

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

Joel Nisa López

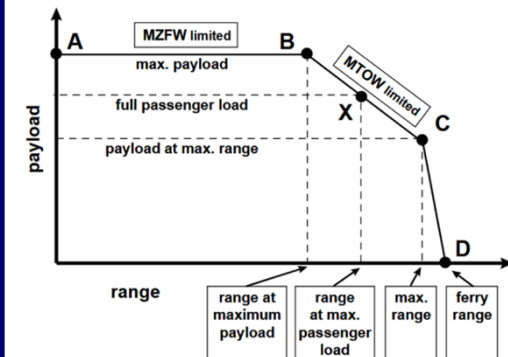
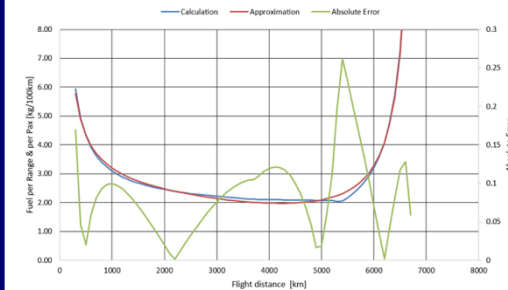
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Presentation of the Bachelor Thesis

German Aerospace Conference 2026

Aachen, 2026-09-10



Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

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Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

Fundamentals

Fundamentals

Breguet Equation and Fuel Mass

$$R = \frac{V}{c} \frac{E}{g} \ln \frac{m_1}{m_2} \quad \begin{array}{l} c \rightarrow \text{SFC} \\ E \rightarrow \text{Glide Ratio, L/D} \end{array}$$

These are not published by the manufacturer

Breguet Factor is defined for cruise

$$B = \frac{V E}{c g} = \frac{R}{\ln \frac{m_1}{m_2}}$$

Fuel fractions include non-horizontal phases

LTO = Landing + Take-off

$$M_{ff} = m_{i+1}/m_i$$

$$M_{ff} = M_{ff,CR-RES-LOI} \cdot M_{ff,LTO}$$

Real Breguet Factor

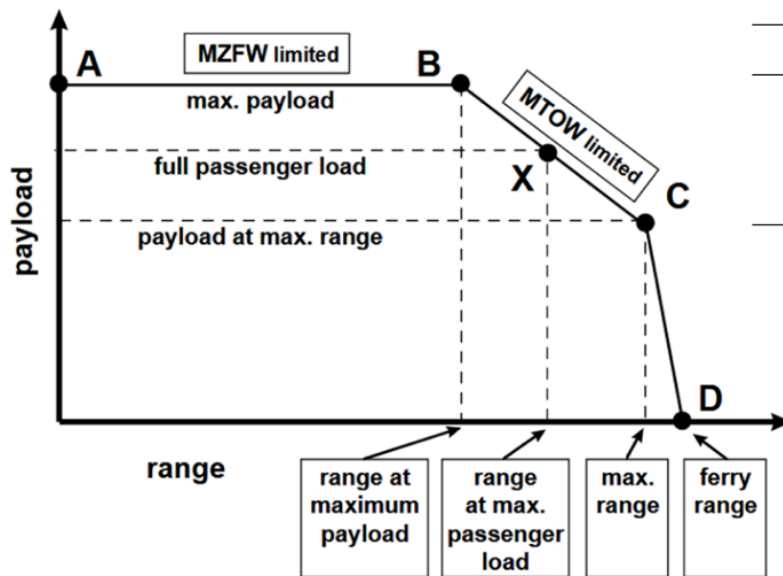
$$B = \frac{R}{\ln \left(M_{ff,LTO} \frac{m_1}{m_2} \right)}$$

Rearranging

$$R = B \cdot \ln \frac{m_1}{m_2} \quad \rightarrow \quad m_{fuel}(R) = m_2 (e^{R/B} - 1)$$

Fundamentals

Payload-Range Diagram



	Range	Take-off	Landing weight
B	R_1	MTOW	MZFW
C	R_2	MTOW	MTOW-MFW
D	Ferry Range	OEW+MFW	OEW

$$PL_1 = MPL$$

$$OEW = MZFW - PL_1$$

$$MFW = MTOW - (OEW + PL_2)$$

Payload-Range Diagram. Source: Scholz (2015)

Breguet Factor can be calculated for each point of the Payload-Range Diagram

Between B and C, and C and D a linear interpolation is made

Fundamentals

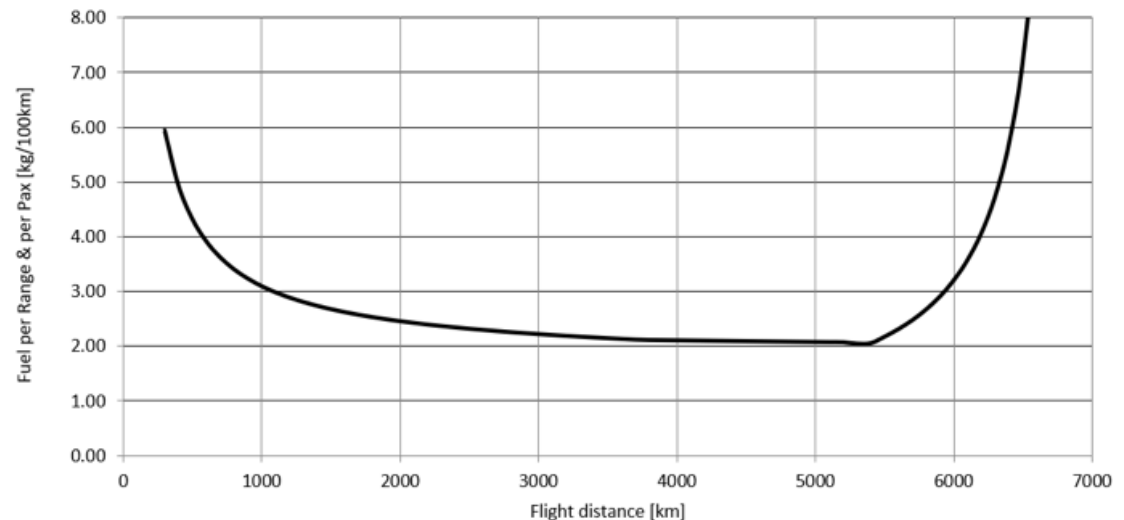
Bathtub Curve

Boeing 737-800

- Aircraft Dataset (Kühn 2024)
- Airplane Characteristics for Airport Planning (Boeing 2025)

<i>MPL</i>	21,184 kg	<i>R</i> ₁	3,750 km
<i>MTOW</i>	79,016 kg	<i>R</i> ₂	5,223 km
<i>MZFW</i>	62,732 kg	<i>R</i> _{ferry}	6,850 km
<i>PL</i> ₂	16,716 kg	<i>M</i> _{cruise}	0.78
<i>m</i> _{pax}	95 kg	<i>n</i> _{seat}	160

$$\frac{m_{fuel} \text{ [kg]}}{R \text{ [km]}/100 \cdot pax}$$



Bathtub curve for B737-800 calculated with the Excel Table from Burzlaff (2017)

Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

Analytical Equation

Analytical Equation

Literature

Atmosfair Emissions Calculator

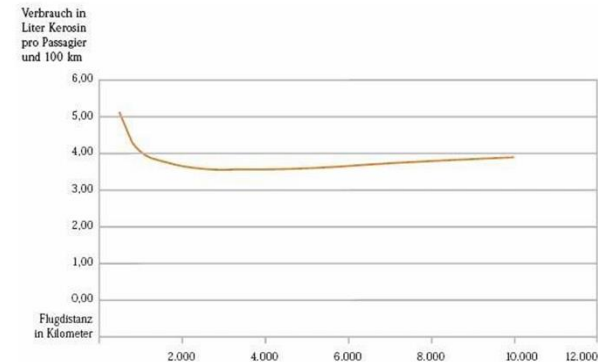
Atmosfair (2008) shows fuel consumption per passenger and 100 km but **does not show the right arm of the curve.**

Flight Emissions Calculator MyClimate

MyClimate (2025) estimates fuel consumption per aircraft kilometer, integrating both cruise and non-cruise phases in a second- order polynomial approximation for fuel consumption. **Only ten aircraft and only two flight distances is a rough approach.**

Egelhofer Analytical Equation

Egelhofer (2008) gives an alternative to calculate relative fuel consumption per flown kilometer. **A table with the parameters** required to calculate the fuel consumption of each aircraft **is not provided.**



Consumption of an Airbus A340. Source: Atmosfair (2021)

$$f(x) + LTO = ax^2 + bx + c$$

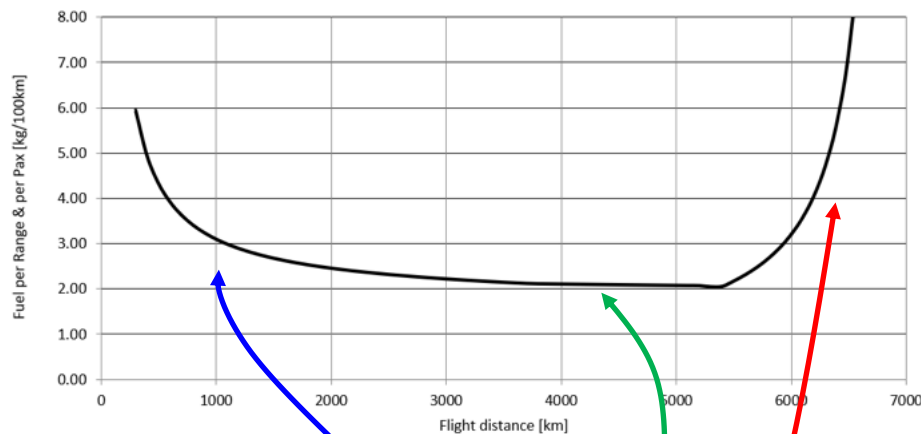
$$y = ax + b + \frac{c}{x}$$

Analytical Equation

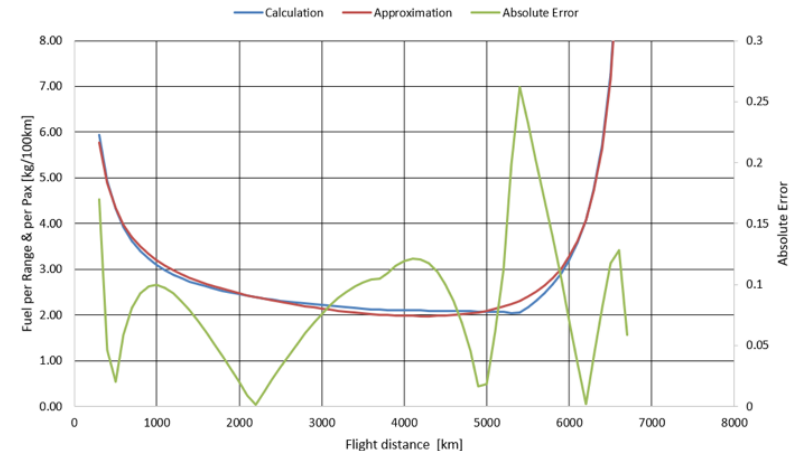
Approximation of the Curve

Fairly complex

- Multiple interpolations → Simplified analytical version
- Many parameters involved



$$y = \frac{a}{x} + \frac{b}{c-x} + d + ex$$

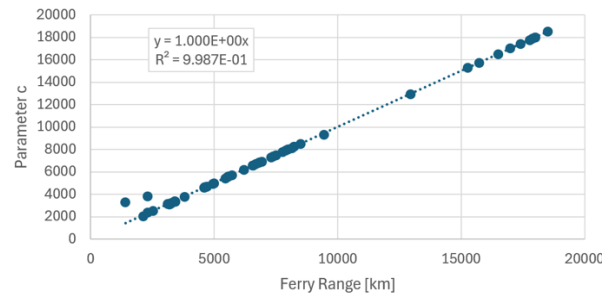


$$MSE = \frac{1}{N} \sum_{i=1}^N (f_i - y_i)^2$$

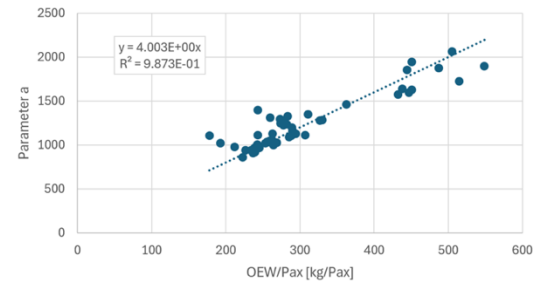
Analytical Equation

Approximation of the Parameters

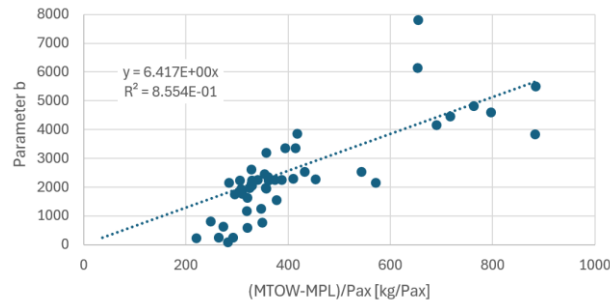
Find a correlation between parameters a-e and aircraft data



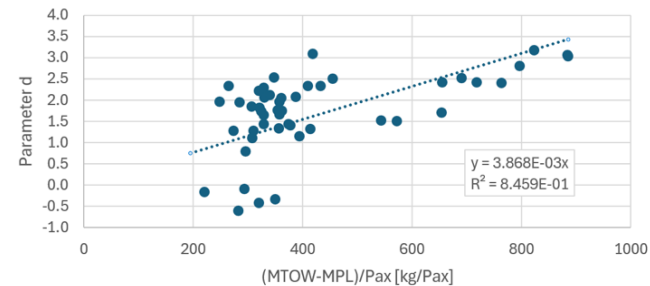
$$c = 1.000 \cdot \text{Ferry Range}$$



$$a = 3.989 \cdot \frac{MZFW - MPL}{n_{seat}}$$



$$b = 6.443 \cdot \frac{MTOW - MPL}{n_{seat}}$$



$$d = 0.003900 \cdot \frac{MTOW - MPL}{n_{seat}}$$

Analytical Equation

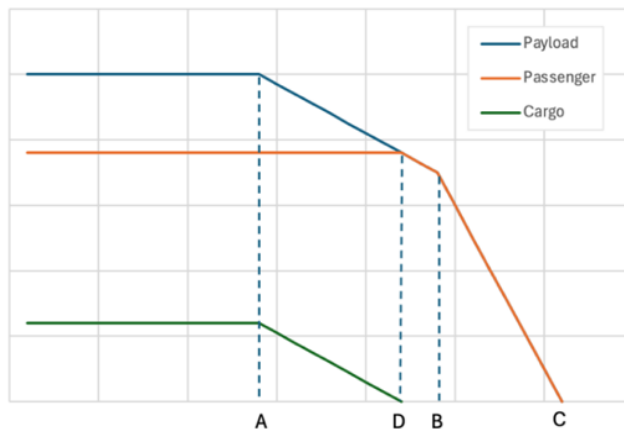
Passenger as a Function of Flight Distance

To obtain the total fuel consumption with the analytical curve the value obtained must be multiplied by the flight distance and number of passengers

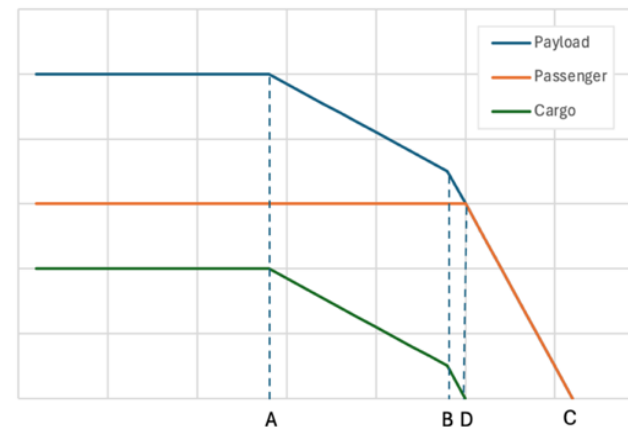
Reduction of Payload

1. Cargo
2. Passengers

Scenario 1



Scenario 2



Analytical Equation

Passenger as a Function of Flight Distance

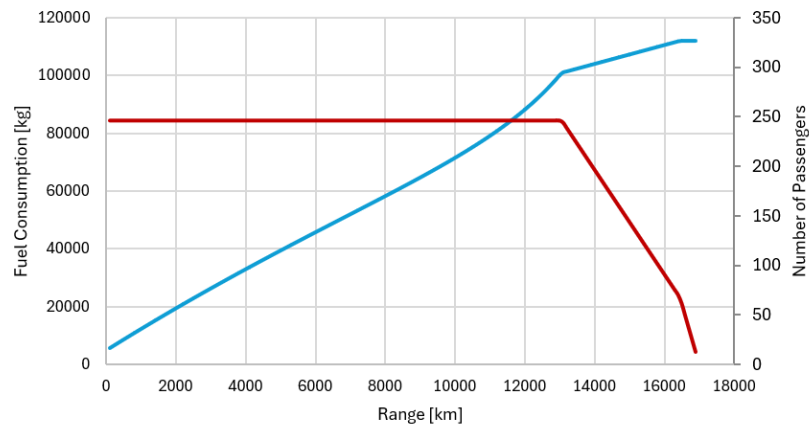
Case	R_D	$n_{pax}(R)$
1	$R_A - (n_{pax} \cdot m_{pax} - PL_A) \cdot \frac{R_B - R_A}{PL_A - PL_B}$	$\begin{cases} n_{pax}, & 0 < R < R_D \\ \left(PL_A - (R - R_A) \cdot \frac{PL_A - PL_B}{R_B - R_A} \right) \cdot \frac{1}{m_{pax}}, & R_D < R < R_B \\ \left(PL_B - (R - R_B) \cdot \frac{PL_B}{R_C - R_B} \right) \cdot \frac{1}{m_{pax}}, & R_B < R < R_C \end{cases}$
2	$R_B - (n_{pax} \cdot m_{pax} - PL_B) \cdot \frac{R_C - R_B}{PL_B}$	$\begin{cases} n_{pax}, & 0 < R < R_D \\ \left(PL_B - (R - R_B) \cdot \frac{PL_B}{R_C - R_B} \right) \cdot \frac{1}{m_{pax}}, & R_D < R < R_C \end{cases}$

Analytical Equation

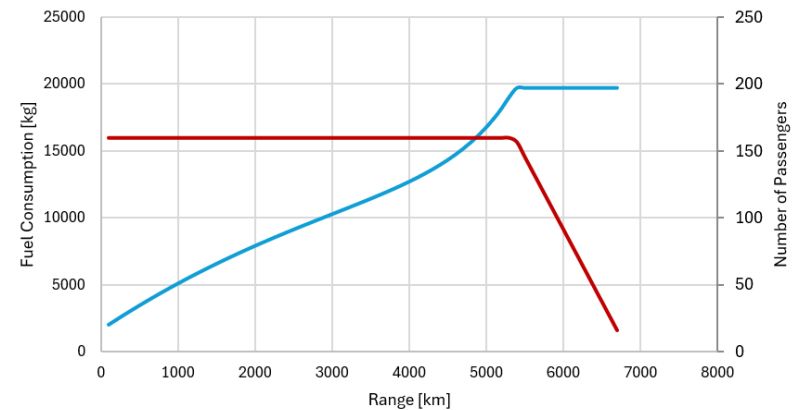
Fuel Consumption versus Flight Distance

Bathtub curve $\times$ number of passengers $\times$ range = absolute fuel consumption

A330-200 (scenario 1)



B737-300 (scenario 2)



Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

50 Most Used Passenger Aircraft

50 Most Used Passenger Aircraft

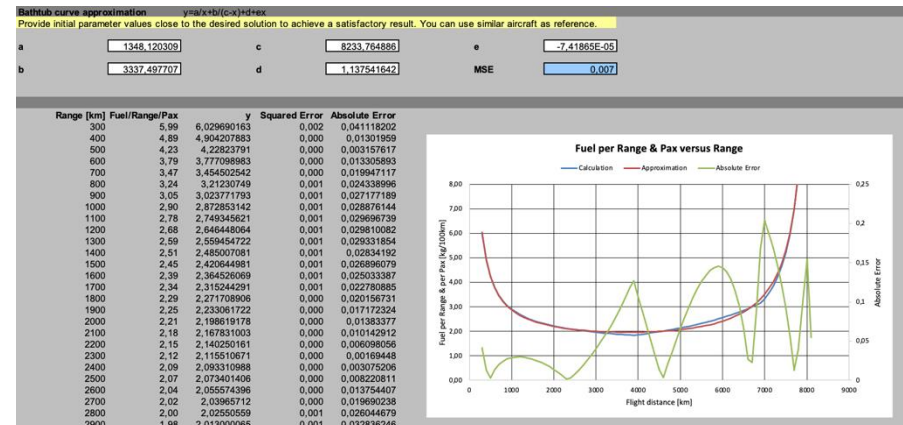
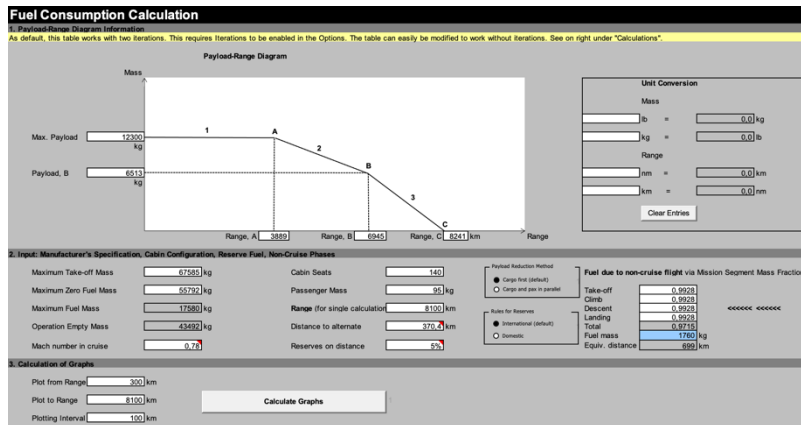
Excel Calculation

The bathtub curve calculation is applied to the 50 most commonly used passenger aircraft.



Airbus
A220-300.xlsm

EXCEL MODEL Burzlaff (2017) + EXTENDED VERSION WITH APPROXIMATION



50 Most Used Passenger Aircraft

Calculation Coverage

The bathtub curve calculation is applied to the 50 most commonly used passenger aircraft.

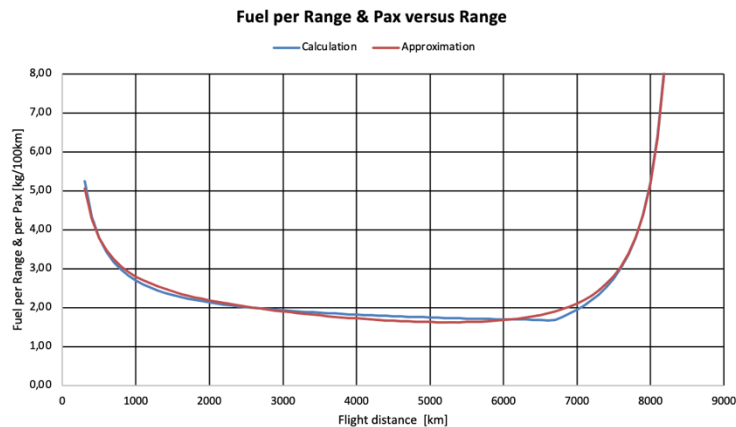
5 parameters/aircraft needed $\times$ 50 aircraft types = 250 parameters

95 % of passenger aircraft fuel consumption covered with a pocket calculator

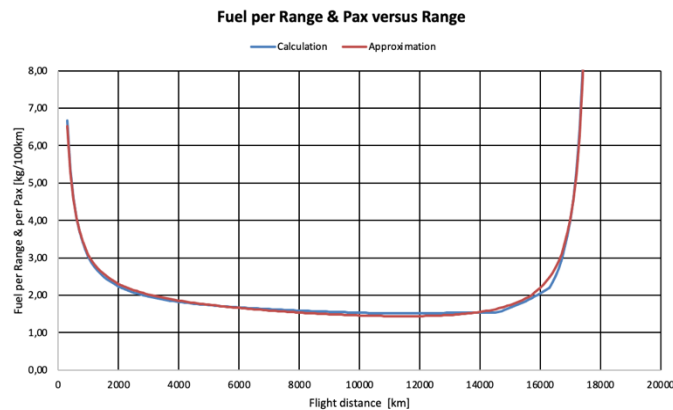
<i>Aircraft Type</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
Airbus A220-300	1348,12031	3337,49771	8233,76489	1,13754164	-7,419E-05
Airbus A319	1113,75406	2519,36874	7297,19973	2,32059919	-0,0003073
Airbus A320	1089,05003	2243,80354	6797,39028	2,0668814	-0,0002967
Airbus A320neo	999,196298	2219,55227	7898,35527	1,74686869	-0,0002174
Airbus A321	1156,73696	2235,46156	7500,23147	1,42895945	-0,0001986
Airbus A321neo	920,134195	2444,50705	8498,74378	1,75714258	-0,0002013
Airbus A330-200	2062,14959	4583,80728	16995,1223	2,79213931	-7,467E-05
Airbus A330-300	1571,74585	7785,79738	16501,8393	2,40711845	-0,0001496
Airbus A330-900	1945,75286	6123,7285	17999,2765	1,69701712	-3,429E-05
Airbus A350-900	1629,38613	4438,50048	17994,373	2,40891967	-0,0001076
Airbus A380-800	1726,00705	5481,70846	17893,6254	3,02129494	-0,0001284
ATR 42	1398,63148	78,2265422	3128,55446	-0,6093329	0,00150163

50 Most Used Passenger Aircraft

Examples



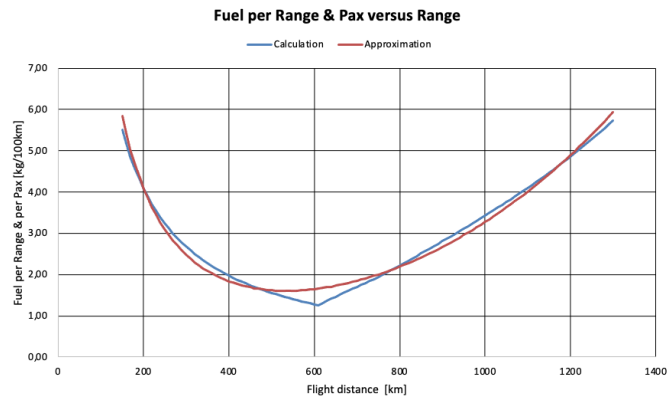
Airbus A321neo. Source: Airbus (2026)



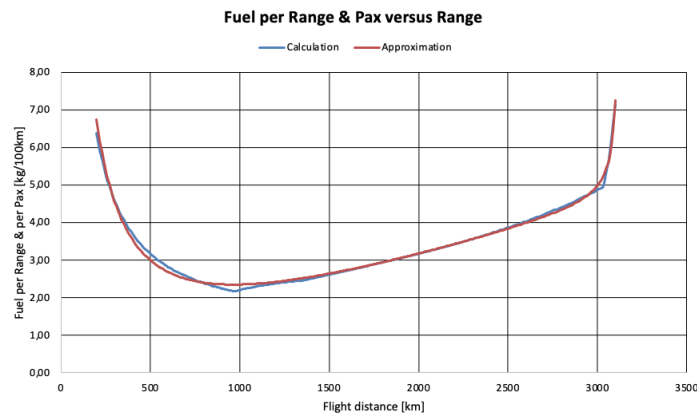
B777-200ER. Source: Austrian Airlines (2026)

50 Most Used Passenger Aircraft

Examples



Twin Otter. Source: Canada.ca (2025)



ATR 42. Source: Air Charter Service GmbH (2026)

50 Most Used Passenger Aircraft

Minimum Consumption

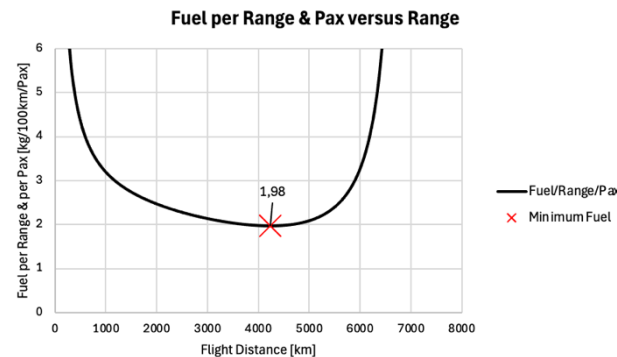
To determine the distance for minimum fuel we use the derivate.



Easy_Consumption.xlsx

$$y = \frac{a}{x} + \frac{b}{c-x} + d + ex$$

$$\frac{dy}{dx} = -\frac{a}{x^2} + \frac{b}{(c-x)^2} + e = 0$$



B737-800 Min Fuel Stage Length

Aircraft Type	Max. Payload (kg)	Payload, B (kg)	Range A (km)	Range B (km)	Range C (km)	Cabin Seats	a	b	c	d	e	Consumption RA (kg/100 km)	Minimum Fuel Stage Length (km)	Minimum Fuel (kg/100 km)
Airbus A220-300	12300	6513	3889	6945	8241	140	1348,12031	3337,49771	8233,76489	1,13754164	-7,419E-05	1,964	3782	1,963
Airbus A319	17400	15600	4630	5413	7300	134	1113,75406	2519,36874	7297,19973	2,32059919	-0,0003073	2,083	4648	2,083
Airbus A320	19750	16125	3882	5200	6800	150	1089,05003	2243,80354	6797,39028	2,0668814	-0,0002967	1,965	4287	1,943
Airbus A320neo	19250	15150	4528	6315	7900	165	999,196298	2219,55227	7898,35527	1,74686869	-0,0002174	1,642	4965	1,626
Airbus A321	24242	20152	4215	5460	7500	185	1156,73696	2235,46156	7500,23147	1,42895945	-0,0001986	1,547	4538	1,537
Airbus A321neo	23950	21350	5649	6482	8500	206	920,134195	2444,50705	8498,74378	1,75714258	-0,0002013	1,641	5270	1,628
Airbus A330-200	45813	6350	8584	16455	17000	246	2062,14959	4583,80728	16995,1223	2,79213931	-7,467E-05	2,936	10052	2,907

Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

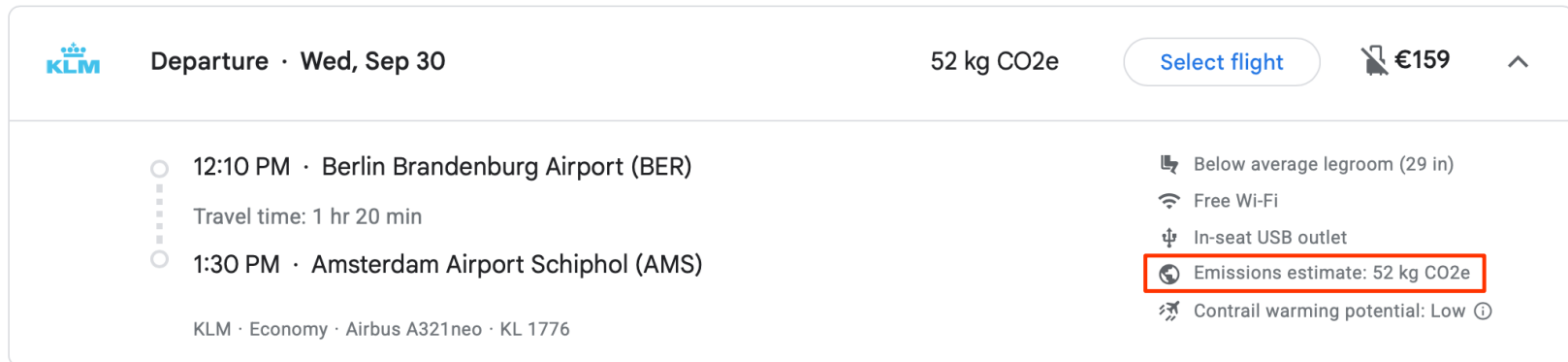
Discussion in Society

Discussion in Society

Easy Calculation of CO₂ Emissions

Fuel consumption directly relates to CO₂

Given a flight distance we can calculate fuel/pax, and consequently emissions



The screenshot shows a flight offer from KLM. At the top, it says 'Departure · Wed, Sep 30' and '52 kg CO₂e'. There is a 'Select flight' button and a price of '€159'. Below this, the flight details are listed: '12:10 PM · Berlin Brandenburg Airport (BER)' and '1:30 PM · Amsterdam Airport Schiphol (AMS)'. The travel time is '1 hr 20 min'. The aircraft is 'KLM · Economy · Airbus A321neo · KL 1776'. On the right side, there are several icons and text: 'Below average legroom (29 in)', 'Free Wi-Fi', 'In-seat USB outlet', and 'Emissions estimate: 52 kg CO₂e' (which is highlighted with a red box). At the bottom right, it says 'Contrail warming potential: Low'.

Flight offer BER-AMS from Google Flights (2026)

A321neo → 20.45 kg/pax (KLM flight)

$20.45 \text{ kg/pax} \times 3.15 \text{ kgCO}_2 / \text{kg fuel} \approx \mathbf{64 \text{ kg CO}_2 / \text{pax}}$



Airbus A321neo from Airbus (2026)

Discussion in Society

Should we fly short range? Or take the train?

The bathtub curve is accessible to anyone and gives fast answers.

We can choose the most suitable aircraft for a given distance.

Berlin – Amsterdam

Desired stage length (km)

A321neo → 20.45 kg/pax = 3.55 kg/pax/100 km (KLM flight)

Twin Otter → 9.35 kg/pax = 1.67 kg/pax/100 km



Fuel_Pax_Calculator.xlsx



Airbus A321neo from Airbus (2026)



Twin Otter from Canada.ca (2025)

Desired stage length 577 (km)																
Aircraft Type	Max. Payload (kg)	Payload, B (kg)	Range A (km)	Range B (km)	Range C (km)	MTOM (kg)	MZFM (kg)	Cabin Seats	a	b	c	d	e	Total Fuel per Passenger (kg/Pax)		
Airbus A220-300	12300	6513	3889	6945	8241	67585	55792	140	1348,12031	3337,49771	8233,76489	1,13754164	-7,419E-05	22.31		
Airbus A319	17400	15600	4630	5413	7300	75500	58500	134	1113,75406	2519,36874	7297,19973	2,32059919	-0,0003073	25.67		
Airbus A320	19750	16125	3882	5200	6800	78000	62500	150	1089,05003	2243,80354	6797,39028	2,0668814	-0,0002967	23.91		
Airbus A320neo	19250	15150	4528	6315	7900	79000	62800	165	999,196298	2219,55227	7898,35527	1,74686869	-0,0002174	21.10		
Airbus A321	24242	20152	4215	5460	7500	93500	77800	185	1156,73696	2235,46156	7500,23147	1,42895945	-0,0001986	21.01		
Airbus A321neo	23850	21350	5649	6482	8500	97000	73300	208	920,134195	2444,50705	8498,74378	1,75714258	-0,0002013	20.45		
Airbus A330-200	45813	6350	8584	16455	17000	242000	170000	246	2062,14959	4583,80728	16995,1223	2,79213931	-7,467E-05	38.09		
Airbus A330-300	45359	34927	7723	10038	16500	242000	175000	300	1571,74585	7785,79738	16501,8393	2,40711845	-0,0001496	31.93		
Airbus A350-900	45813	5000	7723	17372	18000	242000	181000	300	1945,75286	6123,7285	17999,2765	1,69701712	-3,429E-05	31.16		
Airbus A350-900	53700	24800	10797	15890	18000	280000	195700	315	1629,38613	4438,50048	17994,373	2,40891967	-0,0001076	31.31		
Airbus A380-800	83571	34286	12131	16298	17900	575000	369000	555	1726,00705	5481,70846	17893,6254	3,02129494	-0,0001284	36.09		
ATR 42	5045	2455	969	3034	3241	18600	16700	48	1398,63148	78,2265422	3128,55446	-0,6093329	0,00150163	15.65		
ATR 72	7000	4000	926	3087	3426	22500	20500	70	1021,19546	213,726946	3339,14969	-0,1621599	0,00089199	12.69		
Beechcraft 1900D	2189	1896	256	707	2306	7764	7120	19	1307,759	230,607723	2377,1471	-0,0952914	0,00261495	21.97		
Boeing 717-200	12020	8431	2185	3704	4630	49895	42638	106	1196,82939	1957,9112	4626,6299	1,32803563	-0,0002819	21.49		
Boeing 737 MAX 8	20930	16983	4842	6426	8150	82190	65952	162	1225,96207	1539,86988	8125,80198	1,40208079	-7,204E-05	21.29		
Boeing 737 MAX 9	23791	20480	4630	5843	7780	88314	70987	180	1059,14494	1931,27533	7766,19224	1,65600107	-0,0001953	21.05		
Boeing 737-300	15435	10763	3439	5159	6700	61235	48308	128	1032,5886	3189,81182	6701,81861	1,95602518	-0,0003054	23.60		
Boeing 737-400	19979	15478	3258	4630	6200	68039	53070	146	938,482348	2594,42211	6198,83284	2,28615404	-0,0003651	24.02		
Boeing 737-500	15356	10022	2910	4994	6570	60555	46493	108	1105,15914	3838,04122	6567,75043	3,07735743	-0,0004725	30.93		
Boeing 737-700	17554	11589	3945	6186	7408	70080	55202	128	1127,71942	2286,30903	7400,53333	2,32996192	-0,0002736	25.74		
Boeing 737-800	21184	16716	3750	5223	6850	79015	62731	160	1036,45963	2331,88753	6843,21636	2,04216562	-0,0002843	23.35		

Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

Case Study (ISO)

Intermediate Stop Operation (ISO)

Definition

Flight strategy in which a long route is divided into two segments, with a stop for refueling

Not common but can be considered in specific cases because of

- Range limitations
- Payload constraints
- Fuel efficiency

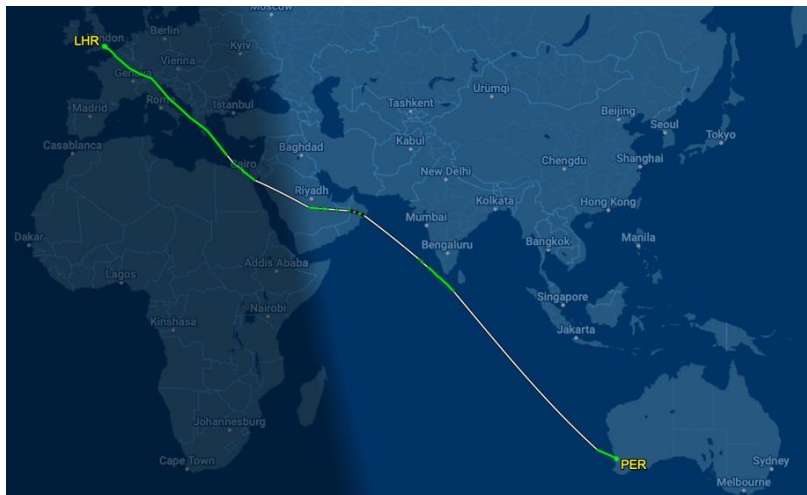
We must assess

- **Fuel consumption**
- Economic implications
- Operational implications
- Regulatory considerations

Intermediate Stop Operation (ISO)

Potential ISO Routes and Aircraft

London-Perth nonstop operated by Qantas



QFA of the 2nd July 2025 Flight from Flightaware (2025)



Boeing 787-9 from Australian Aviation (2023)

QFA9	
Took-off from	Perth, Australia (PER)
Landed at	London, UK (LHR)
Take-off time	WED 02-07-2025 02:17 AM AWST
Landing time	WED 02-07-2025 12:21 PM BST
Total trip time	17 h 4 min
Airline	Qantas
Aircraft	Boeing 787-9 Dreamliner
Actual distance	15,190 km
Direct distance	14,525 km

290 seats

passengers limited to 268

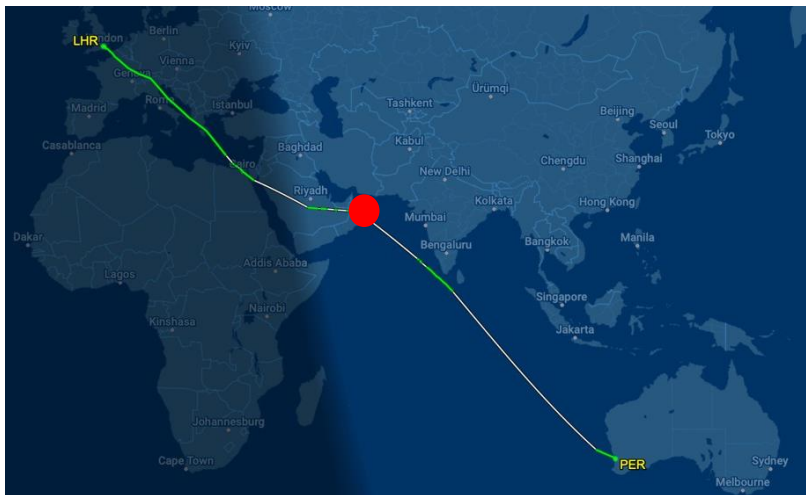


94,129 kg
351.22 kg/pax

Intermediate Stop Operation (ISO)

Same Aircraft but Two Legs (ISO)

Stop to refuel in Dubai (approximately halfway)



QFA of the 2nd July 2025 Flight from Flightaware (2025)

290 seats

No passenger limitation

Max 



Boeing 787-9 from Australian Aviation (2023)



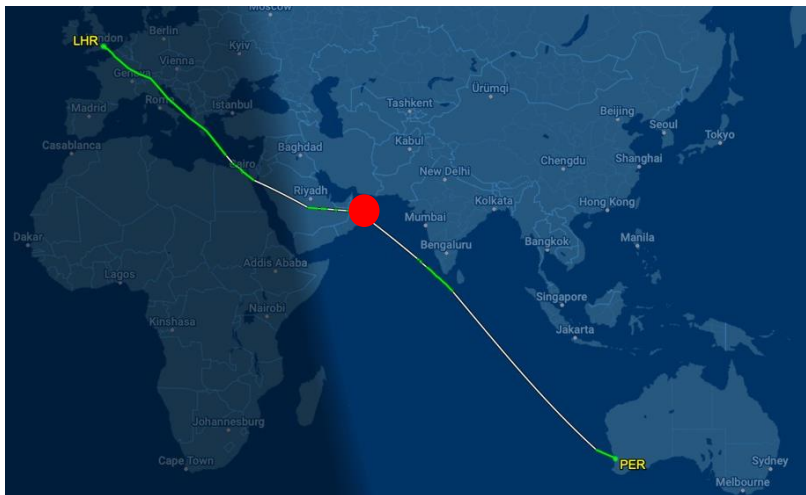
Extra landing and take-off
increase fuel consumption

105,842 kg
364.97 kg/pax

Intermediate Stop Operation (ISO)

Most Suitable Airplane and Two Legs (ISO)

Stop to refuel in Dubai (approximately halfway)



QFA of the 2nd July 2025 Flight from Flightaware (2025)

375 seats

No passenger limitation

Max 



B777-200ER from Austrian Airlines (2026)

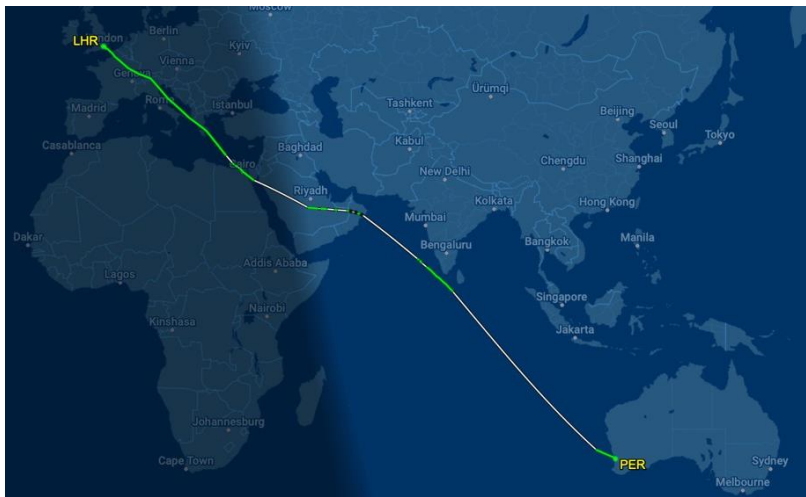


91,334 kg
243.56 kg/pax

Intermediate Stop Operation (ISO)

EXTRA CASE: Most Suitable Airplane and Direct

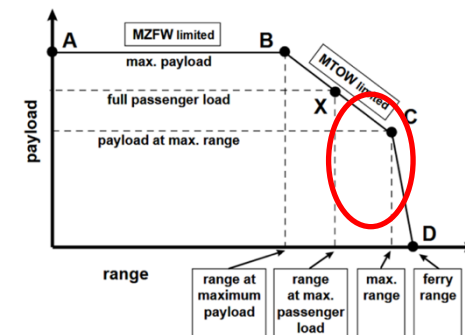
London-Perth nonstop with a B777-200 ER



QFA of the 2nd July 2025 Flight from Flightaware (2025)



B777-200ER from Austrian Airlines (2026)



375 seats
passengers limited to 333



87,593 kg
263.04 kg/pax

Intermediate Stop Operation (ISO)

Conclusions on the Case Study

	B787-9	B787-9 (ISO)	B777-200ER (ISO)	B777-200ER
Total Fuel [kg]	94,129	105,842	91,334	87,593
Change Percentage [%]	0	+12.44	-2.97	-6.94
Number of Passengers	268	290	375	333
Fuel per Passenger [kg/Pax]	351.22	364.97	243.56	263.04
Change Percentage [%]	0	+3.91	-30.65	-25.11
Fuel Consumption [kg/Pax/100km]	2.31	2.40	1.60	1.73
Change Percentage [%]	0	+3.9	-30.7	-25.1

-7.5%

ISO can lead to a higher fuel consumption in some cases

If done with an especially selected aircraft for the stage length, it can reduce the fuel per passenger 7.5%

Fuel Consumption of the 50 Most Used Passenger Aircraft as Function of Flight Distance

Summary and Conclusions

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Summary and Conclusions

- The bathtub curve shows fuel use per passenger and flown distance, an important pattern that isn't well known or understood
- This study created a simple equation for the bathtub curve, using just 5 parameters per aircraft
- Calculated for 50 of the most common aircraft, covering about 95% of passenger aircraft, simple enough to use with a basic calculator
- Built an Excel tool to quickly find the most suitable aircraft for a given route
- The equation can help discuss bigger social questions like flying vs taking the train
- The tool was applied to a case study (Perth–London) on splitting long flights into two shorter legs (ISO) — this can save fuel, but adds costs, time, and passenger inconvenience, so it needs careful evaluation

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Quote this document:

NISA LÓPEZ, Joel, 2026. *Fuel consumption of the 50 Most Used Aircraft as Function of Flight Distance*. Presentation of the Bachelor Thesis. Aircraft Design and Systems Group (AERO), HAW Hamburg, 2026-09-10. Available from: <https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2025-07-11>.

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