTG with corresponding value and time. For the example shown, pilot delay metrics cannot be computed as no aircraft data is available in the simulation platform. However, an example of a plot that displays some of this data is shown below:



Statistics for all single flight aggregated performance measures, computed from a comparable set of test conditions will be computed and reported. Measures of central tendency will be computed and reported either as discrete numbers or as box plots for each comparable conditions.

FIM System State

The state of the FIM system will be reported for each state transition against the common time representation and such state transition timing data can be superimposed on any plots of other measures of performance when necessary.

Flight Technical Error

FTE is defined as the airplane's lateral and vertical error relative to the aircraft guidance path from the FMS. Lateral and vertical deviations from the FMS guidance path are recorded as primary data elements on each FIM aircraft. This data can be used to reconstruct the instantaneous lateral and vertical flight guidance path. However, there is no source of data for FMS guidance path reconstruction times and thus there is no directly observable way to determine when the deviation is due to a guidance path reconstruction event. Deviation data will be inspected for large discrete changes throughout the flight envelope as an attempt to identify FMS TG times. Even in the case this can be done, there is no direct way to determine the FMS guidance path for all segments forward in the trajectory, only the current segment.

Some vertical deviations are expected resulting from operating the aircraft largely on VNAV SPEED mode during FIM operation, whereby the vertical guidance path produced cannot necessarily be maintained for the given target speed. There is no inherent downside to such vertical deviations, except for its effect on FIM trajectory prediction performance (based on the nominal vertical profile), and the increased likelihood of not meeting downstream vertical constraints, which should be mitigated by pilot procedure. Thus the use of the vertical deviation data will mostly focus on two aspects:

- Correlation of the deviation size to FIM trajectory prediction performance, as computed from changes in PSI, and FIM system PDE.
- Verification of meeting vertical constraints for each constrained point in the procedure

The lateral deviation is expected to remain very small given the expectation that the flight will mostly be executed under LNAV lateral control, except in the final approach region, when/if transition to Approach mode occurs. The lateral deviation data will be reported as a plot against distance to go to the PTP and inspected for large deviations.

IFPI Path Definition Error

IFPI path definition error (PDE) is defined as the difference between the FIM generated trajectory, and the airplane's guidance trajectory. This MOP can be computed by comparing the TG generated lateral and vertical errors (subject to monitoring by the lateral and vertical FIM monitor function), to the corresponding lateral and vertical FTE (deviations) at the same instant in time. This MOP is difficult to compute for the longitudinal dimension since no FMS longitudinal trajectory information is available. It could be estimated by comparing the flown speed to the constructed speed profile in the TG post-facto. However, since FIM aircraft will operate a closed-loop speed system, the above can only be performed if an aircraft performs a baseline (open-loop) run against the procedure. These runs will occur anytime one of the two FIM-equipped aircraft acts as the lead Target while itself not performing a FIM operation (e.g., contingency operations when the non-FIM equipped aircraft does not fly).

Finally, in Final Approach Spacing situations, the difference in the computed intercept point and the actually flown transition will be treated as a measure of PDE for that operation.

Fuel Burn Metrics

Fuel burn will be computed from recorded data for each of the two FIM aircraft (Honeywell 757 and United 737) and the F900. Totalizer Fuel will be computed by integrating fuel flow, per engine, subtracted from an initial value for fuel in tanks (left, center, main) obtained from a stable period at the beginning of every flight test condition.

Fuel burn will not be reported comparatively to a known baseline, but rather in absolute terms for each flight condition. NASA proposes to use non-delay cases as baseline cases for fuel burn. These cases technically are not a true non-FIM baseline as the FIM system is expected to issue speed corrections even in the case of zero initial delay as a result of unpredictable changes in the environment (wind, temperature).

It has also been proposed, and the FAA has corroborated interest, in comparative fuel burn across similar operations on the same geometry. For example, comparing both from a FIM performance, but also from a fuel burn performance, the difference between a capture and maintain and an achieve-by and maintain operation on the same geometry for the same aircraft would help determine which of the two operations yield better overall performance.

Absolute fuel burnt for each operation (from transition to EXECUTE state to PTP) will be reported and statistics can be reported against the type of operation, environmental conditions and airplane type.

Wind Prediction Performance

Wind data will be recorded in three forms on the FIM aircraft only:

- Forecast winds entered into the system per the test condition, and recorded as FIM HMI data. (Once per operation)
- Observed winds on board each FIM aircraft as determined by comparing track information (angle and ground speed) to air mass information (heading and true airspeed), available within the defined FIM data (1Hz frequency).
- Blended wind forecast including both above factors, laid against the aircraft trajectory computed by the TG (once per TG generation).

Using the data above, a computed RMS wind speed and direction error per test condition will be computed. Spacing performance MOPs can then be correlated via standard analysis of variance and/or regression techniques to the wind prediction performance to understand the size of the effect of the wind prediction performance FIM performance.

Final Approach Speed

Final approach speed will be recorded through both FIM and non-FIM data.

The actual final approach speed flown will be available from the non-FIM data set, and the assumed final approach speed by the FIM system will be recorded within the FIM system. The lead aircraft (non-FIM) will include FMS selected (weight and wind based) reference speed. It should be noted that no HMI based entry of final approach speed is available within the FIM system, thus it is expected that the final approach speed assumed by the FIM system will be the same regardless of environmental conditions or aircraft type. In fact the final approach speed will be a system parameter selectable at boot time.

The analysis requirement for susceptibility to differences between FIM assumed final approach speed and actual final approach speed is assumed to be concerned with the actual observed compression resulting from that difference, and computed as the actual time (or distance) based spacing post PTP derived from aircraft state data recorded. This compression (evolution of actual spacing post PTP) will not be considered a measure of FIM performance since the system is likely to be inactive in that flight region considering the geometries and test conditions currently planned. However it will be computed and reported.

Analysis Procedure

To the extent possible, analysis and production of the identified MOP and presentation products should occur automatically at the conclusion of each flight day by Matlab scripts operating on the data in the Flight Test Data Repository. A subset of such analysis should be used to determine the success of individual test runs at the flight day conclusion. The timing of the availability of such data depends on:

- Time of day at conclusion of flight test day
- Time of day at availability of flight test data in flight test repository
- Analysis time required to produce MOP and analysis products and availability of personnel
- Time available between successive flight days

On back-to-back flight test days, it may not be possible to fully analyze each test condition flown on the previous day. However, on planned rest days, analysis of data obtained to date should be performed. Also, on days with known issues, data should be analyzed for the identified troublesome conditions and may be available for reporting during de-brief, or at least prior to the next flight test day. In some cases, deep inspection of the data and corresponding analyses may determine what test conditions to reproduce on the next flight test day.

All MOP computed, both for individual test conditions and comparisons across conditions, including supporting graphical artifacts, will be included in the Final Report (Deliverable 4.26).

Annex D: Flight Test Cards

This section contains examples of the five different test card formats used for the ATD-1 flight test, each customized to the particular user. Each format was created in Word, then using the Mail Merge function, the data for that particular day and the proper sequence of runs was created and then sent to everyone the day prior to the flight.

Below are examples of the five flight test cards for each user for 13 Feb, scenario (B4).

ATD-1 Flight Plan **Date: 2/13/2017** **(KMWH 32R)** Published: 2/12, ch 1

Scenario 1: A05 (first half of flight plan)

- **N889H:** **Route: BFI..ZIRAN..BARYN..JELVO, FL350**
- **N757HW:** **Route: BFI..ZIRAN..BARYN..JELVO, FL350**
- **UAL2197:** **Route: SEA..ZIRAN..BARYN..JELVO, FL350**
  - *After SINGG all three aircraft remain in trail and commence next arrival procedure; delay not expected at IPs.*

Scenario 2: B04 (second half of flight plan)

- **N889H:** **IP: RIINO 343010, LT, FL300** **Route: RIINO.SUBDY1.SUBDY.RRZ32R**
- **N757HW:** **IP: MAHTA 274010, RT, FL330** **Route: MAHTA.SUBDY1.SUBDY.RRZ32R**
- **UAL2197:** **IP: JELVO 222010, RT, FL350** **Route: JELVO.SUBDY1.SUBDY.RRZ32R**

Scenario 3: B17

- **N889H:** **IP: RIINO 343010, LT, FL220** **Route: RIINO.SUBDY1.SUBDY.RRZ32R**
- **N757HW:** **IP: MAHTA 274010, RT, FL230** **Route: MAHTA.SUBDY1.SUBDY.RRZ32R**
- **UAL2197:** **IP: NACUN 312010, LT, FL230** **Route: NACUN.UPBOB1.UPBOB.RRZ32R**

Scenario 4: B21

- **N889H:** **IP: SINGG 222015, LT, FL220** **Route: SINGG.SUBDY1.SUBDY.RRZ32R**
- **N757HW:** **IP: MAHTA 274010, RT, FL230** **Route: MAHTA.SUBDY1.SUBDY.RRZ32R**
- **UAL2197:** **IP: SINGG 222030, LT, FL230** **Route: SINGG.SUBDY1.SUBDY.RRZ32R**

Scenario 5: B18 (note: N889H RTB after scenario #5)

- **N889H:** **IP: RIINO 343010, LT, FL220** **Route: RIINO.SUBDY1.SUBDY.RRZ32R**
- **N757HW:** **IP: MAHTA 274010, RT, FL230** **Route: MAHTA.SUBDY1.SUBDY.RRZ32R**
- **UAL2197:** **IP: SINGG 222030, LT, FL230** **Route: SINGG.SUBDY1.SUBDY.RRZ32R**

Scenario 6: C05 (note: sequence swap)

- **UAL2197:** **IP: (A) IWKID 115020, na, 6000** **Route: 30 degree intercept**
- **N757HW:** **IP: WATSY, 220 kts at 25 nmi, 7000** **Route: Straight in**

Scenario 7: C06

- **UAL2197:** **IP: (A) IWKID 115020, na, 6000** **Route: 30 degree intercept**
- **N757HW:** **IP: WATSY, 220 kts at 25 nmi, 7000** **Route: Straight in**

Figure 12: Test Card for ATC

N889H	**B04** (Rwy 32R)	# 2
Date: 2/13/2017		Printed: 2/12, ch 1

File To: JELVO..MAHTA

IP: RIINO 343/010, LT, FL300

ETA at NALTE (from FMS): __________ (LP)

NALTE STA (from FTD): __________

Depart Initial Pt to achieve NALTE STA

<u>Aircraft 1 Ownship Data</u>:

- DESTINATION: **KMWH**
- Runway: **32R**
- Route / STAR: **SUBDY1.RIINO (JELVO)**
- Approach: **RRZ32R.SUBDY**
- Speed Profile: **FL300 270 KT**

<u>Aircraft 1 Route:</u> [FTD freq: 123.525]

- (JELVO) 0.78 M
- (MAHTA) 280
- RIINO 270
- OYOSE 270
- NALTE 270
- SUBDY 210
- WIDKO 210
- HIXOS 210
- ZETEK 190
- ZAVYO 170

AC #1: N889H, RIINO 343/010, FL300
AC #2: N757HW, MAHTA 274/010, FL330
AC #3: UAL2197, JELVO 222/010, FL350

After SINGG all three aircraft remain in trail and commence next arrival procedure; delay not expected at Ips. No Target delay.

Figure 13. Test Card for aircraft #1

N757HW	B04 (Rwy 32R)	# 2
Date: 2/13/2017		Printed: 2/12, ch 1

File To: JELVO
IP: MAHTA 274/010, RT, FL330
ETA at NALTE (from FMS): __________
NALTE STA (from FTD): __________

Depart IP to achieve NALTE STA

Aircraft 2 Ownship FIM Data:

- DESTINATION: **KMWH**
- Runway: **32R**
- Route / STAR: **SUBDY1.MAHTA (JELVO)**
- Approach: **RRZ32R.SUBDY (ENTER DONE)**
- Cruise Descent: **FL350 .78M 270 KT (DONE)**
- CRUISE & DESCENT WINDS: entered

Aircraft 2 FIM Data: [FTD freq: 123.525]
Note: if required, clear FIM data (CANCEL IM) prior to data entry

- IM CLEARANCE: **CAPTURE**
- Test ASG (blue): **111 sec**
- TARGET ID: **N889H**
- TARGET ROUTE: **auto-loaded**
- ACHIEVE BY: **N/A**
- TERMINATE: **ZAVYO (ENTER ARM)**

ARM at JELVO

PSI desired: 210-270 sec Error: -60 sec [Goal: 150-210 sec]

PSI (white, from algorithm): __________ ***PSI to FTD***
ASG (blue, FTD assigned): __________ ***Execute FIM***

AC #1: N889H, RIINO 343/010, FL300
AC #2: N757HW, MAHTA 274/010, FL330
AC #3: UAL2197, JELVO 222/010, FL350

After SINGG all three aircraft remain in trail and commence next arrival procedure; delay not expected at Ips. No Target delay.

Figure 14. Test Card for aircraft #2

UAL2197	**B04** (Rwy 32R)	# 2
Date: 2/13/2017		Printed: 2/12, ch 1

File To: JELVO 222010
IP: JELVO 222/010, RT, FL350
ETA at NALTE (from FMS): _________
NALTE STA (from FTD): _________

Depart Initial Pt to achieve NALTE STA

Aircraft 3 Ownship Data:

- DESTINATION: **KMWH**
- Runway: **32R**
- Route / STAR: **SUBDY1.JELVO (JELVO)**
- Approach: **RRZ32R.SUBDY (ENTER DONE)**
- Cruise Descent: **FL350 .78M 270 KT (DONE)**
- CRUISE & DESCENT WINDS: entered

Aircraft 3 FIM Data: [FTD freq: 123.525]

Note: if required, clear FIM data (CANCEL IM) prior to data entry

- IM CLEARANCE: **MAINTAIN**
- Test ASG (blue): **sec**
- TARGET ID: **N757HW**
- TARGET ROUTE: **auto-loaded**
- ACHIEVE BY: **N/A**
- TERMINATE: **ZAVYO (ENTER ARM)**

ARM at JELVO

PSI desired: 150-210 sec Error: 0 sec [Goal: 150-210 sec]

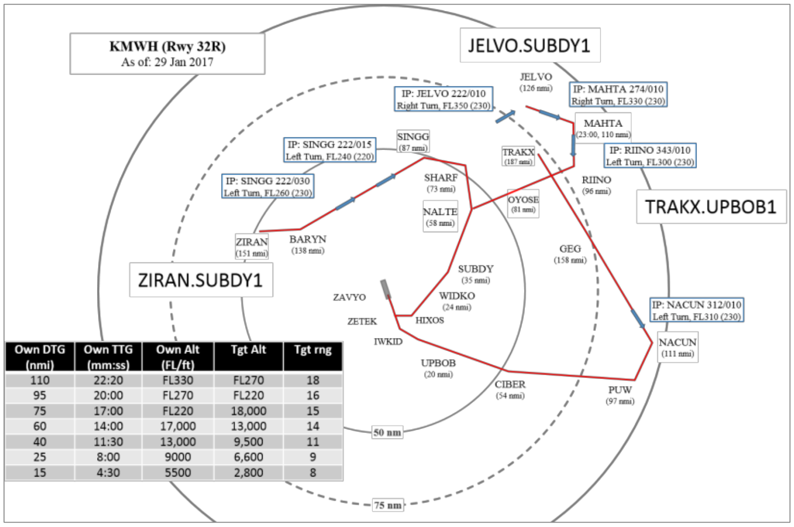
PSI (white, from algorithm): _________ ***PSI to FTD***
ASG (blue, FTD assigned): _________ ***Execute FIM***

AC #1: N889H, RIINO 343/010, FL300
AC #2: N757HW, MAHTA 274/010, FL330
AC #3: UAL2197, JELVO 222/010, FL350

After SINGG all three aircraft remain in trail and commence next arrival procedure; delay not expected at Ips. No Target delay.

Figure 15. Test Card for aircraft #3

Date: 2/13/2017 Seq #: 2 Scenario: **B04** Start/Stop time: Published: 2/12, ch 1



Sequence / Callsign	#1 / **N889H** (LP)	#2 / **N757HW**	#3 / **UAL2197**
IP, Alt	RIINO 343/010, LT, FL300	MAHTA 274/010, RT, FL330	JELVO 222/010, RT, FL350
Route	RIINO.SUBDY1.RRZ32R	MAHTA.SUBDY1.RRZ32R	JELVO.SUBDY1.RRZ32R
Crew to FTD: ETA to:	NALTE:	NALTE:	NALTE:
Diff from LP		+4	+7
FTD to crew: STA to:			
(Delay) FIM Type	(None)	CAPTURE	MAINTAIN
ABP		N/A	N/A
Desired PSI interval		210-270 sec	150-210 sec
Crew to FTD: PSI			
Desired Spacing Error		-60 sec	0 sec
FTD to crew: ASG			
ARM at:		JELVO	JELVO

Notes: After SINGG all three aircraft remain in trail and commence next arrival procedure; delay not expected at Ips. No Target delay.

Figure 16. Test Card for Flight Test Director

Annex E: Minimum Equipment List (MEL)

This Annex outlines the minimum equipment required to conduct FIM operations and RNP AR approaches.

Minimum equipment required to conduct FIM operations:

- 1 ADIRU
- 1 MMR (GNSS position source)
- 1 ARINC 718A-4 transponder
- 1 ARINC 735B-2 TCAS
- GPS RAIM forecast of HPL < 0.6 nmi (NIC ≥ 6) and NAC_p ≥ 7
- VNAV Speed Intervene mode on Mode Control Panel (MCP)
- 1 Fully charged iPhone (as CGD)
- 1 Wireless router
- 1 Electronic Flight Bag
- 1 AID
- 1 laptop for data collection (B-737 only)

Minimum equipment required to conduct RNP AR approaches:

- 2 Flight Management Computers (FMC) with RF leg capability
- 2 GPS receivers, TSO C129 or better
- 2 IRUs in NAV mode (or 2 ADIRUs in NAV mode)
- 1 Auto-pilot capable of LNAV/VNAV
- 2 Flight Directors capable of LNAV/VNAV
- 2 Radar Altimeters
- Early Ground Proximity Warning System (EGPWS)

Revision Record

Revision Letter A

Changes in This Revision Updated to reflect comments received throughout the document from NASA

Authorization for Release

AUTHOR:	Signature on File	9M-PW-ERCS	11 January 2017
	Dan Boyle	Org. Number	Date
AUTHOR (ANNEX C):	Signature on File	66-CB-E111	11 January 2017
	Julien Scharl	Org. Number	Date
APPROVAL:	Signature on File	9M-PW-ERCS	11 January 2017
	Karl J. Rein-Weston	Org. Number	Date
DOCUMENT RELEASE:	Signature on File	9M-PW-ERCS	11 January 2017
	Barbara L. Withers	Org. Number	Date

Revision Record

Revision Letter B

Changes in This Revision Updated to reflect comments made by NASA throughout the document

Authorization for Release

AUTHOR:	Signature on File	9M-PW-ERCS	3/8/2017
	Dan Boyle	Org. Number	Date
AUTHOR (ANNEX C):	Signature on File	66-CB-E111	3/8/2017
	Julien Scharl (Annex C)	Org. Number	Date
APPROVAL:	Signature on File	9M-PW-ERCS	3/8/2017
	Karl J. Rein-Weston	Org. Number	Date
DOCUMENT RELEASE:	Signature on File	9M-PW-ERCS	3/8/2017
	Barbara L. Withers	Org. Number	Date

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01- 03- 2017

2. REPORT TYPE
Contractor Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
NASA ATD-1 Avionics Phase 2 Flight Test Plan

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Brown, John A.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
330693.04.10.07.09

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA-CR-2017-219595

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 03
Availability: NASA STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES Langley Technical Monitor: Denise K. Scearce

14. ABSTRACT
The purpose of this flight test plan is to describe procedures for conducting FIM operations with the FIM Avionics Systems installed in two test aircraft.

15. SUBJECT TERMS
ATD-1; Airspace managment; Aviation; FIM

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	97	STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)* (757) 864-9658

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18