Hamburg Metropolitan Region

HAMBURG AVIATION

Airport2030 – AP4.1

Configuration for Scenario 2015 (Possible A320 Successor)

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Final Presentation, Airbus Hamburg

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Content

- Ground Handling
- Proposals for a new A320
  - Standard Jet Configuration
  - Box Wing Aircraft
  - Smart Turboprop
- Summary
- Outlook

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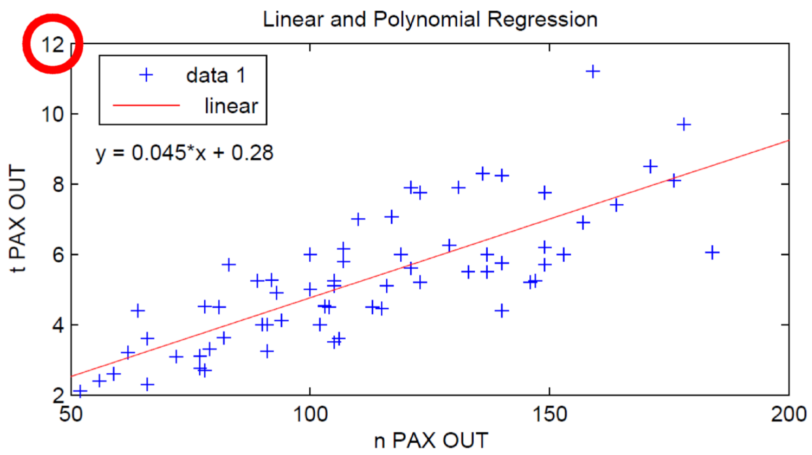
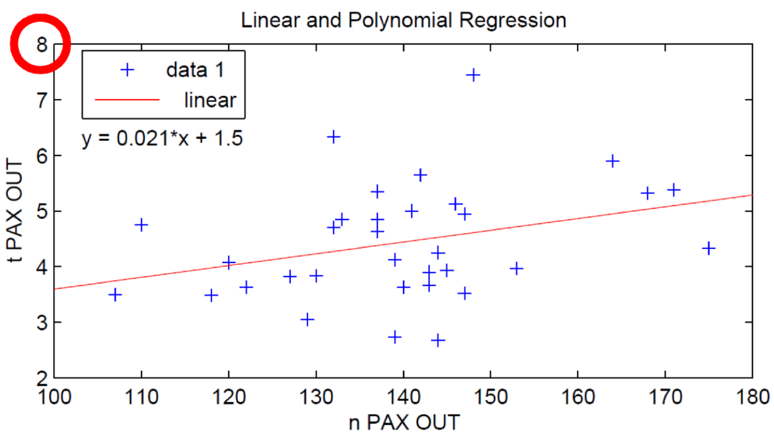
Ground Handling

- **Analysis of 168 turnarounds at 4 German airports**
- **Statistical Evaluation:**
  Often low regression, dependence on many unknown parameters
- **Example: Disembarking**

One Door Disembarking



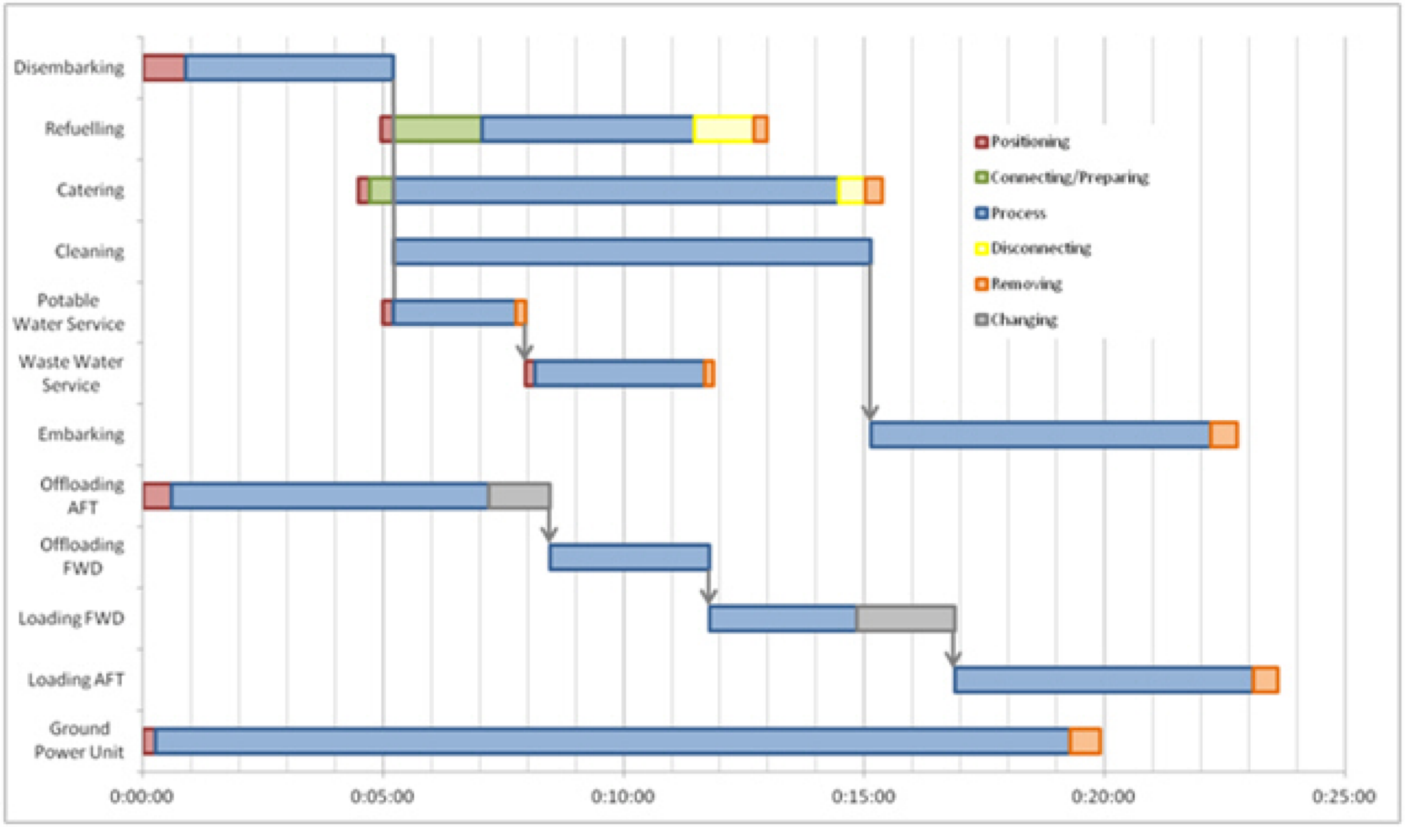
Two Door Disembarking



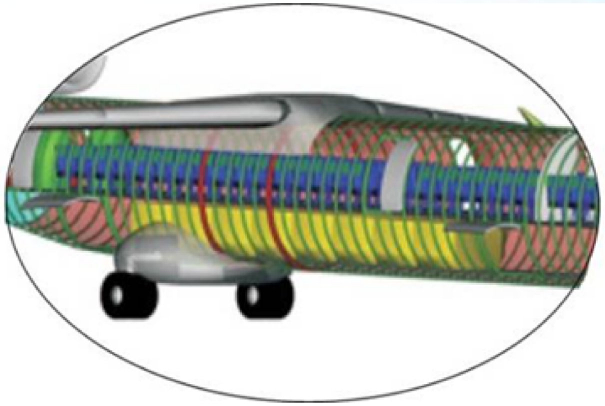
Ground Handling

- **Compilation of Gantt charts**

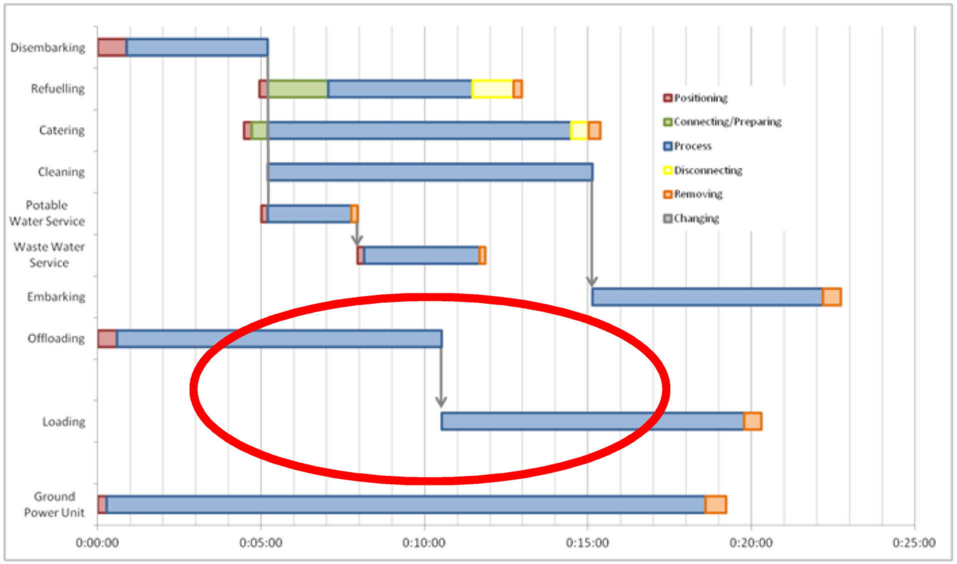
- **Evaluation of possible ground handling improvements**



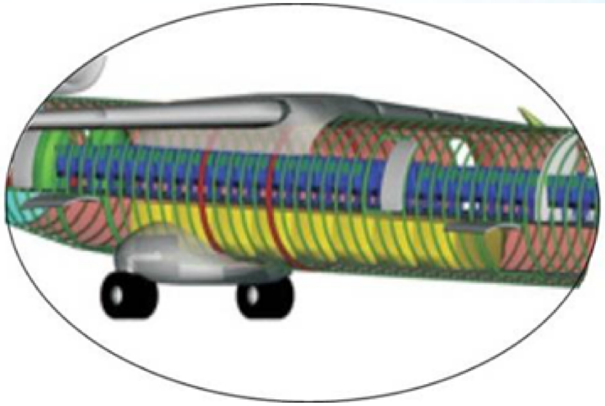
Ground Handling



- **Example: Continuous Cargo Compartment**
  - Time saving: No repositioning of loader
  - Cargo handling is not on critical path for gate positions
  - Slight time advantage only in few cases (e.g. two door oper. on apron)
  - Same costs



Ground Handling



- Example: Continuous Cargo Compartment
  - Time saving: No repositioning of loader
  - Cargo handling is not on critical path for gate positions
  - Slight time advantage only in few cases (e.g. two door oper. on apron)
  - Same costs
- Most evaluated technologies with advantages on the ground impair the DOC of the aircraft
  - Twin-aisle
  - Increase of aisle width
  - Foldable seat (if seat is heavier)
- Ground handling processes need to be robust to avoid delays!

Aircraft need to be optimized for cruise!

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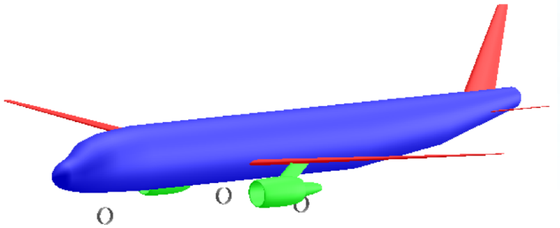
Proposals for a new A320 - Overview

- Standard Jet Configuration

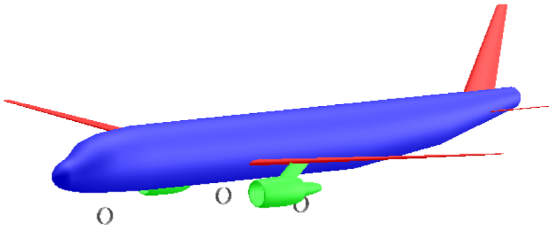


- Non-Standard Jet Configuration

- Standard Prop Configuration

Proposals for a new A320

- Standard Jet Configuration



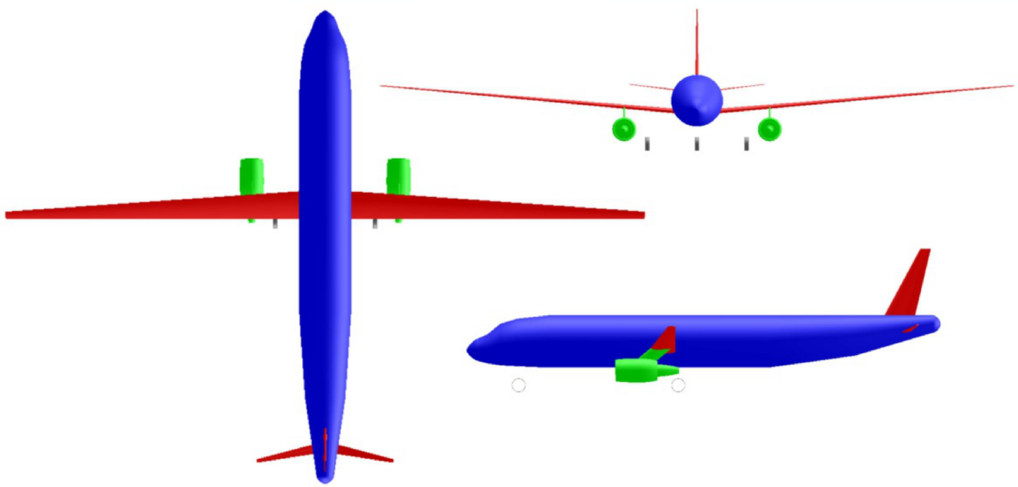
- **Requirements at Airports are Driving Todays Aircraft Design!**
  → Questioning established requirements
  (span limitation, take-off and landing distance, cruise Mach number, …)

Code element 1		Code element 2		
Code number (1)	Aeroplane reference field length (2)	Code letter (3)	Wingspan (4)	Outer main gear wheel span[a] (5)
1	Less than 800 m	A	Up to but not including 15 m	Up to but not including 4.5 m
2	800 m up to but not including 1 200 m	B	15 m up to but not including 24 m	4.5 m up to but not including 6 m
3	1 200 m up to but not including 1 800 m	C	24 m up to but not including 36 m	6 m up to but not including 9 m
4	1 800 m and over	D	36 m up to but not including 52 m	9 m up to but not including 14 m

ICAO: Aerodromes, Volume I – Aerodrome Design and Operations, Annex 14 to the Convention on International Civil Aviation, 5th edition, 2009

- **Considering alternative objective function**
  - DOC (standard), DOC + Added Values
  - Minimum fuel

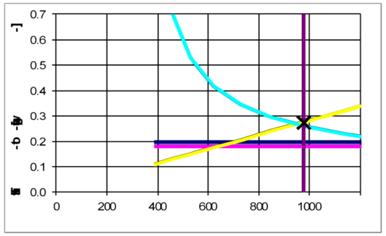
Standard Jet Configuration: A320 "optimized"

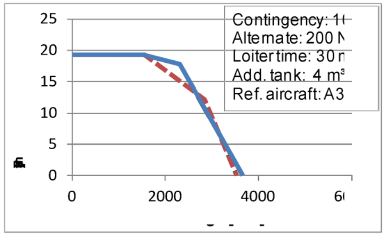


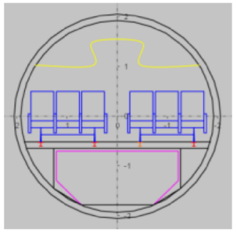
Parameter	Value	Deviation from A320*
Main aircraft parameters		
m_{MTO}	66000 kg	- 10 %
m_{OE}	39200 kg	- 5 %
m_F	7500 kg	- 42 %
S_W	68 m²	- 45 %
$b_{W,geo}$	48.5 m	+ 42 %
$A_{W,eff}$	34.8	+ 266 %
E_{max}	26.1	+ 48 %
T_{TO}	89100 N	- 20 %
BPR	15.5	+ 158 %
SFC	1.03E-5 kg/N/s	- 37 %
h_{ICA}	30000 ft	- 23 %
s_{TOFL}	2490 m	+ 41 %
s_{LFL}	2110 m	+ 45 %
t_{TA}	32 min	0 %

Parameter	Value	Deviation from A320*
Requirements		
m_{MPL}	19256 kg	0 %
R_{MPL}	1510 NM	0 %
M_{CR}	0.55	- 28 %
max(s_{TOFL} , s_{LFL})	2700 m	+ 53 %
n_{PAX} (1-cl HD)	180	0 %
m_{PAX}	93 kg	0 %
SP	28 in	- 3 %

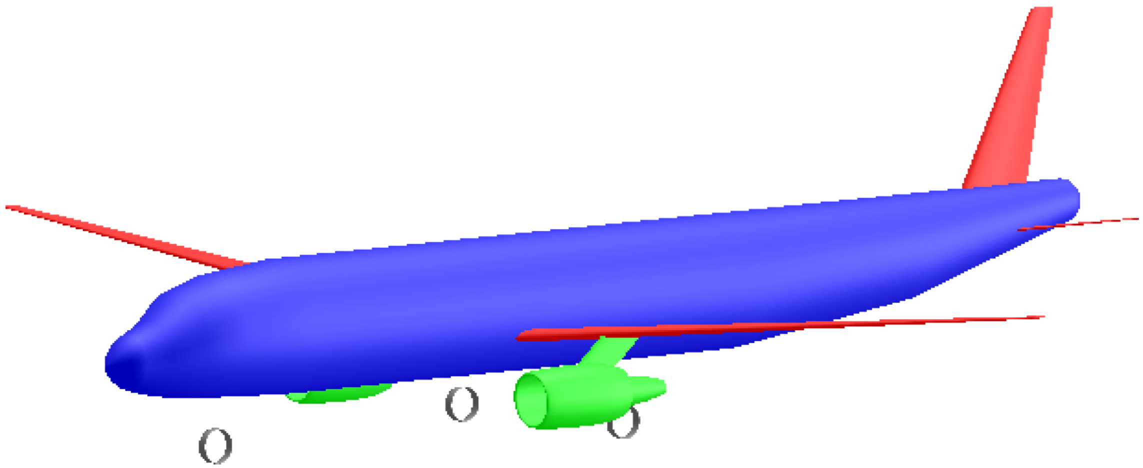
- early conceptual design



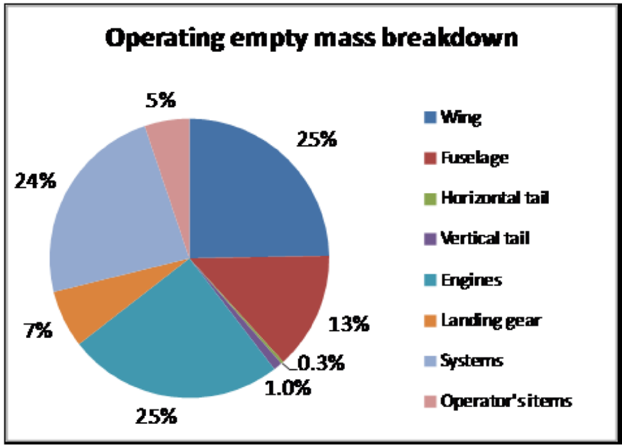


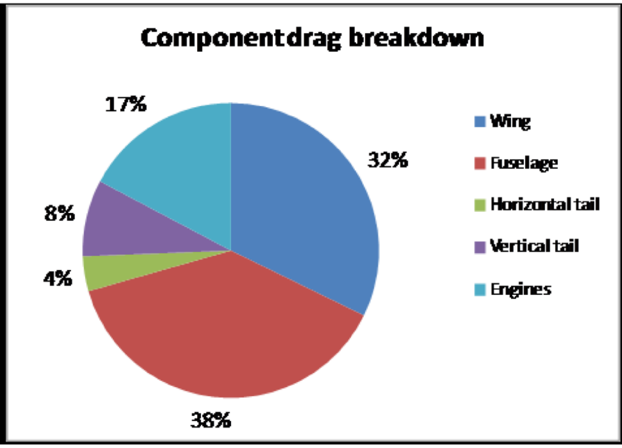


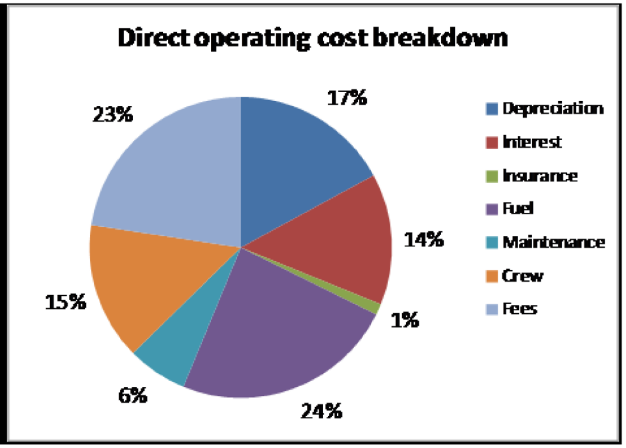
Standard Jet Configuration: A320 “optimized”



Parameter	Value	Deviation from A320*
DOC mission requirements		
R_{DOC}	750 NM	0 %
$m_{PL,DOC}$	19256 kg	0 %
EIS	2030	-----
c_{fuel}	1.44 USD/kg	0 %
Results		
$m_{F,trip}$	3700	- 36 %
$U_{a,f}$	3070	+ 6 %
DOC (AEA)	93 %	- 7 %







Proposal: Horizontal Wing Tip Extension on A320 as Option

Results from an additional study in Airport2030: "Airport Compatibility of Medium Range Aircraft with Large Wing Span"

- **Wingtip devices: Very limited efficiency compared to the same length of material used to horizontally extend the wing (based on Nita 2012)**
- **From aerodynamics: Wings should be extended horizontally (not vertically)**
- **Consider: Extend the wing span and deal with consequences at airports**
- **Airbus should also offer a horizontal wing tip extension as option**

Proposal: Horizontal Wing Tip Extension on A320 as Option

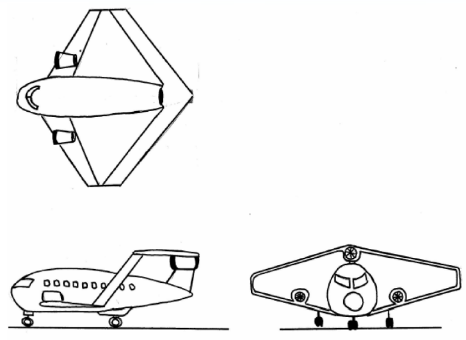
- Optional horizontal wing tip extension limits risk and costs compared to a new wing
- A slow introduction of aircraft with larger wing span (Class C => Class D) will force airports to accept this
- Landing fees are based on MTOW and are hence unchanged
- Study showed: Many airports still have some capacity for a limited number of former Class C aircraft now with larger span
- Airports will start to rearrange gate layout with additional markings

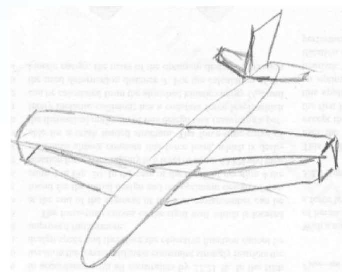
Proposals for a new A320

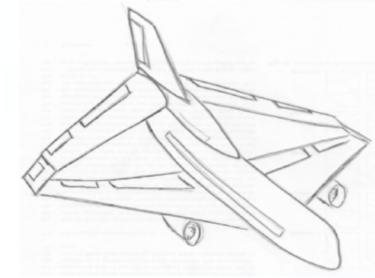
- Non-Standard Jet Configuration
  - Reduction of Induced Drag
  - Box Wing Aircraft (BWA)
    - Diamond BWA
    - Double Decker BWA

Box Wing Aircraft

- Hand Sketches







- Creative Methods
    - Brainstorming
    - Gallery Method

VERHEIRE, E.: Systematic Evaluation of Alternative Box Wing Aircraft Configurations. Bachelor Thesis, HAW Hamburg, 2013

- Modified Morphological Analysis

Morphological Analysis Matrix created after down selection

Stagger	Sweep	Box Wing Vertical Position	Horizontal Stabilizer Position	Vertical Stabilizer Position	Engine Position
=	<<	L – H	Can	Aft	Fuse – aft
–_	>>	L – SH	No		Fuse – mid
_–	< >		Aft		Wing

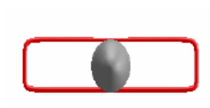
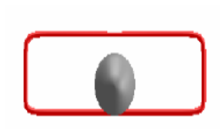
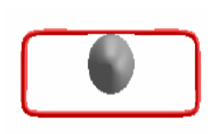
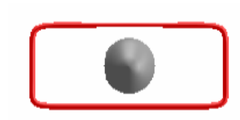
Number of Combinations: 3 · 3 · 2 · 3 · 1 · 3 = 162

BARUA, P; SCHOLZ, D.: Systematic Approach to Analyze, Evaluate and Select Box Wing Aircraft Configurations from Modified Morphological Matrices. TN, HAW Hamburg, 2013

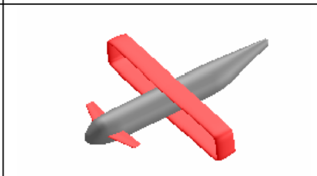
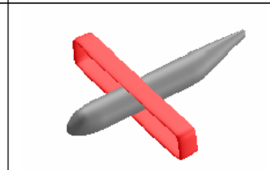
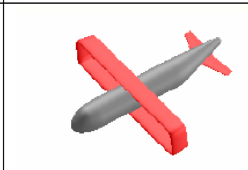
Modified Morphological Analysis:
Successive combination (in „best" order) followed by immediate down selection => 18

Box Wing Aircraft

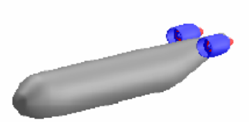
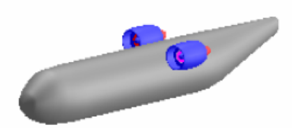
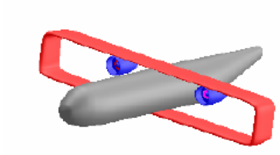
Box wing with different wing vertical position

	Low – High Position	Low – Super High Position	Super Low – High Position	Super Low – Super High Position
OpenVSP front view figure				

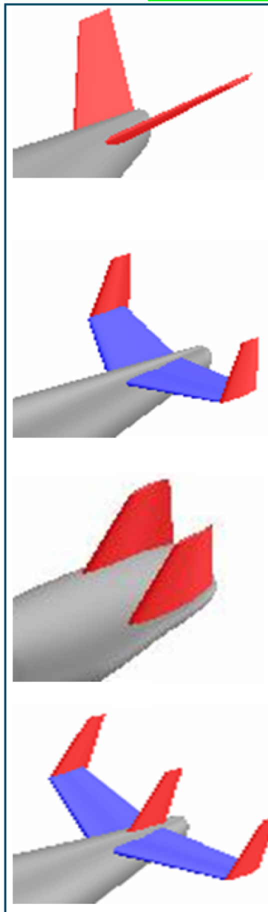
Horizontal tail surface position along the fuselage length

	Canard	No Horizontal tail	Horizontal surface
OpenVSP 3-D figure			

Engine positions for box wing aircraft

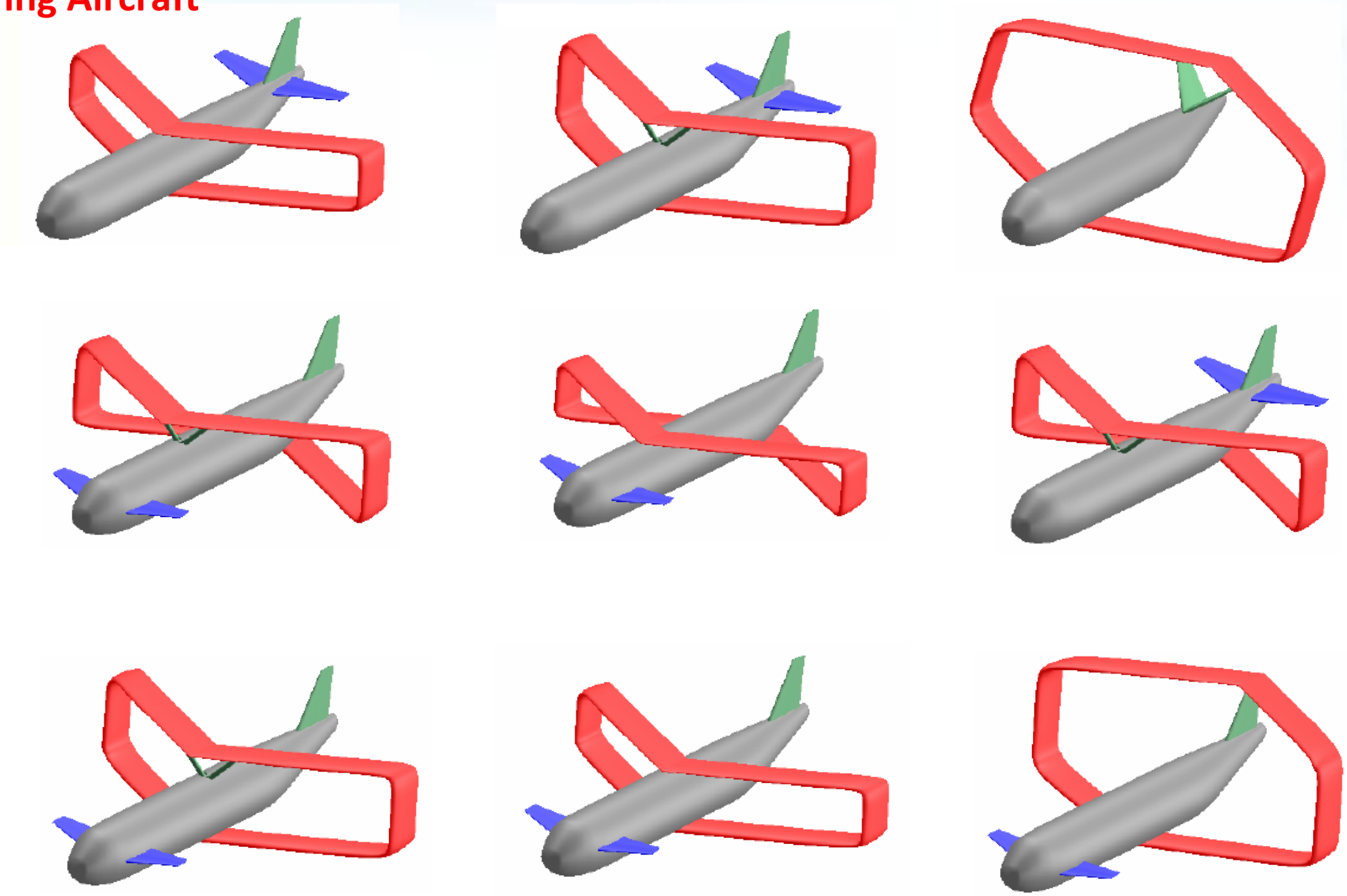
	Fuselage Aft	Fuselage Middle	On the wing
OpenVSP 3-D figure			

Example of possible vertical tails

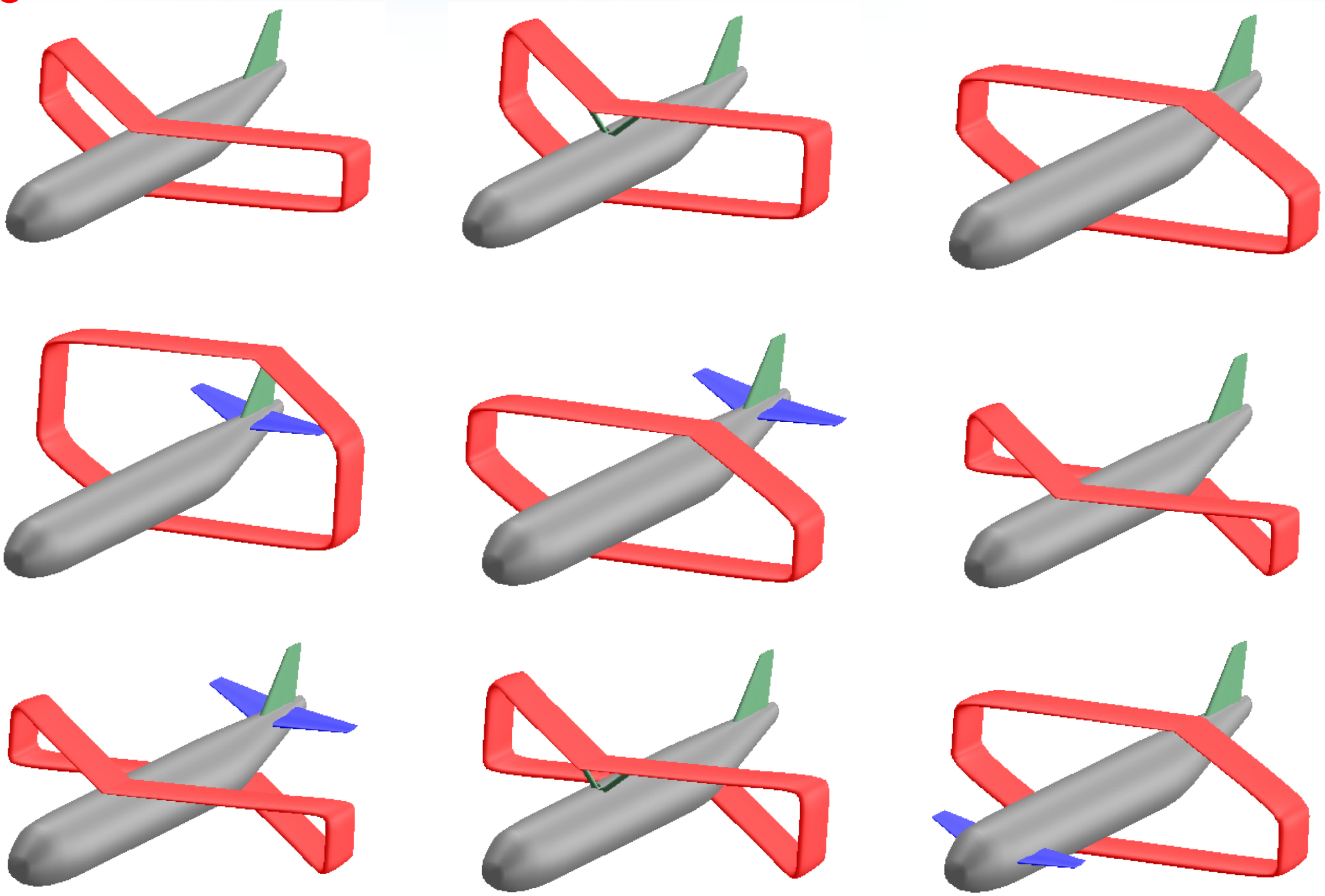


All possible variations together would lead to 31 104 000 combinations (from Bachelor thesis)

Box Wing Aircraft



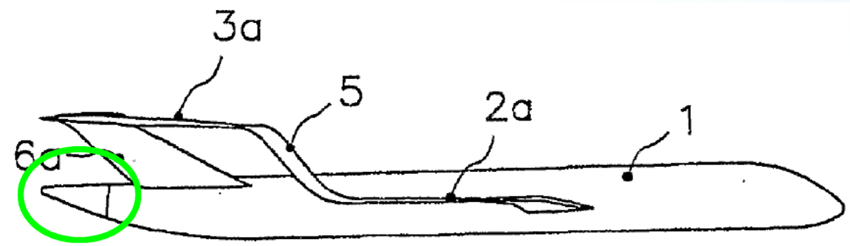
Box Wing Aircraft

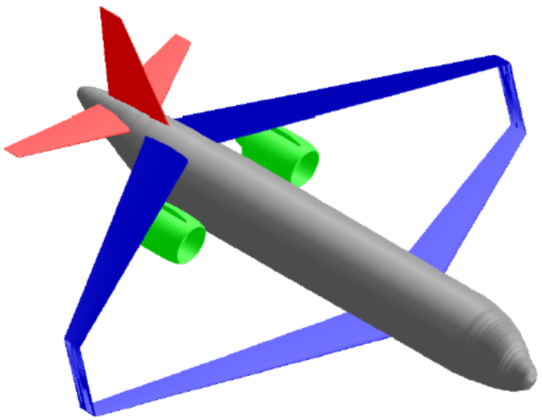


Box Wing Aircraft: General Morphological Analysis

German: „Nutzwertanalyse" (ZANGEMEISTER): Weighted Sum of Evaluation Points

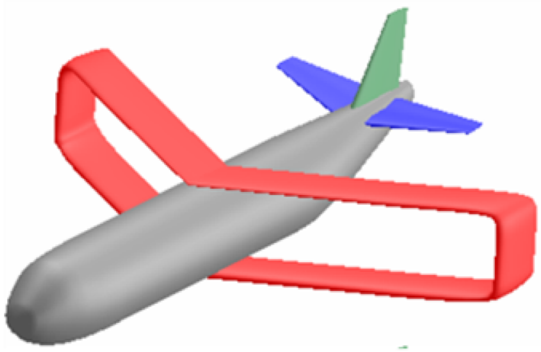
- Configuration
  - Force Fighting
  - Family Concept
- Drag
  - Zero Lift Drag
  - Induced Drag
- Weight
  - Empty Weight
- Flight Mechanics
  - Longitudinal Static Stability and CG Range
- Operation
  - Ground Handling
- Development
  - Time and Cost
  - Risk



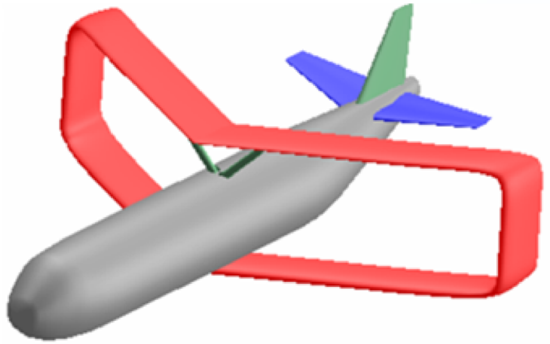


Box Wing Aircraft: General Morphological Analysis: Results

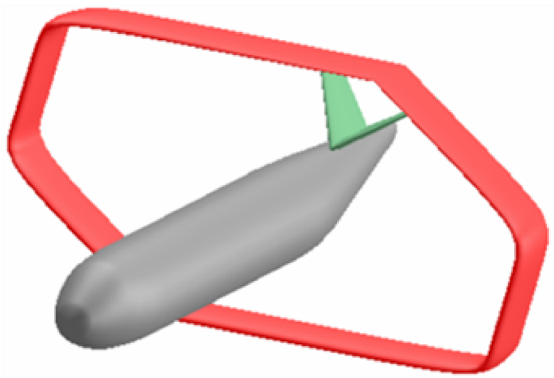
1.



2.

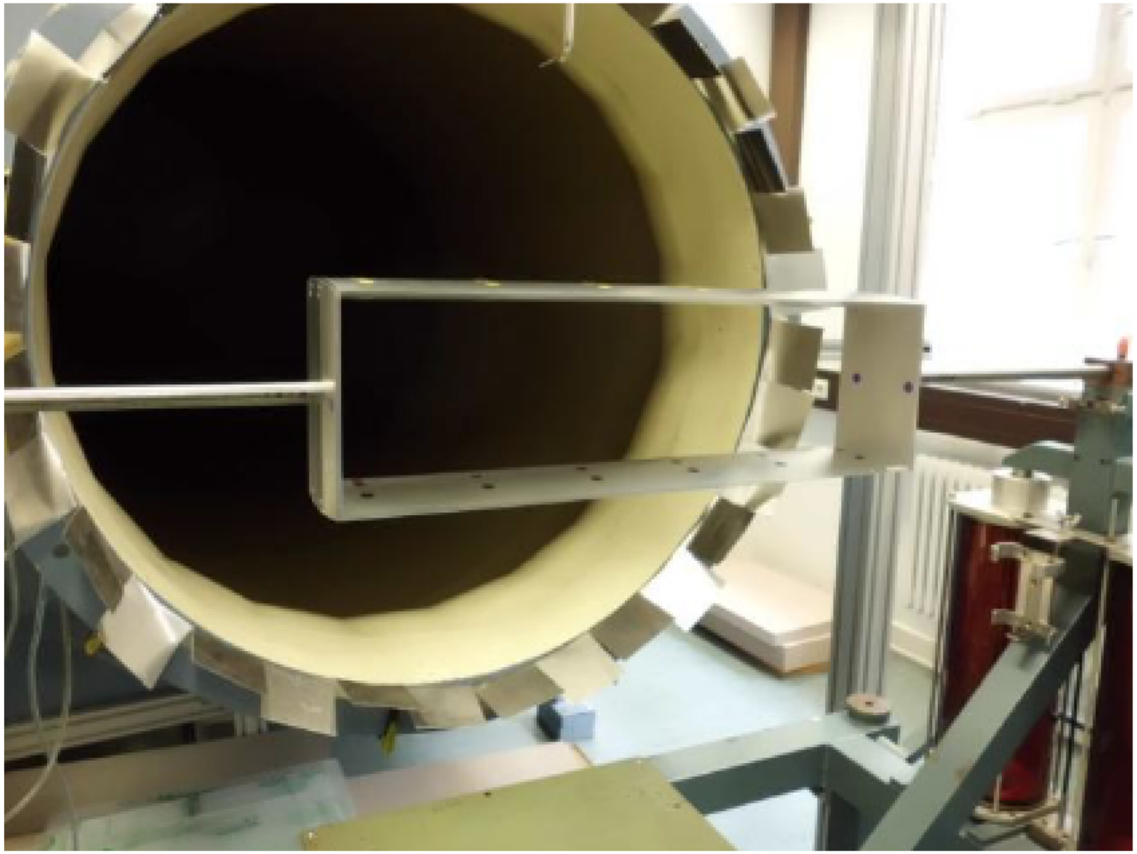


3.



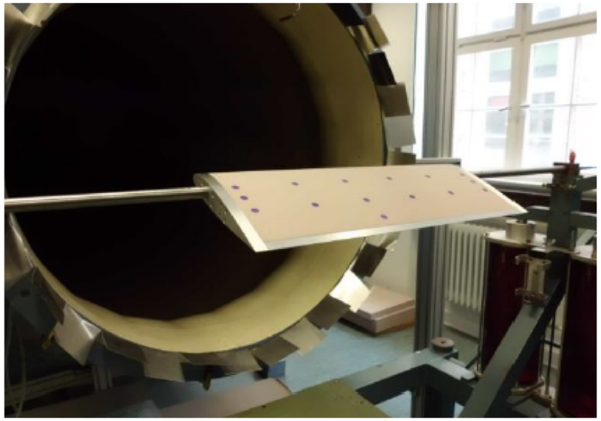
Best unconventional configuration

Box Wing Aircraft: Aerodynamics



Measurements of induced drag of different box wings in the wind tunnel of HAW Hamburg

The reference wing



DORENDORF, G.: Vergleich einer Boxwing-Konfiguration mit einem einfachen Tragflügel. Project, HAW Hamburg, 2012

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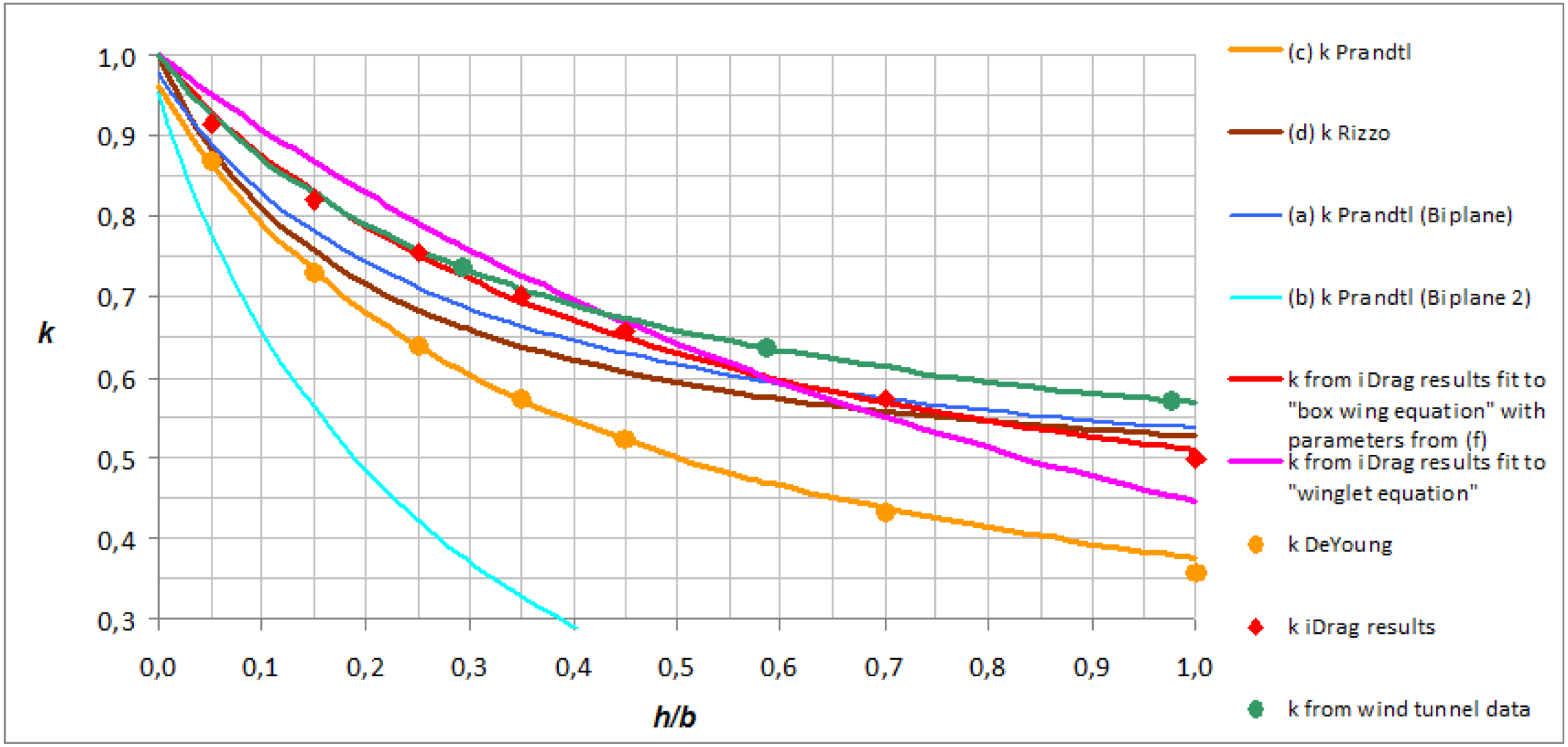
Box Wing Aircraft: Aerodynamics

$$\frac{D_{i,box}}{D_{i,ref}} = \frac{e_{ref}}{e_{box}} = k$$



NITA, M.; SCHOLZ, D.: Estimating the Oswald Factor from Basic Aircraft Geometrical Parameters. Berlin, DLRK 2012

Box Wing Aircraft: Glide Ratio

For E_{max}: $C_{D0} = C_{Di}$??? for Box Wing Aircraft ???

Considering a ratio h/b = 1, it yields to $C_{Di,BW}/C_{Di,ref} \approx 0.5$:

- Box Wing flies at reference Aircraft Altitude

$$\frac{E_{max,BW}}{E_{max,ref}} = \frac{4}{3} = 1.33$$

- Reference Aircraft flies at Box Wing Altitude

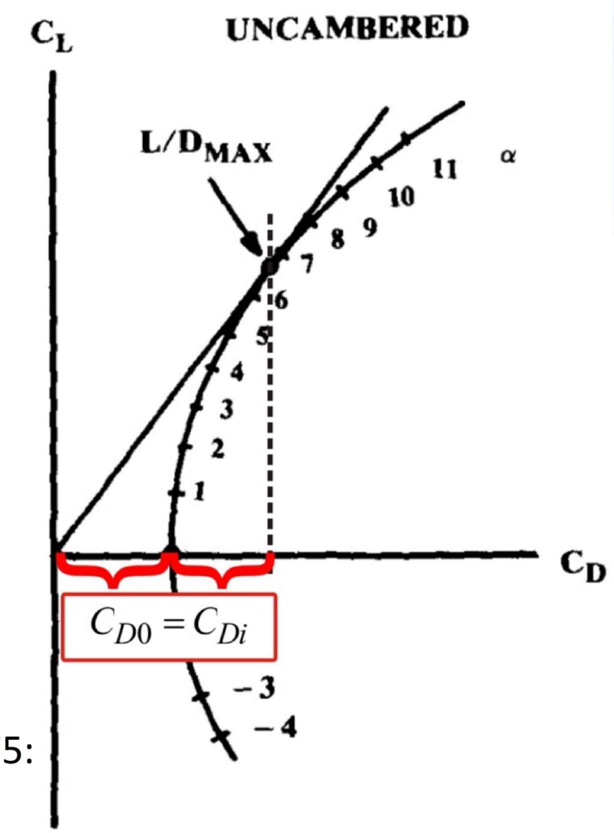
$$\frac{E_{max,BW}}{E_{max,ref}} = \frac{3}{2} = 1.5$$

- „Fair" comparison:

$$\frac{E_{max,BW}}{E_{max,ref}} = \sqrt{2} = 1.41$$

Considering a realistic ratio h/b = 0.25, it yields to $C_{Di,BW}/C_{Di,ref} \approx 0.75$:

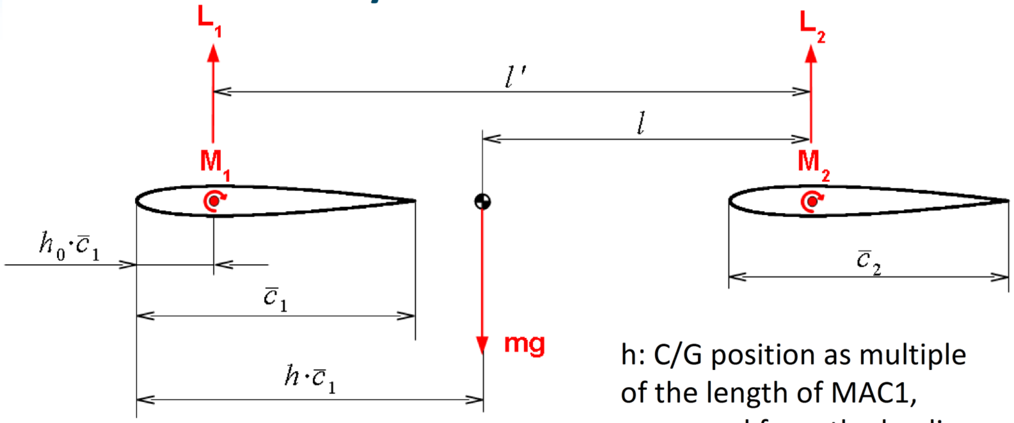
$$\frac{E_{max,BW}}{E_{max,ref}} = 1.15$$



Glide ratio of a Box Wing Aircraft is 15 % higher than that of the reference aircraft

SCHIKTANZ, D.; SCHOLZ, D.:
Maximum Glide Ratio of Box Wing Aircraft –
Fundamental Considerations. Memo, 2012

Box Wing Aircraft: Longitudinal Static Stability



h: C/G position as multiple of the length of MAC1, measured from the leading edge of MAC1

Stability Limit

$$h < h_0 + \frac{dC_{L,2}}{dC_L} \cdot \overline{V}' \frac{\bar{c}}{\bar{c}_1}$$

→ needs to be as high as possible

SCHIKTANZ, D.; SCHOLZ, D.: The Conflict of Aerodynamic Efficiency and Static Longitudinal Stability of Box Wing Aircraft. Venice, CEAS 2011

Control Limit → $C_{L,2}$ needs to be low. Thus for a given C_L $C_{L,1}$ needs to be increased

Trim Condition → $C_{L,2}$ needs to be lower than $C_{L,1}$ => $C_{L,1} / C_{L,2} > 1$

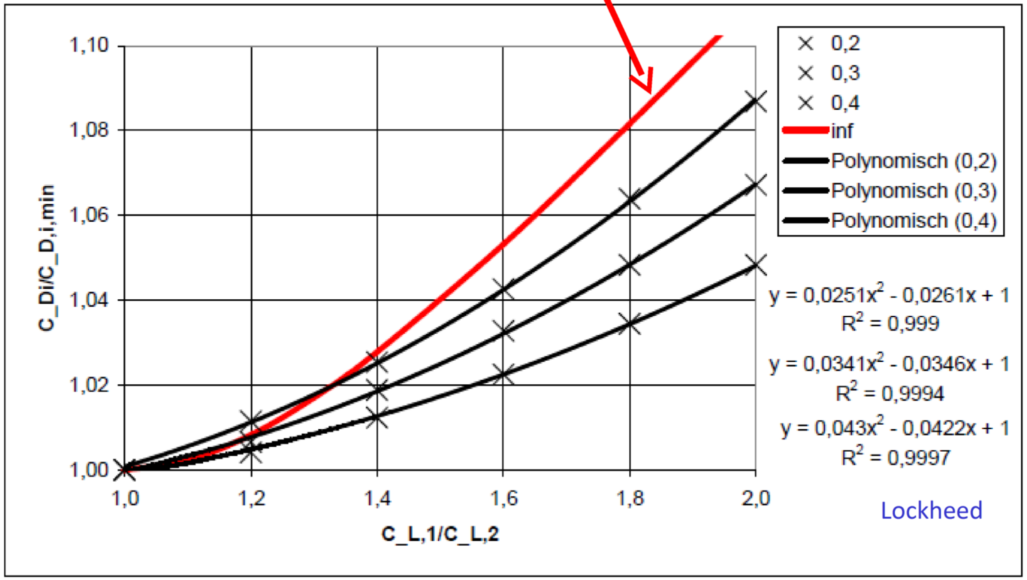
Forward wing needs higher lift coefficient than aft wing

Munk: drag independant of stagger

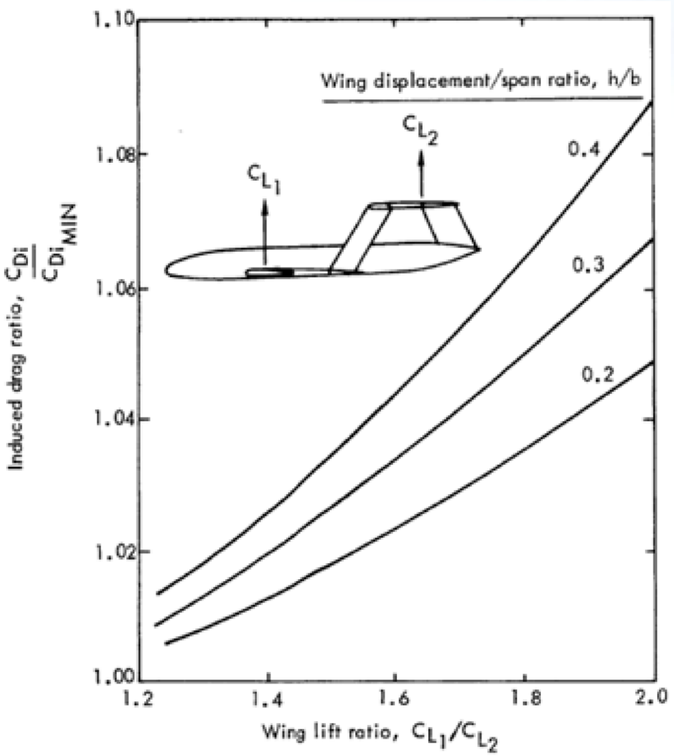
Box Wing Aircraft: Aerodynamics

Prandtl (for h/b = infinity):

$$\frac{C_{D,i}}{C_{D,i,min}} = \frac{2\,(x^2+1)}{(x+1)^2} \quad with \quad x = \frac{C_{L,1}}{C_{L,2}}$$



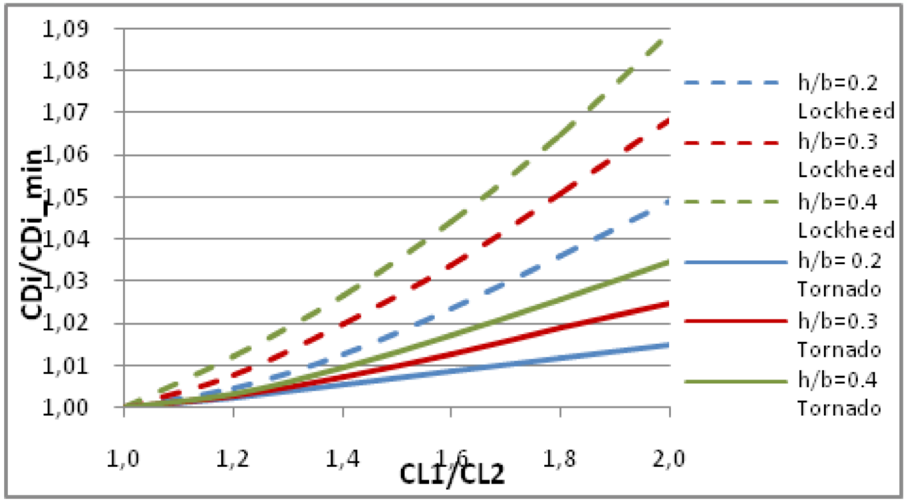
LOCKHEED: Transonic Biplane Concepts. NACA CR 132462, 1974



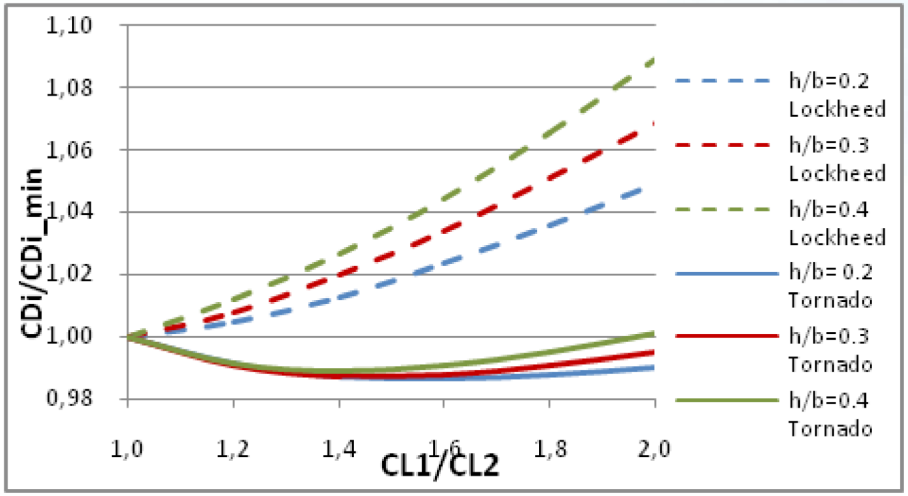
Induced drag increases if lift coefficients are different

CAJA CALLEJA, R.; SCHOLZ, D.: Design Aspects of Passenger Box Wing Aircraft. Berlin, DLRK 2012

Box Wing Aircraft: Aerodynamics

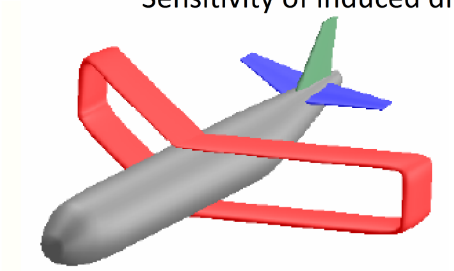


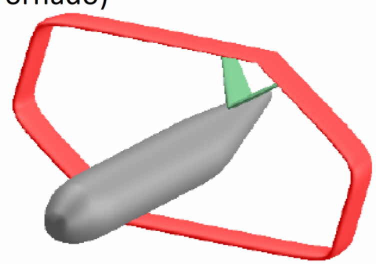
Stagger = 0



Stagger = -0.5b

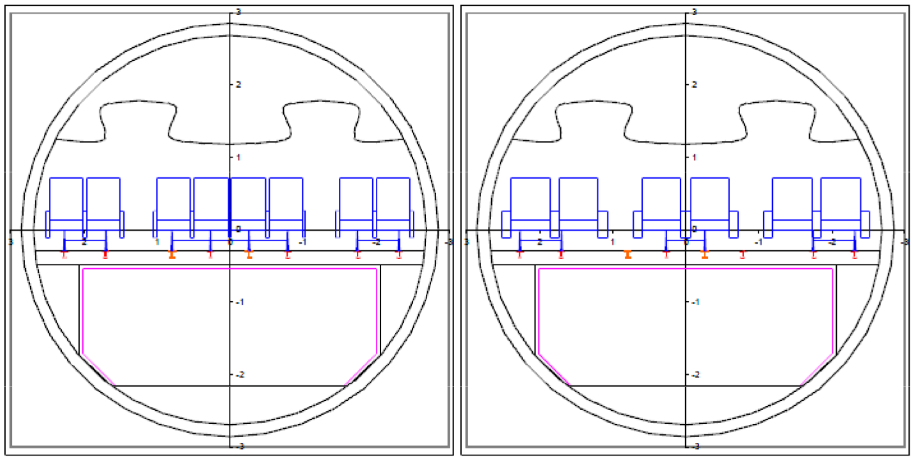
Sensitivity of induced drag to non-optimum lift distributions (Tornado)





If forward wing is in front of aft wing: No induced drag increase!

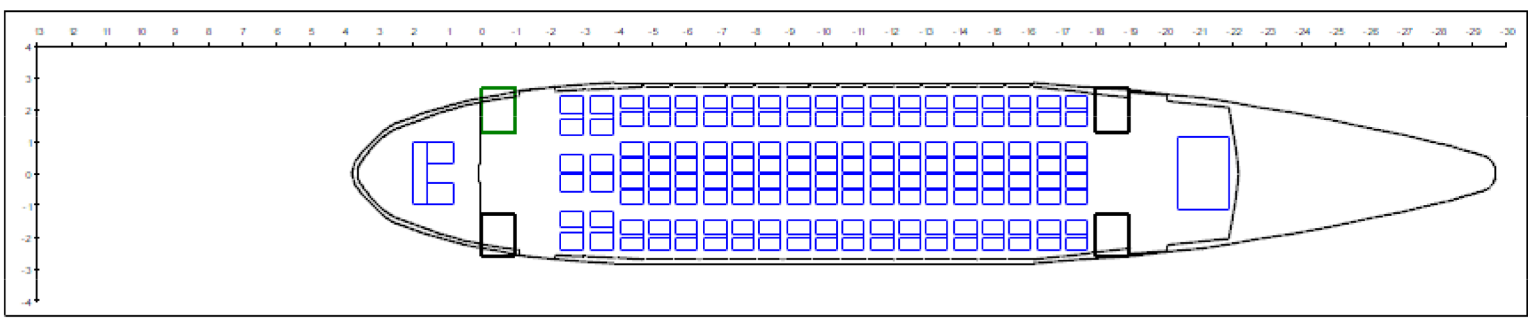
Box Wing Aircraft: Cabin and Fuselage Layout (Configuration A)



Fuselage cross section for economy class and business class (modelled with PreSTo Cabin)

SCHIKTANZ, D.; SCHOLZ, D.: Box Wing Fundamentals – An Aircraft Design Perspective. Bremen, DLRK 2011

SCHIKTANZ, D.: Conceptual Design of a Medium Range Box Wing Aircraft. Master Thesis, 2011



Cabin floor plan of the box wing aircraft (modelled with PreSTo Cabin)

Box Wing Aircraft: Design evolution (Wide Body)

Ideally $\frac{E_{max,BW}}{E_{max,ref}} = 1.5$

Fair comparison $\frac{E_{max,BW}}{E_{max,ref}} = 1.41$

Limited h/b ratio $\frac{E_{max,BW}}{E_{max,ref}} = 1.15$

$\frac{m_{W,BW}}{m_{W,ref}} = 2.2$ Thin wings

$\frac{m_{OE,ref}}{m_{OE,handbook}} = 1.16$ Calibration

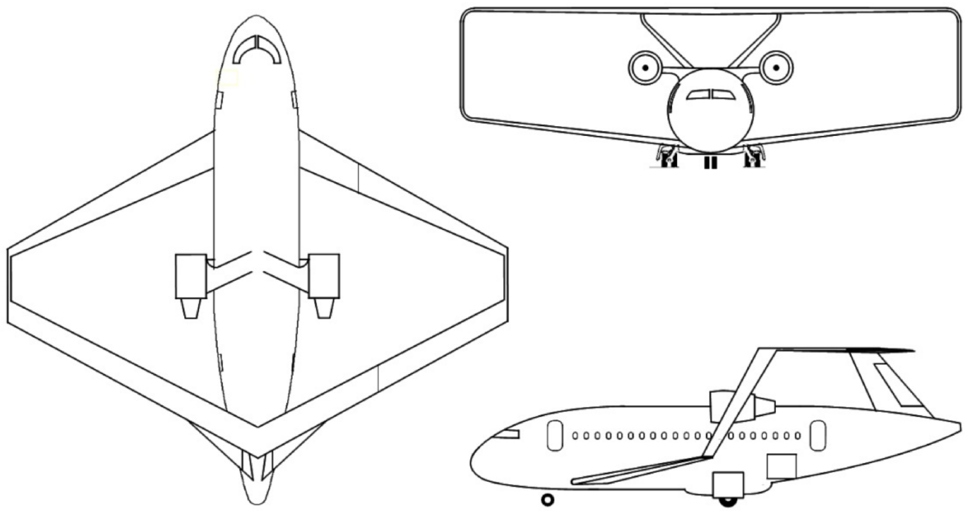
$\frac{m_{OE,BW}}{m_{OE,ref}} = 1.4$ Snowballeffects

Disadvantages outweigh advantages $\frac{m_{F,BW}}{m_{F,ref}} = 1.1$

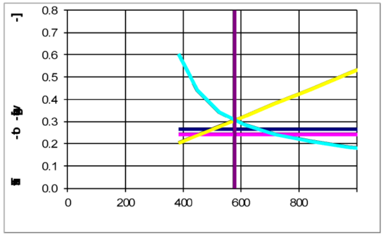
$\frac{DOC_{BW}}{DOC_{ref}} = 1.19$

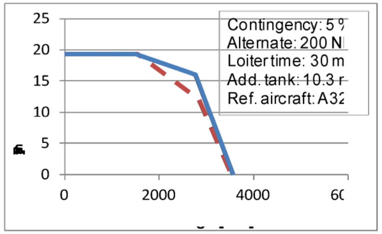
SCHIKTANZ, D.; SCHOLZ, D.:
Maximum Glide Ratio of Box Wing Aircraft – Fundamental Considerations. Memo, 2012

Box Wing Aircraft: Results (Wide Body)

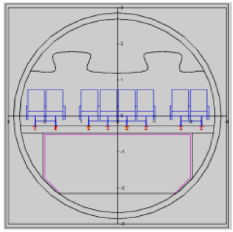


Parameter	Value	Deviation from A320*
Requirements		
m_{MPL}	19256 kg	0 %
R_{MPL}	1510 NM	0 %
M_{CR}	0.76	0 %
max(s_{TOFL} , s_{LFL})	1770 m	0 %
n_{PAX} (1-cl HD)	180	0 %
m_{PAX}	93 kg	0 %
SP	29 in	0 %



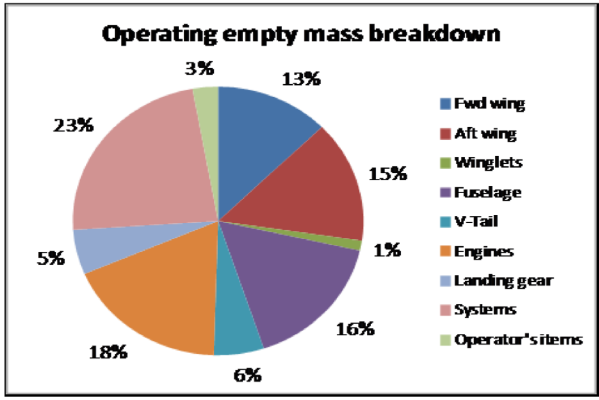


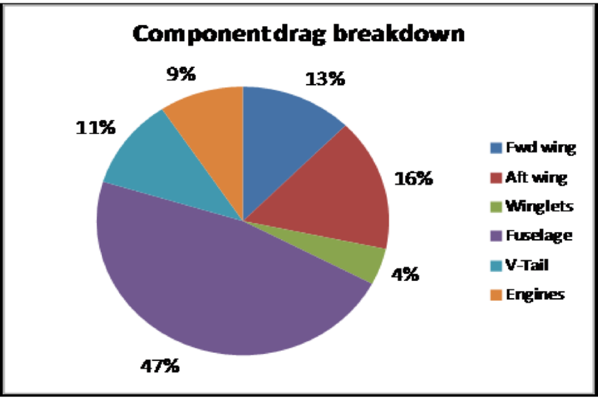
Parameter	Value	Deviation from A320*
Main aircraft parameters		
m_{MTO}	89600 kg	+ 22 %
m_{OE}	55800 kg	+ 35 %
m_F	14500 kg	+ 12 %
S_W	155 m²	+ 27 %
$b_{W,geo}$	35.9 m	+ 5 %
$A_{W,eff}$	18.9	+ 99 %
E_{max}	19.5	≈ + 11 %
T_{TO}	134 kN	+ 21 %
BPR	6	+ 0 %
SFC	1.62E-5 kg/N/s	- 2 %
h_{ICA}	40700 ft	+ 5 %
s_{TOFL}	1770 m	0 %
s_{LFL}	1450 m	0 %
t_{TA}	25 min	0 %

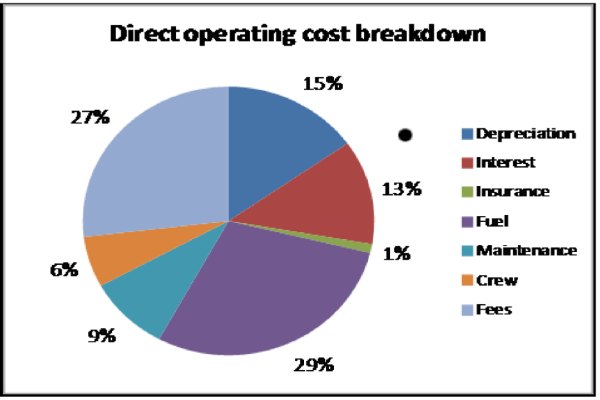


Box Wing Aircraft: Results (Wide Body)

Parameter	Value	Deviation from A320*
DOC mission requirements		
R_{DOC}	755 NM	0 %
$m_{PL,DOC}$	19256 kg	0 %
EIS	2030	-----
c_{fuel}	1.44 USD/kg	0 %
Results		
$m_{F,trip}$	6425 kg	+ 10 %
$U_{a,f}$	2617 h	- 10 %
DOC (AEA)	119 %	+ 19 %







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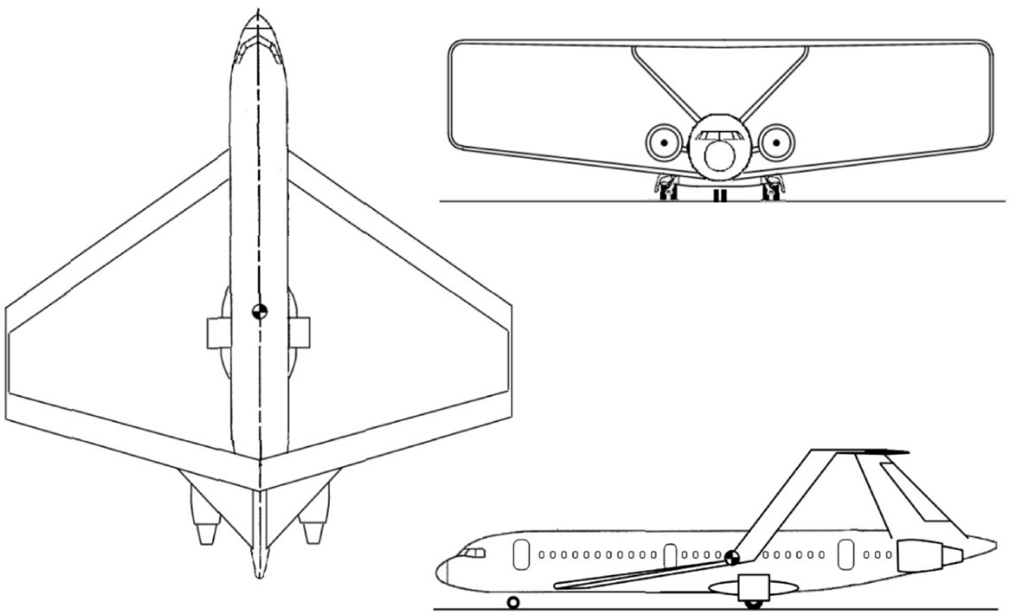
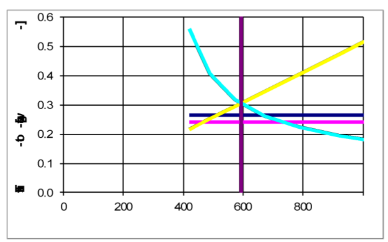
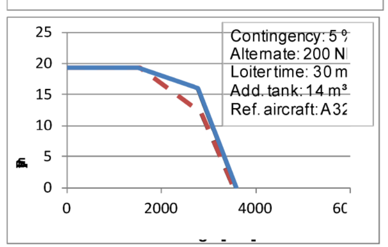
Box Wing Aircraft: Results (Slender Body)

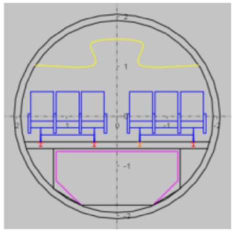


Parameter	Value	Deviation from A320*
Requirements		
m_{MPL}	19256 kg	0 %
R_{MPL}	1510 NM	0 %
M_{CR}	0.76	0 %
max(s_{TOFL} , s_{LFL})	1770 m	0 %
n_{PAX} (1-cl HD)	180	0 %
m_{PAX}	93 kg	0 %
SP	29 in	0 %

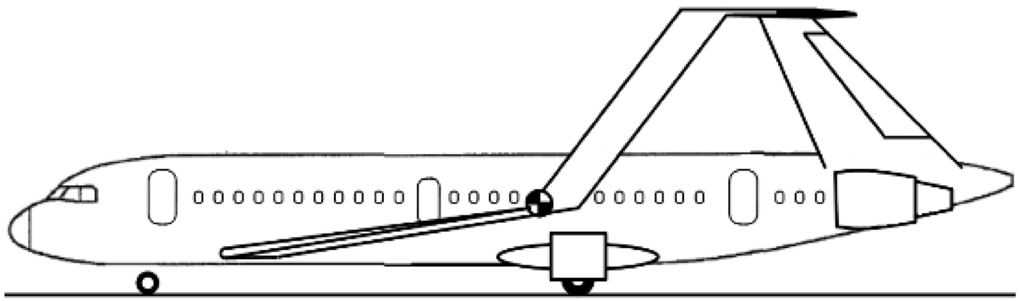




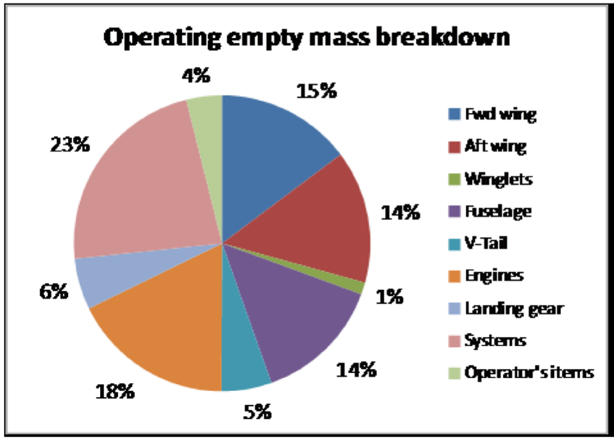
Parameter	Value	Deviation from A320*
Main aircraft parameters		
m_{MTO}	90900 kg	+ 24 %
m_{OE}	57700 kg	+ 40 %
m_F	14000 kg	+ 7 %
S_W	153 m²	+ 26 %
$b_{W,geo}$	36.0 m	+ 5 %
$A_{W,eff}$	17.0	+ 79 %
E_{max}	21.4	≈ + 21 %
T_{TO}	136 kN	+ 22 %
BPR	6	+ 0 %
SFC	1.62E-5 kg/N/s	- 2 %
h_{ICA}	41900 ft	+ 8 %
s_{TOFL}	1770 m	0 %
s_{LFL}	1450 m	0 %
t_{TA}	32 min	0 %

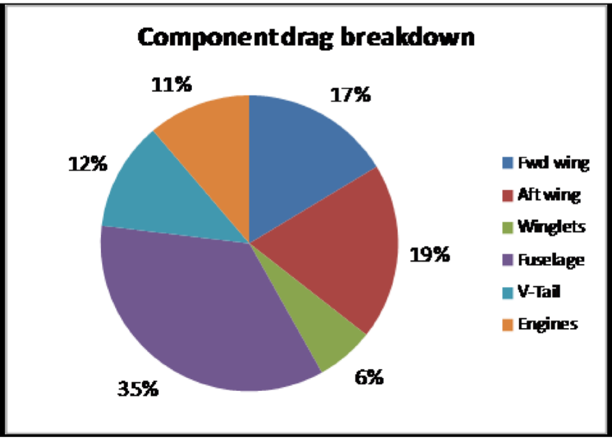


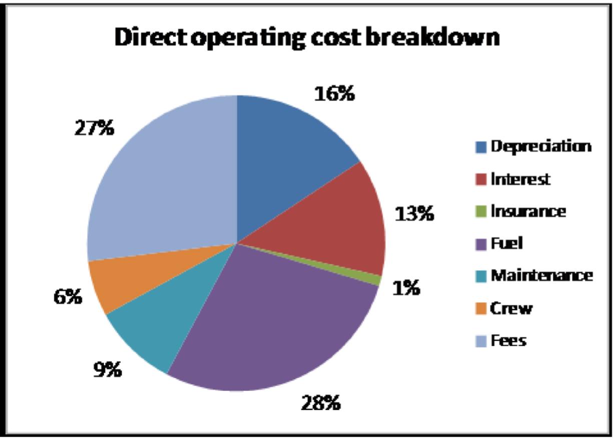
Box Wing Aircraft: Results (Slender Body)



Parameter	Value	Deviation from A320*
DOC mission requirements		
R_{DOC}	755 NM	0 %
$m_{PL,DOC}$	19256 kg	0 %
EIS	2030	-----
c_{fuel}	1.44 USD/kg	0 %
Results		
$m_{F,trip}$	6242 kg	+ 7 %
$U_{a,f}$	2617 h	- 10 %
DOC (AEA)	120 %	+ 20 %







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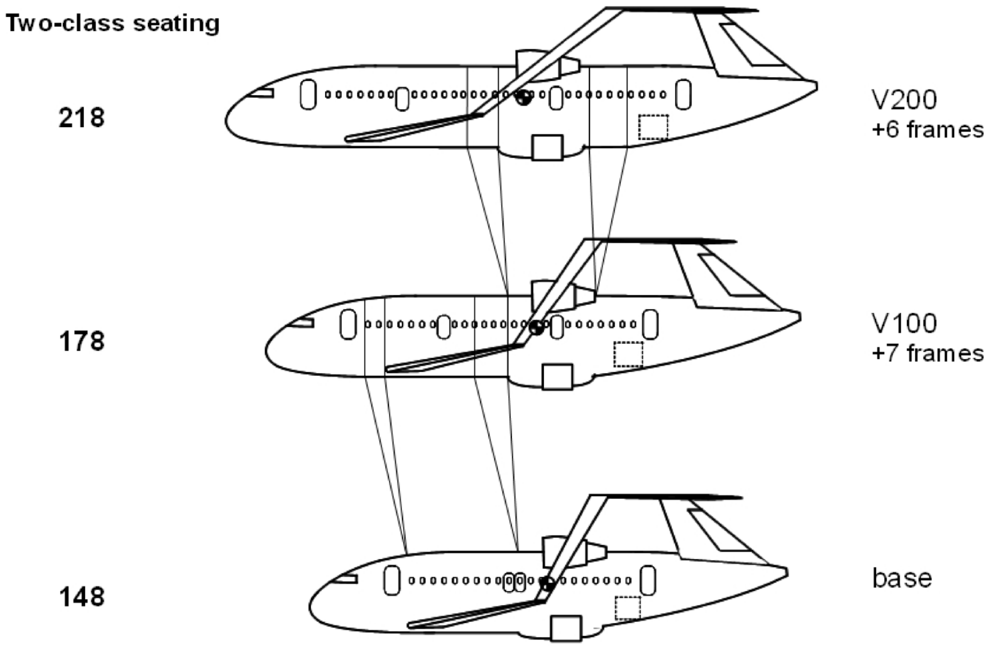
Box Wing Aircraft: Family Concept (Configuration A)

Box Wing
General Familiarization

Twin Aisle Family Highlights



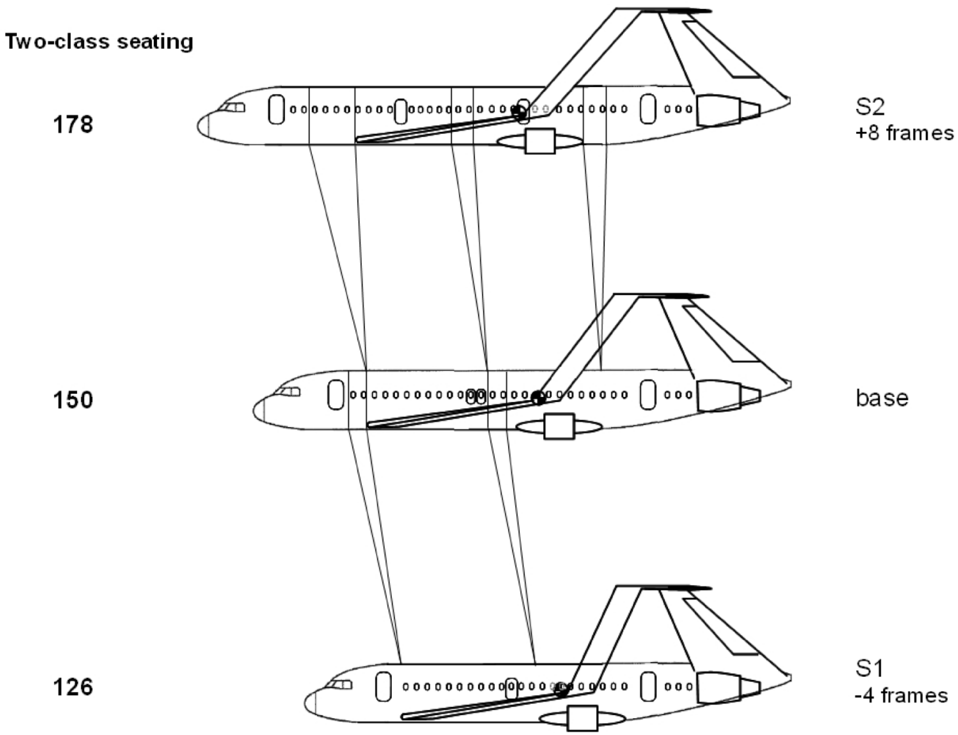
	base	V100	V200
Fuselage Length	33.1 m	37.21 m	41.28 m
Underfloor Volume	34.17 m³	38.42 m³	42.62 m³
Longitudinal distance from AC1 to AC2 (l')	12.50 m	15.50 m	19.57 m
Winglets Sweep (at 25% chord)	28.67°	43.44°	56.12°

AHMED, S.: Family Concepts of Box Wing Aircraft. Memo, 2012

Box Wing Aircraft: Family Concept (Configuration B)

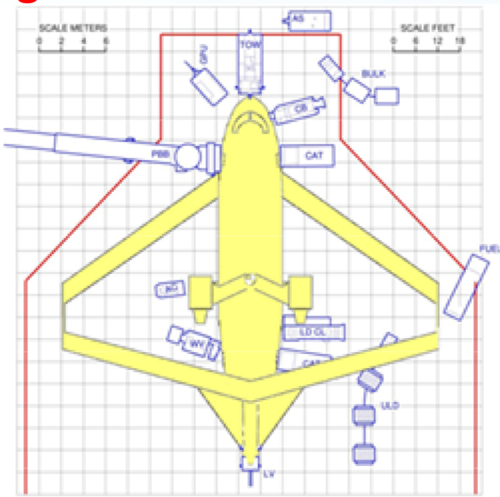
Box Wing
General Familiarization

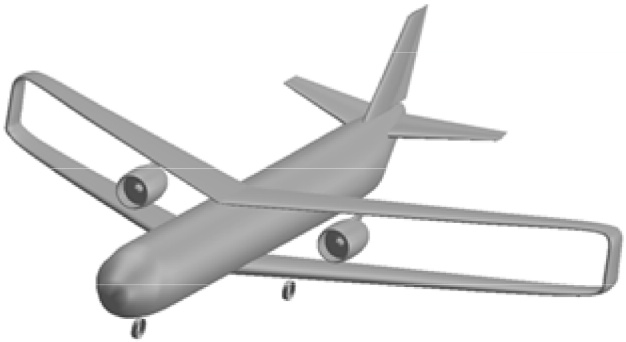
Single Aisle Family Highlights

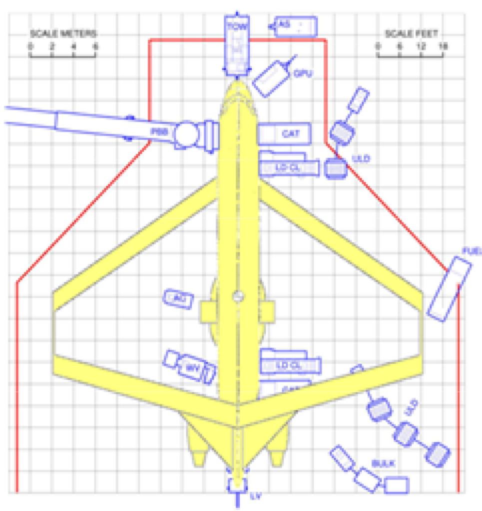


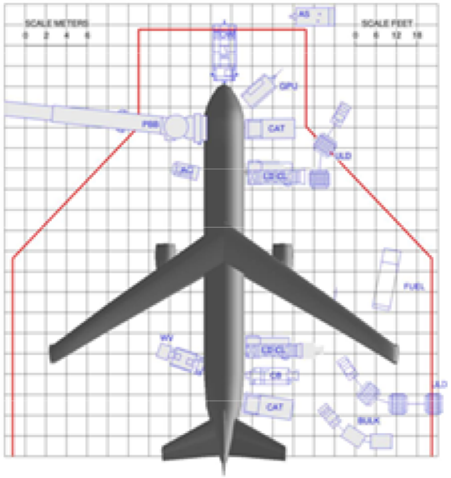
	base	S100	S200
Fuselage Length	37.44 m	34.09 m	41.51 m
Underfloor Volume	38.6 6m³	35.20 m³	42.86 m³
Longitudinal distance from AC1 to AC2 (l')	14 m	12.9 m	16 m
Winglets Sweep (at 25% chord)	36.76°	30.97°	45.39°

Box Wing Aircraft: Ground handling



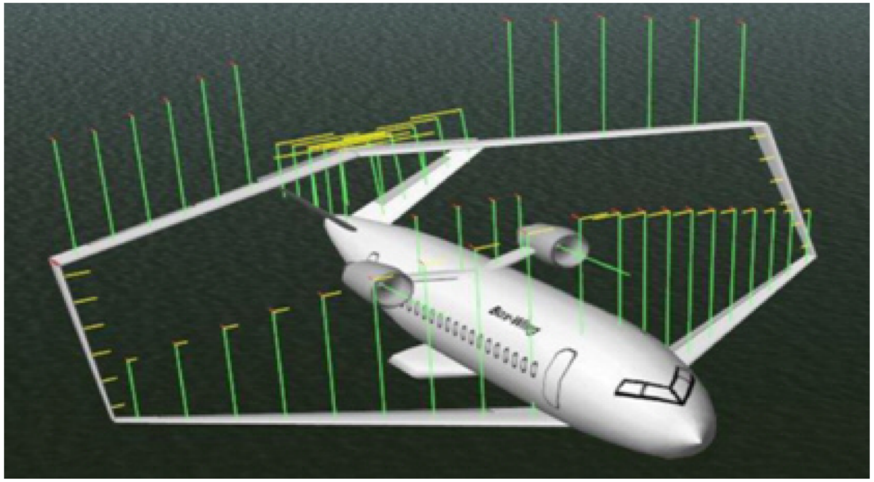




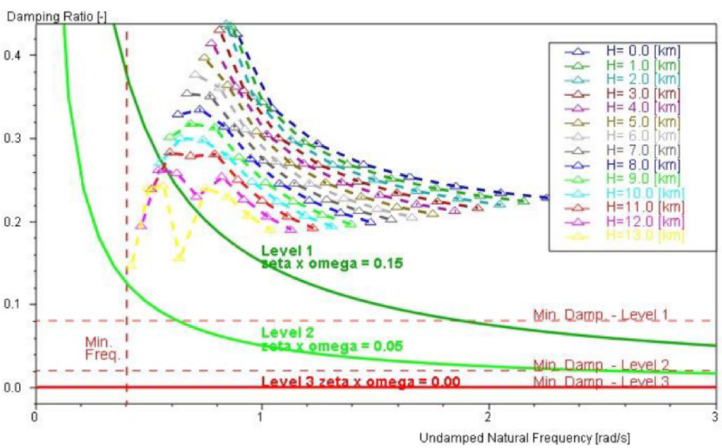


JOHANNING, A.; SCHOLZ, D.: 8.Zwischenbericht.
Verbundprojekt Effizienter Flughafen 2030, 2013

Box Wing Aircraft: Flying Qualities Calculation, Flight Simulation



Simulator X-Plane with Aircraft Generator PlaneMaker



Dutch Roll Mode:

Damping versus Frequency

h = 0 km … 13 km,
V = 100 m/s … 240 m/s

Simulator Flight Gear / Flight Dynamics Model / JSBSim

CAJA CALLEJA, R.; SCHOLZ, D.: Box Wing Flight Dynamics in the Stage of Conceptual Aircraft Design. Berlin, DLRK 2012

CAJA CALLEJA, R.: Flight Dynamics Analysis of a Medium Range Box Wing Aircraft. Master Thesis, 2012

VON AHLEN, T.: Modellierung eines Boxwing-Flugzeuges mit PlaneMaker für den Flugsimulator X-Plane. Project, 2012

Proposals for a new A320

- **Standard Prop Configuration**
  - Turboprop engines are more fuel efficient than turbofan engines
  - Low flying → higher speed of sound → same speed at lower Mach number
  - Additional future technologies:
    - Natural laminar flow
    - Strut braced wing

Smart Turboprop: Results

- **Choosing the optimum aircraft configuration:**

Smart Turboprop optimized for low DOC compared to A320

Turboprop w/o NLF/SBW	T-tail 2 engines	T-tail 4 engines	Conventional tail 2 engines	Conventional tail 4 engines
High wing	-13,6%	-11,4%	-13,3%	-11,1%
Low wing	-12,4%	-11,5%	-12,9%	-11,1%

Best configuration

- **Wisdom from this Optimization Study:**
  - **2 engines better than 4 engines**
  - **For 2 engines: High wing better than low wing (0,4 … 1,2 % PT)**
  - **For 4 engines: Low wing as good as high wing**
  - **NLF improves results by about 2,8 % PT**
  - **Struts improve results by about 0,5 % PT**
  - **NLF and Struts improve results by about 3 % PT**

JOHANNING, A.; SCHOLZ, D.: 9.Zwischenbericht.
Verbundprojekt Effizienter Flughafen 2030, 2013

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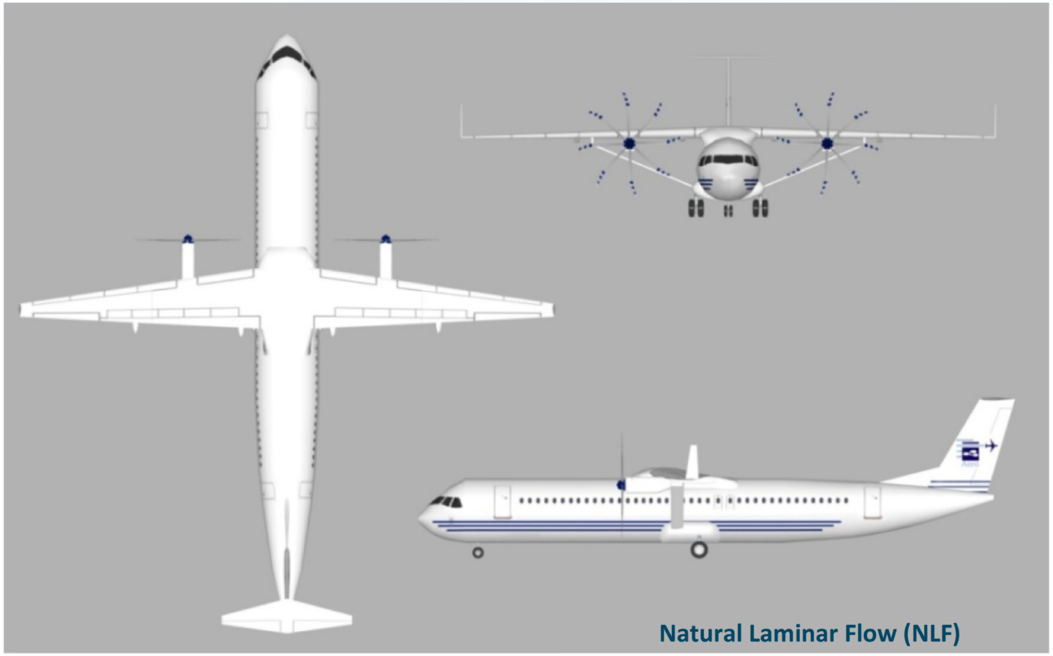
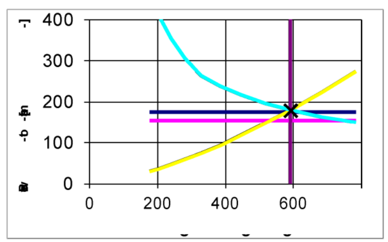
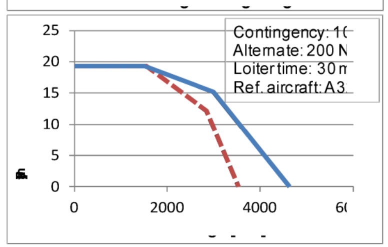
Smart Turboprop: Results

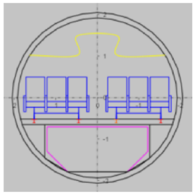


Parameter	Value	Deviation from A320*
Requirements		
m_{MPL}	19256 kg	0 %
R_{MPL}	1510 NM	0 %
M_{CR}	0.51	- 33 %
max(s_{TOFL} , s_{LFL})	1770 m	0 %
n_{PAX} (1-cl HD)	180	0 %
m_{PAX}	93 kg	0 %
SP	29 in	0 %



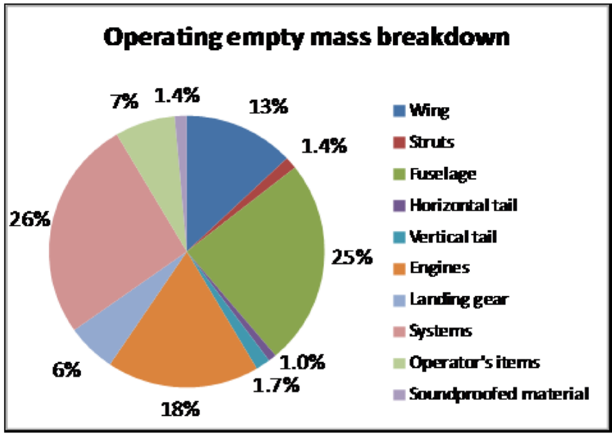


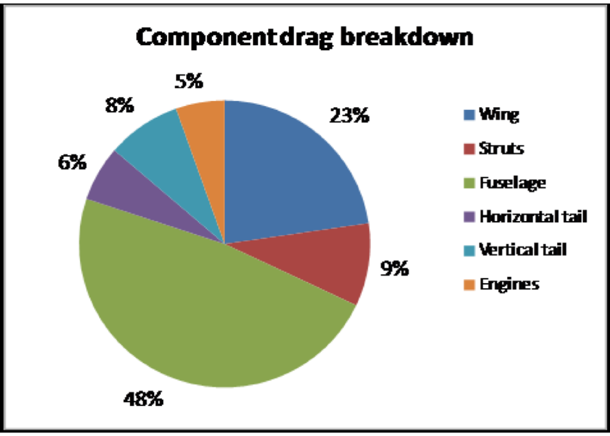
Parameter	Value	Deviation from A320*
Main aircraft parameters		
m_{MTO}	56000 kg	- 24 %
m_{OE}	28400 kg	- 31 %
m_F	8400 kg	- 36 %
S_W	95 m²	- 23 %
$b_{W,geo}$	36.0 m	+ 6 %
$A_{W,eff}$	14.9	+ 57 %
E_{max}	18.8	≈ + 7 %
$P_{eq,ssl}$	5000 kW	------
d_{prop}	7.0 m	------
η_{prop}	89 %	------
$PSFC$	5.86E-8 kg/W/s	------
h_{ICA}	23000 ft	- 40 %
s_{TOFL}	1770 m	0 %
s_{LFL}	1300 m	- 10 %
t_{TA}	32 min	0 %

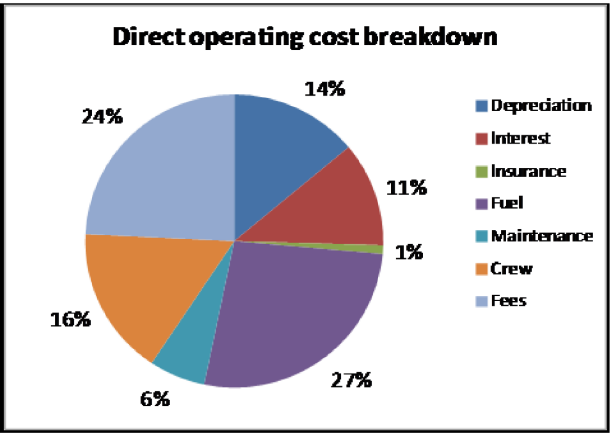


Smart Turboprop: Results

Parameter	Value	Deviation from A320*
DOC mission requirements		
R_{DOC}	755 NM	0 %
$m_{PL,DOC}$	19256 kg	0 %
EIS	2030	-----
c_{fuel}	1.44 USD/kg	0 %
Results		
$m_{F,trip}$	3700 kg	- 36 %
$U_{a,f}$	3600 h	+ 5 %
DOC (AEA)	83 %	- 17 %

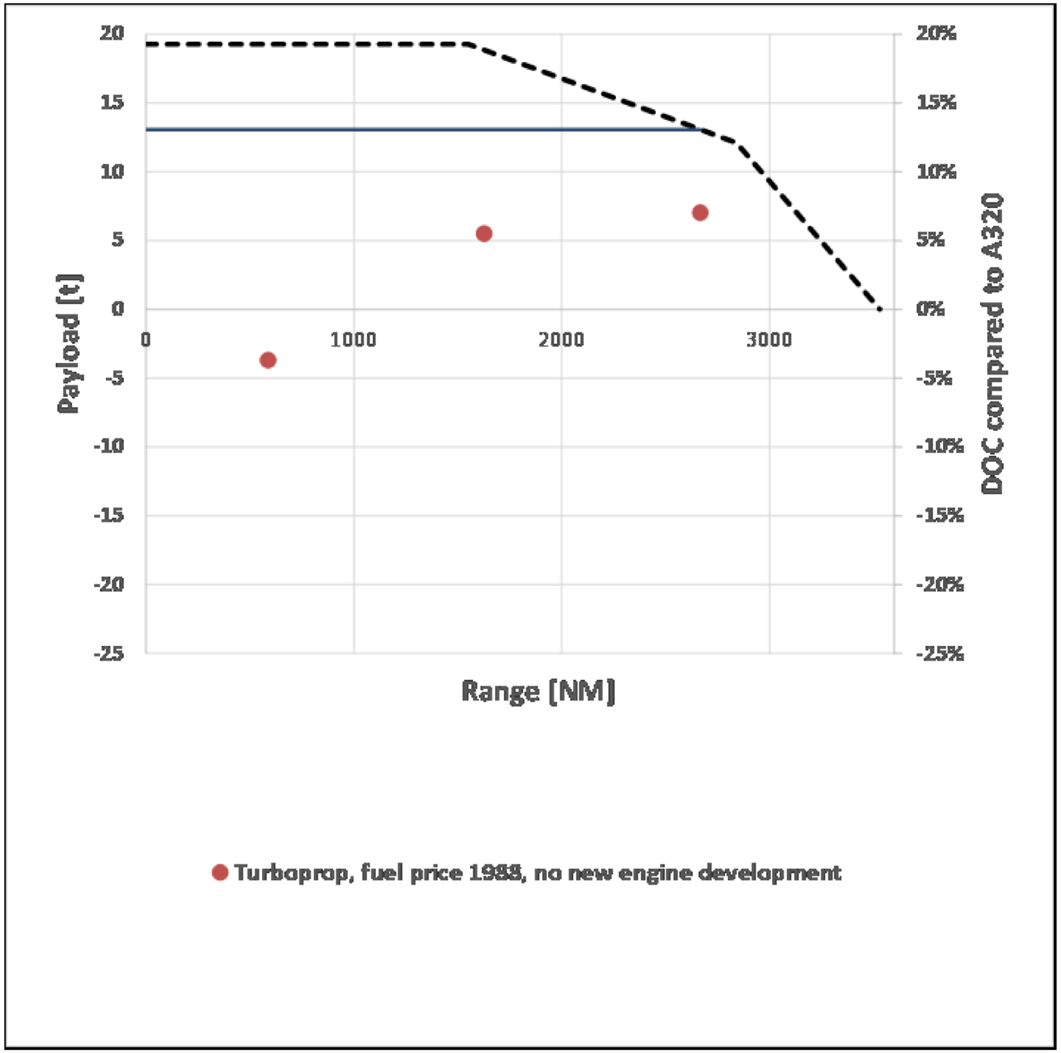






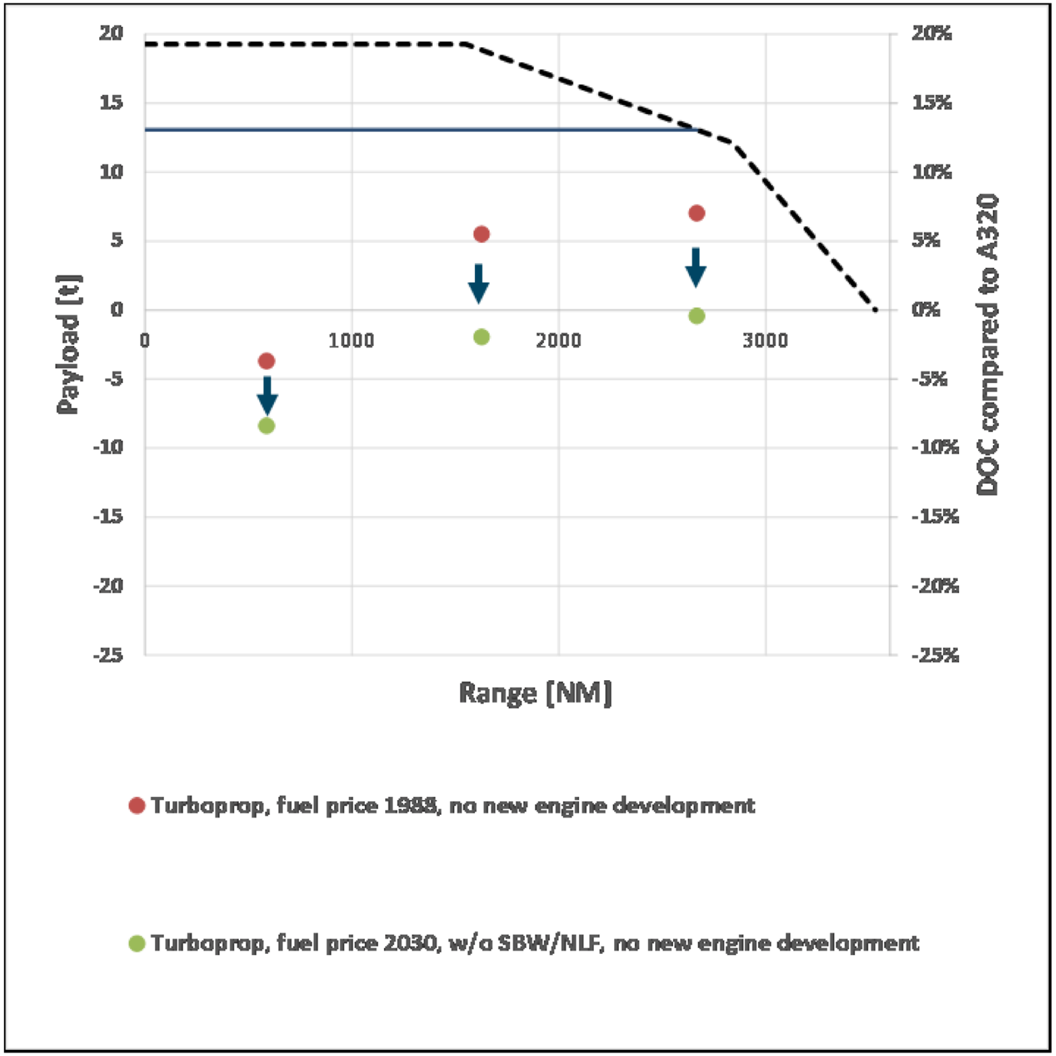
Smart Turboprop: Analysis of the results

- In 1988, we would have preferred a turbofan aircraft as well



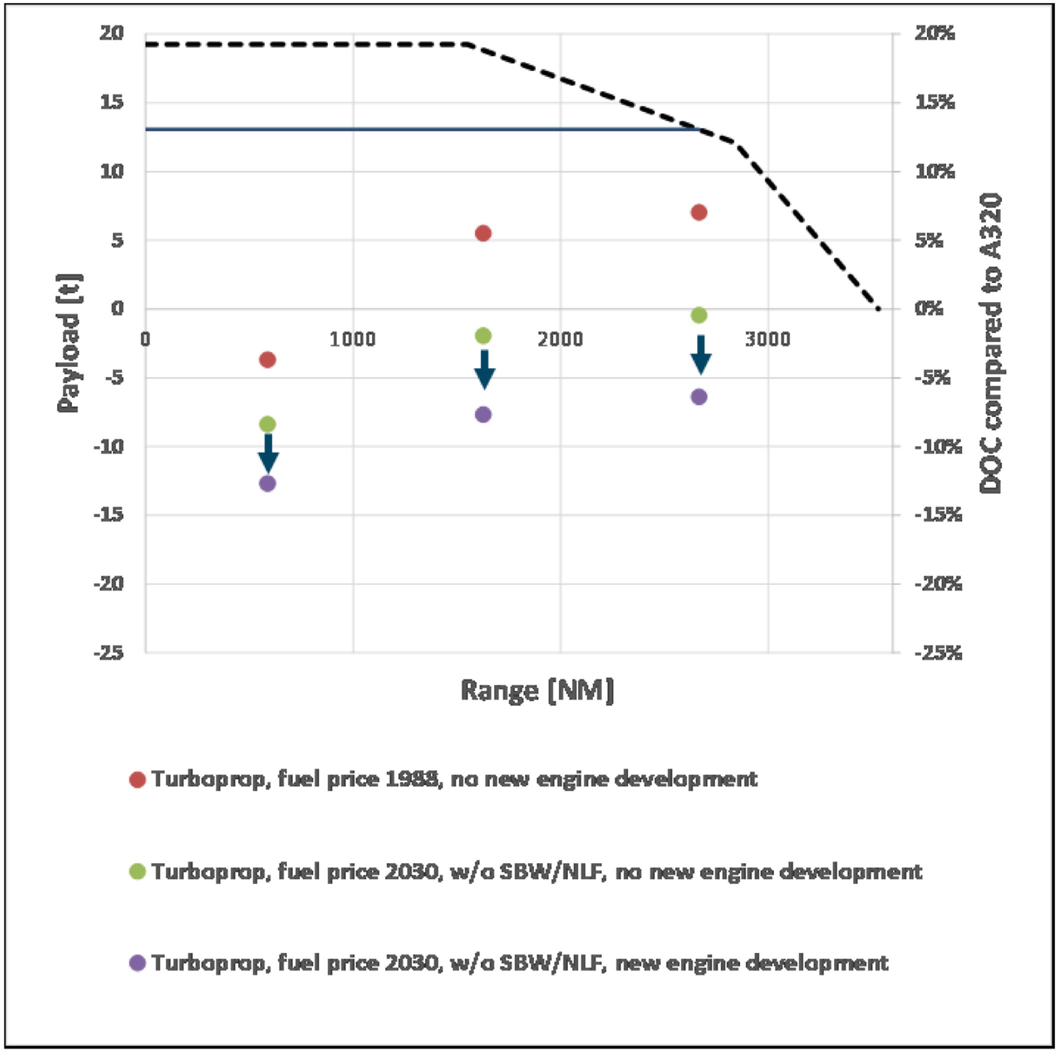
Smart Turboprop: Analysis of the results

- Today, fuel price is <u>four</u> times as high as in 1988 (inflation-adjusted)!



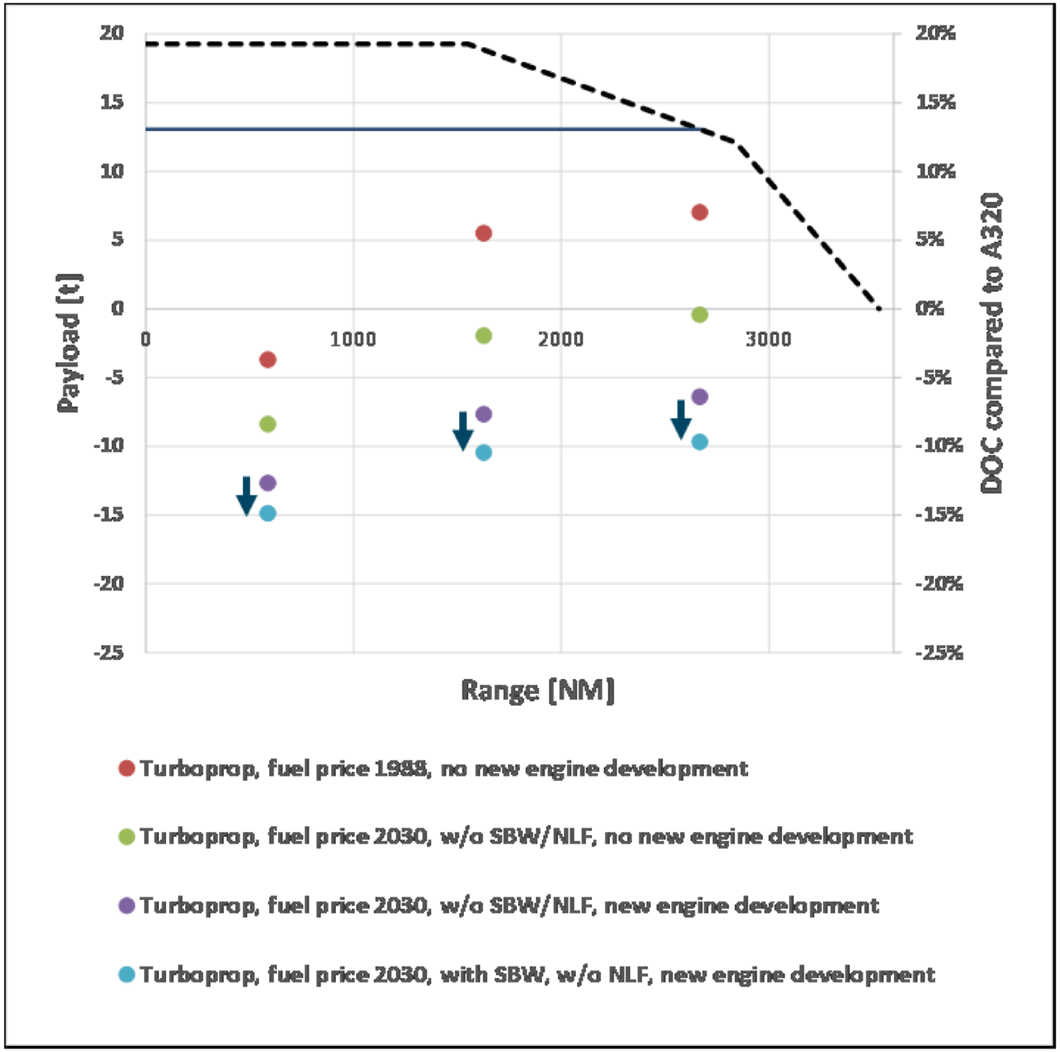
Smart Turboprop: Analysis of the results

- For an A320 successor, a next generation turboprop engine could be used



Smart Turboprop: Analysis of the results

- Strut-braced wing slightly improves DOC



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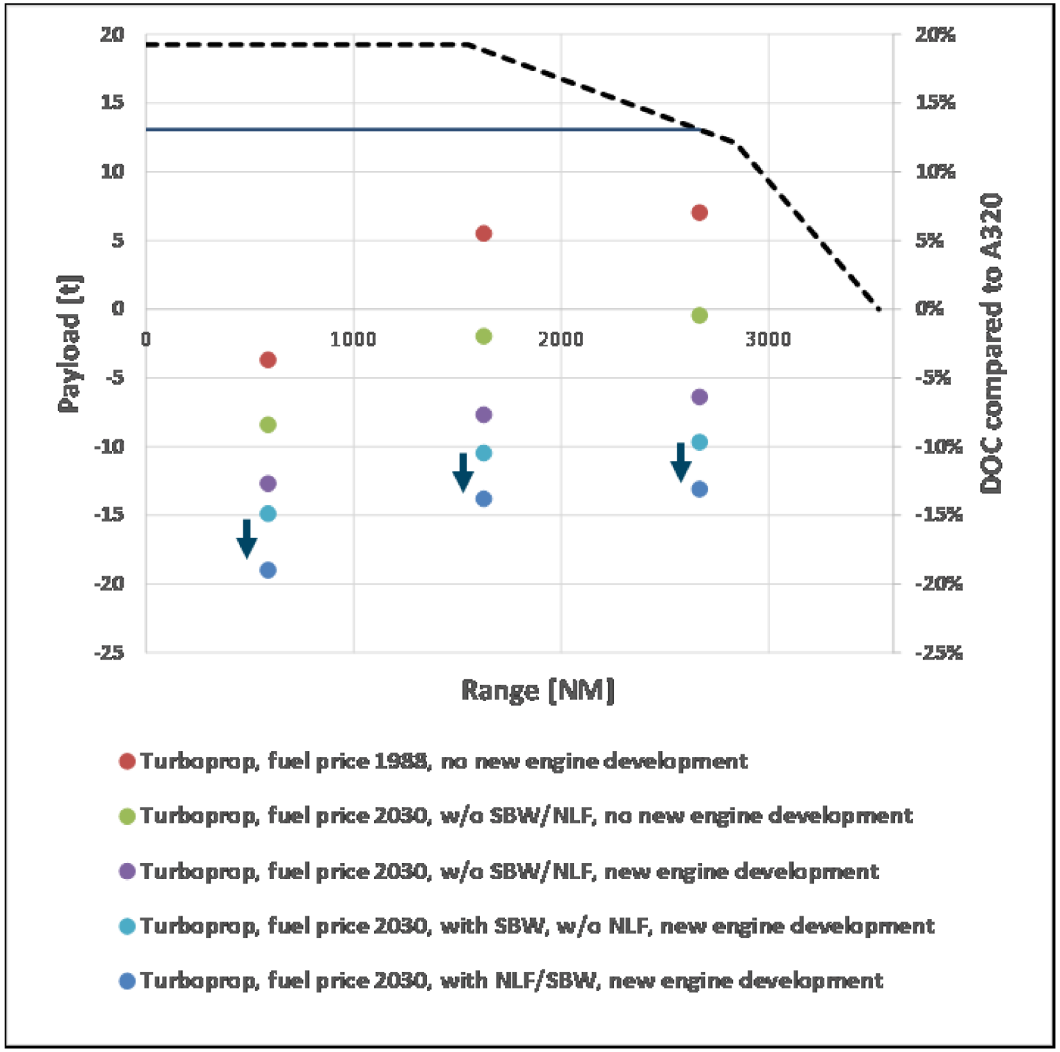
Smart Turboprop: Analysis of the results

- Natural laminar flow slightly improves DOC



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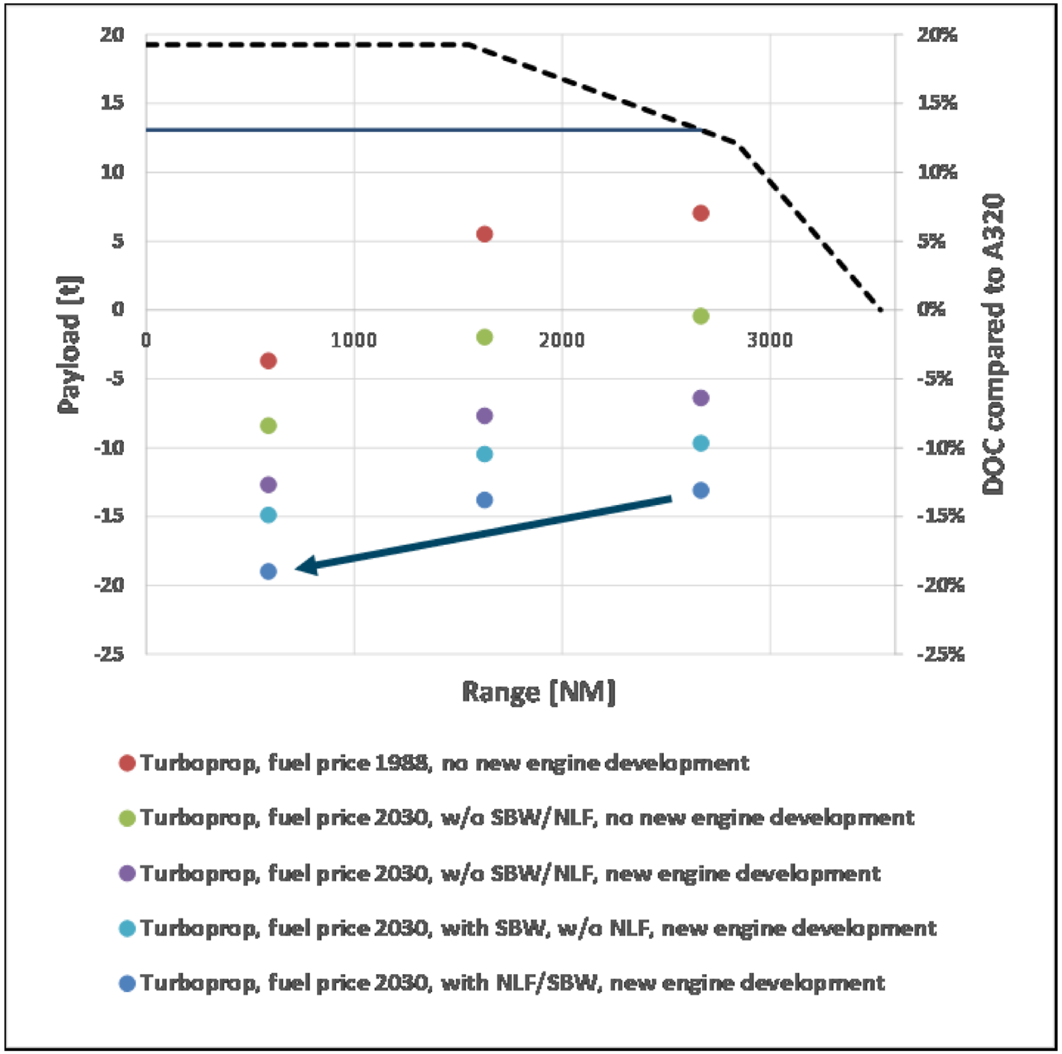
Smart Turboprop: Analysis of the results

- The average stage length of an A320 is quite short (approx. 600 NM)!



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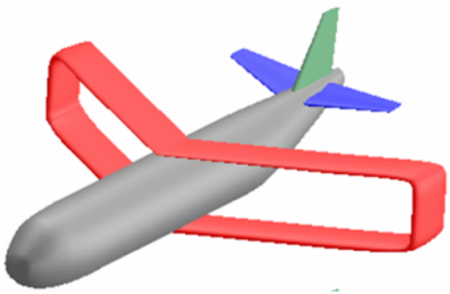
Smart Turboprop: DLR/Airbus Design Challenge

Design Requirements		Smart Turboprop
PAX	190 all economy @ 30" pitch 135 kg/pax payload capacity for high density layout @ 28" pitch	- 5 % / - 3 % - 25 %
Range	2000 NM (90% of flights within Europe and USA < 500 NM range). Technical means to enable up to 2900 NM range	- 25 %
TOFL	2000 m, SL, MTOW, ISA +15°C	- 12 %
LDGFL	1500 m, SL, MLW, ISA +15°C	- 13 %
Mach	0,79	- 35 %
Initial Climb/ Max. Altitude	FL 350 / FL 410	
Span	Max. 36m or technical means to achieve ICAO class C	0 %
Noise	-5 dB cum. vs. Chapter 4	**Achieved:**
Fuelburn	-25% versus A320 (CFM) 2009	**- 36 %**
Emissions	Near zero emissions at gate and during taxi	
CoC	-35% versus A320 (CFM) 2009	**≈ - 16 %**

Summary

- Ground handling needs to be robust – it is NOT a financial game changer
- 36 m requirement drives the design!
- Standard Jet Configuration:
  - Challenge requirements (take-off distance, cruise Mach number, ...)
- Box Wing Aircraft:
  - This may be the best Box Wing configuration:
  - But: DOC are not competitive



- Smart Turboprop:
  - Offers DOC improvements
  - Especially combined with braced wing and natural laminar flow on wing

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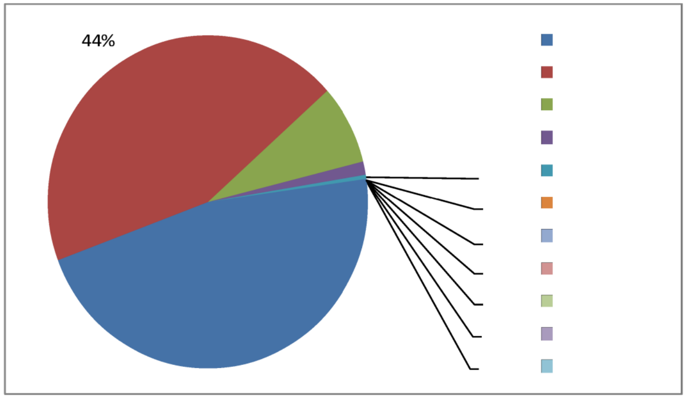
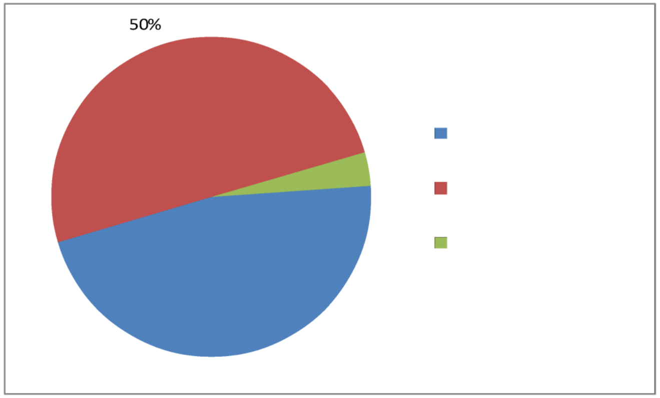
Outlook

Integration of Life Cycle Assessment into Conceptual Aircraft Design
→ Optimization for minimum environmental impact

Contribution of different in- and outputs
to the environmental impact of an Airbus A320-200



Contribution of the endpoint categories
to the environmental impact of an Airbus A320-200



Cooperative PhD Thesis in progress:
Life-cycle based Multidisciplinary Aircraft Design Optimization for Future Scenarios

Technische Universität München

JOHANNING, A.; SCHOLZ, D.: A first step towards the integration of life cycle assessment into conceptual aircraft design. Stuttgart, DLRK 2013

If you want to learn more about the presented aircraft designs, please contact

info@ProfScholz.de

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Deutsche Gesellschaft für Luft- und Raumfahrt Lilienthal-Oberth e.V.

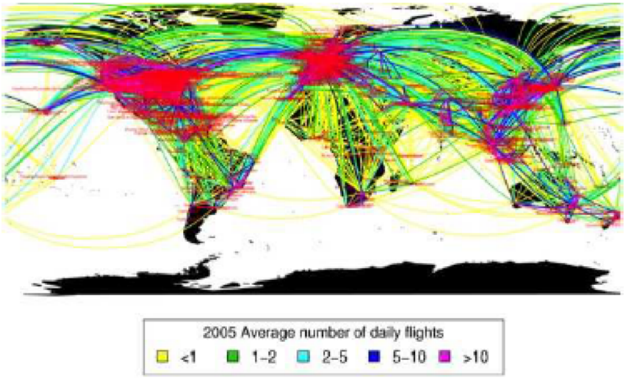
ROYAL AERONAUTICAL SOCIETY
HAMBURG BRANCH e.V.

VDI
Verein Deutscher Ingenieure
Hamburger Bezirksverein e.V.
Arbeitskreis Luft- und Raumfahrt

Invitation to an RAeS/HAW lecture in cooperation with the **DGLR** and **VDI**

Mitigating the Climate Impact of Aviation – Is Technology Enough?

Dr **Antony Evans**
University College London (UCL)
Energy Institute



Lecture followed by discussion

Entry free !
No registration required !

Date: **Thursday, 12th June 2014, 18:00**
Location: **HAW Hamburg**
Berliner Tor 5, (Neubau), Hörsaal 01.12

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences
Praxis Seminar Luftfahrt

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Appendix

Parameter	Explanation	Comments
Requirements		
m_{MPL}	Maximum payload mass [kg]	---
R_{MPL}	Maximum range [kg] (with maximum payload)	---
M_{CR}	Cruise Mach number	---
$\max(s_{TOFL}, s_{LFL})$	Maximum take-off and landing field length [m]	Requirement for the maximum allowable take-off and landing field length
n_{PAX} (1-cl HD)	Number of passengers	one class, high density layout
m_{PAX}	Passenger mass [kg]	---
SP	Seat pitch [in]	Seat pitch for the one class high-density layout

- **most of the given values are rounded**
- **the given deviation refers to the real values and not to the rounded values**

Appendix

Parameter	Explanation	Comments
Main aircraft parameters		
m_{MTO}	Maximum take-off mass [kg]	---
m_{OE}	Operating empty mass [kg]	---
m_F	Fuel mass [kg]	---
S_W	Wing area [m²]	---
$b_{W,geo}$	Geometrical span [m]	---
$A_{W,eff}$	Effective aspect ratio [-]	---
E_{max}	Maximum glide ratio [-]	---
T_{TO}	Take-off thrust [N]	---
$P_{eq,ssl}$	Equivalent take-off power at static sea level [kW]	---
BPR	Bypass-Ratio [-]	---
d_{prop}	Propeller diameter [m]	---
η_{prop}	Propeller efficiency [%]	---
SFC	Thrust specific fuel consumption [kg/N/s]	---
$PSFC$	Power specific fuel consumption [kg/W/s]	---
h_{ICA}	Initial cruise altitude [m]	---
s_{TOFL}	Take-off field length [m]	---
s_{LFL}	Landing field length [m]	---
t_{TA}	Turnaround time [min]	---

Appendix

Parameter	Explanation	Comments
DOC mission requirements		
R_{DOC}	Range for the DOC calculation [NM]	---
$m_{PL,DOC}$	Payload mass for the DOC calculation [kg]	---
EIS	Entry into Service	---
c_{fuel}	Fuel cost [USD/kg]	Fuel costs are estimated for the entry into service
Results		
$m_{F,trip}$	Fuel mass (for the DOC range) [kg]	----
$U_{a,f}$	Utilization [h]	Product of the number of flights per year and the duration of the flight on the DOC-range
DOC (AEA)	Direct Operating Costs	DOC calculated using the method of the Association of European Airlines

Appendix
Additional Parameters – A320 "optimized"

Parameter	Explanation	Value
Cabin		
w_{aisle}	Aisle width	8 in
w_{seat}	Seat width	17 in
$w_{armrest}$	Armrest width	1.6 in
$s_{clearence}$	Sidewall clearence	0.5 in
Wing		
φ_{25}	Wing sweep at 25 % chord	10°
λ	Wing taper ratio	0.25
Vertical tail		
S_V	Vertical tail area	15.8 m²
$\varphi_{25,V}$	Vertical tail sweep at 25 % chord	30°
λ_V	Vertical tail taper ratio	0.34
Horizontal tail		
S_H	Horizontal tail area	5.7 m²
$\varphi_{25,H}$	Horizontal tail sweep at 25 % chord	13°
λ_H	Horizontal tail taper ratio	0.32
DOC		
$k_{delivery,OE}$	Delivery price per kg m_{OE}	1602 USD/kg

Appendix
Additional Parameters – A320 "optimized"

Parameter	Explanation	Value
Zero lift & wave drag		
$C_{D,0}$	Zero lift drag	221 drag counts
$C_{D,W}$	Wave drag	10 drag counts
Induced drag		
a_e	---	-0.00152
b_e	---	10.82
c_e	---	1
M_{comp}	Highest Mach number without compressibility effects	0.3
Q	---	1.08
P	---	0.0088
$A_{W,eff}$	Effective aspect ratio of the wing	34.8
cf_e	Correction factor for Oswald factor	1.17

$$e = \frac{k_{e,M}}{Q + P \cdot \pi \cdot A_{W,eff}}$$

$$k_{e,M} = a_e \cdot \left(\frac{M}{M_{comp}} - 1 \right)^{b_e} + c_e$$

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Appendix
Additional Parameters – Box Wing Aircraft (Wide Body)

Parameter	Explanation	Value
Cabin		
w_{aisle}	Aisle width	20 in
w_{seat}	Seat width	20 in
$w_{armrest}$	Armrest width	2 in
$s_{clearence}$	Sidewall clearence	0.6 in
Wing		
$\varphi_{25,FW}$	Forward wing sweep at 25 % chord	29°
λ_{FW}	Forward wing taper ratio	0.24
$\varphi_{25,AW}$	Aft wing sweep at 25 % chord	-28°
λ_{AW}	Aft wing taper ratio	0.80
V-tail		
S_V	V-tail area	25 m²
$\varphi_{25,V}$	V-tail sweep at 25 % chord	-30°
λ_V	V-tail taper ratio	0.50
DOC		
$k_{delivery,OE}$	Delivery price per kg m_{OE}	1602 USD/kg

Appendix
Additional Parameters – Box Wing Aircraft (Wide Body)

Parameter	Explanation	Value
Zero lift & wave drag		
$C_{D,0}$	Zero lift drag	179 drag counts
$C_{D,W}$	Wave drag	10 drag counts
Induced drag		
e_{ref}	---	0.85
k_1	---	1.04
k_2	---	0.57
k_3	---	1.04
k_4	---	2.13
h/b	---	0.22

$$e_{box} = e_{ref} \cdot \frac{e_{NP}}{e}$$

$$\frac{e_{NP}}{e} = \frac{k_3 + k_4 \cdot \frac{h}{b}}{k_1 + k_2 \cdot \frac{h}{b}}$$

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Appendix
Additional Parameters – Box Wing Aircraft (Slender Body)

Parameter	Explanation	Value
Cabin		
w_{aisle}	Aisle width	20 in
w_{seat}	Seat width	20 in
$w_{armrest}$	Armrest width	2 in
$s_{clearence}$	Sidewall clearence	0.6 in
Wing		
$\varphi_{25,FW}$	Forward wing sweep at 25 % chord	35°
λ_{FW}	Forward wing taper ratio	0.9
$\varphi_{25,AW}$	Aft wing sweep at 25 % chord	-15°
λ_{AW}	Aft wing taper ratio	0.9
V-tail		
S_V	V-tail area	36 m²
$\varphi_{25,V}$	V-tail sweep at 25 % chord	-37°
λ_V	V-tail taper ratio	0.41
DOC		
$k_{delivery,OE}$	Delivery price per kg m_{OE}	1602 USD/kg

Appendix
Additional Parameters – Box Wing Aircraft (Slender Body)

Parameter	Explanation	Value
Zero lift & wave drag		
$C_{D,0}$	Zero lift drag	154 drag counts
$C_{D,W}$	Wave drag	10 drag counts
Induced drag		
e_{ref}	---	0.85
k_1	---	1.04
k_2	---	0.57
k_3	---	1.04
k_4	---	2.13
h/b	---	0.25

$$e_{box} = e_{ref} \cdot \frac{e_{NP}}{e}$$

$$\frac{e_{NP}}{e} = \frac{k_3 + k_4 \cdot \frac{h}{b}}{k_1 + k_2 \cdot \frac{h}{b}}$$

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Appendix
Additional Parameters – Smart Turboprop

Parameter	Explanation	Value
Cabin		
w_{aisle}	Aisle width	20 in
w_{seat}	Seat width	20 in
$w_{armrest}$	Armrest width	2 in
$s_{clearence}$	Sidewall clearence	0.6 in
Wing		
φ_{25}	Wing sweep at 25 % chord	6°
λ	Wing taper ratio	0.20
Vertical tail		
S_V	Vertical tail area	19.3 m²
$\varphi_{25,V}$	Vertical tail sweep at 25 % chord	28°
λ_V	Vertical tail taper ratio	0.69
Horizontal tail		
S_H	Horizontal tail area	12.4 m²
$\varphi_{25,H}$	Horizontal tail sweep at 25 % chord	9°
λ_H	Horizontal tail taper ratio	0.25
DOC		
$k_{delivery,OE}$	Delivery price per kg m_{OE}	1602 USD/kg

Appendix
Additional Parameters – Smart Turboprop

Parameter	Explanation	Value
Zero lift & wave drag		
$C_{D,0}$	Zero lift drag	314 drag counts
$C_{D,W}$	Wave drag	0 drag counts
Induced drag		
a_e	---	-0.00152
b_e	---	10.82
c_e	---	1
M_{comp}	Highest Mach number without compressibility effects	0.3
Q	---	1.08
P	---	0.0119
$A_{W,eff}$	Effective aspect ratio of the wing	14.9
cf_e	Correction factor for Oswald factor	1.56

$$e = \frac{k_{e,M}}{Q + P \cdot \pi \cdot A_{W,eff}}$$

$$k_{e,M} = a_e \cdot \left(\frac{M}{M_{comp}} - 1 \right)^{b_e} + c_e$$

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