Required Time-of-Arrival Trials

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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.
- Now flying: GE Aviation FMS improved “RTA to Runway”
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
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

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

ARINC429 Trajectory Bus → AOC (in 2007!) → ACARS

AOC → ATC
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
1. **OFF message including ETA for Arlanda arrival is sent via data link.**

2. **Periodic (3min) downlink of 4DTs enabled.**
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).
RTA 10:01:12 (ETA - 14) requested by ATC and entered by crew.
En-Route Periodic 4DT

Downlinks continue every 3 minutes
Approx 10 min prior to T/D, AVTECH NowCast winds uplinked
Just before T/D, new RTA 10:02:12 (one minute later than previous RTA) issued by ATC for spacing.
Crew begins descent at FMS computed T/D.
A/C follows FMS-computed idle-thrust performance path
FMS adjusts speeds as necessary to compensate for actual winds/temps.
Green Approach begins at HMR downlinks continue every 3 minutes.
Green Approach flown in LNAV/VNAV
Thrust remains idle
Until ILS is intercepted
Actual TOA at the threshold

10:02:20

(8 seconds late)
Wind Error Absorbed in Descent

Tail Wind Profile

- x 10^4
- altitude (ft)
- tailwind mag (fps)

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

-70.0 -60.0 -50.0 -40.0 -30.0 -20.0 -10.0 0.0 20 40 60 80

Time Before Landing (min)

ETA Error (sec)

New RTA 10:02:12
Issued

Original RTA 10:01:12

ETA Error  Upper Bound  Lower Bound

GE Proprietary Information
Overlay 13 RTA-to-RWY Flights (Dec07)

NowCast winds warned of new headwinds in descent. RTA algorithm corrects.

55 knot unmodeled tailwind resulted in overshoot of localizer.

ATC issued new RTA (Δ60s) here for Arrival Management.
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.

**Typical flight data**

<table>
<thead>
<tr>
<th>Runway</th>
<th>RTA Target</th>
<th>Max</th>
<th>Mean</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of STAR</td>
<td>7 Sec</td>
<td>4.8 Sec</td>
<td>2.7 Sec</td>
<td></td>
</tr>
<tr>
<td>Runway (2001)</td>
<td>21 Sec</td>
<td>12.7 Sec</td>
<td>7.3 Sec</td>
<td></td>
</tr>
<tr>
<td>Runway (2007)</td>
<td>14 Sec</td>
<td>7.8 Sec</td>
<td>4.1 Sec</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing flight data with RTA, Earliest Arrival Time, Latest Arrival Time, Climb, Cruise FL350, Descent Phase]
Results (Sept 2007 Flights)

Excellent Experimental Execution (flight deck and ground)
TRANSCAP Noise results
Results

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

- 204 Metric Ton CO₂ 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 CO₂ 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, Navair

### 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”

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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.

Controlling to time resulted in physical separation of 10NM at OM.
Comparison of Vertical Trajectory Stability

RTA Flight

SK005  LLA-ARN  Sept 25, 2007

![Graph showing tail wind profile with actual and modelled lines.](image)
Comparison of Vertical Trajectory Stability

Baseline Flight

SK007 LLA-ARN Sept 26, 2007
RTA Vertical Profile Stability in Relative Time

[Graph showing RTA vertical profile stability over time and altitude]
Baseline Vertical Profile Stability in Relative Time
RTA Vertical Profile Stability in Absolute Time
Baseline Vertical Profile Stability in Absolute Time

![Graph of LLA-ARN Baseline Absolute Time](image)

The graph shows the altitude (in feet) plotted against ETA (in seconds), demonstrating the vertical profile stability in absolute time for the LLA-ARN baseline.
Vertical Profile Comparison in Absolute Time

Baseline Descent Trajectory

RTA Descent Trajectory
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)

<table>
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<tr>
<th>Trajectory Intent</th>
<th>Supp 1</th>
<th>Supp 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Number of characters</td>
<td>862</td>
<td>4441</td>
</tr>
<tr>
<td>• Transmission time/set</td>
<td>2.9 sec</td>
<td>14.8 sec</td>
</tr>
</tbody>
</table>

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).