NEXTOR Annual Research Symposium
November 14, 1997

Session III
Issues for the Future of ATM

Reusable Launch Vehicles

Antonio Trani, Virginia Tech

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

Massachusetts Institute of Technology

J. Kuchar and K. Khan

Virginia Polytechnic Institute and State University

A. Trani, H. Sherali,
C. Smith and S. Sale

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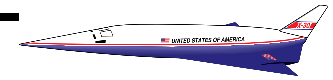


Virginia Tech Scope of Work

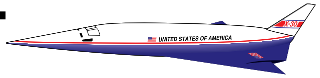
Traffic flow modeling around launch sites for all RLV operational modes developed by MIT

- Identify and quantify periods of flight disruptions
- Baseline year (1997)
- Horizon year (circa 2005)
- KSC and Edwards are primary targets for modeling

Economic cost/benefit analysis

- Cost to users (airlines and general aviation traffic)
- Cost to ATC service providers (FAA)
- Cost to non-airspace users (RLV service providers and others)

RLV Operation Impacts

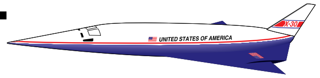


FAA
- ATC Infrastructure
- ATC Workload

GA Operations
- DOC Cost per flight
- Travel time cost

Commercial Ops.
- DOC Cost per flight
- Travel time cost

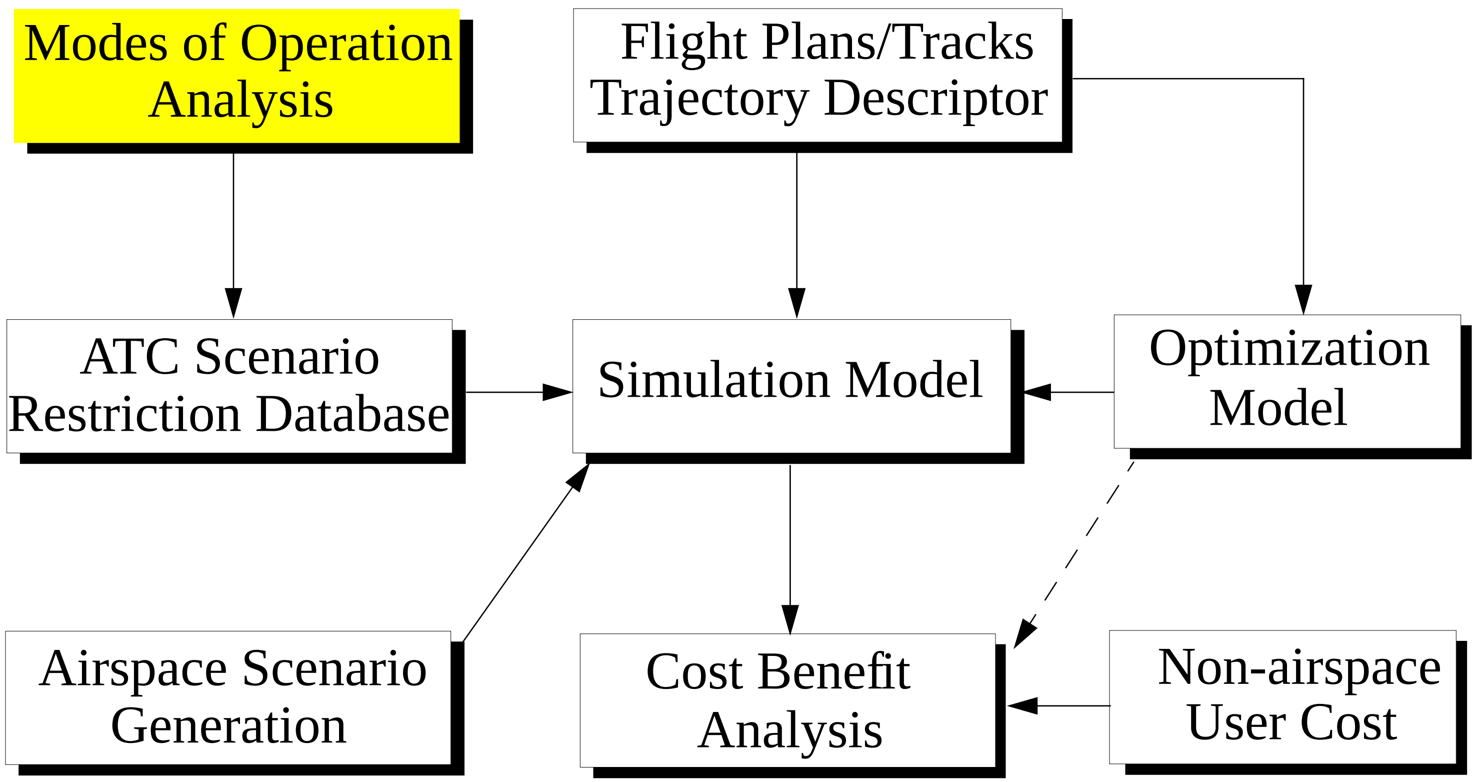
Non-airspace users
- Service costs/benefits
- Launch delay penalties



VPI Activities in Phase I

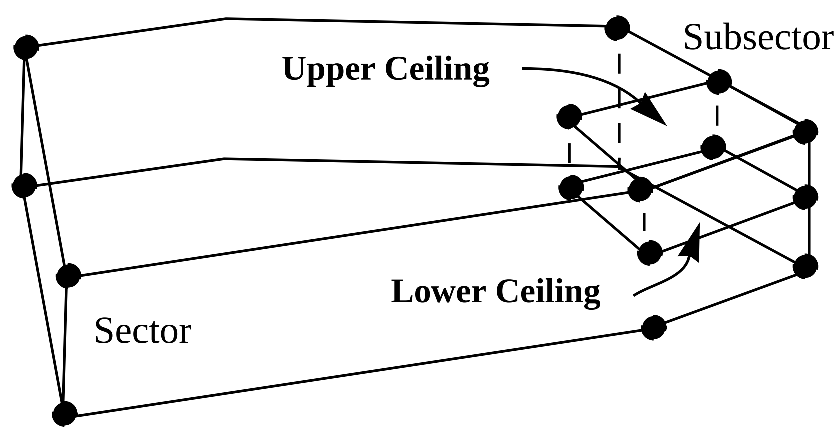
- Traffic flow model analysis and familiarization
  - SIMMOD (good amount of knowledge in place)
  - RAMS - installation and familiarization
- Developed an optimization model to reduce the impacts of RLV operations around sites
- Developed a framework to study cost/benefits of RLV operations around launch sites

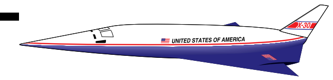
Framework to Model RLV Impacts



ATC Scenario Restriction Database

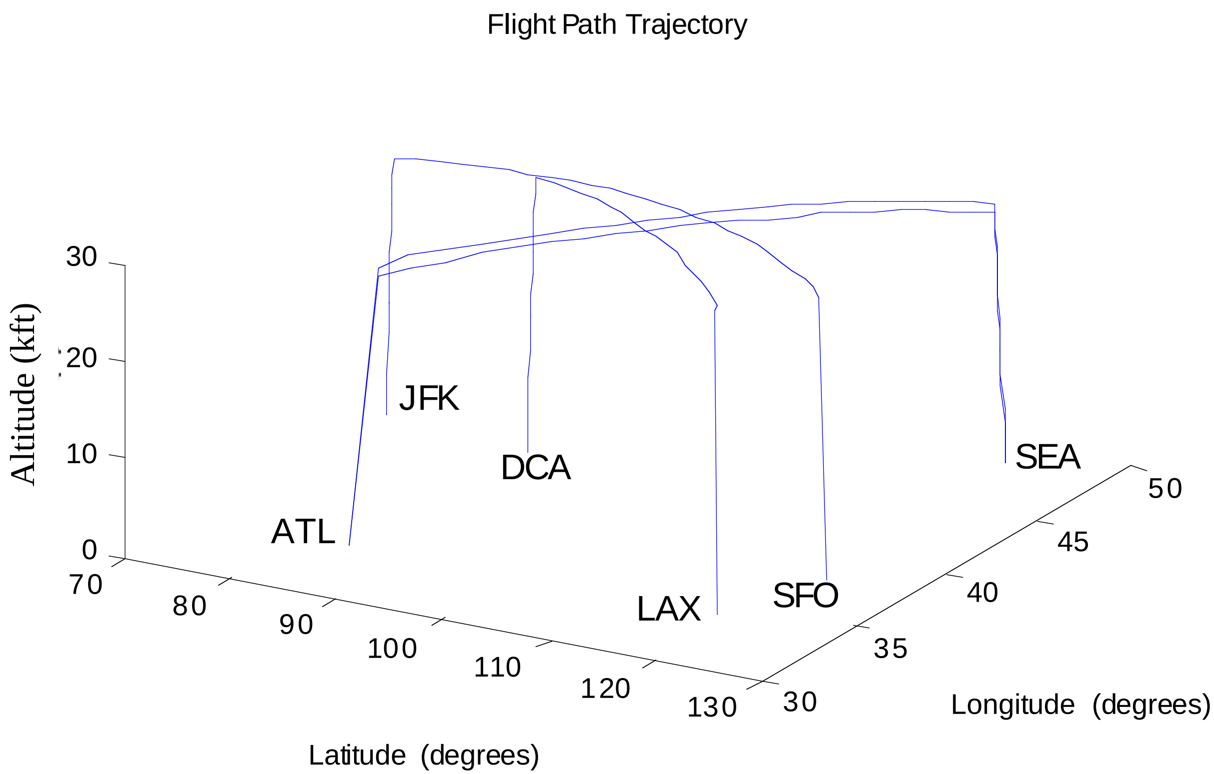
- Establishes a list of sub-sectors or sectors and their operational time restrictions
- Regardless of the type of RLV mode selected an ATC scenario restriction database will be generated for each mode of operation (this represents specific ATC procedures in place)
- Some measure of workload or traffic density is desirable to account for FAA costs.





Flight Plan Generator / Trajectory Descriptor

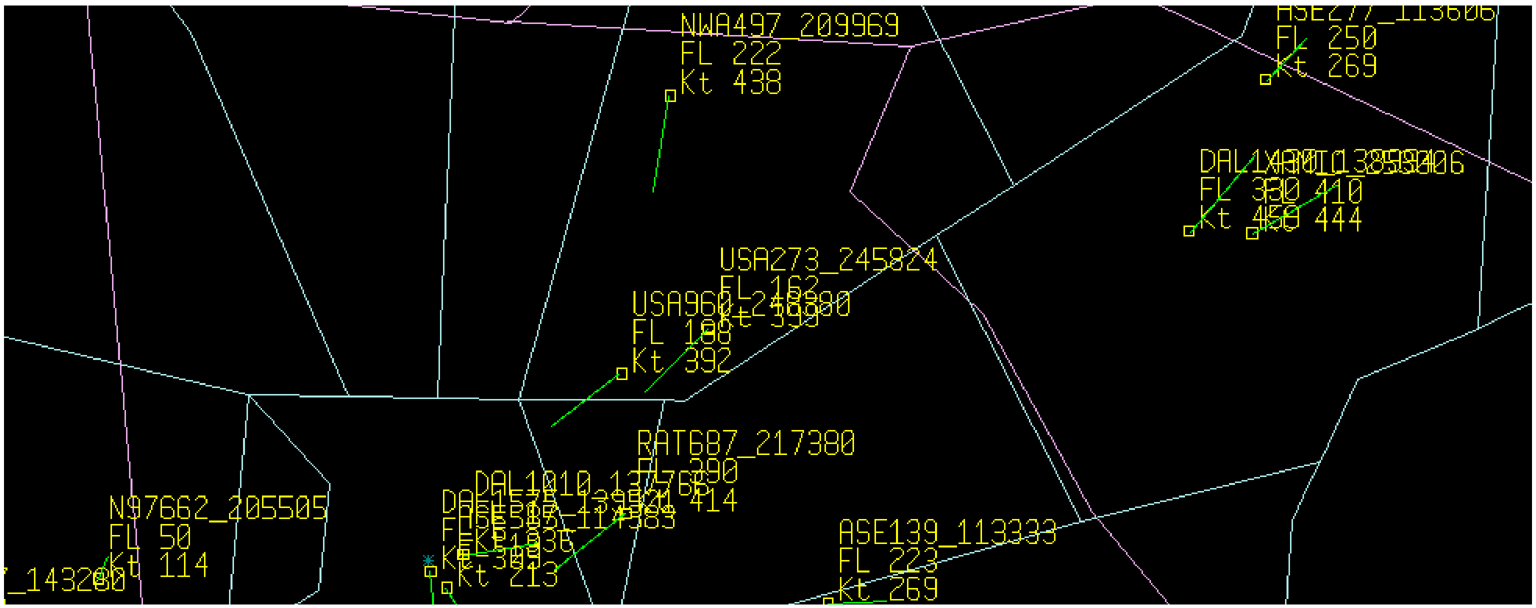
Serves to estimate aircraft trajectories used in the simulation and optimization models

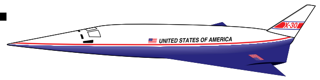


Simulation Models Used

SIMMOD and RAMS are being used to model operations around KSC and Edwards

Estimate cost and travel times for aircraft (current and 2005 ATM scenarios)

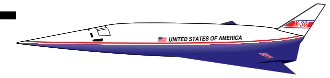




Outputs from Simulation Models

- Aircraft delays
- Travel times
- Direct operating cost per operation (indirectly)
- Some measure of workload (sector capacity violations etc.)
- Assessment of current ATC operational practices
- Limited in the scope as a policy evaluator (i.e., only a few cases can be modeled)

These outputs become inputs to the model to estimate total cost/ benefit of RLV operations



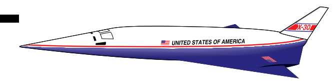
Commercial/GA Flight Disruption Assessment

For various ATM modes of operation an estimate of flight disruptions is possible for current and near future airspace conditions

Some extra work will be required to assess disruptions for a future Free Flight environment

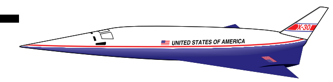
- New flight plan generation will be required
- Some uncertainties remain in the FAA ATM architecture

VPI has developed a computer program to assess Free Flight trajectories. RAMS and OPGEN (NARIM tools) offer some complementary capabilities that are also being used.



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)
- Some 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 to Minimize the Economic Impacts Of RLV Operations

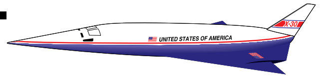
Commercial flight cost, ATC traffic density and user equity constraints can be expressed mathematically, in the form,

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

$$\text{subject to} \sum_{p \in P_i} x_{ip} = 1 \quad \forall \; i \in M \qquad (2)$$

$$\sum_{(i,\,p) \in C_{sk}} x_{ip} - n_s \le 0 \quad \forall \;\; k = 1, 2, \ldots, K_s \;\; s \in S \qquad (3)$$

$$x_l^e \le \sum_{(i,\,p) \in A_f} \alpha_{ip} x_{ip} \le x_u^e \qquad \forall \;\; f = 1, \ldots, F \qquad (4)$$



Optimization Model to Mitigate RLV Impacts

$$n_s = \sum_{n=1}^{\bar{n}_s} n y_{sn} \qquad \forall\, s \in S \qquad (5)$$

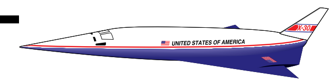
$$\sum_{n=1}^{\bar{n}_s} n y_{sn} \le 1 \qquad \forall\, s \in S \qquad (6)$$

$$\sum_{p \in S_k} x_p \le |S_k| - 1 \qquad (7)$$

for each arc pair $k \in A_{st}, \forall\, t \in H, s \in S$

(x, y) binary, $x_l^e \ge 0$, $x_u^e \le n_e$

Optimization Model Nomenclature (I)



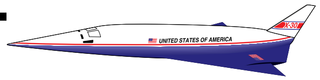
- Planning Horizon H
- Set of flights $i = 1, 2, \ldots, n$ covering this horizon that are relevant to interactions with a particular RLV spaceport

For each flight $i \in \{1, 2, \ldots, m\}$ where set $M = \{1, 2, \ldots, m\}$

- P_i = {set of possible flight plans p composed of flight plans between designated waypoints along the route from an origin to a destination}
- For any given combination (i, p), where $i \in M$ and $p \in P_i$ we can compute a cost factor C_{ip} for adopting plan p for flight i.
- C_{ip} reflects fuel expended, delay costs, as well as penalties or benefits (i.e., negative penalties) based on the selection of the corresponding flight plan.

Optimization Model Nomenclature (II)

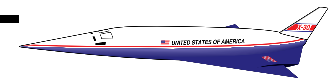
- Accordingly, define the decision variables (x_{ip}),
- $x_{ip} = 1$ if plan $p \in P_i$ is adopted for flight $i \in M$
- $x_{ip} = 0$ if plan $p \in P_i$ is not adopted for flight $i \in M$
- $\forall i \in M, p \in P_i$



Optimization Model Nomenclature (III)

Denote these sets by C_{sk} for $k = 1, 2, \ldots, K_s$. Hence,

- $C_{sk} = \{(i, p)$: flight plan (i, p) belongs to the k^{th} maximal overlapping set for segment s, $\forall \; k = 1, 2, \ldots, K_s$ and $s \in S$.
- The parameter n_{sk} can be chosen by the user dependent on the segments and the nature (i.e., type and number) of the conflicting flights in a sector.

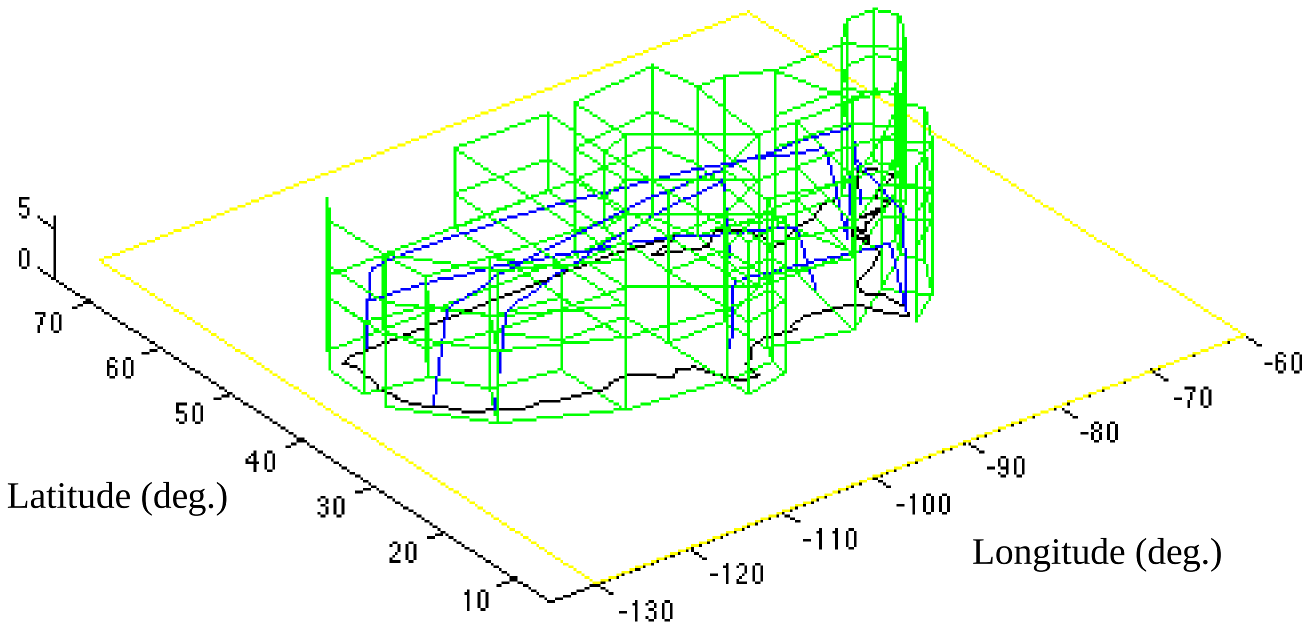


Uses of the Optimization Model

- To study the effect of various ATC policies can be evaluated with respect to their influence on airspace sector parameters n_{sk} (maximum number of flights allowed in a sector)
- To study the effect of alternative flight plans can also be evaluated using this model. In fact, this model can itself serve to evaluate the efficiency of various flight plan generation programs once an RLV operation mode has been adopted.
- To study different regulations imposed by FAA might yield different interpretations on what poses as a “conflict.” These policies would be evaluated by translating them into appropriate constraints and examining their effect on the model solution.

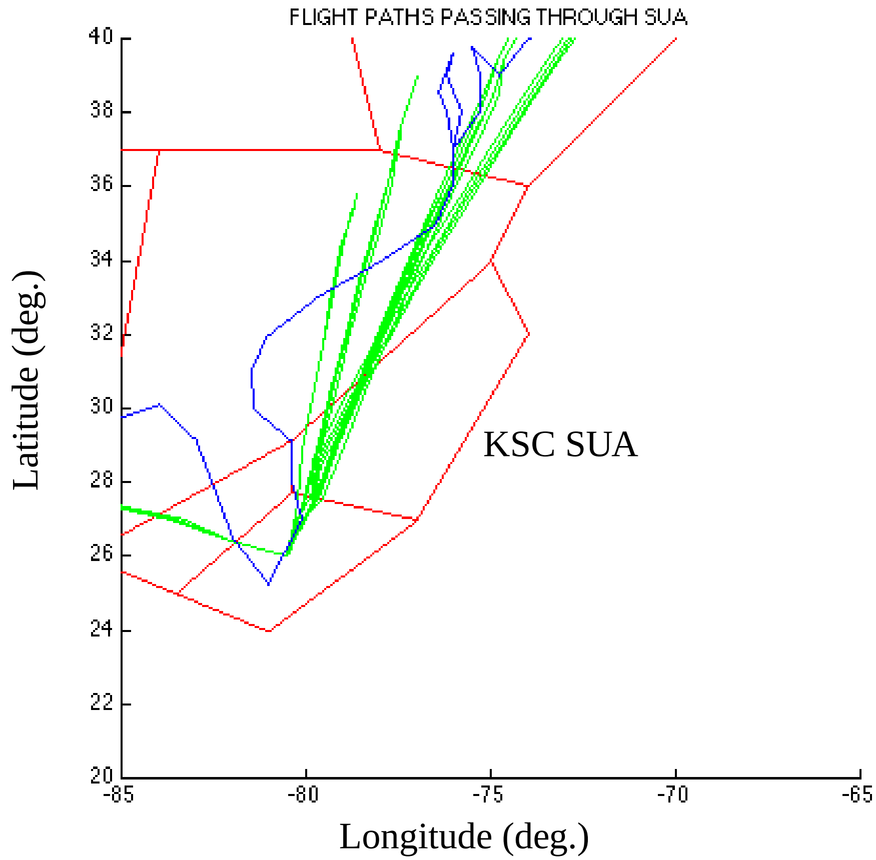
Baseline Scenario

This figure illustrates a simple sectorization used for demonstration



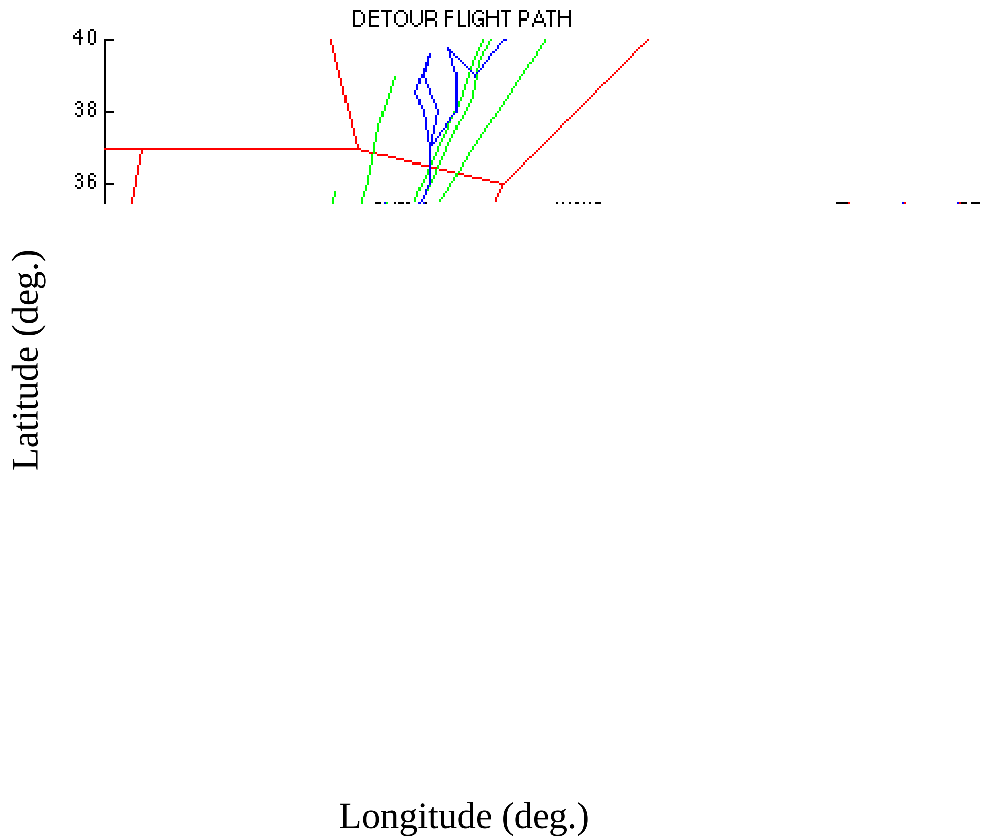
Nominal Trajectories Around KSC

The following diagram shows baseline trajectories (no deviations)



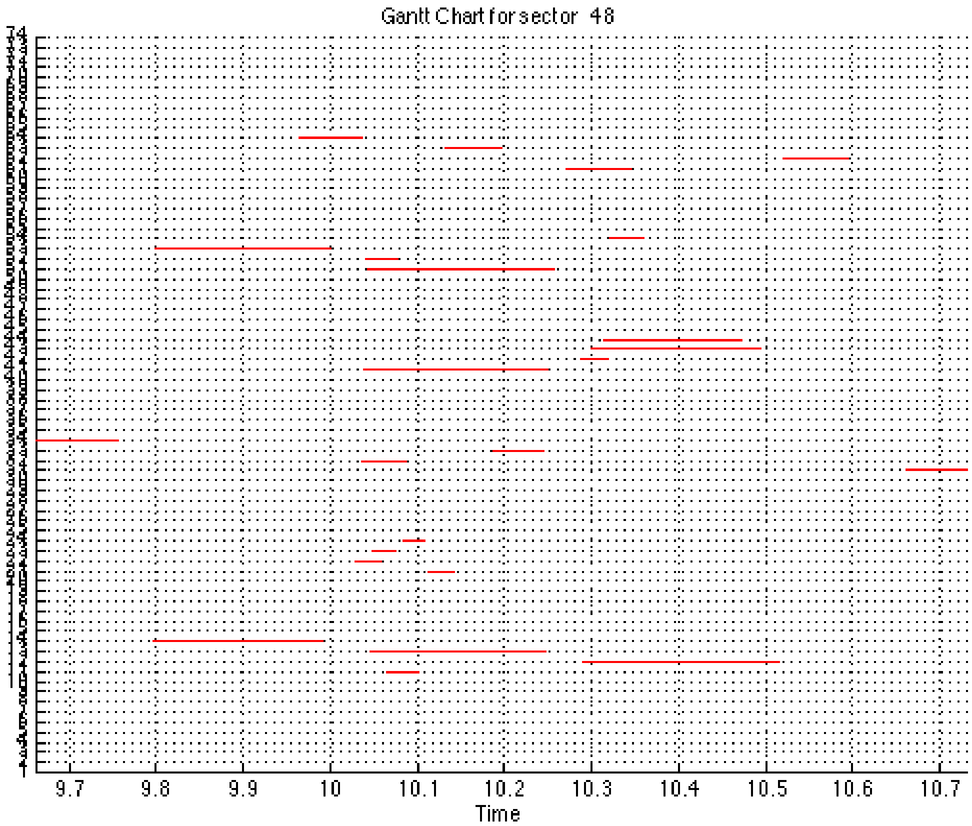
Special Use Airspace Restrictions in Place

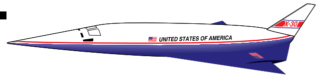
The following diagram shows flights deviated around KSC SUA



Flight Conflicts for the Simple Case Study

The following Gantt chart illustrates flight conflicts for Sector 48

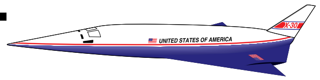




Sample Numerical Results

Case 1 (Sample of a small decision making model)

- 10 flights and two airlines
- Airbus A300-600 and F100 aircraft
- Objective Function Cost = $57466.16 (total cost)
- flights: x_{14}, x_{21}, x_{34}, x_{44}, x_{52}, x_{62}
- maximum equity: 110
- equity disparity: 0
- maximum workload: 2 aircraft simultaneously in a subsector (5 occurrences)



Phase II Tasks at VPI

a) Detailed model of KSC[1] and Edwards A.F.B. launch operations (baseline and 2005 scenarios) using proposed RLV operational modes

b) Application of optimization model to KSC and Edwards A.F.B. scenarios[2]

c) Estimation of FAA infrastructure costs to support RLV operations

d) Estimation of non-user costs/benefits

1. We are currently developing both models

2. The model is complete but we need to insert the actual operational data