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Reverse Engineering of Passenger Jets to Obtain Classified Design Parameters

Revealing the secrets!

Black-box reverse engineering: Reconstruct what the aircraft does. White-box reverse engineering: Reconstruct how the aircraft was designed to do it. This poster shows white-box reverse engineering. It seeks to reconstruct underlying design variables, engineering models, constraints, and design decisions. It does not imply disassembly of a real aircraft. The theoretical reverse engineering is entirely based on external geometry, published data, engineering knowledge, and analytical / computational aircraft design methods. An alternative name: Aircraft Design Reverse Engineering.

PURPOSE

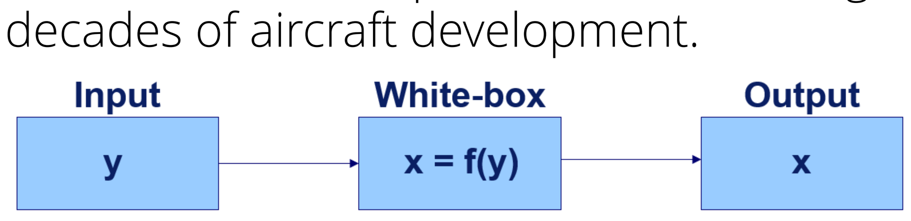
Explain how classified design parameters of existing passenger jets can be determined. The classified design parameters are maximum lift coefficient for landing and take-off, the maximum aerodynamic efficiency (glide ratio, E_{max}) and the specific fuel consumption (*SFC*).

METHODOLOGY

The concept is based on preliminary sizing of jet powered civil airplanes as taught by Scholz (2015). Preliminary sizing and reverse engineering are combined aiming for the classified design parameters as output. Equations are derived to calculate the maximum lift coefficients, the maximum aerodynamic efficiency and the specific fuel consumption (Figure 1). Only aircraft specifications are used made public by the manufacturer. The calculations are quite complex with mutual relations, requiring iterative processes and optimization. Therefore, it becomes necessary to integrate everything into a tool (Figure 2, Figure 3). The tool is built in Microsoft Excel and called "Passenger Jet Reverse Engineering" (PJRE). The tool verifies the results by estimating the classified parameters with handbook methods. The tool is explained in detail in the theses. Operating instructions are given.

FINDINGS

Initially, the reverse engineering method of passenger jets was executed successfully for miscellaneous airplanes: Caravelle 10B (Sud-Aviation), Boeing 707-320C, BAe 146-200 (British Aerospace), A320-200 (Airbus), "The Rebel" (based on A320), Boeing SUGAR High, Boeing 747-400, Blended Wing Body VELA 2 (VELA) and Dassault Falcon 8X. Later a pairwise comparison was done of the A340-300 (Figure 2) and IL-96-300, Boeing 727-200 Advanced and TU-154M, Fokker 100 and MD-82, A319-100 and An-72. Generally, there is good agreement between the reverse engineered values and those from verification. Only the maximum glide ratio in cruise flight, calculated from verification, is often significantly higher than calculated from reverse engineering. Specific fuel consumption in cruise flight has decreased considerably over decades of aircraft development.



$$SFC = -\frac{E \cdot ln\left(\dfrac{\dfrac{m_{PL}}{m_{MTO}} + \dfrac{m_{OE}}{m_{MTO}}}{M_{ff,TO} \cdot M_{ff,CLB}^2 \cdot M_{ff,DES}^2 \cdot M_{ff,L}}\right)}{g \cdot \left(\dfrac{R + s_{RES}}{V_{CR}} + t_{loiter}\right)}$$

$$\frac{2 \cdot \dfrac{T_{TO}}{m_{MTO} \cdot g}}{\dfrac{1}{\left(\dfrac{V}{V_{md}}\right)^2} + \left(\dfrac{V}{V_{md}}\right)^2} \left[E_{max}^{1,19} \cdot (0{,}0576\mu - 1{,}76) \cdot \left(\frac{4 \cdot g \cdot \dfrac{m_{MTO}}{S_W} \cdot \left(\dfrac{V}{V_{md}}\right)^2}{\pi \cdot A \cdot e \cdot M^2 \cdot \gamma \cdot p_0} \right)^{\frac{1}{5{,}258}} \right]$$

$$+ \frac{2 \cdot \dfrac{T_{TO}}{m_{MTO} \cdot g}}{\dfrac{1}{\left(\dfrac{V}{V_{md}}\right)^2} + \left(\dfrac{V}{V_{md}}\right)^2} \cdot (-E_{max}) \cdot (0{,}0328\mu - 1{,}05) + 1 = 0$$

Figure 1: White-box reverse engineering determines the unknown parameters from equations. Equations are often only a simple transformation. The *SFC* calculation includes the Breguet equation and mission segment fuel fractions. E_{max} is given only implicit. The equation is solved with the Newton-Raphson method.

More details in the Master Thesis of De Grave (2017):

https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2017-08-25.017

More details in the Bachelor Thesis of Cheema (2019):

https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2019-04-27.013

PRACTICAL IMPLICATIONS

Due to competition among aircraft manufacturers, many aircraft parameters cannot be made publicly available. The application of PJRE demonstrates how these parameters can nevertheless be approximated.

SOCIAL IMPLICATIONS

A detailed discussion about flight costs, ticket prices, and environmental impact of air travel requires detailed knowledge of aircraft. Reverse engineering allows consumers to engage in this discussion with the industry on equal footing.

ORIGINALITY

The method was first published by De Grave (2017) and applied by Cheema (2019) supervision was by Scholz. This is the first presentation at a conference.

	A	D	E	F	G	H	I
1	**Aeroplane Specifications**						
2							
3	**Data to apply reverse engineering**						
4						*LL*	*UL*
5	Landing field length	Known	s_{LFL}	1830	m		
6	Approach speed	Known	V_{APP}	77.16	m/s	77.2	77.2
7	Temperature above ISA (288,15K)		ΔT_L	0	K		
8	Relative density		σ	1			
9							
10	Take-off field length	Known	s_{TOFL}	3125	m	3125	3125
11	Temperature above ISA (288,15K)		ΔT_{TO}	0	K		
12	Relative density		σ	1.000			
13							
14	Maximum range		R	7300	NM		
15	Cruise Mach number		M_{CR}	0.82			
16							
17	Wing area		S_W	363	m²		
18	Wing span	Known	b_W	60.3	m²	60.3	60.3
19	Aspect ratio		A	10.02			
20							
21	Maximum take-off mass		m_{MTO}	276500	kg		
22	Payload mass (maximum range)		m_{PL}	33160	kg		
23	Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0.120			
24	Maximum landing mass		m_{ML}	192000	kg		
25	Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0.694			
26	Operating empty mass		m_{OE}	129850	kg		
27	Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0.470			
28	Wing loading		m_{MTO}/S_W	761.7	kg/m²		
29							
30	Number of engines		n_E	4			
31	Take-off thrust for one engine		$T_{TO,one\ engine}$	154	kN		
32	Total take-off thrust		T_{TO}	616	kN		
33	Thrust to weight ratio		$T_{TO}/(m_{MTO}*g)$	0.227			
34	Bypass ratio		μ	6.6			
35							
36	Available fuel volume		$V_{fuel,available}$	147.85	m³		

Figure 2: The Excel tool "PJRE": User interface for data input: Airbus A340-300.

	A	D	E	F	G	H–I
56	***Reverse Engineering***					
57						
58	**Reverse engineering & optimization of V/Vmd**					
59						
60		*Quantity*	*Original value*	RE value	*Unit*	*Deviation*
61	Landing field length	s_{LFL}	1830	1830	m	0.00%
62	Approach speed	V_{APP}	77.16	77.2	m/s	0.00%
63						
64	Take-off field length	s_{TOFL}	3125	3125	m	0.00%
65						
66	Span	b_W	60.3	60.3	m	0.00%
67	Aspect ratio	A	10.02	10.02		0.00%
68						
69	Cruise speed	V_{CR}	252.1	243	m/s	-3.52%
70	Cruise altitude	h_{CR}	11700	10672	m	-8.78%
71						
72	**Squared Sum**					**8.96E-03**
73	Absolute maximum deviation					8.8%
74						
75	**Results reverse engineering**					
76						
77	Maximum lift coefficient, landing	$C_{L,max,L}$	2.70			
78	Maximum lift coefficient, take-off	$C_{L,max,TO}$	2.51			Reverse Engineering
79	Maximum aerodynamic efficiency	E_{max}	20.32			
80	Specific fuel consumption (acc. to PL and OE)	SFC	1.53E-05	kg/N/s		
81	Specific fuel consumption (acc. to fuel capacity)	SFC	1.56E-05	kg/N/s		

155	Verification value specific fuel consumption	SFC	0.57	kg/daN/h
156	Verification value specific fuel consumption	SFC	1.58E-05	kg/N/s
157				
158	RE value specific fuel consumption (acc. to PL and OE)	SFC	1.53E-05	kg/N/s
159	3%			
160				
161	RE value specific fuel consumption (acc. to fuel capacity)	SFC	1.56E-05	kg/N/s
162	1%			

Figure 3: The Excel tool "PJRE": Output of reverse engineering (RE) results and verification with handbook.

Associated research data (Harvard Dataverse):

https://doi.org/10.7910/DVN/KPHTG7

Associated research data (Harvard Dataverse):

https://doi.org/10.7910/DVN/DIDFZI

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