Multidisciplinary Design Optimization of a Composite Amphibious Aircraft Fuselage

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The golden age of seaplanes is long gone…

because of:

- Higher weight
- Higher drag
- Corrosion

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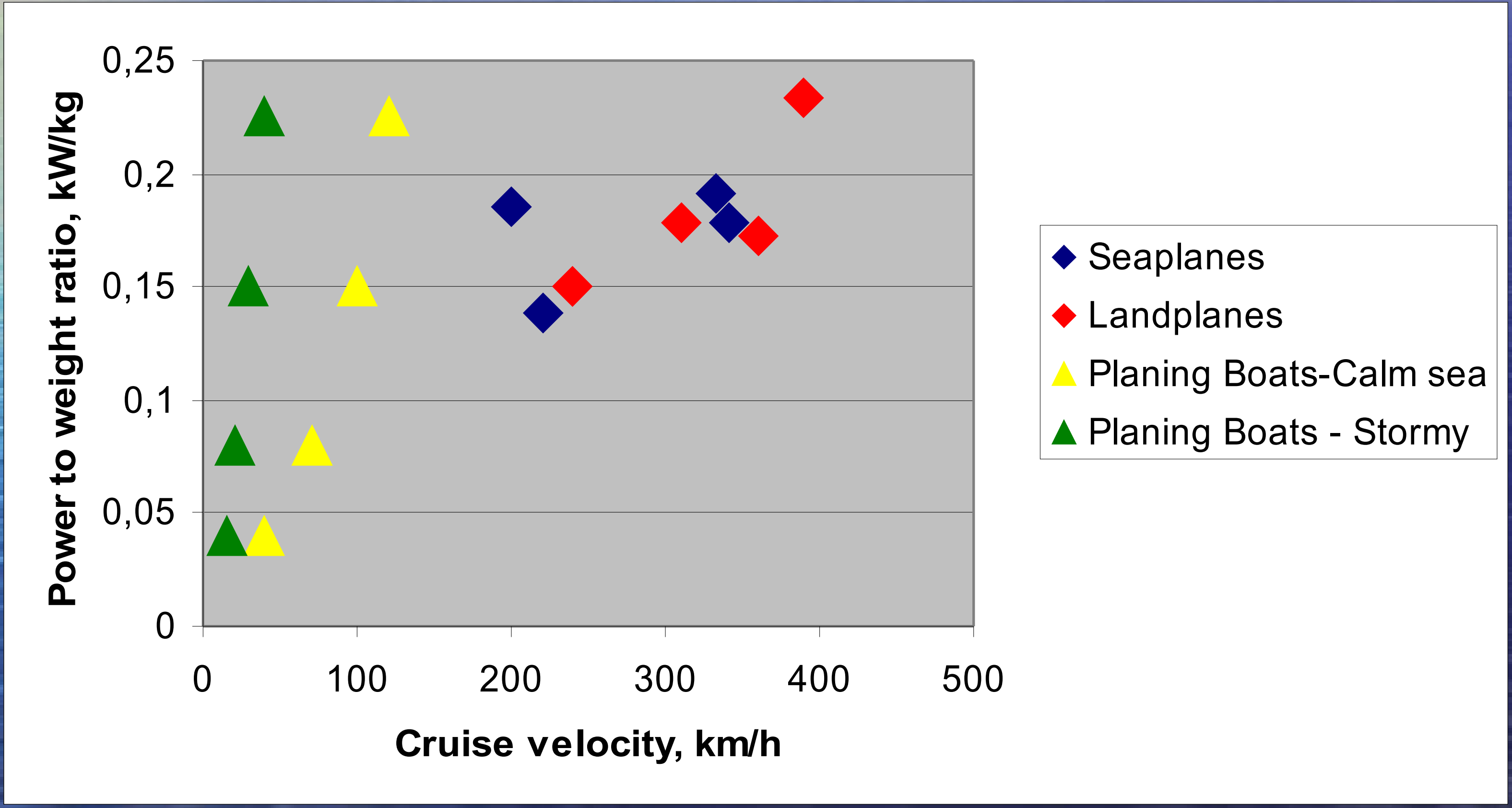
Power-to-weight ratio of planing boats and airplanes



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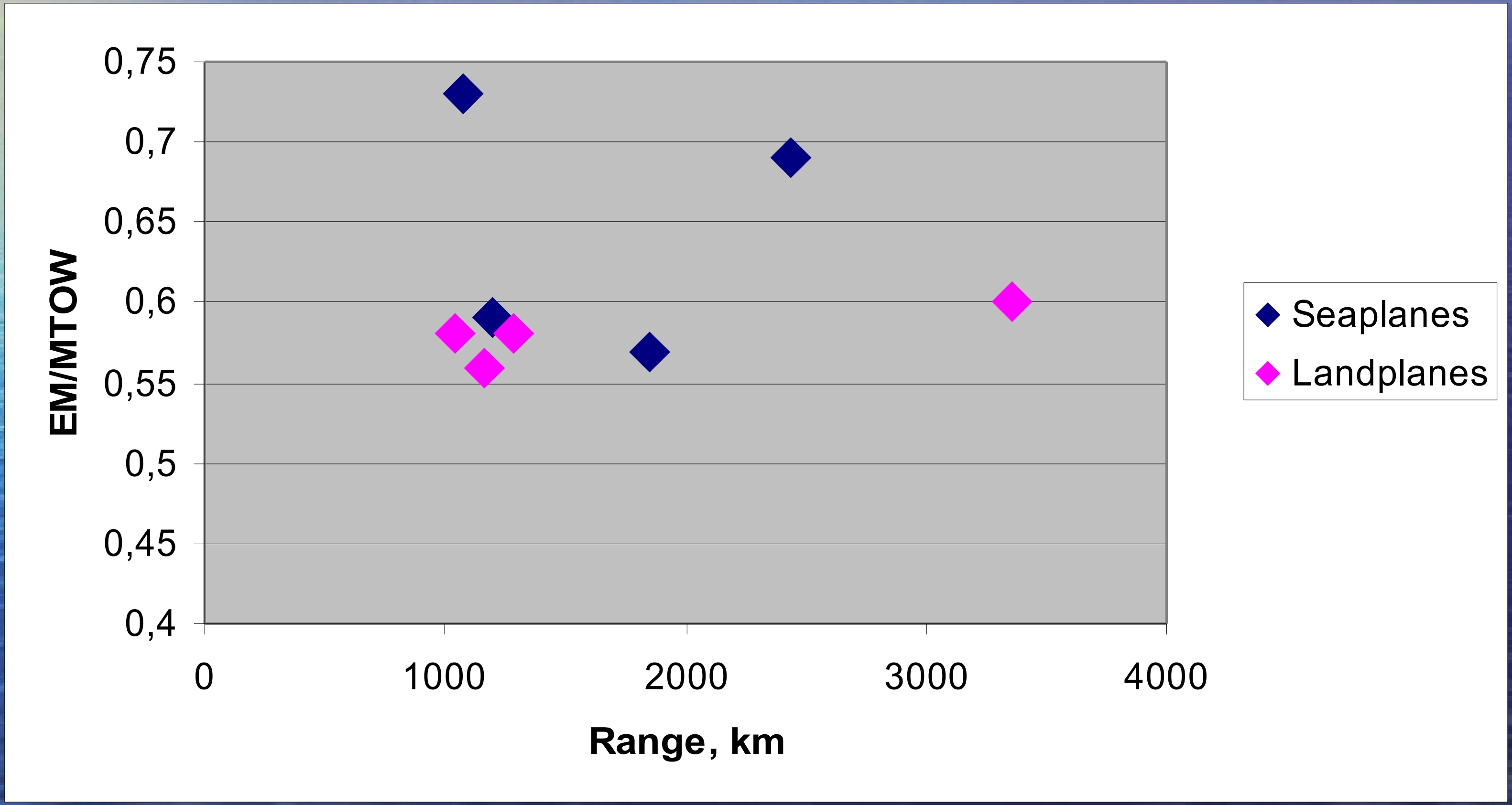
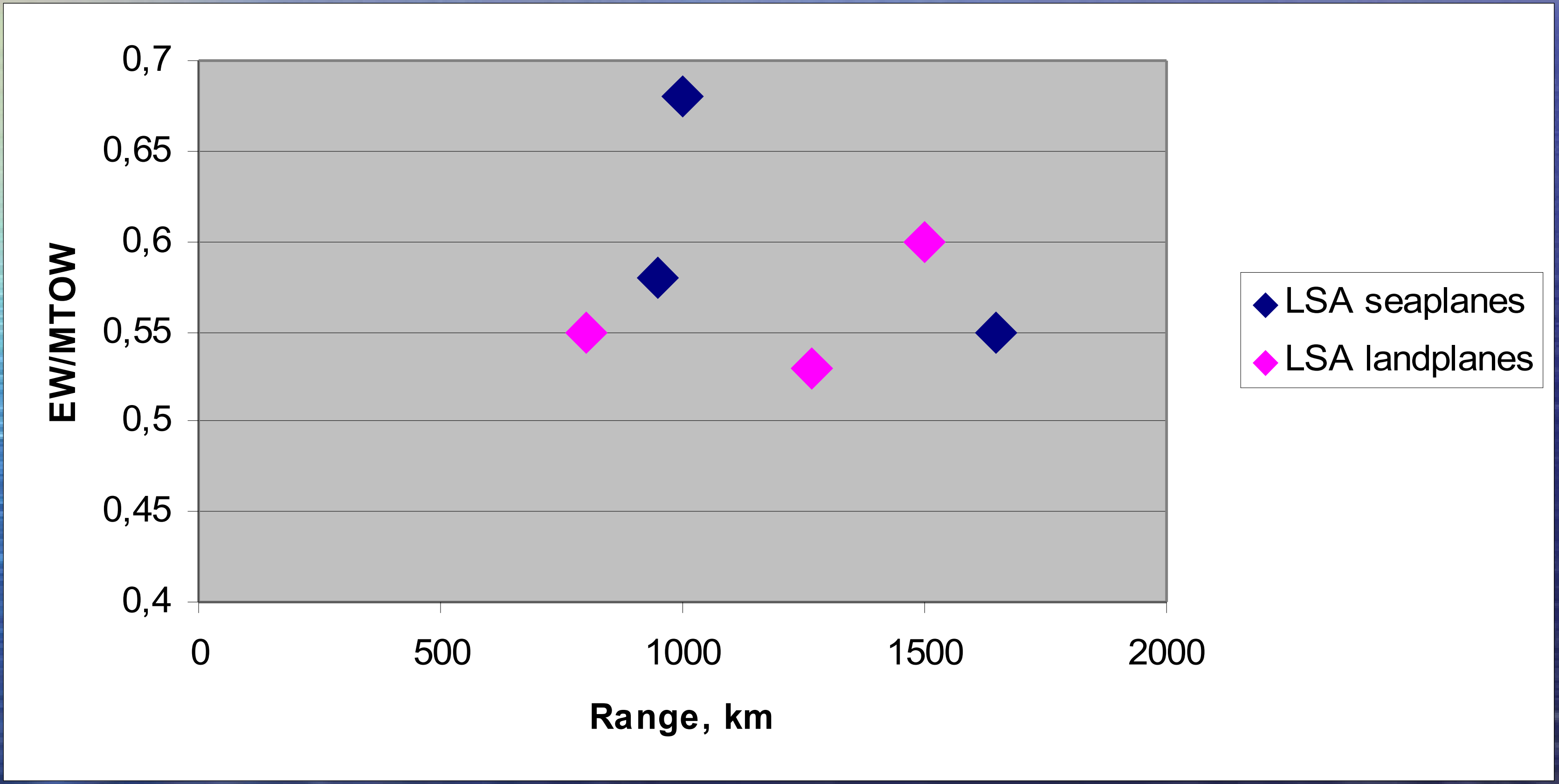
Empty weight to Maximum take-off weight of commercial seaplanes and landplanes



Empty weight to Maximum take-off weight of LSA seaplanes and landplanes



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Advantages of composite structures for amphibious aircraft

- Eliminate corrosion
- Reduce weight
- Cheaper maintenance and longer life
- Improved shape – lower drag

Sandwich structures

-lighter, because they are stiffer
-cost-effective
-can be more damage tolerant

Single Skin Laminate- Blunt Projectile Damage

Sandwich Laminate- Blunt Projectile Damage

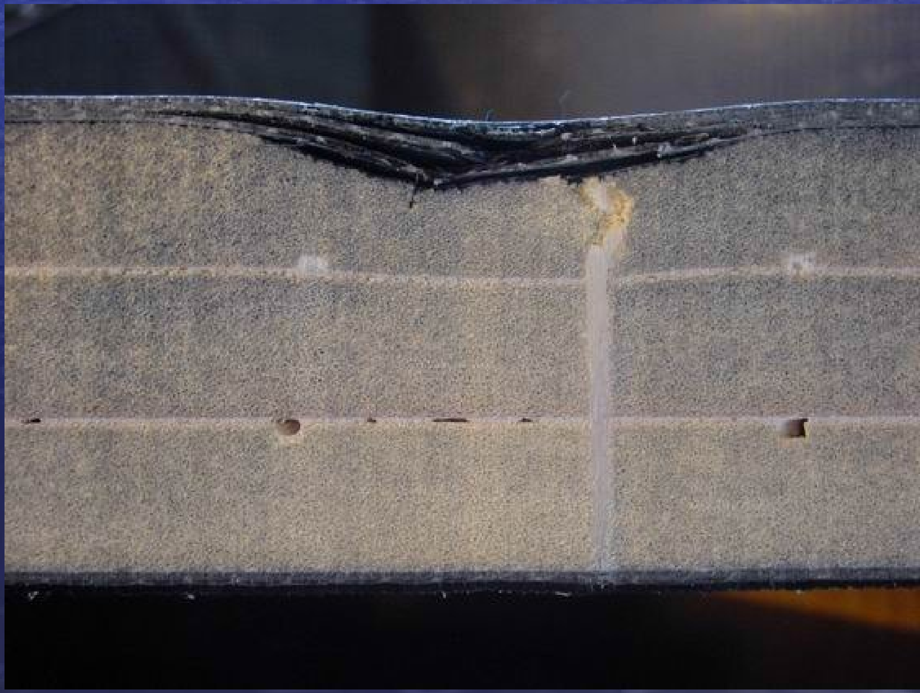

Photo by High Modulus (NZ) Ltd.

Application of the progress in planing boats design

Optimization of planing hullforms

- Resistance
- Longitudinal and lateral stability

Experience with composite hull structures

- Design
- Usage

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Amphibious aircraft design is multidisciplinary by nature – there are contradicting requirements for aerodynamics, structural performance and hydrodynamic properties :

Planing

- Stable Take-off – low drag and spray, longitudinal stability – porpoising
- Hull loads during take-off and landing

Displacement regime

- Seaworthines – hull volume
- Lateral stability

Traditional design of seaplanes

- Use of semi-empirical equations based on statistical data
- Data obtained from model scale tests
- Experience from former projects
- Sequential determination of design parameters

To explore new designs physics based models should be introduced

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Challenges for the high-fidelity CAD based analysis methods(Navier-Stokes fluid flow and FEM structural analyses)

- High complexity of the flow
- Very high computational cost
- Numerical noise due to discretization
- Impossible to explore large design spaces

The solution:

Use metamodels (models of models) for MDO

Benefits of metamodels:

- Merging of data from simulation and experimental analysis
- Filtering of numerical noise and experimental errors
- Low computational cost – rapid exploration of the design space
- Possible to use gradient-based optimization methods
- Visualization of the dependencies

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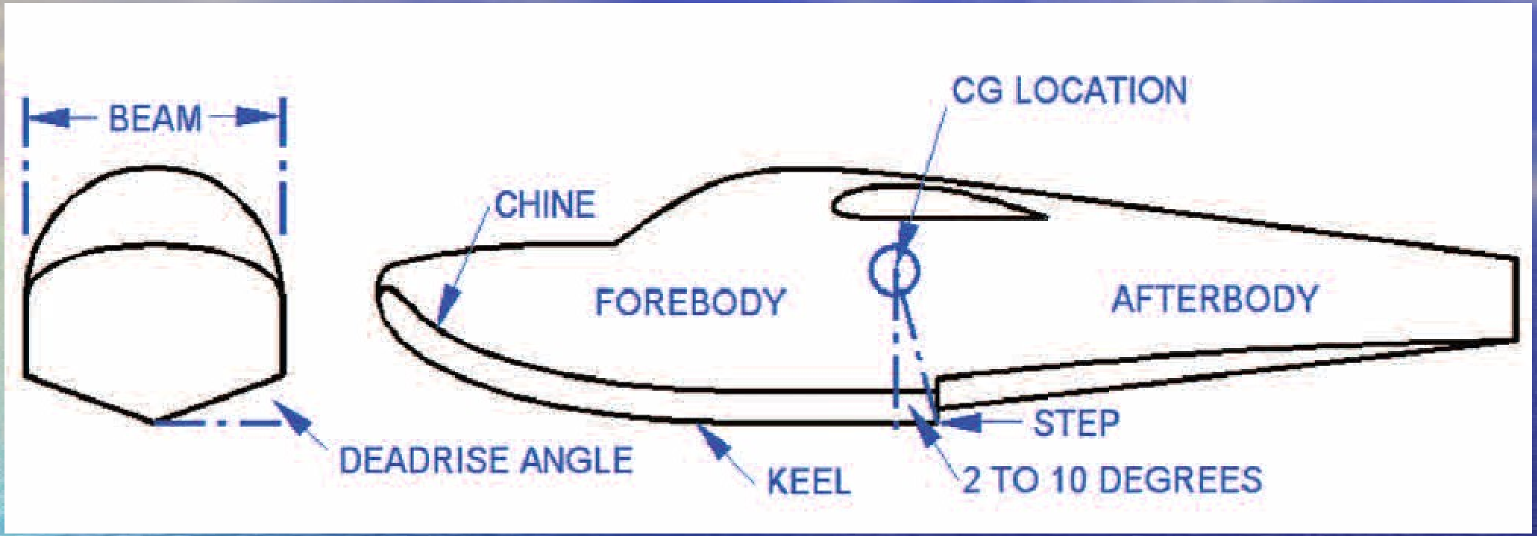
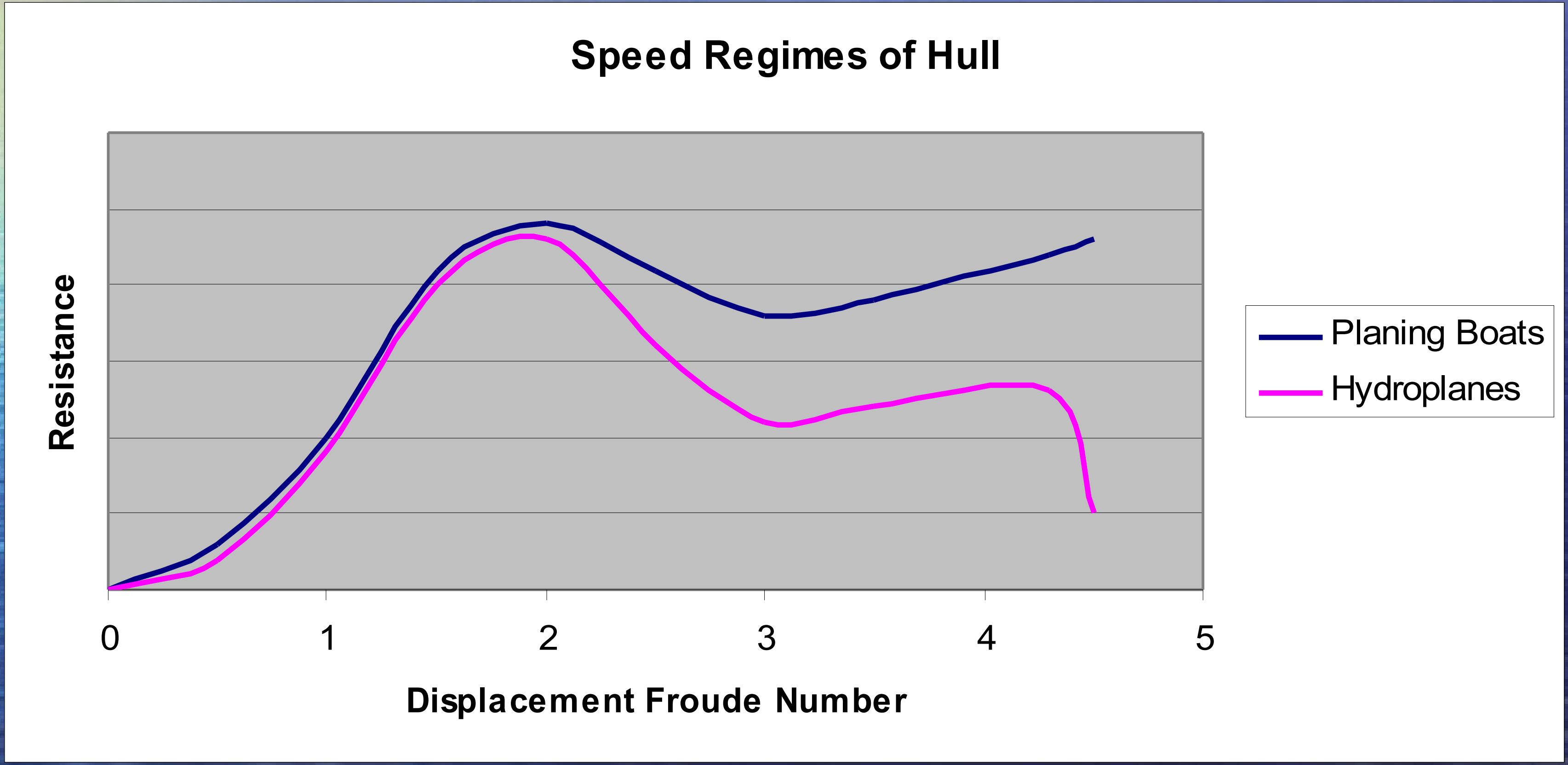
Flying boat hull definitions



- Beam load coefficient $$C_\Delta = \frac{\Delta}{\rho b^3}$$
- Displacement Froude Number $$F_\Delta = \frac{V}{\sqrt{g\sqrt[3]{\Delta}}}$$

Comparison of the hull resistance of planing boats and hydroplanes



Flying boat design is determined by the take-off condition
Most important parameter - beam

- Classic approach – empirical

Munro[2] $$b = 0{,}132\sqrt[3]{\Delta}$$

Δ – weight [kg]

b- beam [m]

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Application of planing boats data: Diehl[1]

Determination of beam from the hydrodynamic lift coefficient

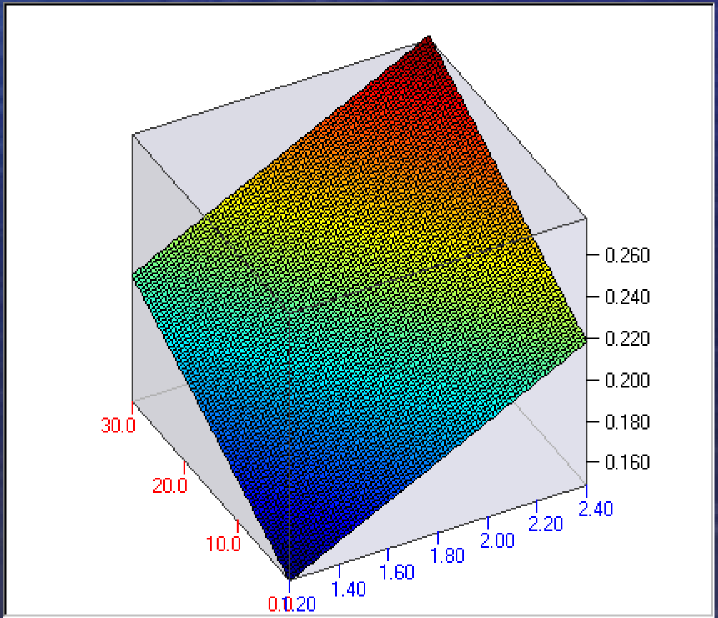
$$Chl = \frac{\Delta}{\frac{\rho V^2}{2} b^2}$$

Beam

$$b = K\sqrt{S}$$

K=K(β, Clmax)

S – wing surface



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Determination of beam for lateral stability in planing

$b_{min}(\beta, \Delta)[m] = 0,5 + 0,0004\ \Delta[kg] - 0,55\ \beta[rad]$

Longitudinal stability in planing

Forebody length/beam>3

Seaworthiness requirements

Hull volume>3*displacement

MDO methodology

- Create physics based metamodels for the drag and weight of a seaplane hull as functions of length to beam ratio and deadrise angle
- Determine the constraints from the hull volume requirements and the necessary forebody length
- Calculate the design pressures(CS-23)
- Build a Pareto front and select the design parameters according to mission and seaworthiness requirements.

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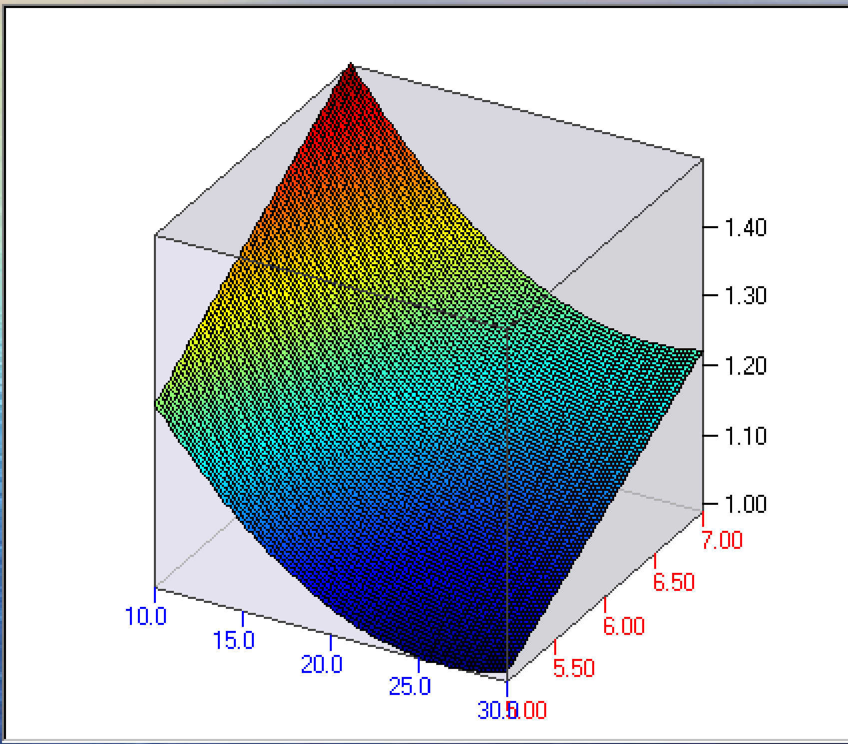
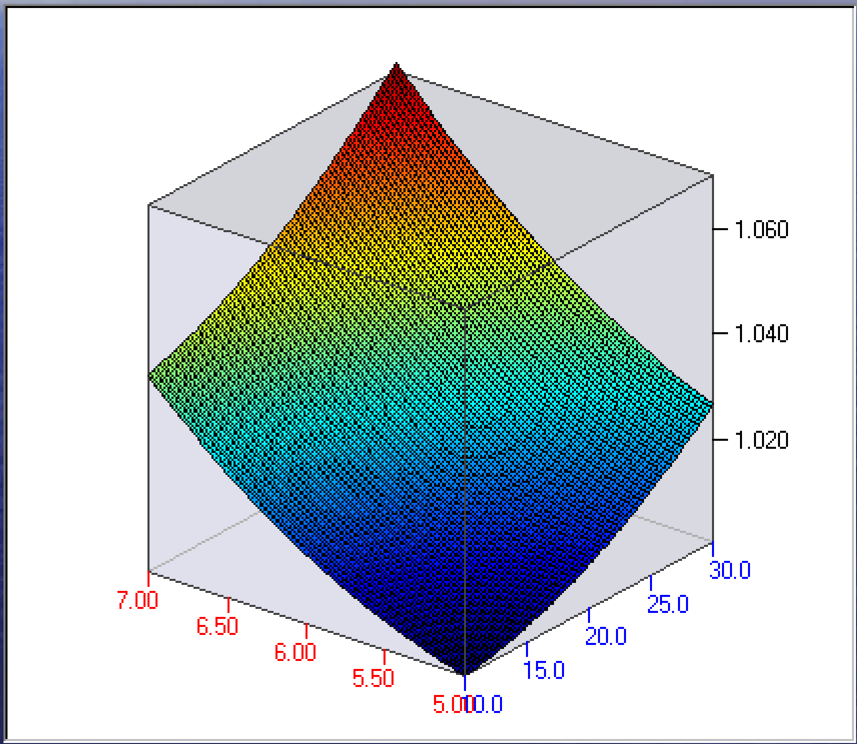
Response surfaces





- Weight / min weight (L/b, β°)
- Constant volume of hull

- Cx / Cxmin (L/b, β°)

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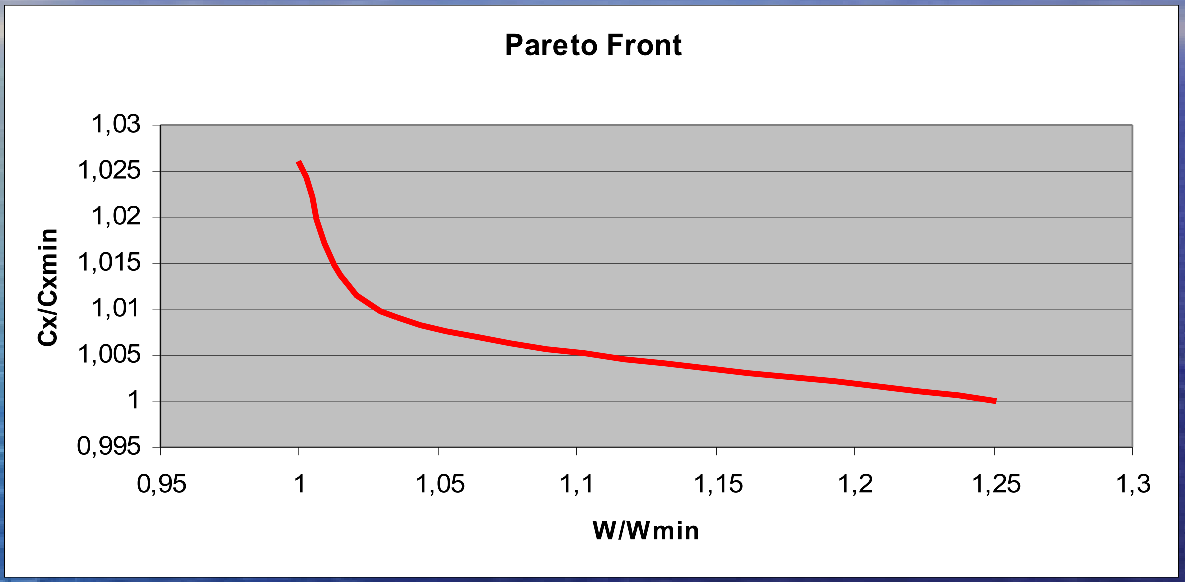
Pareto front
Drag-Weight tradeoff

Drag



Weight

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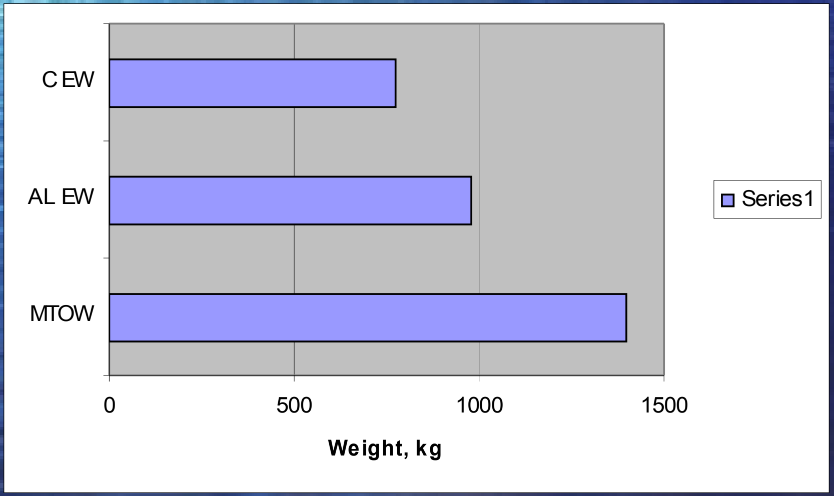
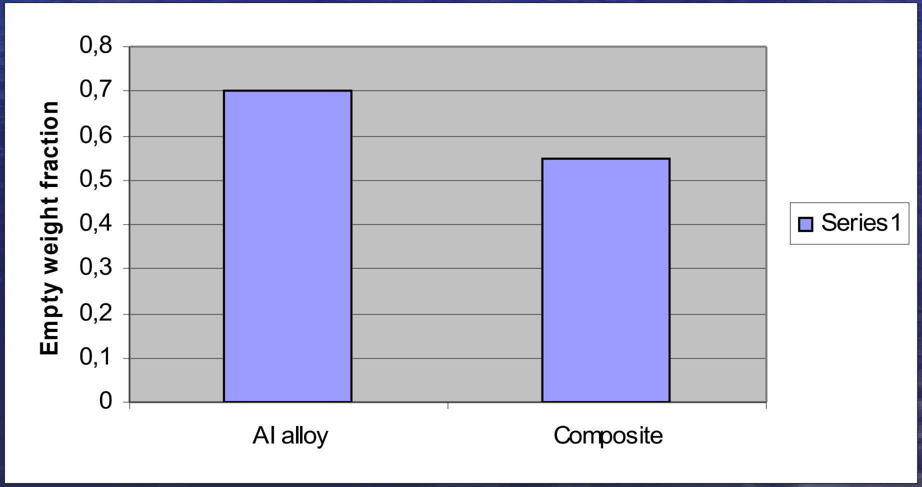
Design Study – Composite amphibious aircraft investigation

The benefits from replacing the Al alloy structure with CFRP sandwich one and optimizing the geometry of the planing hull





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Future Work

- Improve the metamodels with application of kriging or radial basis functions

References

1. Diehl, W. – The application of basic data on planing surfaces to the design of flying-boat hulls, NACA rep No 696, 1940
2. Munro, W. – Проектирование и расчет гидросамолетов – Москва 1935

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