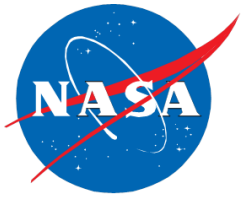

Airspace Technology Demonstration 3 (ATD-3)

Dynamic Routes for Arrivals in Weather (DRAW)

Technology Transfer Document Summary

Version 2.0

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Revision History

Rev	Date	Sections Affected	Description of Change	Author
1.0	06/22/2018	All	Initial version	DIsaacson ABiederman EWang
2.0	09/30/2019	Introduction 2. High-Level Documents 3. Technical Publications 4. Dynamic Routes for Arrivals in Weather Technology Artifacts 5. Simulation and Evaluation Results	Added artifacts for DRAW Tech Transfer #2	DIsaacson ABiederman EWang

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Introduction

Airspace Technology Demonstration – 3 (ATD-3) is part of NASA's Airspace Operations and Safety Program (AOSP) – specifically, its Airspace Technology Demonstrations (ATD) Project. ATD-3 is a multi-year research and development effort which proposes to develop and demonstrate automation technologies and operating concepts that enable air navigation service providers and airspace users to continuously assess weather, winds, traffic, and other information to identify, evaluate, and implement workable opportunities for flight plan route corrections that can result in significant flight time and fuel savings in en route airspace. 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.

This summary document and accompanying technology artifacts satisfy the third Research Transition Product (RTP) defined in the Applied Traffic Flow Management (ATFM) Research Transition Team (RTT) Plan, which is Dynamic Routes for Arrivals in Weather (DRAW). This technology transfer consists of artifacts for DRAW Arrival Metering (AM) Operations delivered in June 2018, DRAW AM updates, and DRAW Extended Metering (XM) Operations. Blue highlighting indicates the new or modified deliverables.

Some of the artifacts in this technology transfer have distribution restrictions that need to be followed. Distribution information is noted in each section.

DRAW is a trajectory-based system that combines the legacy Dynamic Weather Routes (DWR) weather avoidance technology with an arrival-specific rerouting algorithm and arrival scheduler to improve traffic flows on weather-impacted arrival routes into major airports. First, DRAW identifies flights that could be rerouted to more efficient Standard Terminal Arrival Routes (STARs) that may have previously been impacted by weather. Second, when weather is impacting the arrival routing, DRAW proposes simple arrival route corrections that enable aircraft to stay on their flight plan while avoiding weather. The DRAW system proposes reroutes early enough to allow Time Based Flow Management (TBFM) to make the necessary schedule adjustments. As a result, metering operations can be sustained longer and more consistently in the presence of weather because the arrival schedule accounts for the dynamic routing intent of arrival flights to deviate around weather.

The first DRAW tech transfer in June 2018 focused on arrival metering operations with the DRAW algorithm implemented in the NASA Center TRACON Automation System (CTAS) automation software. This tech transfer delivery includes updates for DRAW implemented in FAA's TBFM 4.7 automation software and preliminary research into DRAW for XM operations.

1) Public Outreach Materials

This section contains high-level descriptions and multi-media products appropriate for the general public. Distribution outside of the U.S. Government is permitted without restrictions for artifacts in this section.

1.01. ATD-3 Fact Sheet (April 2017)

The ATD-3 factsheet describes NASA's concept for improving efficiency and throughput in the en-route and arrival phases of flight through the integration of ground- and flight-deck based technologies, including DRAW. The factsheet is publicly available on the NASA Ames Aviation System Division webpage: https://www.aviationsystems.arc.nasa.gov/research/strategic/atd3.shtml.

1.02. ATD-3 Integrated Concept Animation V1.1 (May 2017) [External Link]

This animation illustrates the current operational challenge of convective weather and the goals of the ground and flight-deck tools that comprise the ATD-3 integrated concept. The 5-minute animation, geared for technical audiences, is available for viewing at the NASA Ames Aviation System Division webpage: https://www.aviationsystems.arc.nasa.gov/research/strategic/atd3.shtml.

1.03. ATD-3 Integrated Concept Animation V1.2 (October 2017) [External Link]

This animation provides a high-level overview of the ATD-3 integrated concept. The 2-minute animation for broader audiences is available for viewing at the NASA Ames Aviation System Division webpage: https://www.aviationsystems.arc.nasa.gov/research/strategic/atd3.shtml.

2) High-Level Documents

This section contains the high-level documents that describe the ATD-3 or DRAW Concept of Operations. Distribution outside of the U.S. Government is permitted without restrictions for artifacts in this section.

2.01. NASA/TM–2018–219930 ATD-3 Operational Concept for the Integration of ATD-3 Capabilities, V1.0 (KSheth, June 2018)

This document provides the concept of operations for the ATD-3 Sub-Project, and describes how the integration of NASA-developed automation tools, both ground- and flight-deck-based, can reduce en-route delays by identifying amendments to inefficient or outdated constraint avoidance routes that improve aircraft efficiency and enable traffic flow managers and air traffic controllers to maintain throughput in the presence of airspace constraints, e.g., convective weather.

2.02. ATD-3 Dynamic Routes for Arrivals in Weather (DRAW) Concept of Operations, V2.0 (DIsaacson, September 2019)

The purpose of this document is to provide the concept of operations for the DRAW technology and describe how DRAW provides automated rerouting capabilities for Traffic Management Coordinators in response to inefficient or obsolete weather avoidance routes so that time-based metering may be maintained. This ConOps describes the essential conceptual and operational elements associated with DRAW operations that serve to inform development of solutions across many actors and interested parties involved in implementing DRAW.

2.03. ATD-3 Dynamic Routes for Arrivals in Weather (DRAW) Measures of Performance Specifications Document, V1.1 (MAmer, March 2018)

This document provides the DRAW System's Measures of Performance. The Measures of Performance described in this document explain which performance characteristics of DRAW were used in driving development forward and were considered crucial to DRAW's success. Each Measure is explained with a description, a threshold value, a goal value, the calculation method, and the data sources used in calculation. These specifications are used to assess the outcomes of each DRAW activity, including human-in-the-loop simulations and fast time simulations.

3) Technical Publications

This section describes DRAW at the technology level – including simulation or field trial results, algorithm descriptions, and data analyses. Distribution outside of the U.S. Government is permitted without restrictions for artifacts in this section.

3.01. Laboratory Evaluation of Dynamic Routing of Air Traffic in En Route Arrival Metering Environment (DIsaacson, Aviation2018)

The purpose of this document is to formally present the experimental setup, methodology, results, and conclusions of the DRAW HITL #2 simulation evaluation, conducted in October 2017 at NASA Ames Research Center.

3.02 Evaluation of a Dynamic Weather-Avoidance Rerouting Tool in Adjacent-Center Arrival Metering (MHayashi, ATM2019)

This paper focuses on how DRAW benefits metering delivery accuracy when schedule freeze horizon distance was altered. A human-in-the-loop simulation was conducted at NASA Ames Research Center in October-November 2018, where retired TMCs and controllers performed simulated metering operations for southeast arrivals through the Atlanta and Jacksonville Centers to the Hartsfield-Jackson Atlanta International Airport during convective weather periods.

4) Dynamic Routes for Arrivals in Weather Technology Artifacts

This section contains the DRAW functional requirements and internal documentation related to development of the DRAW prototype implementation. **Distribution outside of the U.S. Government requires prior approval by NASA.**

4.01. ATD-3 Dynamic Routes for Arrivals in Weather (DRAW) Systems Requirements Document Phase 1 – Arrival Metering Operations, V1.4 (ABiederman, September 2019)

This document provides the system requirements for the development of the DRAW Phase 1 simulation systems and products. The requirements provided in this document are maintained in NASA's ATD-3 CORE™ model-based systems engineering database. Each requirement includes a hierarchical number,

permanent project unique identifier (PUID), requirement title, rationale, and verification method. It defines the system conditions and requirements to allow the capabilities to function properly to produce benefits.

This updated document now includes requirements intended for XM use, derived from Subject Matter Expert (SME) feedback on a DRAW-enabled prototype of TBFM with extended metering operations.

4.02 ATD-3 Dynamic Routes for Arrivals in Weather (DRAW) Test Procedures, v1.5 (ABiederman, June 2019)

This document contains the test procedures used verify DRAW system requirements for Arrival Metering operations in TBFM. These procedures verified the DRAW software used in HITL5 in July 2019.

4.03 ATD-3 DRAW TMC Quick Reference Guide (July 2019)

This document was part of the Traffic Management Coordinator (TMC) training during HITL5 in July 2019.

4.04 ATD-3 DRAW Multi-Threaded Dynamic Planner (MTDP) for Arrival Metering Software Design Overview (CLee, September 2019)

This document gives an overview of the DRAW implementation of a multi-threaded version of the TBFM Dynamic Planner functionality. This capability enables the trial planning features of DRAW.

4.05 ATD-3 DRAW How To Install, Configure, and Run TBFM (CLee, September 2019)

This document contains instructions for installing, configuring, and running DRAW in TBFM.

4.06 ATD-3 TBFM 4.7 DRAW Arrival Metering Software and Adaptation Package (September 2019)

This package contains source code for the modified TBFM version 4.7 that includes ATD-3 DRAW arrival metering capabilities. This version of software can be referenced by the SHA hash a2b6f0190b8387eb049f6bc75e5abf96d13e0807 in NASA's git version control system.

This package also contains the ZFW/D10 adaptation for the modified TBFM version 4.7 that includes ATD-3 DRAW arrival metering capabilities. It is based upon the FAA's ZFW referenced by the label ZFW_T4.7.1_5.0. This version of site adaptation can be referenced by the SHA hash 33a7b618be49bee85177ccd8b1800bc2733d169e in NASA's git version control system.

4.07 ATD-3 TBFM 4.7 DRAW Extended Metering Software and Adaptation Package (September 2019)

This package contains source code for the modified TBFM version 4.7 that includes ATD-3 DRAW extended metering capabilities. This version of software can be referenced by the SHA hash c8161431a437cee0f8ec8ac28952846d53cea3ab in NASA's git version control system.

This package also contains the ZFW/D10 and EDC adaptation for the modified TBFM version 4.7 that includes ATD-3 DRAW extended metering capabilities. It is based upon the FAA's ZFW referenced by the label ZFW_T4.7.1_10.1A. This version of site adaptation can be referenced by the SHA hash

b356ef06bba646a67ec1a58bc996b2aa705e8e98 in NASA's git version control system.

4.08 ATD-3 DRAW Gap Analysis (September 2019)

This document provides a summary of items identified by researchers, software developers, and Subject Matter Experts (SMEs) as remaining to be conducted/completed to prepare DRAW for an FAA investment decision. Also included is the estimated software development effort for each task identified in the gap analysis toward TRL5 capability.

5) Simulation and Evaluation Results

This section contains the in-depth summaries of DRAW human-in-the-loop simulations and evaluations. **Distribution outside of the U.S. Government requires prior approval by NASA.**

5.01. Executive Summary: Dynamic Routes for Arrivals in Weather (DRAW) Human-in-the-Loop (HITL) Simulation #1 (CGong, June 2017)

The DRAW HITL #1 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center in May 2017. The primary technical objective of DRAW HITL #1 was to obtain feedback on DRAW technology usage and concept of operations from traffic management and air traffic control subject matter experts (SME) for current single-scheduler, arrival metering operations. This document provides a brief summary of the HITL #1 outcome, preliminary results, and any anomalies presented during the experiment.

5.02. ATD-3 Outbrief for Dynamic Routes for Arrivals in Weather (DRAW) Simulation Evaluation #1 (CGong, August 2017)

The DRAW HITL #1 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center in May 2017. The purpose of this outbrief is to provide a detailed description of how the HITL was conducted as well as the results. It includes the test outcome, analysis and results, Measures of Performance (MOP) results, and future development needs.

5.03. DRAW HITL #1 Verification and Validation Report (MAmer, July 2017)

The DRAW software verification of ATD-3 requirements was completed for requirements selected per the ATD-3 Simulation Requirements Verification Matrix (RVM) and evaluated during DRAW HITL #1 Simulations. The verification of these requirements using the ATD-3 DRAW test procedures is documented in this report, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer.

5.04. Executive Summary: Dynamic Routes for Arrivals in Weather (DRAW) Human-in-the-Loop (HITL) Simulation #2 (CGong, November 2017)

The DRAW HITL #2 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over eleven days in October 2017. HITL #2 expanded the Traffic Management Coordinator (TMC)-focused HITL simulation capability from single to multiple arrival-corner-post

operations. Improvements to the experiment design for HITL #2 allowed for more data points for analysis and additional SME feedback. This document provides a brief summary of the HITL #2 outcome, preliminary results, and any anomalies presented during the experiment.

5.05. ATD-3 Outbrief for Dynamic Routes for Arrivals in Weather (DRAW) Simulation Evaluation #2 (CGong, January 2018)

The DRAW HITL #2 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over eleven days in October 2017. The purpose of this outbrief is to provide a detailed description of how the HITL was conducted as well as the results. It includes the test outcome, analysis and results, Measures of Performance (MOP) results, and future development needs.

5.06. ATD-3 DRAW HITL #2 Verification and Validation Report (MAmer, November 2017)

The DRAW software verification of ATD-3 requirements was completed for requirements selected per the ATD-3 Simulation Requirements Verification Matrix (RVM) and evaluated during DRAW HITL #2 Simulations. The verification of these requirements using the ATD-3 DRAW test procedures is documented in this report, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer.

5.07. Executive Summary: Dynamic Routes for Arrivals in Weather (DRAW) Human-in-the-Loop (HITL) Simulation #3 (DIsaacson, May 2018)

The DRAW HITL #3 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over ten days in April and May 2018. HITL #3 expanded to a new airspace and assessed DRAW operations in a more realistic arrival metering environment. Improvements to the experiment design for HITL #3 allowed for more efficient data collection for analysis and additional SME feedback. This document provides a brief summary of the HITL #3 outcome, preliminary results, and any anomalies presented during the experiment.

5.08. ATD-3 Outbrief for Dynamic Routes for Arrivals in Weather (DRAW) Simulation Evaluation #3 (DIsaacson, June 2018)

The DRAW HITL #3 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over ten days in April and May 2018. The purpose of this outbrief is to provide a detailed description of how the HITL was conducted as well as the results. It includes the test outcome, analysis and results, Measures of Performance (MOP) results, and future development needs.

5.09. ATD-3 DRAW HITL #3 Verification and Validation Report (ABiederman, June 2018)

The DRAW software verification of ATD-3 requirements was completed for requirements selected per the ATD-3 Simulation Requirements Verification Matrix (RVM) and evaluated during DRAW HITL #3 Simulations. The verification of these requirements using the ATD-3 DRAW test procedures is documented in this report, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer.

5.10. DRAW HITL Requirements Verification Matrix (ABiederman, May 2018)

The verification of DRAW requirements using the ATD-3 DRAW test procedures is summarized in this document, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer. This document covers HITLs 1, 2, and 3.

5.11 Executive Summary: Dynamic Routes for Arrivals in Weather (DRAW) Human-in-the-Loop (HITL) Simulation #4 (DIsaacson, November 2018)

The DRAW HITL #4 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over ten days in October and November 2018. HITL #4 was designed to build on preceding studies in three ways: 1) evaluate DRAW metering operations and weather impact mitigation across multiple Air Route Traffic Control Centers (ARTCCs), 2) assess the effects of different schedule freeze horizon distances on DRAW performance, and 3) investigate DRAW reroute coordination with expanded operations including Atlanta Center and Jacksonville Center. This document provides a brief summary of the HITL #4 outcome, preliminary results, and any anomalies presented during the experiment.

5.12 DRAW Human-in-the-Loop Simulation Evaluation #4 Outbrief (DIsaacson, June 2019)

The DRAW HITL #4 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over ten days in October and November 2018. The purpose of this outbrief is to provide a detailed description of how the HITL was conducted as well as the results. It includes the test outcome, analysis and results, Measures of Performance (MOP) results, and future development needs.

5.13 ATD-3 DRAW HITL #4 Verification & Validation Test Report (ABiederman, September 2018)

The DRAW software verification of ATD-3 requirements was completed for requirements selected per the ATD-3 Simulation Requirements Verification Matrix (RVM) and evaluated during DRAW HITL #4 Simulations. The verification of these requirements using the ATD-3 DRAW test procedures is documented in this report, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer.

5.14 ATD-3 DRAW HITL #4 Requirements Verification Matrix (ABiederman, September 2018)

The verification of DRAW HITL #4 requirements using the ATD-3 DRAW test procedures is summarized in this document, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer.

5.15 Executive Summary: Dynamic Routes for Arrivals in Weather (DRAW) Human-in-the-Loop (HITL) Simulation #5 (DIsaacson, August 2019)

The DRAW HITL #5 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over nine days in July and August 2019. HITL #5 was a significant departure from prior DRAW HITLs in three ways. Foremost, HITL #5 was the first study to employ the FAA's Time-Based Flow Management (TBFM) system for arrival metering, whereas prior DRAW HITLs employed a NASA rapid

prototyping system. Second, HITL #5 included only Traffic Management Coordinator (TMC) participants, whereas prior studies included both TMC and controller participants. Lastly, HITL #5 included arrival operations for all four corner posts feeding arrivals into Dallas-Fort Worth TRACON (DFW TRACON, or D10), which had only occurred for a portion of DRAW HITL #2. This document provides a brief summary of the HITL #5 outcome, preliminary results, and any anomalies presented during the experiment.

5.16 DRAW Human-in-the-Loop Simulation Evaluation #5 Outbrief (DIsaacson, September 2019)

The DRAW HITL #5 evaluation was conducted in the Air Traffic Control Laboratory at NASA Ames Research Center over nine days in July and August 2019. The purpose of this outbrief is to provide a detailed description of how the HITL was conducted as well as the results. It includes the test outcome, analysis and results, Measures of Performance (MOP) results, and future development needs.

5.17 ATD-3 DRAW HITL #5 Verification & Validation Test Report (ABiederman, July 2019)

The DRAW software verification of ATD-3 requirements was completed for requirements selected per the ATD-3 Simulation Requirements Verification Matrix (RVM) and evaluated during DRAW HITL #5 Simulations. The verification of these requirements using the ATD-3 DRAW test procedures is documented in this report, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer.

5.18 ATD-3 DRAW HITL #5 Requirements Verification Matrix (ABiederman, July 2019)

The verification of DRAW HITL #5 requirements using the ATD-3 DRAW test procedures is summarized in this document, which contains the results (PASS/FAIL) and supporting comments by the DRAW Systems Engineer.

5.19 ATD-3 DRAW Extended Metering (XM) Requirements Verification Matrix (ABiederman, September 2019)

This document contains DRAW XM requirements added to the HITL #5 RVM for completeness and conformity to the DRAW SRD v1.4. The XM requirements were not implemented or tested in HITL5.