



# ATD-1 Avionics Phase 2 Flight Test: Flight Test Operations and Safety Report (FTOSR)

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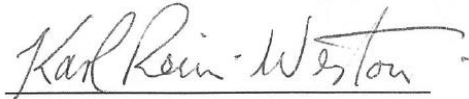
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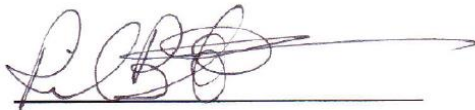
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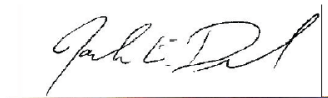
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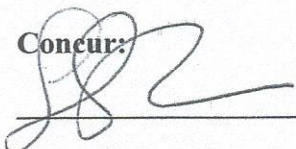


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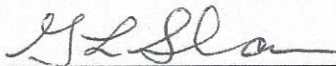
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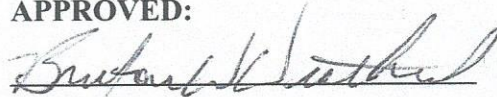


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## ATD-1 Avionics Phase 2 Flight Test using Honeywell and United Airlines Aircraft

### 1. Program Overview

The Air Traffic Management Technology Demonstration-1 (ATD-1) is a major applied research and development activity of NASA’s Airspace Operations and Safety Program (AOSP). The demonstration is the first of an envisioned series of Air Traffic Management (ATM) Technology Demonstration sub-projects that will demonstrate innovative NASA technologies that have attained a sufficient level of maturity to merit more in-depth research and evaluation at the system level in relevant environments.

#### 1.1 Program Objectives and General Description

The overall goal of ATD1 is the operational demonstration of an integrated set of NASA arrival management technologies for planning and executing efficient arrival operations in the terminal environment of a high-density airport. Specifically, for this flight test, the two sub-goals are as follows:

- 1) Develop avionics hardware and a FIM application that provides the automation required for FIM operations
- 2) Integrate FIM avionics into two test aircraft and conduct validation flight tests

The ATD-1 demonstration, scheduled for 2017, will include flight trials with multiple aircraft equipped with prototype avionics supporting FIM operations.

#### 1.2 Project Management

The Project and flight test management members of the team are as follows:

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<p><u>NASA Project Manager:</u> William Johnson NASA LaRC, Hampton, VA (757) 864-3858 William.Johnson@nasa.gov</p>	<p><u>NASA Flight Test Lead:</u> Brian Baxley NASA LaRC, Hampton, VA (757) 864-7317 Brian.T.Baxley@nasa.gov</p>
<p><u>NASA Technical Point of Contact for the Statement of Work:</u> Denise Searce NASA LaRC, Hampton, VA (757) 864-1864 Denise.K.Searce@nasa.gov</p>	

### 1.3 Selected Aircraft

All aircraft used as part of this contract will be operated under that contractor’s FAR Part 91 approval, and will be flown by that contractor’s flight crews, who will be qualified and current in that aircraft for all operations to be performed. Two of the aircraft will be flown under Experimental certificates due to the installation of prototype FIM equipment and software.

#### 1.3.1 Target aircraft (Honeywell Dassault 900)

The research or business transport aircraft is equipped with ADS-B Out technology (DO-260B compliant). Its operating characteristics and functionality are similar to commercial transport category aircraft, and include full IFR capability, GNSS equipage, and capable of LNAV/VNAV, RNAV, and RNP AR.

The alternative or back-up is a transport (non-research) Falcon 900 or an Embraer 170. Each will have the same avionics capabilities as the primary target aircraft. More details will be provided if this option becomes primary.

#### 1.3.2 FIM aircraft #1 (Honeywell Boeing 757)

The first FIM aircraft will be the Honeywell 757 test aircraft that will be equipped with DO-260B-compliant ADS-B Out and In technology, and the FIM Avionics System running the FIM application. The aircraft is a commercial transport category aircraft permanently utilized in the flight test role; its operational capabilities include full IFR, GNSS equipage, and LNAV/VNAV, RNAV, and RNP AR performance.

#### 1.3.3 FIM aircraft #2 (United Airlines Boeing 737)

The second FIM aircraft is a United Airlines (UAL) Boeing 737-900 that will be equipped with DO-260B-compliant ADS-B Out and In technology, and the FIM Avionics System running the FIM application. It is a standard production revenue aircraft which will be modified for this flight test with FIM and additional data-gathering equipment (engineering work station). Like the 757, its operational capabilities include full IFR, GNSS equipage, and LNAV/VNAV, RNAV, and RNP AR performance.

#### **1.4 Proposed Aircraft Modifications and Design Criteria**

The Honeywell aircraft are maintained in accordance with the FAA approved Honeywell Flight Operations Maintenance Inspection Program Manual, per 14CFR 91.409 (e) (f) (4). All modifications are performed by an FAA approved repair facility and follow a 100% buyback process. The Required Inspection Item (RII) allows someone to do the work and inspect it, with a second person inspecting the work. The Honeywell aircraft are maintained, and the modification work performed, at the Honeywell repair station in Phoenix (AV4R064M).

The United Airlines aircraft is also maintained in accordance with their FAA approved procedures, and all modifications to the aircraft also use the RII process and will be performed in their FAA approved repair facility in Denver (CALA014).

The majority of the hardware used in this flight test is existing, FAA certified hardware. Some hardware will be installed specifically for the flight test, and then removed after the flight test to return the aircraft to its original configuration. Portions of the software are prototype, and these have been developed in preparation for certification for commercial use (TPU and transponder) or based on NASA's design (FIM avionics system).

The ATD-1 Avionics Phase 2 software assurance representative evaluated this activity per NPR 7150.2 and classified the software components for this Project as Class D (Basic Science/Engineering Design and Research and Technology Software; failure of the research system results in a minor failure condition for the aircraft). This is documented in the official Software Assurance Classification Report.

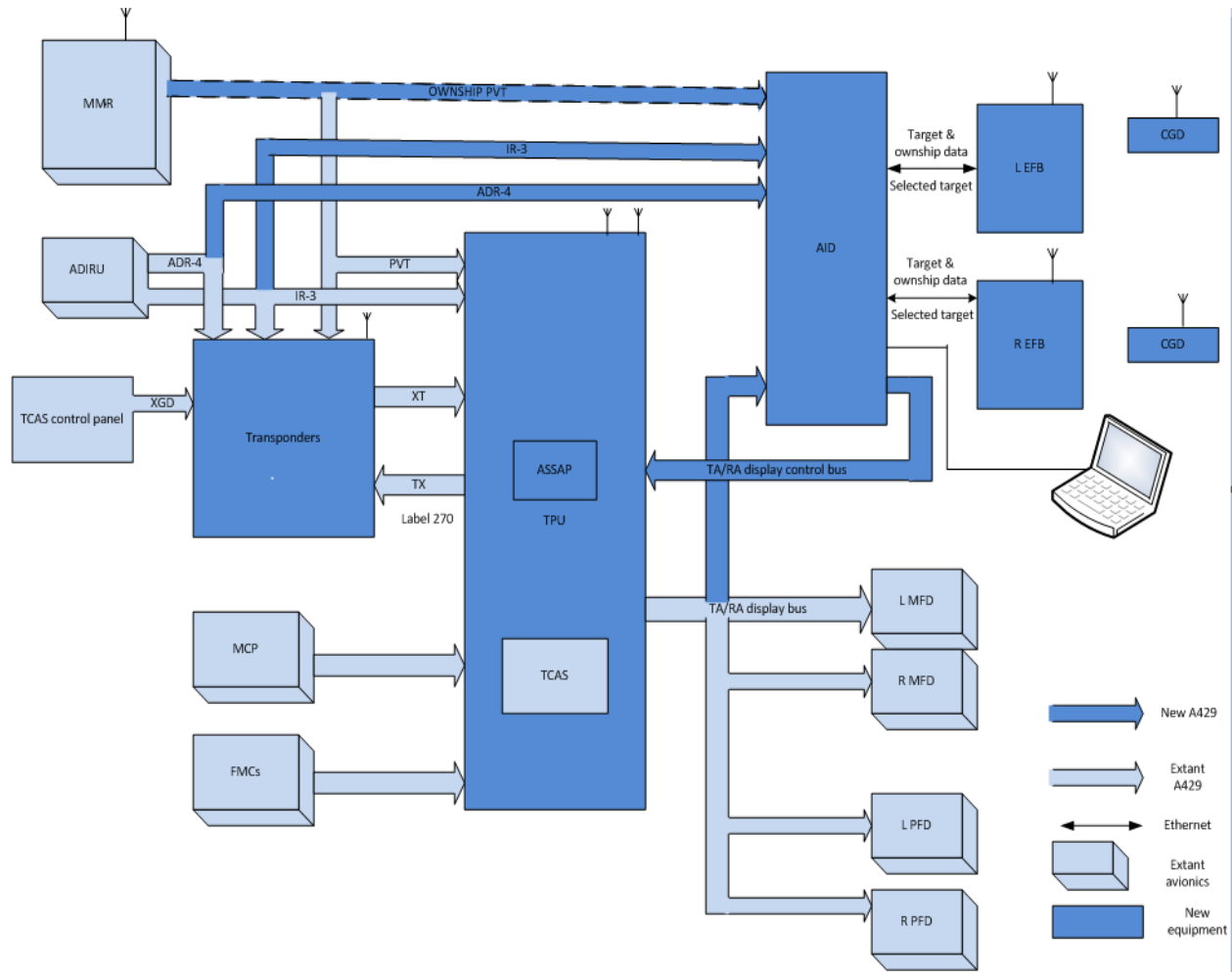


Figure 1: FIM Aircraft Certified Systems

The light blue boxes represent existing, certified systems that are included in the avionics suites of the FIM aircraft. The dark blue boxes are revised (Transponders and TPU) and additional systems. The transponder is DO-260B compliant and will be a unit that will enter airline service. The Traffic Processor Unit (TPU) replaces the TCAS unit and, as such, continues to provide TCAS functionality which is unaffected (regression testing carried out) by addition of the ASSAP function. The Aircraft Interface Device (AID) provides an interface with the Electronic Flight Bags, one of which, acting as master, runs the FIM application using target track data provided by the ASSAP function in the TPU.

Of special significance is the fact that data flow will be one-way, from certified avionics to revised or FIM equipment. Within the FIM-specific functions, the only data that flow back from the FIM application running in the EFB to the TPU is identification of the designated target aircraft. This ensures that the designated target always remains available for display regardless of how many other targets are present. This will be validated during the System Acceptance Review scheduled for December 2016.



## **1.5 Instrumentation Hardware/Software and Flight Test Data Measurement Requirement**

All hardware and software is contractor developed, owned, and provided. The FIM avionics and prototype hardware and software will be delivered to NASA after the Flight Test is complete.

There will be engineering stations in the form of laptop computers (provided by Honeywell) on board each of the FIM-equipped aircraft to record aircraft state data and FIM avionics data. No flight test data are required to be collected from the ground, although it may be possible to obtain flight track files from the FAA ATC facilities.

Data from the aircraft's FMS (QAR / FOQA) will be provided to NASA, and an audio/video recording of the Honeywell B-757 cockpit will also be provided to NASA.

## **1.6 Contractual Requirements**

The NASA Task Order # NNL15AB46T ("ATD-1 Avionics, Phase 2") has been issued for the period of 6/5/2015 to 6/4/2017 under the Flight Critical System Research contract #NNL13AA03B. (This document is also referred to as the Statement of Work, or SOW).

This SOW requires the contractor to "obtain experimental type certificates for each type of aircraft" for equipping with the prototype avionics (SOW paragraph 3.6.1). However, since the target aircraft will not be equipped with prototype equipment, it will operate under its current certificate. The SOW also requires the contractor to "coordinate with aircraft operators and the FAA facilities to obtain flight test approvals" (SOW paragraph 3.6.11). The operators are working with their regulatory authorities to obtain approvals, and Boeing has coordinated with the ATC facilities that will be affected to obtain their approval. In addition, Boeing has designed custom arrival procedures that have been approved by the FAA and published as Special STARs to allow flight test operations to be conducted under Instrument Flight Rules (IFR) (contract deliverable 4.22, Flight Test Plan). This approval process included provision of Letters of No Technical Objection by Seattle Center and Moses Lake TRACON managers. Should these STARs not be approved in time for the flight test, the mitigation plan is use an experimental version of that NDB that would be available for all three airplanes.

## **1.7 Other Involved Agencies**

### **1.7.1 Boeing**

#### **1.7.1.1 Boeing Research and Technology (BR&T)**

Boeing Research & Technology (BR&T) is the prime contractor for the ATD-1 Avionics Phase 2 contract. BR&T has been instrumental in the definition of the FIM operational concept, requirements, and minimum operating performance standards (MOPS). The company is actively involved in the evolution of the ARINC 735/735A/735B standards, in which TCAS/traffic computer aircraft integration requirements have been established for TCAS and ADS-B In applications, as well as addressing such issues as new TCAS logic and spectrum congestion as the industry moves closer to FIM operations in terminal airspace.

#### 1.7.1.2 Boeing Commercial Aircraft

Boeing Commercial Aircraft (BCA) provides support through an Inter-organizational Work Transaction (IWT) contract, and is involved with developing the spacing algorithm, developing cockpit displays, installing hardware, and data gathering/analysis.

#### 1.7.2 Honeywell

Honeywell is a direct sub-contractor to Boeing, and has an extensive background in avionics development, specifically Automatic Dependent Surveillance-Broadcast (ADS-B) and Cockpit Display of Traffic Information (CDTI) applications and flight management computer (FMC) research and technology development. Of particular relevance is Honeywell's experience in developing and implementing the In-Trail Procedure (ITP) application on a fleet of 12 operational UAL aircraft. The plan view traffic display application on the ITP platform is included in the FIM system developed for this project.

#### 1.7.3 United Airlines

UAL is a direct sub-contractor to Boeing, and has direct experience integrating ADS-B In applications with EFB interfaces through participation in the FAA ITP trials with 12 operational 747-400s, and through early development of Version 2 (DO-260-B) ADS-B Out technology, participating in the FAA Operational Benefits Validation project. UAL has also been influentially involved in associated industry standards and rule-making activities.

#### 1.7.4 Jeppesen

Jeppesen is working under a Commercial Item Transfer at Price (CITAP) contract under the BCA IWT. It has provided navigation databases that will be loaded into the FMCs of the target aircraft and into the FMCs and FIM systems of the FIM-equipped aircraft. This database will be used by the aircrafts' FMSs to access the customized arrival procedures (STARs) and standard published instrument approach procedures (IAPs) into KMWH. The FIM systems will access the database to acquire data required to accomplish trajectory prediction. The

databases will also be provided to NASA for use in simulations and to Honeywell for bench testing.

## **1.8 Summary of Supporting Research and Tests**

### **1.8.1 Analytical**

Regression testing of the software will be conducted at Honeywell's Redmond WA facility, and validated by the entire ATD-1 team during the System Acceptance Review in December 2016. Additional studies conducted and provided in the ATD-1 documents for:

- hardware design, equipment interfaces, power required (deliverable 4.23)
- software design, algorithm performance, logic (deliverable 4.4)
- human-machine interface (deliverable 4.10)
- data collection and storage (data analysis working group)

Data will be collected internally by the FIM software, by the engineering work stations on the FIM-equipped aircraft, and on the Boeing 737's Digital Flight Data Recorder. No data will be gathered in the target aircraft. Target aircraft state data delivered via ADS-B will be recorded in the first FIM aircraft in the stream. Analysis consistent with the Statement of Work will be accomplished post-flight by the contracting team.

### **1.8.2 Wind Tunnel – None**

### **1.8.3 Simulation and Training**

Previous research to characterize the ASTAR spacing algorithm and ensure acceptability of the FIM procedures included the following ATD-1 human-in-the-loop experiments conducted at NASA Ames and NASA Langley Research Centers: FIAT-4, CA5.3, RAPTOR, I-SIM, and IMAC.

Another precursor to this flight test activity was the ATD-1 Avionics Phase 1 demonstration of EAGAR in December 2014. This flight test used Boeing's ecoDemonstrator Boeing 787 test aircraft under a Space Act Agreement. This was preceded by a simulation experiment using two of Boeing's engineering simulators (Boeing 737 and 777) and an ASTAR implementation developed by ACSS.

In direct support of this flight test, the contractor will provide rudimentary initial training of the FIM hardware and software for the flight crews. Honeywell and UAL will also provide aircraft familiarization and egress training for all participants (researchers, engineers, observers, etc.).

NASA Langley will provide computer-based training (available upon request) and simulator training on representative aircraft platforms with representative FIM pilot interfaces (planned for the DTS or IFD) to enable training of the flight routes, instrument procedures and flight test procedures. The Langley simulation will also provide training for the Flight Test Director (scenario progression, contingency operations, etc.) and the research observers (data recording, communication with the Flight Test Director, etc.). This training will be based on the following two contract deliverables, which are available upon request:

- FIM Avionics Technical Manual (deliverable 4.16)
- FIM Avionics Operations Manual (deliverable 4.17)

#### **1.8.4 Ground Operations Systems Checkout**

Once the FIM equipment is installed in each aircraft, it will be subjected to ground testing as documented in the Ground Test Plan (deliverable 4.21). The main purpose of ground testing a system is to ensure that the system is properly installed in the aircraft and that other systems such as TCAS are not adversely affected. As such, all equipment associated with the FIM avionics system that is newly installed or modified will be verified on the aircraft for functionality in accordance with the Ground Test Plan. Other ground tests will be developed during the program to verify proper installation and some basic functionality of the FIM system.

The FIM system will be installed in the 757 at Honeywell's FAA-approved repair facility in Phoenix. Ground tests have been initiated, and the final ground and EMI checks will be performed on the 757 by the Honeywell flight test organization in January 2017 before the aircraft is ready for flight. This will be accomplished in accordance with the Ground Test Plan (contract deliverable 4.21).

UAL engineers and mechanics will carry out installation and ground testing of the FIM system and revised avionics boxes in the 737 at a UAL FAA-approved repair facility in Denver prior to any shake-down flight or prior to the first contract test flight if no shakedown flight is performed. The same ground checks will be performed prior to flight in accordance with the Ground Test Plan (contract deliverable 4.21).

Tests will be performed after the initial installation of the equipment and after any significant modifications to the system or the aircraft.

## 1.9 Proposed Schedule Milestones

The ATD-1 Work Plan lists all key milestones for this program and is the source document. Below is a subset of the dates:

- |  |                     |                  |
|--|---------------------|------------------|
| ✓ Preliminary Design Review (PDR)  | 24 Sept 2015        | LaRC             |
| ✓ Briefing to RSD  | 13 Jan 2016         | LaRC             |
| ✓ Introductory briefing to ASRB  | 14 Apr 2016         | Boeing           |
| ✓ Critical Design Review (CDR)   | 5 May 2016          | Honeywell        |
| ✓ Flight test plan delivered   | 29 June 2016        | Boeing           |
| ✓ Langley Research Center IRB approval   | 22 Aug 2016         | NASA             |
| ✓ Johnson Space Center IRB approval  | 22 Sep 2016         | NASA             |
| ✓ Computer based training  | 18 Nov 2016         | LaRC             |
| ✓ Flight training sim  | 29 Nov – 8 Dec 2016 | LaRC             |
| • Operational Safety Review (OSR)  | 8 Dec 2016          | Boeing (D Boyle) |
| ○ <i>LaRC ASRB: Limited Flight Safety Release for calibration and deployment flights</i> |                     |                  |
| • System Acceptance Review (SAR)   | 15 Dec 2016         | Honeywell        |
| • Possible RSD on-site inspections   | TBD                 | at install site  |
| • Ground test plan complete  | 12 Jan 2017         | Boeing           |
| • Company Flight Readiness Review (FRR)  | 17 Jan 2017 (est)   | Honeywell, UAL   |
| ○ <i>Mechanism for Flight Safety Release of individual aircraft</i>                      |                     |                  |
| ○ <i>NASA ASRB issues Flight Safety Release for flight test campaign</i>                 |                     |                  |
| • Project Readiness Review for Flight  | 17 Jan 2017         | all participants |
| ○ <i>Contract deliverable 4.14</i>   |                     |                  |
| ○ <i>All participants demonstrate their readiness for flight test campaign</i>           |                     |                  |
| • Flight test window per Honeywell & UAL letters of commitment                           | 1/12-3/3 2017       |                  |

## 2. Flight Test Operations

The flight test series is to be conducted using arrivals and Required Navigation Performance (RNP) approaches. These arrival/approach combinations will mirror those used in high-density airport operations, but will be flown into Grant County (KMWH) (i.e., Moses Lake, Washington) airfield for the majority of the test points, to economize on test flight costs.

The target aircraft (not FIM equipped but ADS-B Out equipped), which will always lead a string of three test aircraft, will be a Honeywell Dassault Falcon 900 or a business jet with equivalent performance and capability. The trailing (FIM equipped) aircraft in a three-aircraft string will be a Honeywell 757 test aircraft and a UAL 737-900. In Final Approach Spacing test conditions, only two aircraft are required, and the intent is to use the 757 and 737 to maximize flexibility. All aircraft will be flown by qualified company pilots, with research engineers and observers on all three aircraft.

The Flight Test Director (FTD) will be in the Boeing 757 while a back-up FTD will be in the Boeing 737 to allow for continuation of testing should the 757 become unserviceable after launch. Both aircraft will have sufficient onboard FIM and test equipment, as well as ATC and inter-aircraft communications, to enable effective monitoring and management of the test processes by either FTD or backup.

Based on a day's plan, three aircraft will depart individually from their deployed location in the Seattle area, and climb eastbound along a defined route towards KMWH. Normal ATC departures, procedures, and frequencies will be used. Once established at cruise altitude, the first (en route) flight test condition will be executed. Once this test condition has been completed, the aircraft will reposition as needed to accommodate initiation of the second (arrival/approach) test condition. That test will continue throughout the arrival and approach, and will terminate when the second FIM aircraft crosses the final approach fix. The aircraft will continue of the approach and then execute a go-around at decision altitude to commence a repositioning climb-out for the next test condition. Once reestablished at cruise altitude, the next condition will commence and continue until the aircraft again crosses the final approach fix. It is estimated, based on fuel burn, that between four and five test conditions will be accomplished in a flight test day.

If only two aircraft are available, a decision will be made, depending on the circumstances of the lack of availability, to launch the remaining pair or continue the test day with the remaining pair. Test conditions already included in the flight test plan (for pre-launch decisions) or already briefed prior to flight (for post-launch decisions) will always be executed.

Because test aircraft will be based in Seattle, some "target of opportunity" FIM operations may be conducted during the return to the Seattle area (Seattle-Tacoma International Airport (KSEA) for the 737 and Boeing Field (KBFI) for the other aircraft). These FIM operations conducted during the return to the Seattle area are not considered part of the test matrix itself, but rather they represent opportunities to provide data points using participating or non-participating traffic in an unplanned (but pre-coordinated)

ARTCC environment. During “target of opportunity” operations during the return flight to the Seattle area, the rules of engagement are flight crew will not query ATC or other aircraft as to that aircraft’s route of flight, nor state that they intend to conduct a spacing operation behind other aircraft.

All flight test aircraft will comply with all ATC procedures, for example:

- Coordinated operations by single aircraft (i.e. no formation flight, no chase flight),
- Normal aircraft separation criteria (IFR standard in IMC and VMC),
- Utilize ATC surveillance-based services for separation both participating and non-participating traffic, and for traffic awareness,
- Departure and arrival procedures into Seattle and Moses Lake TRACONS,
  - FAA standard departures, arrivals, and approaches from/into Seattle
  - Customized, FAA-approved arrivals (STAR Specials) into Moses Lake (Jeppesen navigation database in all FMSs)
  - FAA standard instrument approaches into Moses Lake
- Avoid Spokane TRACON airspace and two MOAs to the north,
- Minimize exposure to crossing Victor routes (achieved by arrival route design),
- Standard rate turns and airspeeds within 15% of published/custom procedures,
- Regulatory requirements (eg  $\leq 250$  knots  $\leq 10k$ ),
- Compliance with maximum speed restrictions for RF legs in the published public instrument approach procedures,
- ATC instructions (eg vectors, step-down, speed, procedure abort).

All aircraft limitations and company standard operating procedures will be adhered to:

- That contractor’s FAA approved Part 91 approval with Experimental Category certificates,
- Weight and balance, maximum takeoff/landing weights,
- Wind, temperature, icing, turbulence criteria.

## **2.1 Locations**

The Honeywell and UAL aircraft will deploy from their home bases to the Seattle, Washington area, and will operate from KBFI and KSEA respectively (see Figure 1). On flight test days, aircraft will depart individually, but with coordination between ATC Towers, en route to KMWH, where they will fly multiple approaches to missed approaches. The aircraft may or may not refuel at KMWH, and will return every day to the deployed operating airfield in the Seattle area.



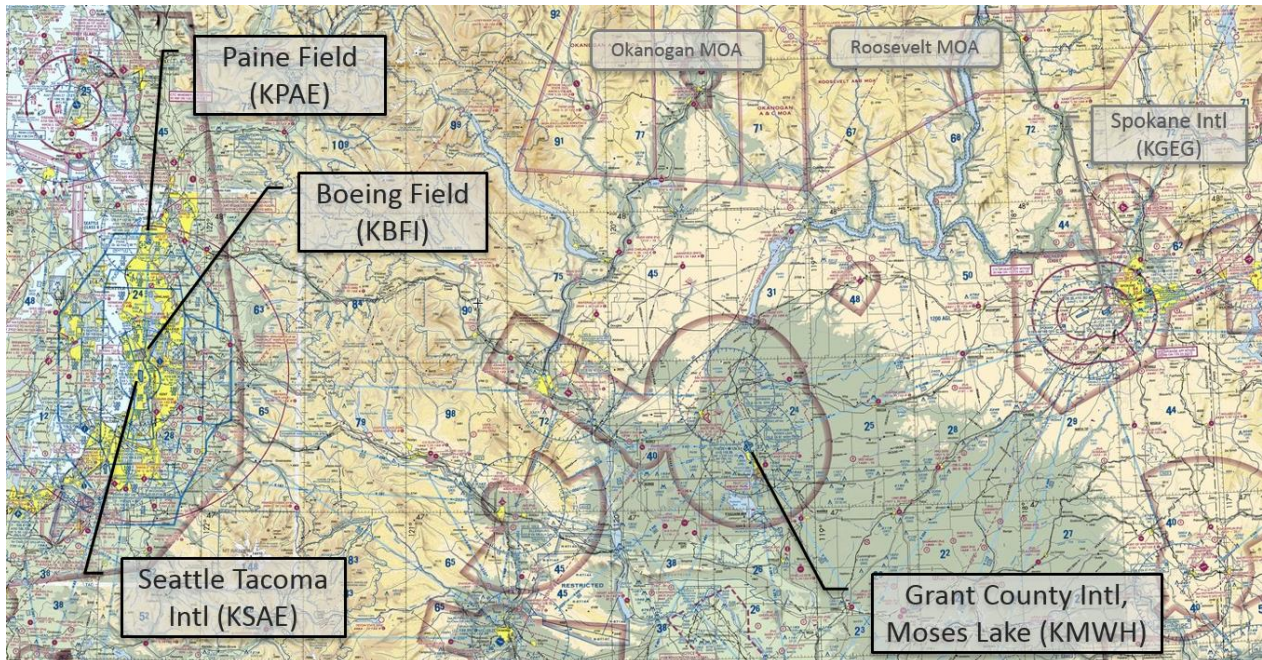


Figure 2: Seattle area and Grant County operating locations

## 2.2 Planned Start of Flight Tests

The flight tests are planned to begin in mid-January 2017, and will be complete by March 2017.

Honeywell will support their Dassault Falcon 900/business jet and Boeing 757 deployments to KBFI for 18 flight days (ferry time and downtime due to equipment delays and ATC coordination not included).

UAL will support their Boeing 737 deployment to KSEA for up to 82 hours of test time (ferry time not included). Utilization of the 737 must be terminated in time for de-modification and return-to-service procedures to be completed to allow revenue service on 7 March.

## 2.3 Planned Number of Flights

The ATD-1 Avionics Phase 2 flight test will be a maximum of 18 flight days, or 15 to 20 flights for all aircraft. The nominal expectation is one flight per day, resulting in approximately 80 to 85 flight hours. This estimate will be updated based on how efficiently multiple test conditions can be conducted per flight.

## 2.4 Frequency of Flights

One (expected norm) or two flights per day per aircraft will be conducted with the intention of conducting 4 to 5 test conditions per day. If only one flight is scheduled, it is anticipated to be a longer flight (~5 to 6 hours), and would depart and return to the appropriate airfield in the Seattle area. If two flights are scheduled, it is anticipated each

will be a shorter flight (~3 to 4 hours) departing and returning to the Seattle area, but with a refueling stop at KMWH between the two flights.

All regulatory and company crew duty day and crew rest restrictions will be adhered to.

## **2.5 Test Procedures**

The goal of the procedures being flight tested is to achieve and/or maintain a precise spacing interval behind a specified target aircraft by a specific waypoint or at a specific rate or better. For the flight test, this spacing interval will always be set to a value that is larger than the IFR minimum separation for the aircraft pairing by a margin that has been agreed with ATC.

The flight test procedures are:

- The flight crew enters the following information into the FIM avionics:
  - Ownship route information
  - Forecast en route or descent wind
  - FIM clearance information from ATC (ATC simulated by the test card)
- The FIM avionics calculate the airspeed for the aircraft to fly based on:
  - Ownship info (from aircraft data bus), target state (from ADS-B in), route info (manual entry by pilot), and forecast wind (manual entry by pilot)
- The flight crew sets the FIM speed manually into the MCP speed window
- All other aircraft and IFR procedures are standard, current-day operations

The flight test will include either two or three aircraft, based on the availability of the UAL aircraft, or whether or not an aircraft had maintenance issues and had to abort. Operations en route to KMWH and all the arrival operations into that airport will only involve the two or three aircraft participating in the ATD-1 Flight Test.

Operations when departing KMWH and returning to the Seattle area include not only the participating aircraft, but may include non-participating aircraft as long as the aircraft geometry is conducive to a FIM operation, and it does not impact Seattle Center's operations.

The Flight Test Director is responsible for developing a minimum research equipment list to be used as a Go / No-Go decision matrix. This minimum research equipment list will be delivered to the FTD prior to the Flight Readiness Review in Jan 2017. The Flight Test Director will also develop backup plans to modify (pre-flight) or make alternate use (after launch) of the daily test plan in order to accommodate aircraft unavailability.

## **2.6 Planned Flight Test Envelope**

All aircraft will operate within the normal operating envelope of the specific aircraft model, and not exceeding that typical of commercial passenger aircraft conducting a revenue flight. There are no research requirements that are more restrictive than the

aircraft's Pilot's Operating Handbook (POH) or the company's Standard Operating Procedures (SOP), nor any research requirements that require the POH or company's SOP to be exceeded.

Flights will occur day or night, in IMC or VMC. All aircraft and operator procedures will be adhered to, as will all ATC procedures and separation criteria. All operations will be conducted under IFR regardless of meteorological conditions.

### **3. Support Requirements**

#### **3.1 Support Organizations and Their Responsibilities**

##### **3.1.1 NASA**

- CSAOB
  - Create CBT and create simulation training for flight test.
  - Assist in developing and executing the flight test.
  - Participate as researcher observers on any of the three aircraft.
  - Participate as researcher observers in Seattle ARTCC (ZSE) or Moses Lake TRACON (MWH) air traffic control facilities.
  - Provide daily summary/update during flight test (via e-mail).
- ATD-1 Project
  - Resolve resource issues or conflicts.
- HQ Public Affairs
  - Coordinate with contractors and airports for photo opportunities.
- LaRC RSD Flight Ops
  - Coordinate with HQ to determine if flight operations review needed.
  - Provide consultation to CSAOB in developing flight test plan and FTOSR.
- LaRC IRB and JSC IRB
  - Review and approve data surveys and procedures to collect data.

##### **3.1.2 Boeing**

- BR&T
  - Lead development of Flight Test Plan.
  - Flight Test Director; provide overall direction and execution of flight test.
- BCA
  - Provide support developing algorithm, FIM cockpit displays, and hardware installation.
  - Develop Data Gathering and Analysis Plan.
  - Analyze flight test data.

##### **3.1.3 Honeywell**

- Avionics
  - Integration of certified and research hardware and software to meet FIM requirements as specified in the NASA SRD.
- Algorithm
  - Develop algorithm and interface to enable FIM operation
- Aircraft
  - Provide target aircraft (Falcon 900, non-FIM equipped) for the flight test.
  - Provide FIM equipped research aircraft (Boeing 757) for the flight test.
  - Aircraft to be maintained and modified by FAA approved repair facility.
- Flight Ops
  - Provide trained crews to participate in flight test.

- Pilots trained by the airframe manufacturer, and 14CFR standards are followed for currency, qualification, and medical (all pilots meet PIC qualification standards).
- Provide training for any onboard participants (researchers, observers, visitors). This training occurs the day of the flight and is conducted by one of the crew members. Participants are not required to have a medical screening prior to boarding.

### **3.1.4 United Airlines**

- Aircraft
  - Provide FIM equipped aircraft (Boeing 737) to participate in flight test.
  - Aircraft to be maintained and modified by FAA approved repair facility.
- Flight Ops
  - Provide trained crews to participate in flight test.
  - Provide training for any onboard participants (researchers, observers, visitors). This training occurs the day of the flight and is conducted by one of the crew members. Participants are not required to have a medical screening prior to boarding.

### **3.1.5 Jeppesen**

- Avionics
  - Provide FMS navigation database (NDB) data to Honeywell for packing and eventual use by Honeywell and NASA. The data have also been provided to General Electric for packing and use by UAL and NASA. The NDBs contain customized arrival procedures into KMWH and published approach procedures into KMWH.
  - NDBs have been provided for integration into the FIM systems, and for loading in the Honeywell FMSs in the Boeing 757, the Falcon 900, and the Embraer 170 (as required). NDBs suitable for loading into General Electric FMCs in the Boeing 737 have also been provided. NDBs for NASA's 757 and 737 simulators have also been provided.

### **3.1.6 ATC**

The following ATC facilities will interact with the ATD-1 Flight Test campaign:

- Seattle TRACON
  - Coordinated departures to set-up the en route FIM operation
  - Coordinate return times, especially when slot times are required
- Seattle ARTCC
  - All of the en route FIM operation occurs in Seattle ARTCC airspace
  - Arrival FIM operations on the special STAR procedures
- Moses Lake TRACON
  - Arrival FIM operations when aircraft are below 10,000 ft msl on special STAR procedures, and on published IAP
  - All of the FINAL FIM operation
- Moses Lake Tower



- When directed by the TRACON, visual approaches, and if landing

### **3.1.7 Airfields**

The following airfields will be used in the ATD-1 Flight Test:

- Moses Lake (KMWH)
  - FIM operations
  - Divert airfield if needed for weather or slot time in Seattle area
- Boeing Field (KBFI)
  - Deployment location for Honeywell F900 and B-757
- Seattle Intl (KSEA)
  - Deployment location for UAL B-737-900

## **3.2 Transportation to Test Location**

Transportation to the test locations (KMWH [observer], KSEA and KBFI) will be provided by that person's respective employer (NASA, Boeing, Honeywell, and UAL). Once at the test location, it is expected that transportation will be provided or coordinated by the aircraft operator (Honeywell or UAL) or the airfield operations department.

## **3.3 Chase – Not Applicable**

## **3.4 Photo and/or TV Coverage**

An airborne photo session (i.e., formation flying where one aircraft films the other aircraft) is not planned and will not be conducted.

NASA Public Affairs is working with their counterparts in each of the companies to arrange a pictures, videos, and interviews with all the participants and the aircraft. These events will occur on the ground and while airborne. The following will be adhered to:

- Ground sessions
  - One or two events, coordinated a week in advance with all the flight operation departments and the airfield (badging requirement)
  - Comply with all company and airfield photo restrictions
  - Only time interviews occur
- Flights
  - One or two sorties, coordinated a week in advance with all the flight operation departments and airfield operations (badging requirement)
  - Aircraft safety briefing by the flight crew or flight engineer
  - Movement about the cabin and taking pictures and video only when authorized by the flight crew or flight engineer
  - No interviewing of the flight crew while airborne

Regardless if a media event or not, at the discretion of the aircraft Captain and if in accordance with that particular airfield rules, personal photos by participants may be

taken while airborne or on the ground. The company rules and airport rules will be documented and provided to all participants.

### **3.5 Tracking – Not Applicable**

### **3.6 Telemetry – Not Applicable**

### **3.7 Communications**

A dedicated VHF flight test frequency has been obtained from Boeing Flight Test for aircraft-to-aircraft and Flight Test Director to pilot communication. However, neither Seattle ARTCC nor Moses Lake TRACON has the capability to tune to and transmit on a VHF frequency not permanently assigned to them. Therefore, the primary method of communication between the controllers and pilots will be conducted on the normal and appropriate ATC frequencies.

Each ATC facility has received several coordination briefings leading up to the beginning of the flight test campaign, and contributed substantially to the design of the custom arrival procedures and missed approach procedures. Each facility will dial into the morning brief and afternoon debrief, and they will discuss their issues for the day (eg predicted heavy arrival times requiring slot control, unexpected events during the flight test, etc.). Furthermore, each control facility will also have their own set of test cards that will be flown for that day.

The tertiary method of communication is via the internet using an aviation software application called “Planet”. The software can:

- provide situational awareness of selected aircraft relative to other aircraft, airways, or airspace;
- provide overlays of forecast wind and current convective weather; and
- allow users to communicate with each other via chat messaging.

While the ATC facilities will not have this software in the vicinity of controllers, there is a possibility the ATC facility managers will be able to have internet access available at the Supervisor or Traffic Flow Management stations to allow direct chat communication between the Flight Test Director and the air traffic control supervisor.

An illustration of the communication options is shown in the figure below.



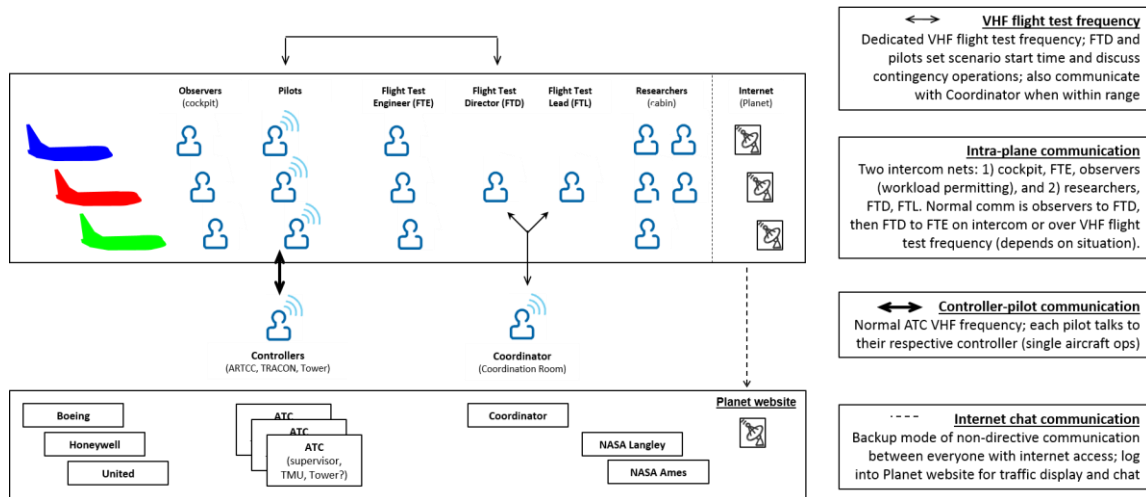


Figure 3: ATD-1 Communication

### 3.8 Meteorological

Flight crews will obtain their own flight weather support during deployed operations using their normal sources.

A single source of forecast wind data for en route test conditions and for descents into KMWH and the Seattle area will be established and used by all aircraft conducting FIM operations.

### 3.9 Data

All data will be recorded on board each aircraft by either ship systems or the FIM avionics. Honeywell will provide an engineering workstation in the form of a laptop as part of this capability.

### 3.10 Other Special Support Requirements

All three aircraft will operate under FAR Part 91, Experimental Category. Initially the experimental sub-category will be “research and development”, which means only required crew-members will be permitted on board. Once experience has been gained, log-book entries will be made to change the experimental sub-category to “market survey”, which allows visitors and non-crew members on board.

NASA Langley will provide researchers that will fly aboard the three aircraft to act as observers, data collection, and conduct pilot surveys. The NASA researchers are considered required crew members.

In addition to members of the ATD-1 Avionics Phase 2 research team (comprised of individuals from NASA and all the contractors), there will also be observers on board all three aircraft. These observers will be from NASA and all the contractors, as well as the FAA and other industry stakeholders. The goal of providing access to observers from outside the flight test team is to allow key decision makers and public outreach individuals to observe first-hand the FIM equipment and procedures. The operators of the aircraft (Honeywell and UAL), will

- Ensure that each person meets all the requirements,
- Provide all required egress and personal training,
- Establish a boarding approval and personnel tracking process
- Have final approval/disapproval authority to board the aircraft.

In addition to the items described above, any NASA employee or visitor invited by NASA will also require boarding authorization from NASA. The NASA Langley Research Center process will be used for this.

## **4 Safety**

### **4.1 System Safety Program**

#### **4.1.1 Hazards Analysis**

The flight test conditions incorporate a combination of normal en route, arrival and instrument approach procedures, and crew reaction to speed guidance from a prototype FIM system. This guidance is intended to result in the achievement and/or maintenance of a spacing value from a preceding or merging aircraft. Thus, the only real difference between everyday operations for air transport aircraft and the flight test operations will be the source of speed guidance. In normal operations, speed-to-fly is provided by the FMS's performance model, or from arrival and approach procedure restrictions and constraints, or by air traffic controller. Since the source of speed guidance in the flight test is prototype hardware and software, this analysis concentrates on hazards associated with this speed guidance and their outcomes.

During the project's introductory briefing to the ASRB (14 April 2016), it was agreed that the contractor team need not analyze the hazards and risks of normal operations since they are adequately mitigated through FAA approved operating certificate, FAA approved mechanics and maintenance procedures, FAA certified commercial pilot certification, type rating on test aircraft, and initial and recurrent training. No hazards that might have an effect only on flight test operational efficiency or ability to complete the flight test series have been considered.

The ASRB further concluded that the Operational Safety Assessment included in the Safety, Performance and Interoperability Requirements Document for Airborne Spacing – Flight Deck Interval Management, RTCA DO-328A, was a suitable source of hazards, risks and mitigations for a certified system. In addition, DO-328A and the supporting system's Minimum Operational Performance Standards (DO-361) were used as the sources of the majority of the requirements that the prototype system was designed to meet or exceed. Although the prototype system will not be certified for operational use, most hardware has been certified for other uses, and commercial best design practices have been followed in development of the prototype software.

Annex A summarizes these hazards, and then analyzes the same hazards and mitigations associated with the provision of speed guidance by a prototype avionics system. Added mitigations for the risks associated with the latter are also offered. The five FIM-specific hazards identified were:

- 1) Incorrect initiation of the FIM procedure
- 2) Incorrect or inappropriate execution of FIM procedure
- 3) Incorrect or abnormal termination of FIM procedure
- 4) Electro-magnetic interference (EMI) of certified aircraft systems
- 5) Insufficient cockpit task management

Flight test day one will be dedicated to data collection. The following day will be dedicated to the analysis of the data recorded on the first day. The second day will also be used by the Flight Test Director and all participants to validate that all hazards have been

identified and mitigated. Any proposed modifications or changes will be communicated and agreed to by the Honeywell flight operations, United Airlines flight operations, and the NASA LaRC ASRB prior to implementation.

#### **4.1.2 Risk Assessments**

The five FIM-specific hazards identified were all assessed as Low risk (flight operation permissible following review and approval) after the mitigations are applied.

The undesirable operational effects that may result from the hazards analyzed are as follows:

- Various levels of increase in flight crew workload
- Various levels of increase in air traffic controller workload
- Reductions in spacing not impinging on separation
- Loss of separation
- Near mid-air collision
- Collision

### **4.2 General Operational Restrictions and Conditions**

#### **4.2.1 Weather**

The research conducted during these flights does not require weather restrictions or conditions more stringent than those required by that aircraft type, and that aircraft operator. Specifically, the ATD-1 flight test can occur day or night, in VMC or IMC, with no additional restrictions to the POH limits to wind, temperature, icing, or turbulence. All ATD-1 scenarios will be flown to the published Decision Altitude (DA).

#### **4.2.2 Personal Equipment**

Personal flotation devices and other appropriate survival and personal protective gear will be provided on-board for all personnel as required by the flight profile.

#### **4.2.3 Minimum On-board Equipment**

For research purposes, the FIM equipment, the experiment's data recording devices, and the method to receive updated wind forecasts must be operational. In addition, existing aircraft avionics sub-systems providing data to the FIM System must be operational. The required number of radios to communicate with ATC and coordinate between aircraft must also be operational.

The go/no-go decision regarding the research equipment and conditions will be the responsibility of Boeing's designated Flight Test Director in coordination with the NASA Flight Test Technical Lead. The final go/no-go decision responsibility will reside with the pilot of each aircraft. Aircraft minimum equipment will be dictated by the appropriate published Minimum Equipment List (MEL) and standard operational practices. System architecture that includes single data sources for the prototype FIM

avionics dictates that the MEL for the flight tests be more restrictive than that utilized in revenue service for the aircraft models.

#### **4.2.4 Weight and Balance**

The aircraft will be flown within the approved weight and balance limits in the Pilot Operations Handbook (POH) and the Aircraft Flight Manual (AFM).

#### **4.2.5 Flight Test Envelope (V-n)**

The aircraft will be flown within the approved envelope in the POH.

### **4.3 Abort Procedures**

There are two general categories that may require the flight test to abort:

- 1) functionality of the FIM equipment, its data sources, and data collection equipment (defined in minimum research equipment list), and
- 2) encroaching on the minimum aircraft spacing value (initially negotiated with ATC as 7 nmi in the ARTCC and 5 nmi, with those values to be reevaluated after experience has been gained conducting the flight test).
  - a. There are no research test conditions with less than 5 nmi separation.
  - b. The flight crews will use spacing values of 150-210 seconds (time-based operations) or 5.5-7 nmi (distance-based operations) when on final.
  - c. Controllers retain their current-day primary responsibility for aircraft separation, and flight crew shall maintain awareness using certified equipment and their company operating procedures.

The pilots, ATC, or researchers have the authority to call for an abort. The flight test abort procedure is to revert to normal operating procedures, requiring either that the airspeed constraint shown for the published procedure be respected, the speed issued by air traffic control be flown, or the speed from that company's standard operating procedure for that phase of flight be flown. ATC shall be informed of abandonment of the FIM procedure and reversion to the standard speed profile.

The Flight Test Director has overall responsibility to determine if all flight research for the day has been met, and is the final decision-maker to launch, delay, suspend, resume, or cancel the flight test.

### **4.4 Emergency Plans and Procedures**

The Flight Test Director, has overall responsibility for on-scene decision making, and communication with all Flight Test partners, air traffic control, flight crew, and airfield managers for issue pertaining to the flight test campaign. Each flight crew remains responsible for their aircraft and their crew, and is responsible for responding to emergencies specific to their aircraft, coordinating with air traffic control for priority

handling (if required), and notifying their company in accordance with their safety processes.

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 objectives are 1) to facilitate safety incident reporting and 2) to register occurrences that affect the performance of the FIM function. Annex B is Honeywell's Hazard Identification and Hazard/Risk Management Tracking Forms, and these should be used for this process. The Flight Test Director will have these forms available during flight test debriefs.

If any problems that threaten aircraft or operation safety are encountered, flight crews should follow their own operators' associated processes and procedures while abandoning the FIM procedure and informing ATC. These processes are summarized as follows (see Annex C, Contingency Response Checklist):

UAL: In the event of an airplane malfunction or other emergency unrelated to the flight test, the UAL crew will follow established procedures in the UAL Flight Operations Manual. In brief, these include notifying and coordinating with UAL Dispatch via ACARS or radio for any required technical assistance or diversion plans. In the event that the crew is unable to initiate the process, any member of the flight test team with knowledge of the issue should contact Craig Stankiewicz at (872) 825-9110 (desk) or (847) 567-3864 (cell).

Honeywell: HONEYWELL FLIGHT TEST OPERATIONS: Any member of the Honeywell Flight Test Crew becoming aware of an incident or accident involving a Honeywell Flight Test Aircraft or Personnel on the ground or airborne, will follow the *Emergency Response Plan* (ERP) process as outlined in Chapter 17 of the *Honeywell Aerospace Flight Test Operations Manual*.

The NASA ATD-1 Flight Test Technical Lead (Brian Baxley) will notify the NASA LaRC Aviation Manager (757-864-7700) of any incidents or accidents as soon as possible as specified in LMS-OP-0939. The backup for notification is the LaRC emergency dispatcher (757-864-2222).

#### **4.5 Configuration Control Responsibilities**

Boeing R&T is the prime contractor and therefore has overall responsibility, and Honeywell and UAL report to Boeing. There are six Boeing deliverables for this contract that pertain to software and configuration management, and are available upon request:

- Software Development Plan (deliverable 4.4a)
- Software Configuration Management Plan (deliverable 4.4b)
- Software Requirement Specification (deliverable 4.4c)
- Software Design Description (deliverable 4.4d)
- Software Test Plan (deliverable 4.4e)
- Software Version Description (deliverable 4.4f)

Configuration Control will be accomplished using the configuration management processes of the aircraft operators (Honeywell and UAL), which are in accordance with FAA guidelines.



## ***References***

1. NASA Langley Research Center, *Task Order “ATD-1 Avionics, Phase 2*, contract NNL13AA03B, 5 June 2015.
2. The Boeing Company, *Proposal for ATD-1 Avionics Phase 2*, Rev A, 8 May 2015
3. Seattle ARTCC Letter of No Technical Objection to the custom Instrument Arrival Procedures dated 28 April 2016
4. Moses Lake TRACON Letter of No Technical Objection to the custom Instrument Arrival Procedures dated 13 May 2016
5. Ground Test Plan (Deliverable 4.21; due Jan 2017)
6. Flight Test Plan (Deliverable 4.22; due Jan 2017)
7. LMS-OP-0939, NASA Langley, *Aviation Accident Reporting, Investigation and Site Management Plan*
8. Introductory briefing to the ASRB (Deliverable 4.5; delivered 14 April 2016)
9. RTCA DO-328A, Safety, Performance and Interoperability Requirements Document for Airborne Spacing – Flight Deck Interval Management
10. RTCA DO-361, Minimum Operational Performance Standards for Flight-deck Interval Management (FIM)

## *Abbreviations & Acronyms*

ADS-B	Automatic Dependent Surveillance – Broadcast
AFM	Aircraft Flight Manual (pseudonym for POH?)
ARTCC	Air Route Traffic Control Center
ASP	Airspace Systems Program
ASRB	Airworthiness and Safety Review Board
ASTAR	Airborne Spacing for Terminal Arrival Routes
ATC	Air Traffic Control
ATD-1	Air Traffic Management Technology Demonstration-1
ATM	Air Traffic Management
CDR	Critical Design Review
CDTI	Cockpit Display of Traffic Information
CGD	Configurable Graphics Display
EFB	Electronic Flight Bag
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FFOV	Forward Field of View
FMS	Flight Management System
FSR	Flight Safety Release
FSR	Flight Safety Review
FTOSR	Flight Test Operations and Safety Report
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Condition
KBFI	Boeing Field / King County International Airport
KMWH	Grant County International Airport
KSEA	Seattle-Tacoma International Airport
LNAV/VNAV	Lateral Navigation/Vertical Navigation
MCP	Mode Control Panel
MOPS	Minimum Operational Performance Standards
MWH	Moses Lake TRACON
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ND	Navigation Display
NDB	Navigation System Database
OSR	Operational Safety Review
PDR	Preliminary Design Review
PER	Preliminary Engineering Review
PFD	Primary Flight Display
PFOV	Primary Field of View
POH	Pilot Operating Handbook (pseudonym for AFM?)
RAC	Risk Assessment Code
RNAV	Area Navigation
RSD	Research Services Directorate
SOW	Statement of Work

SRD	System Requirements Document
STAR	Standard Terminal Arrival Route
TCAS	Traffic Collision Avoidance System
TPU	Traffic Processor Unit
TRACON	Terminal Radar Approach Control Facility
UAL	United Airlines
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
ZSE	Seattle ARTCC

## **Annex A. Hazard Assessment and Operational Effect Mitigation**

### **A.1 INTRODUCTION**

Only flight-safety-related hazards have been considered in this hazard assessment; programmatic effects, like failure to complete a test condition are not discussed. The methodology and process used for hazard assessment and their mitigations is based on the following:

- The Operational Safety Assessment (OSA) for FIM by RTCA SC-186 Working Group 4
- Honeywell Aerospace Flight Test Operations Manual, Chapter 2 Safety Management System, Section 2.5 Safety Assurance and SMS Evaluation
- UAL risk assessment procedures
- FAA Order 4040.26B (Aircraft Certification Service Flight Test Risk Management Program) used by UAL for their experimental STC operations
- NASA Langley's hazard analysis outlined in LF273F

All FIM (section A.2) and non-FIM (section A.3) hazards have been assessed as low risk, or the equivalent to NASA Langley's Risk Assessment code (RAC) of 3.

### **A.2 FIM-SPECIFIC HAZARDS AND MITIGATIONS**

A rigorous Operational Safety Assessment (OSA) for FIM-S was carried out in the industry standards development committee (RTCA SC-186 Working Group 4) during the development of the requirements for the operational application and its supporting system. The results are published in RTCA DO-328A, Safety, Performance and Interoperability Requirements Document for Airborne Spacing – Flight Deck Interval Management, Appendix C. The hazards identified in this assessment along with the mitigations used provide a basis for the Hazard Analysis and the Risk Assessment for the ATD-1 Avionics Phase 2 flight test. All hazards unique to the FIM equipment and procedures were assessed as having low risk (section A.5).

For all of the identified hazards that can result from software errors, one mitigation is the process adopted during software development, which reduces the probability of occurrence of such errors. Although the FIM system, TPU and transponder are not certified systems, they have been subjected to an appropriate level of development rigor, understanding that the resulting system is a prototype and will not be certified for operational use. Both the TPU and the EFB include legacy Honeywell software items.

The risk assessment defines the mitigations that will be employed during the flight test to overcome increased exposure to hazards associated with the use of a prototype system and assure safety in flight testing in the environment that will accommodate the test. The range of undesirable operational outcomes considered in the OSA is wide, but the mitigations adopted for the flight test will reduce associated risks to eminently acceptable levels.

While the arrival, departure and en route procedures will be normal operations with the exception of the source of speeds to fly, any adverse effects of repeated climb-outs and arrivals/approaches in winter conditions will also be considered.

### **A.2.1 Software Development Methodology**

The Software Development Plan explains the approach taken to software development. While Boeing and Honeywell would ordinarily develop avionics software per RTCA DO-178B/C (Software Considerations in Airborne Systems and Equipment Certification), following those processes for this project would have added significant cost without a clear benefit given that the operations supported are not safety-critical. The development proceeded in accordance with commercial best practices and prototype development standards applicable to each development location and as pertains to Class D, non-safety-critical software.

Software requirements were first analyzed at a high level for feasibility of implementation within program constraints and its ability to be verified. Functional architecture was then defined to provide a basis for allocating requirements. System, subsystem and interface requirements were then allocated to the appropriate hardware and software components. Each performance or interface requirement was assigned one or more corresponding verification requirement.

Traceability to requirements was established by performing automated and/or operational system tests in an effort to verify that each requirement was met. The success or failure of the test was documented, capturing the then-current state of the system as far as its ability to meet expected requirements.

### **A.2.2 DO-328A Operational Safety Assessment (OSA) of FIM-Specific Hazards**

#### **A.2.2.1 Overview**

The OSA addresses the Operational Hazards and internal failure modes of a system that enables FIM. Operational Hazards are the result of use of the application in the operating environments defined in the same document or of internal failures of the system enabling the application. An Operational Hazard is any condition, event or circumstance that could lead to an Operational Effect (e.g., accident or incident, workload increase). Mitigations are employed to reduce the probability of the hazard's occurring, and to reduce the probability of the effect's occurring or to reduce the severity of the effect. The overall objective is that safety targets (in terms of probabilities for each level of severity) set by the FAA and EASA be met.

#### **A.2.2.2 Operating Environment**

References in the following are to RTCA DO-238A. Table C.8 of the OSA defines conditions for the operating environment in which FIM procedures will be executed:

- Airspace in which direct air/ground voice communications services are available.
- Surveillance airspace under positive control
- In cruise, arrival and approach phases of flight
- Airspace operating under IFR
- In VMC or IMC

The airspace and operating plan for the ATD-1 flight test satisfy all these conditions.

#### **A.2.2.3 FIM-specific hazards**

Table A.1 lists a summary of hazards identified in the OSA; these include the possible effects of use of uncertified equipment. Each description below includes the hazard, the form of the hazard, the most likely causes, and a reference to the mitigations used. Significantly more detail

can be found in the published DO-328A document. One additional FIM-specific hazard not listed in DO-328A is also included as risk #5, and it is associated with both pilots being head-down focusing on the FIM equipment and not maintaining control of the aircraft (aircraft state awareness, positional awareness, traffic awareness, etc.).

Table A.1: Hazards, Causes and Mitigations: FIM Operations using Prototype Hardware/Software

#	Hazard	Risk Level	Form of Hazard	Cause	Mitigations (see below)
1	Incorrect initiation of the FIM procedure	L	Selection, in the FIM avionics, of the wrong target aircraft	Controller or pilot error	1, 2, 3, 4, 5, 7
				Voice message corruption in clearance	5
				Corruption by FIM system	1, 2, 4
			Selection, in the FIM avionics, of the wrong Assigned Spacing Goal	Controller or pilot error	1, 2, 5, 6, 7
				Voice message corruption in clearance	5, 6
				Corruption by FIM system	1, 2
			Selection, in the FIM avionics, of the wrong Achieve-by Point or Planned Termination Point	Controller or pilot error	1, 2, 7, 8
				Voice message corruption in clearance	5
				Corruption by FIM system	1, 2, 8
2	Incorrect or Inappropriate Execution of FIM	L	Incorrect speed is flown	FIM System corrupts speed guidance calculation	1, 2
				Undetected horizontal position corruption or error, target or FIM aircraft	1, 2
				Incorrect pilot selection (in Mode Control Panel)	1, 2, 7, 9
				EFB or CGD screen failure, or other component of FIM equipment freezes speed guidance value creating failure not immediately recognizable by flight crew	1, 7, 14
			Speed flown is outside the aircraft's normal flight envelope	Inappropriate crew selection	1, 7, 10
			Incorrect target intended flight path information	Controller or pilot error	1, 2, 4, 5, 7, 11
				Voice message corruption in clearance	5
				Corruption by FIM system	1, 2, 4, 11
			3	Incorrect or Abnormal	L
FIM system error	1, 2, 7, 12				



#	Hazard	Risk Level	Form of Hazard	Cause	Mitigations (see below)
	Termination of FIM		Early termination	Pilot error	1, 2, 7
				FIM system error	1, 2, 7
4	EMI of certified aircraft systems	L	Certified systems do not provide the correct information to the flight crew	Non-certified equipment causes electrical interference	13
5	Insufficient cockpit task management	L	Pilots not aware of the aircraft state, its relationship to airspace and routes, or the proximity to other aircraft or terrain	Pilots focus on FIM equipment or procedures and neglect other cockpit duties, including flying the aircraft and scanning for other aircraft when in VMC	1, 7

Table A.2 provides the risk level (or Risk Assessment Code (RAC) in the NASA process), and is described in greater detail in section A.4. The FIM-specific hazards listed above, with hazard number 5 moving from medium to low risk based on mitigations.

Table A.2: Risk Level of FIM-Specific Hazards

	A (Frequent)	B (Occasional)	C (Remote)	D (Improbable)
I (Catastrophic)	<b>H</b>	<b>H</b>	<b>M</b>	<b>L</b>
II (Critical)	<b>H</b>	<b>M</b> ⑤ →	<b>L</b> ⑤ ① ②	<b>L</b> ④
III (Marginal)	<b>M</b>	<b>L</b>	<b>L</b>	<b>L</b>
IV (Negligible)	<b>L</b>	<b>L</b>	<b>L</b> ③	<b>L</b>

### A.2.3 Mitigations

1. Because inappropriate information has been entered or has resulted from corruption in software, the situation does not develop as expected and the flight crew realizes it.

Prior to the flight test, the crews' understanding of such expectations will have been refined through computer-based and simulator training at NASA Langley. In addition, crews will have prior knowledge of the flight identifications and relative positions of flight test aircraft for each specific test condition to be flown that day (test cards, cockpit traffic displays, and flight test engineers on board). Additionally, the flight test will be flown in low-density traffic and has been closely coordinated with the various air traffic control facilities. These facilities are accustomed to unusual and flight test type activities. Probability of the use of corrupted data is much reduced by the algorithm's recalculating guidance speed every second. Display of corrupted data will, therefore, be extremely transitory.

2. The controller identifies a pending or actual loss of separation.

For the flight test, significant coordination has taken place with the ATC facilities concerned, and controllers will have been briefed on the intended flight test operations. No change in the controllers tasking or workload is expected for this flight test. Controllers in those facilities are very familiar with flight test operations of various kinds in the airspace. All operations will be conducted under IFR, and crews will be briefed to give absolute priority to ATC instructions over flight test needs. Controllers have specified spacing buffers with which they are comfortable to assure separation-plus-buffer at merges, and when aircraft are following common paths, particularly during the instrument approach procedures. Furthermore, each ATC facility will be able to dial into the morning flight briefing, and there will be an ATD-1 representative at each facility to answer questions.

3. System functionality prevents duplicate aircraft IDs being presented to the pilot.
4. The potential for an incorrect target's being or remaining on the entered intended flight path is low, resulting in high probability of an alert for lack of lateral conformance and suspension of the operation.
5. Controller error and corruption of data in provision of voice communication is eliminated by exclusion of the controller from the FIM-specific data provision function.

For the flight test, selection of appropriate FIM application information that would, in operational conditions, be provided by the controller, will be initiated by the flight crew. All information elements will be included in the test card for the specific test condition. These information elements include target flight identification, achieve-by point, planned termination point and target intended flight path information. An added protection in the case of target flight identification selection is that, for all runs, flight crews will choose only one of two identifications that will be well known to them.

6. See 5 above. In the case of the Assigned Spacing Goal, the value will be defined using a combination of test card and FIM system information. The test card will define a minimum value in terms of time (seconds) or distance (NM) depending on the requirements of the test condition, and crews will be trained to adjust spacing to ensure that initiation values of MSI or PSI are at or above the minimum values. The FIM system will display current Measured Spacing Interval (MSI) or Predicted Spacing Interval (PSI), depending on the clearance type

entered into the system. The test card will also define the initiation error value required for the specific test condition; the error value will have a positive (+) sign if the value must be added to the displayed MSI or PSI, and a negative (-) sign if the error value must be subtracted from the displayed MSI or PSI value. Minimum required spacing values will have been established at merge points and on common routes, in distance for distance-based operations and in a time value that translates to a similar longitudinal distance in time-based operations.

7. Pilots will be concentrating on the flight and test processes with strong emphasis on the FIM task, thus reducing the probability of all forms of pilot error that might contribute to the hazards. However, to prevent over-concentration on the FIM function to the exclusion of other essential operational tasks, each operator's Crew Resource Management (CRM) procedures will be rigorously applied. In particular, one pilot functions as the Pilot Monitoring (PM) and does the FIM and FMS data entry, while the other functions as the Pilot Flying (PF), maintaining control of the aircraft and scanning visually for other aircraft. Each pilot also receives an electronic copy of a FIM user's manual and is provided with access to a computer-based training (CBT) program, as well as a receiving simulator training covering both normal and off-nominal operations and equipment failure. This extensive training should reduce the amount of time required to enter data and the process to make a decision.
8. Achieve-by Point and Planned Termination Point must be waypoints included in the Intended Flight Path Information for target and FIM aircraft if their entry is not to be rejected by the system. For many test conditions, lack of a valid Achieve-by Point and Planned Termination Point (even the Default value is subject to crew selection) precludes FIM initiation.
9. The probability of the pilot's selecting the wrong speed (i.e., not consistent with the speed guidance) is not worse than in present-day operations in the same airspace. In many cases, the FIM function will alert the pilot to lack of speed conformance, and failure to fly at the speed provide by the system will result in a new speed's being presented. Furthermore, the FIM spacing algorithm is also constrained to remain within 15% of the published speed of each segment of that arrival or approach procedure, and the flight crew can set the minimum speed the spacing algorithm commands based on that aircraft type, weight, and environmental conditions.
10. Aircraft have high and low speed alerting functions to warn crews of excursions outside the normal flight envelope, preventing damage caused by excessive speed or loss of control as a result of a stall. In addition, flight crews' airmanship prevents extra-envelope excursions when speed instructions are provided by ATC, and the FIM system constraints the speed range that can be offered to within the normal flight envelope.
11. Use of incorrect target or FIM aircraft intended flight path information will result, in many cases, in the system's recognizing that the aircraft is not conforming to the intended path and suspending the procedure.

For the flight test, crews will have prior knowledge of the intended flight path of the target aircraft for each test point, and only a limited number of routes will be used, reducing the probability of associated error.

12. If speed guidance is provided after planned termination on final approach, the crew will ignore the guidance either because they know the Planned Termination Point has been passed (test card) or because there is a need to begin deceleration to Final Approach Speed.

For the flight test, crews will have been briefed and trained to discontinue use of speed guidance once they determine that adjustment to final approach speed is needed to achieve a stabilized approach, regardless of whether the Planned Termination Point has been passed.

13. Once the prototype systems have been installed on both FIM aircraft, ground testing will include checks for radiated frequencies to which on-board systems are known to be sensitive, and observation of anomalies that might be associated with EMI from the prototype system. Any effects that are considered operationally significant, given the flight test environment, will be resolved. Known issues on the 737 flight deck displays with the use of Wi-Fi have been avoided by choosing an aircraft in which the issue has already been resolved.
14. Two EFBs and two CGDs are provided to mitigate the operational effects of failure of one of the devices causing an insidious failure not recognizable by the pilots. Furthermore, a certified navigation display (ND) and Traffic Alert and Collision Avoidance System (TCAS) is available for each pilot to crosscheck the Target information provided by the EFB.

#### **A.2.4 Operational Effects**

The undesired operational effects of all the hazards range from additional workload for flight crew and/or controller at increasing levels, through a reduction in spacing not affecting separation, loss of separation and near mid-air collision, to collision.

The most likely residual operational effect of the hazards is an increase in flight crew workload. The flight tests will be carried out in low density airspace using instrument procedures with which the crews will be familiar through training and, in the course of the flight test period, through experience. Background workload will thus be low compared with operations in busy terminal areas. Minor increases in workload associated with the hazards, including increases in probability resulting from the use of prototype equipment, will be easily accommodated. Flight crews will be briefed to ensure that data entries are correct and system behavior is as expected before declaring themselves ready for the next test condition. Holding (as needed) at initiation points will allow adequate time for all pre-test activities, including those resulting from completion of the preceding test condition and recovery to the start of the next test condition.

The instrument procedures will be flown as in normal line operations with the exception that speed 'instructions' will be provided by the FIM system. Crews are accustomed to receiving multiple speed instructions from controllers in the course of such operations and in ensuring that procedural constraints are respected, so no significant change in workload associated with the operational task is postulated.

The OSA also describes cases in which air traffic controller workload will increase as a result of associated hazards' occurring. Given the low traffic density, the low probability of the hazards' occurring, controllers' familiarity with the aims of the flight test and of exposure to other flight tests, and the reduction in tactical control requirements resulting from the use of FIM, controller workload is not expected to be impacted.

### A.3 NON-FIM SPECIFIC HAZARDS AND MITIGATIONS

There are also hazards that may be encountered in everyday commercial air transport operations totally independent of FIM operations and flight test. All non-FIM specific hazards are assessed to be medium risk. These hazards whose probability is not enhanced nor the severity of the operational effect increased by the FIM operation, by the use in the FIM operation of prototype equipment, or by virtue of the operations being validation flight tests have not been analyzed, are summarized below:

Table A.3: Air Transport Flight Operations Hazards, Causes and Operational Effects

<b>Hazard</b>	<b>Cause(s)</b>	<b>Operational Effect</b>
CG out of normal envelope	Miss-loading; payload inadequately secured	Loss of control
Aircraft emergency	Engine fire/failure, electrical or hydraulic malfunction, etc.	ATC to provide priority handling, other aircraft directed by ATC to avoid, arrival operation not valid as ATD-1 scenario (no data)
Rapid decompression	System failure; airframe rupture	Emergency descent
Failure to conform to instrument procedures	Equipment malfunction; loss of situational awareness; excessive workload	Controlled flight into terrain
Occupants' emergency egress impeded	Equipment located inappropriately	Unable to exit aircraft in a timely fashion following incident either before takeoff or after landing
Inadequate equipment racks	Design does not meet regulatory requirements resulting in sharp edges/corners or rack failure	Crew injury
Failure to detect traffic conflict	Loss of crew and/or controller traffic situational awareness	Loss of separation from other traffic; near mid-air collision; collision
Meteorological conditions acceptability criteria not met	Inaccurate forecast; crew fails to follow associated procedures (eg anti-icing selection, use of turbulence penetration speed)	Loss of control; aircraft must divert

The above hazards and their associated operational effects are adequately mitigated in the following ways:

- Aircraft model certification and regulatory approval of the flight test configuration
- Rules of the air (air traffic control regulations, procedures, and minimum separation criteria)
- Operators' operating certificate procedures and processes
- Pilot certification, qualifications, and experience on test aircraft model

- Pilots' initial and recurrent training on model.

#### A.4 RISK ASSESSMENT METHODOLOGY

Each company shall follow their respective FAA mandated and approved safety processes for all normal flight operations. This Annex draws on the three safety analysis process described below to assess and mitigation operations and events unique to conducting FIM operations. The process was used to assign risk assessment codes (RAC) given in Annex A.1 and A.2, is based on:

- Honeywell's Aerospace Flight Test Operations Manual, Chapter 2 (Safety Management System) and Chapter 16 (Safety Risk Management),
  - Appendix C of FAA Order 4040.26B (used by UAL for experimental STC), and
  - NASA Langley's hazard and risk assessment process described in LF273.
- Hazard Severity:
    - I. CATASTROPHIC: death, permanent disability, extended hospitalization, and/or equipment damage in excess of \$2 million.
    - II. CRITICAL: may cause lost-time injury or illness, and/or equipment damage between \$500,000 and \$2 million.
    - III. MARGINAL: may cause lost-time minor injury or illness, and/or equipment damage between \$50,000 and \$500,000.
    - IV. NEGLIGIBLE: may cause non lost-time injury and/or equipment damage between \$1000 and \$50,000.
  - Probability:
    - A. FREQUENT: neither safety feature nor approved procedures exist to prevent the undesired event from occurring, likely to occur repeatedly during the life cycle of the system test or operation.
    - B. OCCASIONAL: safety feature does not exist but the use of approved procedures should prevent the undesired event from occurring, likely to occur sometime during the life cycle of the system test or operation.
    - C. REMOTE: approved procedures do not exist but an existing safety feature should prevent the undesired event from occurring, may occur during the life cycle of the system test or operation.
    - D. IMPROBABLE: both a safety feature and approved procedures, or two independent safety features exist which, collectively, should prevent the undesired event from occurring, likely not to occur during the life cycle of the system test or operation.

These two parameters are used to assign the risk level (or Risk Assessment Code, RAC) of:

- **High:** imperative to suppress risk to a lower level
- **Medium:** a waiver is required to conduct operations
- **Low:** the flight operation permissible following review and approval

The following table provides the correlation of severity and probability to the RAC:

Table A.4: RAC by Severity and Probability

	A (Frequent)	B (Occasional)	C (Remote)	D (Improbable)
I (Catastrophic)	<b>H</b>	<b>H</b>	<b>M</b>	<b>L</b>
II (Critical)	<b>H</b>	<b>M</b>	<b>L</b>	<b>L</b>
III (Marginal)	<b>M</b>	<b>L</b>	<b>L</b>	<b>L</b>
IV (Negligible)	<b>L</b>	<b>L</b>	<b>L</b>	<b>L</b>



## **Annex B. Honeywell Hazard Identification Form**

Annex B is an extract from the Honeywell Aerospace Flight Test Operations Manual, and retains the paragraph numbering to allow cross-referencing of the document. The two documents and their associated process defined by Honeywell will be used by the ATD-1 Flight Test team to identify and mitigate hazards discovered during the conduct of the flight test and are not discussed in Annex A. Blank copies and all completed versions of the documents will be maintained the Flight Test Director and the NASA Flight Test Lead.

### **B.1 18.4 Hazard Identification**

#### **Instructions for Hazard Identification Form 18.4**

The purpose of the Hazard Identification Form is to identify potential flight test hazards and/or report hazardous events, which have occurred in the past. The process of completing this form is to describe the potential hazard and/or report an event, provide a brief analytical summary, propose remedial actions and have management either accept or reject the proposal.

In case the proposed remedial action is rejected, management should explain the reasons for rejection and offer alternative actions if applicable. Each entry on the Hazard Identification Form is explained on page 10b – 10c

### **B.2 18.5 Hazard / Risk Management Tracking**

#### **Instructions for Hazard / Risk Management Tracking Form 18.5**

The Hazard / Risk Management Tracking Form serves as a listing of hazards and risks, which have not been itemized in Chapter 18 Appendix B SMS/Safety Risk Management, Chapter 18.3 Identified Hazard Listing.

If the remedial actions were accepted, the Hazard / Risk Management Tracking Form tracks implementation and prompts a review of the remedial actions.

The Form tracks all reported hazards, whether substantiated or perceived, even if remedial actions were rejected. However, only those identified hazards that have an accepted remedial action will be implemented and reviewed.

If the review validates the hazard it should be adopted into Chapter 18.3 Identified Hazard Listing.

**18.4 Hazard Identification Form** Report Number: \_\_\_\_\_

---

Describe the event you observed: Date: \_\_\_\_\_ Time: \_\_\_\_\_

Location: \_\_\_\_\_

Name: \_\_\_\_\_ Date: \_\_\_\_\_

Phone Number: \_\_\_\_\_

---

Summary of Analyses

Name: \_\_\_\_\_ Date: \_\_\_\_\_

---

Propose Remedial Action

Accepted  Rejected  If rejected, explain reason and proposed alternative action.

Chief Pilot / Site Leader: \_\_\_\_\_ Date: \_\_\_\_\_

---

Remedial Action Implemented Date: \_\_\_\_\_

---

Post Implementation Review conducted by \_\_\_\_\_ Date: \_\_\_\_\_

Figure 4: 18.4 Hazard Identification Form

#### 18.4 Hazard Identification Form

- 1 = Hazard Identification Report number Form 18.4
- 2 = **Report Number** consists of consecutive numbers from 001 to 999, preceded by the 2-digits of the year, For Example: 16.001
- 3 = Insert factual description of the event observed
- 4 = Insert Date, Time and location of the event
- 5 = Enter Name of person submitting report. Include date and phone number
- 6 = Provide a brief analysis, describing possible / actual observed hazards
- 7 = Enter name of person submitting analysis and date
- 8 = Enter recommended remedial action, designed to avoid reoccurrence or potential future occurrence
- 9 = Check mark if proposed remedial action is either accepted or rejected by Chief Pilot / Site Leader.
- 10 = State reason if proposed remedial actions were rejected.
- 11 = Enter name of Chief Pilot / Site Leader and date
- 12 = Enter date when remedial action was implemented
- 13 = Enter date when remedial action was reviewed

Figure 5: 18.4 Hazard Identification Form



18.5 Hazard / Risk Management Tracking Form

- 1 = **From:** Enter date of first row entry, **To:** Enter date of last row entry
- 2 = Report Number: YYXXX... [YY = Last two digits of the year of the event. XXX = 3 digits, starting with 001, adding 1 for each new event until the end of that event year; e.g. 16001, 16002, 16003, ... 17001, 17002...,etc.]
- 3 = Select functional category from drop down Table: EN = Engineering, FO = Flight Operations, GS = Ground Support, MX = Maintenance, OTH = Other.
- 4 = Insert date when event was reported
- 5 = Brief description of the Hazard / Risk
- 6 = Select Risk Level from Drop Down Table: L = Low, M = Medium, H = High
- 7 = Brief description of proposed remedial action
- 8 = Date the remedial action was accepted by Site Leader / Chief Pilot
- 9 = Date the remedial action was implemented
- 10 = Date the remedial action was reviewed

Figure 7: 18.5 Hazard/Risk Management Tracking Form

## **Annex C. Contingency Response Checklist**

Based on section 4.4, Annex C provides a checklist of action items to be accomplished in response to a contingency. The procedures of that aircraft's operator (Honeywell or United Airlines) will be utilized, and the operator would investigate any non-NASA, non-FAA/NTSB mishap and cooperate fully with other investigating agencies.

The ATD-1 Flight Test Director has the primary responsibility to communicate with all participants as soon as possible. The Flight Test Director may enlist support from the NASA Flight Test Lead to expedite the communication.

### **C.1 Organizations and their contact information**

- Honeywell Flight Safety Officer, Helmuth Eggeling, 602-231-2697 or 602-363-9316
- United Airlines Project Manager, Craig Stankiewicz, 872-825-9110 or 847-567-3864
- NASA Langley Aviation Manager, Shane Dover, 757-864-7700
  - Backup: Flight Safety Officer, Greg Slover, 757-864-8135 or 757-751-2851
- Seattle ARTCC (ZSE), Leon Fullner, Support Manager, 253-351-3620
- Seattle TRACON, Tod Thomas, Air Traffic Manager, 206-241-4601
- Moses Lake TRACON, Debra Hernke, Air Traffic Manager, 509-762-1367

### **C.2 Definitions (extract from NPR 8621.1C, paragraph 1.1)**

- Mishap: injury or illness caused by NASA operations, destruction of property caused by NASA-funded operations.
- Close Call: no injury or only minor injury, damage less than \$20,000 to equipment and property, but which possesses the potential to cause a mishap.
- Not a NASA mishap or close call: accidents involving aircraft operated as civil use, owned by civil operators, and accomplishing missions for NASA where there is no NASA property damage or Federal employee injury.

### **C.3 Suggested Mishap and Close Call report format (extract from LMS-OP-0939)**

- Aircraft type and tail number
- Personnel involved and injuries
- Accident description
- Accident site
- Current condition of the site
- Time of accident
- Your name, phone number, and location

### **C.4 Other considerations**

- Participants should make a written record of the event and provide it to the investigation board if requested
- Flight Test Director and Flight Test Lead with support from flight crews to determine corrective action; notify all flight operations and NASA flight safety officer of update
- Notify the LaRC IRB and the JSC IRB if issue relevant to the safety of human subjects

**REPORT DOCUMENTATION PAGE**

*Form Approved*  
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 The Air Traffic Management Technology Demonstration-1 (ATD-1) is a major applied research and development activity of NASA's Airspace Operations and Safety Program (AOSP). The demonstration is the first of an envisioned series of Air Traffic Management (ATM) Technology Demonstration sub-projects that will demonstrate innovative NASA technologies that have attained a sufficient level of maturity to merit more in-depth research and evaluation at the system level in relevant environments.

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