MDO Techniques and Novel Aircraft Control Systems

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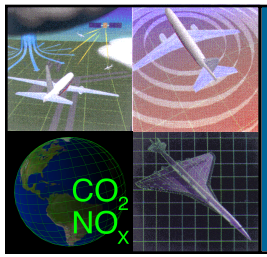
MDO Branch Web site: http://fmad-www.larc.nasa.gov/mdob/MDOB/

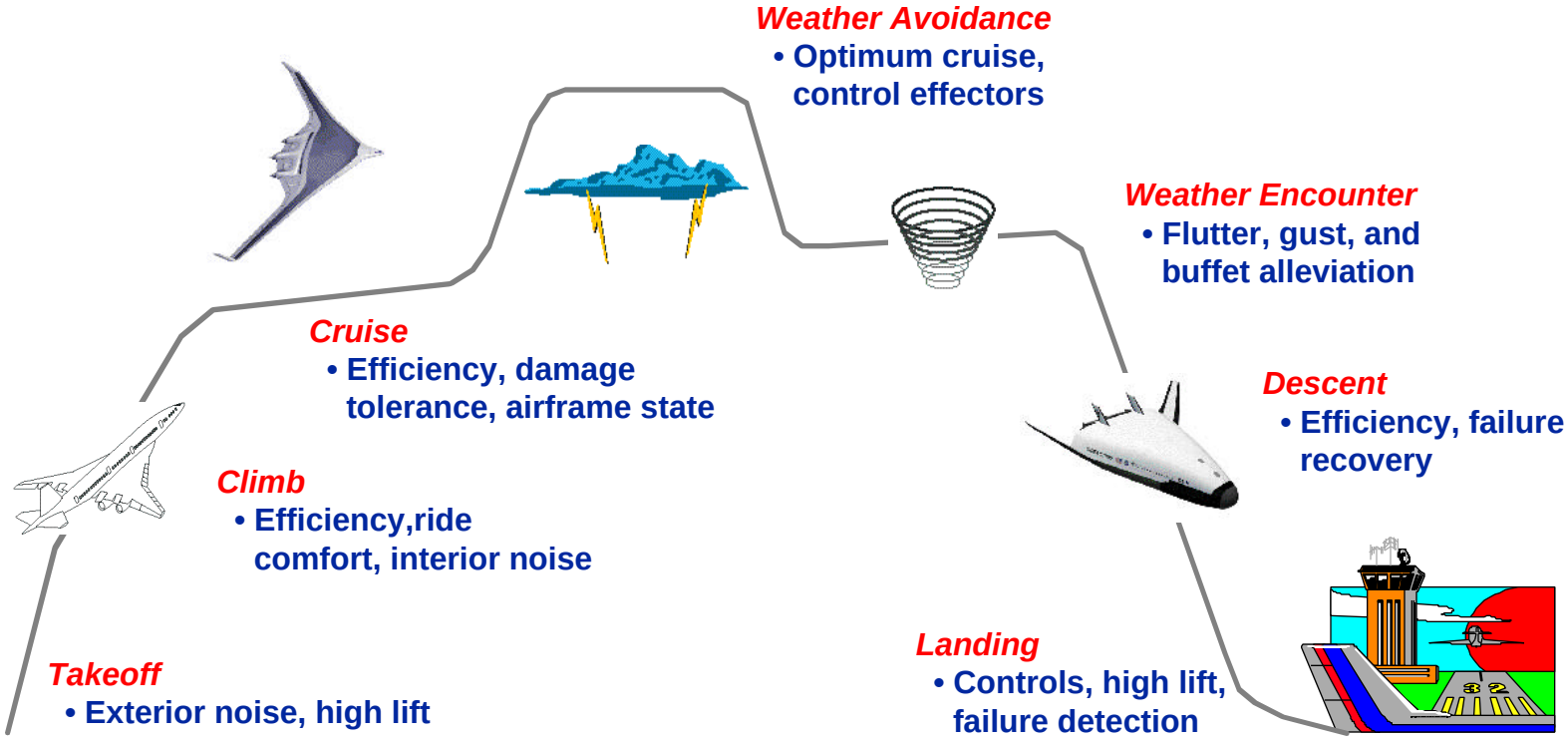
Outline

- Background - NASA Morphing Program
- Control system design - conventional systems
- Control system design - novel systems
  - Create CFD model
  - Predict control moments
  - Select best locations using genetic algorithm (GA)
  - Design and test control laws
- Summary - value added by MDO

NASA Langley Morphing Program
Goal and Vision

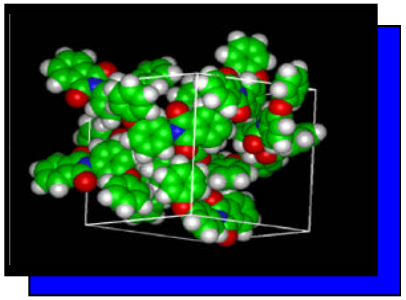


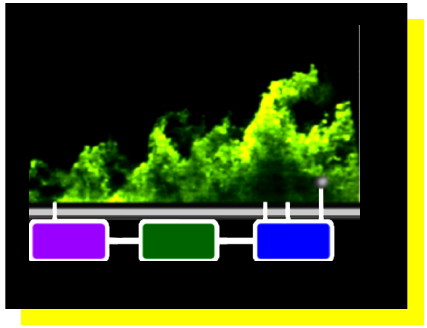
Develop smart devices using active component technologies to enable self-adaptive flight for a revolutionary improvement in efficiency and safety



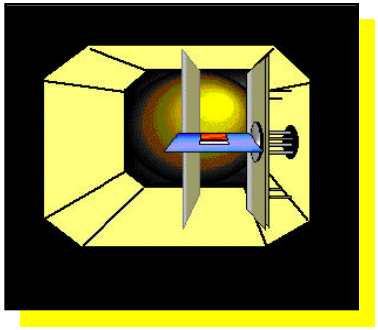
Morphing - Program Elements

Materials



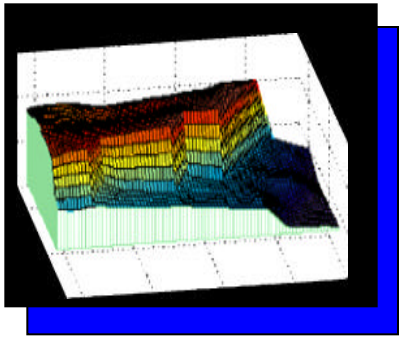


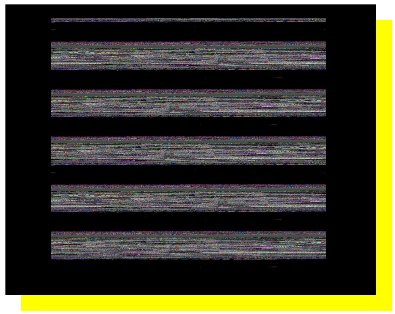
Active Flow Control



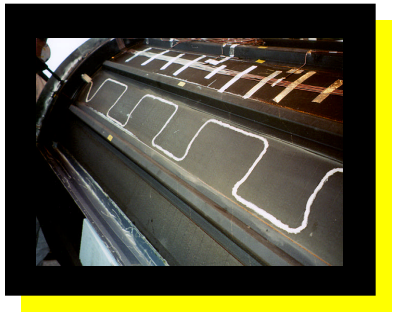
Aeroservoelasticity

Tools



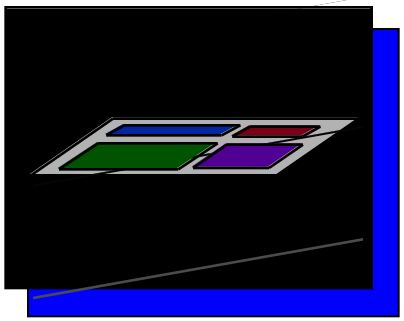


Noise Control

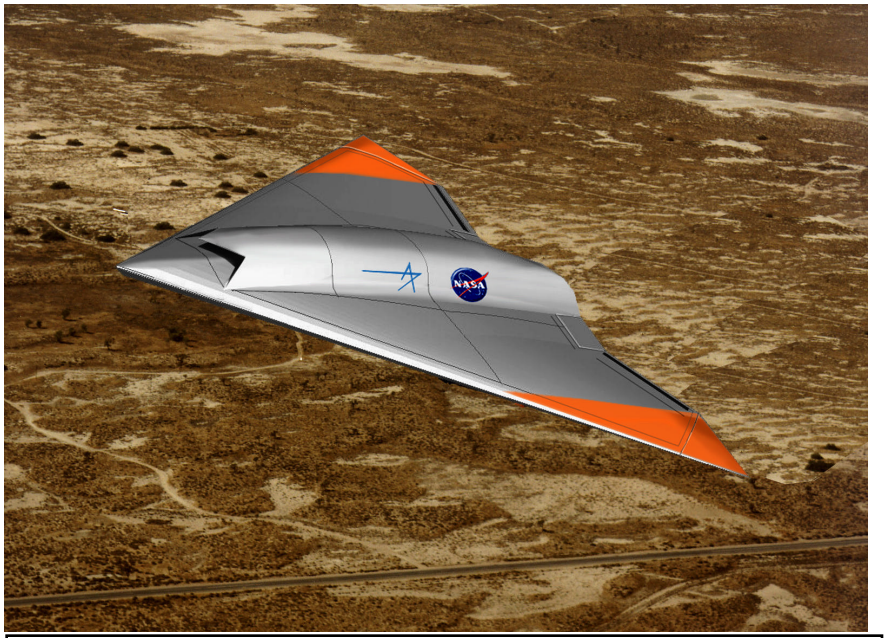


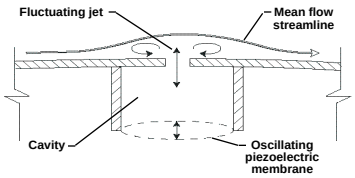
Health Monitoring

Integration

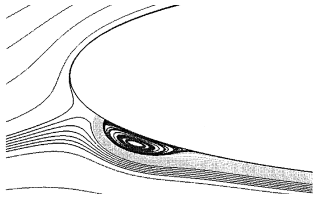


NASA Morphing Program Studies
Novel Flight Control Options





Synthetic Jet



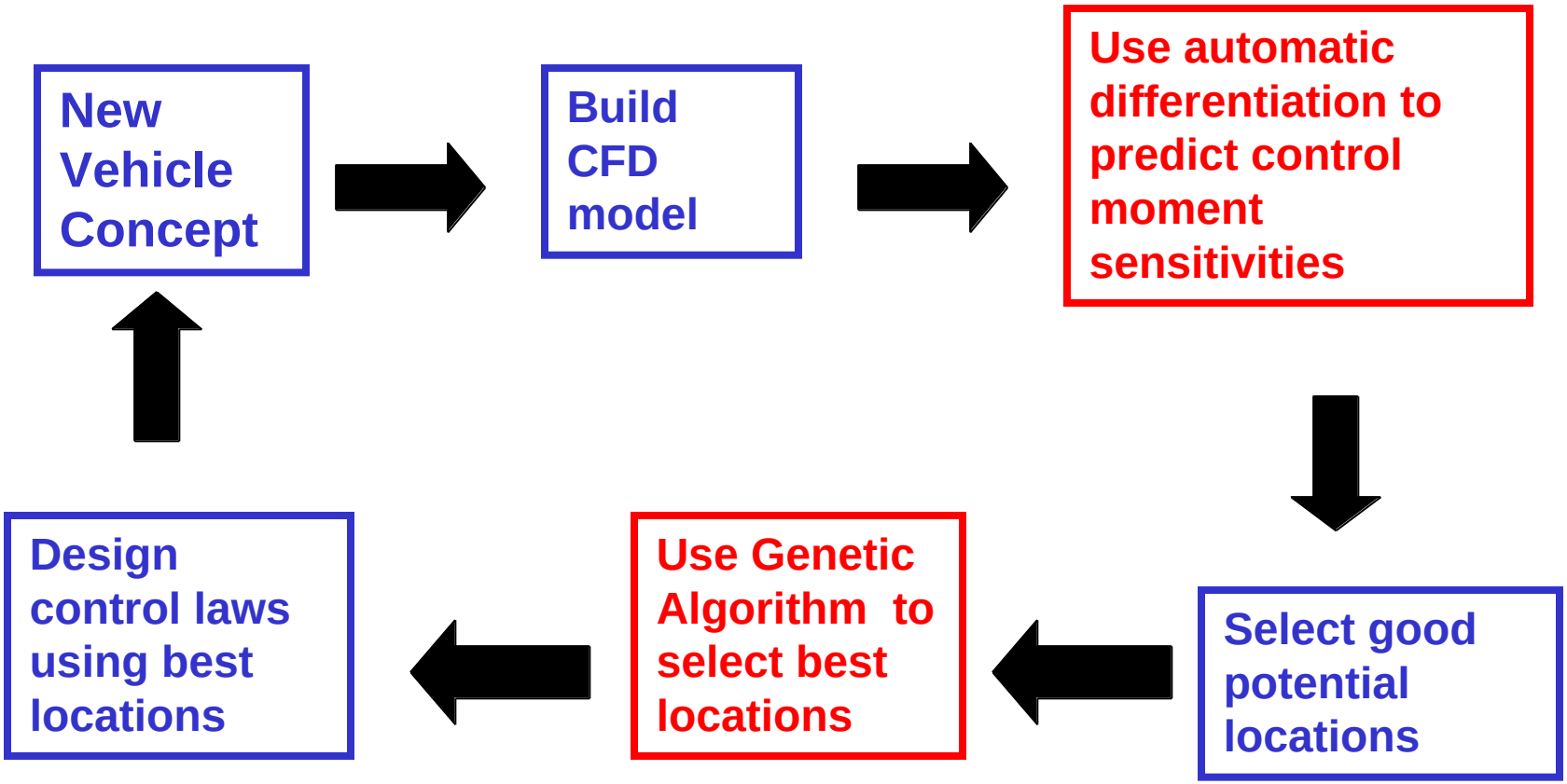
Virtual bump

- **Effectors:** zero mass-flow jets which change apparent shape of wing
- **Challenges:** (1) provide uncoupled pitch, roll and yaw with fewest number of devices (2) design highly distributed control system with one-sided effectors
- **Goal:** stealthy maneuvering

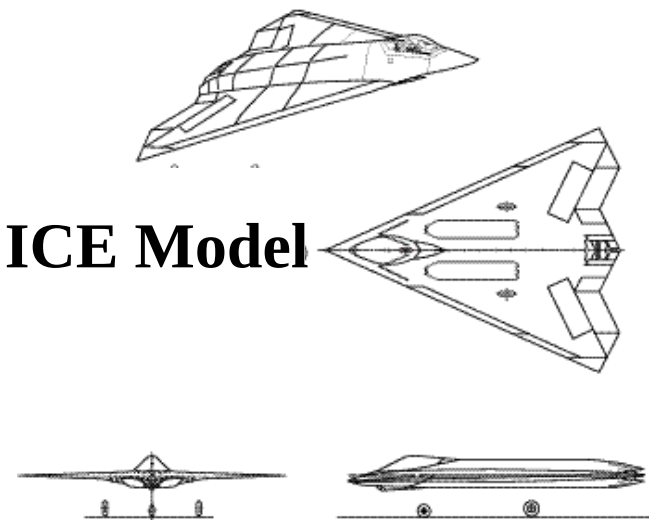
Conventional Control System Design

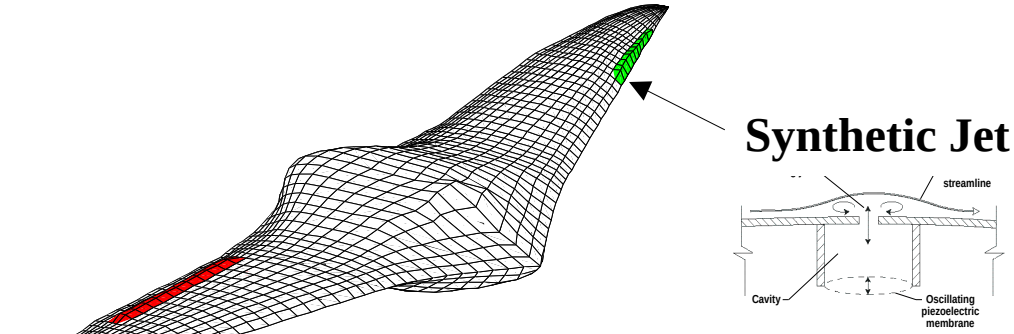
- Current designs use a small number of conventional control devices (e.g. flaps)
- Conceptual design relies on historical database for locating and sizing control devices
- Aircraft configuration is frozen before control law designers are included
- Control law designers use measured data to predict control effectiveness

Novel Control System Design Process Using MDO Techniques



MDO Techniques Tested on Lockheed-Martin ICE Configuration





Stealthy tactical vehicle concept → CFD model → Device placement

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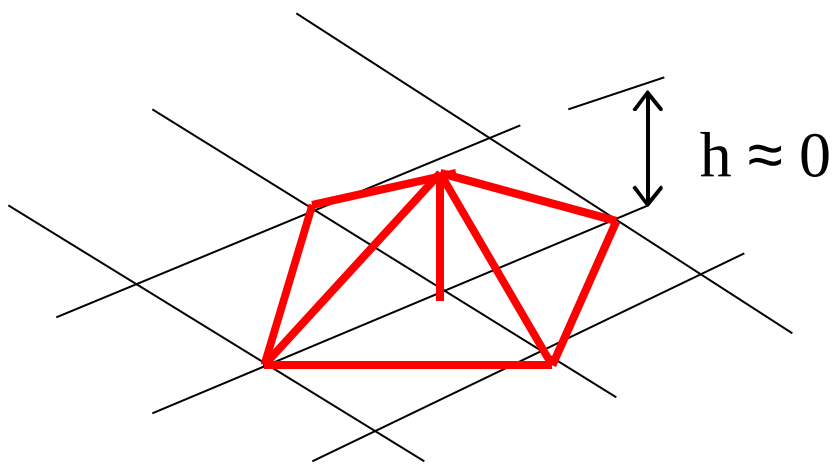
Predict Control Moments
Use Linear CFD Code (PMARC)

(1) Distort grid to model virtual shape change.

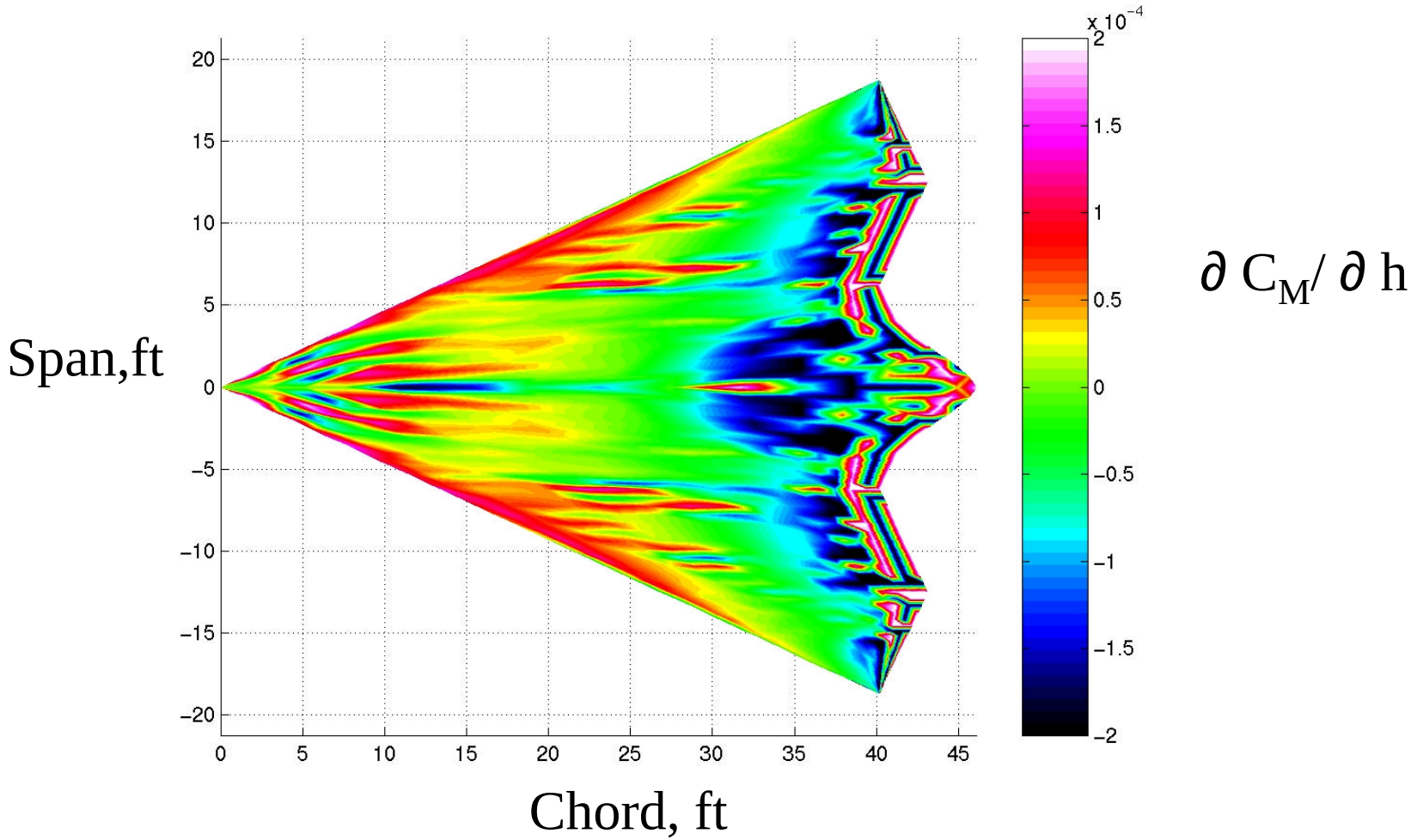


(2) Calculate $\partial C_M / \partial h$ for each grid point.

Use finite difference approx or automate using adjoint option in ADIFOR.

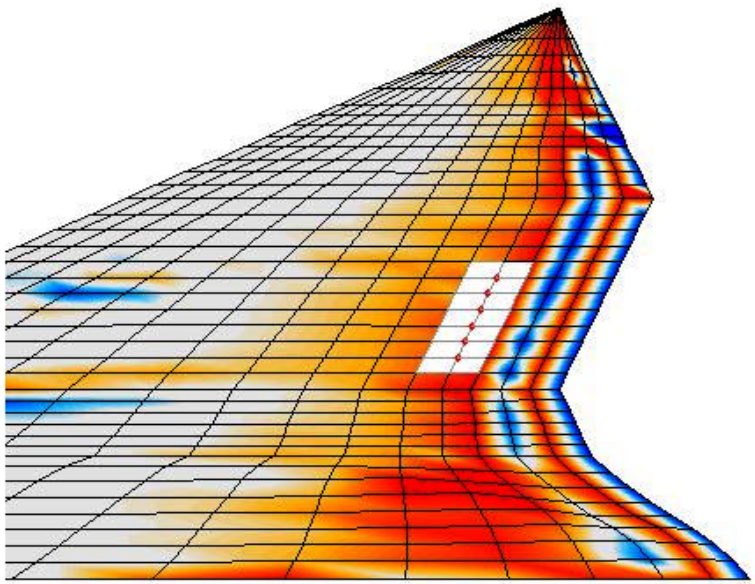
(3) Produce contour plots as a guide for control law designers.

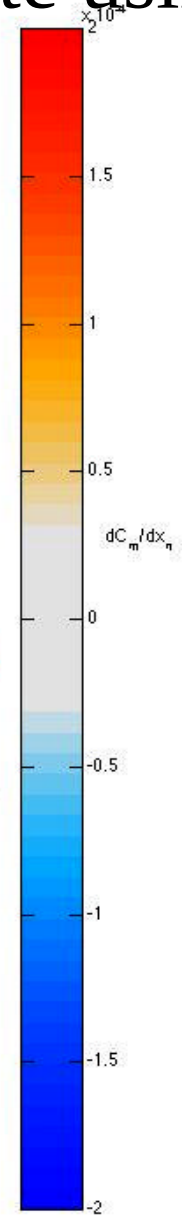
Predicted Change in Pitching Moment due to a Normal Displacement at Grid Points



Reference: AIAA Paper 99-3136 (Park, Green, Montgomery, and Raney)

Select Potential Effector Arrays and Evaluate using PMARC





Select

Zoom

Height

Eval

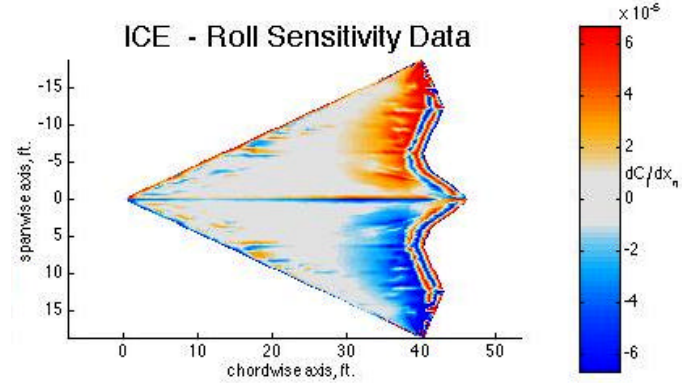
Grid

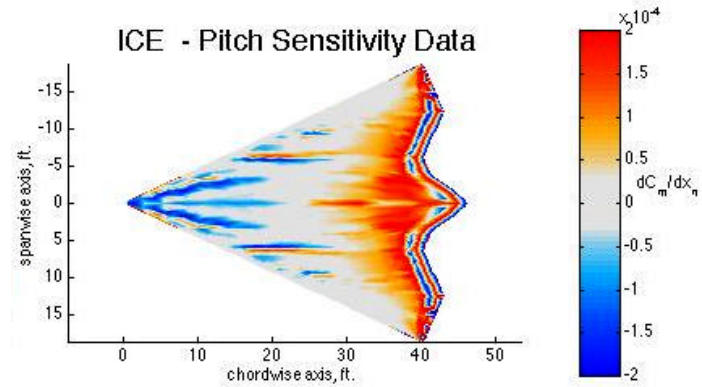
PMARC

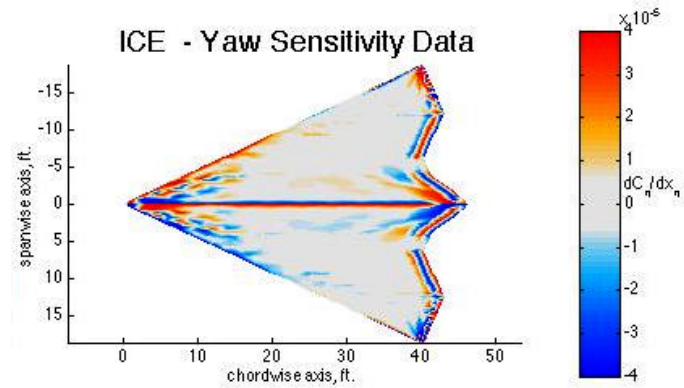
Clear

Info

Close



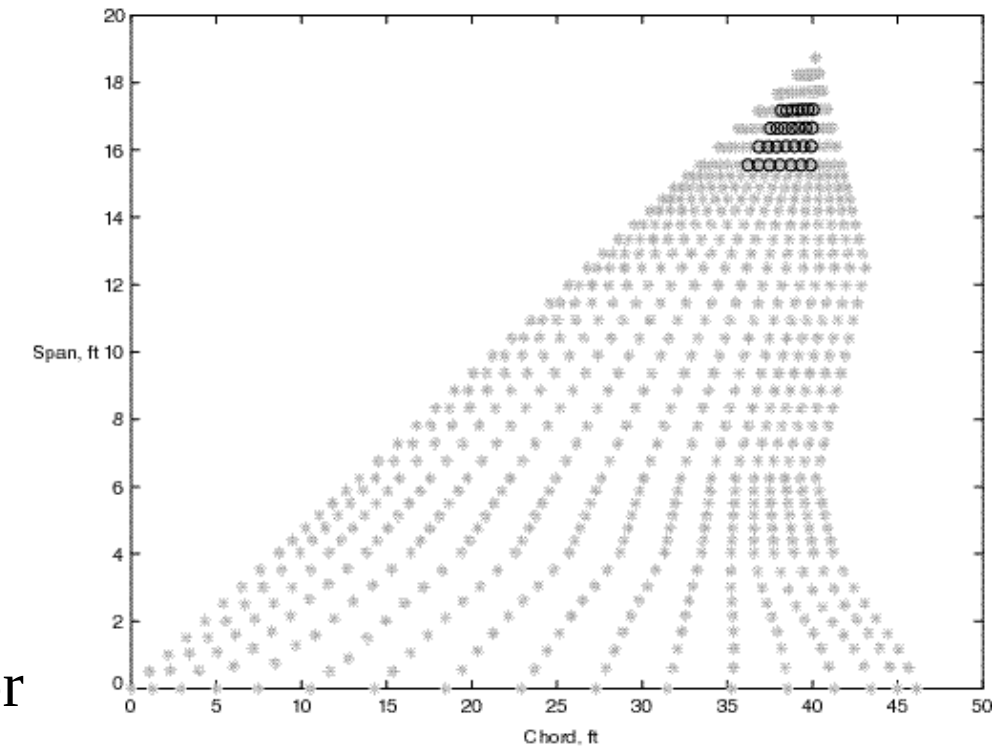




Estimated Cl per unit deflection:
0.00008050
Estimated Cm per unit deflection:
0.00020783
Estimated Cn per unit deflection:
0.00000012
Effectiveness of previously evaluated designs (Cl,Cm,Cn, ordered latest to first):

Select Potential Effector Arrays

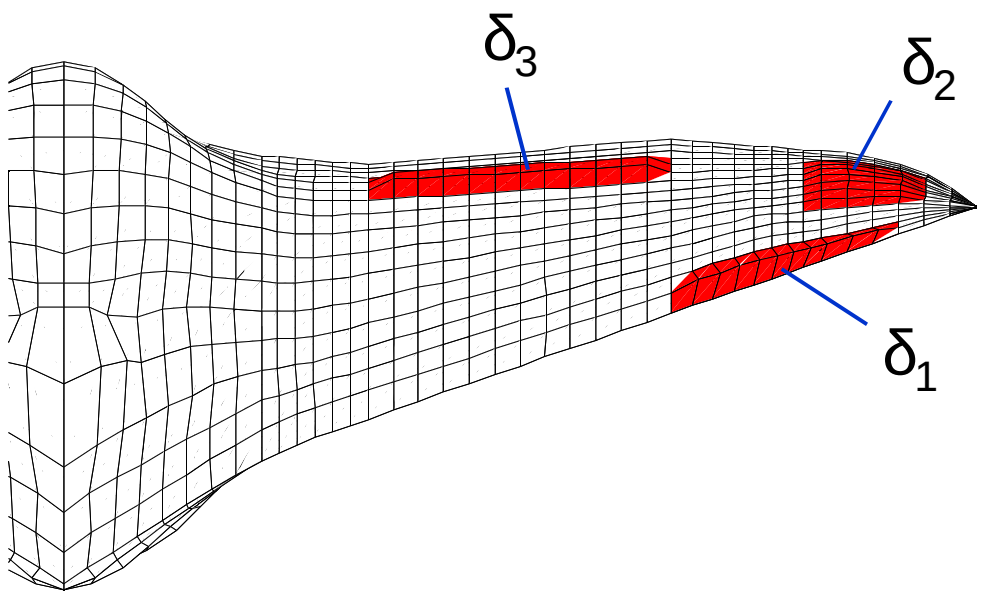
- Use 17x41 grid of potential locations
- Assume linear superposition
- Use engineering judgement to select workable choices
- Evaluate each effector array with PMARC



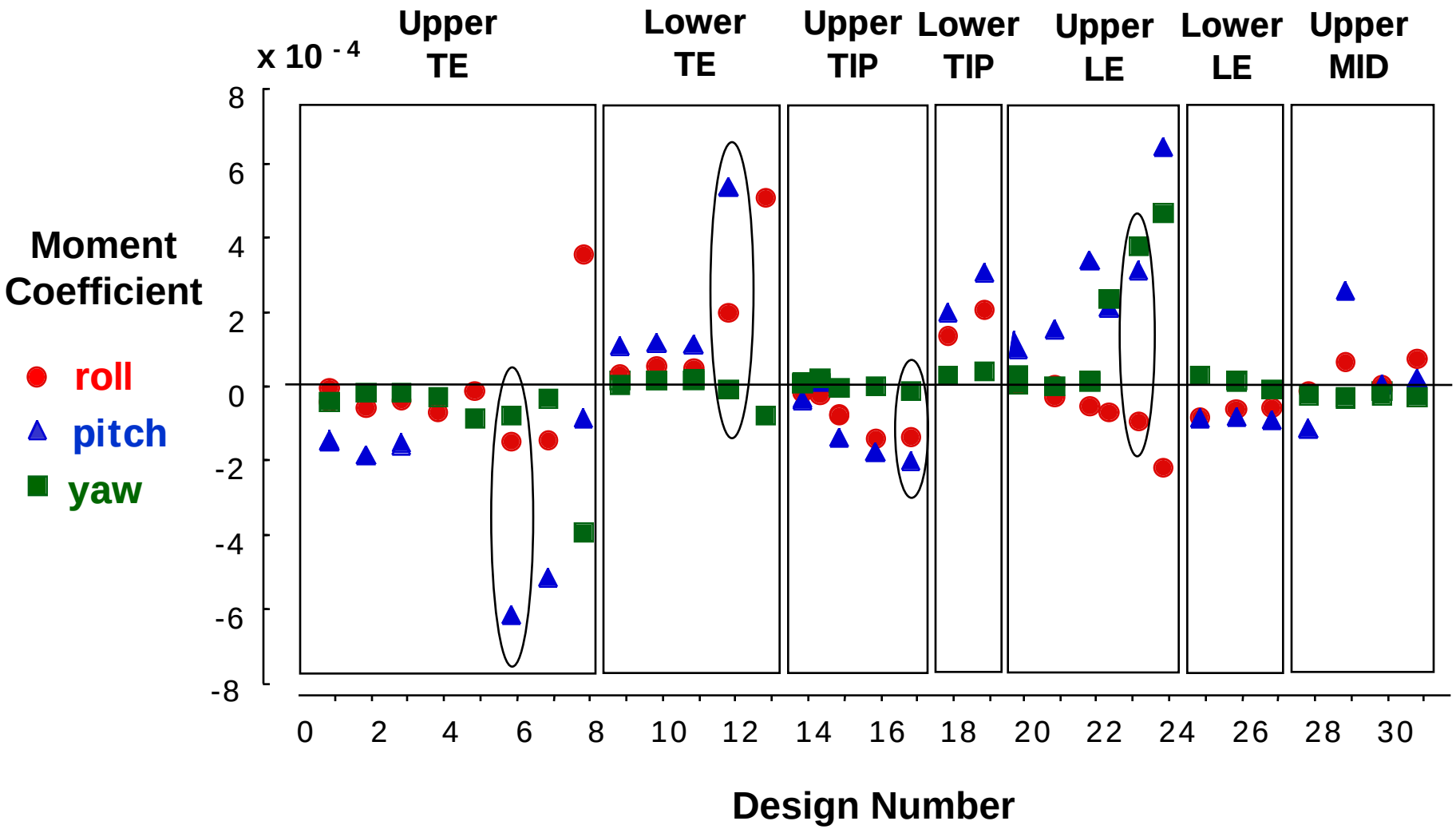
o = selected locations

Modeling Caveats

- Potential flow (PMARC)
- Control deployments do not induce separation
- No actuator deployment dynamics
- Static control effectiveness predictions
- Effector array interactions are not considered (δ_1 does not change the effectiveness of δ_2 or δ_3)



Evaluate Promising Effector Arrays



- Generally, low-authority coupled moment producers

Improve Control Effectiveness

- Select & evaluate combinations of effector arrays
- Place arrays on upper and/or lower surface of semi-span model (i.e., assume symmetric pairs of arrays)
- Estimate moments for Roll (C_l), Pitch (C_m) and Yaw (C_n) using control moment sensitivities
- Change height of each effector array to produce desired uncoupled moment (e.g. C_l without C_m or C_n)
- Alternately, automate the above and use GA to find the best possible combinations

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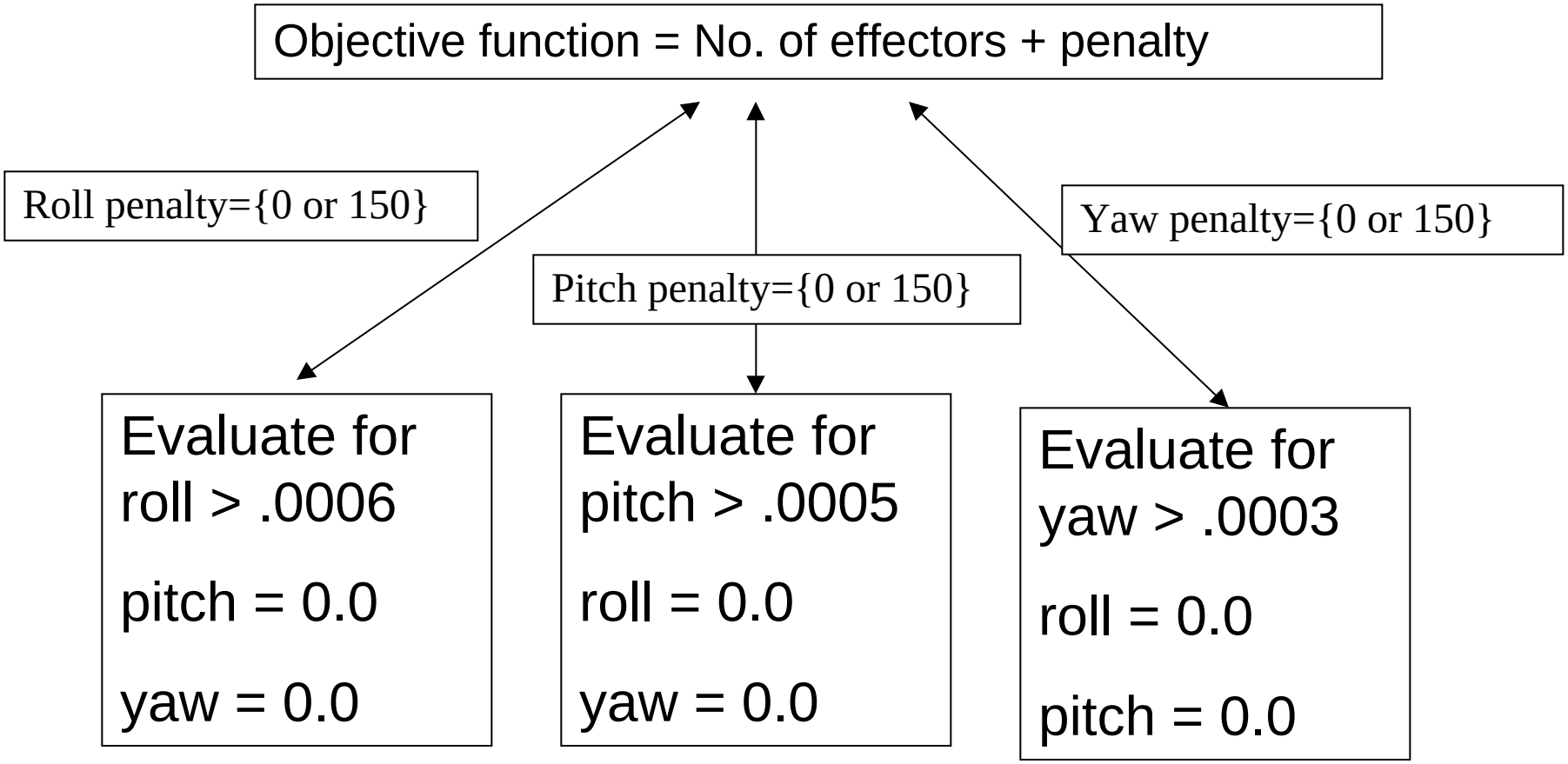
GA Selects Best Effector Suite from Combinations of Potential Arrays



Use GA to Select Best Effector Suite

- Phase I
  - Choose suites of effectors from arrays selected by controls expert
  - Choose from arrays numbered 1-8 in each of seven areas
  - Set target moments based on best suite found manually
- Phase II
  - Enormous design space
  - Choose up to 100 effectors from 349 individual devices
  - Set targets based on the performance found in Phase I

Phase I - Results

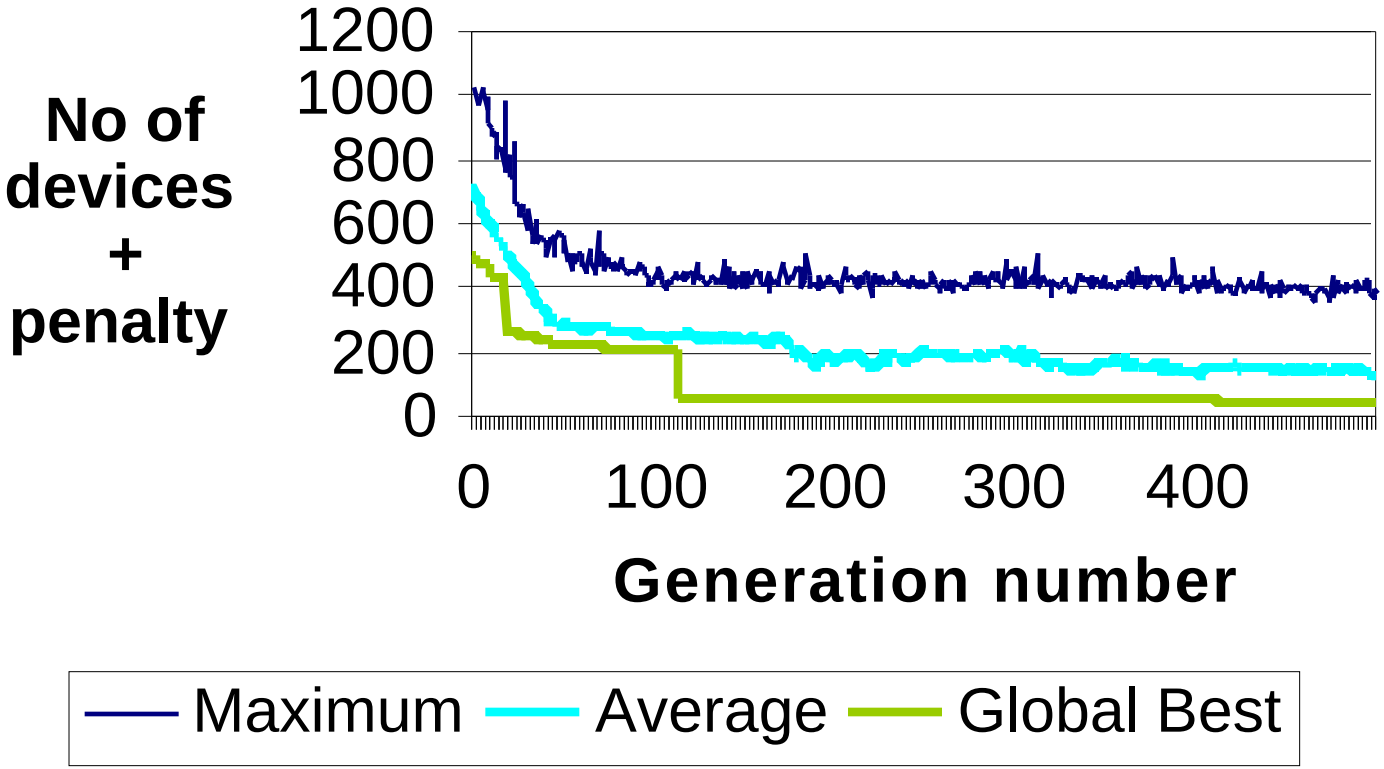
- GA identifies a suite of five arrays with 96 devices which meets all targets
- GA performance
  - Possible combinations about 4,800,000
  - Population size = 200
  - Max number of generations = 300
  - Percentage of design space searched = 1%
  - Approximate CPU time on SUN Ultra-II = 1 hour

Phase II Results

- GA finds suite of 45 devices which meets all targets
- Targets reset based on best suite found in Phase I.
- GA performance
  - Possible combinations of 349 taken 100 at a time about 4×10^{99}
  - Population size = 300
  - Max number of generations = 500
  - GA finds good solution after 150,000 evaluations
  - Approximate CPU time on SUN Ultra-II = 8 hours

Typical GA Convergence

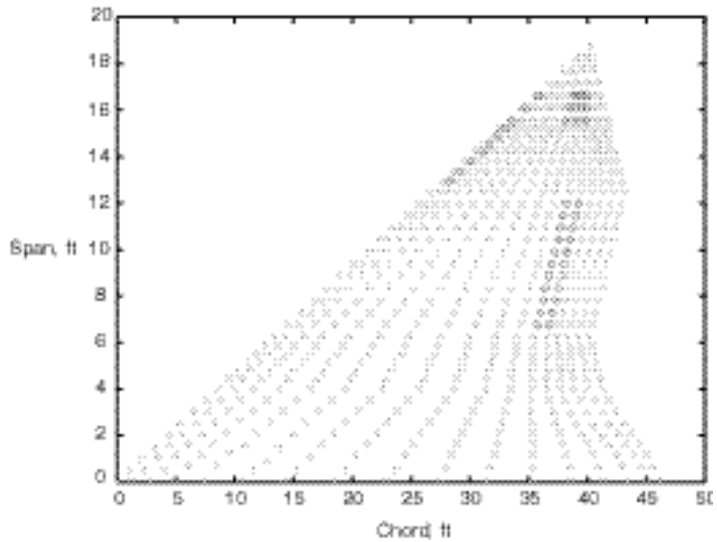
Phase-II GA finds feasible solution after 100 Generations

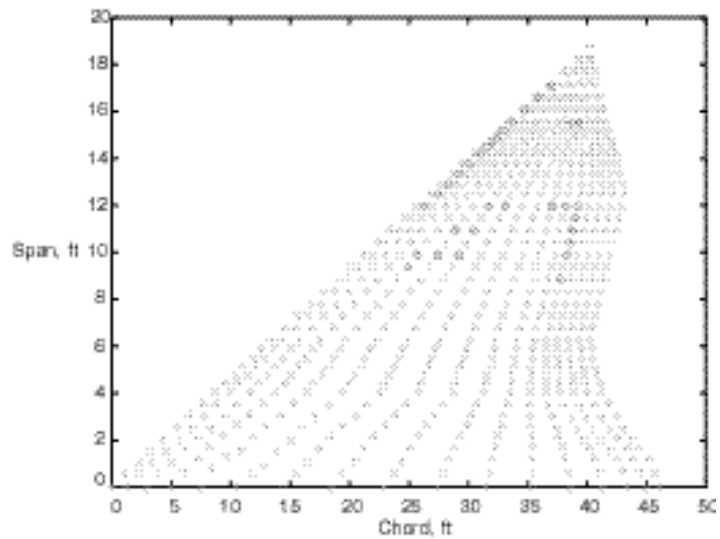


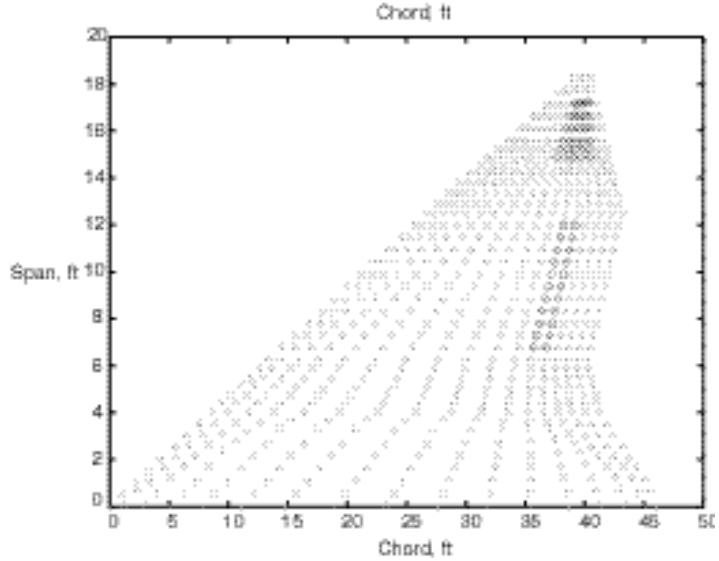
Comparison of Phase I and Phase II Results

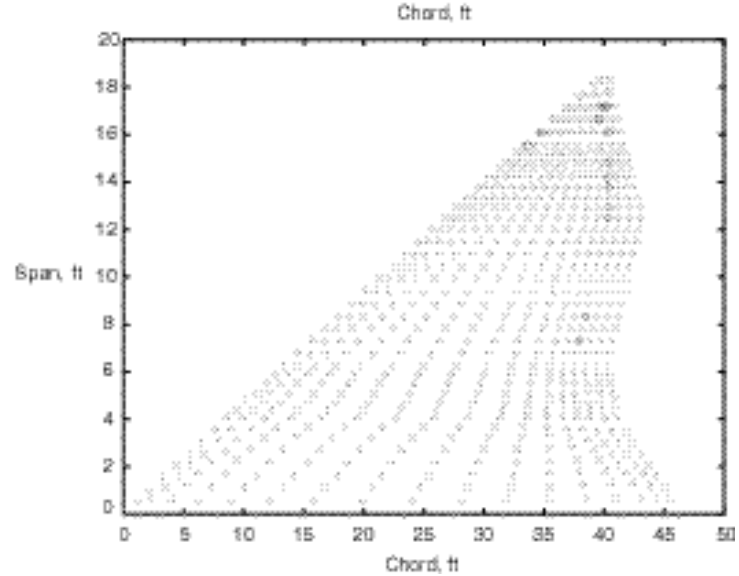
Phase I - 96 devices

Phase II - 45 devices









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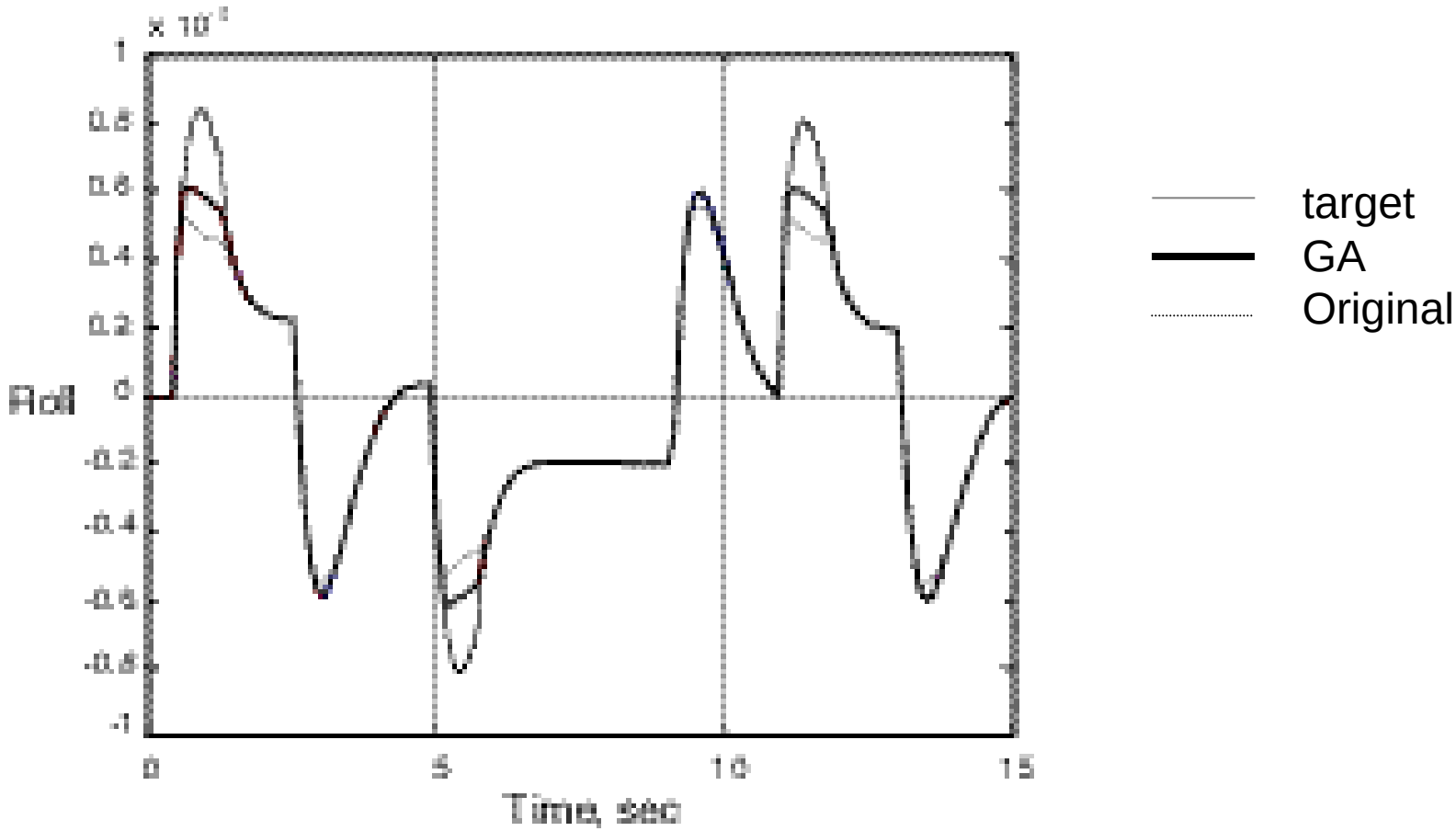
Test of Simulated Controller

Suite chosen by GA performs slightly better than original suite



Note: this is a + - 20 degree bank angle doublet with roll rate < 10 deg/s

Summary

- NASA Langley Morphing Program studies control options generated by application of smart materials concepts
- MDO tools add value to the control system design process
  - ADIFOR provides control moment sensitivities from CFD model
  - Thus control laws can be simulated & tested at early design stage
  - Genetic algorithm selects best effector suites
- Issues still under investigation at Langley:
  - Accurate CFD models of synthetic jets needed
  - Interaction of adjacent devices must be considered
  - Time lag required to activate an effector must be included in controls simulation