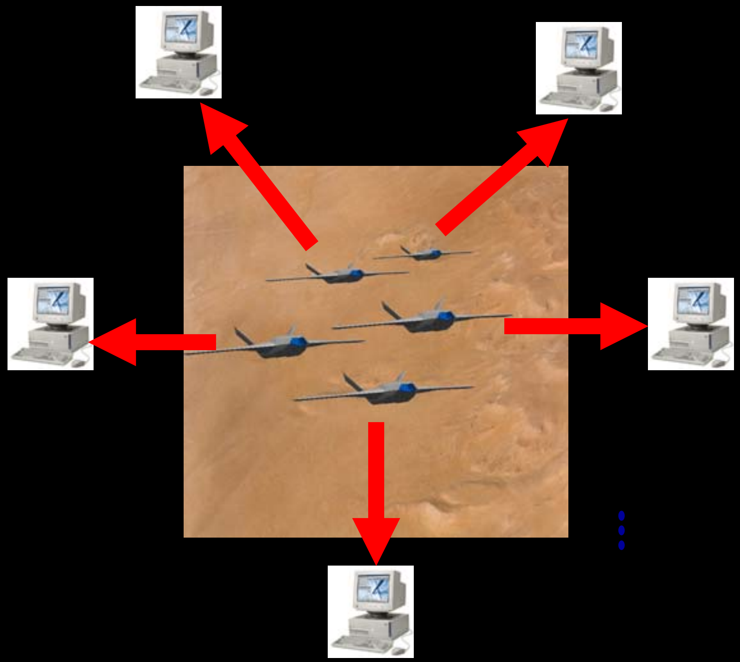
ADVENT

ADVanced EvolutioN Team



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Aim : To Develop advanced numerical tools and apply them to optimisation problems in engineering.

Outline

- Why research in other numerical optimisation techniques
- The Method
- Results so far
- Current and Future Research

Needs

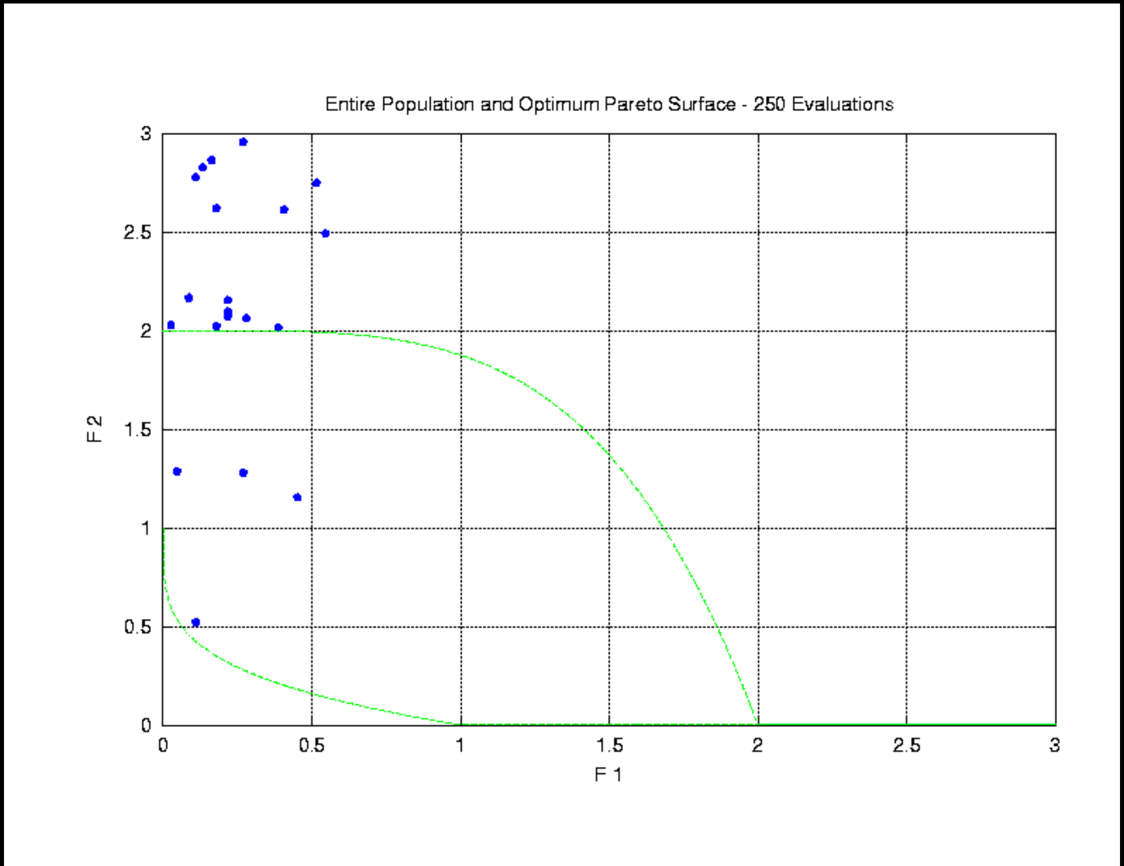
- Traditional optimisation methods will fail to find global solutions in a number of engineering problems.

- Numerical techniques such as Evolution Algorithms are able to explore large search spaces and are robust towards noise and local minima, are easy to parallelise.

- Can be designed to provide optimal solutions for single and multi-objective problems.

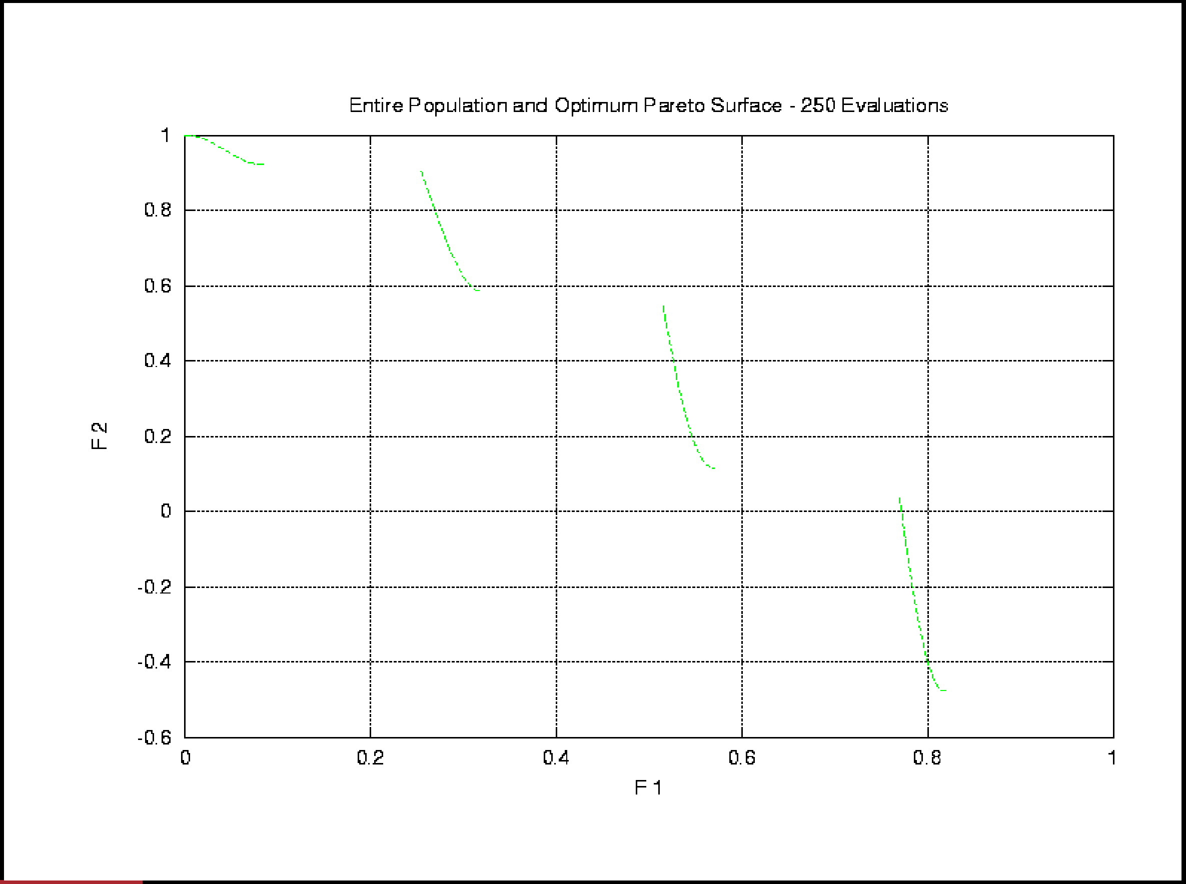
Some Examples

Here our EA solves a two objective problem with two design variables. There are two possible Pareto optimal fronts; one obvious and concave, the other deceptive and convex.



Some More Examples (2)

Again, we solve a two objective problem with two design variables however now the optimal Pareto front contains four discontinuous regions.



The Method

Research methodologies and numerical tools include:

- Evolution Algorithms
- Genetic Algorithms
- Neural Networks
- Multi objective Optimisation, Pareto optimality and Nash Game theory

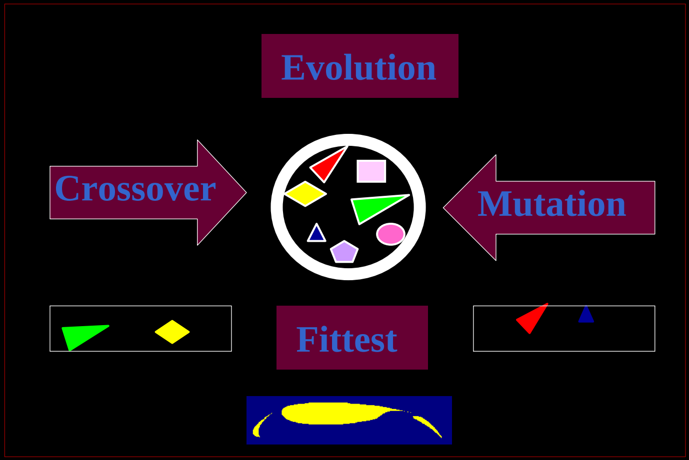
Why this tools….

- Research indicates that this tools provide optimal solutions that are not found by tradition optimisers

Evolution Algorithms

What are EAs.

❖ Based on the Darwinian theory of evolution → Populations of individuals evolve and reproduce by means of mutation and crossover operators and compete in a set environment for survival of the fittest.



❖ Computers can be adapted to perform this evolution process.

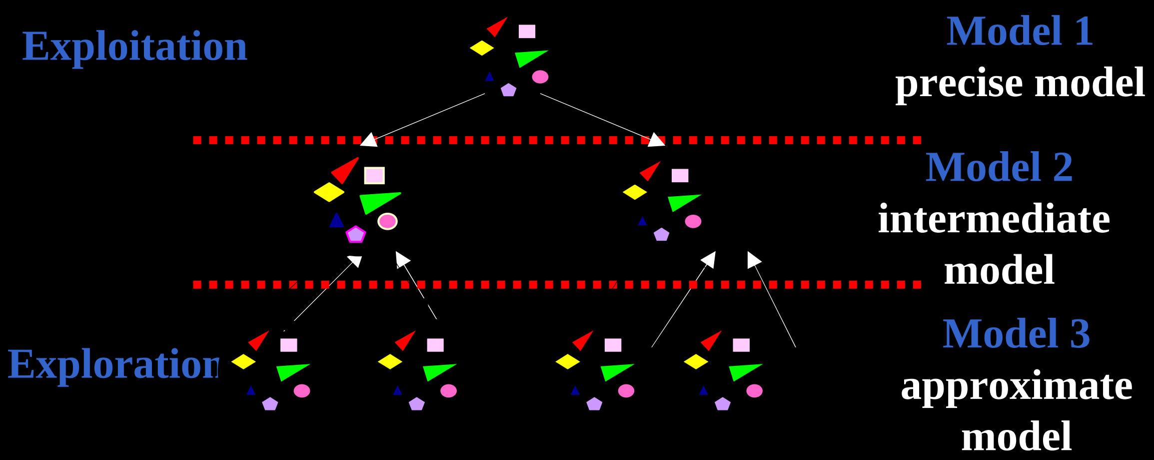
❖ EAs are able to explore large search spaces and are robust towards noise and local minima, are easy to parallelise.

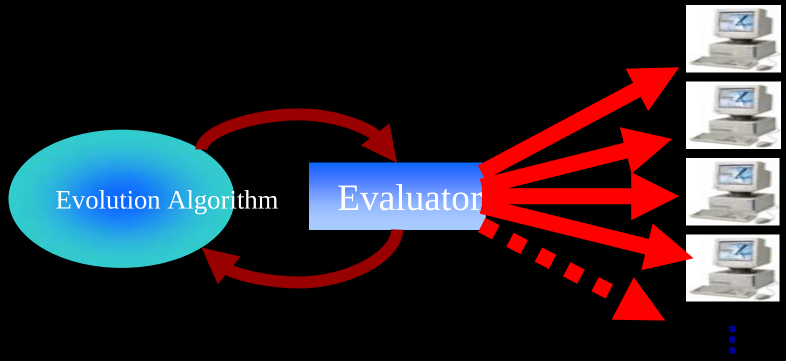
❖ EAs are known to handle approximations and noise well.

❖ EAs evaluate multiple populations of points.

❖ EAs applied to sciences, arts and engineering.

Hierarchical Topology-Multiple Models





- We use a technique that finds optimum solutions by using many different models, that greatly accelerates the optimisation process. Interactions of the 3 layers: solutions go up and down the layers.
- Time-consuming solvers only for the most promising solutions.
- Parallel Computing

Results so far… Algorithms

- The new technique is 3 times faster than other similar EA methods

	Evaluations	*CPU Time*
Traditional	2311 ± 224	152m ± 20m
New Technique	504 ± 490 (-78%)	48m ± 24m (-68%)

- A testbench for single and Multi objective problems has been developed and tested

- Successfully coupled the optimisation code to different compressible and incompressible CFD codes and also to some aircraft design codes

CFD

HDASS MSES XFOIL

FLO22 Nsc2ke

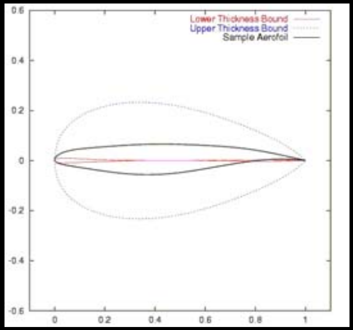
Aircraft Design

Flight Optimisation Software (FLOPS)

ADS (In house)

Results so far… Applications

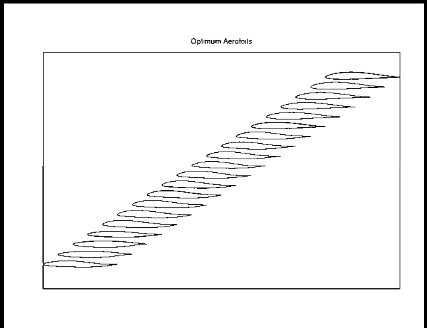
- Constrained aerofoil design → 3% Drag reduction



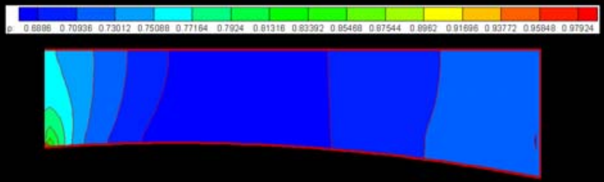
- UAV Aerofoil Design

  -Drag minimisation for high-speed transit and loiter conditions.

  -Drag minimisation for high-speed transit and takeoff conditions.

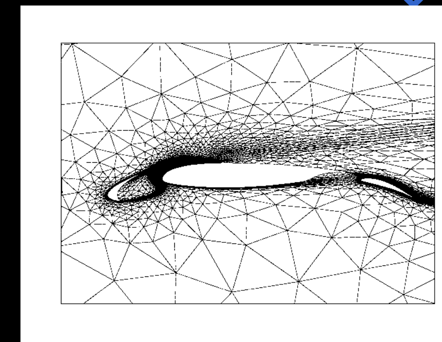


- Nozzle Design



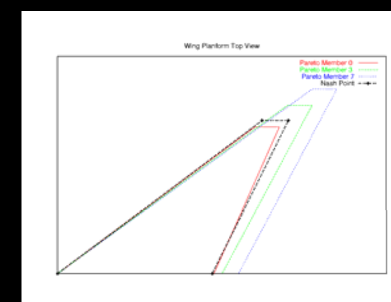
...Results so far.. Applications(2)

- 3 element aerofoil reconstruction



- UCAV MDO

Whole aircraft multidisciplinary design.
Gross weight minimisation and cruise efficiency
Maximisation. Coupling with NASA code FLOPS
2 % improvement in Takeoff GW and Cruise Efficiency



- **AF/A-18 Flutter Model Validation**

- **VTOL UAV Trajectory Optimisation using Evolution Strategies**

Current Research

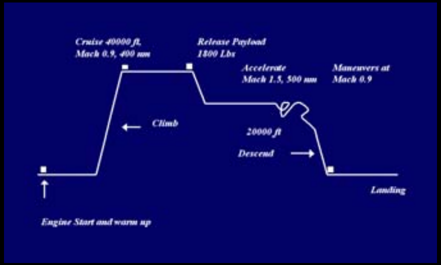
Algorithms

- A Hybrid EA -Deterministic optimiser.
- EA+ MDO : Evolutionary Algorithms Architecture for Multidisciplinary Design Optimisation
  We intend to couple the aerodynamic optimisation with:
  - Electromagnetics - Investigating the tradeoff between efficient aerodynamic design and RCS issues.
  - Structures - Especially in three dimensions means we can investigate interesting tradeoffs that may provide weight improvements.
  - Acoustics - How to maintain efficiency while lowering detectability.
  - And others...
- CFD – EA coupling
  Mesh adaptation, unstructured grid analysis , 3D Compressible Navier Stokes solver (LANS3D)

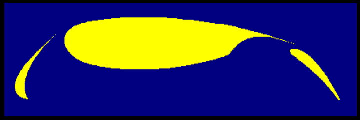
Applications....

…Applications

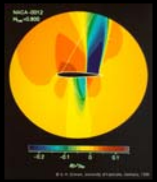
Multi- Fidelity Aircraft MDO



Multi-Element High Lift Design

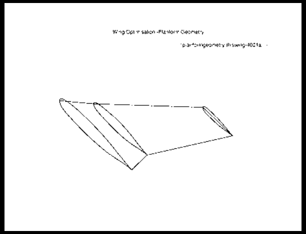


Transonic Viscous Aerodynamic Design



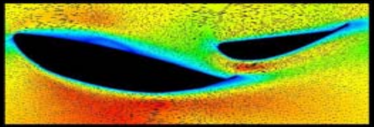
Propeller Design

Multi-Discipline Transonic Wing Design using compressible Navier Stokes Solver LANS3D



Turbomachinery Aerofoil Optimisation

F3 Rear Wing Aerodynamics



Adaptive wing Design

Wind Turbine Blade Design and optimisation

Outcomes of the research

- The new technique with multiple models: Lower the computational expense dilemma in an engineering environment (at least 3 times faster than similar approaches for EA)
- The multi-criteria HAPEA has shown itself to be promising for direct and inverse design optimisation problems.
- A wide variety of optimisation problems including Multi-disciplinary Design Optimisation (MDO) problems can be solved.
- Need to research on MDO architectures, hybrid techniques and their applications to engineering problems.
- The process finds traditional classical aerodynamic results for standard problems, as well as interesting compromise solutions.
- The benefits of using parallel computing, hierarchical optimisation and evolution algorithms to provide solutions for multi-criteria problems has been demonstrated.

Details on Applications

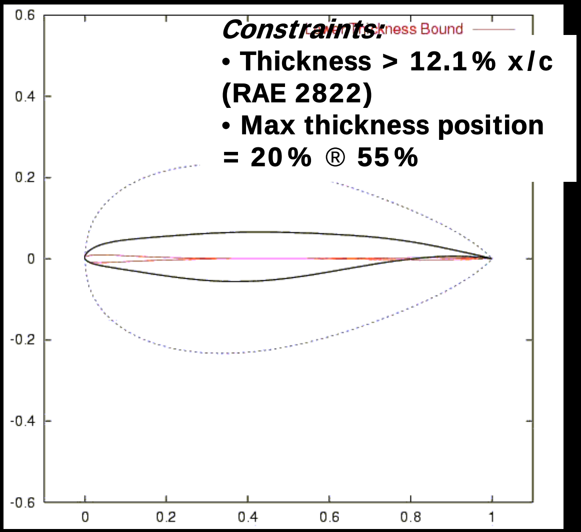
- For more details on this research and applications continue the presentation or go to: http://www.aeromech.usyd.edu.au/optimise/

Aerofoil at Two Different Lifts

Property	Flt. Cond. 1	Flt Cond.2
Mach	0.75	0.75
Reynolds	9 x 10^6	9 x 10^6
Lift	0.65	0.715

To solve this and other problems standard industrial flow solvers are being used.

Aerofoil	c_d [c_l = 0.65]	c_d [c_l = 0.715]
Traditional Aerofoil RAE2822	0.0147	0.0185
Conventional Optimiser [Nadarajah [1]]	0.0098 (-33.3%)	0.0130 (-29.7%)
New Technique	**0.0094 (-36.1%)**	**0.0108 (-41.6%)**

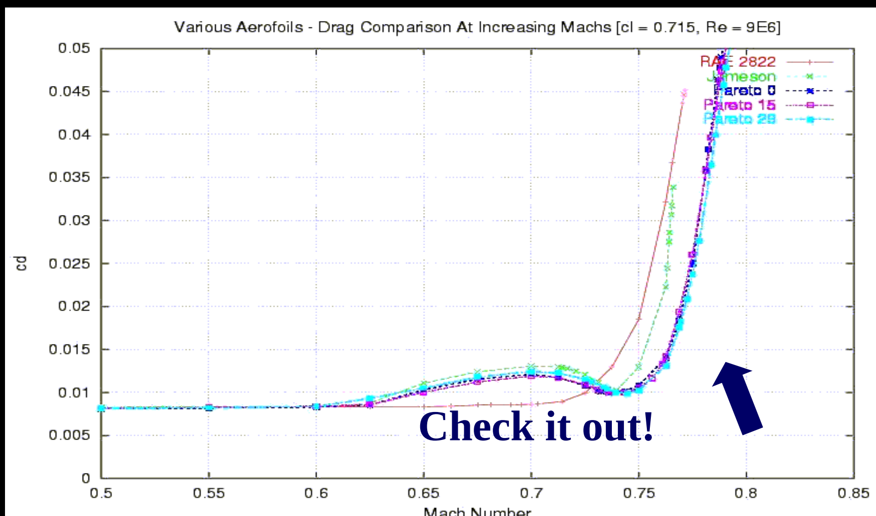


- ***For a typical 400,000 lb airliner, flying 1,400 hrs/year:***
- ***3% drag reduction corresponds to 580,000 lbs (330,000 L) less fuel burned.***

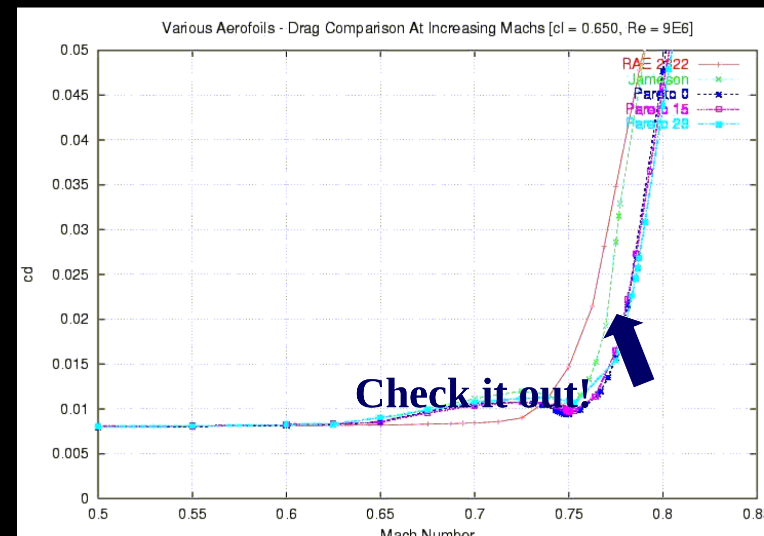
- [1] Nadarajah, S.; Jameson, A, " Studies of the Continuous and Discrete Adjoint Approaches to Viscous Automatic Aerodynamic Shape Optimisation," AIAA 15th Computational Fluid Dynamics Conference, AIAA-2001-2530, Anaheim, CA, June 2001.

Aerofoil at Two Different Lifts (2)

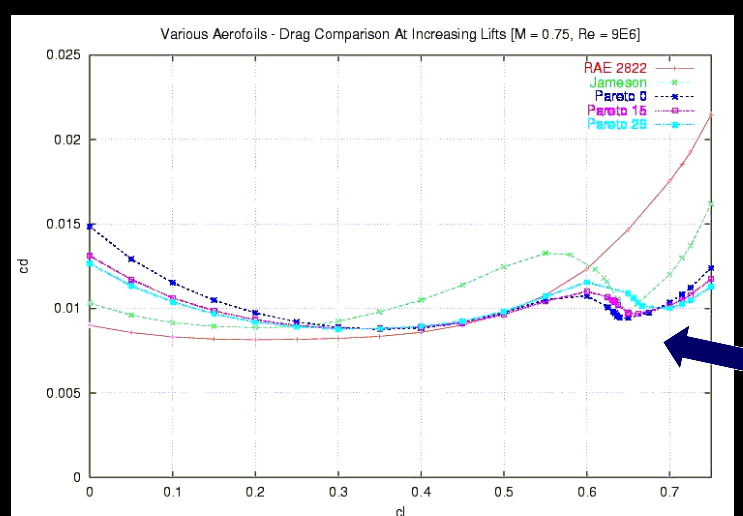
Aerofoil Characteristics $c_l = 0.715$



Aerofoil Characteristics $c_l = 0.65$

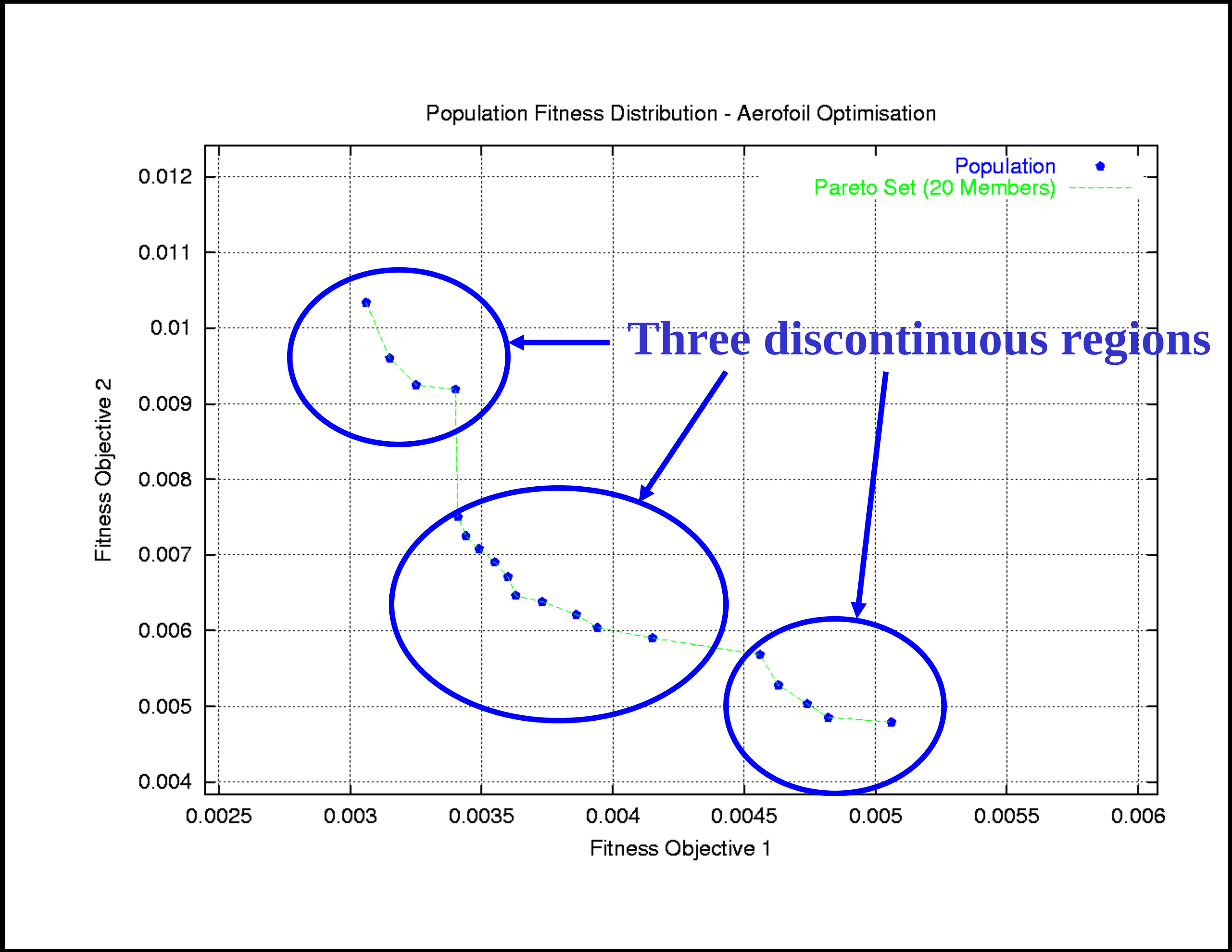


Aerofoil Characteristics $M_\infty = 0.75$

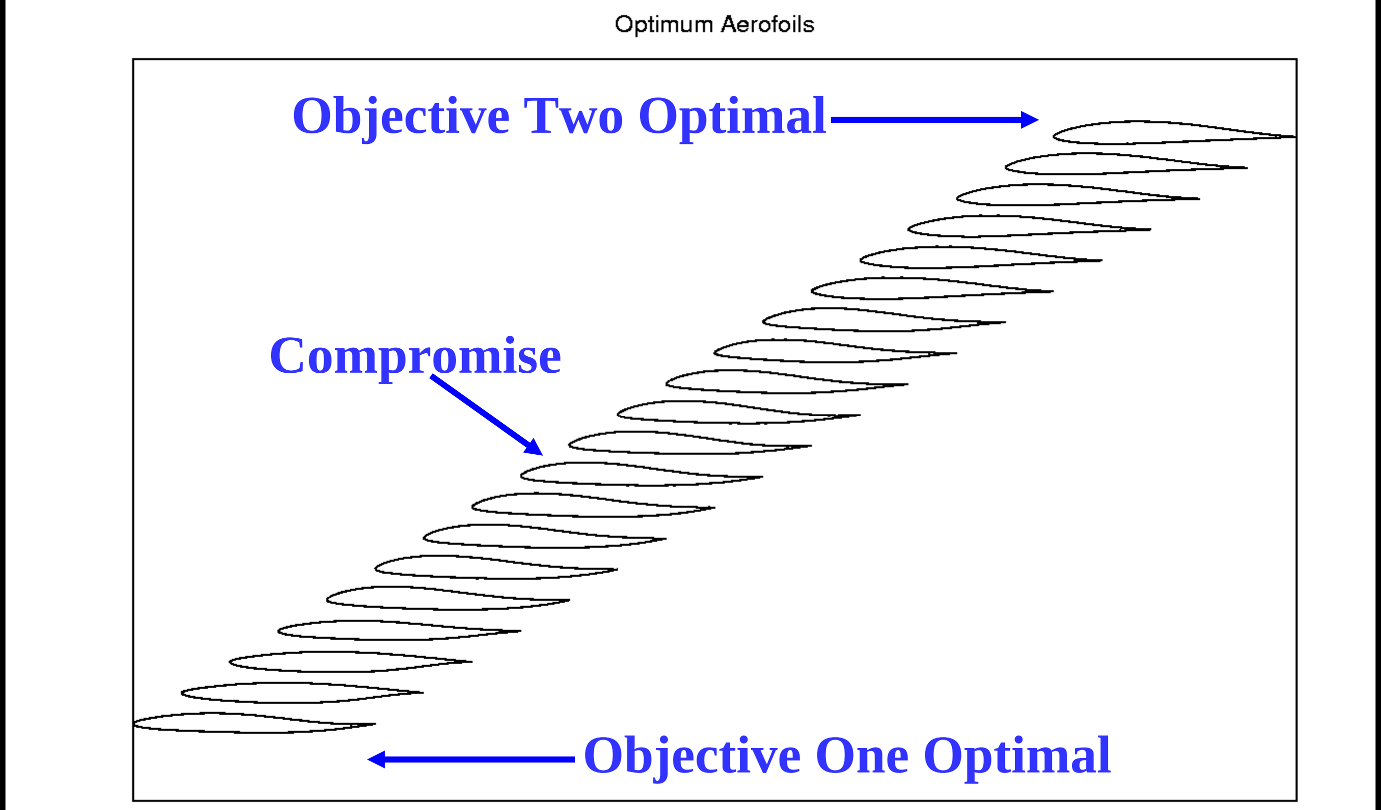


Check it out!

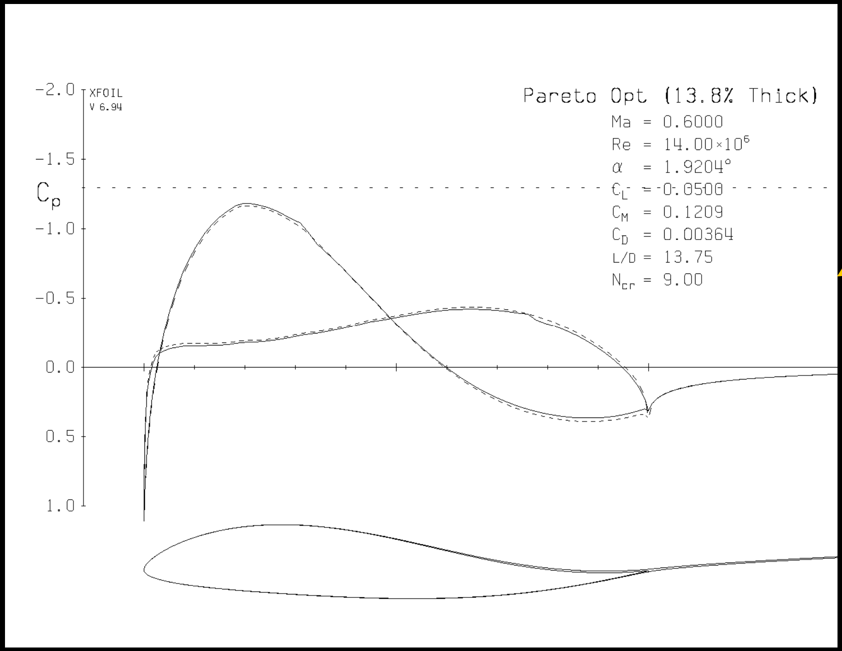
UAV Aerofoil Design



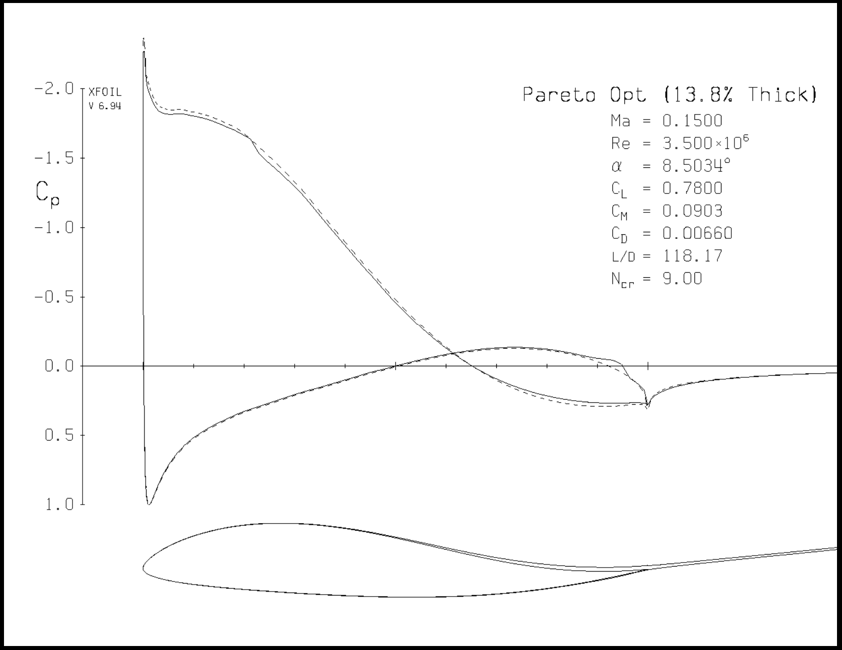
UAV Aerofoil Design (2)



UAV Aerofoil Design (3)



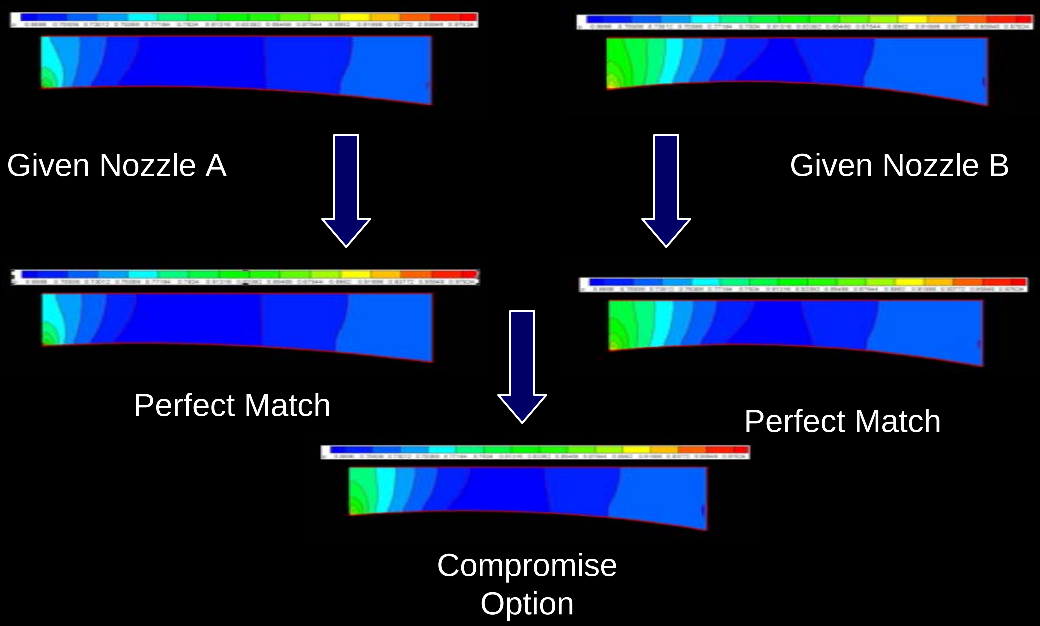
Compromise Solution - Transit Condition



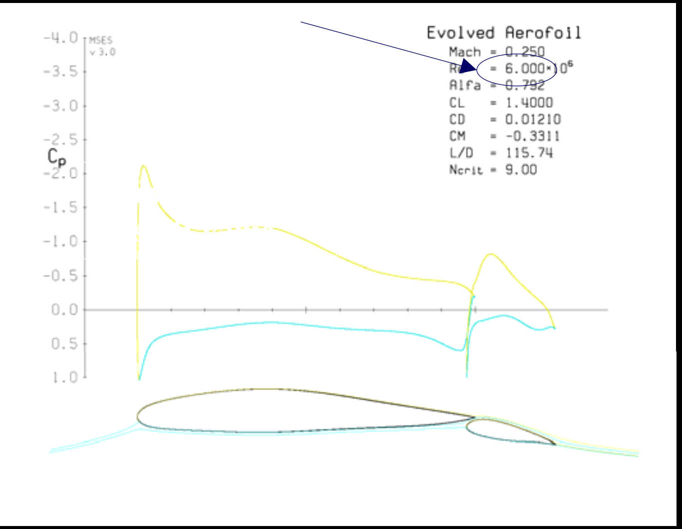
Compromise Solution - Loiter Condition

Applications in the Department

❖2D Nozzle Inverse Optimisation Problem

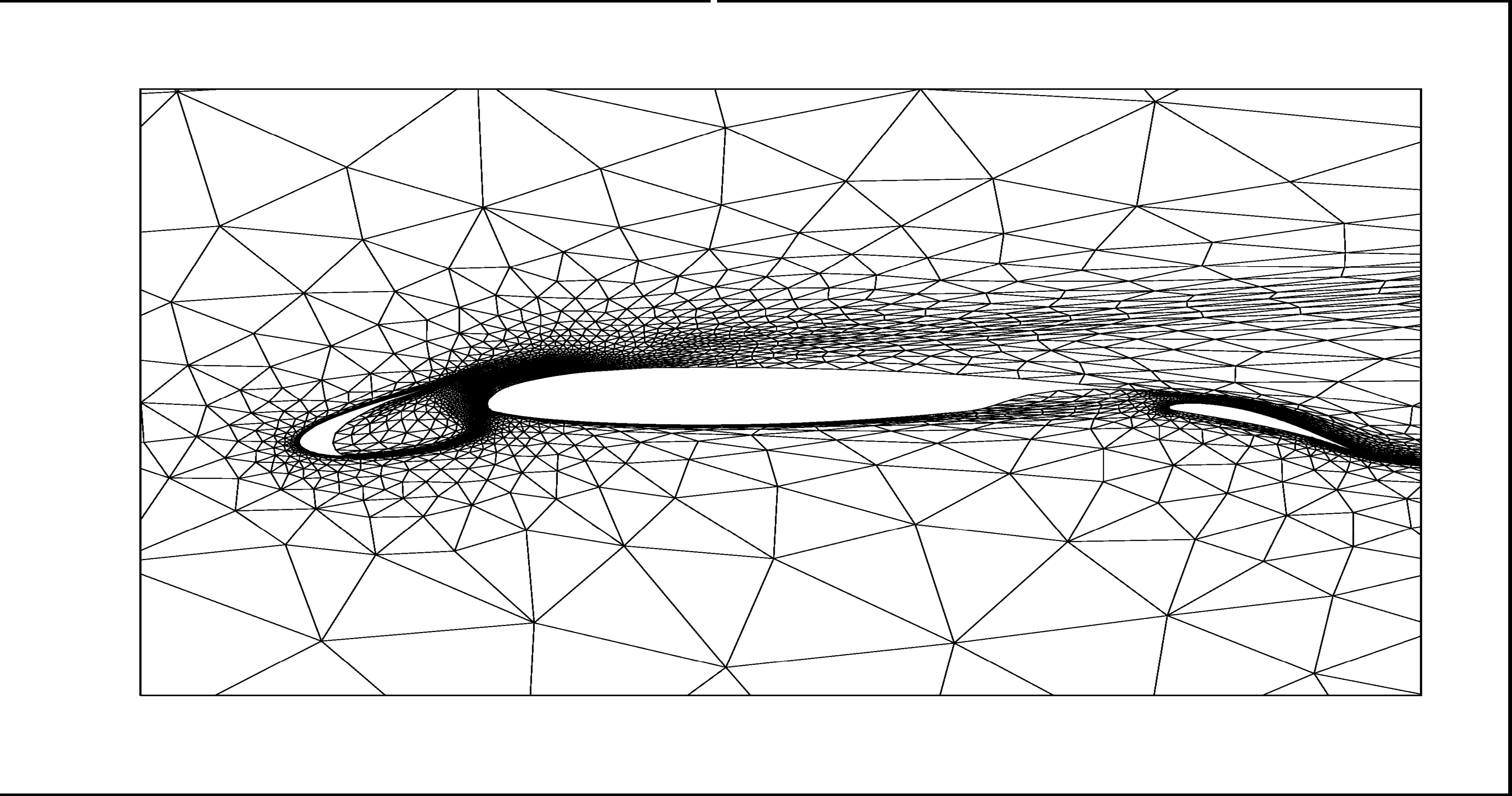


❖Two Element Aerofoil Optimisation Problem



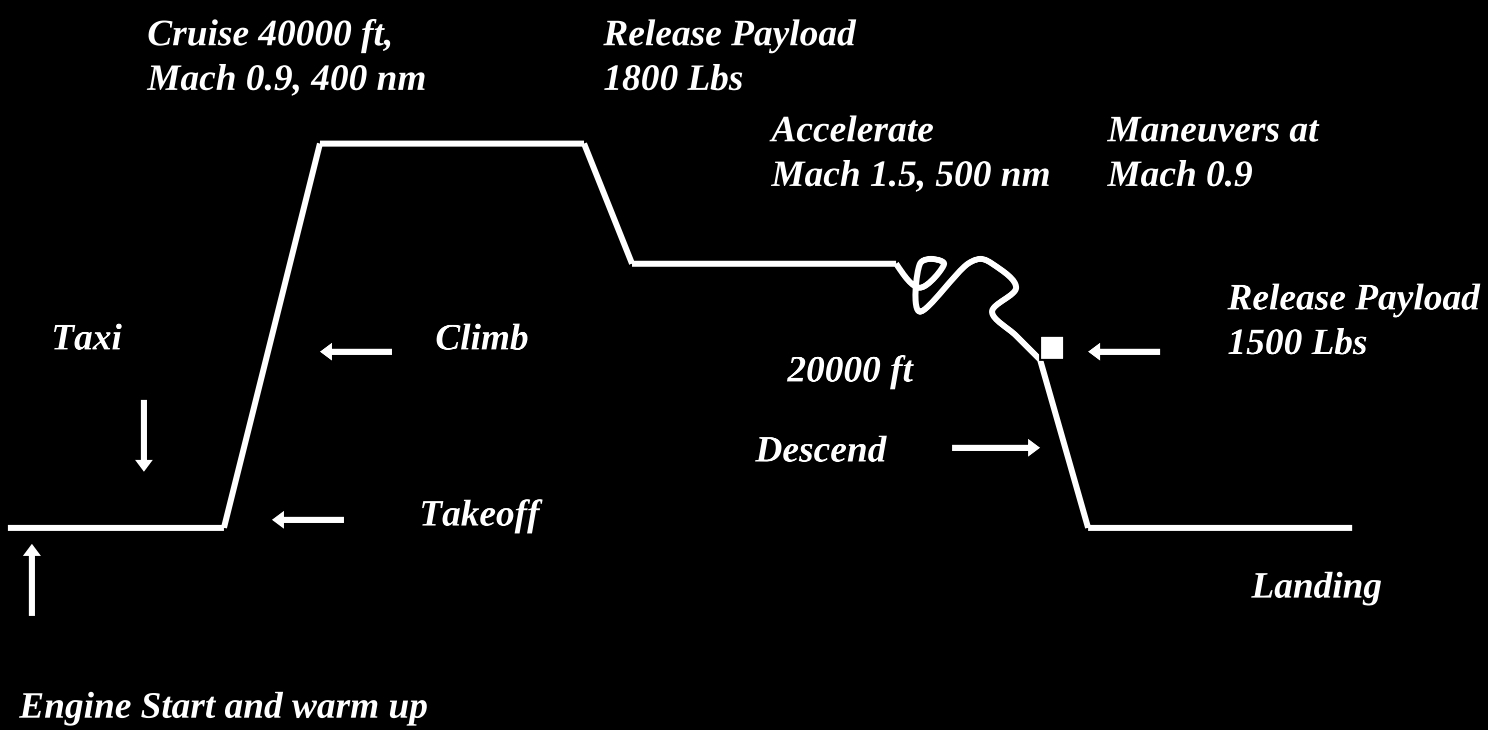
Three Element Aerofoil Reconstruction

Mesh Adaptation : Mesh 15

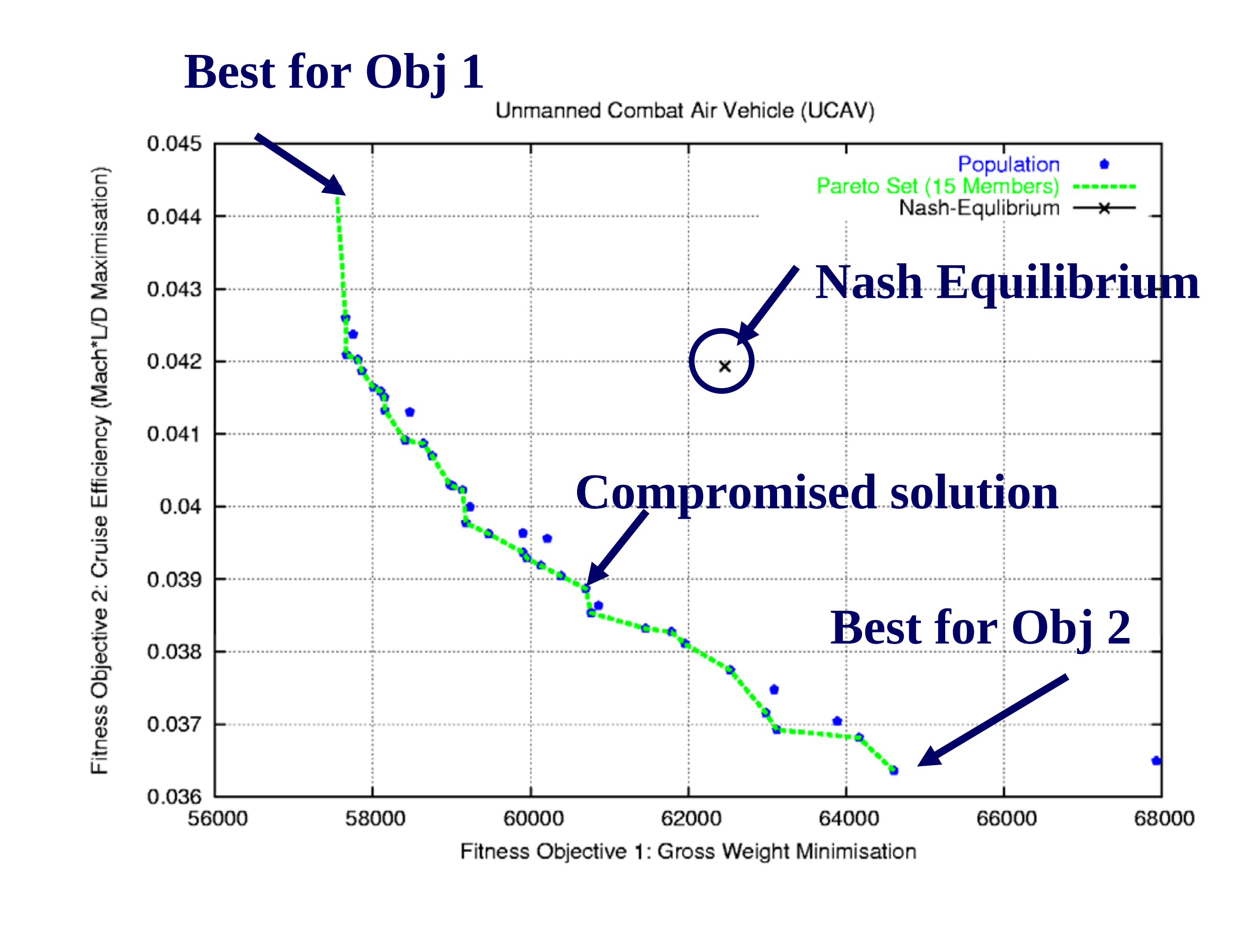


UCAV Multidisciplinary Design Optimisation
Two Objective Problem

Cruise Efficiency Maximisation– Gross Weight Minimisation



UCAV MDO Design (2)



UCAV MDO-MO (2) Comparison

Variables	Pareto Member 0	*Pareto Member 3*	Pareto Member 7	*Nash Equilibrium*
Aspect Ratio	4.76	*5.23*	5.27	*5.13*
Wing Area (sq ft)	629.7	*743.8*	919	*618*
Wing Thickness (t/c)	0.046	*0.050*	0.041	*0.021*
Wing Taper Ratio	0.15	*0.16*	0.17	*0.17*
Wing Sweep (deg)	28	*25*	27	*28*
Engine Thrust (lbf)	32065	*32219*	32259	*33356*

Gross Weight (Lbs)	57540	*59179*	64606	*62463*

← Decreasing Gross Weight

Nash Point

$M_{CRUISE}.L/D_{CRUISE}$	22.5	*25.1*	27.5	*23.9*

Increasing Cruise Efficiency →

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UCAV MDO-MO (3) Comparison