Required Time-of-Arrival Trials

Presented to "E-Operations" Workshop
Georgia Tech
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GE Aviation – Digital Systems

Why is CDA use so limited?

Myth: "CDAs reduce capacity"

- Idle descent vertical and time profiles can vary widely from aircraft to aircraft
- This uncertainty drives the need for ATC to block large chunks of airspace

Thus, CDAs are practiced today generally during off-peak hours and/or sub-optimal descents (least-common-denominator fixed vertical profiles)

Solution: Use of 4D-trajectory downlink, and if needed, onboard time-guidance (RTA)

- supplies ATC with observability and predictability to use CDAs during dense operations

Requirements:

- Aircraft – 4D FMSs already predict reliable 4D Trajectories (4DT) and guide to Required Times of Arrival. Need appropriate downlink of the 4DT
- ANSP – Operational shift toward Trajectory Based Operations (TBO) to incorporate the 4DT and the development of necessary support applications

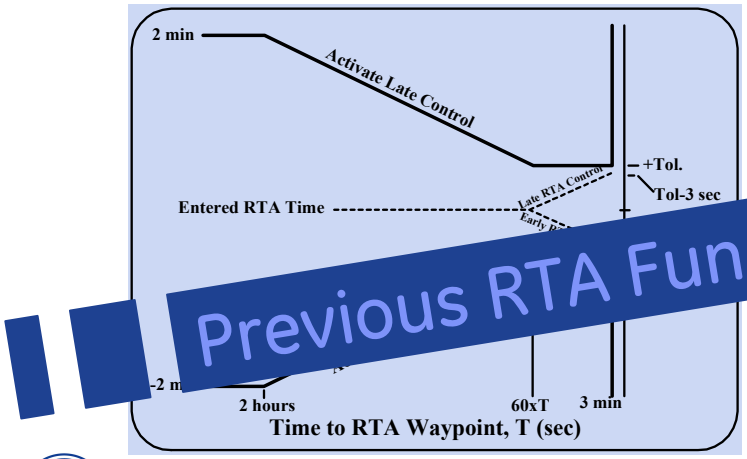
Required Time of Arrival (RTA)

Algorithm is based on speed variation.

- Fixed lateral path, fixed cruise altitude

RTA is enabled for any point in the flight plan.

- Available on 737 aircraft since 1986.
- Demonstrated performance in trials with SAS in 2001.
- Now flying: GE Aviation FMS improved “RTA to Runway”



Previous RTA Function

GE Aviation
“RTA to RWY”
Improvement

Trajectory-Based Operations

NextGen and SESAR aim to set vision and path to achieve TBO / 4DT ATM

In-service operational evaluations represent "forays" into the future:

- Validation of concepts
- Validation of benefits
- Results and data informs decisions of political activities (NextGen, SESAR)
- Provide input toward standardization activities

These vanguard activities require effective teaming across domains

- ANSP (and equipment suppliers)
- Operators (and OEM + suppliers)
- Airport Authority

... basis for the integrated system seen by NextGen and SESAR.

The European Commission's NUP2+ Program is presented here.

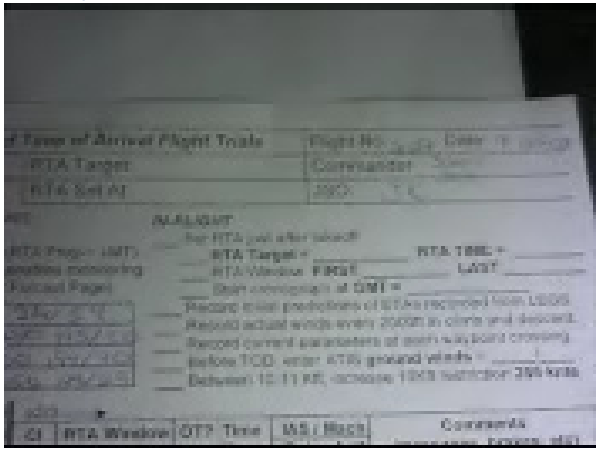
Objectives and Experimental Setup

OBJECTIVES:

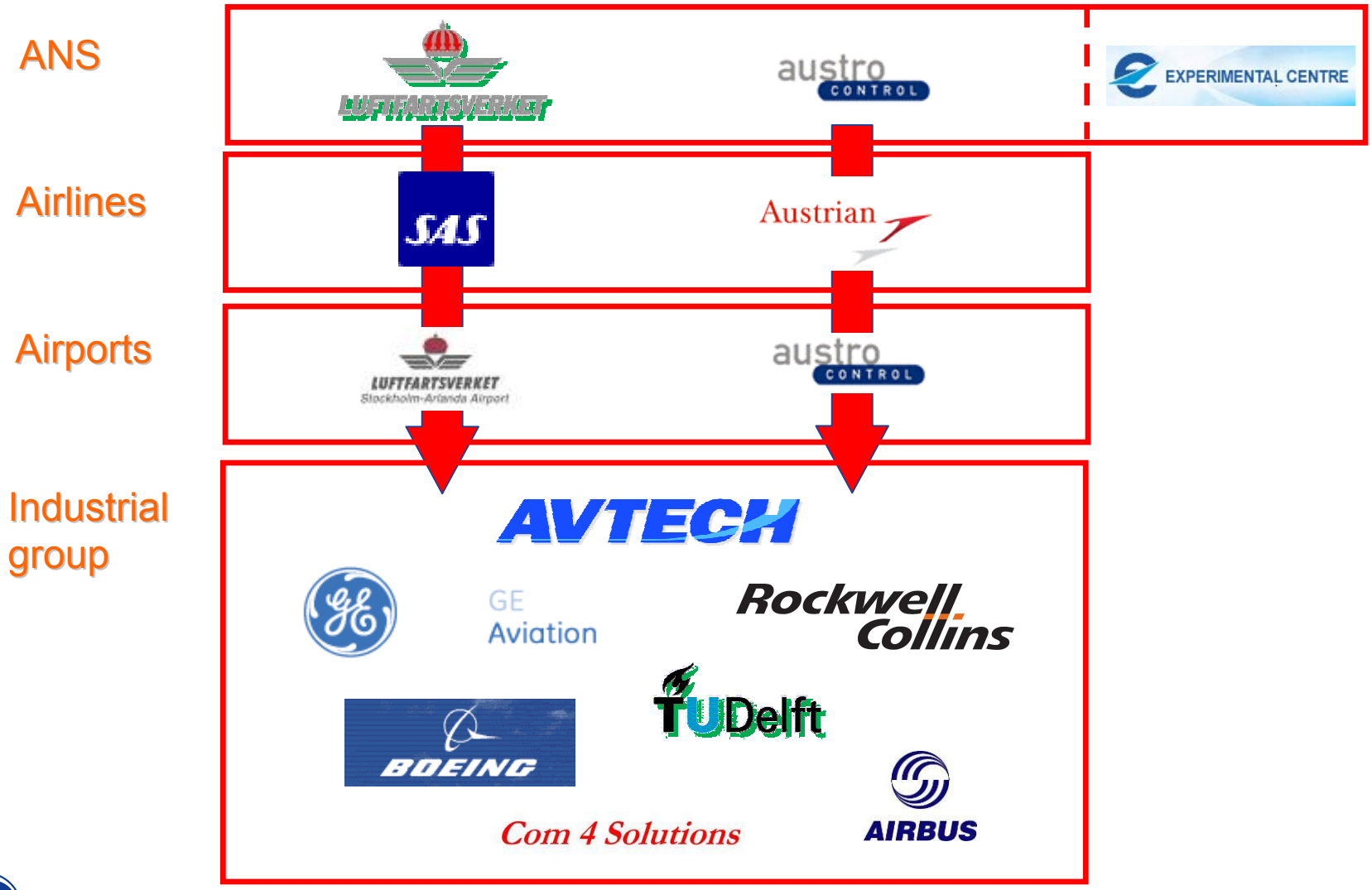
- Datalink bandwidth requirements for air/ground TBO apps?
- Identify areas for further FMS or application improvements
- Study 4DT stability, reliability… Lay groundwork for metrics

Flight Trials :

- 30 flights (6 with U10.6 in 2006, 24 with U10.7 in 2007)
- U10.7 change validation (4D predictions, “RTA to RWY”)
- Green Approaches and NowCast wind uplinks at ToD



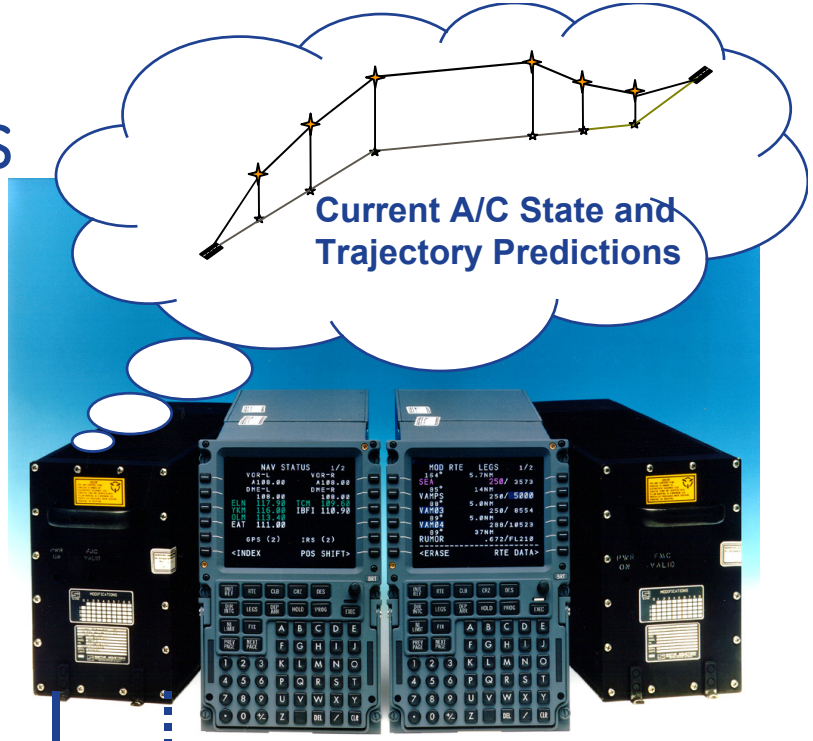
NUP 2+ Partners



Intent Bus in B737 U10.6 & U10.7 FMS

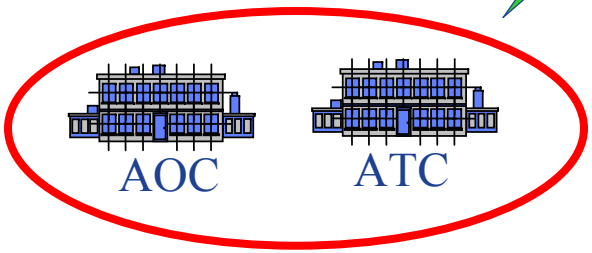
First application in 2005 – Provide FMS 4D trajectory to ATC!

- **ARINC 702A-1 Trajectory Bus**
  - **Aircraft current-state information 2Hz**
  - **Aircraft 4D trajectory predictions (Intent)**
    - **Each minute or when FP changes**
    - **Full trajectory to runway**
    - **Includes vertical wpts and turns**
  - **Dedicated ARINC 429 Bus**
    - **As per ARINC702A-1**

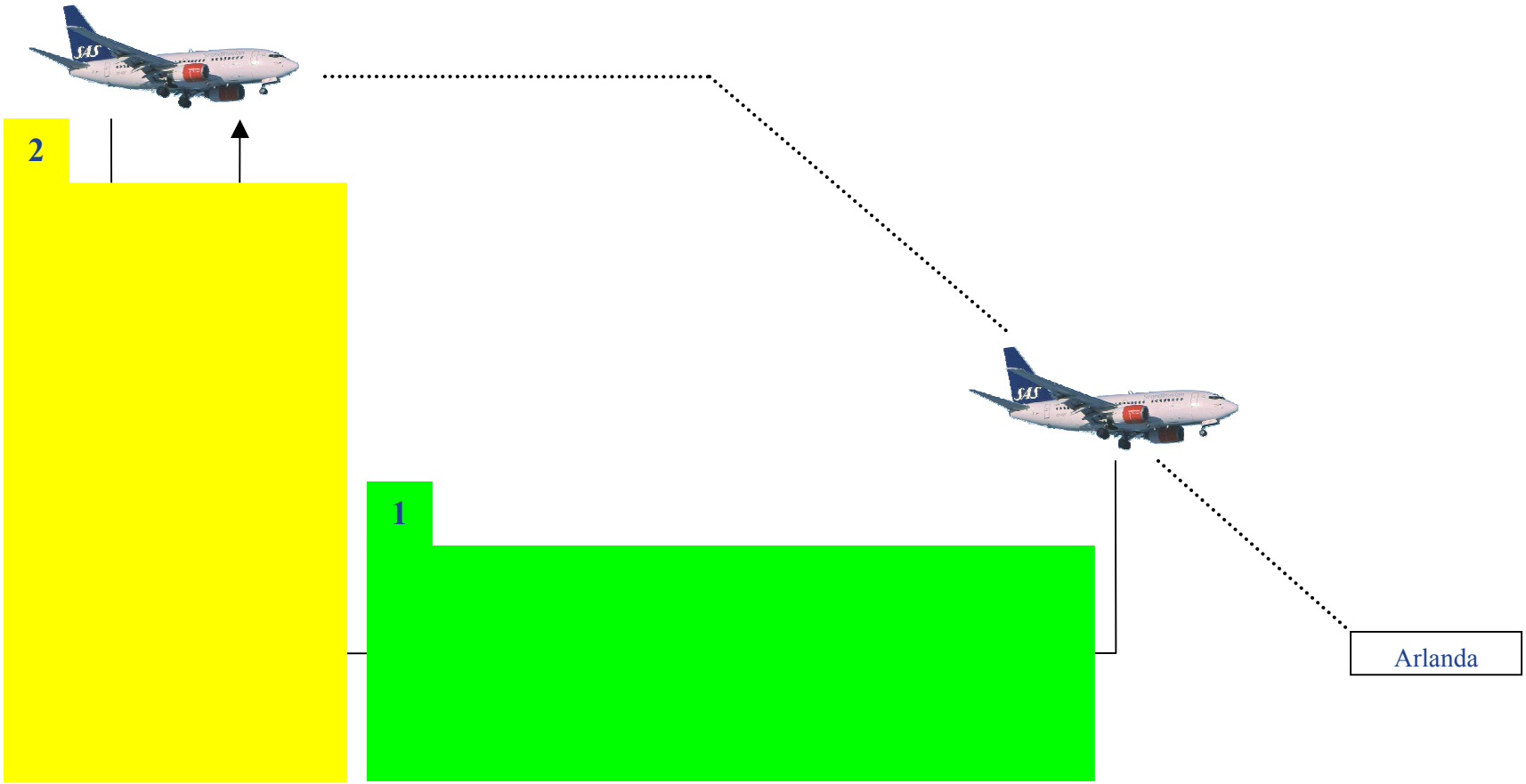


in 2007!

- **ACARS messages added for interim use in flight trials**
  - **By REQ from ATC**
  - **One-time or periodic downlink**



AVTECH NowCast wind uplink



Arrival Management

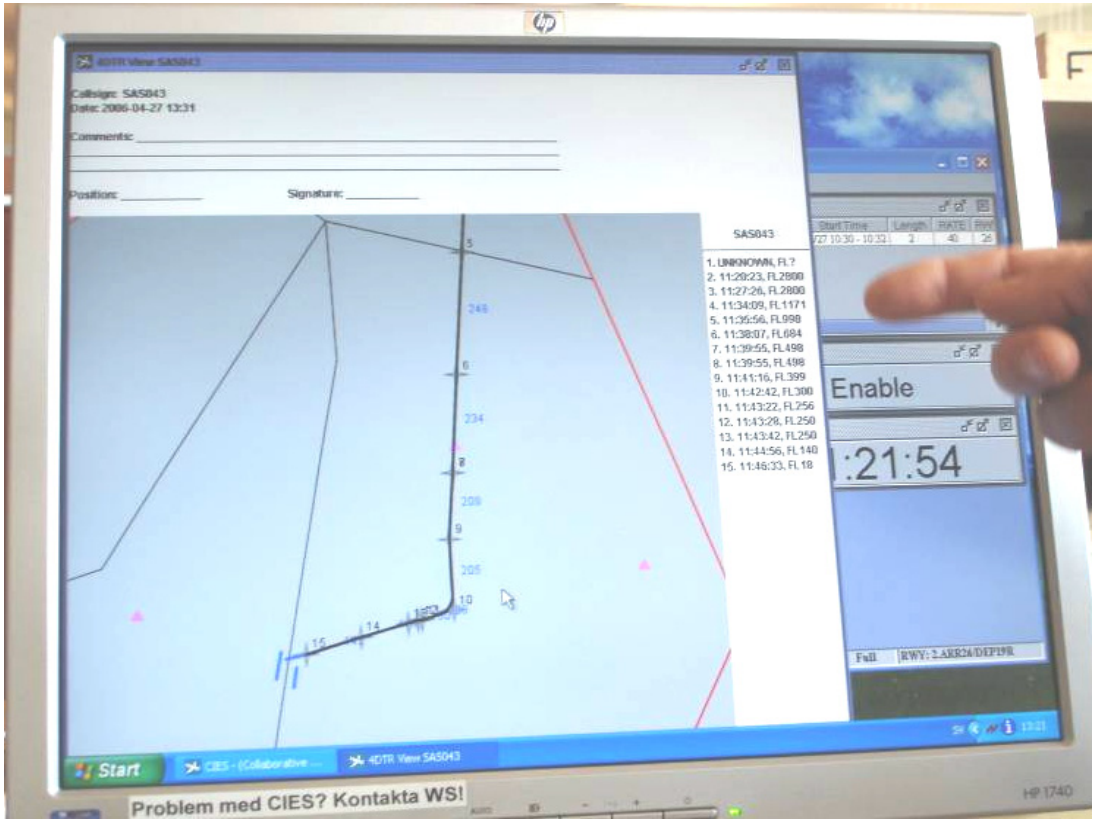
LFV Collaborative Information Exchange System (experimental implementation)

- Designate flight for Green Approach
- Send approach to aircraft
- Enable request of trajectory downlink

Arrival Management

Flight details display

- Trajectory profile is plotted
- Time and altitude at each point is displayed



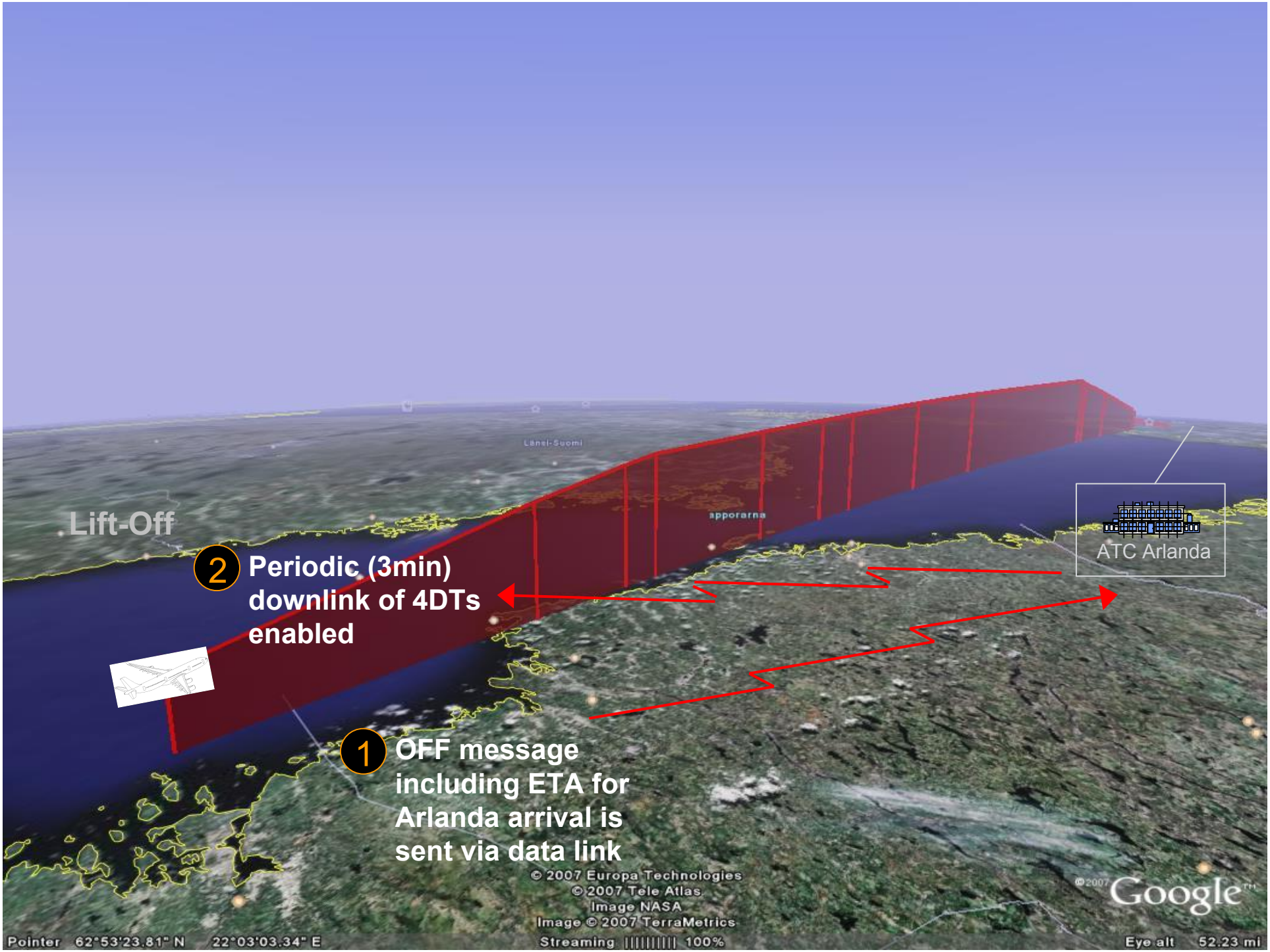
Strategic Communication w/ RTA

Example from live trial

SK005

LLA-ARN

Sept 24, 2007


Lift-Off
2
Periodic (3min) downlink of 4DTs enabled
1
OFF message including ETA for Arlanda arrival is sent via data link
ATC Arlanda
© 2007 Europa Technologies
© 2007 Tele Atlas
Image NASA
Image © 2007 TerraMetrics
Streaming 100%
Google
Pointer 62°53'23.81" N 22°03'03.34" E
Eye alt 52.23 mi

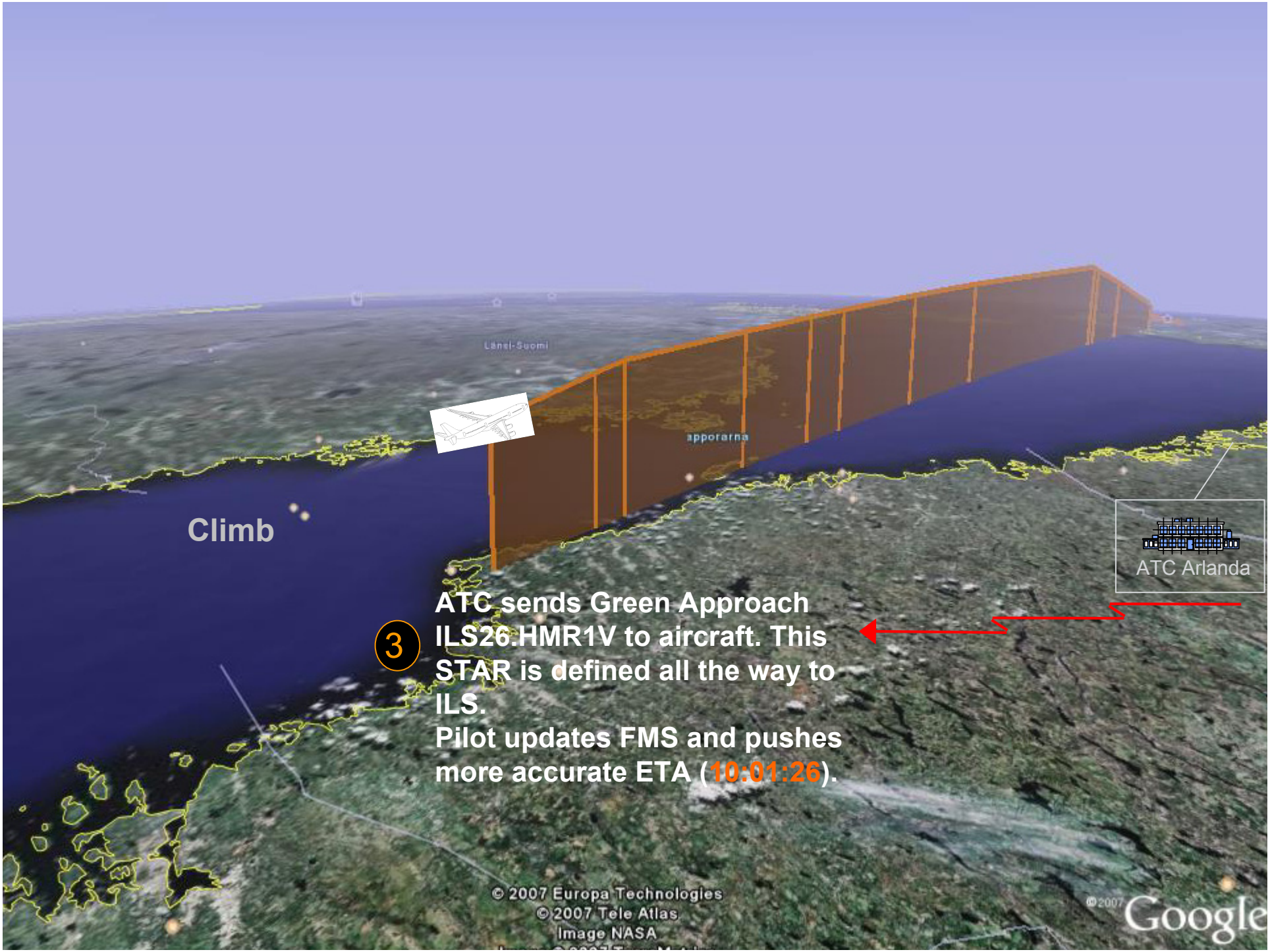

Länsi-Suomi
apporarna
Climb
ATC Arlanda
3
ATC sends Green Approach ILS26.HMR1V to aircraft. This STAR is defined all the way to ILS.
Pilot updates FMS and pushes more accurate ETA (10:01:26).
© 2007 Europa Technologies
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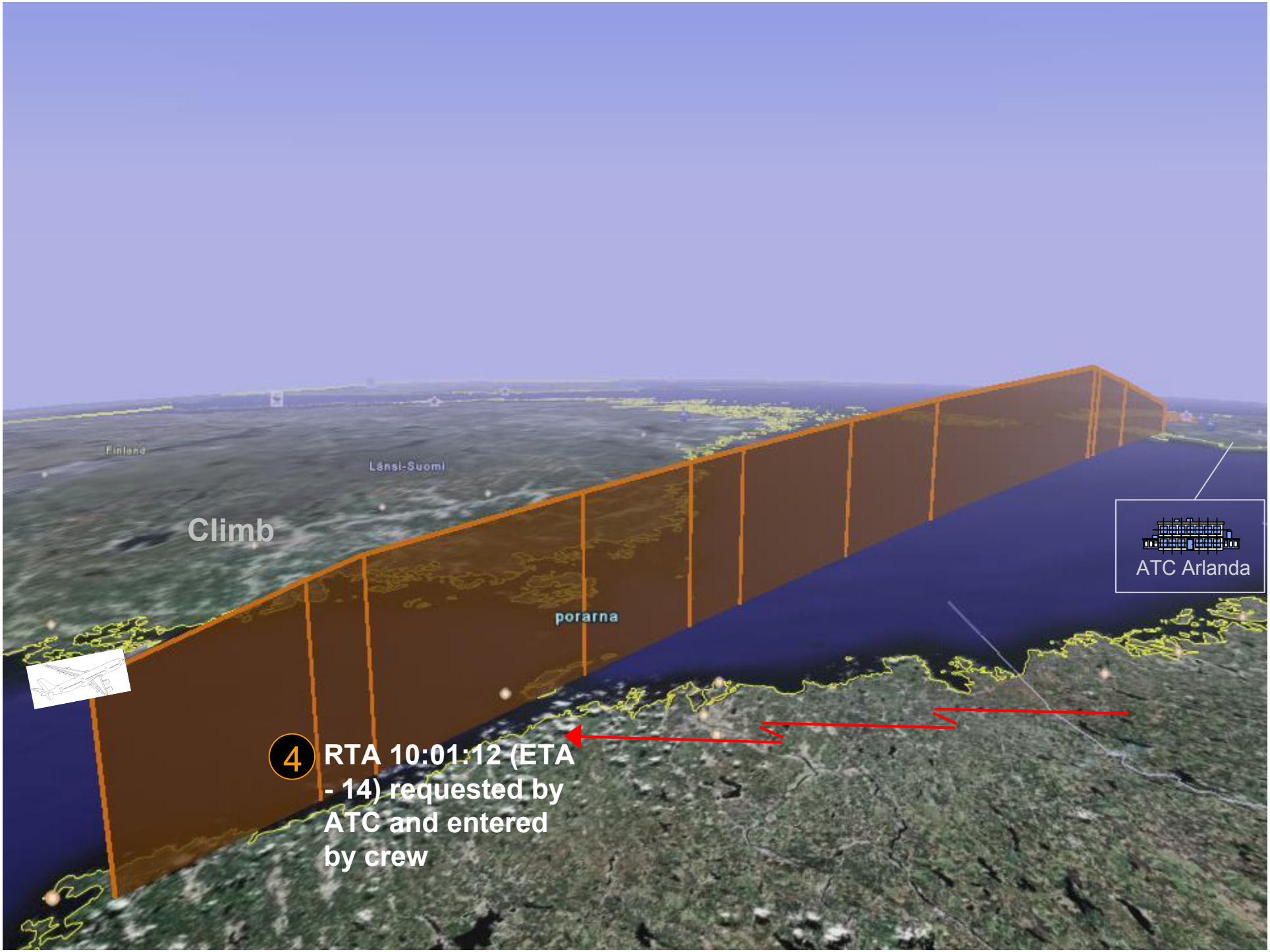
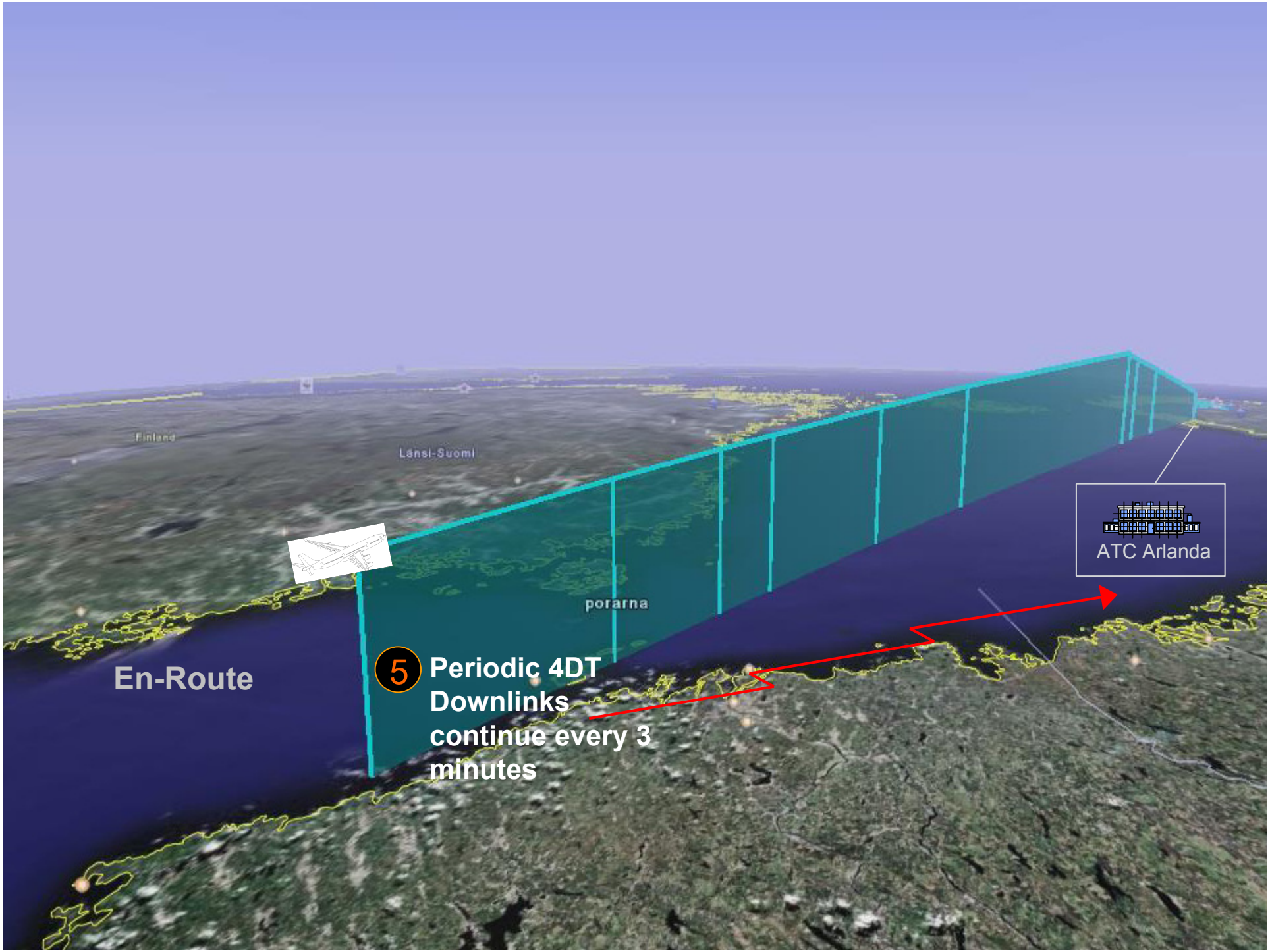
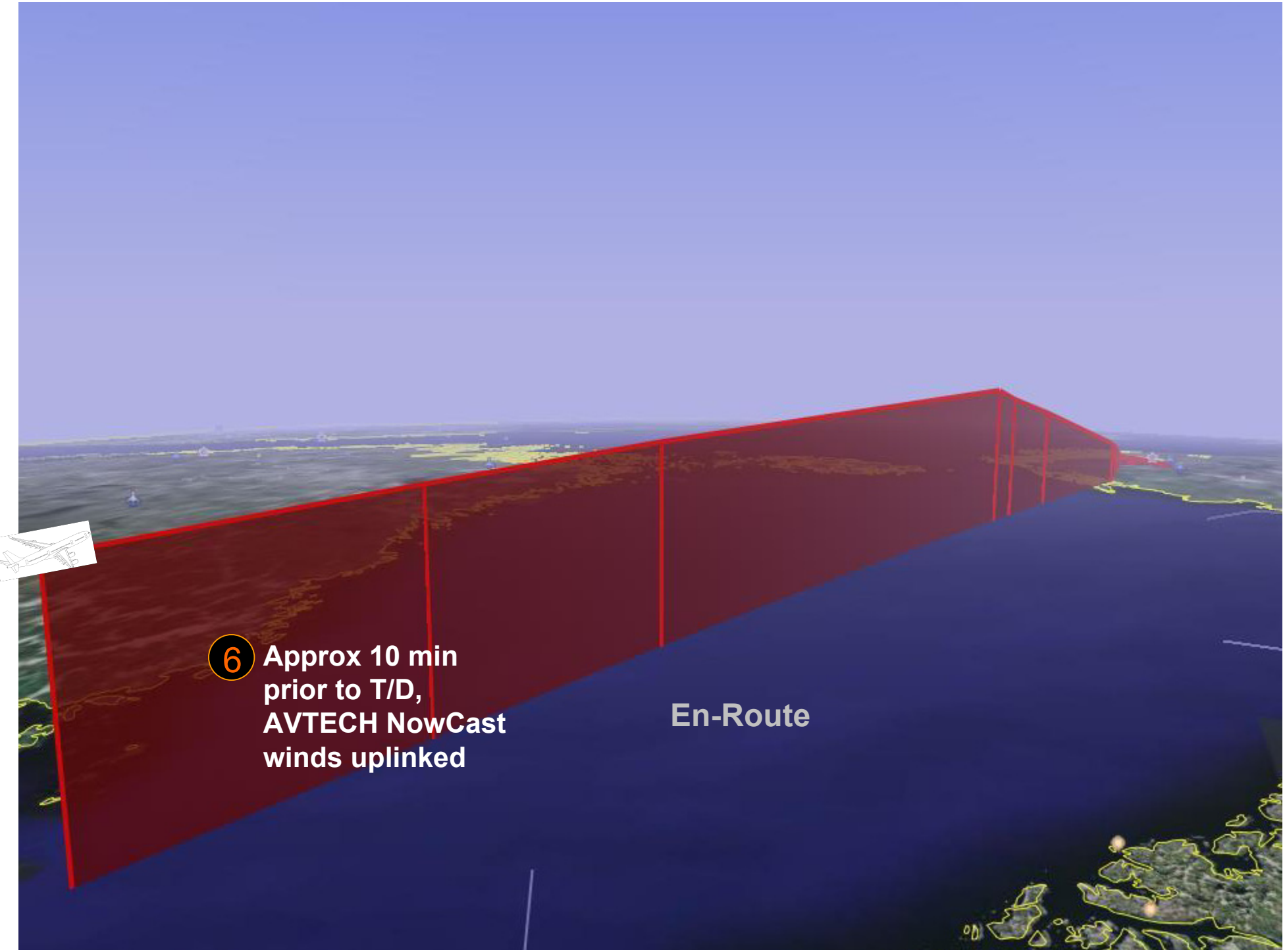
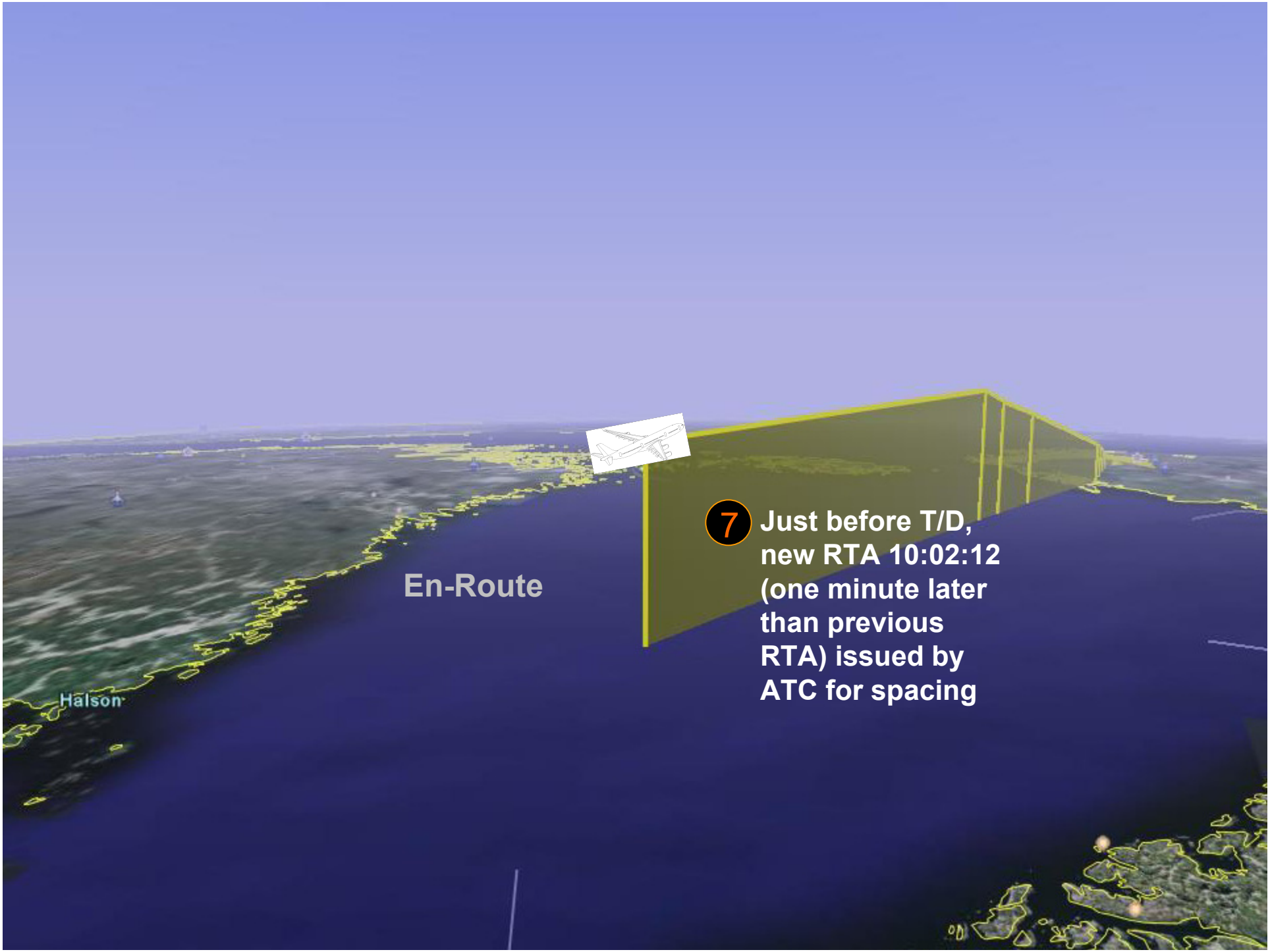
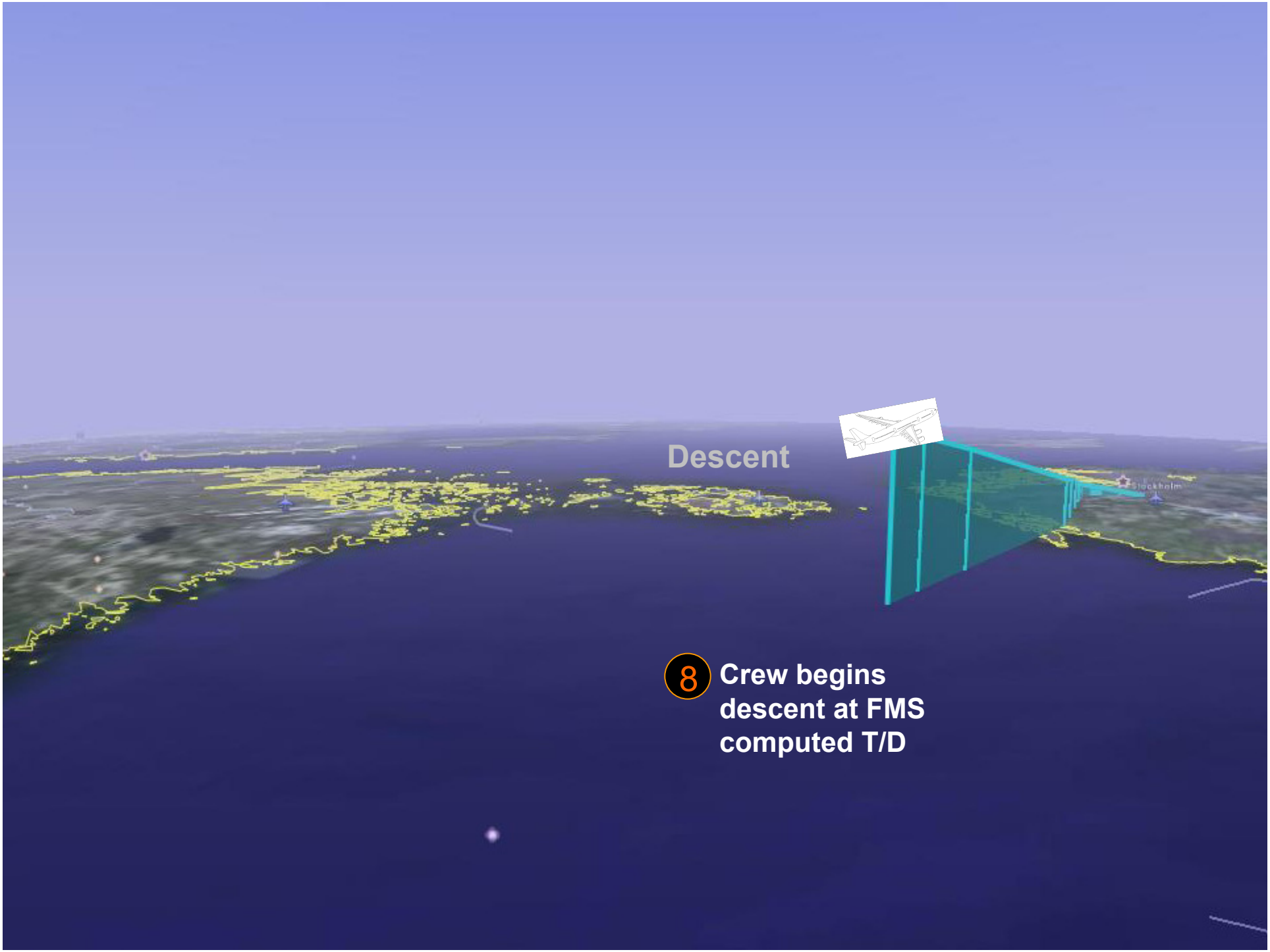
Image NASA
©2007 Google

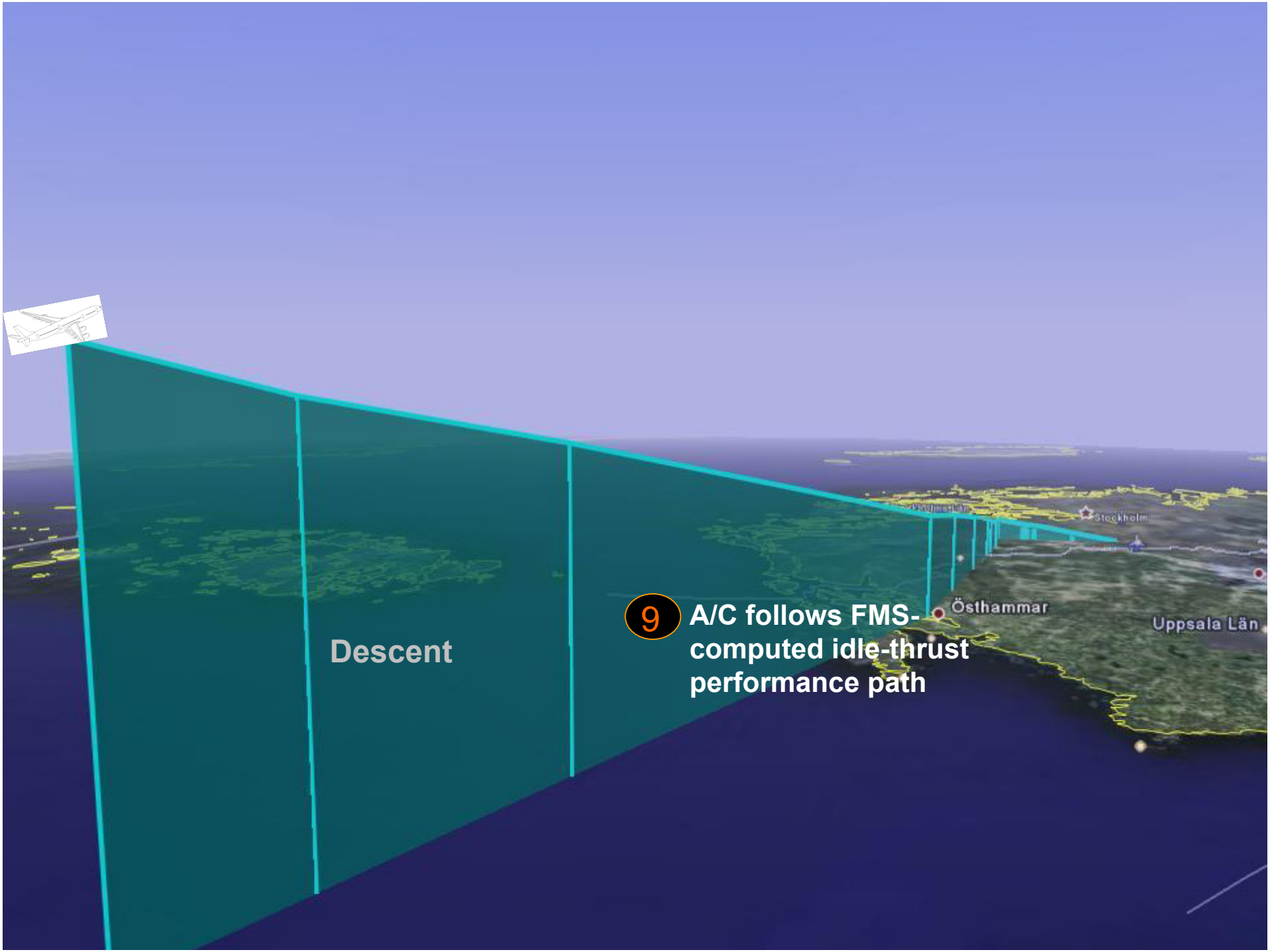

Finland
Länsi-Suomi
Climb
porarna
ATC Arlanda
4
RTA 10:01:12 (ETA - 14) requested by ATC and entered by crew


Finland
Länsi-Suomi
porarna
ATC Arlanda
En-Route
5
Periodic 4DT Downlinks continue every 3 minutes


6
Approx 10 min prior to T/D, AVTECH NowCast winds uplinked
En-Route


En-Route
7
Just before T/D, new RTA 10:02:12 (one minute later than previous RTA) issued by ATC for spacing
Halson


Descent
8
Crew begins descent at FMS computed T/D


Descent
9
A/C follows FMS-computed idle-thrust performance path
Östhammar
Uppsala Län

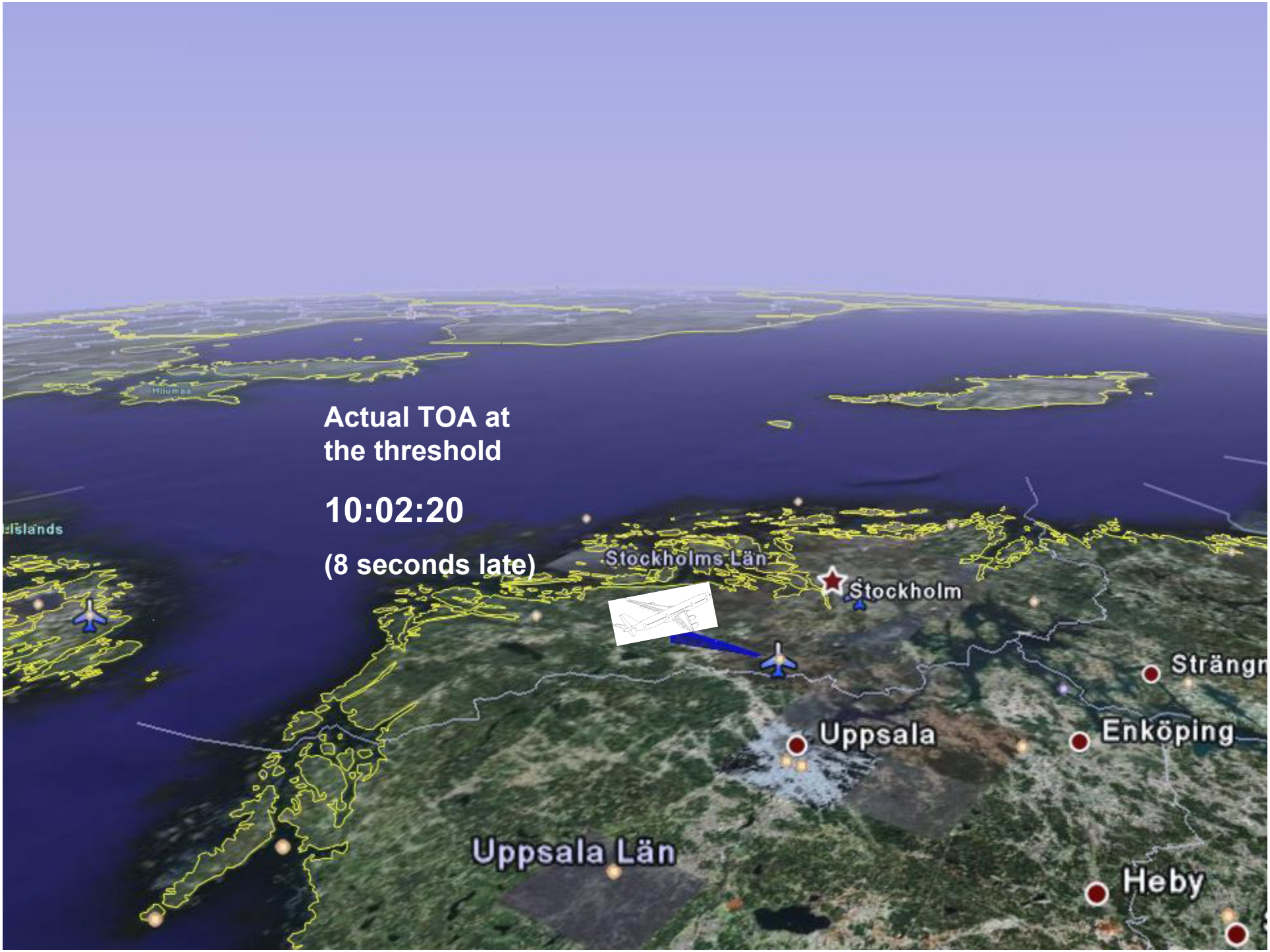

FMS adjusts speeds as necessary to compensate for actual winds/temps
Stockholm
Östhammar
Uppsala Län


Green Approach begins at HMR
4DT Downlinks continue every 3 minutes
HMR /-FL150
Stockholms Län
Stockholm
Uppsala
Östhammar
Uppsala Län
Tierp

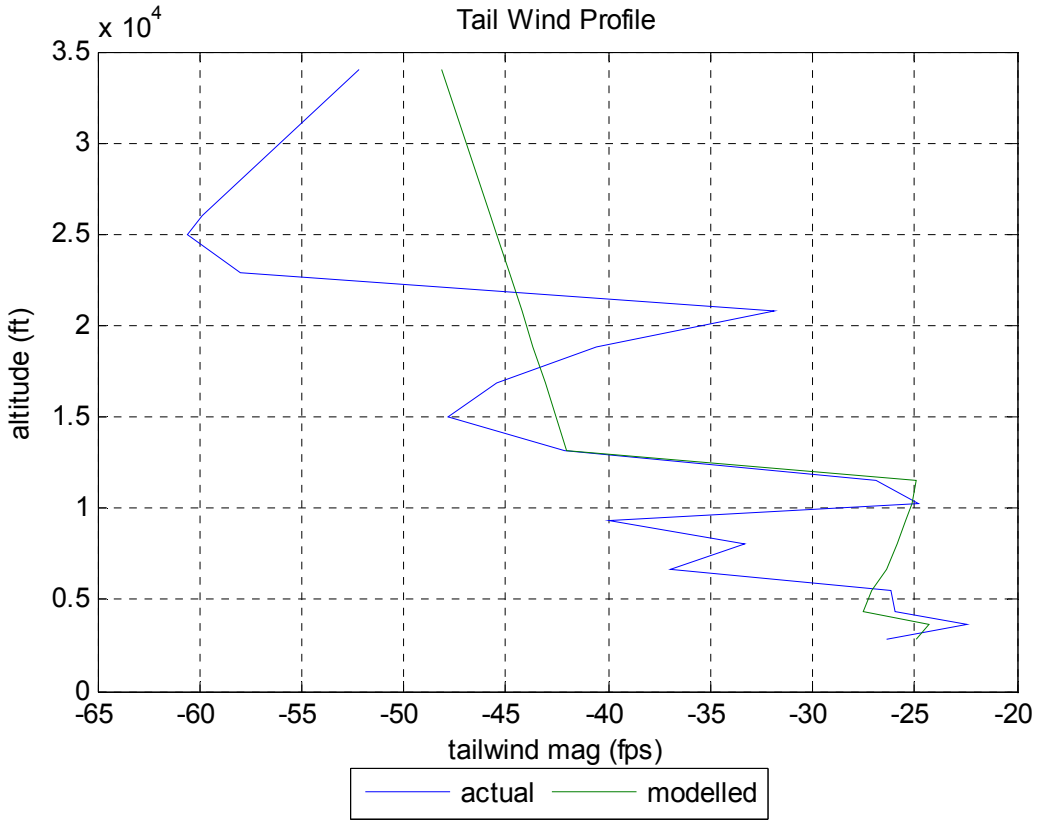

Green Approach
flown in
LNAV/VNAV
Stockholms Län
Stockholm
Uppsala
Enköping
Uppsala Län
Heby


Thrust
remains idle
Stockholms Län
Stockholm
Uppsala
Enköping
Uppsala Län
Heby

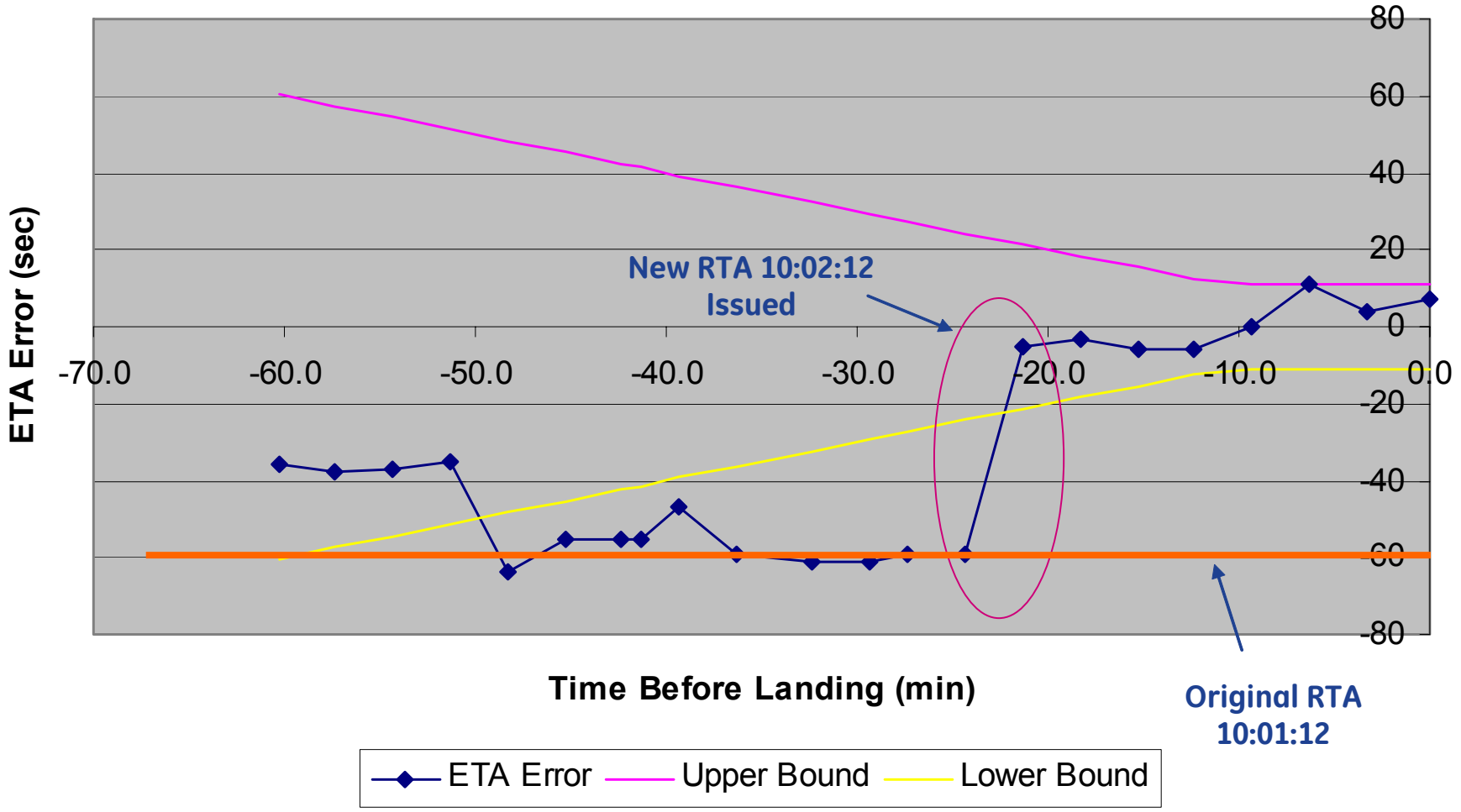

Until ILS is intercepted
Stockholms Län
Stockholm
Uppsala
Enköping
Uppsala Län
Heby


Actual TOA at
the threshold
10:02:20
(8 seconds late)
Stockholms Län
Stockholm
Uppsala
Enköping
Uppsala Län
Heby

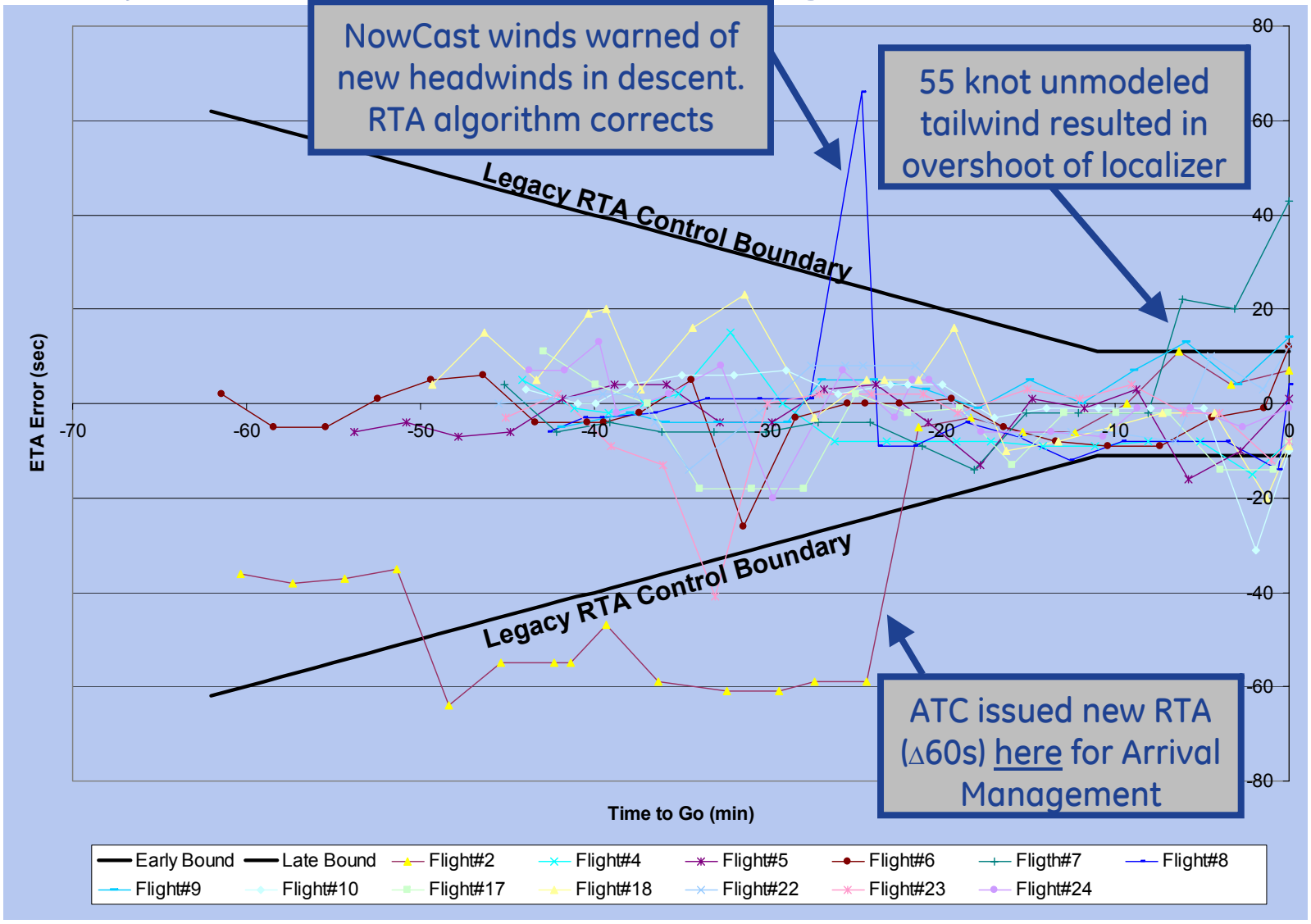
Wind Error Absorbed in Descent



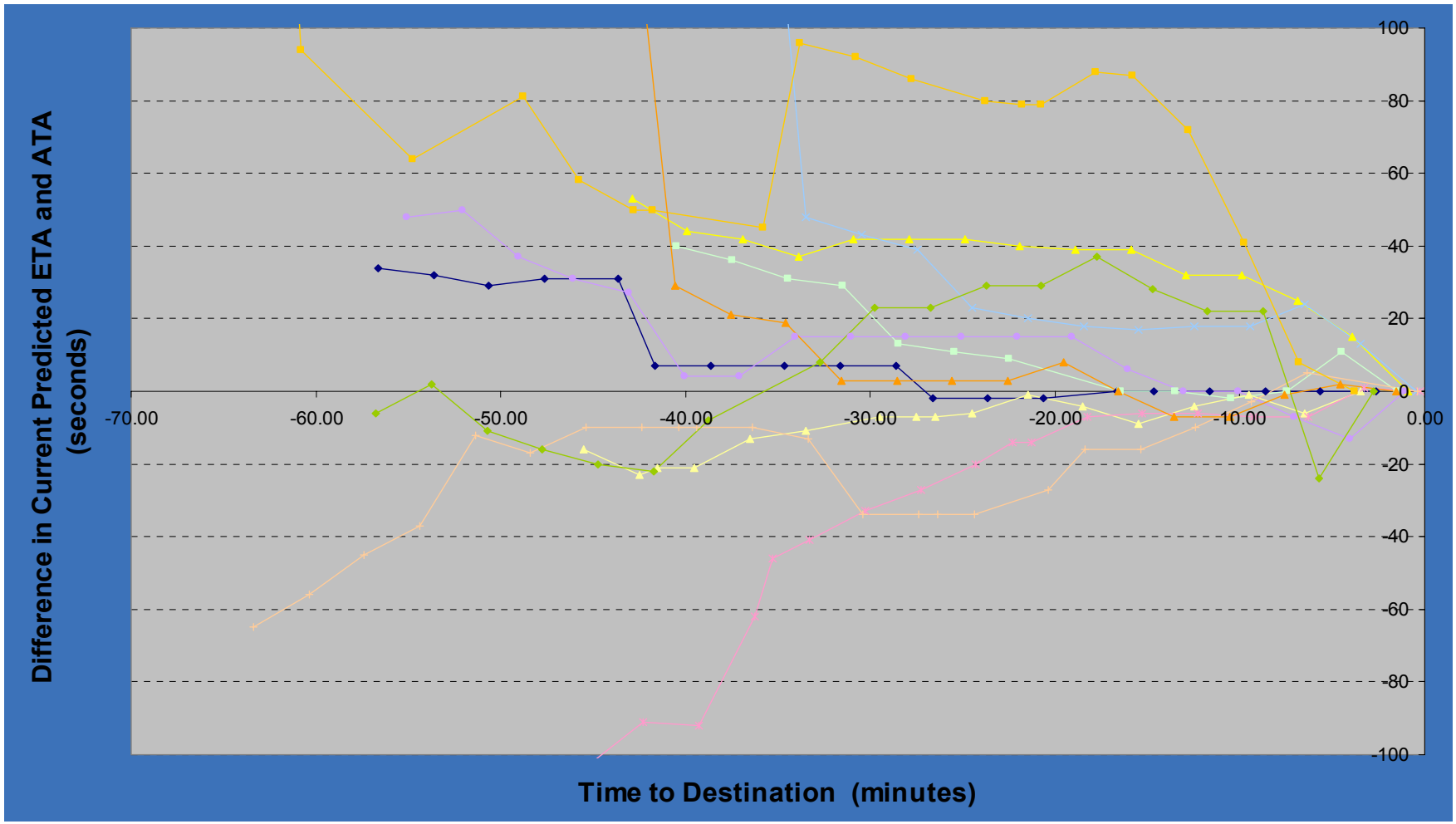
SK005 Sep 24, 2007 : Reported ETA Error relative to RTA



Overlay 13 RTA-to-RWY Flights (Dec07)



Current reported ETA compared to last reported ETA (11 non-RTA flights shown)



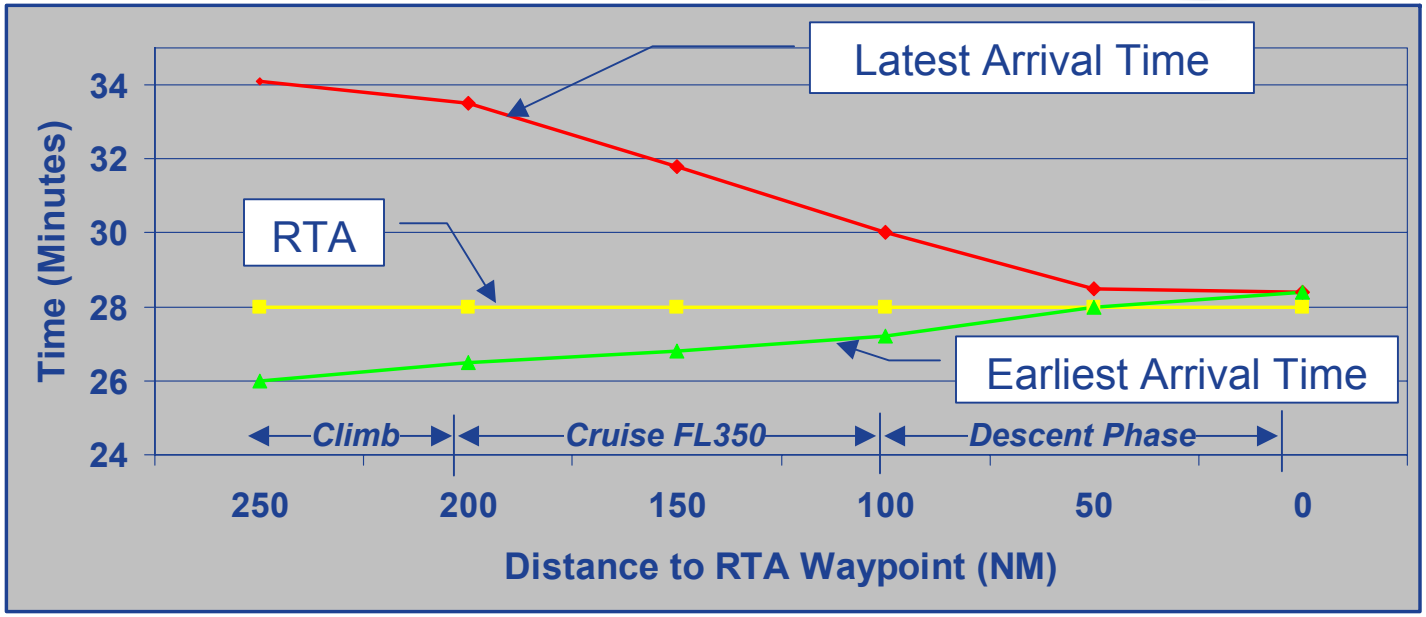
RTA to the Runway

Results from SAS trials in 2001 and 2007.

- Larger deviation at runway due to constrained speed late in descent.

RTA Target	Max	Mean	STD
Top of STAR	7 Sec	4.8 Sec	2.7 Sec
Runway (2001)	21 Sec	12.7 Sec	7.3 Sec
Runway (2007)	14 Sec	7.8 Sec	4.1 Sec

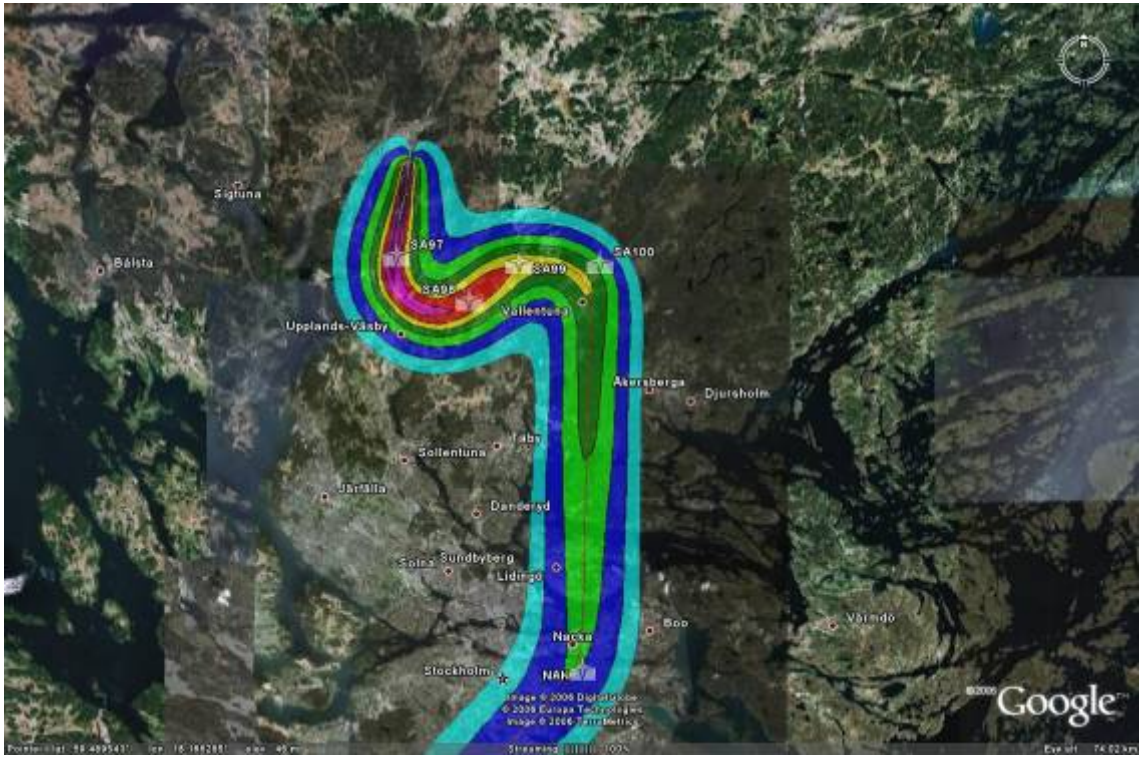
Typical flight data



Results (Sept 2007 Flights)

Excellent Experimental Execution (flight deck and ground)

TRANSCAP Noise results



50 dBA
55 dBA
60 dBA
65 dBA
70 dBA
75 dBA
80 dBA
85 dBA
90 dBA
95 dBA
100 dBA

Results

More than 2000 Green Approaches flown to date… (and counting) resulted in:

- 204 Metric Ton CO_2 reduction yearly
- 715 kg of NOx reduction yearly
- 200,000 kg of fuel saved

SAS-Sweden 36,000 Green Approaches per year into Stockholm alone

- $5.8M fuel reduction plus $4M yield improvement yearly
- 23,000 Metric Ton CO_2 reduction yearly
- 79 Metric Ton of NOx reduction yearly
- Noise reduced by 50% (65db exposure area)

SAS and LFV are expanding Green Approaches throughout domestic Sweden

Conclusions

NUP2+ air/ground infrastructure provides excellent testbed for study and definition of TBO trajectory and datalink requirements

30 "Trajectory Gathering" flights conducted with and without RTA

4DT downlink refresh requirements >3 minutes to service TBO applications

RTA-to-RWY performance demonstrated <15sec

RTA to TMA Entry Point within 6 seconds

Wind NowCast uplinks improved overall trajectory stability and RTA performance

Future needs for world-wide implementation

Trajectory downlink protocol

- Message protocol for trial was custom built
- No standard for downlink message with required data exists

Trajectory downlink content requirements

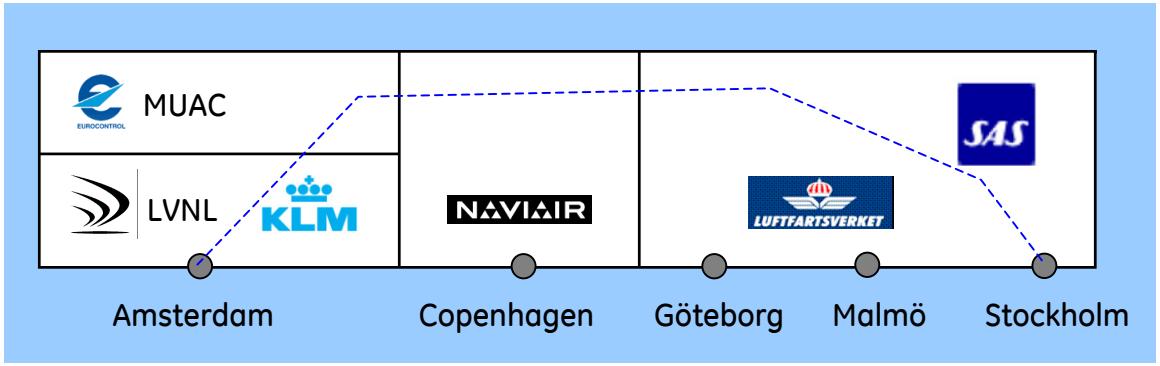
- ARINC 702A Supplement 3 provides for variable content to accommodate different capability levels
- Needs to be minimum standard requirements for data content

Performance standard for predictions

- Quality of trajectory predictions (altitude and time) have no tolerance requirements
- Compensation for control error tolerance may be needed when reporting trajectory early in the flight.

Next Steps

BridgeT



- "Bridge" operations into core Europe
- Focus on requirements, safety analysis, standards

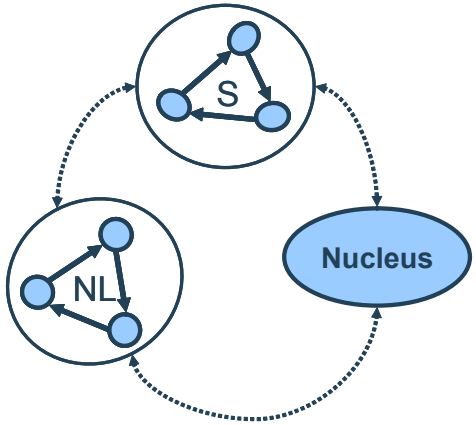
Deployment triplets

- NL (KDC): LVNL AAS KLM
- S: LFV ARN SAS

MUAC
Naviair

Development 'Nucleus'

- GE Aviation (form Smiths)
- Rockwell Collins (Fr)
- Lockheed Martin (UK)
- TietoEnator (form Ericsson)
- NLR
- Boeing
- Eurocontrol
  - R&D: EEC, HQ
  - Ops: MUAC (assoc triplets)



Next Steps

Air Services Australia / Qantas

- Use of RTA & 4D Trajectory at Brisbane to supplement Tailored Arrivals Research

Next Steps

TMA 2010+

- Eurocontrol Initiative
- Develop & Validate Controlled Time-of-Arrival (CTA) Concept of Operations at different airports
- ANSPs : NATS, LVNL, LFV
- Research : Avtech, NLR
- Industry : GE Aviation, Rockwell-Collins

QUESTIONS?

Backup Slides

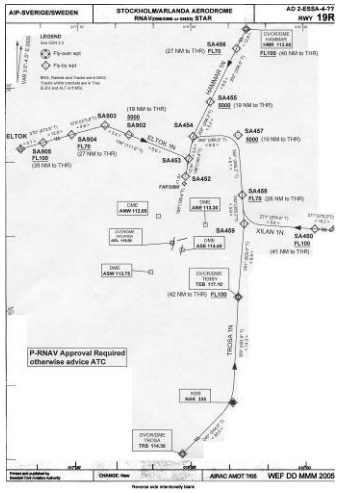
Controlled Time of Arrival

Generated by a Time-Based Metering system to merge traffic from metering fixes to a runway.

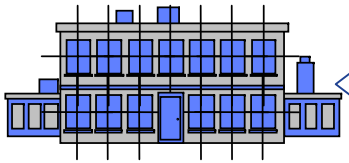
- A key capability of an FMS is to "self-deliver" to a specified waypoint at a Required Time of Arrival (RTA).
- The FMS efficiently operates a flight with a user selected **Cost Index (CI)** and a **Continuous Descent Approach (CDA)**.
- Accurate ETAs (potentially becoming RTAs) need to be downlinked from the aircraft to close the loop with ground control.
- Traditionally used in Enroute segments only
- Series of 33 trial flights with SAS in 2001 explored the use of "RTA to the Runway"

RTA Target	Max	Mean	STD
Top of STAR	7 Sec	4.8 Sec	2.7 Sec
Runway	21 Sec	12.7 Sec	7.3 Sec

NUP2+ Trajectory Usage



ACARS
ARINC 702A-1 standard



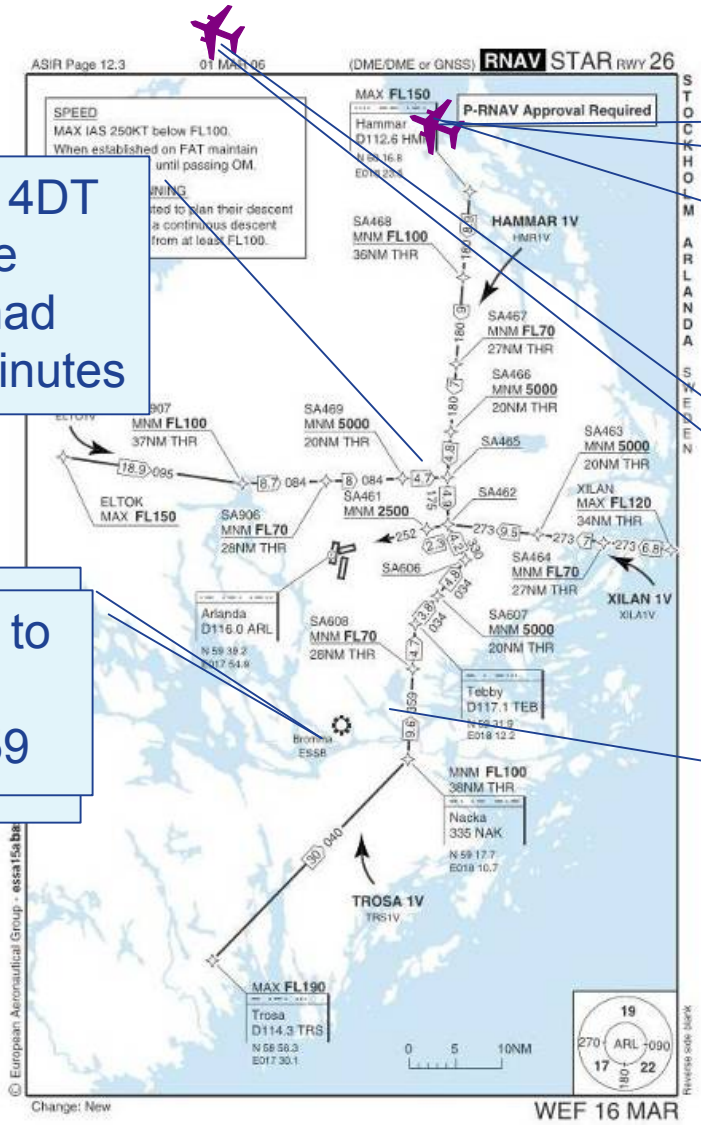
AOC
SAS
RC Hermes

ANSP - Airport
LFV CIES

Spacing at Metering Fix HMR

In the new downlinked 4DT messages, the time separation at HMR had increased from 1 to 2 minutes

Sends RTA 06:48:00 to SAS075 and RTA 06:51:00 to SAS2059



RTA Accepted

via 4DT downlink SAS075 confirms GA HAMMAR1V with ETA 06:49

RTA Accepted

link SAS2059 confirms GA HAMMAR1V with ETA 06:50

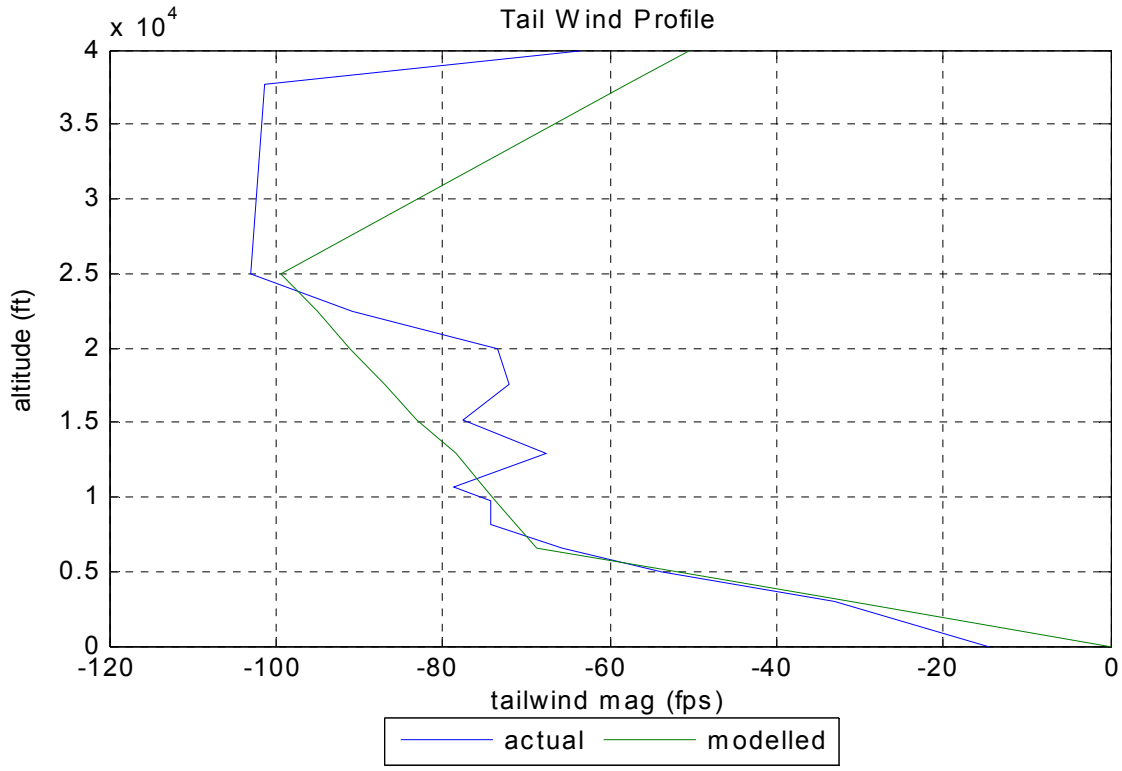
Controlling to time resulted in physical separation of 10NM at OM

imagination at work

Comparison of Vertical Trajectory Stability

RTA Flight

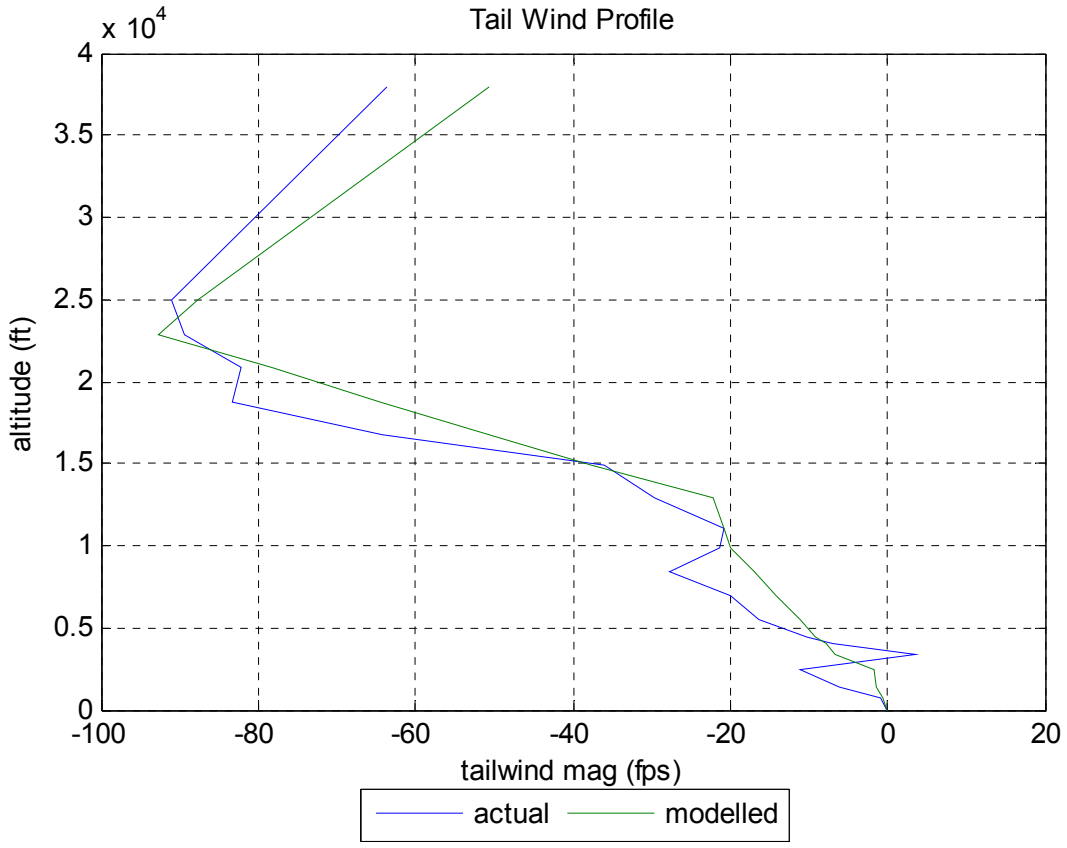
SK005 LLA-ARN Sept 25, 2007



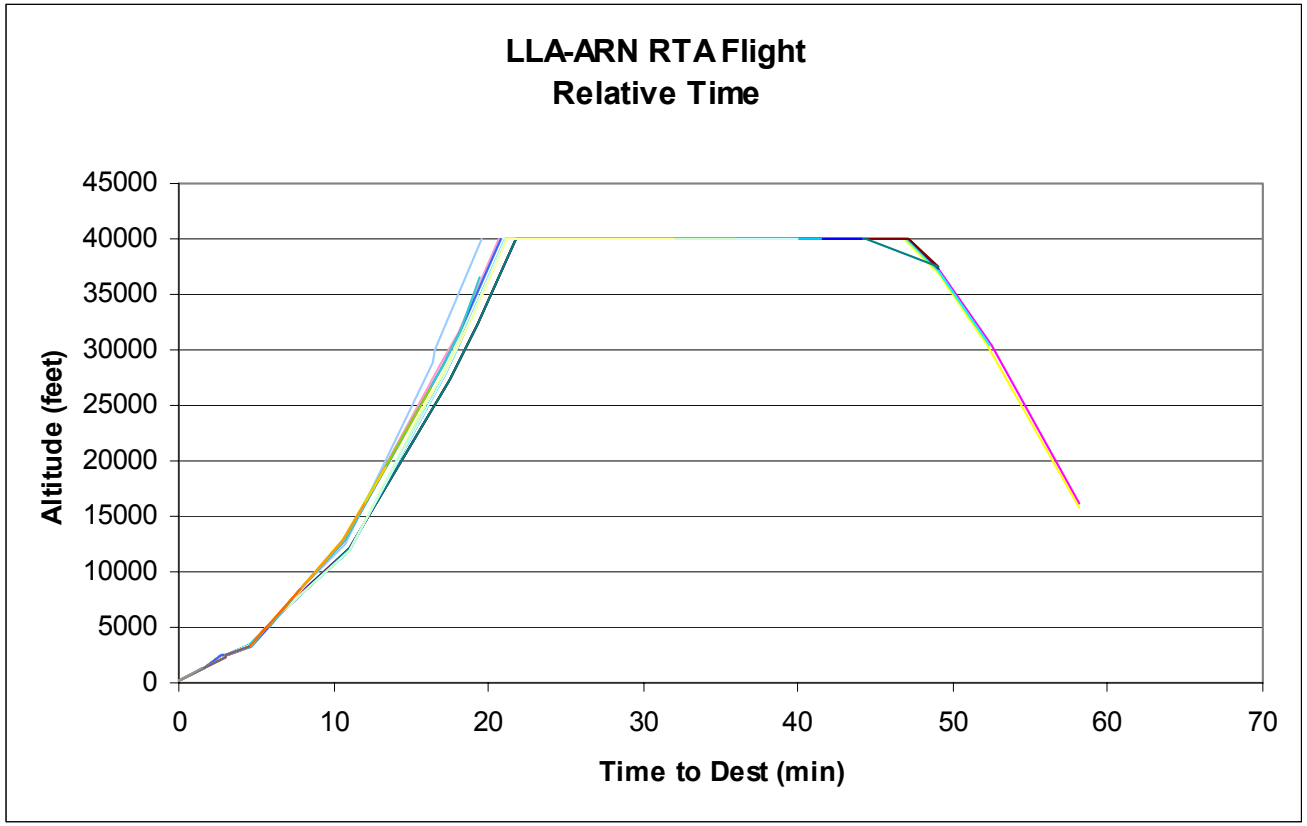
Comparison of Vertical Trajectory Stability

Baseline Flight

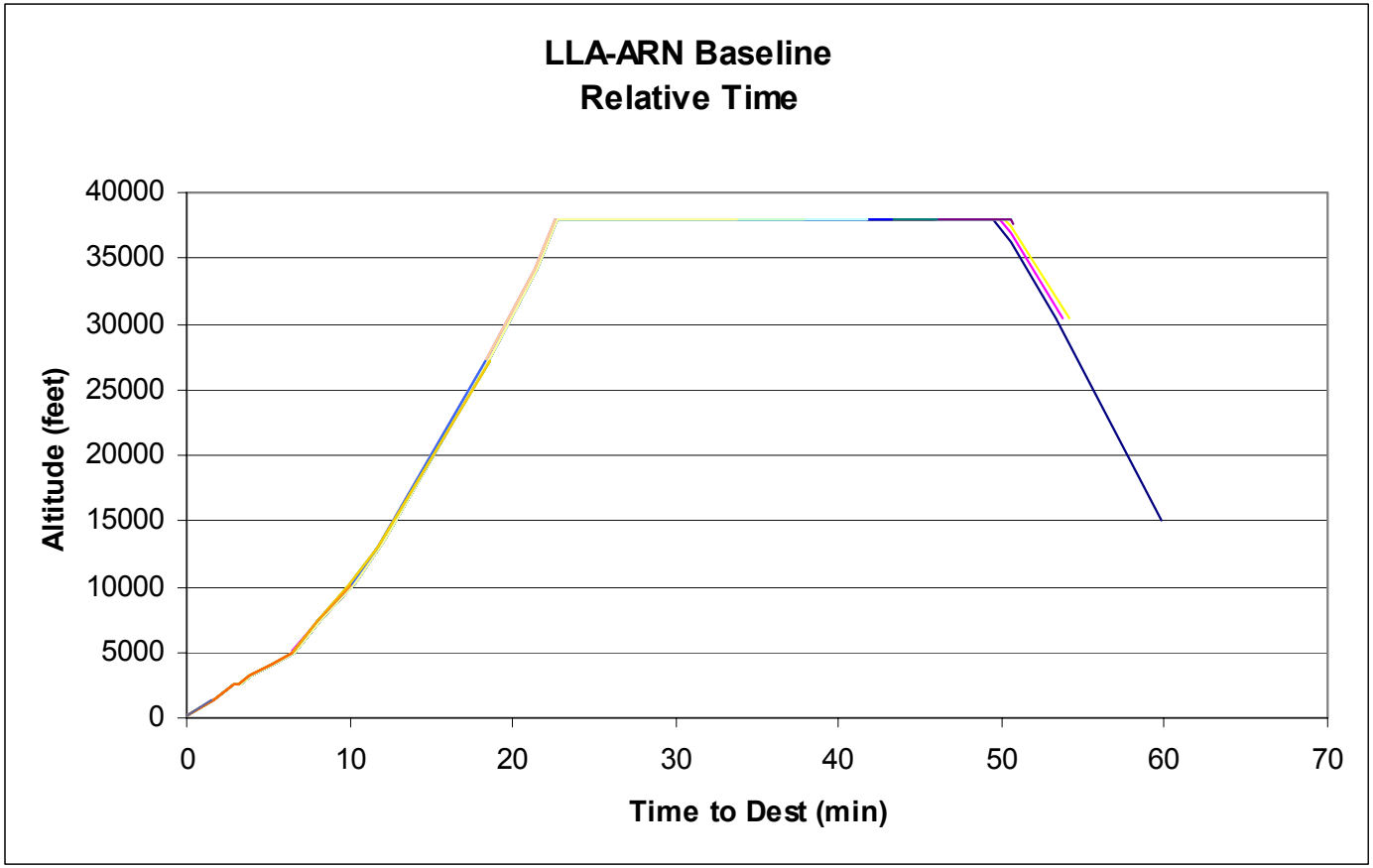
SK007 LLA-ARN Sept 26, 2007



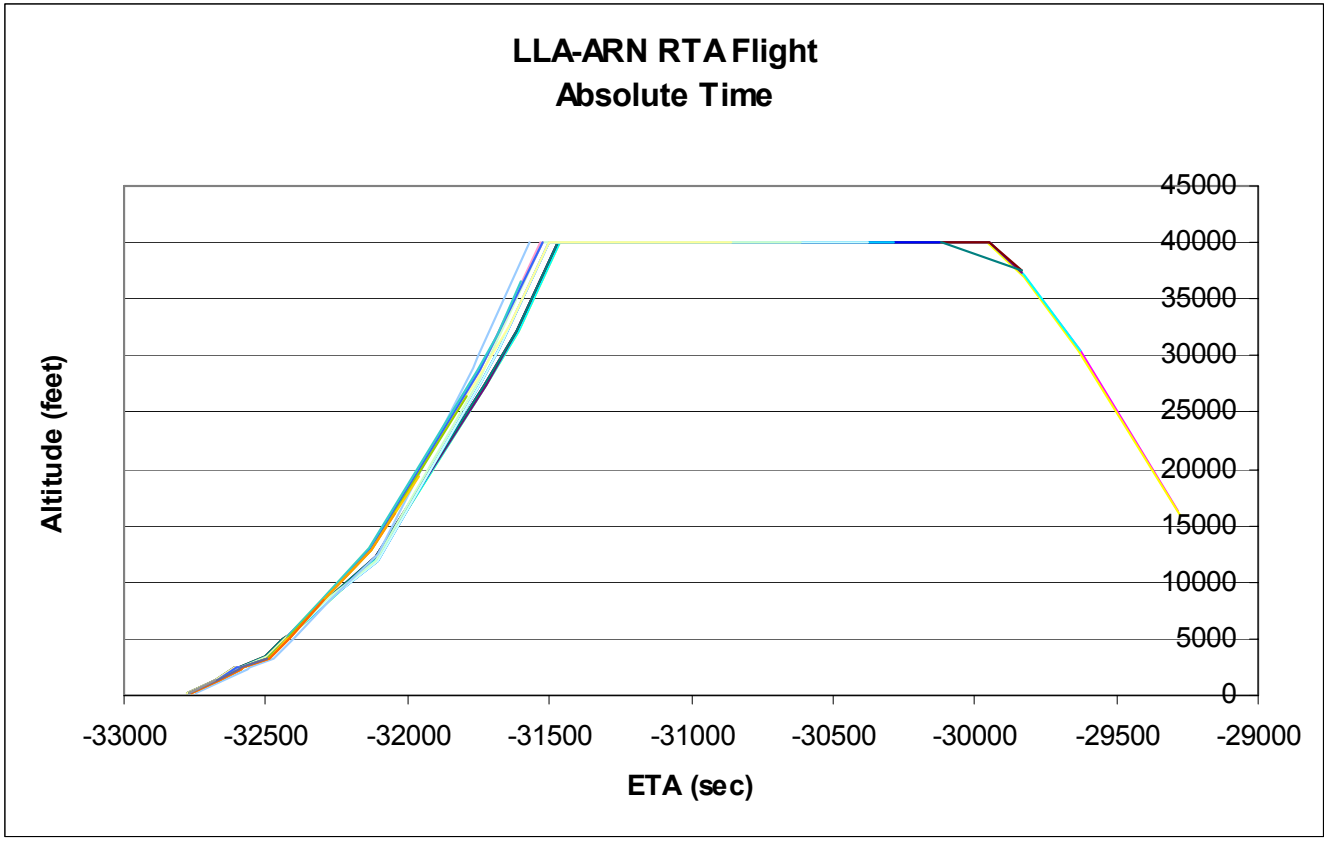
RTA Vertical Profile Stability in Relative Time



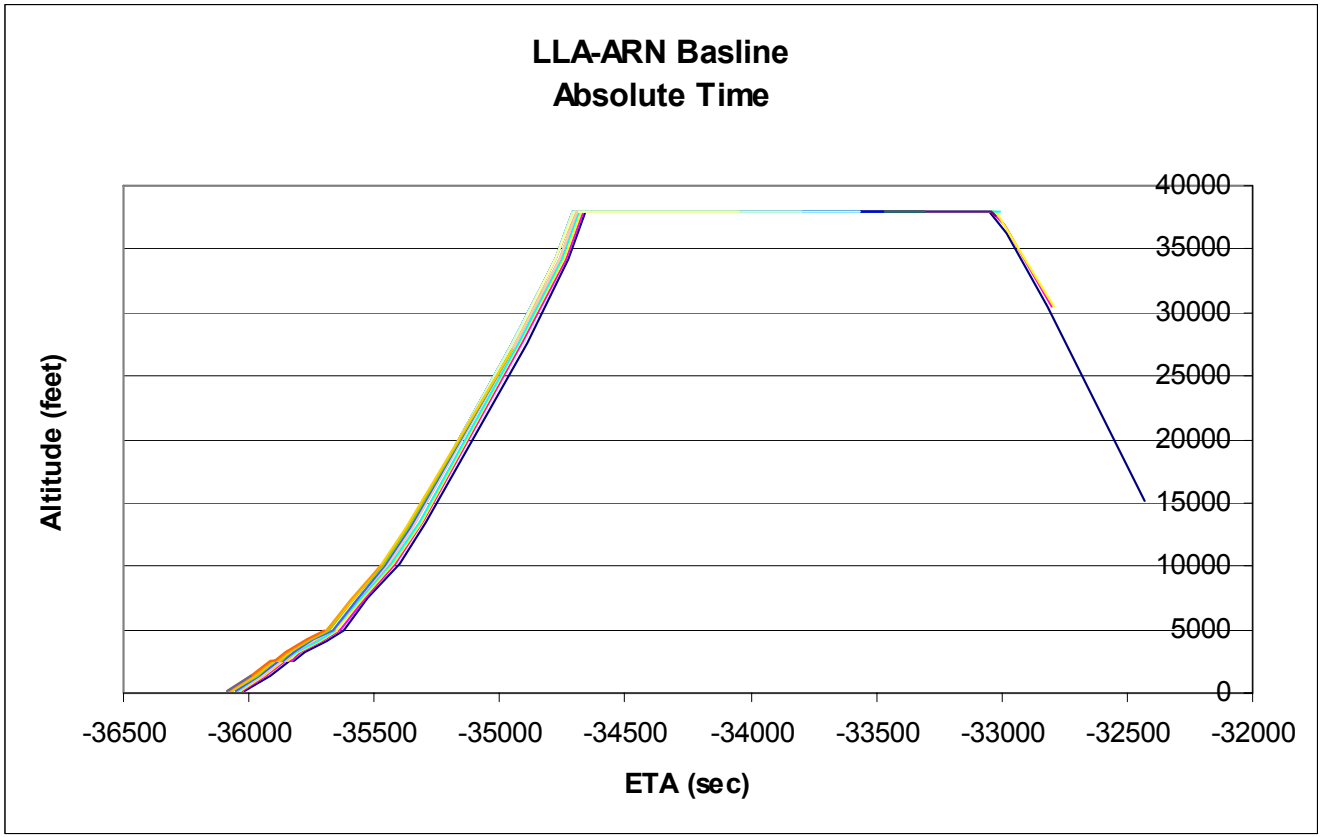
Baseline Vertical Profile Stability in Relative Time



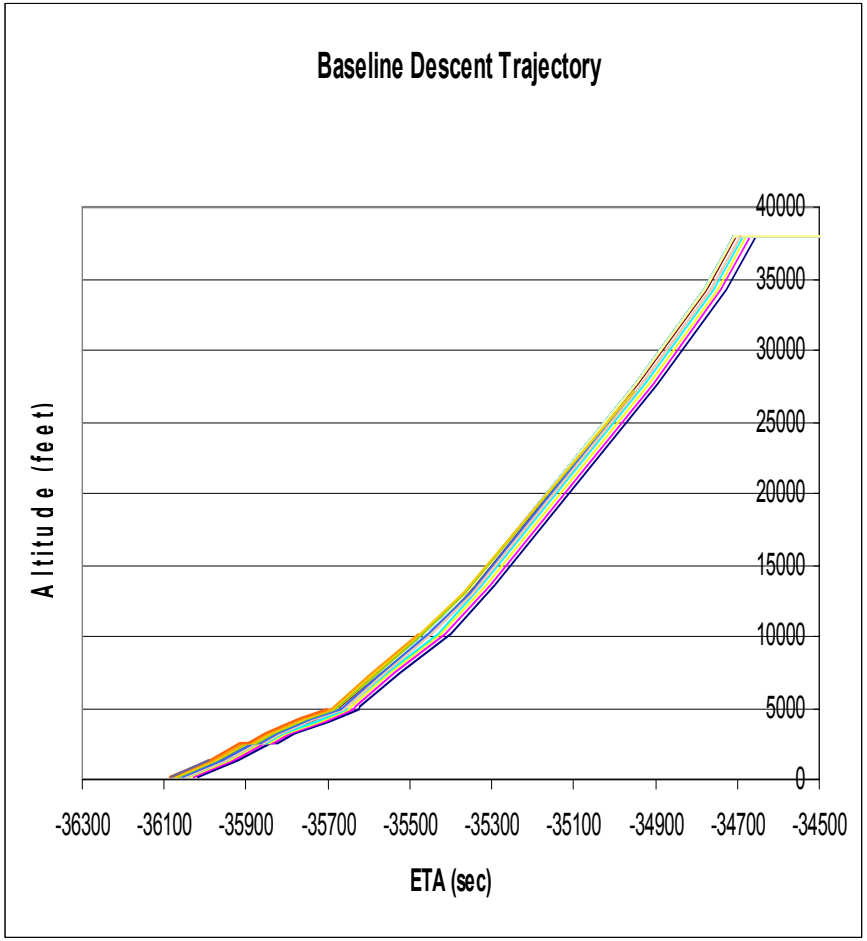
RTA Vertical Profile Stability in Absolute Time

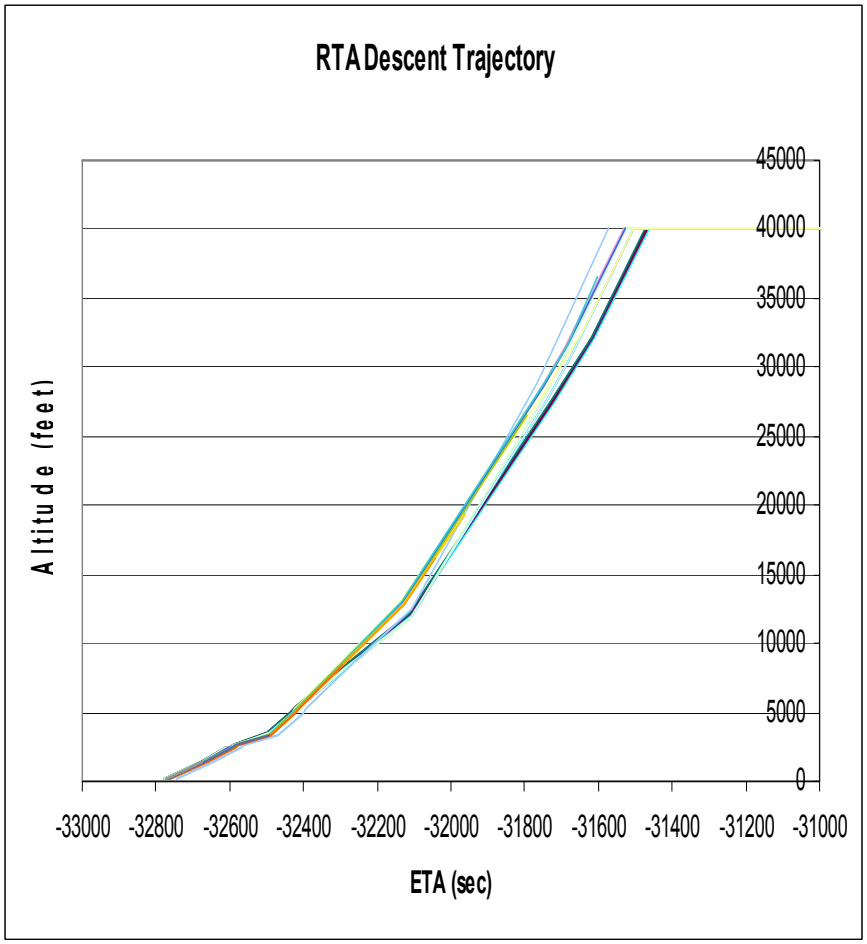


Baseline Vertical Profile Stability in Absolute Time



Vertical Profile Comparison in Absolute Time





Trajectory Reporting – Intent Bus Definition

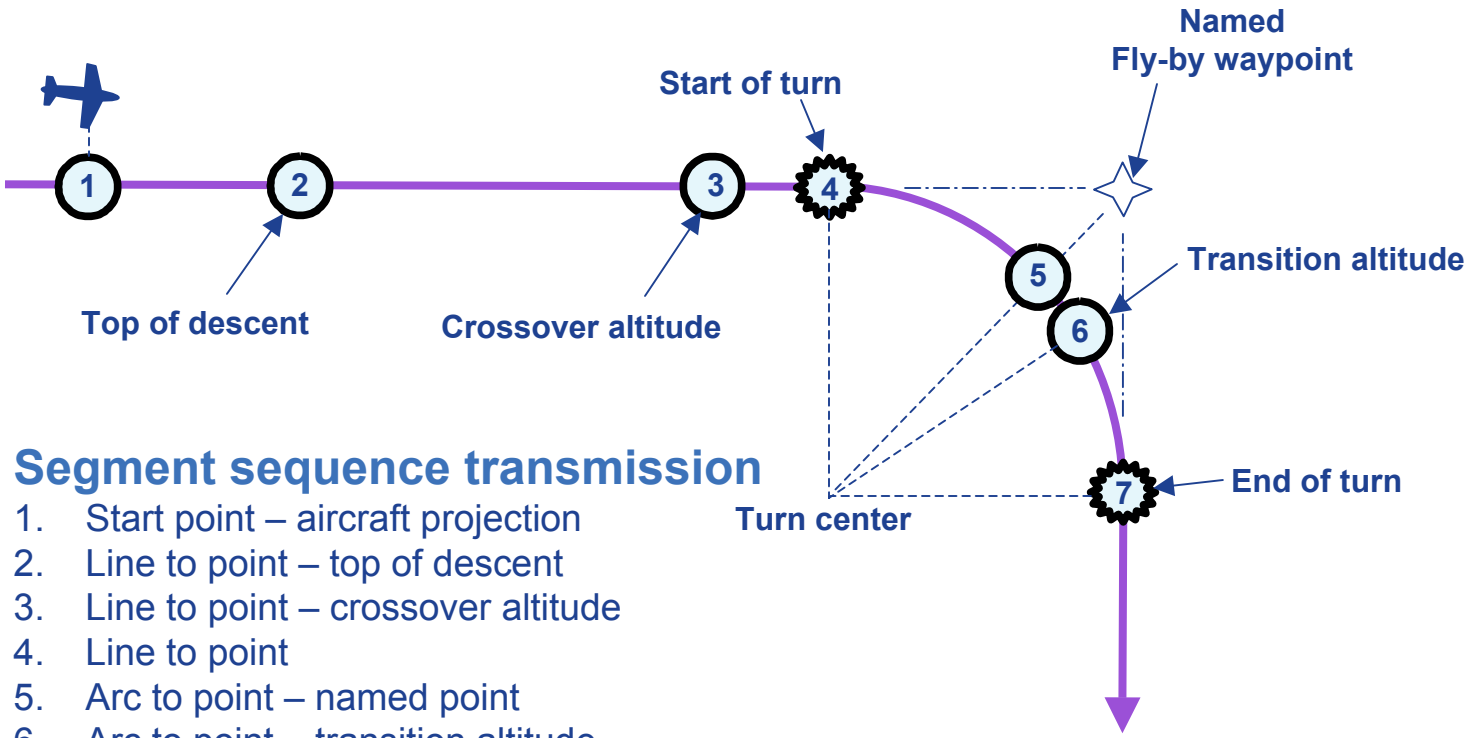
ARINC 702A Supplement 3 defines significantly more data important for air traffic use.

Aircraft State Data is output at 0.5 second rate.

Trajectory Intent is reported:

- Whenever an active flight plan change occurs.
- When a lateral waypoint is passed.
- Whenever there has been a significant change to the predicted trajectory.
- When a defined period has elapsed (one minute) since the last transmission

Example of the trajectory downlink (Supp 3):



Segment sequence transmission

1. Start point – aircraft projection
2. Line to point – top of descent
3. Line to point – crossover altitude
4. Line to point
5. Arc to point – named point
6. Arc to point – transition altitude
7. Arc to point

Transmission Time – VHF ACARS (character-oriented data)

Trajectory Intent	Supp 1	Supp 3
• Number of characters	862	4441
• Transmission time/set	2.9 sec	14.8 sec

Notes: Typical 25 point trajectory.
Transmission is VHF ACARS (2400 bits/sec).

Transmission Time – VDL Mode 2 (binary data)

Trajectory Intent	Supp 1	Supp 3
• Number of 32-bit words	132	680
• Transmission time/set	.2-.4 sec	.9-2.2 sec

Notes: Typical 25 point trajectory.
Transmission bus is VDL Mode 2 (10,000 - 24,000 effective bits/sec).