TASAR

NASA Airborne Technology Application for En Route Flight Optimization

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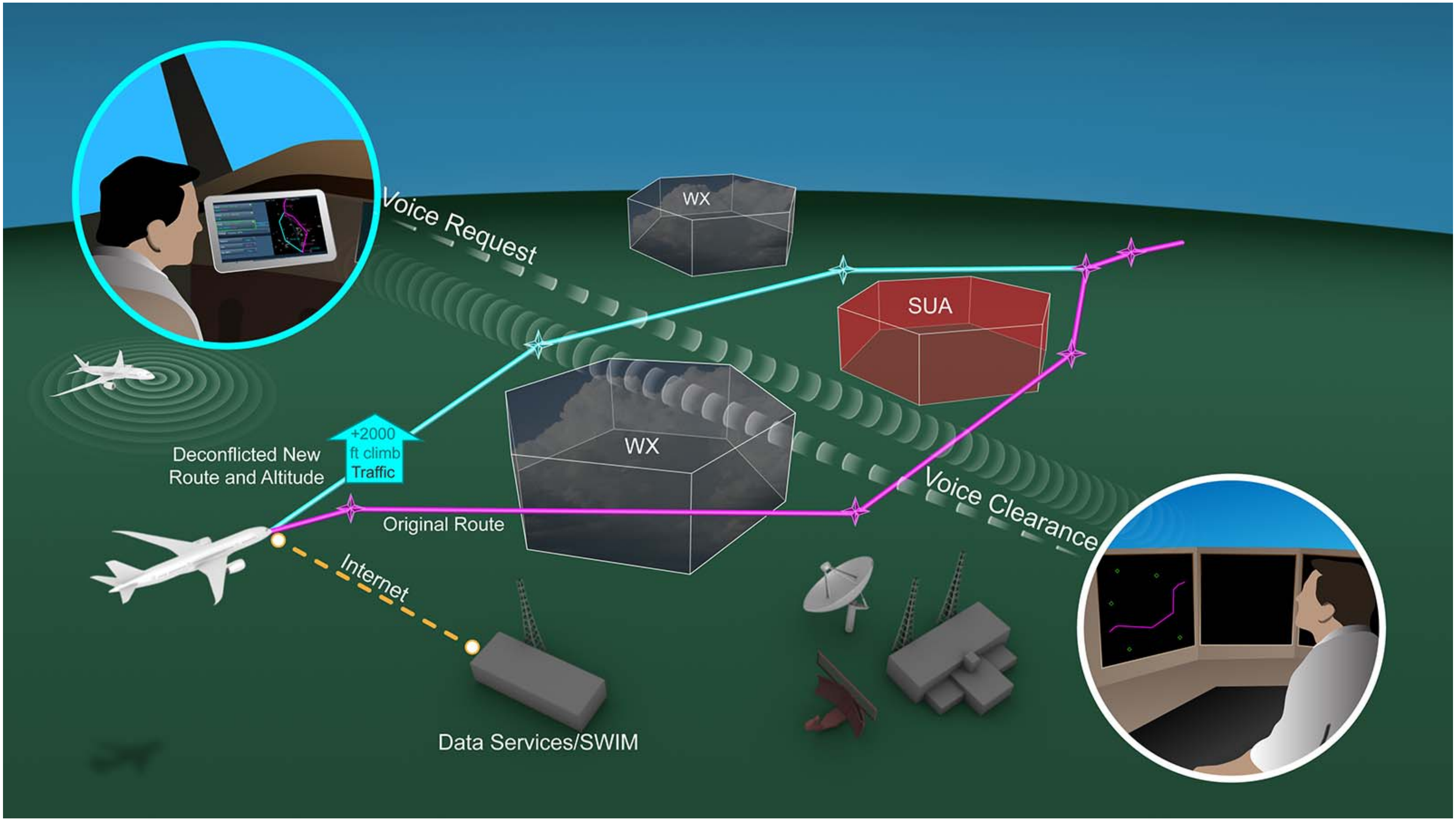
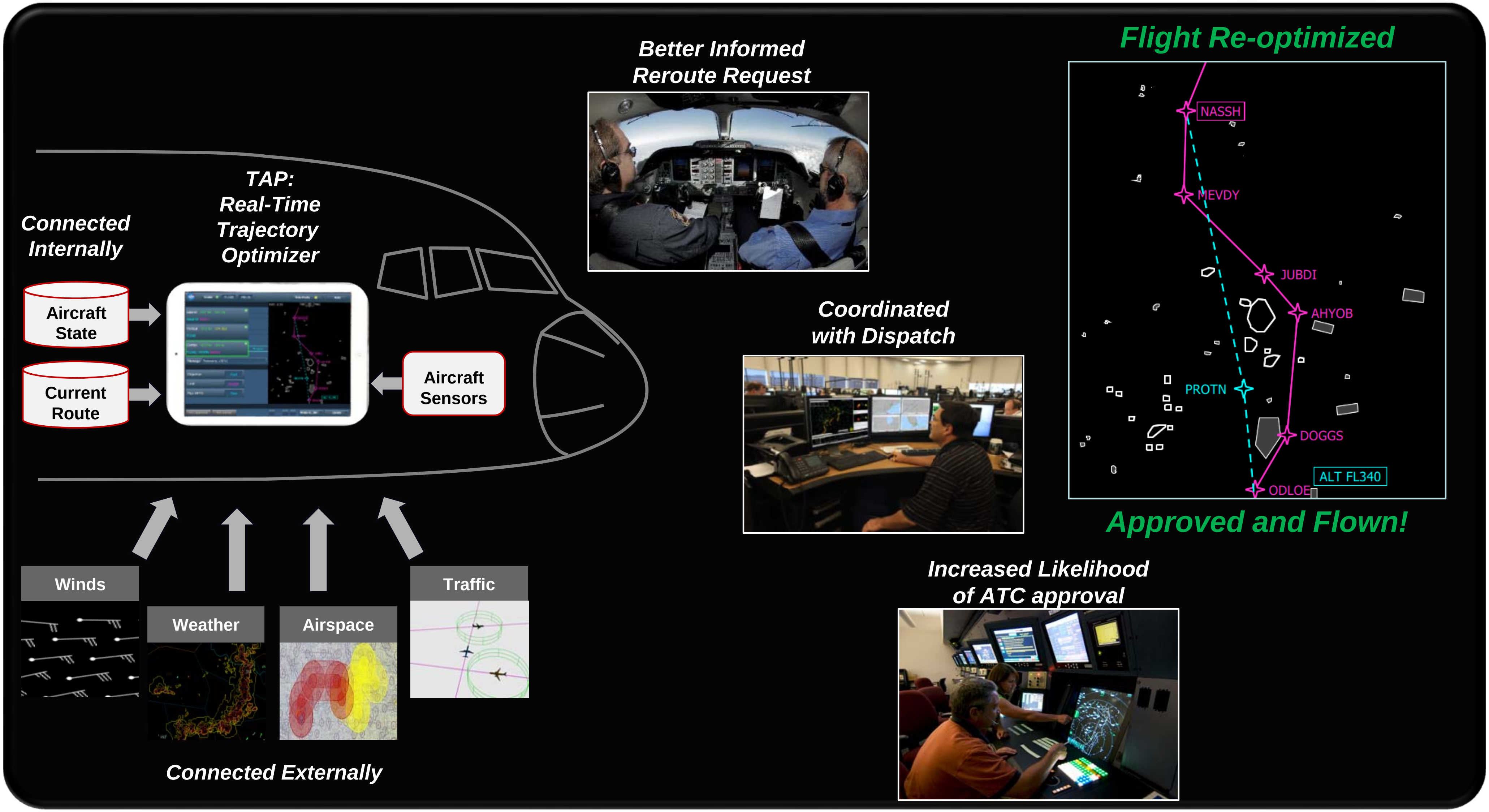
Optimizing in a Dynamic Complex Environment



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*



An Early Adopter Application

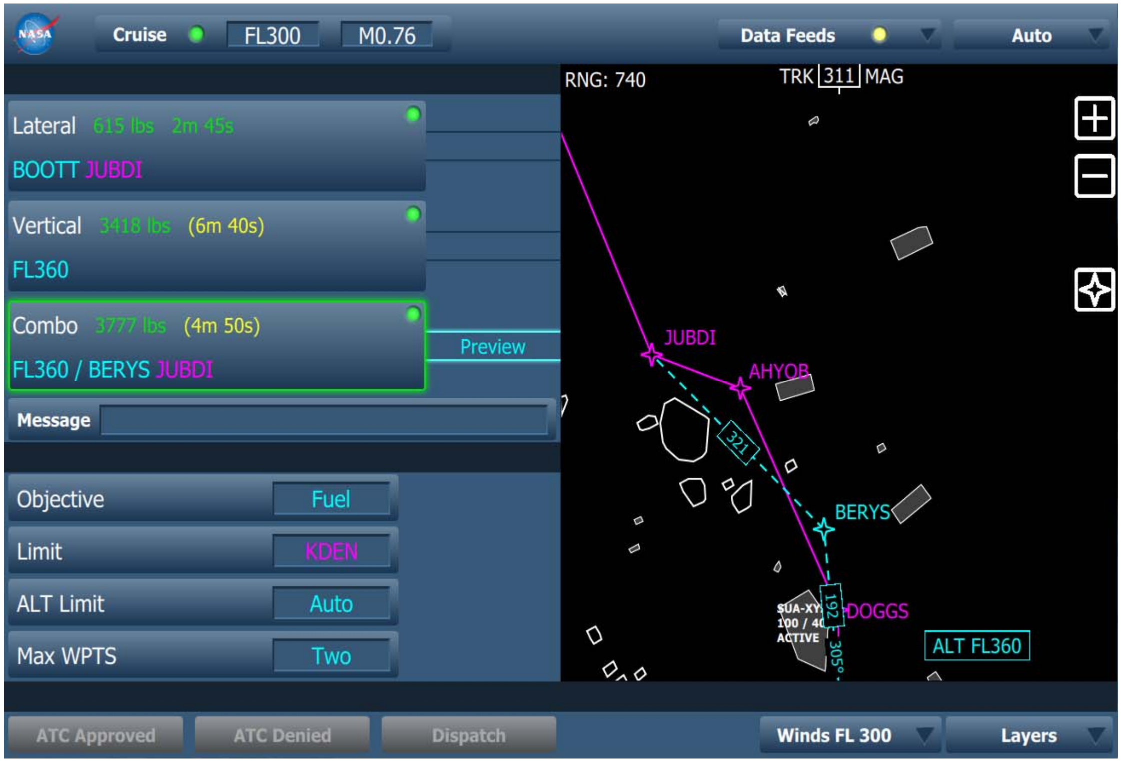
TASAR Attributes	Benefits
Consistent with current operations *Requires no changes to existing FAA systems, policies, roles, training*	**Near term**
Low threshold for FAA approval *Non-safety-critical intended function*	**Low Cost**
Per-aircraft capability *Allows gradual implementation with immediate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

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

TAP Display in Landscape Orientation



- 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.

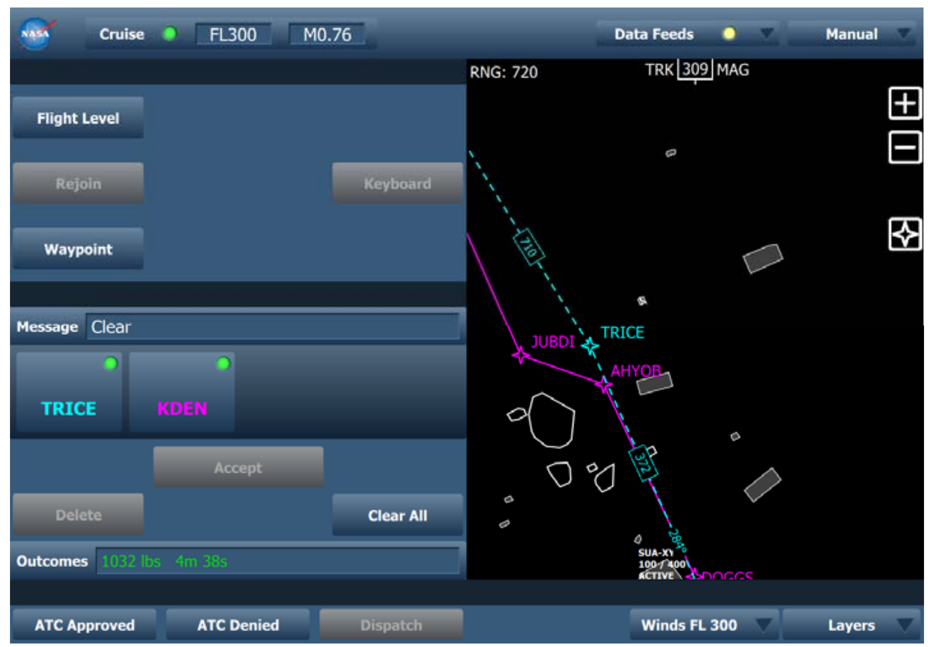
Two Modes of Operation

Auto Mode

Computes real-time route optimizations

Manual Mode

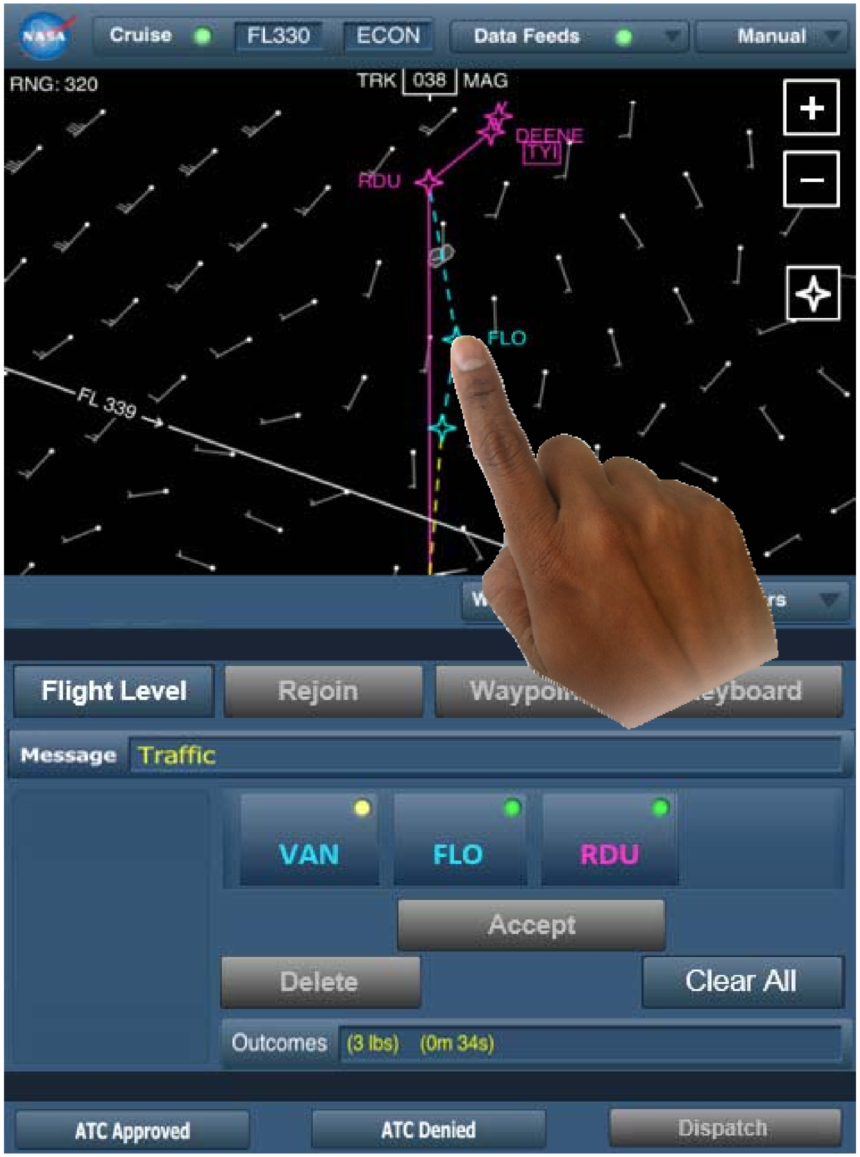
Analyzes pilot-entered route changes



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

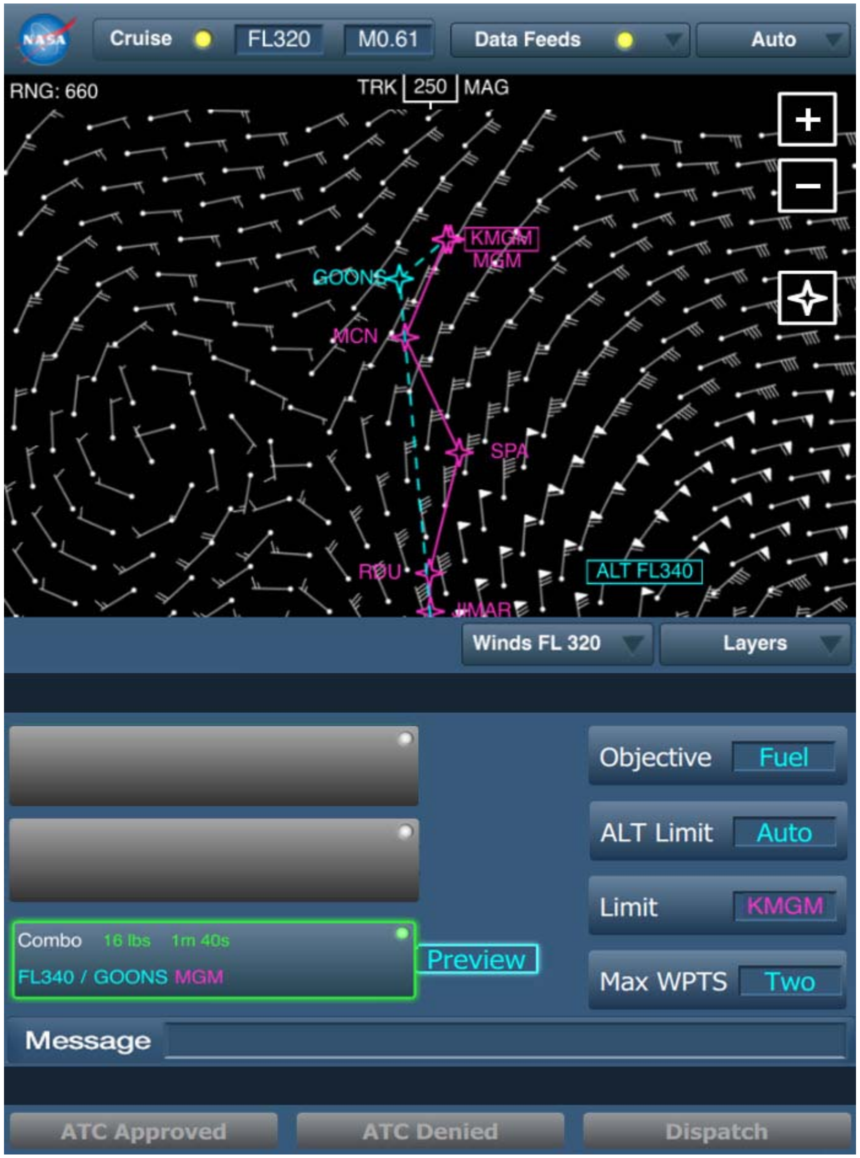
– Flexible optimization: trip cost, fuel, or time

– Multiple solution types: lateral, vertical, combo

– Displays time & fuel outcomes of each solution

– Intuitive, extensively tested, highly rated user interface

TAP Display in Portrait Orientation



TAP Integrates
Route Optimization with Conflict Avoidance

Pre-installed data

Dynamically updated data

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)

Updates Cyclically Every 60 Seconds

TAP PBGA
(Pattern-Based Genetic Algorithm)

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

'Survival of the Fittest'
= Flyable, optimal, & conflict free

TAP Trajectory Generator

TAP Conflict Detector

Aircraft Performance Model Data

Source: Airline

Traffic

Source: ADS-B

SUA Polygons w/ Schedules

Source: FAA via EDS

Convective Weather Polygons

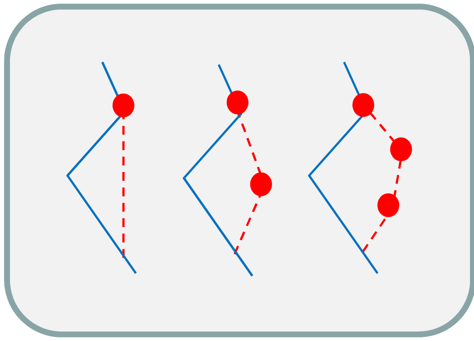
Source: WSI/other via EDS

User Interface Extensively Tested By Airline Pilots
Highly User Rated

Special Qualities of TAP's Optimization Engine

Pattern-Based | **Mix of Exhaustive Search and GA** | **Viable Solutions Only** | **Highly Efficient**

Lateral Patterns:



- Generate All Directs
- Rank

Pre-process

- Best Direct
- 19 Random 1WP or 2WP
- Rank

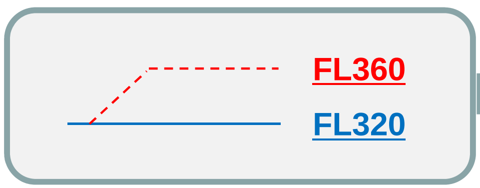
1st Generation

- Keep Top 10
- 10 New (1WP or 2WP) via Mating
- Mutate a portion (exclude top 2)
- Rank

Generations 2-20

Top Ranked of 20th Generation Is Lateral Solution

Vertical Patterns:



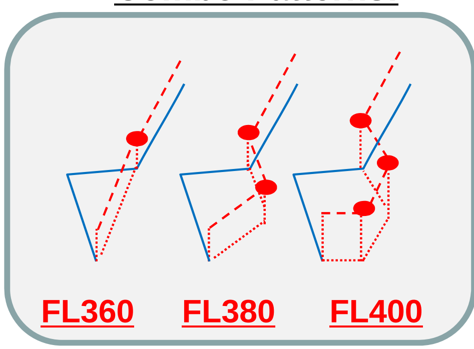
All Allowable Cruise Altitudes

Rank All Candidates

Single Generation (exhaustive search)

Top Ranked is Vertical Solution

Combo Patterns:



- Generate All Direct/Alt
- Rank

Pre-process

- Best Direct/Alt
- 19 Random 1WP/Alt or 2WP/Alt

1st Generation

- Keep Top 10
- 10 New (1 or 2 WP/Alt) via Mating
- Mutate a portion (exclude top 2)
- Rank

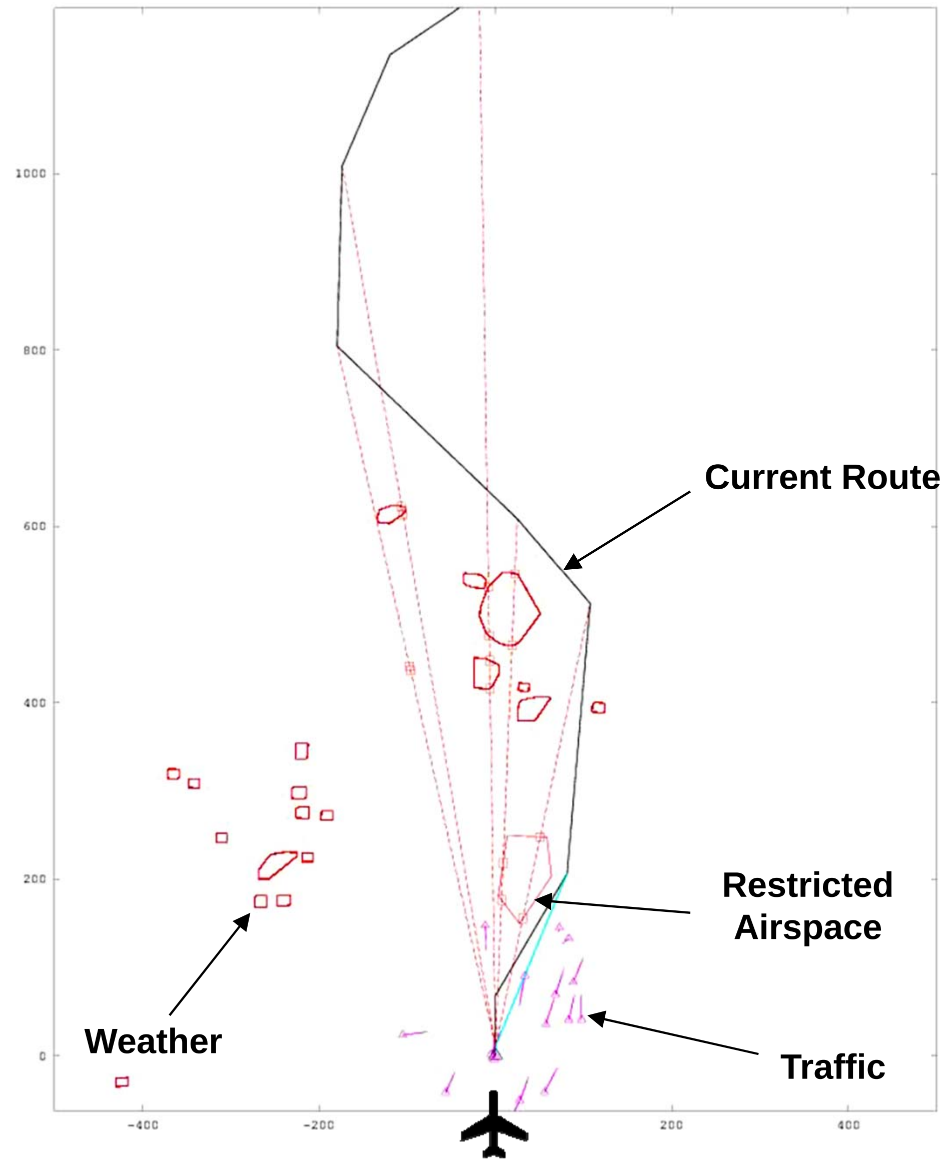
Generations 2-20

Top Ranked of 20th Generation Is Combo Solution

Watch it Work (Video)

(black line)	**Current Route**
(green line)	**Candidate – conflict free**
(red line)	**Candidate – conflicted**
(light blue line)	**Best in Generation**

- **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

HF Evaluation - TASAR HITL-1, Flight Trial 1

Data Collection

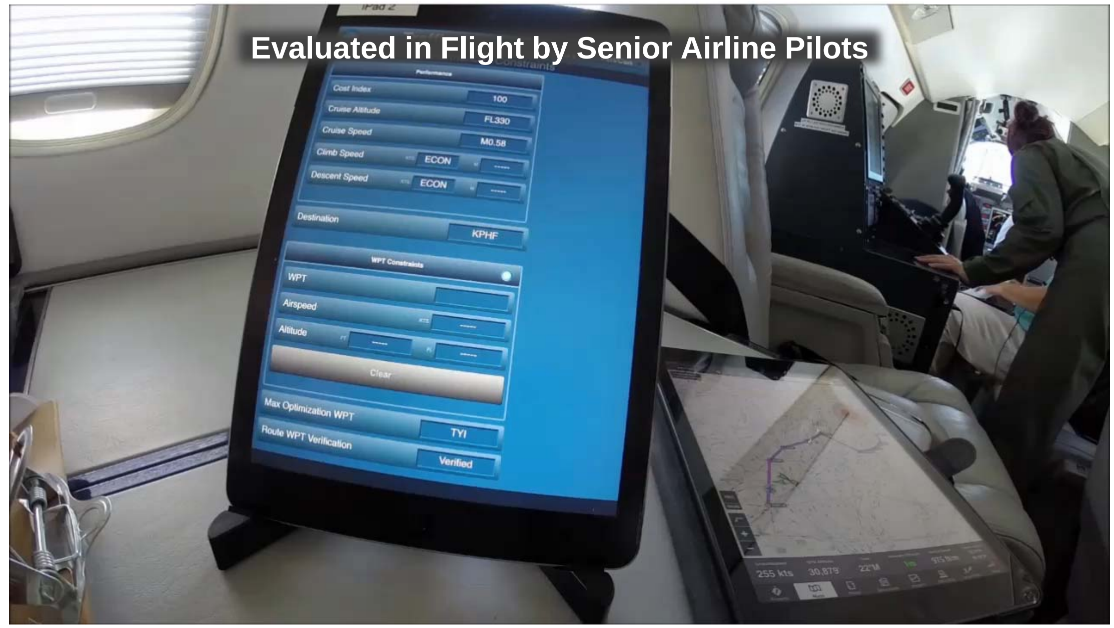
Current HMI Design

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

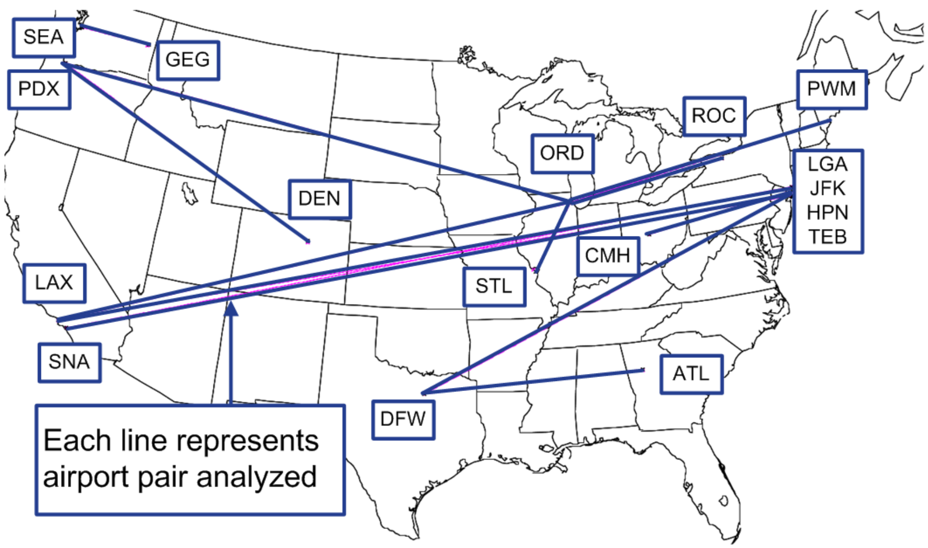
Operated in Congested Airspace


Also Assessed from ATC Perspective


Tested on Airline Hardware

Preliminary TASAR Benefits Estimate

All Airspace User Classes are Projected to Benefit



Mean savings per flight

Class of Airspace User	Optimization Objective					
	(1) Save Time		(2) Save Fuel		(3) 50/50 Weighted	
	ΔT	ΔF	ΔT	ΔF	ΔT	ΔF
Network	**4.2**	-122	3.4	**575**	3.6	543
Low Cost	**2.9**	-123	2.5	**406**	2.6	344
Regional	**1.0**	-88	0.8	**137**	1.0	66
Business	**1.2**	-22	1.6	**64**	1.5	53

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

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

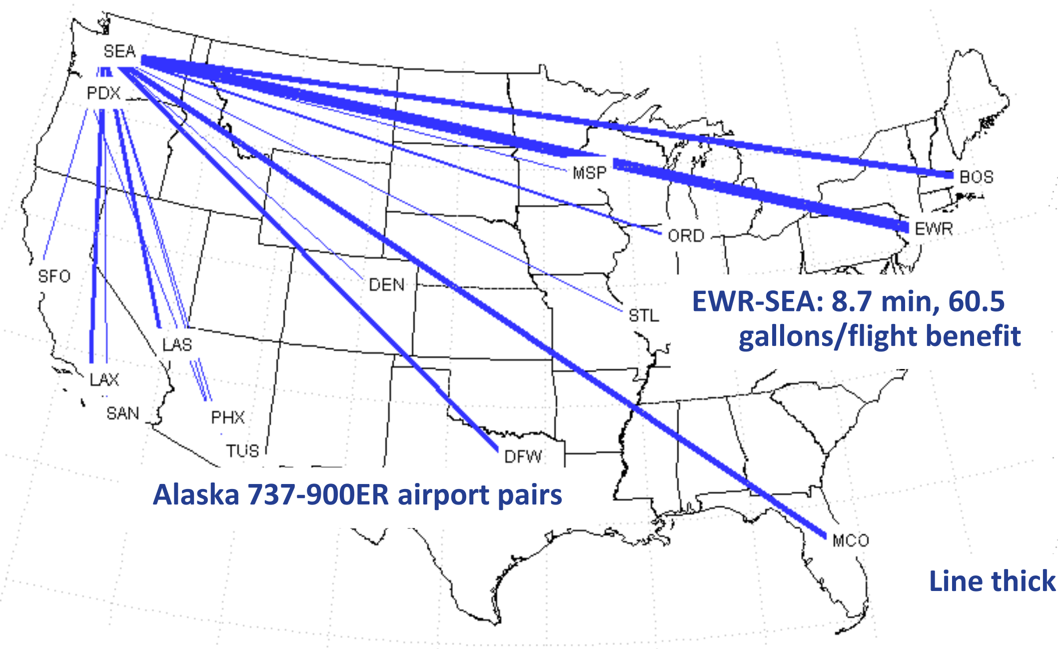
- No requests during initial climb
- No requests with conflicts
- One request per sector
- No requests near handoff
- No requests within 200 nmi of destination

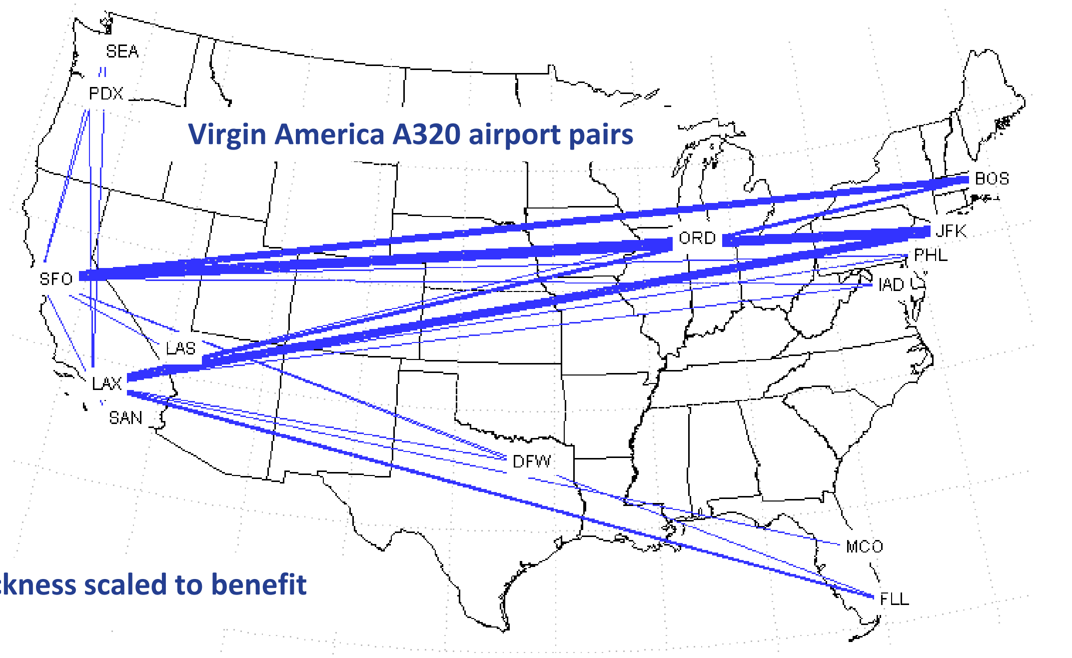
Three flight optimization objectives studied

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

Reference AIAA-2012-5684

Benefits Estimate Tailored to Partner Airlines





Operator	Annual TASAR Fuel Benefit	Annual TASAR Time Benefit	Annual Benefit (est.) ‡
Alaska* **109 737s**	**1,040,000 gallons** @ $3.26/gallon = $3,390,000/year	**110,700 min** @ ($17 to $28/min) = $1,759,000/year	**$5.15M**
Virgin **53 A320s**	**1,411,000 gallons** @ $3.03/gallon = $4,275,000/year	**133,500 min** @ about $6/min = $812,000/year	**$5.09M**

*** Excludes Alaska, Oceanic, and international operations**
‡ Fuel, maintenance, and depreciation. Excludes crew costs.

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 <u>all</u> flights, even those that did not benefit

Safety, Certification/Operational Approval

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)

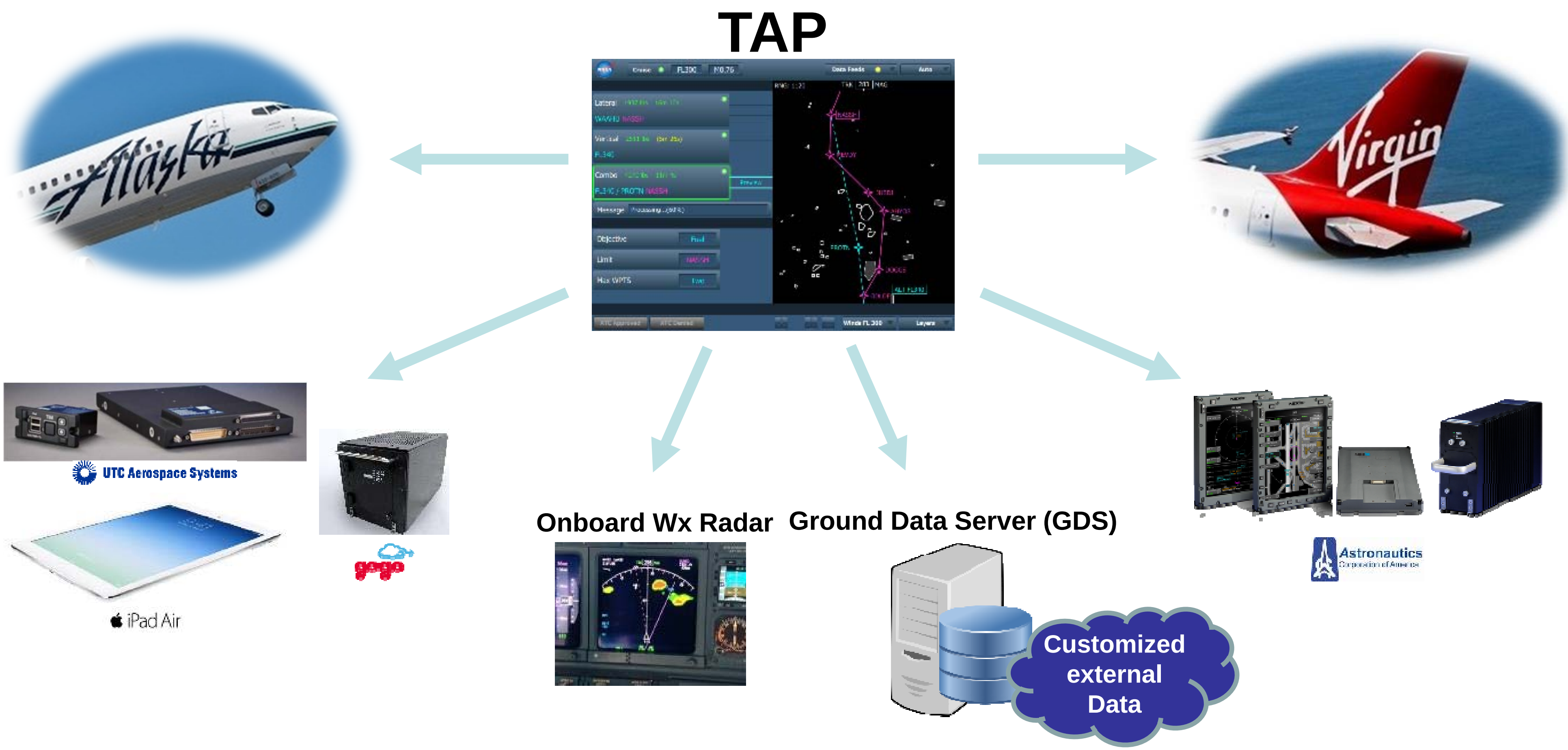
- Also decided:
  - FAA declared TASAR is not an "ADS-B In Application" (it's a performance/planning app w/ optional ADS-B input)
  - FAA sees no need for an industry "TASAR Standard"

Existing policies allow for TASAR operations now, via POI approval

DER: Designated Engineering Representative
FEC: Failure Effects Classification
POI: Principal Operations Inspector

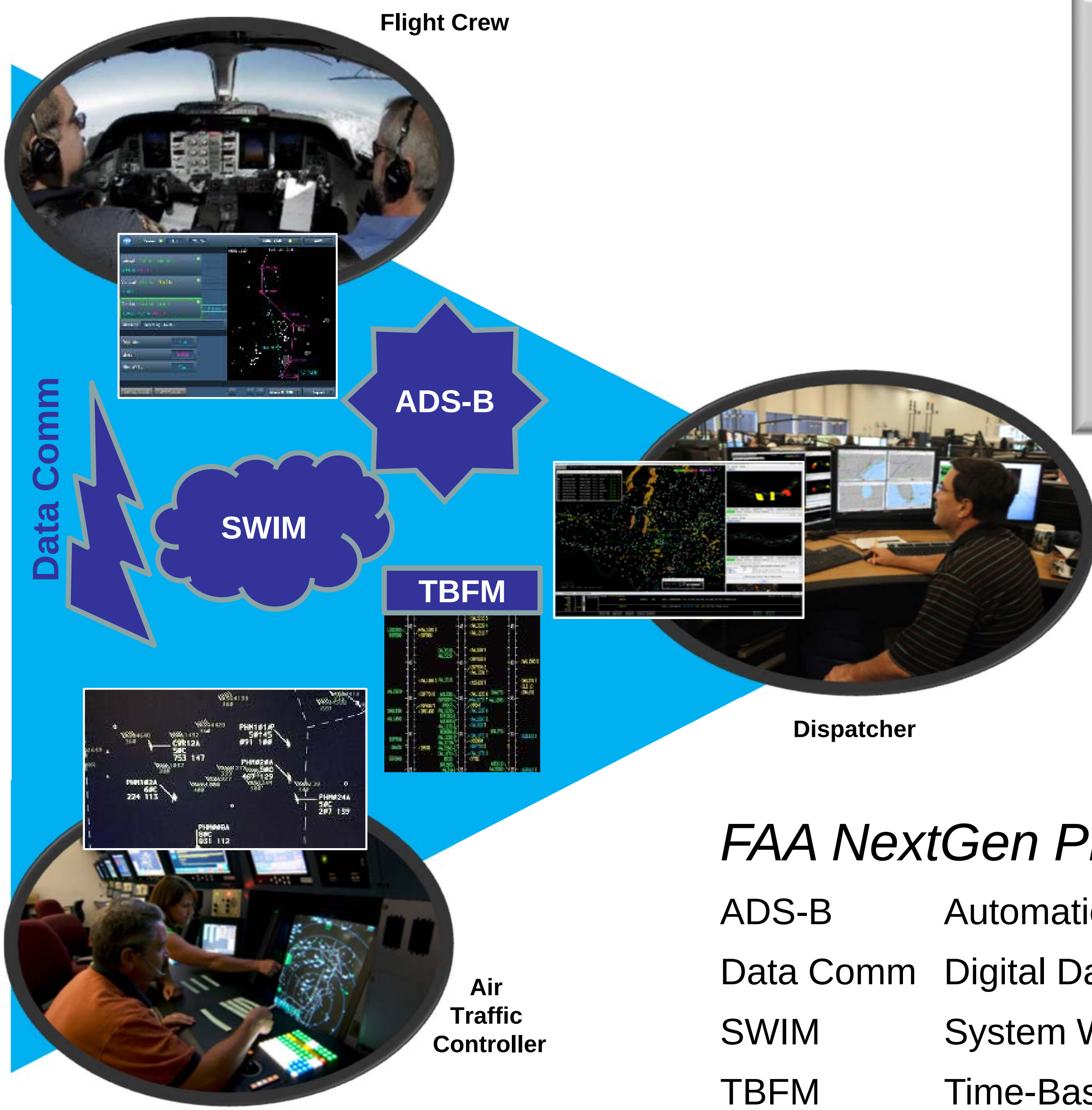
*NASA-CR/2015-218708, 2015

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

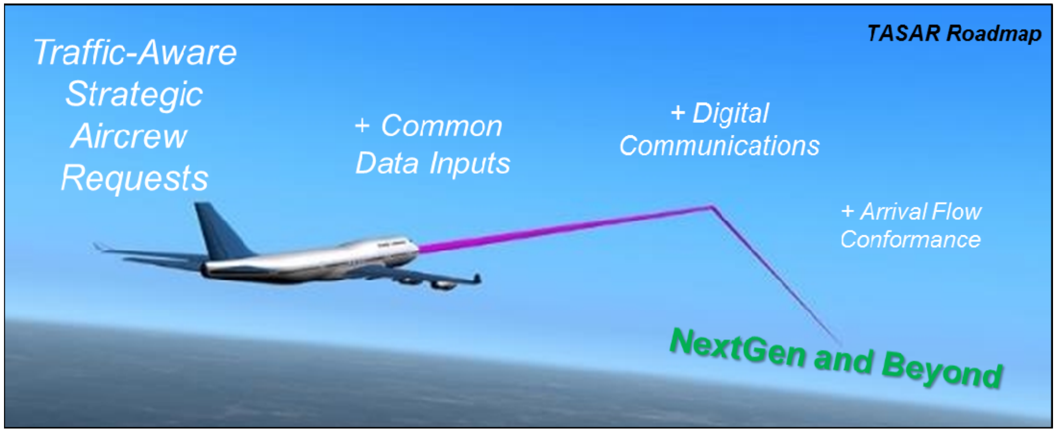
ADS-B	Automatic Dependent Surveillance Broadcast
Data Comm	Digital Data Communications
SWIM	System Wide Information Management
TBFM	Time-Based Flow Management

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***

From the Ground Up: How the Internet of Things Will Give Rise to Connected Aviation, published by Gogo LLC, 2016.

*"Autonomy will take time – However, **applications such as NASA's TASAR program [TAP] leverage some elements of autonomy** to achieve complete optimization…"*

For More Information on TASAR

Available at ntrs.nasa.gov:

- **Project summary & status**
  - AIAA-2015-3400, AIAA-2013-4231, NASA/CR-2016-219197
- **Concept description**
  - NASA/CR-2013-218001, AIAA-2012-5623
- **TAP software application description**
  - AIAA-2016-4067, AIAA-2013-4967, AIAA-2013-4968
- **User benefits**
  - AIAA-2012-5684, NASA/CR-2015-218786, NASA/CR-2015-218787
- **Safety and operational hazards**
  - NASA/CR-2013-218002, DASC.2013.6712530
- **Certification and operational approval**
  - NASA/CR-2015-218708, DASC.2013.6712530
- **HITL simulation experiments (2013, 2014)**
  - Pending NASA TM (HITL-1, 2)
- **Flight Trials (2013, 2015)**
  - AIAA-2014-2166, NASA-CR-2015-218673 (FT1), Pending NASA TP (FT2), NASA/CR-2016-219215 (FT2 ATC analysis)
- **Future Roadmap**
  - AIAA-2016-4212, NASA/TM-2016-219176

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