# Flight Trials of CDA with Time-Based Metering at Atlanta International Airport

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**JPDO Operations Panel – NASA Ames**

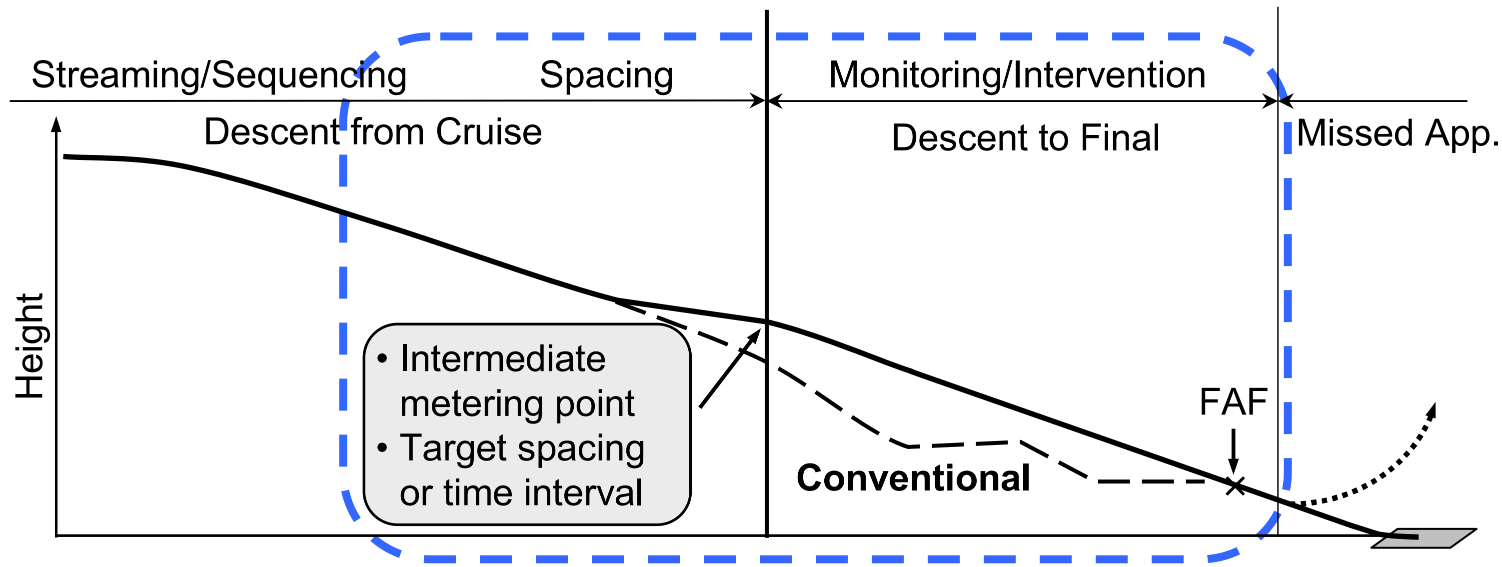
# Agenda

- Background
- Operational Concept
- Time-Based Separation Analysis
- Time-Based Metering
- KATL KIRMT RNAV CDA Design
- KATL CDA Spacing Matrix
- KATL CDA Initial Benefit Results
- KATL CDA Merging and Spacing

# Benefits of CDA

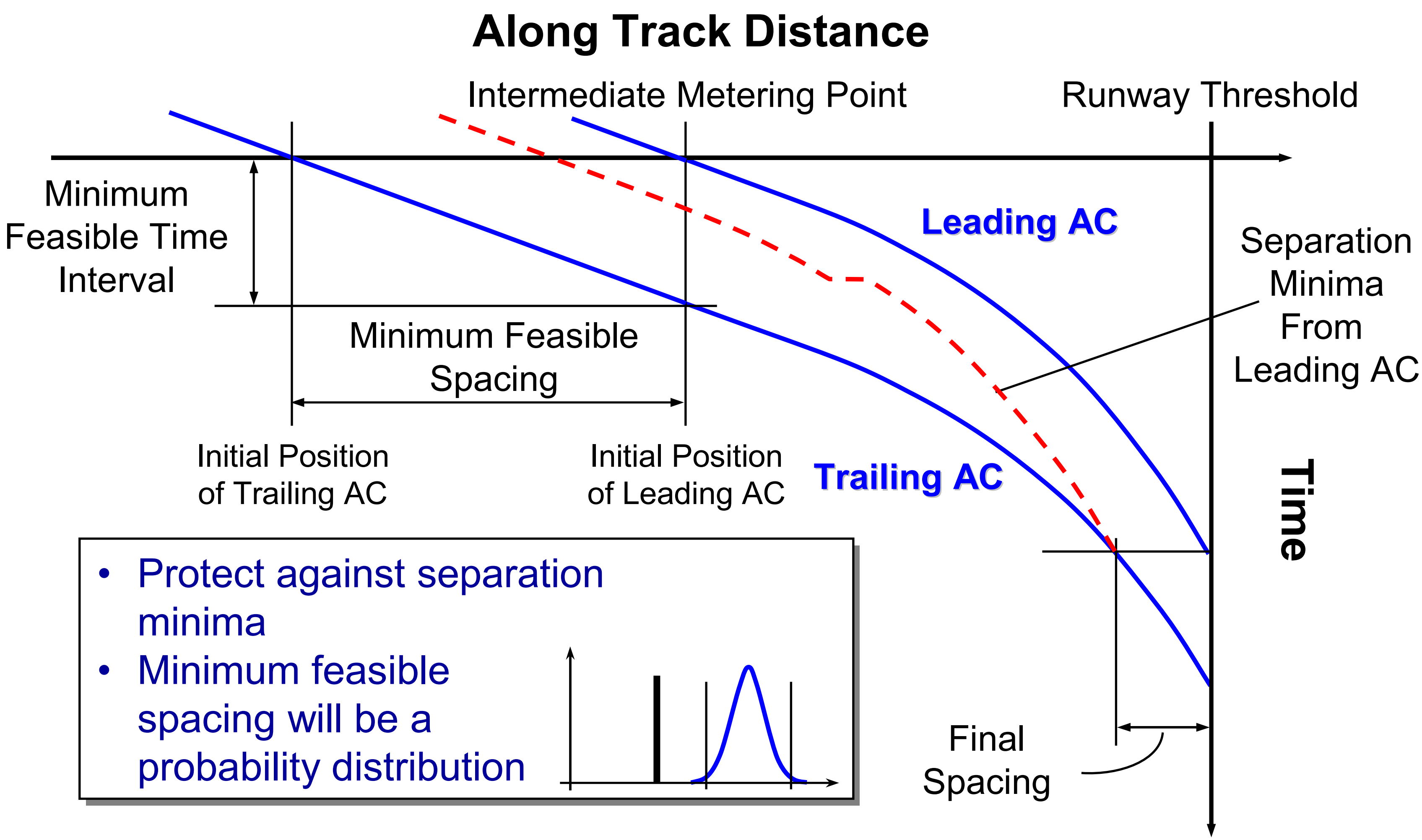
- **Environment**
  - Higher trajectory and reduced thrust over much of the arrival and approach results in reduced noise impact
  - Less time spent below “mixing height” and reduced thrust results in reduced emissions
- **Fuel burn**
  - Fuel savings due to less vectoring and less time flying low and slow with flaps extended
- **Flight time**
  - Time to complete arrival and approach reduced due to less vectoring and less time flying low and slow
- **Lower controller and pilot workload**

# Operational Concept




- Intermediate metering point connects descent from cruise, to final
- Target spacing (or time interval) recommended at metering point
  - Uninterrupted operation at a desired probability, but not absolute
- Key is to determine the recommended value of target spacing or time interval and establish these values in real world operations
  - Modeling and managing trajectory variation and uncertainty

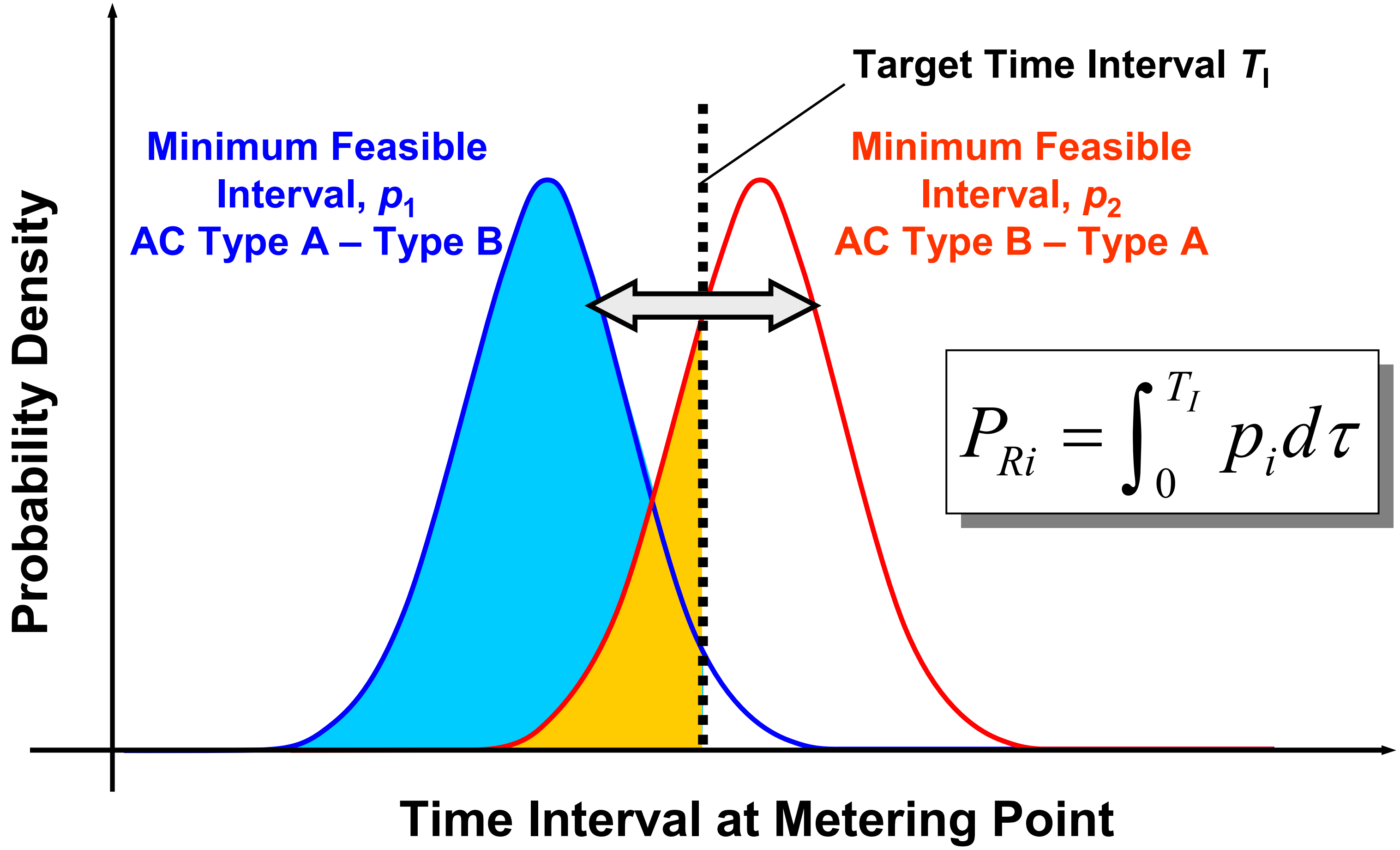
# Minimum Feasible Time Interval




- Protect against separation minima
- Minimum feasible spacing will be a probability distribution

# Separation Analysis Methodology

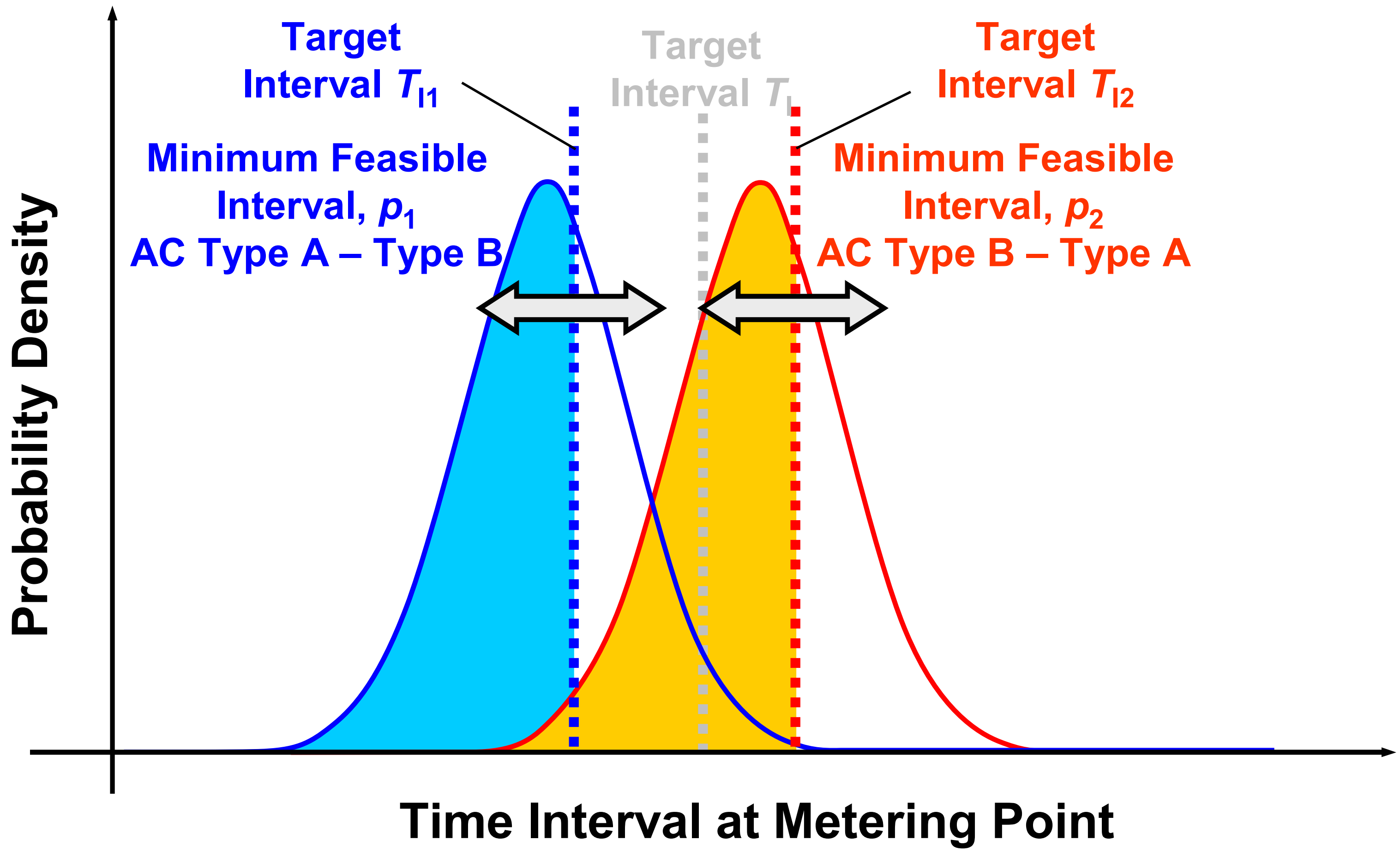
- **Conditional Probability for Given Target Time Interval**
  - Integral of minimum feasible interval pdf from zero to the target interval




$$P_{Ri} = \int_0^{T_I} p_i d\tau$$

# Sequence Specific Separation Analysis

- Sequence Specific Metering for Better Throughput

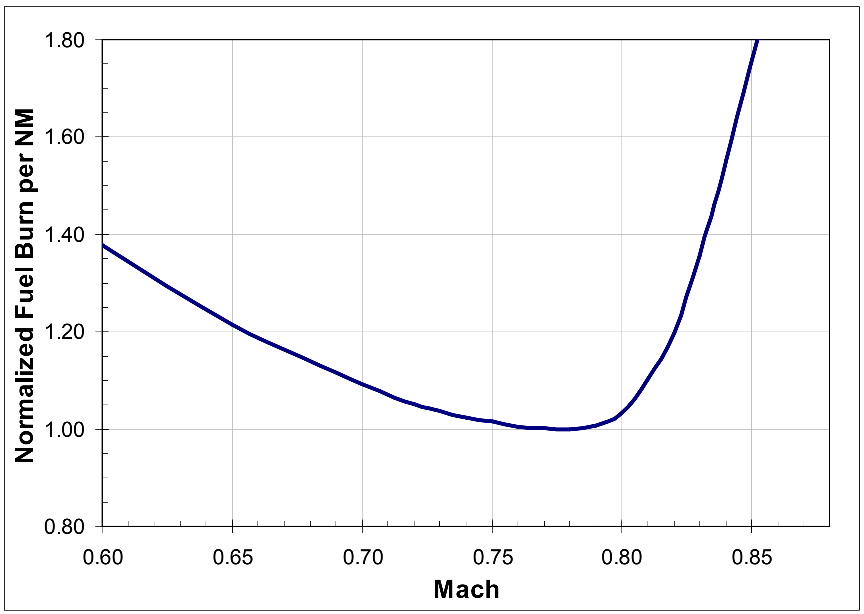


# Time-Based Metering

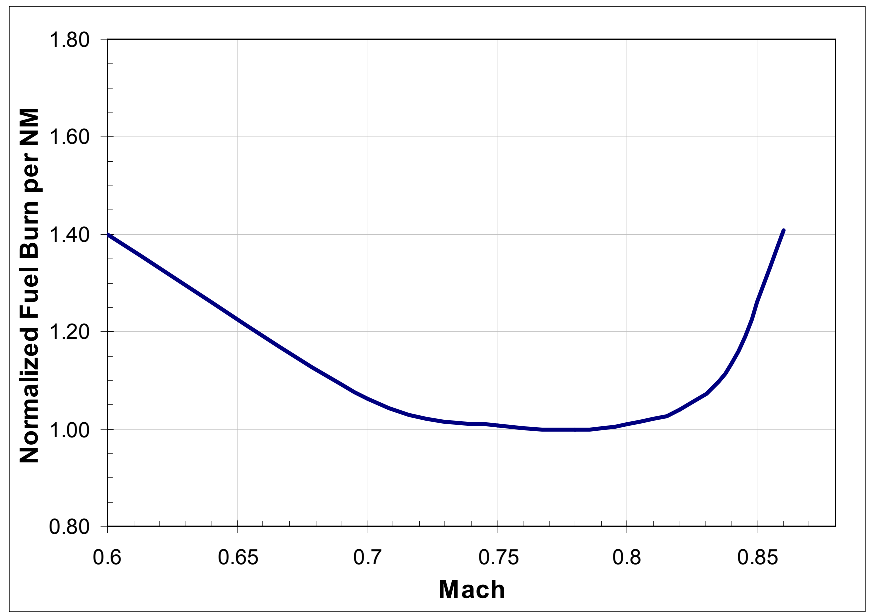
- Achieving target time interval through minor speed adjustments
  - Speed adjustment given during en route
- Rely on accurate estimation of time of arrival at the metering point
  - Routing, vertical profile, speed profile, winds
- Speed adjustment optimized for system wide efficiency
  - Total fuel burn, total flight time
  - Subject to flight schedule and other operational constraints
- More complex objective function with multiple operators
  - Next steps

# Time-Based Metering

- **Use minor speed adjustments**
  - Act early, adapt to uncertainty
  - Within ATC permitted speed deviation range (±0.02 Mach) if possible
  - Minimum deviation from optimum speed




**Example Narrow Body Jet**

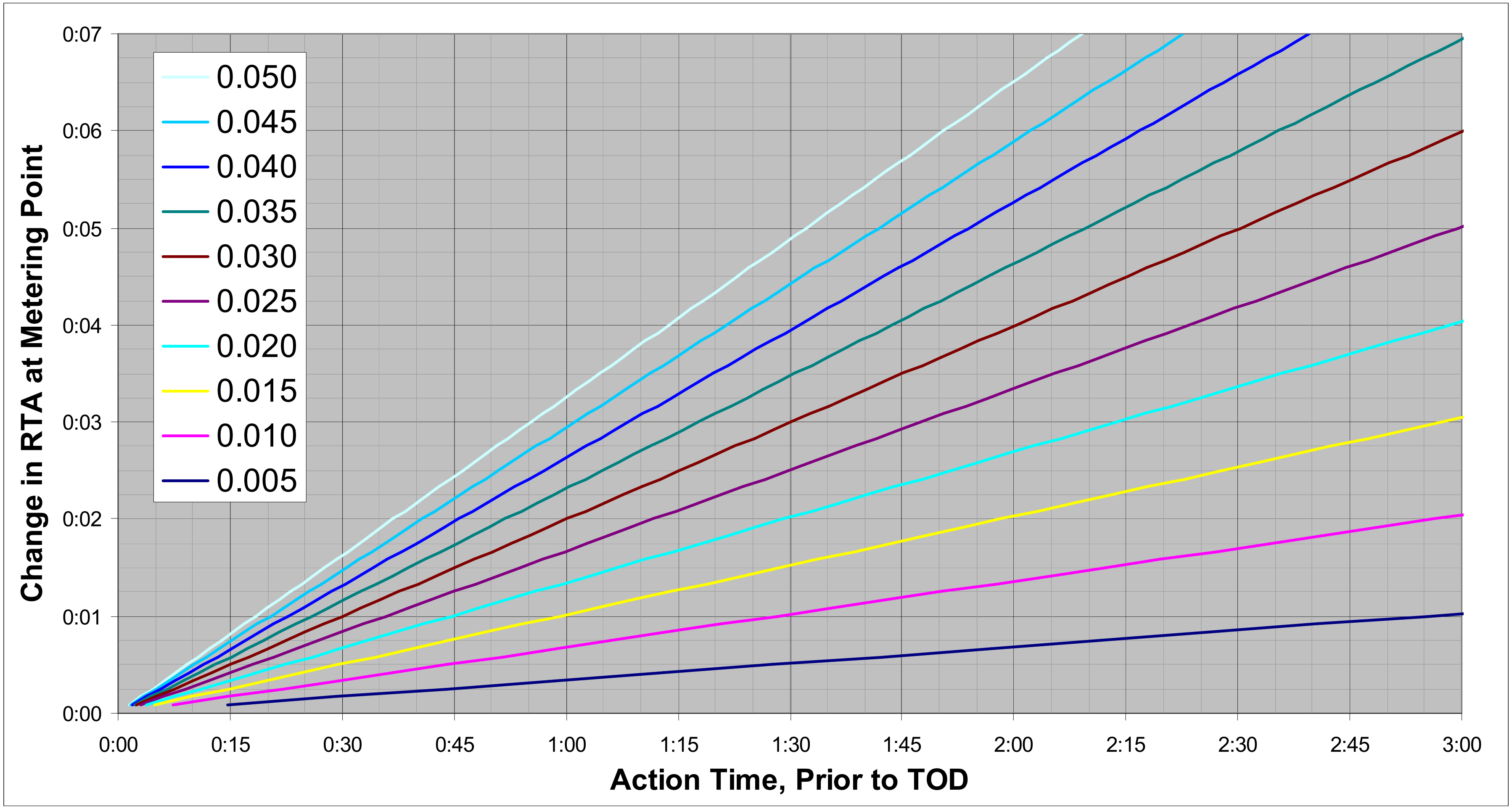



**Example Wide Body Jet**

# Time-Based Metering

## ❑ Change in RTA vs. Speed Adjustment

- Cruise at FL360 or above, ground speed at TOD = 500 kt



# KATL KERMT RNAV CDA Design

- **Unrestricted CDA from cruise altitude**
  - Idle descent from cruise altitude to base leg
- **Designed for overnight arrivals from the west of US**
- **Overlaid on current traffic pattern**
- **Designed for multiple aircraft types**
  - B737-800, B757-200, B767-300, B767-400
- **RMG selected as the metering point**
  - 55 nm to runway 09R; 66 nm to runway 26R; 16,000 ~ 20,000 ft
- **Merging occurs at RMG**
  - KSDF 2004 flight test merging occurred at cruise altitude
- **Most challenging task:**
  - Efficiently managing spacing/timing at metering point

| D-ATIS Arrival 119.65 | Apt Elev 1026' | Alt set: INCHES Trans level: FL 180 Trans alt: 18000' | 1. ATC RADAR required<br>2. Turbojet aircraft only.<br>3. DME/IRU or GPS required.<br>4. For GPS and DME/DME/IRU equipped aircraft only<br>5. Primary landing runways: 9R/26R. |
|---|---|---|---|

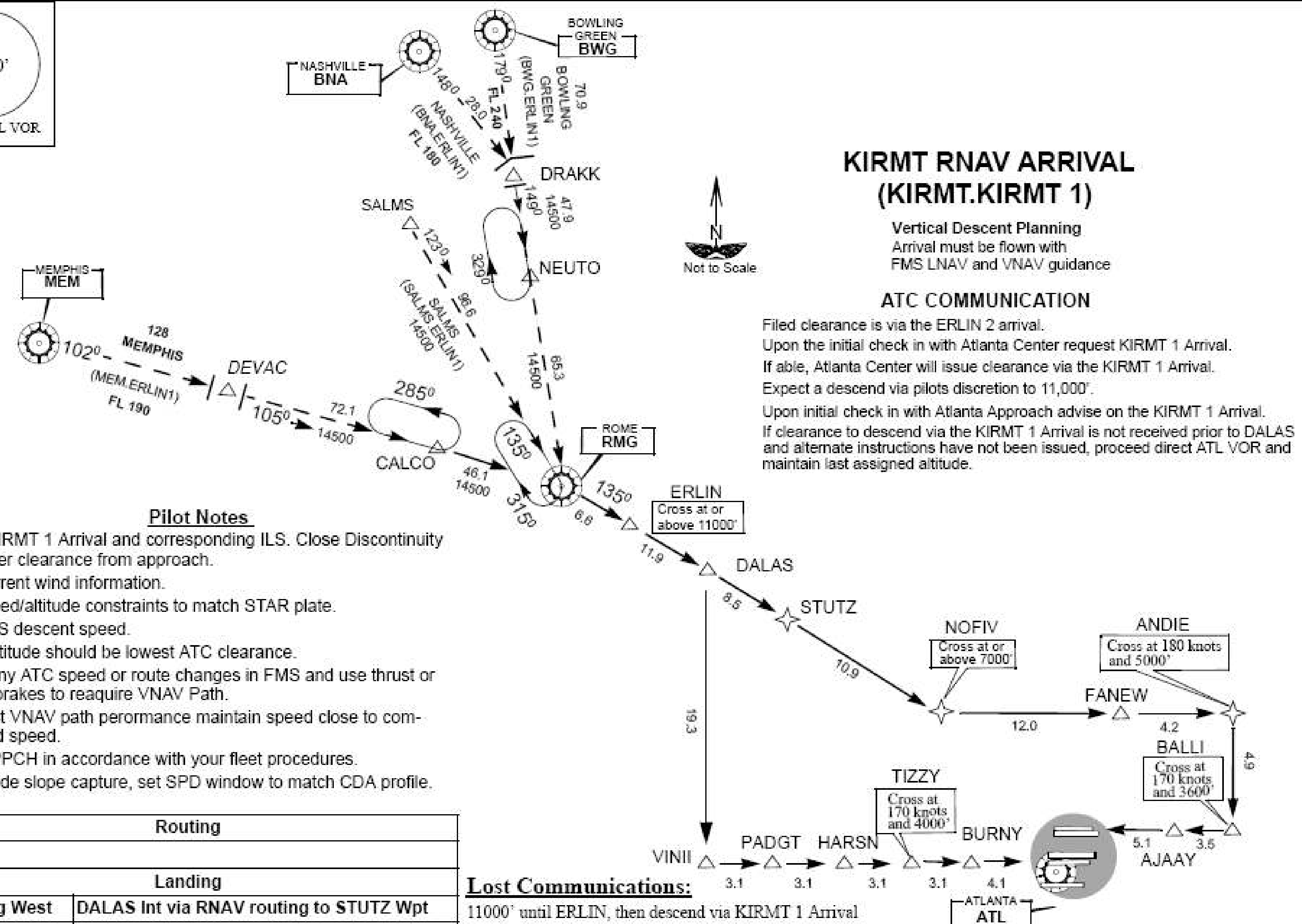
3100'
MSA ATL VOR

# KIRMT RNAV ARRIVAL (KIRMT.KIRMT 1)

**Vertical Descent Planning**
Arrival must be flown with FMS LNAV and VNAV guidance

## ATC COMMUNICATION

Filed clearance is via the ERLIN 2 arrival.
Upon the initial check in with Atlanta Center request KIRMT 1 Arrival.
If able, Atlanta Center will issue clearance via the KIRMT 1 Arrival.
Expect a descend via pilots discretion to 11,000'.
Upon initial check in with Atlanta Approach advise on the KIRMT 1 Arrival.
If clearance to descend via the KIRMT 1 Arrival is not received prior to DALAS and alternate instructions have not been issued, proceed direct ATL VOR and maintain last assigned altitude.



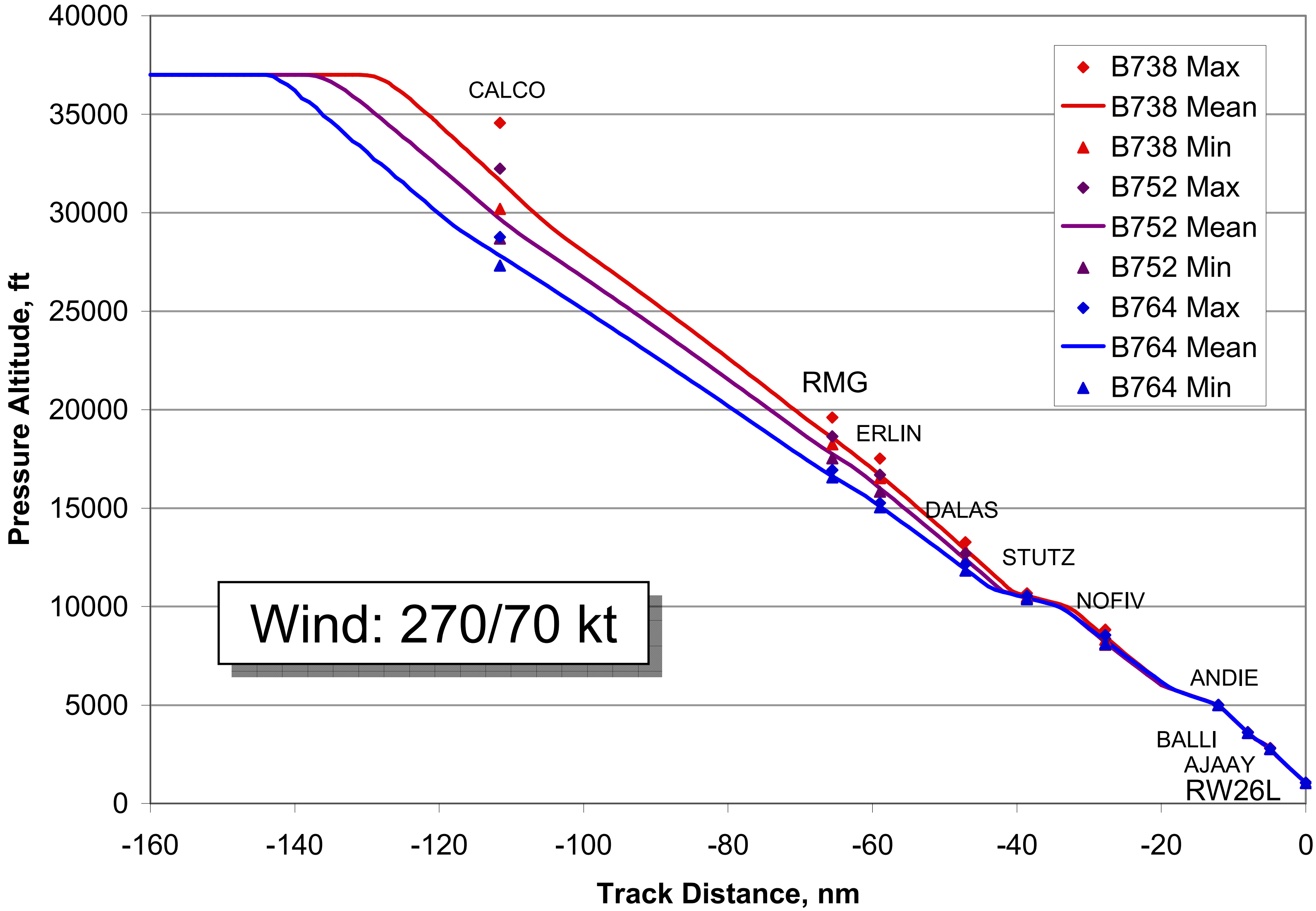

## Pilot Notes

- Load KIRMT 1 Arrival and corresponding ILS. Close Discontinuity only after clearance from approach.
- Set Current wind information.
- Set speed/altitude constraints to match STAR plate.
- Set FMS descent speed.
- MCP altitude should be lowest ATC clearance.
- Enter any ATC speed or route changes in FMS and use thrust or speed brakes to reaquire VNAV Path.
- For best VNAV path peromance maintain speed close to commanded speed.
- Arm APPCH in accordance with your fleet procedures.
- After glide slope capture, set SPD window to match CDA profile.

| Routing | |
|---|---|
| | |
| **Landing** | |
| **Landing West** | **DALAS Int via RNAV routing to STUTZ Wpt** |
| **Landing East** | **DALAS Int via RNAV routing to VINII Wpt** |

**Lost Communications:**
11000' until ERLIN, then descend via KIRMT 1 Arrival

# Typical Vertical Profiles



# Typical Target Time Intervals

CDA to Runway 26R, Wind: 270/70 kt at 37,000 ft

| Target Time Interval at RMG, seconds | | Trailing Aircraft | |
|---|---|---|---|
| | | B738 | B764 |
| Leading Aircraft | B738 | 72.8 | 71.8 |
| | B752 | 134.8 | 131.1 |
| | B764 | 137.6 | 107.2 |

# Initial Benefit Results

**CDA** **B757-200** Simulation data 24-Apr-07

| | | | | |
|---|---|---|---|---|
| **Cruise altitude** | FL390 | | | |
| **Wind** | 281 deg, 74kt, at FL370 | | | |
| **Aircraft Weight** | 179,700 (Delta average) | | | |
| | **Fuel, TOD to runway** | | **Time, RMG to runway** | |
| | lb | gal | sec | minute |
| **CDA09R** | 783.80 | 116.99 | 773.00 | 12.88 |
| **CDA26R** | 830.38 | 123.94 | 893.00 | 14.88 |

**CDA** **B767-300** Simulation data 24-Apr-07

| | | | | |
|---|---|---|---|---|
| **Cruise altitude** | FL370 | | | |
| **Wind** | 281 deg, 74kt, at FL370 | | | |
| **Aircraft Weight** | 265,800 (Delta avergage) | | | |
| | **Fuel, TOD to runway** | | **Time, RMG to runway** | |
| | lb | gal | sec | minute |
| **CDA09R** | 1122.07 | 167.47 | 771.75 | 12.86 |
| **CDA26R** | 1172.74 | 175.04 | 892.25 | 14.87 |

**Conventional** **B757-200** Aircraft estimated data 24-Apr-07

| | | | | |
|---|---|---|---|---|
| **Cruise altitude** | FL390 | | | |
| **Wind** | 281 deg, 74kt, at FL370 | | | |
| **Aircraft Weight** | 180,550 (Average of two flights) | | | |
| | **Fuel, TOD to runway** | | **Time, RMG to runway** | |
| | lb | gal | sec | minute |
| **STD09R** | | | | |
| **STD26R** | 1850.00 | 276.12 | 1110.00 | 18.50 |

**Conventional** **B767-300** Aircraft estimated data 24-Apr-07

| | | | | |
|---|---|---|---|---|
| **Cruise altitude** | FL370 | | | |
| **Wind** | 281 deg, 74kt, at FL370 | | | |
| **Aircraft Weight** | 264,150 (Average of two flights) | | | |
| | **Fuel, TOD to runway** | | **Time, RMG to runway** | |
| | lb | gal | sec | minute |
| **STD09R** | | | | |
| **STD26R** | 2500.00 | 373.13 | 1140.00 | 19.00 |

**Est. Reduction** **B757-200** 24-Apr-07

| | | | | |
|---|---|---|---|---|
| | **Fuel, TOD to runway** | | **Time, RMG to runway** | |
| | lb | gal | sec | minute |
| **CDA09R** | | | | |
| **CDA26R** | 1019.62 | 152.18 | 217.00 | 3.62 |

**Est. Reduction** **B767-300** 24-Apr-07

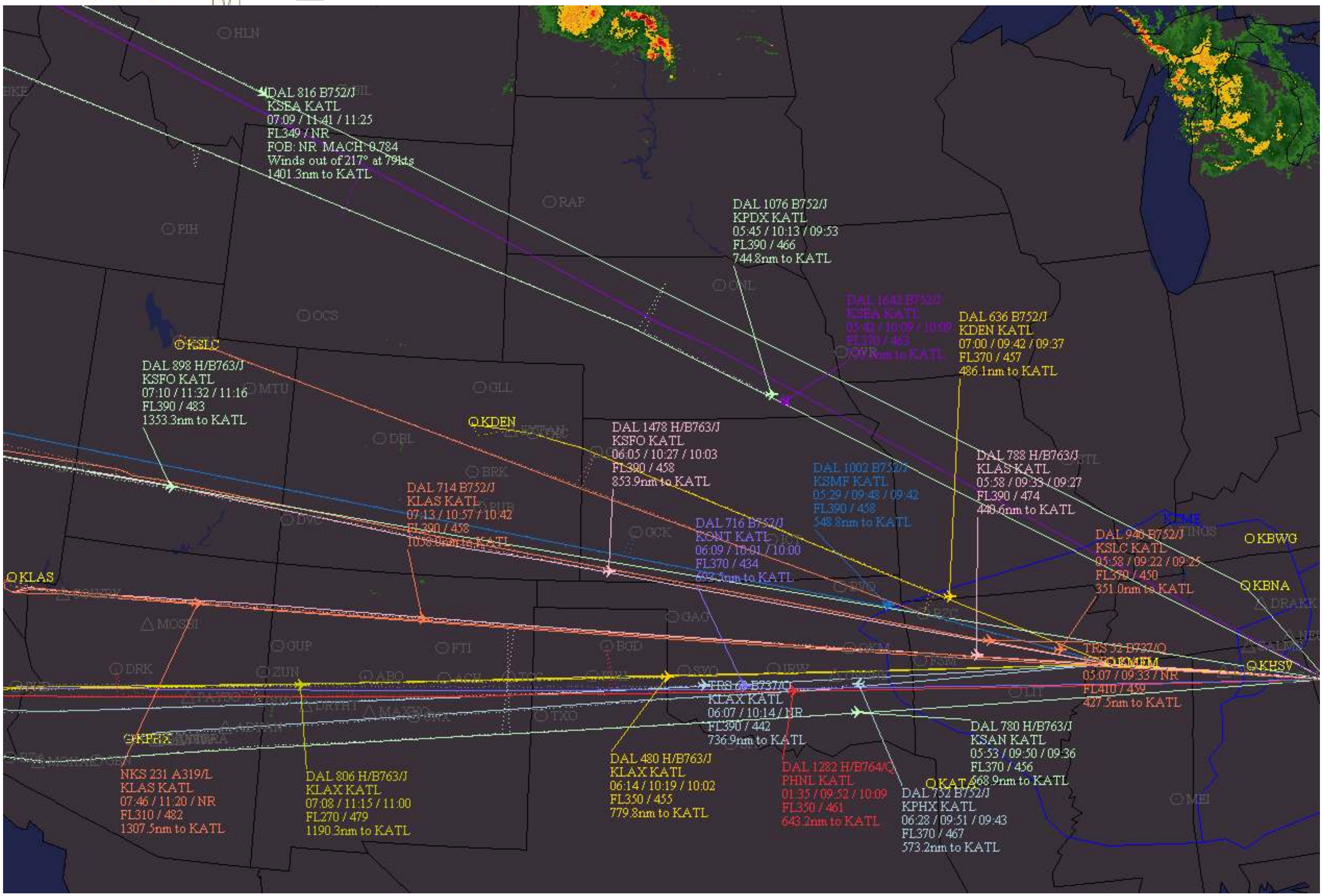
| | | | | |
|---|---|---|---|---|
| | **Fuel, TOD to runway** | | **Time, RMG to runway** | |
| | lb | gal | sec | minute |
| **CDA09R** | | | | |
| **CDA26R** | 1327.26 | 198.10 | 247.75 | 4.13 |

**Note:**
1. All data based on 24-Apr-2007 wether environment and equipment assignment
2. Simulation data obtained using Georgia Tech fast time simulation tool, aircraft weight based on Delta average over a month
3. Aircraft estimated fuel data obtained from flight plan.
4. Aircraft estimated time data obtained from crew reports. These numbers were reported before CDA was loaded, thus considered conventional (STD)
5. Runway 09R estimated data not available

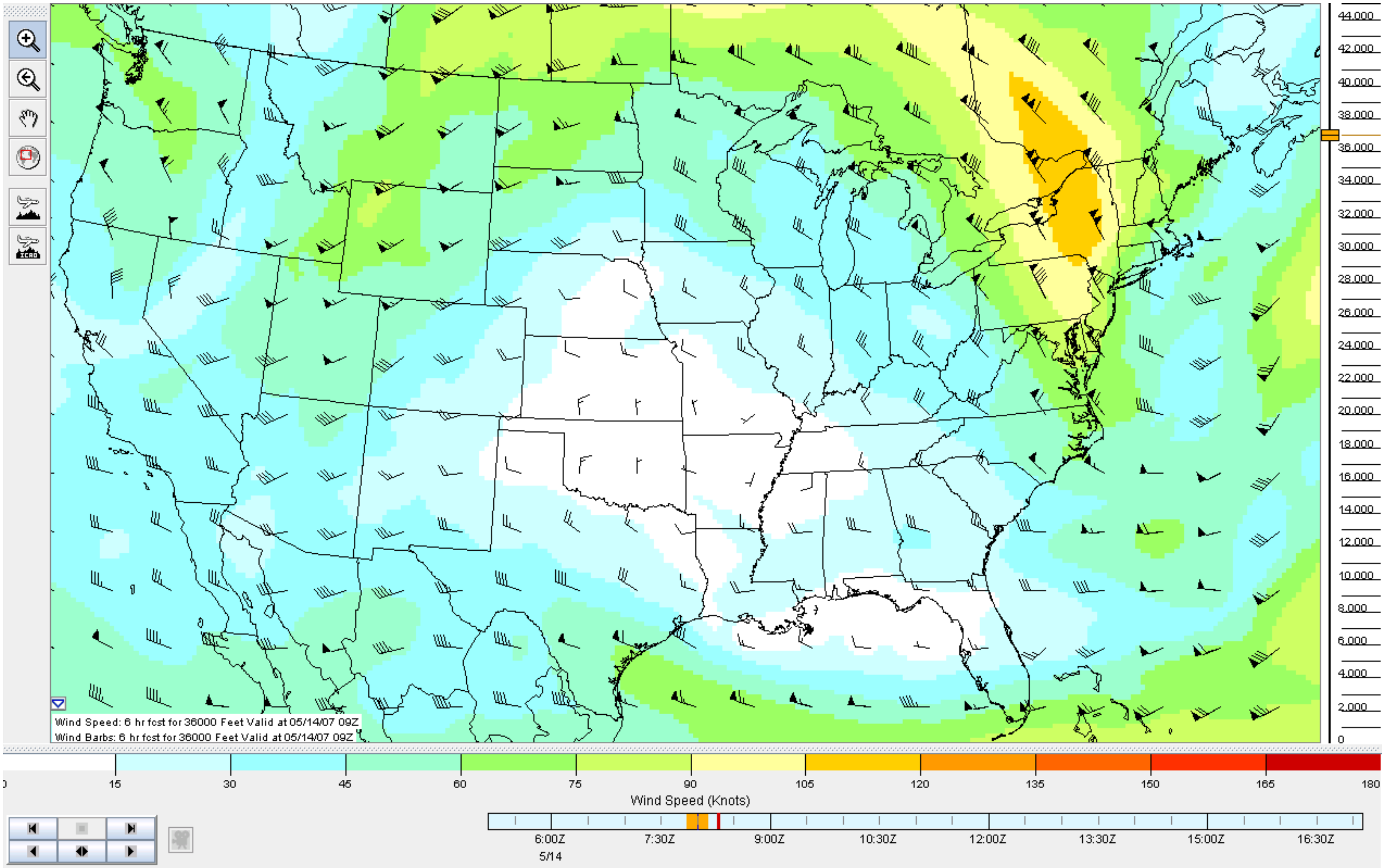
# Operations at Delta OCC


**Clayton Tino and Heinrich Souza (Georgia Tech) processing CDA profiles and wind data, Marcus Lowther participated on other days**

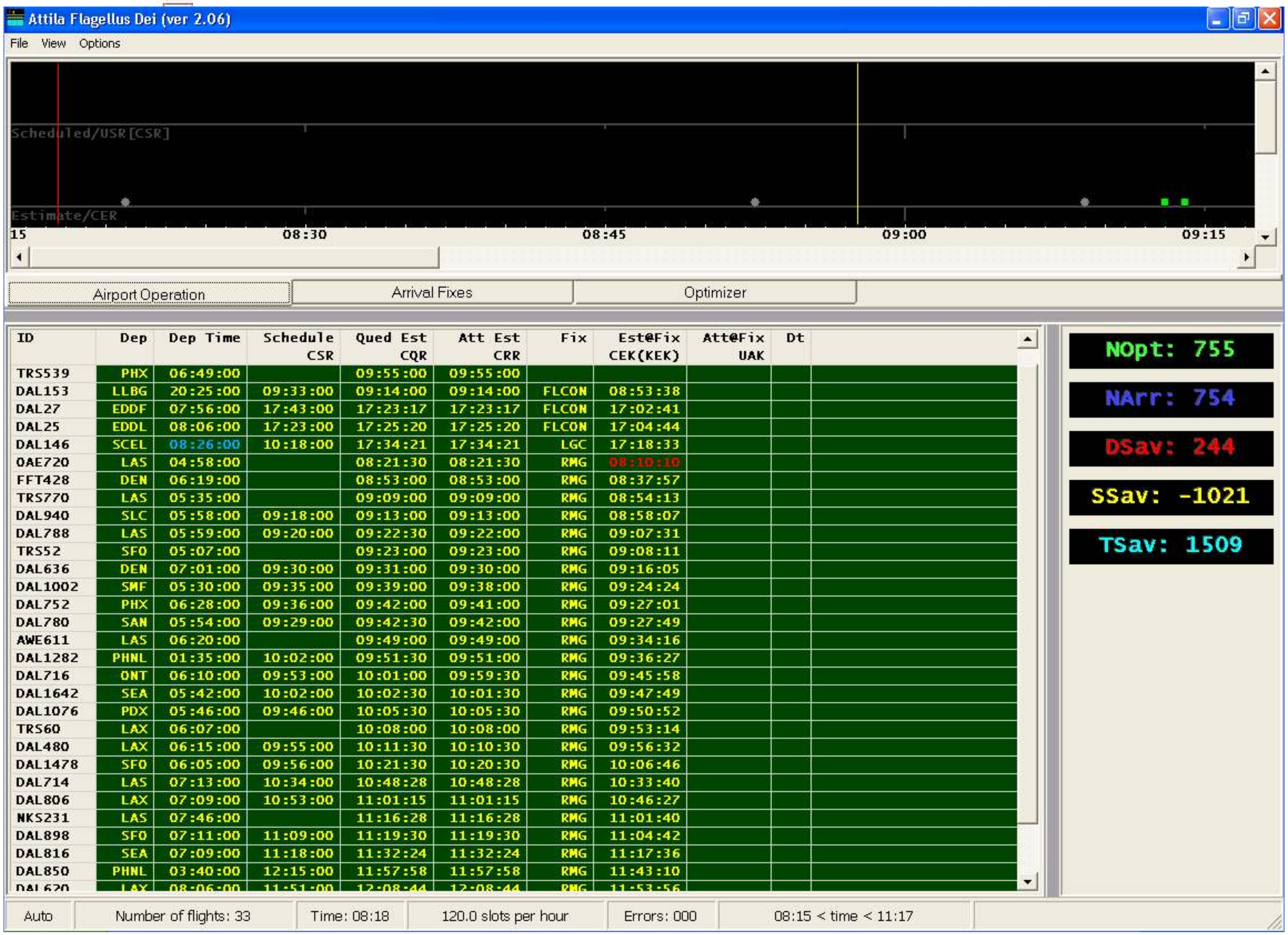
# Merging and Spacing Task (GFF)



# Forecast Winds (Flight Plan Tool)



# Estimated Time of Arrival (Attila$^{TM}$)

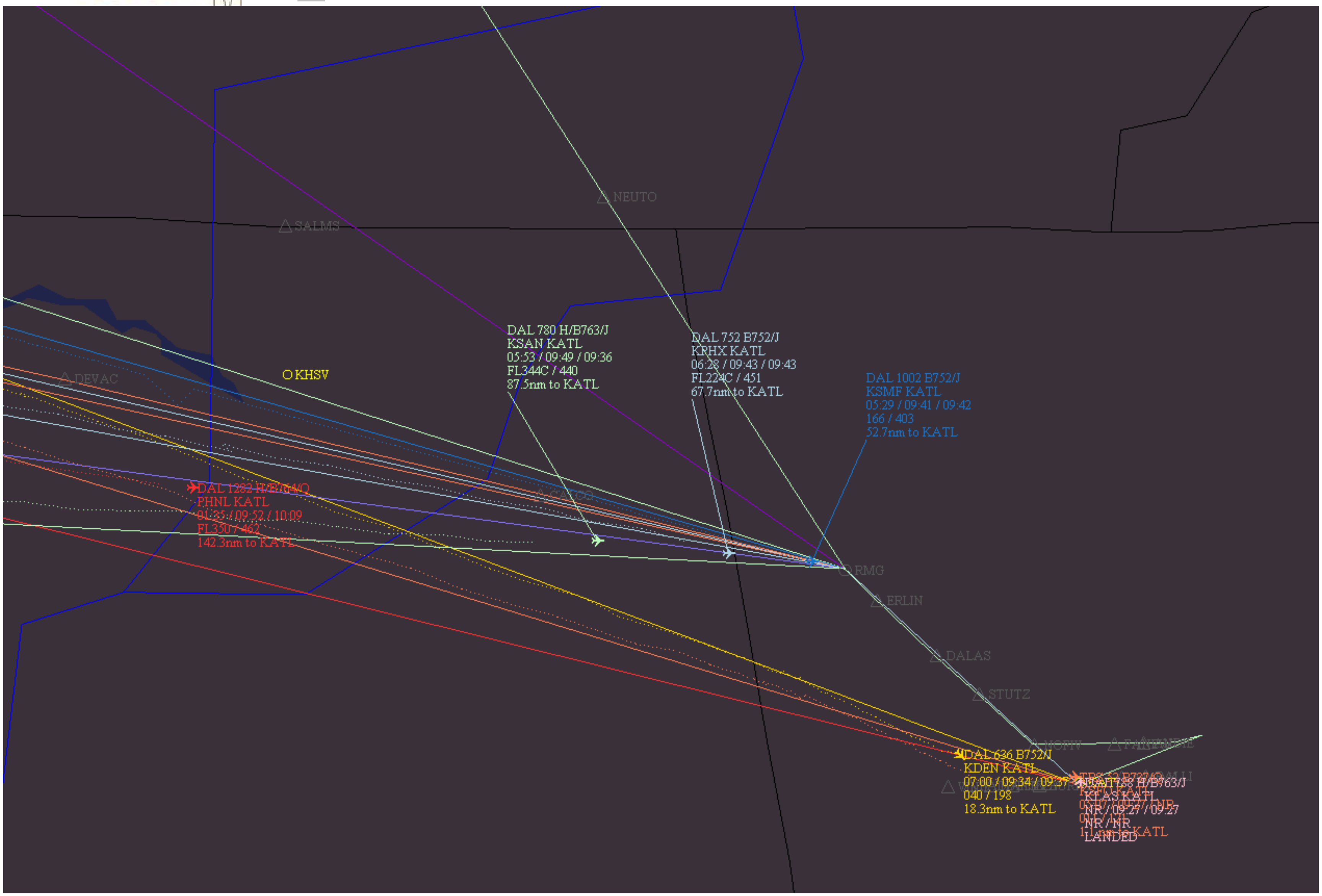



| ID | Dep | Dep Time | Schedule CSR | Qued Est CQR | Att Est CRR | Fix | Est@Fix CEK(KEK) | Att@Fix UAK | Dt |
|---|---|---|---|---|---|---|---|---|---|
| TRS539 | PHX | 06:49:00 | | 09:55:00 | 09:55:00 | | | | |
| DAL153 | LLBG | 20:25:00 | 09:33:00 | 09:14:00 | 09:14:00 | FLCON | 08:53:38 | | |
| DAL27 | EDDF | 07:56:00 | 17:43:00 | 17:23:17 | 17:23:17 | FLCON | 17:02:41 | | |
| DAL25 | EDDL | 08:06:00 | 17:23:00 | 17:25:20 | 17:25:20 | FLCON | 17:04:44 | | |
| DAL146 | SCEL | 08:26:00 | 10:18:00 | 17:34:21 | 17:34:21 | LGC | 17:18:33 | | |
| OAE720 | LAS | 04:58:00 | | 08:21:30 | 08:21:30 | RMG | 08:10:10 | | |
| FFT428 | DEN | 06:19:00 | | 08:53:00 | 08:53:00 | RMG | 08:37:57 | | |
| TRS770 | LAS | 05:35:00 | | 09:09:00 | 09:09:00 | RMG | 08:54:13 | | |
| DAL940 | SLC | 05:58:00 | 09:18:00 | 09:13:00 | 09:13:00 | RMG | 08:58:07 | | |
| DAL788 | LAS | 05:59:00 | 09:20:00 | 09:22:30 | 09:22:00 | RMG | 09:07:31 | | |
| TRS52 | SFO | 05:07:00 | | 09:23:00 | 09:23:00 | RMG | 09:08:11 | | |
| DAL636 | DEN | 07:01:00 | 09:30:00 | 09:31:00 | 09:30:00 | RMG | 09:16:05 | | |
| DAL1002 | SMF | 05:30:00 | 09:35:00 | 09:39:00 | 09:38:00 | RMG | 09:24:24 | | |
| DAL752 | PHX | 06:28:00 | 09:36:00 | 09:42:00 | 09:41:00 | RMG | 09:27:01 | | |
| DAL780 | SAN | 05:54:00 | 09:29:00 | 09:42:30 | 09:42:00 | RMG | 09:27:49 | | |
| AWE611 | LAS | 06:20:00 | | 09:49:00 | 09:49:00 | RMG | 09:34:16 | | |
| DAL1282 | PHNL | 01:35:00 | 10:02:00 | 09:51:30 | 09:51:00 | RMG | 09:36:27 | | |
| DAL716 | ONT | 06:10:00 | 09:53:00 | 10:01:00 | 09:59:30 | RMG | 09:45:58 | | |
| DAL1642 | SEA | 05:42:00 | 10:02:00 | 10:02:30 | 10:01:30 | RMG | 09:47:49 | | |
| DAL1076 | PDX | 05:46:00 | 09:46:00 | 10:05:30 | 10:05:30 | RMG | 09:50:52 | | |
| TRS60 | LAX | 06:07:00 | | 10:08:00 | 10:08:00 | RMG | 09:53:14 | | |
| DAL480 | LAX | 06:15:00 | 09:55:00 | 10:11:30 | 10:10:30 | RMG | 09:56:32 | | |
| DAL1478 | SFO | 06:05:00 | 09:56:00 | 10:21:30 | 10:20:30 | RMG | 10:06:46 | | |
| DAL714 | LAS | 07:13:00 | 10:34:00 | 10:48:28 | 10:48:28 | RMG | 10:33:40 | | |
| DAL806 | LAX | 07:09:00 | 10:53:00 | 11:01:15 | 11:01:15 | RMG | 10:46:27 | | |
| NKS231 | LAS | 07:46:00 | | 11:16:28 | 11:16:28 | RMG | 11:01:40 | | |
| DAL898 | SFO | 07:11:00 | 11:09:00 | 11:19:30 | 11:19:30 | RMG | 11:04:42 | | |
| DAL816 | SEA | 07:09:00 | 11:18:00 | 11:32:24 | 11:32:24 | RMG | 11:17:36 | | |
| DAL850 | PHNL | 03:40:00 | 12:15:00 | 11:57:58 | 11:57:58 | RMG | 11:43:10 | | |
| DAL620 | LAX | 08:06:00 | 11:51:00 | 12:08:44 | 12:08:44 | RMG | 11:53:56 | | |

# Example Speed Adjustments

- **Speed adjustment up-linked via ACARS by way of dispatcher**
- **For DAL1002, DAL0752, DAL0780**
  - 8:14:51, DAL1002, M0.789, CHANGE TO M0.800
  - 8:46:50, DAL0752, M0.802, CHANGE TO M0.820
  - 9:03:24, DAL1002, M0.805, CHANGE TO M0.820
    - Resume normal speed of M0.780 prior to TOD
  - Speed increase selected because all three flights are behind schedule. Slowdown of trailing aircraft are used otherwise to save more fuel

# Properly Spaced Arrival Flow



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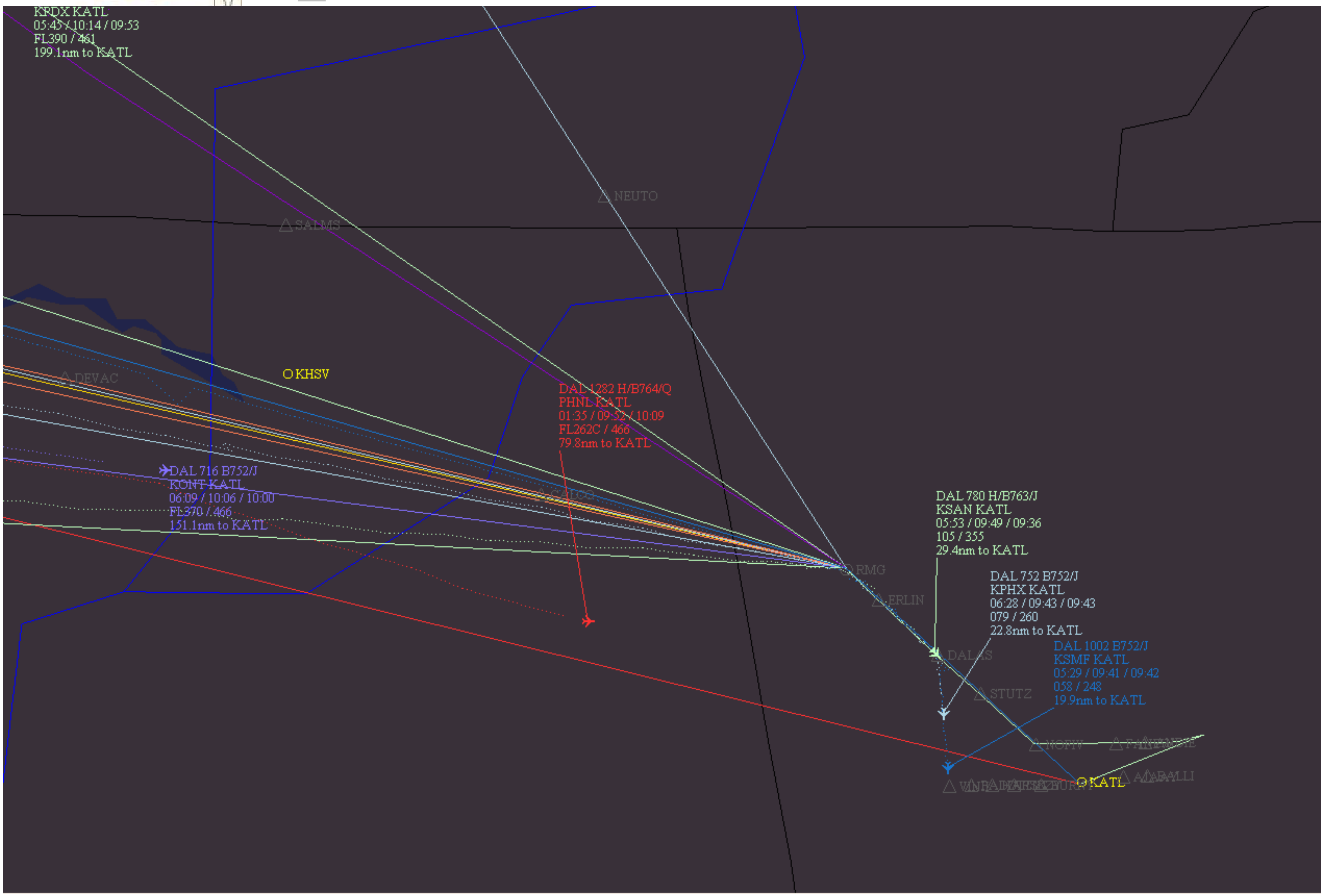

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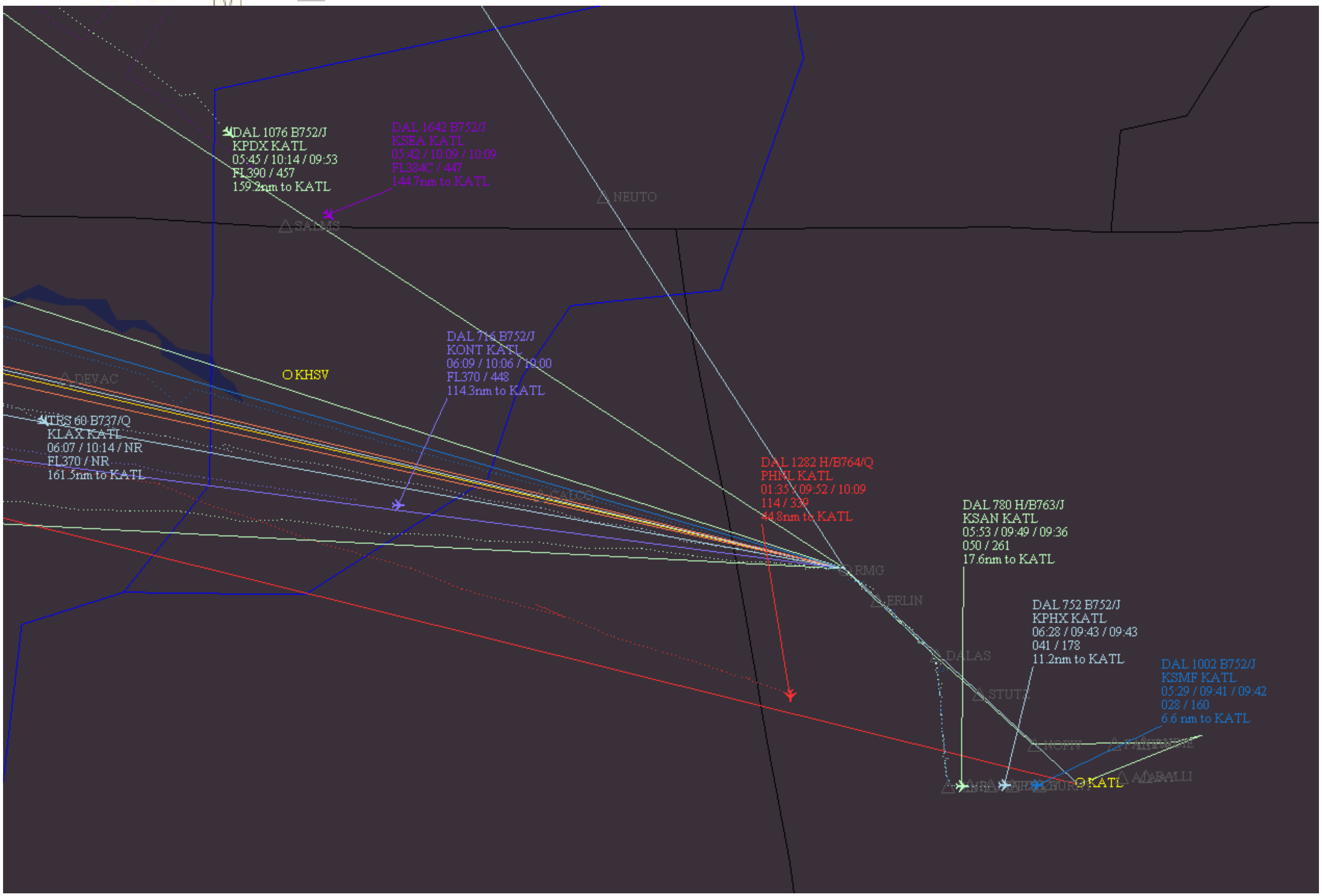

# Challenges

- **Modeling of CDA trajectory variations**
  - Assure accurate spacing matrix
  - TASAT verified by ATL and previous flight tests
- **Optimization algorithm**
  - Systems approach, multiple objectives
  - Schedule and other operational constraints
  - Dynamic, may change over time
- **En route trajectory prediction**
  - Winds, winds, winds: forecast, wind mix, use of ACARS report
  - Aircraft routing uncertainty: convective weather a major factor
  - Aircraft operational uncertainty: speed change by crew
  - Ground based or air based?
    - Attila™ ETA more consistent and stable than aircraft report