# Symbolic Regression With Genetic Algorithms for Early Conceptual Design of Helicopters





Linkoping, Sweden

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Research project:

System-of-Systems - Trade Space Exploration (S2TEP)

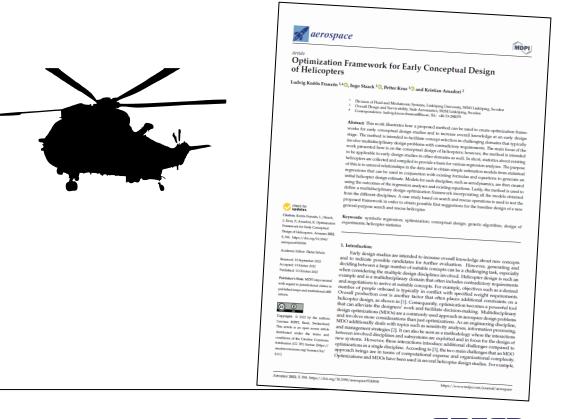


## Agenda

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

## **"Optimization Framework for Early Conceptual Design of Helicopters"**

- In MDPI Aerospace 2022, 9, 598. https://doi.org/10.3390/aerospace9100598





#### 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







#### **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

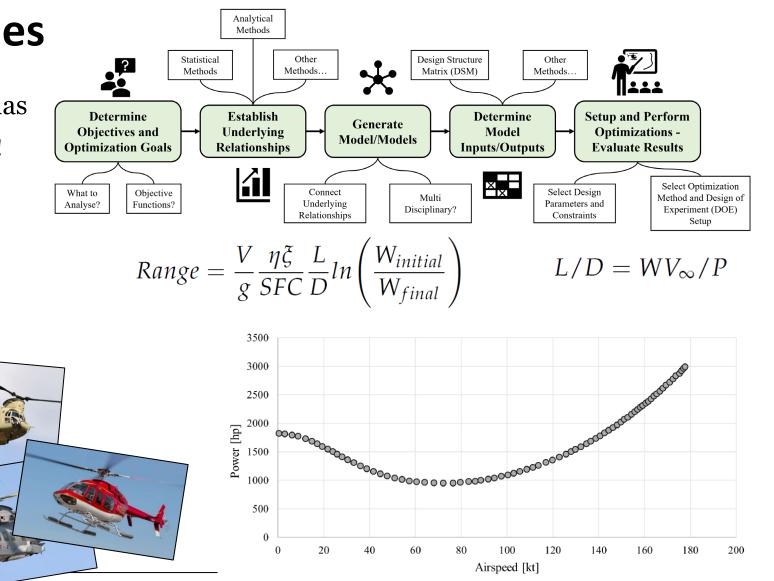




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#### **Method and Approaches**

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





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#### **Method and Approaches**

- Own Statistical Database
  - Over 75 different helicopters

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Airbus H130	1	6	10,68		3,34	18,465 40 17,5
Airbus H135	1	7	10,2		3,51	11,415 20,282 10,113 12,09
Airbus H145	2	9	13,03		3,45	22,4 0,50 4,27
Airbus AS365 N3+	2	11	13,73		4,06	11
Airbus H155	2	13	14,3		4,35	
Airbus H160	2	12	13,96	3,54	4,91	
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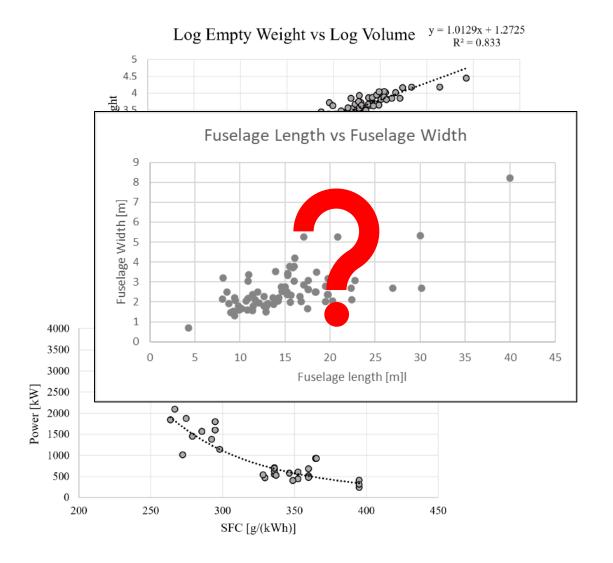
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#### **Method and Approaches**

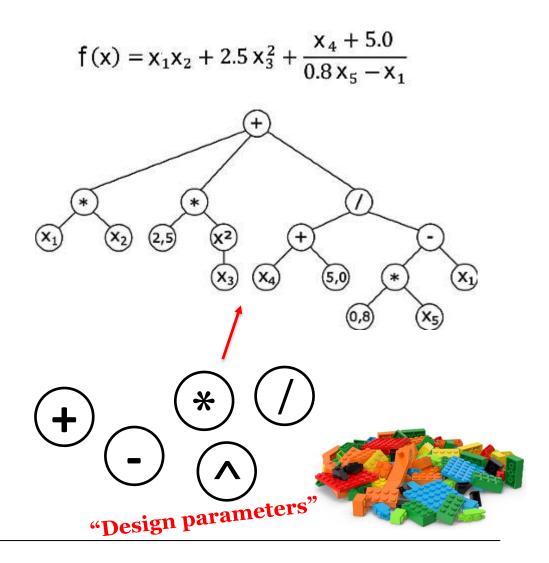
- Own Statistical Database
  - Over 75 different helicopters
- Regression analyses to obtain formulas and models for the optimization framework
  - Linear (and Linear LogLog)
  - Other trendlines e.g., exponential
- However, regressions can become tricky, and intuition is not always "best"...
- So, what 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



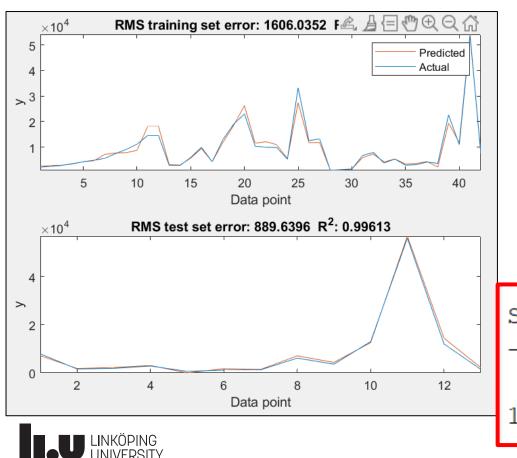


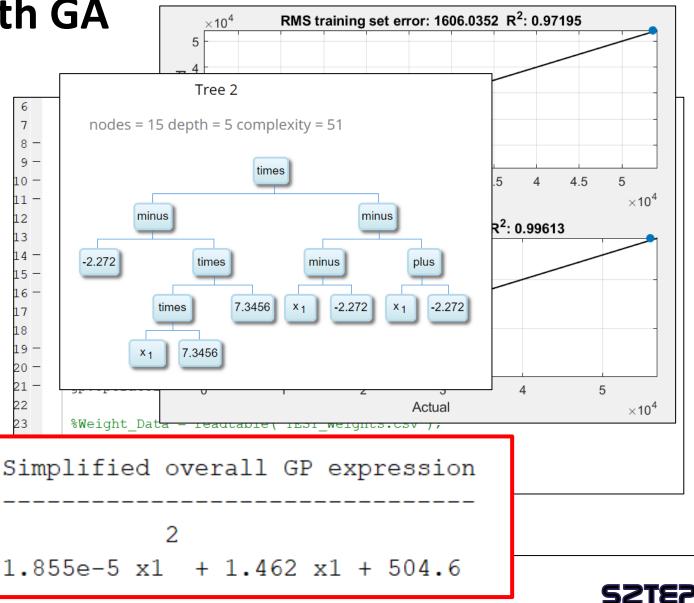
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#### **Symbolic Regression With GA**

• MATLAB Toolbox:

- GPTIPS

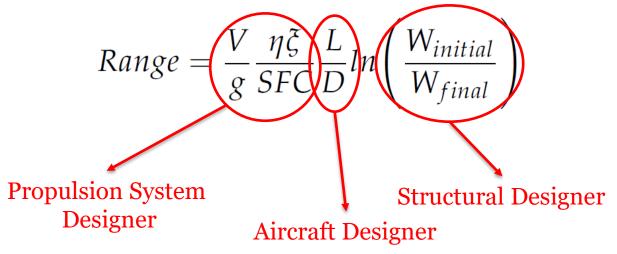




- Breguet's range equation
- What models have I ended up with?
  - Helicopter Dimensions Model (Matlab)
  - Weight Estimation Model (Excel)
  - Aerodynamics Model (Matlab)
  - Propulsion Model (Matlab)
  - Range Model (Excel)
  - Cost Model (Excel)
- Multidisciplinary Optimization
- How are the models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



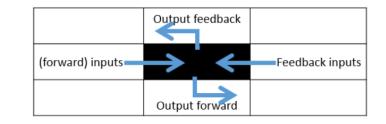
The Breguet range equation for helicopters:





- 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	Х		
Cost			X			





- ModeFRONTIER implementation
  - Model and Workflow

#### HelicopterDimensionsModel

<pre>FuselageLength = 11; % Input</pre>	
FuselageWidth = $0.126$ *FuselageLength + $0.6553$ ;	
<pre>FuselageHeight = 0.2243*FuselageLength + 1.0241;</pre>	
<pre>FuselageVolume = FuselageLength*FuselageHeight*FuselageWidth;</pre>	% Output

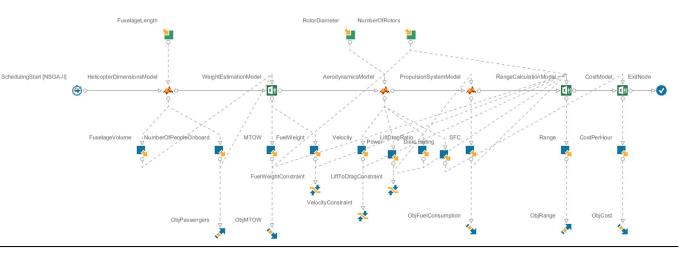






- ModeFRONTIER implementation
  - Model and Workflow
  - Optimization setup
    - NSGA-II
    - 150 generations
  - DOE
    - Uniform Latin Hypercube
    - 20 designs

)	Category	Fuselage Length [m]	Number of Rotors [-]	Rotor Diameter [m]
	ULH	13.678	2	20.066
	ULH	39.668	1	4.835
	ULH	7.581	1	13.182
	ULH	37.910	1	15.783
	ULH	12.680	1	5.864
	ULH	19.227	2	21.868
	ULH	4.470	2	8.406
	ULH	28.758	1	24.122
	ULH	33.890	2	12.229
	ULH	16.208	1	13.831
	ULH	35.622	2	10.291
	ULH	30.580	1	19.087
	ULH	31.198	2	15.332
	ULH	27.331	2	7.275
	ULH	10.134	2	6.408
	ULH	24.421	1	10.590
	T TT T T	00 E04	1	01 015

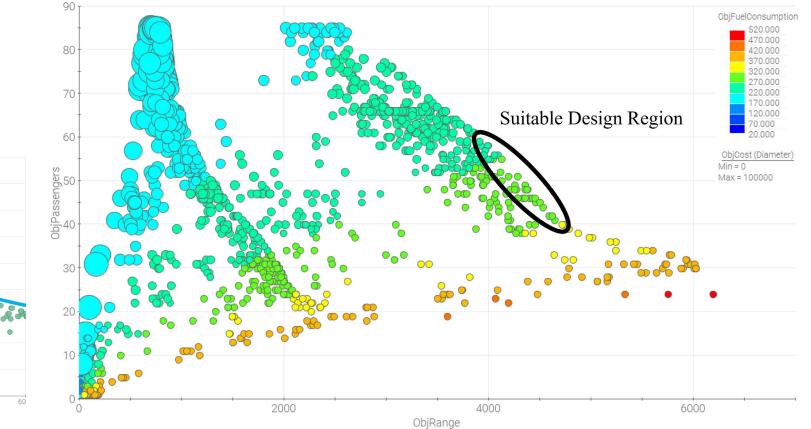


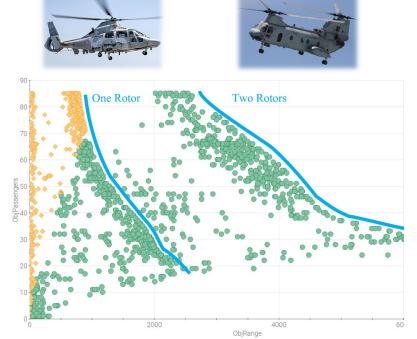


### Results

- ModeFRONTIER results:
  - Design Space











2/26/2024 Slide 14/15

### **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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## **Thank you for listening!**



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Ni iston of Fuid and Mechatronic Systems, Lanktping University, \$8583 Lank, Verall Design and Survivability, Sash Aeronautos, \$9254 Lanköping, Sweden Unrespondence: hulvig knook franzenillinaw; Tel: +46-15-284079

Advances Talss work illustration have a persponder structure can be used to create optimization frame-works for early compared advances to the structure of th using the outsome of the segment analyses and existing equations. Lastly, the method is used to define a multidisciplinary design optimization framework incorporating all the models existing from the different diseptimes. As ease using based on earch the accuracy operations is used to not the proposed immercively in order to obtain possible first suggestions for the baseline design of a new proposed. eneral-purpose search and rescue helicopter. Keywords: symbolic regression; optimization; conceptual design; genetic algori

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#### **Questions or want to know more?**

**Contact me!** 



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