Aircraft/Spacecraft Mass Distribution Optimization Using Genetic Algorithms

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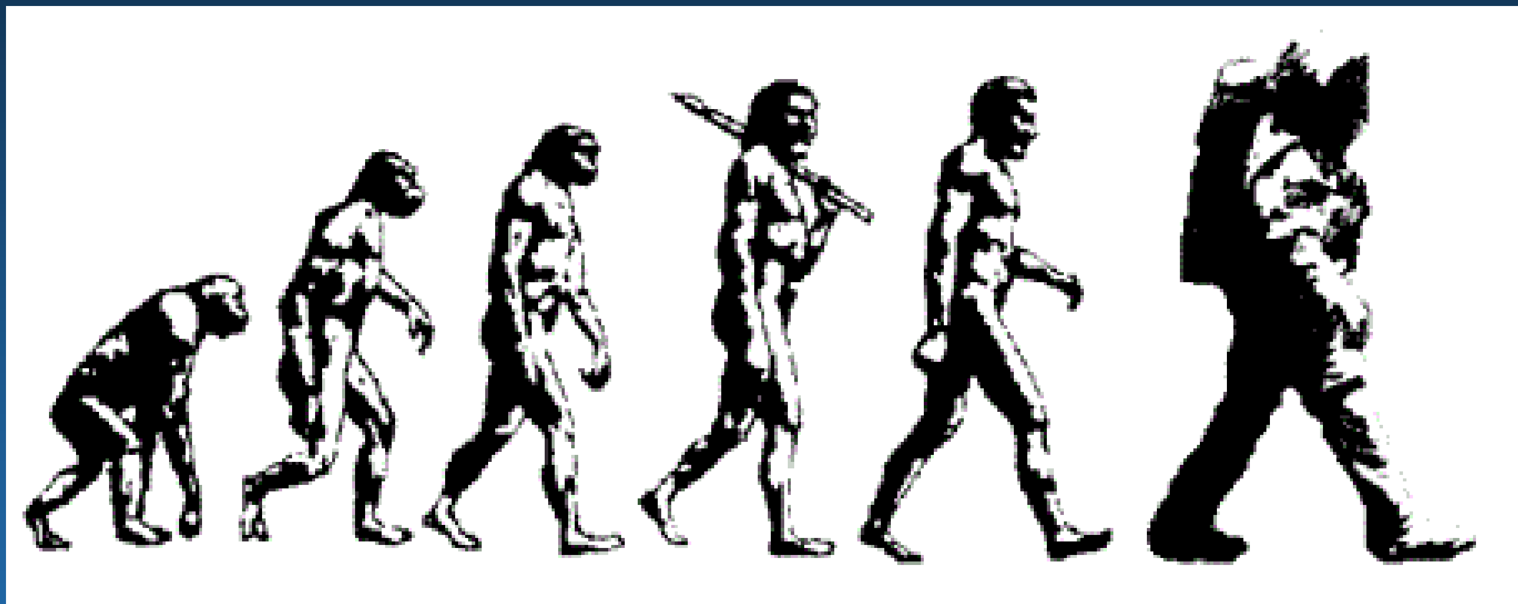

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Mass Distribution Problem – Problem Statement

• **Background:** Component placement is often critical to the performance, and stability & control of aircraft, spacecraft, surface ships, submarines, etc. These components can include fixed items such as electrical or hydraulic equipment, consumables such as fuel or air, and payloads. For an aerospace example, the longitudinal center-of-mass (c.g.) location of an aircraft must be within a narrow region that aligns with the lift produced by the wings and within the trim capabilities of the control surfaces. Consequently, proper placement of these components is important during both the vehicle design phase and over its operational life.

• **Problem:** Optimize the distribution of components within a vehicle, while meeting various constraints and using a composite cost function comprised of numerous figure-of-merit.

• **Solution:** Develop a Matlab-based Genetic Algorithm tool to perform this optimization, by quickly and robustly finding a near optimal solution.

Genetic Algorithm Primer

- **What:** Genetic Algorithms (GAs) are a class of highly-adaptable optimization approaches used by LM in a number of applications.

- **How:** A GA is a computer program that finds a near optimal solution by mimicking the evolutionary concepts of Charles Darwin. A given problem solution is characterized by a series of chromosomes and is compared against rival solutions in a solution population. The best performing solutions are permitted to survive to the next generation, and to breed and yield offspring that are also compared. A near optimal solution is quickly reached by application of the "survival of the fittest" filter over a number of generations. (Hence the method's name *Genetic Algorithms*.)

A British Two Pound Coin Commemorating The 200th Anniversary of Darwin's Birth

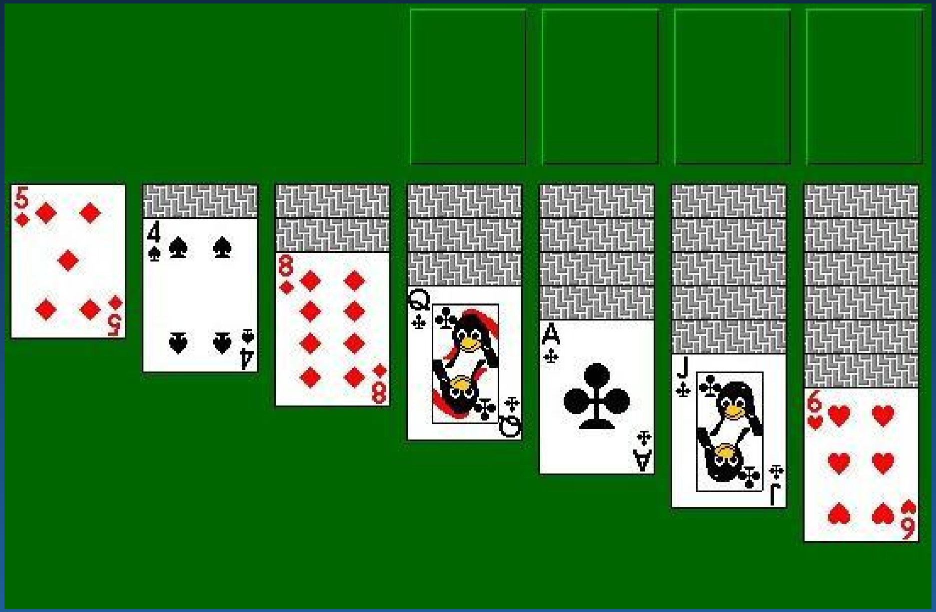
- **Why:** Experience has shown that GAs are very adaptable and can quickly find a near optimal solution. A broad range of constraints and cost functions can be incorporated. GAs can be employed both strategically (i.e. defining a design or payload loading) and tactically (i.e. real-time adaptation such as flying through Mach 1, or in combat) and have proven to be far more flexible than other optimization approaches.

Genetic Algorithm Primer

- **The Chromosome:** The solution to the optimization problem is decoded from a chromosome. Each chromosome is a series of bits and represents one member of a solution population.
- **The Population:** A GA finds optimal solutions by interbreeding the chromosomes within a given solution population. Additionally, the best members of each population are carried over to the next generation.
- **The Constraints:** Constraints are included by not permitting certain chromosomes from existing in the population.
- **The Cost Function:** Each solution is evaluated via a cost function, which can include a wide variety of economic and non-economic factors. Additionally, the cost function can be a composite of a number of parameters that all need to be optimized together.
- **Convergence History:** Experience has shown that GAs are very adaptable and can quickly find a near optimal solution. This is a distinct advantage for design analysis through-put, and for dynamic applications with a short characteristic time.

Genetic Algorithm Application to Mass Distribution Optimization

- In a Game of Solitaire, an Initial Distribution of Cards is Manipulated to Pursue a Desired Result

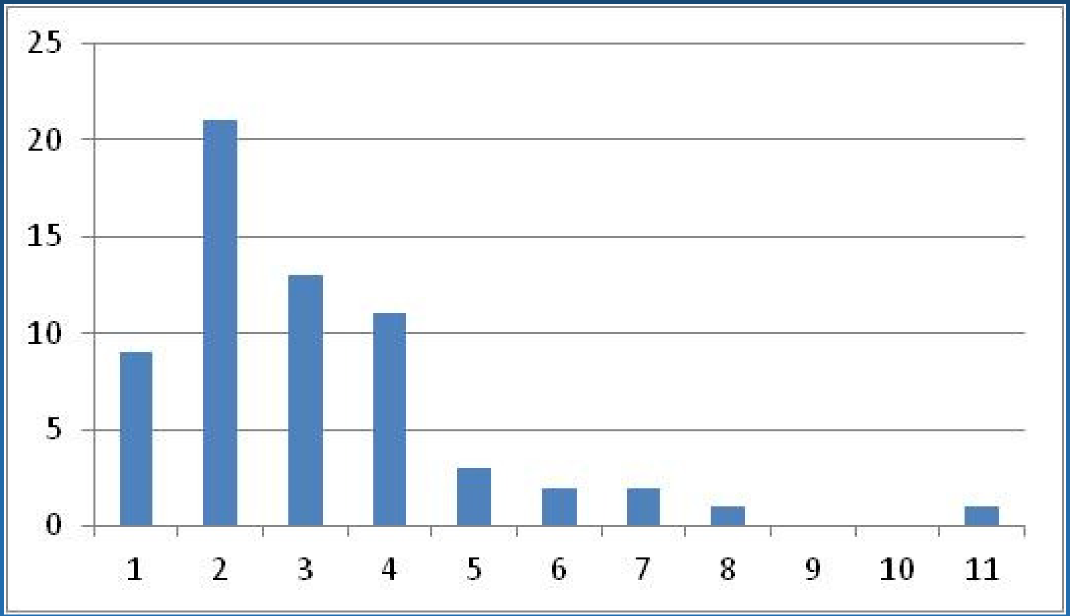


- In the Mass Distribution Optimization Problem, the GA Manipulates an Initial Package Distribution to Achieve a Desired Result
- The GA Manipulations are a Series of Location Trades for Pairs of Packages
- The Pairing Selections and the Order of the Trades are Optimized
- Some Packages may be Held Fixed due to Proximity Requirements
- This tool Matlab uses the *Genetic Algorithm and Direct Search Toolbox*
- Execution Times vary from a Few Seconds to a Few Minutes

Problem Constraints: Package List

- The Spacecraft Capsule Packing Problem
  - Multiple bag sizes
  - Wide range of individual bag weights for each size
- NASA Uses a Number of Package Sizes (Half Cargo Transfer Bags, Single CTB, Double CTB, M-01, M-02)
- Data for a Typical Half CTB Bag Mass Distribution

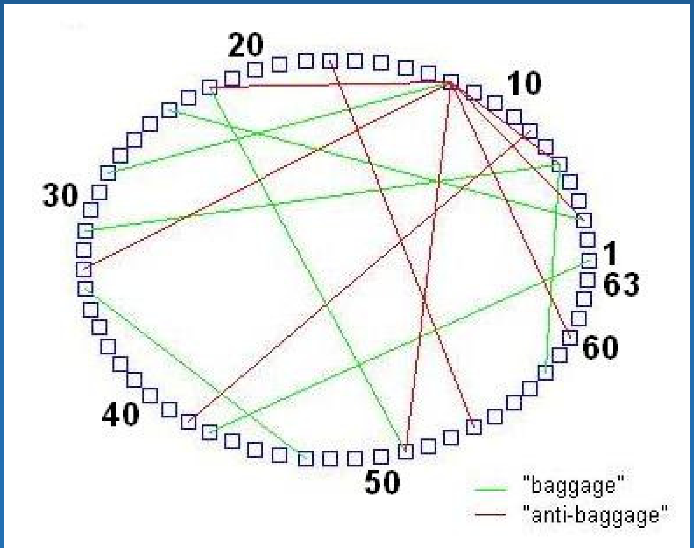
Mass (lbsm)	# at that mass
10	9
15	21
20	13
25	11
30	3
35	2
40	2
45	1
50	0
55	0
60	1
	63



- The Mass and Location Data are read from Input Files
- For Convenience, this list of 63 Packages is used in All Examples

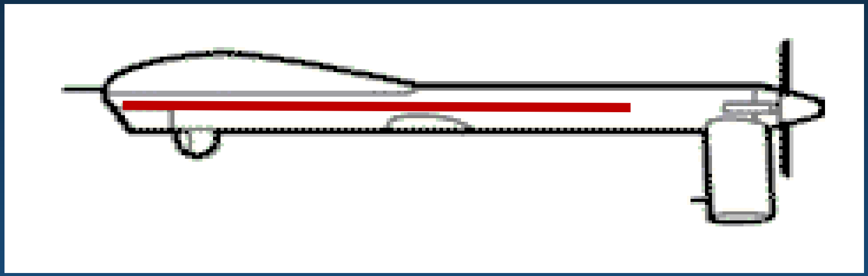
Problem Constraints: Baggage and Anti-Baggage

- Packing Requirements often include Placing Some Items in Preferred Locals
  - Locate safety equipment together
  - Frequently used packages should be easily accessible
  - “Last-on” and/or “first-off” packages should be near access points
- Package Pairs Often Require Separation “baggage” and “anti-baggage”
  - Separating packages with incompatible contents (e.g. chemicals)
  - Environmental requirements (e.g. overheating or overcooling)
  - Radiation, EMF, other types of interference
- Such Requirements are Established in the Initial Distribution and Remain Fixed, or Reposition if Necessary

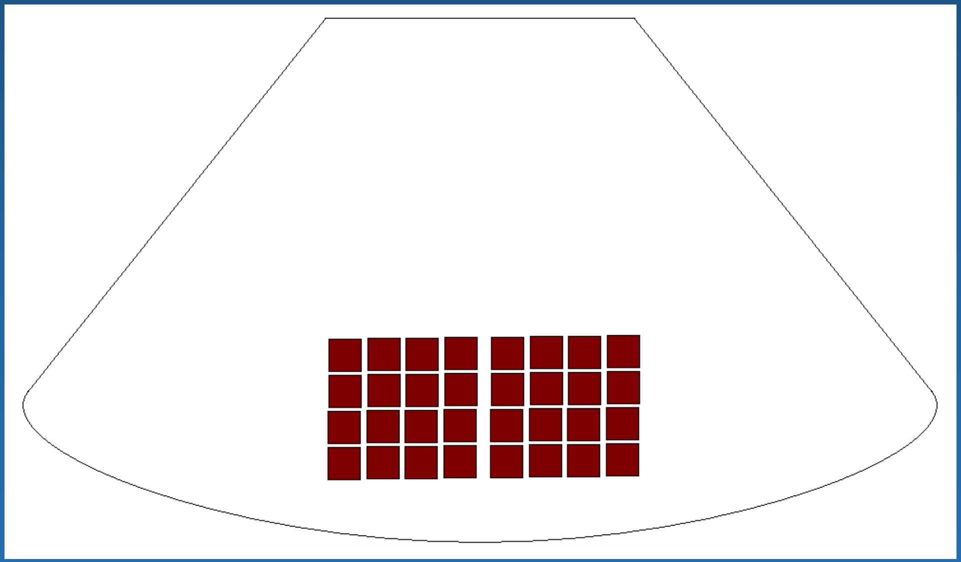


Problem Constraints: Available Positions

- **1D Problems**
  - **(X) locations are defined along a line (shown in red)**



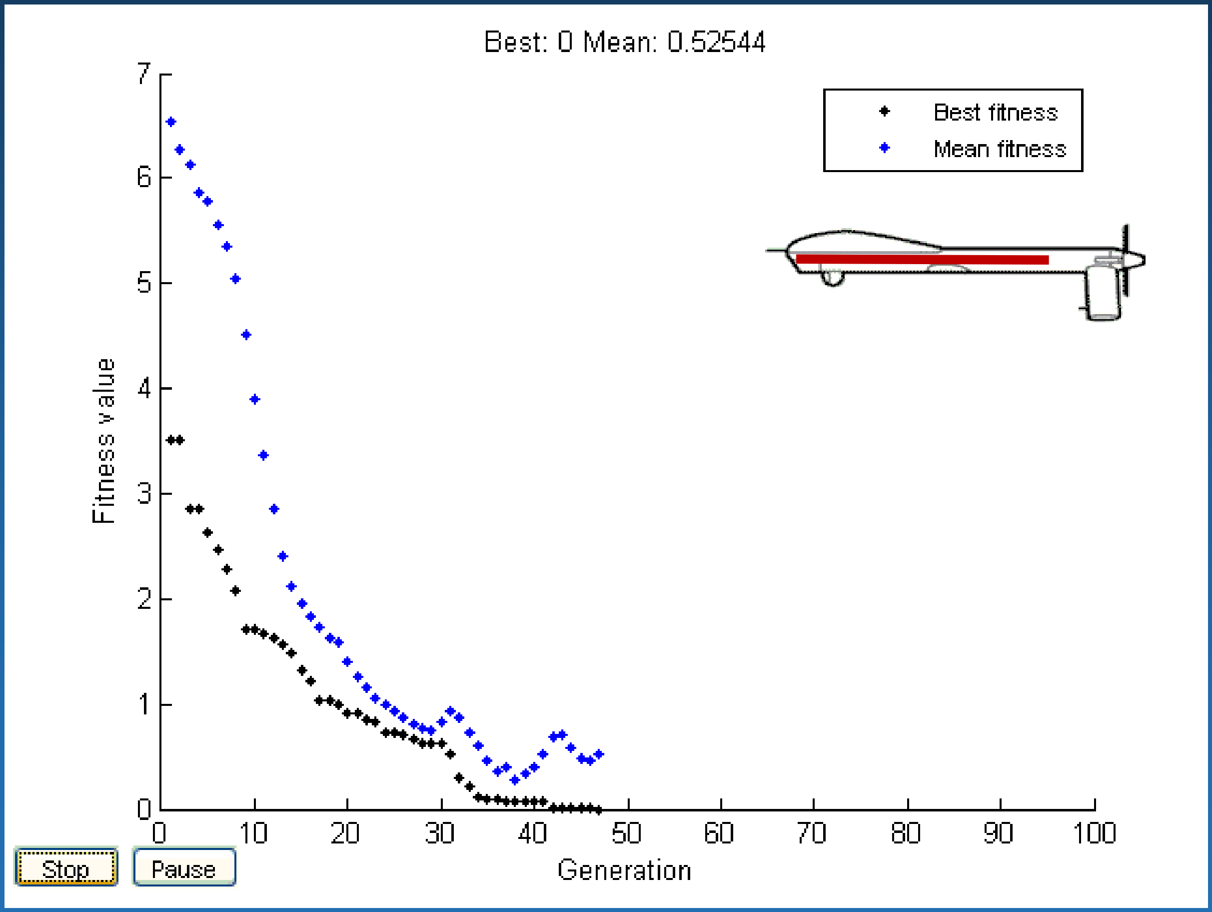
- **2D Problems**
  - **(X,Y) locations are defined by a matrix of positions (shown in red)**



- **In all Examples, 80 Unique Positions were Employed**

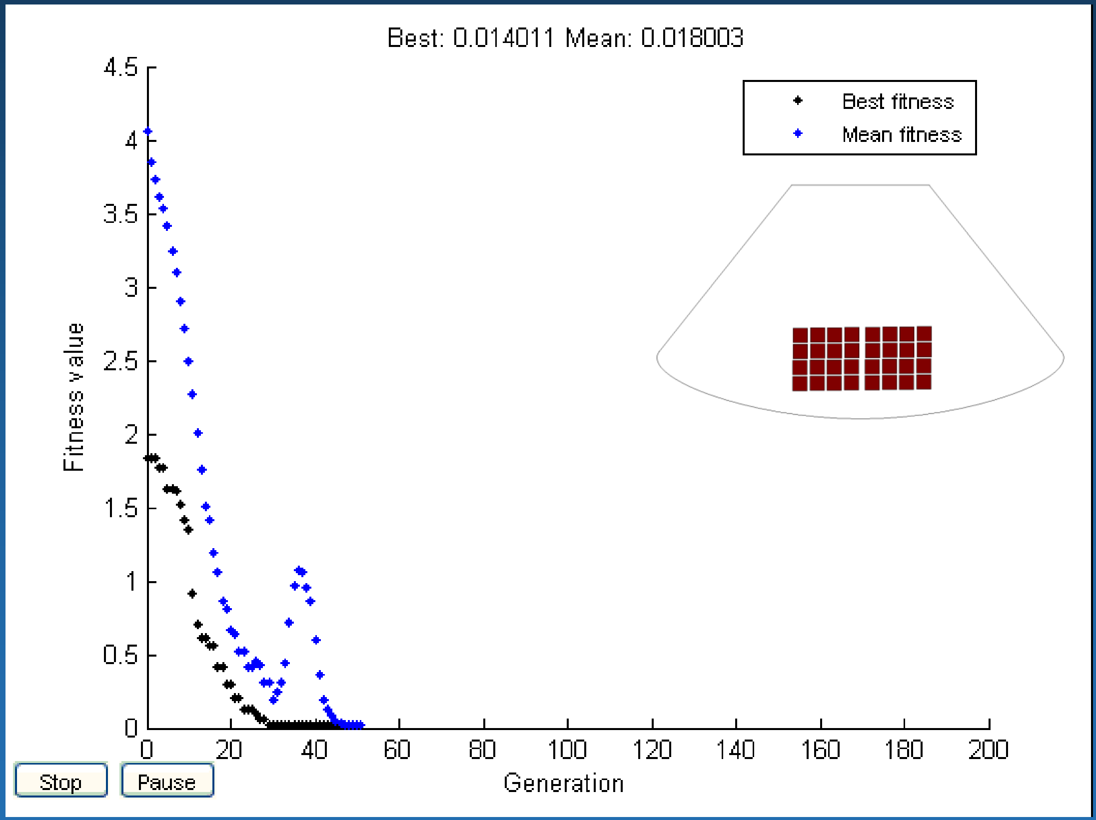
Aircraft / UAV / Airship: Fix Center-of-Mass

- Position the (X) Location of the Center-of-Mass at a Specific Value (ΔX=5”)
- 63 Payload Packages, 80 Possible Locations (linearly arranged)
- 40 Trades/Chromo., Population Size=400, Number of Generations <50
- Fitness Value is the Absolute Distance Between Xcg_actual – Xcg_wanted (“)



Space Capsule : Fix Xcg and Ycg

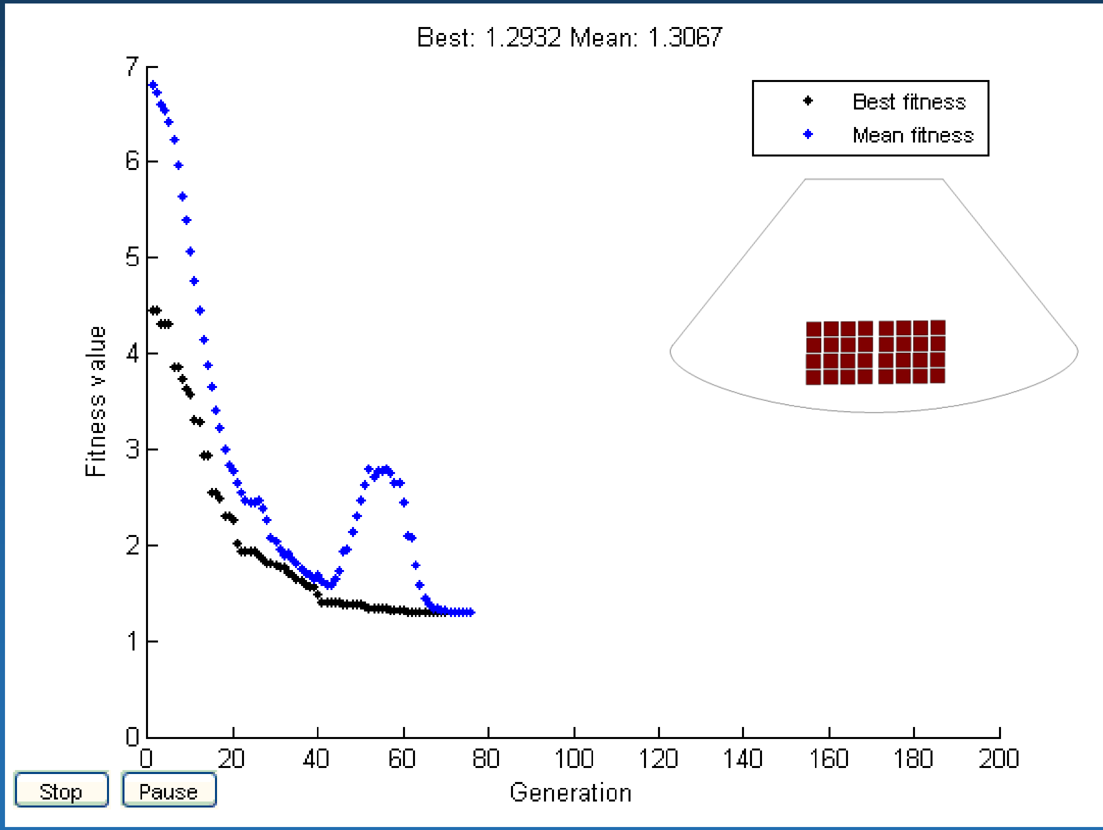
- Position Spacecraft's Center-of-Mass at a Specific Point (ΔX=5", and ΔY=4")
- 63 Payload Packages, 80 Possible Locations (2D matrix)
- 200 Trades/Chromo., Population Size=400, Number of Generations < 50
- Fitness Value = RSS(ΔX,ΔY)"



- Final Answer = 0.014" ≠ 0", not physically possible or could not be found

Space Capsule : Fix Xcg and Ycg (with no solution)

- **Position the c.g. to (Xcg, Ycg), (ΔX=10", ΔY=6"), Fitness = RSS(ΔX,ΔY)"**
- **Insufficient Ability of the Payload Packages to Shift c.g. to (Xcg,Ycg)**
- **Many Other Optimization Methods would give *No Answer***
- **The Genetic Algorithm Approach Provides the *Best Possible Answer***



- **Useful to Define Ballast Mass and Location Requirements**

Additional Optimization Capabilities

- Composite Mass Properties Cost Functions can be Employed:
  - Aircraft/UAX/Airship: fixed c.g. and fixed Ixx,Iyy,Izz (e.g. same c.g. location and Iii for various payload combinations, eases FC challenges)
  - Re-entry capsule: fixed c.g. and maximize Ixx (e.g. set trim angle-of-attack, with lengthened dynamic motion time scale)
  - Increase maneuverability: fix c.g. and minimize Iii (e.g. consistent c.g., with higher rotation rates for given control inputs)
- Pareto Front for Ballast Mass vs. Location
- Multiple Packages Sets, either with Unique or Shared Locations
  - Sequential Optimization (e.g. heaviest to lightest, or biggest to smallest)
  - Parallel Optimization
- Include Mass and Location Uncertainties to Perform *Optimization Under Uncertainties* Analysis
- Combine Mass Properties with Other Disciplines for Integrated Optimization

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