# A Parallel Approach to Optimum Actuator Selection with a Genetic Algorithm

**James L. Rogers**
**NASA Langley Research Center**

**AIAA**
**Guidance, Navigation, and Control Conference**

**Denver, CO**

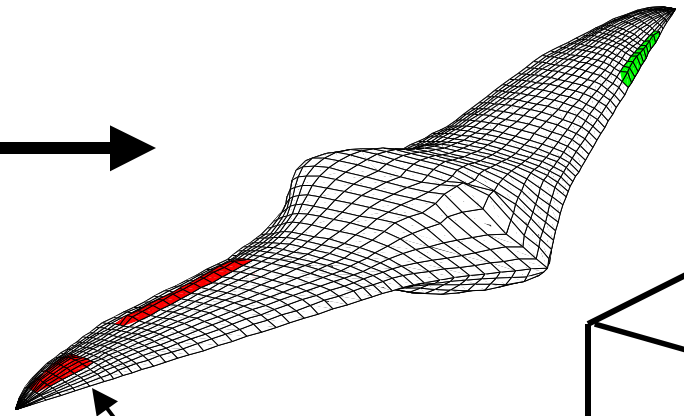
**August 14-17, 2000**

# Outline

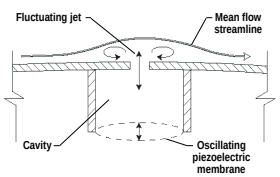
- **Background and models**
- **Genetic Algorithm (GA) approach**
- **Single processor results**
- **Parallel processor results**
- **Timing results**
- **Future plans**
- **Concluding remarks**

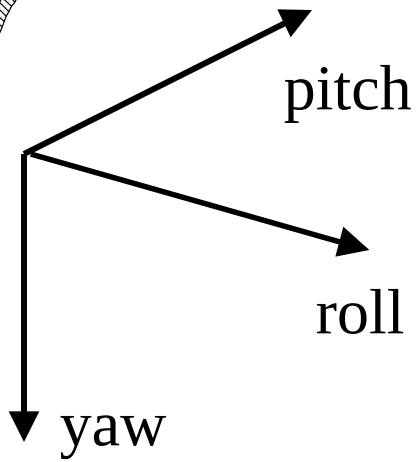
# Why Do This Research?

Example of a seamless aircraft



**Synthetic Jet Actuators**




Replace conventional control devices like flaps and ailerons with synthetic jet actuators to create a seamless aircraft with no moving control surfaces

# Problem Statement

**Problem**
Minimize the number of actuators needed to provide the uncoupled moments about the pitch, roll, and yaw axes.

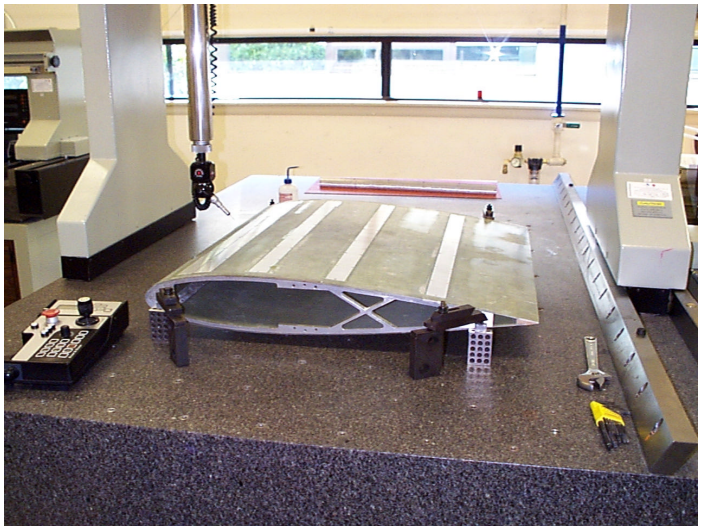
**Concern**
Developing control laws is a time consuming process. Only the most promising configurations should be presented to the Controls specialist.

**Our task**
Develop software tools to significantly reduce the time required to optimally select and distribute the actuators over the aircraft surface.

**Phase 1 -** Develop tools for a simplified model as a proof of concept
Single processor
Parallel processor
**Phase 2 -** Expand to a more complex model

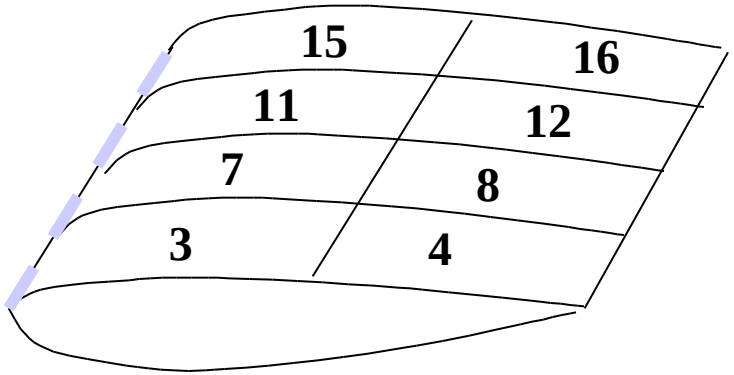
# Simplified Model

## Untapered, unswept wing based on NACA 0015 airfoil

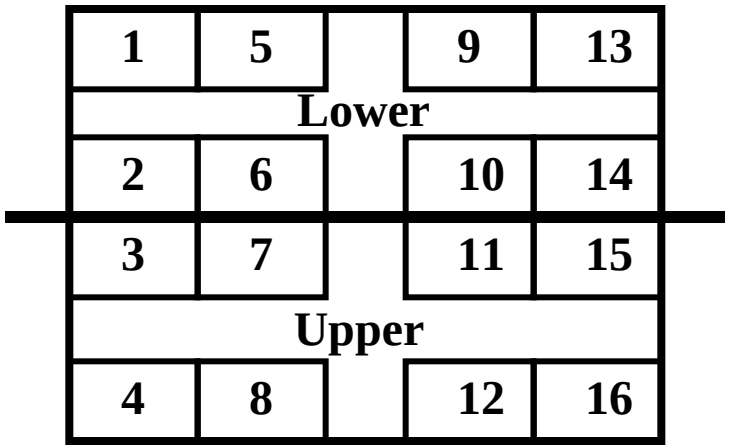


**Wind tunnel model**

**Analysis model**

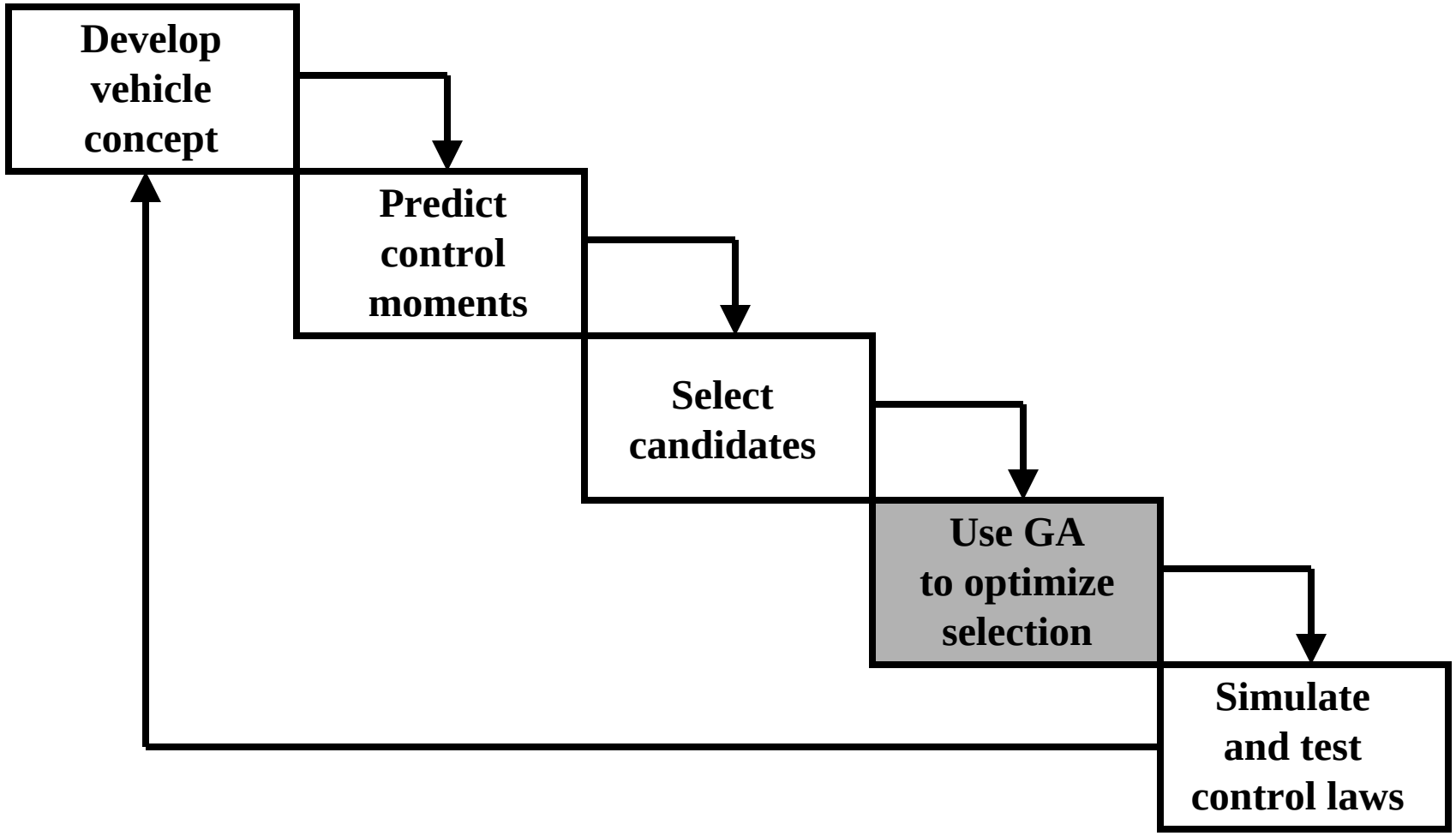



**Unwrapped model**




**Leading Edge**

# Control System Design Process



# Multi-Objective Application

## (One Objective for Each of Pitch, Roll, and Yaw Subproblems)

Given 16 actuator locations, find the minimum number of actuators and their placement to provide uncoupled pitch, roll, and yaw moments.

Penalize the objective function for the **pitch subproblem** if:

- $|C_l| > .001$
- $|C_n| > .001$
- number actuators < 2 (take advantage of engineering knowledge)
- $|\mathbf{C_m}| < .001$

Similar penalties for the roll and yaw subproblems.

# Genetic Algorithm Approach

- Rapidly examine a large number of candidate actuator placements.
- Select the optimum placement based on the minimum number of actuators as well as the moment and coupling data.
- The fitness of a population member is determined by calling a 3D, low-order, potential-flow panel program. Must have very fast function evaluations because it is called so often.
- Penalize fitness if constraints are violated.

# GA Information

- Population size = 100 (different populations for each subproblem)

- Population member - string of length 16 (0 1 0 1 0 0 1 1 0 1 1 1 0 0 0 1)
  1 indicates an active actuator while 0 indicates an unused actuator

- Fitness function = sum of active actuators plus constraint (if any)

- Absolute values used for moments

# GA Operations

**Selection - based on fitness**

Tournament approach retains the best patterns for next generation

0011001100110011 f(x) = 8 → Tournament → 1000000100000010

1000000100000010 f(x) = 3 → Tournament

**Single point crossover - combines features of two parents**

Parent 1 - 1 1 1 1 1 1 Parent 2 - 0 0 0 0 0 0

Randomly generated crossover point - 2

Child 1 - 1 1 0 0 0 0 Child 2 - 0 0 1 1 1 1

**Mutation - introduces new patterns, rate = .01**

Before - 0 0 0 0 0 0

Randomly generated mutation point - 4

After - 0 0 0 1 0 0

# Computing the Composite Fitness

## Multilevel Optimization

The string 0 1 1 0 0 0 1 0 0 0 0 1 0 0 1 0
indicates there are actuators in locations 2 3 7 12 and 15

Composite fitness computed using an OR function

| | |
|---|---|
| Location | 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 |
| Pitch (4) | 0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 1 |
| Roll (4) | 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 |
| Yaw (4) | 0 0 0 0 0 0 0 0 0 1 1 0 1 0 0 1 |

---

| | |
|---|---|
| Composite (9) | 0 0 0 1 0 1 1 1 1 1 1 0 1 0 0 1 |
| Location | 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 |

# Problems Encountered and Resolved

•Crossovers kept producing the same strings

Corrected by only crossing different strings

• Originally looked at composite strings inefficiently by computing the composite a member at a time, for example:

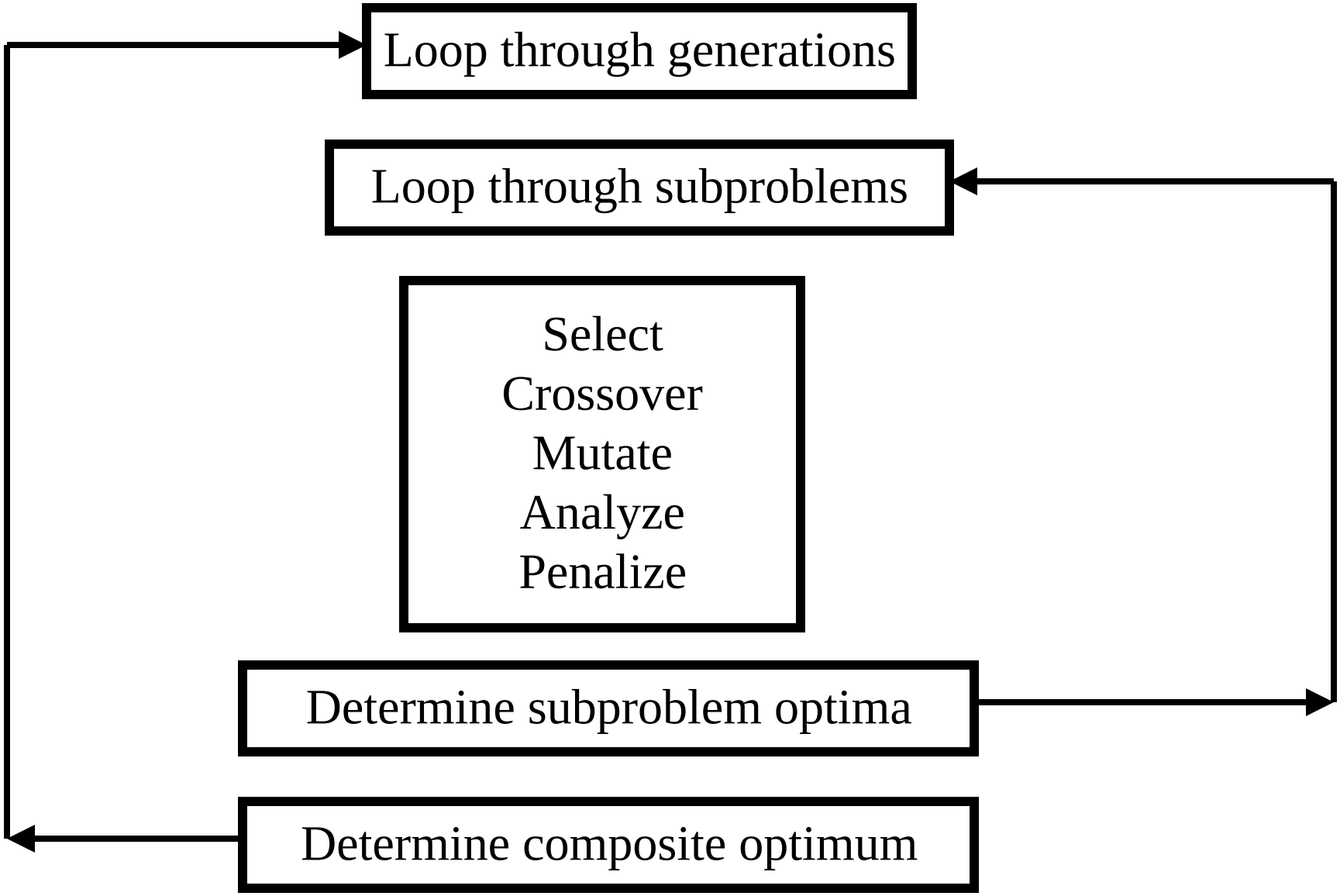
Member 5 pitch = 4 roll = 10 yaw = 4 composite = 13
Member 10 pitch = 10 roll = 4 yaw = 10 composite = 10

Corrected by saving all valid strings and comparing

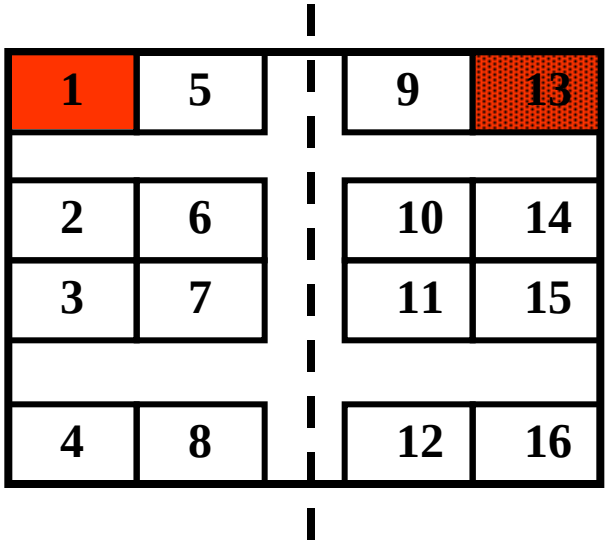
pitch = 4 roll = 4 yaw = 4 composite = 9

# Single Processor Flow

## Multi-objective and Multi-level

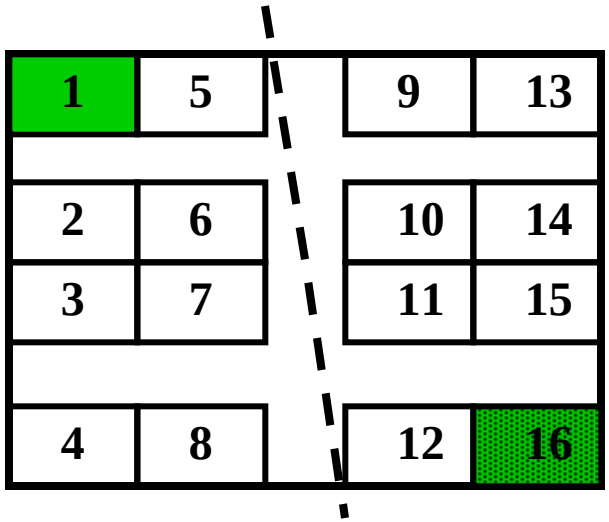


# Wing Symmetry

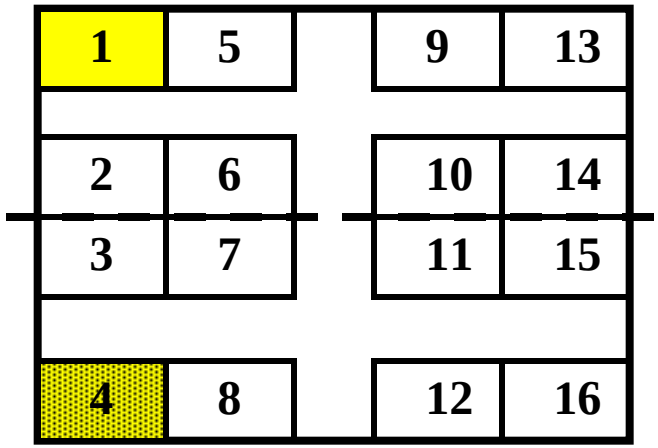



Pitch symmetry left to right

Wing model is symmetric so information can be used to determine a composite model for all six uncoupled moments



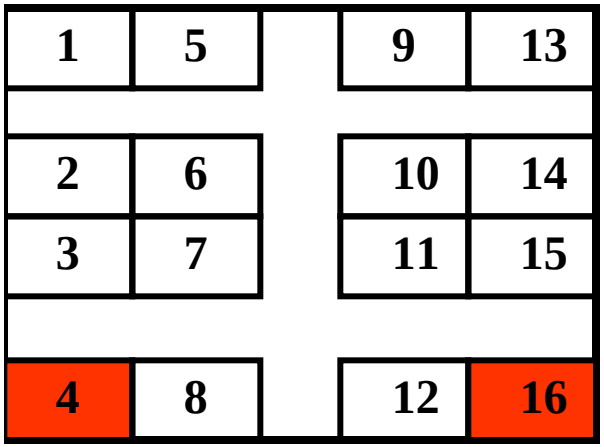

Roll symmetry top left to bottom right



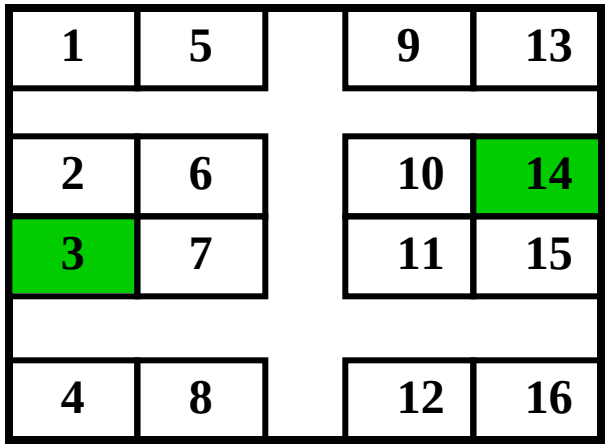

Yaw symmetry top to bottom

# Actuator Placement
# (Single Processor - 65 hours)

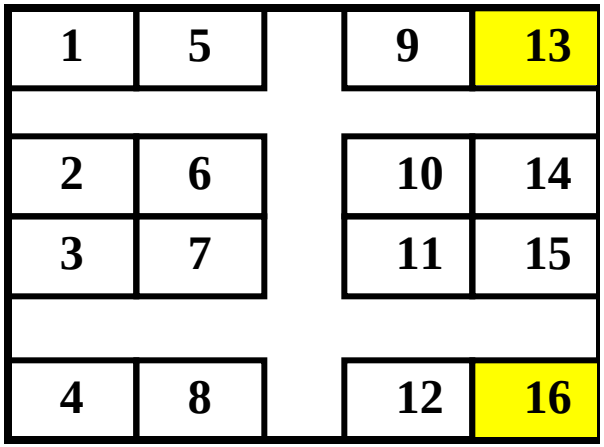
**Pitch up**



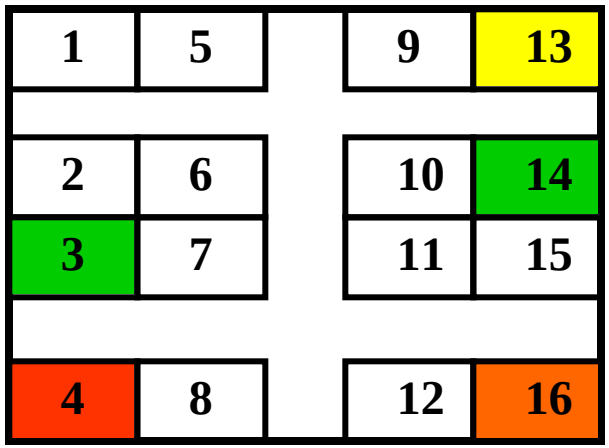

**Roll right**



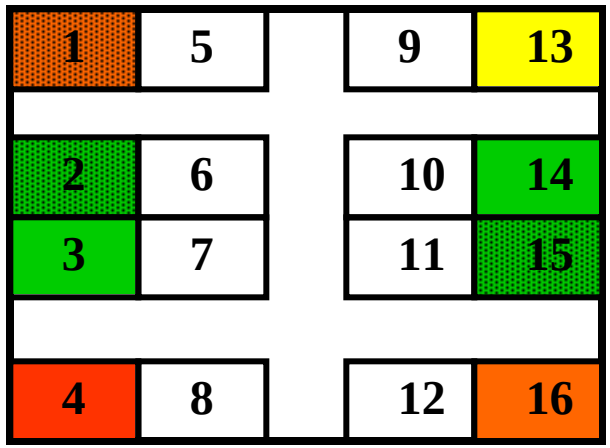

**Yaw right**



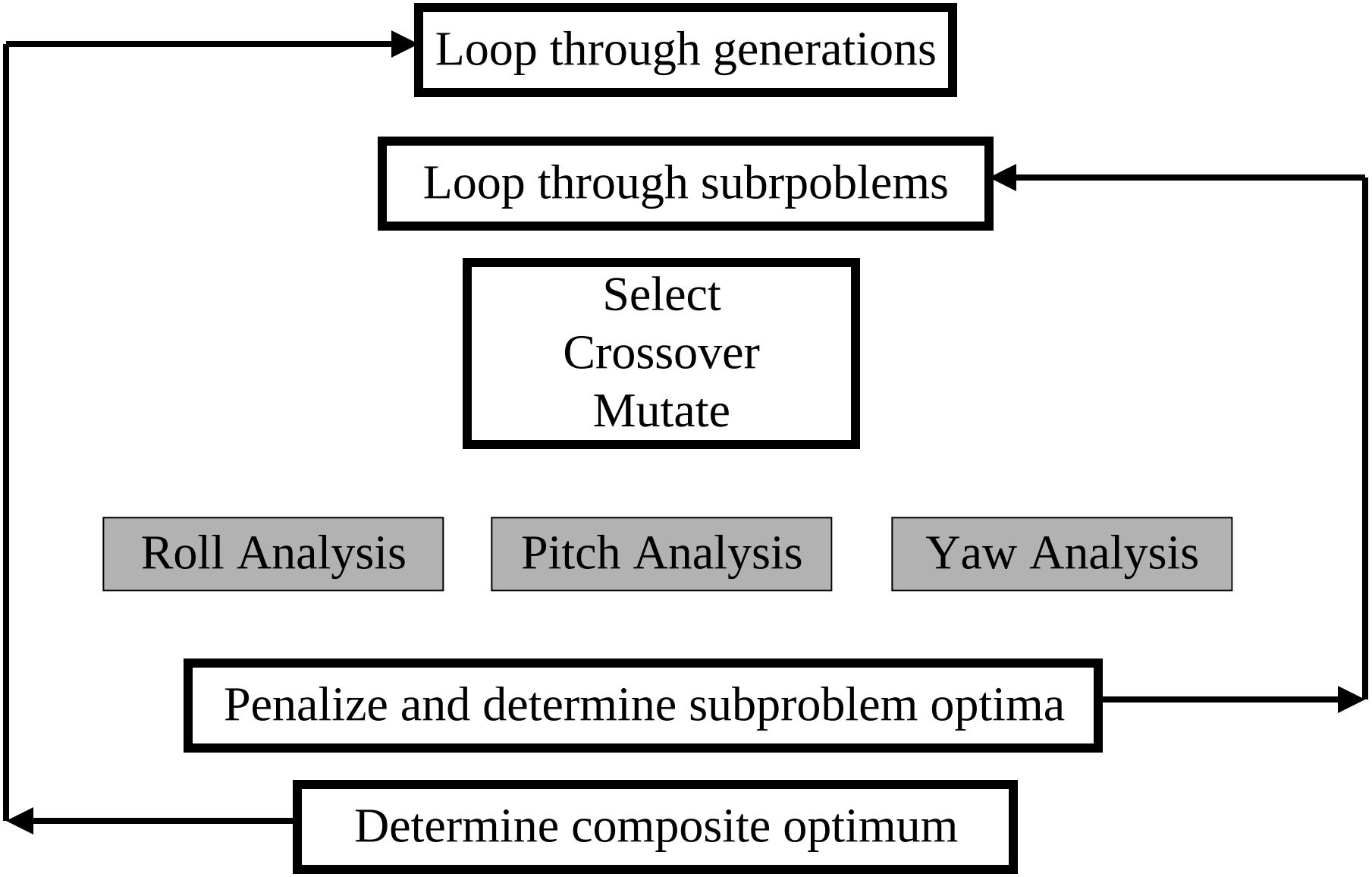

**Three maneuvers**




**Six maneuvers**

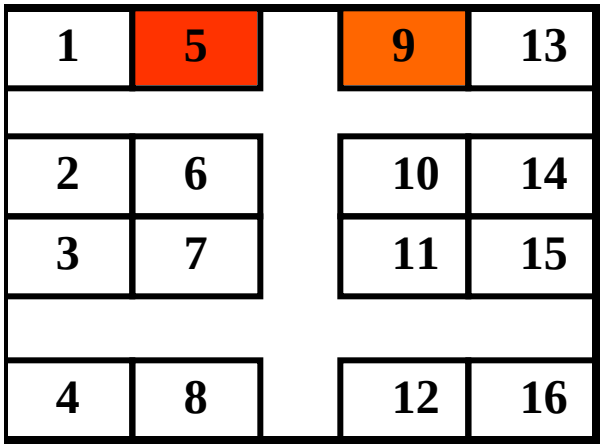


# Parallel Processor Flow

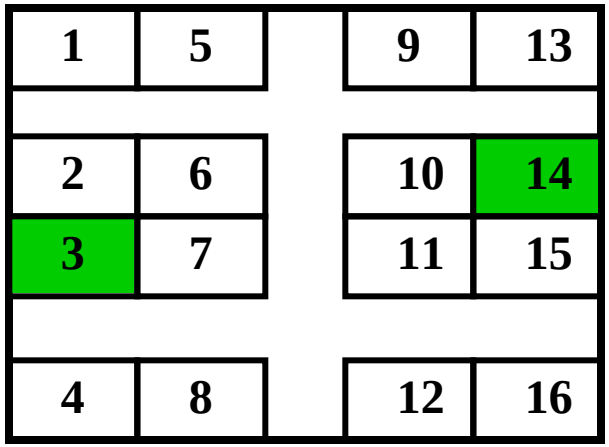


# Actuator Placement
# (Parallel Processors - 22 hours)

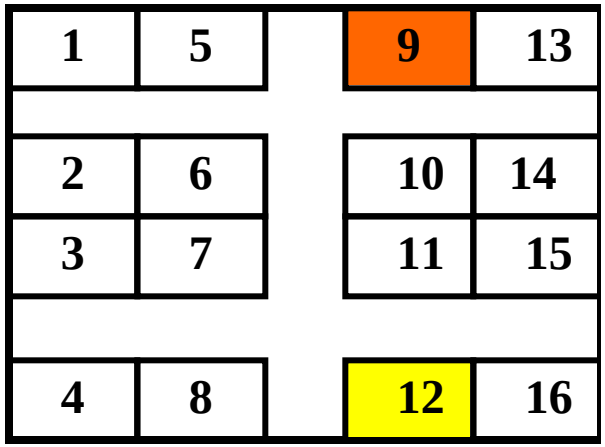
**Pitch down**



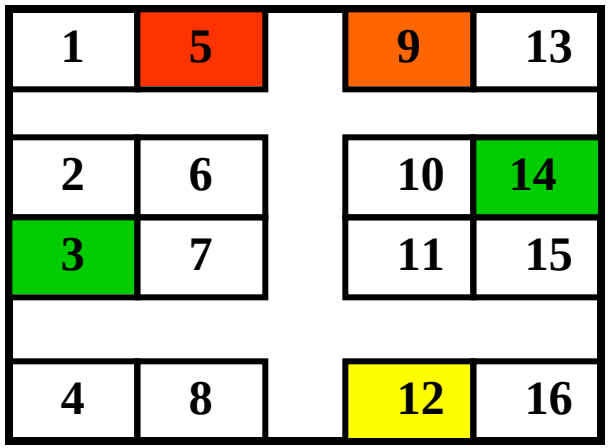

**Roll right**



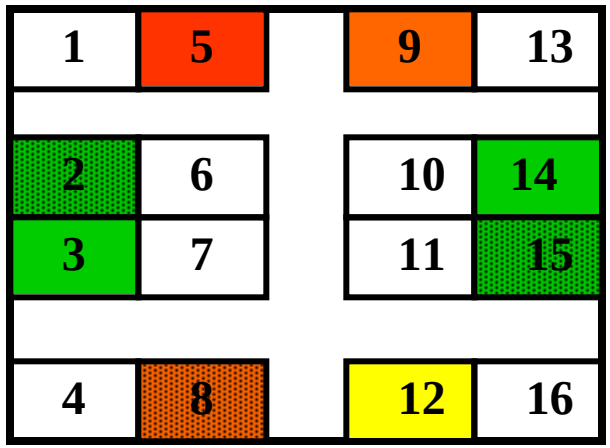

**Yaw right**




**Three maneuvers**




**Six maneuvers**



# Timing Results

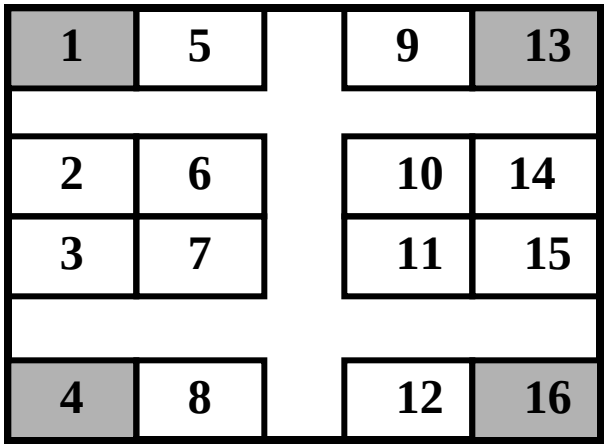
Each analysis takes one minute.
GA has 300 analyses per generation with 13 generations (3900 analyses).

| Actuators | Combinations | Search Design Space | GA Time |
|---|---|---|---|
| 16 | 65,536 | ~1,100 hours | 65 hours (one processor) |
| 16 | 65,536 | ~1,100 hours | 22 hours (multi-processor) |
| 34 | 1.7B | ~286M hours | |
| 100 | Do not even think about it! | | |

# Future Plans

- Refine GA approach to take more advantage of wing symmetry
  - Reduces design space using only 8 locations
  - 256 possible combinations
  - Reduces member length and population size
  - Finds optimum in one hour (20 minutes if done in parallel, estimated)

**Six maneuvers**




•Apply GA approach to seamless aircraft model (1) with 34 potential effector arrays and (2) 349 potential individual device locations

# Concluding Remarks

- A problem that appeared to be unsolvable using enumeration, now looks promising with the application of a GA

- GA approach significantly reduces computation time

- GA approach is portable to larger problems and can handle a large number of discrete variables with few changes to the code

- GA approach is portable to parallel computers and reduces time by 1/3

- GA approach can take advantage of problem symmetry