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

10th European Workshop on Aircraft Design Education 2011

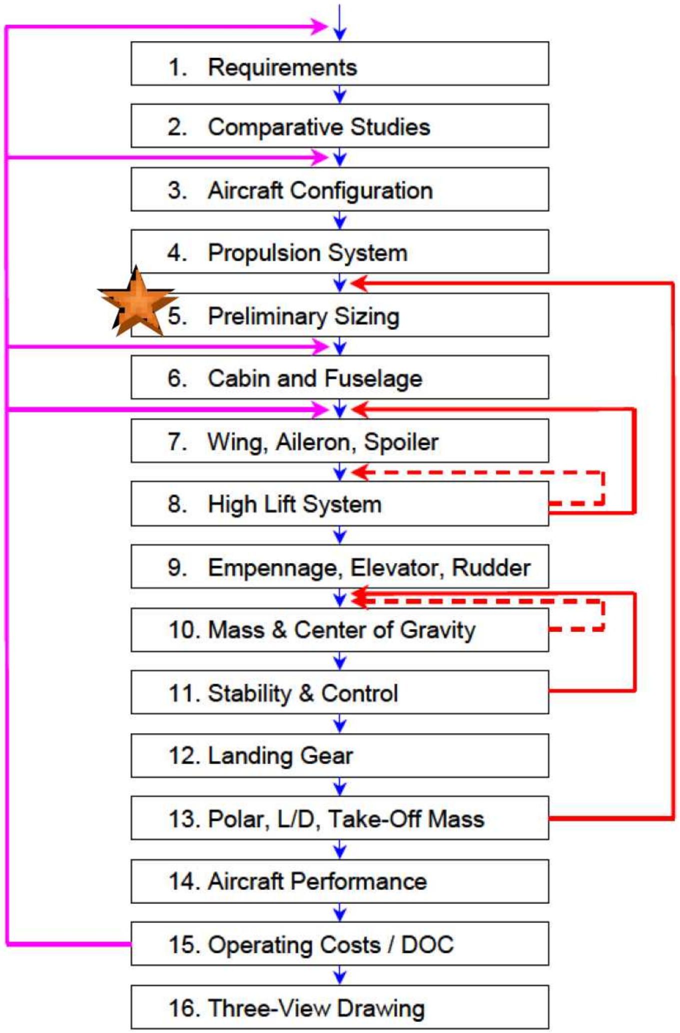
Naples, Italy, 24-27.05.2011

EWADE 2011

Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

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


1. Requirements
2. Comparative Studies
3. Aircraft Configuration
4. Propulsion System
5. Preliminary Sizing
6. Cabin and Fuselage
7. Wing, Aileron, Spoiler
8. High Lift System
9. Empennage, Elevator, Rudder
10. Mass & Center of Gravity
11. Stability & Control
12. Landing Gear
13. Polar, L/D, Take-Off Mass
14. Aircraft Performance
15. Operating Costs / DOC
16. Three-View Drawing

The Problem

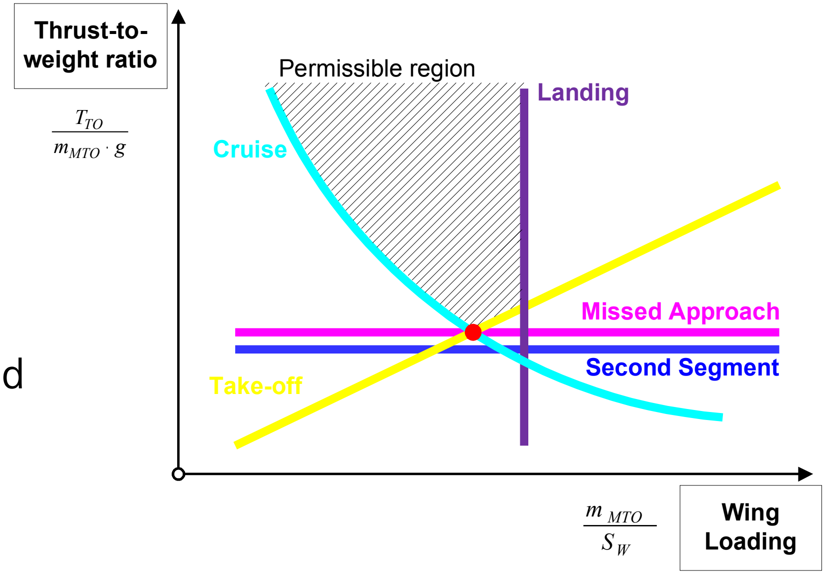
- Design requirements are given: landing distance, take-off distance, cruise Mach number, ...
- Other design parameters are required: aspect ratio, maximum lift coefficients, ...
- The best combination of design parameters leading to a good design needs to be found.

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.

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.

Extensions of PreSTo

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

$$m_{OE} = \underbrace{m_{OE,preliminary}}_{\text{From thrust-to-weight ratio, based on Loftin}} - \overbrace{\underbrace{m_{W,redesign}}_{\text{Based on the parameters of the redesigned baseline aircraft}} + \underbrace{m_{W,Optimus}}_{\text{Based on the parameters found by Optimus}^{\circledR}}}^{\text{From Torenbeek}}$$

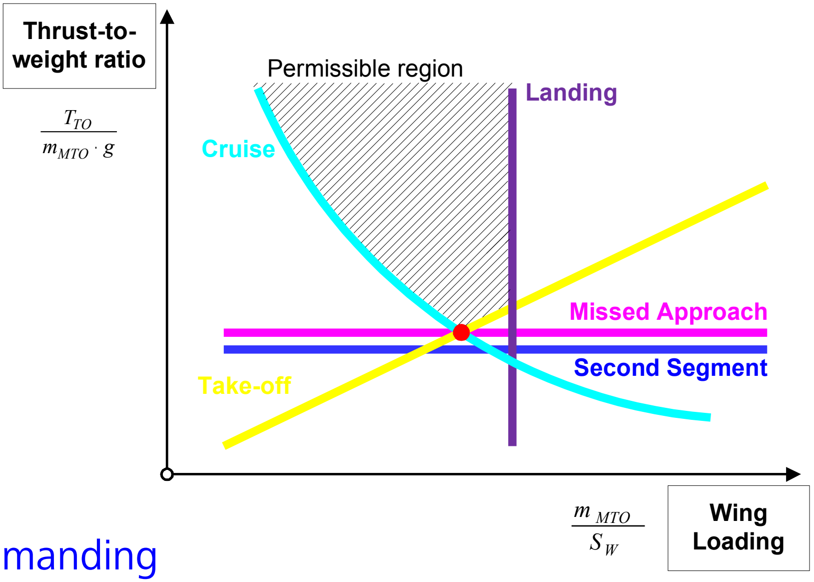
Extensions of PreSTo

- Automation of the cruise line in the matching chart by adjusting the value of V/V_m.

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

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

$$E = \frac{2\,E_{max}}{\frac{1}{\left(\frac{C_L}{C_{L,md}}\right)} + \left(\frac{C_L}{C_{L,md}}\right)}$$



- 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.

SFC Calcullation Models

- Mattingly 1996

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

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

SFC Calcullation Models

- Isikveren 2002

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

calibrated for BPR = 5.2 with k_1 = 1.586 lb/lb.hr; k_2 = -0.303; k_3 = 8.40 X 10^{-4} per FL;

k_4 = -0.760; k_5 = 5.45 X 10^{-4} lb/lb.hr.FL; k_6 = -0.307 lb/lb.hr; k_7 = -9.54 X 10^{-5} lb/lb.hr .FL;
k_8 = 0.694 lb/lb.hr

- Sforza 2004

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

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

- Howe 2000

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

where c_1 = 0.85 *N/Nh* for low λ (BPR)

and c_1 = 0.7 *N/Nh* for high λ (BPR)

SFC Calcullation Models

- Herrmann 2010

  necessary parametrs: BPR, OAPR, TET, ΔP/P and engine component efficiencies:

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

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

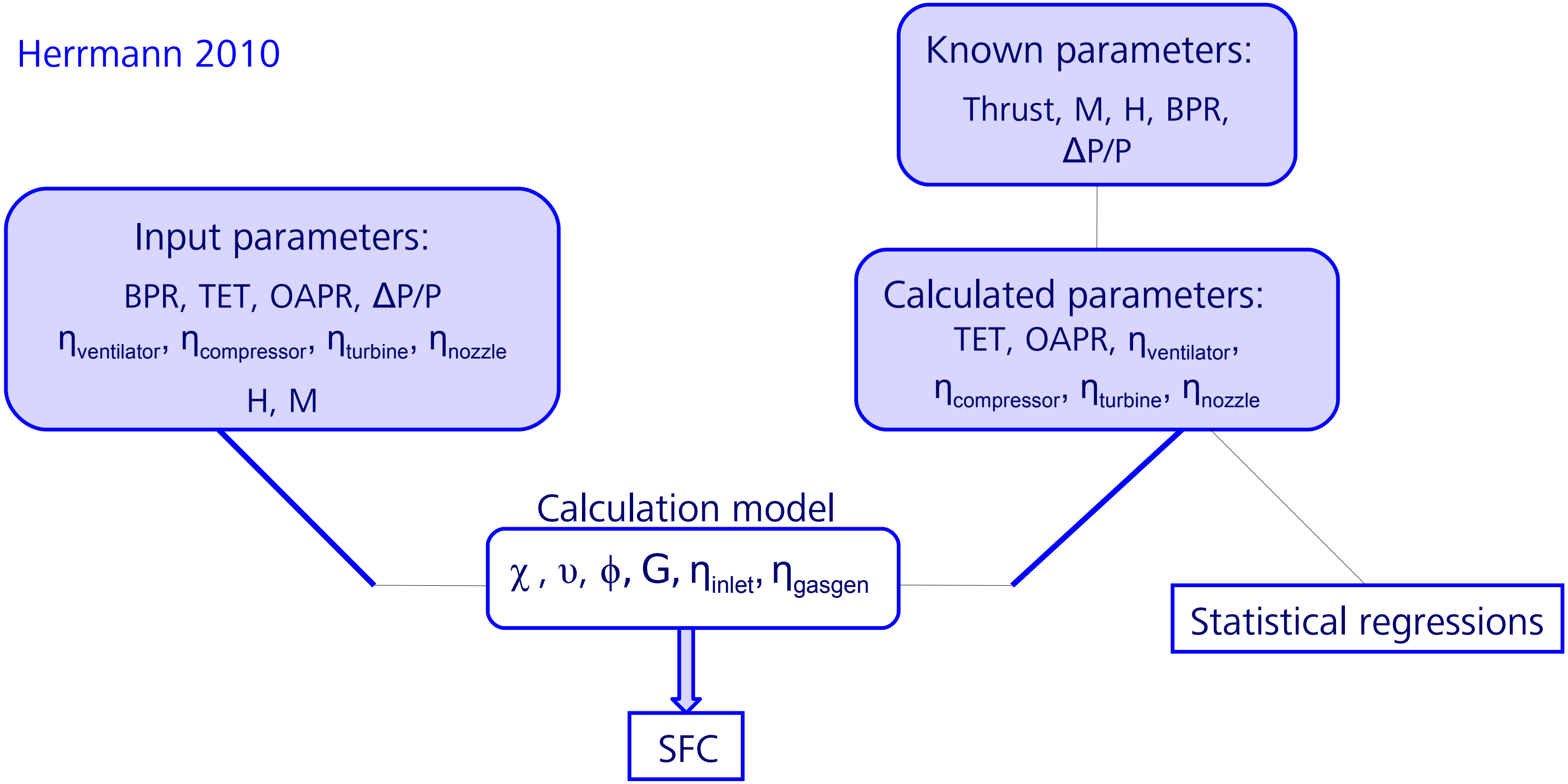
, where

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

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

SFC Calcullation Models

- Herrmann 2010



Known parameters:
Thrust, M, H, BPR, $\Delta P/P$

Input parameters:
BPR, TET, OAPR, $\Delta P/P$
$\eta_{ventilator}$, $\eta_{compressor}$, $\eta_{turbine}$, η_{nozzle}
H, M

Calculated parameters:
TET, OAPR, $\eta_{ventilator}$, $\eta_{compressor}$, $\eta_{turbine}$, η_{nozzle}

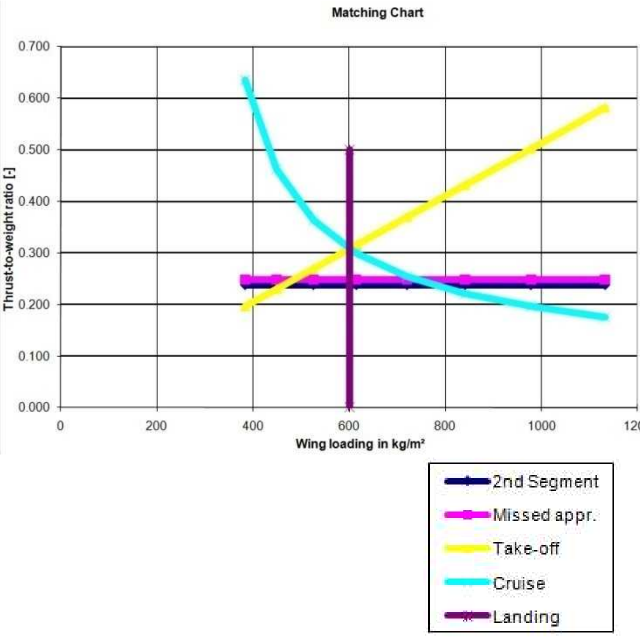
Calculation model
χ, υ, ϕ, G, η_{inlet}, η_{gasgen}

Statistical regressions

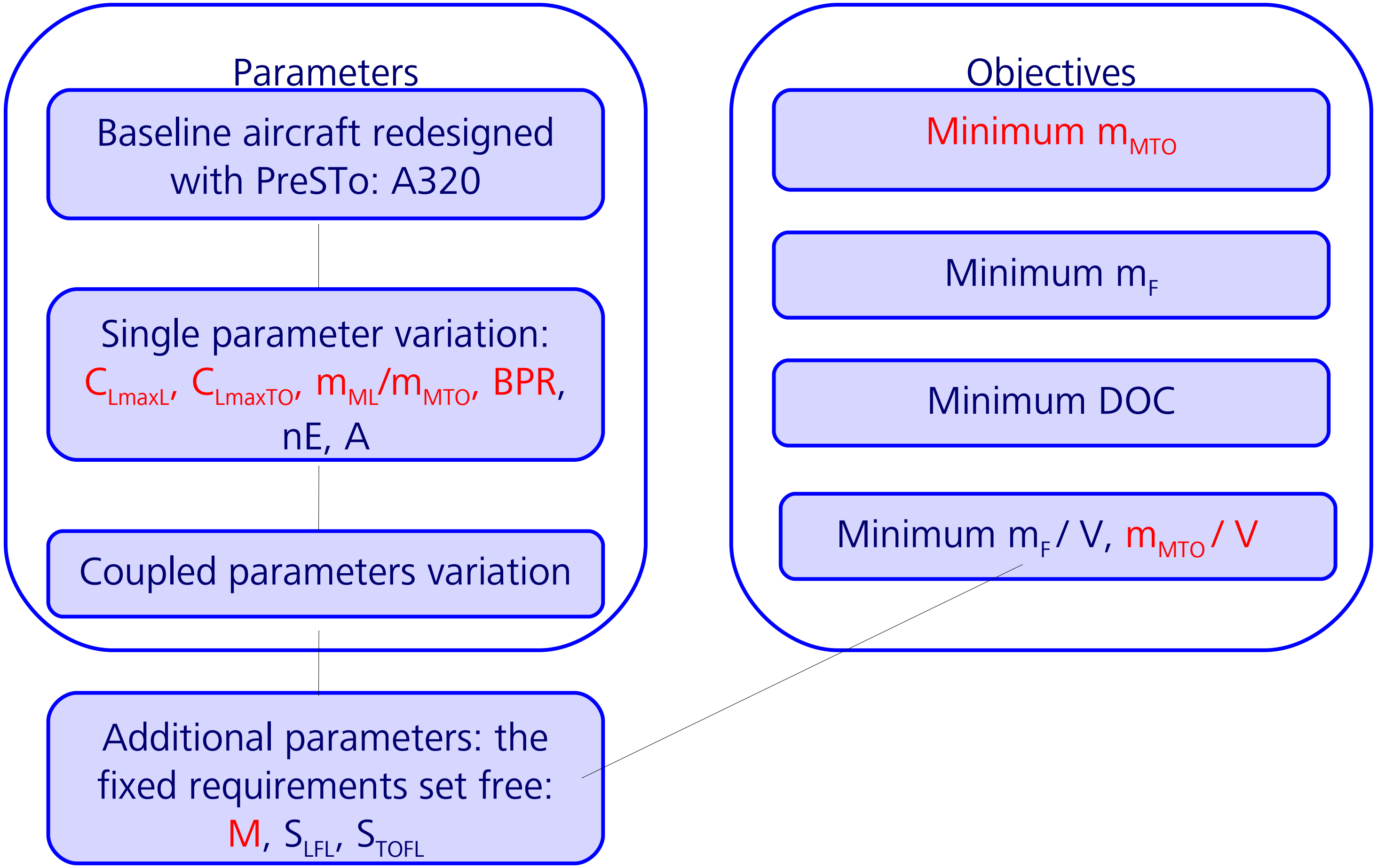
SFC

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	-	

Approach



Parameters

Baseline aircraft redesigned with PreSTo: A320

Single parameter variation: C_{LmaxL}, C_{LmaxTO}, m_{ML}/m_{MTO}, BPR, nE, A

Coupled parameters variation

Additional parameters: the fixed requirements set free: M, S_{LFL}, S_{TOFL}

Objectives

Minimum m_{MTO}

Minimum m_F

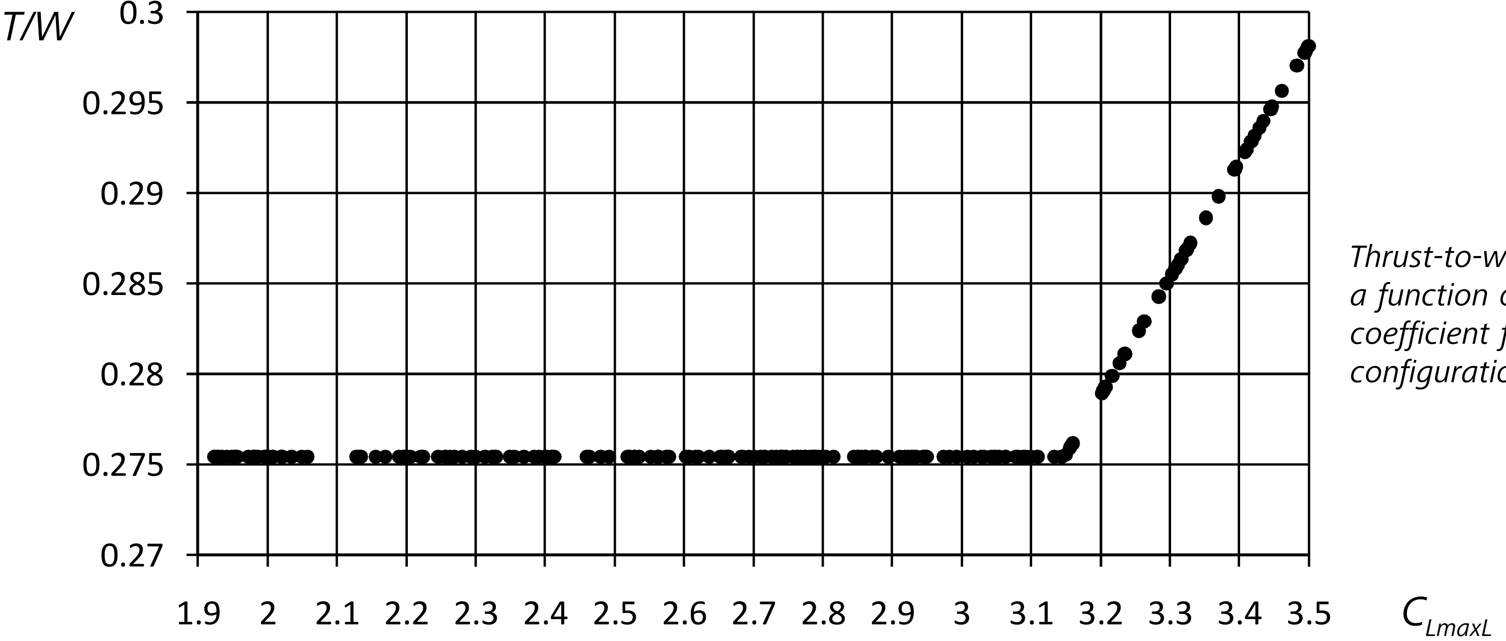
Minimum DOC

Minimum m_F / V, m_{MTO} / V

Influence of C_{LmaxL} and C_{LmaxTO}

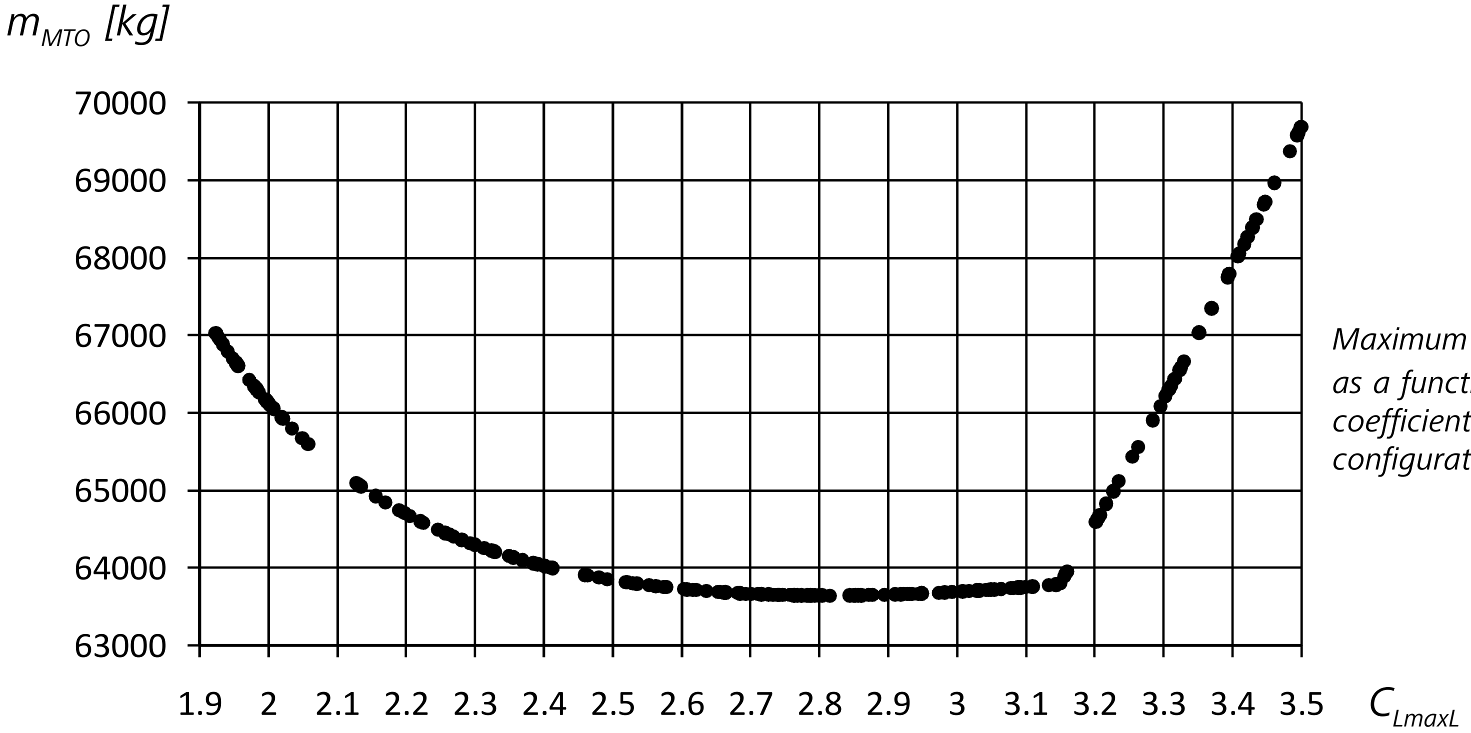
- C_{LmaxL} varied in the interval [1.9, 3.5]
- $C_{LmaxTO} = 80\ \% \cdot C_{LmaxL}$
- The rest of the parameters were kept as for the A 320

} coupled



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

Influence of C_{LmaxL} and C_{LmaxTO}



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

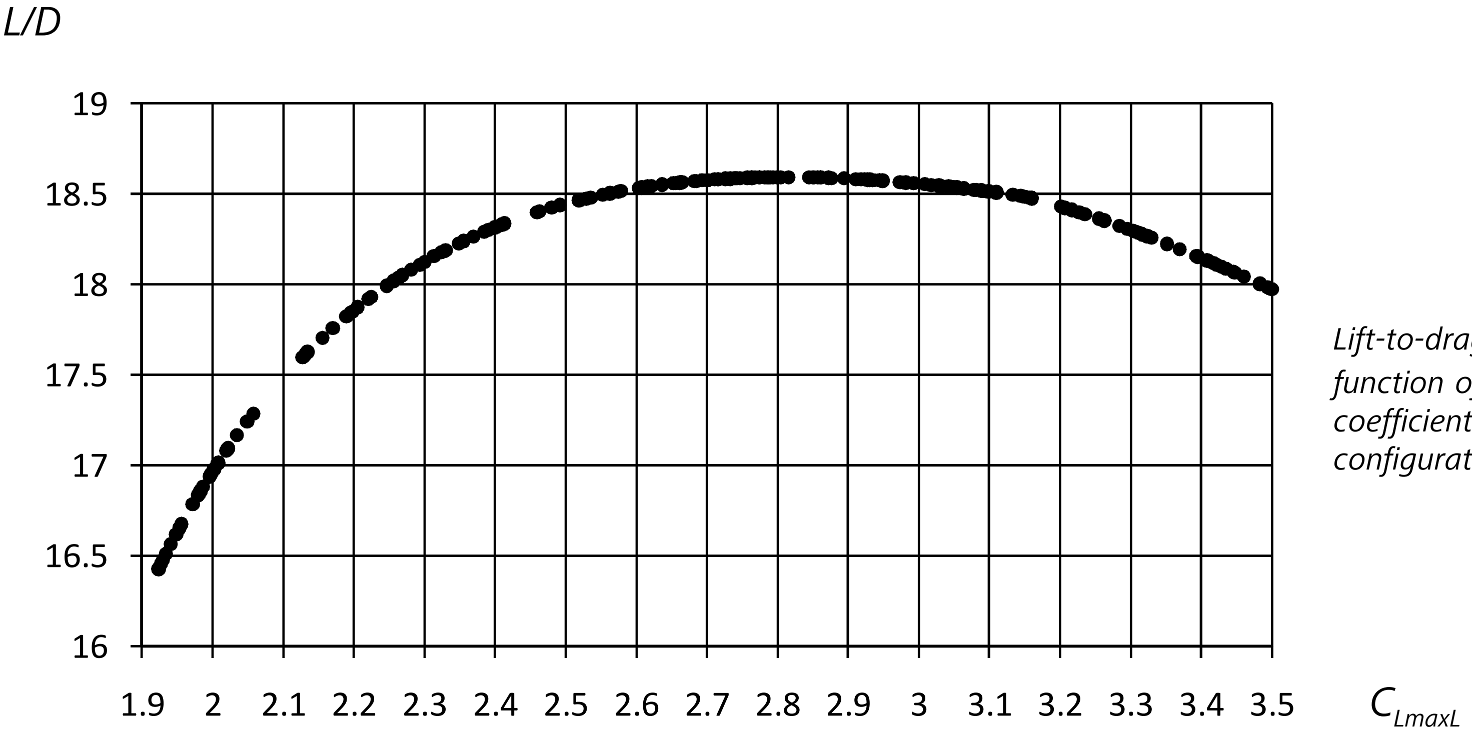
Influence of C_{LmaxL} and C_{LmaxTO}

Wing mass, m_W as a function of maximum lift coefficient for landing configuration, C_{LmaxL}

Influence of C_{LmaxL} and C_{LmaxTO}

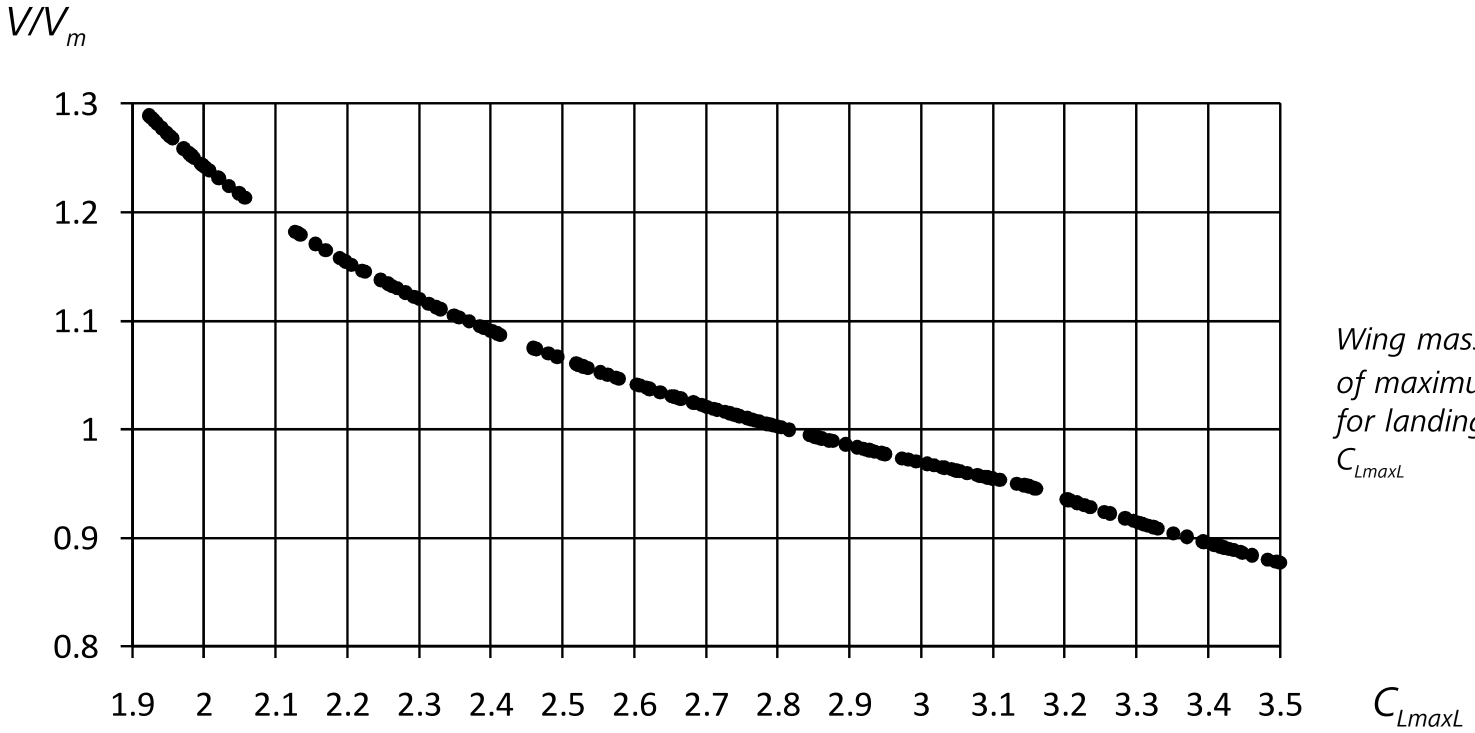
Wing areq, S_W as a function of maximum lift coefficient for landing configuration, C_{LmaxL}

Influence of C_{LmaxL} and C_{LmaxTO}



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

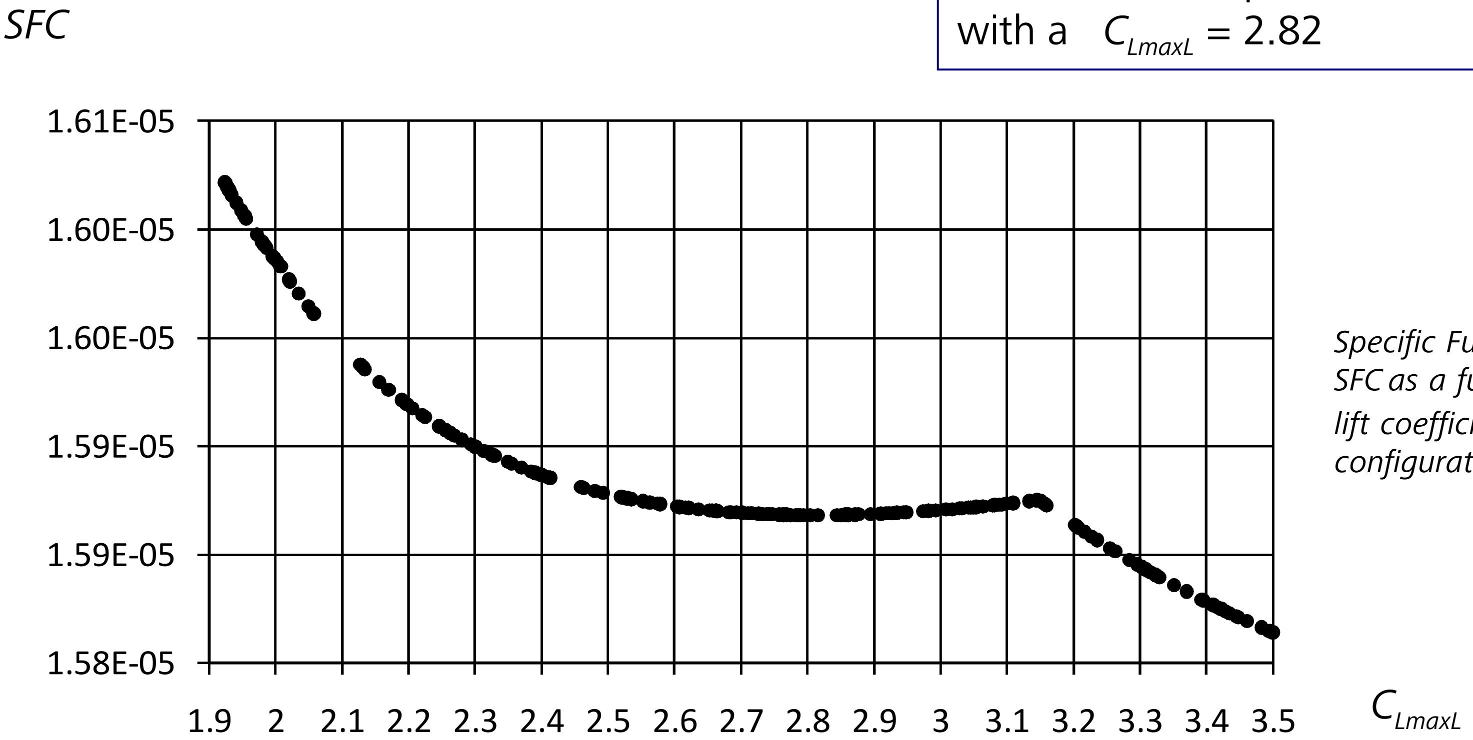
Influence of C_{LmaxL} and C_{LmaxTO}



Wing mass, m_W as a function of maximum lift coefficient for landing configuration, C_{LmaxL}

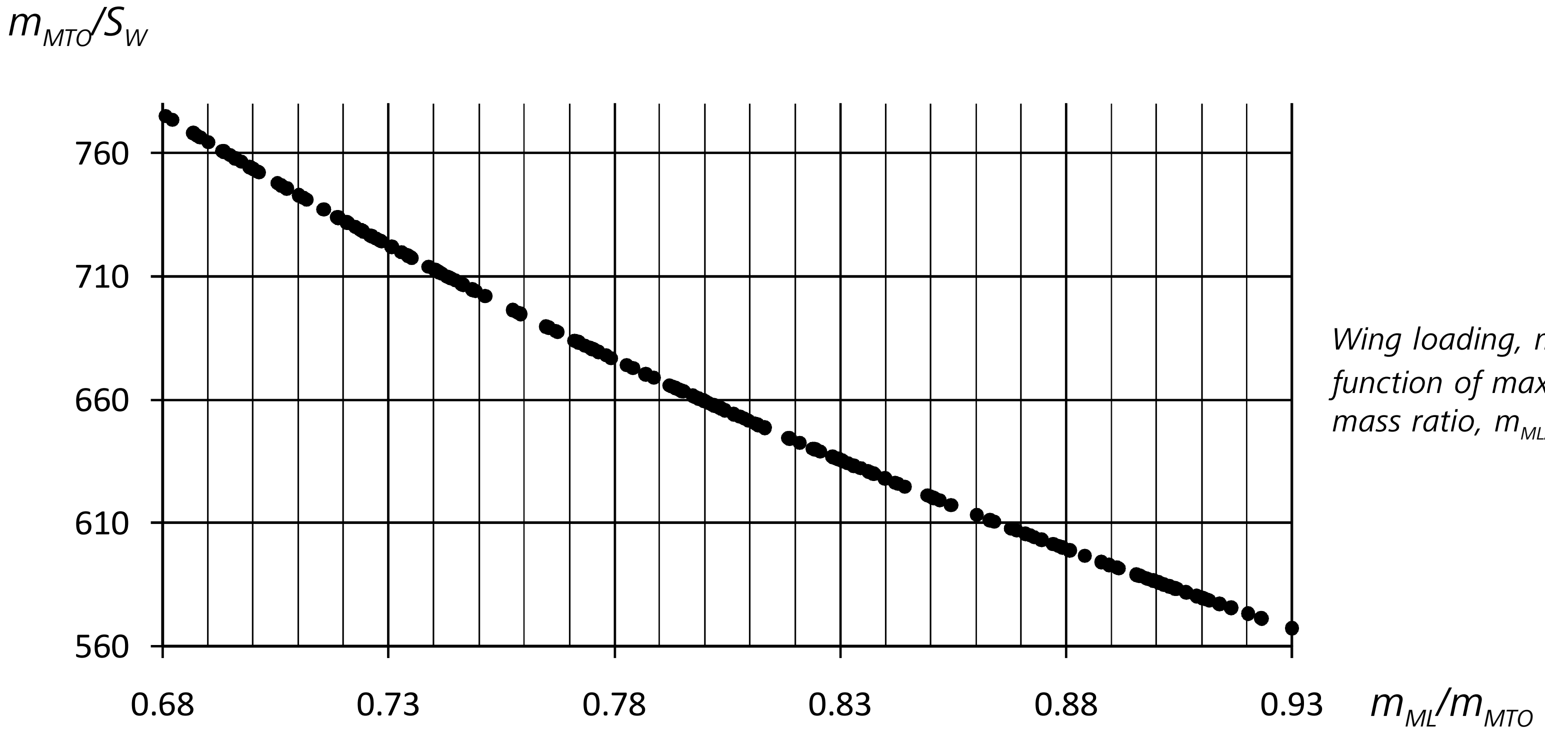
Influence of C_{LmaxL} and C_{LmaxTO}

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



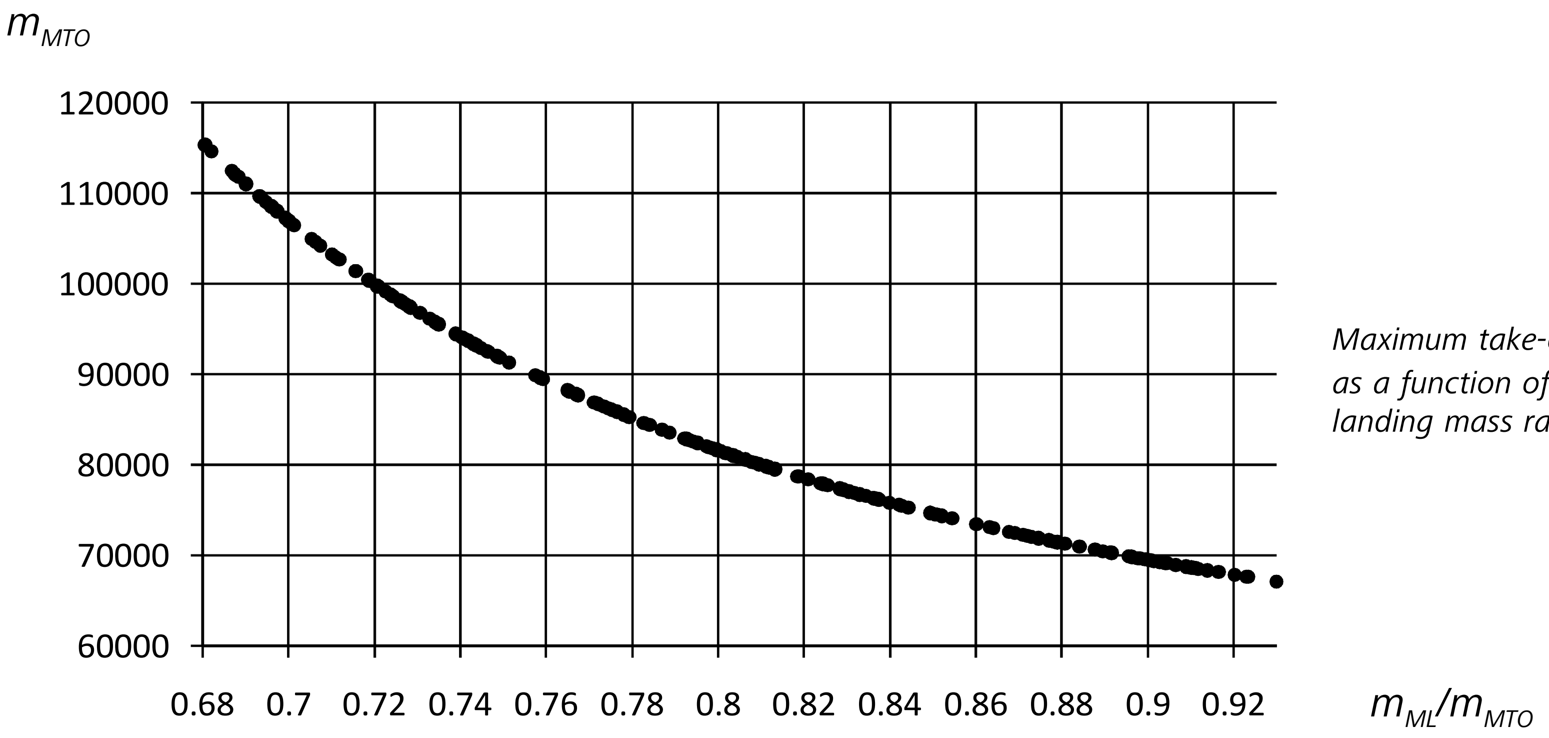
Specific Fuel Consumption, SFC as a function of maximum lift coefficient for landing configuration, C_{LmaxL}

Influence of m_{ML}/m_{MTO}



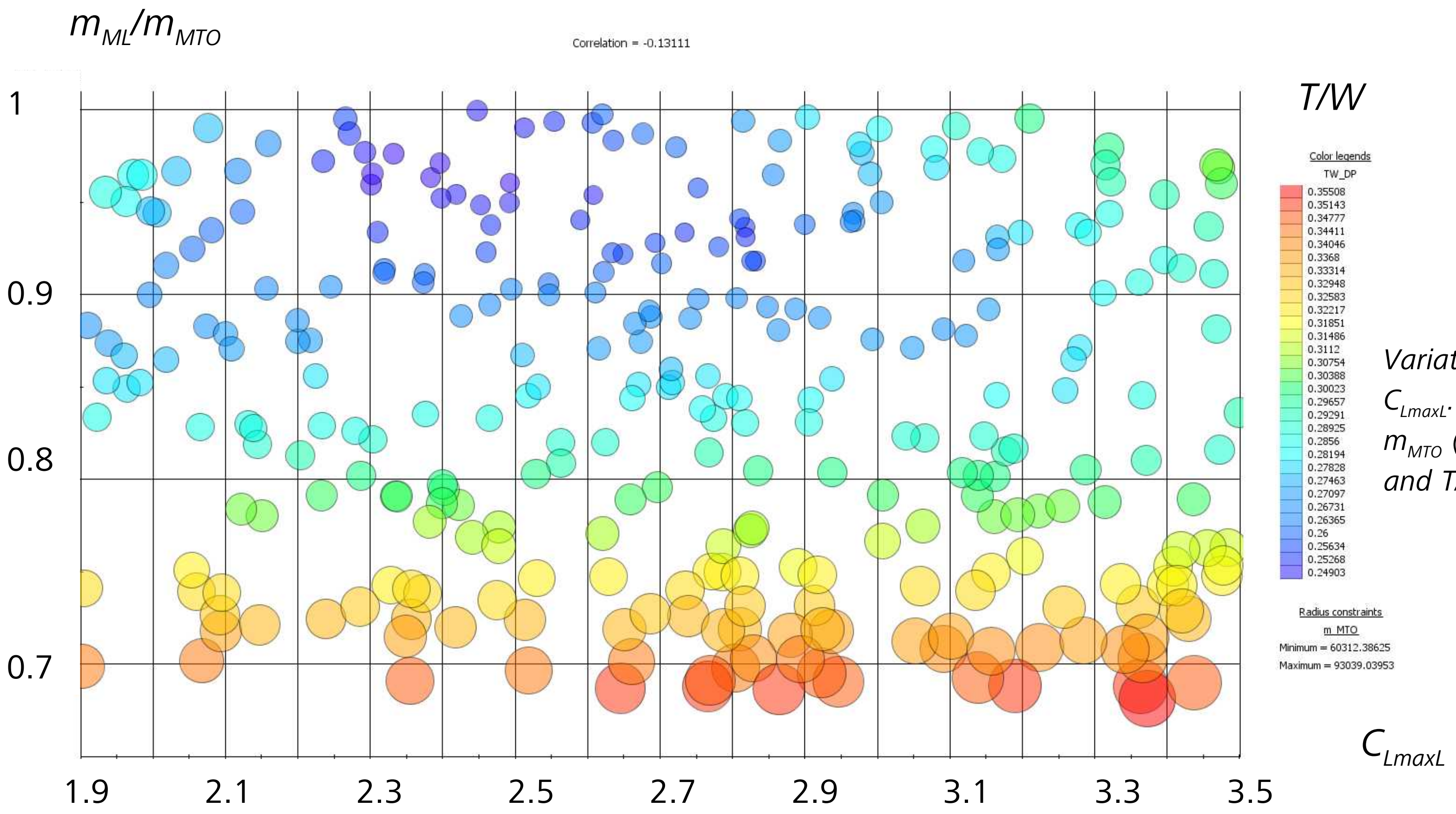
Wing loading, m_{MTO}/S_W as a function of maximum landing mass ratio, m_{ML}/m_{MTO}

Influence of m_{ML}/m_{MTO}



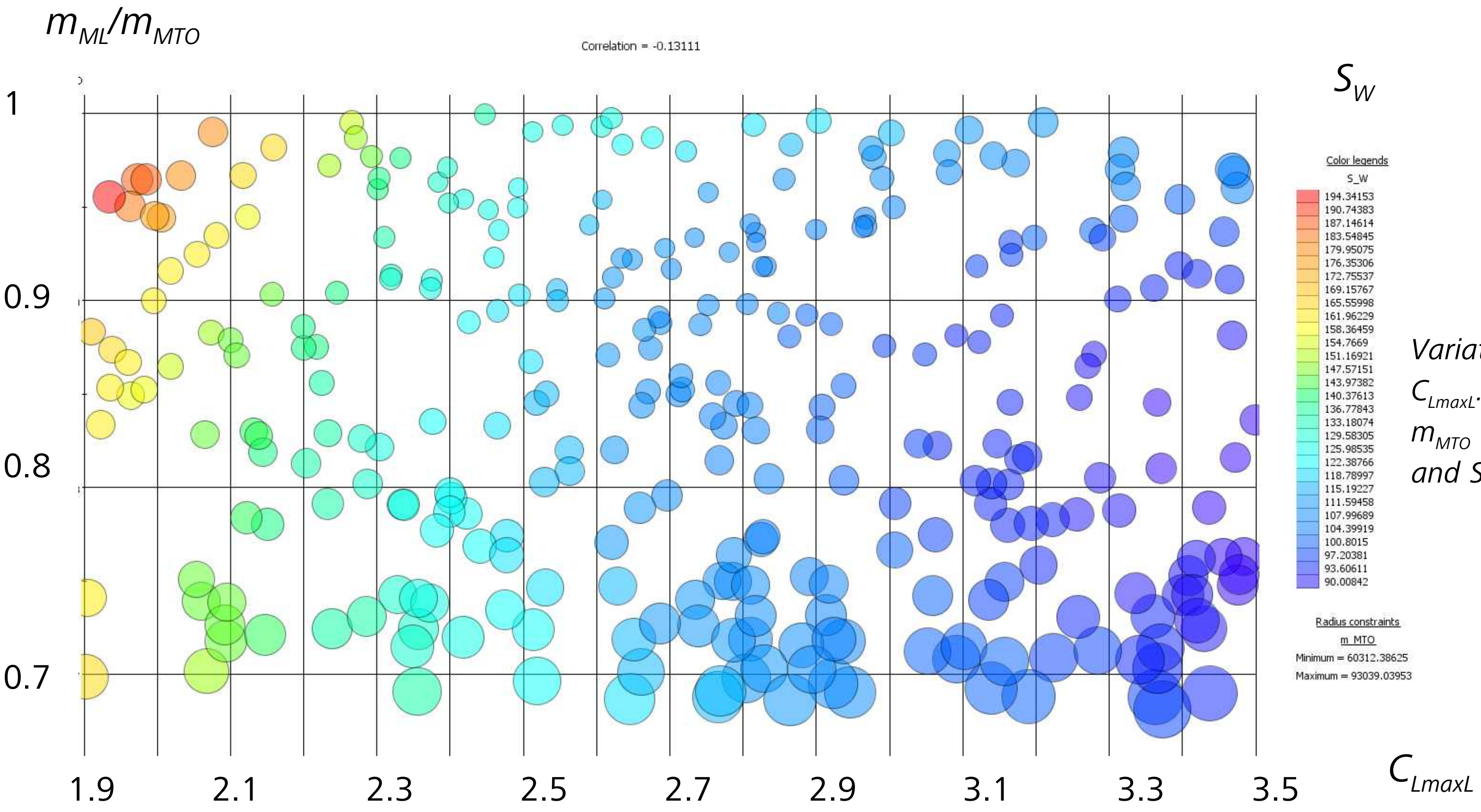
Maximum take-off mass, m_{MTO} as a function of maximum landing mass ratio, m_{ML}/m_{MTO}

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



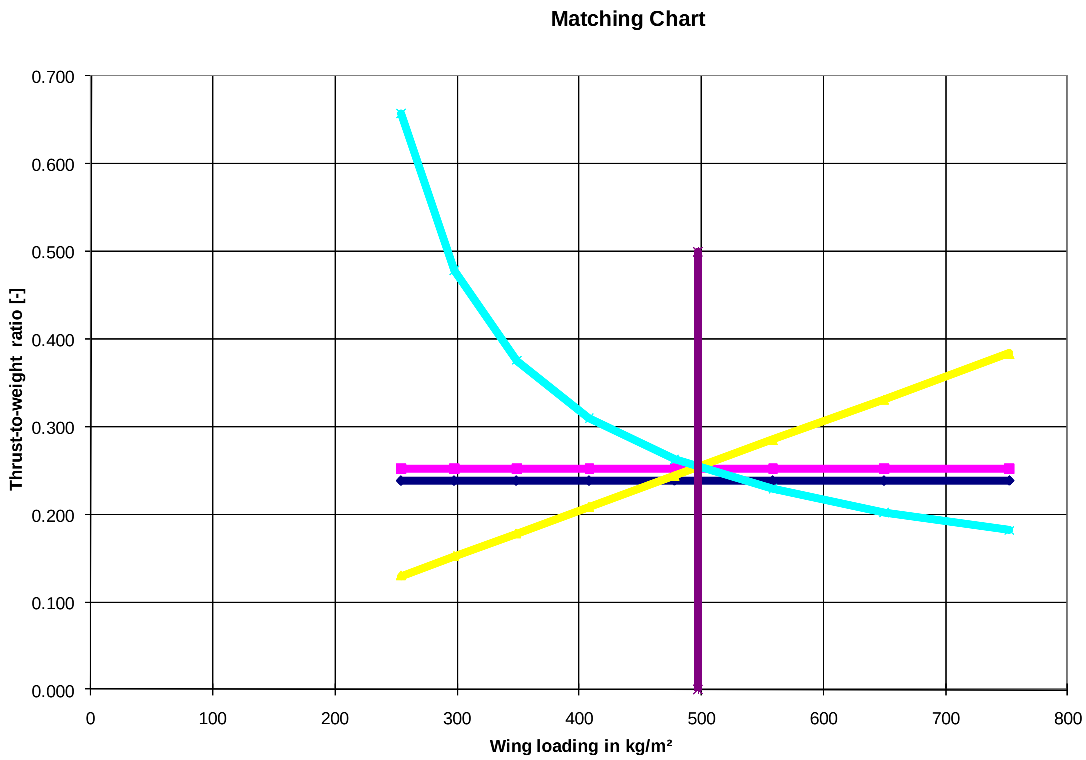
Variation of m_{ML}/m_{MTO} and C_{LmaxL}. Results shown are m_{MTO} (bubble diameter) and T/W (color).

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

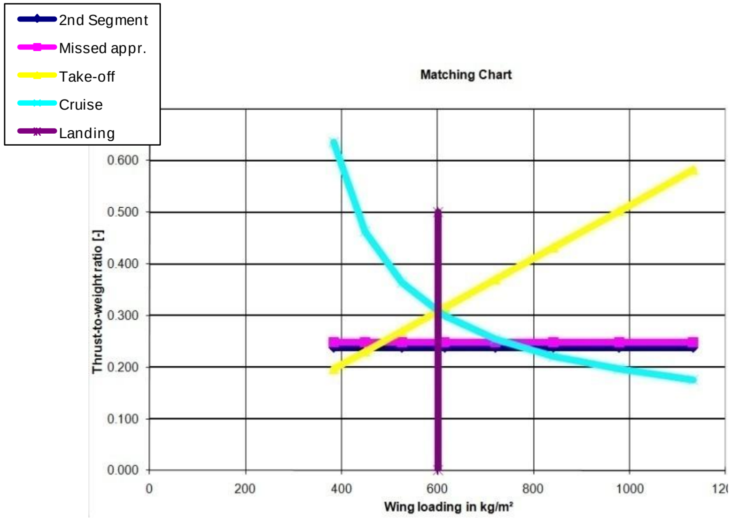


Variation of m_{ML}/m_{MTO} and C_{LmaxL}. Results shown are m_{MTO} (bubble diameter) and S_W (color).

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

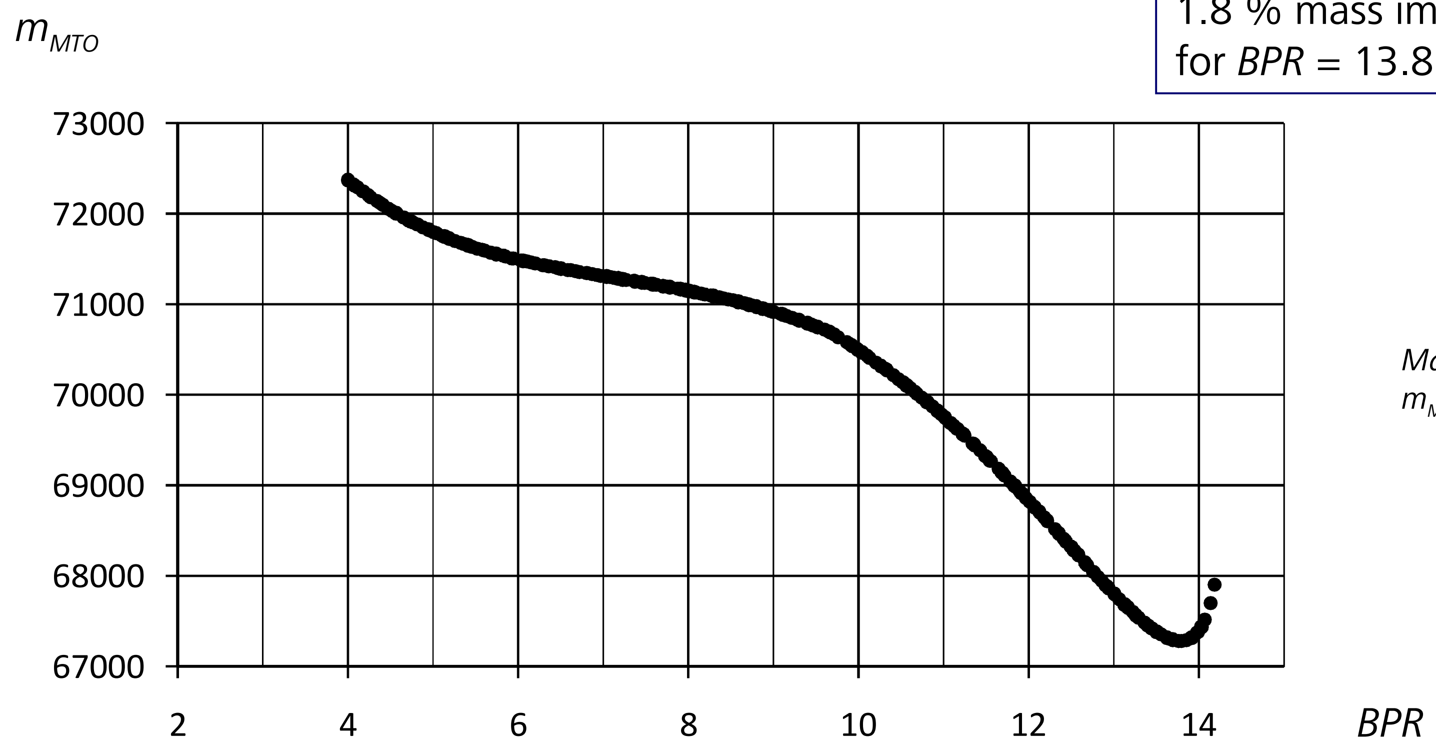


17.9 % mass improvement for C_{LmaxL} = 2.61 and m_{ML}/m_{MTO} = 0.95



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

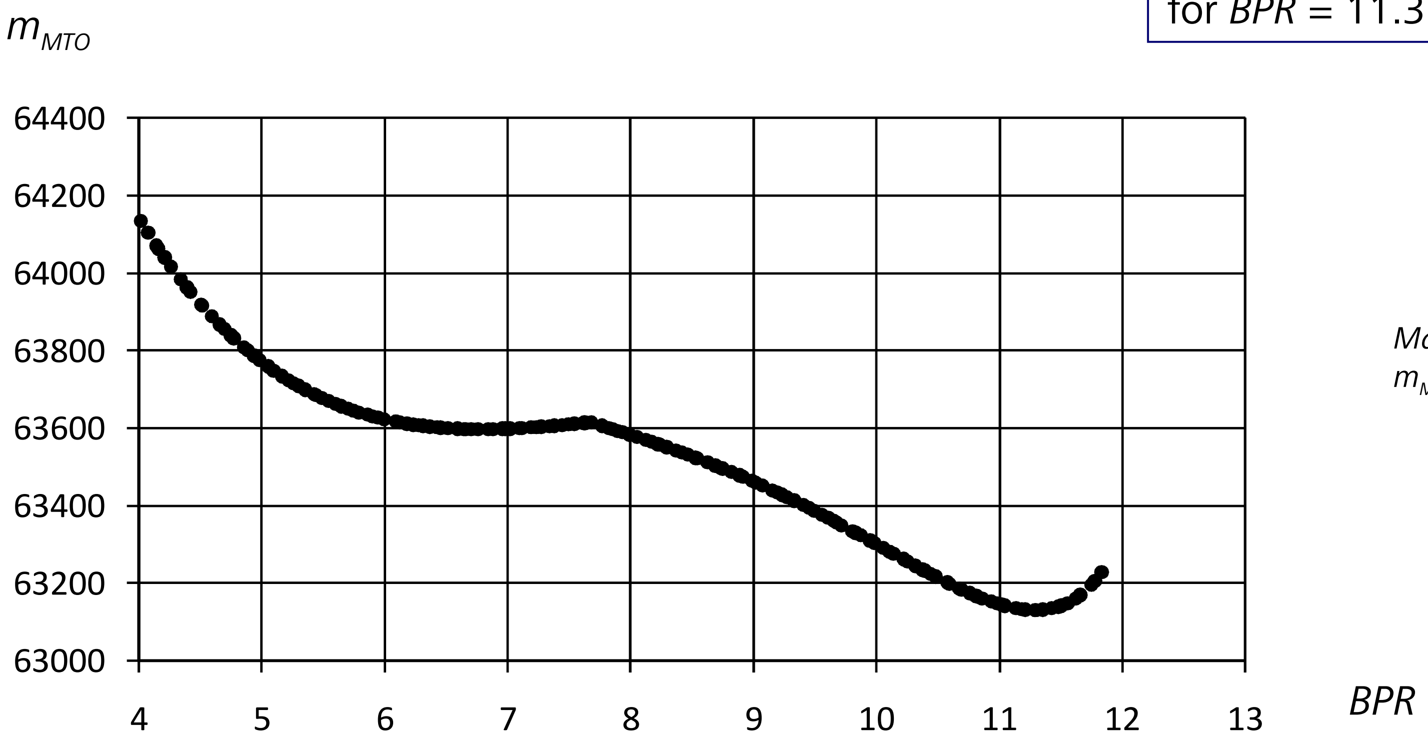
1.8 % mass improvement
for *BPR* = 13.8



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

Influence of *BPR*, with $C_{LmaxTO} = 80\ \%\ C_{LmaxL}$ of the redesigned aircraft, i.e. $C_{LmaxTO} = 2.32$

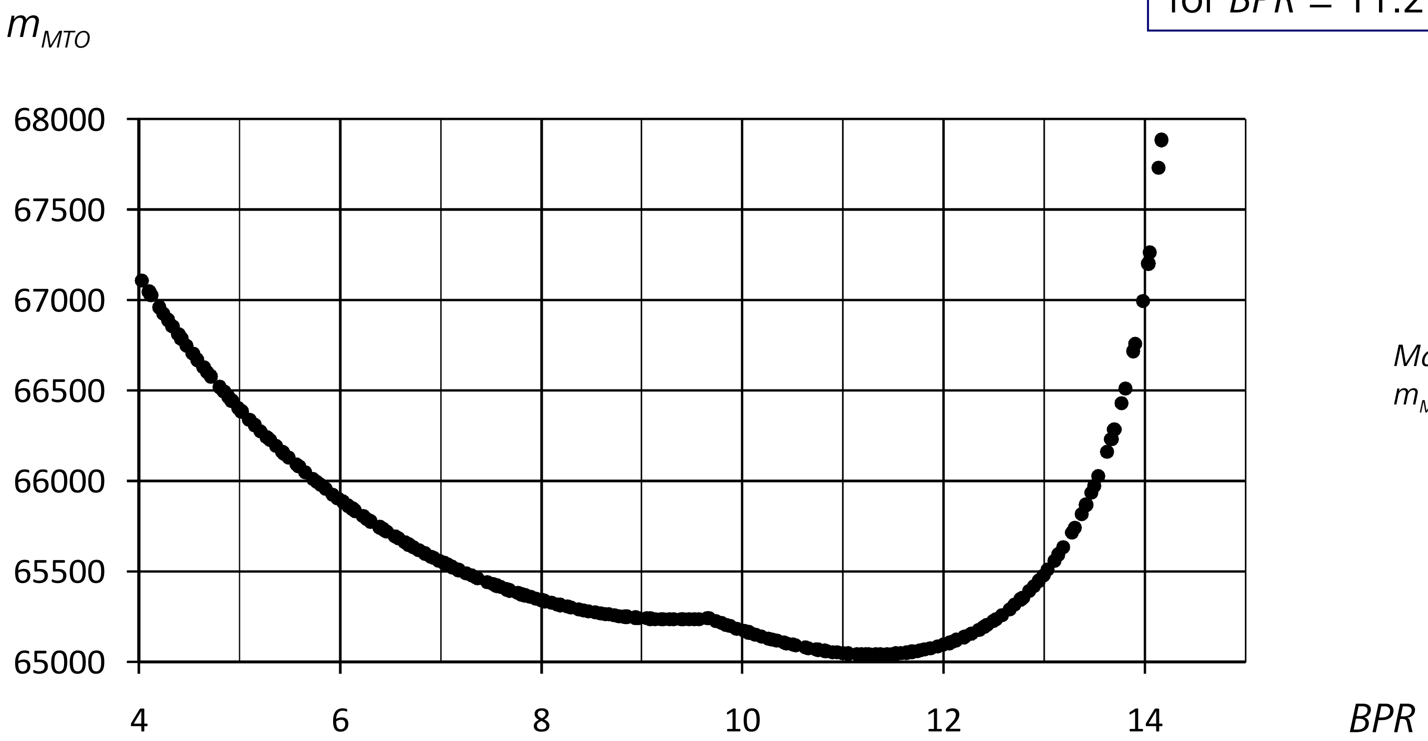
14.1 % mass improvement
for *BPR* = 11.3



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

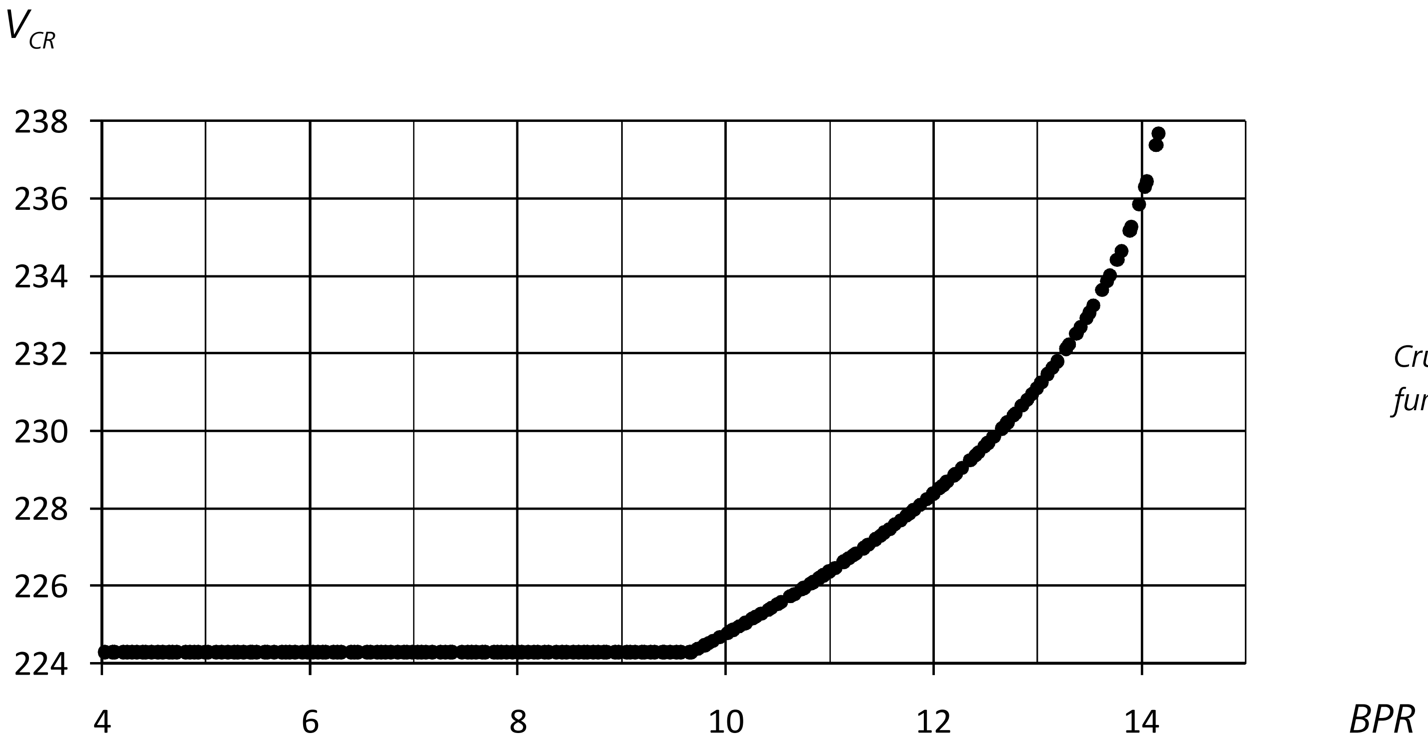
Influence of *BPR* with C_{LmaxTO} = *2.07* , model Herrmann

11.5 % mass improvement
for *BPR* = 11.2



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

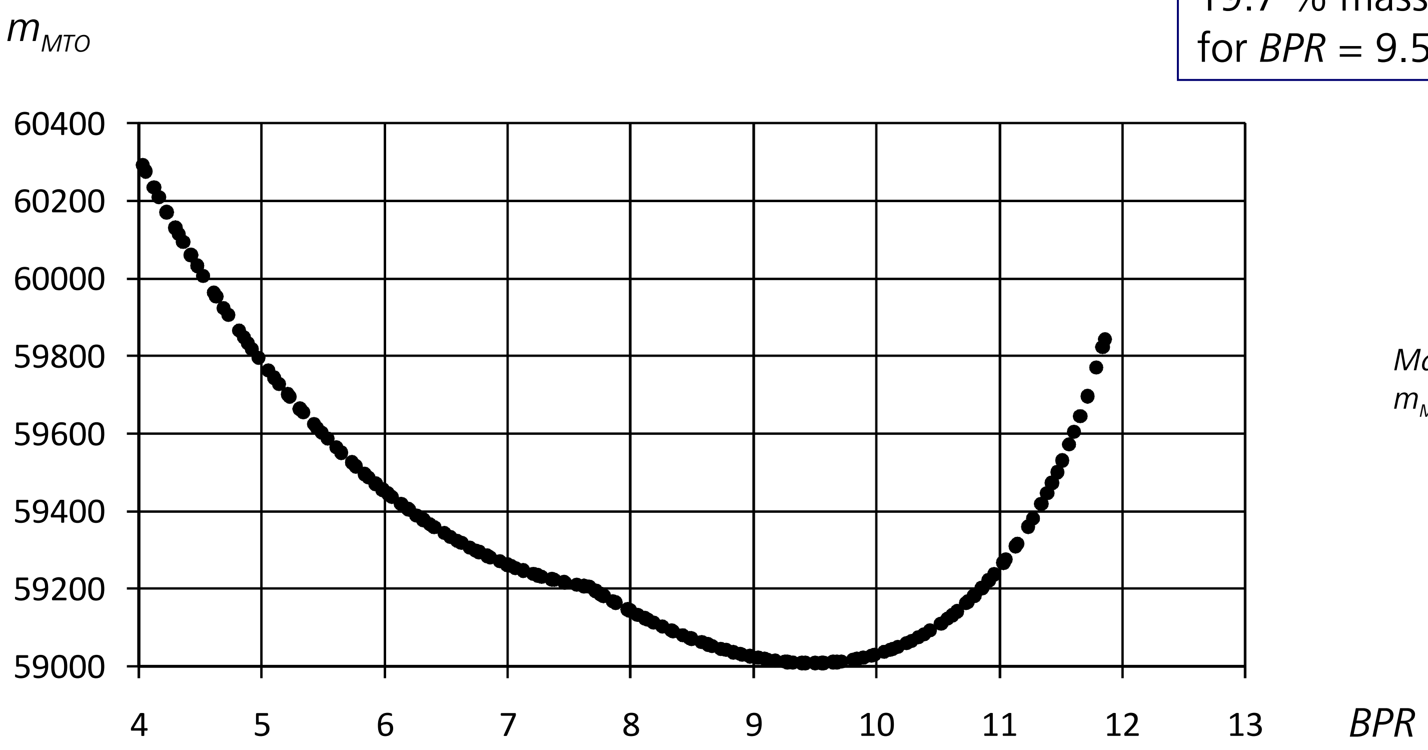
Influence of *BPR* , with C_{LmaxTO} = *2.07* , model Herrmann



Cruise speed, V_{CR} *as a function of BPR*

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

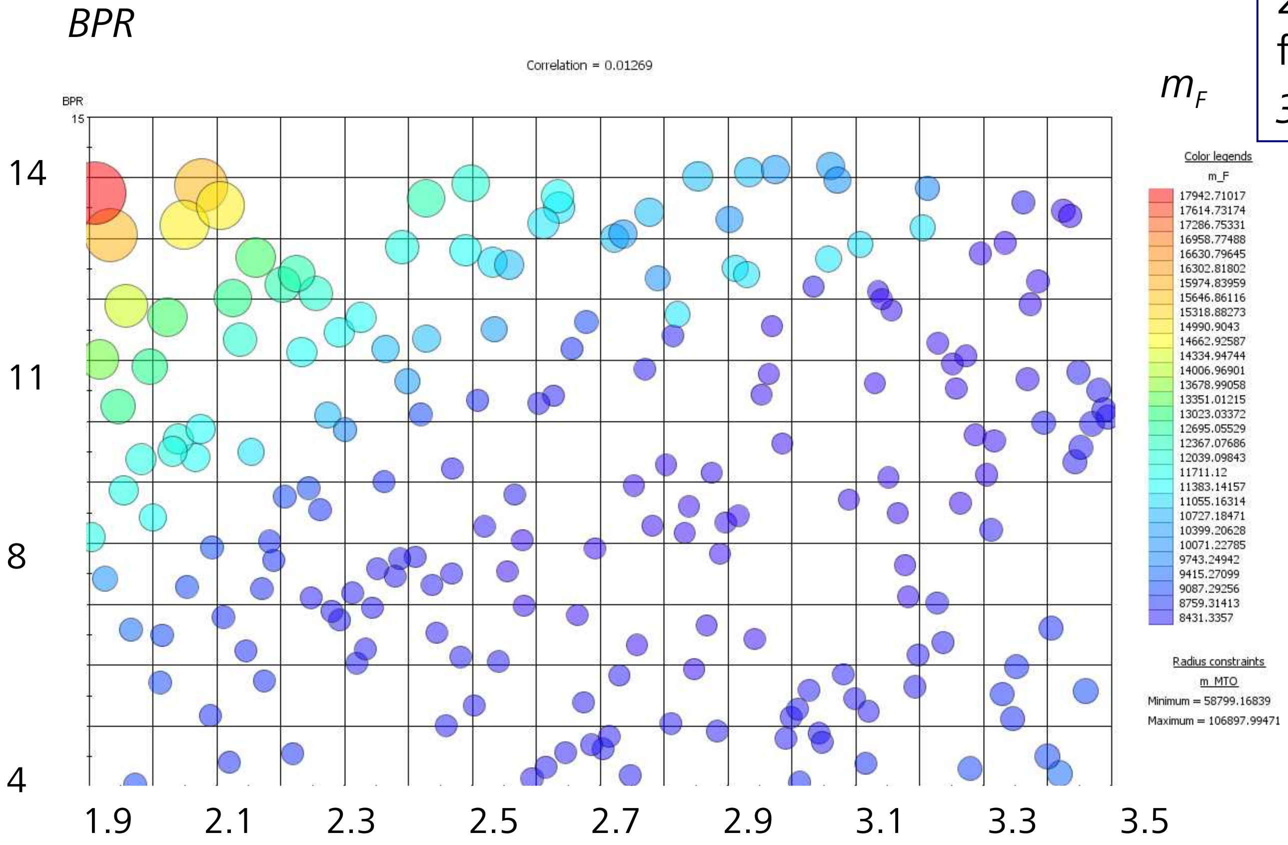
19.7 % mass improvement
for *BPR* = 9.5



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

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

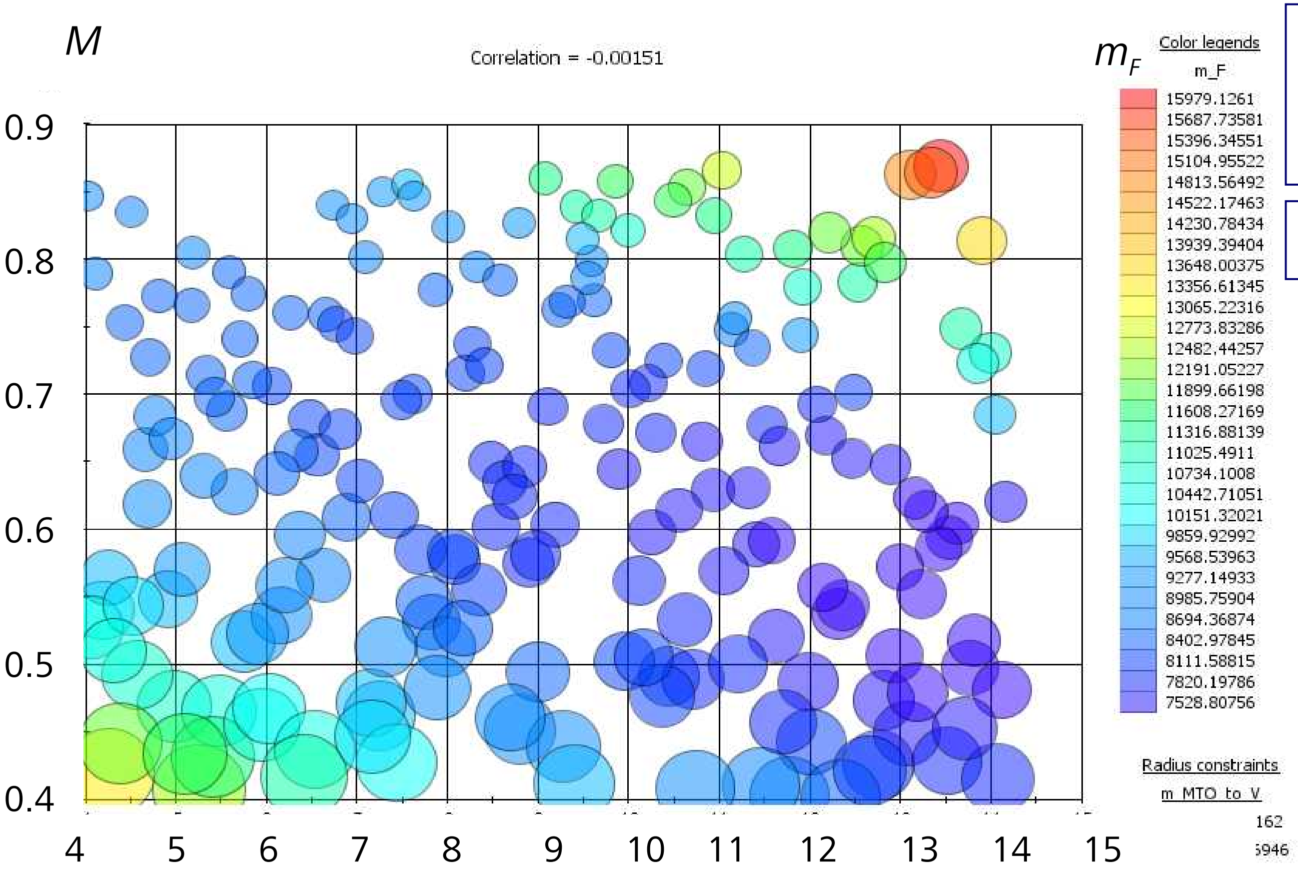
20.0 % mass improvement for *BPR* = 10.6 and C_{LmaxL} = 3.13



C_{LmaxL}

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

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*

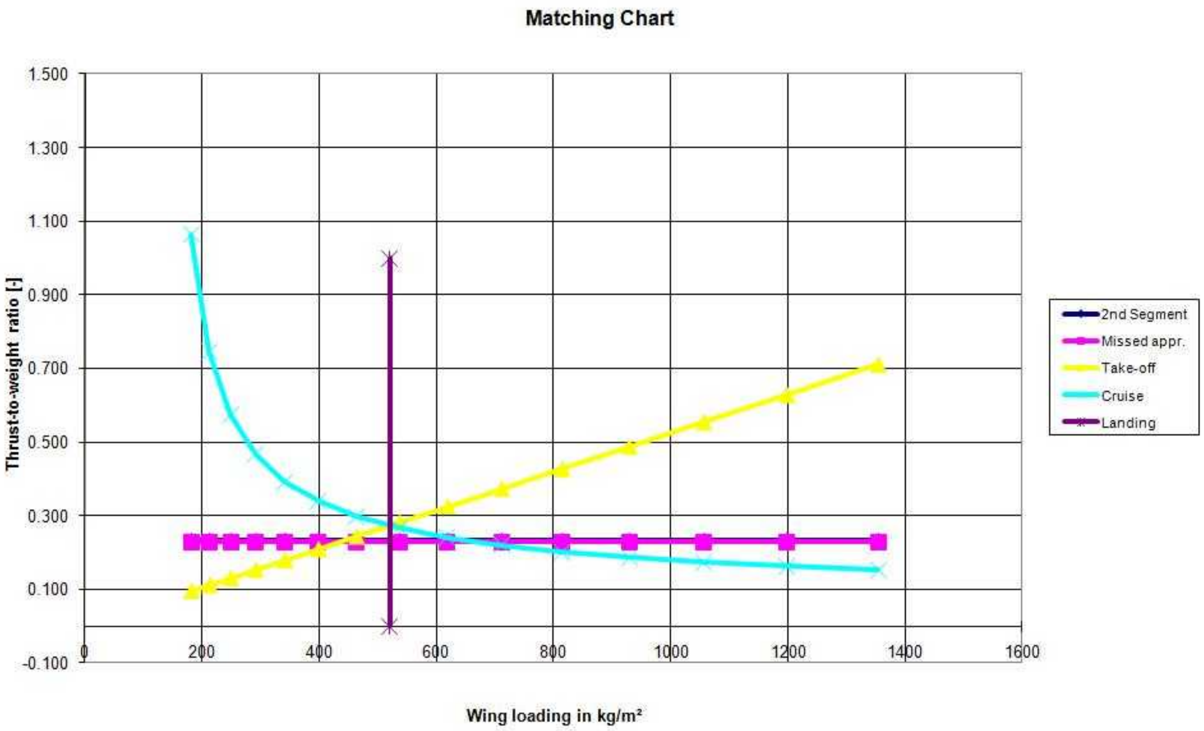
Objective: min m_{MTO} / V

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

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



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.

PARAMETER OPTIMIZATION FOR AN INTERACTIVE AIRCRAFT DESIGN

Thank you!

Contact

Mihaela.Nita@HAW-Hamburg.de
http://PreSTo.ProfScholz.de
http://OPerA.ProfScholz.de

Aero

PreSTo

Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences