NASA/TM–2019-220405

# Air Traffic Management Technology Demonstration-1 (ATD-1) Avionics Phase 2 Flight Test Training for Interval Management

*Roy D. Roper, Brian T. Baxley, Kurt A. Swieringa, and Clay E. Hubbs*
*Langley Research Center, Hampton, Virginia*

September 2019

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

September 2019

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# Table of Contents

## List of Figures

# Abbreviations and Acronyms

| | |
|---|---|
| ABP | achieve-by point |
| ADS-B | Automatic Dependent Surveillance-Broadcast |
| ASG | Assigned Spacing Goal |
| ATC | Air Traffic Control |
| ATD-1 | Air Traffic Management Technology Demonstration–1 |
| B-737 | Boeing 737-900 |
| B-757 | Honeywell owned Boeing 757-200 |
| CBT | Computer Based Trainer |
| CGD | Configurable Graphics Display |
| CMS | Controller-Managed Spacing |
| ConOps | Concept of Operations |
| DTS | Development and Test Simulator |
| EFB | Electronic Flight Bag |
| ETA | estimated time of arrival |
| F-900 | Honeywell owned Dassault Falcon 900 |
| FAA | Federal Aviation Administration |
| FAF | Final Approach Fix |
| FIM | Flight Deck Interval Management |
| FSI | Fast/Slow Indicator |
| FTD | Flight Test Director |
| GNSS | Global Navigation Satellite System |
| HMI | Human Machine Interface |
| IFD | Integrated Flight Deck |
| IM | Interval Management |
| IP | Initial Point |
| KMWH | Grant County International Airport |
| LaRC | Langley Research Center |
| LP | Long Pole |
| LT | Left Turn |
| MOPS | Minimum Operational Performance Standard |
| PBN | Performance-based Navigation |
| PSI | Predicted Spacing Interval |
| PTP | Planned Termination Point |
| RNP AR | Required Navigation Performance Authorization Required |
| RT | Right Turn |
| STAR | Standard Terminal Arrival Route |
| TMA-TM | Traffic Management Advisor with Terminal Metering |

# Abstract

*Prior to the successful flight test validation of a new avionics prototype, participants from Boeing, Honeywell, and United Airlines underwent group training at NASA Langley Research Center. New prototype software for an algorithm which enables greater efficiency in high-density airspace, called Interval Management, was to be incorporated into Electronic Flight Bags and placed in the cockpit for pilot usage. The goals of the training were to teach the flight test pilots how to operate the new software, establish techniques to simultaneously position three aircraft prior to each test scenario, and ensure a common communication protocol among team members when coordinating the position of aircraft for the next scenario.*

*The multi-tiered interactive training regimen consisted of a process that continually built upon previous foundational material. The primary learning elements were 1) a portable computer-based trainer that was provided to the pilots prior to classroom training sessions, 2) classroom learning, 3) full mock-up simulator training, and 4) refresher training just prior to the flight test. Each part of the regimen was designed to repeat and build upon the previous element.*

*The purpose of this Technical Memorandum is to inform the aviation industry how flight training for Interval Management was conducted at Langley Research Center in order to reduce overall development costs of future Interval Management training programs. Secondly, the paper provides insight regarding the decision-making process when attempting to conduct a flight test.*

# 1 Introduction

## 1.1 Background

To prepare the National Airspace System for a predicted increase in traffic volume and to improve the efficiency of the air transportation system, the Airspace Operations and Safety Program in NASA's Aeronautics Research Mission Directorate created the Air Traffic Management Technology Demonstration 1 (ATD-1) sub-project. This sub-project was designed to support commercial aviation stakeholders including the Federal Aviation Administration (FAA), manufacturers, and airspace users with relevant and timely research to improve the efficiency of aircraft arriving at high density airports. The NASA Langley Research Center (LaRC) Interval Management (IM) research team has been an integral part of the joint NASA Ames Research Center and LaRC effort to develop and test the Concept of Operations (ConOps) for ATD-1. This NASA ATD-1 ConOps integrates three separate NASA research elements, each developed with the FAA and industry partners, to achieve high throughput, fuel-efficient arrival operations into a busy terminal airspace (refs. 1 and 2). This ConOps was developed concurrently and kept closely aligned to the FAA concept for IM operations (refs. 3 and 4).

The ATD-1 ConOps consists of three research elements (figure 1). The first research element, Traffic Management Advisor with Terminal Metering (TMA-TM), generates a precise arrival schedule to the runway threshold and metering points in both Air Route Traffic Control Center and Terminal Radar Approach Control Facility airspace. The second element, Controller-Managed Spacing (CMS), provides information to help terminal area air traffic controllers manage aircraft delay using speed control. The third element, IM, provides the speed guidance necessary to allow flight crews to manage their spacing behind an assigned lead aircraft. The objective of the research conducted under ATD-1 is to improve the efficiency of arrival operations, resulting in decreased fuel use, emissions, and noise, while improving runway throughput and reducing delay.

The first two elements (TMA-TM and CMS) were evaluated at the FAA's William J. Hughes Technical Center in 2015 and transferred to the FAA. The final element, Interval Management, was evaluated during the ATD-1 Avionics Phase II flight test in early 2017.

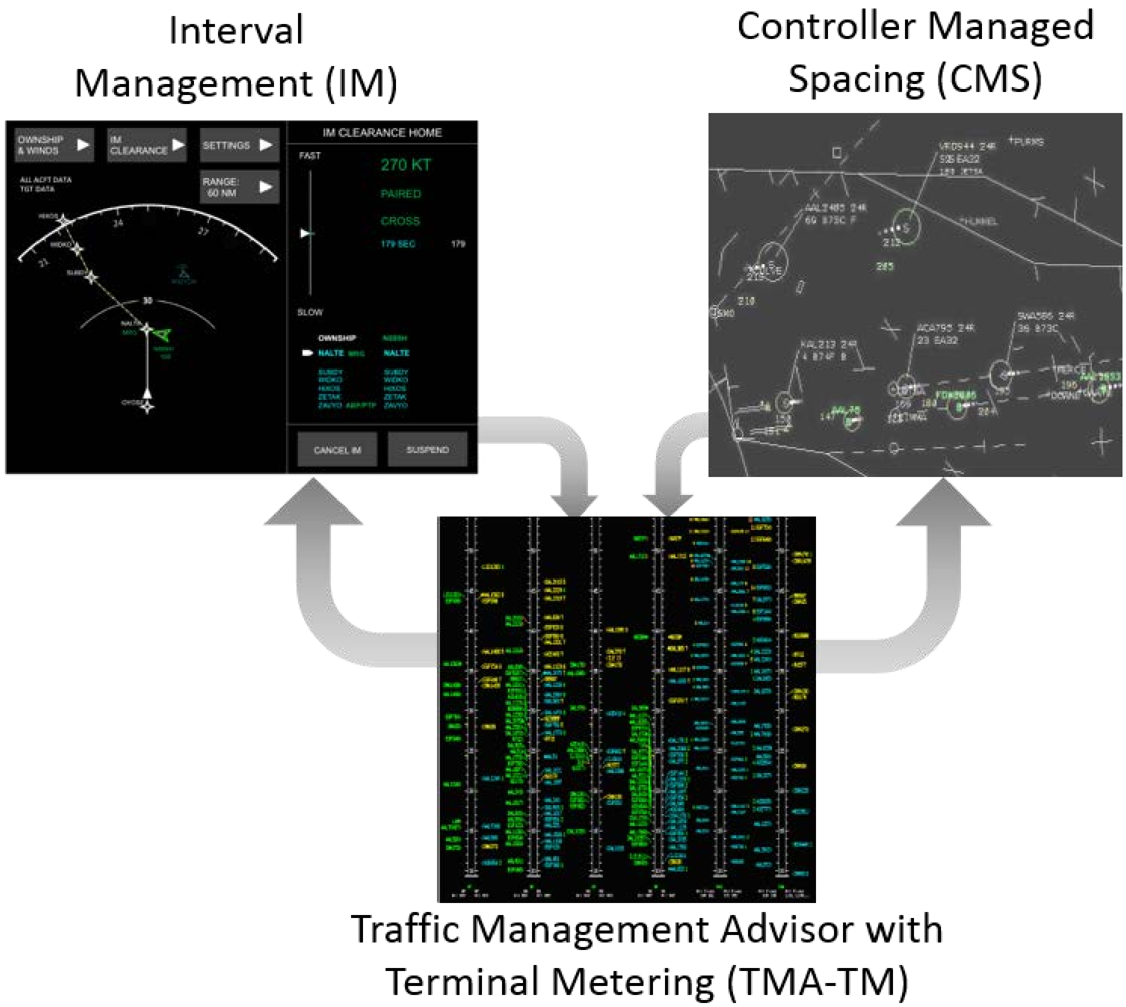


**Figure 1. Integrated NASA technologies used in the ATD-1 ConOps.**

## 1.2 Project Goal and Flight Test Goals

The goal of the ATD-1 Project is to increase throughput at high-density airports while increasing the efficiency of aircraft arrival operations. The ConOps provides deconflicted and efficient operations of multiple aircraft arrival streams from a point prior to Top of Descent until the Final Approach Fix. Aircraft on these arrival streams primarily use speed control along their optimized profile descents to achieve precise schedule conformance or spacing between aircraft, thereby decreasing the number of instances when aircraft are vectored off path or required to fly level-flight segments. When aircraft speed control can be used as the mechanism to achieve the schedule and the desired spacing intervals, the en route controller issues an IM clearance to the flight crew of those aircraft equipped with the IM avionics. Precise speed control calculated by an algorithm allows an aircraft equipped with the prototype IM system, known as the Ownship, to reach a specified interval from a designated Target aircraft by a chosen achieve-by point (ABP, figure 2). The pilot continues to dial in speed commands to the mode control panel until the planned termination point (PTP), which may be co-located with the ABP.

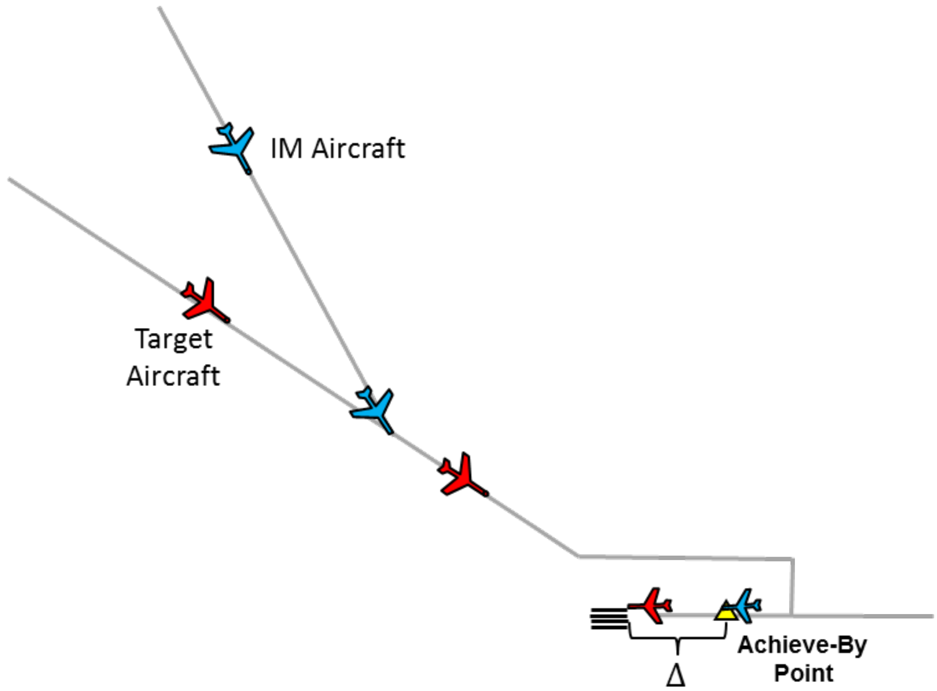


**Figure 2. Interval Management Spacing Operations**

This IM clearance can include the following elements: the call sign of the aircraft to follow, known as the Target aircraft, the Target aircraft's route of flight, the assigned spacing goal (ASG), when the spacing interval must be achieved (ABP), and when the IM operation is complete (PTP). The flight crew enters their route of flight and IM clearance information into the IM avionics, then flies the speeds calculated by the IM Avionics to either achieve or maintain the desired spacing interval behind the Target aircraft.

## 1.3 Flight Test and Training

In order to achieve the project goals and validate the performance of IM, a flight test was conducted as part of the ATD-1 Phase 2 avionics contract (refs. 5 and 6). The goals of the flight test were to:

- develop an IM application to support IM operations, and
- integrate IM avionics into two test aircraft and conduct validation flight tests.

Prior to the flight test, the NASA team identified a need to provide classroom and simulator training to the flight test team. Core training elements as identified by Bell and Kozlowski were an integral part of the training regimen (ref. 7). The objective of the training was to:

- ensure the flight test pilots could correctly input all IM information to a human-machine interface (HMI) without prompting;
- ensure the flight test pilots could position the aircraft at the correct waypoint and time for the subsequent scenario;
- ensure the flight test pilots could correctly fly the IM operation;
- ensure the flight test pilots could complete post-run and end-of-day surveys in a timely manner.

Elements for the training were drawn from comprehensive plans to use three aircraft to fly IM operations in high-altitude en route airspace, arrival operations from en route altitudes to the Final Approach Fix (FAF), and operations intercepting final approach within the terminal airspace.

The flight test directors (FTDs) and researchers were a necessary component to crew communications in order to ensure vehicle positioning, and as such, were included in the flight crew training. The TMA-TM scheduler and CMS tools were not available for this flight test, which meant the flight test director would coordinate start positions with the flight test aircraft pilots prior to IM operations. This allowed the pilots, flight test directors, and researchers to practice as a team before the actual flight test.

The Avionics Phase 2 flight test was conducted under a NASA contract with Boeing, Honeywell, and United Airlines which developed an IM avionics prototype based on NASA's ASTAR spacing algorithm (ref. 8), and performed in-flight testing of that prototype. The flight test occurred January 2017 in the vicinity of Grant County International Airport (KMWH), Moses Lake, Washington.

# 2 Key Training Elements

Described below are several key aspects of the flight test design which were incorporated into the training program in order to produce a realistic simulation environment from which flight test personnel could train for the flight test.

## 2.1 Arrival and Approach Procedures

Three special Standard Terminal Arrival Routes (STARs) that were developed for the flight test were included in the training program. These STARS connected to the existing Required Navigation Performance Authorization Required (RNP AR) instrument approach procedure at KMWH (see Appendix A). This allowed the use of performance-based navigation (PBN) procedures from the high-altitude en route environment to KMWH. These STARs were developed in accordance with FAA guidance (ref. 9), and were designed to allow for various combinations of merge points and route geometries, as well as support landing on Runway 14L or 32R, depending on wind conditions. The research team preferred to use PBN procedures to fly all scenarios to runway 32R since this runway had a published straight-in and a published RNP curved approach that merged at the Final Approach Fix. Although winds seemed typically favorable to runway 32R, routing and approach to both runways were included in the training program.

As an example, figure 3 is a composite map of the SUBDY and UPBOB STARs connecting to the runway RNAV Z 32R approach. The legend for figure 3 is as follows:

- Blue-green line: high altitude en route operations at FL350; in-trail geometries only; initiated at ZIRAN, terminating at SINGG
- Red lines: arrival operations; in-trail, medium-altitude merge (NALTE), or low-altitude merge (ZAVYO) geometries; initiated in vicinity of SINGG, JELVO, MAHTA, or NACUN, terminating at ZAVYO
- Purple lines: final approach spacing; in-trail or merging geometries; initiated about 25 nmi from the runway, with the PTP at 6.25 nmi from the runway threshold

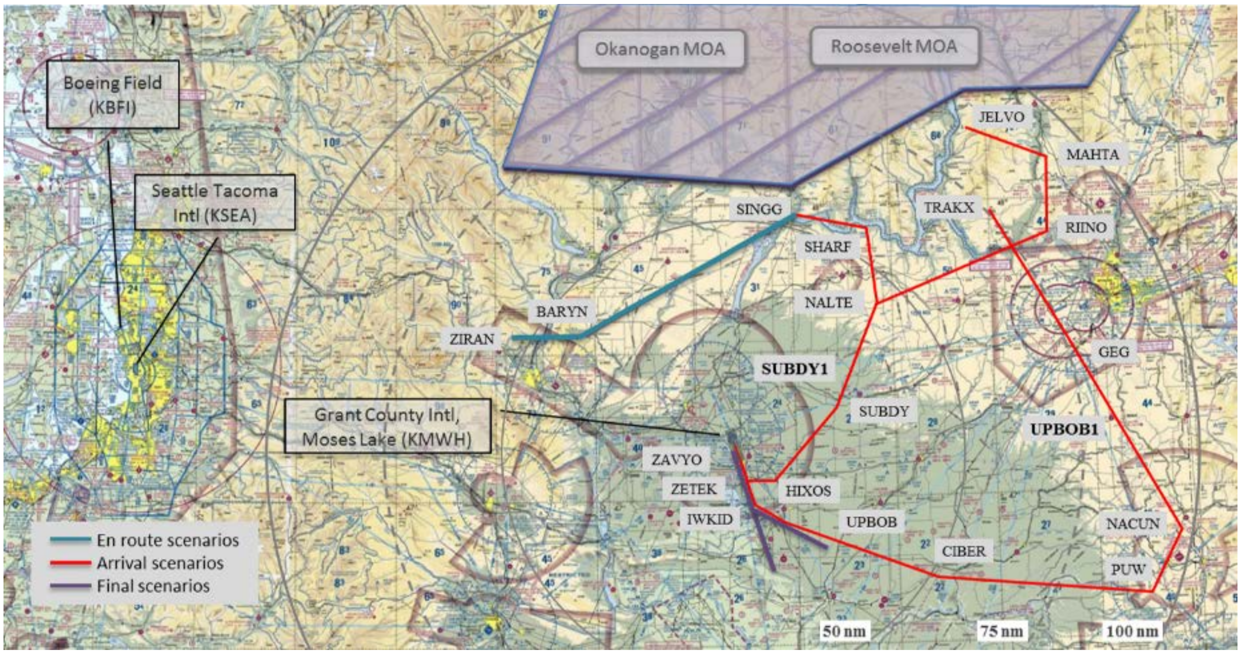


**Figure 3. Airspace and routes used in ATD-1 flight test.**

The en route scenarios were planned at FL350 from ZIRAN to SINGG (blue-green line), potentially extending to JELVO if vehicles were in-trail of one another. The first arrival scenario (red line) of each day would initiate shortly after the aircraft crossed SINGG/JELVO. All subsequent arrival scenarios would initiate at mid-altitude ranges (FL230 or FL220) to reduce transit time from the go-around point to the next start point, reduce fuel burn to an unnecessarily high altitude, avoid traffic inbound to or departing from the Seattle area, and reduce controller workload by avoiding a handoff to a different air traffic control sector. The final approach spacing scenarios (purple lines) involved only two aircraft climbing to 6000 and 7000 feet, then proceeding to the start points approximately 30 nmi south of KMWH.

Hold points and IM initiation points were selected to prevent the aircraft from entering special use airspace to the north and from crossing certain sector boundaries, reducing the amount of coordination with air traffic control required to conduct the flight test.

## 2.2 Flight Test Aircraft

The flight simulators used in training emulated the actual flight test aircraft. A Honeywell Dassault Falcon 900 (F-900) (figure 4, center aircraft) was used as the first aircraft in the flight test arrival stream. A Honeywell Boeing 757-200 (B-757) and a United Airlines Boeing 737-900 (B-737) (figure 4, left and right aircraft) served as the two following aircraft and were equipped with the IM avionics prototype.

Recordings of an aircraft on the flight test routes were made by flying the NASA LaRC Development and Test Simulator (section 3.3.1). Those recordings were later played back during live training sessions as the lead aircraft. Since there were several different routes, several different recordings were required.


**Figure 4. Aircraft used in ATD-1 Avionics Phase 2 flight test.**

## 2.3 IM Operation Types

Four different types of IM clearances were trained for the flight test, which included a time or distance interval between the Ownship aircraft conducting the IM operation and the Target aircraft to be followed. The clearances were described to the pilots as seen below in order of complexity, beginning with the simplest. The order is also in line with order of occurrence during the flight trials. The four clearances in the ATD-1 flight test were Maintain, Capture, Cross, and Final Approach Spacing:

**MAINTAIN:** The Maintain clearance can be given when the Ownship and Target aircraft are on a common path and the controller wants the Ownship to maintain the current in-trail spacing. The algorithm determines speeds that will continuously maintain the in-trail spacing until the operation terminates at the PTP. The Maintain clearance is used during en route and arrival operations.

**CAPTURE:** The Capture clearance occurs when the Ownship and Target aircraft are on a common path and the controller wants to specify an exact spacing dimension between the two aircraft. The Ownship is assigned a specific ASG to capture, captures that ASG, and then maintains it until the operation terminates. The Capture clearance is used during en route and arrival operations.

**CROSS:** The Cross clearance is used when the controller wants the Ownship to achieve the ASG by the achieve-by point, then maintain that spacing interval until the operation terminates. This clearance is particularly relevant to aircraft on separate routes that merge at some point. The Cross clearance is used during arrival operations.

**FINAL APPROACH SPACING:** The Final Approach Spacing clearance is used when the final controller wants to use IM to precisely achieve an ASG behind the preceding aircraft on final approach. This clearance is given to the Ownship when one aircraft is established on the final approach course, and the other aircraft is either also established or flying a vector to intercept the final approach course.

## 2.4 Electronic Flight Bags and Configurable Graphics Displays

Both the hardware and software were emulated in the simulators for the training program. The hardware consisted of dual, Class 3 electronic flight bags (EFBs) (figure 5, large orange circle). The EFBs hosted the IM application, provided the touchscreen functionality for data entry and application control, displayed the IM application data entered by the pilots, displayed the IM application processed data, and displayed other traffic in the area. Critical information from the EFB was replicated on the configurable graphics displays (CGDs) (figure 5, small orange circle). The two CGDs were installed in the primary forward field-of-view of each pilot and provided speed guidance and other IM information to the pilots. During development of simulator graphics for training, the final locations of the installed hardware were still in flux. Actual CGDs on the B-757 did not exactly match training locations (rightmost rectangle in the right monitor, figure 11), but the pilots had already become familiar with the information and were able to compensate for the dislocation.

**Figure 5. Honeywell B-757 CGD and EFB.**

The received data consisted of Ownship and Target state data (latitude, longitude, altitude, heading, speed, etc.). The input data entered by the pilot consisted of destination airport, forecast winds, the Target aircraft's call sign, Ownship and Target aircraft routes of flight, the IM clearance type, and the ASG. Either EFB could be used for data entry, and the display on each EFB could be selected independently of the other. The flight crew IM procedure defined during training ensured that any single data-entry field would not be accessed simultaneously by both pilots.

The IM prototype software written by Honeywell was based on NASA (ref. 7) and RTCA (ref. 10) documents. The EFB and CGD displays (refs. 11 and 12) were influenced by earlier NASA designs (ref. 13).

Figure 6 illustrates the IM prototype displays where the Target is approaching NALTE and the Ownship has just passed OYOSE. As mentioned earlier, the CGD repeats four essential display elements from the EFB (Fast/Slow Indicator (FSI), Progress Indicator, IM commanded speed, and IM state), and a subset of the IM avionics status messages. The CGD colors were changed to white and the font size made larger to compensate for installations above the glare shield and exposure to direct sunlight. The numbers of the data elements in the list below correspond to the numbers shown on the EFB and CGD in figure 6:

1. Ownship: solid white triangle shown at the bottom 1/3 of traffic display
2. Target: hollow white chevron outlined by green chevron; data tag if selected
3. Fast/Slow Indicator: Ownship's deviation from the IM instantaneous speed; always shown on both the EFB and CGD
4. Progress Indicator: shown when the Ownship is within 30 nmi of the ABP during the achieve phase, or anytime during the maintain phase; Ownship's position deviation from the ASG is labeled as Early/Late (time-based) or Near/Far (distance-based)
5. IM commanded speed: the speed displayed by the avionics to be set by the flight crew into the mode control panel (green on EFB and white on CGD)
6. IM state: options are "OFF," "ARMED," "AVAILABLE," "PAIRED," "SUSPENDED," and "TERMINATE" (the same as "OFF")
    - EFB: "PAIRED" shown in green, all other states in white
    - CGD: "PAIRED" shown in white, all other states not shown
7. IM clearance type: shown in green when Paired; otherwise shown in white
8. ASG: spacing value for the Ownship behind the Target; shown in seconds (time-based) or nmi (distance-based); manually entered by the flight crew; shown in cyan in Paired state only
9. Predicted/Measured Spacing Interval: the IM avionics' estimate of the predicted spacing interval or measured spacing interval; shown in white when available; unique to the flight test and not expected to be shown on future IM systems

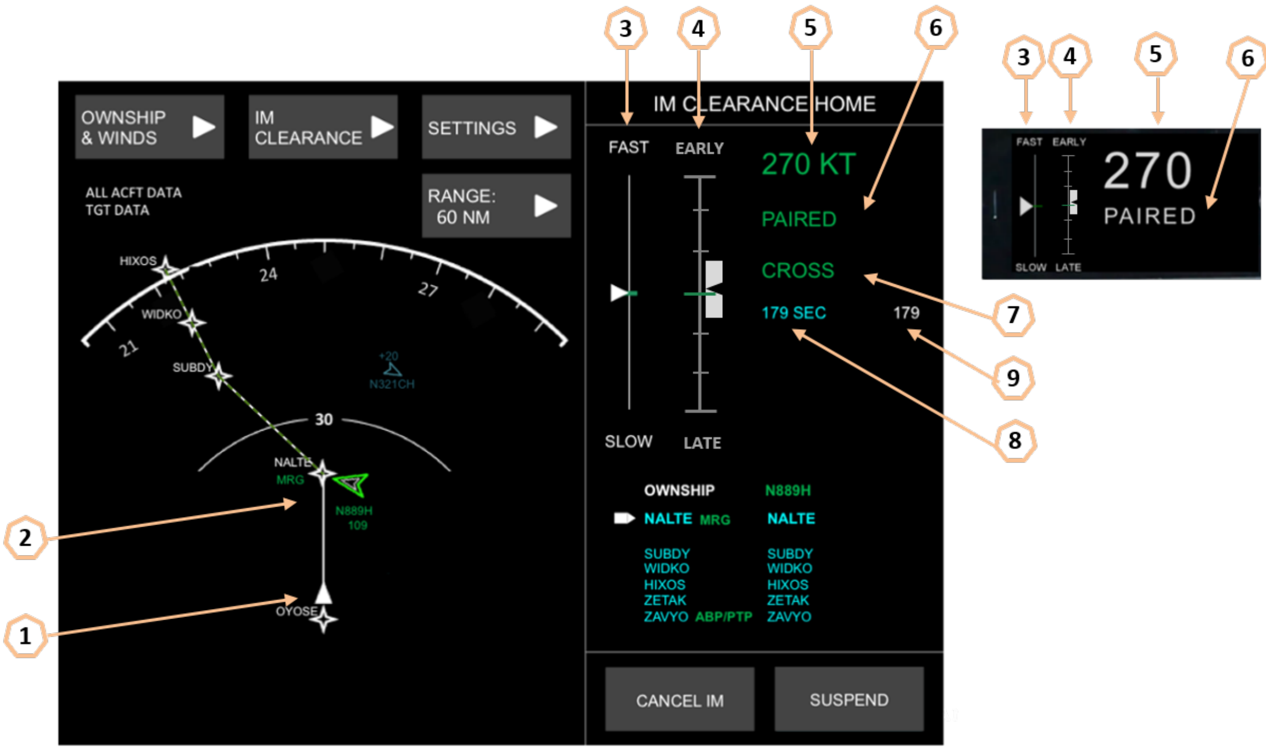


**Figure 6. IM avionics prototype EFB in arc mode (left) and CGD (right).**

## 2.5 Flight Test Director Tools

The FTD, a Boeing employee, was included as part of the training program. As coordinator for the flight test, the FTD was tasked with keeping track of all vehicles and coordinating with the flight test pilots so that all aircraft reached the correct start positions on time. This would be especially important when verifying aircraft positioning prior to the start of each scenario, but also a means to monitor progress during IM operations. If an aircraft had a bad run or somehow managed to end up in the wrong location, early intervention was best to return to aircraft start positions or reconfigure the vehicle sequence for the following scenario which occurred shortly after go-around. A cockpit display of traffic information defaulted to Arc Mode on the EFB (figure 6, left) to show relevant aircraft in the vicinity. Unfortunately, the Arc Mode view was a limiting factor even at long range, because all three aircraft may be on dissimilar routes and the view only displayed the forward 90-degree quadrant.

A new 360-degree view mode was created on the EFB for training, called Plan Mode. Plan Mode was integrated with the EFB software as a settings option and was usable at the FTD simulation station. Plan Mode could only display a single aircraft route, which meant the FTD might not always see test aircraft that were on a separate but merging route. In the example below (figure 7), the Ownship is following the F-900 (N889H) on the same route, but the third aircraft exists both off-route and outside the range currently displayed. Positioning was also unfixed, which meant the graphics rotated as the aircraft turned, further hindering positional awareness.

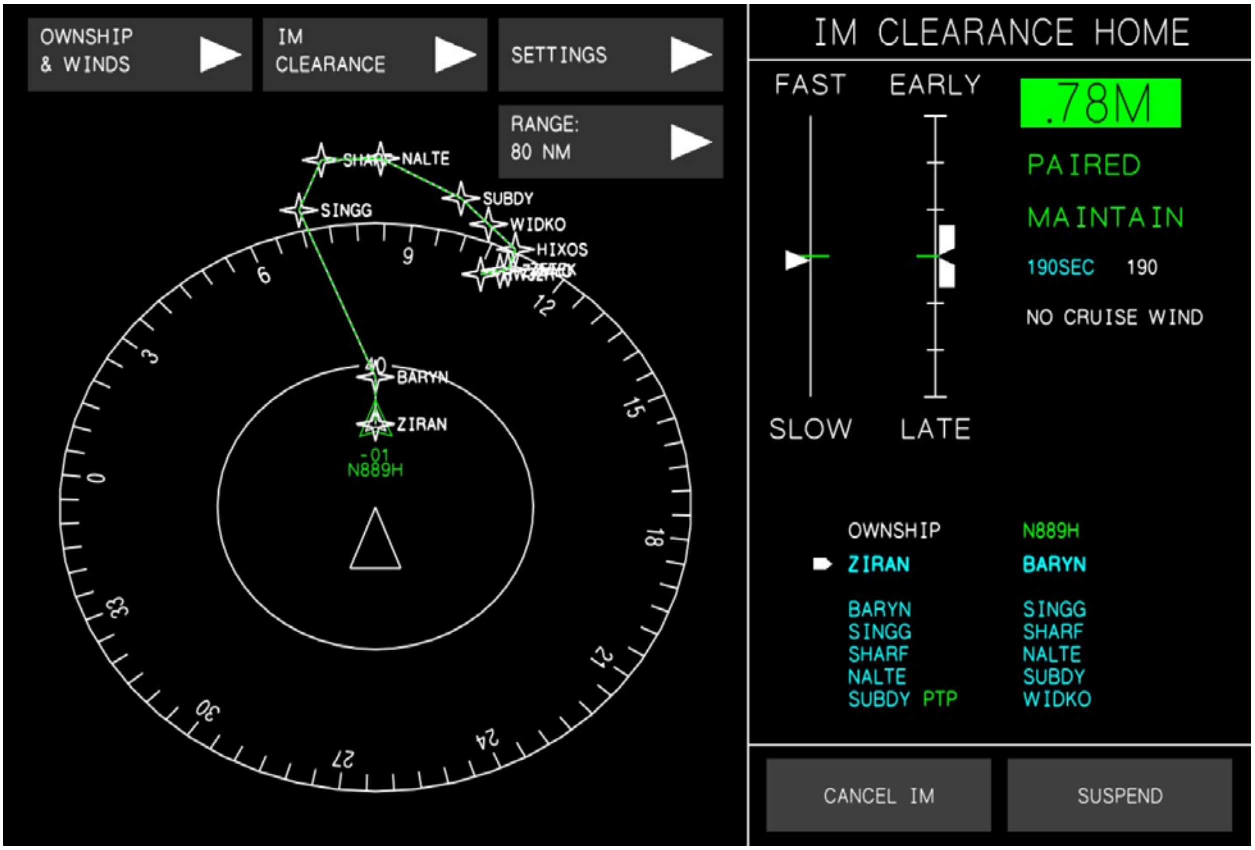


**Figure 7. FTD Plan Mode on the EFB.**

After training, the Honeywell flight test department acquired access to a previously used traffic and weather software program by ATMOSPHERE called PLANET which exchanged data in real time between airborne and ground users by utilizing satellite and cellular networks for ubiquitous connectivity. ATMOSHPERE also tailored the software by enabling selectable overlays for the wind forecast, arrival and approach procedures, and the display of special use airspace (figure 8). Although PLANET software was used in the flight test, the procedures provided during training still remained relevant to the successful conduct of the flight test. Experience gained from a challenging training display made a geographically fixed-window display much simpler for situational awareness.

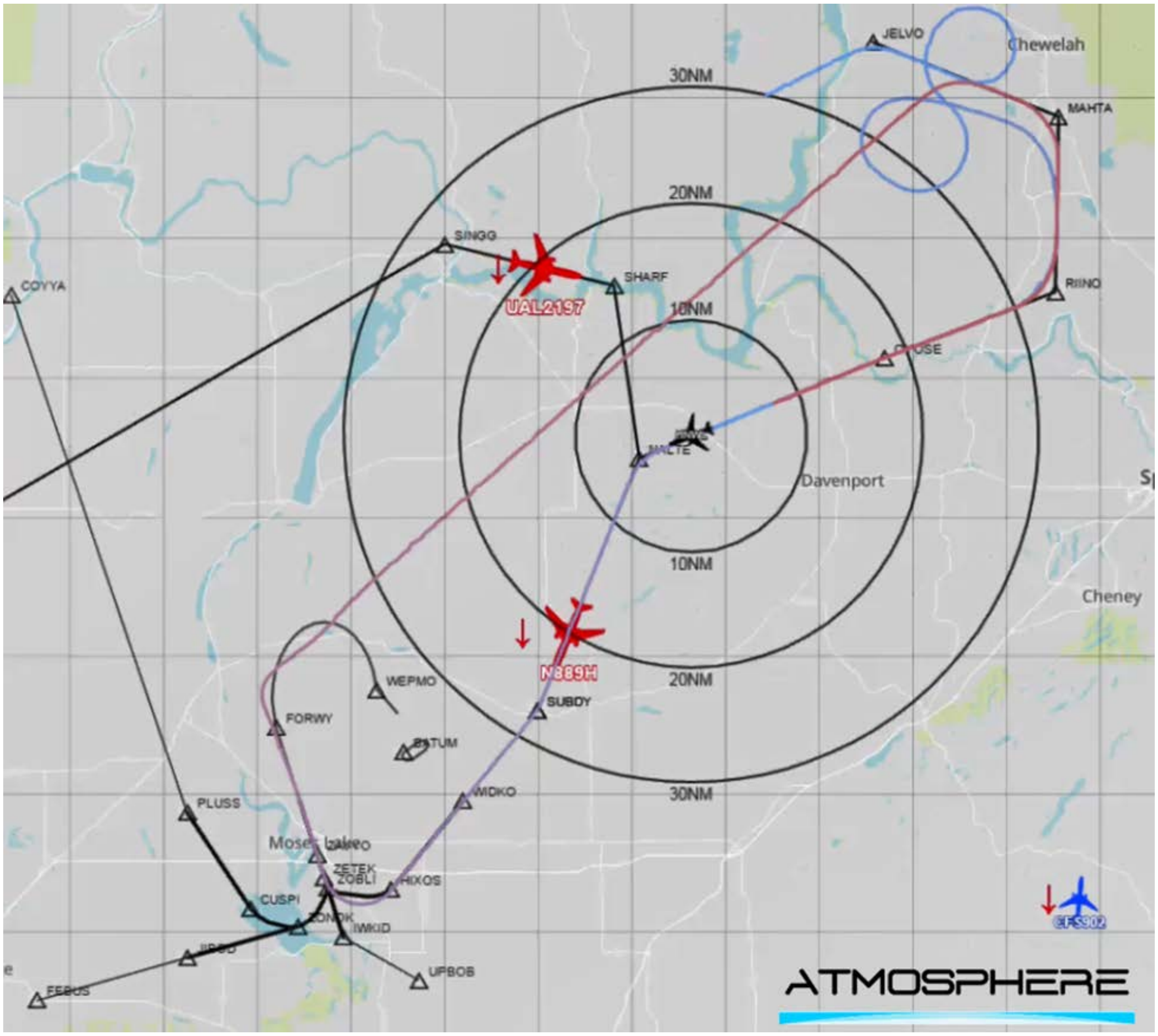


**Figure 8. PLANET Software Display from the Flight Test.**

# 3 Training Schedule and Attributes

A multi-tiered, incremental approach was used to train the flight test pilots. This training regimen consisted of four steps: computer-based training (CBT), classroom training, simulator training, and reiterative training (Table 1).The FTD was also included in the classroom and simulator training, providing briefings to the pilots and coordination during the simulation training sessions.

**Table 1. Training Syllabus**

| Timeframe | Training Type | |
|---|---|---|
| 3 weeks prior to classroom training | CBT training | |
| Langley Day 1 | 1.5 hour classroom | 4.5 hours simulator training |
| Langley Day 2 | 1.0 hour classroom | 4.5 hours simulator training |
| Langley Day 3 | 1.5 hour FTD briefing | 4.5 hours simulator training |
| Langley Day 4 (if needed) | 1.0 hour FTD briefing | 3.0 hours simulator training |
| 1 day prior to flight test (6 weeks later) | 1 hour classroom reiteration training | |

Since repeated exposure can help with the acquisition of basic concepts, the IM prototype display (a focal point of the flight test) was included in every learning exercise. The computer-based training and user guide for the prototype was initially provided to participants ahead of training at NASA LaRC. It contained reading material, video, and was implemented with guided training that utilized a touch-screen interface. Later instruction occurred in a classroom setting using interactive training, accompanied by fully immersive training in flight simulators to conduct simulated scenarios in the flight test airspace. One day prior to the flight test, reiterative classroom training was provided as a refresher to the pilots.

Considerations for the training program led to the following desired scenario attributes and drove development of the simulation training regimen. A representative set of test scenarios were selected from the flight test plans which encompassed all test conditions that may be encountered during the flight test, provide contextual variety, and also maximize the number of scenarios included in the limited training timeframe.

- All four clearance types
- Time- and distance-based operations
- “+” and “-” spacing error calculations
- IM to occur during cruise, descent, and final approach operations
- All three designed STARs
- Change of runway during an IM operation due to wind shift
- Change in order of arrival of test aircraft while conducting the experiment
- Calculate the ASG by summing the error with the predicted spacing interval (PSI)

Aircraft anomalies were not specifically addressed in the training. If a maintenance issue occurred on one vehicle from the set of three during flight, operations could still continue as a two-aircraft, single IM set. Training was considered unnecessary for this condition since only minor details of the programming would change, which could be relayed by the FTD to the remaining pilots.

There were several stages to the development of the simulator training program:

- Build the simulation and test it with pilot researchers first.
    - Developmental testing of displays and basic functionality
- Dry Run using two groups of two confederate crews each
    - Testing of simulator functionality and training program acceptability
- Dress Rehearsal using two groups of two confederate crews each
    - Re-testing of simulator functionality and training program acceptability using returning confederates allowed comment on improvement and retrogression.

- Pilot Orientation Simulation training event
    - Two groups each consisting of two flight test crews, one flight test director, and NASA participants working directly with the FTD
    - Both flight test directors appeared during the last week, the first to observe the second, ensuring consistency between the two.

Exploratory learning was guided during initial simulator training, and then a “hands off” approach was used during later lessons while instructors added realism to the simulation by providing radio inputs as ATC and other traffic. Quick reference guides were provided to manage programming the EFB, if needed. Data cards were also developed detailing key information specific to each run (Appendix B).

## 3.1 Computer Based Trainer

The first training program goal was to teach the pilots the procedure required to conduct IM operations. The CBT addressed this goal by detailing the local airspace and instrument procedures, proper information entry into the IM avionics prototype, and procedures to manage aircraft airspeed and vertical path while conducting the IM operation. Because studies have demonstrated that prior training on a PC-based flight simulation package (regardless of the method to manipulate the flight controls) resulted in better overall performance than an untrained operator (ref. 14), the CBT was electronically sent to all pilots three weeks prior to arriving at NASA LaRC for the classroom and simulator training regimen. This allowed the pilots to interact with the representative EFB and to practice entering the required IM information, which reduced the simulator training time required.

The NASA LaRC CBT was designed to provide a walk-through of the prototype Flight Deck IM (FIM) avionics, simulating the operator environment while allowing the user to learn the layout of the system (figure 9). While the CBT was a manipulable product that could be completed in approximately 80 minutes, users could also conduct training at their convenience, repeat as often as desired, and were not subject to pass/fail pre-qualification, enabling the user to make mistakes without fear of negative repercussions. Guided instruction was provided before most button presses in beginning modules. Later modules followed similar button pathways without instruction, forcing the learner to actively develop the cognitive template for the required task, and only provided guided instruction when new information was encountered. Sized to the EFB, the CBT looked dimensionally similar when viewed on an iPad and operated much like the FIM prototype to be used for the flight test, therefore creating a realistic product that moved at the learning pace of the trainee.

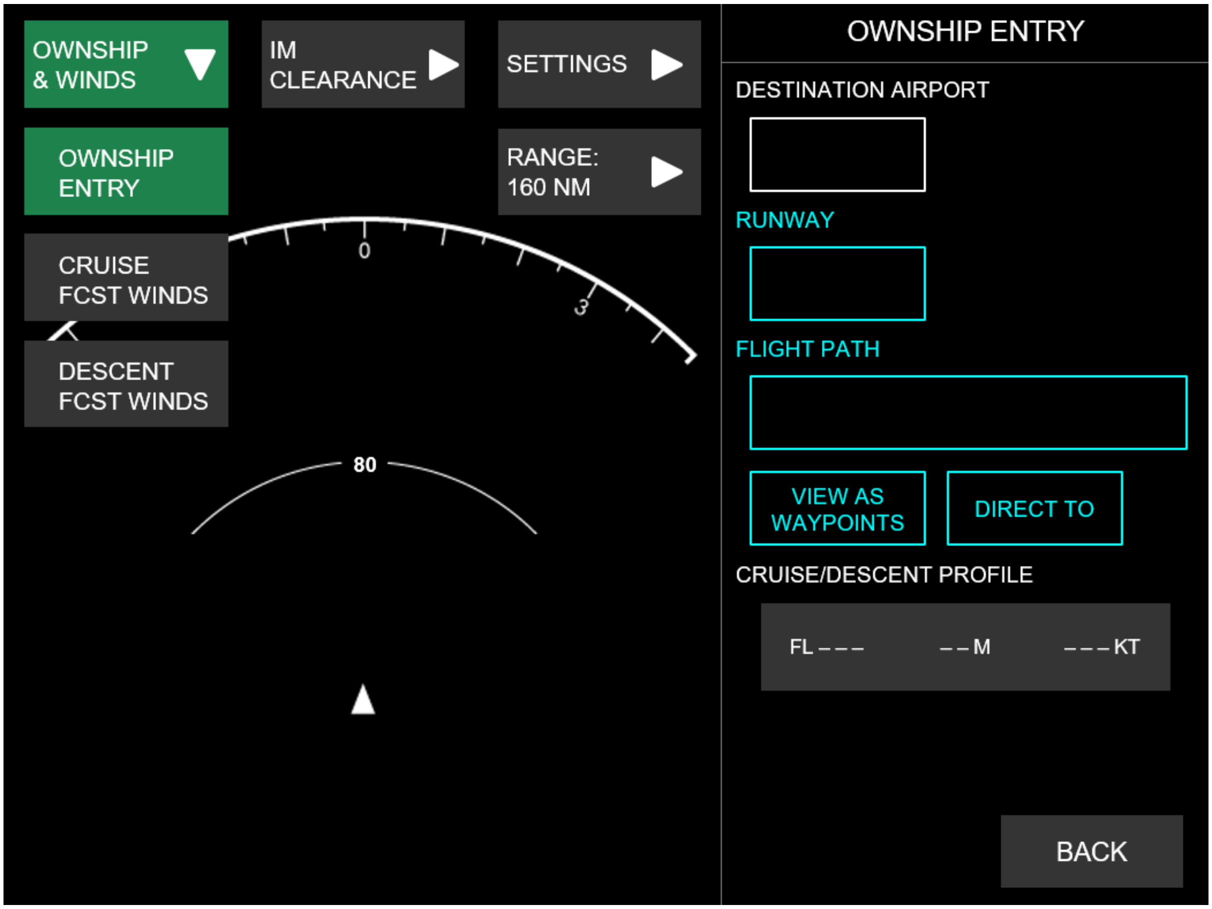


**Figure 9. Computer Based Trainer (CBT)**

Supplemental materials appended to the CBT included charts describing the published procedures (Appendix A) and a pilot guide describing IM clearance types with associated vehicle graphics for each operation overlaid on a STAR, legends for all FIM displays, and descriptions of functionality for every button in the EFB.

The CBT chapters included (1) *CBT Info*: How to operate the CBT, (2) *Introduction*: General overview of IM and primary aircraft components, (3) *Ownship Entry*: How to input Ownship information into the EFB, (4) *Clearances*: How to input Target information into the EFB by clearance type, and (5) *Operation*: Air crew procedures and operational techniques once engaged in IM.

The CBT discussed the flight test airspace, special STARs for the flight test, specific definition and description of four IM clearance types, a walkthrough of the FIM prototype HMI, and the flight crew procedures.

## 3.2 Classroom Training

The second element was classroom instruction which included a standard brief that reviewed the information in the CBT and allowed for a more in-depth exploration of the topics and resolution of questions. Pilot roles and actions to accomplish the scenario setup and conduct the IM operation were further defined. The classroom instruction at NASA LaRC was designed to provide graduated daily training to coincide with the simulator training regimen. One and a half hours on the first day and one hour on the second day was dedicated to classroom instruction. Focus was on the Interval Management clearance types, a walk-through review of EFB functionality, flight crew procedures, flight test card formats, and methods of managing the aircraft's energy to conform to the vertical path and IM speed commands. The third and fourth day classroom instruction focused on crew and FTD integration and communication for the flight test. The FTD provided a morning briefing of the simulation scenarios to be flown that day, and answered questions from the pilots, which set the stage for a common rhythm, or method to ingest information, which became recognizable and acceptable to the pilots during the flight test experiment. Attendees included one FTD, one B737 flight crew, one B757 flight crew, instructor, and researchers associated with the learning task for the day. All remaining time during the four-day training session was spent in simulator training. Each training day concluded with debriefing sessions to clarify irregularities and solidify lessons learned.

## 3.3 Flight Simulator Training

The third training element was flight simulator training. The first part of simulator training was to ensure the pilots were able to manipulate the IM software in an active setting, while the second part was to practice positioning the aircraft for the next scenario. Since the ATD-1 ground-based components were not part of this flight test, the FTD communicated with the pilots, who in turn coordinated with controllers to efficiently position the three aircraft for each test run. This included identifying when holding was required and where that holding would occur. The test cards later used in the flight test were refined during the training regimen with significant input from the pilots and included data required to assist in the correct filing and positioning of aircraft between each scenario. An important component of the scenario setup was establishing an ASG that would achieve the scenario objective while maintaining the appropriate separation between aircraft (ref. 15). When the aircraft reached their initiation point, the flight crews used the IM avionics to determine the current spacing interval. This value was added by the pilots to the spacing interval shown on the flight test card to calculate the ASG used by the aircraft for that IM operation. If the calculated ASG was outside of the bounds defined for this flight test (i.e., 150 to 210 seconds), the flight crew coordinated with the FTD, and the FTD then determined an alternate ASG. This process was individually repeated by each crew for each scenario.

Live, interactive training utilized one full-scale B-757 simulator, one B-737 simulator, and a desktop station emulating the displays expected to be available to the FTD when onboard the B-757. The NASA LaRC B-757 and B-737 simulators were the primary locations for practicing EFB manipulation of the IM display and understanding interactions between prototype outputs and IM operational vehicle spacing. Integrated simulator training developed operational experience (including data entry on a labor intensive prototype), confidence, and scan technique with the FIM prototype. Following the classroom instruction on the first day, the flight crews initially went to their respective simulator for familiarization and part-task training of the IM procedure. Afterward, the two simulators and FTD desktop station were connected together to simulate the scenarios to be flown during the flight test, with the pre-recorded Target serving as the lead aircraft in all cases. During the flight test itself, the flight test director was expected to operate from within one of the test aircraft using voice communications to disseminate information to the pilots of all three aircraft. Therefore, during training at NASA LaRC, the FTD used a separate desktop simulator station that was designed to provide information to the FTD that was representative of the real-world test. The simulation provided audio connectivity and Cockpit Display of Traffic Information between all simulators and also included simulated traffic similar to typical traffic in the planned flight test location.

A wind forecast was given to the pilots each day of the flight training. The numbers were the same from day to day, but served as a means for the pilots to practice entering information. Winds provided were a reasonable assumption of the typical altitudes where vehicles would spend the majority of their time and were based on a summary analysis of winds for that region and season. Furthermore, realistic winds were used in the simulation environment.

### 3.3.1 Test Protocol

Once again, using a stepwise training regimen, scenarios were organized based on design simplicity, with the least invasive changes to normal pilot action first. The training scenario design from simple clearance types to complex progressively increased pilot workload. Simulation sessions were also distributed across several incremental categories: (1) stand-alone sessions, (2) integrated sessions, and (3) FTD sessions.

Stand-alone sessions were the first step for the simulator training, where the two simulators were not connected together. A single simulator followed a pre-recorded target allowing the trainer to familiarize a single crew with data entry into the IM prototype and practice the pilot procedures to conduct an IM operation. The cruise segment provided an already configured vehicle so crews could focus on programming the EFB, while the arrival segment allowed the crew to integrate IM actions with normal flight operations. Same route operations were also used for both Ownship and Target to clearly describe MAINTAIN and CAPTURE clearances, and also time- and distance-based operations. Training time was maximized with both simulator crews performing this training concurrently.

Integrated sessions were the second step for the simulator training in which both flight crews reiterated previously learned clearance types while increasing scenario complexity to a three-aircraft set. Multi-route operations were introduced along with the CROSS clearance, spacing error calculations, and consecutive scenarios. This lengthened training duration while also focusing the pilot's mindset toward vehicle set up following completion of the previous scenario. The pilot's ability to correctly position the aircraft during set up was a crucial aspect of the flight test.

FTD sessions integrated the test director, who was observing up to this point. Vehicle positioning was further clarified through pilot/FTD-interaction, and the training period was increased to more closely match flight test intervals by using multiple, long scenarios in a single session. Flight test particulars including post-run surveys and ATC radio calls (from trainers) established the pacing for data entry. Higher order decisions for the FTD were incorporated such as reordering aircraft positions, and runway change due to wind shift. The FTD was specifically given extra opportunities for exploratory learning to develop the correct mental model of aircraft positions by testing various time intervals between aircraft and start locations to see what worked best. The FTD was able to develop correction strategies to manage cases where the initial spacing error was too far out of range. In some cases, towards the end of the training program, the NASA instructor left the training area during critical phases of decision-making and remotely observed the FTD and pilot interactions to ensure the scenarios were being executed as desired.

Throughout all of the simulator sessions, trainers allowed both pilots and the FTD to make mistakes and gave positive encouragement for successful planning and execution. Instructors narrated a run summary prior to each start, emphasizing specific pitfalls to recognize and avoid, including an explanation of the FIM algorithm operation. The trainers explained that the IM algorithm is a closed-loop system whereby errors or delays in implementing the commanded FIM speed simply result in issuance of a new speed command when the original command is not followed. Once this was known, the pilot fixated less on the speed command window and focused on the operation in general, to which the trainers perceived reduced pilot workload and stress when attempting to adhere to the assigned task.

### 3.3.2 Procedure to Conduct IM Operations

The flight crew procedure to conduct IM operations was divided into two phases: (1) programming the data required for the IM operation into the prototype avionics via the EFB, and (2) entering the IM commanded speed into the mode control panel speed window. Simulator sessions reiterated phase one knowledge introduced by the CBT and provided live feedback for phase two.

In the first phase, the flight crew programmed the IM avionics using the side-mounted EFB shown in figure 10 to enter information about the Ownship's route and destination, forecast en route and descent winds, and the IM clearance itself. The Ownship information and winds could be entered at any time. The FMC needed Ownship's route and forecast wind information to calculate a valid estimated time of arrival to the waypoint specified on the next test card. Because of this, identical information was entered separately into the FMC and EFB to set up for the next test run. Feedback from the training program resulted in a designated waypoint by which the IM clearance would be entered by the pilot and a waypoint where the IM operation would be initiated.


**Figure 10. Side-mounted EFB.**

In the second phase, when the IM commanded speed was displayed, the flight crew entered that speed into the mode control panel airspeed window, similar to entering an airspeed issued via voice instruction from the controller. While this speed was shown on the EFB (the green 260 knots in figure 10), the CGD located in the pilot's primary forward field of view repeated this airspeed (figure 6, right) and other critical information needed to execute the IM operation. Displaying critical information on the CGD also allowed the EFB to be used for other applications once the IM information had been entered.

The aircrew flew the arrival and approach procedures using the IM commanded speed while meeting all altitude constraints by using thrust or drag as needed. The aircrew configured the aircraft as the airspeed decreased below flap maneuvering speeds to achieve stabilized approach criteria by 1000 feet above ground level. A go-around was initiated at the missed approach point, and the flight crew reprogrammed the FMC and EFB for the next run during climb-out.

### 3.3.3 Procedure to Precisely Position Aircraft

In the ATD-1 concept of operations, controllers use the schedule and decision support tools to ensure the aircraft are aligned so that speed control can be used to achieve the desired spacing interval. Since the schedule and tools were unavailable for the flight test, another critical goal of training led to a two-part process utilizing the aircraft's flight management system and the IM avionics prototype to set up the test scenario. This two-step set-up process to position the aircraft for the scenario was unique to the flight test environment, and would not be used when controllers have access to a schedule and decision support tools. In future operations with the ATD-1 concept fully deployed, when ATC issues a spacing goal, the pilot might not have knowledge of the exact spacing error, but would simply follow speed commands output by the algorithm to the conclusion of the IM operation.

During training, both pilots and flight test directors were trained to work together in order to coordinate the set-up of flight vehicles prior to initiating a test run. By using a pre-recorded vehicle as a Target, FTD training benefitted from known en route flight times to calculate against the progress of the crewed simulators. Unfortunately, when mistakes in positioning were made by training crews, the dynamic simulator cabs sometimes progressed outside the desired spacing range while working with a static recording, which could not make any corrections to ease the problem. Difficulties in obtaining precise simulated aircraft positioning during training resulted in a slightly modified procedure during the flight test.

Prior to initiating a test run, all three aircraft were required to be in a position which would place vehicles approximately three minutes apart when crossing a common predefined waypoint, typically the FAF. Starting waypoints were defined for each route transition at which a test aircraft could perform a hold maneuver (if necessary) to meet a time constrained goal defined by the FTD. Each aircraft had to fly to a waypoint specific to the run which helped define the 1st, 2nd, and 3rd position in the three aircraft set. The aircraft which took the longest time to reach the initial start position was designated the "long pole in the tent" (LP for Long Pole) and therefore least likely to perform a hold maneuver (see data cards in Appendix B**)**. Estimated times of arrival (ETAs) for all other aircraft were derived from the Long Pole aircraft. To manage initial self-separation, the aircraft other than the Long Pole aircraft could vary speed inputs while inbound to their start location, or else hold once at the start location in order to meet the time requirements. An example follows of crew coordination to position vehicles for each run, where the Long Pole is in position 2:

1. Each simulator crew relayed the FMC acquired ETA to the FAF across a common frequency to the FTD, in this case 1242 Z and 1248 Z.
2. The known travel time for the pre-recorded Target was added to the start time of the simulation by the FTD, which gave an ETA of 1240 Z.
3. The FTD then relayed ETAs back to the simulator crews. E.g., “DTS, your ETA will be 1243 Z, slow down if able, or expect to hold 1 minute. IFD, your ETA will be 1246 Z, speed up if able.”
4. Both aircraft 1 and 3 confirmed the instructions back to the FTD, then adjusted speeds or went into a holding pattern, as necessary, to cross their individual start positions with ETAs to the FAF at 1243 Z and 1246 Z, respectively.

In this case, if all three vehicles remain on autopilot to the FAF, Aircraft 1, 2, and 3 will cross the FAF at 1240, 1243, and 1246 Z, respectively. This level of granularity for time constraints between vehicles typically placed most spacing intervals close to 150–210 seconds, which were the desired values for the flight test in order to ensure that the aircraft were separated from each other at all times.

Further refinement of vehicle spacing was required in order to meet the desired initial spacing error for the flight test run. In the case of the IM prototype-equipped aircraft (crewed simulators), a measured interval provided by the algorithm was displayed on the EFB (figure 10, white 170). The predicted spacing interval was the instantaneous spacing between Target and Ownship at that time. The Ownship pilot would communicate this number to the FTD in order to derive an appropriate ASG to be used for the test run. The FTD was critical during this period to mitigate errors due to undesirable aircraft positioning and provide alternatives when the intended ASG was unachievable. An example follows of crew coordination to implement the ASG at the beginning of a test run:

1. After pressing EXECUTE on the EFB, a PSI of 170 is displayed.
2. Ownship pilot relays a PSI of 170 to the FTD.
3. FTD checks test card for the run which states the desired error is 30 seconds late (i.e., behind schedule).
4. FTD relays back to Ownship pilot to set ASG of 200.
5. Ownship pilot sets ASG of 200 in the EFB and presses EXECUTE again to initiate the IM operation and begin a test run.

#### 3.3.4 Modified Set-up Procedure

Modified set-up procedures derived from training helped reduce coordination timeframes and also radio chatter when positioning vehicles for each scenario during the flight test. During training each crew was responsible to relay ETA information to the FTD. During the flight test though, it was sufficient for just the Long Pole aircraft to call in for vehicle positioning since it was the limiting factor and all aircraft could adjust as necessary.

In the following example, the Long Pole is the 2nd aircraft in the planned vehicle sequence.

1. The Long Pole aircraft obtains the ETA to the FAF from the FMC, then relays across a common frequency the ETA to the FTD, in this case 1243 Z.

2. The FTD then relays ETAs to the other aircraft. E.g., “Aircraft 1, your ETA will be 1240 Z. Aircraft 3, your ETA will be 1246 Z.”
3. Both aircraft 1 and 3 adjust speeds or hold, as necessary, to cross their individual start position with ETAs to the FAF at 1240 Z and 1246 Z, respectively.

In the case of training, the FTD received a spacing value from the pilot, calculated the error, and decided whether a different spacing error was necessary, which left the pilot waiting in most cases before taking action. For the training and flight test, both the pilots and FTD made concurrent spacing error calculations, which proved good practice to verify calculations between participants. The pilot was practiced enough by the flight test to recognize whether the aircraft was well placed within the spacing boundaries, therefore the pilot made the spacing error calculation and relayed it to the FTD who was able to make the higher order decisions. In some cases, by the time the FTD confirmed the calculated ASG, the pilot had already input the expected value. The effect was that the pilot could execute the program right after confirmation was received from the test director.

### 3.3.5 Questionnaires

Beginning the third day of training, as pilots began putting together all aspects of training, post-run paper surveys were given to each pilot following each IM operation. One goal was to inform the pilot of areas of interest to the researchers; therefore, pilots might better remember that aspect of data when filling out surveys later. Secondly, incorporating the questionnaires into training highlighted time constraints between the previous scenario and positioning for the following. This directly resulted in a revision of survey questions down to essential wording to ensure there was enough time for pilots to complete the surveys. As a risk reduction strategy, this also served to inform researchers, who weren’t necessarily pilots, of appropriate times to hand out surveys without distracting the pilots from their flight duties. The pilots were also given an end-of-day survey during the debrief for informational purposes and were not required to fill them out. Some of the comments back during the debriefs were direct answers to the survey questions, which resulted in minor training changes.

### 3.3.6 Development and Test Simulator (DTS)

The Development and Test Simulator (DTS) (figure 11) is a full-scale, high-fidelity, fixed-base simulator representative of a large generic commercial transport category aircraft and was deemed suitable for the Honeywell B-757 flight crew training. It features Boeing 757-200 subsystem panels, a Boeing 767 center aisle stand with throttle quadrant, Honeywell Pegasus flight management computer, Research Mode Control Panel, dual Collins Business radio tuning units, and dual EFBs.

The DTS is driven by a high-fidelity B-757-200 aerodynamic mathematical model. There are three Smiths Industries Boeing 737 Multifunction Control Display Units. Two units are located in the normal forward outboard sections of the aisle stand and a third in the aft center section of the aisle stand for use by the researcher. The overhead panel was not populated.

Cockpit displays are incorporated in four 17-inch liquid crystal display screens and include dual Primary Flight Displays, dual Navigation Displays, an Engine Indication and Crew Alerting System, and dual CGDs in the lower corner to support IM operations. The stand-by altimeter, airspeed indicator, and attitude indicator are located forward of the throttle quadrant. Pilots control the simulator by using dual side-stick controllers and dual rudder pedals.

The simulator's out-the-window visual system provided a 210-degree horizontal by 45-degree vertical field of view. The visual scene used for this training was the Grant County International Airport local flight environment in day visual meteorological conditions.

**Figure 11. The Development and Test Simulator**

### 3.3.7 Integration Flight Deck (IFD)

The Integration Flight Deck (IFD) (figure 12) is a full-mission, full-scale, high-fidelity Boeing 737-800 flight deck simulator with a full suite of flight deck panels replicating aircraft functionality and was deemed suitable for the United B-737 flight crew training. The forward panel consists of six ARINC D-sized display monitors which provide fully programmable heads-down displays. Displays include dual Primary Flight Displays, dual Navigation Displays, an Engine Indication and Crew Alerting System, dual EFBs, and dual CGDs. A Boeing 737 Mode Control Panel is positioned above the forward panel, while directly overhead is the B737 NextGen Forward Overhead Panel.

The Control Aisle Stand hosts a Boeing 737 dual auto-throttle system and two tunable navigation and communication radios. Guidance and navigation flight management is interfaced through three Smiths Industries Aerospace Color Boeing 737 MCDUs, also on the aisle stand. A General Electric Flight Management Computer facilitates operations within the cockpit simulator. The IFD has dual hydraulic wheel/columns and dual digital rudder pedals.

The simulator's out-the-window visual system provided a 200-degree horizontal by 40-degree vertical field of view. The visual scene used for this training was the Grant County International Airport local flight environment in day visual meteorological conditions.

**Figure 12. The Research Flight Deck**

### 3.3.8 Flight Test Director Simulation Station

Although in development during the training program, the flight test director station onboard the B-757 was expected to have operational awareness of that vehicle's state (altitude, speed, etc.), situational awareness of other aircraft in the local airspace, a camera to the cockpit, oversight of the active prototype software, access to any associated paperwork for the flight test, a direct communication line to the pilots onboard, and a common communication frequency between all test aircraft. The actual station is depicted in figure 13, where Bay 7 displays the Planet software (top) and aircraft state data (bottom), Bay 6 displays the IM prototype (top) and real-time video of the cockpit (bottom). Bay 5 replicates the aircraft state data display for the flight test engineer, while the ring-binder on the tabletop is open to the current flight test card.


**Figure 13. Honeywell B-757 Flight Test Configured FTD Station**

To better meet the needs of the FTD during simulation training, the NASA FTD simulation station emulated oversight capabilities for the flight test onboard the B-757 test aircraft by displaying B-757 simulator information and also displaying similar information from the B-737 simulator. For conceptualization purposes, more visual information was provided to the FTD than expected for the flight test which allowed the FTD to observe pilot strategies when conducting vehicle set up. This also allowed the FTD better oversight of crew interaction and reaction to FTD guidance. The station was configured with a hand-held microphone and three information display screens. The display monitor in figure 14 depicts (clockwise from top left) the DTS primary flight display, multi-function display, Captain EFB, First Officer EFB, right CGD, cockpit camera, left CGD, both left and right FMC, and actuator quadrant (speed brake, thrust lever, flaps, landing gear). The primary flight display gave awareness of vehicle state data, while the multi-function display provided insight into pilot viewpoint with respect to the displayed route, which was useful especially during set up holding maneuvers where the map rotated during turns. With both EFBs available, observers could witness any programming conducted by either pilot and also ascertain any personal preferences or difficulties each pilot may have. A similar display monitor was provided for the IFD as added information for training, which would be unavailable for the flight test.


**Figure 14. DTS Flight Simulator Overview Monitor**

The third display monitor was a touchscreen EFB (figure 15, left side) configurable with the Plan Mode display option (figure 7) which provided location awareness of flight vehicles and was manipulable by the FTD. Data ported to this EFB was the same information available to pilots of the DTS. This emulated a similar capability for the flight test since the FTD station resided on the B-757, therefore data streaming to both the cockpit and FTD stations would be the same. The settings were manipulable by the FTD to some respect in order to facilitate training. During the flight test, the EFB menu buttons could not be accessed by the FTD.

**Figure 15. Flight Test Director Simulation Station with EFB and DTS screens visible**

Researchers and the test director sat together during training in order to enhance crew collaboration between flight test participants. This helped solidify roles, and through the collaborative process, ensured relevant questions were recognized and answered during training. The FTD simulation station was also used for pilot observational training, which gave insight into FTD decision-making and the effect of pilot actions on the set-up process.

## 3.4 Reiteration Training

Immediately prior to the flight test a one-hour classroom review session was given to the first set of flight crews, and later to the relief flight crews. This consisted of a short walk-through of the prototype FIM avionics, aircraft operations while performing IM, and a question and answer period. This training was performed approximately six weeks after training at NASA LaRC, because outside factors such as weather affected the start date of the experiment.

# 4 Simulation Training Participants

## 4.1 Confederate Pilots

Prior to training the pilots participating in the flight test, two separate groups of four pilots each were recruited for development of the training program and scenarios flown in the simulators. Each group consisted of two crews qualified to fly the B-737 or B-757. Each development crew was made up of one pilot with previous IM research experience and one without. The groups were each staggered by two weeks for two sessions, allowing researchers to observe learning retention over a one-month period between each test group's session. This was intentional since the pilots participating in the actual flight test were expected to have approximately one to two months between the simulation training and the flight test. When brought back after one month, all developmental pilots needed retraining and simulator practice sessions to reach similar levels of proficiency as the previous session. These pilots did not have access to the CBT since it was in development at the time, and for some, it took nearly the full week to get back up to speed.

### 4.2 Flight Test Pilots and Flight Test Directors

Pilots participating in the flight test were selected by their respective Honeywell and United Airlines flight operations departments. All of the pilots were current and qualified to fly the aircraft in the position(s) they flew during the flight test and were authorized to fly the RNP AR approaches at KMWH. Nine pilots were selected and trained, and eight of them flew in the flight test itself. Boeing provided two FTDs who were also a part of the group training sessions. Both were familiar with the airspace used during the flight test, and one was a former air traffic control manager for the test area. While none of the flight test pilots had previous IM experience, the FTDs had participated in a previous IM experiment and were familiar with the concept. Because the confederate pilots demonstrated a loss of understanding of IM during the interim period between simulation sessions, the CBT and all supporting materials were left fully accessible for flight test participants during the interim period between training and actual flight. Plus, a brief one-hour refresher was given the day prior to the flight test.

## 5 Training Program Effectiveness/Results

Critical components of the training regimen that led to the success of the flight test were pilot understanding of Interval Management, the development of flight test cards for the pilots, setting time goals to ensure correct aircraft positioning, and establishing constructive interactions between flight test crew members. After the conclusion of the flight test, six of eight test pilots completed a survey about the effectiveness of each learning method and any need for improvement. During the flight test, the Ownship used a spacing interval of either time or distance to determine separation from the Target aircraft. Pilot actions to conduct both operations were identical in either case. Numerical analysis of time-based operations is used below to provide an empirical example of learning transfer since these were the majority of flight test results. More detailed analysis of the flight test can be found in reference 17. The success of the training is discussed below in terms of pilot feedback of the CBT, classroom training, knowledge transport in simulation training, and operational effectiveness during the actual flight test. Also included are changes to the flight test directly influenced by training ahead of time.

### 5.1 Computer-Based Trainer

The ATD-1 Avionics Phase 2 flight test program used an HMI that evolved from previous research with very limited redesign and testing. The prototype interface that was used required 110 to 165 button presses to enter the required forecast wind, Ownship, and IM clearance data into the EFB. Comments from trainers and pilot participants suggested that the high number of button presses would result in a workload level that would be too high for line pilots. The high workloads observed during training led to initial IM clearances being entered on the ground during the flight test to reduce overall workload when departing the Seattle area.

The majority of pilots indicated the CBT was successful in meeting their needs through repetitive physical programming and overview of IM clearance types. Following the flight test, pilots suggested additional modules that should be incorporated into future CBTs. Those modules include contingencies to FIM abnormalities and an instructional data entry video prior to the interactive portion. The authors believe a data entry video showing entry for each IM clearance type would be beneficial to the learner. The CBT and flight simulator EFB were created during different development periods of the prototype FIM software, leading to slight differences between the display emulated in the CBT and the display used in the simulator training. Several responses stated the need for identical training products to prevent confusion during training. The pilots also reported that the CBT would have benefited from a clearer description of the IM avionics prototype, in particular the displays and messages shown to the pilots. They also stated a defined correlation between the Target aircraft's behavior and its impact on the IM operation would be relevant to future IM pilots.

Other observations following the flight test regarding HMI and content that relate to creating more robust future CBTs come from the software engineers, researchers, and pilots and are listed below:

- The Honeywell IM avionics prototype used in this flight test had more functionality and met more Minimum Operational Performance Standards (MOPS) requirements compared to the IM system used by NASA in previous experiments. However, by implementing the majority of the MOPS requirements in an operating environment without Data Comm, the pilot's data entry procedure became more complex, more time consuming, and more prone to error.
    - The increased complexity required pilots to navigate multiple pages, making it challenging to maintain awareness of where they were in the data entry process.
- The position and text of several hot-keys were not standardized across the prototype platform. In particular, the function and location of the "BACK," "DONE," and "RETURN" buttons, as well as the "CANCEL" and "TERMINATE" buttons, needed further development.
- It was confusing to the flight crews that the IM clearance information was cleared when the software automatically terminated the IM operation (i.e., the aircraft crossed the PTP), but the IM clearance data was retained when the flight crew manually terminated the IM operation. The interface should be modified to have the IM clearance information treated uniformly, whether terminated automatically or manually.
- The IM progress indicator (EARLY/LATE) was not used very often and appeared to have the least amount of usefulness to the crew because unlike most other aircraft gauges, the bounded range was undescribed. Many pilots assumed it represented the boundaries of a successful IM operation and therefore, when the boundaries were reached, the IM state should change to UNABLE and the flight crew should coordinate with air traffic control.
- The FSI was not always present (by design), which led some to believe that while the IM prototype could calculate a speed in order to achieve a spacing interval, it did not have enough confidence to estimate the relative location to the desired position.

## 5.2 Classroom Training

The majority of pilot responses to the training survey stated classroom time devoted to IM should be minimal to none, indicating higher knowledge transport from the CBT and flight simulator training for the majority of pilots. The maximum classroom time desired by pilot respondents in future training was two hours. However, from the instructor's perspective, two pilots benefitted more readily from the classroom setting than the CBT due to highly interactive conversations. Classroom debriefs following simulator training were invaluable to pilot understanding.

Changes to the training regimen and flight test were most affected by the end-of-day debriefs. Streamlined schedules for pilot actions led to a revision of the test cards in both cases. Pilot surveys questions were also shortened to meet the challenging schedule of the flight test.

### 5.2.1 Test Briefing (The Importance of Briefing and Debriefing)

Besides observing the pilot learning regimen, training for the FTD consisted of a morning briefing, so that he could get comfortable briefing various aspects of the flight test through practice. The training program informed researchers and both test directors of key roles needed to comprehensively describe each day's activity during the flight test. In other words, by training for the perceived roles of the flight test, individual strengths and weaknesses were discovered, which allowed reallocation of personnel resources. For example, based on training observation, one of the test pilots (rather than the FTD) was tasked with daily weather briefings, which provided clear understanding among all flight crew members. As developer of the scenario profiles, the Principal Investigator served as the expert for the daily test cards. Reallocation of both tasks allowed the FTD to focus on other areas of oversight, such as managing the briefing workflow and collaboration with Air Traffic Control (ATC) facilities, discussing ATC procedures, and communicating relevant points to specific groups.

While the classroom setting provided the FTD 1.5 hours to practice the morning brief, the briefing during the actual flight test typically lasted 30 to 45 minutes. As the flight test progressed and participant experience increased, briefing times generally became even shorter.

Debrief during training lasted between 1–2 hours each day and solidified actions for the flight test. Flight test cards used by the pilots during training were streamlined for the flight test due to debriefed pilot feedback. In general, most pilots verbally commented their confidence in the test plan increased as a result of the post-training discussions.

## 5.3 Simulator Training

During flight simulator training, researchers observed that seven of nine flight test pilot trainees with no Interval Management flight experience were able to adequately program the EFB and follow most speed commands by the end of the first day (<4 simulation hours). All were able to do so by the end of the second training day (<7 total simulation hours). When asked, "How many hours of simulator time do you think it took before you felt comfortable performing Interval Management following a Target aircraft?", the average response was four hours. Pilots suggested IM integration with line operation training would be preferred over stand-alone IM training to minimize simulation training time. One pilot commented simulator training time and value would be optimized if early scenarios were short and focused on EFB programming up to the point when FIM guidance is initialized. Subsequent simulation training could concentrate on operational techniques while FIM is active. When asked, "What percentage of simulation time was spent learning how to program the EFB?", pilot perceptions ranged from 20 to 80 percent with an average of 59 percent. While the sample size is very small, this does indicate the FIM avionics prototype required a high mental workload as currently implemented. Some pilots believe an overall reduction of button presses for subsequent prototypes will reduce training time. Unless changed, a quick reference guide would be "extremely helpful" in the training environment.

Respondents noted that simulation time could be minimized if FIM and RNP approach training were integrated, since both are expected NextGen products and could be accomplished using similar training tactics already in place.

Development of a simulation training schedule also eased the creation process for a more comprehensive flight test schedule usable by air traffic control and the flight test director (figure 22, Appendix B). The derived daily schedule ensured each participant with oversight of the operation knew the routes and order of each aircraft for every scenario. The new test cards, derived from simulator training responses, provided flight plan filing information, which also minimized workload for the pilot. Spacing error values were also changed slightly as a result of data from the simulation training.

## 5.4 Operational Effectiveness

### 5.4.1 General

In general, the flight test pilots were able to accomplish the goals set out during the training: position the aircraft, program the IM prototype, and follow speed commands until the conclusion of the IM operation. The pilots were able to accomplish 157 flight test runs over 19 days (ref. 17). Though exceeding the desired goal of 124 runs, not all runs fit within the planned test matrix. Initial flights of the prototype software revealed critical anomalies allowing only a few runs per day. Coordination between the FTD and pilots ensured initial start times were relatively accurate, but some runs were filtered from the data set due to the anomalies. As the underlying issues were corrected and pilot and FTD experience increased, the number of planned runs increased to seven per day. A total of 129 time based runs were recorded with FIM spacing goals ranging from 124 to 300 seconds and a mean spacing interval of 178 seconds. Of the 118 time-based operations deemed feasible for evaluation at the FAF, the mean error from spacing goal at the FAF (i.e., completion point) was approximately two seconds (ref. 18). This indicated the pilots correctly executed the procedures they learned during training and used the FIM avionics to achieve the desired spacing goal.

While the spacing goal for 23 of 129 time-based operations was calculated by the IM avionics prototype to maintain the current spacing between aircraft, 106 required the pilot to enter an assigned spacing goal. The desired range of correction was from 60 seconds early to 60 seconds late (–60 to +60 seconds). Across the 106 analyzed runs, the pilots were able to position their aircraft (on average) within 28 seconds of the desired initial spacing error, which indicates a reasonable degree of accuracy for initial positioning considering the pilots were self-positioning without the help of ATC. The training and procedures described within this document were positive impacts to this metric, which trained flight test participants to set up within approximately half a minute of the desired start location. However, the result may have been adversely affected by differences between aircraft flight management systems used in training and the flight test or the difference between the forecast winds and actual winds.  Had these differences not existed, it's possible the vehicles may have been even closer to the correct start positions. Training strategies employed by the FTD to mitigate instances where aircraft positioned outside the desired range also influenced this metric.

As a measure of learning transfer, we can observe how trained versus untrained crews positioned aircraft prior to each run. The crews onboard two of the three flight test aircraft had undergone simulator training at NASA LaRC to practice the operational setup of aircraft prior to the start of a run. Of runs analyzed, 57 run setups involved both Ownship and Target crews which had trained (i.e. B-737 and B-757 pair), while the remaining 49 contained one crew without training (i.e. B-757 and F900 pair). During the flight test, the crew of every aircraft acted independently using holds and speed inputs to meet the STA given by the FTD by the start of the run. Considering 60 seconds as the maximum deviation for initial spacing error, the setups with wholly trained crews achieved this criterion 95 percent of their attempts, while the setups with one untrained crew achieved this criterion in 73 percent of their attempts. Additional information was unavailable to conduct a more complete analysis. However, the fact that crews trained at Langley consistently positioned their aircraft closer to the conditions on the test card compared to the crews not trained at Langley is suggestive of the effectiveness of the training program. Over the course of 19 flight days, the deviation from the desired initial spacing error did not appreciably improve for either type, indicating further improvement was not necessarily a function of experience, and potentially due to the tools unavailable to the flight test participants attempting to position the aircraft as ATC would in the NextGen environment (i.e. CMS and TMA-TM).

During the time-based runs analyzed, the pilot responded to new commanded speeds an average of 10.6 times per run, which corresponded to 0.57 speed changes per minute of operation using the mode control panel to enter a speed command (ref. 19). The pilot took an average of 8.51 seconds to input each new speed command with a standard deviation of 5.8 seconds. The flight crew typically programmed all variables to the EFB correctly, allowing active engagement of the FIM system, and responded to speed commands in a timely manner as trained, leading to a high degree of accuracy for the operation. Based on previous research (refs. 20 and 21) and researchers' observations during the training regimen and flight test, the authors speculate there was strong retention of knowledge from training.

#### 5.4.2 Fast / Slow Indicator

Deviation from the instantaneous speed was depicted on the IM avionics prototype's display as the Fast/Slow Indicator; however, the FSI cue was unintuitive and difficult for some pilots to follow. As a result, there were several instances where the pilots ignored the FSI and continued decelerating toward the IM Speed, as would be expected in typical operations. On the other hand, many of the participating pilots perform test missions for their respective companies, and in those missions, are expected to achieve very exact parameters. This meant some pilots on some runs were overly focused on minimizing the spacing error throughout the IM operation, and intervened more with throttles and speed brake to maintain the vertical profile than would be expected by the typical line pilot. These pilots became very adept at following the FSI and consistently achieved very low spacing error at the FAF, though at the cost of increased workload to intervene with throttle and speed brake.

Previous NASA research (ref. 20) and the flight test training the flight crew received used the flashing IM speed as a cue to the flight crew that they had not set the IM commanded airspeed within 10 seconds of it being displayed (e.g., figure 7, 0.78 M). For the flight test, however, the IM avionics prototype did not have access to the value set in the mode control panel speed window. Therefore, the MOPS conformance logic was used to trigger the flashing of the IM speed indicating to the flight crew that the aircraft was not decelerating or accelerating at a specified rate.

The immediate consequence was the logic to trigger the flashing of the IM speed was frequently met, indicating to the pilot that the deceleration or acceleration to the new IM speed was not occurring at the desired minimum rate. Because of this, the flight crew became more assertive keeping the FSI indication centered (indicating the deceleration or acceleration was as expected), which was not the intended nor pilot-trained procedure to conduct an IM operation. As one pilot commented, “Constantly monitoring and responding to the Fast/Slow Indicator, instead of setting the IM commanded speed in the MCP speed window, is too labor intensive and not feasible for normal operations.”

Also, flight crew comments indicated a lack of foreknowledge of the next IM speed meant that the flight crew could only be reactive. Future designs of the IM display will likely not include the PSI value, which provides the instantaneous spacing value between Ownship and Target, but this may make the FSI a trigger point for pilot workload management.

### 5.4.3 Auto-Throttles

Good aircraft speed control is beneficial for IM operations, and the auto-throttle systems of the B-757 and B-737 did not exhibit rapid and consistent control to the airspeed set in the mode control panel. The systems of both aircraft responded very slowly to any speed deviation of less than ±12 knots of the airspeed set in the mode control panel speed window. Furthermore, the auto-throttles seemed to respond to speed changes in an inconsistent manner, with sometimes the system aggressively reducing power and decelerating the aircraft, while at other times the system allowed for a much more gradual deceleration. This auto-throttle system performance caused the aircraft’s airspeed to deviate from the expected speed, which contributed to the actual acceleration and deceleration rates not aligning well with what the IM avionics prototype expected. This lack of close speed tracking by the auto-throttles may have also contributed to the number of IM speed commands if the aircraft exhibiting this behavior was the Traffic aircraft.

To cause system behavior that was more optimized for an IM operation, the pilots adopted two mitigation strategies. Either the pilot set the thrust levers such that acceleration or deceleration of the aircraft matched the FSI, or the pilot intentionally set a speed window value in the mode control panel different from the IM commanded speed in order to trigger throttle changes. For example, if the IM commanded speed changed by 10 knots, the auto-throttle system was sometimes unresponsive to the new MCP window speed due to inherent deadband. The pilots would intentionally set a 15 knot speed difference to activate the auto-throttles and then immediately set the commanded speed once the throttles began moving. In all cases, the pilots took specific additional actions to compensate for the auto-throttle system behavior which slightly increased their workload to conduct an IM operation. The same circumstance occurred during simulation training, but the trainers emphasized setting the commanded speed in the MCP window with no further action, since most similarly equipped aircraft should operate with the same dead zone.

# 6 Future Training

In the future, IM operations may become commonplace and require less extensive training for understanding the use of the procedures. It would be expected that initial IM information from the FAA would be followed by training materials and CBT products developed by individual airlines and training vendors. Within the airline industry, CBT can maximize pilot availability, allow the airline to track student understanding and time spent on each subject area, and can register whether the learner has completed coursework. Using CBT, the pilot can preview the subject material ahead of instructor-guided classroom learning. A fully functional version of the system interface can permit the user to gain operable experience through exploratory learning, and testing the interface. The classroom experience can be maximized by using that time to reiterate and interactively test working knowledge with an expert instructor, thereby developing user confidence and trust in the system. Regarding future FIM flight simulation training, pilot comments suggest introducing ATC communications across multiple controller handoffs to create additional realism for better transfer of knowledge. As real-time wind data becomes more commonplace, future trainers may consider incorporating live winds into flight training simulations. Pilots stated that understanding the algorithm behind FIM was not required for training, but specific procedures for Ownship programming and Target selection must be trained.

Based on the experience of the flight test, the close timeframe of CBT, classroom training, and flight simulator training resulted in a cohesive program that was satisfactory and relevant for all participants. After completion of such a program, pilot responses indicated access to a CBT should be a minimum requirement for the interim period between training and later flight use to refresh skills as needed. Continued access to learning materials following the program would help promote continuity of training.

# 7 Summary

Prior to conducting a flight test of a prototype FIM system for ATD-1, NASA realized pilots and FTD training prior to the first flight was critical due to the unique and complex nature of the software and the operations themselves. A learning regimen was devised that incorporated CBT, classroom instruction, and distributed live simulator training. All three phases were interactive and occurred over a short timeframe to allow learners to progress from rudimentary understanding of the concept and software, to manipulation and control of the aircraft, to setting up the scenarios and flying the IM operation. Key features found to be successful in assisting the pilots to correctly set up the scenarios and conduct the IM operation included repetitive physical programming to learn the system, CBT to minimize or make classroom time more constructive for the learner, integrated training with other team members, and progressive training of more realistic and complex simulation scenarios. The results of the ATD-1 flight test training regimen offer strong evidence that a fully functional CBT enabled the pilots and FTD to have effective exploratory learning prior to the classroom instruction and simulator training. The integrated simulator training allowed the pilots and FTD to practice conducting the IM operations in a live and interactive manner, which proved to be essential during the flight test itself to maximize the number of scenarios flown each day. The short duration between the three training methods, and also the short duration between the conclusion of the training regimen and the beginning of the flight test, contributed significantly to the overall effectiveness of the ATD-1 training program.

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# Appendix A. Arrival and Approach Procedures

The following figures are the arrival and approach procedures planned for the ATD-1 flight test. Operations were planned to opposite arrivals to compensate for changes in wind conditions. Only runway 32R was used during the flight test, therefore the WIPES1 STAR shown in figure 17 was not used.

The PBN arrival (figures 16-18) and approach procedures (figures 19 and 20) used in the flight test were designed in accordance with FAA guidelines (ref. 9), and were intended to allow the aircraft to fly from en route altitudes to the runway with minimal use of throttles and speed brakes. Testing of the routes was accomplished in full-scale simulators at both NASA LaRC and United Airlines, as well as in-flight validation at KMWH by one of the flight test aircraft. LaRC identified the transition to RNAV 14L created excessive deceleration during the turn to final and was not desirable. In some locations the procedures were too steep or too fast to fly the aircraft at a near-idle descent without the use of speed brakes, and one waypoint had a speed constraint that was too slow for the location and altitude (210 knots at SUBDY).

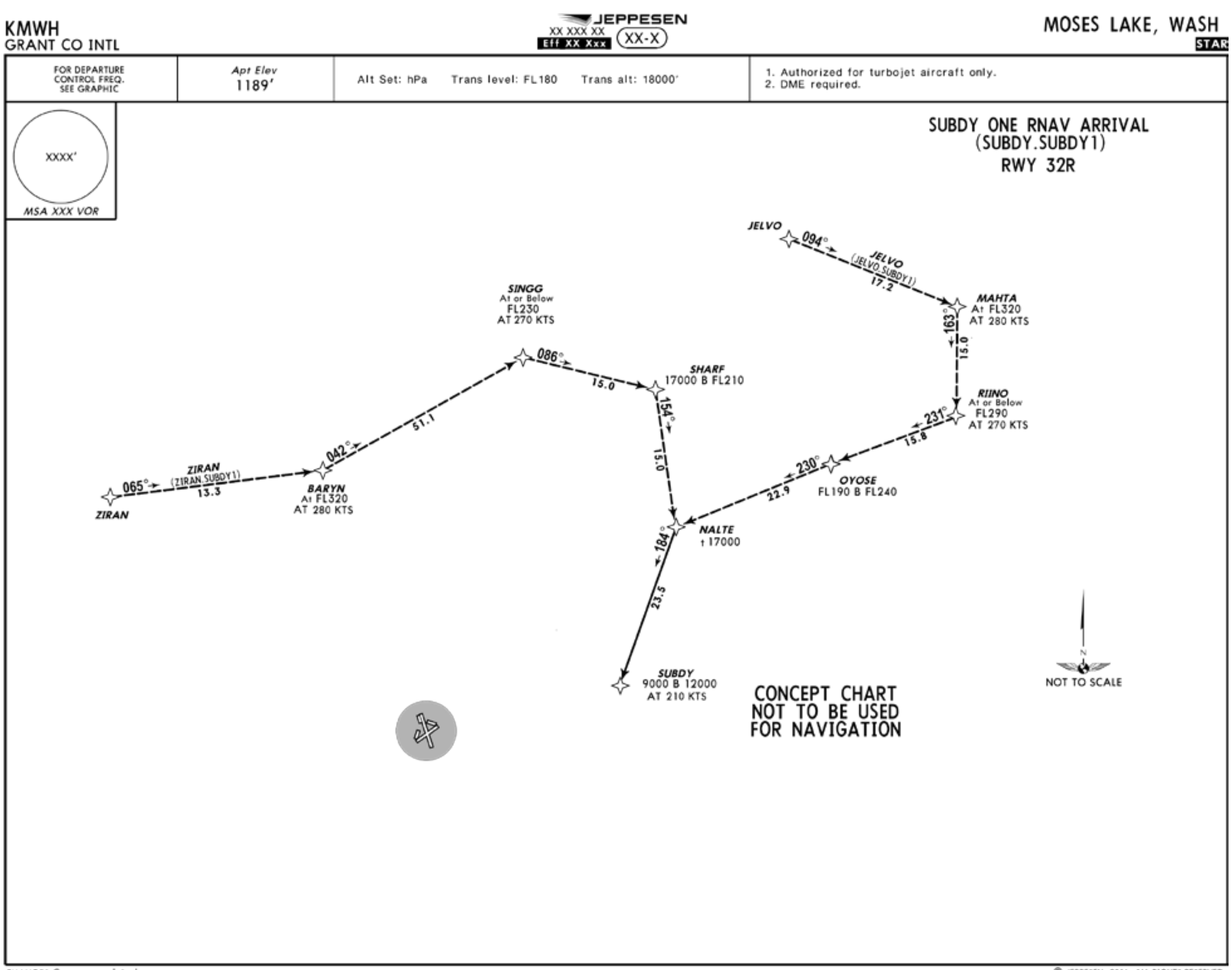



Figure 16. SUBDY1 RNAV STAR to runway 32R at KMWH.

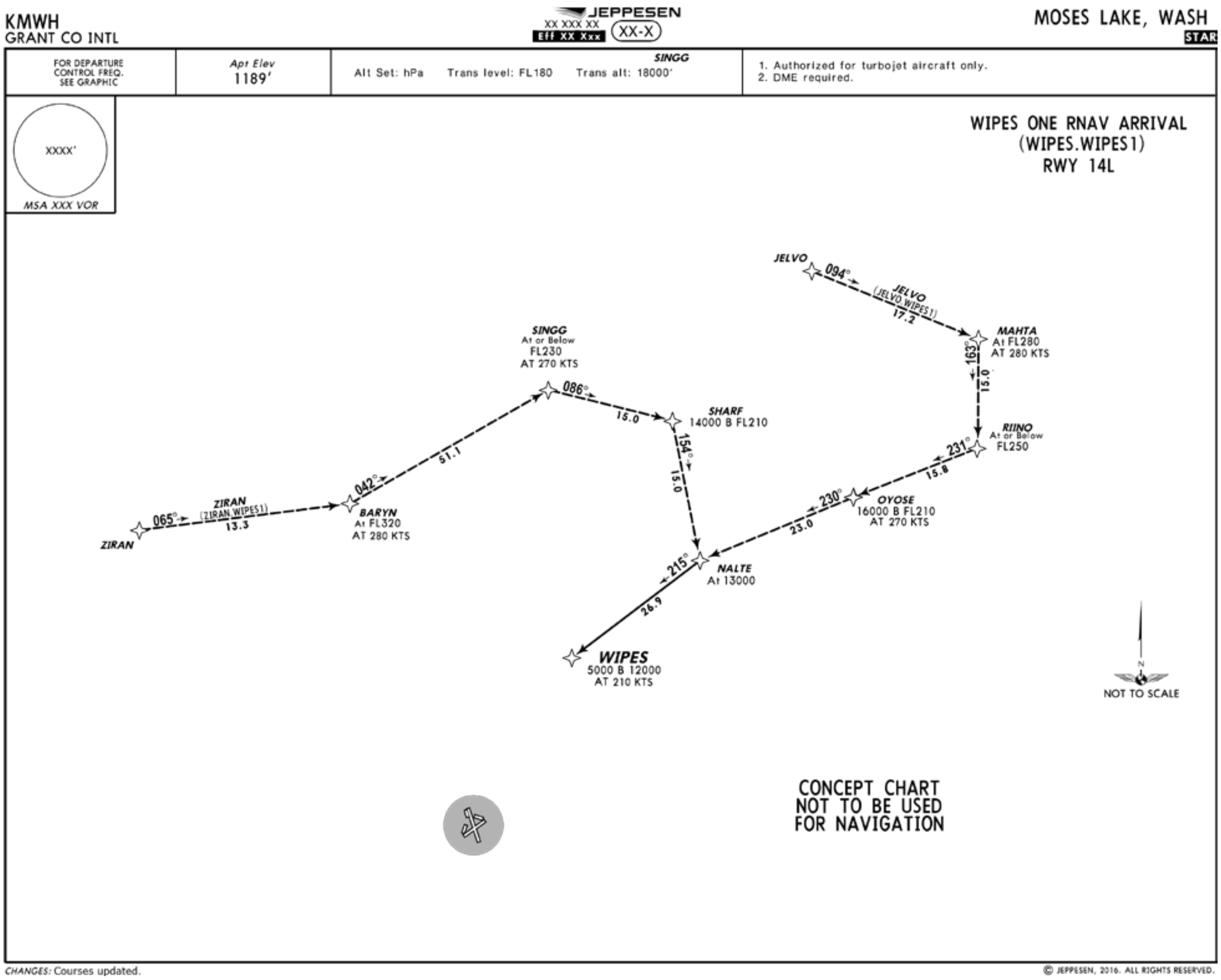



**Figure 17. WIPES1 RNAV STAR to runway 14L at KMWH.**

The UPBOB1 STAR connected to either the RNAV 14L or RNAV 32R approach from the UPBOB waypoint, which allowed for varying wind conditions.

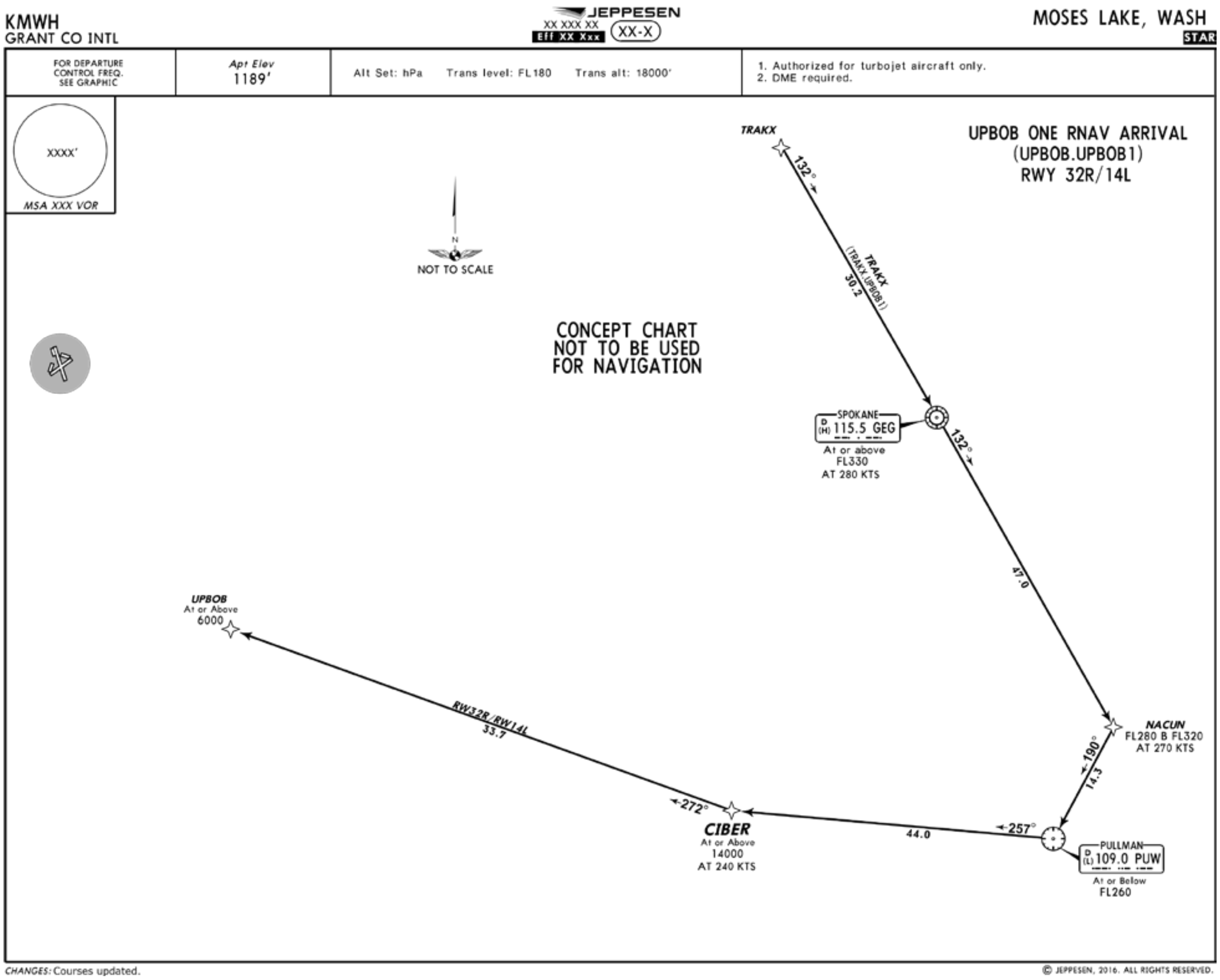



**Figure 18. UPBOB1 RNAV STAR at KMWH.**

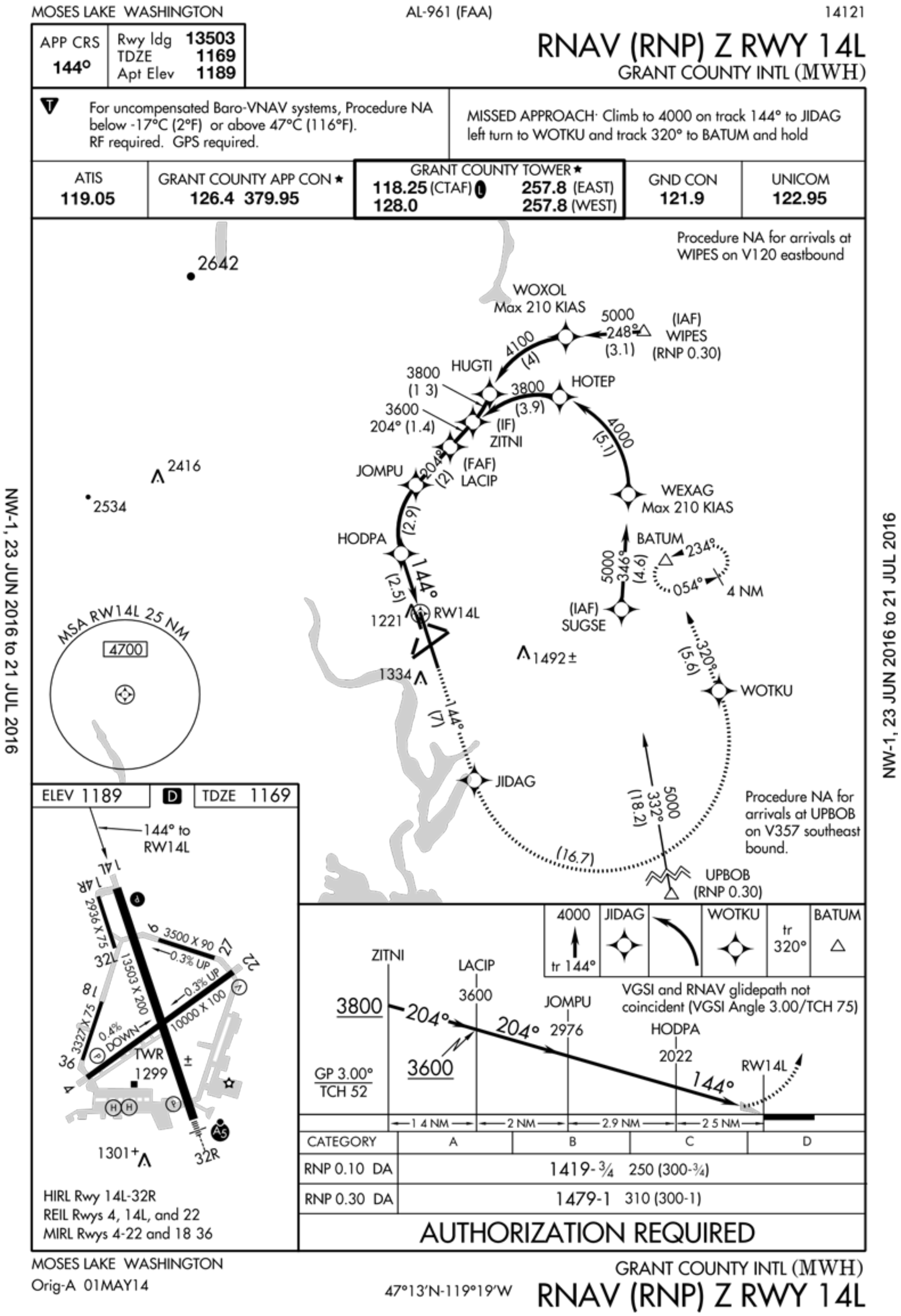



**Figure 19. RNP AR approach to runway 14L at KMWH.**

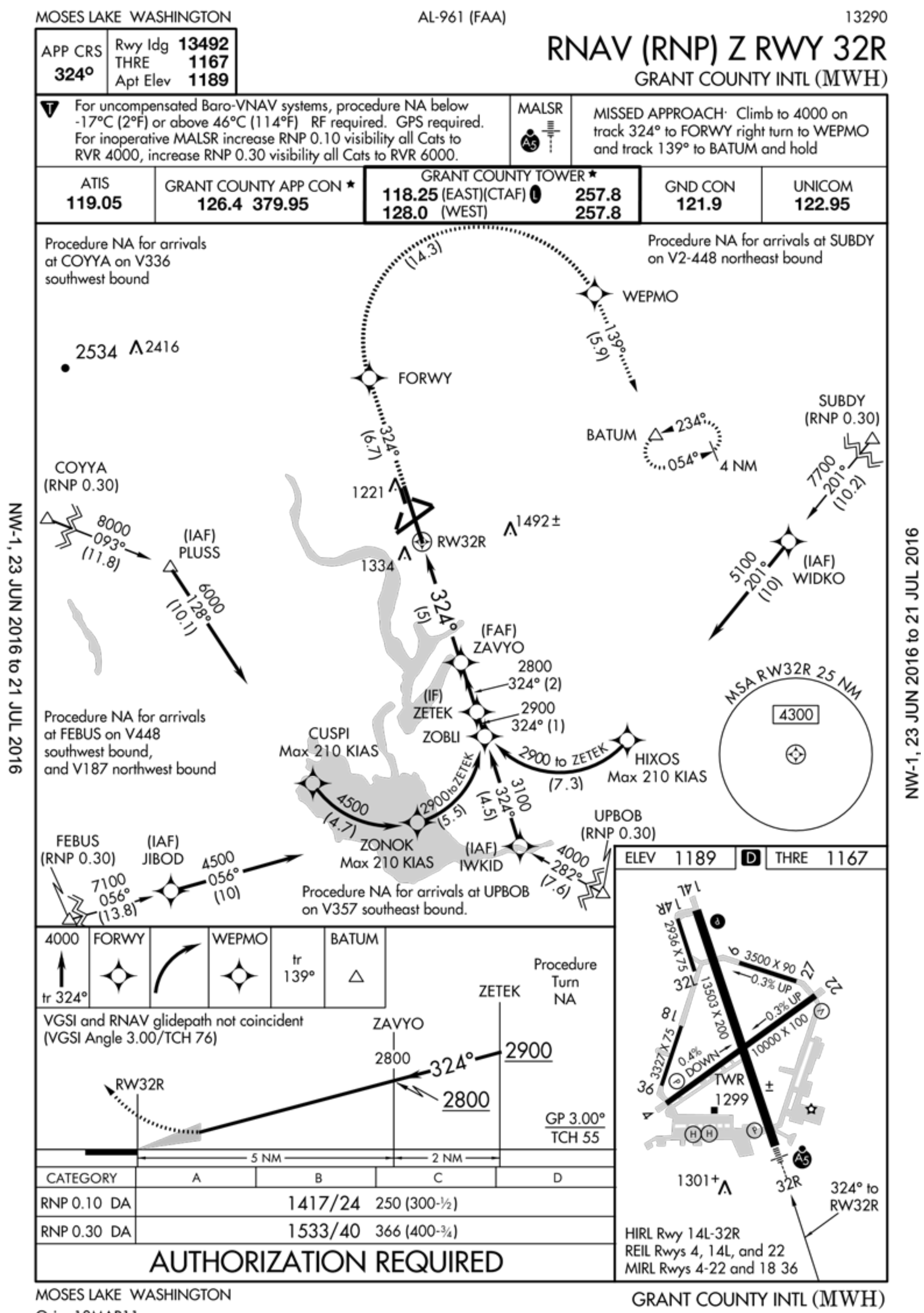



**Figure 20. RNP AR approach to runway 32R at KMWH.**

# Appendix B. Test Card Examples

The test cards used during the flight test were refined during the training regimen with significant input from the pilots, to include data required to assist in the correct filing and positioning of aircraft between each scenario. The test cards were also streamlined to reflect relevant inputs in the order of occurrence.

A format was needed for researchers to keep track of the scenario schedule. The result was a summary format usable by the flight controllers, which contained all the scenarios for that day on one page (figure 21). The letters “IP” indicate the “Initial Point” the aircraft was to head to after the previous IM operation was complete, and “LT” or “RT” indicated a “left turn” or “right turn” for Hold maneuvering.

**ATD-1 Flight Plan** **Date: 2/21/2017** **(KMWH 32R)** Published: 2/16

**Scenario 1: A04 (first half of flight plan)**

- N889H: Route: BFI..ZIRAN..BARYN..JELVO, FL230
- UAL2197: Route: SEA..ZIRAN..BARYN..JELVO, FL230
- N757HW: Route: BFI..ZIRAN..BARYN..JELVO, FL230

**Scenario 2: B04 (second half of flight plan)**

- N889H: IP: RIINO 343010, LT, FL220 Route: RIINO.SUBDY1.SUBDY.RRZ32R
- UAL2197: IP: MAHTA 274010, RT, FL230 Route: MAHTA.SUBDY1.SUBDY.RRZ32R
- N757HW: IP: JELVO 222010, RT, FL230 Route: JELVO.SUBDY1.SUBDY.RRZ32R

**Scenario 3: B04**

- N889H: IP: RIINO 343010, LT, FL220 Route: RIINO.SUBDY1.SUBDY.RRZ32R
- UAL2197: IP: MAHTA 274010, RT, FL230 Route: MAHTA.SUBDY1.SUBDY.RRZ32R
- N757HW: IP: JELVO 222010, RT, FL230 Route: JELVO.SUBDY1.SUBDY.RRZ32R

**Scenario 4: B03**

- N889H: IP: SINGG 222015, LT, FL220 Route: SINGG.SUBDY1.SUBDY.RRZ32R
- UAL2197: IP: MAHTA 274010, RT, FL230 Route: MAHTA.SUBDY1.SUBDY.RRZ32R
- N757HW: IP: NACUN 312010, LT, FL230 Route: NACUN.UPBOB1.UPBOB.RRZ32R

**Scenario 5: B03**

- N889H: IP: SINGG 222015, LT, FL220 Route: SINGG.SUBDY1.SUBDY.RRZ32R
- UAL2197: IP: MAHTA 274010, RT, FL230 Route: MAHTA.SUBDY1.SUBDY.RRZ32R
- N757HW: IP: NACUN 312010, LT, FL230 Route: NACUN.UPBOB1.UPBOB.RRZ32R

**Scenario 6: B05**

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

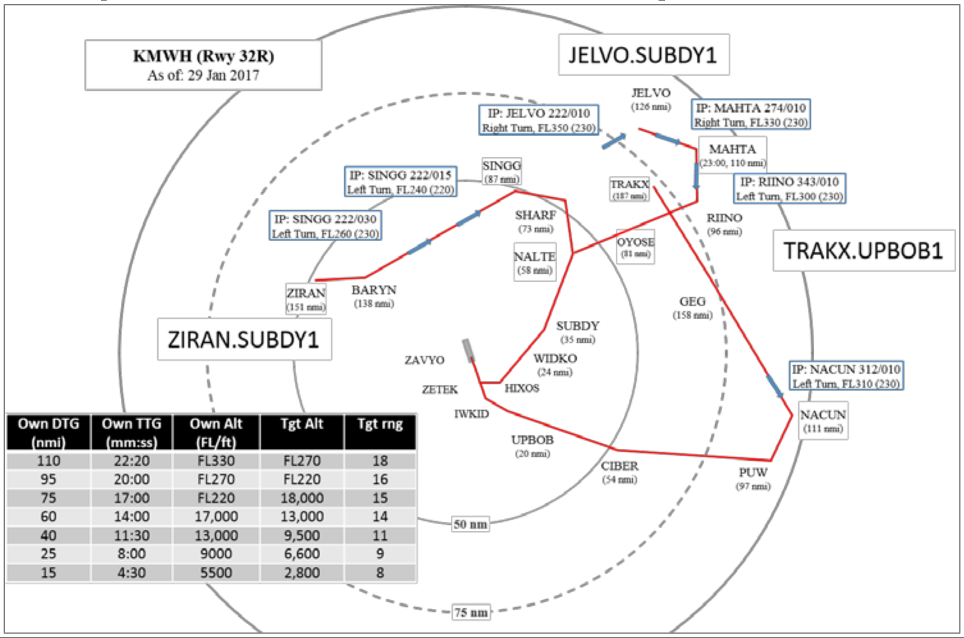
**Scenario 7: B05**

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

**Figure 21. Flight test card for air traffic controllers.**

The FTD formatted test card contained one page per scenario, with the date, sequence of scenario, scenario number, database, start/stop time, and publication date and change number at the top (figure 22). A schematic of the route structure was at the top, with the bottom half of the page a worksheet organized by aircraft arrival flow (left to right), and by tasks to be accomplished (top to bottom). The "*Diff from LP*" meant the difference in time the FTD had to add or subtract from the 'long pole' aircraft to calculate the schedule time of arrival for the other aircraft. The spacing error (SE) uses the reverse convention where the "+" indicates the aircraft is early.

2/21/2017 Seq. #: 5 Scenario: **B03** NDB: 1 Start/Stop time: Published: 2/16

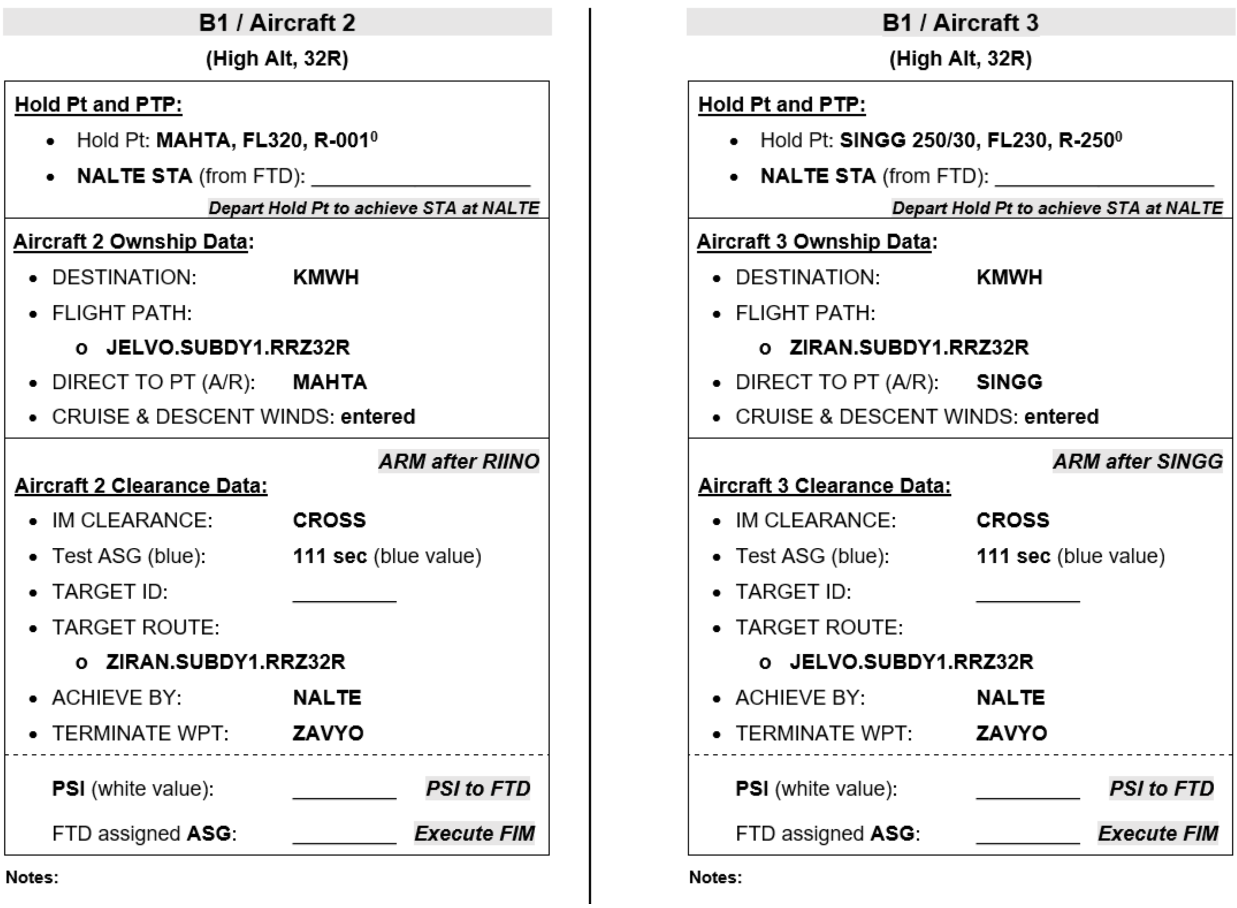



| Sequence / Call sign | #1 / **N889H** | #2 / **UAL2197** | #3 / **N757HW** (LP) |
|---|---|---|---|
| IP, Alt | SINGG 222/015, LT, FL220 | MAHTA 274/010, RT, FL230 | NACUN 312/010, LT, FL230 |
| Route | SINGG.SUBDY1.RRZ32R | MAHTA.SUBDY1.RRZ32R | NACUN.UPBOB1.RRZ32R |
| *Crew to FTD*: ETA to: | ZAVYO: | ZAVYO: | ZAVYO: |
| *Diff from LP* | -5 | -3 | |
| *FTD to crew*: STA to: | | | |
| (Delay) FIM Type | (None) | CROSS | CROSS |
| ABP | | ZAVYO | ZAVYO |
| Desired PSI | | 90-150 sec | 120-180 sec |
| *Crew to FTD*: PSI | | | |
| Desired SE | | +60 sec | +30 |
| *FTD to crew*: ASG | | | |
| ARM at: | | RIINO | PUW |

Notes: Target speed: no delay.

**Figure 22. Flight test card for the Flight Test Director.**

Aircraft specific test cards given to each pilot were knee-board sized. Figure 23 illustrates the flight training test cards for Aircraft 2 and Aircraft 3 in an arrival stream. Aircraft type was not designated for training versatility. Hold points designated initial start positions for each aircraft per scenario. Prototype specific inputs described the planned scenario relative to each Ownship vehicle which also included target specific information. There was also a blank area at the bottom of the test card to write the Predicted Spacing Interval output and Flight Test Director assigned spacing goal. Although the lead vehicle for the three aircraft did not have a prototype IM system onboard, a flight test card was provided for that aircraft which described expected actions by the vehicle, including speed inputs to emulate high, medium, and low delay. Figure 24, 25, and 26 were the final versions of test card used for the ATD-1 flight test.



**B1 / Aircraft 2**

**(High Alt, 32R)**

**Hold Pt and PTP:**

- Hold Pt: **MAHTA, FL320, R-001⁰**
- **NALTE STA** (from FTD): ____________________

***Depart Hold Pt to achieve STA at NALTE***

**Aircraft 2 Ownship Data:**

- DESTINATION: **KMWH**
- FLIGHT PATH:
  - **JELVO.SUBDY1.RRZ32R**
- DIRECT TO PT (A/R): **MAHTA**
- CRUISE & DESCENT WINDS: **entered**

***ARM after RIINO***

**Aircraft 2 Clearance Data:**

- IM CLEARANCE: **CROSS**
- Test ASG (blue): **111 sec** (blue value)
- TARGET ID: _________
- TARGET ROUTE:
  - **ZIRAN.SUBDY1.RRZ32R**
- ACHIEVE BY: **NALTE**
- TERMINATE WPT: **ZAVYO**

**PSI** (white value): _________ ***PSI to FTD***

FTD assigned **ASG**: _________ ***Execute FIM***

**Notes:**

**B1 / Aircraft 3**

**(High Alt, 32R)**

**Hold Pt and PTP:**

- Hold Pt: **SINGG 250/30, FL230, R-250⁰**
- **NALTE STA** (from FTD): ____________________

***Depart Hold Pt to achieve STA at NALTE***

**Aircraft 3 Ownship Data:**

- DESTINATION: **KMWH**
- FLIGHT PATH:
  - **ZIRAN.SUBDY1.RRZ32R**
- DIRECT TO PT (A/R): **SINGG**
- CRUISE & DESCENT WINDS: **entered**

***ARM after SINGG***

**Aircraft 3 Clearance Data:**

- IM CLEARANCE: **CROSS**
- Test ASG (blue): **111 sec** (blue value)
- TARGET ID: _________
- TARGET ROUTE:
  - **JELVO.SUBDY1.RRZ32R**
- ACHIEVE BY: **NALTE**
- TERMINATE WPT: **ZAVYO**

**PSI** (white value): _________ ***PSI to FTD***

FTD assigned **ASG**: _________ ***Execute FIM***

**Notes:**

**Figure 23. Simulation training test cards**

| **N889H** | **B03** (Rwy 32R) | # 5 |
|---|---|---|
| Date: 2/21/2017 | NDB: 1 | Printed: 2/16 |

**File To: SINGG 222015..SINGG**

**IP: SINGG 222/015, LT, FL220**

**ETA at ZAVYO** (from FMS): __________

**ZAVYO STA** (from FTD): __________

***Depart Initial Pt to achieve ZAVYO STA***

**Aircraft 1 Ownship Data:**

- DESTINATION: **KMWH**
- Runway: **32R**
- Route / STAR: SUBDY1.SINGG (ZIRAN)
- Approach: RRZ32R.SUBDY
- Speed Profile: FL220 270 KT

**Aircraft 1 Route:** [FTD freq: 123.525]

- SINGG 270
- SHARF 270
- NALTE 270
- SUBDY 210
- WIDKO 210
- HIXOS 210
- ZETEK 190
- ZAVYO 170

**AC #1:** N889H, SINGG 222/015, FL220

**AC #2:** UAL2197, MAHTA 274/010, FL230

**AC #3:** N757HW, NACUN 312/010, FL230

Target speed: no delay.

**Figure 24. Flight test card for the lead aircraft.**

Although the lead vehicle for the three aircraft did not have a prototype IM system onboard, a flight test card was provided for that aircraft which described expected actions by the vehicle, including speed inputs to emulate high, medium, and low delay.

This page illustrates the test card for the second aircraft in the arrival stream (the United Airlines B-737). From top to bottom, it contains information to setup the scenario, Ownship data, IM data, and the arrival sequence and starting location of all three aircraft. The spacing error indicates the aircraft will be in a start position of 60 seconds early.

**UAL2197** **B03** (Rwy 32R) # 5

Date: 2/21/2017 NDB: 1 Printed: 2/16, ch1

**File To: JELVO**

**IP: MAHTA 274/010, RT, FL230**

**ETA at ZAVYO** (from FMS): __________

**ZAVYO STA** (from FTD): __________

***Depart IP to achieve ZAVYO STA***

**Aircraft 2 Ownship FIM Data:**

- DESTINATION: **KMWH**
- Runway: **32R**
- Route / STAR: SUBDY1.MAHTA (JELVO)
- Approach: RRZ32R.SUBDY (ENTER DONE)
- Cruise Descent: FL230 .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: **CROSS**
- Test ASG (blue): **111 sec**
- TARGET ID: **N889H**
- TARGET ROUTE: ZIRAN.SUBDY1.SUBDY.RRZ32R
- ACHIEVE BY: **ZAVYO**
- TERMINATE: ZAVYO (ENTER ARM)

***ARM at RIINO***

- PSI desired: 90-150 sec Error: +60 sec [Goal: 150-210 sec]
- **PSI** (white, from algorithm): __________ ***PSI to FTD***
- **ASG** (blue, FTD assigned): __________ ***Execute FIM***

**AC #1:** N889H, SINGG 222/015, FL220

**AC #2:** UAL2197, MAHTA 274/010, FL230

**AC #3:** N757HW, NACUN 312/010, FL230

Target speed: no delay.

**Figure 25. Flight test card for the second aircraft (1st Ownship).**

This page illustrates the test card for the third aircraft in the arrival stream (the Honeywell B-757). The spacing error indicates the aircraft will be in a start position of 30 seconds early.

**N757HW** **B03** (Rwy 32R) # 5

Date: 2/21/2017 NDB: 1 Printed: 2/16, ch1

**File To: NACUN 312010**

**IP: NACUN 312/010, LT, FL230**

**ETA at ZAVYO** (from FMS): __________ (LP)

**ZAVYO STA** (from FTD): __________

***Depart Initial Pt to achieve ZAVYO STA***

**Aircraft 3 Ownship Data:**

- DESTINATION: **KMWH**
- Runway: **32R**
- Route / STAR: UPBOB1.NACUN (TRAKX)
- Approach: RRZ32R.UPBOB (ENTER DONE)
- Cruise Descent: FL230 .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: **CROSS**
- Test ASG (blue): **111 sec**
- TARGET ID: **UAL2197**
- TARGET ROUTE: JELVO.SUBDY1.SUBDY.RRZ32R
- ACHIEVE BY: **ZAVYO**
- TERMINATE: ZAVYO (ENTER ARM)

***ARM at PUW***

- PSI desired: 120-180 sec Error: +30 [Goal: 150-210 sec]
- **PSI** (white, from algorithm): __________ ***PSI to FTD***
- **ASG** (blue, FTD assigned): __________ ***Execute FIM***

**AC #1:** N889H, SINGG 222/015, FL220

**AC #2:** UAL2197, MAHTA 274/010, FL230

**AC #3:** N757HW, NACUN 312/010, FL230

Target speed: no delay.

**Figure 26. Flight test card for the third aircraft (2nd Ownship).**

| REPORT DOCUMENTATION PAGE | *Form Approved* *OMB No. 0704-0188* |
|---|---|



**1. REPORT DATE** *(DD-MM-YYYY)*: 1-09-2019

**2. REPORT TYPE**: Technical Memorandum

**3. DATES COVERED** *(From - To)*:

**4. TITLE AND SUBTITLE**
Air Traffic Management Technology Demonstration-1 (ATD-1) Avionics Phase 2 Flight Test Training for Interval Management

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Roper, Roy D.; Baxley, Brian R.; Swieringa, Kurt A.; Hubbs, Clay E.

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**
330693.04.10.07.07

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

**8. PERFORMING ORGANIZATION REPORT NUMBER**
L-20896

**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-TM-2019-220405

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

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

The purpose of this Technical Memorandum is to inform the aviation industry how flight training for Interval Management was conducted at Langley Research Center in order to reduce overall development costs of future Interval Management training programs. Secondly, the paper provides insight regarding the decision-making process when attempting to conduct a flight test.

**15. SUBJECT TERMS**
Flight test; Interval Management; air traffic management; pilot training

| 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 | 55 | 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