# Use of Linear Aircraft Intent Response for Tactical Trajectory Based Operations

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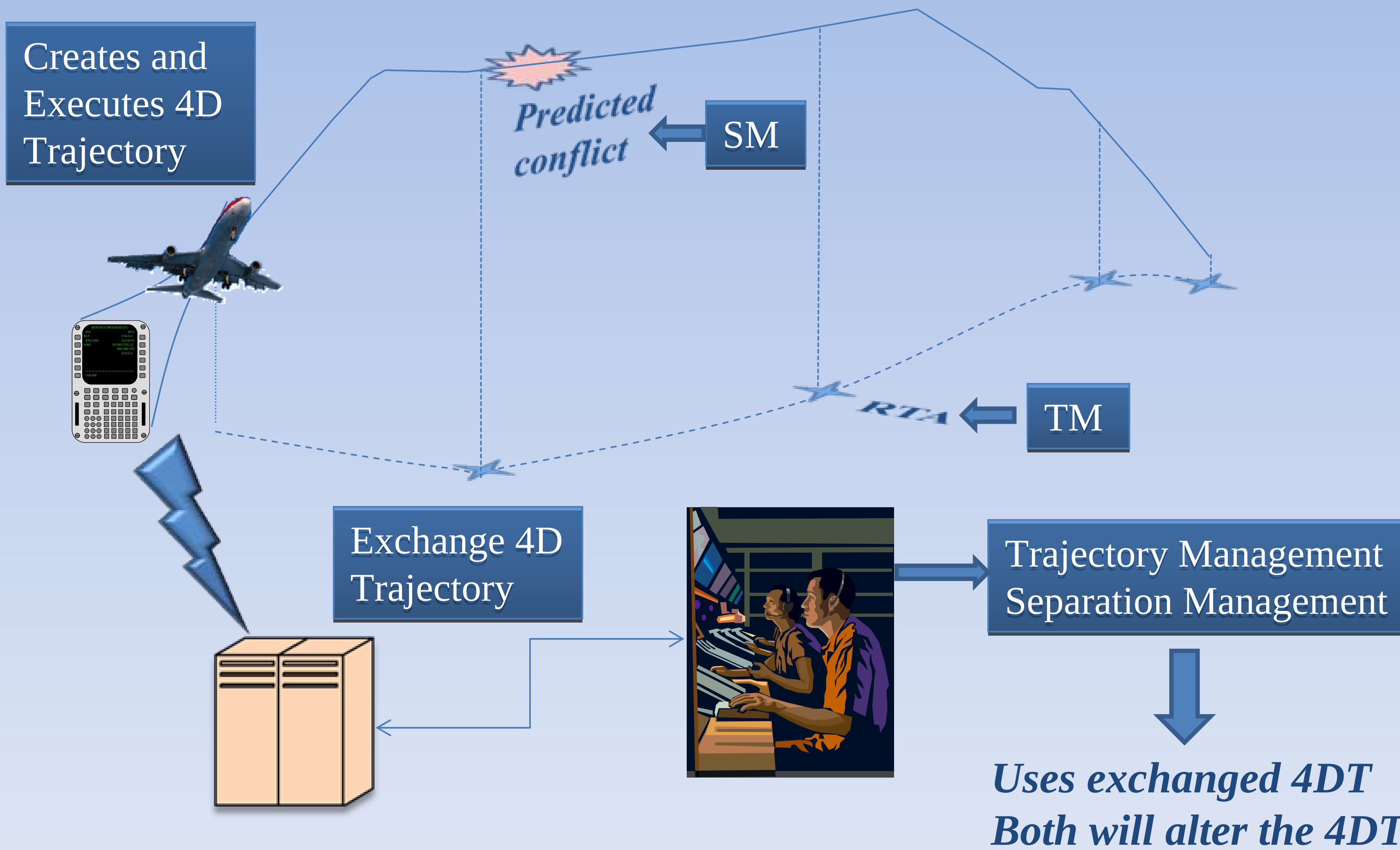
*This work was conducted under contract for the FAA while Dr. Mondoloni was employed at CSSI Inc.*

# Overview

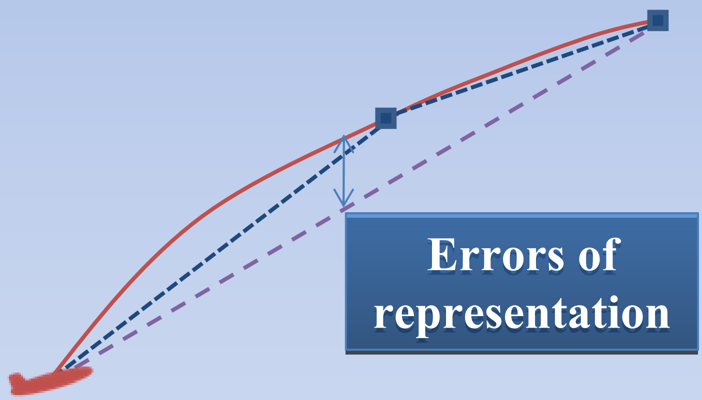
- Motivation
- What is Aircraft Intent Response?
- Evaluation of Approach
  - Metrics
  - Path stretch
  - Altitude
- Summary & Conclusions

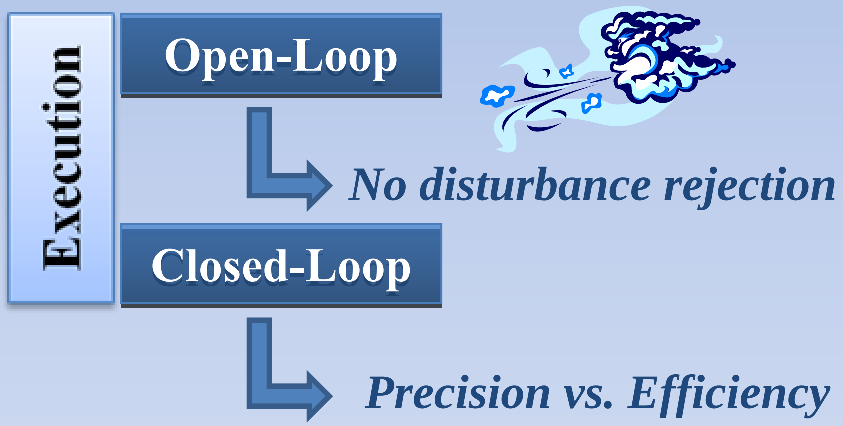
# Trajectory & Separation Management



# The exchanged 4DT

- Exchanged 4DT subject to errors, e.g.:

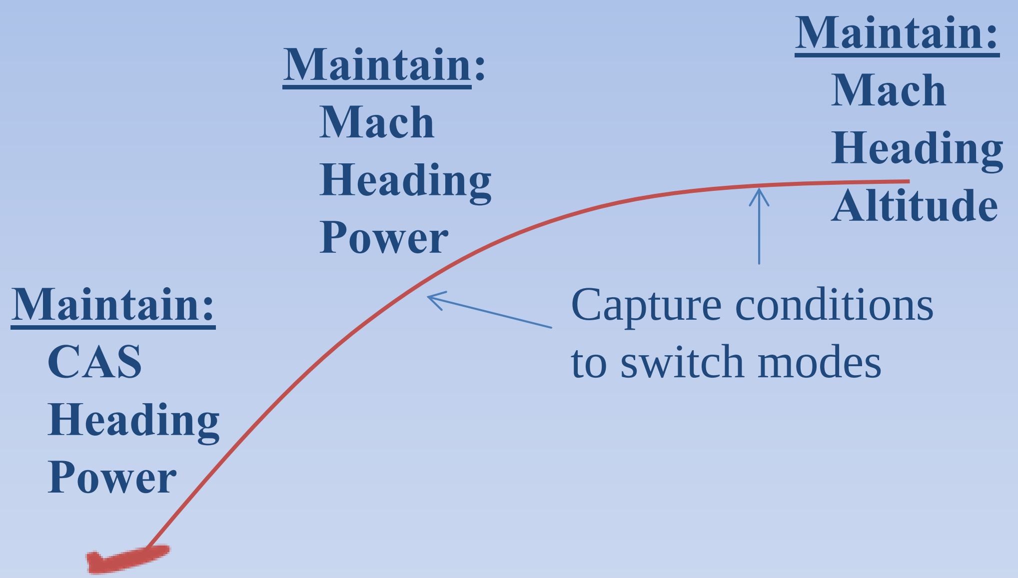



- Exchanging aircraft intent† :
  - Can reduce errors of representation
  - Provide means to model excursions

† *References [15-19] in paper*

# Aircraft Intent Example




Ground DST uses aircraft intent:

- Constructs continuous aircraft trajectory
- Updates effects of disturbances with surveillance data
- Trajectory used for problem detection

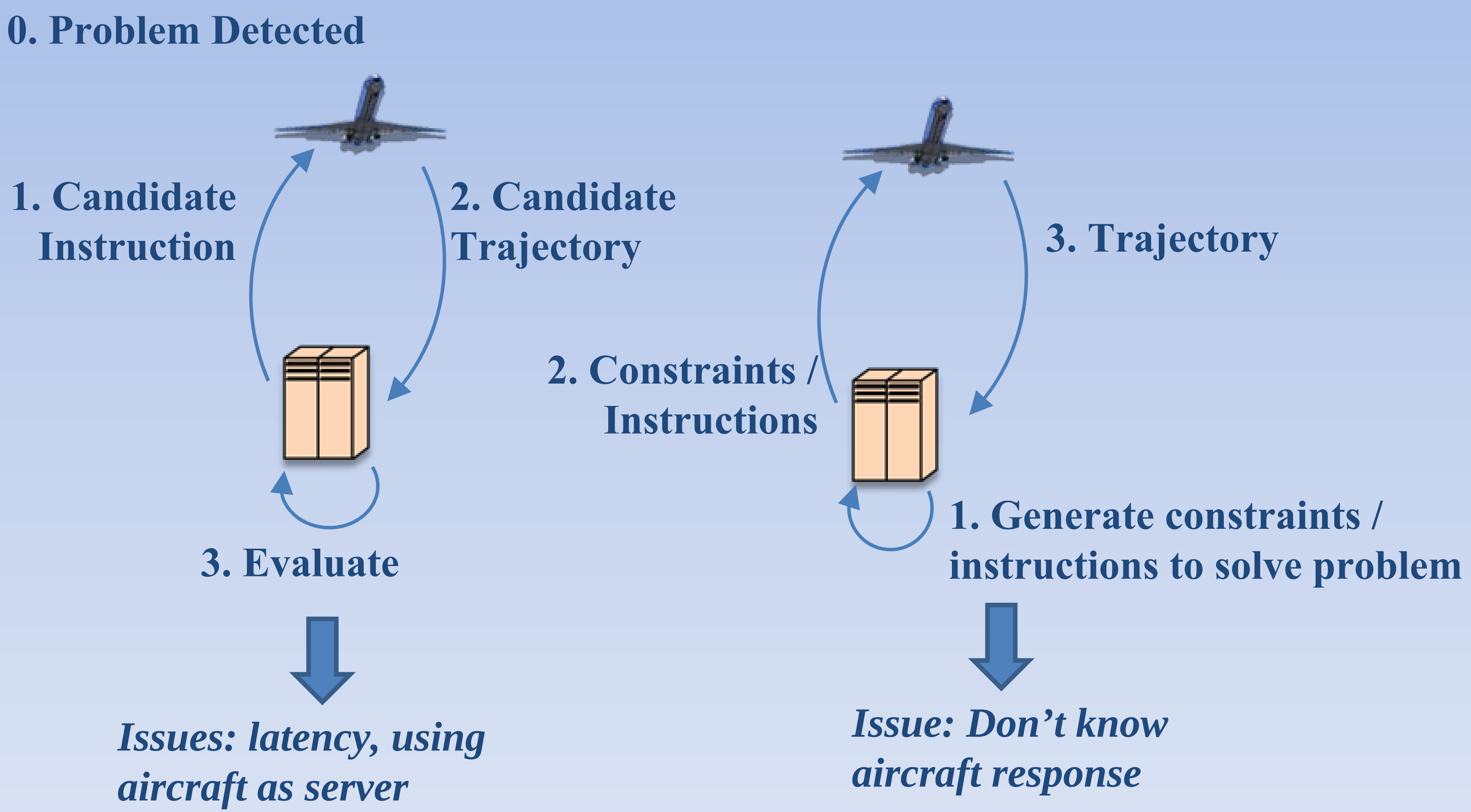
# Modifying the 4DT

- Problem is detected with shared 4DT
- Several DOF available to solve:

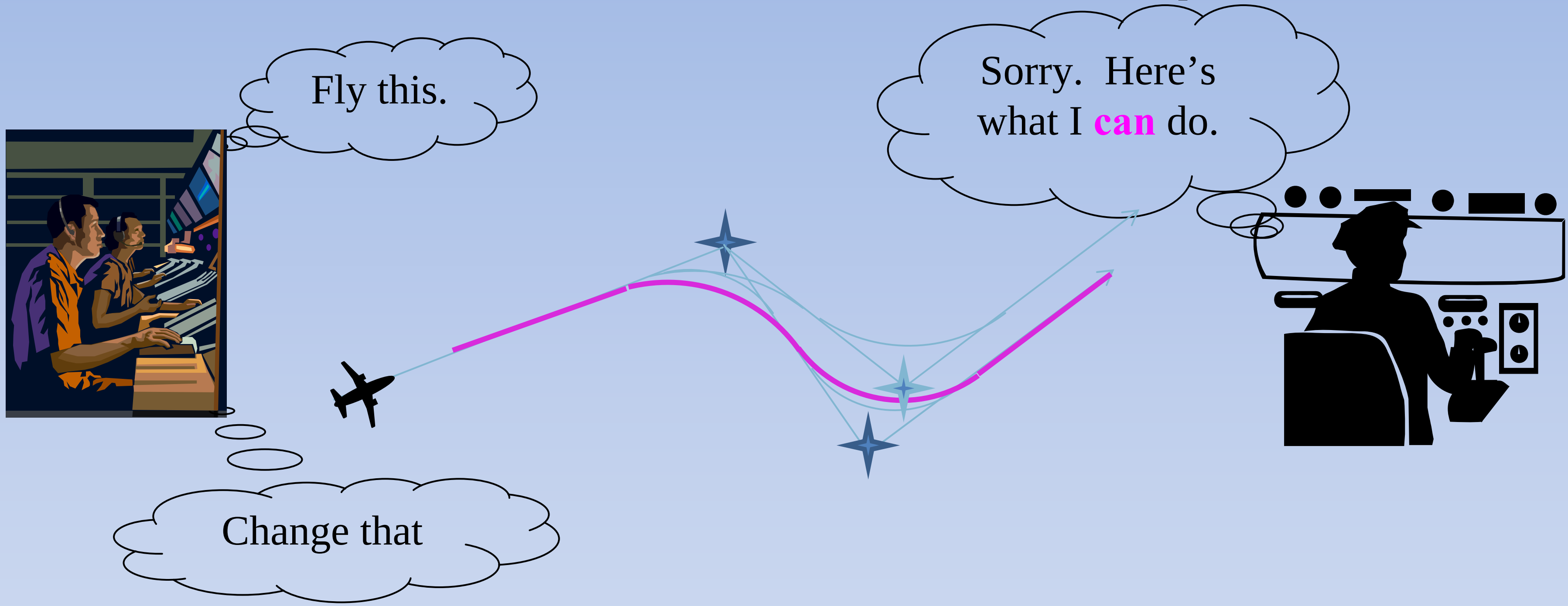

**The "what-if?" case**

- **DST evaluates alternative "instructions"**
- **Ensure instructions yield a problem-free 4DT**
- **Predicted 4DT must be <u>feasible</u> & <u>accurate</u>**
- **Uplink instructions, not a 4DT**

# Options for What-if?



# Don’t know aircraft response

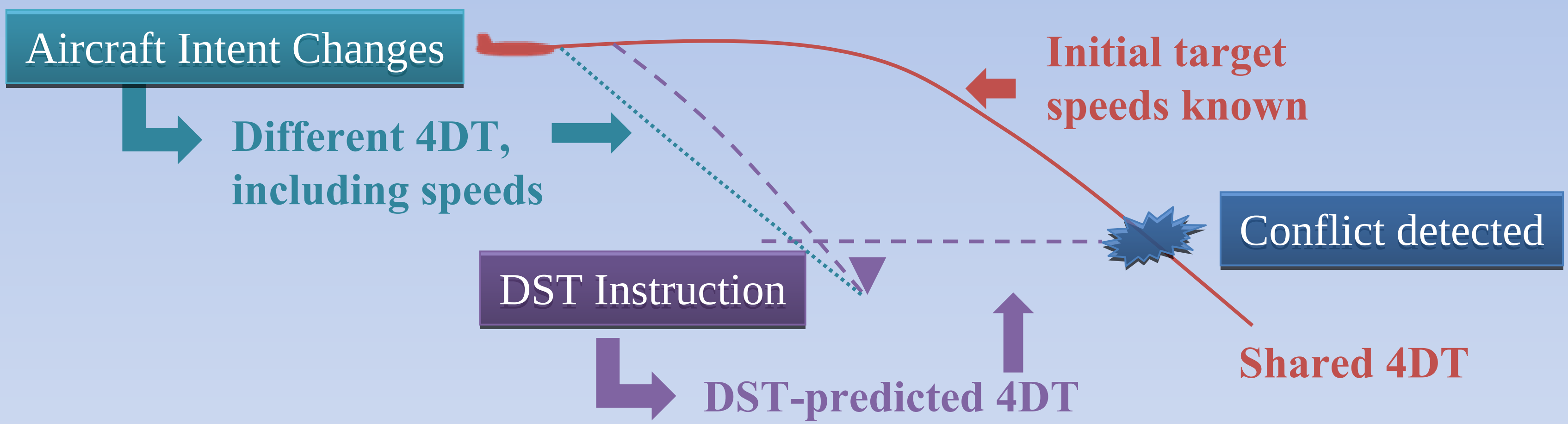



- Tactical decisions – time criticality impacts allowable exchange
- Could use buffers – but leads to inefficiencies and loss of capacity

➢ What information can we use to do better “what-if-ing”?

# The Problem

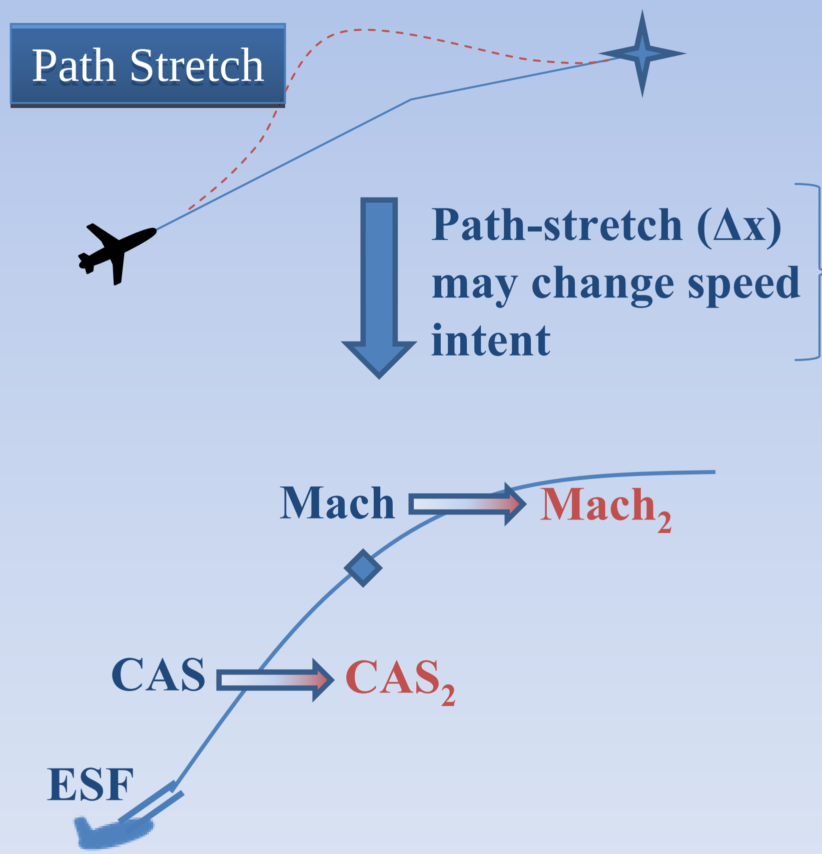
- Instructions can change the aircraft intent*




- Look at using 1st order change in aircraft intent based on instruction to improve accuracy

**Aircraft intent in this case does not represent aircraft objective functions, but represents an unambiguous description of how the trajectory is to be executed.*

# Linear Aircraft Intent Response




Why?

- Explicit CTA
- Implicit Time Target
- Open-loop on time

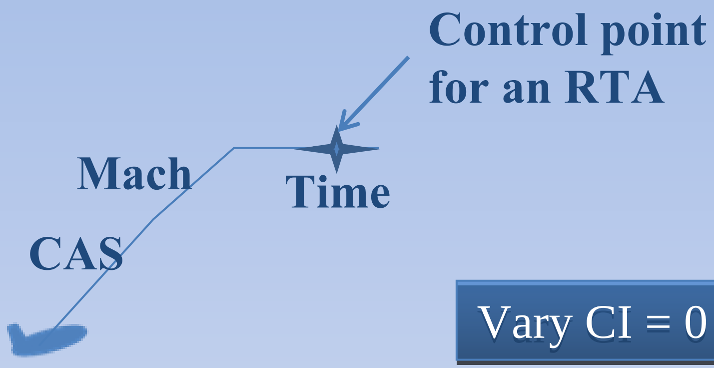
➢ **Solution is under-determined**

Apply very simple linear formulation:

$$M_2 = M + \frac{\partial(M)}{\partial(\Delta x)}\Delta x$$

$$CAS_2 = CAS + \frac{\partial(CAS)}{\partial(\Delta x)}\Delta x$$

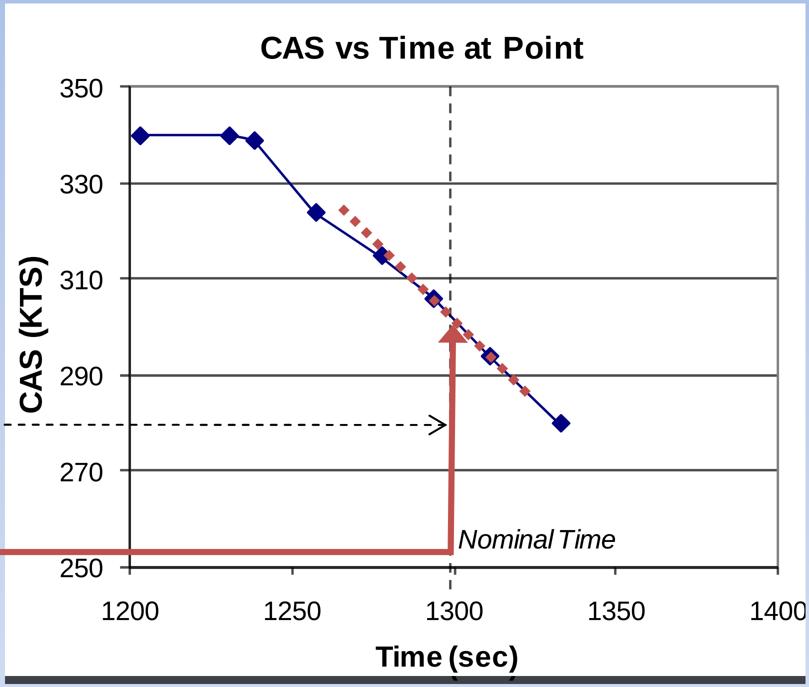
# LAIR – Example path-stretch




Vary CI = 0 → 999

But there is an RTA

Obtain slope



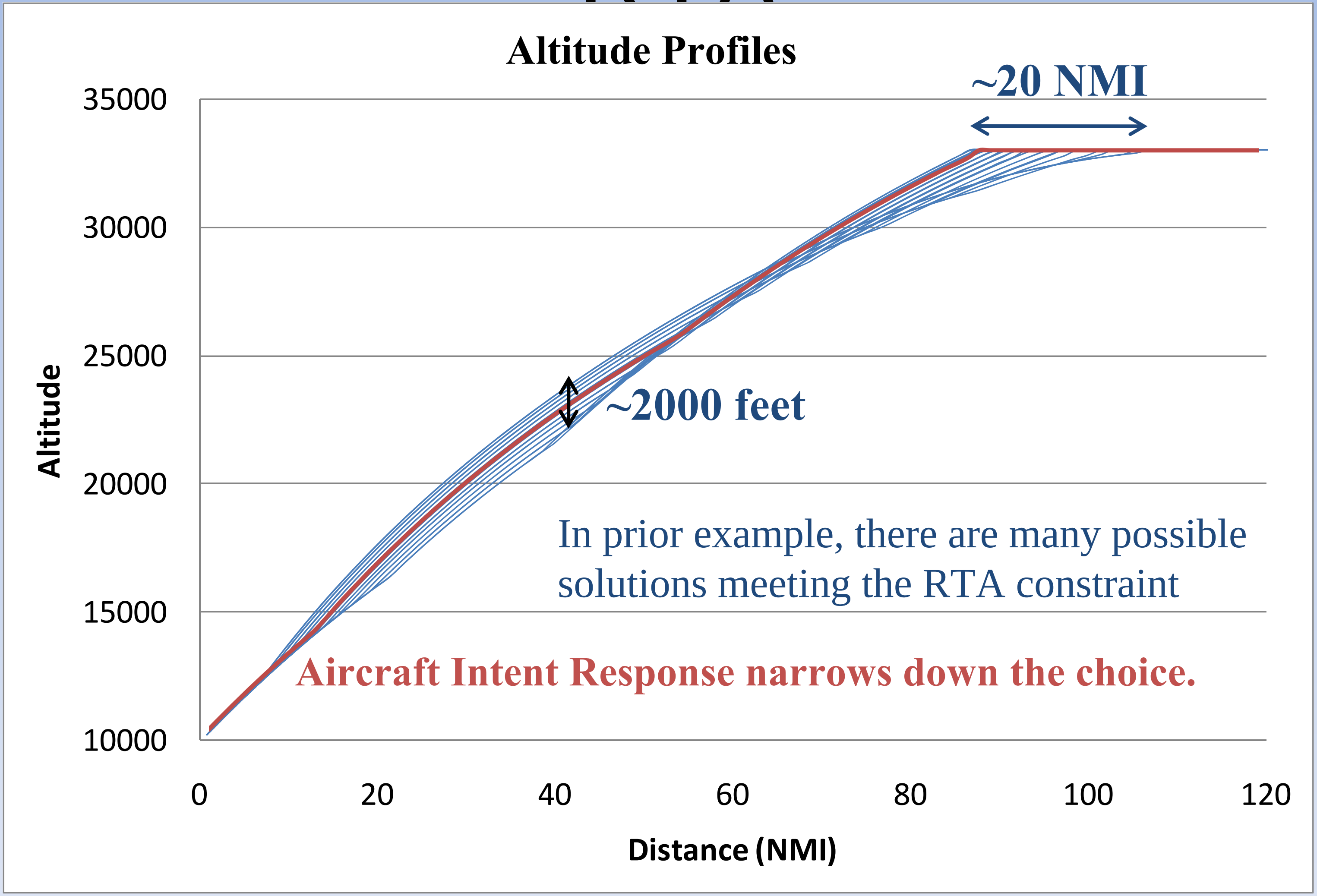

$$\frac{\partial(CAS)}{\partial(\Delta x)} = \frac{1}{V_{avg}} \frac{\partial(CAS)}{\partial(\Delta t)}$$

*Estimated time at the control point as vary CI*

**→ With sensitivity, ground better estimates effect of path stretch**

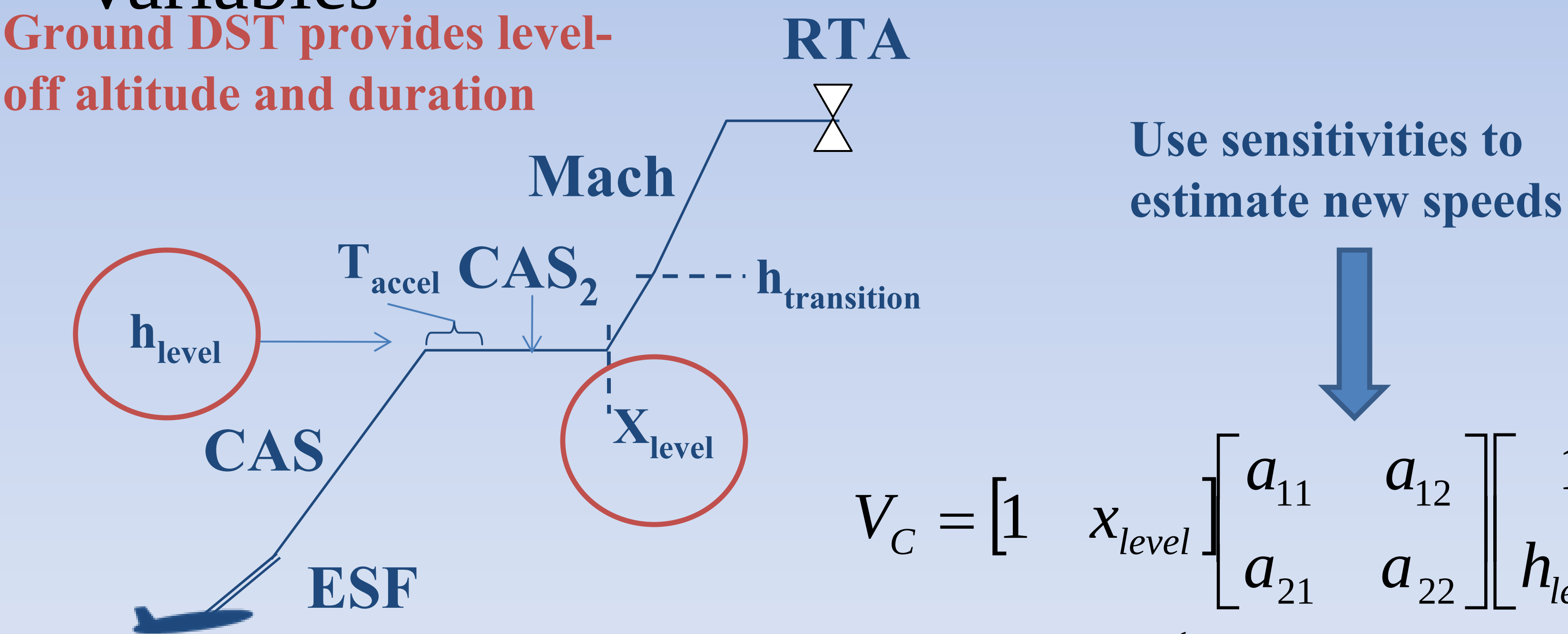
**→ Aircraft knows its own meet-time algorithm, provides sensitivity**

# Alternative Profiles Meeting RTA



# LAIR – Level off example

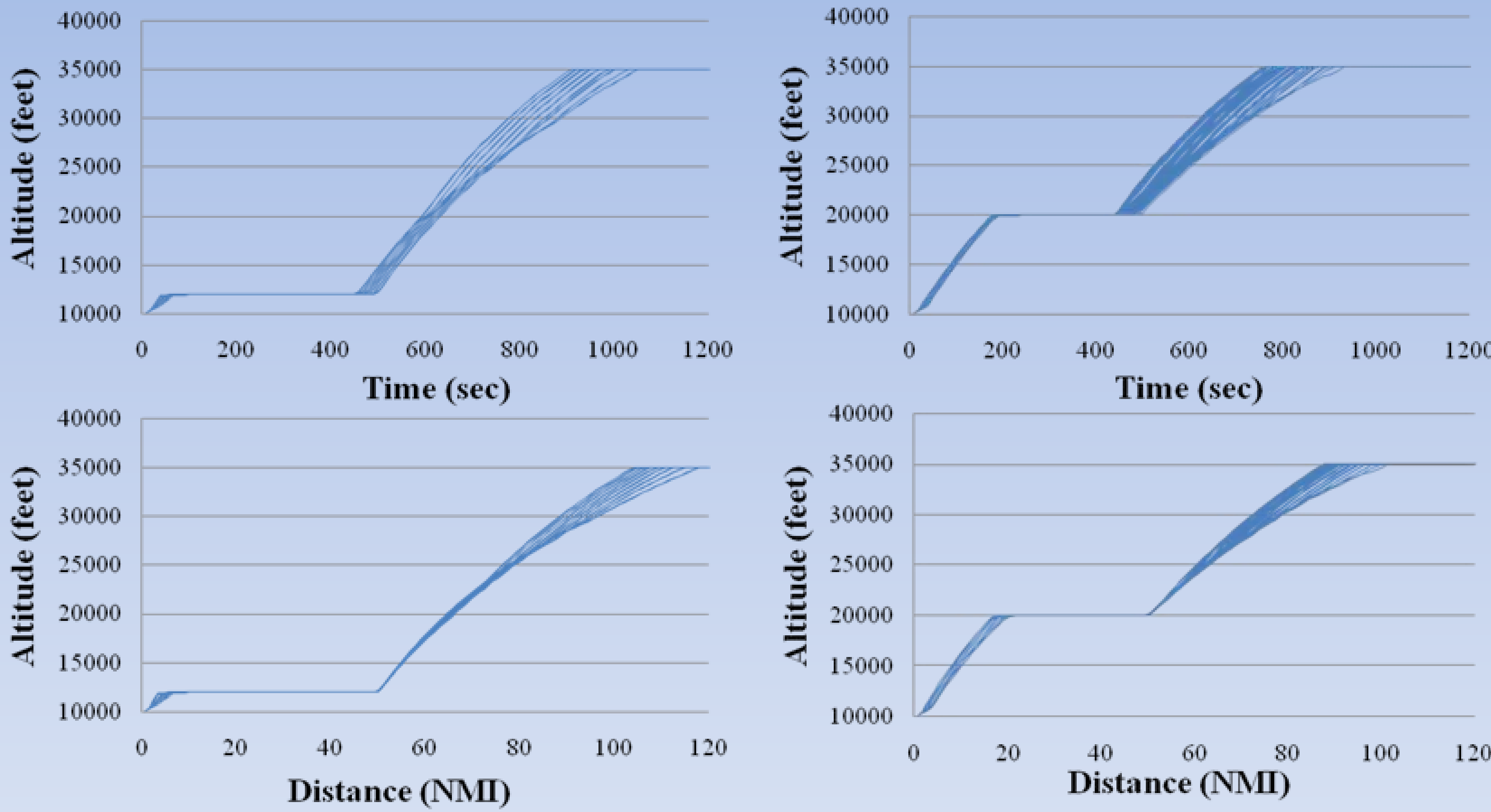
- Temporary altitude in climb has more variables




$$V_C = \begin{bmatrix} 1 & x_{level} \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} 1 \\ h_{level} \end{bmatrix}$$

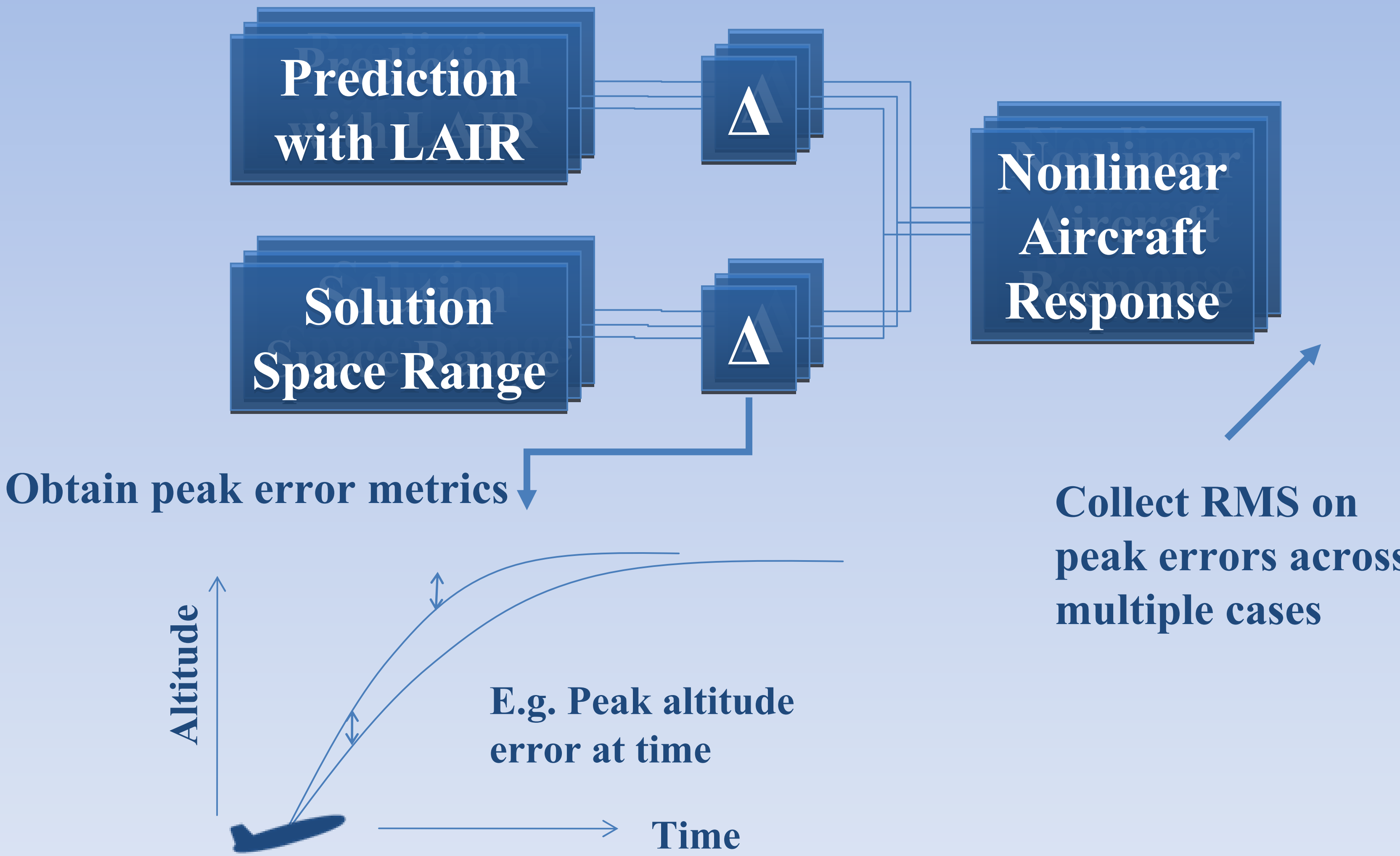
$$V_{CAS_2} = \max\{V_{\min}, \min(V_{\max}, V_c)\}$$

# Alternative level-off profiles

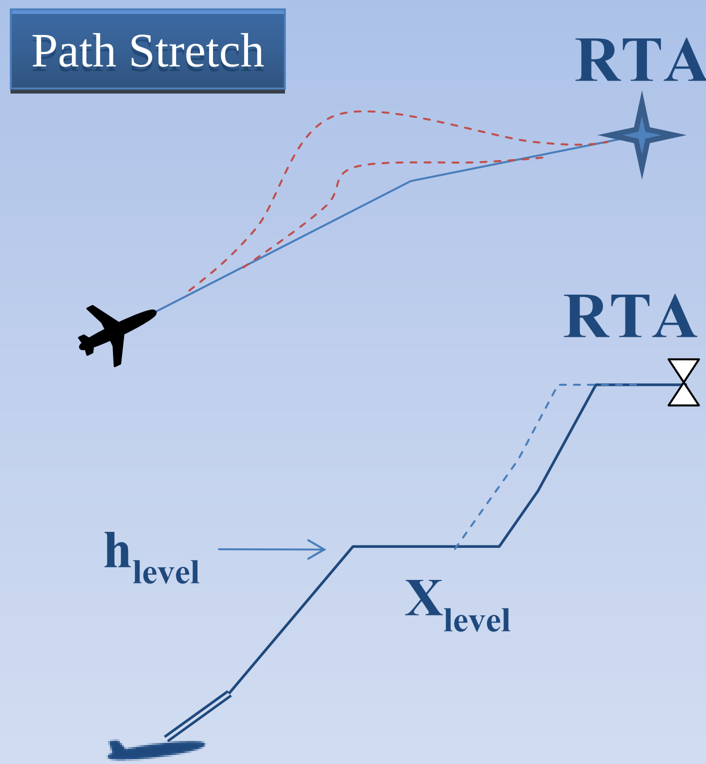



Identical instructions → Different aircraft response → 4D Trajectory variation

# Obtaining Metrics



# Cases




**PS-40: Path stretch w/ 40 seconds delay**

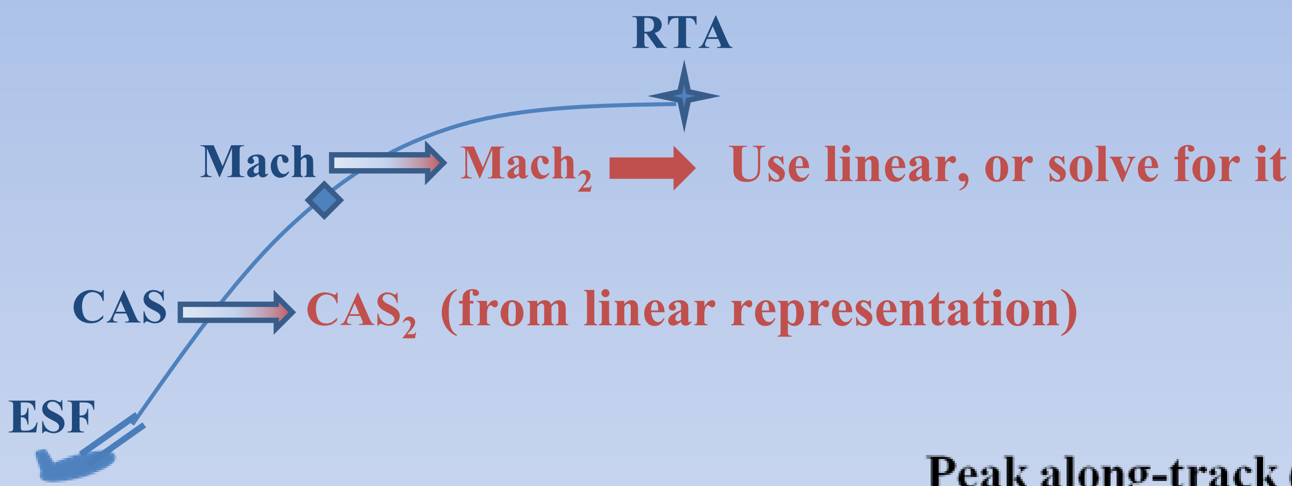
**PS-80: Path stretch w/ 80 seconds delay**

**Alt-50: Altitude hold for 50 NMI**

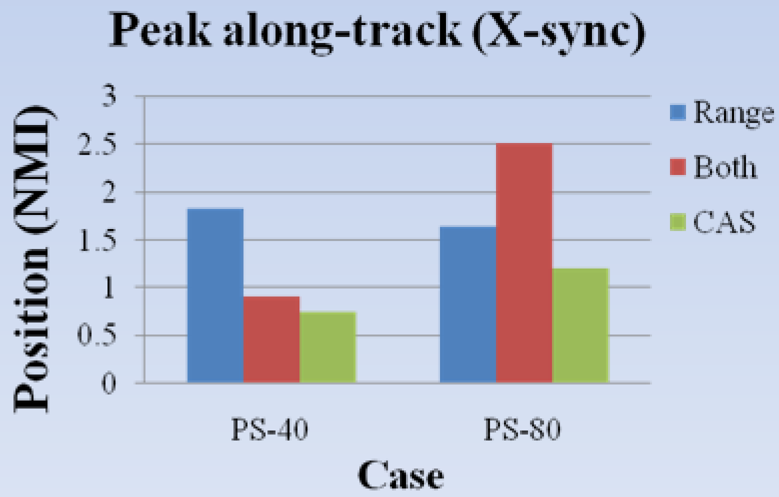
**Alt-75: Altitude hold for 75 NMI**

***Vary flight parameters: cruise level, weight, level-off altitude***

# Appropriate Representation

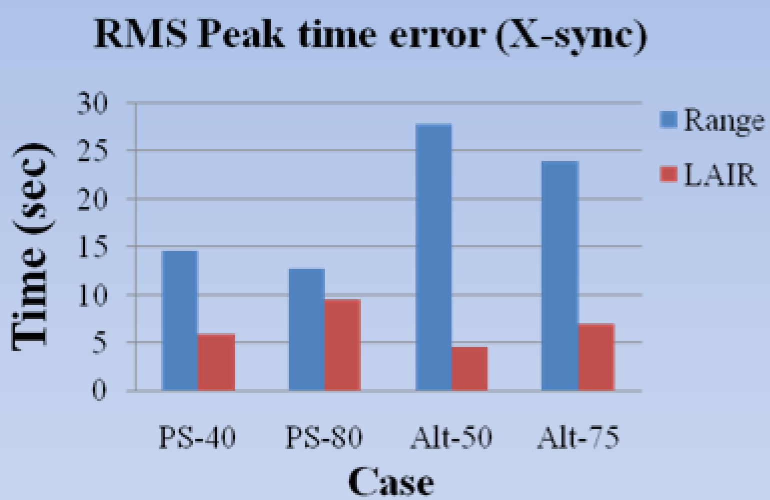


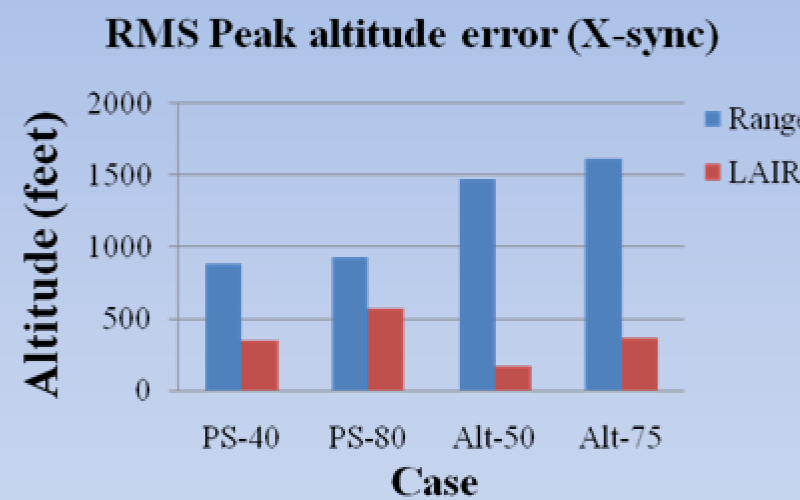

**Using both as linear, don't meet the RTA for PS-80!**

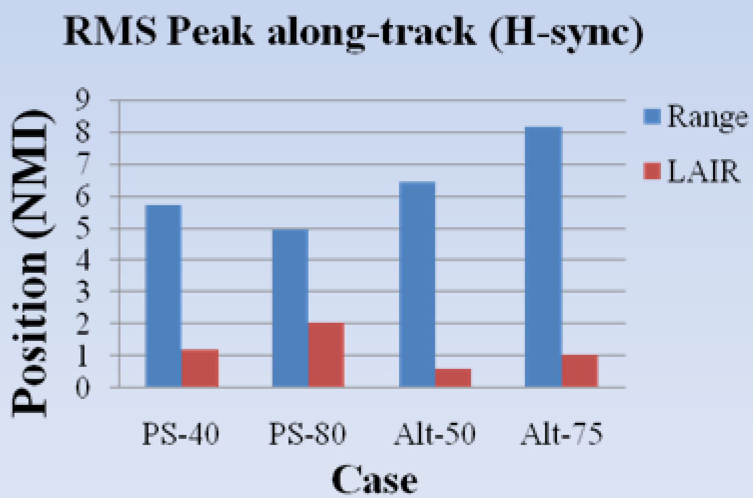



**→Use enough parameters, but no more**

# Results – LAIR reduces errors




***N.B. Errors due to lack of precise intent***

# Summary

- Aircraft intent exchange
  - Reduces errors of representation
  - Provides ability to model excursions
- Ground-based, tactical DSTs need 4DT Prediction
  - Feasible – instructions must be executed
  - Accurate – efficiency & capacity impact via buffers
- Exchange of linear aircraft intent response for "what-if"
  - Significantly improves accuracy due to lack of intent
  - Can provide limits (for feasibility)

# Conclusions

- Linear aircraft intent response
  - Provides one approach for removing the "*but you don't know what the aircraft's going to do*" anxiety
  - First order sensitivity provides large intent-error reductions (34-90+% reduction in various metrics)
  - Small additional information exchange required
  - No need to exchange objectives and cost functions
- This effort was exploration
  - Further investigation into general formulations for exchange
  - Compatibility with aircraft intent approach