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Air Traffic Management Technology Demostration Phase 1 (ATD) Interval Management for Near-Term Operations Validation of Acceptability (IM-NOVA) Experiment

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Abstract

The Interval Management for Near-term Operations Validation of Acceptability (IM-NOVA) experiment was conducted at the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) in support of the NASA Airspace Systems Program's Air Traffic Management Technology Demonstration-1 (ATD-1). ATD-1 is intended to showcase an integrated set of technologies that provide an efficient arrival solution for managing aircraft using Next Generation Air Transportation System (NextGen) surveillance, navigation, procedures, and automation for both airborne and ground-based systems. The goal of the IM-NOVA experiment was to assess if procedures outlined by the ATD-1 Concept of Operations were acceptable to and feasible for use by flight crews in a voice communications environment when used with a minimum set of Flight Deck-based Interval Management (FIM) equipment and a prototype crew interface. To investigate an integrated arrival solution using ground-based air traffic control tools and aircraft Automatic Dependent Surveillance-Broadcast (ADS-B) tools, the LaRC FIM system and the Traffic Management Advisor with Terminal Metering and Controller Managed Spacing tools developed at the NASA Ames Research Center (ARC) were integrated into LaRC's Air Traffic Operations Laboratory (ATOL). Data were collected from 10 crews of current 757/767 pilots asked to fly a high-fidelity, fixed-based simulator during scenarios conducted within an airspace environment modeled on the Dallas-Fort Worth (DFW) Terminal Radar Approach Control area. The aircraft simulator was equipped with the Airborne Spacing for Terminal Area Routes (ASTAR) algorithm and a FIM crew interface consisting of electronic flight bags and ADS-B guidance displays. Researchers used "pseudo-pilot" stations to control 24 simulated aircraft that provided multiple air traffic flows into the DFW International Airport, and recently retired DFW air traffic controllers served as confederate Center, Feeder, Final, and Tower controllers. Analyses of qualitative data revealed that the procedures used by flight crews to receive and execute interval management (IM) clearances in a voice communications environment were logical, easy to follow, did not contain any missing or extraneous steps, and required the use of an acceptable workload level. The majority of the pilot participants found the IM concept, in addition to the proposed FIM crew procedures, to be acceptable and indicated that the ATD-1 procedures could be successfully executed in a near-term NextGen environment. Analyses of quantitative data revealed that the proposed procedures were feasible for use by flight crews in a voice communications environment. The delivery accuracy at the achieve-by point was within ±5 sec, and the delivery precision was less than 5 sec. Furthermore, FIM speed commands occurred at a rate of less than one per minute, and pilots found the frequency of the speed commands to be acceptable at all times throughout the experiment scenarios.

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Symbols & Abbreviations

ADS-B	Automatic Dependent Surveillance-Broadcast
AGD	ADS-B Guidance Display
ARC	Ames Research Center
ASG	assigned spacing goal
ASTAR	Airborne Spacing for Terminal Area Routes
ASTOR	Aircraft Simulation for Traffic Operations Research
ATC	air traffic control
ATD-1	Air Traffic Management Technology Demonstration–1
ATOL	Air Traffic Operations Laboratory
ATOS	Airspace and Traffic Operations Simulation
CAS	calibrated airspeed
CMS	controller-managed spacing
ConOps	Concept of Operations
CPDLC	Controller-Pilot Data Link Communications
DFW	Dallas-Fort Worth International Airport
DSR	Display System Replacement
EFB	electronic flight bag
ETA	estimated time of arrival
FAA	Federal Aviation Administration
FAF	final approach fix
FDB	full data block
FIM	Flight Deck-based Interval Management
FMS	Flight Management System
GUI	graphical user interface
HITL	human-in-the-loop
IFD	Integration Flight Deck
ILS	Instrument Landing System
IM	interval management
IM-NOVA	Interval Management for Near-term Operations Validation of Acceptability
LaRC	Langley Research Center
MACS	Multi-Aircraft Control System
MCH	Modified Cooper-Harper
N	number of observations
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
OPD	optimized profile descent
p	*p*-value (note: a value < 0.05 indicates a statistically significant difference between sample means)
PF	pilot flying
PM	pilot monitoring
RAPP	Remote ASTOR Pseudo-Pilot

RNAV	area navigation
SD	standard deviation
STA	scheduled time of arrival
STAR	standard terminal arrival route
STARS	Standard Terminal Automation Replacement System
TMA	Traffic Management Advisor
TMA-TM	Traffic Management Advisor with Terminal Metering
TOD	top-of-descent
TRACON	terminal radar approach control

1 Introduction

Air traffic demand is predicted to increase by 2 to 3 percent per year over the next 20 years, with the number of revenue passenger miles nearly doubling by 2032 (ref. 1). If the current air transportation system is left unmodified, this projected growth will lead to increased delays, fuel costs, noise pollution, and greenhouse gas emissions. The Federal Aviation Administration's (FAA) Next Generation Air Transportation System (NextGen) concept envisions a comprehensive transformation of the National Airspace System (NAS) to support this continued growth in a safe, reliable, and efficient manner (ref. 2). The National Aeronautics and Space Administration (NASA) is collaborating with the FAA and other industry partners to develop advanced technologies and automation tools necessary for NextGen.

Improving the efficiency of terminal area arrival operations is an especially complex task. Conditions in busy terminal areas today often result in inefficient arrival paths involving frequent changes in speed, heading, and altitude to maintain safe separation between aircraft and absorb large amounts of delay. These inefficiencies lead to increased fuel burn and noise pollution, as well as higher controller workload and traffic congestion. Furthermore, greater uncertainty in the current system causes controllers to add separation buffers between aircraft, thus reducing throughput and increasing delays. Although more efficient arrivals are available, current technology limits their use to periods of light to moderate traffic conditions. New concepts and technologies are needed to make efficient arrival procedures feasible during heavy traffic.

NASA's Air Traffic Management Technology Demonstration–1 (ATD-1) will operationally demonstrate the feasibility of efficient arrival operations by combining ground-based and airborne NASA technologies (refs. 3, 4, and 5). The ATD-1 integrated system consists of the following three core components:

- Traffic Management Advisor with Terminal Metering (TMA-TM), which generates precise time-based schedules to the runway and merge points within the terminal area
- Controller-managed spacing (CMS) decision support tools, which provide controllers with speed advisories and other information needed to meet the schedule
- Flight Deck-based Interval Management (FIM) avionics and procedures, which allow flight crews to adjust their speed to achieve precise relative spacing

The Traffic Management Advisor (TMA) was originally developed at NASA Ames Research Center (ARC) and is currently used at Air Route Traffic Control Centers nationwide to determine an appropriate arrival schedule (ref. 6). TMA-TM is an enhanced form of TMA that includes terminal area metering and enables the use of more efficient arrival procedures. CMS decision support tools were also developed at NASA ARC. They provide controllers with the information necessary to achieve arrival schedule conformance using speed commands, thus reducing the use of tactical vectoring (refs. 7 and 8). The use of TMA-TM in conjunction with CMS tools has been assessed, and results indicate an increase in airport throughput (refs. 9–12).

FIM is an airborne spacing concept in which the flight crew is responsible for flying their aircraft at a speed that achieves their assigned time-based spacing interval behind a target aircraft, while Air Traffic Control (ATC) remains responsible for ensuring that all aircraft maintain safe separation. Typically, ATC designates a spacing buffer in addition to the separation requirement to ensure that separation is always maintained. The goal of airborne spacing is to decrease this spacing buffer by decreasing the variability of the time error associated with an aircraft's arrival at a specific point along its arrival route. The precise merging and spacing enabled by FIM avionics and flight crew procedures reduces excess spacing buffers and results in higher terminal throughput. Studies conducted by MITRE (refs. 13–15), EUROCONTROL (refs. 16–19), and NASA Langley Research Center (LaRC) (refs. 20–22) have demonstrated an increase in efficiency through the use of FIM operations.

In addition to utilizing these advanced technologies, aircraft will fly new, more direct area navigation (RNAV) routes that extend from en route airspace to the runway. Optimized profile descent (OPD) procedures will also be implemented to provide a fuel-efficient continuous descent approach rather than the step-down descents used today. The Automatic Dependent Surveillance-Broadcast (ADS-B) infrastructure currently being implemented by the FAA will also be leveraged. The FIM tools will calculate speed commands using information provided by ADS-B, which is more accurate than traditional radar. The ability of flight crews to make more precise speed adjustments will enable a reduction in spacing buffers resulting in higher terminal throughput.

These technology components and procedures have been evaluated independently, and each has demonstrated benefits. As an integrated system, these technologies are intended to increase throughput, reduce delay, and minimize environmental impacts. Initial studies at NASA ARC to demonstrate the ATD-1 concept and validate operational feasibility indicate that the concept is viable and operations are acceptable (refs. 23–25).

1.1 Current Study

As part of the preparations for an ATD-1 flight demonstration, the Interval Management for Near-Term Operations Validation of Acceptability (IM-NOVA) human-in-the-loop (HITL) experiment was conducted at NASA LaRC. The objective of this experiment was to assess if the procedures outlined in the ATD-1 Concept of Operations (ConOps) document (ref. 5), when used with the integrated ATD-1 technologies, were acceptable to and feasible for use by flight crews in a voice communications environment when precision to an achieve-by point (i.e., the final approach fix) was expected. This paper describes the experiment's methodology, results associated with the pilot participants' acceptability and workload ratings, and results of the evaluation of the flight crew procedures' feasibility.

2 Method

2.1 Experiment and Scenario Design

Data were collected from current 757/767 pilot participants asked to fly a high-fidelity, fixed-base simulator during scenarios conducted within an airspace environment modeled after the Dallas-Fort Worth (DFW) terminal radar approach control (TRACON) area. Each experiment scenario consisted of multiple air traffic flows involving 25 arrival aircraft flying into DFW airport and landing on runways 17C and 18R. All aircraft flew RNAV arrivals to the Instrument Landing System (ILS) approaches. Some aircraft initialized in level cruise and flew the full arrival and approach to the runway, whereas others initialized in descent and flew only a portion of the arrival before flying the approach. One of the arrival aircraft in the arrival stream was a high-fidelity, fixed-base simulator with pilot participants operating as a two-person crew. This simulator was equipped with NASA LaRC's airborne spacing algorithm, Airborne Spacing for Terminal Area Routes (ASTAR) (version 11.06.22) (ref. 26), and a prototype FIM crew interface (shown in Figs. Figure 1 and Figure 2). The remaining 24 arrival aircraft were flown by two researcher pseudo-pilots, each of whom used a graphical user interface (GUI) to control multiple medium-fidelity aircraft simulators. To provide a realistic traffic environment, each scenario also included 25 departure aircraft. Recently retired DFW air traffic controllers served as confederate Center, Feeder, Final, and Tower controllers issuing speed commands, vectors, and IM clearances.

When performing FIM operations, pilot participants were expected to use ASTAR-provided speed guidance whenever possible. This speed guidance is designed such that the FIM, or spacing, aircraft will achieve the assigned spacing goal (ASG) behind its target, or lead, aircraft at a predefined achieve-by point while remaining within 10 percent of the published RNAV arrival airspeed. In this experiment, the final approach fix (FAF) served as the FIM aircraft's achieve-by point. The prototype FIM crew interface shown in Figure 1 and Figure 2 consisted of two side-mounted electronic flight bags (EFBs) and two ADS-B guidance displays (AGDs) mounted under the glare shield within the flight crew's forward field-of-view. Figure 1 shows the position of a side-mounted EFB as well as a screen shot of the FIM application used for data entry and speed conformance monitoring. Figure 2 shows the position of an AGD as well as an image of the AGD displaying the IM-commanded speed and the aircraft's deviation from the commanded speed.

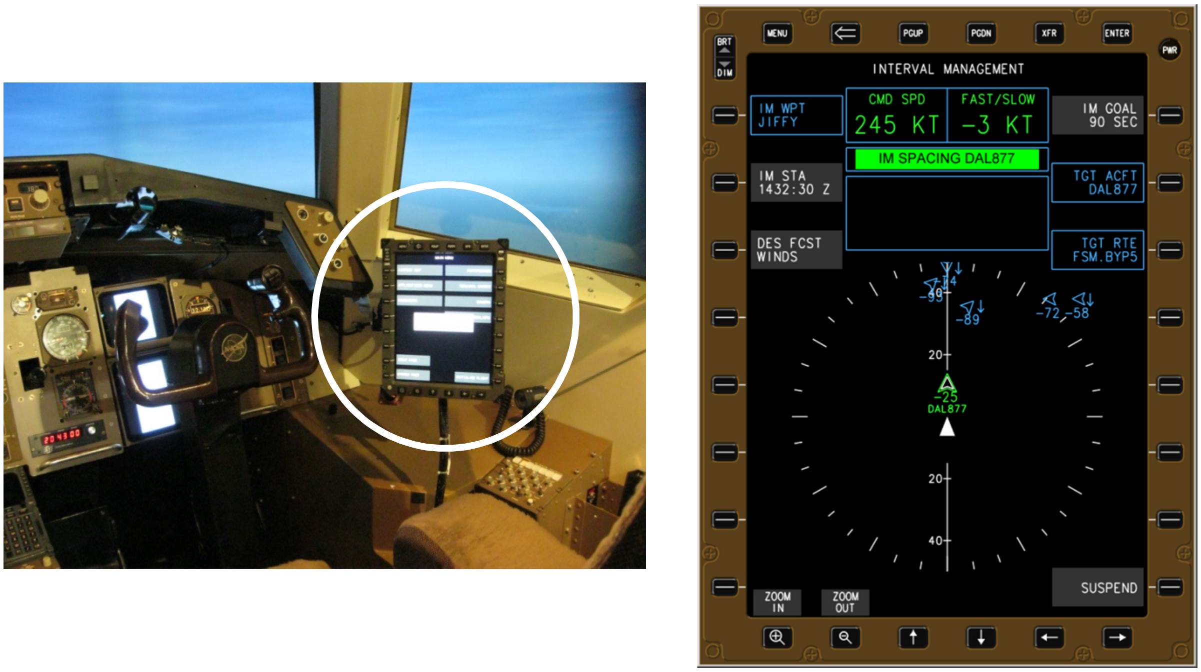

Figure 1. Side-mounted electronic flight bag (EFB) and Flight Deck-based Interval Management (FIM) application.

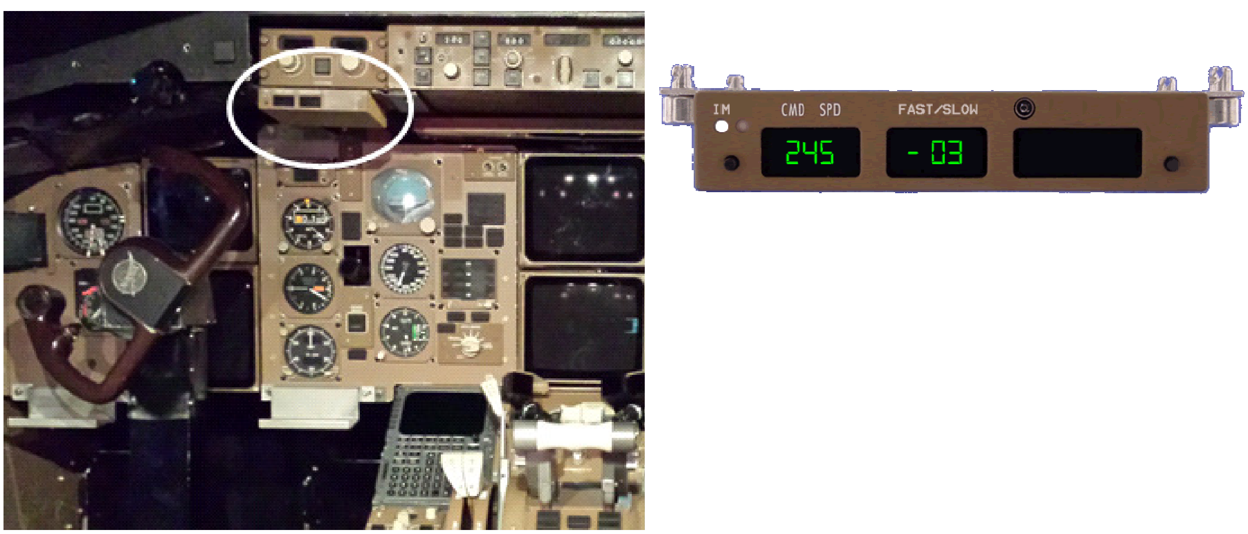

Figure 2. ADS-B guidance display (AGD) presenting target and error speed values.

Previous FIM research conducted at NASA LaRC has utilized data link to transfer information from ATC to the flight crew. However, since the ground infrastructure necessary to support data link will not be available during the execution of near-term FIM operations, voice communications will be relied upon to transfer necessary information. In the IM-NOVA experiment, confederate controllers issued IM clearances to the flight crews, who then entered information into the EFBs, and activated the FIM avionics. The IM procedure required the flight crew to enter the following pieces of information included in the IM clearance into the EFBs:

- IM achieve-by point (i.e., FAF)
- Scheduled time of arrival at the IM achieve-by point
- Target aircraft callsign
- ASG (spacing interval required at the IM achieve-by point)
- Target aircraft flight path (arrival and transition)

Five flight scenarios were defined using the 1×5 experiment matrix shown in Table 1 to allow an examination of the five flight crew procedures outlined in the ATD-1 ConOps document. Additional details regarding the design of the experiment's scenarios and graphical representations of the research standard terminal arrival routes (STARs) used within the experiment are included in Appendix A.

Table 1. Experiment design matrix.

Flight Crew Procedure	Nominal	Amend ASG	ATC Termination of FIM	Suspend/Resume FIM	ADS-B Loss

1. The Nominal scenario consisted of an IM clearance issued by ATC prior to top of descent (TOD). After the FIM aircraft reported that spacing had commenced, the pilot participants' aircraft (i.e., the FIM aircraft) maintained nominal FIM operations until reaching the achieve-by point.
2. During the Amend ASG scenario, the initial IM clearance was issued shortly after TOD. Approximately two minutes after the FIM aircraft reported that spacing had commenced, ATC issued an amended clearance to increase spacing by 20 sec.
3. In the ATC Termination of FIM scenario, the initial IM clearance was issued shortly after TOD. Once the FIM aircraft and target aircraft were inside the DFW TRACON, ATC cancelled the IM clearance and vectored the target aircraft for landing on runway 13R. ATC then issued a new IM clearance with a new target for the FIM aircraft.
4. The Suspend/Resume FIM scenario consisted of an IM clearance issued by ATC prior to TOD. After the FIM aircraft reported that spacing had commenced, ATC suspended the IM clearance and issued a speed change of 20 kt for the FIM aircraft. Approximately two minutes later, ATC cleared the FIM aircraft to resume IM spacing.
5. During the ADS-B Loss scenario, ATC issued the initial IM clearance prior to TOD. After the FIM aircraft reported that spacing had commenced and both the pilot participants' aircraft and target aircraft were inside the TRACON, the target aircraft experienced a loss of ADS-B capability. The pilot participants notified ATC that they were "IM Unable" due to a loss of the target aircraft's ADS-B signal, and ATC then cancelled the initial IM clearance and issued a new clearance with a new target aircraft.

During all five scenarios, the closest aircraft in the arrival stream for the same runway as the FIM aircraft was designated as the initial target aircraft. If a new target was designated later in the scenario, it was always the next closest aircraft in the arrival stream. For both the ATC Termination of FIM and ADS-B Loss scenarios, the second clearance was issued in the TRACON at an altitude below 10,000 ft.

2.1.1 Hypotheses

The IM-NOVA experiment was designed to meet the experiment objective and investigate the following a priori hypotheses:

Hypothesis 1: The use of the procedures for receiving and executing IM clearances in a voice communications environment will be acceptable to the flight crew, with mean ratings of the procedures' completeness and acceptability higher than 4.5 on a 7-point scale.

Hypothesis 2: At least 90 percent of the pilots will report that the procedures are complete.

Hypothesis 3: Pilots will report the workload level required to execute the procedures to be acceptable, with a mean rating of less than 3 on the Modified Cooper-Harper (MCH) rating scale[1] (ref. 27).

Hypothesis 4: Pilots will report no increase in workload with the Amend ASG, ATC Termination of FIM, Suspend/Resume FIM, or ADS-B Loss scenarios as compared to the Nominal scenario (i.e., a difference of less than 1 unit on the MCH rating scale).

Hypothesis 5: Pilots will report that the crew interface was usable, with mean ratings of the acceptability of heads-down time required and usability of the displays higher than 4.5 on a 7-point scale.

Hypothesis 6: The data entry procedures will be acceptable to the flight crew, with mean ratings of ease and intuitiveness of entering information higher than 4.5 on a 7-point scale.

Hypothesis 7: The rate of speed commands will be acceptable to the flight crew, with speed commands occurring at a rate of less than two per minute, and mean ratings of operational acceptability and acceptability of the frequency of speed commands higher than 4.5 on a 7-point scale.

Hypothesis 8: The spacing error at the FAF will be within ±5 sec with a standard deviation of less than 5 sec.

2.2 Pilot Participants

The study involved 20 current 757/767 pilots from major U.S. air carriers who participated in the experiment in 10 groups of two-person crews. All pilots were male and ranged in age from 40 to 62 years. On average, each of the pilots had 23 years of airline experience and over 13,000 hours of commercial airline flight time. To minimize potential effects associated with different airline operating procedures, all two-person crews were paired from the same airline, and the pilots flew in their current operational position (captain or first officer) using their company's standard operating procedures modified to include FIM operations.

[1] A rating of 3 on the MCH rating scale indicates that the instructed task is fair and/or has mild difficulty, and acceptable operator mental effort is required to attain adequate system performance. The full MCH rating scale is presented in Appendix C.

2.3 Experiment Procedure

The pilot participants received training materials and had access to computer-based training prior to arriving at LaRC. After arriving at LaRC, pilot participants received four hours of classroom and hands-on training involving the completion of three simulated flight training scenarios prior to completing the first data collection run. Each two-person crew participated in a two-day experiment session and completed a total of 10 data collection flights. The first day began with training which was followed by data collection flights. Each data collection flight lasted approximately 25 min, and pilots were asked to complete a post-run questionnaire immediately following each flight. The second day consisted of the remaining data collection flights and post-run questionnaires, the completion of one exploratory scenario involving the presentation of aural cues in conjunction with commanded speed changes, and the completion of a post-experiment questionnaire and debriefing session.

Every crew flew each experiment scenario twice: once with the captain as the pilot flying (PF) and the first officer as the pilot monitoring (PM), and once with the first officer as the PF and the captain as the PM. The run order of the scenarios was partially counterbalanced, and within each crew the pilots switched PF and PM responsibilities between runs. Additional details regarding the experiment run order are included in Appendix B.

2.4 Scheduling and Spacing Technologies

This experiment utilized an integrated set of ground-based and airborne technologies consisting of TMA-TM, CMS decision support tools, and FIM avionics and procedures. These scheduling and spacing technologies are described below.

2.4.1 Traffic Management Advisor with Terminal Metering (TMA-TM)

TMA-TM is an extension of the operational TMA that determines an arrival schedule based on airport conditions, airport capacity, required spacing, and weather conditions. This scheduling tool calculates the estimated time of arrival (ETA) and the corresponding scheduled time of arrival (STA) at various meter and merge points along the aircraft flight path. The TMA-TM data are broadcast to the en route and TRACON controller positions for use by the CMS tools to assist the controllers in maintaining optimum flow rates to the runways.

The TMA-TM display used during the IM-NOVA experiment (shown in Figure 3) included a total of six timelines. From left to right, the first four timelines show the TMA schedule for each of the four metering fixes around the DFW TRACON. The fifth timeline shows the arrival schedule for DFW runway 18R, and the sixth timeline shows the arrival schedule for runway 17C. The current clock time (1541:01z) appears in the upper left corner. The white numbers located in the middle of each timeline indicate minutes after the hour. As time progresses, the timelines scroll toward the bottom of the screen with the current time at the bottom and one hour in the future at the top. On the left of each timeline, each aircraft's ETA at the applicable metering fix or runway threshold is shown in green. On the right side of the timeline, each aircraft's STA is shown in amber or blue. An amber callsign indicates that an aircraft is outside of the TMA freeze horizon for the corresponding fix/runway (set at 19 minutes in the future). Until the freeze horizon is passed, TMA continuously recalculates the STA. When the freeze horizon is reached, the STA is frozen, and the aircraft callsign turns blue. If the green indicator on the left side of the timeline is below the corresponding indicator on the right, the aircraft is early; if it is above the corresponding indicator, the aircraft is late.

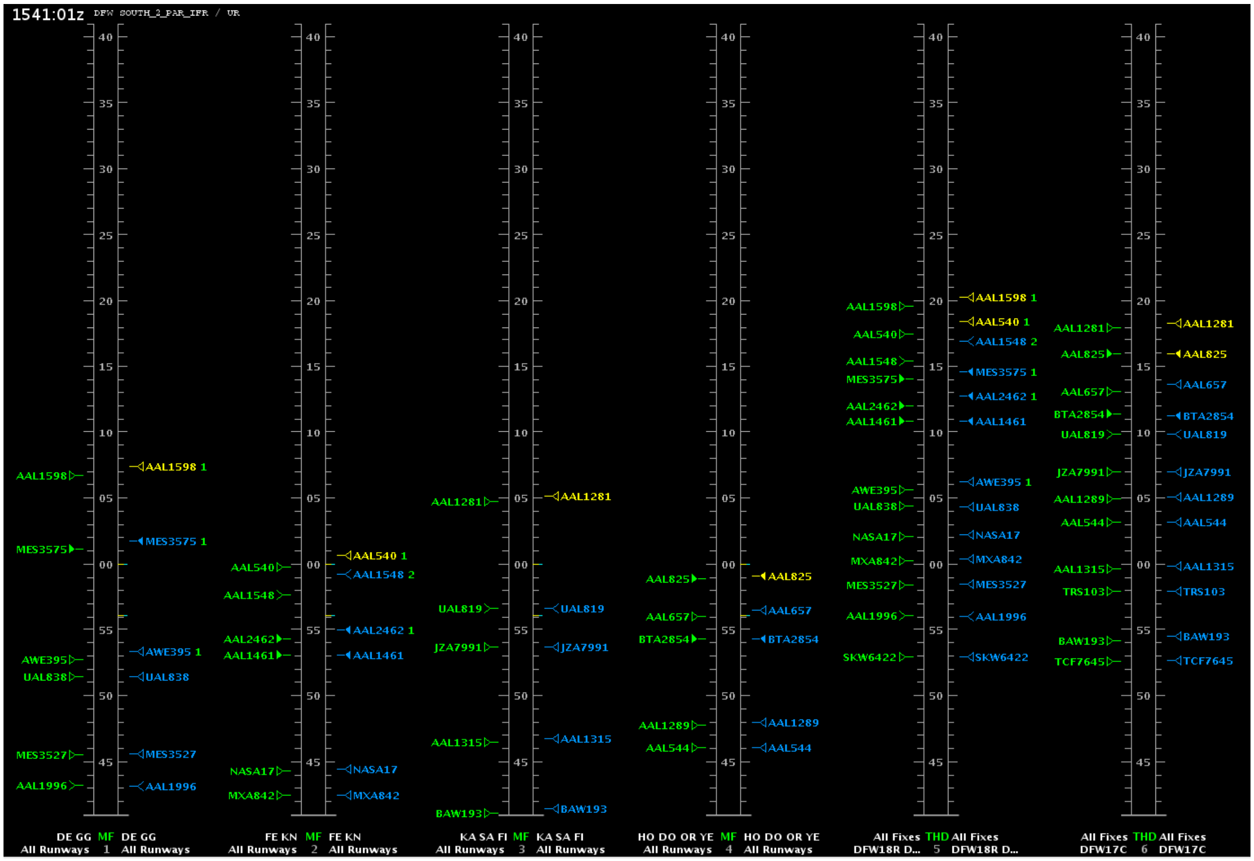

Figure 3. Screenshot of the Traffic Management Advisor with Terminal Metering (TMA-TM) display used in the IM-NOVA experiment.

2.4.2 Controller-Managed Spacing (CMS)

During the IM-NOVA experiment, three CMS tools were used to provide the confederate controllers with information needed to meet the TMA-TM generated schedule: (1) early/late indicators, (2) slot marker circles, and (3) speed advisories. Early/late indicators located in the aircraft full data blocks (FDB) enabled controllers to quickly assess the schedule-conformance information for that aircraft. Elements included in the FDB shown on the Center controller's display, including an early/late indicator, are depicted and described in Figure 4.

Line 1: Aircraft callsign
Line 2: Aircraft altitude (in hundreds of feet)
Line 3:
- Item 1: Computer assigned aircraft identification number
- Item 2: Ground speed
- Item 3: Magenta symbols, manually toggled by ATC
  - ® = Aircraft's STA has been assigned, but no IM clearance has been issued
  - ® S = IM clearance has been issued, but IM has not yet been engaged (i.e., the aircraft is still flying to its STA)
  - S = Aircraft is operating in IM mode

Line 4: Aircraft type (B752 = B757-200)
Line 5: Early/Late indicator (shows that aircraft is currently 24 sec early)

Figure 4. Elements in the aircraft full data block (FDB) shown on the IM-NOVA Center controller's display.

Figure 5 depicts and describes the elements of an FDB with a slot marker circle and a speed advisory as shown on the Feeder controller's display. The IM-NOVA experiment's confederate TRACON controllers' displays presented slot marker circles that indicated where an aircraft should be located at a given time if it were to fly the RNAV arrival, meeting all published speed and altitude restrictions and meeting the STA at the next scheduling fix. The relative position of the aircraft symbol and the slot marker circle provided a quick visual indication of how an aircraft was positioned relative to its STA. The diameter of the slot marker circle represented 15 sec of flying time at the aircraft's current ground speed. If the aircraft was on schedule, the aircraft symbol was centered within the slot marker circle.

Speed advisories in an aircraft's FDB helped confederate controllers formulate speed clearances for aircraft not performing FIM operations. The speed advisory provided a recommended calibrated airspeed (CAS) intended to place an aircraft back on schedule before reaching a scheduling fix.

Line 1:
  Item 1: Aircraft callsign
  Item 2: Assigned runway
Line 2:
  Item 1: Aircraft altitude (in hundreds of feet)
  Item 2: Ground speed
  Item 3: Aircraft class (F = 757)
  Item 4: S (in magenta) = Aircraft is operating in IM mode
Line 3: Speed advisory (i.e., recommended CAS)
Slot marker circle with aircraft symbol “H”

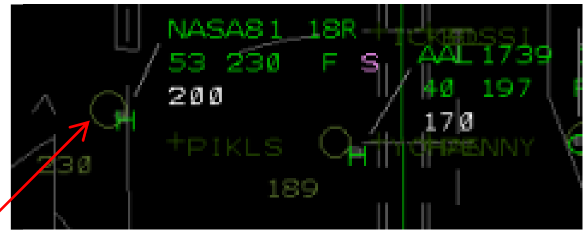

Figure 5. Full data block (FDB) with speed advisory and slot marker circle as shown on the IM-NOVA Feeder controller’s display.

2.4.3 Flight Deck-based Interval Management (FIM)

The FIM tools provide onboard speed guidance to the flight crew, enabling them to achieve a precise spacing interval behind a target aircraft and thereby meet a schedule set by TMA-TM. To allow the performance of FIM operations during the IM-NOVA experiment, the simulator flown by the pilot participants (described in a subsequent section of this document) was equipped with NASA’s ASTAR airborne spacing algorithm and the prototype FIM crew interface.

The ASTAR algorithm produces speed guidance by determining time-to-go until an aircraft and its target reach an achieve-by point along a 4D trajectory. During the IM-NOVA experiment, ASTAR (version 11.06.22) utilized design features intended to reduce the number of required speed changes while maintaining arrival precision. One such feature consisted of a gain schedule that made commanded speed changes more sensitive to a given time error as the aircraft approached the runway. Another feature consisted of a look-ahead function that looked 10 seconds ahead for a profile speed decrease and inhibited speed increases during that 10-second period. Additionally, ASTAR also included mechanisms intended to keep it from generating unacceptable commanded speeds and features intended to help ensure adherence to various regulations. For example, to keep the commanded speeds within an acceptable range, ASTAR limited commanded speed deviations to ±10 percent of the nominal profile speed and adhered to the 250 kt speed restriction below an altitude of 10,000 ft.

As described previously, the prototype FIM crew interface (shown above in Figure 1 and Figure 2) consisted of two side-mounted EFBs and two AGDs positioned within the flight crew’s forward field of view. The IM application residing on the EFB enabled the flight crew to use the EFB’s bezel buttons and touch screen to enter the following information, communicated via an ATC radio-issued IM clearance, into the EFB: achieve-by point, STA, ASG, target aircraft callsign, and target aircraft route. After entering this information into the EFB, the flight crew pressed an “activate” button and then flew speeds to meet their STA until ADS-B information from their target aircraft was acquired and FIM operations could begin.

During FIM operations, the EFB displayed the target aircraft’s callsign; a commanded speed (“CMD SPD”), in Mach or knots, to indicate the FIM aircraft speed needed to achieve precise interval spacing behind the target upon reaching the FAF; and a "FAST/SLOW" indication, in knots, to provide trend information and guidance regarding required FIM aircraft decelerations and accelerations to conform with the ASTAR algorithm. In order to provide the pilot participants with key information in an easily viewable location, the AGD supplied the following three information elements during an IM operation:

- A white "IM" light located in the upper left corner of the device that, when illuminated, indicated that the FIM aircraft was actively spacing relative to a target aircraft
- The commanded speed ("CMD SPD") required to achieve precise interval spacing behind a target aircraft
- A "FAST/SLOW" indication that showed the difference between the FIM aircraft's current speed and the speed that ASTAR expected

Upon reaching the FAF, the ASTAR spacing algorithm switched to VREF mode, and the flight crew began decelerating to their landing speed.

Appendix E provides an example IM clearance and illustrates the use of the EFB for data entry, activation, suspension, resumption, cancellation, and termination of FIM operations. Additionally, illustrations of the information elements presented on the AGD during FIM operations are provided in Appendix E.

2.5 Facilities and Equipment

The IM-NOVA experiment made use of two NASA LaRC facilities: the Air Traffic Operations Laboratory (ATOL) and the Integration Flight Deck (IFD). Descriptions of each facility and the equipment utilized during the IM-NOVA experiment are provided below.

2.5.1 Air Traffic Operations Laboratory (ATOL)

The ATOL operates a network of hundreds of real-time, medium-fidelity aircraft simulators and utilizes a simulation platform, known as the Airspace and Traffic Operations Simulation (ATOS), which can be used for both batch and real-time HITL experiments. During the IM-NOVA experiment, the ATOL provided 24 Aircraft Simulation for Traffic Operations Research (ASTOR) aircraft, four remote ASTOR pseudo-pilot (RAPP) stations, 25 simulated Multi-Aircraft Control System (MACS) aircraft, and four ATC controller stations.

2.5.1.1 *Aircraft Simulation for Traffic Operations Research (ASTOR)*

ASTOR components include: a six degrees-of-freedom aircraft model, primary flight display, multi-function display, autopilot and auto-throttle systems, flight management computer, multi-function control display unit, mode control panel, and ADS-B (ref. 28). During the IM-NOVA experiment, two researchers used a total of four Remote ASTOR Pseudo-Pilot (RAPP) stations (described below) to control the 24 ASTOR aircraft that provided multiple air traffic flows into DFW.

2.5.1.2 *Remote ASTOR Pseudo-Pilot (RAPP) stations*

The use of RAPP stations allowed a single operator, or pseudo-pilot, to control the basic functions of multiple ASTORs. Each RAPP station displays a GUI (shown in Figure 6) that allows the operator to view a selection list showing each simulated aircraft controlled by that RAPP station, a list of ATC frequencies that can be assigned, and the current airspeed, altitude, and heading of each aircraft as it is selected. To command a change in airspeed, heading, altitude, or frequency, the RAPP operator enters the desired change in the appropriate command window and clicks on the corresponding "Send" button. A message containing the desired command is then sent to the selected ASTOR. The sent message and a response from the ASTOR are displayed in the scratch pad at the bottom of the RAPP station GUI.

Since the majority of the ASTORs in each scenario independently flew their assigned flight plan without ATC intervention, the RAPP station operators primarily handled the radio transmissions for their assigned aircraft. However, there were cases in each scenario where the RAPP operators executed ATC-directed speed changes to keep aircraft on the TMA arrival schedule. In the ATC Termination of FIM scenario, the RAPP station operator executed ATC heading, airspeed, and altitude changes required to vector the ASTOR for an approach to runway 13R, although the approach and landing were not actually executed.

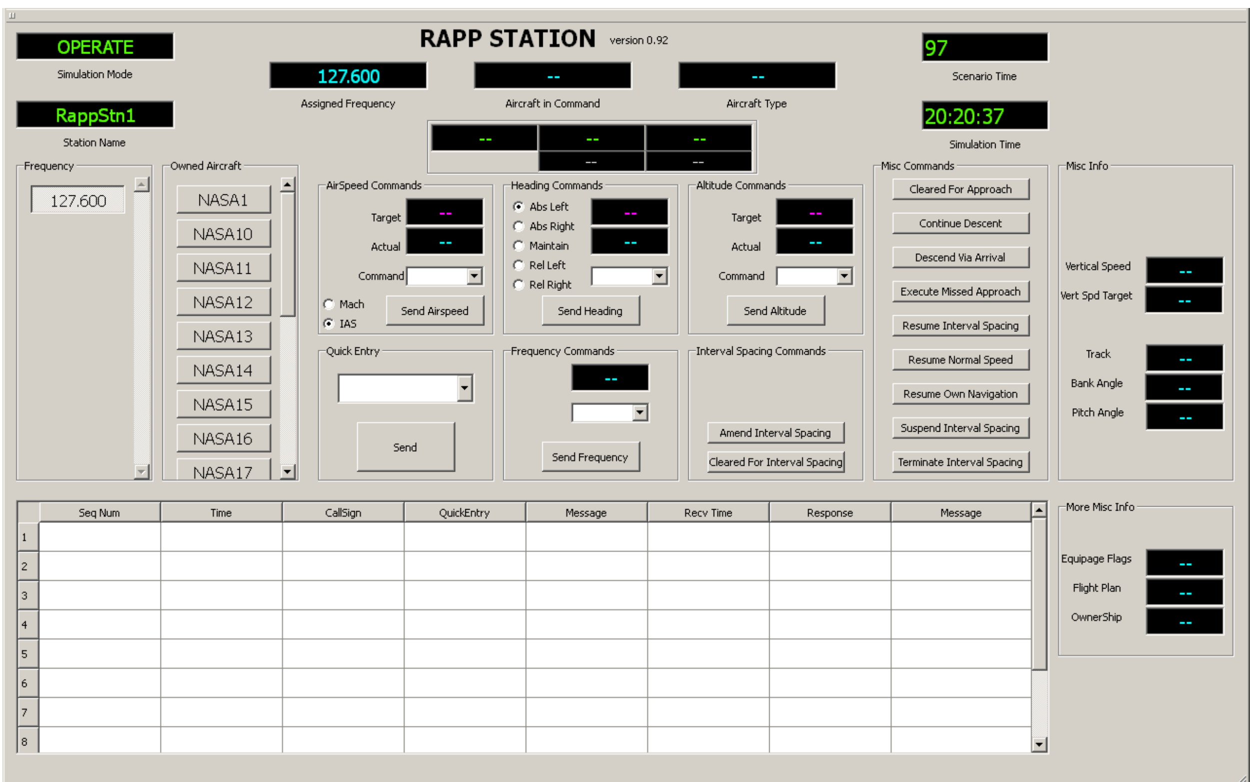

Figure 6. Remote ASTOR Pseudo-Pilot (RAPP) station graphical user interface.

2.5.1.3 *Multi-Aircraft Control System (MACS) aircraft*

In addition to the arriving aircraft being simulated with ASTORs, each experiment scenario included 25 departing aircraft to provide a more realistic traffic picture for the air traffic controllers. The departing aircraft were simulated using the NASA ARC MACS software (ref.

29). These aircraft took off from DFW runways 17R and 18L at intervals ranging from 30 seconds to 120 seconds and were flown solely by a computer-based pilot model.

2.5.1.4 *ATC controller stations*

ATC controller stations equipped with MACS were utilized within the ATOL to enable confederate air traffic controllers to provide a realistic ATC environment. The confederate controllers used either standard Display System Replacement (DSR) or Standard Terminal Automation Replacement System (STARS) displays augmented with CMS decision support tools.

A screenshot of the Center controller's DSR display for an IM-NOVA scenario is shown in figure 7. FDBs associated with arrival aircraft are displayed in yellow and include early/late indicators. FDBs associated with departure aircraft are displayed in white.

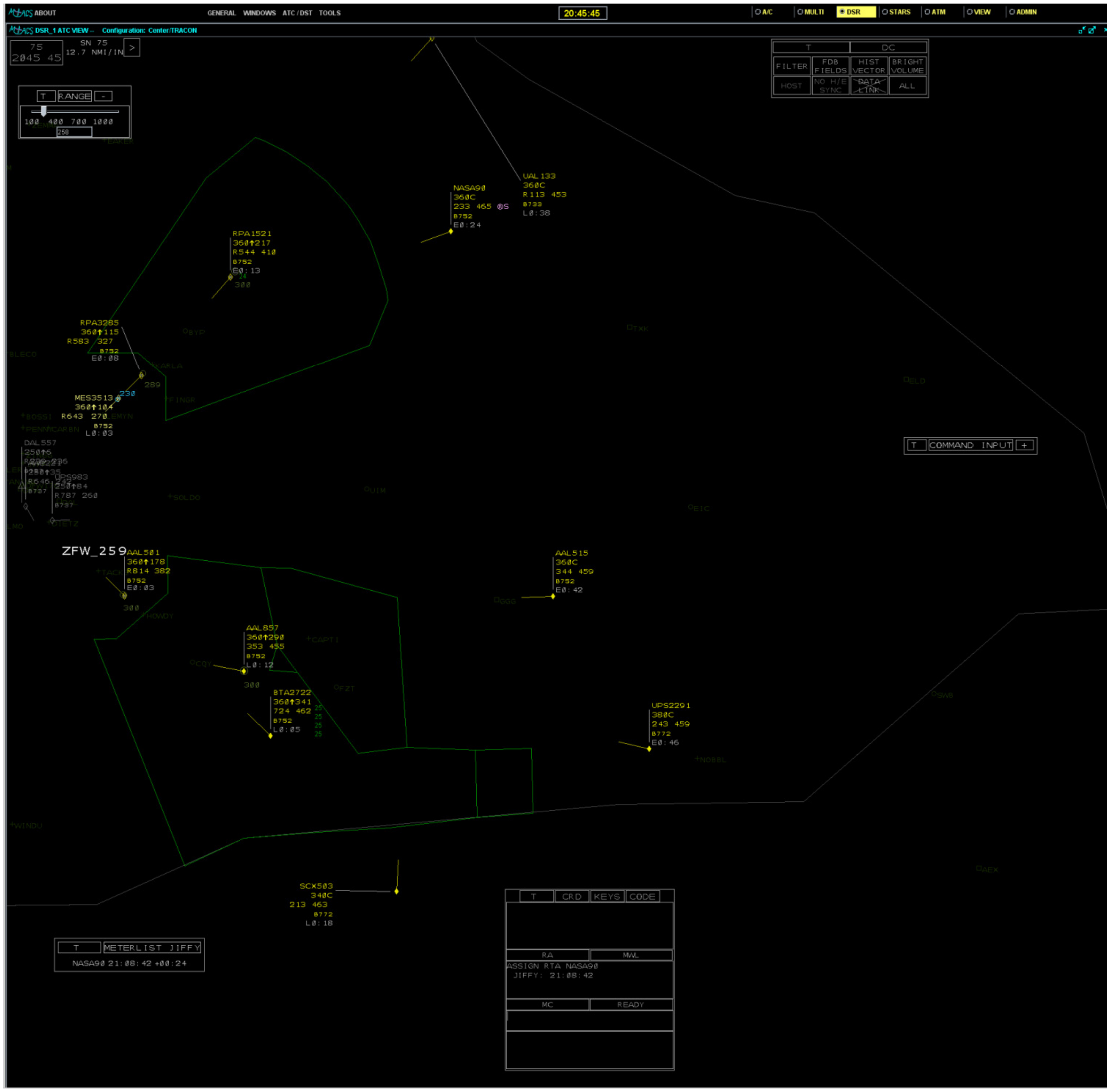

Figure 7. IM-NOVA Center controller's Display System Replacement (DSR) display.

Figure 8 shows a screenshot of the STARS display provided on the IM-NOVA Feeder ATC station. White FDBs indicate aircraft owned by the Feeder controller. Green FDBs indicate aircraft that are owned by the Final controller, and yellow FDBs are associated with departure aircraft. Slot marker circles and speed advisories are displayed for all arrivals, and TMA timelines for both runways are displayed on the left and right sides of the STARS display.

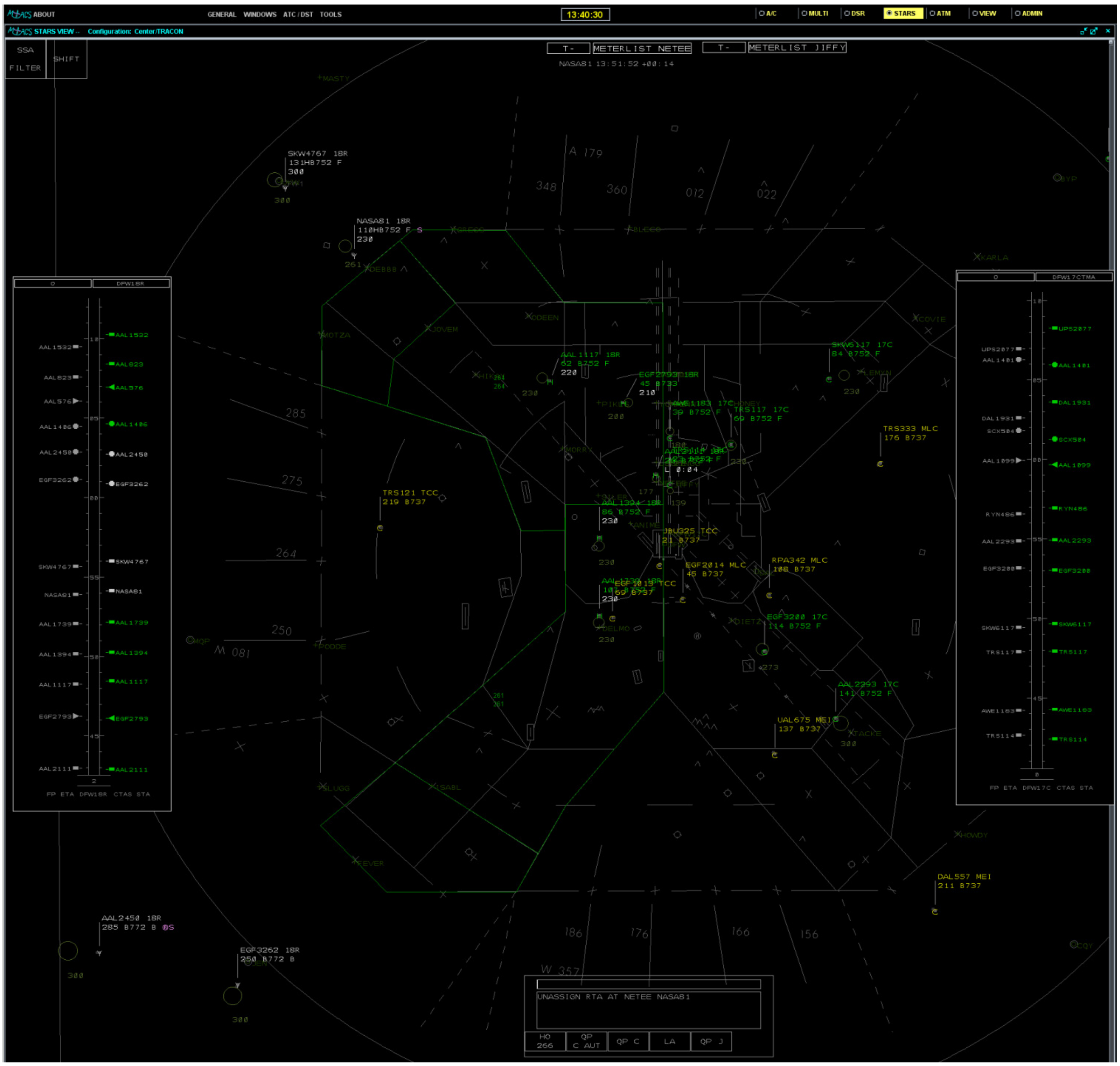

Figure 8. IM-NOVA Feeder controller's Standard Terminal Automation Replacement System (STARS) display.

2.5.2 Integration Flight Deck (IFD)

The IFD is a full-scale simulator representative of a large commercial transport category aircraft and is driven by an appropriate aircraft dynamics mathematical model (ref. 30). The cockpit includes standard instruments representative of a line operations aircraft, and the cockpit's visual system is a panorama system that provides 200° horizontal by 40° vertical field-of-view. During the IM-NOVA experiment, all pilot participants flew the IFD, and the visual scene used was the DFW terminal environment in a daytime setting. As noted previously, the IFD simulator was equipped with the ASTAR algorithm and the prototype FIM crew interface to enable flight crews to perform FIM operations.

Figure **9** shows the positions of the EFBs and AGDs within the IFD.

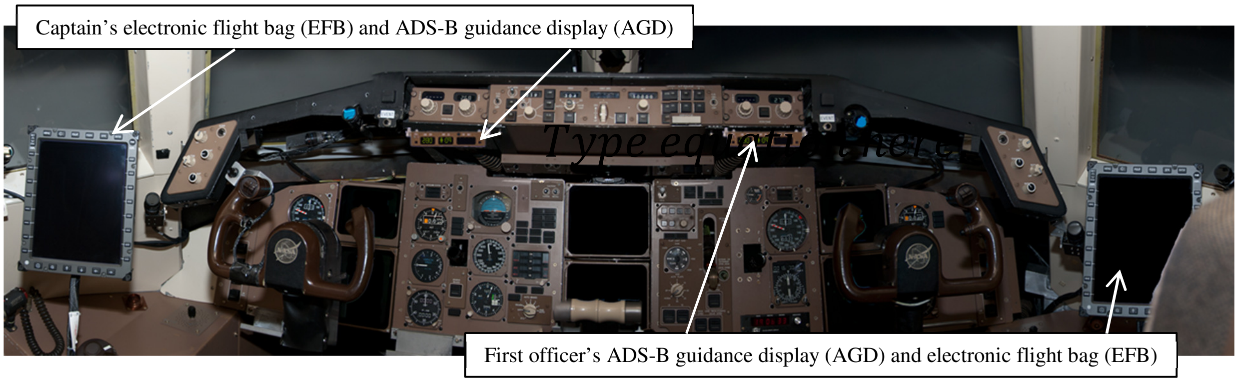

Figure 9. Integration Flight Deck (IFD) equipped with IM-NOVA's prototype FIM crew interface.

2.6 Dependent Measures

To assess the acceptability of the procedures and test Hypotheses 1–7, qualitative data were collected from pilots via electronic questionnaires. Following each run, the pilots were asked to rate the level of workload during the scenario they had just completed using the MCH Subjective Workload Rating Scale. They were also asked to characterize the following: the acceptability of the use of the procedures in a voice communications environment, the completeness of the procedures, the usability of the crew interface, the acceptability of the data entry procedures, and the operational acceptability of the rate of speed commands. At the end of the second day of the two-day experiment session, each flight crew participated in an interactive group debrief session with the research team.

To assess the feasibility of the procedures and test Hypotheses 7 and 8, quantitative data, including a spacing error at the FAF and the rate of ASTAR commanded speed changes, were collected during each run. Although the achieve-by point was the FAF, the spacing error at the runway threshold was an additional metric of interest. Since the ATD-1 procedures used in this experiment required that a complex voice clearance be issued to the flight crew by ATC using radio communications, data were collected during each run to allow an assessment of the time required for clearance issuance and read back, as well as the time required for the flight crew to enter information included in the clearance into the EFB.

3 Results and Discussion

To assess the acceptability of the proposed ATD-1 flight crew procedures, subjective response data were collected in the form of acceptability, workload, and usability ratings via electronic post-run and post-experiment questionnaires (questionnaires are included in Appendix C and Appendix D). To assess the feasibility of the procedures, quantitative data were collected, including the rate of speed commands and the spacing error at the FAF. An a priori hypothesis associated with the spacing error at the runway threshold was not generated; however, a spacing error at the runway threshold was computed for each run. Similarly, a priori hypotheses associated with data collected during the exploratory scenario were not generated; however, descriptive statistics calculated using the exploratory scenario data are included in Table 2–Table 13.

Results from pilot participant crew #2, Scenario 5 (ADS-B Loss), with the first officer as PF and the captain as PM, were excluded from this analysis due to a simulation error.[2] Results associated with the time required for IM clearance issuance and read back as well as the time required for the flight crew to enter information included in the clearance into the EFB are reported elsewhere (ref. 31).

3.1 Acceptability of the Procedures

Hypothesis 1 is as follows: the use of the procedures for receiving and executing IM clearances in a voice communications environment will be acceptable to the flight crew, with mean ratings of the procedures' completeness and acceptability higher than 4.5 on a 7-point scale.

To assess Hypothesis 1, data from the following two items of the post-run questionnaires were used:

5f. The use of voice communications to provide the IM clearance(s) was acceptable in this scenario.

5j. The flight crew procedures for the events in this scenario were complete and acceptable.

Descriptive statistics associated with the pilot participants' acceptability ratings are shown in Table 2 and Table 3. Statistical analysis was performed using the Wilcoxon signed rank test, a nonparametric test appropriate for analyzing ordinal data (ref. 31). There were no statistically significant differences between the mean responses from the PF and PM for either questionnaire item 5f or 5j in any scenario ($p \geq 0.236$),[3] except for questionnaire item 5j in the Nominal scenario ($p = 0.036$). In this case, the mean acceptability rating was slightly higher for the PM (mean = 6.9, SD = 0.3) than for the PF (mean = 6.5, SD = 0.9). For all five scenarios, both the PF and PM generally found the proposed ATD-1 procedures to be acceptable in a voice communications environment ($p \leq 0.002$). However, concerns regarding the acceptability of the

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[2] Researchers responsible for communicating information regarding the target aircraft's loss of ADS-B capability to pilot participant crew #2 failed to provide this information at the appropriate time during the experiment scenario.

[3] A p-value < 0.05 indicates a statistically significant difference between sample means.

proposed procedures were raised by several pilot participants as evidenced by a total of 10 ratings of 3 (Slightly Disagrees) or less recorded in response to questionnaire item 5f and a total of two ratings of 3 or less recorded in response to questionnaire item 5j. These low ratings of acceptability were consistently associated with pilots' reported uneasiness with the issuance of IM clearances below 10,000 ft. Specific pilot participant comments referenced concerns with "task saturation below 10,000 ft" and a hesitancy to enter data associated with an IM clearance into an EFB while completing other tasks required within a potentially "high demand terminal environment."

Table 2. Descriptive statistics for acceptability ratings (from post-run questionnaire item 5f).

Scenario	N	PF					PM				
		Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.7	0.7	4	7	7	6.6	0.9	3	7	7
Amend ASG	20	6.4	1.1	3	7	7	6.4	1.2	2	7	7
ATC Terminates	20	6.8	0.9	3	7	7	6.6	1.0	3	7	7
Suspend/Resume	20	6.9	0.4	6	7	7	6.7	0.7	5	7	7
ADS-B Loss	19	6.2	1.5	2	7	7	6.1	1.6	2	7	7
Exploratory	10	6.9	0.3	6	7	7	6.6	1.0	4	7	7

Table 3. Descriptive statistics for acceptability ratings (from post-run questionnaire item 5j).

Scenario	N	PF					PM				
		Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.5	0.9	4	7	7	6.9	0.3	6	7	7
Amend ASG	20	6.6	0.7	5	7	7	6.6	0.8	4	7	7
ATC Terminates	20	6.7	0.6	5	7	7	6.6	0.9	3	7	7
Suspend/Resume	20	6.5	0.8	5	7	7	6.8	0.5	5	7	7
ADS-B Loss	19	6.5	1.0	4	7	7	6.3	1.4	2	7	7
Exploratory	10	6.9	0.3	6	7	7	6.8	0.4	6	7	7

3.2 Completeness of the Procedures

Hypothesis 2 is as follows: pilots will report that the procedures are complete (i.e., at least 90 percent of the pilots will report that the procedures are complete).

To assess Hypothesis 2, data from the following three items of the post-run questionnaires were used:

6a. The procedures did not contain missing steps.

6b. The procedures did not contain extra steps that were unnecessary.

6c. The procedural steps were logical and easy to follow.

Table 4 shows the proportion of pilots who agreed with questionnaire items 6a, 6b, and 6c. Using Fisher's exact test, there were no statistically significant differences between the proportion of PF and PM who reported the procedures were complete in any scenario ($p \geq 0.487$) (ref. 31). Statistical analysis was performed using the binomial test of one proportion to test whether the proportion of pilots who reported the procedures were complete was at least 90 percent vs. less than 90 percent (ref. 31). For all five scenarios, the proportion of pilot participants who reported that the procedures contained no missing steps, no unnecessary steps, and that the steps were logical and easy to follow was not significantly less than 90 percent ($p \geq 0.580$). This implies that the pilots felt the procedures were complete.

Table 4. Percentage (%) of pilots who reported procedures were complete (from post-run questionnaire items 6a, 6b, and 6c).

Scenario	N	Questionnaire Item 6a		Questionnaire Item 6b		Questionnaire Item 6c	
		PF	PM	PF	PM	PF	PM
Nominal	20	95.0	100.0	100.0	90.0	95.0	100.0
Amend ASG	20	95.0	95.0	95.0	90.0	100.0	100.0
ATC Terminates	20	100.0	95.0	100.0	100.0	100.0	90.0
Suspend/Resume	20	95.0	100.0	100.0	100.0	100.0	100.0
ADS-B Loss	19	89.5	94.7	100.0	94.7	100.0	94.7
Exploratory	10	100.0	100.0	100.0	90.0	100.0	100.0

3.3 Pilot Workload

Hypothesis 3 is as follows: pilots will report the workload level required to execute the procedures to be acceptable, with a mean rating of less than 3 on the MCH rating scale.

Hypothesis 4 is as follows: pilots will report no increase in workload with the Amend ASG, ATC Termination of FIM, Suspend/Resume FIM, or ADS-B Loss scenarios as compared to the Nominal scenario (i.e., a difference of less than 1 unit on the MCH rating scale).

To assess Hypotheses 3 and 4, workload rating data collected using the MCH flow chart presented in the post-run questionnaires were used.

Descriptive statistics associated with the pilot participants' workload ratings are shown in Table 5. Statistical analysis was performed using the Wilcoxon signed rank test. There were no statistically significant differences between the mean responses from the PF and PM in any scenario ($p \geq 0.221$). For all five scenarios, both the PF and PM found the workload level required to execute the procedures to be acceptable ($p < 0.0005$). Pilots also reported no significant increase in the workload for the Amend ASG, ATC Termination of FIM, Suspend/Resume FIM, or ADS-B Loss scenarios as compared to the Nominal scenario for either PF or PM ($p \leq 0.003$).

Table 5. Descriptive statistics for pilot workload ratings (from post-run questionnaire item 3).

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	1.6	0.7	1	1	3	1.5	0.6	1	1	3
Amend ASG	20	1.6	0.6	1	2	3	1.3	0.5	1	1	2
ATC Terminates	20	1.5	0.5	1	1	2	1.6	0.6	1	2	3
Suspend/Resume	20	1.5	0.7	1	1	3	1.5	0.6	1	1	3
ADS-B Loss	19	1.7	0.7	1	2	3	1.8	0.8	1	2	3
Exploratory	10	1.3	0.5	1	1	2	1.3	0.7	1	1	3

3.4 Usability of the Crew Interface

Hypothesis 5 is as follows: pilots will report that the crew interface was usable, with mean ratings of the acceptability of heads-down time required and usability of the displays will be higher than 4.5 on a 7-point scale.

To assess Hypothesis 5, data from the following two items of the post-run questionnaires were used:

5g. The amount of heads-down time required to input information from the IM clearance(s) into the EFB was acceptable.

5i. During this scenario, it was easy to obtain needed information from the IM displays.

Descriptive statistics associated with the pilot participants' ratings of the amount of heads-down time and display usability are shown in Table 6 and Table 7. Statistical analysis was performed using the Wilcoxon signed rank test. There were no statistically significant differences between the mean responses from the PF and PM for either questionnaire item 5g or 5i in any scenario ($p \geq 0.141$). For all five scenarios, pilots reported the amount of heads-down time required to input information from the IM clearance(s) into the EFB was acceptable ($p \leq 0.001$), and found that it was easy to obtain needed information from the IM displays ($p < 0.0005$). This indicates that the pilots generally felt that the prototype FIM crew interface was usable. However, several pilots expressed concerns regarding the usability of the crew interface as evidenced by a total of six ratings of 3 or less recorded in response to questionnaire item 5g and a total of four ratings of 3 in response to questionnaire item 5i. Specific concerns focused on the amount of heads-down time required to input information from an IM clearance into the EFB during operations occurring below 10,000 ft and the limited amount of pertinent information presented within the forward field of view by the AGD.

Table 6. Descriptive statistics for ratings of the amount of heads-down time (from post-run questionnaire item 5g).

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.5	0.7	5	7	7	6.8	0.4	6	7	7
Amend ASG	20	6.6	1.0	3	7	7	6.6	0.7	5	7	7
ATC Terminates	20	6.6	0.8	4	7	7	6.3	1.4	1	7	7
Suspend/Resume	20	6.6	0.8	4	7	7	6.8	0.6	5	7	7
ADS-B Loss	19	6.0	1.4	3	7	7	6.1	1.6	2	7	7
Exploratory	10	6.4	1.0	4	7	7	6.6	0.7	5	7	7

Table 7. Descriptive statistics for ratings of the usability of the displays (from post-run questionnaire item 5i).

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.5	1.0	3	7	7	6.6	0.7	5	7	7
Amend ASG	20	6.7	0.5	6	7	7	6.4	1.1	3	7	7
ATC Terminates	20	6.6	0.7	5	7	7	6.7	0.7	5	7	7
Suspend/Resume	20	6.7	0.6	5	7	7	6.7	0.6	5	7	7
ADS-B Loss	19	6.3	1.1	3	7	7	6.5	1.1	3	7	7
Exploratory	10	6.9	0.3	6	7	7	6.8	0.4	6	7	7

3.5 Acceptability of Data Entry Procedures

Hypothesis 6 is as follows: the data entry procedures will be acceptable to the flight crew, with mean ratings of ease and intuitiveness of entering information being higher than 4.5 on a 7-point scale.

To assess Hypothesis 6, data from the following post-run questionnaire item were used:

5h. During this scenario, entering IM clearance information into the EFB was easy and intuitive.

Descriptive statistics associated with the pilot participants' ratings of the ease and intuitiveness of entering information are shown in Table 8. Statistical analysis performed using the Wilcoxon signed rank test found no statistically significant differences between the mean responses from the PF and PM in any scenario ($p \geq 0.100$). For all five scenarios, pilots found the data entry procedures to be acceptable ($p < 0.0005$). However, three ratings of 3 recorded in response to questionnaire item 5h were associated with concerns expressed regarding the input of data into the EFB at low altitudes within the terminal environment.

Table 8.Descriptive statistics for ratings of the ease and intuitiveness of entering information (from post-run questionnaire item 5h).

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.6	0.8	4	7	7	6.9	0.3	6	7	7
Amend ASG	20	6.4	1.1	4	7	7	6.5	1.0	4	7	7
ATC Terminates	20	6.6	0.9	4	7	7	6.6	1.0	3	7	7
Suspend/Resume	20	6.7	0.7	4	7	7	6.8	0.4	6	7	7
ADS-B Loss	19	6.3	1.2	4	7	7	6.3	1.3	3	7	7
Exploratory	10	6.6	1.0	4	7	7	6.8	0.6	5	7	7

3.6 Rate of Speed Commands

Hypothesis 7 is as follows: the rate of speed commands will be acceptable to the flight crew, with speed commands occurring at a rate of less than two per minute, and mean ratings of operational acceptability and acceptability of the frequency of speed commands being higher than 4.5 on a 7-point scale,

To assess Hypothesis 7, the rate of speed commands during each segment of flight as well as data from the following two post-run questionnaire items were used:

5c. The IM commanded speeds were operationally acceptable and appropriate.

5d. The frequency of the IM speed commands was acceptable at all times throughout the scenario.

For each run, the rate of speed commands was computed. Table 9 presents the mean rate of speed commands over the entire flight, as well as for each segment of flight: from Flight Level (FL) 240 to FL180, FL180 to 11,000 ft, 11,000 ft to 6,000 ft, and 6,000 ft to the FAF. Statistical analysis was performed using the one-sample Poisson rate test, a hypothesis test appropriate for analyzing the number of occurrences of an event in a given length of time (ref. 33). For all five scenarios, the mean rate of speed commands was less than two per minute for each flight segment ($p < 0.0005$).

Table 10 and

Table 11 show descriptive statistics associated with the pilot participants' ratings for questionnaire items 5c and 5d. Statistical analysis was performed using the Wilcoxon signed rank test. There were no statistically significant differences between the mean responses from the PF and PM for either questionnaire item 5c or 5d in any scenario ($p \geq 0.205$). For all five scenarios, pilots generally reported that the IM commanded speeds were operationally acceptable and appropriate ($p \leq 0.001$), and pilots found the frequency of the IM speed commands to be acceptable ($p \leq 0.001$). When referencing Table 9 and

Table 10, note that only two of the 20 pilots provided ratings of 3 or less during the experiment scenarios. One pilot commented that the issuance of a new clearance below 10,000 ft during the ADS-B Loss scenario resulted in too much heads-down time by the PM, and comments from the other pilot indicated that two speed commands occurred in less than five seconds during two of the scenarios.

Table 9. Mean rate of speed commands (number of speed commands per minute) for each segment of flight.

Scenario	N	FL240 to 180	FL180 to 11,000 ft	11,000 ft to 6,000 ft	6,000 ft to FAF	Total
Nominal	20	0.22	0.44	0.35	0.76	0.49
Amend ASG	20	0.09	0.65	0.53	0.67	0.54
ATC Terminates	20	0.12	0.50	n/a	0.67	0.53
Suspend/Resume	20	0.13	0.40	0.35	0.61	0.43
ADS-B Loss	19	n/a*	0.43	n/a	0.72	0.61
Exploratory	10	0.29	0.60	0.63	0.70	0.59

*Note that mean rate = “n/a” indicates aircraft was conducting FIM operations less than 75% of the time.

Table 10. Descriptive statistics for ratings of operational acceptability and appropriateness of IM commanded speeds (from post-run questionnaire item 5c).

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.3	1.3	2	7	7	6.8	0.4	6	7	7
Amend ASG	20	6.9	0.4	6	7	7	6.7	0.6	5	7	7
ATC Terminates	20	6.6	0.8	4	7	7	6.5	1.4	1	7	7
Suspend/Resume	20	6.5	0.9	4	7	7	6.8	0.4	6	7	7
ADS-B Loss	19	6.3	1.5	1	7	7	6.4	1.3	2	7	7
Exploratory	10	6.7	0.7	5	7	7	6.5	0.7	5	7	7

Table 11. Descriptive statistics for ratings of acceptability of the frequency of the IM speed commands (from questionnaire item 5d).

		PF					PM				
Scenario	N	Mean	SD	Min	Med	Max	Mean	SD	Min	Med	Max
Nominal	20	6.6	0.6	5	7	7	6.7	0.5	6	7	7
Amend ASG	20	6.6	0.8	5	7	7	6.5	0.9	4	7	7
ATC Terminates	20	6.5	0.8	4	7	7	6.2	1.4	1	7	7
Suspend/Resume	20	6.6	0.8	4	7	7	6.6	0.8	4	7	7
ADS-B Loss	19	6.4	1.5	1	7	7	6.5	1.1	3	7	7
Exploratory	10	6.6	0.7	5	7	7	6.3	1.3	3	7	7

3.7 Spacing Error at the Final Approach Fix

For each run, the spacing error at the FAF was recorded to assess the following a priori hypothesis:

> Hypothesis 8: The spacing error at the FAF will be within ±5 sec with a standard deviation of 5 sec.

Descriptive statistics associated with the spacing error at the FAF are provided in Table 12, and histograms for each scenario are shown in Figure 150–Figure 19. The one-sample *t*-test and one-sample variance test were used to test the mean and standard deviation, respectively (ref. 33). For all five scenarios, the spacing error at the FAF had a mean within ±5 sec ($p < 0.0005$) and a standard deviation less than 5 sec ($p < 0.0005$).

Table 12. Descriptive statistics for spacing error at the FAF (sec).

Scenario	N	Mean	SD	Min	Median	Max
Nominal	20	–1.7	1.0	–4.1	–1.5	–0.1
Amend ASG	20	–1.8	1.3	–5.3	–1.6	0.5
ATC Terminates	20	–0.8	1.1	–3.4	–0.9	0.9
Suspend/Resume	20	1.2	1.5	–1.7	1.5	3.4
ADS-B Loss	19	–0.5	0.9	–1.6	–0.7	1.7
Exploratory	10	–1.3	1.4	–3.0	–1.4	1.5

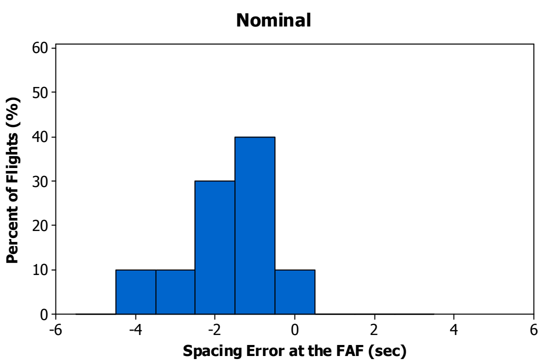

Figure 10. Spacing error at the FAF (sec) for the Nominal scenario.

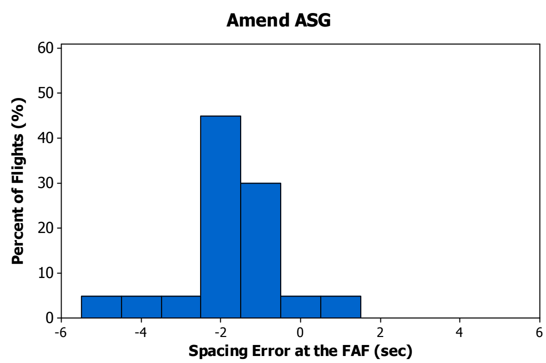

Figure 11. Spacing error at the FAF (sec) for the Amend ASG scenario.

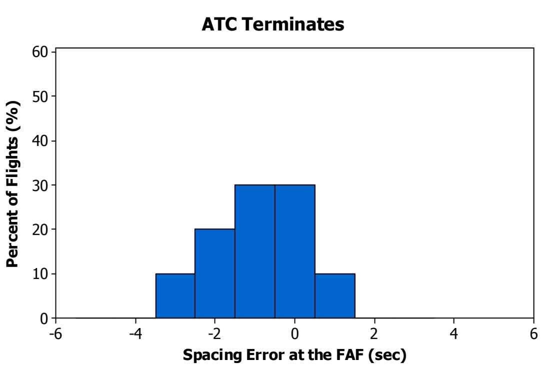

Figure 12. Spacing error at the FAF (sec) for the ATC Termination of FIM scenario.

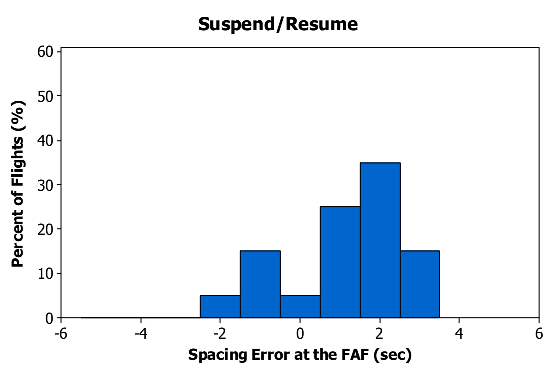

Figure 13. Spacing error at the FAF (sec) for the Suspend/Resume scenario.

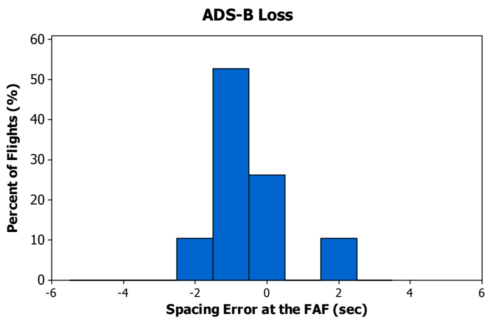

Figure 14. Spacing error at the FAF (sec) for the ADS-B Loss scenario.

3.8 Spacing Error at the Runway Threshold

The spacing error at the runway threshold was computed for each run. Table 13 gives descriptive statistics associated with this metric, and Figure 15–Figure 19 show histograms for each scenario. For all five scenarios, the observed mean spacing error at the runway threshold was within ±2 sec, and the observed standard deviation was less than 3 sec.

Table 13. Descriptive statistics for spacing error at the runway threshold (sec).

Scenario	N	Mean	SD	Min	Med	Max
Nominal	20	–0.7	2.2	–4.1	–0.6	3.8
Amend ASG	20	–0.5	2.9	–8.5	–0.2	5.0
ATC Terminates	20	–1.6	2.3	–6.3	–1.7	1.9
Suspend/Resume	20	0.4	2.9	–5.8	0.8	5.3
ADS-B Loss	19	–1.3	2.5	–5.1	–1.8	5.1
Exploratory	10	–0.7	2.0	–4.8	0.2	0.9

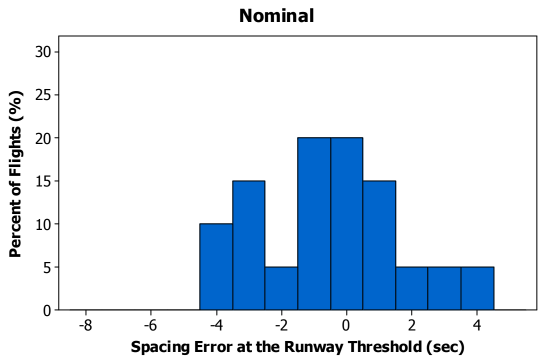

Figure 15. Spacing error at the runway threshold (sec) for the Nominal scenario.

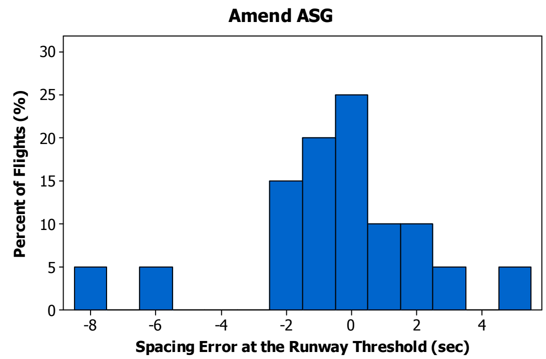

Figure 16. Spacing error at the runway threshold (sec) for the Amend ASG scenario.

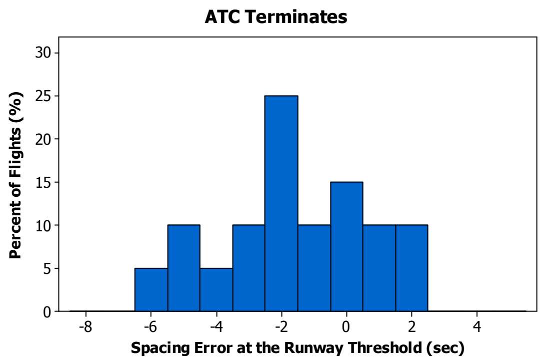

Figure 17. Spacing error at the runway threshold (sec) for the ATC Termination of FIM scenario.

Figure 18. Spacing error at the runway threshold (sec) for the Suspend/Resume scenario.

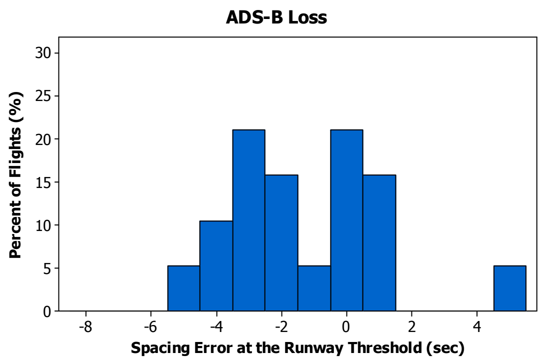

Figure 19. Spacing error at the runway threshold (sec) for the ADS-B Loss scenario.

4 Conclusions

NASA has developed a set of ground-based and airborne arrival management technologies, including TMA-TM, CMS decision support tools, and FIM avionics and procedures. The integration of these technologies will increase throughput, reduce delay, and minimize environmental impacts. ATD-1 will operationally demonstrate the efficient arrival operations provided by this integrated system of NextGen technologies.

The HITL experiment described in Section 1.1 was conducted as part of initial preparations for an ATD-1 flight demonstration. It was designed to assess the acceptability and feasibility of the proposed air/ground procedures in a voice communications environment. Five flight scenarios were defined to allow flight crews to fully exercise the procedures during different flight phases and operational events. These scenarios consisted of a nominal IM clearance flown to landing, an amended IM clearance on arrival, a terminated IM clearance with a reissue of a new clearance, a suspension and resumption of the IM clearance, and a system error causing a flight crew termination of IM (ADS-B loss) with a subsequent new clearance issued at low altitude (below 10,000 ft).

Overall, the FIM crew procedures were deemed acceptable and feasible for use by the flight crew in all scenarios and phases of flight flown in the experiment. Analyses of qualitative data revealed that the procedures used by flight crews to receive and execute IM clearances in a voice communications environment were logical, easy to follow, did not contain any missing or extraneous steps, and required the use of an acceptable level of workload. The majority of the pilot participants found the IM concept and the proposed FIM crew procedures to be acceptable and indicated that the ATD-1 procedures could be successfully executed in a near-term NextGen environment. Analyses of quantitative data revealed that FIM speed commands occurred at a rate of less than two per minute, and pilot participants found the frequency of the speed commands to be acceptable at all times throughout the experiment scenarios. Pilots also reported that the IM commanded speeds were operationally acceptable and appropriate during all scenarios. In addition, the delivery accuracy at both the FAF and the runway threshold was within ±5 sec, and the delivery precision was less than 5 sec. The results of this experiment demonstrate the effectiveness of the airborne spacing algorithm and the air/ground procedures investigated. Future research is planned to investigate the effects of winds, weather, and turbulence on the acceptability and feasibility of the ATD-1 air/ground procedures.

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Appendix A. Simulated Airspace and Scenario Design

The Interval Management for Near-Term Operations Validation of Acceptability (IM-NOVA) experiment's common scenario consisted of 25 arrival aircraft created at various points on the arrival routes into Dallas-Fort Worth (DFW) airport and landing on runways 17C and 18R. To provide a realistic traffic environment, each scenario also included 25 departure aircraft generated by the Multi-Aircraft Control System (MACS) developed at NASA Ames Research Center (ARC).

All IM-NOVA inbound aircraft approached the DFW airport via one of four standard terminal arrival routes (STARs) with a total of 10 different transitions. The distribution of aircraft over the STARs/Transitions is shown in Table A-1, and the research STAR charts are included in Figure A-1–Figure A-4.

Table A-1. Distribution of aircraft over the STARs/Transitions.

STAR	Transition	Number of Aircraft
Bonham Five	Fort Smith	3
	Little Rock	2
	Paris	1
Bowie One	Borger	5
	Texico	2
Cedar Creek Six	Alexandria	2
	Gregg County	2
	Humble	2
Glenn Rose Nine	San Antonio	5
	Wink	1

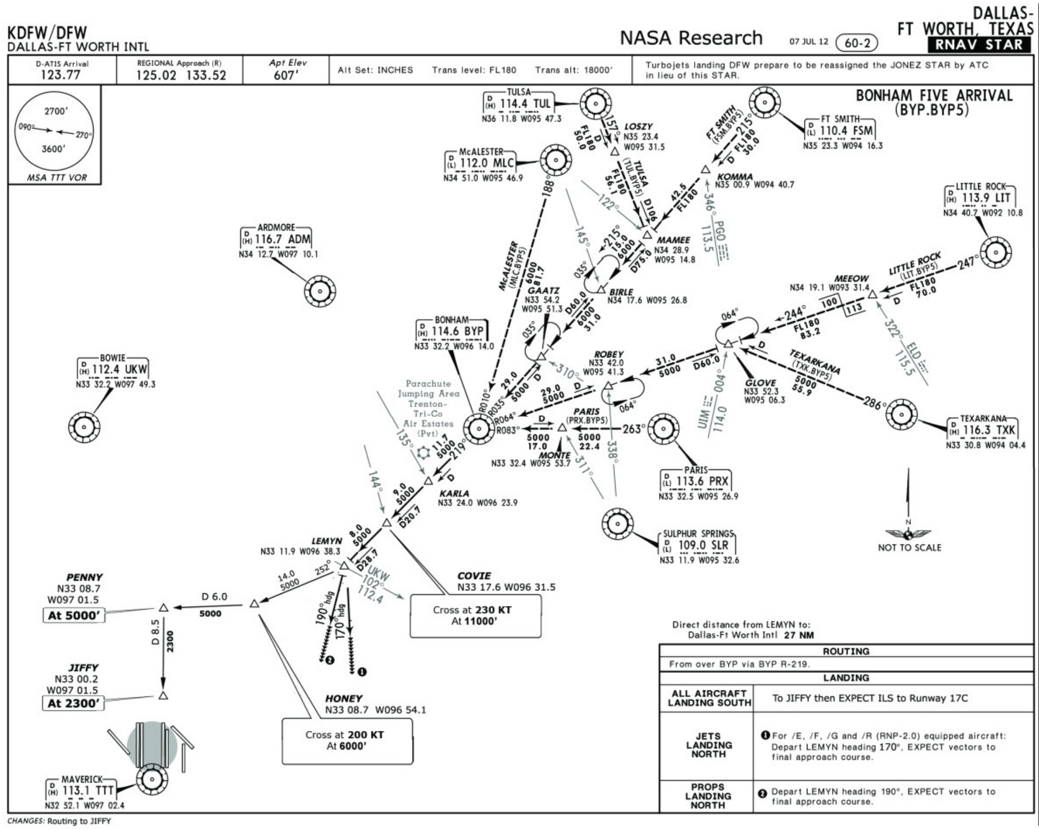


Figure A-1. NASA Research STAR for the Bonham Five Arrival into DFW.

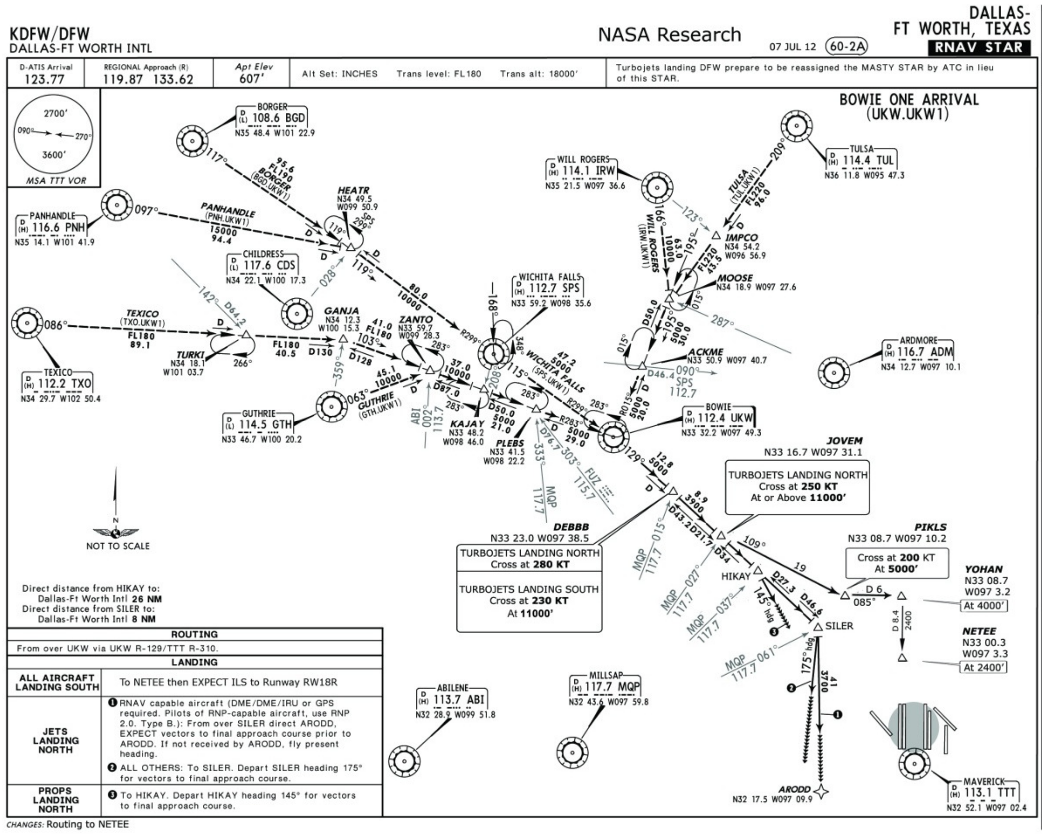


Figure A-2. NASA Research STAR for the Bowie One Arrival into DFW.

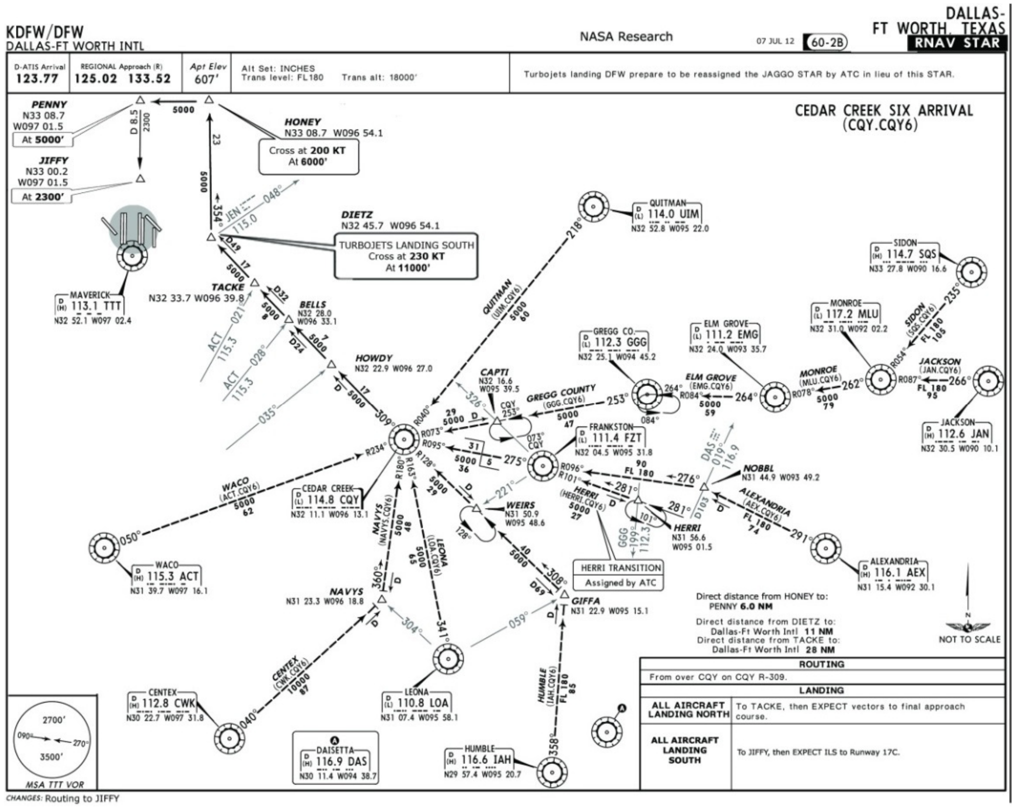


Figure A-3. NASA Research STAR for the Cedar Creek Six Arrival into DFW.

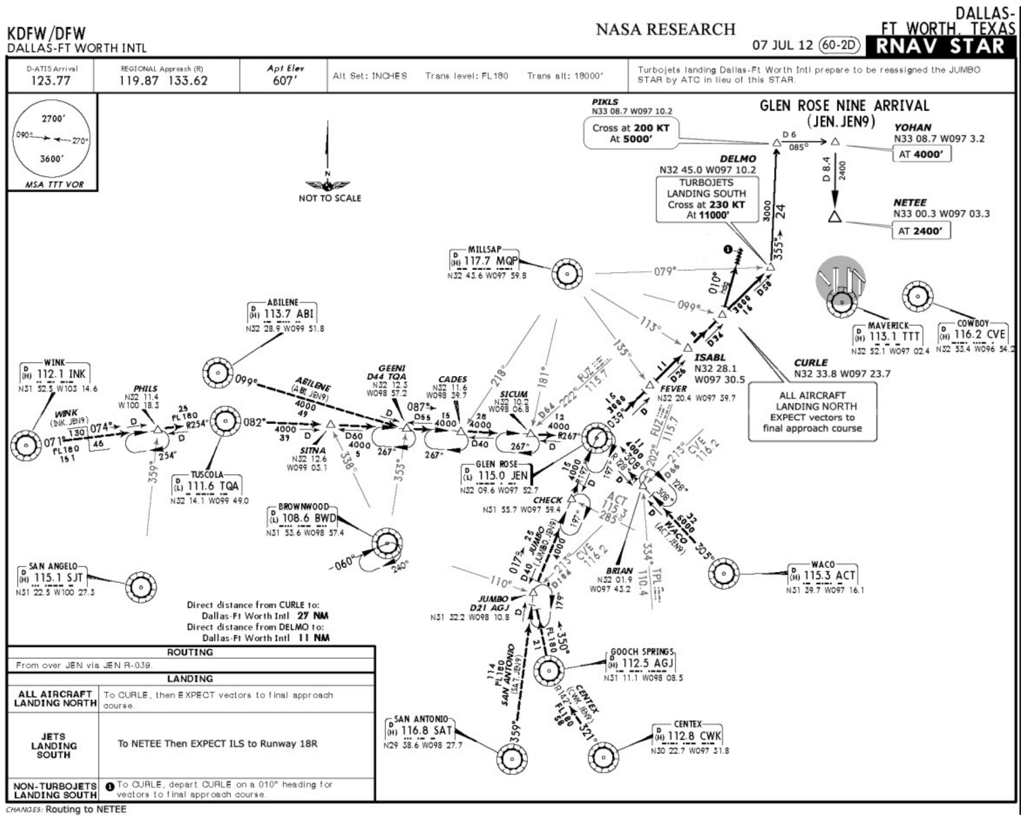


Figure A-4. NASA Research STAR for the Glen Rose Nine Arrival into DFW.

Each inbound aircraft was represented by an instantiation of the NASA Langley Research Center (LaRC) Aircraft Simulation for Traffic Operations Research (ASTOR). Each ASTOR instantiation represents a commercial transport aircraft, its flight deck systems, and the airborne components of a realistic future communications, navigation, and surveillance infrastructure and runs on a single Windows XP workstation. Some aircraft initialized in level cruise and flew the full arrival and approach to the runway, while others initialized in descent and flew only a portion of the arrival before flying the approach. All aircraft started outside the DFW Terminal Radar Approach Control (TRACON) boundary so that the Traffic Management Advisor with Terminal Metering (TMA-TM) could develop a workable arrival schedule.

Five experiment scenarios were developed from a common scenario in order to assess the viability of the IM spacing procedures during each of the operational scenarios defined in the ATD-1 Concept of Operations (ConOps). Each experiment scenario included the same 25 aircraft defined in the common scenario, with one ASTOR in each scenario replaced by the NASA LaRC Integration Flight Deck (IFD): a full-scale simulator representative of a large commercial transport category aircraft flown by the pilot participants. The pilot participants' (i.e., Flight Deck-based Interval Management (FIM)) aircraft were changed for each scenario to provide variety, exercise all use cases defined in the ATD-1 ConOps, and keep the scenario length to less than 30 minutes. The closest aircraft in the arrival stream for the same runway as the FIM aircraft was designated as the initial IM spacing target. If a new target was designated later in the scenario, it was always the next closest aircraft in the arrival stream.

The experiment scenarios were as follows:

1. Nominal Scenario: ATC issued an IM clearance before top of descent (TOD). After the FIM aircraft reported that spacing had commenced, the FIM aircraft maintained nominal IM spacing operations until passing the final approach fix (FAF).

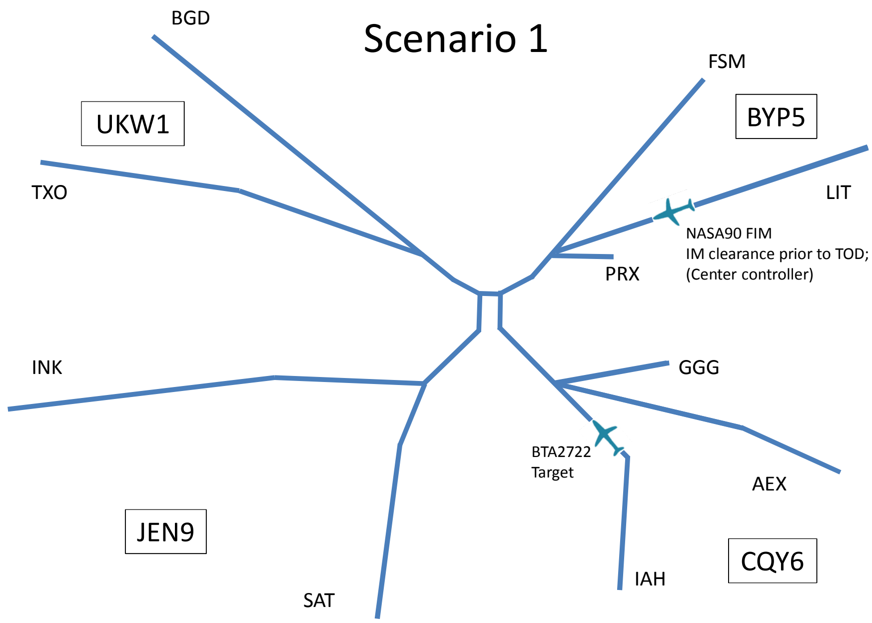


Figure A-5. Nominal Scenario.

2. Amend Assigned Spacing Goal (ASG): The initial IM clearance was issued shortly after TOD. Approximately two minutes after the FIM aircraft reported that spacing had commenced, ATC issued an amended clearance to increase spacing by 20 seconds.

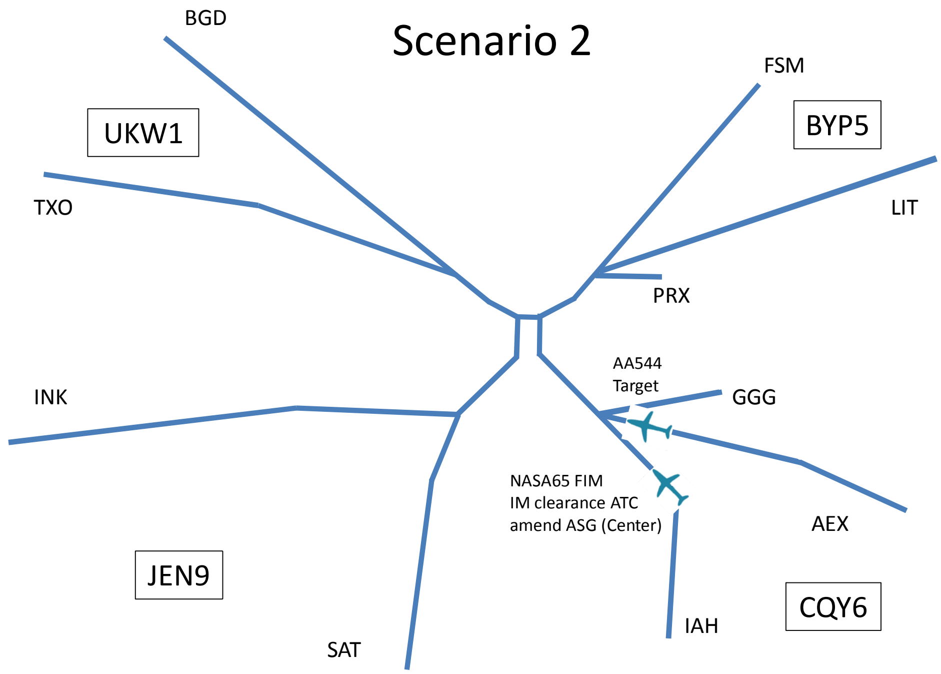


Figure A-6. Amend ASG Scenario.

3. ATC Termination of FIM: The initial IM clearance was issued shortly after TOD. After both the target and FIM aircraft were well inside the DFW TRACON, ATC cancelled the IM clearance and vectored the target aircraft for landing on runway 13R. ATC then issued a new IM clearance with a new target for the FIM aircraft.

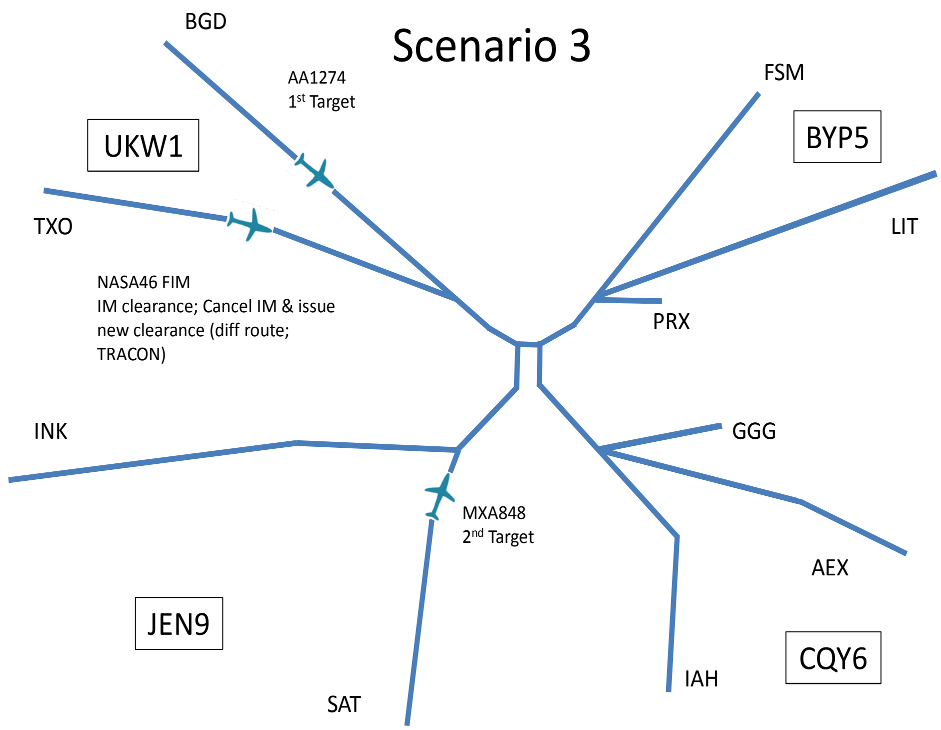


Figure A-7. ATC Termination of FIM Scenario.

4. Suspend / Resume FIM: The initial IM clearance was issued shortly after TOD. After the FIM aircraft reported that spacing had commenced, ATC suspended the IM clearance and issued a speed change of 20 kt for the FIM aircraft. Approximately two minutes later, ATC cleared the FIM aircraft to resume IM spacing.

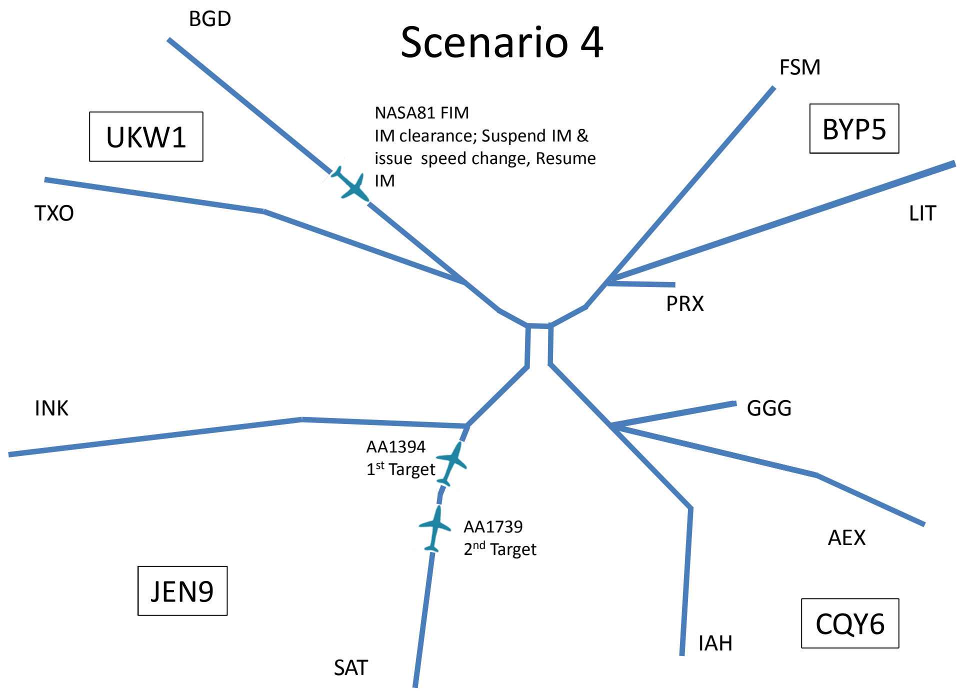


Figure A-8. Suspend / Resume FIM Scenario.

5. ADS-B Loss: ATC issued the initial IM clearance before TOD. After the FIM aircraft reported that spacing had commenced and both aircraft were well within the DFW TRACON, the target aircraft experienced a loss of ADS-B capability. After the pilot participants notified ATC that they were "IM Unable" due to the loss of the target aircraft's ADS-B signal, ATC cancelled the initial IM clearance and issued a new clearance with a new target for the FIM aircraft.

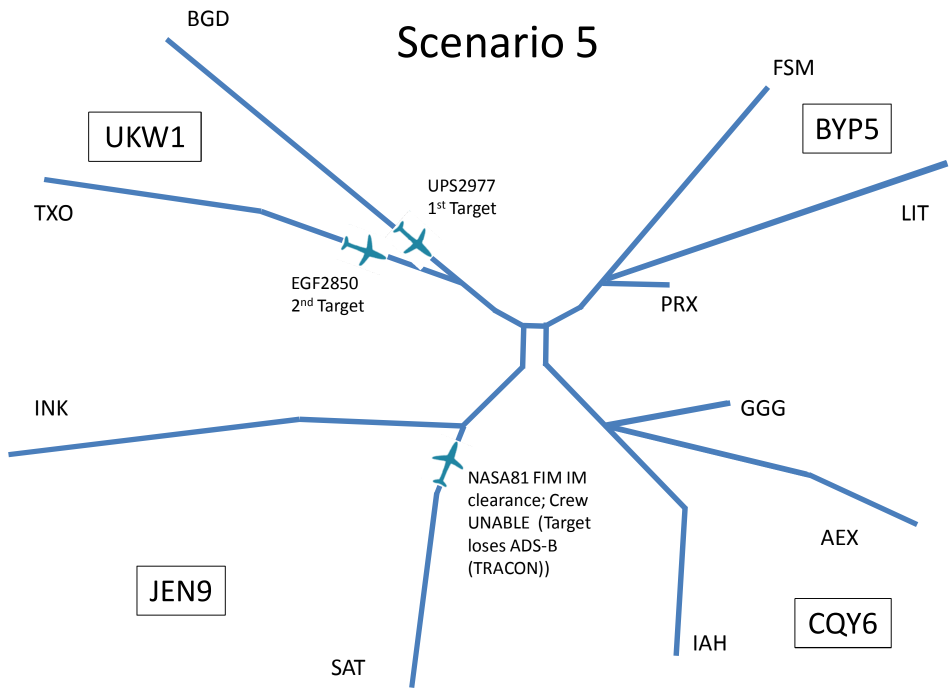


Figure A-9. ADS-B Loss Scenario.

In addition to the five experiment scenarios, three training scenarios were developed to allow the pilot participants to practice the IM spacing procedures prior to beginning the experiment's data collection runs. These training scenarios contained all of the elements of the experiment scenarios but with a different sequence of events and different initial conditions. The exploratory scenario that pilot participants were asked to fly after completing all experiment scenarios consisted of the Amend ASG scenario with the addition of aural alerts associated with commanded speed changes from the Airborne Spacing for Terminal Area Routes (ASTAR) algorithm.

Appendix B. Experiment Run Order

Each two-person crew (with both members employed by the same airline) participated in a two-day experiment session. Every crew flew each scenario twice: once with the captain as the pilot flying (PF) and the first officer as the pilot monitoring (PM), and once with the first officer as the PF and the captain as the PM. One additional exploratory scenario was created to examine the effect of aural alerts associated with Airborne Spacing for Terminal Area Routes (ASTAR) algorithm commanded speed changes. Therefore, each crew flew a total of 11 runs.

This experiment utilized two 2-replicate Latin square designs[4] with "crew" and "run order" as the two blocking factors (see Table B-1). The first 2-replicate Latin square design was used to partially counterbalance the run order of the scenarios with the captain as PF and the first officer as PM. The second 2-replicate Latin square design was used for the scenarios with the first officer as PF and the captain as PM. These two designs are shown below, where "crew" represents the row blocks and "run number" represents the column blocks. Within each crew, the pilots switched responsibilities between runs. For example, crew 1 flew scenario 5 with the captain as PF, then scenario 4 with the first officer as PF, followed by scenario 2 with the captain as PF, etc. This resulted in the run order shown in Table B-2. The exploratory scenario was always flown after the pilot participants had completed all 10 data collection runs.

Table B-1. Latin square designs.

Captain as PF and First Officer as PM					
	Run 1	Run3	Run5	Run7	Run9
Crew 1	5	2	1	4	3
Crew 2	3	4	5	2	1
Crew 3	1	3	2	5	4
Crew 4	2	1	4	3	5
Crew 5	4	5	3	1	2
Crew 6	2	1	3	5	4
Crew 7	3	4	2	1	5
Crew 8	4	3	5	2	1
Crew 9	5	2	1	4	3
Crew 10	1	5	4	3	2

First Officer as PF and Captain as PM					
	Run2	Run4	Run6	Run8	Run 10
Crew 1	4	3	2	1	5
Crew 2	3	2	5	4	1
Crew 3	2	4	1	5	3
Crew 4	1	5	4	3	2
Crew 5	5	1	3	2	4
Crew 6	1	4	5	3	2
Crew 7	2	5	1	4	3
Crew 8	3	1	2	5	4
Crew 9	5	3	4	2	1
Crew 10	4	2	3	1	5

[4] Dean, A. and Voss, D.. *Design and Analysis of Experiments*. Springer-Verlag New York, Inc., New York, NY, 1999.

Table B-2. Experiment run order.

PF:	Run1 Capt	Run2 F/O	Run3 Capt	Run4 F/O	Run5 Capt	Run6 F/O	Run7 Capt	Run8 F/O	Run9 Capt	Run10 F/O
Crew 1	5	4	2	3	1	2	4	1	3	5
Crew 2	3	3	4	2	5	5	2	4	1	1
Crew 3	1	2	3	4	2	1	5	5	4	3
Crew 4	2	1	1	5	4	4	3	3	5	2
Crew 5	4	5	5	1	3	3	1	2	2	4
Crew 6	2	1	1	4	3	5	5	3	4	2
Crew 7	3	2	4	5	2	1	1	4	5	3
Crew 8	4	3	3	1	5	2	2	5	1	4
Crew 9	5	5	2	3	1	4	4	2	3	1
Crew 10	1	4	5	2	4	3	3	1	2	5

Appendix C. Post-Run Questionnaire

Pilot participants were asked to complete the following post-run questionnaire immediately following each of the experiment's scenarios:

This questionnaire is intended to capture measures of workload and ratings for the events that occurred in the scenario that was just completed. You will be asked to complete a more extensive questionnaire at the end of the experiment, so please try and keep written comments as concise as possible.

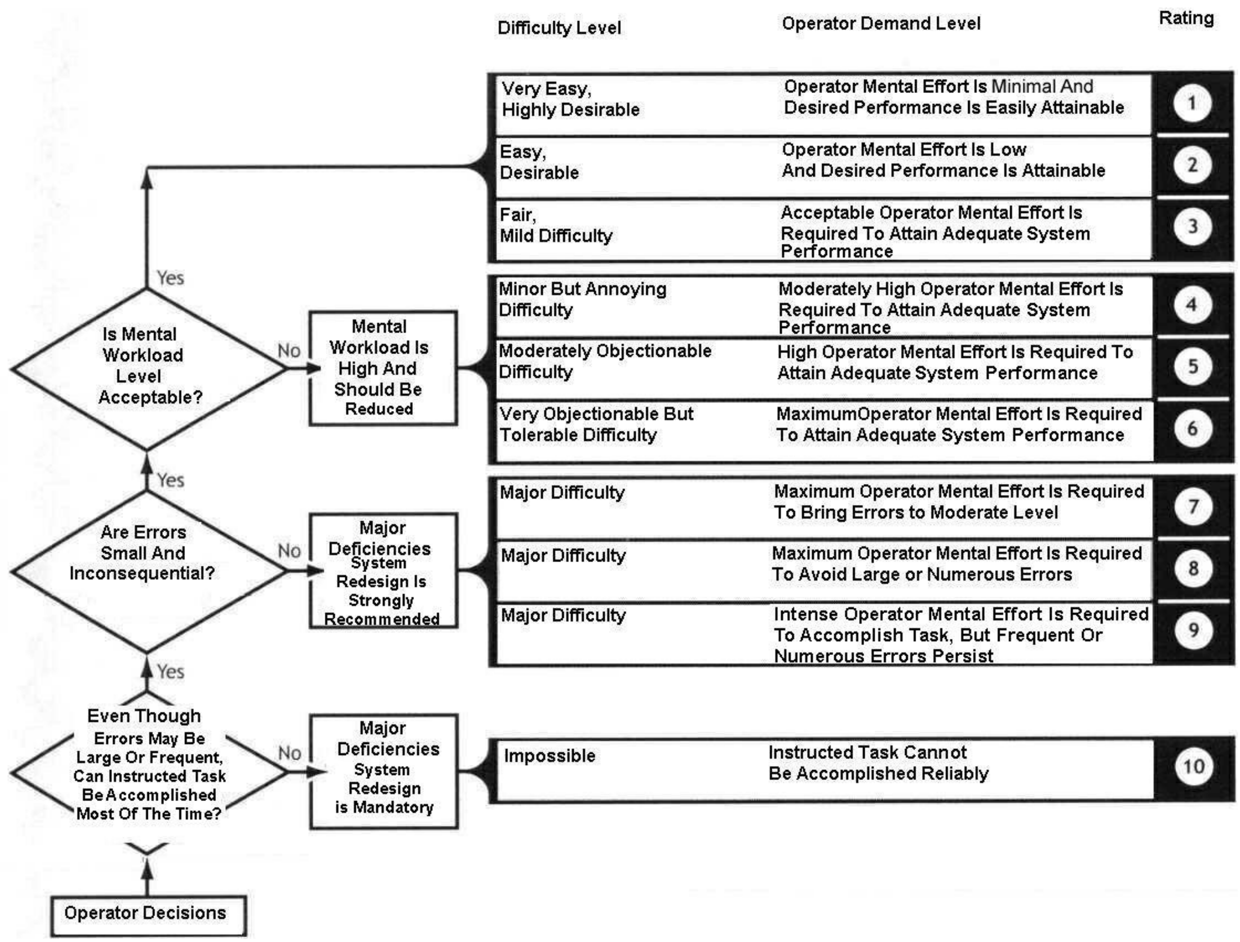
1. Please circle the scenario you just completed from the list below:

- Scenario 1
- Scenario 2
- Scenario 3
- Scenario 4
- Scenario 5
- Scenario 6
- Scenario 7
- Scenario 8
- Scenario 9
- Scenario 10

2. Please circle your role during the scenario you just completed from the list below:

- Pilot Flying
- Pilot Not Flying / Pilot Monitoring

Average Workload Ratings (Modified Cooper-Harper)

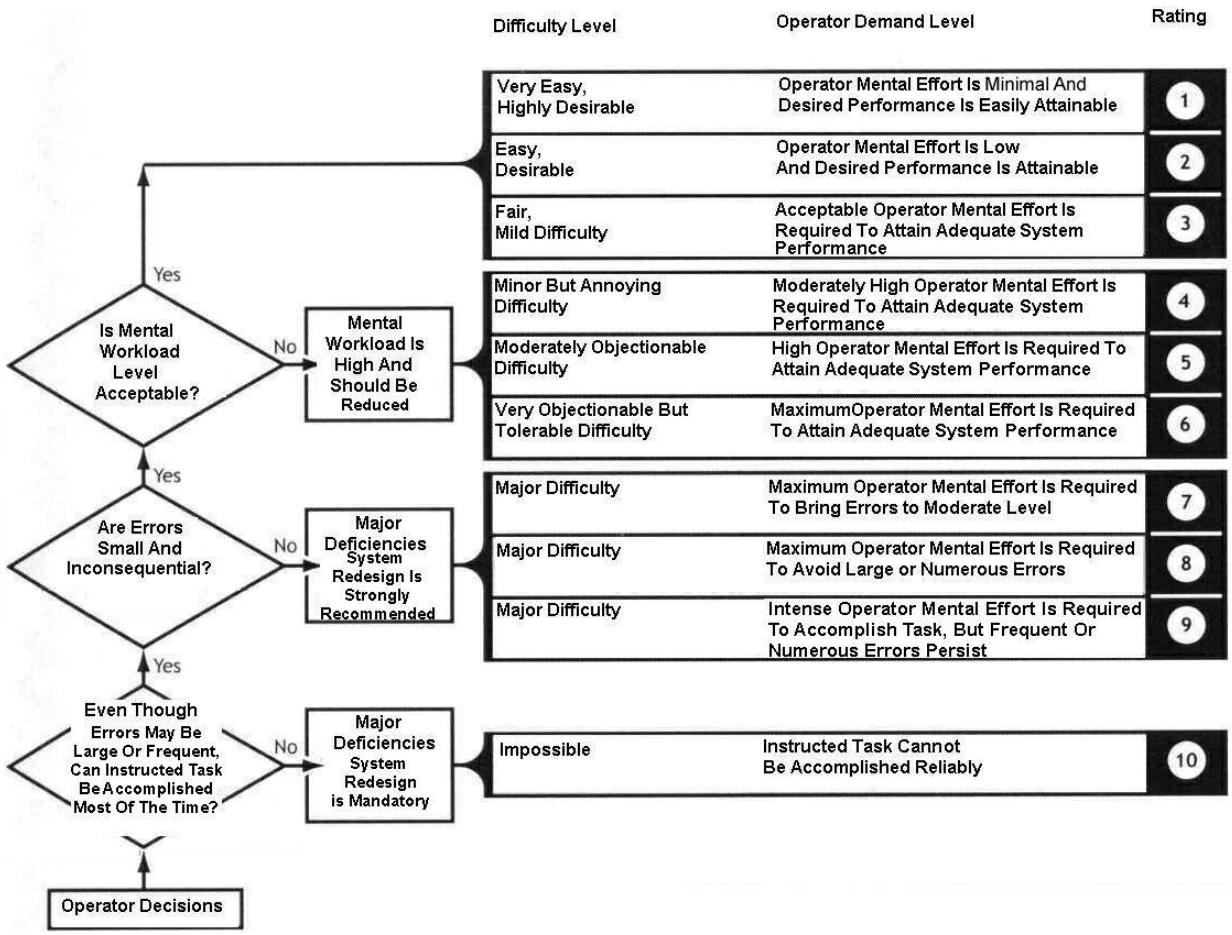


3. **Follow the flow chart above to select the <u>average</u> workload you experienced during the scenario you just completed.**

   - **Rating of your average workload level: ________**

(Optional) Use the space provided below to record any clarifying comments or interesting observations related to the workload level you experienced during the last run:

Peak Workload Ratings (Modified Cooper-Harper)



4. **Follow the flow chart above to select the peak workload you experienced during the scenario you just completed.**
   - **Rating of your peak workload level: ________**
   - **Please select the segment of flight during which your peak workload level occurred (you may select more than one segment if appropriate):**
     - o >18,000ft (cruise, initial descent)
     - o 18,000ft–11,000ft (descent, approach check)
     - o 11,000ft–5,000ft (TRACON, low altitude merge)
     - o <5,000ft (final approach, configure aircraft)

(Optional) Use the space provided below to record any clarifying comments or interesting observations related to the workload level you experienced during the last run:

5. **Respond to each of the statements shown below using a scale ranging from "1" (Completely Disagree) to "7" (Completely Agree). Circle one number in conjunction with each statement.**

	Rating Scale						
	1 **Completely Disagree**	**2**	**3**	**4**	**5**	**6**	**7** **Completely Agree**
Relevant information, including operational plans, decisions, and changes in aircraft state, were effectively communicated between yourself and your crewmember.	1	2	3	4	5	6	7
The time available for tasks was well managed.	1	2	3	4	5	6	7
The IM commanded speeds were operationally acceptable and appropriate.	1	2	3	4	5	6	7
The frequency of the IM speed commands was acceptable at all times throughout the scenario.	1	2	3	4	5	6	7
I understood why the IM commanded speeds were provided (i.e. the IM commanded speeds made sense).	1	2	3	4	5	6	7
The use of voice communications to provide the IM clearance(s) was acceptable in this scenario.	1	2	3	4	5	6	7
The amount of head down time required to input information from the IM clearance(s) into the EFB was acceptable.	1	2	3	4	5	6	7
During this scenario, entering IM clearance information into the EFB was easy and intuitive.	1	2	3	4	5	6	7
During this scenario, it was easy to obtain needed information from the IM displays	1	2	3	4	5	6	7
The flight crew procedures for the events in this scenario were complete and acceptable.	1	2	3	4	5	6	7

6. **Please answer the following questions regarding the IM procedures you were asked to exercise in the scenario that you just completed.**
   a. **Did the procedures contain missing steps?**

      YES ___

      NO ___

   b. **Did the procedures contain extra steps that were unnecessary?**

      YES ___

      NO ___

   c. **Were the procedural steps logical and easy to follow?**

      YES ___

      NO ___

7. **Please briefly explain any undesirable ratings from the statements above:**

____
____
____
____

8. **Describe any unusual or unexpected event(s) and your reaction(s), if applicable:**

____
____
____
____

9. **(Optional) This space is reserved for any additional comments related to awareness and acceptability issues. If you have any clarifying comments or interesting observations related to awareness and acceptability issues, please provide them below:**

____
____
____
____

Appendix D. Post-Experiment Questionnaire

Pilot participants were asked to complete the following post-experiment questionnaire prior to participating in a group debrief session with the research team:

This questionnaire is intended to gather your comments and suggestions regarding the experiment itself as well as the Interval Management concept

This questionnaire contains items associated with each of the following categories:

- Simulator and Flight Scenarios
- Training
- Interval Management Procedures
- Interval Management Displays
- Spacing Tool
- Additional Comments

Simulator and Flight Scenarios

1. **Was the workload required to operate the simulator much less than, the same as, or greater than the workload required to fly an actual aircraft?**

Much More	Moderately More	Slightly More	The Same	Slightly Less	Moderately Less	Much Less
1	2	3	4	5	6	7

Please provide any additional comments regarding the simulator:

2. **Please share your impressions of the flight scenarios (e.g., comment on their level of realism, appropriateness, and/or diversity) and comment on how the design of the scenarios impacted your ability to perform the spacing task:**

Training

3. **Did you receive adequate training with respect to flying the simulator?**

YES ___

NO ___

If not, briefly describe how simulator training can be improved:

4. **Did you receive adequate training with respect to the IM spacing procedure and the spacing tool?**

   YES ___

   NO ___

   If not, briefly describe how IM procedure or spacing tool training can be improved:

5. **Did you receive adequate training with respect to the entry and interpretation of information presented on the EFB?**

   YES ___

   NO ___

   If not, briefly describe how EFB training can be improved:

6. **Did you receive adequate training with respect to the interpretation of information presented on the AGD?**

   YES ___

   NO ___

   If not, briefly describe how AGD training can be improved:

Interval Management Procedures

7. **Within this experiment four different aspects of the IM procedures were tested: terminating the IM operation, suspending and then resuming the IM operation, amending the IM spacing goal, and the loss of the lead aircraft's ADS-B, as well as nominal operations. The following questions are intended to gather your feedback about the procedures used for each aspect of the IM operation that was tested (note that the last question asks about the general IM procedures).**

   a) **Were the procedures for terminating IM operation complete, accurate, and logical?**

      YES ___

      NO ___

      Please provide any suggestions regarding the way(s) in which the procedures for terminating the IM operation may be improved:

b) **Were the procedures for suspending and then resuming an IM operation complete, accurate, and logical?**

YES ___

NO ___

Please provide any suggestions regarding the way(s) in which the procedures for suspending the IM operation may be improved:

c) **Were the procedures for amending the IM spacing goal complete, accurate, and logical?**

YES ___

NO ___

Please provide any suggestions regarding the way(s) in which the procedures for amending the IM spacing goal may be improved:

d) **Were the procedures for reacting to the loss of your lead aircraft's ADS-B signal complete, accurate, and logical?**

YES ___

NO ___

Please provide any suggestions regarding the way(s) in which the procedures for reacting to the loss of your lead aircraft's ADS-B signal may be improved:

e) **Were the general (nominal) IM procedures complete, accurate, and logical?**

YES ___

NO ___

Please provide any suggestions regarding the way(s) in which the general IM procedures may be improved:

8. Was the IM phraseology used in this experiment correct and intuitive?

YES ___

NO ___

If "no," why not, and what could be done to improve the phraseology?

9. **How difficult do you think it would be for a typical flight crew to learn and integrate the IM spacing procedures into their current daily operational flight procedures?**

Very Difficult	Moderately Difficult	Slightly Difficult	Neutral	Slightly Easy	Moderately Easy	Very Easy
1	2	3	4	5	6	7

Briefly describe any challenges involved with integrating the IM procedures with existing procedures:

10. **Do you think the division of tasks between the Pilot Flying (PF) and Pilot Monitoring (PM) was both desirable and fit within the current distribution of tasks between PF and PM?**

YES ___

NO ___

If "no," what was wrong with the division, and how would you reallocate the tasks?

11. **Given the experience with IM that you gained during this simulation, what is your overall assessment of the safety of the spacing procedure compared with current day operations? ("Safety" in this question refers to your holistic opinion to include workload, awareness, position relative to other aircraft, etc.)**

Not Safe At All	Moderately Less Safe	Slightly Less Safe	As Safe	Slightly More Safe	Moderately More Safe	Much More Safe
1	2	3	4	5	6	7

Briefly describe any characteristic or event that determined your rating (if appropriate):

Interval Management Displays

12. **In general, did you find the process of entering IM clearance information into the EFB easy and intuitive?**

YES ___

NO ___

If "no," what can be done to improve the process of loading information into the EFB?

13. **Did the AGD and EFB provide you with the information you needed/desired to safely and correctly conduct IM, and was this information easy to obtain when needed?**

    YES ___

    NO ___

    If "no," what information was missing, or how can the information be presented better?

Function Allocation and the Spacing Tool

14. **Did following the IM commanded speed and procedure ever cause unexpected or undesirable behavior?**

    YES ___

    NO ___

    If "yes," please explain what the unexpected or undesirable behavior was:

15. **Did you find the responsibility of using onboard automation to achieve a spacing interval behind a lead aircraft acceptable (when ATC is responsible for separation)?**

    YES ___

    NO ___

    If "no," why not, and what could be done to make the responsibility or workload acceptable?

16. **Did you find your level of engagement with the IM automation acceptable (i.e. the level of decision making ability you had, and your understanding of the reasoning behind IM speeds that were commanded)?**

    YES ___

    NO ___

    Please explain your answer.

Additional Comments

17. **Do you have any additional comments about the experiment?**

Appendix E. Example Interval Management (IM) Clearance and Related Use of and Display of Information on the Prototype Flight Deck-based Interval Management (FIM) Crew Interface

The initial (empty) page of the Interval Management (IM) application residing on the electronic flight bag (EFB) portion of the prototype Flight Deck-based Interval Management (FIM) crew interface used during the Interval Management for Near-term Operations Validation of Acceptability (IM-NOVA) experiment is shown in Figure E-1.

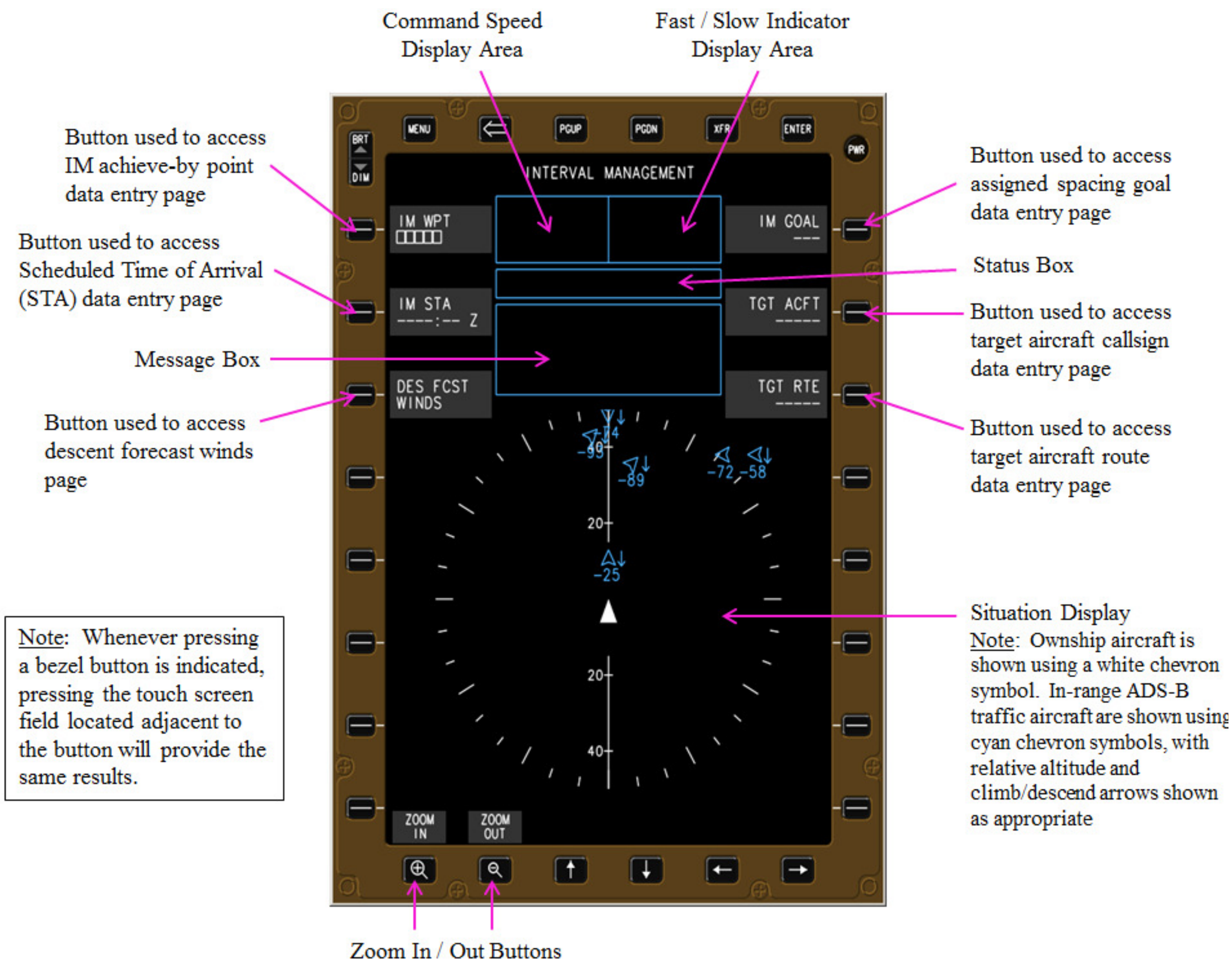
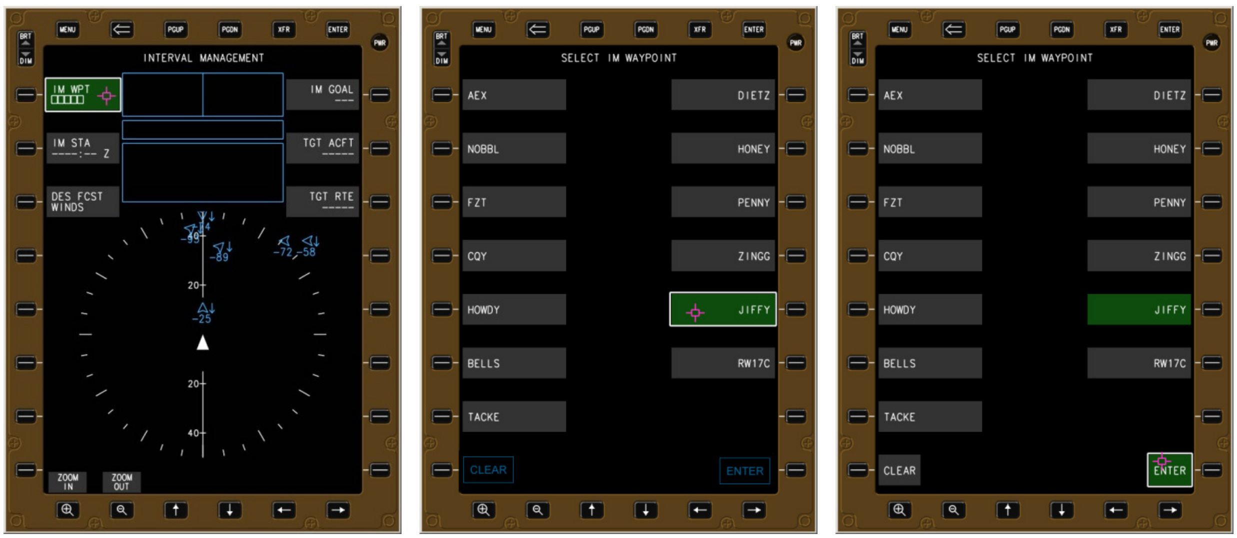


Figure E-1. Initial page of the IM application residing on the prototype FIM crew interface's EFB.

Figure E-2–Figure E-11 illustrate the use of the prototype FIM crew interface during IM clearance data entry activities as well as the activation, suspension, resumption, and cancellation/termination of FIM operations. Below is an example of an IM clearance issued via voice communications to a flight crew by air traffic control (ATC):

> NASA 3, for Interval Spacing, cross JIFFY at 1432 plus 30 sec, when able space 90 sec behind Delta Alpha Lima 877 on Bonham 5, Fort Smith Transition. Report commencing interval spacing.[5]

As shown in Figure E-2, a three-step procedure is used to enter information associated with the IM achieve-by point (i.e., JIFFY) into the IM application that resides on the EFB. First, the "IM WPT" button is pressed. This action brings up a page that displays all the published waypoints on the arrival, allowing the flight crew to press a button associated with "JIFFY." Lastly, the "ENTER" button is pressed.



Step 1 Step 2 Step 3

Figure E-2. Three-step procedure for inputting IM achieve-by point information into the prototype FIM crew interface's EFB

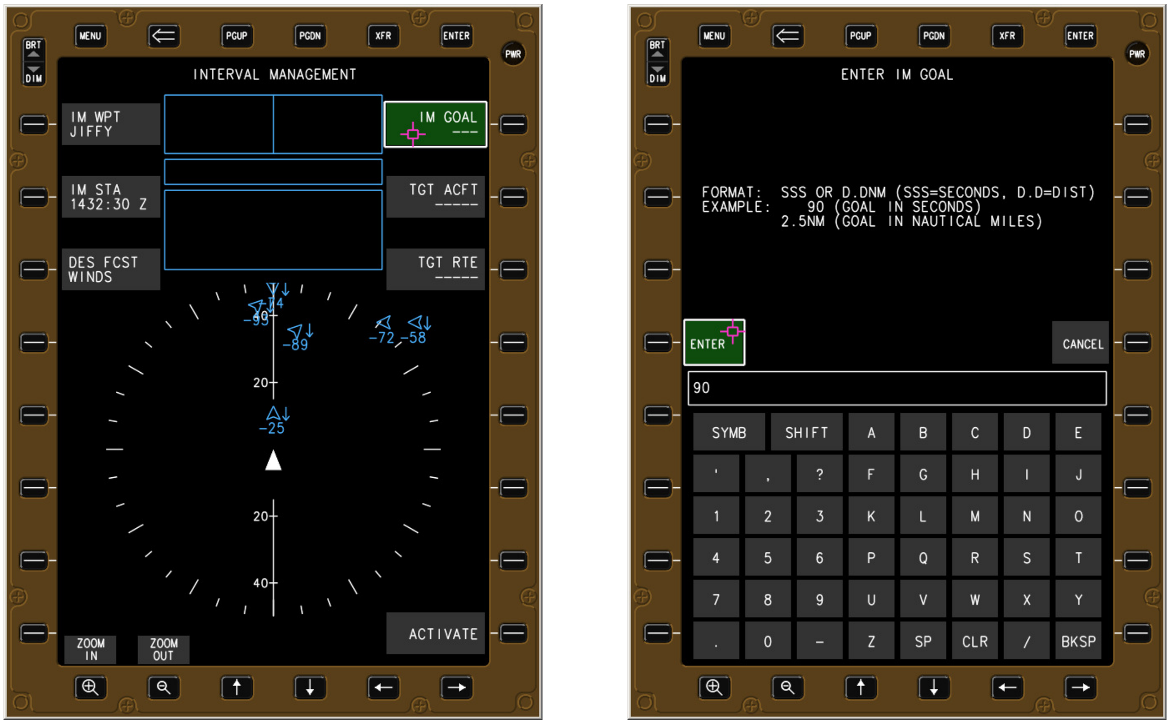
[5] Note that the IM clearance was designed to provide the flight crew with all required information in an expected format. The target aircraft is identified using its three letter phonetic callsign, which corresponds with the callsign included in the target aircraft callsign list presented on the EFB (as shown in Figure E-5). The three letter identifier was used to assist with the identification on lesser known callsigns.

Figure E-3 shows the two-step procedure associated with inputting the scheduled time of arrival (STA) at the IM achieve-by point (i.e., 1432 plus 30 sec) into the EFB. First, the “IM STA” button is pressed. Then, the touch screen’s keypad is used to enter required data into a “scratchpad” area, and the “ENTER” button is pressed.

Step 1 Step 2

Figure E-3. Two-step procedure for inputting STA at the IM achieve-by point information into the prototype FIM crew interface’s EFB.

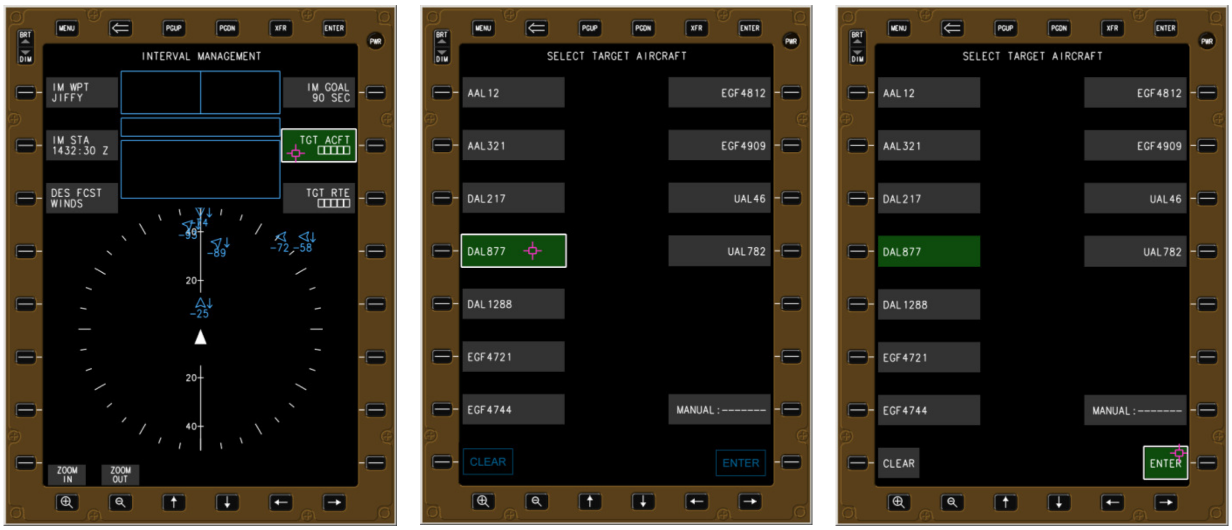
Figure E-4 shows the two-step procedure associated with inputting the assigned spacing goal (ASG) (i.e., 90 sec) information into the EFB. First, the "IM GOAL" button is pressed. Then, the touch screen's keypad is used to enter required data into a "scratchpad" area, and the "ENTER" button is pressed.



Step 1 Step 2

Figure E-4. Two-step procedure for inputting assigned spacing goal information into the prototype FIM crew interface's EFB.

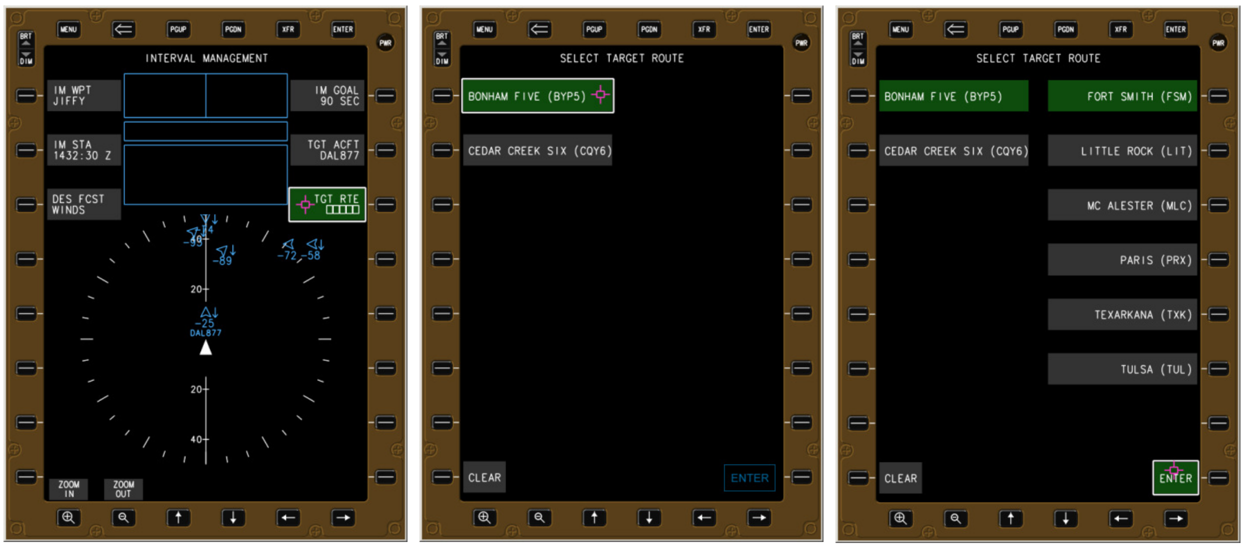
Figure E-5 shows the three-step procedure associated with inputting a target aircraft's callsign (i.e., Delta Alpha Lima 877) into the EFB. First, the "TGT ACFT" button is pressed. When the target aircraft is within Automatic Display Surveillance–Broadcast (ADS-B) range, its callsign can be selected, with a button press, from a selectable list. Lastly, the "ENTER" button is pressed.



Step 1 Step 2 Step 3

Figure E-5. Three-step procedure for inputting a target aircraft's callsign into the prototype FIM crew interface's EFB.

Figure E-6 shows the three-step procedure associated with inputting a target aircraft's arrival and transition (i.e., Bonham 5, Fort Smith Transition) information into the EFB. First, the "TGT RTE" button is pressed. Next, the target aircraft's arrival is selected, with a button press, from a selectable list. Then, the target aircraft's transition is selected, with a button press, from a selectable list, and the "ENTER" button is pressed.



Step 1 Step 2 Step 3

Figure E-6. Three-step procedure for inputting a target aircraft's arrival and transition information into the prototype FIM crew interface's EFB.

After entering the achieve-by point, STA, ASG, target aircraft callsign, and target aircraft route information into the EFB, the flight crew can activate the IM clearance by pressing the "ACTIVATE" button located in the lower right portion of the EFB's touch screen (shown in Figure E-7). Once pressed, the "ACTIVATE" button changes to a "SUSPEND" button, and the IM system indicates that it is performing various calculations by displaying the word "CALCULATING" in the EFB's status box (shown in Figure E-7).

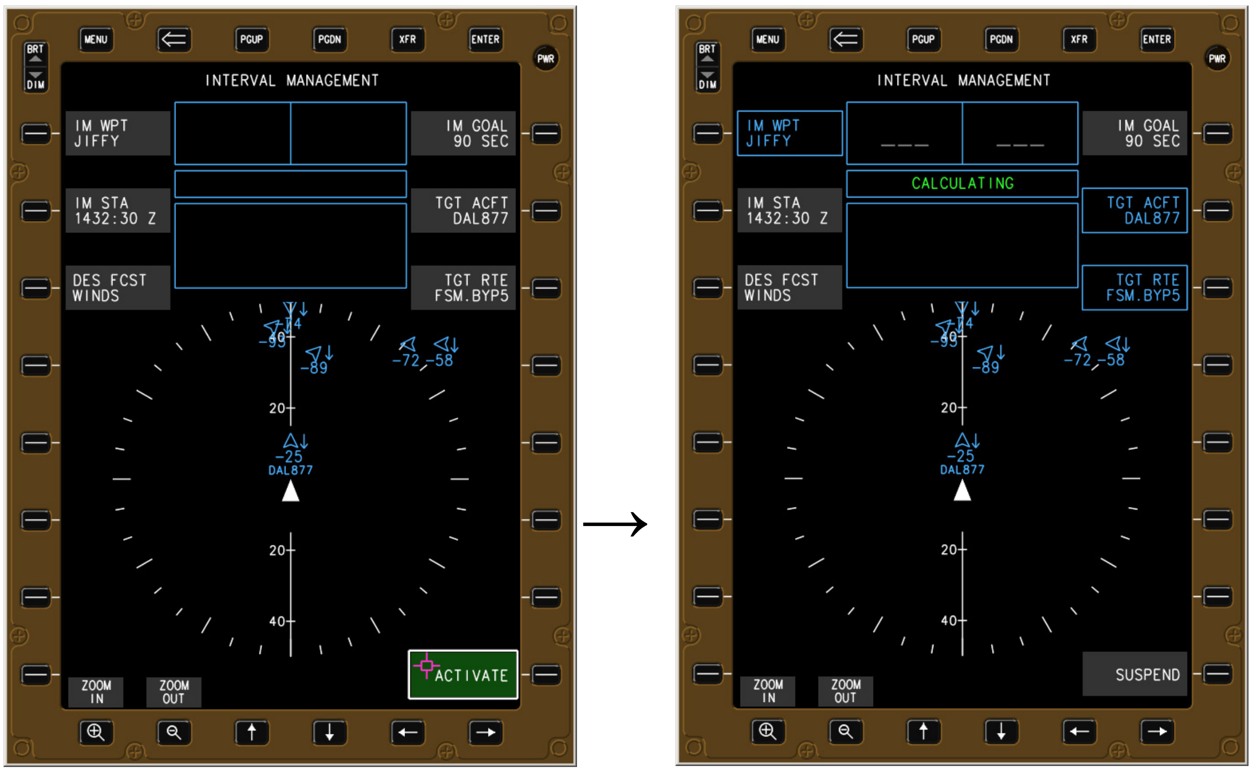


Figure E-7. IM clearance activation.

The flight crew flies in STA mode until ADS-B information from their target aircraft is acquired and FIM operations begin. As shown in Figure E-8, an indication of STA mode is displayed in the EFB's status box, and a "CMD SPD," in Mach or knots, and a "FAST/SLOW" indication, in knots, are displayed on both the EFB and ADS-B guidance display (AGD) components of the prototype FIM crew interface.

EFB AGD

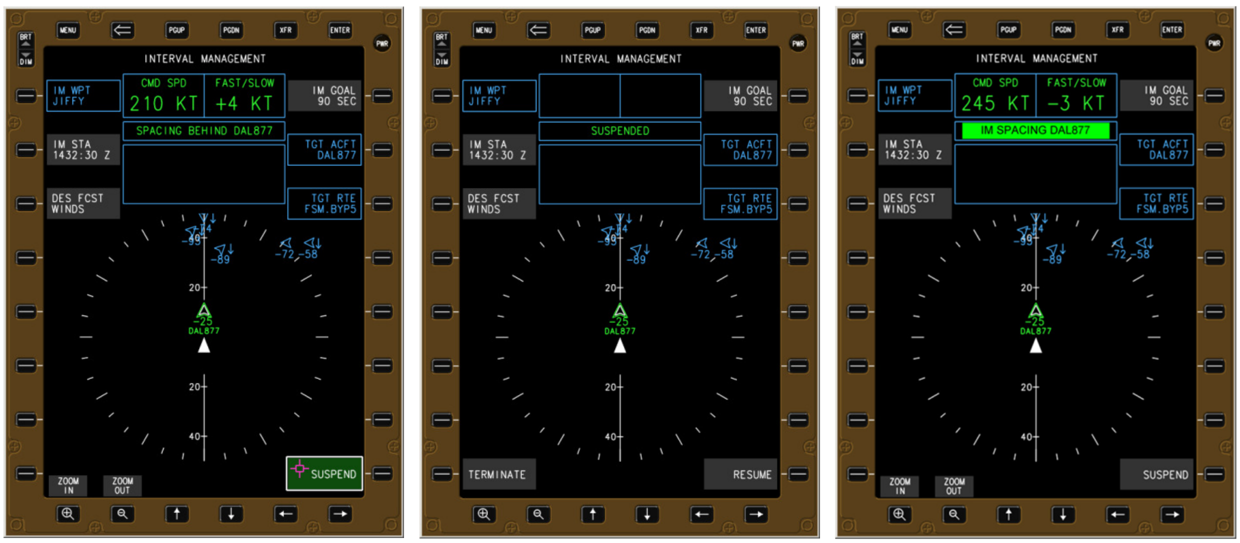
Figure E-8. Information elements associated with STA mode displayed on the EFB and AGD components of the prototype FIM crew interface.

When ADS-B information from the target aircraft is acquired and FIM operations are underway, the EFB displays the target aircraft's callsign, a commanded speed, and a "FAST/SLOW" indication (as shown in Figure E-9). Additionally, as shown in Figure E-9, the AGD supplies a white "IM" light located in the upper left corner of the device that indicates that the FIM aircraft is actively spacing relative to a target aircraft, and the AGD repeats the commanded speed and "FAST/SLOW" indications presented on the EFB.

EFB AGD

Figure E-9. Information elements associated with FIM operations displayed on the EFB and AGD components of the prototype FIM crew interface

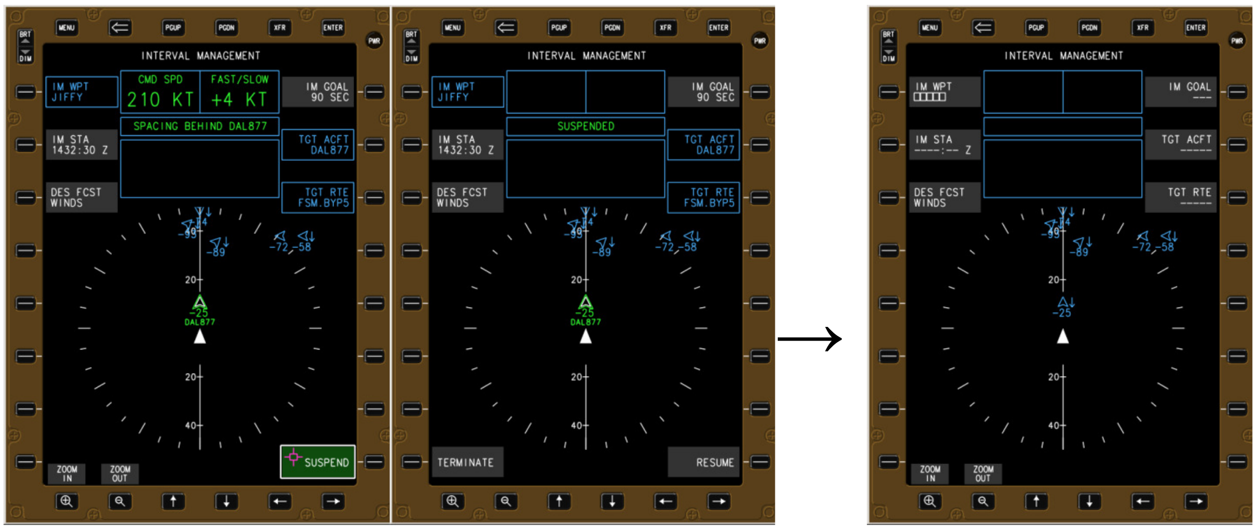
Figure E-10 shows the three-step procedure associated with using the EFB to suspend and resume FIM operations. First, the “SUSPEND” button is pressed. This causes several things to happen: the “SUSPEND” button changes to a “RESUME” button, and a “TERMINATE” button appears; the commanded speed (“CMD SPD”) and “FAST/SLOW” indication are removed; and the word “SUSPENDED” is displayed in the EFB’s status box. At this point, the flight crew follows ATC’s speed commands. When instructed by ATC to resume FIM operations, the flight crew presses the “RESUME” button, causing the following things to happen: the “RESUME” button changes to a “SUSPEND” button; the “CMD SPD” and “FAST/SLOW” indication are presented; and the target aircraft’s callsign is displayed in the EFB’s status box. At this point, the flight crew resumes FIM operations and follows IM commanded speeds.



Step 1 Step 2 Step 3

Figure E-10. Three-step procedure for suspending and then resuming IM spacing using the prototype FIM crew interface’s EFB.

Figure E-11 shows the two-step procedure and resulting data re-entry screen associated with using the EFB to terminate FIM operations. First, the “SUSPEND” button is pressed, causing the following things to happen: the “SUSPEND” button changes to a “RESUME” button, and a “TERMINATE” button appears; the “CMD SPD” and “FAST/SLOW” indication are removed; and the word “SUSPENDED” is displayed in the EFB’s status box. Next, the “TERMINATE” button is pressed; all IM clearance data are removed from the EFB; and ATC instructions are followed. If FIM operations are to take place at this point, information from a new IM clearance must be entered into the EFB using the initial (empty) page of the IM application.



Step 1

Step 2

Initial page of IM application

Figure E-11. Two-step procedure, and resulting data (re-)entry screen, associated with terminating IM spacing using the prototype FIM crew interface’s EFB.

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14. ABSTRACT
The Interval Management for Near-term Operations Validation of Acceptability (IM-NOVA) experiment was conducted at the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) in support of the NASA Airspace Systems Program's Air Traffic Management Technology Demonstration-1 (ATD-1). ATD-1 is intended to showcase an integrated set of technologies that provide an efficient arrival solution for managing aircraft using Next Generation Air Transportation System (NextGen) surveillance, navigation, procedures, and automation for both airborne and ground-based systems. The goal of the IMNOVA experiment was to assess if procedures outlined by the ATD-1 Concept of Operations were acceptable to and feasible for use by flight crews in a voice communications environment when used with a minimum set of Flight Deck-based Interval Management (FIM) equipment and a prototype crew interface. To investigate an integrated arrival solution using ground-based air traffic control tools and aircraft Automatic Dependent Surveillance-Broadcast (ADS-B) tools, the LaRC FIM system and the Traffic Management Advisor with Terminal Metering and Controller Managed Spacing tools developed at the NASA Ames Research Center (ARC) were integrated into LaRC's Air Traffic Operations Laboratory (ATOL). Data were collected from 10 crews of current 757/767 pilots asked to fly a high-fidelity, fixed-based simulator during scenarios conducted within an airspace environment modeled on the Dallas-Fort Worth (DFW) Terminal Radar Approach Control area.

15. SUBJECT TERMS
Acceptability; Air traffic; Air transportation; Control system; Flight management; Flight crews; Ground based controls; Simulators; Voice communications

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