



Hochschule für Angewandte Wissenschaften Hamburg

Hamburg University of Applied Sciences

AERO – AIRCRAFT DESIGN AND SYSTEMS GROUP

PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Mihaela Niță Hamburg University of Applied Sciences

Dieter Scholz Hamburg University of Applied Sciences

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EWADE 2011



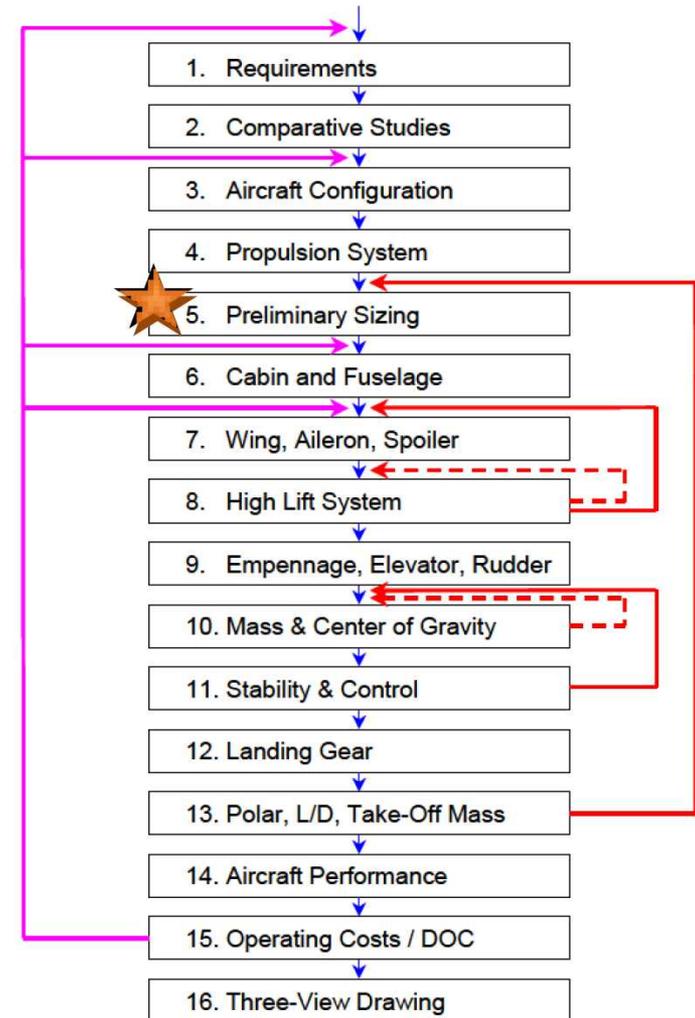
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PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Background

- **PreSTo – Preliminary Sizing Tool** was developed at Hamburg University of Applied Sciences
<http://PreSTo.ProfScholz.de>
- PreSTo is divided into several modules:
preliminary sizing, cabin and fuselage, wing, high lift, empennage, landing gear, mass and CG, drag and DOC calculation.
- Right figure: one possibility of sequencing and iterating these design steps



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The Problem

- Design **requirements** are given: landing distance, take-off distance, cruise Mach number, ...
- Other design **parameters** are required: aspect ratio, maximum lift coefficients, ...
- The **best combination of design parameters** leading to a good design needs to be found.

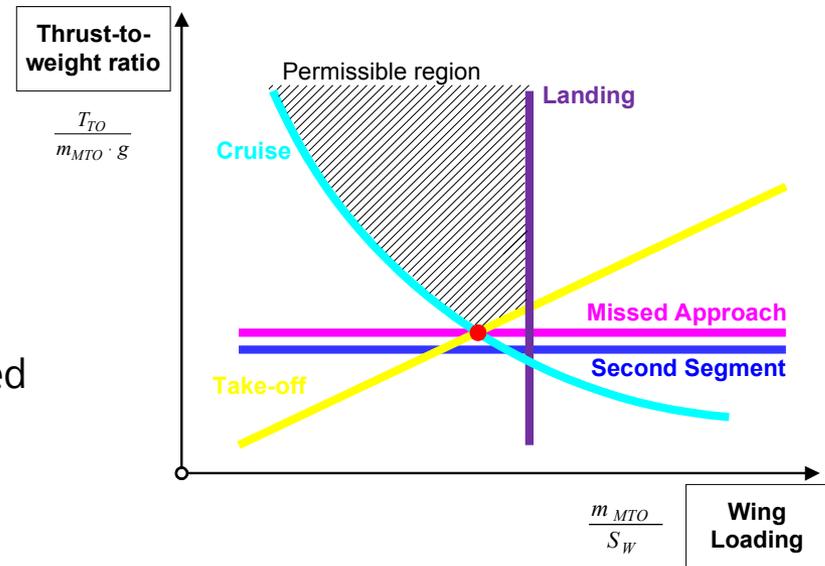
The Solution

- To **formally optimize** the **aircraft design** parameters and present these optimized values to the users as a starting point.
- To combine formal optimization with a subsequent **interactive and experienced driven aircraft design**.

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The Starting Point

- Two-dimensional optimization problem: thrust-to-weight ratio (for jets) versus wing loading...
- ... for five requirements: landing distance, take-off distance, second segment and missed approach climb gradients and cruise Mach number.



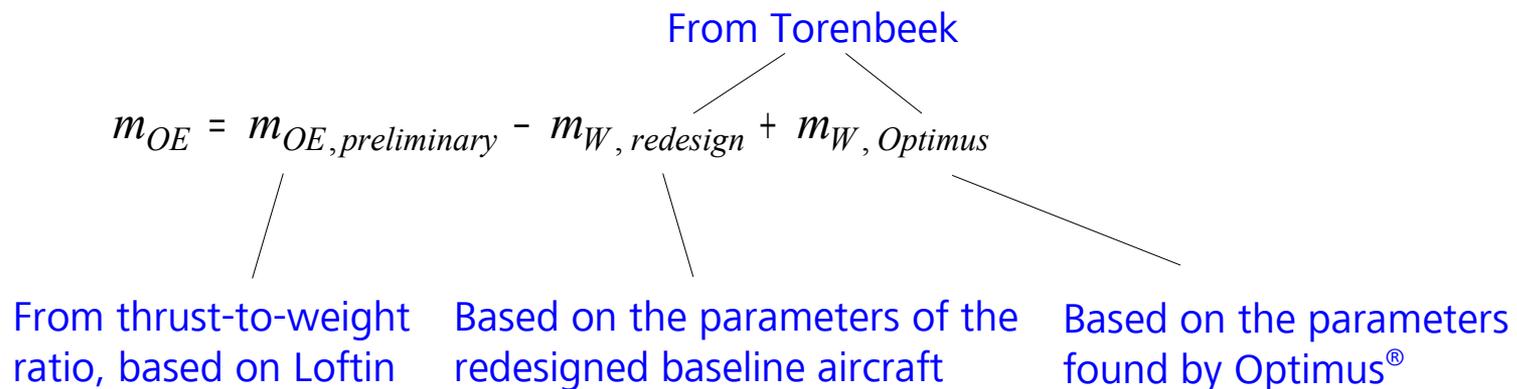
Application of a Formal Optimization Program

- Optimus[®] was connected to the Excel preliminary sizing sheet from PreSTo. This made it possible to optimize any design output parameter for any combination of design input parameters.
- Optimus[®] by Noesis Solutions (Belgium) is a Process Integration and Design Optimization software. It bundles design exploration and numerical optimization methods.
- The original Excel preliminary sizing sheet was extended.

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Extensions of PreSTo

- Incorporation of both benefits (L/D, SFC, ...) and penalties (structural mass, drag, ...). For example:



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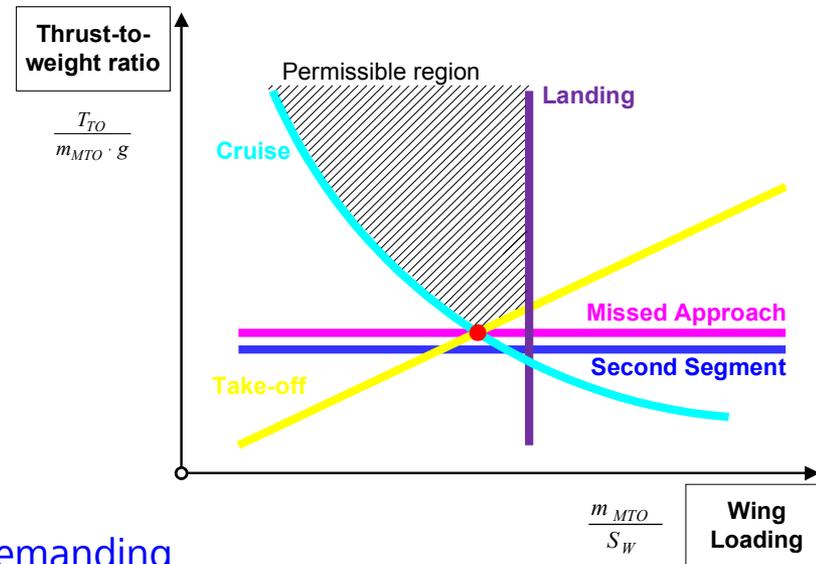
Extensions of PreSto

- Automation of the cruise line in the matching chart by adjusting the value of V/V_{md} .

$$C_{L,DESIGN} = C_{L,md}$$

$$C_L / C_{L,md} = 1 / (V / V_{md})^2$$

$$E = \frac{2 E_{max}}{\left(\frac{C_L}{C_{L,md}}\right) + \left(\frac{C_{L,md}}{C_L}\right)}$$



- In this way we are sure that the **most demanding** requirements are met **in the same time**.
- Implementation and testing of **different SFC calculation models**.

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SFC Calculation Models

- Mattingly 1996

$$TSCF = (0.4 + 0.45M)\sqrt{\theta}, \quad \theta = T/T_{ref}$$

where M is the Mach number at the engine inlet

- Svoboda 2000

$$SFC_{CR}(\text{lb/lb h}) = 0.8 - 0.00096\sqrt{T_{TO}(\text{lb})},$$

$$SFC_{TO}(\text{lb/lb h}) = 0.71 - 0.15\sqrt{\alpha(\sim)},$$

$$T_{CR}(\text{lb}) = 200 + 0.2T_{TO}(\text{lb}),$$

$$\alpha(\sim) = 3.2 + 0.01\sqrt{T_{TO}(\text{lb})},$$

where α is BPR

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SFC Calculation Models

- Isikveren 2002

$$c = k_{\theta} \left\{ k_1 h^{-k_2} \left(\frac{T}{T_0} \right)^{(k_3 h + k_4)} M + (k_5 h + k_6) \left(\frac{T}{T_0} \right) + k_7 h + k_8 \right\}$$

calibrated for BPR = 5.2 with $k_1 = 1.586 \text{ lb/lb.hr}$; $k_2 = -0.303$; $k_3 = 8.40 \times 10^{-4} \text{ per FL}$;
 $k_4 = -0.760$; $k_5 = 5.45 \times 10^{-4} \text{ lb/lb.hr.FL}$; $k_6 = -0.307 \text{ lb/lb.hr}$; $k_7 = -9.54 \times 10^{-5} \text{ lb/lb.hr .FL}$;
 $k_8 = 0.694 \text{ lb/lb.hr}$

- Sforza 2004

$$TSCF = 0.7 - \frac{T_{CR}}{10^5} \quad (\text{lbm} / \text{h} / \text{lbf})$$

$$T_{CR} = 14.3 \sin \left(\frac{T_{TO}}{10^5} \cdot \frac{\pi}{2} \right)$$

- Howe 2000

$$c = c_1 (1 - 0,15 \lambda^{0,65}) (1 + 0,25 (1 + 0,063 \lambda^2) M) \sigma^{0,08}$$

where $c_1 = 0.85 \text{ N/Nh}$ for low λ (BPR)
and $c_1 = 0.7 \text{ N/Nh}$ for high λ (BPR)

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SFC Calculation Models

- Herrmann 2010

necessary parametrs: BPR, OAPR, TET, $\Delta P/P$ and engine component efficiencies:

$\eta_{ventilator}$, $\eta_{compressor}$, $\eta_{turbine}$, η_{nozzle} , η_{inlet}

$$SFC = \frac{0.697 \cdot \sqrt{\frac{t}{t_0}} \cdot \left(\phi - \vartheta - \frac{\chi}{\eta_{compressor}} \right)}{\sqrt{5 \eta_{nozzle} \cdot (1 + \eta_{ventilator} \cdot \eta_{turbine} \cdot BPR) \cdot (G + 0.2 \cdot M^2 \cdot BPR \cdot \frac{\eta_{compressor}}{\eta_{ventilator} \cdot \eta_{turbine}}) - M \cdot (1 + BPR)}}$$

, where

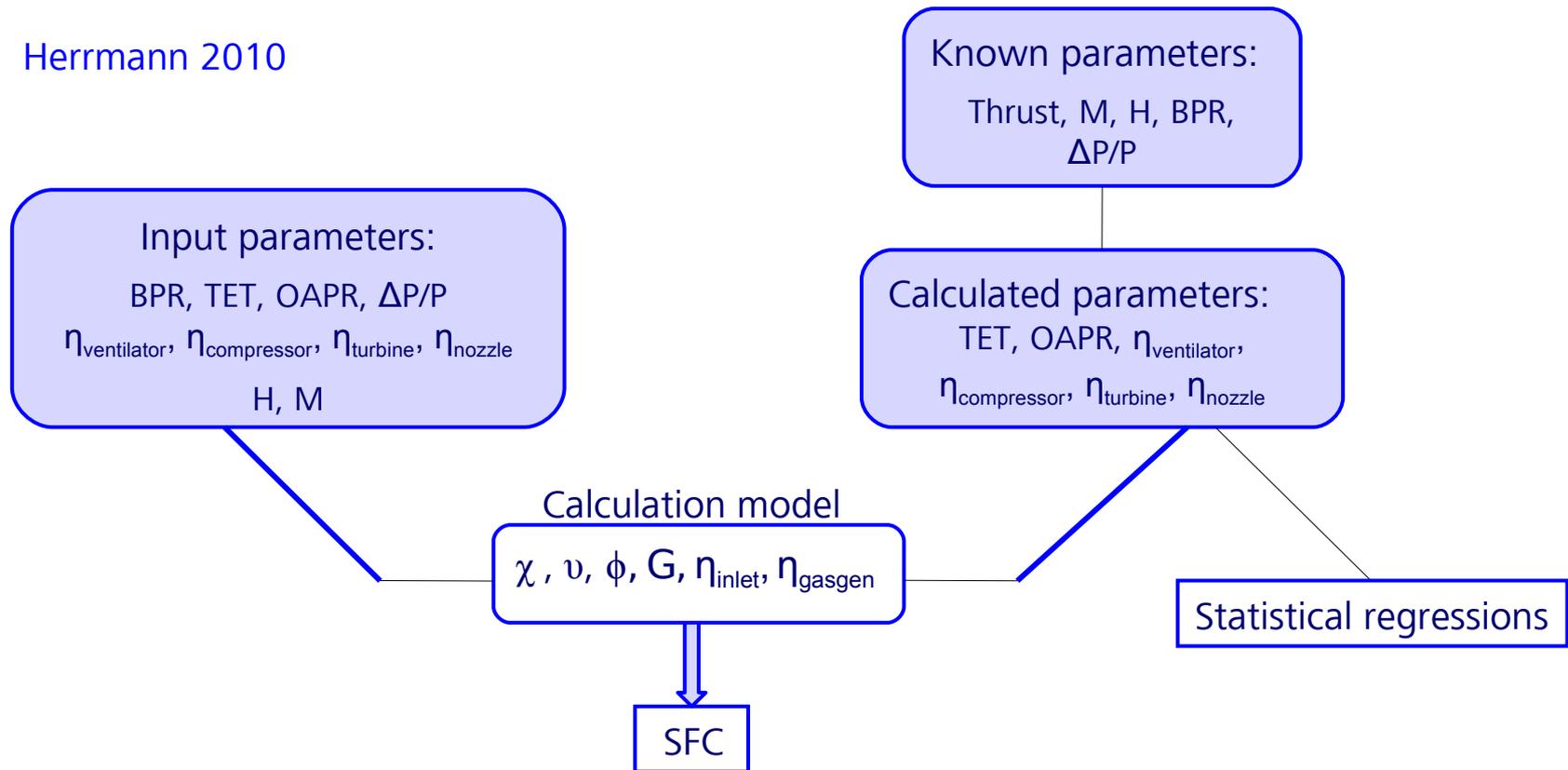
$$G = \left(\phi - \frac{\chi}{\eta_{compressor}} \right) \cdot \left(1 - \frac{1.01}{\eta_{gasgen}^{\frac{\kappa-1}{\kappa}} \cdot (\chi + \vartheta) \cdot \left(1 - \frac{\chi}{\phi \cdot \eta_{compressor} \cdot \eta_{turbine}} \right)} \right);$$

$$\phi = T/t = 1 + \frac{\kappa-1}{2} \cdot M^2; \quad \chi = \vartheta \cdot \left(OAPR^{\frac{\kappa-1}{\kappa}} - 1 \right); \quad \eta_{gasgen} = 1 - \frac{0.7M^2(1 - \eta_{inlet})}{1 + 0.2M^2}$$

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SFC Calculation Models

- Herrmann 2010



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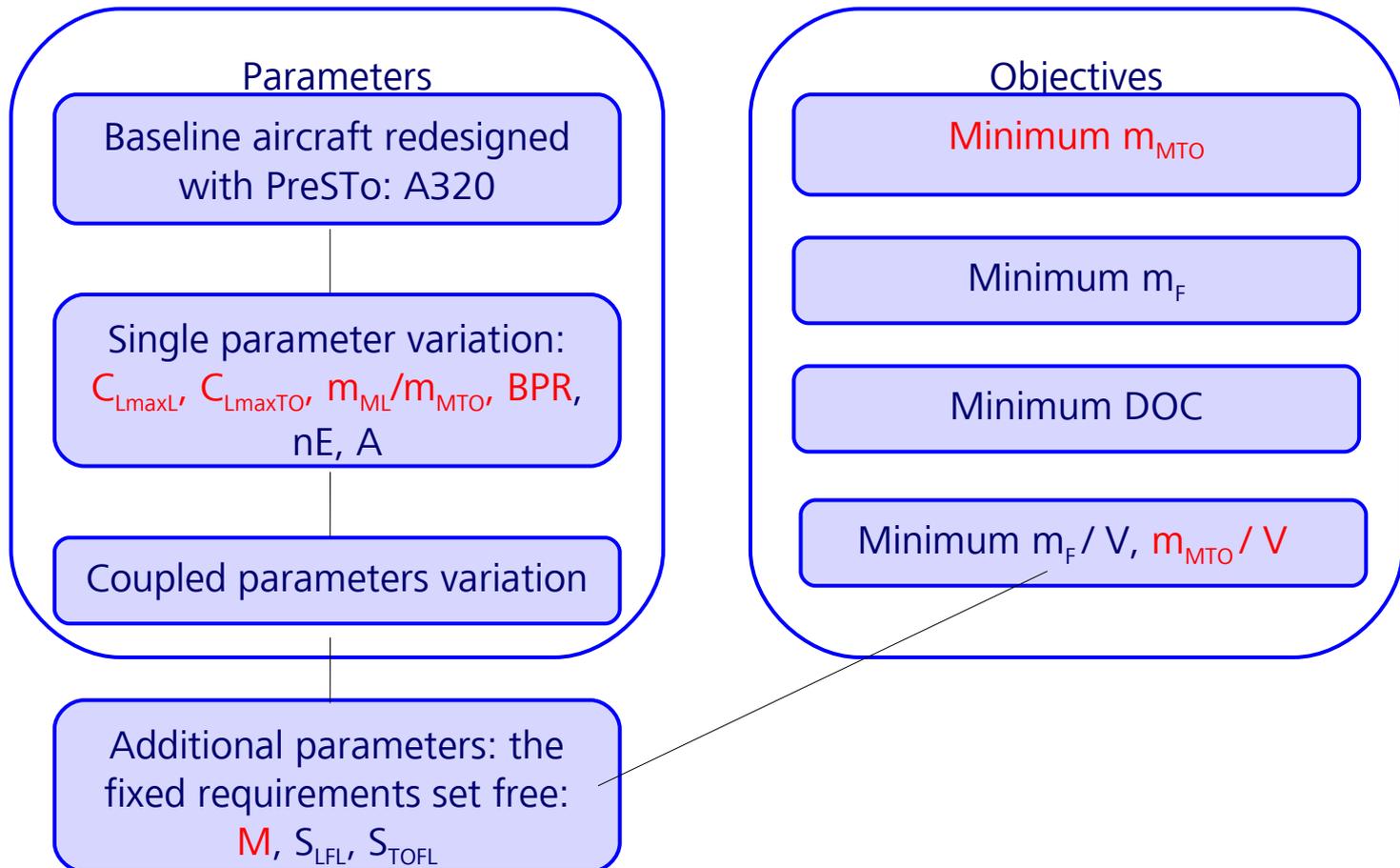
Selected Results

- Tests were performed starting from the parameters of an **Airbus A320** redesigned as closely as possible to the real aircraft.

Parameter	Symbol	Original A320	Redesigned A320	Deviation	Matching chart
Max. lift coefficient, landing	$C_{L,max,L}$	-	2.9	-	
Max. lift coefficient, take-off	$C_{L,max,TO}$	-	2.07	-	
Mass ratio, landing-take-off	m_{ML}/m_{MTO}	0.878	0.878	-	
Aspect ratio	A	9.5	9.5	-	
Max lift-to-drag ratio	L/D_{max}	17.88	18.59	-	
By-Pass ratio	BPR	6	6	-	
Speed-to-speed minimum drag	V/V_m	-	0.94	-	
Relative operating empty mass	m_{OE}/m_{MTO}	0.550	0.551	-	
Mission fuel fraction	M_{ff}	-	0.171	-	
Max. take-off mass	m_{MTO}	73500 kg	71960 kg	-2.10 %	
Max. landing mass	m_L	64500 kg	63180 kg	-2.05 %	
Operating empty mass	m_{OE}	40430 kg	39654 kg	-1.92 %	
Fuel mass	m_F	12500 kg	12305 kg	-1.56 %	
Wing area	S_W	122.4 m ²	119.8 m ²	-2.15 %	
Wing mass	m_W	-	7037.4 kg	-	
Take-off thrust of one engine	T_{TO}	11000 N	108965 N	-1.83 %	
Fuel volume needed	V_F	-	16.8 m ³	-	

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Approach

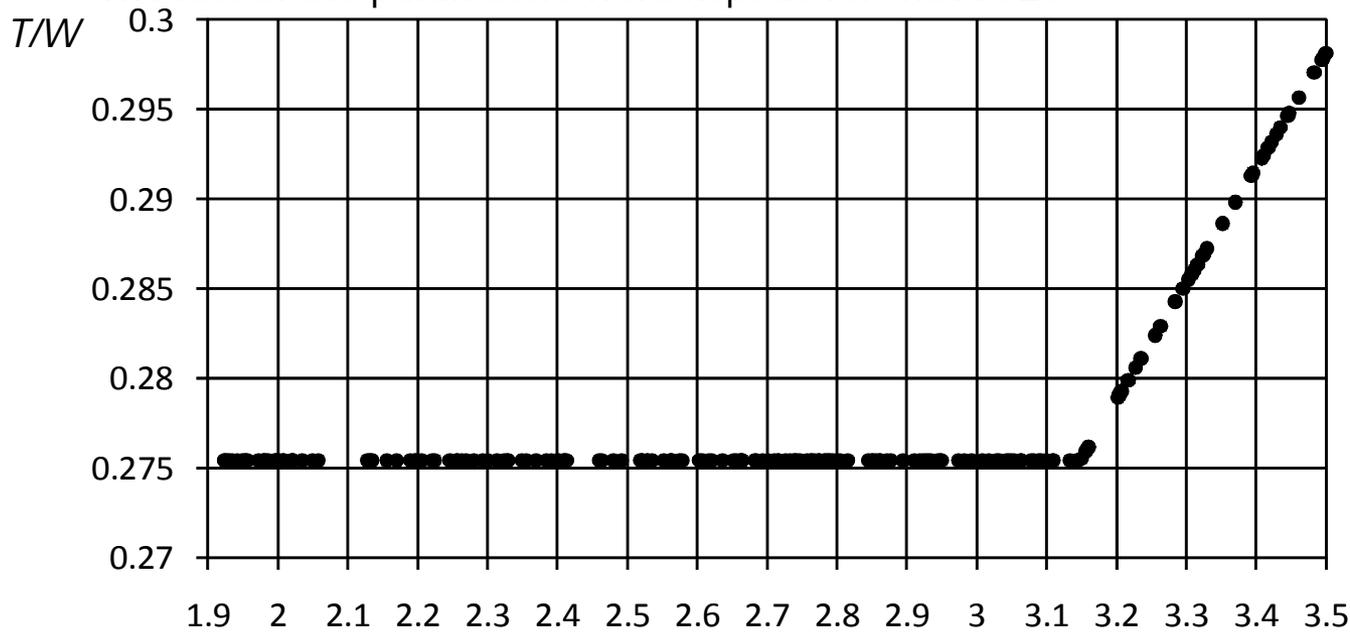


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Influence of C_{LmaxL} and C_{LmaxTO}

- C_{LmaxL} varied in the interval [1.9, 3.5]
- $C_{LmaxTO} = 80 \% \cdot C_{LmaxL}$
- The rest of the parameters were kept as for the A 320

} coupled

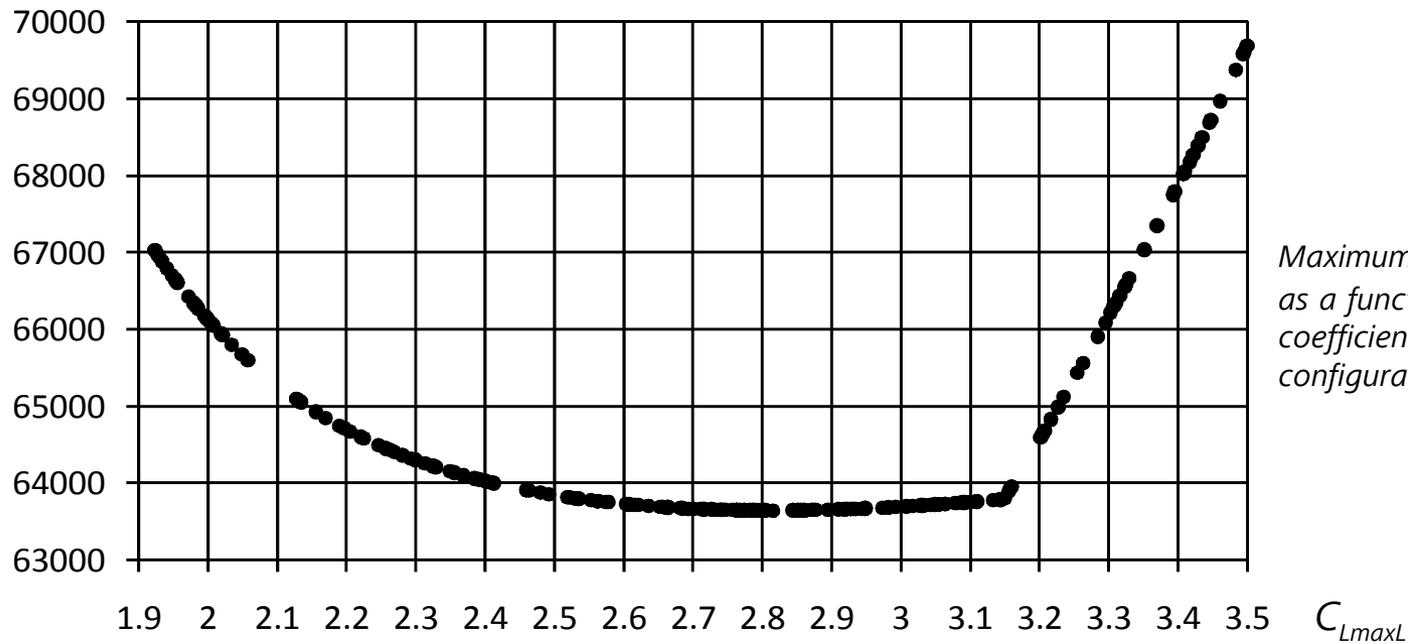


Thrust-to-weight ratio, T/W as a function of maximum lift coefficient for landing configuration, C_{LmaxL}

PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Influence of C_{LmaxL} and C_{LmaxTO}

m_{MTO} [kg]

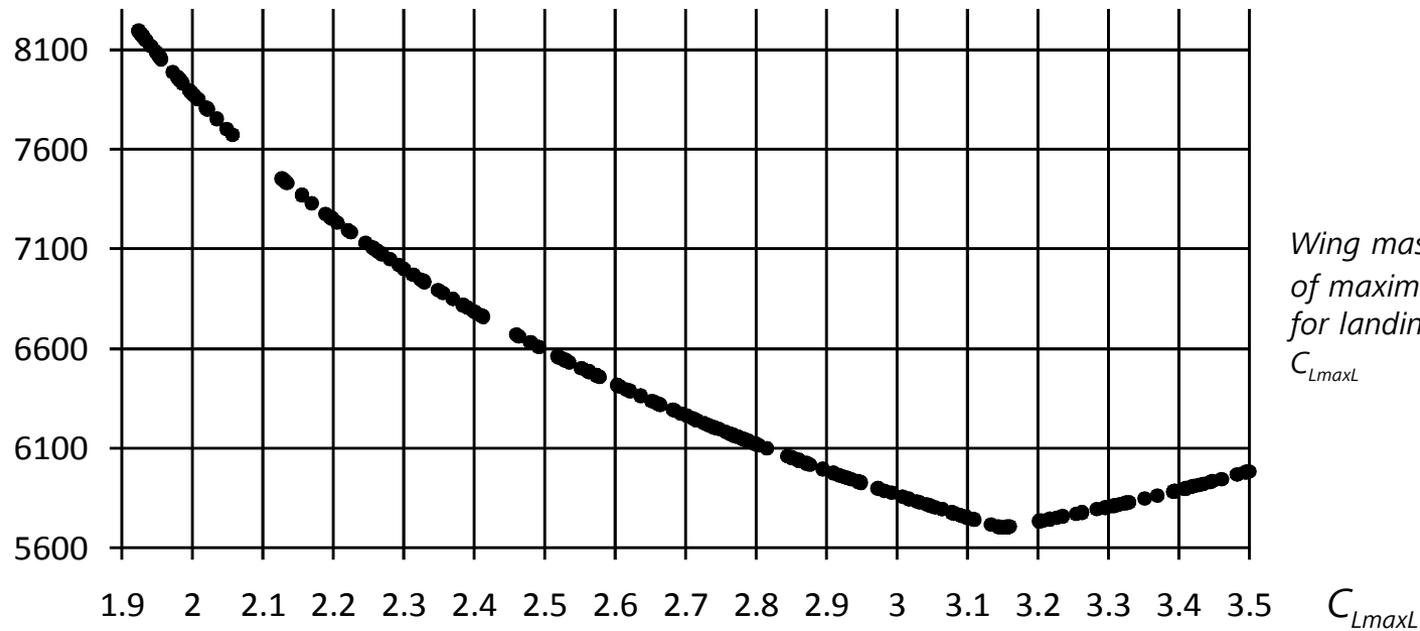


Maximum take-off mass, m_{MTO}
as a function of maximum lift
coefficient for landing
configuration, C_{LmaxL}

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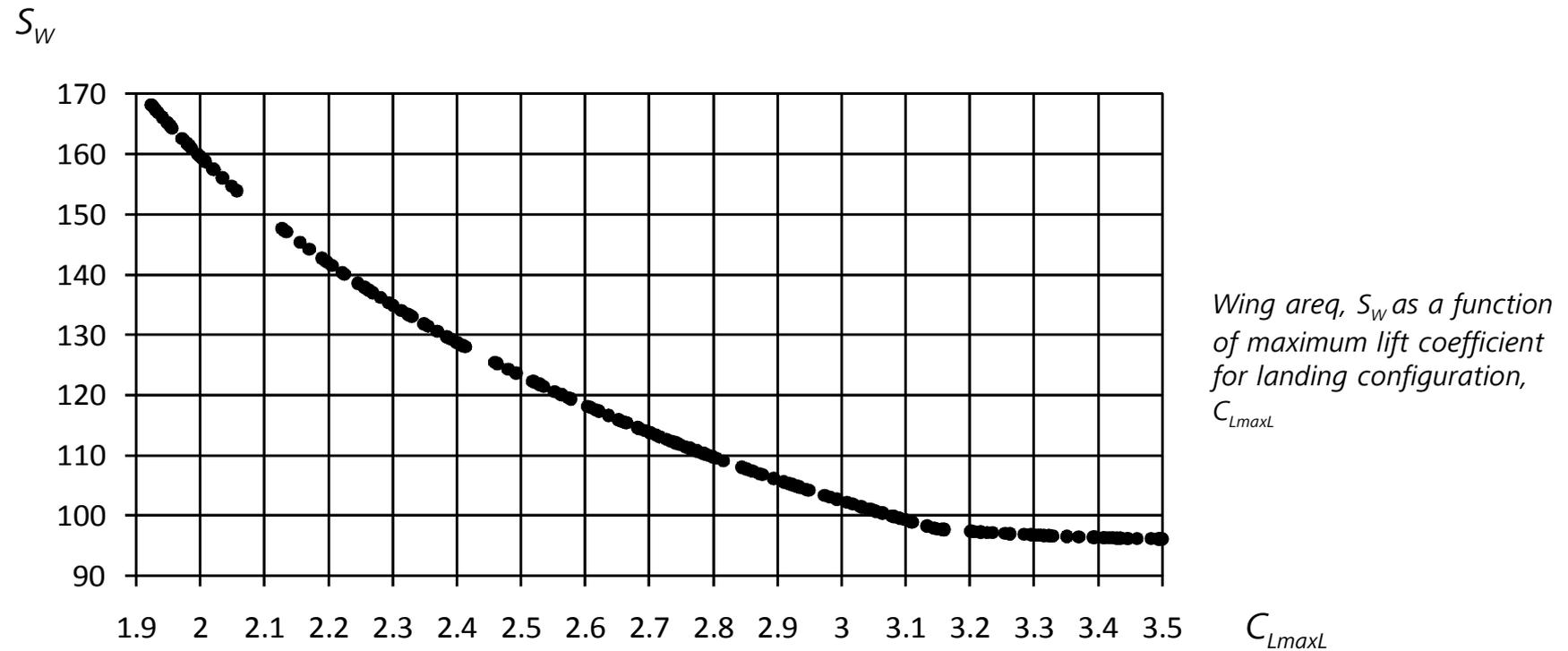
Influence of C_{LmaxL} and C_{LmaxTO}

m_w [kg]



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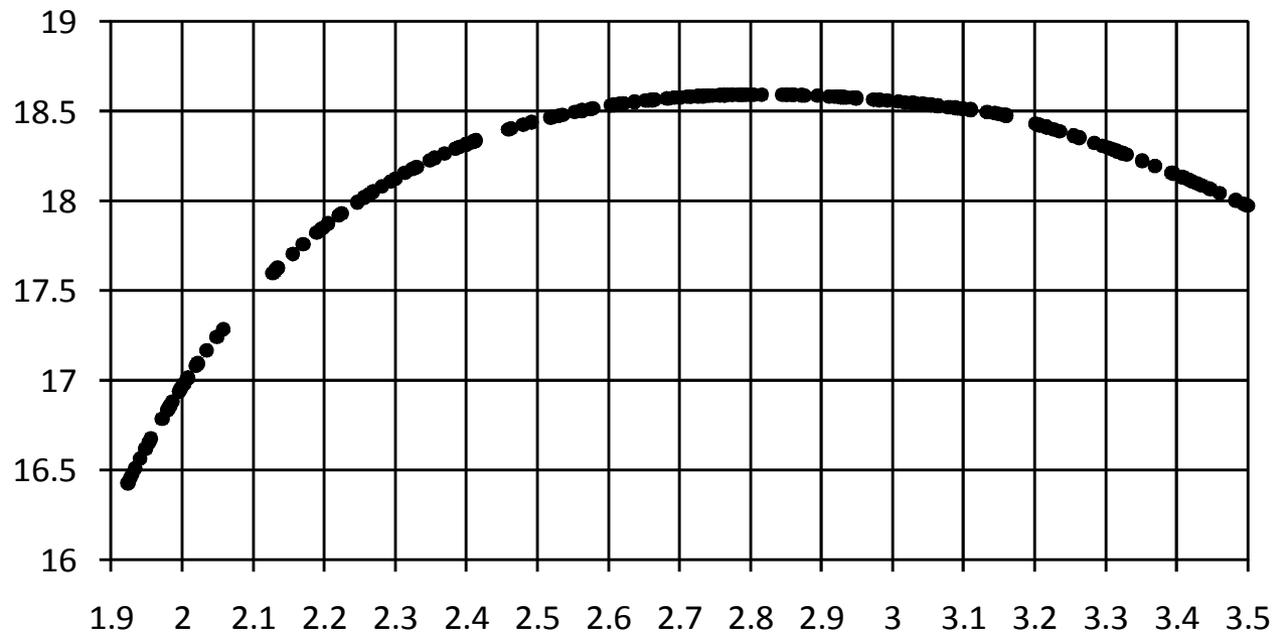
Influence of C_{LmaxL} and C_{LmaxTO}



PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Influence of C_{LmaxL} and C_{LmaxTO}

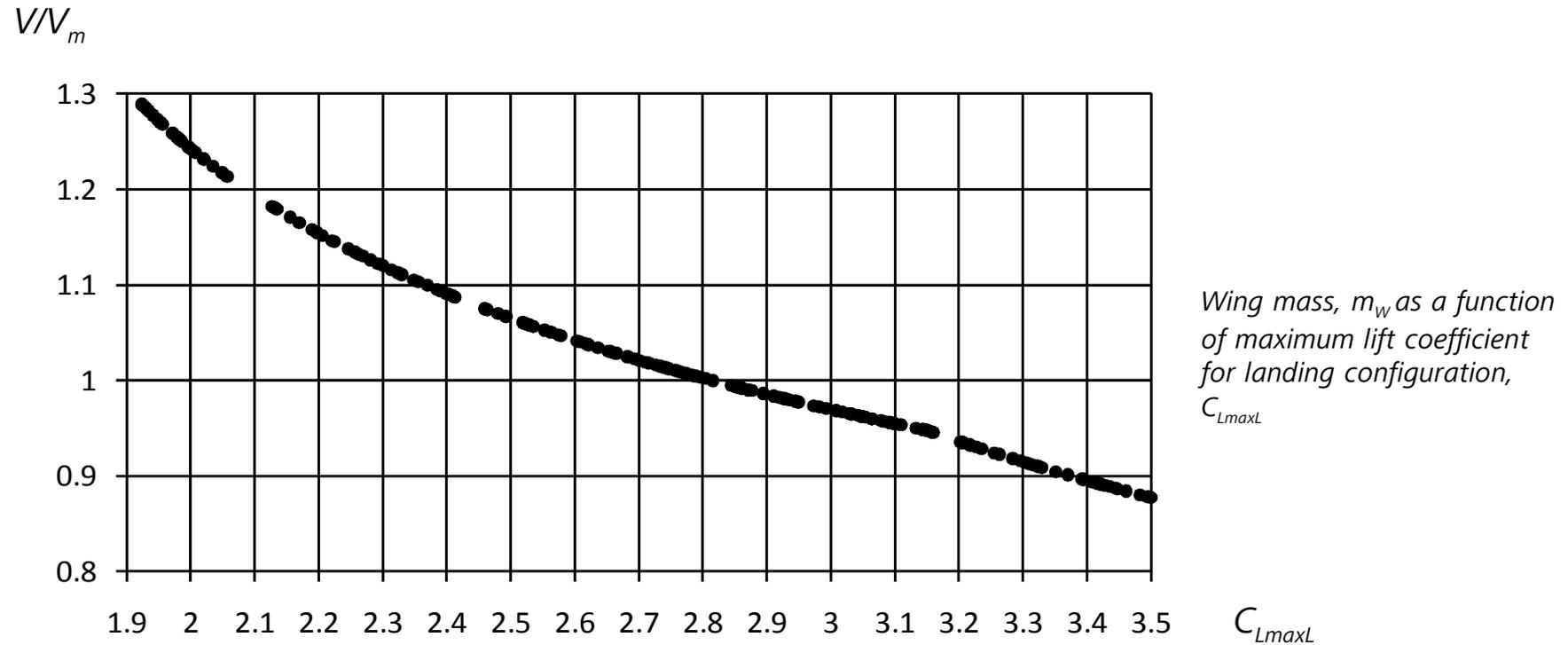
L/D



Lift-to-drag ratio, L/D as a function of maximum lift coefficient for landing configuration, C_{LmaxL} .

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Influence of C_{LmaxL} and C_{LmaxTO}

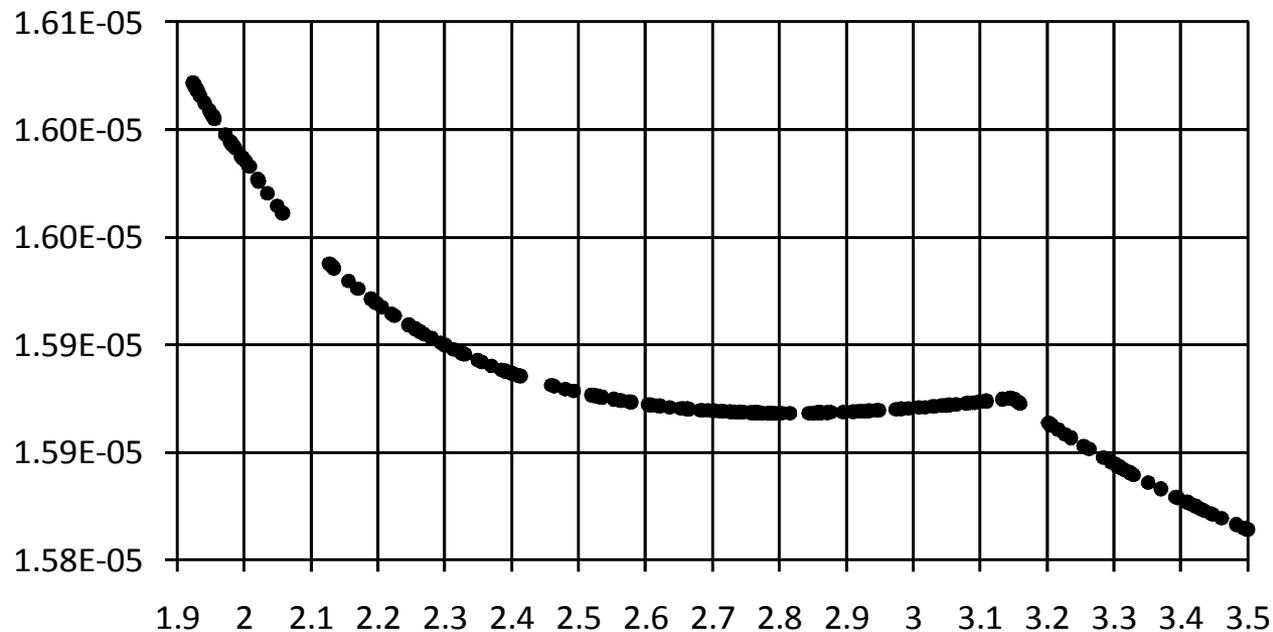


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Influence of C_{LmaxL} and C_{LmaxTO}

SFC

13.4 % mass improvement
with a $C_{LmaxL} = 2.82$



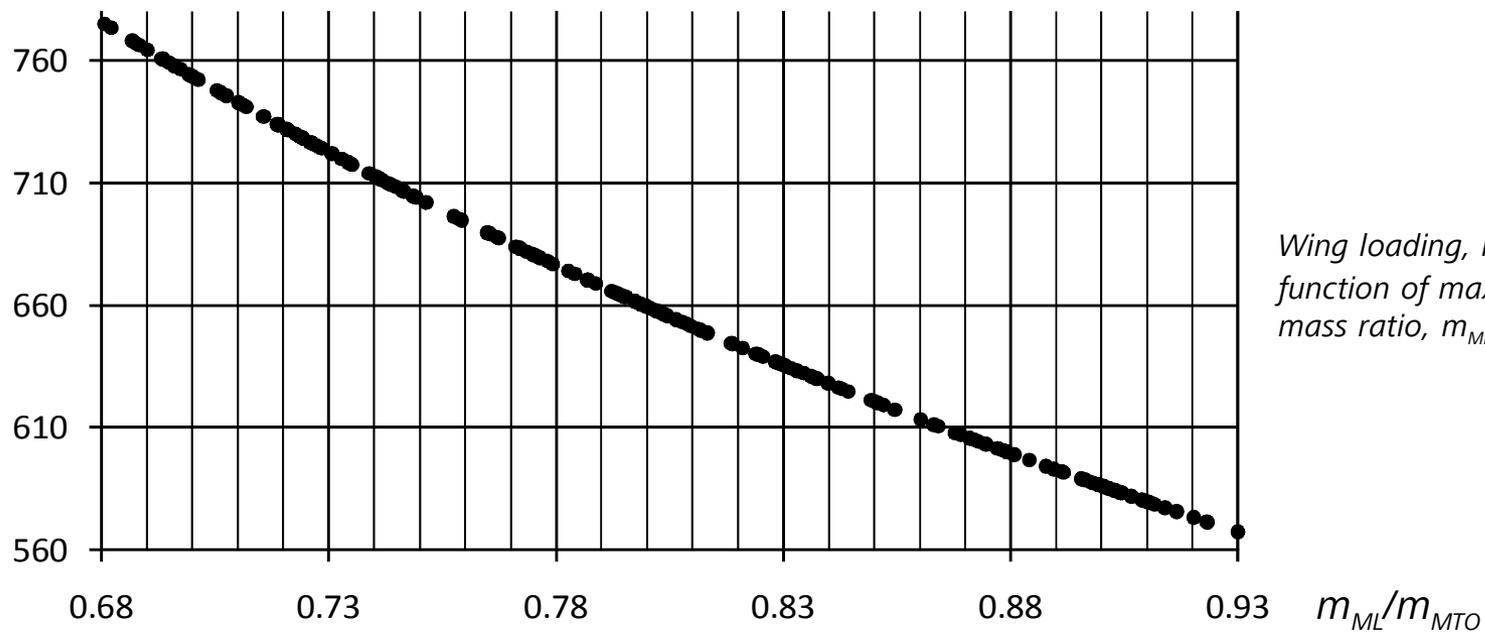
Specific Fuel Consumption,
SFC as a function of maximum
lift coefficient for landing
configuration, C_{LmaxL}

C_{LmaxL}

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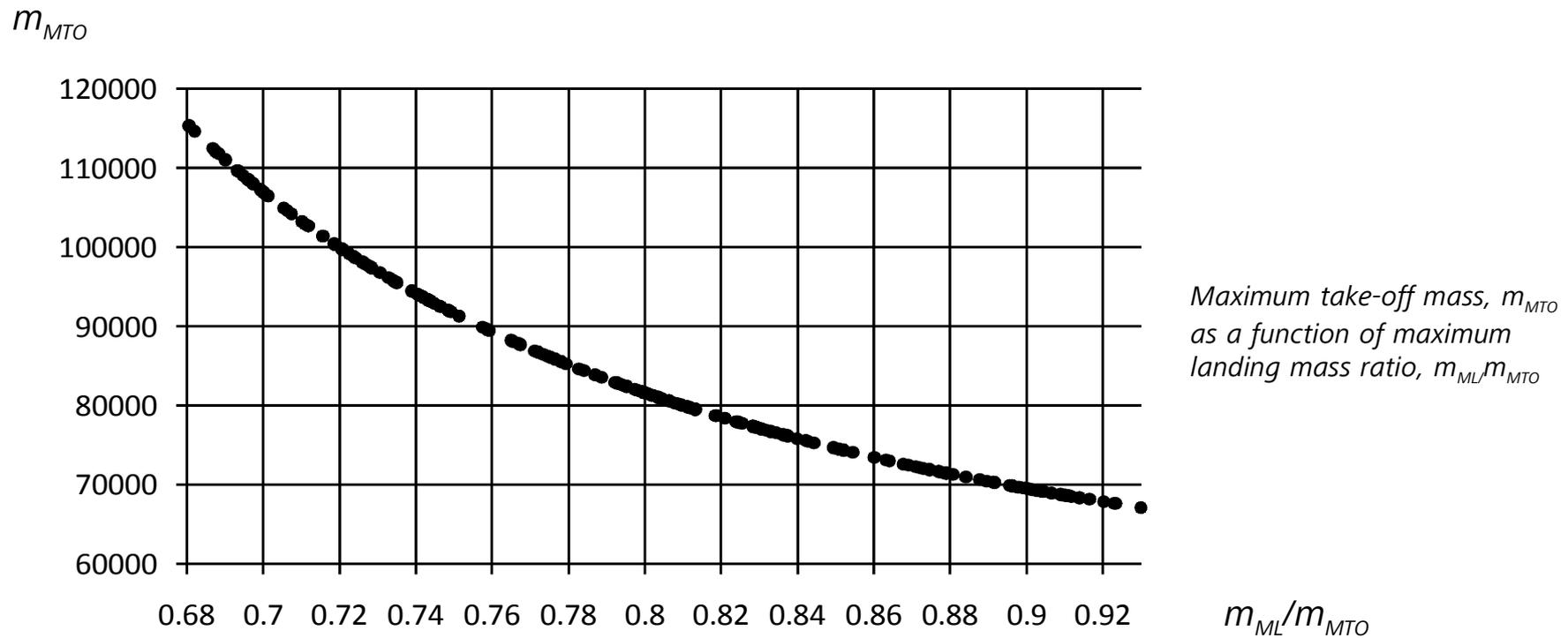
Influence of m_{ML}/m_{MTO}

m_{MTO}/S_W



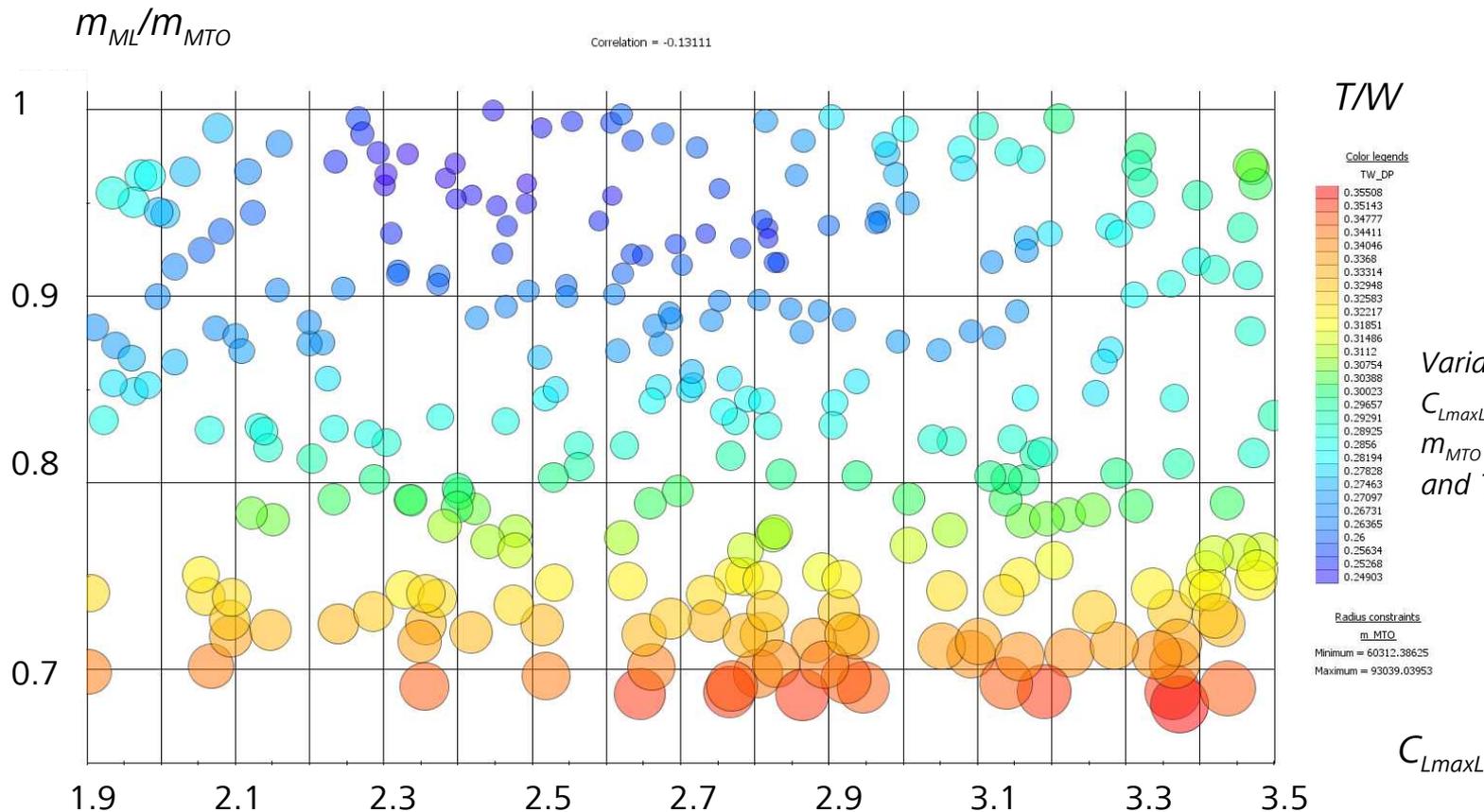
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Influence of m_{ML}/m_{MTO}



PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

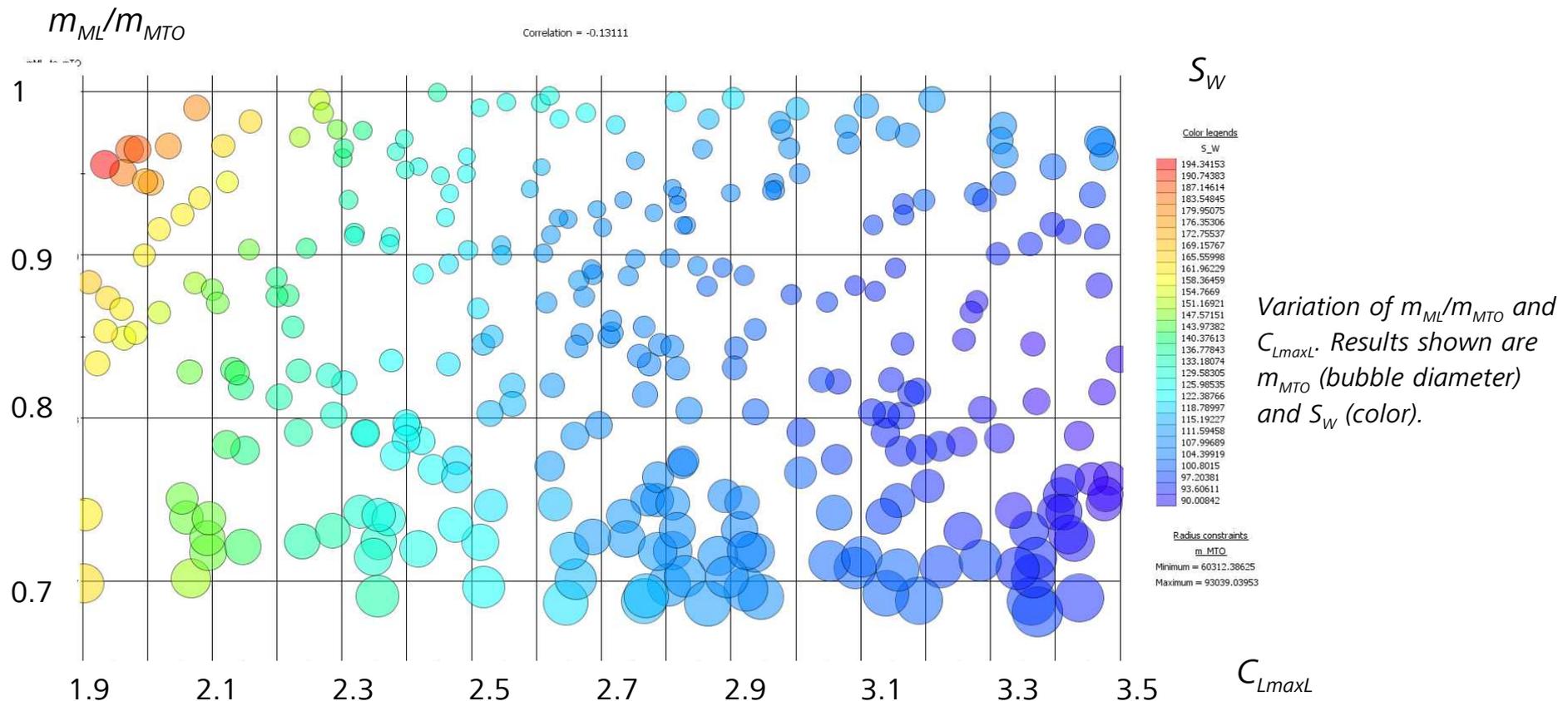
Influence of both m_{ML}/m_{MTO} and C_{LmaxL} , C_{LmaxTO}



Variation of m_{ML}/m_{MTO} and C_{LmaxL} . Results shown are m_{MTO} (bubble diameter) and T/W (color).

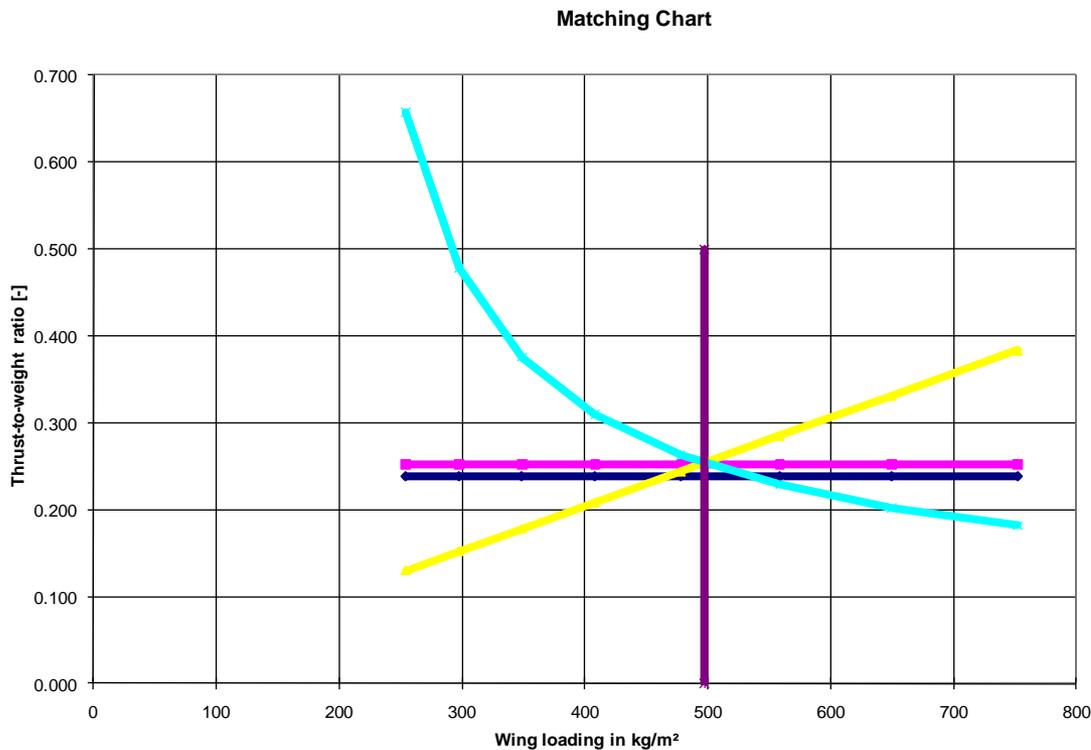
PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Influence of both m_{ML}/m_{MTO} and C_{LmaxL} , C_{LmaxTO}

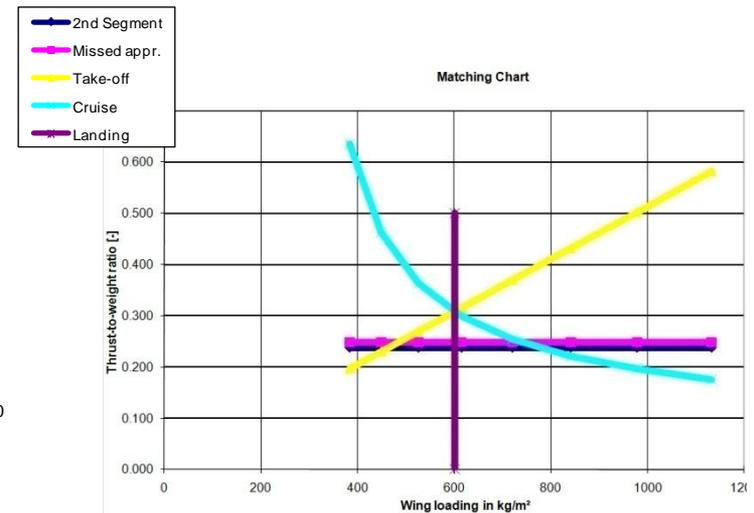


PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Influence of both m_{ML}/m_{MTO} and C_{LmaxL} , C_{LmaxTO}



17.9 % mass improvement
for $C_{LmaxL} = 2.61$ and
 $m_{ML}/m_{MTO} = 0.95$

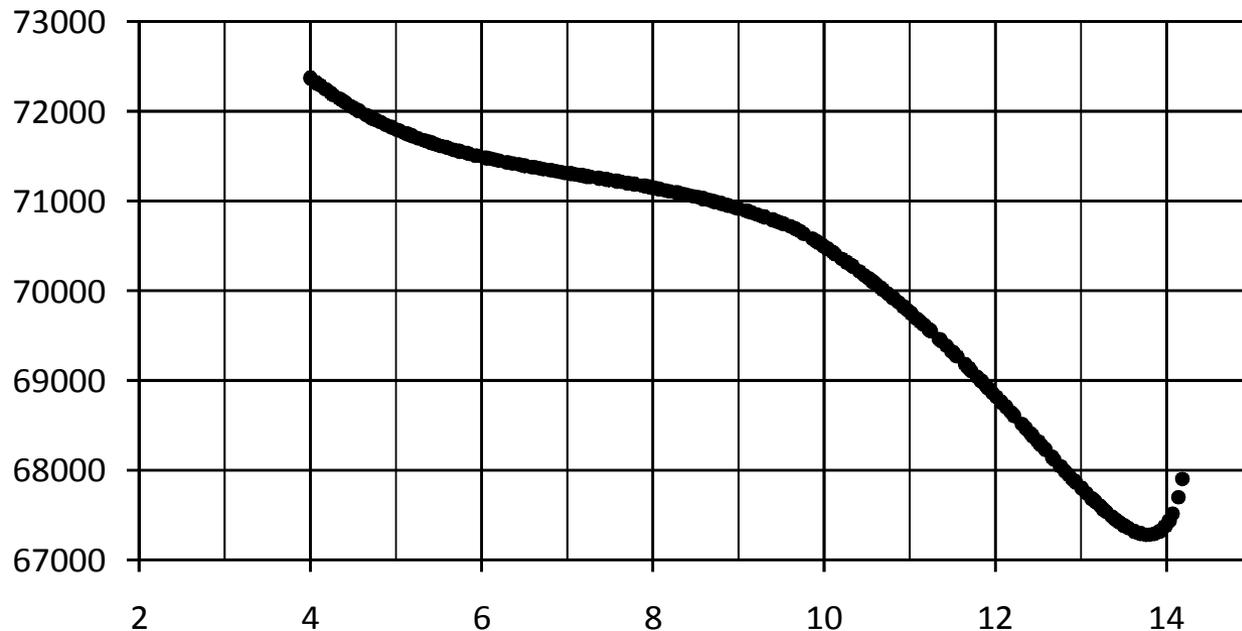


PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Influence of BPR , on the redesigned aircraft (i.e. with $C_{LmaxTO} = 2.07$)

m_{MTO}

1.8 % mass improvement
for $BPR = 13.8$



Maximum take-off mass,
 m_{MTO} as a function of BPR

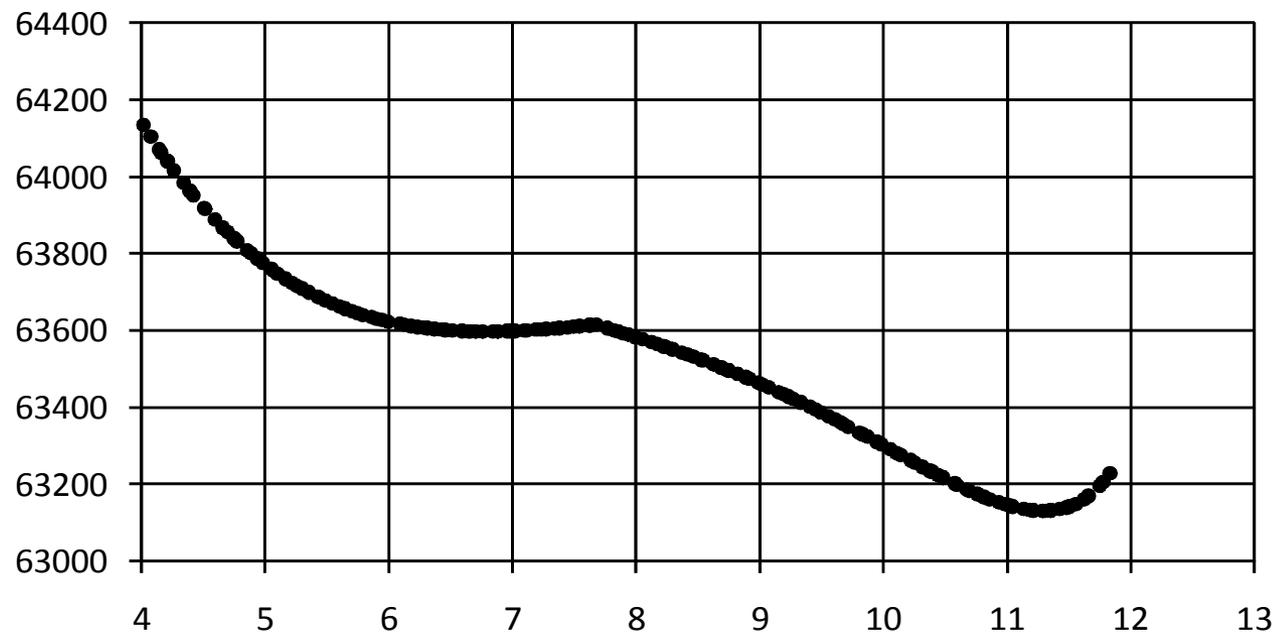
PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Influence of BPR , with $C_{LmaxTO} = 80 \% C_{LmaxL}$ of the redesigned aircraft, i.e.

$$C_{LmaxTO} = 2.32$$

14.1 % mass improvement
for $BPR = 11.3$

m_{MTO}



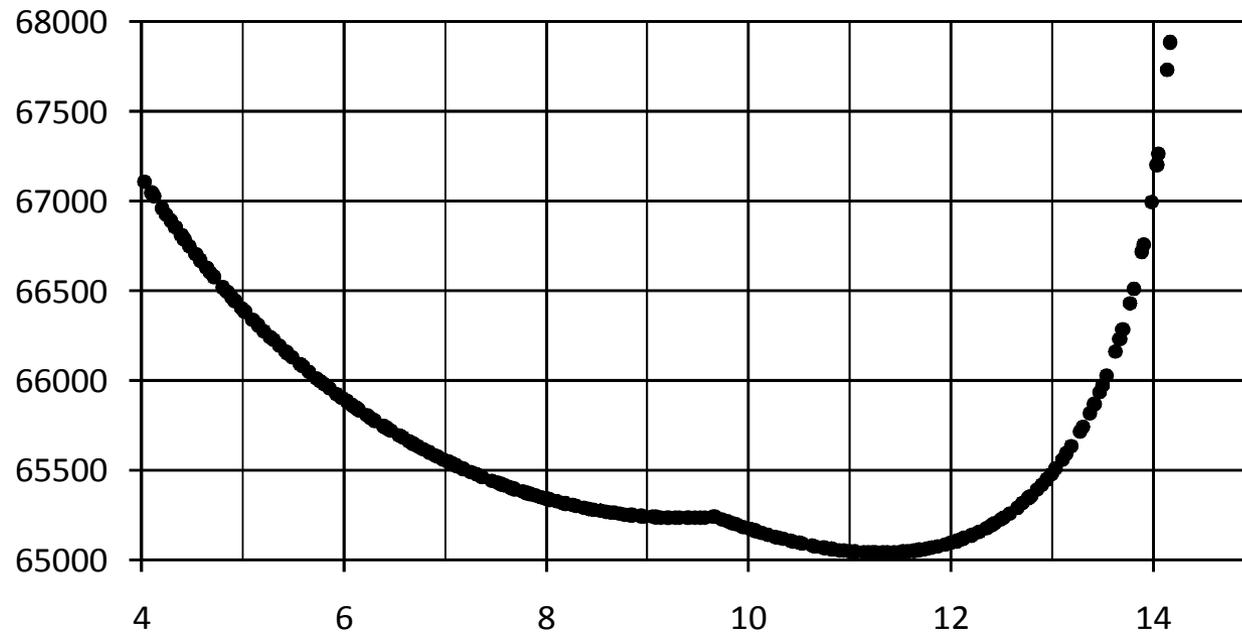
*Maximum take-off mass,
 m_{MTO} as a function of BPR*

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Influence of BPR with $C_{LmaxTO} = 2.07$, model Herrmann

11.5 % mass improvement
for $BPR = 11.2$

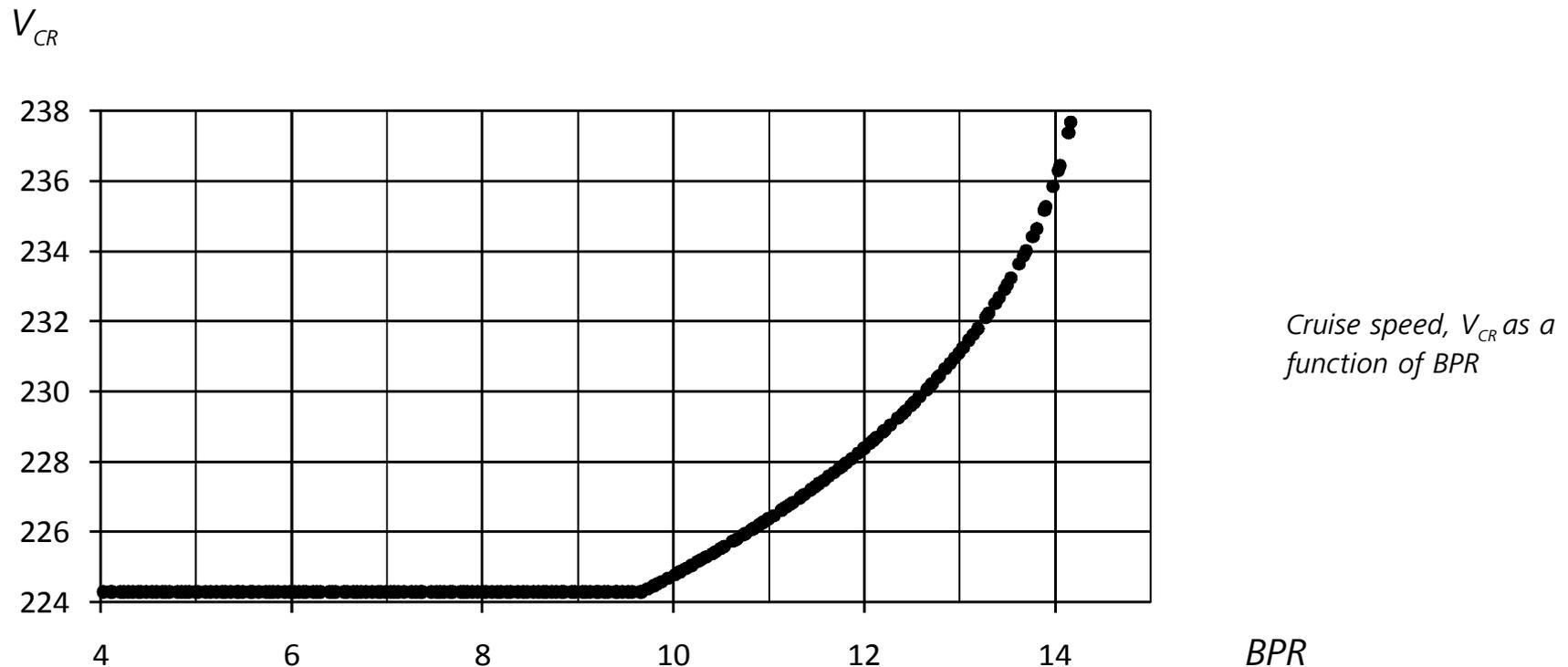
m_{MTO}



Maximum take-off mass,
 m_{MTO} as a function of BPR

PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Influence of BPR with $C_{LmaxTO} = 2.07$, model Herrmann

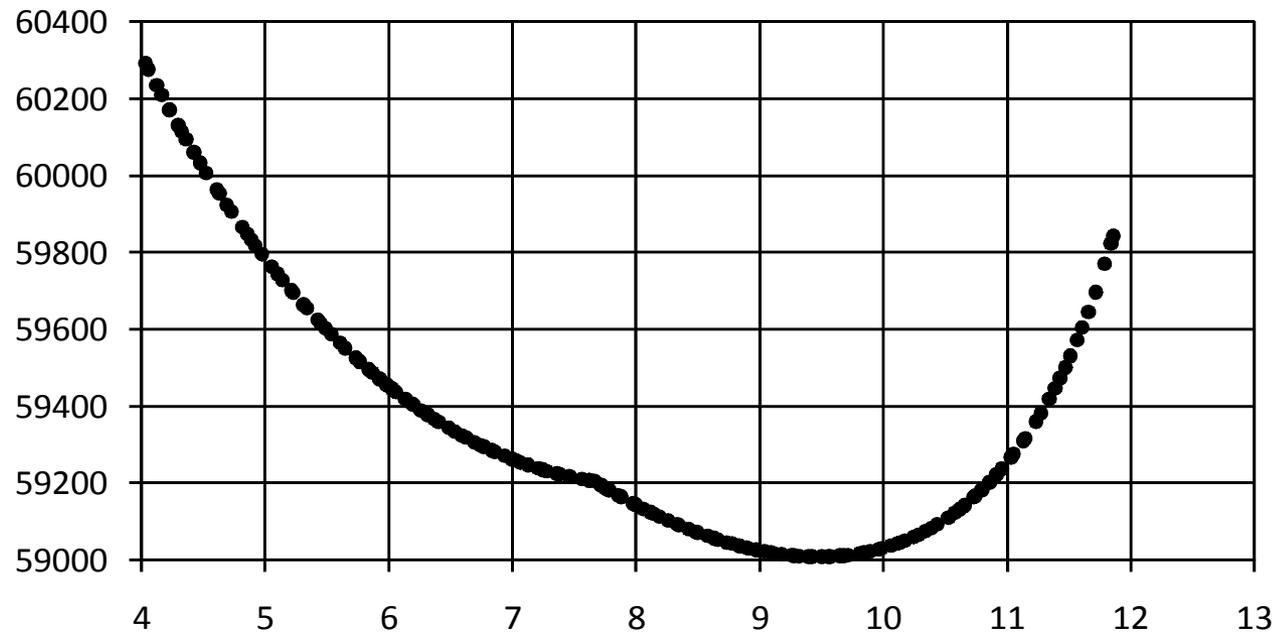


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Influence of BPR , with $C_{LmaxTO} = 2.32$ model Herrmann

19.7 % mass improvement
for $BPR = 9.5$

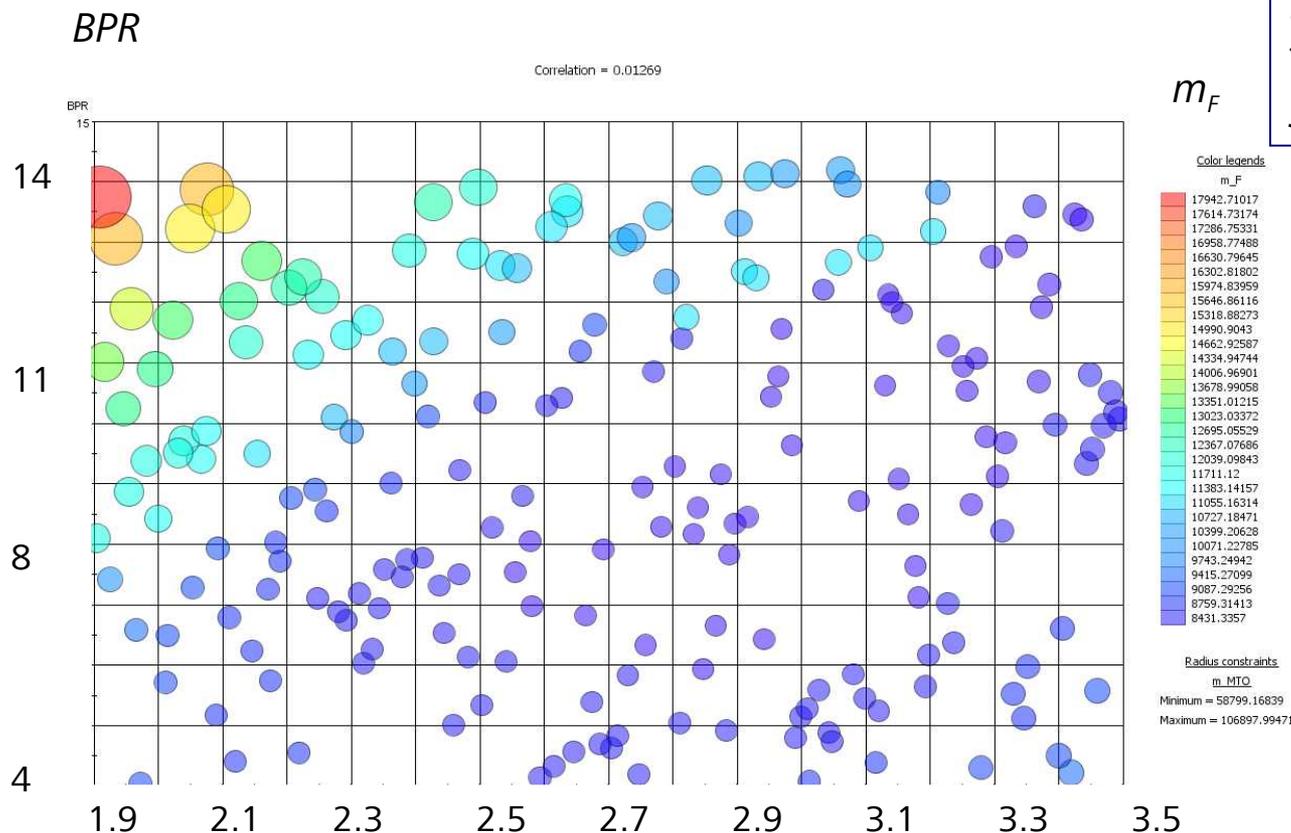
m_{MTO}



Maximum take-off mass,
 m_{MTO} as a function of BPR

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Influence of both BPR and C_{LmaxL} , C_{LmaxTO} , model Herrmann

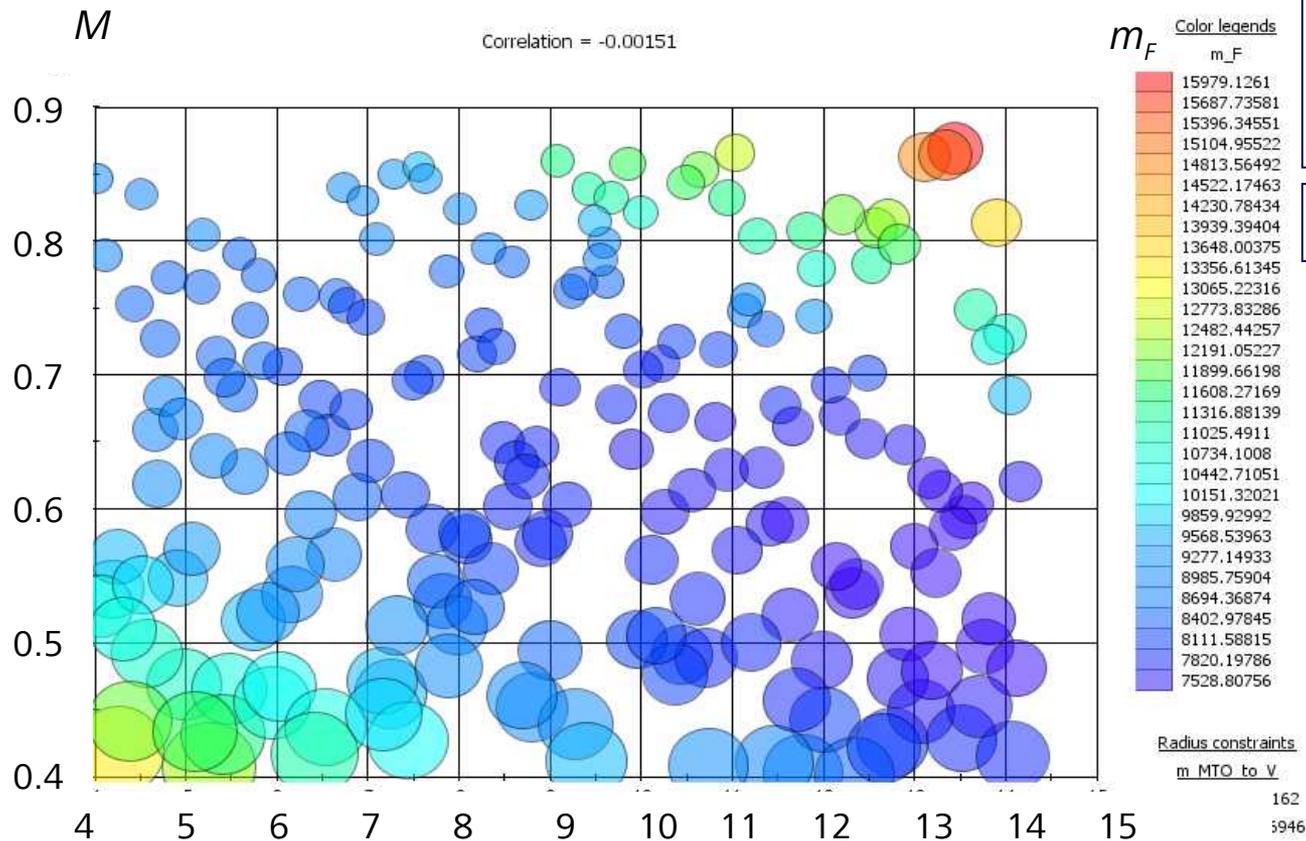


20.0 % mass improvement
for $BPR = 10.6$ and $C_{LmaxL} = 3.13$

Variation of BPR and C_{LmaxL} . Results shown are m_{MTO} (bubble diameter) and m_F (color).

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Influence of both BPR and M , with $C_{LmaxTO} = 2.32$, model Herrmann



15.7 % mass improvement
for $BPR = 7.6$ and
 $M = 0.86$

Objective: $\min m_{MTO} / V$

Variation of BPR and M .
Results shown are m_{MTO}
(bubble diameter) and m_F
(color).

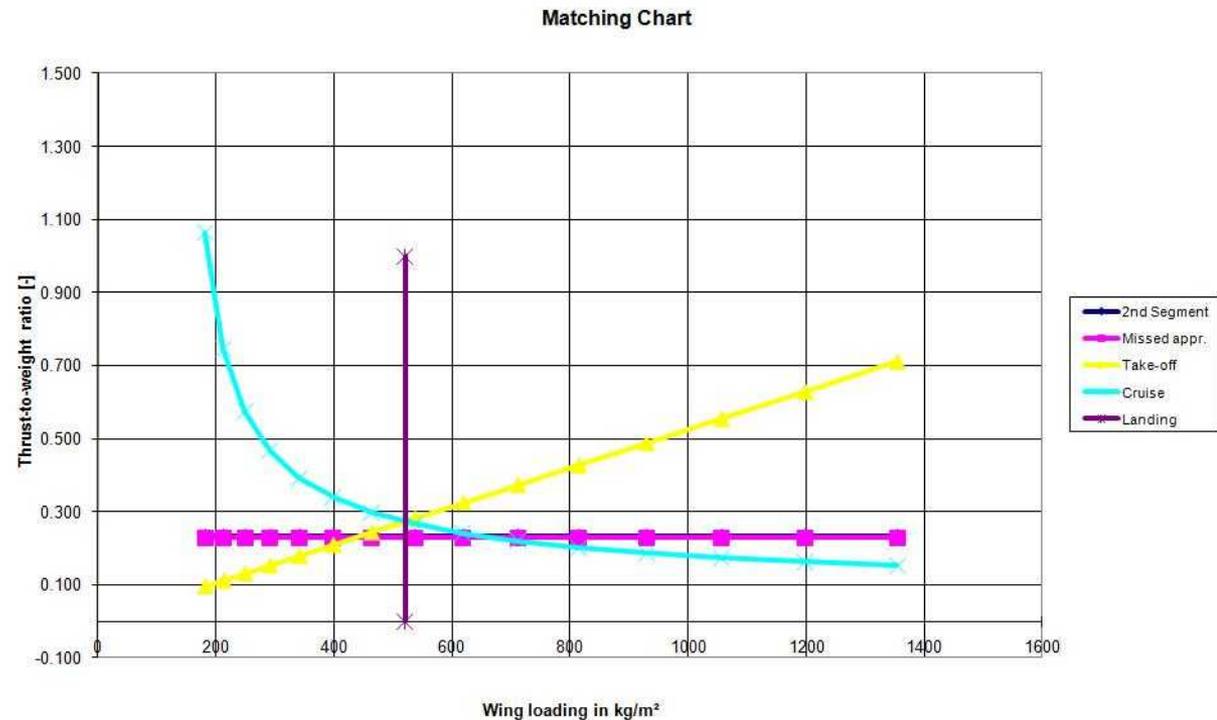
BPR

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Influence of BPR , M , C_{LmaxL} and m_{ML}/m_{MTO} model Herrmann

17.4 % mass improvement
for $BPR = 10.7$, $M = 0.76$,
 $C_{LmaxL} = 2.53$, $m_{ML}/m_{MTO} =$
 0.887

Objective: $\min m_{MTO} / V$



PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Outlook

- To question additional parameter variations for innovative configurations (S_{TOFL} , S_{LFL})
- To test further objective functions: DOC , m_{F} , m_{F}/V , m_{MTO}/V
- To include the nacelle drag penalty and landing gear weight penalty for high BPR

- The final goal is to offer formal optimization of aircraft design parameters as a starting point for further interactive parameter changes in PreSTo [independent from a commercial tool like Optimus®](#).

- This shall be achieved by programming a suitable optimization algorithm with VBA in PreSTo. The user can then "on pressing a button" find a "pre-optimized" design in the preliminary sizing module.

- This "pre-optimized" design can then be manually improved and made ready for airline operation considering further expert knowledge.



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Thank you!

Contact

Mihaela.Nita@HAW-Hamburg.de

<http://PreSTo.ProfScholz.de>

<http://OPerA.ProfScholz.de>

