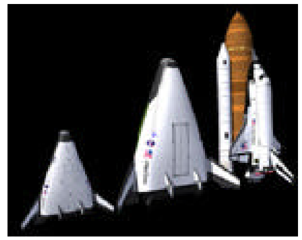
Integration of Reusable Launch Vehicles (RLV) into the Air Traffic Management System



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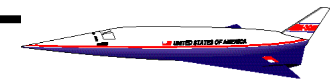
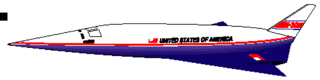


Motivation

- Current mode of airspace utilization for space operations
  - Activate Special Use Airspace (SUA), reroute air traffic
  - Large spatial and temporal safety buffers
  - Limited flexibility
  - Disparity between air and space user costs
- Improvements in sensors & datalink capabilities
  - Potential to reduce uncertainty of some vehicle trajectories
  - More efficient information flow between ATC - space operator
  - Example: launch delay of STS-87 (with John Glenn) due to intruding GA aircraft
- Advanced ATM models could streamline the integration of RLVs with ATC



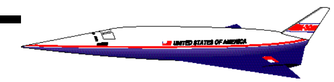
Opportunities and Key Issues

- Some vehicle types / missions might be integrated with air traffic
  - Reusable Launch Vehicles with conventional phases of flight
- Key Research Issues

1) What is required for integrated operations to occur?
   Equipage, communications, surveillance requirements

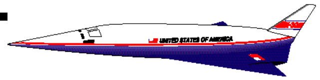
2) How should those operations be carried out?
   Flow management procedures

3) What are the user & service provider cost / benefit trade-offs?



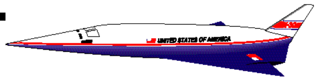
Scope of Work

- Investigate current and future methods of RLV-aircraft separation in use at the Special Use Airspace (SUA) areas around the US Launch Ranges (Cape Canaveral, Vandenberg AFB, and Wallops AFB)
- Identify mission profiles of the proposed RLVs and characteristics of the respective phases of flight
- Develop a generalized model of airspace / air traffic / RLV operations to provide a consistent framework to describe and evaluate options
- Define potential modes of operation / airspace utilization for RLV operations by understanding current requirements and procedures, and explore possible alternatives
- Develop a methodology to estimate RLV operation impacts



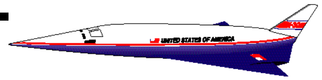
Summary of Previous Activities

- Collected data on proposed RLVs
- Surveyed typical phases of flight / mission profiles
- Identified 8 potential modes of operation
  - Continue use of SUA (strategic segregation)
  - Activate new SUA
  - Mission-specific SUA
  - Controlled Space Activity Zone (c.f. Class B airspace)
  - RLV corridor
  - RLV as high-priority vehicle (vectors)
  - RLV as nominal-priority vehicle
  - Self-separation

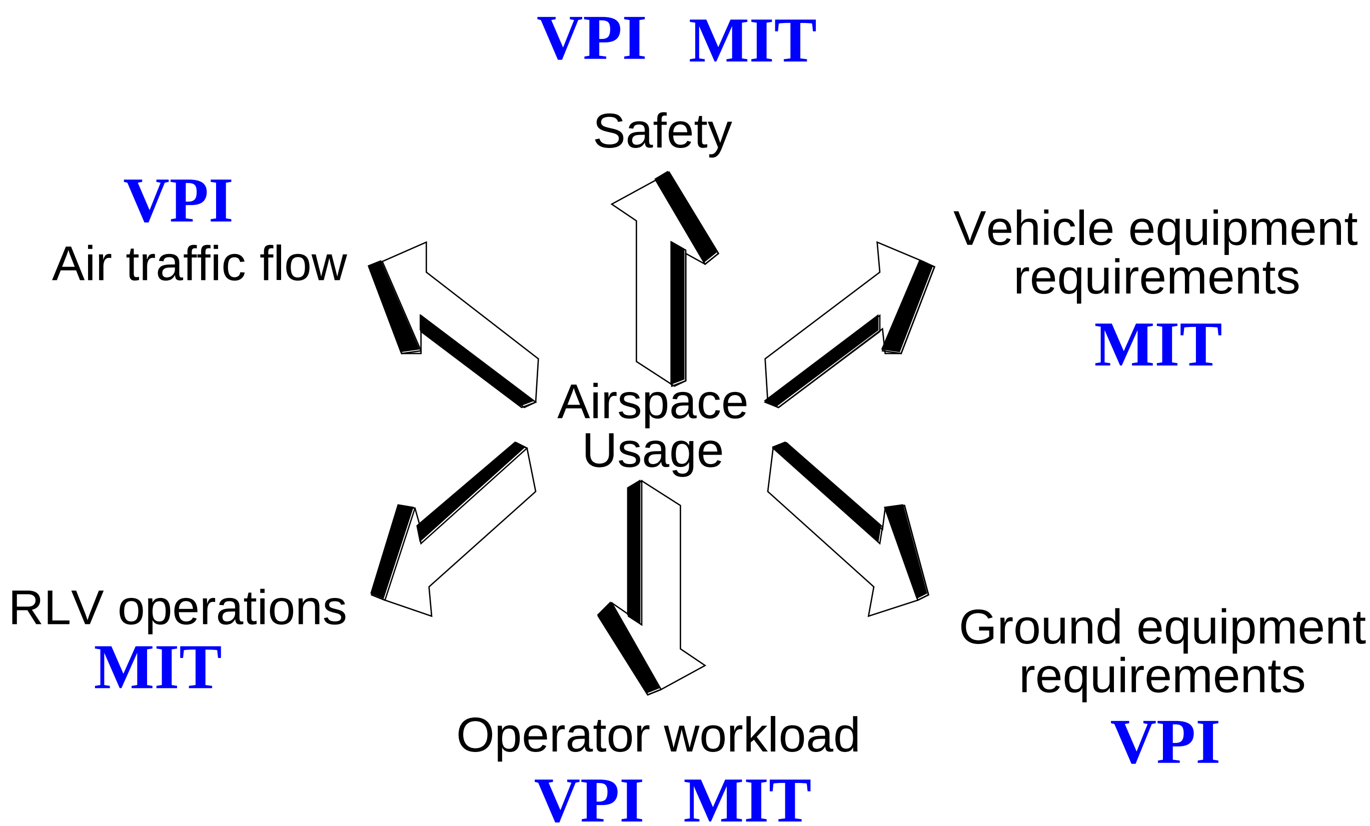


Phase II Activities

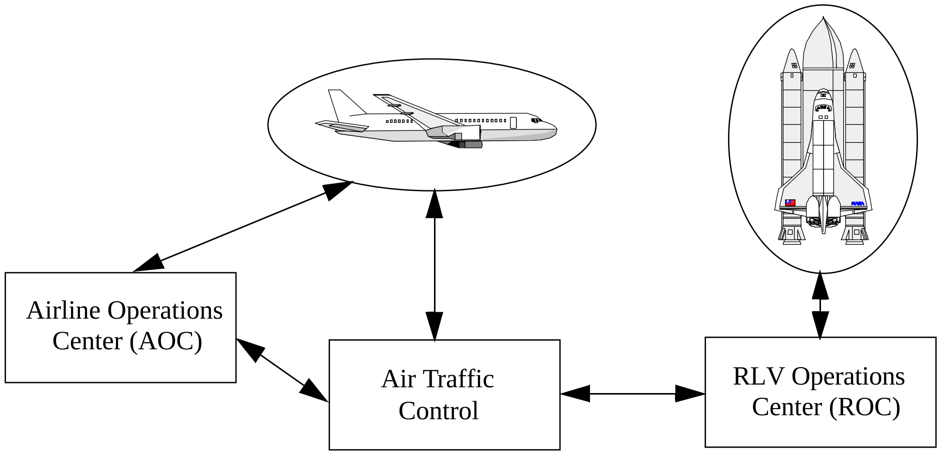
- Investigate trade-offs in tactical modes of operation
  - Appropriate safety buffer size and duration
  - Equipage and procedural requirements
  - Explore limits of tactical ATC vectors (heading / altitude / speed)
  - Ability to manage high speeds / vertical rates
  - Display / procedure / control issues
- Preliminary model development
  - Describe when SUA vs. Tactical operation can/should be used
  - Impact of state uncertainties, vehicle profile & performance
  - Airspace conflict and sector analysis models
  - Airspace planning model development and validation



RLV Airspace Usage Implications



RLV Operation Modes



Current Operational Mode

a) Strategic

b) Large SUA

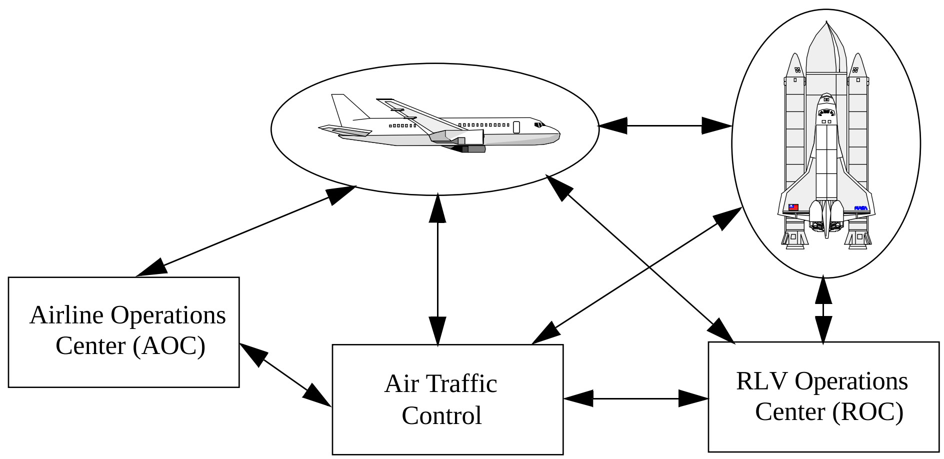
c) Indirect integration

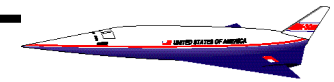
Future Operational Modes

a) Tactical

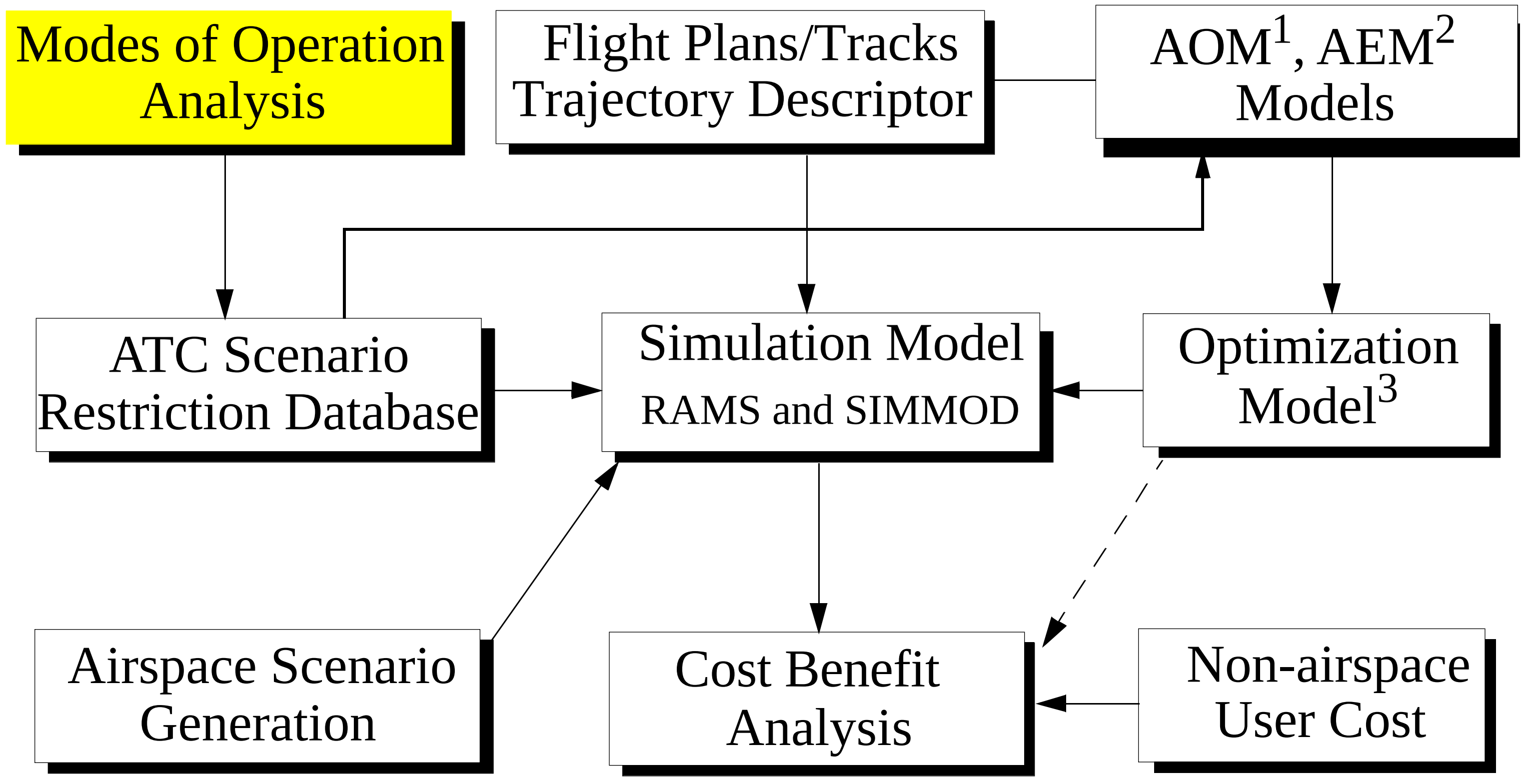
b) Smaller SUA

c) Direct integration



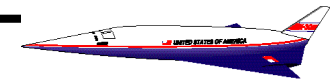


Framework to Model RLV Impacts



[1] AOM = Airspace Occupancy Model
[2] AEM = Aircraft Encounter Model

[3]Airspace Planning Model



NEXT OR/MITRE Relationship

MITRE (Looking at current operational practices)

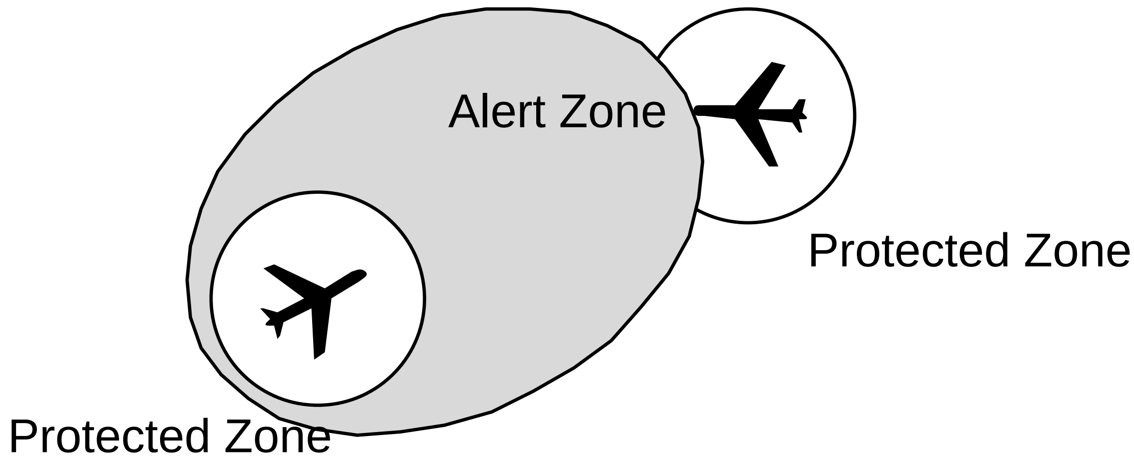
- Quantified operational cost for two launches from CCAS using actual traffic data and perceived delays
- Same approach to evaluate Kodiak Island operations

NEXTOR (Studying future operational practices)

- Identified possible tactical separation envelopes and SUA regions
- Modeling generic size spaceports (Phase III) using simulation tools
- Quantifying costs for future *Free Flight* conditions
- Minimizing detour impacts (optimization model)

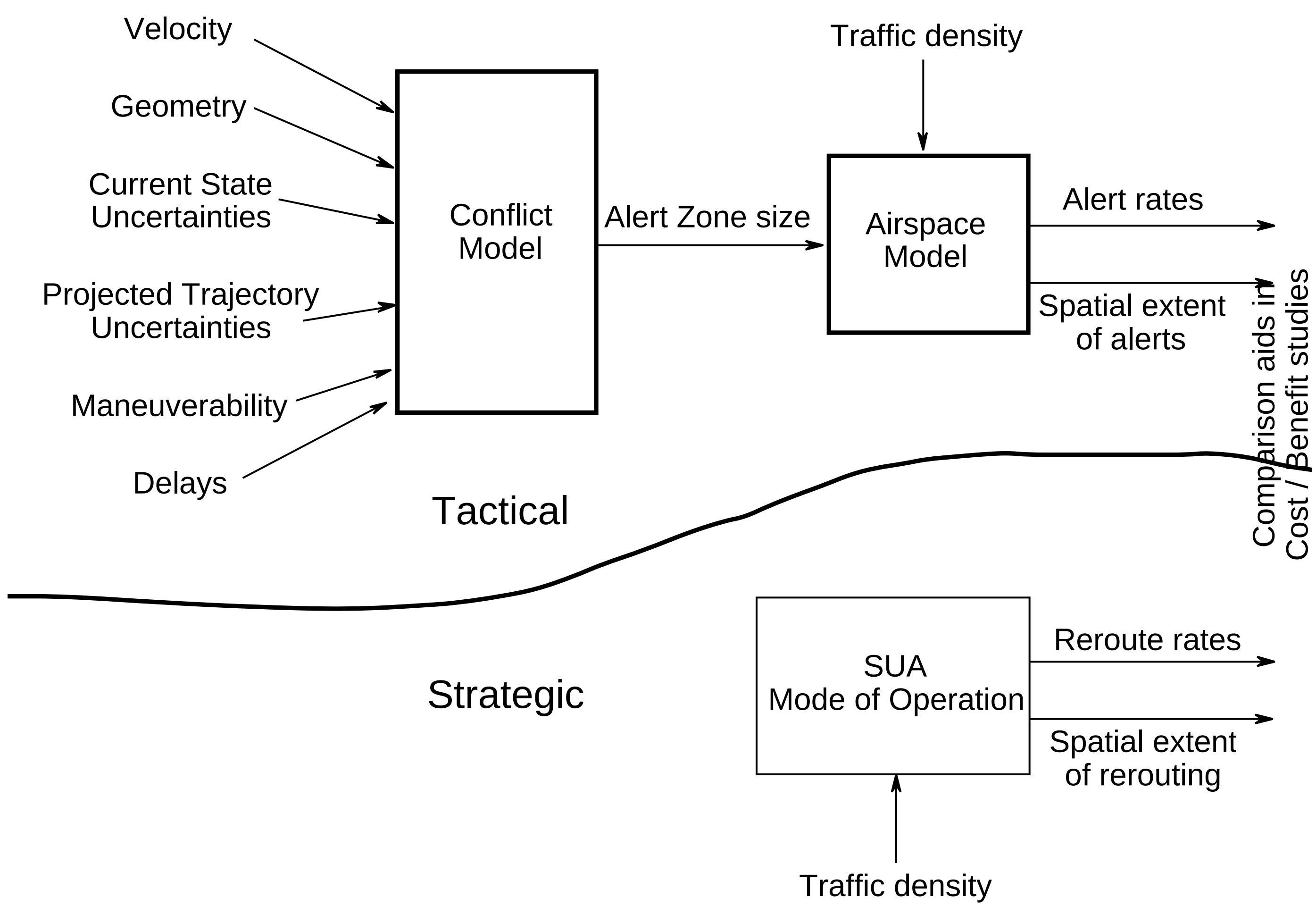
Conflict Detection and Resolution

- Protected Zone: safety buffer around each vehicle
  - Aircraft: 5 nmi, ± 1000 or 2000 ft.
- Alert Zone: Space in which action must be taken to prevent PZ violation

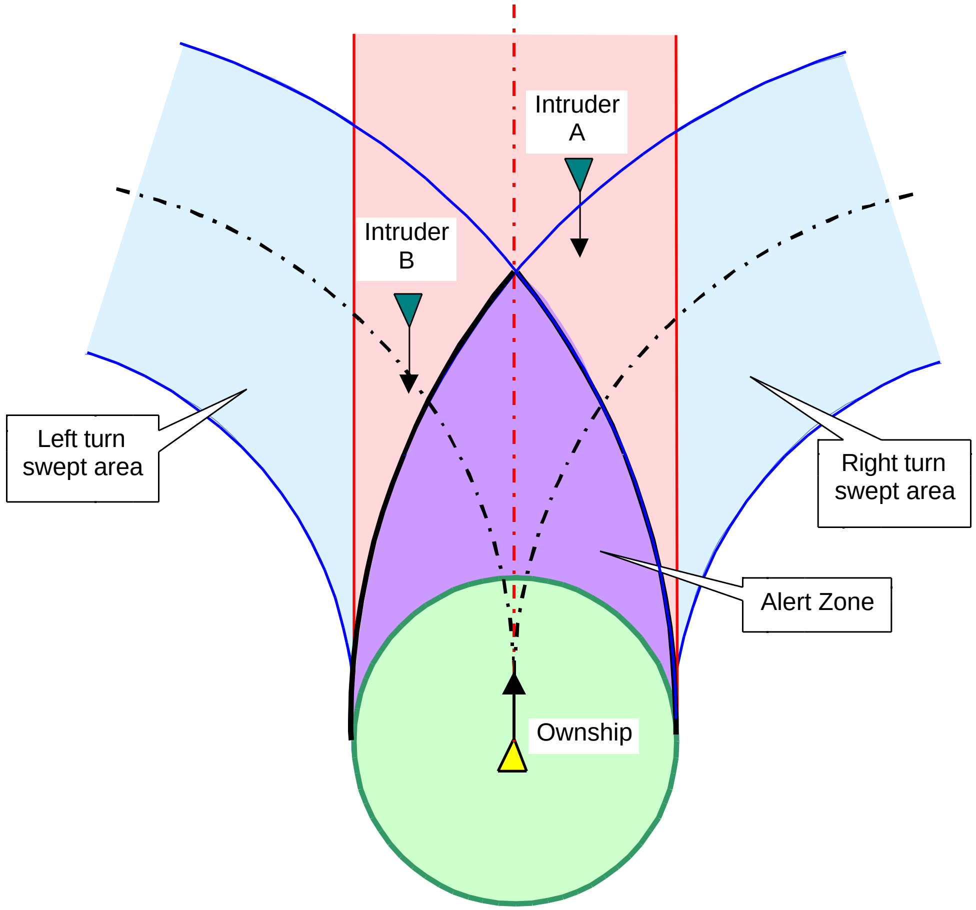


- As Alert Zone size increases, SUA becomes more attractive

Tactical/Strategic Conflict Evaluation



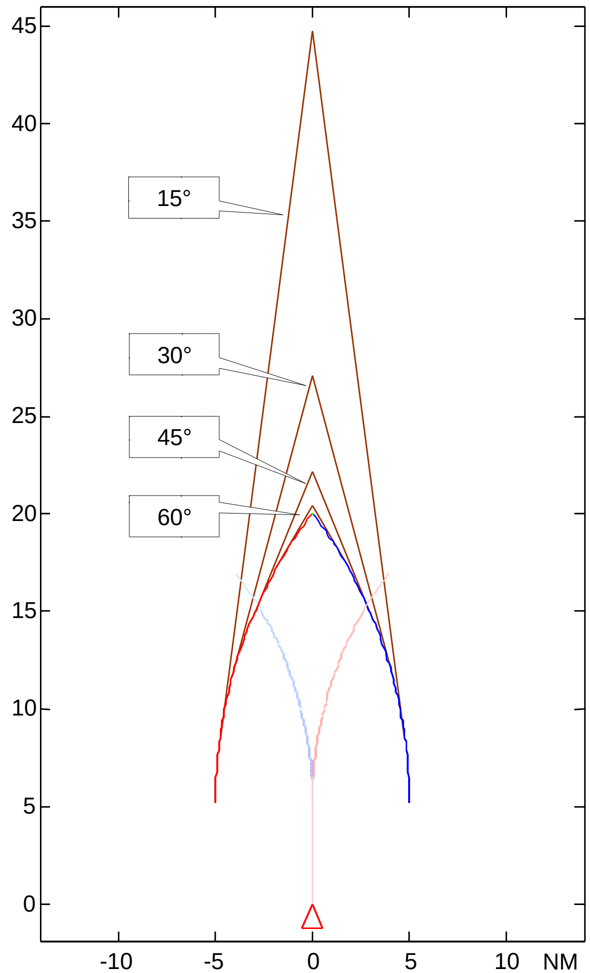
Simplified Tactical Alert Zone Model



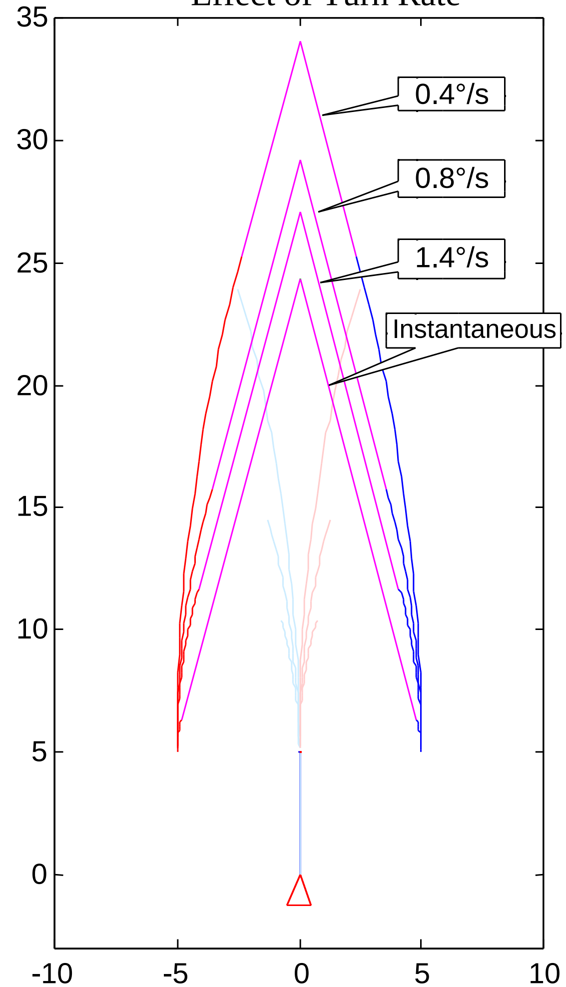
Enables first-order tradeoff analysis (uncertainty vs. AZ)

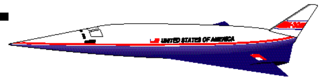
Example Preliminary Trade Studies

Effect of Maximum Turning Angle

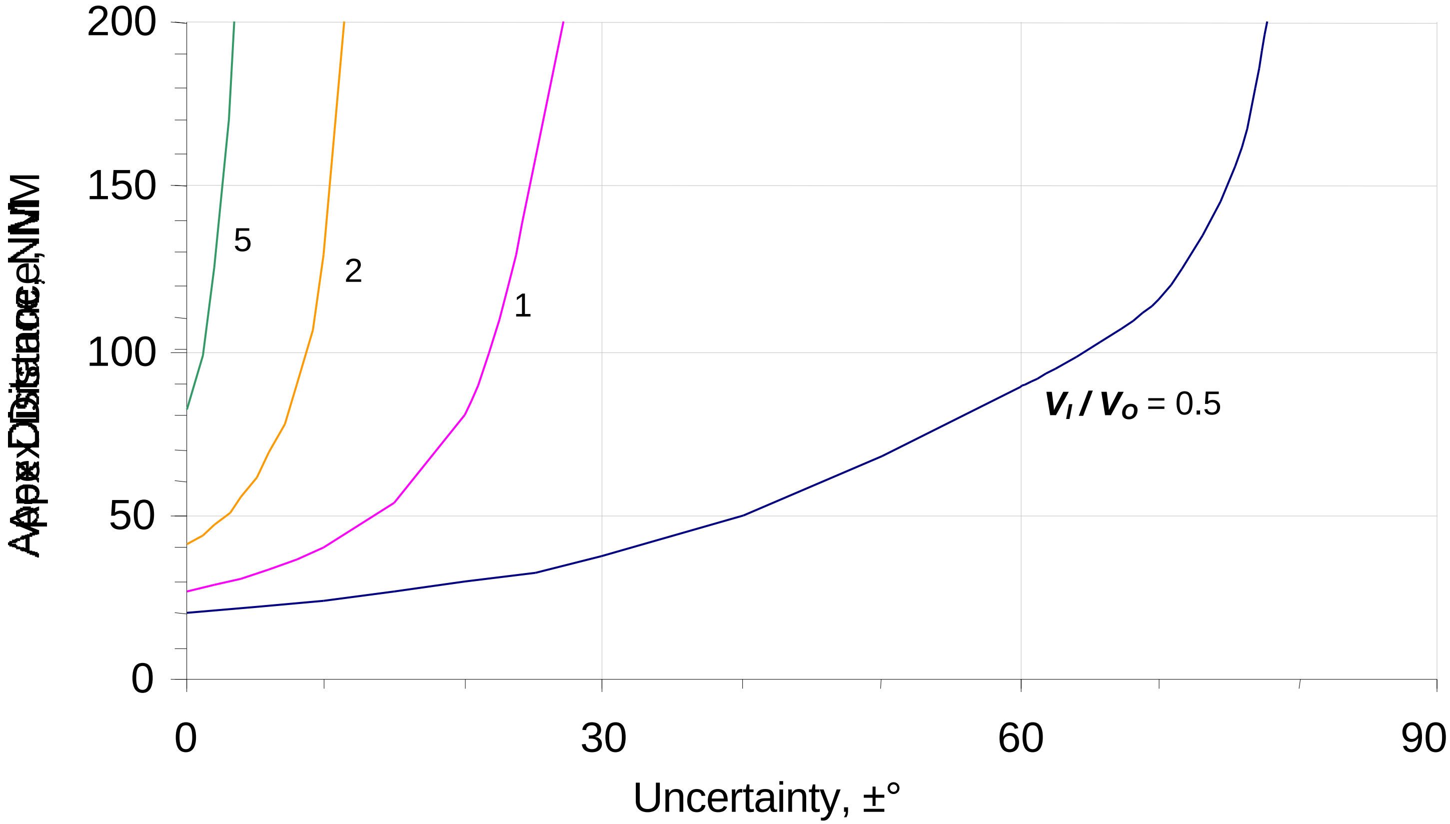


Effect of Turn Rate

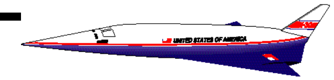




Alert Zone Growth Due to Trajectory Uncertainty



Tactical conflict resolution untenable at large trajectory uncertainties & velocities



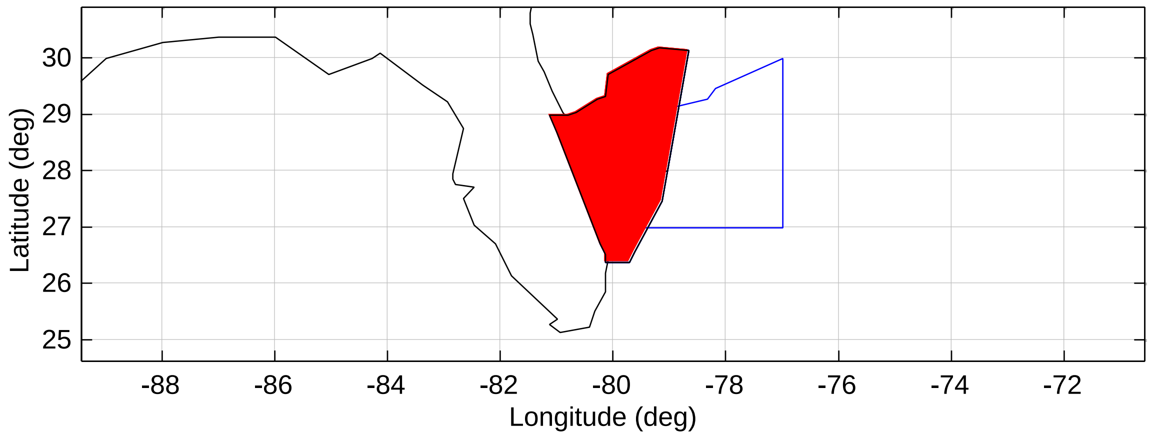
Netw ork Flo w Modeling and Optimization

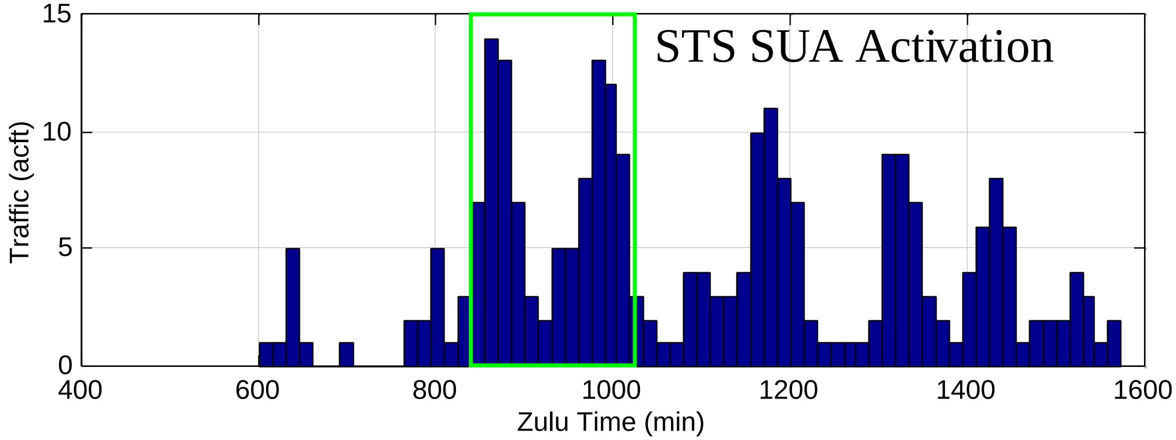
- Traffic flow model analysis tools
  - SIMMOD - predicts delays and changes in travel times for current scenario conditions)
  - RAMS - predicts delays, travel times and sector workload for current and anticipated 2005 conditions (i.e., Free Flight)
- Development of an optimization model to reduce the impacts of RLV operations around sites
  - Dynamically schedules flights affected by RLV operations to minimize a performance index (cost and workload)
  - Model development tools: Matlab[1] and CPLEX[2]

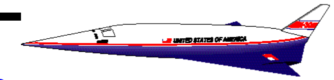
1.Matlab is a trademark of the Mathworks Inc.

2.CPLEX is a trademark of ILOG International

Sample Sector Occupancies



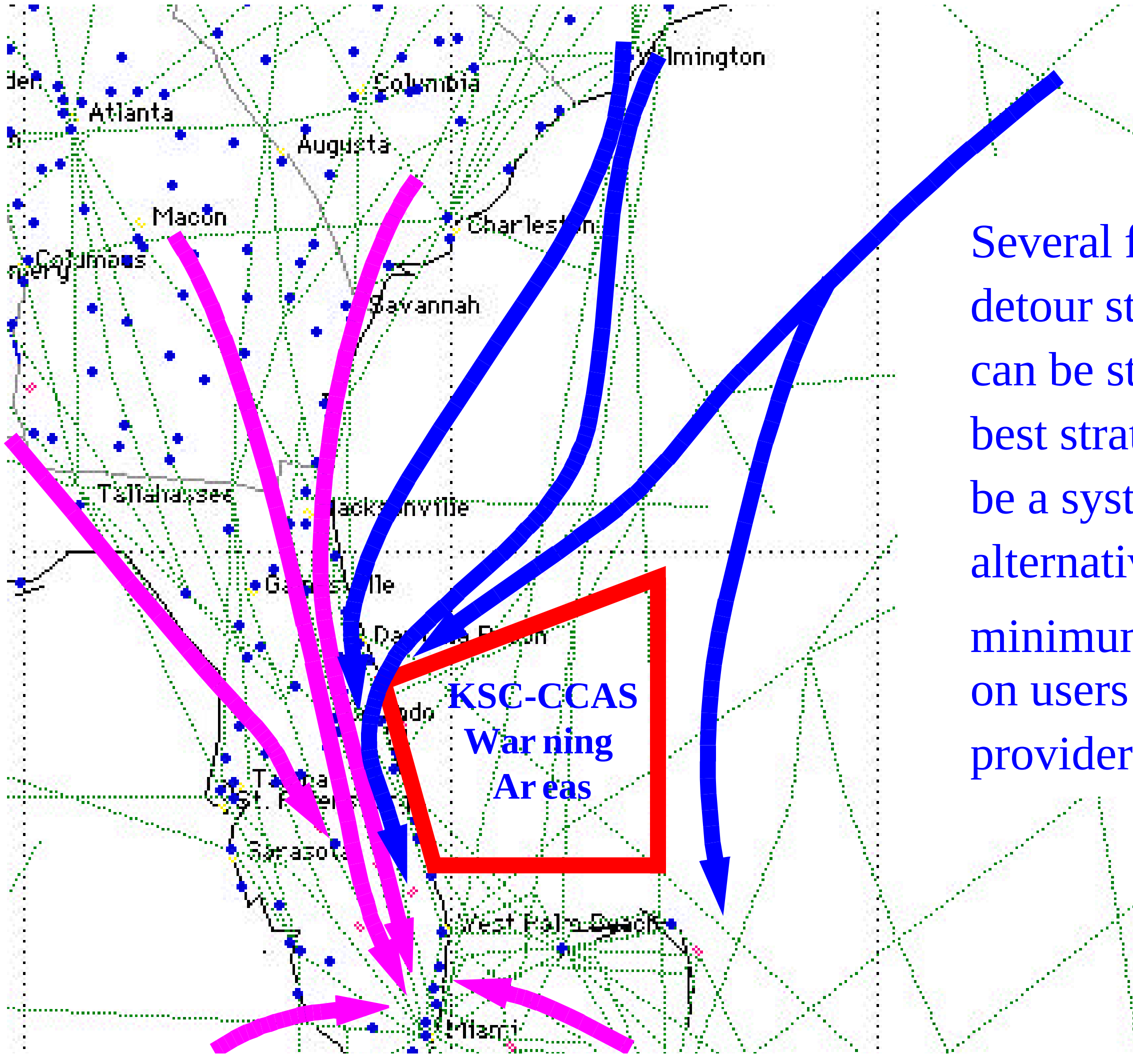




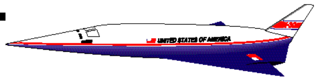
Optimization Model to Integrate RLV with Minimum Cost to FAA and Airspace Users

- Attempts to mimic and advanced ATM system of the future (i.e., 2005, 2010)
- A mature form of Collaborative Decision Making is in place (i.e., airlines and FAA share information about flight schedules and possible delays associated with each flight)
- *Free Flight* operations will be routine across NAS for all enroute sectors and flight levels
- Considers FAA resources (i.e., a function of traffic density), sector and airline equity constraints
- Serves as a policy tool to evaluate operations around spaceports

Optimization Model Rationale



Several flight plan detour strategies can be studied. The best strategy should be a system optimal alternative with minimum effects on users and service providers



Airspace Planning Model Optimization Model

Objective function

$$\text{Min} \sum_{i \in M} \sum_{p \in P_i} C_{ip} x_{ip} + \sum_{s \in S} \sum_{n=1}^{\bar{n}_s} \mu_{sn} y_{sn} + \mu_e (x_u^e - x_l^e) + \mu_u x_u^e$$

Cost of adopting flight plan *(i,p)*

Penalty associated with sector load

Penalty to maintain equity among airlines

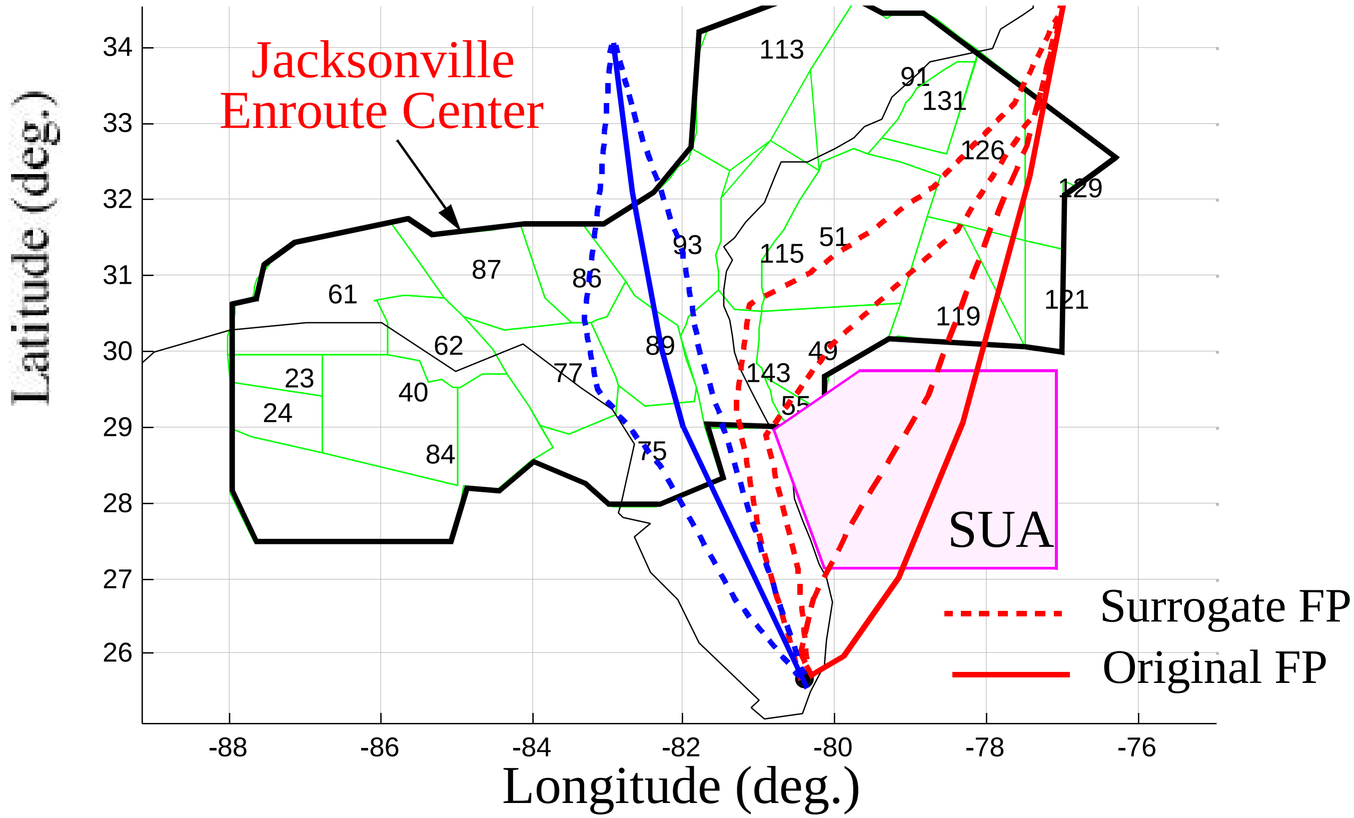
Assignment Constraint (a single flight plan is selected)

Sector Load Constraint (restricts the number of flights to sector n_s)

Airline Equity Constraint (penalizes equally all airlines flying)

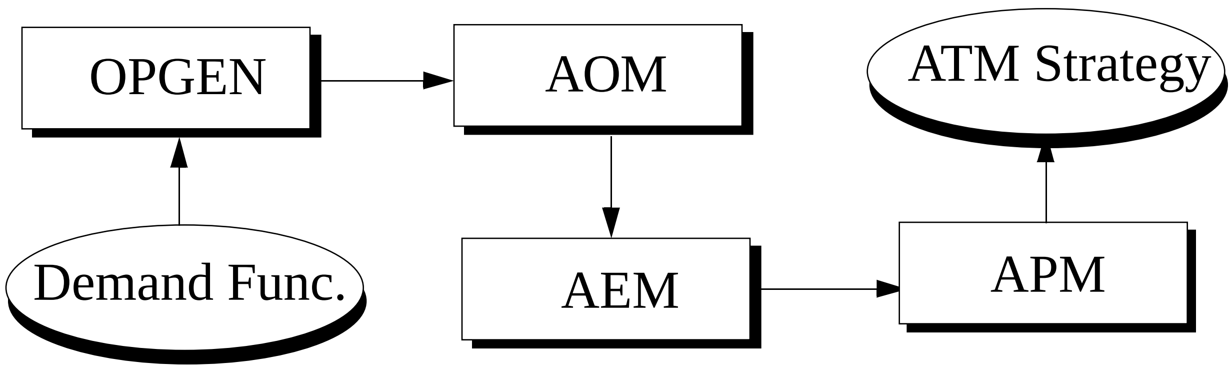
Application of the Optimization Model

The optimization model selects among *surrogate* flight plans to minimize the cost to users and service providers

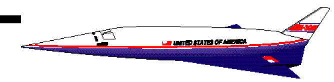


Integration with Existing NARIM Tools

- Currently generation of surrogate flight plans is done using a simple globe circle flight planning module
- Future will use proven tools such as OPGEN[1]
- OPGEN output data structure is already integrated in AOM/AEM

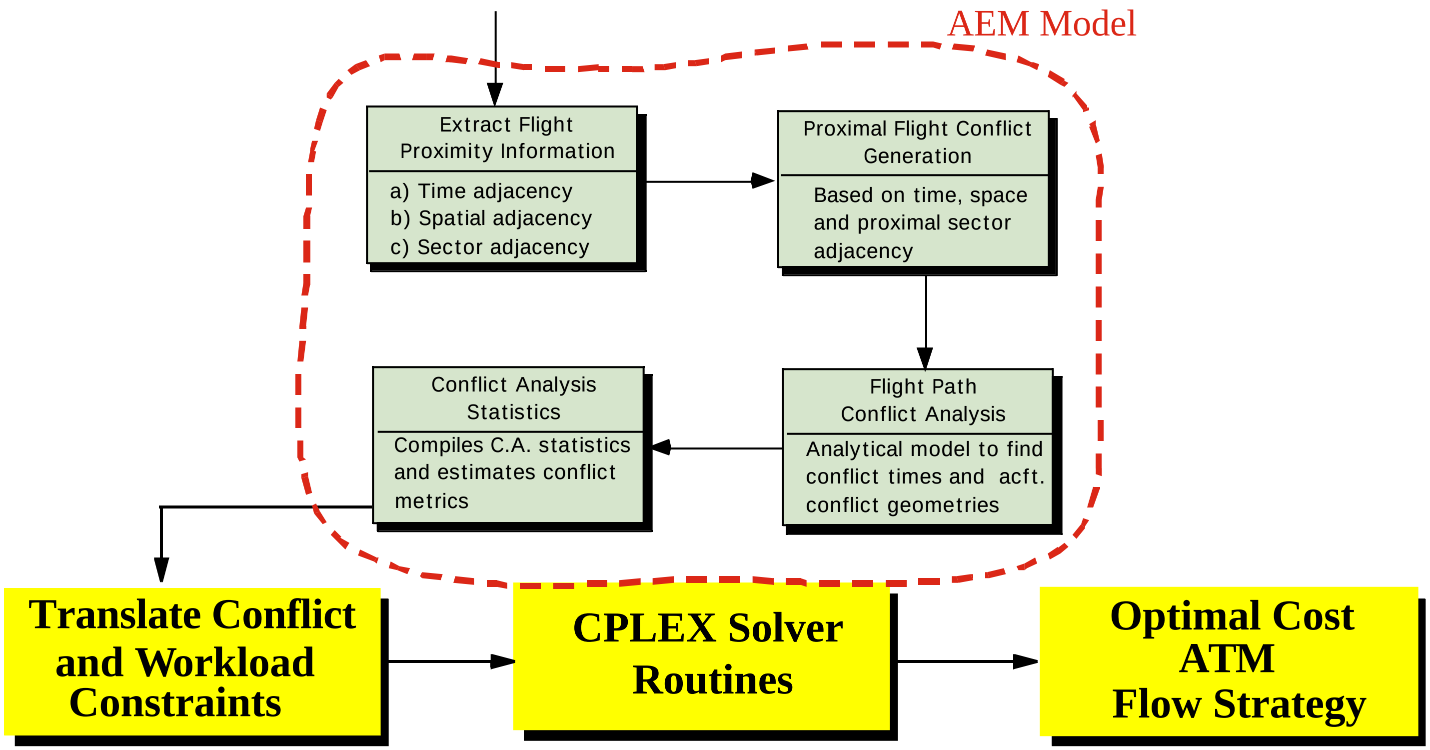


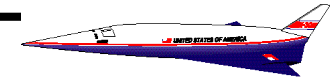
1.A single flight optimization program developed by CSSI for FAA



Implementation of Optimization Model

The current optimization model is implemented in CPLEX a standard mixed-integer programming solver





Possible ATM Extensions of the Optimization Model

- Analysis of catastrophic RLV failures (i.e., estimation of the number of aircraft affected)
- Special Use Airspace is only one of many possible airspace restrictions in NAS
- Bad weather phenomena can be treated as a special case of SUA (i.e., dynamic SUA)
- Dynamic allocation of flight plans in the future will continue be a mutual agreement between airlines and FAA and without any doubt will consider the ATC resources available (i.e., decentralized control)
- Dynamic airspace sectorization problems (time varying airspace sectors to balance sector loads)