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Traffic Aware Strategic Aircrew Requests (TASAR) Analysis and Development Final Report

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May 2016

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PREFACE

This document is the final report and deliverable 30 of Contract No. NNL12AA06C, the Traffic Aware Strategic Aircrew Requests (TASAR) contract awarded via the NASA Research Announcement (NRA). It documents the accomplishments of the contract, the evolution of its role in the overall TASAR project, and lessons learned from its execution.

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1 OVERVIEW

1.1 Contract Objective

The Traffic Aware Strategic Aware Requests (TASAR) project investigates the benefits, technical requirements and operational capabilities of a cockpit-based tool that provides traffic-free optimizations to an aircraft's route. Contract No. NNL12AA06C, "TASAR Analysis and Development," the first of two NASA Research Announcement (NRA) contracts within the TASAR project, was awarded to Engility Corporation and had four main tasks:

- TASK 1 – A Benefits Analysis and a Concept of Operations
- TASK 2 – Development of a Software Prototype, the Traffic Aware Planner (TAP)
- TASK 3 – Certification and Operational Approval of Flight Trial 1 (FT-1)
- TASK 4 – Conduct FT-1 and Analyze Results

The contract initially had a period of performance of two years from February, 2012 to February, 2014. A second NRA contract under the TASAR project, Contract No. NNL12AA1C, "TASAR Implementation and Pilot Assessments," awarded in March 2012 to Rockwell Collins, explored the certification and operational approval requirements of the TASAR concept, as well as the conduction of a human-in-the-loop (HITL) experiment to assess its use by pilots and controllers. This final report documents the accomplishments of the Engility Corporation contract.

1.1.1 Contract Modifications

As development of the software prototype and preparations for FT-1 progressed, requirements for integrating into real cockpit environments, and the need to investigate data sources and expand analysis capabilities necessitated modifications to the contract, including:

- Modification 2 (September, 2012)
    a. Develop a Data Concentrator Emulator (DCE)
    b. Investigate Internet-based data sources
    c. iOS Feasibility Analysis
- Modification 4 (May, 2013)
    a. Provide technical support for HITL experiment on parallel NRA
    b. Present a conference paper of the FT-1 results
- Modification 6 (July, 2013)
    a. Develop benefit analysis tools for TAP recorded data
    b. Handle ARINC-702A-1 data in both DCE and TAP
    c. Develop a generic trajectory generator (TG) to support multiple aircraft types

With the success of FT-1, which was conducted in November, 2013, and the positive response to the results of the Benefits Analysis under Task 1, the TASAR project expanded toward performing operational trials of the concept, using TAP, on two partner airlines. Subsequently, the NRA was modified to add a second flight trial (FT-2) to verify TAP's ability to operate on partner airline hardware, expand analysis capabilities and conduct on-site observations of air traffic control (ATC). Development of the software prototype, which expanded extensively in preparation for the operational trials, was shifted from the NRA to the Langley Information Technology Enhanced Services (LITES) contract, and the period of performance of the NRA was extended to January 31, 2016.

- Modification 7 (February, 2014)
    a. Preliminary assessment of integration and certification requirements for installing TAP on two partner airlines
- Modification 8 (March, 2014)
    a. Benefits Analysis for two partner airlines
    b. Moved development and documentation of TAP to LITES contract, including the generic TG development under Modification 6
    c. Perform an external data sources analysis
    d. Perform a trajectory-change constraints analysis
- Modification 9 (May, 2014)
    a. Prepare, certify, and conduct FT-2
- Modification 10 (August, 2014)
    a. Expand data source analysis to include weather sources used by partner airlines
    b. Develop system requirements for pilot/dispatcher coordination
    c. Installation and adaptation requirements for partner airlines
    d. Certification and operational approval of TAP on partner airlines
    e. Conduct on-site observations of ATC during FT-2
- Modification 11 (February, 2015)
    a. Further develop TASAR concept with aircraft-dispatch connectivity/integration (C/I)
    b. Develop benefit analysis approach for aircraft-dispatch C/I
    c. Develop requirements for including turbulence and icing hazards
    d. Augment quantitative analysis of FT-2 objectives
    e. Develop data collection and analysis plans for each partner airline
- Modification 14 (September, 2015)
    a. Create an update of the TAP software conference paper
    b. Extend data source analysis to include sources available via FAA System Wide Information Management (SWIM)
    c. Extend data source analysis to include feasibility of using onboard radar weather data
    d. Develop tools to implement partner airline data analysis
    e. Remove deliverables that are overtaken by events (OBE)

1.1.2 Future work

Since TASAR is expected to promote operational autonomy in the Next Generation Air Transportation Systems (NextGen), the project is expected to continue as part of the ATD-3 initiative beyond January, 2016 under the support of the Langley Information Technology Enhanced Services-II (LITES-II) contract. The operational trials of the TAP system on the first of the two partner airlines, Alaska Airlines (Alaska) are currently scheduled to begin in April, 2015.

1.2 Contract Team

Engility Corporation (Engility) was the prime contractor for the NRA, with Advanced Aerospace Solutions (AdvAero) as a sub-contractor. Engility handled the analysis and software development, and AdvAero planned, certified and conducted the two flight trials as well as provided support in identifying certification issues for the operational trials on the partner airlines. Status reporting and contract management was done by Sharon Woods of Engility.

The benefits analysis, concept of operations and data source analysis work was primarily performed by Dr. Jeffrey Henderson of Engility. Dr. Husni Idris and Dr. Gabriele Enea performed the ATC observations portion of FT-2. Robert Vivona, who was also the contract's subject matter expert (SME), developed the methodology to analyze TAP's computed outcomes for accuracy and assisted Dr. Henderson in several analysis tasks.

Software development was initially performed by Sharon Woods and Brendan LeFebvre of Engility Corporation. When the development work was shifted to the LITES contract, David Roscoe, Dr. David Karr, Stephen DePascale and Andres Danzinger joined the effort, under the lead of Robert Vivona.

John Maris of AdvAero was the principal investigator (PI) of both flight trials, as well as safety pilot for many of the flight trial flights. Mark Haynes of AdvAero was the Test Director of both flight trials, including all post-analysis and reporting. Marie-Helene Larose and Ludovic Laberge of AdvAero were the flight engineers of both flight trials and Eric Cardon was the aircraft captain and safety pilot.

1.3 Contents

This document will contain the following:

1. A brief description of each task of the contract, followed by which deliverables were submitted under that task, and a summary of what was accomplished in the contract's period of performance (POP).
2. A brief summary of the lessons learned from the contract, as discussed during the final technical meeting held in December, 2015.

2 PROJECT TASKS

2.1 CDR - Contract Documentation Requirements

This task covers the contract reporting requirements as defined in Exhibit B of the TASAR NNL12AA06C Contract. Table 1 summarizes all the documents sent to NASA under this task. These reports were written by Sharon Woods of Engility with input from all team members as necessary.

Under Modification 8, the maintenance of the Software Development Plan (SDP) and all its subsections was shifted to the LITES contracts. The deliverables listed here are the last versions of the SDP documents delivered under the NRA.

Table 1 - Contract Documentation Requirements Deliverables

DEL #	Task	Description	Submitted
CDR 1	CDR	Monthly Status (POP 2/10/12 – 3/9/12)	March 9, 2012
CDR 1	CDR	Monthly Status(POP 3/12/12 – 4/13/12)	April 13, 2012
CDR 1	CDR	Monthly Status(POP 4/16/12 – 5/11/12)	May 11, 2012
CDR 1	CDR	Monthly Status(POP 5/14/12 – 6/8/12)	June 8, 2012
CDR 1	CDR	Monthly Status(POP 6/11/12 – 7/13/12)	July 13, 2012
CDR 1	CDR	Monthly Status(POP 7/13/12 – 8/10/12)	August 10, 2012
CDR 1	CDR	Monthly Status(POP 9/13/12 – 10/12/12)	October 15, 2012
CDR 1	CDR	Monthly Status(POP 10/15/12 – 11/9/12)	November 9, 2012
CDR 1	CDR	Monthly Status(POP 11/12/12 – 12/14/12)	December 14, 2012
CDR 1	CDR	Monthly Status(POP 12/17/12 – 1/11/13)	January 11, 2013
CDR 1	CDR	Monthly Status(POP 1/14/13 – 2/8/13)	February 7, 2013
CDR 1	CDR	Monthly Status(POP 3/16/13 – 4/12/13)	April 12, 2013
CDR 1	CDR	Monthly Status(POP 4/15/13 – 5/10/13)	May 10, 2013
CDR 1	CDR	Monthly Status(POP 5/13/13 – 6/14/13)	June 14, 2013
CDR 1	CDR	Monthly Status(POP 6/17/13 – 7/12/13)	July 12, 2013
CDR 1	CDR	Monthly Status(POP 7/15/13 – 8/9/13)	August 8, 2013
CDR 1	CDR	Monthly Status(POP 8/12/13 – 9/13/13)	September 16, 2013
CDR 1	CDR	Monthly Status(POP 9/16/13 – 10/18/13)	October 18, 2013
CDR 1	CDR	Monthly Status(POP 11/14/13 – 12/13/13)	December 13, 2013
CDR 1	CDR	Monthly Status(POP 12/16/13 – 1/13/14)	January 13, 2014
CDR 1	CDR	Monthly Status(POP 1/13/14 – 2/14/14)	February 14, 2014
CDR 1	CDR	Monthly Status(POP 2/17/14 – 3/14/14)	March 13, 2014
CDR 1	CDR	Monthly Status(POP 3/17/14 – 4/11/14)	April 11, 2014
CDR 1	CDR	Monthly Status(POP 4/14/14 – 5/16/14)	May 16, 2014
CDR 1	CDR	Monthly Status(POP 5/19/14 – 6/13/14)	June 13, 2014
CDR 1	CDR	Monthly Status(POP 7/22/14 – 8/15/14)	August 15, 2014
CDR 1	CDR	Monthly Status(POP 8/18/14 – 9/12/14)	September 15, 2014
CDR 1	CDR	Monthly Status(POP 9/15/14 – 10/17/14)	October 17, 2014
CDR 1	CDR	Monthly Status(POP 10/20/14 – 11/14/14)	November 14, 2014
CDR 1	CDR	Monthly Status(POP 11/17/14 – 12/12/14)	December 12, 2014
CDR 1	CDR	Monthly Status(POP 12/15/14 – 1/9/15)	January 9, 2015
CDR 1	CDR	Monthly Status(POP 1/12/15 – 2/13/15)	February 13, 2015

CDR 1	CDR	Monthly Status(POP 2/17/15 – 3/13/15)	March 13, 2015
CDR 1	CDR	Monthly Status(POP 3/16/15 – 4/10/15)	April 9, 2015
CDR 1	CDR	Monthly Status(POP 4/13/15 – 5/8/15)	May 8, 2015
CDR 1	CDR	Monthly Status(POP 6/10/15 – 7/10/15)	July 13, 2015
CDR 1	CDR	Monthly Status(POP 7/13/15 – 8/14/15)	August 14, 2015
CDR 1	CDR	Monthly Status(POP 8/17/15 – 9/11/15)	September 15, 2015
CDR 1	CDR	Monthly Status(POP 9/14/15 – 10/9/15)	October 9, 2015
CDR 1	CDR	Monthly Status(POP 10/13/15 – 11/13/15)	November 12, 2015
CDR 1	CDR	Monthly Status(POP 11/16/15 – 12/11/15)	December 11, 2015
CDR 2	CDR	Software Development Plan (SDP) v1.0	March 9, 2012
CDR 2	CDR	Software Development Plan (SDP) v1.1	April 30, 2012
CDR 2	CDR	Software Development Plan (SDP) v1.2	May 7, 2012
CDR 2	CDR	Software Development Plan (SDP) v2.0	September 20, 2013
CDR 2	CDR	Software Requirements Spec. (SRS) v1.0	April 30, 2012
CDR 2	CDR	Software Requirements Spec. (SRS) v1.1	May 7, 2012
CDR 2	CDR	Software Requirements Spec. (SRS) v2.0	September 20, 2013
CDR 2	CDR	Software Test Plan (STP) v1.0	August 29, 2012
CDR 2	CDR	Software Test Plan (STP) v1.1	September 17, 2012
CDR 2	CDR	Software Test Plan (STP) v2.0	September 20, 2013
CDR 2	CDR	Software Design Description (SDD) v1.0	June 15, 2012
CDR 2	CDR	Software Design Description (SDD) v2.0	September 20, 2013
CDR 2	CDR	Software Version Description (SVD) Build 1.0	November 16, 2012
CDR 2	CDR	SVD – Build 1.0 (Revision)	November 20, 2012
CDR 2	CDR	Software Version Description (SVD) Build 2.0	February 15, 2013
CDR 4	CDR	IT Security Implementation Plan	March 7, 2012
CDR 5	CDR	Annual IT Security Training Report (Year 1)	June 28, 2012
CDR 5	CDR	Annual IT Security Training Report (Year 2)	June 26, 2013
CDR 7	CDR	Veteran's Report	Submitted annually by Engility to NASA directly

2.2 Semi-Annual Technical Meetings and Reports

Status of the NRA contract was reviewed periodically throughout the project at a series of technical meetings. Initially, these technical meetings were held semi-annually at Langley Research Center (LaRC). As the contract was modified and the POP extended, these meetings were shifted to being held during the flight trials or by telecon. Each meeting had a presentation package that reviewed the status of the project, deliverables accomplished, current risks and mitigations, and the work plan for the next time period of the contract. These presentations took the place of the CDR monthly status reports on the month the technical meeting was held.

In addition to the technical meetings, a Year 1 Status Report and a Final Report (this document) reported the accomplishments of the contract at the date of their writing. Per agreement with NASA, the Year 1 Report was accompanied by the following paper that was presented at the 12th AIAA Aviation Technology, Integration and Operations (ATIO) conference that focused on the accomplishments and results from Task 1 (See Section 3.3) of the project.

Henderson, J., Idris H., and Wing, D.J., "Preliminary Benefits Assessment of Traffic Aware Strategic Aircrew Requests (TASAR)", AIAA-2012-5684, *AIAA 12th Aircraft Technology, Integration, and Operations Conference (ATIO)*, Indianapolis, IN, USA, September 2012.

Table 2 lists all the meetings and presentations delivered under this task. These presentations and reports were written by Sharon Woods with input from all team members as needed.

Table 2 – Status Meetings and Reports Deliverables

DEL #	Task	Description	Submitted
1	Meetings/Reports	Kickoff Meeting – (3/15/12 -3/16/12 at LaRC)	March 14, 2012
9	Meetings/Reports	Semi-Annual Tech Meeting (9/11/12 at LaRC)	September 11, 2012
17A	Meetings/Reports	Year 1 Report (Draft)	January 31, 2013
17B	Meetings/Reports	Year 1 Report (Final)	February 28, 2013
18	Meetings/Reports	Semi-Annual Tech Meeting (3/13/13 at LaRC)	March 12, 2013
26	Meetings/Reports	Tech Meeting during FT-1 (11/13/13 at LaRC)	November 13, 2013
56	Meetings/Reports	Semi-Annual Tech Meeting (7/23/14 at LaRC)	July 23, 2014
31	Meetings/Reports	Tech Meeting during FT-2 (6/10/15 at LaRC)	June 9, 2015
44	Meetings/Reports	Final Tech Meeting (12/17/15 via telecon)	December 17, 2015
30A	Meetings/Reports	Final Report (Draft)	January 6, 2016
30B	Meetings/Reports	Final Report (Final)	January 29, 2016

2.3 TASK 1 – Concept of Operations, Use Cases and Benefits Analysis

Task 1's objectives were to develop a Concept of Operations, identify Operational Use Cases, and to perform and report on a Benefits Analysis of the TASAR concept. Jeff Henderson of Engility Corporation led the task and conducted the majority of the work. Table 3 summarizes the deliverables submitted to NASA for the task. With the exception to the final update to the Concept of Operations, work under Task 1 was conducted between February 2012 and February 2013.

Table 3 lists all the documents delivered to NASA under Task 1.

Table 3 - Task 1 Deliverables

DEL #	Task	Description	Submitted
3A	1	Concept of Operations Draft 1	April 30, 2012
4	1	Operational Use Cases	May 31, 2012
10A	1	Benefits Assessment Draft 1	August 30, 2012
10B	1	Benefits Assessment Report Final	September 27, 2012
3B	1	Concept of Operations Draft 2	December 20, 2012
3C	1	Concept of Operations Final	January 29, 2016

Engility began Task 1 by conducting an internal review of the TASAR concept with NASA and Engility personnel to establish a common understanding of the concept, and to identify which parts needed refinement. Results of this review were used to write an abstract of the planned Benefits Analysis and submit it to the American Institute of Aeronautics and Astronautics (AIAA) Aviation Technology Integration and Operations (ATIO) conference in February, 2012. NASA also submitted an abstract of the TASAR concept to ATIO 2012, which Engility also reviewed.

2.3.1 Concept of Operations

Following the initial review, Engility developed a draft of the TASAR Concept of Operations, and then iterated with TASAR team members, NASA and a pilot SME to refine it. A telecon with former ATC controllers was organized and conducted by Dr. Jeff Henderson to get feedback and further refine the concept. Results from these discussions and reviews were used to draft the initial Concept of Operations (DEL 3A) and the Operational Use Cases (DEL 4.)

Following NASA and SME pilot reviews, the Concept of Operations was updated with results from the benefits analysis, updated scenarios for use cases, and additional verification steps and capabilities. This revised Concept of Operations (DEL 3B) was delivered to NASA in December, 2012.

An update to the Concept of Operations (DEL 3C) was delivered at the end of the contract, incorporating the concept elements devised under the Dispatch Coordination Requirements (a Modification 10 task – see Section 2.13.2).

2.3.1.1 Publication of Concept of Operations

In May, 2013, DEL 3B, the Concept of Operations Draft 2, was re-formatted and published as a NASA Contractor Report (CR):

Henderson, J., "Traffic Aware Strategic Aircrew Requests (TASAR) Concept of Operations", NASA/CR-2013-218001, NASA Langley Research Center, Hampton, VA, 2013.

2.3.2 Benefits Analysis

To perform the benefits analysis, Engility configured a Future ATM Concepts Evaluation Tool (FACET)-based fast-time simulation platform to support TASAR use cases and provide benefit metrics. Using historical data from the National Airspace System (NAS), this simulation was then used by Engility to perform the benefits analysis, using selected use cases. Results from the analysis were then used to conduct the benefits assessment, which is also included in the Benefits Analysis deliverable. (DEL 10 A/B)

Some of the key findings of the analysis include:

- Benefits from the TASAR concept increased on longer flights compared to ones of shorter length
- Benefits increased for flights between large hub airports, largely due to less efficient historically flown trajectories between large airports
- On average, simulated aircraft equipped with TASAR, saved about 1-4 minutes of time and 50 to 550 lbs of fuel per operation compared to aircraft not equipped with TASAR

2.3.2.1 Publication of Benefits Analysis

The results of the Benefits Analysis were published in a conference paper presented by Dr. Jeff Henderson of Engility at the 12th AIAA ATIO conference held in September, 2012 in Indianapolis, Indiana. The results presented have been cited by the partner airlines as one of the reasons they agreed to partner with NASA for the operational trials. This paper was also used to summarize the accomplishments of Task 1 as part of the Year 1 report, and was delivered as part DEL 17B.

Henderson, J., Idris H., and Wing, D.J., "Preliminary Benefits Assessment of Traffic Aware Strategic Aircrew Requests (TASAR)", AIAA-2012-5684, *AIAA 12th Aircraft Technology, Integration, and Operations Conference (ATIO)*, Indianapolis, IN, USA, September 2012.

2.4 TASK 2 – Software Prototype Development

Task 2's objectives were to design and develop a software prototype of the Traffic Aware Planner (TAP), a flight-deck decision-support tool to support research of the TASAR concept. The prototype TAP system was used in both FT-1 and the first Human-in-the-Loop (HITL-1) Simulation Tests conducted at the Operator Performance Laboratory (OPL) of University of Iowa. Later versions of the prototype, which were used in the second HITL (HITL-2) study and FT-2, were developed under the LITES contract after Modification 8.

This task was led by Sharon Woods of Engility, and was supported by Brendan LeFebvre of Engility and the Engility AOP development team working under the LITES contract. Robert Vivona of Engility was the chief technical advisory and the author of the ICD documentation delivered in DEL 14. AdvAero also provided technical support and developed the software for the Human Machine Interface (HMI) Mockup of DEL 6.

Table 4 summarizes the deliverables submitted to NASA under this task. Note, this table only shows the initial deliverable of SDP documentation, which was part of Task 2. Later versions of the SDP were delivered as part of the CDR task (see Table 1). Also note that development was shifted to LITES after Build 3 of the software prototype was delivered.

Table 4 - Task 2 Deliverables

DEL #	Task	Description	Submitted
2	2	Software Development Plan (SDP) v1.0	March 9, 2012
2	2	Software Requirements Spec. (SRS) v1.0	April 30, 2012
2	2	Software Test Plan (STP) v1.0	August 29, 2012
2	2	Software Design Description (SDD) v1.0	June 15, 2012
14	2	Interface Control Document (ICD)	November 16, 2012
32	2	HMI Design Document	June 15, 2012
6	2	HMI Mockup	July 13, 2012
13	2	EFB Selection & Procurement	May, 2012
14	2	Build 1 of Software Prototype	November 16, 2012
20	2	Build 2 of Software Prototype	February 15, 2013
21	2	Conference Paper describing software	September 9, 2013
25	2	Build 3 of Software Prototype	September 9, 2013

Under Task 2, the Engility team procured two development machines and configured them to work with the LITES ClearCase server for configuration management. Initial functional requirements for TAP were developed based on the initial Concept of Operations developed under Task 1. A Software Development Plan (SDP) was then developed, detailing how the TAP development effort would utilize as much of the

LITES development protocol as possible. The initial functional requirements were also used to produce a first version of the Software Requirements Specification (SRS).

The development of the functional requirements involved initial discussions with both the developers of Autonomous Operations Planner (AOP), the system TAP is derived from, and the users at the three operational environments that TAP was required to function within: 1) Airspace and Traffic Operations Simulation (ATOS), 2) University of Iowa's Operator Performance Laboratory (OPL) and 3) the AdvAero Piaggio Avanti flight test aircraft used for Task 4. It became clear early in the design process that a Data Concentrator Emulator (DCE) would need to be developed for the simulation environments to emulate the functionality of the data concentrator hardware that existed on the flight test aircraft. OPL agreed to develop the DCE for their simulation environment. Funding for the development of a DCE for ATOS was added in Modification 2 (see Section 2.7).

Since AOP does not have an active user interface, the design phase also identified the need to develop a graphical user interface (GUI), the TAP Display. A Human Machine Interface (HMI) Design document was developed detailing a preliminary look for this display, and also acted as the first definition of TAP's capabilities. This HMI Design document was reviewed by NASA and pilot SMEs, and feedback was incorporated in the development of a HMI Mock-up executable. The HMI Mock-up executable was used at the Year 1 mid-year technical meeting (DEL 9, September, 2012) to further refine the look and functionality of TAP Display.

A third executable identified in the design phase was the TAP Engine, which performs all the processing functionality of TAP. The TAP Engine is a configuration of the AOP system, and includes new development to cover the unique data input environment of the EFB data interface, the optimization functionality and the handling of a new user interface.

The results of the initial design were incorporated in the first version of the Software Design Description (SDD). As development continued and the design was refined, the SDD was updated. This effort continued until the SDP documentation was shifted to LITES in Modification 8.

With guidance from John Maris of AdvAero, SME of flight trial operations, Engility selected the United Technologies Corporation Aeronautical Systems (UTAS) G500 SmartDisplay™ Class 2 Electronic Flight Bag (EFB) to use for HITL-1 and FT-1. Three of these EFB's were procured: one for the Engility development team in Billerica, one for OPL and one to use on the flight test aircraft for Task 4. (DEL 13)

As part of the SDP, a Software Test Plan (STP) was also developed, based on the test procedures used in AOP development under the LITES contract. An initial version of this test plan was submitted to NASA.

In order to enable OPL to develop a DCE, an Interface Control Document (ICD) for TAP was developed by Bob Vivona of Engility. It has been refined and expanded to document the data formats and availability of all three of TAP's operational environments. This document later became an integral part of the SDP.

Build 1 of the TAP prototype, which included the ATOS DCE and the first versions of TAP Engine and TAP Display, was developed and delivered to NASA in November, 2012. Build 1 was demoed remotely on November 27, 2012. A later version of TAP was demoed in person at LaRC on December 18, 2012.

The capabilities of Build 1 were:

- A fully functional DCE for the ATOS
- TAP Engine capable of getting to Auto Mode Operational Mode within an ATOS scenario
- Lateral optimizations of 1 and 2 waypoints
- Monitoring of selected optimizations
- Processing of ADS-B traffic, weather / Special Use Airspace (SUA) from ATOS
- Display configuration settings

Build 2 of TAP was delivered on February 15, 2013 and was demoed during the Technical Meeting (DEL 18, March, 2013). Added capabilities of TAP in Build 2 included

- Executable to create Navigational Database from ARINC 424 data
- Discretize Optimization Waypoints (i.e. use names instead of latitude/longitude)
- Direct Lateral Auto Mode Optimizations
- Vertical Auto Mode Optimizations
- Combo Auto Mode Optimizations
- Validity monitoring on Selected Optimizations
- Manual Mode Evaluate Functionality

In July, 2013, Engility produced Build 2.2, a non-deliverable version of TAP that was used for HITL-1 at OPL. This build contained all the functionality required to operate in OPL's simulator and included a fully functional manual mode (with waypoint selection) and route visualization.

Build 3 of the TAP was delivered in September, 2013, with all functionality required for FT-1 in place. Development continued between September and November to fix bugs and refine functionality, leading to Build 3.2, the version of the software used during FT-1 in November, 2013.

After FT-1, development continued on the prototype until March, 2014, on which funding was transferred over to the LITES contract.

2.4.1 Publication of Conference Paper describing prototype

In January, 2013, an abstract of a conference paper describing the TAP software and its capabilities was submitted to the 2013 AIAA Guidance, Navigation, and Control (GNC) conference, which was held in Boston, MA in August, 2013. It was accepted and presented by Sharon Woods of Engility as part of DEL 21.

Woods, S., Vivona, R., Roscoe, D., Lefebvre, B., Wing, D., and Ballin, M., "A Cockpit-based Application for Traffic Aware Trajectory Optimization," AIAA-2013-4967, *AIAA Guidance, Navigation and Control Conference (Boston, MA, 2013),* AIAA, Washington, DC, 2013.

During the same conference, Dr. David Karr of Engility, who contributed to TAP development under the LITES contract, also presented a paper detailing the development of TAP's capability to limit its trajectory optimizations to published waypoints. (AOP used latitude, longitude locations.)

Karr, D.A., Vivona, R.A., and Wing, D.J., "Costs of Limiting Route Optimization to Published Waypoints in the Traffic Aware Planner," AIAA-2013-4968, *AIAA Guidance, Navigation and Control Conference (Boston, MA, 2013),* AIAA, Washington, DC, 2013.

2.5 TASK 3 – Flight Certification

Task 3 covers obtaining all the necessary certification and approvals for conducting FT-1. This work was done by John Maris and Mark Haynes of AdvAero. Table 5 summarizes all the deliverables submitted to NASA under this task.

Table 5 - Task 3 Deliverables

DEL #	Task	Description	Submitted
7	3	Flight Trial Approval Requirements	June 28, 2012
7	3	Flight Trial Approval Requirements (Revision)	February 22, 2013
8	3	PER presentation	August 30, 2012
12	3	Flight Trial Hazard Analysis	November 9, 2012
12	3	Flight Trial Hazard Analysis – (Revision)	February 14, 2013
16	3	Flight Trial IRB Approval Package	January 28, 2013
19A	3	Flight Test Operations and Safety Report	February 28, 2013
19B	3	ASRB Presentation	March 11, 2013
22	3	FER Presentation	May 29, 2013
23	3	Flight Trial Approval Package	May 29, 2013

Under this task a FTOSR kickoff presentation was developed and presented to NASA Airworthiness and Safety Review Board (ASRB) members at the kickoff meeting in March, 2012, which met the requirements for a Preliminary Safety Review. Input from this review was used to finalize the Flight Trial Approval Requirements deliverable in June, 2012. A draft Flight Trial Plan was then developed, which was subsequently used to support the Preliminary Experiment Review (PER) presentation and Flight Trial IRB Approval Package. A Flight Trial Hazard Analysis was also prepared and delivered to NASA.

Per NASA's request, DEL 7 and DEL 12 were revised and resubmitted to NASA in February, 2013 to remove any proprietary information and wording.

The ASRB briefing for TASAR occurred on March 14, 2013, which the board accepted.

Following the ASRB briefing, the Flight Trial Test Plan, Flight Trial PER and Flight Trial Approval package were finalized. The Final Experiment Review (FER) and Flight Trial Approval package were delivered in May, 2013.

2.6 TASK 4 – Flight Trial 1 (FT-1)

Task 4 covers the design, preparation and operation of FT-1, the in-flight assessment of the TASAR concept using the TAP prototype developed in Task 2. It includes equipping the flight test aircraft for the test. This task also provided technical support to Task 2 by 1) developing the HMI Mockup and 2) providing technical support in interpreting the avionics interface and the ARINC 834 specifications on the test aircraft.

All work under this task was performed by AdvAero, which used their own test aircraft and engineering staff to conduct the test. Table 6 summarizes the deliverables submitted to NASA under this task.

Table 6 - Task 4 Deliverables

DEL #	Task	Description	Submitted
5	4	Aircraft Modification Plan	May 31, 2012
11A	4	Flight Trial Research Plan Draft 1	August 30, 2012
15	4	Flight Trial Pilot Procedures	December 21, 2012
11B	4	Flight Trial Research Plan	December 21, 2012
24	4	FTRR Package	October 2, 2013
27A	4	Flight Trial Informal Report	March 13, 2014
27B	4/Mod4	FT-1 Conference Paper	April 8, 2014
27C	4/Mod4	FT-1 Conference Paper Presentation	April 25, 2014

Under this task, the AdvAero team identified a source of ADS-B-In data (the ACSS TCAS 3000 SP) and procured and installed it in the test aircraft. This equipment was certified and approved for flight. (DEL 5)

Once the Flight Trial Approval Requirements were acquired under Task 3, AdvAero developed a Flight Trail Research Plan and Pilot Procedures. A Flight Trial Readiness Review (FTRR) presentation package was prepared and presented on October 2, 2014, and was approved. AdvAero engineering staff coordinated with Engility developers to test Build 3 of the TAP software to identify issues before the flight trial.

FT-1 was conducted from November 11 – 22, 2013, and consisted of 10 independent flights involving two TASAR team pilots and 8 test pilots from potential early TASAR concept adopters, such as airlines. The key objective of the test was to identify the operational factors unique to the in-flight environment that affect the TASAR concept. This involved examining four factors: operational data flows, TAP functionality, test pilot interactions with TAP and ATC interactions in response to TAP-inspired trajectory optimization requests. During the flights, 12 TAP-generated optimization requests were made to ATC, 9 of which were approved and 2 denied. (Another request had no response, possibly due to excessive workload at ATC.)

Overall, FT-1 was considered very successful, and produced a large amount of data and pilot feedback that was used to extensively redesign the HMI interface for HITL-2 and FT-2.

The data and results of FT-1 were compiled into a Flight Trial Report (DEL 27A), which was delivered to NASA in March, 2013.

2.6.1 Publication of FT-1 results

As part of Modification 4 (See Section 2.8), a conference paper detailing the planning, operation and results of FT-1 was presented by John Maris of AdvAero at the 14th AIAA ATIO conference in Atlanta, GA during June, 2014.

Maris, J., Haynes, M., Wing, D., Burke, K., Henderson, J., and Woods, S. "Traffic Aware Planner (TAP) Flight Evaluation," AIAA-2014-2166, *AIAA Aviation Technology, Integration, and Operations Conference (Atlanta, GA, 2014),* AIAA, Washington, DC, 2014.

2.7 Modification 2

During the initial development of the TAP prototype and preparation for FT-1, it became clear that to test TAP in ATOS, a data concentrator emulator (DCE) was needed. The DCE would emulate the operations and data feed of the EFB Aircraft Interface Device (AID). This was a separate development effort than the TAP prototype.

Also, in the development of the TASAR concept, NASA became interested in expanding TAP's capabilities to include data sources available through broadband internet, rather than just cockpit-sourced data. Requirements to use this data was added to the prototype development, but to test it during FT-1, broadband internet access needed to be added to the flight test aircraft.

Finally, during NASA's active efforts to partner with airlines for operational trials, it became clear that several airlines had adapted the Apple iPad® as their EFB platform. The original design of TAP, geared to the UTAS SmartDisplay™ platform, was intended to work on UNIX and Windows operating systems only, not the iOS operating system used by the iPad®.

To address these needs, Modification 2 was applied to the NRA in September, 2012. This modification funded the effort to develop the DCE, identify internet-based data sources and add the capability to use it to TAP, install broadband internet access to the test aircraft and to conduct a feasibility analysis of what it would take to run TAP on an Apple iPad®. Details of these efforts is summarized in the subsections below.

Table 7 summarizes the deliverables submitted to NASA under Modification 2.

Table 7 - Mod 2 Deliverables

DEL #	Task	Description	Submitted
34	Mod 2	Flight Test Aircraft Broadband Internet Capabilities	February 14, 2013
35	Mod 2	Apple iPad 2	November 11, 2015
36	Mod 2	Apple Mini Mac computer	November 11, 2015
37	Mod 2	Port of TAP data feed to laptops	December 3, 2013

2.7.1 Data Concentrator Emulator

This part of Modification 2 covered the design, development and delivery of the DCE used in ATOS. Development was conducted by the Task 2 development team.

The development of the DCE became necessary due to the requirement to demonstrate TAP on a Class 2 EFB in the ATOS. A Class 2 EFB receives data from avionics via Ethernet using the ARINC 834-1 Simple Text Avionics Protocol (STAP). In order to create this feed within ATOS, the DCE was developed to pull avionics data from the ATOS's AvionicsBus and translate it into STAP format.

The development of the DCE was completed and delivered as part of Build 1 (DEL 14) of the TAP software in November, 2012. The demonstration of TAP Build 1 on ATOS, which was performed on a Class 2 EFB, demonstrated the capability of this executable.

2.7.2 Software Internet Capability

This part of Modification 2 covers identifying internet data sources for TAP and enabling the TAP prototype to receive data from at least one internet source in FT-1. The investigation of data sources was conducted by Dr. Jeff Henderson of Engility Corporation. Brendan LeFebvre of Engility was the chief developer of the TAP prototype capabilities to read in internet-based data sources.

Dr. Henderson conducted an investigation to identify internet data sources and to assess their cost and feasibility to obtain on an aircraft given existing equipage. An informal report was generated summarizing the results of this investigation called "TASAR Broadband Internet Data Sources." This document was distributed to NASA and AdvAero in October, 2012.

Per recommendations from this report, the TAP prototype was expanded to include another system, the External Data Server (EDS), to accept National Oceanographic and Atmospheric Administration (NOAA) Rapid Refresh (RAP) winds and temperature aloft data for FT-1. The capability was developed and delivered as part of TAP Build 3, and successfully tested during FT-1.

2.7.3 Install Internet Capability on the Test Aircraft

In order to test the internet capabilities of TAP, the test aircraft needed broadband internet access. This part of Modification 2 covered identifying equipment to provide this access and installing it on the test aircraft.

The Honeywell Swift64 satellite broadband system was installed, flight tested and certified on the aircraft in November, 2012. A report documenting the selection and installation of this system was delivered to NASA as part of DEL 34.

Installation of the Honeywell system also enabled the porting of the data to additional instances of TAP running in the back of the aircraft during FT-1. (DEL 37)

2.7.4 iOS Feasibility Analysis

This part of Modification 2 consisted of a feasibility analysis of developing and running a version of the TAP prototype on an Apple iPad® implementation of a Class 2 EFB. This analysis was conducted by Sharon Woods of Engility.

As part of the investigation, Engility procured an Apple iPad® and an Apple Mac® Mini, both of which reverted to NASA's ownership at the end of the contract. These systems were used to assess the effort required to convert TAP to an iOS operating system environment, and to analyze if the processing and data input capabilities of the Apple iPad® EFB are sufficient for normal TAP operation.

The feasibility analysis concluded that an operation on the iPad® was possible with a system configuration where just the user interface ran on the iPad®, and the processing units ran on another Windows/Unix system. The user interface (the TAP Display) would need to be redeveloped to use a framework that could work on Windows, Unix and iOS. At the time of the feasibility study, no such framework was available, but Qt Project had announced plans to release an iOS cross-platform framework in Qt version 5.2, which was released in December 2013. When TAP Display was redeveloped for FT-2 to operate on iPad®, it was redeveloped (under LITES) using Qt 5.2 and was successfully demonstrated on an iPad® Class 2 EFB platform. The Mac® Mini and iPad® 2 were used in this development effort.

2.8 Modification 4

Modification 4 provided funding for two efforts: 1) Engility assisting OPL in the run-up to HITL-1, and the publication of the results of FT-1 at the 14th AIAA ATIO conference in Atlanta, GA during June, 2014.

Engility development staff provided support to OPL development staff by analyzing test data of TAP running on their simulator and identifying issues in the OPL data feed. Sharon Woods of Engility also travelled to Iowa City, IA in May, 2013 to provide assistance in the HITL-1 test planning.

Section 3.6.1 details the publication of the FT-1 results in a conference paper.

2.9 Modification 6

Modification 6 added two TAP prototype development tasks: modifying TAP and the DCE to support/emulate ARINC 702A-1 and General Aviation Manufacturers Association (GAMA) industry standard data formats, and develop a general trajectory generator (TG) that can support multiple aircraft types. Both these development efforts were for preparing TAP to operate on partner airlines in operational trials, and were completed after the prototype development work was transferred to the LITES contract.

The other part of Modification 6 was to fund the development of a methodology and tools to analyze TAP performance and benefits, based on TAP data recordings. This effort was chiefly done by Dr. Jeff Henderson of Engility, with SME advice and assistance from Bob Vivona of Engility. Table 8 summarizes all the deliverables submitted to NASA under Modification 6.

Dr. Henderson analyzed the data available from TAP data recordings and devised a methodology to analyze TAP trajectories compared to the trajectories that would have been flown without TAP. He then developed tools, based on MATLAB®, to perform these analyses. Both a report detailing the methodology and the analysis tools were delivered to NASA in February, 2014. (DEL 38)

Table 8 - Mod 6 Deliverables

DEL #	Task	Description	Submitted
38A	Mod 6	TAP in-flight performance analysis methodology	February 7, 2014
38B	Mod 6	Performance analysis tools	February 7, 2014

2.10 Modification 7

Modification 7 clarified the B/C pieces of DEL 27 (added in Mod 4), the conference paper on FT-1, and added a preliminary assessment of the effort it would take to certify, gain operational approval and install TAP on two partner airlines: Virgin America Airlines (Virgin) and Alaska Airlines (Alaska.) This work was largely performed by John Maris of AdvAero.

At the time of the assessment, neither Alaska nor Virgin had finalized the Class 2 EFB hardware system they planned to install in their aircraft. John Maris based his assessments on the most likely candidates: the UTAS Table Interface Module (TIM) system, with Class 2 EFBs on Apple iPad Air®s for Alaska, and the Astronautics NEXIS™ system for Virgin. He performed interviews with personnel at Alaska and Virgin, UTAS and Astronautics and assembled the Integrations Assessment Report (DEL 39) and Certification Assessment Report (DEL 40) into a joint report which was delivered to NASA in March, 2014.

Table 9 summarizes all the deliverables submitted to NASA under Modification 7.

Table 9 - Mod 7 Deliverables

DEL #	Task	Description	Submitted
39	Mod 7	Integration Assessment Report	March 26, 2014
40	Mod 7	Certification Assessment Report	March 26, 2014

2.11 Modification 8

As the development requirements of the TAP prototype expanded with the drive to perform operational trials with partner airlines, the development work was moved from the NRA to the LITES contract within Modification 8. With the removal of the deliverables related to development, Modification 8 shifted efforts to a set of new analysis tasks, and the deliverables listed in Table 10 were added:

Table 10 - Mod 8 Deliverables

DEL #	Task	Description	Submitted
41 A	Mod 8	Annualized Benefits for Alaska Airlines	August 29, 2014
41 B	Mod 8	Annualized Benefits for Virgin America	September 30, 2014
42	Mod 8	Trajectory Change constraints analysis	December 31, 2014
43	Mod 8	Internet Data Sources Report	June 30, 2014

Dr. Jeff Henderson performed all the work in these new analysis tasks. Bob Vivona provided strategic analysis support for the trajectory change constraints analysis.

2.11.1 External Data Sources Analysis

For characterization of external data sources, Dr. Henderson looked at sources for turbulence, icing, convective weather, SUA activation schedules and traffic and examined what parsing/processing software was available for integration of this data into TAP. (For instance, he examined polygon tools that converted gridded convective weather data into airspace hazard polygons, which is the format TAP uses to process area hazards in its algorithms.) He attended telecons with both Alaska and Virgin to discuss their use of convective weather data sources, both public and proprietary, in both pilot and dispatcher operations. He also reviewed flight operations guidance documentation from the partner airlines to analyze how they integrate convective weather and turbulence data into their procedures. This analysis was then summarized in an Internet Data Sources Report and delivered to NASA. (DEL 43)

2.11.2 Annualized Benefits for Alaska and Virgin

For both airlines, Dr. Henderson arranged telecons to discuss benefits assessments, and ran simulations of historical data to assess TAP-equipped flights benefits compared to non-TAP-equipped flights. He then performed data analysis on the simulation results to generate annualized benefits. In the final report, a cost savings estimate was presented for the benefits.

For both airlines, switching to a more wind-optimal trajectory was found to be the use case that generated the highest benefits. For both airlines, a fleet-wide implementation of TAP was estimated to save in excess of $5 million due to fuel, maintenance and depreciation cost savings.

Dr. Henderson traveled to Seattle, WA on October 27-28, 2014 and Burlingame, CA on October 29, 2014 to present his annualized benefits analysis to Alaska and Virgin respectively.

2.11.2.1 Publication of Virgin and Alaska Annualized Benefits

The annualized benefits for both Alaska and Virgin were published as NASA CRs, with all proprietary data removed from the original NRA deliverables (DEL 41 A/B).

Henderson, J., "Annualized TASAR Benefit Estimate for Virgin America Operations", NASA/CR-2015-218786, NASA Langley Research Center, Hampton, VA, 2015.

Henderson, J., "Annualized TASAR Benefit Estimate for Alaska Airlines Operations", NASA/CR-2015-218787, NASA Langley Research Center, Hampton, VA, 2015.

2.11.3 Trajectory Change Analysis

Dr. Henderson began this analysis by studying historical data to determine where lateral and vertical changes in flight routes occur in NAS and the range of locations where lateral changes reconnect to Standard Terminal Arrival Routes (STARs). He then generated scripts to process historical flight data and generate data to analyze for identifying trajectory-change constraints that could be incorporated into TAP to improve ATC approvability of TAP solutions. These identified constraints were reported in DEL 42.

2.12 Modification 9 (FT-2)

As part of the effort to prepare TAP for operational trials with the partner airlines, NASA modified the NRA to add a second flight trial, FT-2. This modification covered the preparation, certification, approval, planning, conducting and post-flight trial reporting for FT-2. All work under Modification 9 was performed by AdvAero. Engility provided task leadership on several of the objectives and provided personnel to run/monitor TAP during the flight trial. Table 11 summarizes all the deliverables submitted to NASA under Modification 9.

Table 11 - Mod 9 Deliverables

DEL #	Task	Description	Submitted
45A	Mod 9	FT-2 PER Package	July 23, 2014
45B	Mod 9	FT-2 FER Package	March 2, 2015
45C	Mod 9	FT-2 IRB Package	March 4, 2015
46	Mod 9	FT-2 FTOSR	February 5, 2015
47	Mod 9	FT-2 Aircraft Modification Plan	August 18, 2014
48	Mod 9	FT-2 Flight Trial Test Plan	March 2, 2015
49	Mod 9	FT-2 FTRR Package	May 12, 2015
50A/B	Mod 9	FT-2 Flight Trial Report and Presentation	January 6, 2016

The preparation of FT-2 took lessons learned from FT-1 into account. Data gathering procedures and ground testing that were deemed not necessary were eliminated in favor to airborne testing during charter flights of the test aircraft. Identifying the objectives of the test was moved to the forefront of the effort, and the responsibility of defining and designing the procedures for the objectives was each given a task leader to handle all test design and reporting. Another key factor was to arrange for the flights to have different arrival and destination airports (unlike the round-robin flights used in FT-1.) After a series of telecons and the PER, (presented during the Technical Meeting at LaRC in July, 2014) the research team agreed on the following objectives for the test:

1. Verify TAP software operates on Alaska Airline EFB hardware
2. Verify Processing of External Data Sources
3. Assess Methodology to Characterize TAP Computed Outcomes
4. Assess Air Traffic Controller Acceptability of TASAR Requests
5. Assess Evaluation Pilot Acceptability of TASAR Requests
6. Assess the Usability and Acceptability of the TAP HMI
7. Assess Effect of TASAR on Crew Resource Management (CRM)

The procedure for getting safety and readiness approval for the flight followed the same course as FT-1. (DEL 45, 46, 48 and 49). Based on the difficulties in FT-1 due to some of the flight route designs, considerable time was taken to plan the destination airports to work within the test aircraft's performance limits and best serve all the objectives, particularly the ATC Observations objective, which had to coordinate the flights with in-person observations at two ATC facilities. Procedures throughout the flight were coordinated such that the objectives did not interfere with one another, though as reported in lessons learned, this coordination needed more review before implementation.

Hardware to emulate the EFB hardware used by Alaska (UTAS TIM systems, with associated iPad Air® Class 2 EFB's) was purchased and installed on the target aircraft. (DEL 47)

LITES continued to support the software development required for FT-2. This encompassed three efforts:

1. Creating a cross-platform TAP Display (iOS, UNIX, Windows)
2. New generic TG
3. Expansion of EDS to include Weather Services International (WSI) convective weather data and SUA scheduling

Modification 10 provided the funding to add the Engility staff to perform the assessment of ATC acceptability of TASAR Requests.

FT-2 was conducted on June 7-21, 2015, and consisted of 14 primary flights, including 12 flights with airline industry pilots and two positioning flights with TASAR team pilots. All objectives were successfully met, including the overall objective to assess if TAP is ready to deploy in operational trials with a partner airline. Several areas for improving TAP capabilities were identified, many of which are currently being implemented under the continued development under LITES and LITES-II. A final report and presentation summarizing FT-2 was delivered to NASA on January 6, 2015, (DEL 50) along with a compilation of all data gathered during the test. NASA expects to take this report and data and prepare published results of the test.

2.13 Modification 10

Modification 10 provided funding for adding ATC observations (Objective 4A) to FT-2. This work was performed by Dr. Husni Idris and Dr. Gabriele Enea of Engility, with SME advice provided by Bob Vivona of Engility. In addition, Modification 10 added three tasks, all of which were performed by Dr. Jeff Henderson of Engility:

- Expand the data source analysis (DEL 43) to include primary weather data sources used by Virgin and Alaska.
- Determine and report the TAP system requirements for adding pilot/dispatch coordination functionality
- Provide an informal report detailing the installation and adaptation requirements for installing TAP for the operational trials on Virgin and Alaska.

One other task in Modification 10 was to determine and report the FAA approval requirements for certification and operational approval of the operational flight trials of TASAR. This work was performed by John Maris of AdvAero.

Table 12 summarizes all the deliverables submitted to NASA under Modification 10.

Table 12 - Mod 10 Deliverables

DEL #	Task	Description	Submitted
51	Mod 10	Partner Airline Weather Data Integration Design	April 28, 2015
52	Mod 10	TASAR Dispatch Coordination Requirements	October 29, 2015

53	Mod 10	Installation and Adaptation Requirements	January 29, 2016
54	Mod 10	FAA Approval Requirements	January 21, 2016
57A	Mod 10	FT-2 ATC Observation Plan	April 17, 2015
57B	Mod 10	FT-2 ATC Observation Results	January 6, 2016

2.13.1 Adding Weather Data to Data Sources Analysis

This deliverable required proprietary information from both the weather data providers of the airlines, and had to be delayed until the non-disclosure agreements (NDA) were in place to perform the work. Once Dr. Henderson had access to the weather providers, he conducted interviews with their technical personnel to determine the format of their data, and then worked with the TAP development team defining the requirements needed to work with that data.

2.13.2 Dispatch Coordination Requirements

This task involved Dr. Henderson utilizing data from interviews with Virgin and Alaska dispatch personnel to develop ideas for enhancing pilot/dispatcher coordination on TAP-generated trajectory changes. He also coordinated with the TAP development team to determine the best way to implement the ideas through added TAP functionality and system design.

2.13.3 Installation and Adaptation Requirements

Dr. Henderson attended several telecons with Virgin and Alaska to determine the installation and adaptation issues and procedures. He then assembled this data into a report (DEL 53) which was delivered at the end of the contract in January, 2016.

2.13.4 FAA Approval Requirements

John Maris provided an initial draft of these requirements in November, 2014 based on information he had obtained during visits to the two partner airlines. The draft was updated over the ensuing year with new information from the airlines regarding approval requirements, and delivered (DEL 54) in January, 2016.

2.13.5 FT-2 ATC Observations

Dr. Husni Idris and Dr. Gabriele Enea started this task by reviewing the concept literature of TASAR and the research plan presented at the FT-2 PER. They held a kickoff meeting for the observation effort in August, 2014 to define the objectives of the observations and review the hours and travel time needed for the observations.

FT-2 PER designated that the flight trial would be based out of Newport News/Williamsburg International Airport (KPHF), and ATC observations were planned for the Atlanta, GA (ZTL) and Jacksonville, FL (ZJX) ATC centers. In order to determine the best destination airports for the FT-2 flights, the team created a MATLAB® utility to plot and visualize historical track data for each sector. This utility was used to visualize the flows in each sector at different times of the day and to identify which sectors would be more likely to cause controller issues. This tool helped in determining, in coordination with AdvAero team (who provided test aircraft performance advice), that the three destination airports of FT-2 would be Tampa International Airport (KTPA), Birmingham-Shuttlesworth International Airport (KBHM), and Montgomery Regional Airport (KMGM).

Dr. Idris and Dr. Enea visited both ZTL and ZJX in October, 2014 to solicit information about issues, events and sectors that they identified to observe, as well as to work out the operational logistics to conduct the ATC observations during the test. Information gathered during this trip and interviews with controllers was used to develop scenarios of trajectory change solutions to which they wanted to observe ATC responses.

The LITES development team provided support in designing a software tool to create these scenarios during FT-2, and Engility provided personnel on the aircraft to act as the TAP Engineer, who was largely responsible for coordinating the airborne side the ATC Observations effort.

The results of the ATC Observations during FT-2 were reported in Objective 4A of the FT-2 Final Report (DEL 50) and the ATC Observation Informal report (DEL 57A.) In all, the team found that controllers were enthusiastic about the concept of pilots being aware of sector boundaries and accounting for them during their requests. Awareness of these boundaries and avoiding certain conditions would improve the chances the TAP request would be accepted. They also found that TAP "Combo" (both lateral and vertical maneuvers) were acceptable, and that limiting TAP solutions to two off-route waypoints is recommended, especially in high-workload centers.

2.14 Modification 11

Modification 11 added another set of analysis tasks that were performed by Dr. Jeff Henderson of Engility. Table 13 summarizes all the deliverables submitted to NASA under Modification 11.

Table 13 - Mod 11 Deliverables

DEL #	Task	Description	Submitted
58A	Mod 11	Expand TASAR concept to include Dispatch C/I	June 26, 2015
60	Mod 11	TAP Requirements for Turbulence/Icing	October 1, 2015
61	Mod 11	Engineering Test Plan and Quantitative Analysis Report	January 6, 2016
62A	Mod 11	CITI training completion certificate	February 2, 2015
62B	Mod 11	Data Collection/Analysis Plan – Alaska	December 7, 2015
62C	Mod 11	Data Collection/Analysis Plan – Virgin	December 7, 2015

2.14.1 Aircraft-Dispatch Connectivity/Integration (C/I)

This task involved investigating how to expand the TASAR concept with respect to aircraft-dispatch C/I. An initial report on this effort was delivered to NASA on May 29, 2015. Based on feedback from NASA and discussions during the technical meeting in June, 2015, this deliverable was revised and re-submitted to NASA on June 26, 2015.

2.14.2 Turbulence/Icing

This task involved developing TAP requirements for utilizing turbulence and icing hazard data in computing route solutions.

Dr. Henderson reviewed the turbulence and icing data available from WSI (turbulence only) and Schneider Electric systems used by the partner airlines. He then consulted with the TAP development team regarding how to use this data for TAP solution computation. Based on this information, he developed a set of TAP functional requirements for turbulence and icing which was delivered to NASA. (DEL 60)

2.14.3 Engineering Test Plan and Quantitative Analysis

In preparation for the airline operational trials, this task entails preparing an engineering test plan and quantitative analysis report that can be shared with the partner airline engineering departments that will be supporting the operational trials. This plan was tested as part of Objective 1 and 2 in FT-2.

Dr. Henderson updated the MATLAB® scripts that were used to analyze TAP recorded data from FT-1 to perform the additional analysis capabilities required by FT-2. Once FT-2 was complete, he performed analysis on FT-2 data, and modified the MATLAB® scripts to handle unanticipated data collection events during the flight trial. He then updated the Objective 1 and 2 sections of the FT-2 Final report based on the results. These results were also incorporated into the final report of the task which was delivered on January 6, 2016. (DEL 61)

2.14.4 Data Collection/Analysis Plans

This task involved developing a data collection and analysis plan for each of the partner airlines. It also included a requirement that Dr. Henderson take the Collaborative Institutional Training Initiative (CITI) training for the protection of human subjects. (DEL 62A)

Dr. Henderson participated in a series of telecons with each of the partner airlines where he shared his initial ideas on data collection and analysis plans. He then created draft reports of his plans and had them reviewed by both NASA and the respective partner airlines. These reports were further refined based on information he obtained via a trip to Alaska Airlines in September, 2015. He also quantified which Alaska routes should be targeted for initial operational trials to best demonstrate benefits.

An initial version of each of the plans was delivered to NASA on November 12, 2015. An updated version of each plan, based on NASA feedback, was submitted to NASA December 7, 2015. (DEL 62B/C)

2.15 Modification 14

Modification 14 was the last modification to the contract, and “cleaned up” the contract deliverables that had been overtaken by events (OBE). Due to a push in the schedule for the operational trials, it was no longer possible to generate reports on operational trial data within the POP of the contract. These deliverables were removed and replaced with new deliverables that augmented the analysis of data sources and provided tools and templates for the data analysis of the operational trials when they occur. All these tasks were performed by Dr. Jeff Henderson of Engility.

Another deliverable had been incomplete due to the direction of the TAP development shifting away from generating HMI guidelines. It was replaced with a requirement to update the conference paper describing the TAP prototype, with emphasis placed on the new HMI design that was implemented based on feedback from pilots in FT-1. This task was performed by Sharon Woods of Engility.

Table 14 summarizes the deliverables submitted to NASA under Modification 14.

Table 14 - Mod 14 Deliverables

DEL #	Task	Description	Submitted
64A	Mod 14	Abstract of updated TAP Software Conference Paper	October 1, 2016
64B	Mod 14	Updated TAP Software Conference Paper	January 29, 2016
65	Mod 14	SWIM Data Selection & Processing Report	January 29, 2016
66	Mod 14	Onboard Weather Radar Feasibility Report	January 29, 2016
67A	Mod 14	Analysis Tools and Test Scenarios Report	January 6, 2016
67B	Mod 14	Quarterly Report Template	January 29, 2016

2.15.1 Update of TAP Software Paper

The conference paper published at 2013 GNC conference (see Section 2.4.1) was based on the earliest version of the TAP Display used for HITL-1 and FT-1. Since that time, TAP Display was significantly redesigned with a new HMI based on feedback from HITL-1 and FT-1, and to utilize a software framework that allows it to be cross-platform capable across Windows, iOS and UNIX systems.

Sharon Woods updated the original paper and submitted the abstract for NASA review in October, 2016. (DEL 64A) After NASA's review approved the abstract, it was submitted on November 2, 2015 to the 2016 ATIO Conference, which is due to be held in Washington, DC in June, 2016. Notification of the status of the submittal is expected from AIAA in February, 2016. An updated version of the paper was submitted to NASA at the end of the contract. (DEL65B)

2.15.2 SWIM Data Processing Report

This task involved extending the data sources analysis to include sources available through FAA SWIM.

Dr. Henderson held discussions with NASA Ames in October, 2015 to review the suitability of using Convective Weather Avoidance Model (CWAM) data. He also reviewed services that provided access and processed data available over SWIM. A report detailing all his findings was delivered at the end of the contract. (DEL 65)

2.15.3 Onboard Weather Radar Feasibility Report

This task involved analyzing the feasibility of TAP processing and using onboard weather radar data in its hazard analysis.

Dr. Henderson attended a telecon with Rockwell Collins, a manufacturer of onboard weather radar systems, to gain information about the format of their onboard weather data. He also assessed tools that generated polygons from gridded convective weather, which TAP could possibly use to convert the radar data to the format it uses for hazard analysis.

A report detailing Dr. Henderson's findings was delivered at the end of the contract. (DEL 66)

2.15.4 Analysis Tools, Test Scenarios and Template

This task entails producing a report describing the data analysis tools, and to develop ATOS scenarios to test TAP with the conditions expected during the operational trails. It also includes the development of a template for the partner airlines quarterly reports on the operational trails.

Dr. Henderson has successfully developed the tools and test scenarios (based on a historical Seattle to Boston flight) as part of this task. A description of these scenarios as well as a description of the methods to process the TAP recorded data using the MATLAB® data analysis tools was delivered on January 6, 2016. (DEL 67A) The quarterly template was delivered at the end of the contract. (DEL 67B)

3 LESSONS LEARNED

Overall, this contract has been regarded to be successful, and the TASAR project is expected to continue under LaRC's direction. However, there were some lessons learned that are reported here in the hopes they will be helpful for future, similar contracts.

3.1 Fixed Price

This NRA was a fixed price contract, which is a reasonable arrangement if all the requirements of the work effort are known during the proposal period. For instance, the part of the contract regarding the requirements of conducting a flight trial (Task 3 and 4) were well defined. This allowed the contractor to reasonably bid what the effort cost. Task 1 also was reasonable in this regard.

However, since TASAR was a research project, starting from a concept, the requirements to build the software prototype were unknown during the bidding process. This created the biggest risk item in the initial NRA. Fortunately, this was mitigated by the development support that was provided by the LITES contract. However, throughout the project, several requirements arose that were unanticipated, and required additional funding through modifications or additional support through LITES.

Since fixed price contracts are expected to continue to be the norm, it is suggested that future contracts take the following approach:

- Explore the possibility of a Fixed Price Level of Effort (FP LOE) approach
- Emphasize an approach of mutual trust between the contractor and NASA in regards to handling the unknown scope of a research contract. NASA can be trusted by the contractor to propose deliverables, but be open to adjustments, and the contractor can be trusted to do more than the minimum (known at proposal time) work they propose.

3.2 OBE Deliverables

One lesson learned during the contract was to address deliverables that are OBE as soon as possible. As the contract progressed and its objectives evolved, some deliverables, notably DEL 29, no longer fit in the work schedule and project goals. Rather than address them as soon as this became clear, the deliverable was left in a "to be determined" state for over two years, and was only resolved in Modification 14.

One part of the contract that went well was NASA's willingness to adjust the due dates of deliverables that were constrained by events outside the contractor's control. For instance, some deliverables were contingent on NDAs being signed, which were beyond the control of both NASA and Engility. NASA allowed these deliverable dates to be shifted to meet these constraints.

3.3 Software Documentation

The development of a SDP, which was added as a CDR requirement in Modification 1, was a significant effort that was not reasonably presented in the initial Request for Proposal. It is suggested that future proposals take into account the expected cost of such extensive documentation so that contractors can bid documentation support more effectively.

3.4 Flight Trials

Both FT-1 and FT-2 were successful, especially in regards to gathering data that helped redesign the software prototype to better meet user needs. Both flight trial reports have a "Lesson Learned" section detailing the insights for future improvements of the process based on each flight. This section augments those two reports with more general lessons learned relating to the planning and scheduling of the flight trials.

One aspect of both flight trials that went especially well was obtaining all the certification and safety approvals from NASA to conduct the flight trial. The series of deliverables and the scheduling of these events, most notably for FT-2, would stand to be a good example for gaining approval for similar scale flight trials in the future. The deliverables were well defined and reasonable, and the ASRB board commented that the presentation met or exceeded their expectations.

Another aspect of both flight trials that went well was NASA's handling of the evolving hardware requirements of the test aircraft. When the aircraft modification plans identified equipment needed to meet requirements not expected initially, NASA handled the modification to the contracts and scheduling to purchase, install and certify the equipment without major issues. Anticipating the need for such flexibility is a crucial part of research-oriented flight trials.

One lesson learned from FT-1 was to better define the flight trial objectives from the beginning, and assign responsibility for managing each objective to a lead. This allowed the Test Director to coordinate with each of the objective leads and take into consideration their respective needs when designing the flight plans of the test. This worked extremely well in the planning for FT-2, though in hindsight, a more comprehensive review of the final plan by all parties, perhaps during a technical meeting or telecon, could have identified procedures of one objective that interfered with another. For instance, some of the evaluations of the HMI interface inadvertently affected data analysis, which could have been identified during such a review.

The importance of arranging for a realistic test environment, one that includes actual airborne testing or a simulation that can completely replicate airborne data conditions is of paramount importance. In both flight trials, the TAP software was not completely tested until the repositioning flight of the flight trial. Also, during FT-1, scenarios of the planned flight paths were not tested until the flight trial itself began to identify issues with the "round-robin" flights. In order to avoid these issues, airborne or simulation testing needs to be an integral part of the planning and budget of the flight trial.

Both FT-1 and FT-2 were constrained in when they could be scheduled due to the availability of the aircraft, expected traffic and weather conditions, and the amount of lead time needed to schedule and prepare the test pilots. In both cases, the start date of the flight trial had to be locked down before the development of the software was complete. This resulted in any delays in development reducing testing time during the run-up to the test. In FT-2, where charter flights were expected to be used for airborne testing, this caused problems because the availability of charter flights (which neither the contractor nor NASA could control) was constrained. It is suggested in future flight trials that testing be designed such that the software must pass a crucial functionality smoke test before the date of the flight trial is frozen.

4 CONCLUSIONS

Work performed under this NRA contract, in concert with work accomplished under LITES, LITES-II, and the Rockwell Collins NRA contract, has propelled TASAR from a state of conceptual formulation to operational deployment readiness in just four years, with two airline partners poised to test it operationally over the next few years. Among the contract's accomplishments that will have a lasting impact on TASAR's future are:

- A full documentation of NASA's TASAR concept, enabling widespread dissemination to the aviation community. (DEL 3B and NASA/CR-2013-218001)
- A preliminary user benefits analysis that enabled more effective outreach to the user community and was instrumental to NASA in building airline partnerships. (DEL 10 A/B and ATIO 2012 paper)
- An annualized benefits analysis of fleet-wide TAP adoption for NASA partner airlines: Alaska Airlines and Virgin America. (DEL 41A/B, NASA/CR-2015-218786, NASA/CR-2015-218787)
- An operationally deployable software prototype TASAR automation system, Traffic Aware Planner (TAP), designed to be expandable with future capabilities and adaptable to additional aircraft platforms and cockpit configurations.
- A user interface with an iteratively developed HMI that has been highly rated by airline pilots and verified ready for operational use by line pilots.
- Thorough analyses of external data sources for weather, traffic and airspace data for initial use and future capabilities. (DEL 43, DEL 51, DEL 60, DEL 65, DEL 66)
- Thorough analyses of partner airline aircraft integration and operational approval requirements, thereby accelerating readiness for operational trials with partner airlines. (DEL 39, DEL 40, DEL 53, DEL 54)
- A fully documented plan and MATLAB®-based analysis tools for assessing TASAR's performance, which will be used by the partner airlines during the operational trials. (DEL 61, DEL 62 B/C, DEL 67 A/B)
- An analysis of ATC acceptability of TASAR requests, which bolsters outreach to the aviation community of the TASAR concept's near-term viability. (DEL 57B)
- Expansion of the TASAR concept to include aircraft/dispatch integration, laying the framework for continued development of TASAR under NASA's Airspace Technology Demonstration Project (ATD-3). (DEL 52, DEL 3C)
- Completion of two high-fidelity simulation experiments (under the Rockwell Collins contract) that quantified the human factors of workload, distraction, and usability of TAP in a variety of TASAR use cases
- Completion of two flight trials that demonstrated the TASAR concept operating in the National Airspace System, including making TAP-generated requests to ATC, which garnered significant interest and press coverage from the aviation community. (FT-1, FT-2)

All these tasks have left the TASAR project well situated to prepare and conduct operational trials with commercial airlines starting in 2016, analyze the results for benefits, and continue expansion of TAP's capabilities under LITES-II and ATD-3.

5 ACRONYMS

AdvAero	Advanced Aerospace Solutions
AIAA	American Institute of Aeronautics and Astronautics
AID	EFB Aircraft Interface Device
Alaska	Alaska Airlines
AOP	Autonomous Operations Planner
ASRB	Airworthiness and Safety Review Board
ATD-3	NASA Airspace Technology Demonstration Project
ATIO	Aviation Technology, Integration and Operations conference
ATOS	Airspace and Traffic Operations Simulation
CDR	Contract Documentation Requirements
C/I	Connectivity/Integration
CITI	Collaborative Institutional Training Initiative
CR	Contractor Report
CRM	Crew Resource Management
CWAM	Convective Weather Avoidance Model
DCE	Data Concentrator Emulator
EDS	External Data Server
EFB	Electronic Flight Bag
FT-1	Flight Trial 1 (November 2014)
FT-2	Flight Trial 2 (June 2015)
FACET	Future ATM Concepts Evaluation Tool
FER	Final Experiment Review
FP LOE	Fixed Price Level of Effort
FTRR	Flight-trial Readiness Review
GAMA	General Aviation Manufacturers Association
GUI	Graphical User Interface
HITL	Human-in-the-Loop
HITL-1	First HITL test at OPL
HITL-2	Second HITL test at OPL
HMI	Human-Machine Interface
ICD	Interface Control Document
LaRC	Langley Research Center
LITES	Langley Information Technology Enhanced Services
LITES-II	Langley Information Technology Enhanced Services – II
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NDA	Non-disclosure Agreement
NextGen	Next Generation Air Transportation System
NOAA	National Oceanographic and Atmospheric Administration
OBE	Overtaken by Events
OPL	University of Iowa's Operator Performance Laboratory
PER	Preliminary Experiment Review
PI	Principal Investigator
POP	Period of Performance
SDD	Software Design Description
SDP	Software Development Plan

SME	Subject Matter Expert
SOW	Statement of Work
SRS	Software Requirements Specification
STAP	Simple Text Avionics Protocol (ARINC 834-1)
STAR	Standard Terminal Arrival Route
SUA	Special Use Airspace
SWIM	System Wide Information Management
TASAR	Traffic Aware Strategic Aircrew Requests
TAP	Traffic Aware Planner
TG	Trajectory Generator
TIM	Tablet Interface Module
UTAS	United Technologies Corporation Aeronautical Systems
Virgin	Virgin America Airlines
WSI	Weather Services International

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14. ABSTRACT
This document is the final report and deliverable 30 of Contract No. NNL12AA06C, the Traffic Aware Strategic Aircrew Requests (TASAR) contract awarded via the NASA Research Announcement (NRA). It documents the accomplishments of the contract, the evolution of its role in the overall TASAR project, and lessons learned from its execution.

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