TASAR

NASA Airborne Technology Application for En Route Flight Optimization

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Optimizing in a Dynamic Complex Environment

SUA – Special Use Airspace
SWIM – FAA System Wide Information Management
WX – Weather
Traffic Aware Strategic Aircrew Requests

Leveraging cockpit **automation and connectivity** to real-time operational data to enhance coordination with Dispatchers and ATC for **flight optimization** benefits.
### TASAR Attributes

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>Consistent with current operations</td>
<td>Near term</td>
</tr>
<tr>
<td>Requires no changes to existing FAA systems, policies, roles, training</td>
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<tr>
<td>Low threshold for FAA approval</td>
<td>Low Cost</td>
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<tr>
<td>Non-safety-critical intended function</td>
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<tr>
<td>Per-aircraft capability</td>
<td>Immediate Savings</td>
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<tr>
<td>Allows gradual implementation with immediate benefits</td>
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<tr>
<td>Leverages aircrew availability / low workload en route</td>
<td>Accelerated ROI</td>
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<tr>
<td>Provides more opportunities to accrue benefits</td>
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<tr>
<td>Encourages crews to become proactive about efficiency</td>
<td></td>
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<tr>
<td>Platform for future innovations in cockpit automation</td>
<td>Growth Potential</td>
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<tr>
<td>Integrate with avionics, dispatch, data sources, data communications</td>
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Traffic Aware Planner (TAP)

Innovative Qualities

- Onboard interactive “app” used directly by the pilot to enhance real-time flight operations
- Turns data connectivity into immediate operational benefits
- Powerful route-optimization function able to find common and unexpected solutions
- Handles complex, dynamic constraints of nearby traffic, weather, and restricted airspace
- Multi-dimensional optimization provides flexibility unmatched by other software applications
- Versatility to change optimization objective in real time during the flight
- Adaptable, low-cost implementation with proven appeal to early adopters
TAP and the Emerging “Connected Aircraft”

Designed as an Electronic Flight Bag (EFB) application

- **Ownship data via standard avionics interfaces (read only)**
  - Aircraft current state, active route, traffic data

- **Environment data via air/ground connectivity**
  - Latest winds, weather, airspace status, etc.

**Two Modes of Operation**

**Auto Mode**
Computes real-time route optimizations

**Manual Mode**
Analyzes pilot-entered route changes
TAP’s “Manual Mode”

Analyzes pilot-entered route changes

- Easy route/altitude entry via touch interface
- Supports lateral and/or vertical route changes
- Automatically finds nearest published waypoint to selected location
- Single-touch editing of added and rejoin waypoints
- Displays time & fuel outcomes of entered route/alt
- Depicts conflicts with traffic, weather, restricted airspace graphically and in text
TAP’s “Auto Mode”

**Computes real-time route optimizations**

- Integrates route optimization with conflict avoidance
  - Avoids traffic, weather, restricted airspace
  - Employs pattern-based genetic algorithm
  - Processes 400-800 candidates every minute
  - “Snaps” to published waypoints

- Pilot control of optimization objective, limiting waypoint, and solution complexity

- Flexible optimization: trip cost, fuel, or time

- Multiple solution types: lateral, vertical, combo

- Displays time & fuel outcomes of each solution

- Intuitive, extensively tested, highly rated user interface
TAP Integrates
Route Optimization with Conflict Avoidance

Published Waypoints Database
Source: FAA / ARINC 424

Optimization Goal
(Trip Cost, Fuel, Time)

User Constraints
(Max Off-Route Waypoints, Rejoin Limit)

Source: TAP Display

Active Route Aircraft State
Source: Avionics

Atmospheric Model
(pressure, temperature, winds)
Source: NOAA via EDS (External Data Server)

TAP Trajectory Generator

TAP Conflict Detector

‘Survival of the Fittest’
= Flyable, optimal, & conflict free

400-800 viable candidate routes are generated, evolved, and competed

TAP PBGA
(Pattern-Based Genetic Algorithm)

Source: TAP Display

Conflict-Free Solutions
Time/Fuel Outcomes

User Interface
Extensively Tested
By Airline Pilots
Highly User Rated

Pre-installed data
Dynamically updated data

Traffic Source: ADS-B
SUA Polygons w/ Schedules Source: FAA via EDS
Convective Weather Polygons Source: WSI/other via EDS

Aircraft Performance Model Data

Source: Airline

External Data Server

Airline Operations Workshop, Ames Research Center, Aug 3 2016
**Special Qualities of TAP’s Optimization Engine**

**Pattern-Based**

**Lateral Patterns:**
- FL320
- FL360

**Vertical Patterns:**
- FL360
- FL380
- FL400

**Combo Patterns:**
- FL360
- FL380
- FL400

**Mix of Exhaustive Search and GA**

- Generates all directs
- Best direct
- 19 random 1WP or 2WP
- Rank

**Viable Solutions Only**

- Keep top 10
- 10 new (1WP or 2WP) via mating
- Mutate a portion (exclude top 2)
- Rank

**Highly Efficient**

- Top ranked of 20\textsuperscript{th} generation is lateral solution

**Pre-process**

- Best direct
- 19 random 1WP or 2WP
- Rank

**1\textsuperscript{st} Generation**

- Generate all directs
- Rank

**Generations 2-20**

- Rank all candidates

**Single Generation (exhaustive search)**

- All allowable cruise altitudes

**Pre-process**

- Generate all direct/alt
- Rank

**1\textsuperscript{st} Generation**

- Best direct/alt
- 19 random 1WP/Alt or 2WP/Alt
- Rank

**Generations 2-20**

- Top ranked of 20\textsuperscript{th} generation is combo solution
Watch it Work (Video)

- Solutions updated cyclically every 60 seconds
- 400-800 viable candidate routes
- Convergence through ‘Natural Selection’ process over 20 generations
- ‘Survival of the Fittest’ = Flyable, most optimal, & conflict free
Human Factors Iterative Design Process

- Interactive HMI mockup
- Computer-based trainer (CBT)
- Human Factors evaluations (2 HITL sims, 2 flight trials)
- TAP pilot procedures document

Original HMI Design

Current HMI Design

HF Evaluation - TASAR HITL-1, Flight Trial 1

HF Evaluation - TASAR HITL-2, Flight Trial 2
System Tested in Relevant Environment

Flown in Aircraft Certified for Normal Operations
AdvAero Piaggio Avanti

Evaluated in Flight by Senior Airline Pilots

Operated in Congested Airspace

Also Assessed from ATC Perspective

Tested on Airline Hardware
**Preliminary TASAR Benefits Estimate**

**All Airspace User Classes are Projected to Benefit**

![Map of airport pairs analyzed](image)

Each line represents an airport pair analyzed.

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**Fast-time simulation study (2012)**

- Historical trajectories between 12 representative airport pairs analyzed
- 510 flights between July 11-20, 2012
- 300-2000 TASAR-like alternative trajectories evaluated for each flight
  - At five minute intervals
  - Convective weather on East Coast, Midwest

**Conservative measures applied**

- No requests during initial climb
- No requests with conflicts
- One request per sector
- No requests near handoff
- No requests within 200 nmi of destination

**Three flight optimization objectives studied**

- (1) Save Time, (2) Save Fuel, and (3) 50/50 Weighted

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**Mean savings per flight**

<table>
<thead>
<tr>
<th>Class of Airspace User</th>
<th>Optimization Objective</th>
<th>(1) Save Time</th>
<th>(2) Save Fuel</th>
<th>(3) 50/50 Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>∆T ∆F</td>
<td>∆T ∆F</td>
<td>∆T ∆F</td>
<td></td>
</tr>
<tr>
<td>Network</td>
<td>4.2 -122</td>
<td>3.4 575</td>
<td>3.6 543</td>
<td></td>
</tr>
<tr>
<td>Low Cost</td>
<td>2.9 -123</td>
<td>2.5 406</td>
<td>2.6 344</td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td>1.0 -88</td>
<td>0.8 137</td>
<td>1.0 66</td>
<td></td>
</tr>
<tr>
<td>Business</td>
<td>1.2 -22</td>
<td>1.6 64</td>
<td>1.5 53</td>
<td></td>
</tr>
</tbody>
</table>

**ΔT**: Time savings (minutes) **ΔF**: Fuel savings (pounds)

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Reference: AIAA-2012-5684
### Benefits Estimate Tailored to Partner Airlines

#### Operators and Fuel/Energy Savings

<table>
<thead>
<tr>
<th>Operator</th>
<th>Annual TASAR Fuel Benefit</th>
<th>Annual TASAR Time Benefit</th>
<th>Annual Benefit (est.) ǂ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska*</td>
<td>1,040,000 gallons @ $3.26/gallon = $3,390,000/year</td>
<td>110,700 min @ ($17 to $28/min) = $1,759,000/year</td>
<td>$5.15M</td>
</tr>
<tr>
<td>Virgin</td>
<td>1,411,000 gallons @ $3.03/gallon = $4,275,000/year</td>
<td>133,500 min @ about $6/min = $812,000/year</td>
<td>$5.09M</td>
</tr>
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* Excludes Alaska, Oceanic, and international operations

ǂ Fuel, maintenance, and depreciation. Excludes crew costs.

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**Historical trajectories used as a baseline for estimating benefits**

- 1,606 Alaska flights analyzed
- 1,554 Virgin flights analyzed

**Benefits Per Flight**

- Alaska: 2.89 min/flight, 27.8 gallons/flight
- Virgin: 2.75 min/flight, 28.0 gallons/flight

Annualized average across all flights, even those that did not benefit.
Two analyses performed by Rockwell Collins under contract* to NASA

**Analysis 1: Operational hazards / safety requirements**
- Applied two aviation-industry-accepted methods of safety analysis to TASAR
  - SAE ARP 4761 system safety analysis
  - ED78A/RTCA DO-264 Operational Safety Assessment (abbreviated)
- FEC determination likely to be “Minor” or “No Effect” for workload, “No Effect” for loss of function

**Analysis 2: Certification and operational approval requirements**
- Reviewed 17 regulations, standards, and guideline documents applicable to proposed TASAR system:
  - Class 2 EFB installation – determined no special requirements beyond hardware and installation approval
  - Type B software application – TASAR similar to other “dynamic calculation” non-safety-critical applications
- Rockwell Collins DERs reviewed TASAR approval basis: no concerns identified

**Conclusions confirmed** by FAA AIR-130 and AFS-430 (policy makers for EFB applications)
- Also decided:
  - FAA declared TASAR is not an “ADS-B In Application” (it’s a performance/planning app w/ optional ADS-B input)
  - FAA sees no need for an industry “TASAR Standard”

*Existing policies allow for TASAR operations now, via POI approval*
Partner Airline Operational Implementations

- Avionics data connectivity
- Aircraft performance models
- Navigation database
- Hardware operating systems
- User interface adaptation

- STCs / wiring installation
- External connectivity
- Integrated performance testing
- Weather radar integration
- GDS development & integration

- Data recording & retrieval
- Pilot training materials
- FAA & airline approvals
- Operational use / observations
- Performance analysis
Interface with User and NextGen Technologies

Integration Benefits
- Improved coordination
- Optimized flight trajectories
- Shared data sources
- Traffic-aware solutions
- Digitally shared route changes
- Improved schedule conformance

FAA NextGen Programs
- ADS-B Automatic Dependent Surveillance Broadcast
- Data Comm Digital Data Communications
- SWIM System Wide Information Management
- TBFM Time-Based Flow Management
TASAR Roadmap Aligns w/ NextGen Programs

- **TASAR** – cockpit-integrated flight optimization technology, first of its kind
  - Designed to enable substantial first-adopter efficiency benefits at minimal cost
  - Leverages ground-derived info for better solutions
  - **ADS-B IN** increases ATC approval rate

- **Digital TASAR** – sharing data via **SWIM** and trajectories via **Data Comm**
  - Common wind, weather, SUA status, sector data, traffic intent, …
  - Complex requests, lat/lon WPTs, reduced workload & errors, …

- **4D TASAR** – sharing constraints with **TBFM / IM**
  - Business trajectory with metering input, schedule achievement / conformance
Impact: Near Term and Far Term

- **Near term: TAP Fills a Void**
  - Pilots have the time, but no tools for optimization
    - Dispatchers, ATC are focused on other things
  - TAP enables pilots to request route changes that are *truly beneficial*, more likely to be approved
  - Approved route changes equate to direct benefits, with *immediate payback*
    - Trip cost savings, fuel burn & emissions reduction, delay recovery

- **Far Term: TAP as a Catalyst for Transformation**
  - Change to air traffic management is onerous, years to implement
  - TAP will encourage pilots to exercise more authority over their flight path
  - Maturing tomorrow’s technology through in-service use today
  - Transformation to *on-demand mobility* and *increased operational autonomy*

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“Autonomy will take time – However, applications such as NASA’s TASAR program [TAP] leverage some elements of autonomy to achieve complete optimization…”
Available at ntrs.nasa.gov:

- **Project summary & status**

- **Concept description**
  - NASA/CR-2013-218001, AIAA-2012-5623

- **TAP software application description**

- **User benefits**

- **Safety and operational hazards**

- **Certification and operational approval**

- **HITL simulation experiments (2013, 2014)**
  - Pending NASA TM (HITL-1, 2)

- **Flight Trials (2013, 2015)**

- **Future Roadmap**
  - AIAA-2016-4212, NASA/TM-2016-219176