A Pragmatic Concept of Operations for 4-D Trajectory Management

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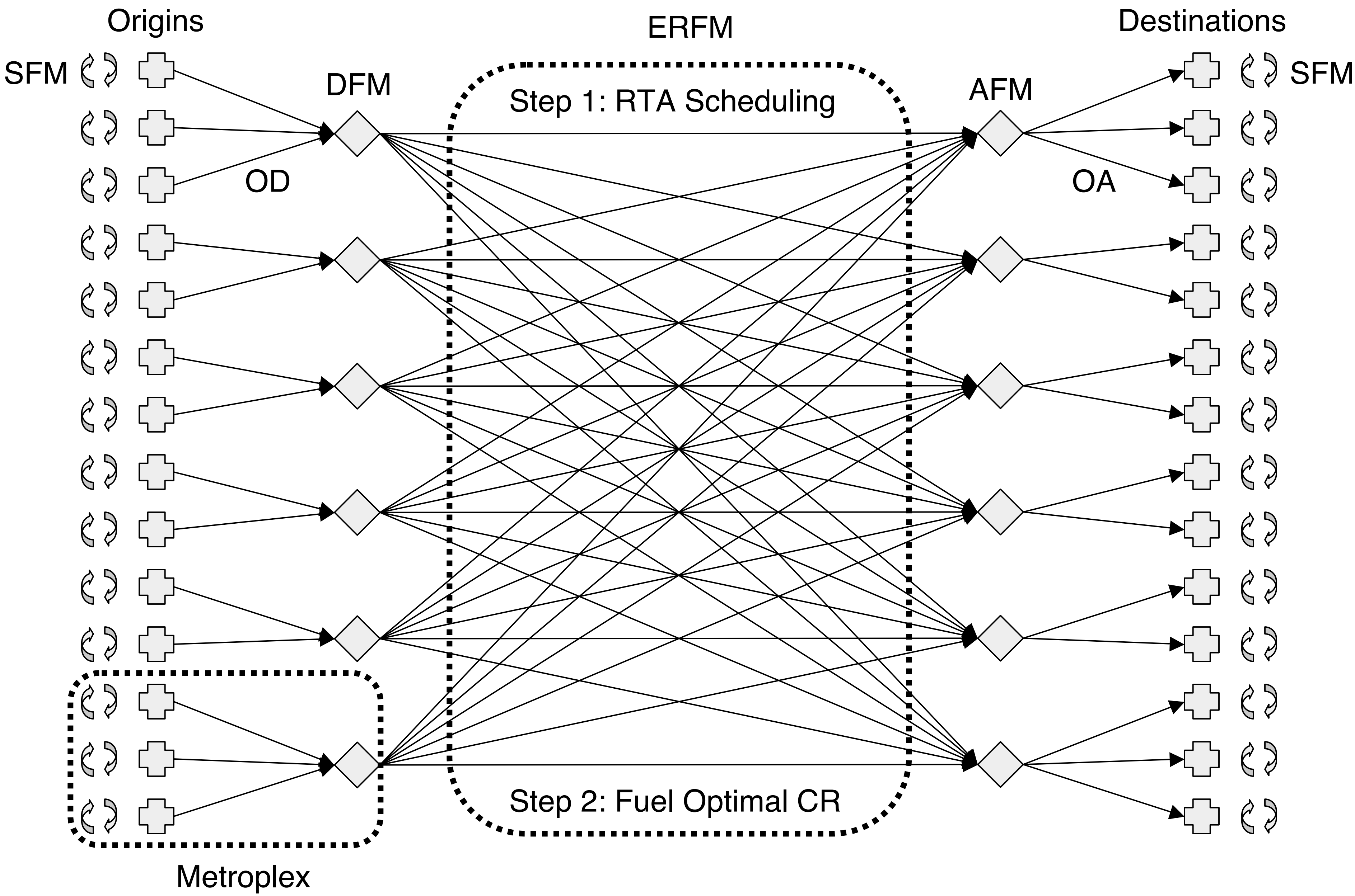
Overview

- **“Big giant head” approach to 4-D trajectory management in not tenable**
  - Combinatorial problem
  - Uncertain operating environment
  - Limits on trajectory prediction performance
  - Limits on communication bandwidth
- **Pragmatic approach is to…**
  - Solve the trajectory management in stages where the transition between stages are the points where we compensate for the uncertainties
    - Analogous to “stage stops” for buses as opposed to trying to schedule the precise times at each bus stop
  - Leverage existing and developing technologies in a holistic way

The Idea



Origins
ERFM
Destinations
SFM
DFM
Step 1: RTA Scheduling
AFM
SFM
OD
OA
Step 2: Fuel Optimal CR
Metroplex

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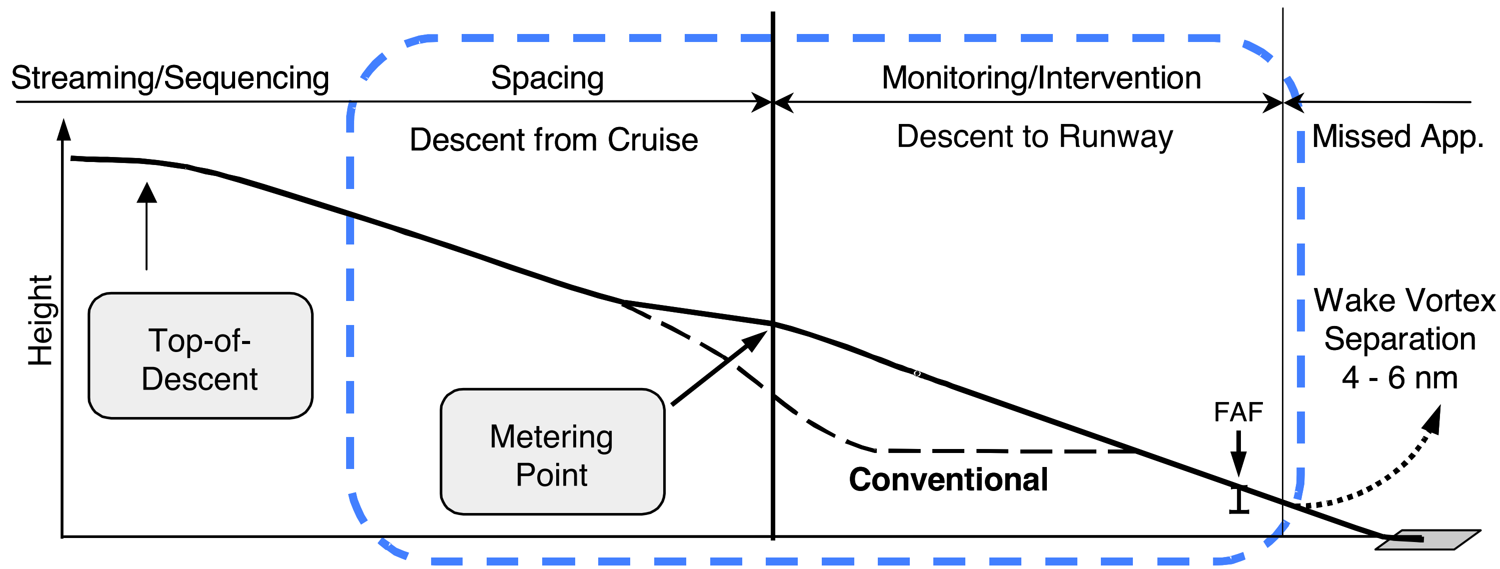
Optimized Arrivals --- Optimizing the Descent (Lateral and Vertical)

Continuous Descent Arrival



- Sequence and spacing achieved during descent from cruise altitude (top-of-descent) to altitude at metering point
- No vectoring during descent to runway i.e. below altitude at metering point
- Location of metering point dependent on traffic conditions

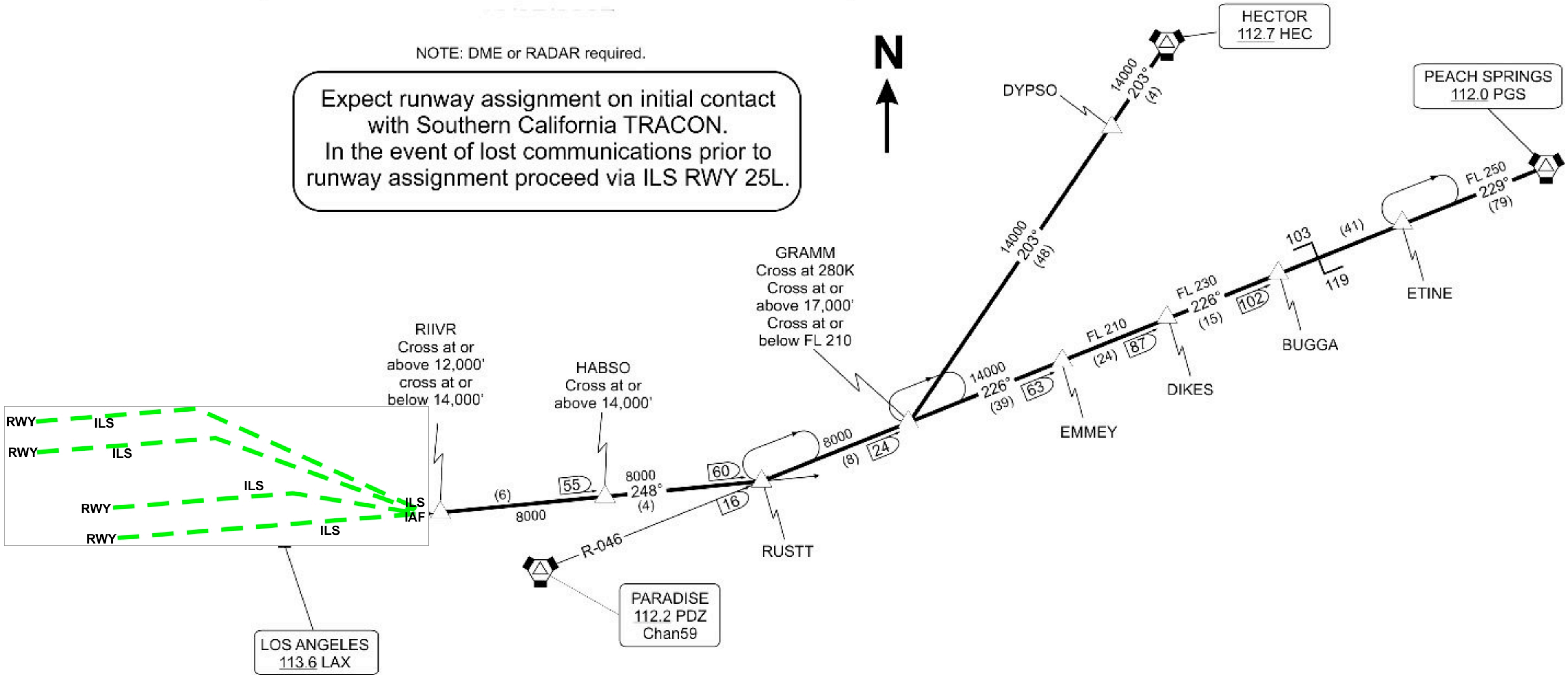
What are the benefits and challenges of CDA?

- **Benefits**
  - 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 and flight time
    - Fuel and flight time savings due to less vectoring and less time flying low and slow
  - Lower controller and pilot workload
- **Challenge**
  - Need to determine the “right” spacing at the top of descent or transition (metering) point
    - Spacing determined so as to achieve a target cost (in terms of costly interventions) later in the descent
  - Requires quantitatively rigorous design methodology

RIIVR TWO ARRIVAL
(Optimized Profile Descent)

NOTE: DME or RADAR required.

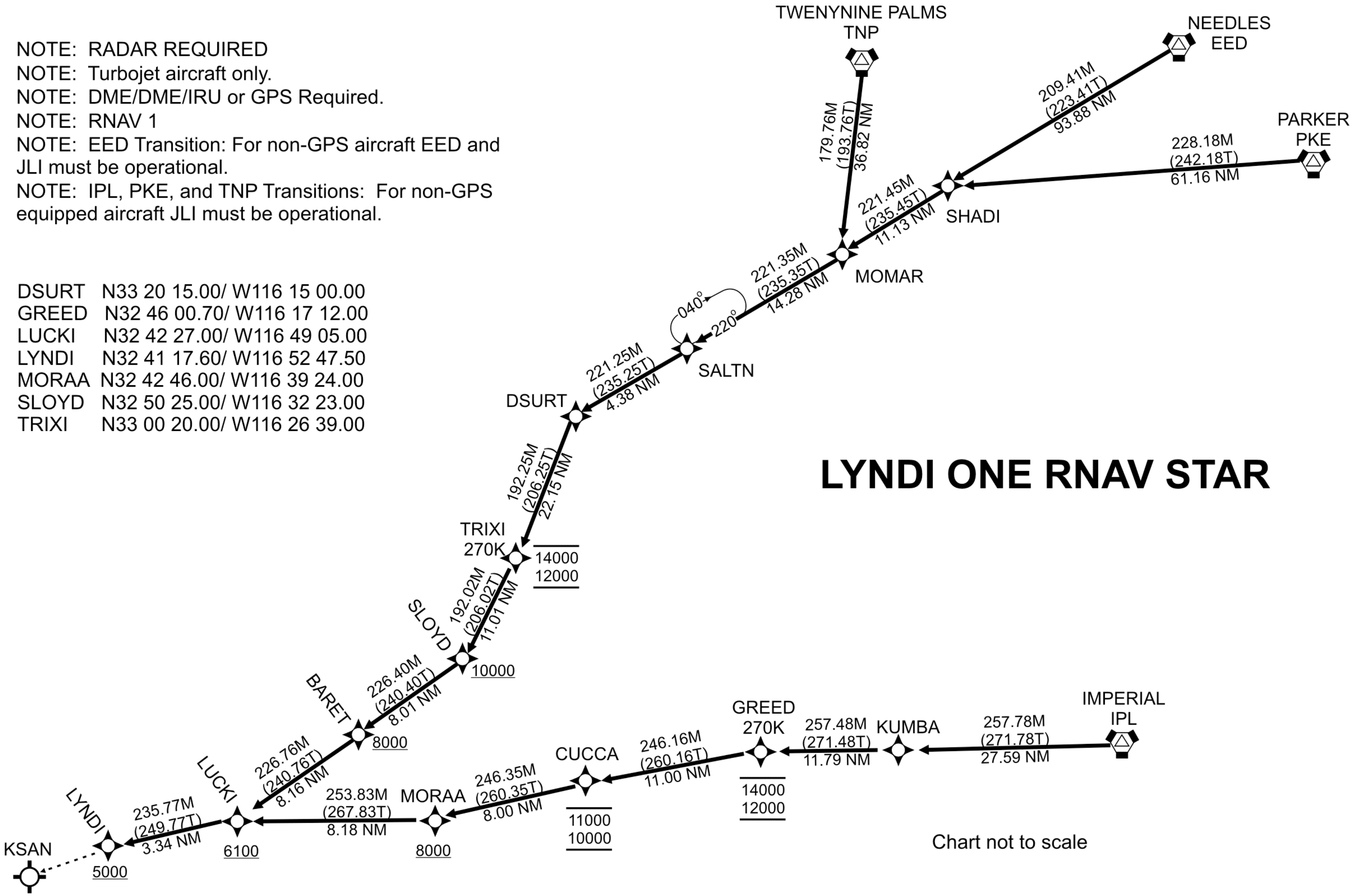
Expect runway assignment on initial contact with Southern California TRACON.
In the event of lost communications prior to runway assignment proceed via ILS RWY 25L.



LYNDI ONE RNAV STAR

NOTE: RADAR REQUIRED
NOTE: Turbojet aircraft only.
NOTE: DME/DME/IRU or GPS Required.
NOTE: RNAV 1
NOTE: EED Transition: For non-GPS aircraft EED and JLI must be operational.
NOTE: IPL, PKE, and TNP Transitions: For non-GPS equipped aircraft JLI must be operational.

DSURT	N33 20 15.00/ W116 15 00.00
GREED	N32 46 00.70/ W116 17 12.00
LUCKI	N32 42 27.00/ W116 49 05.00
LYNDI	N32 41 17.60/ W116 52 47.50
MORAA	N32 42 46.00/ W116 39 24.00
SLOYD	N32 50 25.00/ W116 32 23.00
TRIXI	N33 00 20.00/ W116 26 39.00

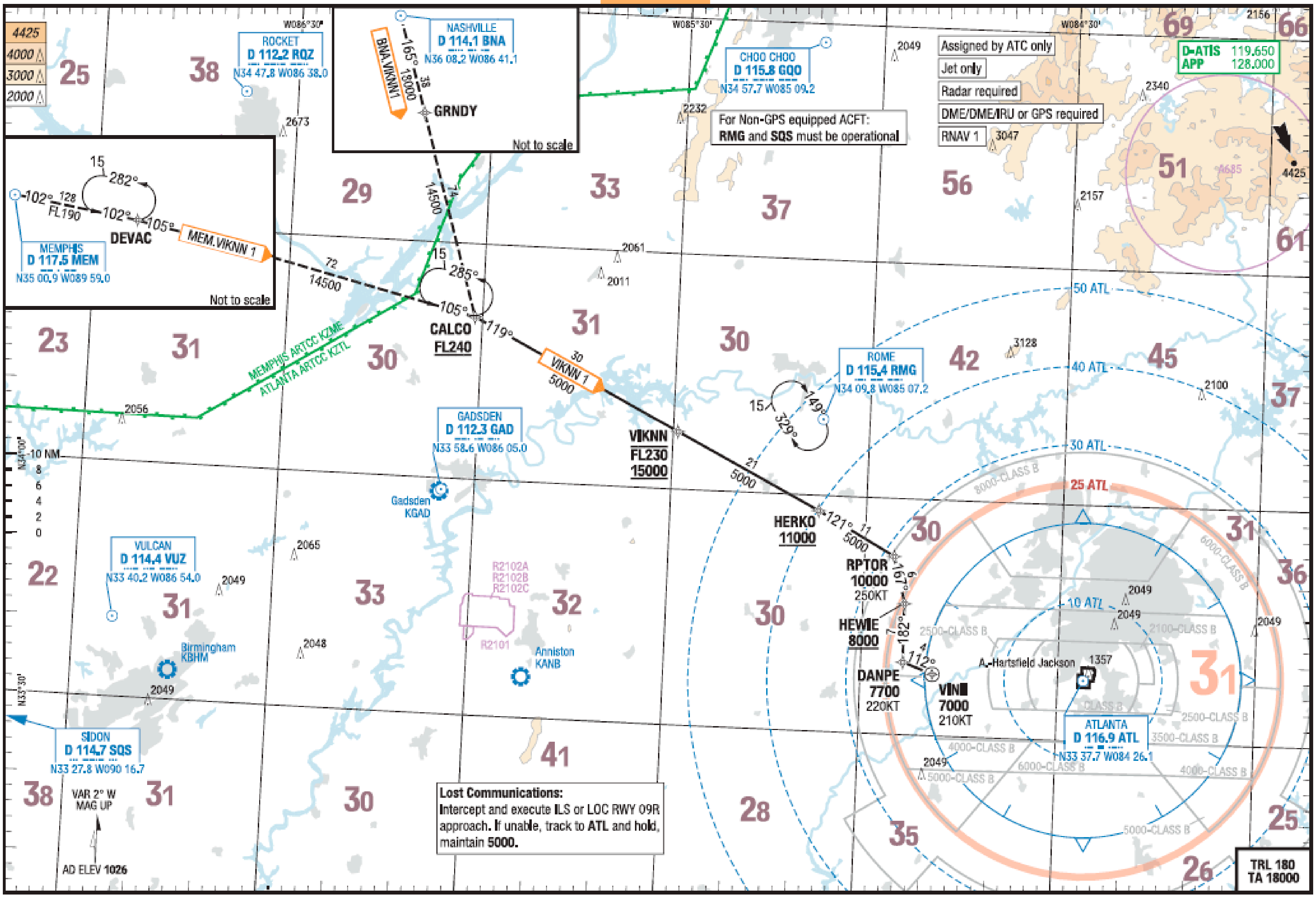


United States **Atlanta** Hartsfield-Jackson Atlanta Int
NIL

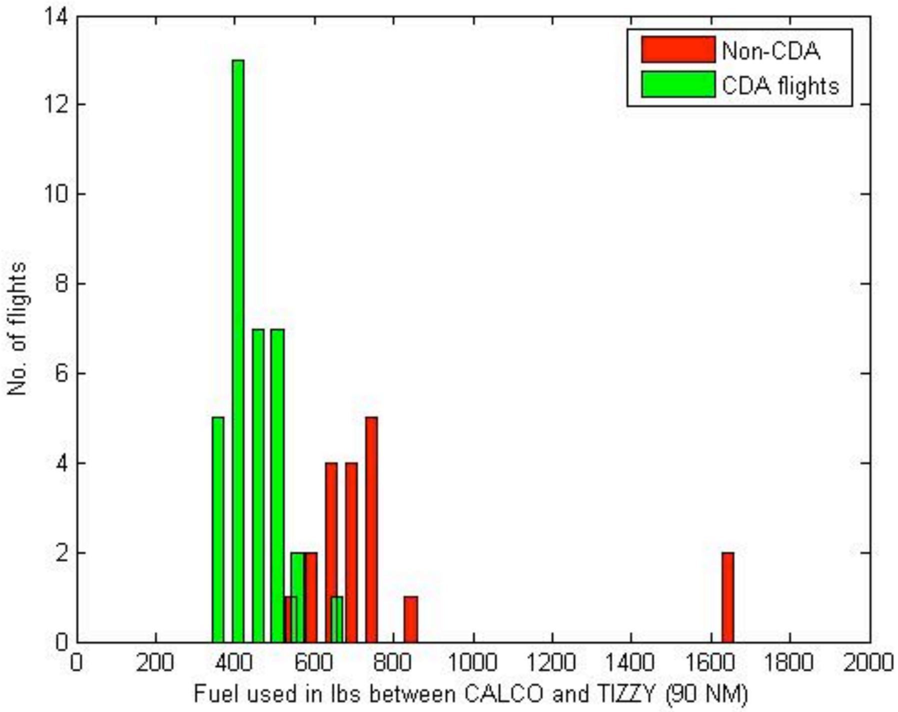
VIKNN 1 RNAV

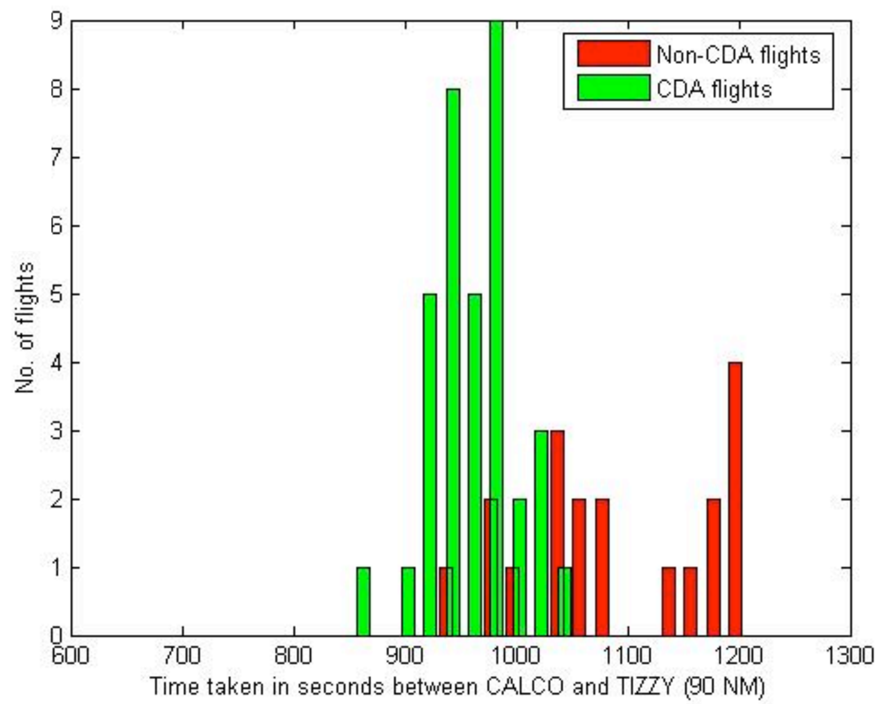
STAR STAR

Hartsfield-Jackson Atlanta Int **Atlanta** United States
NIL
VIKNN 1 RNAV



VIKNN Fuel and Time Savings





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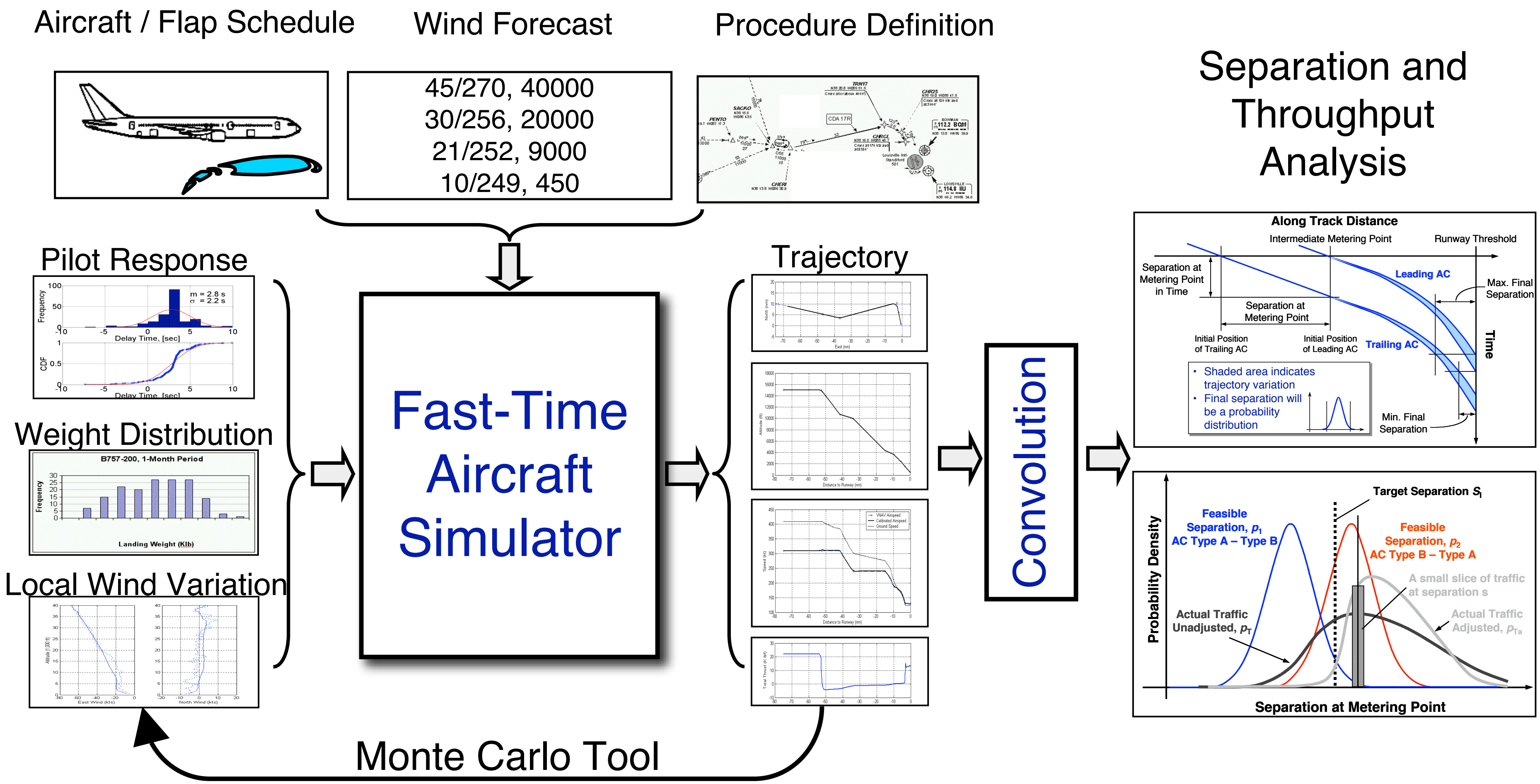
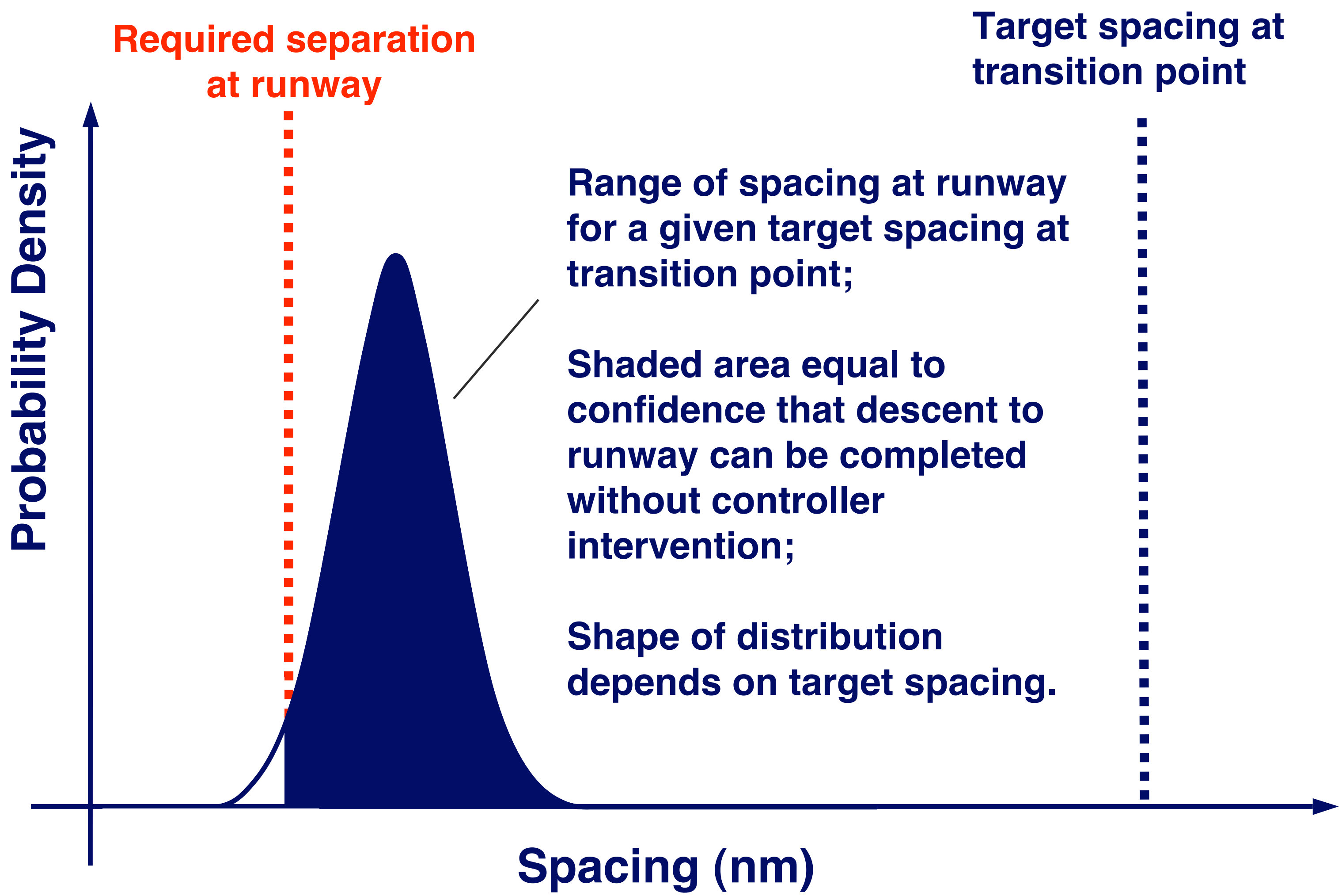
Arrival Flow Management -- Metering the Merge and Descent

Tool for Analysis of Separation and Throughput

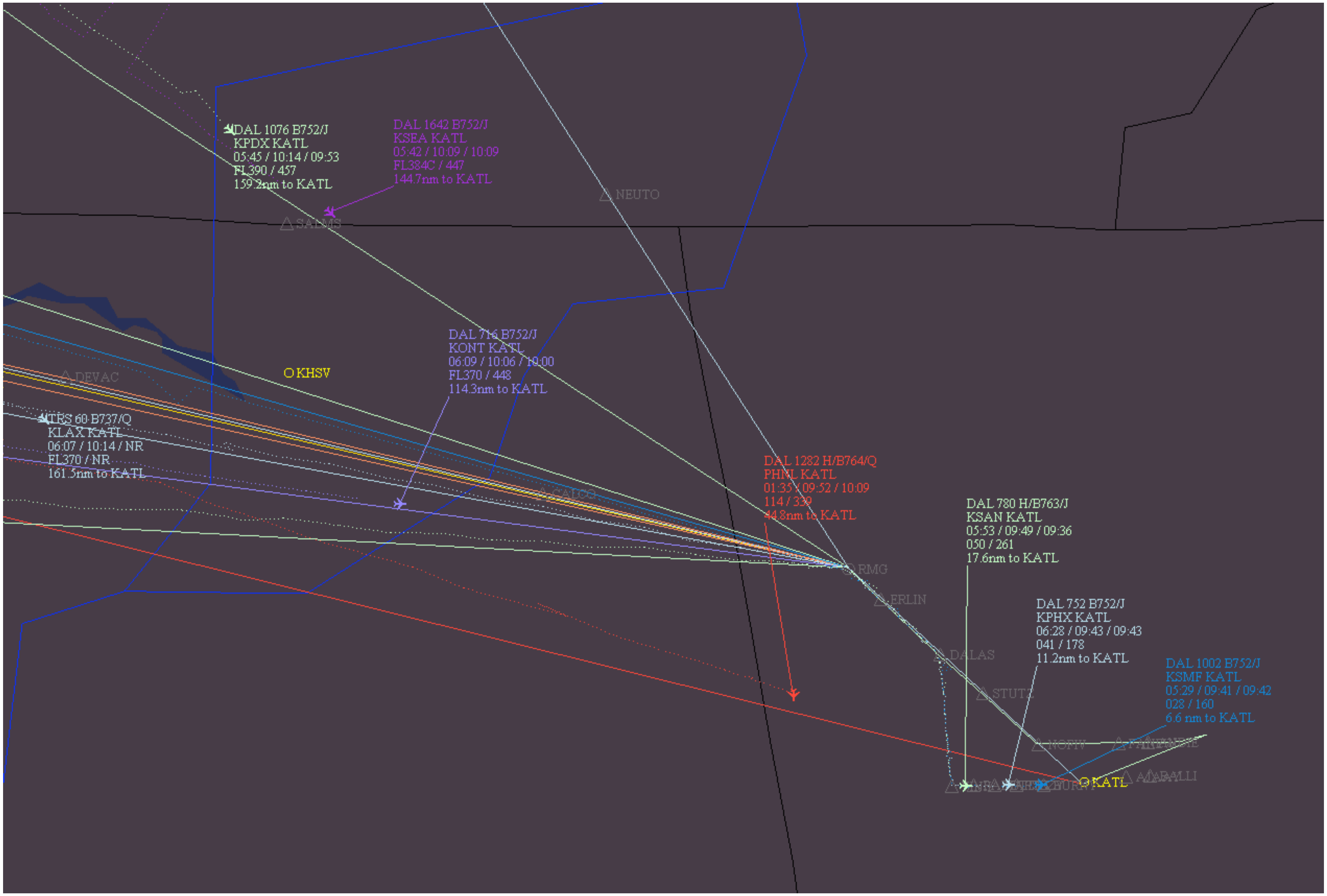


Separation Analysis Methodology

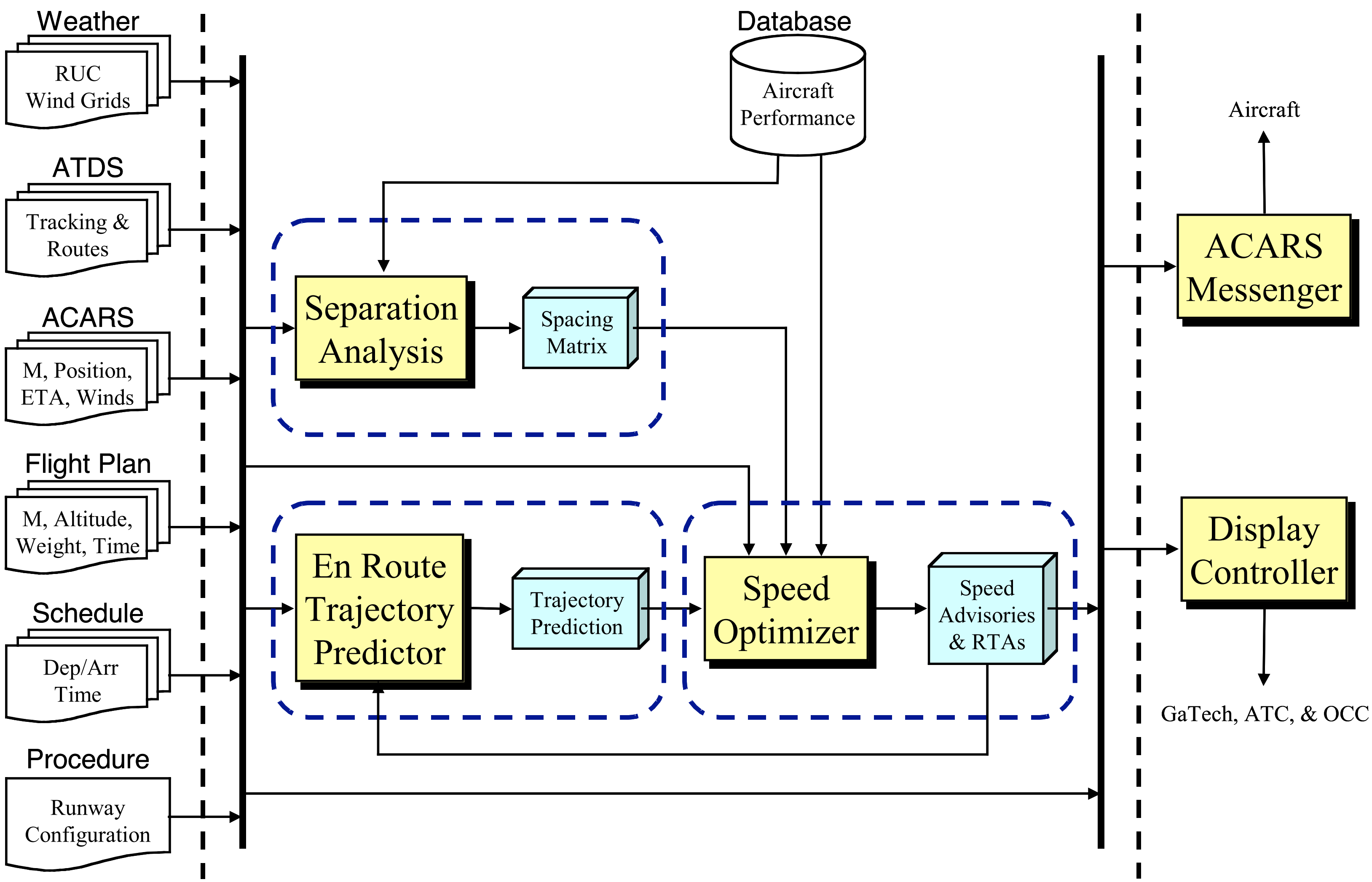
"The direct problem"



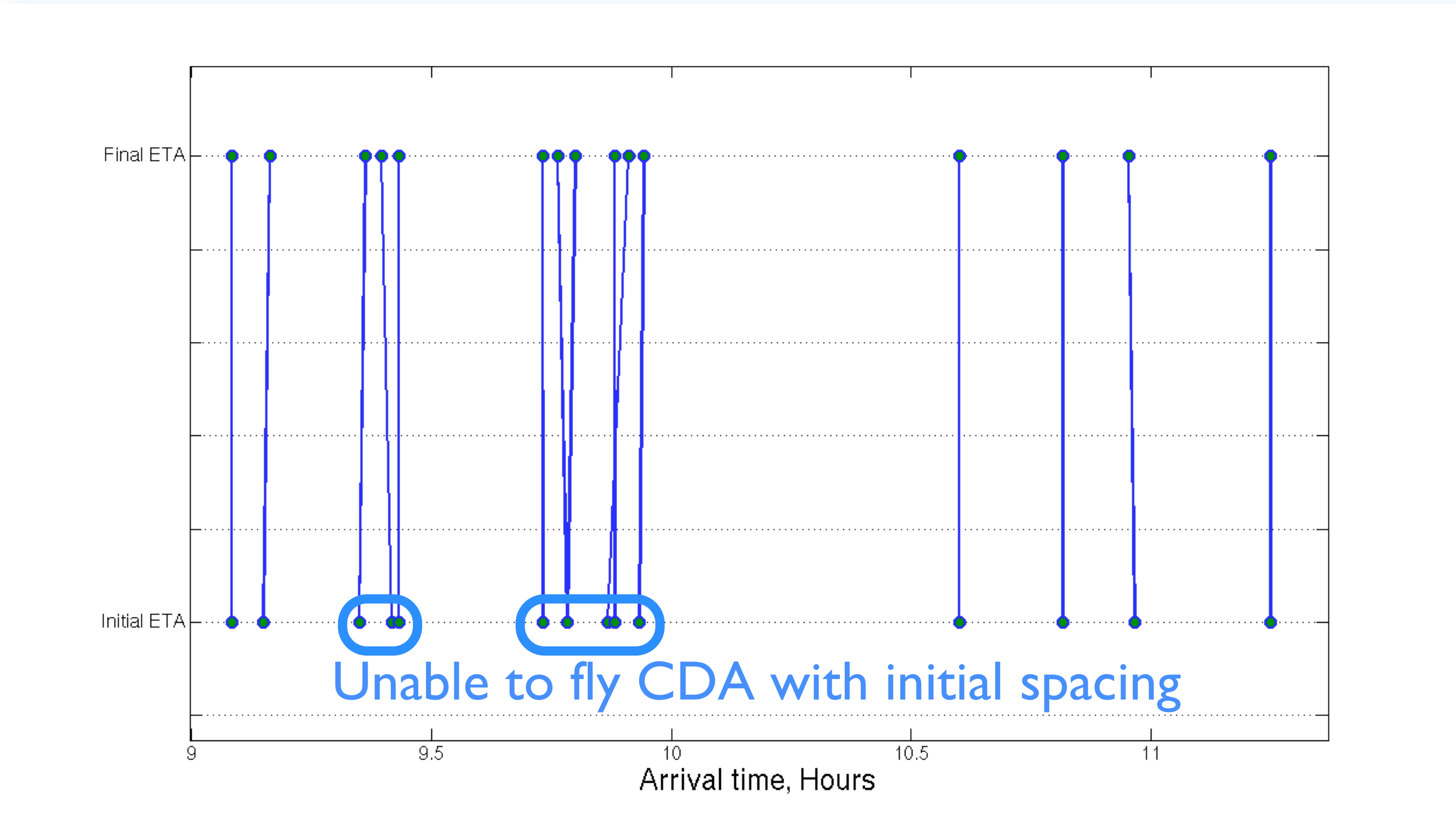
Achieving the Desired Spacing



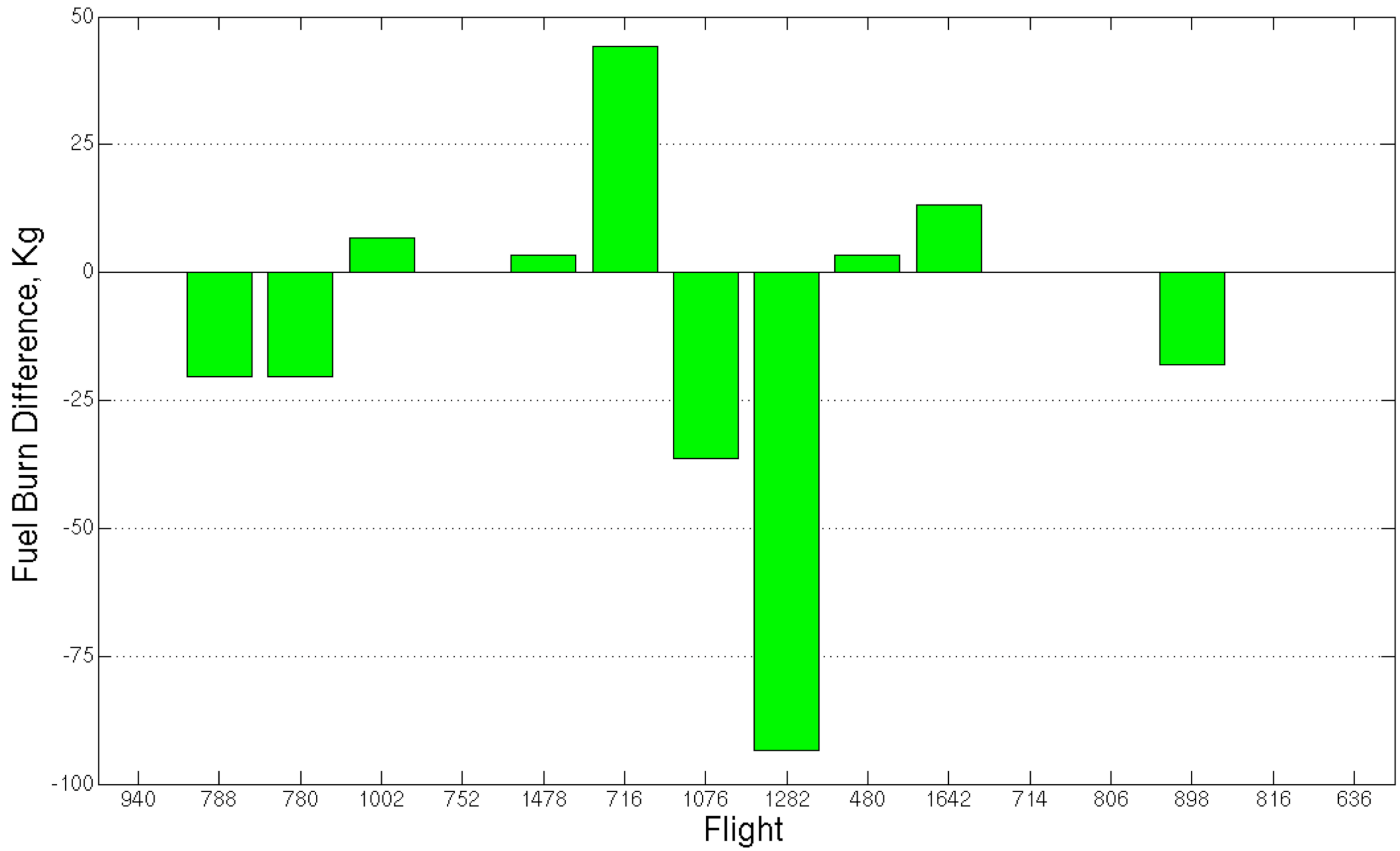
Optimization Overview



Example CDA Scenario (cont'd)



Example CDA Scenario (cont'd)



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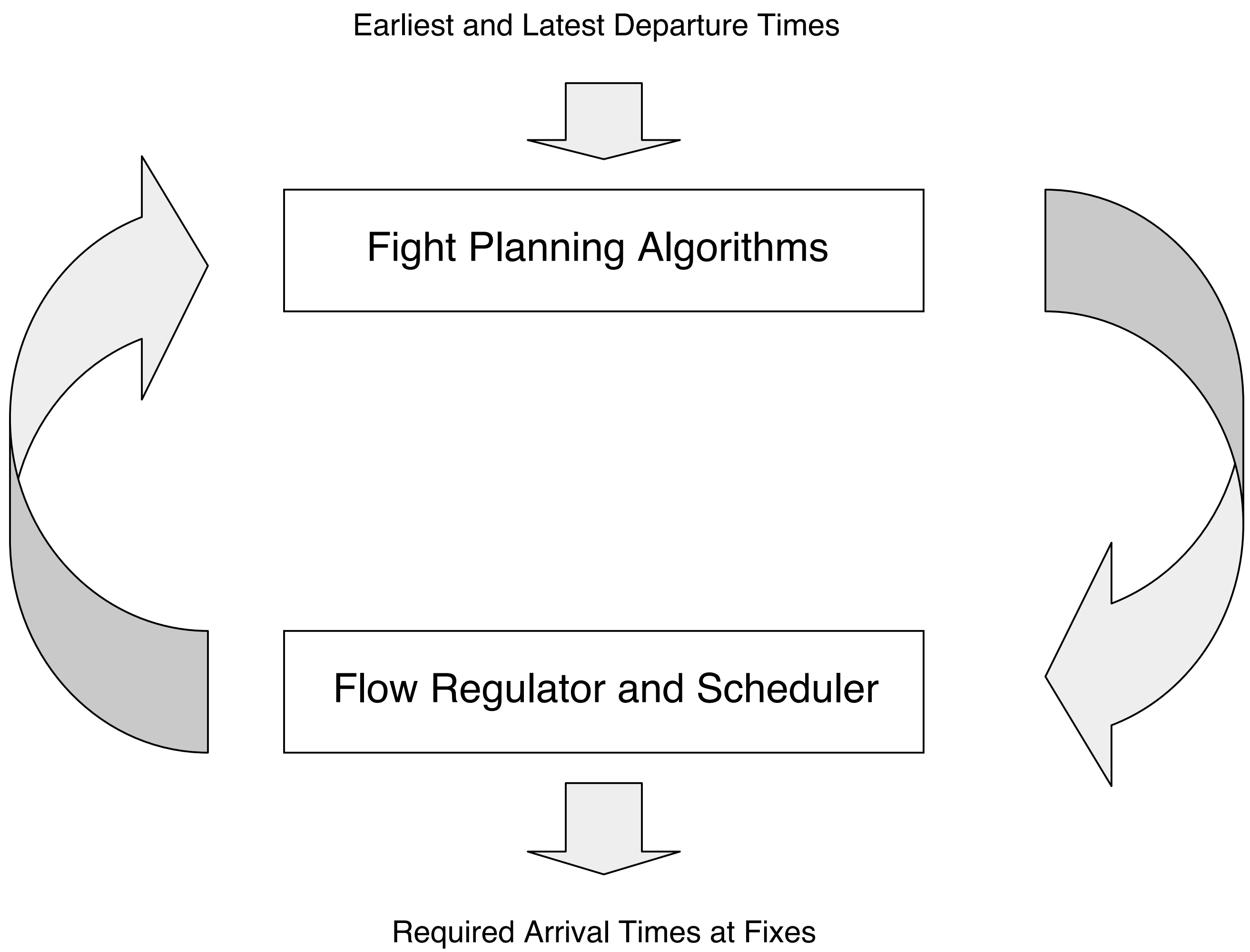
En Route Flow Management -- RTA Scheduling

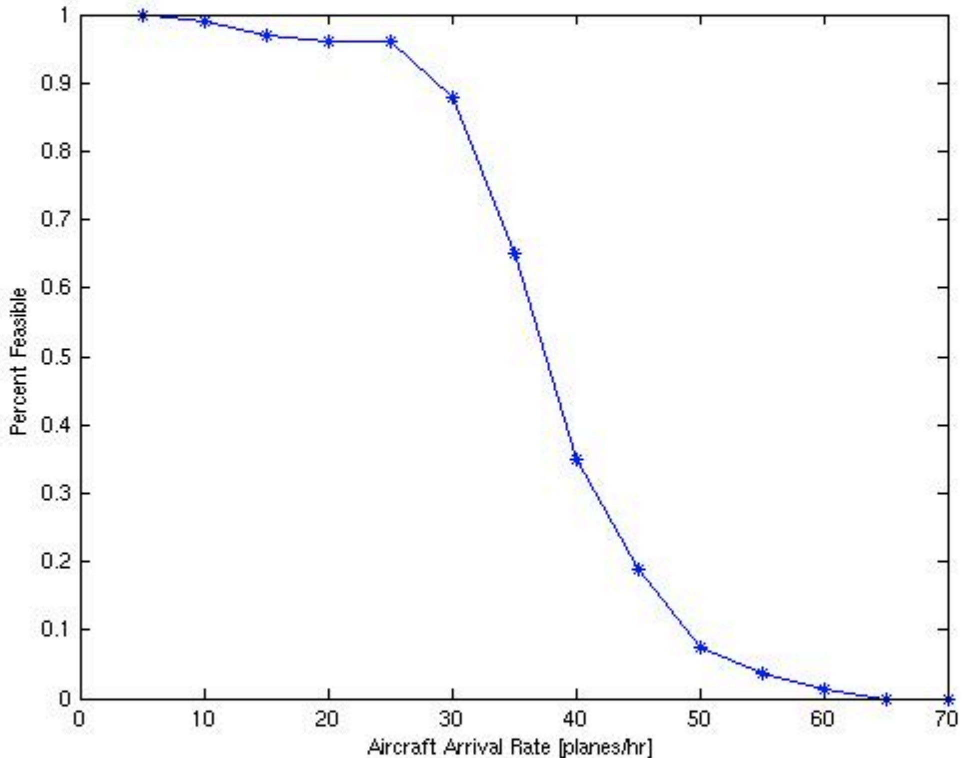
Interactive-Iterative Optimization of Flight Plans



En Route Flow Regulation

- Step 1: Develop set of airspace blockage scenarios for given volume of airspace that are “consistent” with probabilistic convective weather forecast
- Step 2: Develop efficient (fuel-optimal) conflict-resolution algorithm
- Step 3: Derive “probabilistic capacity” over time using Monte Carlo simulation that combines elements of Steps 1 and 2
- Step 4: Determine number of aircraft to send towards volume of airspace using probabilistic capacities and two-stage stochastic program

Stochastic Capacity



P(cap · 10) = 0:01
P(10 < cap · 20) = 0:03
P(20 < cap · 30) = 0:07
P(30 < cap · 40) = 0:54
P(40 < cap · 50) = 0:25
P(50 < cap · 60) = 0:08
P(60 < cap) = 0:02

P(low cap) = 0.04

P(medium cap) = 0.61

P(high cap) = 0.35

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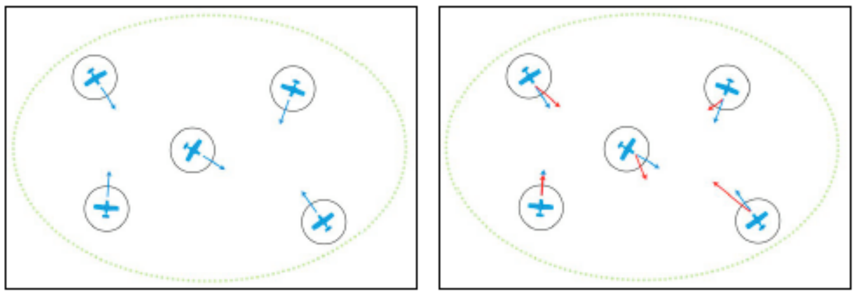
En Route Flow Management -- Resolving Conflicts with Minimum Economic and Environmental Cost

Fuel-Optimal Conflict Resolution

Routing Approach

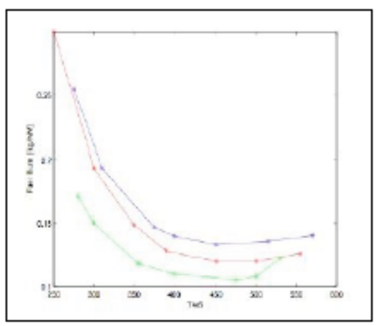
Given an initial set of conditions describing aircraft (position, airspeed, heading) in a region determine the instantaneous optimal rerouting solution to clear the airspace.



Cost Formulation

The cost function is the sum of group fuel burn costs and heading deviations, as well as individual fuel burn and heading costs.

Fuel burn is considered by minimizing fuel burn per unit distance traveled [kg/NM]. Appropriate weighting can be applied to individual planes to account for short or long distance flights.



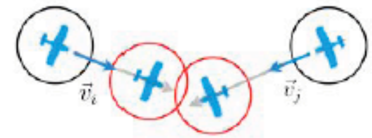
$$f_0 = \underbrace{\sum_{i=0}^{n}[g_{1,i}(||\vec{v}_i||) + g_{2,i}(\theta_i)]}_{\text{Individual Costs}} + \underbrace{||g_1(||\vec{v}||)||_\infty + ||g_2(\theta)||_\infty}_{\text{Group Costs}}$$

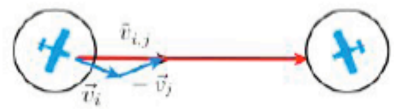
Individual Costs

Group Costs

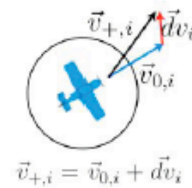
Optimization Methodology

Projecting flight paths forward in time increases complexity of avoidance problem by expanding the number of variables.

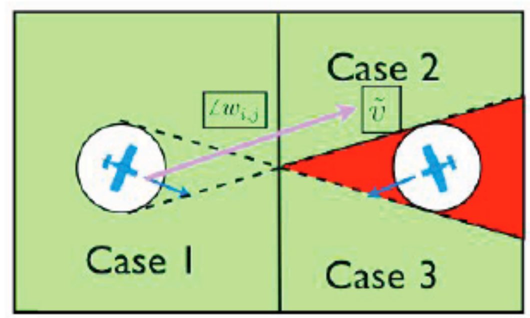




Time variables can be reduced in the problem by projecting the relative velocity between aircrafts to determine conflict

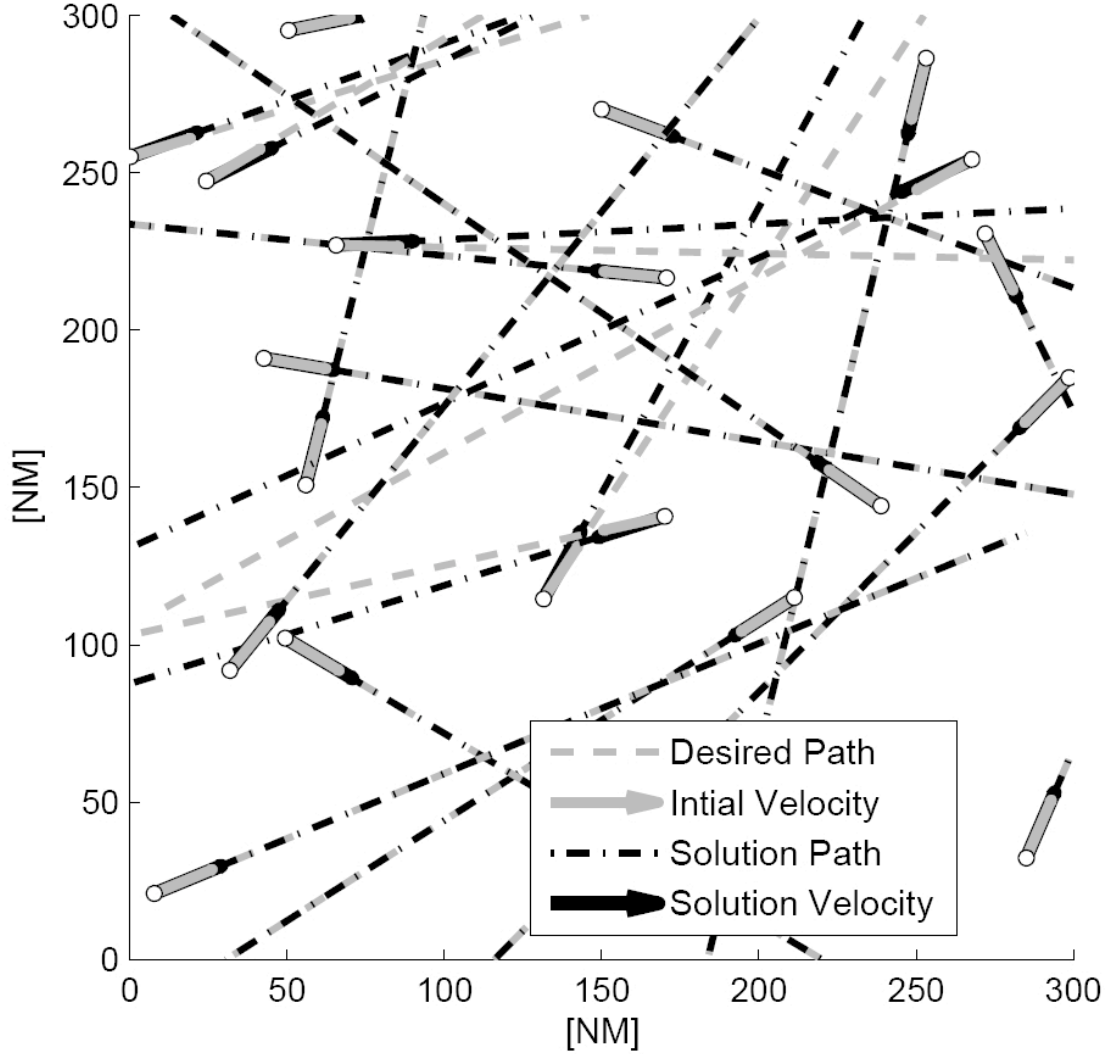


This formulation leads to a mixed integer linear program (MILP), where aircraft velocity and heading variables are defined by vector components.

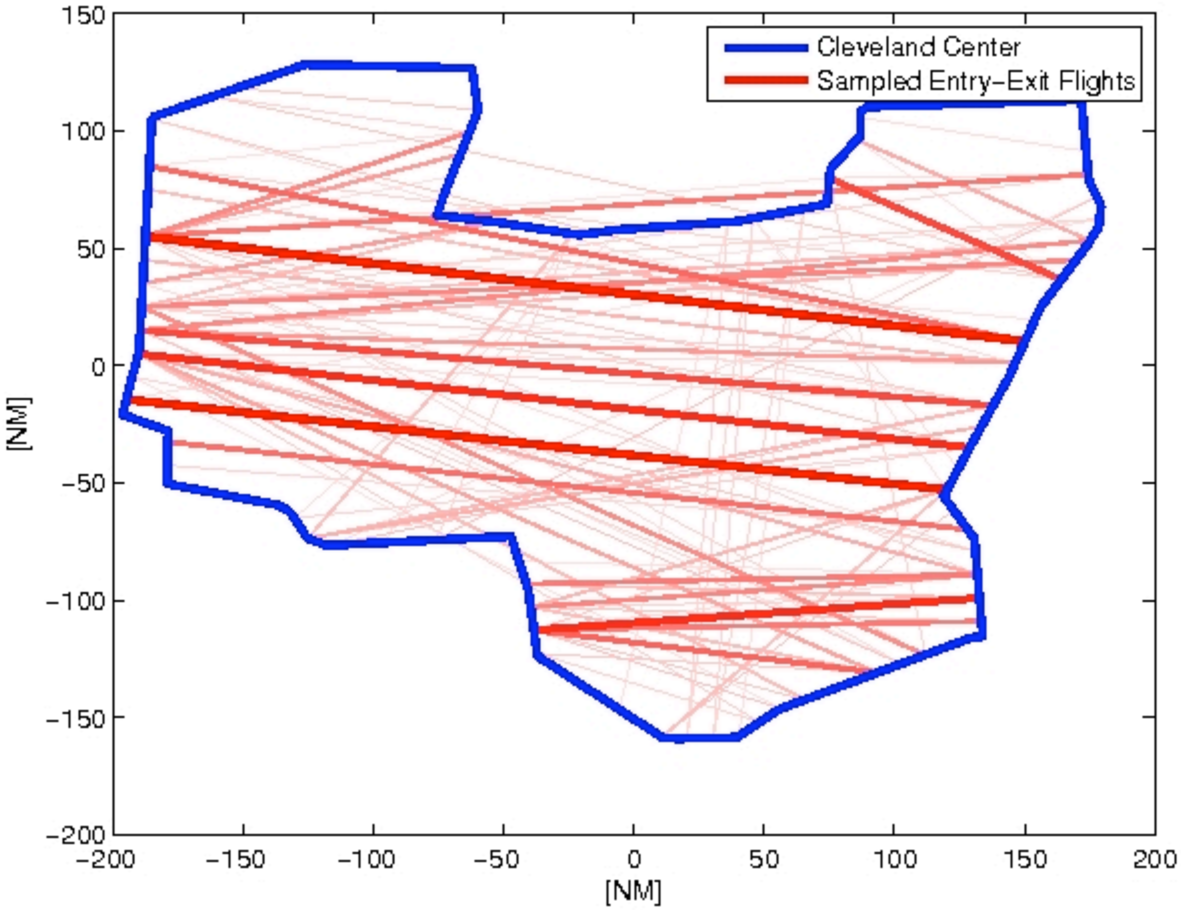


Pair of airplanes generate constraints based on safety regions.

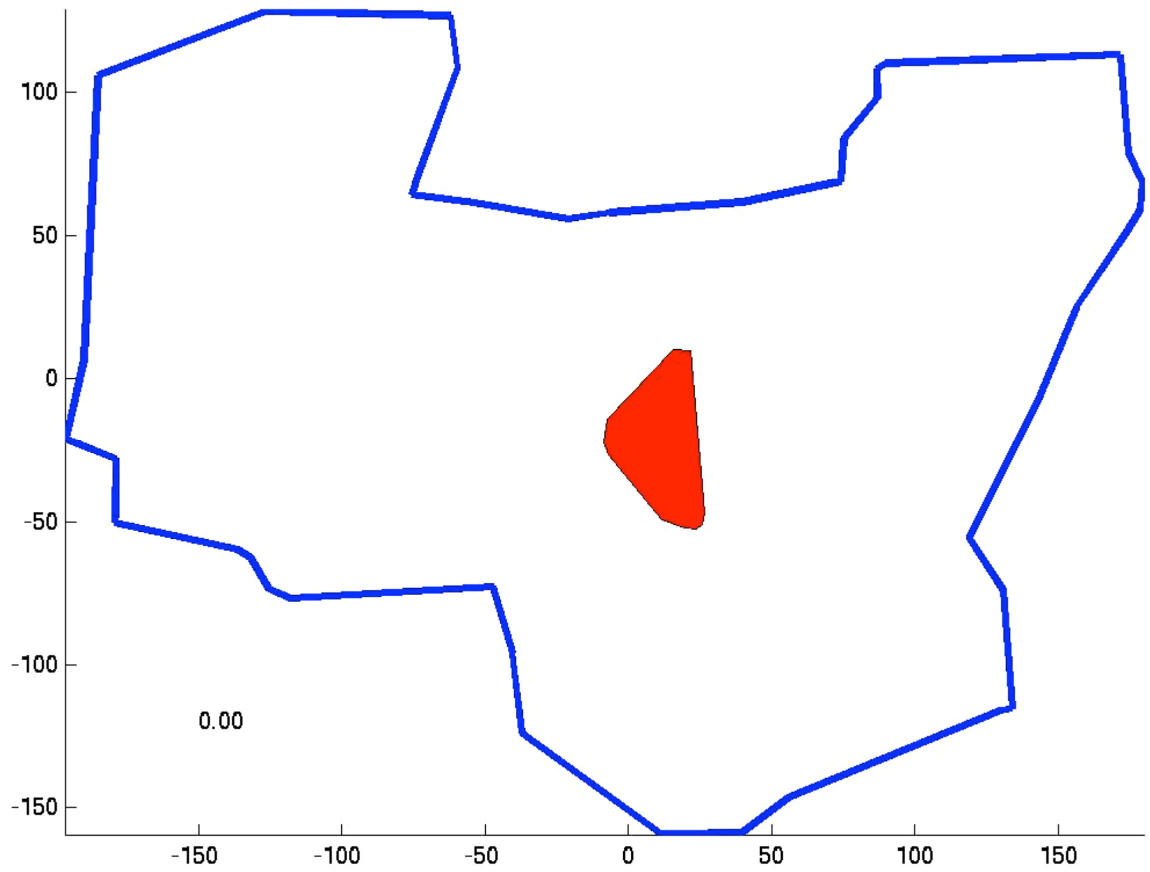
Optimal En Route Heading & Speed Changes



Numerical Example



Numerical Example (cont'd)



Numerical Example (cont’d)

- Possible achieved savings compares results to historical data if aircraft traveled at optimal speeds. Minimum fuel saving is 1.4%, a result of direct routing.
- If historical aircraft traveled at speeds 10% or 15% below optimal speed, the potential savings are 3.37% and 6.13%

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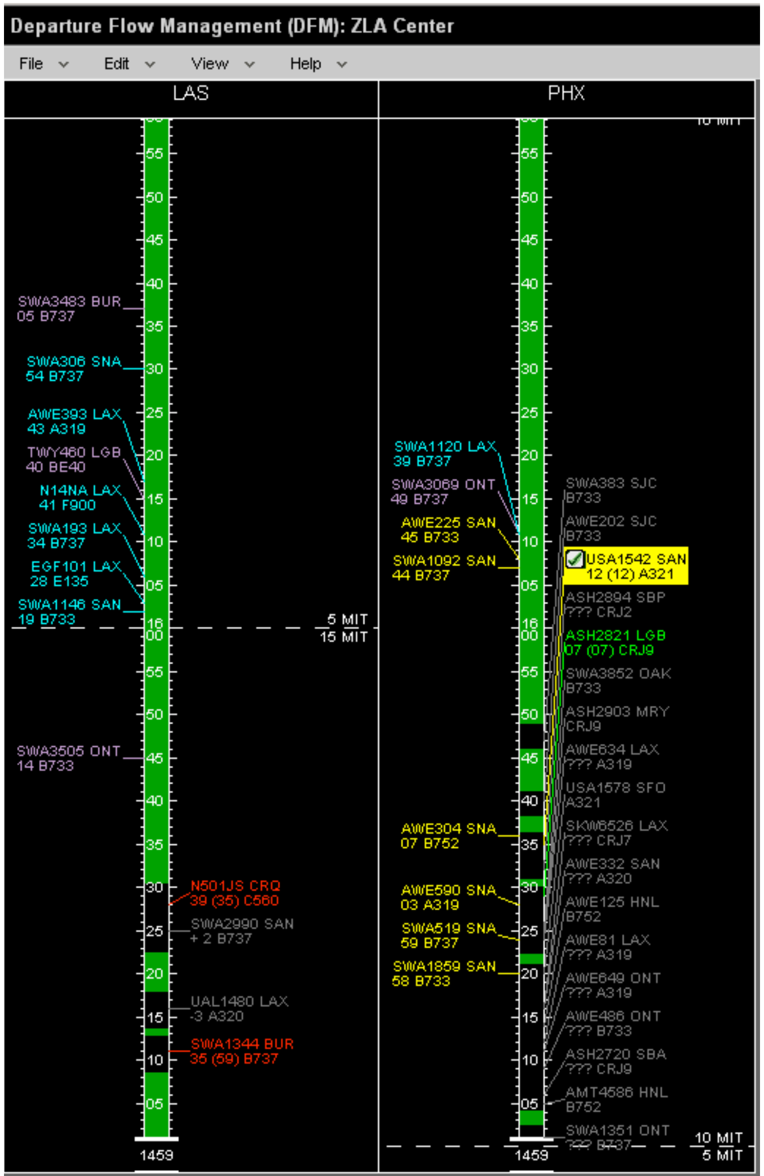
Departure Flow Management -- Managing the Merge and Diverge

Departure Flow Management (DFM)



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DFM Problem Statement

- **PROBLEM - Current air traffic management (ATM) operations provide limited automation capabilities for coordinating departure operations.**
  - Very labor intensive and slow process
  - Process is inflexible as
    - ATCTs only get the time that the TMC provides
    - ATCTs have no knowledge of full range of release time options
    - ATCTs have to repeat the process to adjust their release time when it cannot be met

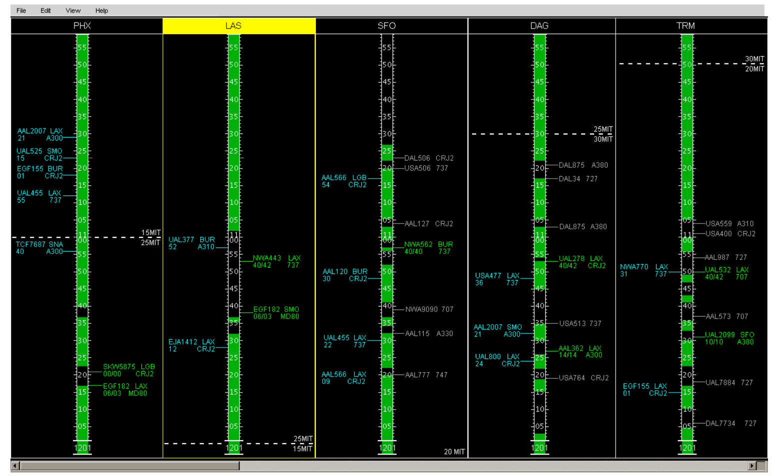
- **SOLUTION – Initial Build of DFM is a web-based capability that automates the APREQ release process**
  - Automated process with connectivity to all Towers
  - Provides timelines of available release times to the Towers

DFM Solution

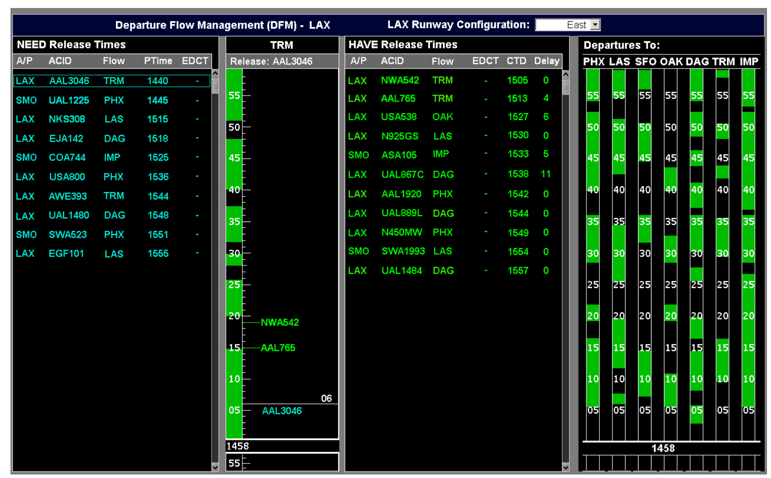
SOLUTION – Initial Build of DFM is a web-based capability that automates the APREQ release process

❖ How it works (high-level)

- The ARTCC TMC creates FEAs using a TSD to define the flows they need to monitor
- The ARTCC TMC enters restrictions on the flows using the DFM web application
- DFM queries TFMS for the FEA flight list and entry times
- DFM identifies all gaps in the restricted flow and presents a timeline for the TMC to monitor
- When a pilot calls for taxi, the ATCT looks for the flight on their DFM web application
- If the flight is restricted, DFM shows all of the available release times for the flight
- The ATCT selects the desired release time
- DFM assigns the flight to the first available release time at or after the desired time and sends this

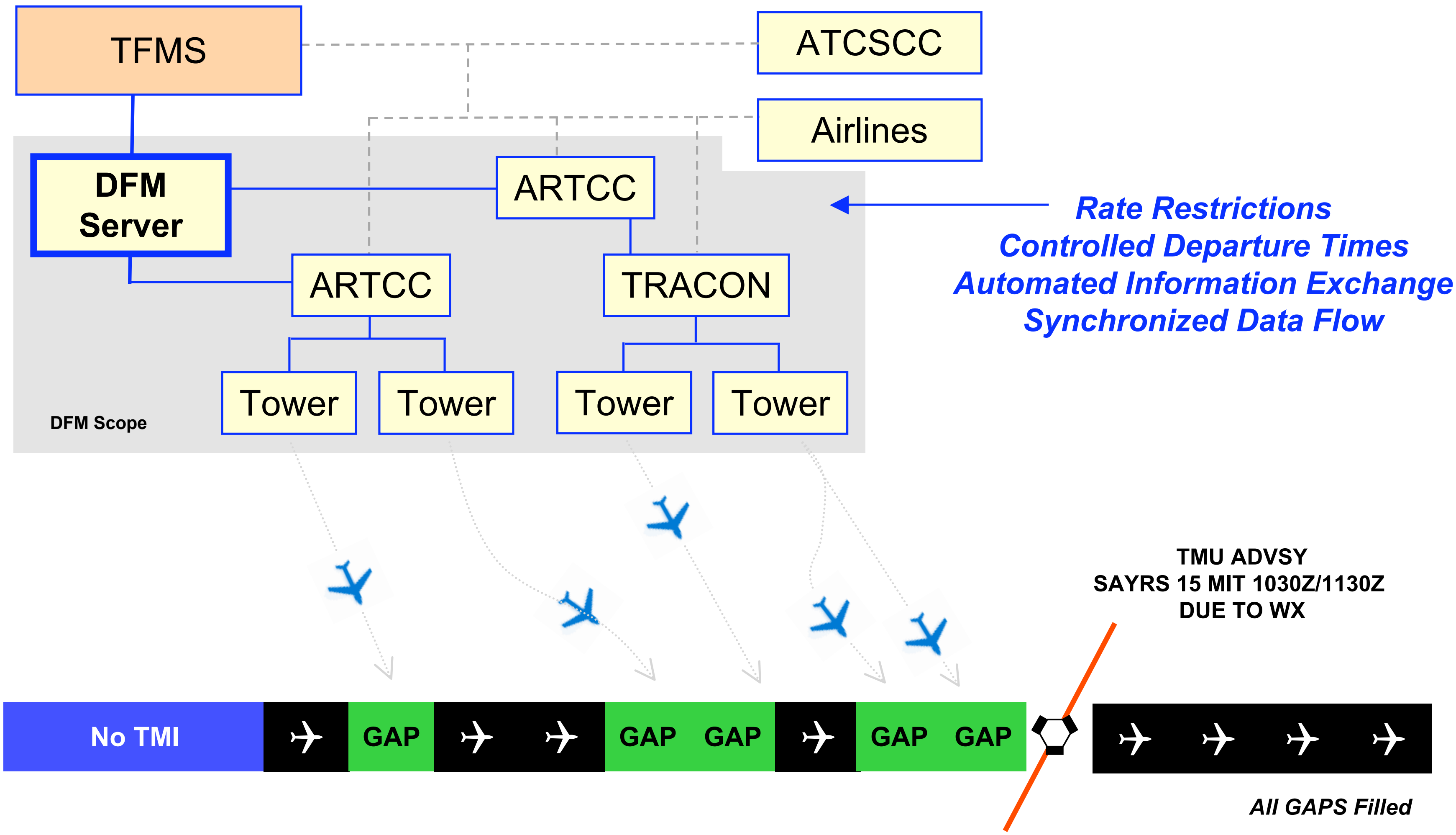


Center Browser Display



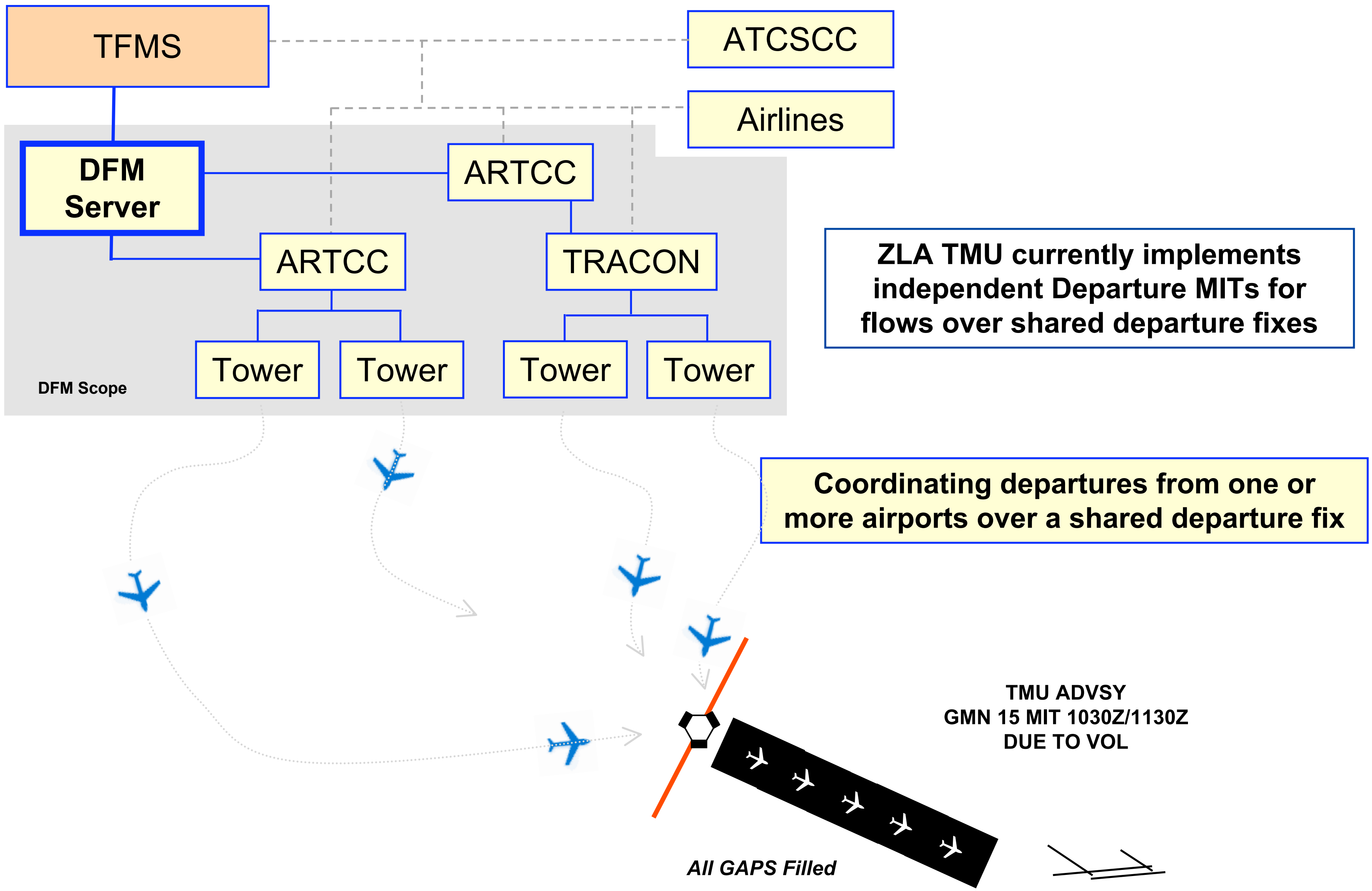
Tower Browser Display

ZOB Scenario



Merging departures into congested overhead flows, particularly flows subject to MIT restrictions

ZLA Scenario



DFM Assignment of Release Times

Increased Automation

- **Current Call for Release (CFR) Process**
  - Similar to TMA and EDC Paradigm
  - Phone call to Center
  - Assignment by the Center using DFM
- **Manual Approval Mode**
  - Electronic version of current CFR process
  - Phone call to Center eliminated
- **Automatic Approval Mode**
  - Towers assign their own release times
  - Center monitors times
- **TFDM**
  - Time assigned by A/DMT

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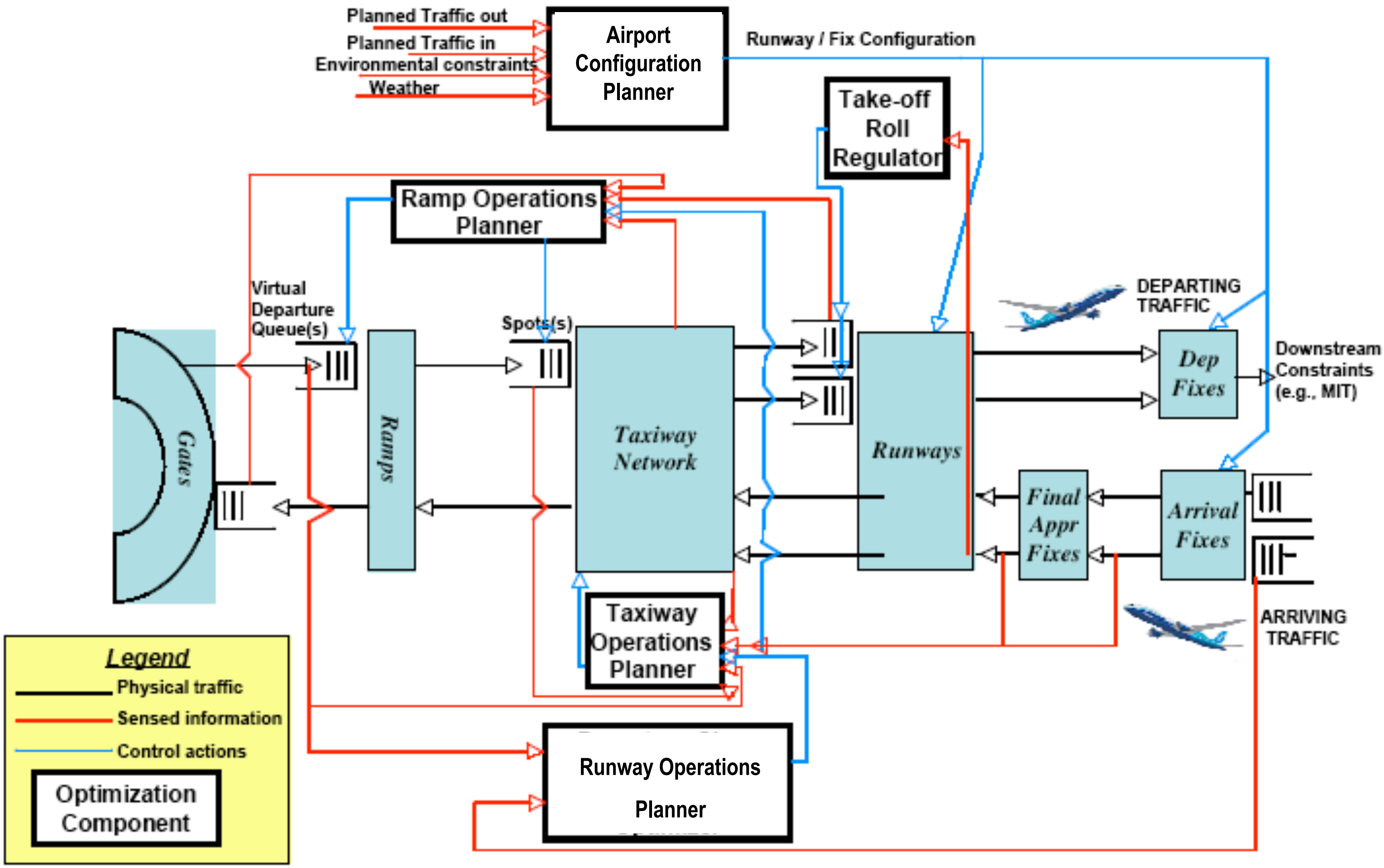
Surface Flow Management

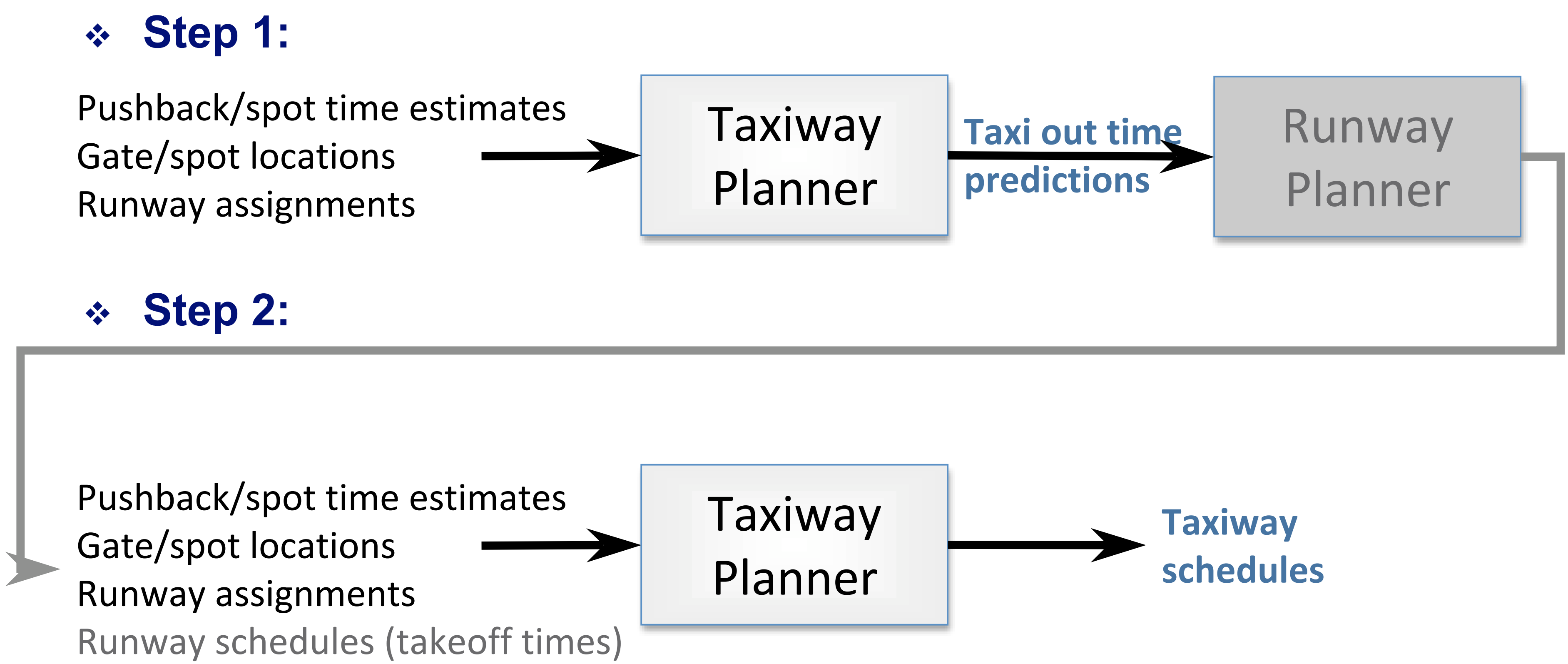
Preliminary Architecture



Runway Operations Planner

	Deterministic Tradeoff Model	Stochastic Two-Stage Model
One runway	**Single-Runway Deterministic Tradeoff Model**	**Single-Runway Stochastic Two-Stage Model**
More than one Runway	**Two-Runway Deterministic Tradeoff Model**	**Multi-Runway Stochastic Two-Stage Model**

Taxiway Operations Planner



Ramp Operations Planner