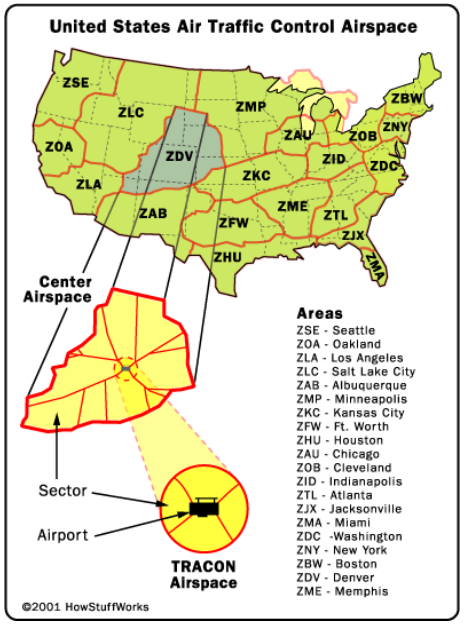
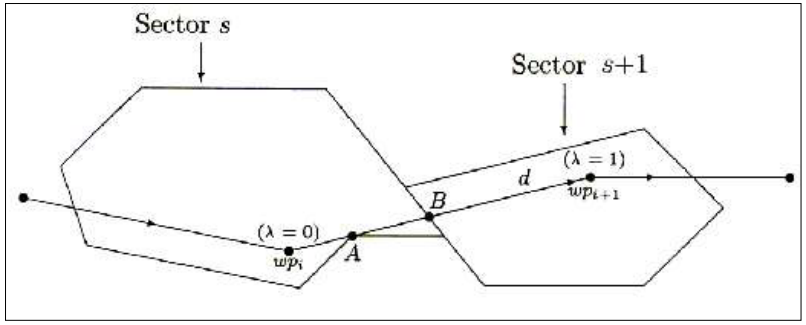
Airspace Occupancy Model (AOM)

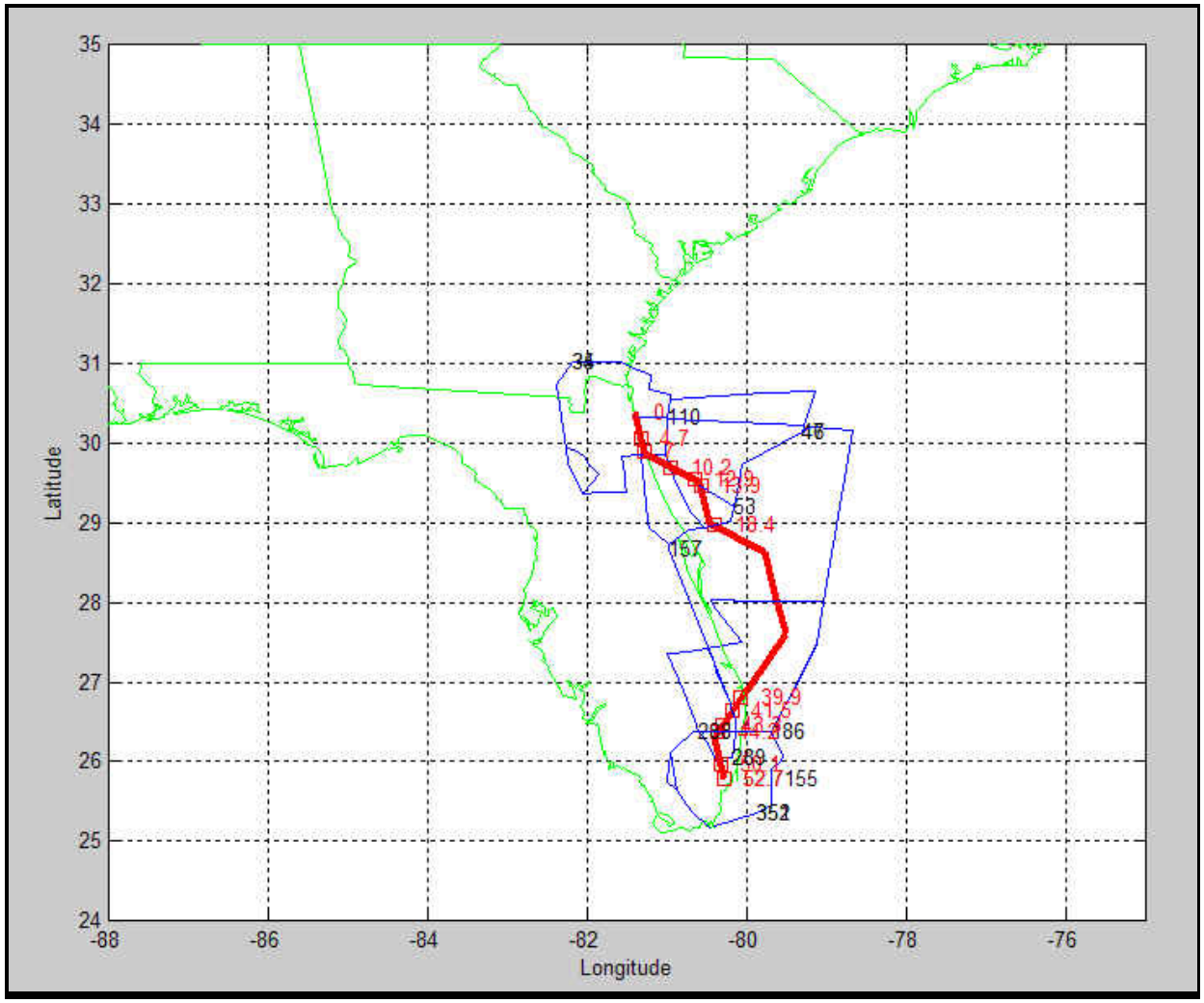


- Mathematical NAS representation
- 20 centers each divided into sectors



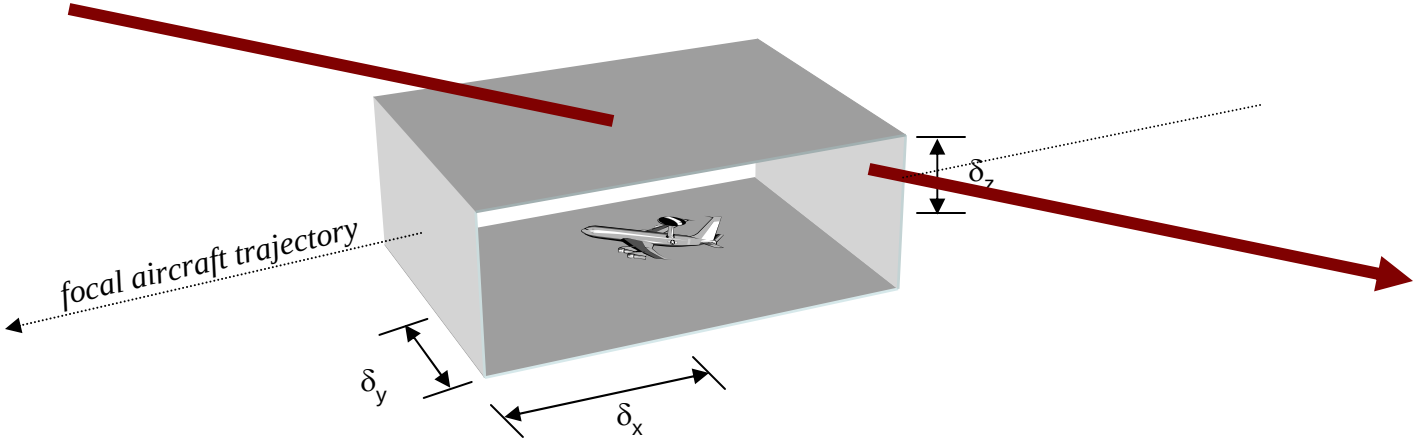
- Flight plans processed to determine sector occupancy time intervals
- Occupancy data used:
  - To characterize sector occupancy workloads
  - As pre-processing data for PAEM conflict analysis

Airspace Occupancy Model (AOM)



Probabilistic Aircraft Encounter Model (PAEM)

- Proximity Shell Around Each Focal Aircraft

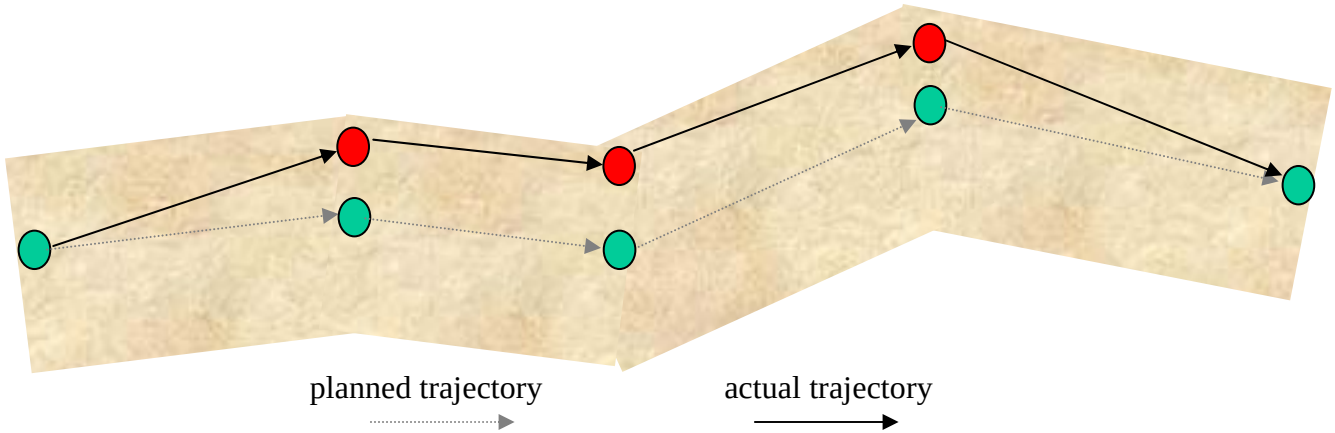


- Moves with aircraft as it traverses its flight trajectory

- Conflict occurs when another aircraft pierces the proximity shell

Probabilistic Aircraft Encounter Model (PAEM)

- Aircraft Position & Trajectory Not Known With Certainty
  - Weather Effects
  - Navigation System Inaccuracy
  - Pilot Error



Airspace Planning and Collaborative Decision Model (APCDM)

- Flight Plan Selection
  - For each flight, select one flight-plan from among alternatives
  - Minimize Flight Costs (Objective Function)
  - Subject to Considerations (Penalty Terms in Objective Function):
    - Sector Workload
    - Safety (Conflict Resolution)
    - Decision Equity

Model APCDM

$$\min \sum_{f=1}^{F}\sum_{p\in P_{f0}} c_{fp}x_{fp} + \sum_{f=1}^{F} c_{f0}x_{f0} + \sum_{s=1}^{S}\sum_{n=0}^{\bar{n}_s} \mu_{sn}y_{sn} + \mu^e x^e + \mu^D \sum_{\alpha=1}^{\bar{\alpha}} \varpi_\alpha [1 - E_\alpha(x)] + \mu^e_{\max} E^e_{\max} + \sum_{s=1}^{S} \gamma_s w_s + \sum \varphi_{PQ} z_{PQ}$$

$$\text{subj to: } \sum_{p\in P_{f0}} x_{fp} = 1 \quad \forall f = 1,\ldots,F$$

Workload Constraints

$$n_s \le \bar{n}_s \quad \forall s = 1,\ldots,S$$

$$\sum_{n=0}^{\bar{n}_s} y_{sn} = 1 \quad \forall s = 1,\ldots,S$$

$$n_s - w_s = \sum_{n=0}^{\bar{n}_s} n y_{sn} \quad \forall s = 1,\ldots,S$$

$$w_s = \frac{1}{|H|} \sum_{(f,p)\in\Omega_s} t^s_{fp} x_{fp} \quad \forall s = 1,\ldots,S$$

$$\sum_{(f,p)\in C_{si}} x_{fp} \le n_s \quad \forall i = 1,\ldots,I_s, s = 1,\ldots,S$$

Conflict Resolution Constraints

$$\sum_{j\in J_{sk}(P)} z_{(PQ)} \le r_s x_P, \quad \forall P \in N_{sk}$$

$$\text{s.t. } |J_{sk}(P)| \ge r_s + 1, \ \forall (s,k)$$

$$x_P + x_Q \le 1 \quad \forall (P,Q) \in FC$$

$$x_P + x_Q - z_{PQ} \le 1 \quad \forall (P,Q) \in A$$

$$\sum_{(P,Q)\in M_{sk}} z_{PQ} \le r_s, \quad \forall (s,k)$$

CDM Constraints

$$E_\alpha(x) = \frac{D_{\max}\sum_{f\in A_\alpha} w_f c^*_f - \sum_{f\in A_\alpha}\sum_{p\in P_f} w_f c_{fp} x_{fp}}{(D_{\max} - 1)\sum_{f\in A_\alpha} w_f c^*_f} \quad \forall \alpha = 1,\ldots,\bar{\alpha}$$

$$E_\alpha(x) \ge 0 \quad \forall \alpha = 1,\ldots,\bar{\alpha}$$

$$E^e_\alpha(x) = E_\alpha(x) - \left(\sum_{\alpha=1}^{\bar{\alpha}} \omega_\alpha E_\alpha(x)\right) \quad \forall \alpha = 1,\ldots,\bar{\alpha}$$

$$w_\alpha E^e_\alpha(x) \ge -E^e_{\max} \quad \forall \alpha = 1,\ldots,\bar{\alpha}$$

$$\sum_{\alpha=1}^{\bar{\alpha}} w_\alpha v_\alpha = x^e \le v^e$$

$$v_\alpha \ge -E^e_\alpha(x) \text{ and } v_\alpha \ge E^e_\alpha(x) \quad \forall \alpha = 1,\ldots,\bar{\alpha}$$

Research Directions

- Development of a dynamic/stochastic TDSP algorithm to consider uncertainties in severe weather pattern.
- Application of the APCDM in concert with AOM and PAEM to scenario based on ETMS data in order to evaluate the quality of the resulting solutions under alternative conditions:
  - a bad weather day or
  - a space launch day.
- Resectorization strategies, resource allocation schemes, effects of FAA/NASA policy guidelines, and incorporation of SATS into NAS can also be studies by the model.