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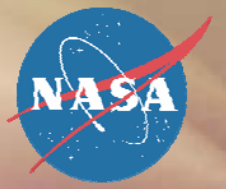

Genetic Algorithm Optimization of Inlet Geometry for a Hypersonic Jet Engine with Mode Transition

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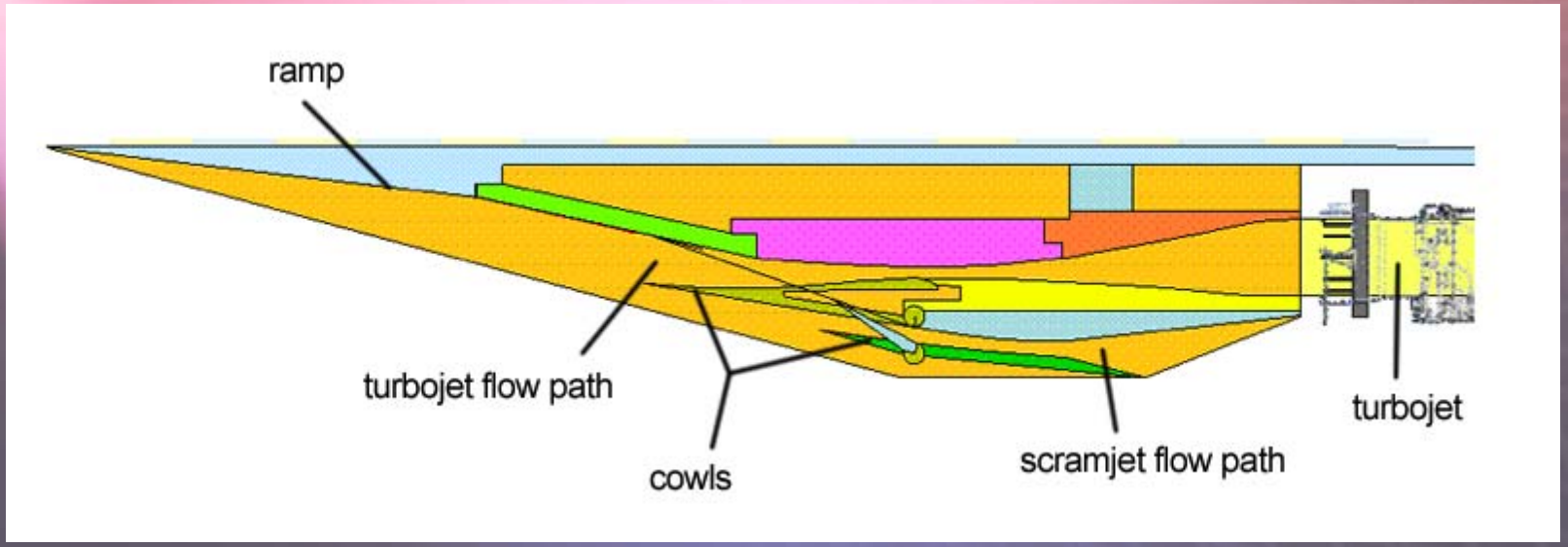
Introduction

- **The role of computational fluid dynamics (CFD) and optimization through CFD**
  - **Simulation data helps to focus experiments.**
  - **Reduce wind tunnel expenses**
- **The promise of genetic algorithm optimization**
  - **“natural selection” in a “population” of designs**
  - **Selection takes care of design process → little knowledge required**
  - **Multiple designs in a population → parallel computing**

Introduction

- **Baseline design for this GA optimization**
  - **The Large-scale Inlet Mode Transition (L/IMX) inlet**
  - **The need for transitional inlets on high-Mach aircraft**

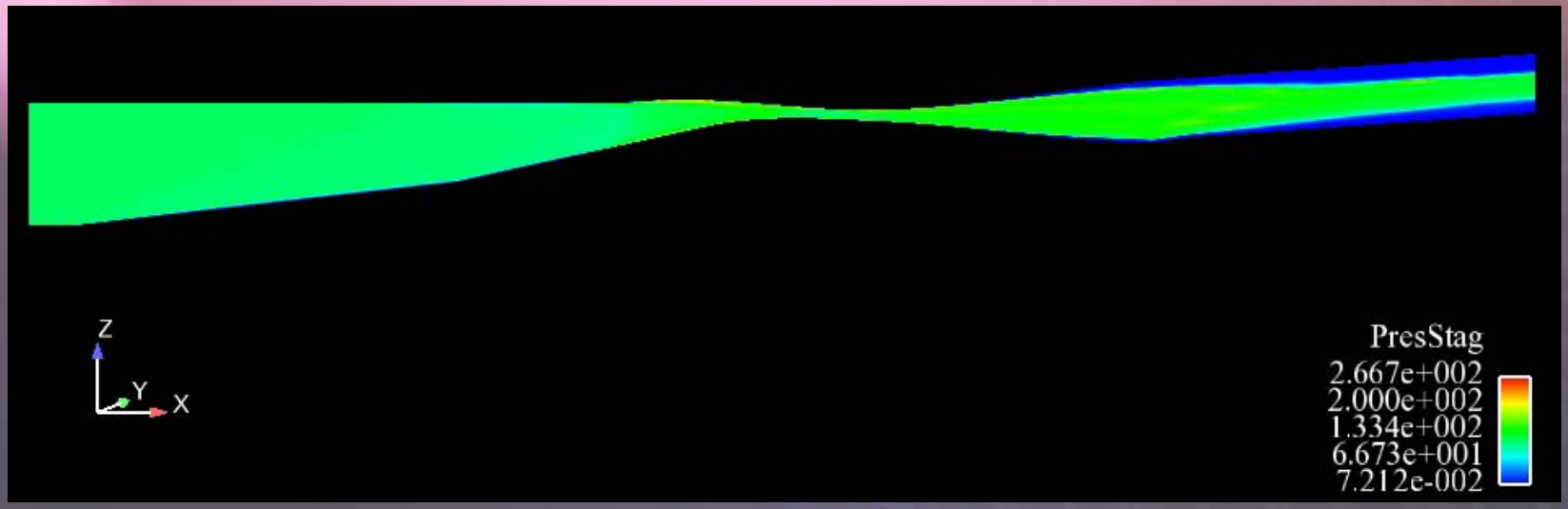


Problem Definition

- **Optimize inlet's contribution to the efficiency of the engine**
- **Significance of total pressure for efficiency**
  - **a.k.a stagnation pressure**
  - **Decreases with entropy generation**
  - **Reflects flow's ability to do work**
  - **Total pressure recovery = $p_{t,\ exit}$ / $p_{t,\ entrance}$**
- **Concerns:**
  - **The shock train → shock losses**
  - **Boundary layers → entropy, more shock loss**

Objective

- **“Implement a GA to design an optimum geometry for the turbojet flow path of a hypersonic jet engine inlet at Mach 4, using the L/IMX inlet as a baseline.”**
- **Mach 4 = cutoff for turbojet**
- **Optimum = highest possible total pressure recovery**
- **Non-uniform flow at exit → use average total pressure recovery over cross-section**

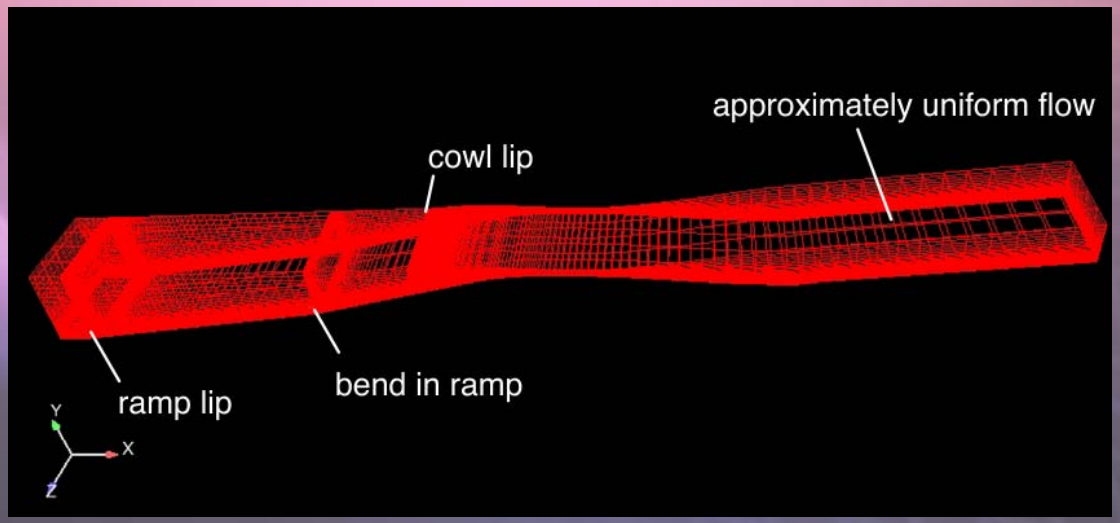


Approach

- **Define and implement key components of the GA**
  - **Alleles**
  - **Chromosomes**
  - **Fitness**
  - **Initialization**
  - **Parent selection**
  - **Crossover**
  - **Mutation**
  - **Elitism**
  - **Design constraints**
- **Validate the GA through tests**
- **Lay out how the GA interacts with auxiliary programs, data files, and scripts**

Approach: Alleles

- **Definition: design parameter values that define an individual**
- **25 total, 3 types:**
  - **Coordinates of key points along the inlet**
  - **Bias values: which way does the wall bend?**
  - **Tightness values: how sharply does it bend?**



Approach: Chromosomes

- **Definition: a list of an individual's alleles**
- **Alleles are listen in order of type:**
  - **X-coordinate of cowl lip**
  - **Y-coordinates of all key points (x fixed)**
  - **Bias values**
  - **Tightness values**

Approach: Initialization

- **Definition: the generation of an initial population**
- **Initial population generator (IPG) separate from GA**
- **Individuals distributed randomly in design space**
  - **Uniform probability for all possibilities, each allele**
- **L/IMX design always included**

Approach: Fitness

- **Definition: the cross-sectional average total pressure recovery**
- **CFD output (density, velocity) → total pressure**
- **CFD output is nondimensional**
- **Accommodating non-uniform exit flow**
  - **CFD results only at discrete grid points**
  - **Riemann sum, divide by area → $p_{t,\ exit}$, $p_{t,\ entrance}$**
  - **Total pressure recovery = $p_{t,\ exit}$ / $p_{t,\ entrance}$**

Approach: Parent Selection

- **Definition: selection of individuals to pass on their alleles to the next generation**
- **Check: 2 unique parents for crossover**
- **Higher fitness → more likely to be chosen**
- **Roulette Wheel**
  - **Individual's "wedge on the wheel" proportional to fitness**
  - **"roulette ball" stops at a random point around the wheel**

Approach: Crossover

- **Definition: 2 parent chromosomes swap or blend alleles to form 2 children**
- **Occurs with 70% probability**
- **If crossover, then for each allele, numbered 1-25:**
  - **1/3 chance alleles remain unchanged**
  - **1/3 chance alleles swapped between parents**
  - **1/3 chance blended crossover**
- **Blended crossover**
  - **Children's alleles = randomly weighted averages of parents**

$$a_{child1} = \gamma a_{parent1} + (1-\gamma)a_{parent2}$$

$$a_{child2} = \gamma a_{parent2} + (1-\gamma)a_{parent1}$$

Approach: Mutation

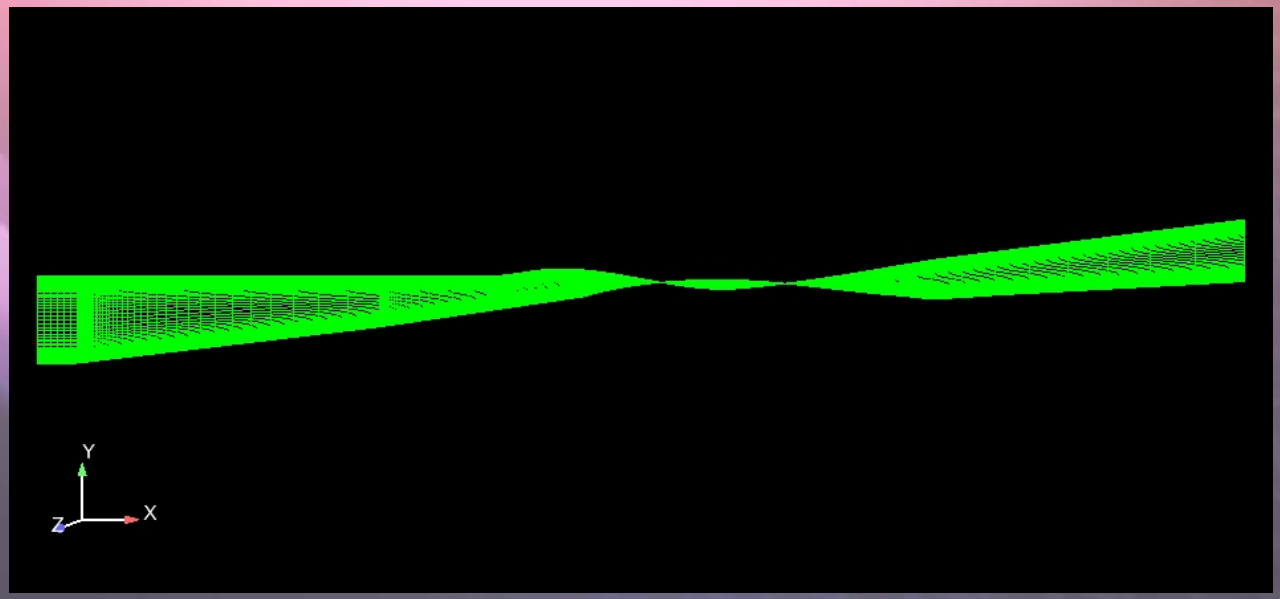
- **Definition: a random allele changes its value**
- **Occurs for every new individual except the one copied through elitism**
- **One allele chosen at random per individual**
- **Allele value changes to any value in design space**
- **Uniform probability of all possibilities**

Approach: Elitism

- **Definition: automatically copy the individual with the highest fitness is into the nest generation**
- **The only exception to crossover and mutation**
- **The best fitness cannot decrease over generations.**
- **Speeds convergence**
  - **Favors high fitness**
  - **May converge too soon for small populations**

Approach: Design Constraints

- **The inlet walls cannot intersect**
- **The cowl lip must be upstream of the shock off the ramp**
- **Retry generating the individual if it violates a constraint**

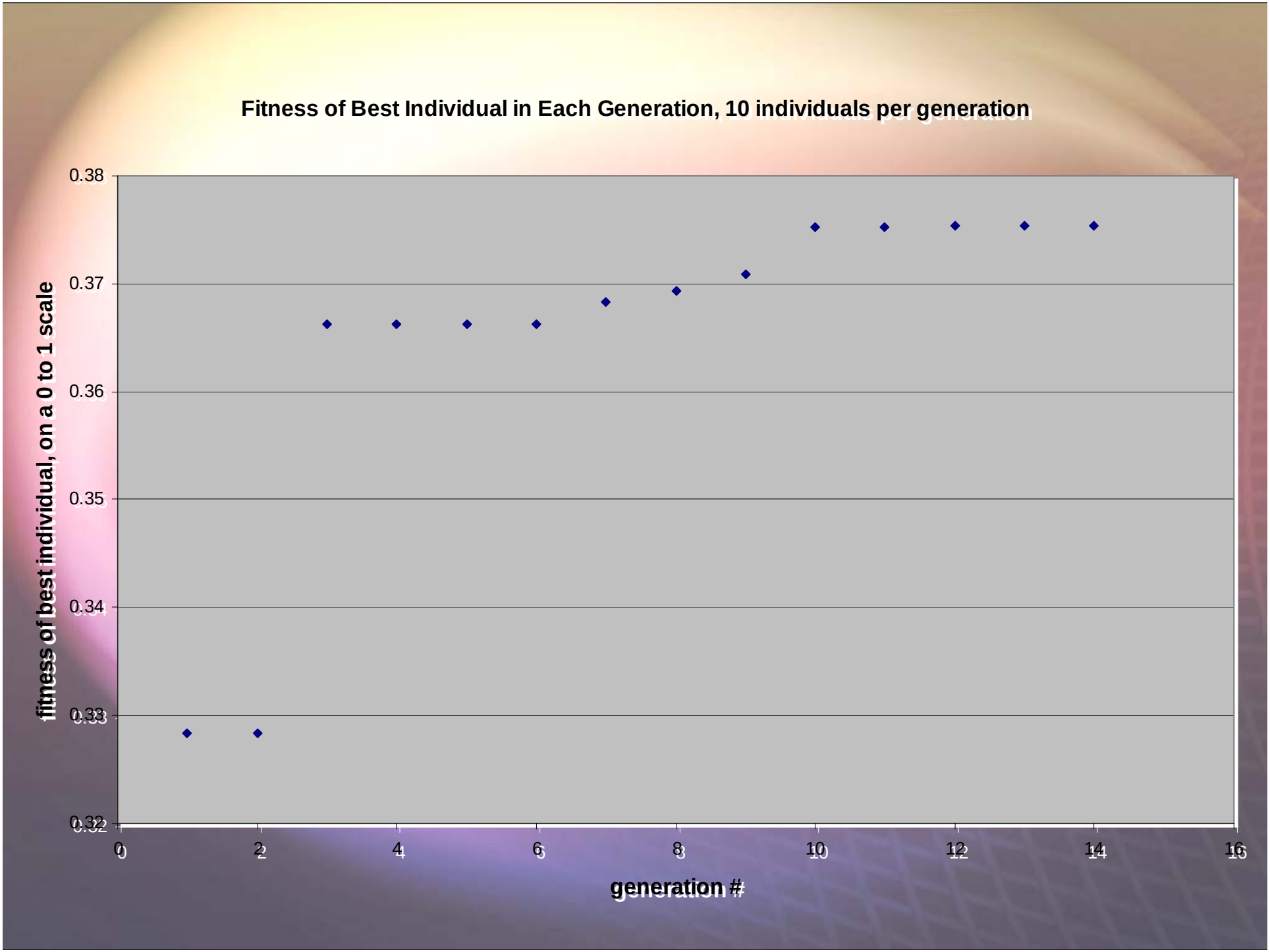


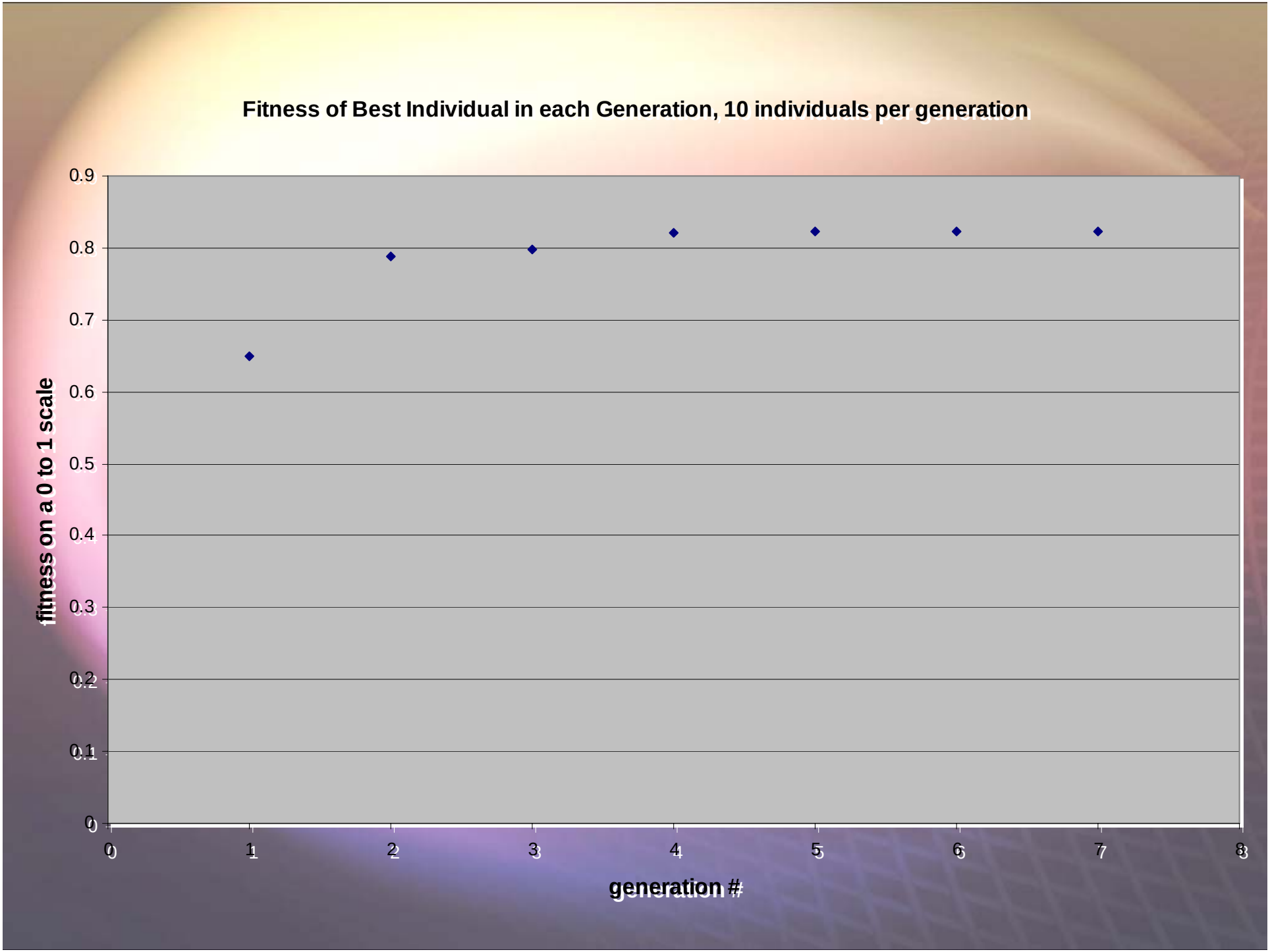
Approach: Validation

- **Use dummy fitness function to test GA performance**
- **Dummy fitness function:**

$$f(x) = \left| \cos((x-400)/25) * e^{-|(x-400)/400|} \right|$$

- **x = sum of allele values**
- **Resulting changes for improvement:**
  - **Don’t have all designs on one side of optimum**
  - **Give initial population uniform probability across design space**
  - **Give mutation uniform probability across design space**
  - **Increase mutation to 100% probability of occurrence**


Fitness of Best Individual in Each Generation, 10 individuals per generation
fitness of best individual, on a 0 to 1 scale
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0
2
4
6
8
10
12
14
16
generation #


Fitness of Best Individual in each Generation, 10 individuals per generation
fitness on a 0 to 1 scale
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
generation #

Approach: Validation

- **Use L/IMX inlet to test actual fitness calculations**
- **After debugging, total pressure recovery = 0.4377**
- **Resulting changes for improvement:**
  - **gridline distribution function from grid generator -> average by area**
  - **Read from binary result file, not ASCII**

Approach: Analysis Tools

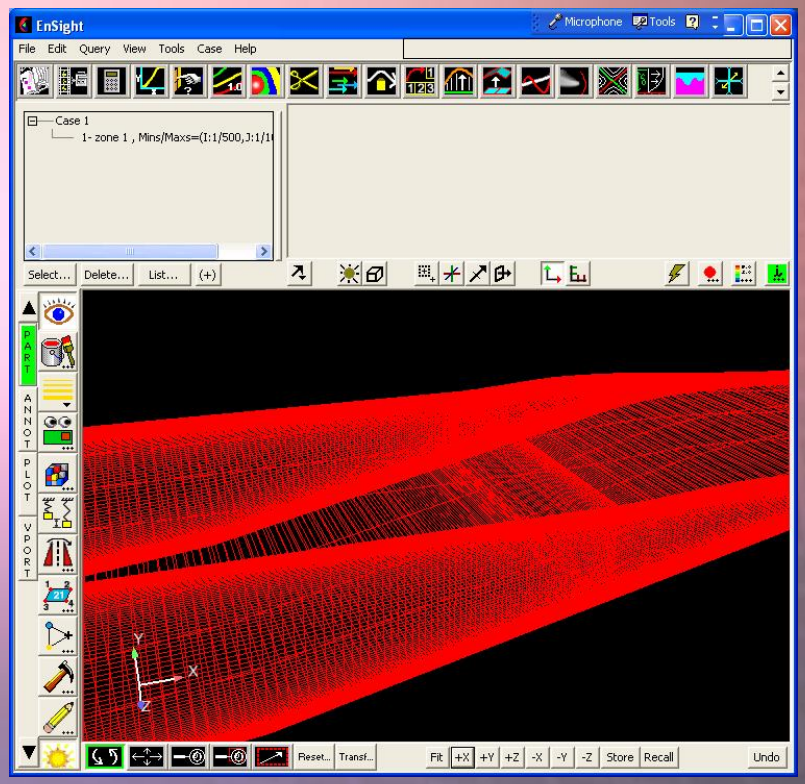
- **Overflow**
  - **CFD software, calculates flow behavior**
  - **Input: Plot3D grid, boundary conditions, “restart” options**
  - **Output: density, velocity vectors at gridline intersections**
  - **Boundary conditions: inviscid approaching inlet, viscid inlet walls**

Approach: Analysis Tools

- **Grid generation**
  - **GA outputs 2D grid file**
  - **“makegrid” script converts to nominally 3D file for Overflow**
  - **Grid concentration near walls, ramp corners, cowl lip**

Approach: Analysis Tools

- **EnSight**
  - **Visualizes grid files, Overflow result files**
  - **Color codes according to flow properties (temperature, Mach, pressure, etc.)**



Approach: Program Interaction

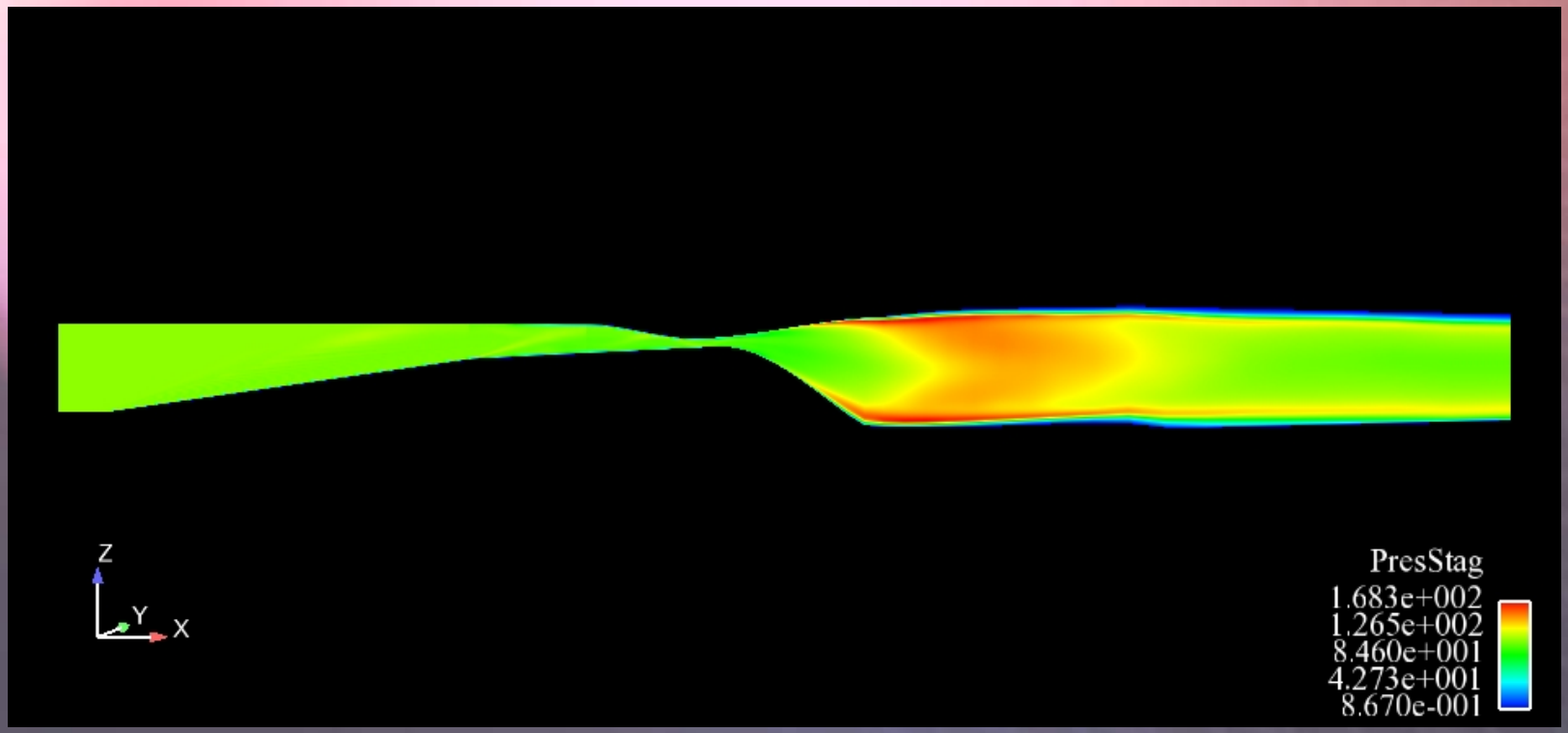
- **Programs and files across 2 machines**
  - **Columbia, NASA supercomputer at Ames**
  - **Lou, NASA mass storage machine**
- **Batch script calls:**
  - **IPG to begin**
  - **GA for each generation**
  - **moves files as needed.**
- **Columbia stores executables**
  - **GA**
  - **IPG**
  - **Overflow**
  - **Scripts**
- **Lou stores archives**
  - **grid files**
  - **Chromosomes**
  - **Fitnesses**
  - **best scores**

Results

- **Functional Initial Population Generator (IPG)**
  - **Well distributed across design space**
  - **Avoids constraint violations**
- **Functional fitness calculation**
- **Functional random number generator**
  - **Does not repeat between runs of the program**
  - **Does not repeat when called repeatedly in program**
- **Functional GA**
  - **Fitness improves from baseline and never backslides**
  - **Performance improves with larger populations, but computing time limited for this project**
  - **Avoids constraint violations**
  - **Well-tested grid generation**

Results

- **Improved design from small-scale run**
  - **Total pressure recovery of baseline = 0.4377**
  - **Improved total pressure recovery = 0.4450**



Future Work

- **Improved compatibility with Columbia**
- **Run large-population, many-generation cases**
  - **Possibly multiple days each to run on Columbia**
  - **Generations of >100 individuals**
  - **Thoroughly explore design space**
- **Tweak GA to improve efficiency**
  - **Alternate parent selection methods**
  - **Crossover, mutation probabilities**
  - **Alternate crossover, mutation setup**
- **Tweak constraints, coordinating with L/IMX**

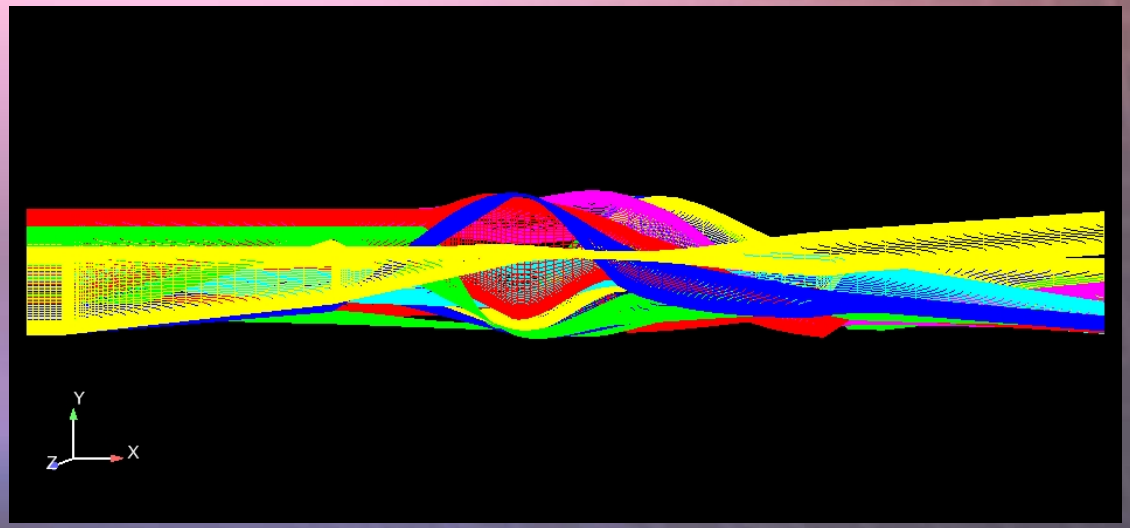
Conclusions

Pros of GA Approach

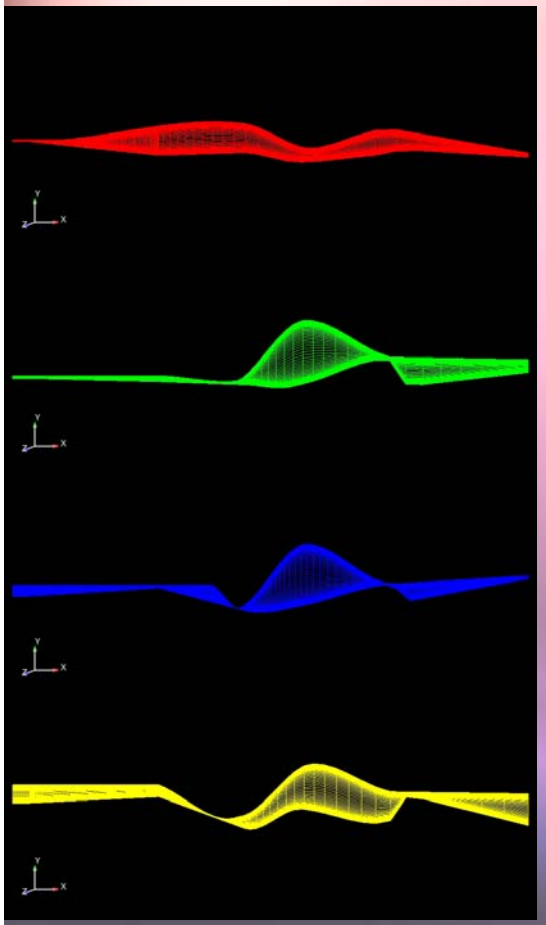
- GAs explore parts of design space far from baseline
- Multiple designs to test → Parallel (efficient) computing
- adaptable

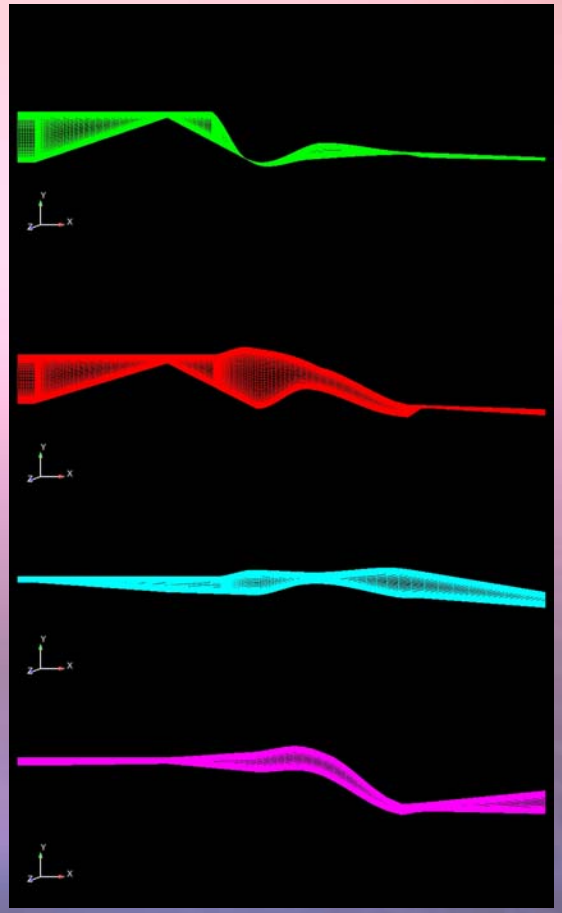
Cons of GA Approach

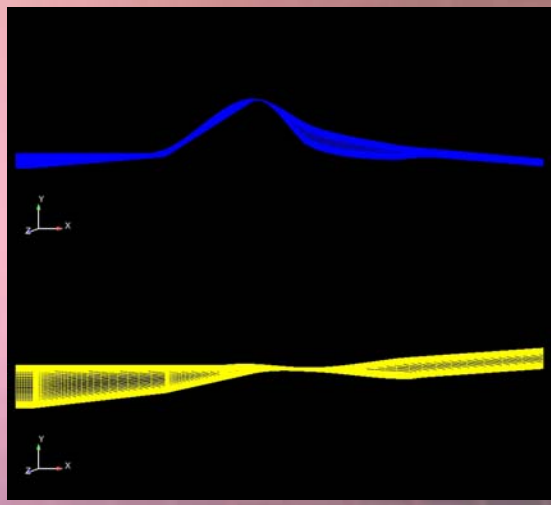
- Requires great (expensive) computational power
- Requires extensive computing time



Conclusions







Acknowledgements

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