Symbolic Regression With Genetic Algorithms for Early Conceptual Design of Helicopters

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Research project:
System-of-Systems - Trade Space Exploration (S2TEP)

SAAB TECHNOLOGIES SAAB S2TEP SARC

nffp VINNOVA Sweden's Innovation Agency

Agenda

- Optimization Problem
- My Method and Approaches
  - Statistical Regression
- Optimization Framework
  - DSM
  - ModeFRONTIER
- Results
- Conclusions and Outlook

"Optimization Framework for Early Conceptual Design of Helicopters"

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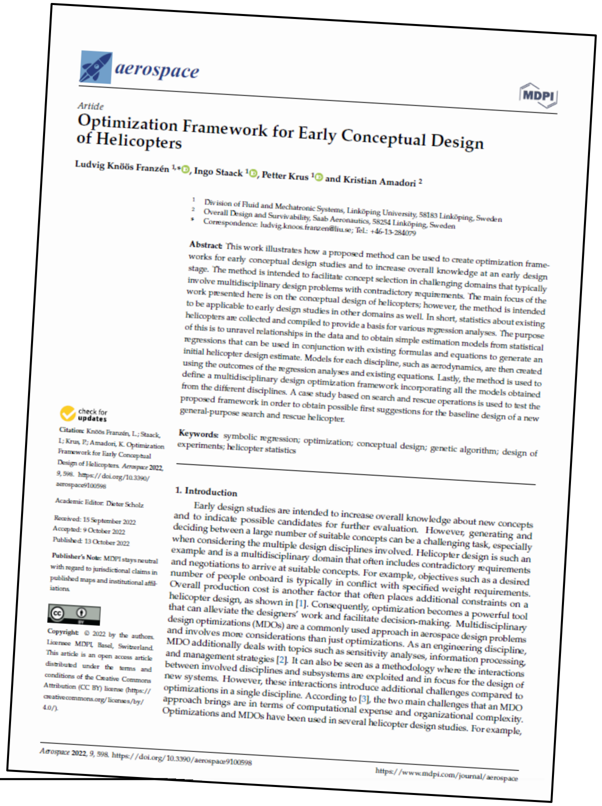

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Article

Optimization Framework for Early Conceptual Design of Helicopters

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Keywords: symbolic regression; optimization; conceptual design; genetic algorithm; design of experiments; helicopter statistics

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1. Introduction

Early design studies are intended to increase overall knowledge about new concepts and to indicate possible candidates for further evaluation. However, generating and deciding between a large number of suitable concepts can be a challenging task, especially when considering the multiple design disciplines involved. Helicopter design is such an example and is a multidisciplinary domain that often includes contradictory requirements and negotiations to arrive at suitable concepts. For example, objectives such as a desired number of people onboard is typically in conflict with specified weight requirements. Overall production cost is another factor that often places additional constraints on a helicopter design, as shown in [1]. Consequently, optimization becomes a powerful tool that can alleviate the designers' work and facilitate decision-making. Multidisciplinary design optimizations (MDOs) are a commonly used approach in aerospace design problems and involves more considerations than just optimizations. As an engineering discipline, MDO additionally deals with topics such as sensitivity analyses, information processing, and management strategies [2]. It can also be seen as a methodology where the interactions between involved disciplines and subsystems are exploited and in focus for the design of new systems. However, these interactions introduce additional challenges compared to optimizations in a single discipline. According to [3], the two main challenges that an MDO approach brings are in terms of computational expense and organizational complexity. Optimizations and MDOs have been used in several helicopter design studies. For example,

Introduction

- This paper proposes a method for generating optimization frameworks for early conceptual design studies
- Early design of a general-purpose search and rescue helicopter is used as case study
- Multi-disciplinary problem with typically conflicting requirements
  - Range, number of passengers, cost, weight, etc…
- Available helicopter design methods and approaches include a lot of details, and a designer must be quite familiar with the topic to make an initial concept selection
- Desirable to facilitate an early concept selection from simpler means
- Statistics of existing solutions

Search and Rescue Case Study

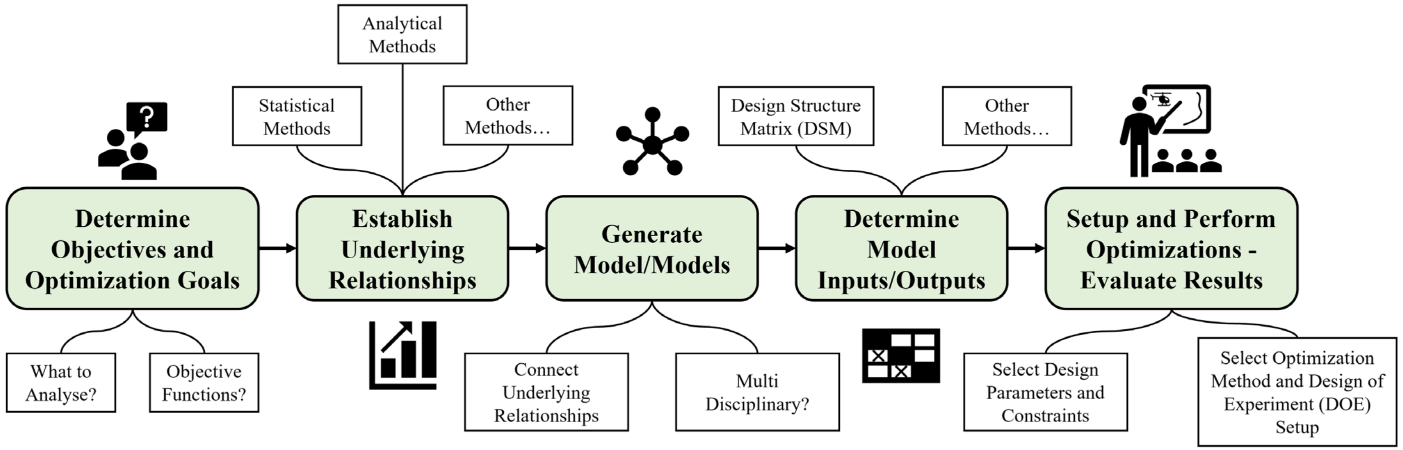
Optimization Problem

- General-purpose search and rescue helicopter
- Objectives:
  - **Maximize:** Range and Rescue/Passenger Capacity
  - **Minimize:** Fuel Consumption, Weight and Cost per Hour
- Design parameters:
  - Fuselage length (≈Helicopter Size)
  - Helicopter Rotor diameter
  - Number of Rotors
- Constraint
  - On flight velocity to avoid stalling rotor blades

Search and Rescue Case Study

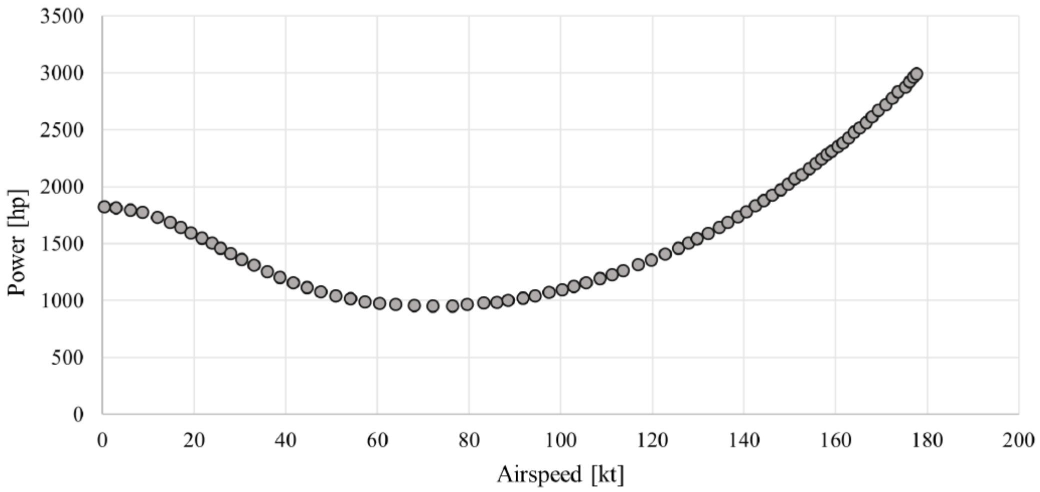
Method and Approaches

- Find suitable equations and formulas
  - Proved to be harder than expected!
- Make my own formulas based on statistics and regressions
  - Collecting helicopter data



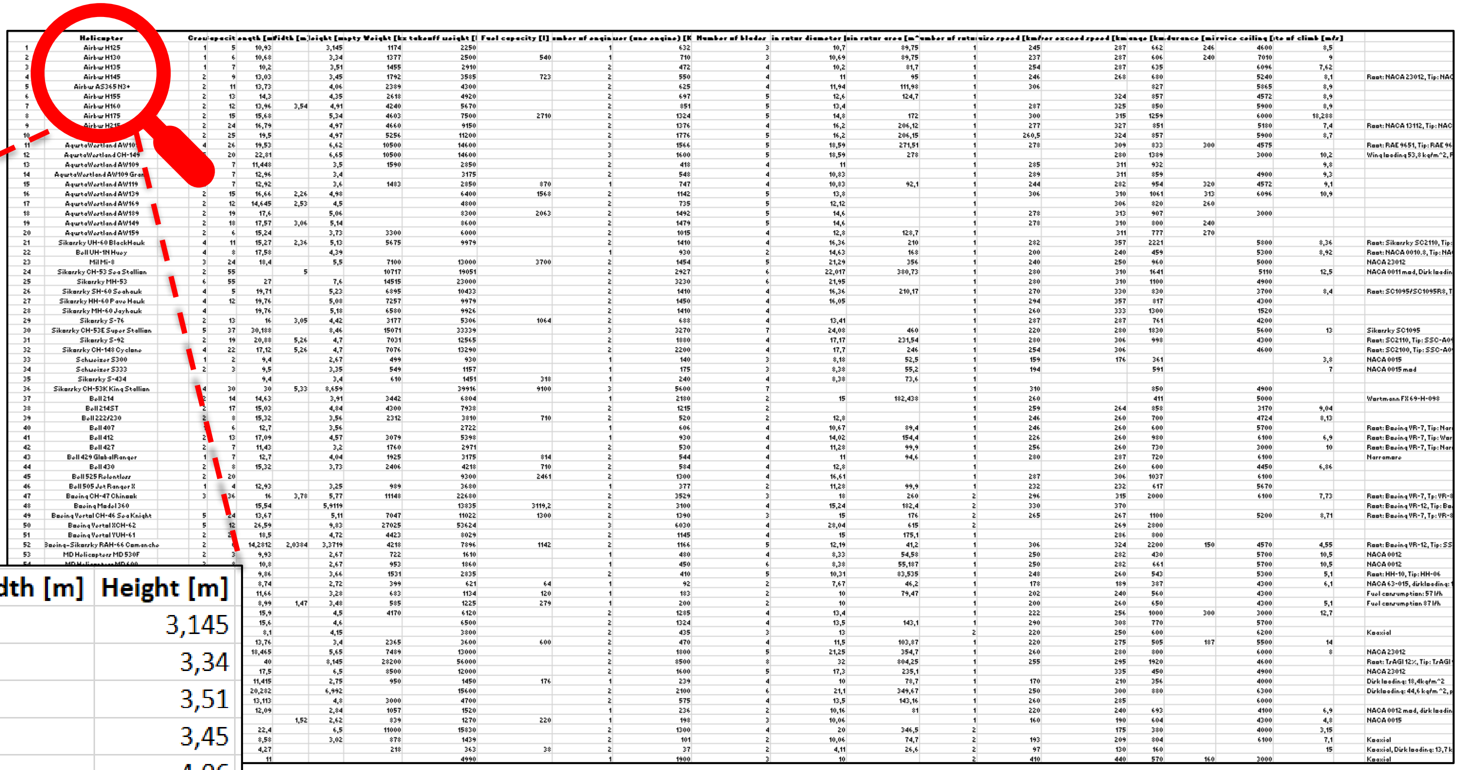
$$Range = \frac{V}{g}\frac{\eta\xi}{SFC}\frac{L}{D}ln\left(\frac{W_{initial}}{W_{final}}\right)$$

$$L/D = WV_{\infty}/P$$



Method and Approaches

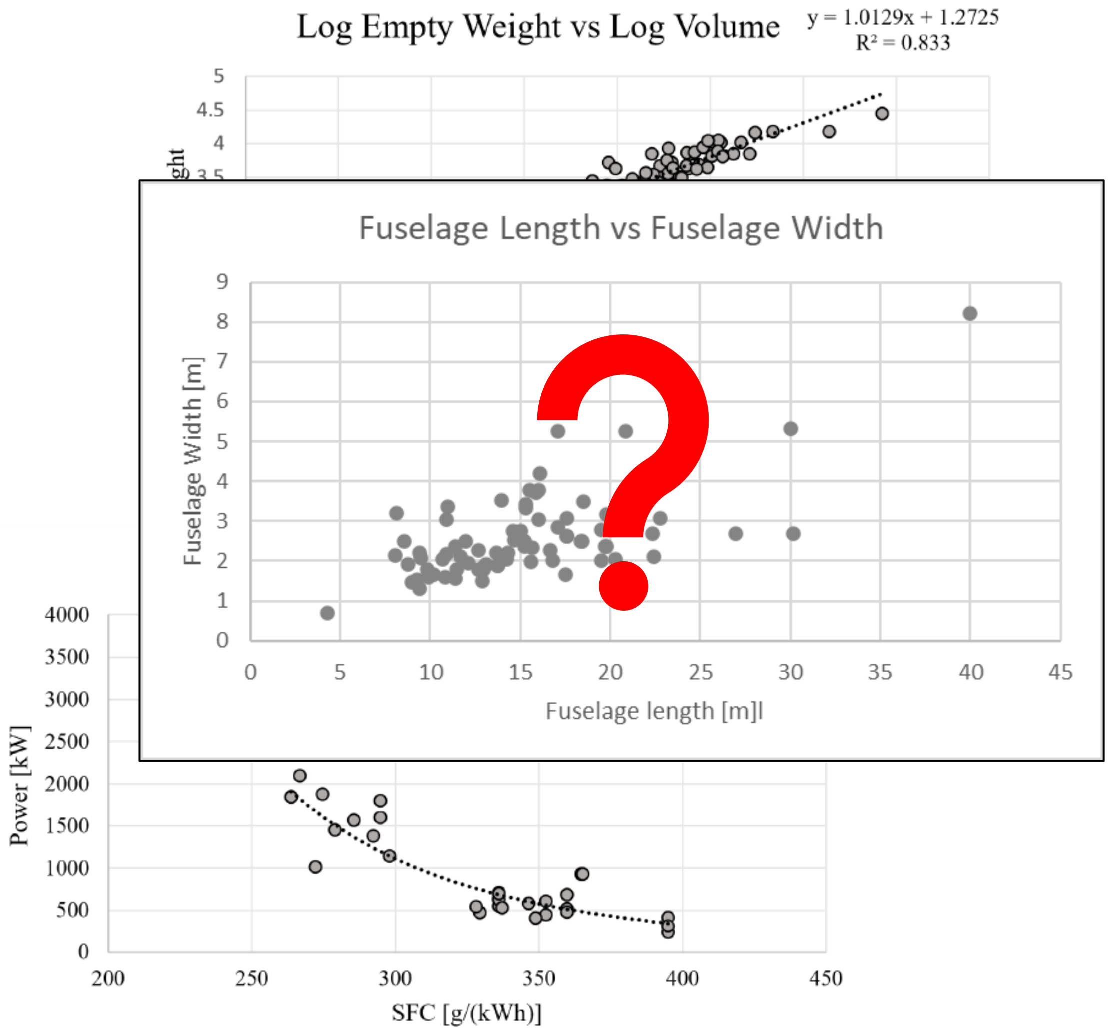
- Own Statistical Database
  - Over 75 different helicopters



Helicopter	Crew	Capacity	Length [m]	Width [m]	Height [m]
Airbus H125	1	5	10,93		3,145
Airbus H130	1	6	10,68		3,34
Airbus H135	1	7	10,2		3,51
Airbus H145	2	9	13,03		3,45
Airbus AS365 N3+	2	11	13,73		4,06
Airbus H155	2	13	14,3		4,35
Airbus H160	2	12	13,96	3,54	4,91

Method and Approaches

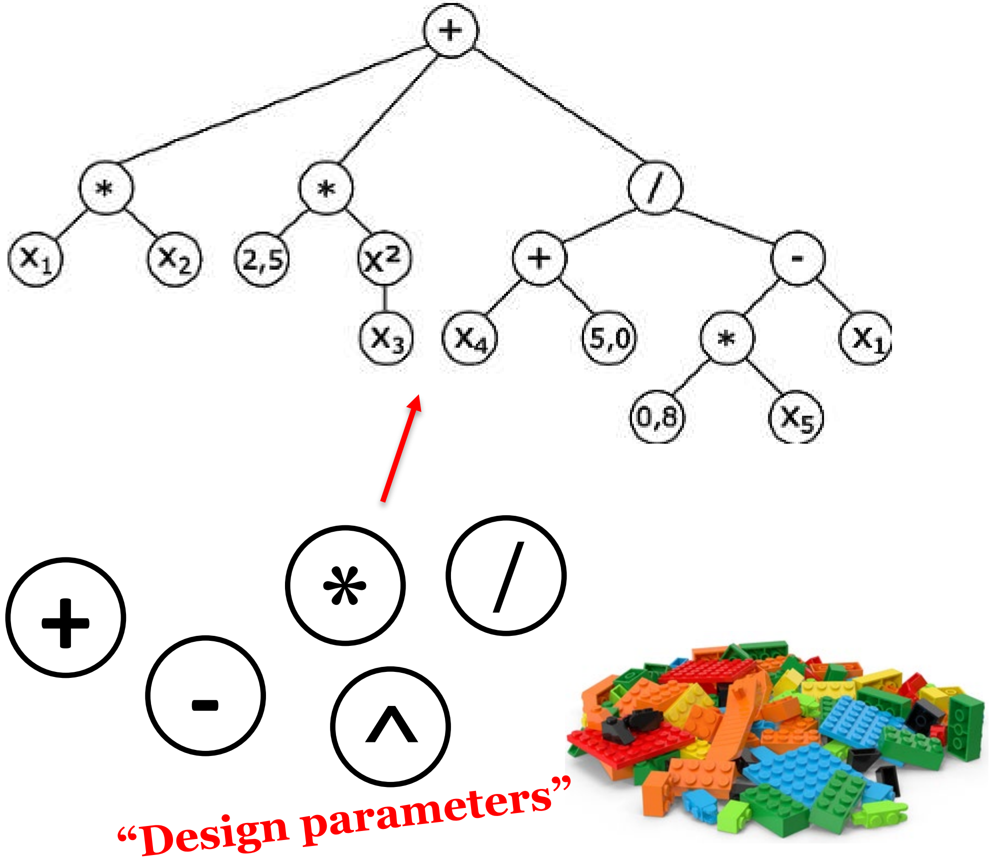
- Own Statistical Database
  - Over 75 different helicopters
- Regression analyses to obtain formulas and models for the optimization framework
  - Linear (and Linear LogLog)
  - Other trendlines e.g., exponential
- However, regressions can become tricky, and intuition is not always “best”…
- So, what do we do?
  - Optimization?!
- Symbolic Regression using Genetic Algorithms



Symbolic Regression With GA

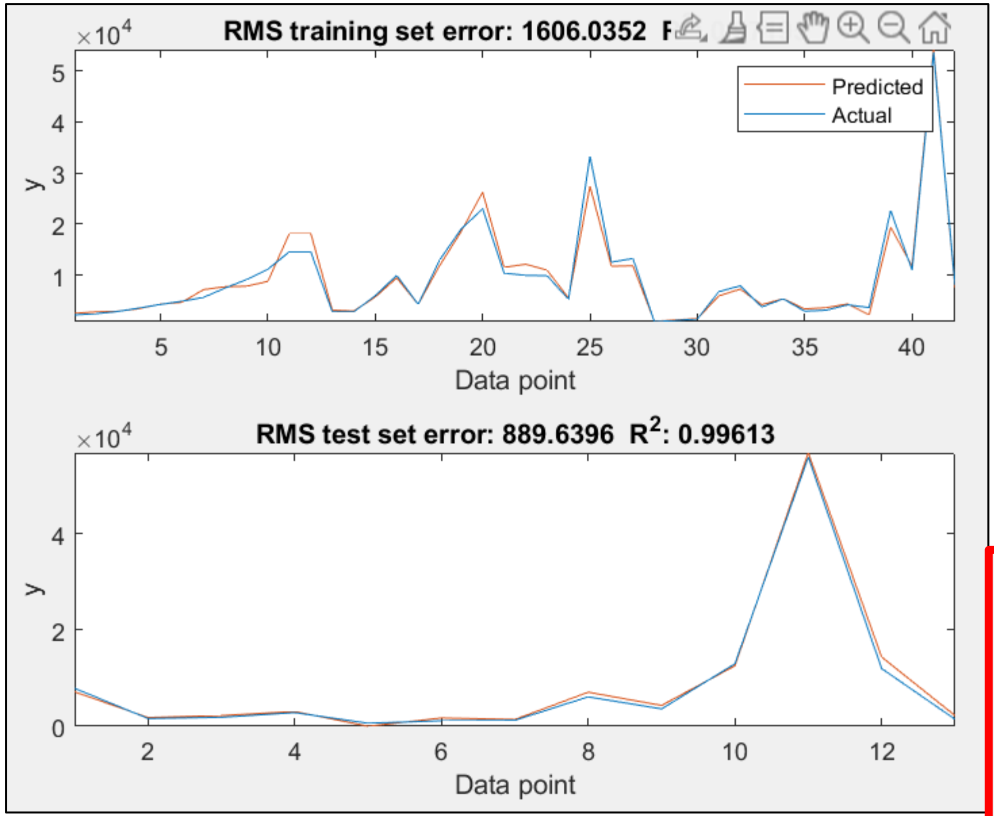
- What is Symbolic Regression?
  - Symbolic Regression is a type of regression analysis that searches the space of mathematical expressions to find the model that best fits a given dataset, both in terms of accuracy and simplicity.
  - Randomly combining mathematical building blocks with Genetic Algorithms
  - Objective: Minimize, for example, mean square error
  - Penalizes complex/lengthy expressions
  - Reduces human bias
  - Results in an equation/function/expression

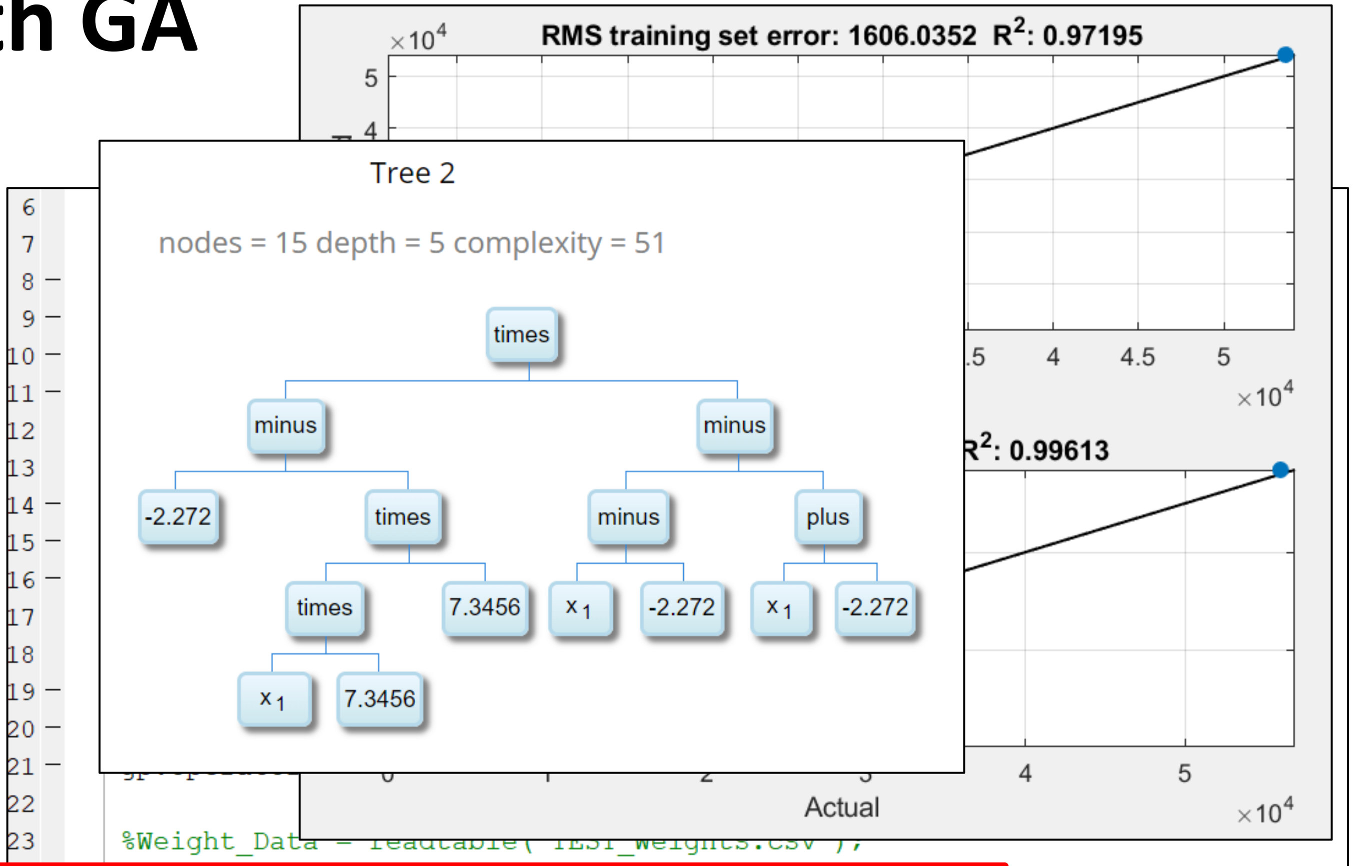
$$f(x) = x_1 x_2 + 2.5\,x_3^2 + \frac{x_4 + 5.0}{0.8\,x_5 - x_1}$$



Symbolic Regression With GA

- MATLAB Toolbox:
  - GPTIPS






```
Simplified overall GP expression
--------------------------------
             2
1.855e-5 x1  + 1.462 x1 + 504.6
```

Optimization Framework

- Breguet's range equation
- What models have I ended up with?
  - Helicopter Dimensions Model (Matlab)
  - Weight Estimation Model (Excel)
  - Aerodynamics Model (Matlab)
  - Propulsion Model (Matlab)
  - Range Model (Excel)
  - Cost Model (Excel)
- Multidisciplinary Optimization
- How are the models connected?

The Breguet range equation for helicopters:

$$Range = \frac{V}{g}\frac{\eta\xi}{SFC}\frac{L}{D}\ln\left(\frac{W_{initial}}{W_{final}}\right)$$

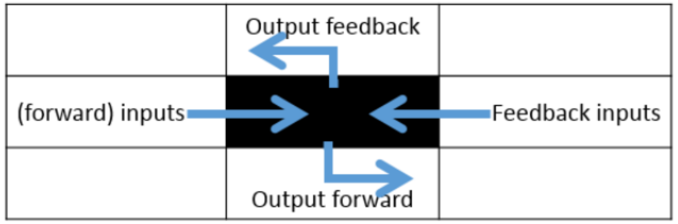
Propulsion System Designer

Aircraft Designer

Structural Designer

Optimization Framework

- Model
  - Inputs/Outputs
  - Dependency Structure Matrix (DSM)



Model	Fuselage Length	Rotor Diameter	Number of Rotors	Helicopter Volume	Passenger Capacity	Maximum Takeoff Weight	Fuel Weight	Velocity	Power	Lift to Drag Ratio	Disk Loading	SFC	Range	Cost per Hour
Helicopter Dimensions														
Weight Estimation														
Aerodynamics														
Propulsion														
Range														
Cost														

	Helicopter Dimensions	Weight Estimation	Aerodynamics	Propulsion	Range	Cost
Helicopter Dimensions						
Weight Estimation	X					
Aerodynamics		X				
Propulsion			X			
Range		X	X	X		
Cost			X			

Optimization Framework

- ModeFRONTIER implementation
  - Model and Workflow

HelicopterDimensionsModel

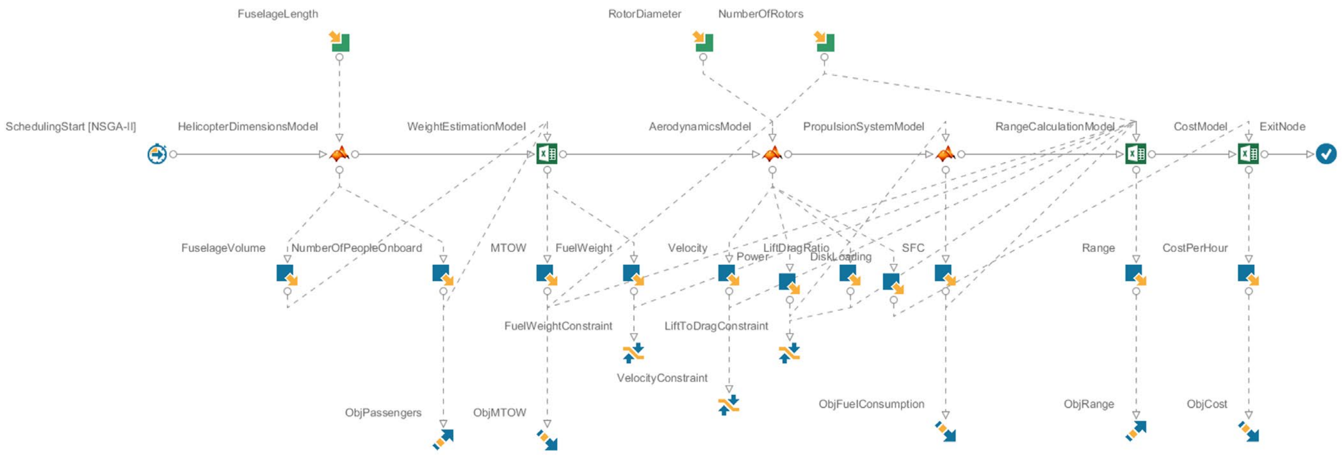
```
FuselageLength = 11; % Input

FuselageWidth = 0.126*FuselageLength + 0.6553;
FuselageHeight = 0.2243*FuselageLength + 1.0241;
FuselageVolume = FuselageLength*FuselageHeight*FuselageWidth; % Output
```

MATLAB

Optimization Framework

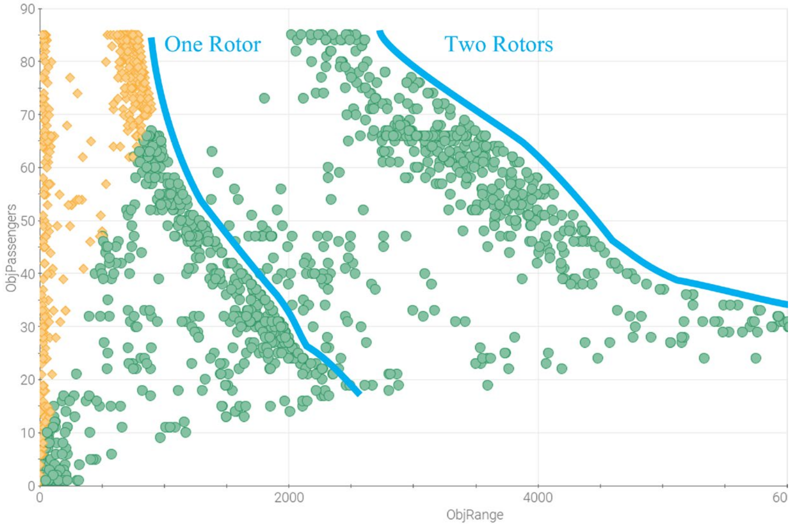
- ModeFRONTIER implementation
  - Model and Workflow
  - Optimization setup
    - NSGA-II
    - 150 generations
  - DOE
    - Uniform Latin Hypercube
    - 20 designs

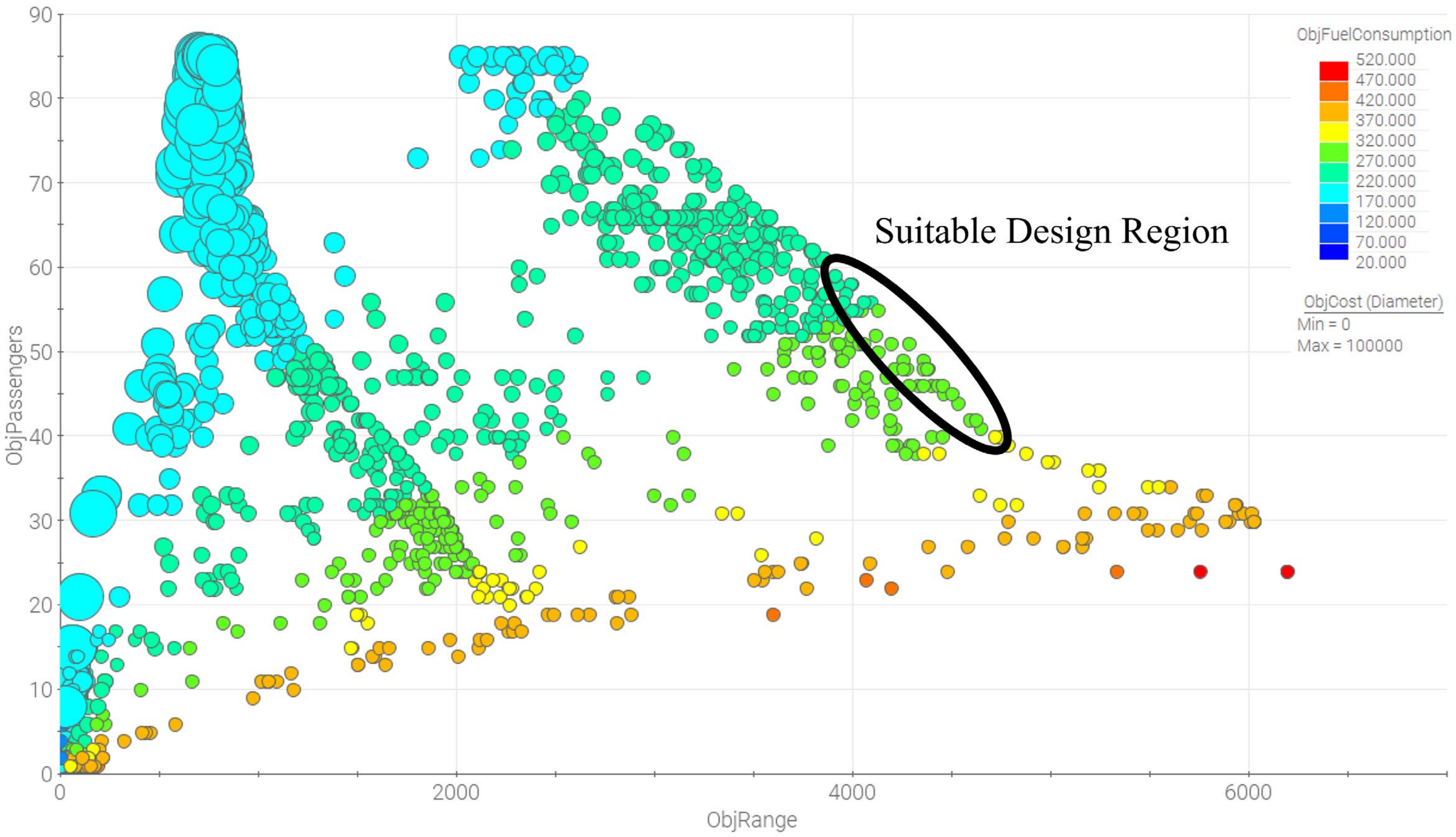
ID	Category	Fuselage Length [m]	Number of Rotors [-]	Rotor Diameter [m]
0	ULH	13.678	2	20.066
1	ULH	39.668	1	4.835
2	ULH	7.581	1	13.182
3	ULH	37.910	1	15.783
4	ULH	12.680	1	5.864
5	ULH	19.227	2	21.868
6	ULH	4.470	2	8.406
7	ULH	28.758	1	24.122
8	ULH	33.890	2	12.229
9	ULH	16.208	1	13.831
10	ULH	35.622	2	10.291
11	ULH	30.580	1	19.087
12	ULH	31.198	2	15.332
13	ULH	27.331	2	7.275
14	ULH	10.134	2	6.408
15	ULH	24.421	1	10.590



Results

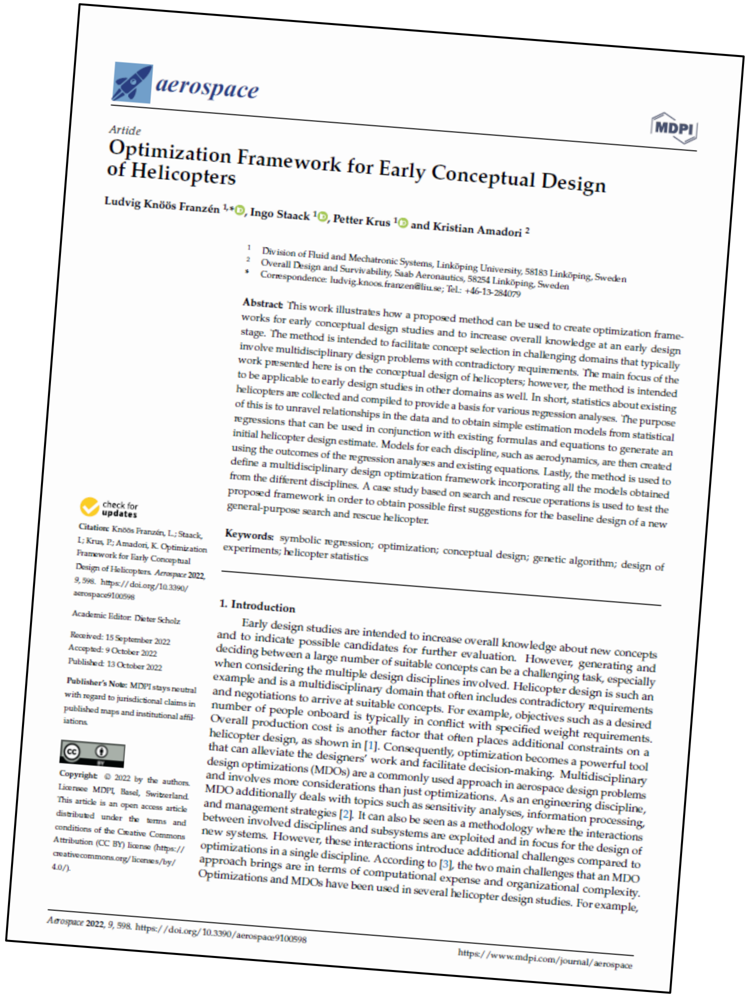
- ModeFRONTIER results:
  - Design Space





Conclusions and Outlook

- Conclusions
  - This work illustrates how optimizations and relatively few details about a domain can be used to make fairly accurate “ballpark” estimates at an early conceptual design stage
- Future Work
  - Increase overall details
  - More design variables
  - Try the method on something else than helicopters
  - Creation of surrogate models from the obtained results



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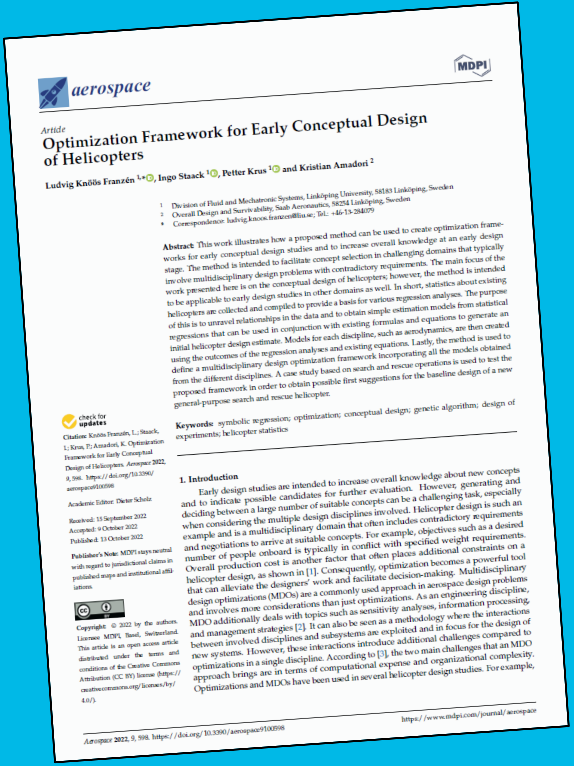

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Questions or want to know more?

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