NASA/TM—2014–220214

Air Traffic Management Technology Demonstration – 1 (ATD-1) Tech Transfer Document Summary

Version 3.0

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July 2014

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Space Administration

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Revision History

Rev	Date	Sections Affected	Description of Change	Author
1.0	09/27/2013		Version 1.0	John Robinson
2.0	02/24/2014	3 Technical Publications 5 STARS Development 7 TMA Documents 8 Simulation Outbriefs 9 Internal Documents	Version 2.0 STARS with FIM plus new documents	John Robinson
3.0	07/10/2014	3 Technical Publications 5 STARS Development 7 TMA Documents 8 Simulation Outbriefs	Version 3.0 STARS SCOUT Release 1 plus new documents	John Robinson

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Introduction

This document summarizes transfer of NASA's terminal sequencing and spacing (TSS) and interval management (IM) technologies to the FAA, as part of its Air Traffic Management Technology (ATM) Demonstration #1 activity. This activity, referred to as ATD-1, is part of NASA's Airspace Systems Program (ASP) – specifically, its System Analysis, Integration, and Evaluation (SAIE) Project. ATD-1 is a multi-year research and development effort aimed at accelerating implementation and deployment of NASA-developed ATM technologies by the FAA. These technologies are designed to improve the utilization of Performance-Based Navigation (PBN) procedures inside congested terminal airspace. In terms of NASA's Technology Readiness Levels (TRLs), ATD-1 is focused on maturing its associated technologies from the Technology Development stage (TRL 4) to the Technology Demonstration stage (TRL 6). In order to ensure that the products of this tech-transfer are relevant and useful, NASA has created strong partnerships with the FAA and key industry stakeholders.

Technology Transfer Process

The transfer of NASA's ATD-1 technologies is planned as a series of incremental transfers of NASA's research and development products related to all aspects of ATD-1 technology maturation.

Early work involved concept development, cognitive walk-throughs of potential controller and pilot procedures, prototype TSS and IM algorithms, and mid-fidelity simulations of air traffic and flight deck operations using these capabilities. Portions of these products were previously transferred to the FAA in March 2012. This initial tech-transfer was responsible for building advocacy for ATD-1 within the FAA. These initial tech-transfer products are noted by "Formerly Paper X" in their descriptions.

Subsequent work has further refined the ATD-1 operational concept, implemented the TSS capabilities in prototype versions of operational air traffic systems, and conducted several high-fidelity controller- and pilot-in-the-loop simulations to validate these capabilities. These products are the specific focus of this next tech-transfer to the FAA. The FAA intends to use the products contained in this package to support their acquisition process for deployment of the TSS capabilities to the National Airspace System (NAS). TSS is currently being considered for Work Package 3 of the Time-Based Flow Management (TBFM) Program. A Final Investment Decision (FID) is expected in 2014.

Remaining work will implement the IM capabilities in prototype versions of aircraft avionics, conduct additional high-fidelity controller- and pilot-in-the-loop simulations to validate the entire operational concept, and evaluate the TSS and IM capabilities in realistic operational environments. These products will be transferred to the FAA as early as 2014.

Subsequent tech-transfers will add products to this package. It will note where new products supersede or amend previous products. This approach will ensure that the final tech-transfer package is complete documentation of the entire lifecycle of ATD-1. All of the deliverables highlighted in blue throughput this document are newly added or modified since the previous version.

Document Structure

Each document is described by 3-5 sentences in order to facilitate navigation through the 100+ individual documents included in the tech-transfer package. The users of the material will be varied and have widely different needs. These summaries are intended to help those recipients understand what is available in the tech-transfer package and what requires additional consultation with NASA.

The tech-transfer document summary identifies ten categories of products. In general, these categories are ordered from high-level material describing the overall ATD-1 concept down to low-level technical details of the prototype development. These categories are explained below. Some of the categories of documents have restrictions that need to be followed.

Public Outreach Materials: These documents are high-level descriptions and multi-media products appropriate for the general public. Distribution outside of the U.S. Government is permitted without restrictions.

High-Level Publications: This section describes ATD-1 at the Concept of Operations level. Distribution outside of the U.S. Government is permitted without restrictions.

Technical Publications: This section describes ATD-1 at the technology level – including simulation results, algorithm descriptions, and data analyses. Distribution outside of the U.S. Government is permitted without restrictions.

Cost/Benefit Assessment Publications: This section describes the assessment of the lifecycle costs and benefits of different combinations of the expected NextGen arrival management capabilities. The ATD-1 capabilities are part of these broader NextGen capabilities. These documents were the deliverables of a NASA Research Announcement award. These documents may contain third-party proprietary information. Distribution outside of the U.S. Government requires prior approval by NASA.

STARS Prototype Development Publications: This section describes the technical details of the STARS prototype implementation of the ATD-1 capabilities – including requirements definition, design recommendations, functional descriptions, and software specifications. These documents were the deliverables of both Phase 1 and Phase 2 of the STARS prototype development activities. These documents may contain third-party proprietary information. Distribution outside of the U.S. Government requires prior approval by NASA.

Avionics Prototype Development Publications: This section describes the technical details of the avionics prototype implementation of the ATD-1 capabilities – feasibility, concept engineering, and design recommendations. These documents were the deliverables of Phase 1 of the avionics prototype development activities. These documents may contain third-party proprietary information. Distribution outside of the U.S. Government requires prior approval by NASA.

TMA Development Publications: This section describes the technical details of the TMA prototype implementation of the ATD-1 capabilities – algorithm descriptions, functional descriptions, and software modification summaries. Distribution outside of the U.S. Government is permitted without restrictions.

Simulation Outbriefs: This section contains the in-depth summaries of each ATD-1 large-scale controller- or pilot-in-the-loop simulation. These briefings are required exit criteria for ATD-1 simulations. Distribution outside of the U.S. Government is permitted without restrictions.

ATD-1 Project Documents: This section contains specific ATD-1 project documents that have been requested by particular FAA stakeholders. Distribution outside of the U.S. Government is permitted without restrictions.

Additional Technical Publications: This section contains supporting information. Distribution outside of the U.S. Government is permitted without restrictions

Within each category, the documents are ordered by their publication date. New documents will be added to each section for subsequent tech-transfer packages. Each document is described by a short 3-5 sentence summary in order to facilitate navigation through the many documents included in the tech-transfer package.

Post-Technology Transfer Activities

The tech-transfer package and this summary document are not the end of the technology transfer process. NASA expects to provide and is committed to providing on-going additional assistance to the FAA during its acquisition process. At the very least, NASA expects to provide subject matter expertise regarding the ATD-1 technologies to the FAA and its contractors.

Additional lower-level working papers are available to interested parties in the FAA or its contractors. These documents are not suitable for broad distribution so they are not included in the official package. Examples of these types of documents include: low-level data analysis, simulation traffic and wind scenarios, controller and pilot questionnaires, multi-media materials, etc. Requests for these additional materials can be made to the ATD-1 project management.

1) Public Outreach Materials

There are two separate factsheets included in this package. These factsheets are publicly available on the NASA webpage.

Paper 1.01. <u>TAPSS – Terminal Area Precision Scheduling System</u>
The TAPSS factsheet describes the terminal sequencing and spacing technologies. [Formerly Paper 1A]

Paper 1.02. <u>Air Traffic Management (ATM) Technology Demonstration – 1 (ATD-1): Interval Management – Terminal Area Precision Scheduling and Spacing (IM-TAPSS)</u>
The ATD-1 factsheet describes intended demonstration of the terminal sequencing and spacing technologies in conjunction with flight deck interval management. [Formerly Paper 1B]

Paper 1.03 <u>ATD-1 Animation Sequence</u> – Windows Media Video format (dated September 20, 2013)
Paper 1.04 <u>ATD-1 Animation Sequence</u> – QuickTime Movie format (dated September 20, 2013)
These 2-minute animation videos compare current arrival operations (on the left side) and ATD-1 arrival operations (on the right side). Current arrival operations are typified by the use radar surveillance only, frequent terminal vectoring, excess spacing, and step-down descents. ATD-1 arrival operations include mixed radar and ADS-B Out surveillance, less frequent and smaller amounts of terminal vectoring, reduced excess spacing, and efficient continuous descents.

2) High-level Publications

This list covers all of the high-level publications that describe the ATD-1 Concept of Operations published to date. These documents are the highest level descriptions of the entire ATD-1 project.

Paper 2.01. Concept for Robust, High Density Terminal Air Traffic Operations (ATIO 2010)
This paper describes the entire breadth of NASA Super Density Operations research. All of the elements of Terminal Sequencing and Spacing and Flight Deck Interval Management are reflected in the functional architecture diagram in Figure 2. [Formerly Paper 2A]

Paper 2.02. Air Traffic Management Technology Demonstration-1 Concept of Operations (ATD-1 ConOps), Version 1.0 (NASA/TM-2012-217585)
This document describes the ATD-1 Concept of Operations Version 1.0. It has been superseded by the ATD-1 Concept of Operations Version 2.0. The latest ATD-1 ConOps is described in Paper 2.04.

Paper 2.03. NASA's ATM Technology Demonstration-1: Transitioning Fuel Efficient, High Throughput Arrival Operations from Simulation to Reality (HCI Aero 2012)
This paper describes the goals and objectives of the ATD-1 Project. It includes descriptions of the overall operational concept, and the terminal metering, controller-managed spacing and flight deck interval management technologies. Sample results from preceding simulations are discussed to demonstrate the potential benefits of the ATD-1 technologies. It also includes a summary of the intended development approach and a notional path for simulation and operational testing of the integrated technologies. It should be noted that the proposed timeline of activities have been modified in later ATD-1 planning activities.

Paper 2.04. Air Traffic Management Technology Demonstration-1 Concept of Operations (ATD-1 ConOps), Version 2.0 (NASA/TM-2013-218040)
This document describes the ATD-1 Concept of Operations Version 2.0. The key changes to the concept of operations were: (1) removed the STA portion of the FIM clearance, added of FIM procedures when arrival procedure does not connect to the approach procedure, updated Appendix E for assumptions and requirements, updated Appendix F for terminal metering algorithm calculations, and updated FIM phraseology. Additional changes were made to improve the overall readability and clarity of the document. This version of ATD-1 ConOps completely replaces the previous version described in Paper 2.02.

Paper 2.05. NASA's ATM Technology Demonstration-1: Moving NextGen Arrival Concepts from the Laboratory to the Operational NAS (Journal of Air Traffic Control, July 2013)
This paper describes the goals and objectives of the ATD-1 Project. It includes descriptions of the overall operational concept, and the terminal metering, controller-managed spacing and flight deck interval management technologies. It also includes a discussion of the intended development approach, challenges specially related to the maturation of the operational capabilities, and a notional path for simulation and operational testing of the integrated technologies in prototype versions of operational systems. It should be noted that the proposed timeline of activities have been modified in later ATD-1 planning activities.

3) Technical Publications

This list covers all of the ATD-1 technical publications published to date. It covers all of those publications related specifically to terminal metering, controller-managed spacing tools, and flight deck interval management. There is a fair amount of duplicate information - certainly duplicate introductory material. The papers are ordered by date to show the progression.

2010 Publications

Paper 3.01. Controller-Managed Spacing – A Human-in-the-Loop Simulation of Terminal Area Operations (GNC 2010)
This paper documents the results of Controller-Managed Spacing Study #2, CMS-2. The traffic scenario consisted of nominal traffic to a single runway at LAX (Runway 24R) in the presence of analytical wind errors (up to +/-10 knots) and TRACON delivery errors (up to +/-40 seconds). The schedule/sequence was scripted. This paper represents the first published results of the CMS series of experiments. CMS-1 was not explicitly documented since it was not sufficiently mature. Limitations of the experiment and early versions of the CMS toolset caused there to be little apparent improvement in the spacing precision and throughput achieved. However, workload was significantly reduced while route conformance was maintained for all flights. [Formerly Paper 2D]

Paper 3.02. Benefits of Continuous Descent Operations in High-Density Terminal Airspace Under Scheduling Constraints (ATIO 2010)
This paper estimates the relative benefits of removing vertical inefficiencies from operations at 8 of the 10 largest TRACONs in the NAS. The analyses conducted in this paper are critical to understanding how fuel-efficiency benefits will scale across the NAS and across demand-to-capacity ratios. Earlier studies generally analyzed a small and isolated fraction of operations. These studies also likely overestimated the benefits by using the behavior of undelayed flights during periods of arrival delay. [Formerly Paper 2B]

Paper 3.03. Design Considerations for a New Terminal Area Arrival Scheduler (ATIO 2010)
This paper investigated the trades between delay, schedule buffer (i.e., throughput), control margin (i.e., max TRACON delay), controller intervention rate and delivery accuracy. For each of the variables, there were 4-5 values tested across 500 Monte Carlo runs – amounting to about 1.25M individual runs. The results of these stochastic fast-time simulations were used to set the meter fix and runway buffers and the max TRACON delay for the subsequent TAPSS experiments. The approach presented in this paper provides a logical and methodical way to determine the appropriate initial scheduler operating point. The TAPSS experiments were focused on fine-tuning around this initial scheduling operating point. [Formerly Paper 2C]

Paper 3.04. Human-in-the-Loop Simulation of Trajectory-Based Terminal-Area Operations (ICAS 2010)
This paper documents more results of the Controller-Managed Spacing Study #2, CMS-2 (See Paper 3.01). The traffic scenario consisted of nominal traffic to a single runway at LAX (Runway 24R) in the presence of analytical wind errors (up to +/-10 knots) and TRACON delivery errors (up to +/-40 seconds). The schedule/sequence was scripted. The results are specifically focused on the spacing accuracy attained during the simulation. The key result shows that most of the spacing inaccuracy occurs inside of the final approach fix due to simulation artifacts. [Formerly Paper 2E]

2011 Publications

Paper 3.05. An Overview of a Trajectory-Based Solution for En Route and Terminal Area Self-Spacing to Include Parallel Runway Operations (NASA/CR-2011-217194)
This paper documents the ASTAR algorithm Version 10. In-depth descriptions of the trajectory computation, spacing interval calculation, speed control law, and operational constraints on spacing behavior are provided. This paper is superseded by Paper 3.24 that describes ASTAR algorithm Version 11.

Paper 3.06. Controller Support Tools for Schedule-Based Terminal-Area Operations (ATM 2011)
This paper documents the results of the Controller-Managed Spacing Study #3, CMS-3. The traffic scenario consisted of nominal traffic to both runways at LAX (Runway 25L and 24R) in the presence of analytical wind errors (up to +/-10 knots) and TRACON delivery errors (up to +60/-30 seconds). The schedule/sequence was scripted. Route conformance continues to be very high. Some results are presented on the relative benefits, as well as the usefulness and usability, of the different CMS tools. Comparisons of performance with and without the CMS tools was not shown because the results were similar to earlier published results. [Formerly Paper 2G]

Paper 3.07. Design and Evaluation of the Terminal Area Scheduling and Spacing System (ATM 2011)
This paper documents the results of the Terminal Area Scheduling and Spacing System simulation #1, TAPSS-1. The traffic scenario consisted of arrival traffic to two parallel runways at LAX (Runways 25L and 24R) with demand varied up to 20% of nominal. Winds were not incorporated into the TAPSS-1 simulation. The schedule/sequence was determined by TMA; en route controllers used TMA metering times and/or EDA tools to all meter fixes; terminal controllers used CMS tools throughout the entire TRACON. The results show increased throughput, decreased delay, improved route conformance, increased spacing precision, and improved vertical profile. This experiment was the first large-scale integration of TMA, EDA, and, terminal scheduling and spacing. [Formerly Paper 2H]

Paper 3.08. Acceptability and Effects of Tools to Assist with Controller Managed Spacing in the Terminal Area (HCI 2011)
This paper documents the results of the Controller-Managed Spacing Study #3, CMS-3. The traffic scenario consisted of nominal traffic to both runways at LAX (Runway 25L and 24R) in the presence of analytical wind errors (up to +/-10 knots) and TRACON delivery errors (up to +60/-30 seconds). The schedule/sequence was scripted. The results presented in this paper were focused on the human factors metrics – task success, acceptability, usability and tool usage. [Formerly Paper 2L]

Paper 3.09. Efficiency Benefits Using the Terminal Area Precision Scheduling and Spacing System (ATIO 2011)
This paper documents the horizontal and vertical efficiency improvements associated with TAPSS-1. The traffic scenario consisted of arrival traffic to two parallel runways at LAX (Runways 25L and 24R) with demand varied up to 20% of nominal. Winds were not incorporated into the TAPSS-1 simulation. The schedule/sequence was determined by TMA; en route controllers used TMA metering times and/or EDA tools to all meter fixes; terminal controllers used CMS tools throughout the entire TRACON. The TAPSS tools (EDA en route and CMS terminal) are found to reduce level distance flown in the terminal area by 55-85% depending upon traffic demand level. The TAPSS tools are also found to reduce flight time and distance for traffic demand levels especially for higher traffic levels. Some estimates of fuel savings were calculated using the techniques described in Paper 3.02. [Formerly Paper 2I]

Paper 3.10. Use of Data Comm by Flight Crew to Conduct Interval Management Operations to Parallel Dependent Runways (ATIO 2011)
This paper documents the results of the Interval Management with Spacing to Parallel Dependent Runways experiment, IMSPDR. The experiment investigated the use of CPDLC for communicating complex FIM clearances to dependent runways. It did not include TSS operations. The simulation scenarios consisted of arrival traffic to two parallel runways at DFW (Runway 17C and 18R), and separate analytical truth and forecast winds. The arrival routes were modeled as RNAV OPDs. The runways were artificially modeled as parallel dependent runways. Additional DFW departures, as well as DAL arrivals were included as non-subject aircraft. The test conditions investigated the

effects of aircraft delay (prescribed as 30 seconds) and wind errors (based upon NOAA forecast accuracy data). Data are presented in the paper regarding flight crew read and response times of the CPDLC FIM messages and the acceptability of the associated FIM operations in terms of head-down time.

Paper 3.11. Evaluation of an Airborne Spacing Concept, On-board Spacing Tool, and Pilot Interface (ATIO 2011)
This paper documents the results of the Interval Management with Spacing to Parallel Dependent Runways experiment, IMSPDR. The experiment investigated the use of CPDLC for communicating complex FIM clearances to dependent runways. It did not include TSS operations. The simulation scenarios consisted of arrival traffic to two parallel runways at DFW (Runway 17C and 18R), and separate analytical truth and forecast winds. The arrival routes were modeled as RNAV OPDs. The runways were artificially modeled as parallel dependent runways. Additional DFW departures, as well as DAL arrivals were included as non-subject aircraft. The test conditions investigated the effects of aircraft delay (prescribed as 30 seconds) and wind errors (based upon NOAA forecast accuracy data). Data are presented in the paper regarding runway delivery performance, pilot adherence to speed commands, pilot acceptance of the FIM concept, pilot workload, frequency of speed commands, display usefulness, non-conformance alerting, and system predictability.

Paper 3.12. Effects of Scheduling and Spacing Tools on Controllers' Performance and Perceptions of their Workload (DASC 2011)
This paper documents the controller workload associated with TAPSS-1. The traffic scenario consisted of arrival traffic to two parallel runways at LAX (Runways 25L and 24R) with demand varied up to 20% of nominal. Winds were not incorporated into the TAPSS-1 simulation. The schedule/sequence was determined by TMA; en route controllers used TMA metering times and/or EDA tools to all meter fixes; terminal controllers used CMS tools throughout the entire TRACON. The en route and terminal controllers reported that the TAPSS tools (EDA+CMS) helped them use speed control only to absorb delay along the simulation's RNAV OPDs. With the TAPSS tools, terminal controllers could provide the necessary level of precise control to maintain RNAV OPDs, but without the tools, they could not. However, terminal final controllers reported higher workload because the tools operated differently than their current practices (but not unsafely or incorrectly). [Formerly Paper 2J]

Paper 3.13. Investigating the Impact of Off-Nominal Events on High-Density 'Green' Arrivals (DASC 2011)
This paper documents the results of the Controller-Managed Spacing Study #4, CMS-4. The traffic scenario consisted of nominal traffic to both runways at LAX (Runway 25L and 24R) in the presence of off-nominal events (like go-arounds, lost comm., missed approaches, sequence swaps, etc.), analytical wind errors (up to +/-10 knots), and TRACON delivery errors (up to +60/-30 seconds). The schedule/sequence was scripted. Results suggest that the development of standard techniques to handle off-nominal events will help ensure robust tool performance in the presence of off-nominal events. The TAPSS-2 experiment looked at a similar set of scenarios using the entire TAPSS system with dynamic schedules. [Formerly Paper 2K]

2012 Publications

Paper 3.14. Evaluation of the Terminal Area Precision Scheduling and Spacing System for Near-Term NAS Application (AHFE 2012)
This paper documents the results of the Terminal Area Precision Scheduling and Spacing simulation #3, TAPSS-3. The simulation investigated the suitability of near-term implementation of the TSS capabilities with minimal changes to the existing arrival procedures. It did not include FIM operations. The simulation scenarios consisted of arrival traffic to two parallel runways at LAX

(Runway 24R and 25L). Winds were not incorporated into the TAPSS-3 simulation. The arrival routes were modeled as today's published LAX STARs. The test conditions investigated the effects of increased traffic demand for route topologies with and without vectors to the final approach course. Data are presented in the paper regarding the number of flights vectored, schedule conformance, and controller-reported workload for different TSS toolsets (full tools, and limited tools). This simulation also included NASA's Efficient Descent Advisor (EDA) capabilities for en route controllers.

Paper 3.15. Controller-Managed Spacing within Mixed-Equipage Arrival Operations involving Flight-Deck Interval Management (AHFE 2012)
This paper documents the results of the Controller-Managed Spacing for ATD-1 simulation #1, CA-1. The experiment evaluated the initial integration of the TSS and FIM capabilities. It is the first ATD-1 simulation to study mixed TSS and FIM operations. The simulation scenarios consisted of arrival traffic to a single runway at DFW (Runway 17C). Winds were not incorporated into the CA-1 simulation. The arrival routes were modeled as RNAV OPDs from 3 of the 4 primary DFW arrival meter fixes augmented with connections to the respective final approach courses. The test conditions investigated the controller acceptance of FIM operations, in particular the procedures and phraseology for FIM initiating and monitoring. Data are presented in the paper regarding controller-reported workload, tool usability ratings, and FIM operation acceptability.

Paper 3.16. Initial Investigations of Controller Tools and Procedures for Schedule-Based Arrival Operations with Mixed Flight-Interval Management Equipage (ATIO 2012)
This paper documents the results of the Controller-Managed Spacing for ATD-1 simulation #3, CA-3. The experiment evaluated the continued integration of the TSS and FIM capabilities. The simulation scenarios consisted of arrival traffic to two parallel runways at DFW (Runway 17C and 18R), and separate analytical truth and forecast winds. The arrival routes were modeled as RNAV OPDs from the 4 primary DFW arrival meter fixes augmented with connections to the final approach courses. The test conditions investigated the performance and controller acceptance of FIM operations, in particular the procedure and phraseology for FIM initiating and monitoring. Data are presented in the paper regarding runway throughput, use of radar vectors, flight time and distance flown, in-trail spacing accuracy, schedule conformance, number of uninterrupted FIM operations, clarity of FIM phraseology, TSS tool usefulness, and controller-reported workload for both tools and no-tools conditions.

Paper 3.17. Interval Management with Spacing to Parallel Dependent Runways (IMSPIDR) Experiment and Results (ICAS 2012)
This paper documents the results of the Interval Management with Spacing to Parallel Dependent Runways experiment, IMSPDR. The experiment investigated the use of CPDLC for communicating complex FIM clearances to dependent runways. It did not include TSS operations. The simulation scenarios consisted of arrival traffic to two parallel runways at DFW (Runway 17C and 18R), and separate analytical truth and forecast winds. The arrival routes were modeled as RNAV OPDs. The runways were artificially modeled as parallel dependent runways. Additional DFW departures, as well as DAL arrivals were included as non-subject aircraft. The test conditions investigated the effects of aircraft delay (prescribed as 30 seconds) and wind errors (based upon NOAA forecast accuracy data). Data are presented in the paper regarding spacing error, speed brake/throttle use, and number of speed changes all with respect to the flight's position in the arrival steam (i.e., string stability).

Paper 3.18. Aircraft Configuration and Flight Crew Compliance with Procedures While Conducting Flight Deck based Interval Management (FIM) Operations (ATIO 2012)
This paper documents the results of the Interval Management with Spacing to Parallel Dependent Runways experiment, IMSPDR. The experiment investigated the use of CPDLC for communicating complex FIM clearances to dependent runways. It did not include TSS operations. The simulation scenarios consisted of arrival traffic to two parallel runways at DFW (Runway 17C and 18R), and separate analytical truth and forecast winds. The arrival routes were modeled as RNAV OPDs. The runways were artificially modeled as parallel dependent runways. Additional DFW departures, as well as DAL arrivals were included as non-subject aircraft. The test conditions investigated the effects of aircraft delay (prescribed as 30 seconds) and wind errors (based upon NOAA forecast accuracy data). Data are presented in the paper regarding spacing error, speed brake/throttle use, gear and flap deployment, flight crew reaction time to speed commands, and flight crew compliance with operating procedures.

Paper 3.19. Development and Evaluation of the Terminal Precision Scheduling and Spacing System for Off-Nominal Condition Operations (DASC 2012)
This paper documents the results of the Terminal Area Precision Scheduling and Spacing simulation #2, TAPSS-2. The simulation investigated the performance of the TSS system performance in the presence of missed approaches. It did not include FIM operations. The simulation scenarios consisted of arrival traffic to two parallel runways at LAX (Runway 24R and 25L). Winds were not incorporated into the TAPSS-2 simulation. The arrival routes were modeled as today's published LAX STARs augmented with connections to the final approach courses. Additional missed approach routes were defined that had connections back to the final approach courses. The test conditions investigated the effects of increased traffic demand and missed approach frequency. Data are presented in the paper regarding the missed approach track miles flown, runway throughput, number of controller instructions, and controller-reported workload for operations with and without missed approach rescheduling.

Paper 3.20. How To Compute a Slot Marker – Calculation of Controller-Managed Spacing Tools for Efficient Descents with Precision Scheduling (DASC 2012)
This paper documents the first- and second-generation of slot marker and speed advisory calculation algorithms. The first algorithm provided a single speed advisory to a specific downstream waypoint in order to absorb the delay. The second algorithm reduces the speed profile by the necessary fraction in order to absorb the desired delay. These algorithms were originally resident in the ATD-1 simulation platform rather than the TMA system as it is now. The latest slot marker and speed advisory calculation algorithm is described in Paper 7.01.

Paper 3.21. Flying Scheduling-Matching Descents to Explore Flight Crews' Perceptions of their Workload and Task Feasibility (DASC 2012)
This paper documents the results the first flight crew evaluation of TSS operations. The simulation investigated the impact of TSS operations on the flight crews' performance and procedures, especially those related to energy management. The simulation scenarios consisted of arrival traffic to two parallel runways at LAX (Runway 24R and 25L), and separate analytical truth and forecast winds. The arrival routes were modeled as today's published LAX STARs augmented with connections to the final approach courses. The participating flight crews only flew the SADDE arrival to Runway 24R and the RIIVR arrival to Runway 25L. The test conditions investigated the effects of purposely excessive variations in the commanded speed changes, realistic wind error, and speed instruction phraseology. Data are presented in the paper regarding speed profile conformance, and flight crew-reported workload for various speed change scenarios.

Paper 3.22. Air Traffic Controller Usage of Terminal-Area Speed Advisories (DASC 2012)
This paper documents the speed advisory usage for a series of three simulations: Controller-Managed Spacing study #3, CMS-3, Controller-Managed Spacing study #4, CMS-4, and the Controller-Managed Spacing for ATD-1 simulation #1, CA-1 (referred to as CMS-5 in the paper). The simulation scenarios for CMS-3 and CMS-4 consisted of arrival traffic to two parallel runways at LAX (Runway 24R and 25L), and separate analytical truth and forecast winds. The simulation scenarios for CA-1 consisted arrival traffic to a single runway at DFW (Runway 17); Winds were not incorporated into the CA-1 simulation. The arrival routes for each simulation were modeled as RNAV OPDs augmented with connections to the respective airport's final approach courses. The test conditions varied between the simulations, but investigated the TRACON controllers' acceptance and use of speed advisory information. Data are presented in the paper regarding the controllers' usage of the speed advisory information for different simulations, different controller positions (feeder or final), and different speed advisory resolutions (5kt or 10kt).

Paper 3.23. Benefits of Precision Scheduling and Spacing for Arrival Operations (DASC 2012)
This paper analyzes the observed in-trail spacing for operations to 29 runways at 15 airports in 8 of the 10 busiest TRACONs in the NAS. A fixed routing structure, representative of PBN arrival procedures, is constructed using the actual flight tracks for these operations. Methods are developed to characterize the excess spacing, and amount of path stretch delay for both visual and instrument approach conditions. These results are combined with a scheduling model to determine the potential benefit of advanced sequencing and spacing capabilities.

2013 Publications

Paper 3.24. An Overview of a Trajectory-Based Solution for En Route and Terminal Area Self-Spacing, 4th Revision (NASA/CR-2013-218044)
This paper documents the ASTAR algorithm Version 11. In-depth descriptions of the trajectory computation, spacing interval calculation, speed control law, operational constraints on spacing behavior, and future design considerations are provided.

Paper 3.25. Evaluation of the Controller-Managed Spacing Tools, Flight-deck Interval Management and Terminal Area Metering Capabilities for the ATM Technology Demonstration #1 (ATM 2013)
This paper documents the results of the Fully Integrated ATD-1 Test #1, FIAT-1. The simulation investigated the performance and controller acceptability of the complete ATD-1 system for enabling mixed-equipage TSS and IM operations. It is considered the first fully integrated high-fidelity ATD-1 simulation. The simulation scenarios consisted of arrival traffic to two parallel runways at LAX (Runway 24R and 25L). Winds were not incorporated into FIAT-1. The arrival routes were modeled as today's published LAX STARs. The test conditions investigated the effects of the TRACON delay allocation settings, and ARTCC FIM status indications. Data are presented in the paper regarding track miles flown, off-path time, schedule conformance, number of uninterrupted PBN arrivals, number of uninterrupted FIM operations, FIM spacing precision, and controller-reported workload with respect to the type of operation being conducted (controller-managed PBN or flight deck IM).

Paper 3.26. Simulations of Continuous Descent Operations with Arrival-Management Automation and mixed Flight-Deck Interval Management Equipage (ATM 2013)
This paper documents the results of the Controller-Managed Spacing for ATD-1 simulation #4, CA-4. The simulation investigated the performance and controller acceptability of the complete ATD-1 system for enabling mixed-equipage TSS and IM operations. It represents the initial integration of ATD-1 capabilities with a PHX traffic simulation. The simulation scenarios included two parallel runways at PHX (Runway 25L and 26). CA-4 attempted to incorporate separate RUC-based truth and forecast winds, but encountered some integration issues. The arrival routes were modeled as

today's PHX RNAV STARs augmented with connections to the final approach courses. It is ATD-1 simulation that used PHX operations. The test conditions investigated the effects of meter fix delivery accuracy and TRACON FIM status indications. Data are presented in the paper regarding the runway schedule and route conformance for precise and imprecise meter fix delivery accuracy.

Paper 3.27. Incentivizing Aircraft Equipment Upgrade Through Preferential Merging: A Phoenix Case Study (ATIO 2013)
This paper analyzes the potential system benefits of a preferential merging algorithm for time-based metering in order to motivate airline equipage. Under this concept, preference in the arrival schedule is given to a subset of flights – in particular, those equipped with ADS-B In. PHX arrival operations are used as a case study. Data are presented in the paper regarding number of passing opportunities, number of other flights passed, flight time saved, and effectiveness of the preferential treatment as ADS-B In equipage increases.

Paper 3.28. Estimation of Airline Benefits from Avionics Upgrades Under Preference Merge Re-Sequence Scheduling (ATIO 2013)
This paper analyzes the potential airspace user benefits of a preferential merging algorithm for time-based metering in order to motivate airline equipage. Under this concept, preference in the arrival schedule is given to a subset of flights – in particular, those equipped with ADS-B In. PHX arrival operations are used as a case study. The results are used to translate from the flight time benefits of preferential scheduling due of ADS-B In equipped flights to reductions in the ADS-B In equipment payback period. Data are presented in the paper regarding number of passing opportunities, flight time saved, and fleet-wide monetary savings due to the associated fuel and operating cost reductions.

Paper 3.29. Analysis of Excess Wake Vortex Separation on Arrival Delay (ATIO 2013)
This paper develops a statistical model of delay savings due to excess in-trail spacing reduction using operations to KATL Runway 27L and KDEN Runway 35R. "Compression" models are described that remove excess path distance flown to achieve excess in-trail spacing and flight time reductions. In contrast to Paper 3.23, this model only uses TRACON entry and runway threshold crossing information to perform its estimation. It can be used to estimate the potential benefit of advanced sequencing and spacing capabilities without reconstructing individual aircraft trajectories.

Paper 3.30. Spatio-Temporally Correlated Wind Uncertainty Model for Simulation of Terminal Airspace Operations (ATIO 2013)
This paper documents an approach to develop spatio-temporally correlated wind error grids based upon a comparison of NOAA's RAP product and its MADIS data. These statistically-based wind error grids will eventually be used in lieu of analytical wind errors using linear wind models (see Paper 3.16) and empirical wind error models using temporally-separated RUC products (see Paper 3.36).

Paper 3.31. Flight-Deck Strategies and Outcomes When Flying Schedule-Matching Descents (GNC 2013)
This paper documents the results the first flight crew evaluation of TSS operations. The simulation investigated the impact of TSS operations on the flight crews' performance and procedures, especially those related to energy management. The simulation scenarios consisted of arrival traffic to two parallel runways at LAX (Runway 24R and 25L), and separate analytical truth and forecast winds. The arrival routes were modeled as today's published LAX STARs augmented with connections to the final approach courses. The participating flight crews only flew the SADDE arrival to Runway 24R and the RIIVR arrival to Runway 25L. The test conditions investigated the effects of purposely excessive variations in the commanded speed changes, realistic wind error, and

speed instruction phraseology. Data are presented in the paper regarding flight time variability, and speed profile conformance for various speed change scenarios and speed instruction phraseology. Also, strategies for flight deck speed transition and altitude constraint compliance, as well as mode and energy state awareness issues, are discussed.

Paper 3.32. Acceptability of Flight Deck-Based Interval Management Crew Procedures (GNC 2013)
This paper documents the results of the Interval Management for Near-term Operations Validation of Acceptability simulation, IM-NOVA. The simulation assessed the acceptability and feasibility of the FIM flight crew procedures defined in the ATD-1 Concept of Operations. The simulation scenarios consisted of arrival traffic to two parallel runways at DFW (Runway 17C and 18R). Winds were not incorporated into the IM-NOVA simulation. The arrival routes were modeled as RNAV OPDs augmented with connections to the final approach courses. The test conditions investigated the acceptability of five FIM scenarios: a nominal FIM operation, an amended FIM operation, a terminated FIM operation, a suspended and resumed FIM operation, and the loss of ADS-B data for the traffic-to-follow aircraft. Data are presented in the paper regarding acceptability and completeness of the FIM flight crew procedures, and the flight crew-reported workload of the FIM operation.

Paper 3.33. Evaluation of Flight Deck-Based Interval Management Crew Procedure Feasibility (GNC 2013)
This paper documents the results of the Interval Management for Near-term Operations Validation of Acceptability simulation, IM-NOVA. The simulation assessed the acceptability and feasibility of the FIM flight crew procedures defined in the ATD-1 Concept of Operations. The simulation scenarios consisted of arrival traffic to two parallel runways at DFW (Runway 17C and 18R). Winds were not incorporated into the IM-NOVA simulation. The arrival routes were modeled as RNAV OPDs augmented with connections to the final approach courses. The test conditions investigated the acceptability of five FIM scenarios: a nominal FIM operation, an amended FIM operation, a terminated FIM operation, a suspended and resumed FIM operation, and the loss of ADS-B data for the traffic-to-follow aircraft. Data are presented in the paper regarding the rate of FIM speed commands, the flight crew-reported acceptability and appropriateness of these commands and their frequency, and the FIM spacing error at the achieve-by point and the runway threshold.

Paper 3.34. Evaluation of the Terminal Area Precision Scheduling and Spacing System for PBN Arrivals (DASC 2013)
This paper documents the results of the Terminal Sequencing and Spacing simulation #0, TSS-0. NASA has also referred to this simulation as RNP Enabled by ATD-1 Controller Tools (REACT). The simulation was conducted by jointly NASA, FAA and CSC as part of the FAA's RNAV/RNP Demonstration Project. The simulation investigated the performance and controller acceptability of the TSS system for enabling PBN arrivals. It did not include FIM operations. The simulation scenarios consisted of arrival traffic to two parallel runways at DAL (Runway 13L and 13R). Winds were not incorporated into the TSS-0 simulation. The arrival routes were modeled as RNAV overlays of today's published DAL STARs. Additional RNP-AR arrival routes were defined with downwind connections to the final approach courses. The test conditions investigated the effects of moderate mixed-equipage traffic demand, realistic winds and wind errors, and controller training/experience. Data are presented in the paper regarding track miles flown, number of controller instructions, number of uninterrupted PBN arrivals, controller-reported workload, and controller-reported usability of various TSS capabilities with respect to the chosen TSS toolset (full tools or limited tools).

Paper 3.35. Evaluation of the Terminal Sequencing and Spacing System for Performance-Based Navigation Arrivals (DASC 2013)
This paper documents the results of the Full ATD-1 Integrated Test #2, FIAT-2, and the Terminal Sequencing and Spacing simulation #2, TSS-2. The TSS-2 simulation was conducted by jointly NASA, FAA and MITRE CAASD as part of the FAA's Terminal Sequencing and Spacing project. The simulation investigated the performance and controller acceptability of the TSS system for enabling PBN arrivals. It included FIM operations but these results are not reported. The simulation scenarios consisted of arrival traffic to two parallel runways at PHX (Runway 25L and 26), and separate RUC-based truth and forecast winds. FIAT-2 and TSS-2 were the first simulations to successfully incorporate fully realistic winds and wind errors. The arrival routes were modeled as today's published PHX STARs. Additional RNP-AR arrival routes were defined with downwind connections to the final approach courses. The test conditions investigated the effects of heavy mixed-equipage traffic demand, realistic winds and wind errors, and controller training/experience. Data are presented in the paper regarding track miles flown, runway throughput, number of controller instructions, number of uninterrupted PBN arrivals, controller-reported workload, controller-reported usability of various TSS capabilities, and learning effects.

2014 Publications

Paper 3.36. Large-Scale Data Analysis for Characterization of the Effect of Wind Forecast Errors on ETAs (ATIO 2014)
This paper characterizes the wind forecast errors at PHX and evaluates their impact on the estimated times-of-arrival from top-of-descent to touchdown. These results are based upon the spatio-temporally correlated model of wind errors described in Paper 3.30. Two types of metrics – a wind magnitude metric and a wind uncertainty metric – are used to evaluate the impact of wind forecast errors on ETA predictions for the entire 2011 calendar year. The associated raw data for this paper is available for further analyses, if desired.

Paper 3.37. An Evaluation of Retrofit Flight Deck Displays for Interval Management (ATIO 2014)
This paper documents the results of an evaluation of retrofit flight deck displays for interval management, called I-SIM. The simulation assessed the acceptability and feasibility of two different display designs – the "existing" numerical speed guidance display and a proposed graphical speed guidance display. The simulation scenarios consisted of arrival traffic to two parallel runways at PHX (Runway 25L and 26) along the EAGUL5 and KOOLY5 arrival routes. Realistic winds were modeled using separate truth and forecast RUC grids. The test conditions investigated the acceptability of the different FIM displays for nominal conditions (target aircraft at profile speed) and perturbed conditions (target aircraft slower than profile speed). Data are presented in the paper regarding the flight crew-reported acceptability and workload, the usefulness of the various display elements, the speed command execution latency, the delivery accuracy at the achieve-by point, and the rate of FIM speed commands. Overall, the graphical speed guidance display was preferred and corresponded to improved performance. However, the pilots also reported that the numerical speed guidance display would suffice if changes of the speed command were made more salient.

Paper 3.38. Assessing Relation between Performance of Schedule-Based Arrival Operation and Schedule Nonconformance (Aviation 2014)
This paper proposed a schedule non-conformance metric suitable for measuring the performance of TSS operations. The metric was found to be correlated to the fraction of aircraft flying extra track miles, the ratio of the planned and achieved makespan, and the number of heading and altitude instructions given. The metric was not found to be correlated with the average fuel consumption. The metric was evaluated using data from the Joint NASA/FAA TSS-2 simulation (See Paper 3.35).

Paper 3.39. An Evaluation of a Flight Deck Interval Management Algorithm including Delayed Target Trajectories (ATIO 2014)
This paper documents the results of batch studies evaluating the performance of the new ASTAR12 FIM algorithm. The ASTAR algorithm was redesigned to better respond to conditions involving a Target Aircraft flying faster or slower than the nominal arrival procedure. The simulation scenarios consisted of arrival traffic to PHX Runway 26 and eight separate realistic wind scenarios. The arrival routes were today's published PHX EAGUL5 and MAIER5 STARs. Six different Target Aircraft speed profiles were evaluated in order to represent the range of conditions expected to be encountered in real operations. Data are presented in the paper regarding delivery accuracy at the Achieve-by Point, number of speed command changes, spacing error dissipation, and number of speed reversals.

Paper 3.40. Flight Deck Crew Experiences Flying Profile Descents During Metering Operations (AHFE 2014)
This paper documents the results of the second flight crew evaluation of TSS operations. The simulation investigated the impact of TSS operations on the flight crews' performance and procedures as related to time-of-arrival variability. The simulation scenarios consisted of arrival traffic to PHX Runway 26, and separate analytical truth and forecast winds. The arrival route was modeled as today's published PHX EAGUL5 STAR with a connection to the final approach course. NASA's Advanced Concepts Flight Simulator (ACFS) was configured as a Boeing 737-800. The test conditions investigated the effects of realistic variations in the commanded speed changes, and two speed instruction phraseologies. Data are presented in the paper regarding vertical profile efficiency, speedbrake usage, and flight crew-reported workload for the two speed instruction phraseologies.

Paper 3.41. System-Level Performance Evaluation of ATD-1 Ground-Based Technologies (ATIO 2014)
This paper documents the results of the Controller-Managed Spacing for ATD-1 simulation #5 (Phases 1, 2, and 3), known as CA-5.1, CA-5.2, and CA-5.3, respectively. This simulation series investigated the system-level performance and controller acceptability of the ATD-1 technologies. CA-5.1 represented today's operations in both en route and terminal airspace; CA-5.2 added the Terminal Sequencing and Spacing (TSS) capabilities of ATD-1; and CA-5.3 added the Flight Deck Interval Management (FIM) capabilities of ATD-1. This simulation series was focused on measuring the system-level performance of the ATD-1 capabilities across a wide range of traffic and wind conditions using realistic operational procedures. No experimental variations of operational procedures, application settings, or scheduling algorithms were made. The simulation scenarios included both sets of parallel arrival runways at PHX (Runways 25L and 26 for West Flow and Runways 07R and 08 for East Flow). The simulation incorporated separate RUC-based truth and forecast winds in the form of 4 wind scenarios in West Flow and 4 wind scenarios in East Flow. The arrival routes were modeled as today's PHX STARs (both RNAV and conventional) augmented with additional routes for turbo-prop and piston aircraft. High-altitude, satellite airport, departure sectors, and adjacent Los Angeles ARTCC sectors were included. It is the most advanced ATD-1 simulation of PHX operations executed to date with the specific purpose of measuring the current performance of the ATD-1 technologies. Data are presented in the paper regarding the PBN conformance, flight time and distance profiles through the arrival phase of flight, demand manageability, and controller workload.

4) Cost/Benefit Assessment Publications

This list covers publications specifically related to cost/benefit assessments of the ATD-1 technologies. Publications in the other sections will generally discuss cost and/or benefits separately.

NextGen-Airportal Project Technologies: Systems Analysis, Integration, and Evaluation (SAIE) Contract #NNL10AB83T

4.01 NextGen-Airportal Project Technologies: Systems Analysis, Integration, and Evaluation (SAIE) Final Report Update, Option Year 1 (dated October 29, 2012)
This Saab Sensis report is a cost/benefit assessment of different combinations of the envisioned NextGen arrival management capabilities. The capabilities compared were: the Traffic Management Advisor with en route metering, the Traffic Management Advisor with terminal metering, the Controller-Managed Spacing tools, the Efficient Descent Advisor, and Flight Interval Management. The benefits of flight time savings due to less delay and fuel savings due to more efficient flight profiles were compared to the costs of deploying such systems. The cost estimate used the standard FAA Work Breakdown Structure categories. The analysis was performed for 16 airports and extrapolated to all TMA airports using their most common airport configuration. Follow-on analysis investigated additional airports, as well as airport configurations including dependent runway operations.

5) STARS Prototype Development Publications

This list covers all of the contract deliverables for the NASA contracts related to development of a STARS prototype implementation of the ATD-1 capabilities. There are two phases – Phase 1 was a one-year SE2020 task with Raytheon Corporation and Phase 2 is a multi-year GSA contract with Raytheon. The major deliverables are included in the Tech Transfer Package. Additional lower-level documentation is also available for these activities.

Controller-Managed Spacing Concept Engineering and Prototype Development – SE2020 TORP #1303 (Phase 1)

5.01 Work Plan (Rev A)
This Raytheon document is the complete statement of work for the Controller-Managed Spacing Concept Engineering and Prototype Development – SE2020 TORP #1303.

5.02 Technical Kickoff Meeting for TORP #1303 (dated November 4, 2011)
This Raytheon briefing was presented at the official kickoff of the SE2020 TORP #1303 activity. It introduces the Raytheon team, presents the revised workplan and near term milestones, and discusses the critical GFE actions for NASA. The kickoff meeting was held at NASA Ames Research on November 4, 2011.

5.03 TAPSS Briefing for Technical Kickoff Meeting (dated November 4, 2011)
This NASA briefing was presented at the official kickoff of the SE2020 TORP #1303 activity. It provides an in-depth introduction to the ATD-1 technologies.

5.04 Initial Feasibility Assessment Report (Rev G)
This Raytheon report documents the initial feasibility assessment of incorporating the Controller Managed Spacing (CMS) tools and displays into the STARS automation platform (Task 1). It evaluates 3 configurations for allocating the automation aids and algorithms between TMA and STARS.

5.05 Trade Study: Prototype Implementation of Controller Managed Spacing Tools in the Standard Terminal Automation Replacement System (Rev A)
This Raytheon report documents the design trade studies for the implementation of the Controller Managed Spacing (CMS) tools and displays into the STARS automation platform (Task 2). Only the two most likely configurations were evaluated. These key attributes of each configuration were evaluated: automation system resources, schedule risk, architectural integrity, and terminal automation growth potential.

5.06 Engineering Prototype Development Demonstration Report (Version Final)
This Raytheon report documents the results of the prototype demonstration (Task 3). The lab demonstration of the prototype STARS capabilities used a combination of data sent by a NASA prototype TMA system and data sent by a STARS CMS Interface Test Program. Results of the validation process are provided for each STARS requirement. New and incomplete requirements are documents for the follow-on Phase II contract.

5.07 Design Recommendations for Simulations and Field Use (Version 1.0)
This Raytheon report documents the design recommendations and challenges for implementing the prototype CMS tools in the STARS automation platform (Task 4). These recommendations and an accompanying ROM estimate were used as the basis to develop the follow-on Phase 2 contract.

5.08 Final Report for SE2020 TORP 1303 (Version 1.0)
This Raytheon report summarizes all of the work done for the activity (Tasks 1-4), discusses the expanded use of the STARS AIG messages for CMS, and provides some recommendations for subsequent maturation of the operational CMS capability.

ATD-1 STARS Enhancement and Simulation and Field Support Contract #NNA12AC88T (Phase 2)

5.09 Work Plan (Rev B)
This Raytheon document is the complete statement of work for the ATD-1 STARS Enhancement and Simulation and Field Support Contract.

5.10 NASA STARS CMS Prototype Kickoff Briefing (dated October 29-30, 2012)
This Raytheon briefing was presented at the official kickoff of the Contract #NNA12AC88T activity. It introduces the Raytheon team, presents the revised workplan and near term milestones, and discusses the critical GFE actions for NASA. Detailed descriptions of the 13 individual tasks are included. The kickoff meeting was held October 29-30, 2012 at NASA Ames Research.

5.11 ATD-1 Implementation Strategy and Approach
This NASA briefing was presented at the official kickoff of the Contract #NNA12AC88T activity. It details the ATD-1 implementation objectives and approach for the further maturation of the prototype CMS capabilities.

5.12 CMS Prototype Capabilities Specification (dated January 30, 2013)
This Raytheon report provides a specification of the functional capabilities to be implemented in the STARS CMS Prototype. Software requirements derived from these capabilities are also included.

5.13 Task 1 Prototype Completion Report (Rev A)
5.14 Task 1 Prototype Completion Demonstration Briefing (Rev A)
5.15 Task 1 Prototype Completion Demonstration Debrief Briefing (Rev A)
5.16 Demonstration Plan for CMS Capabilities: Slack and Overlap Display in STARS (Version 1 Rev 0)

5.17 Demonstration Plan for CMS Capabilities in STARS (Rev A)
These Raytheon reports and briefings document the proceedings of the STARS ATM Technology Demonstration #1 (ATD-1) Task 1 Prototype Completion Demonstration and capture the issues and actions from the demonstration and de-briefing session(s) associated with Task 1. The objectives of Task 1 were to demonstrate all of the STARS CMS prototype capabilities with the exception of FIM capabilities, and to implement the message interface in accordance with the prototype General NAS User Services ICD.

5.18 Task 3 MACS/STARS/TMA Integration Briefing (Rev A)
This Raytheon briefing provides information on the integration of MACS, TMA, and STARS in NASA's ATD-1 simulation facility at NASA Ames.

5.19 Task 2 Software and Adaptation Modification Capabilities Demo Plan and Task 4 Adaptation Creation and Modification Demo Plan Briefing (Version –)
5.20 Task 4 PHX Adaptation Verification Demo Plan Briefing (Version –)
These Raytheon briefings describe three demonstrations at NASA Ames – STARS software creation/modification capabilities, STARS adaptation creation/modification capabilities, and STARS PHX adaptation verification.

5.21 NASA STARS ELITE String Startup and Shutdown Procedures (Version –)
This Raytheon report describes the startup and shutdown procedures for the STARS ELITE system integrated into the ATD-1 simulation facility at NASA Ames.

5.22 NASA STARS Software Development Environment Startup and Shutdown Procedures (Version –)
This Raytheon report describes the startup and shutdown procedures for the STARS Clearcase-based software development environment integrated into the ATD-1 simulation facility at NASA Ames.

5.23 Task 5 Onsite Training of STARS at NASA Ames Task Completion Report (Version 1)
5.24 Task 5 Onsite Training of STARS at NASA Ames Demonstration Briefing (dated June 26, 2013)
This Raytheon report and briefing document the proceedings of the on-site training of STARS (operational use and software/adaptation development) at NASA Ames.

5.25 NASA ATD-1 STARS CMS Software Integration Plan (SIP) (Rev -, dated September 27, 2013)
5.26 Task 8 Field Site Software Integration Plan Task Completion Report (Version -)
5.27 Task 8 Field Site Software Integration Plan Task Completion Briefing (dated September 28, 2013)
These Raytheon reports and briefing describes a plan for the "up-leveling" of the STARS CMS prototype software from the NASA simulation environment to create a pre-production version suitable for release to the FAA. The plan details the development processes for raising the capability of the software from a Technology Readiness Level (TRL) 5, suitable for a lab simulation environment, to TRLs 6 and 7, suitable for transfer to the FAA to complete production development, Operational Test and Evaluation (OT&E), and deployment. The plan also includes documentation requirements to support these activities.

5.28 STARS with CMS GeNUS ICD (Rev D Draft, dated May 9, 2014)
This Raytheon document describes the ATD-1 STARS ICD. It includes complete definition of the AIG messages that were either added or modified to support ATD.1

5.29 STARS ATD-1 Software Package (Version 1.006) [Externally Delivered]
This software package contains source code and adaptation for the modified STARS ELITE build that includes the complete set of ATD-1 terminal sequencing and spacing capabilities and most of its expected flight deck interval management capabilities. This version of STARS ELITE software was used to conduct the ATD-1 FIAT-3 human-in-the-loop simulation at NASA Ames. Due to the proprietary nature of this software, the modified STARS ELITE software must be requested from the Raytheon Company by referencing the official label ELITE_ATD1_MACS_V1.006. NASA can assist in transfer of this software build between Raytheon and the FAA STARS Program. Raytheon must contractually provide all ATD-1-funded STARS changes to the appropriate parties in the FAA.

5.30 STARS ATD-1 Training Materials – Module 14
5.31 STARS ATD-1 Training Materials – Module 15
5.32 STARS ATD-1 Training Materials – Module 16
5.33 STARS ATD-1 Training Materials – Module 17
These Raytheon documents are the STARS training materials for the prototype ATD-1 capabilities. The ATD-1 concept of operations, controller-managed spacing tools, site adaptation support, and user interface are discussed.

5.34 Task 6 On-site Software Support at NASA Ames Task Completion Report (Version -, dated November 14, 2013)
5.35 STARS ATD-1 Task 6 Demonstration Briefing for On-site Software Support at NASA Ames (dated November 20, 2013)
This Raytheon report and briefing document the proceedings of the on-site software support of STARS (for real-time human-in-the-loop simulations) at NASA Ames. This support includes assistance for execution of the HITLs involving the STARS platform as well as on-site minor software modifications and recompilation of functions related to Tasks 1-4 and 7. Summaries of the Software Trouble Reports (STRs) are provided in Tables 2.2, 2.3, and 3.1. The STARS terminal controller workstation commands for the ATD-1 functionality are listed in Section 3.1. This same task is expected to be used for equivalent support during the Operational Integration Assessment at the FAA Tech Center.

5.36 Task 7 Prototype FIM Operations Task Completion Report For ATD-1 STARS Enhancement and Simulation and Field Evaluation Support (Version -, dated November 14, 2013)
This Raytheon report documents the proceedings of the STARS ATM Technology Demonstration #1 (ATD-1) Task 7 Prototype Completion Demonstration. The objectives of Task 7 were to demonstrate all of the STARS FIM prototype capabilities, and to implement the message interface in accordance with the prototype General NAS User Services ICD.

5.37 STARS ATD-1 Software Package (Version 2.001) [Externally Delivered]
This software package contains source code and adaptation for the modified STARS ELITE build that includes the complete set of ATD-1 terminal sequencing and spacing and flight deck interval management capabilities. This version of STARS ELITE software was used to conduct the ATD-1 FIAT-4 human-in-the-loop simulation at NASA Ames. Due to the proprietary nature of this software, the modified STARS ELITE software must be requested from the Raytheon Company by referencing the official labels ELITE_ATD1_MACS_V2.001 (compatible with NASA's ATC lab environment) or ELITE_ATD1_FAA_V2.001. NASA can assist in transfer of this software build between Raytheon and the FAA STARS Program. Raytheon must contractually provide all ATD-1-funded STARS changes to the appropriate parties in the FAA. This software package superseded Item 5.29 that describes the STARS ATD-1 Software Package Version 1.006.

5.38 STARS CMS Prototype Draft SDD SUM Redlines and User Manual Addenda to FSL TCW/TDW Operator's Manual (dated May 20, 2014)
This Raytheon document contains the proposed changes of the STARS FSL TCW/TDW Operator's Manual. NOTE: While NASA's SCOUT prototype used the STARS ELITE system, the STARS FSL TCW/TDW Operator's Manual was redlined since it will be the eventual pathway to deployment.

5.39 STARS Simulator to Operational System Interface Design Document (Rev K, dated June 11, 2013)
This Raytheon document specifies the interface between the ATCoach simulator and the operational STARS system. It is used for testing and controller training. The interface was extended and the NASA MACS simulation was modified to emulate this interface for the purpose of integrated TMA-STARS simulations at NASA Ames.

5.40 STARS CMS Tools Thin Spec (Excerpt) (Rev –, dated April 17, 2014)
This standard Raytheon document records the basis for development of new capabilities. In the case of TSS, this excerpt gives a functional overview and draft system-level requirements.

5.41 Timelines & Trajectories Thread CMS Production Qualification Test 1 (Test Cases 2 & 5, dated May 7, 2014)
5.42 Controller Managed Spacing Tools Production Qualification Test 2 (Test Cases 1, 3, 4, 6)
5.43 FIM Thread Production Qualification Test 3 & 4a (Test Case 8, dated May 8, 2014)
5.44 Operator Controls Production Qualification Test 3 (Test Case 7, not applicable)
5.45 Stale/Obsolete Flight Data Thread Production Qualification Test 4 (Test Case 10)
5.46 CMS Flight Runway and Sequence Number Thread Production Qualification Test 4 (Test Case 11)
5.47 CMS Support for Monitoring TMA Interface Thread Production Qualification Test 4 (Test Case 12)
5.48 Data Recording and Playback Thread Production Qualification Test 4 (Test Case 13)
5.49 De-clutter CMS Tools on Final Approach Thread Production Qualification Test 4 (Test Case 14)
5.50 Adaptation Production Qualification Test x (Test Case 9, deferred effort)
These standard Raytheon documents contain the detailed demonstration and test procedures used to verify the CMS prototype functionality as implemented in the up-leveled SCOUT software and demonstrated to NASA on May 21-22, 2014. They were developed in accordance with the standard STARS/TAMR program processes.

5.51 Task 9 Up-leveling of CMS and FIM prototype to SCOUT Release Task Completion Report (Version 1, dated May 28, 2014)
5.52 STARS ATD-1 Demonstration Briefing for Task 9 Up-leveling of CMS and FIM prototype to STARS CMS Opeval Up-leveled Tools (SCOUT) release (Version –, dated May 13, 2014)
5.53 NASA ATD-1 STARS CMS/FIM Task 9 Demonstration Plan (dated May 14, 2014)
5.54 NASA STARS ATD-1 Prototype Transition Review: Task 9 Transition to IDS (dated June 10, 2014)
These Raytheon reports and briefing document the up-leveling of the STARS CMS prototype software to the STARS CMS Opeval Up-leveled Tools (SCOUT) system and its subsequent release to Raytheon IDS. The SCOUT system includes both TSS functionality and FIM functionality. The up-leveled software has been written, documented, integrated, and tested in a way that is as consistent as possible with the TAMR Program's processes, given the constraints of the ATD-1 prototyping environment.

5.55 STARS ATD-1 Software Package (Version V3.001) [Externally Delivered]
This software package contains source code and adaptation for the modified STARS ELITE build that includes the complete set of ATD-1 terminal sequencing and spacing and flight deck interval management capabilities. This version of STARS ELITE software was used for initial integration testing for the ATD-1 FIAT-5 human-in-the-loop simulation at NASA Ames. Due to the proprietary nature of this software, the modified STARS ELITE software must be requested from the Raytheon Company by referencing the official labels ELITE_ATD1_MACS_V3.001 (compatible with NASA's ATC lab environment) or ELITE_ATD1_FAA_V3.001. NASA can assist in transfer of this software build between Raytheon and the FAA STARS Program. Raytheon must contractually provide all ATD-1-funded STARS changes to the appropriate parties in the FAA. This software package superseded Item 5.37 that describes the STARS ATD-1 Software Package Version 2.001.

6) Avionics Development Publications

This list covers all of the contract deliverables for the NASA contracts related to development of an avionics prototype implementation of the ATD-1 capabilities. There are two phases – Phase 1 was a one-year task with Boeing Company and Phase 2 will be a multi-year contract starting next year. The major deliverables are included in the Tech Transfer Package. Additional lower-level documentation is also available for these activities.

ATD-1 Avionics Contract #NNL12AC59T (Phase 1)

6.01 Statement of Work (Mod 1) [Externally Delivered]
This NASA task order is the complete statement of work for the ATD-1 Avionics Contract with Boeing Research and Technology. Due to the proprietary nature of this document, it must be requested from the Boeing Company. NASA can assist in transfer of this document between Boeing and the FAA. Boeing must contractually provide all ATD-1-funded avionics reports to the appropriate parties in the FAA.

6.02 Kickoff Briefing (dated July 26-27, 2012) [Externally Delivered]
This Boeing briefing was presented at the official kickoff of the Contract #NNL12AC59T activity. It introduces the Boeing team, presents the high-level workplan and near term milestones, and discusses the overall approach of the prototype development. Detailed descriptions of the 4 main tasks are included. The kickoff meeting was held July 26-27, 2012 at NASA Langley Research. Due to the proprietary nature of this document, it must be requested from the Boeing Company. NASA can assist in transfer of this document between Boeing and the FAA. Boeing must contractually provide all ATD-1-funded avionics reports to the appropriate parties in the FAA.

6.03 Task 3.1 Feasibility Assessment Report (Rev New) [Externally Delivered]
6.04 Task 3.1 Feasibility Assessment Briefing (dated September 20, 2012)
This Boeing report and briefing document the initial feasibility assessment of incorporating the Flight Deck Interval Management tools and displays into retrofit and forward-fit avionics packages (Task 3.1). The feasibility criteria included: information requirements, HMI implementation requirements, and operational feasibility with respect to the expected avionics systems that will be in service from 2016 to 2020. Due to the proprietary nature of these documents, they must be requested from the Boeing Company. NASA can assist in transfer of these documents between Boeing and the FAA. Boeing must contractually provide all ATD-1-funded avionics reports to the appropriate parties in the FAA.

6.05 Task 3.2 Concept Engineering Trade Studies Report (Rev New) [Externally Delivered]
This Boeing report documents the trade studies across architectural designs for incorporating the Flight Deck Interval Management tools and displays into retrofit and forward-fit avionics packages (Task 3.2). A total of 28 architectures involving seven trade variables were evaluated for the Boeing 787-8 and Boeing 737NG aircraft types. The trade variables included: voice versus datacomm, single versus dual side displays, single versus dual speed guidance displays, coupled versus manual speed control, location of speed control algorithm, and location of trajectory generator algorithm. Due to the proprietary nature of this document, it must be requested from the Boeing Company. NASA can assist in transfer of this document between Boeing and the FAA. Boeing must contractually provide all ATD-1-funded avionics reports to the appropriate parties in the FAA.

6.06 Task 3.3 Concept Engineering Prototypes Report (Rev A) [Externally Delivered]
6.07 Task 3.3 Concept Engineering Prototypes Briefing (dated February 28, 2013)
This Boeing report and briefing document the prototype demonstrations of the Flight Deck Interval Management tools and displays for retrofit and forward-fit avionics packages (Task 3.3). The details of the four configurations – Boeing 737NG versus Boeing 777, retrofit versus forward fit – are provided. The lab demonstration of the concept engineering prototypes was conducted February 28 – March 1, 2013 at Boeing's facilities in Seattle. Due to the proprietary nature of these documents, they must be requested from the Boeing Company. NASA can assist in transfer of these documents between Boeing and the FAA. Boeing must contractually provide all ATD-1-funded avionics reports to the appropriate parties in the FAA.

6.08 Task 3.3 Prototype Recommendation Report (Rev New) [Externally Delivered]
This Boeing report documents the ROM cost and schedule estimates for integrating the FIM prototype avionics into three government simulators and a test aircraft (Task 3.3). The simulators evaluated were the Integrated Flight Deck at NASA's Langley Research Center, the Advanced Concepts Flight Simulator at NASA's Ames Research Center, and a Boeing 737-800 engineering simulator at FAA's W. J. Hughes Technical Center. Due to the proprietary nature of this document, it must be requested from the Boeing Company. NASA can assist in transfer of this document between Boeing and the FAA. Boeing must contractually provide all ATD-1-funded avionics reports to the appropriate parties in the FAA.

6.09 Task 8 Final Report (Rev New) [Externally Delivered]
This Boeing report summarizes the contents of Papers 6.03, 6.05, 6.06, and 6.08. It is the final deliverable of the ATD-1 Avionics Phase 1 activity. Due to the proprietary nature of this document, it must be requested from the Boeing Company. NASA can assist in transfer of this document between Boeing and the FAA. Boeing must contractually provide all ATD-1-funded avionics reports to the appropriate parties in the FAA.

7) TMA Development Publications

This list covers all of the internal documentation related to development of a TMA prototype implementation of the ATD-1 capabilities. There are two phases – Phase 1 was integration of the ATD-1 capabilities into NASA's TMA and Phase 2 was integration of the ATD-1 capabilities into the Research TMA. The major documentation artifacts are included in the Tech Transfer Package. Additional lower-level documentation is also available for these efforts.

Paper 7.01. ATD-1 Scheduling Algorithm Overview (Version 2.0)
This document details the ATD-1 terminal metering scheduling algorithm implemented into both NASA's TMA and the Research TMA (based upon the FAA's TMA v3.12). The ATD-1 algorithm's

objectives, assumptions, and functional architecture are described in terms of its differences with respect to the original TMA algorithm. Flowcharts illustrating the algorithm's methods for scheduling and delay allocation are provided. Appendix A describes the key software changes (code additions as well as bug fixes) that were made to NASA's TMA as part of its Phase 1 development.

Paper 7.02. Controller Managed Spacing Tool Advisory Algorithm (Version 1.0)
This document details the ATD-1 controller-managed spacing algorithm implemented into both NASA's TMA and the Research TMA (based upon the FAA's TMA v3.12). The ATD-1 algorithm's goals, inputs/outputs, and numerical algorithm are described.

Paper 7.03. Overview of TMA RNP Route Processing (Version 1.0)
This document summarizes the changes made to support construction of RNP routes by both NASA's TMA and the Research TMA (based upon the FAA's TMA v3.12). These routes are constructed based upon the equipment identifier provided by the aircraft's ARTCC flight plan.

Paper 7.04. Overview of RTMA Trajectory Synthesis Changes (Version 1.0)
This document summarizes the changes made to support more precise TRACON trajectory synthesis by the Research TMA (based upon the FAA's TMA v3.12). Overall, there were just a few minor changes to the existing RTMA TS and its interface with the RA.

Paper 7.05. Overview of RTMA Dynamic Planner Changes (Version 1.0)
This document summarizes the changes made to support terminal metering by the Research TMA (based upon the FAA's TMA v3.12). Overall, these changes were made to the RTMA DP and its interface to the RA.

Paper 7.06. STARS-RTMA Functional Description (Version 1.0)
This document details the two-way message protocol between STARS and TMA and associated processing by components of Research TMA.

Paper 7.07. Required Navigation Performance (RNP) Radius Fix (RF) Leg Implementation for ATD-1 (Version 7)
This document details the algorithm used to build RNP Radius-to-Fix turns by both NASA's TMA and the Research TMA (based upon the FAA's TMA v3.12). This logic, in conjunction with the route building interface described in Paper 7.03, is needed to produce ATD-1 trajectories for aircraft flying RNP-AR turns from downwind to the final approach course.

Paper 7.08. Staggered Parallel ILS Approaches Algorithm in TMA (Version 1.0)
This document details the algorithm used to schedule with stagger runway separation for dependent parallel runway operations by NASA's TMA and Research TMA (based upon the FAA's TMA v3.12). This logic, in conjunction with the broader terminal metering capabilities was used to produce ATD-1 schedules for aircraft performing staggered operations to dependent parallel runways.

Paper 7.09. RTMA Source Code Change Analysis (Version 2.0)
This document provides information on the magnitude of code changes made to the RTMA 3.12 baseline in order to implement the ATD-1 Terminal Sequencing and Spacing capabilities.

Paper 7.10. RTMA 3.12 Software Package (File ID rtma-3.12-9f9d21)
This software package contains source code for the baseline RTMA version 3.12. It is a modified version of the FAA's TMA version 3.12. It was modified to run in the Linux environment used by NASA. There were no intentional functional changes made to this version of TMA. This version of

software can be referenced by the SHA hash acdda2c0d47dd88a8a770cc6db1755957b9f9d21 in NASA's git version control system.

Paper 7.11. RTMA ATD-1 Software Package (File ID rtma-atd1-9b12a1)
This software package contains source code for the modified RTMA version 3.12 that includes ATD-1 terminal sequencing and spacing capabilities. This version of software can be referenced by the SHA hash c798c5340148a2732a76ac548ea1321fa99b12a1 in NASA's git version control system.

NOTE: Earlier versions of the RTMA ATD-1 Software Package (Tech Transfer 1 and 2) can be referenced by the File ID rtma-atd1-d29f7e and the SHA hash e2025f79a9ba73bb6d32f023f5bec4c8eed29f7e in NASA's git version control system.

Paper 7.12. RTMA 3.12 Site Adaptation Package (File ID zab-faa-ZAB_T3.13.3_8.0E)
This RTMA site adaptation package contains the ZAB/PHX site adaptation for the baseline RTMA version 3.12. The ATD-1 CA-5.1 human-in-the-loop simulation was conducted using this site adaptation in order to compare ATD-1 operations with current operations. This version of site adaptation can be referenced by the label ZAB_T3.13.3_8.0E in NASA's ClearCase version control system.

Paper 7.13. RTMA ATD-1 Site Adaptation Package (File ID zab-atd1-d4258d)
This RTMA site adaptation package contains the ZAB/PHX site adaptation for the modified RTMA version 3.12 that includes ATD-1 terminal sequencing and spacing capabilities. It is based upon the FAA's ZAB/PHX referenced by the label ZAB_T3.13.3_1.0. All ATD-1 human-in-the-loop simulations that included ATD-1 tools, starting with the CA-4 simulation, were conducted using this site adaptation. This version of site adaptation can be referenced by the SHA hash 99f33f6c9b45464c86d437ee699b80535dd4258d in NASA's git version control system. Additional, but less mature, ZLA/LAX, ZFW/DFW, and ZFW/DAL site adaptations can be requested from NASA, if desired.

NOTE: Earlier versions of the RTMA ATD-1 Site Adaptation Package (Tech Transfer 1 and 2) can be referenced by the File ID zab-atd1-a84e10c and the SHA hash f1aa8562caae91b95d12f9c04bab10df7a84e10c in NASA's git version control system.

Paper 7.14. User Interface and Algorithmic Support for Controller Managed Spacing Tools (dated November 14, 2011)
This document details the first-generation ATD-1 controller-managed spacing algorithm implemented into NASA's Multi-Aircraft Control System (MACS). The CHI definition described in this document was used to formulate the initial STARS Enhancement and Simulation and Field Support contract (See Section 5). This paper is superseded by Paper 7.02.

Paper 7.15. RTMA Software Update (Version 1.0)
This document summarizes the additional changes made since September 2013 to support ATD-1 by the Research TMA (based upon the FAA's TMA v3.12). Refer to Paper 7.01 through 7.08 for the previous changes.

8) ATD-1 Simulation Outbriefs

This lists contains the internal simulation outbriefs for ATD-1 experiments. These outbriefs contain information about all aspects of the simulation including objectives, ConOps elements simulated, traffic and wind scenarios, metrics collected, and results. All substantial ATD-1 simulations are required to provide these outbriefs to the entire ATD-1 team shortly after execution of the simulation. Additional lower-level documentation, such as traffic scenarios, wind scenarios, controller and pilot training packages, and post-simulation controller and pilot questionnaires, are also available for these simulations.

Paper 8.01. ATD-1 Sim Experiments Overview (dated June 27, 2014)
This briefing provides high-level summaries of all of the ATD-1 large-scale simulations to date.

Paper 8.02. IM-NOVA Outbrief (dated October 30, 2012)
This briefing summarizes the entire IM-NOVA simulation.

Paper 8.03. TSS-1 Outbrief (dated February 22, 2013)
This briefing summarizes the entire TSS-1 simulation.

Paper 8.04. FIAT-1 Outbrief (dated February 12, 2013)
This briefing summarizes the entire FIAT-1 simulation.

Paper 8.05. CA-4 Outbrief (dated February 21, 2013)
This briefing summarizes the entire CA-4 simulation.

Paper 8.06. FIAT-2 and TSS-2 Outbrief (dated July 23, 2013)
This briefing summarizes the entirety of both the FIAT-2 and TSS-2 simulations.

Paper 8.07 I-SIM Outbrief (dated September 23, 2013)
This briefing summarizes the entire I-SIM CHI experiment.

Paper 8.08 FIAT-3 Outbrief (dated November 25, 2013)
This briefing summarizes the entire FIAT-3 simulation.

Paper 8.09 ASTAR Batch Study #1 Outbrief (dated August 15, 2013)
This briefing summarizes the entire ASTAR Batch Study #1.

Paper 8.10 CA-5.1 & 5.2 Outbrief (dated March 20, 2014)
This briefing summarizes the entire CA-5.1 and CA-5.2 simulations.

Paper 8.11 RAPTOR Outbrief (dated March 21, 2014)
This briefing summarizes the entire RAPTOR simulation.

Paper 8.12 FIAT-4 Outbrief Part 1 (dated March 14, 2014)
Paper 8.13 FIAT-4 Outbrief Part 2 (dated March 27, 2014)
These briefings summarize the entire FIAT-4 simulation. NOTE: These results were adversely impacted by a software problem associated with the forecasted temperature. Direct comparison of these results to other ATD-1 simulations is not advised.

Paper 8.14 AMPS Outbrief (dated June 26, 2014)
This briefing summarizes the entire AMPS simulation.

Paper 8.15 CA-5.3 Outbrief (dated June 30, 2014)
This briefing summarizes the entire CA-5.3 simulation.

Paper 8.16 TSS-1 Task Completion Report (dated September 28, 2012))
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the TSS-1 simulation.

Paper 8.17 CA-4 Task Completion Report (dated December 28, 2012)
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the CA-4 simulation.

Paper 8.18 FIAT-2 Task Completion Report (dated April 12, 2013)
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the FIAT-2 simulation.

Paper 8.19 FIAT-3 Task Completion Report Revision 1 (dated September 13, 2013)
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the FIAT-3 simulation.

Paper 8.20 FIAT-4 Task Completion Report Revision 1 (dated March 31, 2014)
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the FIAT-4 simulation.

Paper 8.21 CA-5.3 Task Completion Report Revision 1.2 (dated May 2, 2014)
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the CA-5.3 simulation.

Paper 8.22 RAPTOR Task Completion Report Revision 1.2 (dated May 28, 2014)
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the RAPTOR simulation.

Paper 8.23 Arrival Metering Precision Study (AMPS) Draft Task Completion Report (dated June 23, 2014)
This report documents the observations and recommendations provided by the Human Solutions, Inc. subject matter experts and human factors observers for the AMPS simulation.

9) ATD-1 Project-Level Documents

This list contains various internal documents that have specifically been requested by the FAA.

Paper 9.01 ATD-1 Site Survey Briefing (dated October 24, 2012)
This NASA briefing documents the initial site survey approach and results used to select PHX for more in-depth ATD-1 human-in-the-loop simulations.

Paper 9.02 ATD-1 Measures of Performance (Rev B)
This NASA document defines the system engineering measures of performance that must be tracked for each large-scale ATD-1 human-in-the-loop simulation.

Paper 9.03 ATD-1 Traffic Scenario Description (Rev 1.0, dated February 18, 2014)
This NASA document lists the traffic periods that are available to generate traffic scenarios for ATD-1 human-in-the-loop simulations. These prescribed traffic periods were identified to cover a broad range of traffic levels, arrival rush topologies, and airport configurations. A primary reason for constraining the traffic scenario development to a limited set of traffic conditions was to develop a

common set of ATD-1 traffic scenarios that were based upon actual PHX operations. Note: the ATD-1 traffic and wind scenarios are independently specified and only need to match their corresponding landing direction.

Paper 9.04 ATD-1 Wind Scenarios Description (Version 2.0, dated June 7, 2013)
This NASA document lists the wind scenarios that are available to use for ATD-1 human-in-the-loop simulations. These prescribed wind files were identified to cover a broad range of wind direction, magnitude, and time-of-day. Each wind scenario includes a "truth" wind and a "forecast" wind specifically chosen to match expected wind prediction errors. A primary reason for constraining the wind scenario development to a limited set of wind conditions was to develop a common set of ATD-1 wind scenarios that were based upon actual PHX conditions. Note: the ATD-1 traffic and wind scenarios are independently specified and only need to match their corresponding landing direction.

10) Additional Technical Publications

This list covers all of the ATD-1 technical publications published to date. It covers publications indirectly related to ATD-1 technologies (terminal metering, controller-managed spacing tools, and flight deck interval management) and their development. The papers are ordered by date to show the progression.

Paper 10.01. Knowledge-based Runway Assignment for Arrival Aircraft in the Terminal Area (GNC 1997)
This paper dates back to our Passive Final Approach Spacing Tool (pFAST). The TAPSS and ATD-1 work leverages the simpler delay-minimizing runway allocation logic of TMA. The earlier pFAST work was much more complex and considered tactical decisions that terminal controllers were making at DFW. This information might be helpful in addressing some of the research questions listed in the Terminal Metering Concept of Operations for the Mid-Term document authored by MITRE. [Formerly Paper 3D]

Paper 10.02 Speed Control Law for Precision Terminal Area In-Trail Self Spacing (NASA/TM-2002-211742)
This paper describes an earlier flight deck interval management algorithm called the Advanced Terminal Area Approach Spacing (ATASS). This algorithm was designed only for the final approach phase of flight. This concept was extended to include paired spacing initiation much further from the runway near top-of-descent. This paper is superseded by Paper 3.24 that describes the ASTAR algorithm Version 11.

Paper 10.03. Human-in-the-Loop Evaluation of NextGen Concepts in the Airspace Operations Laboratory (MST 2010)
This paper provides an overview of the NASA Ames Airspace Operations Lab (AOL). I am listing it here more as reference. Historically, CMS experiments have been run in the AOL, while TAPSS experiments have been run in the NASA Ames Air Traffic Management Lab (ATML). For the duration of ATD-1, these labs will have all of same capabilities and be indistinguishable. [Formerly Paper 3C]

Paper 10.04. Design of an Optimal Route Structure Using Heuristics-Based Stochastic Schedulers (DASC 2010)
This paper investigated the impact of route topology on scheduling efficiency (i.e., delay). The fundamental question being posed (but left unanswered) is "How does route topology affect the

efficiency of the schedule and/or the complexity of the scheduler. Unfortunately, this area of research was suspended when the PI left NASA and I started ATD-1. I believe there are likely route design constraints related to the scheduler/scheduling that should augment the route design constraints related to the controller/pilot. [Formerly Paper 3B]

Paper 10.05. <u>Estimating ATM Efficiency Pools in the Descent Phase of Flight</u> (ATM 2011)
This FAA/EUROCONTROL paper extended the NASA study presented in Paper 3.02 to include horizontal efficiency benefits. These results show that upstream (i.e., en route) use of speed control is needed to effectively recover the lost horizontal and vertical efficiency during periods of delay. [Formerly Paper 2F]

Paper 10.06. <u>Relative Position Indicator for Merging Mixed RNAV and Vectored Arrival Traffic</u> (DASC 2011)
This paper compared the performance of distance-based spacing tools (like RPI) and trajectory-based spacing tools (like CMS). Figures 10 and 11 show that the trajectory-based approach caused many fewer vectored flights (i.e., flights taken off their RNAV route). [Formerly Paper 3A]