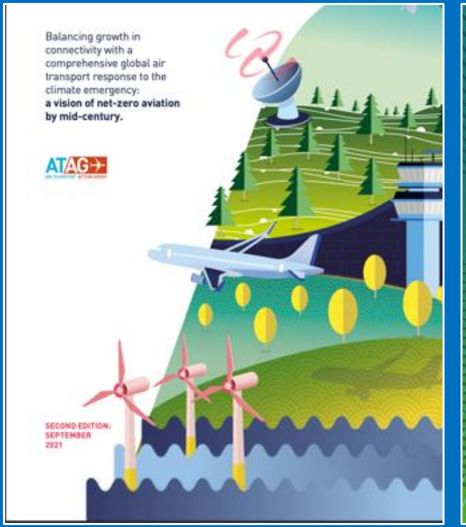
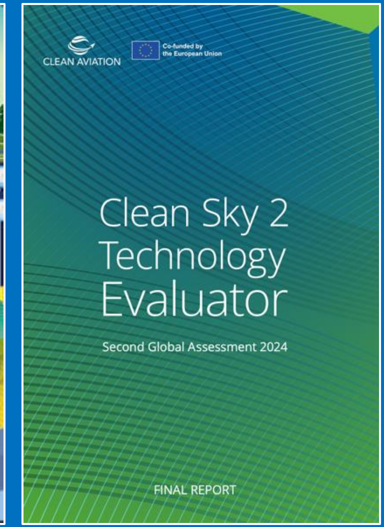
How to get to Aviation Net-Zero CO_2 in 2050

“Challenges and Potential”

(Market/Growth, SAF, RDT&E, Optimal aircraft, Airbus and Boeing)

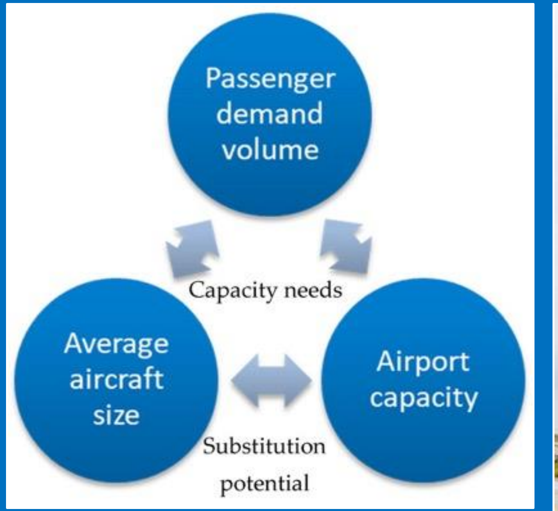


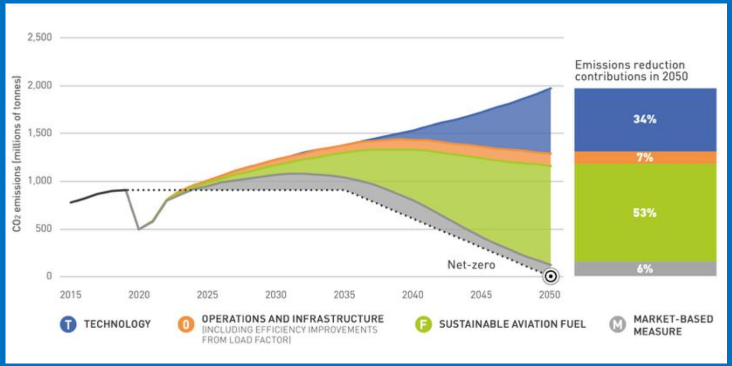


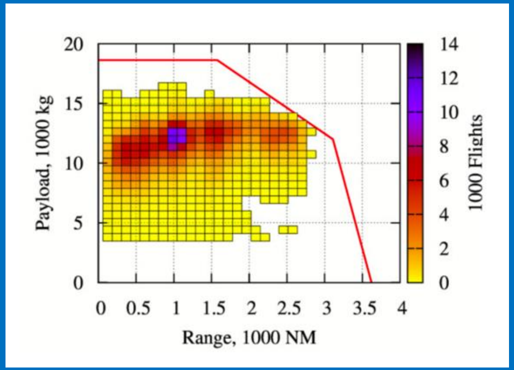
Fred Abbink

HFAIAA & FRAeS

CEAS President 2014-2016

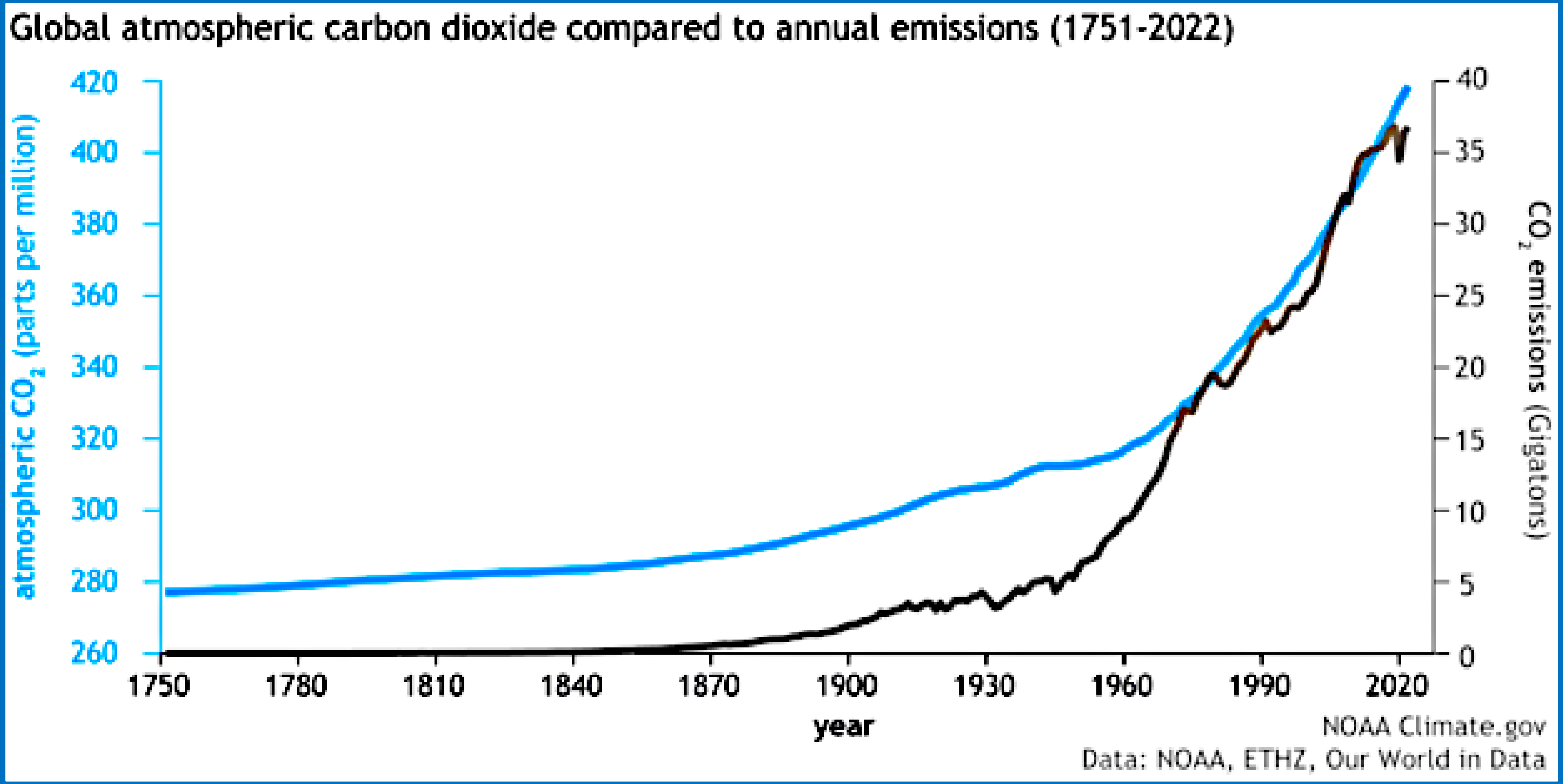


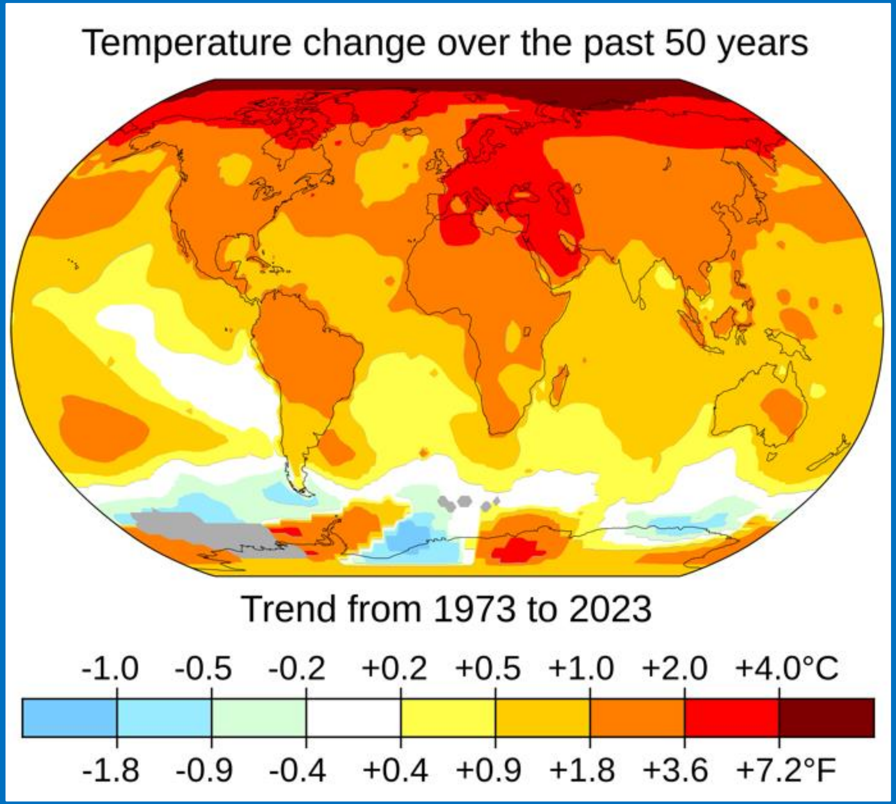




June 4, 2025, SVFW, Zürich

Low-cost fossil energy provided great prosperity and mobility, but also CO2 and Global Warming





2015: Paris Agreement – The World leaders agreed that the global temperature should not rise more than 1.5 C above the 19th Century (To global warming there are also important Non-CO2 contributions)

Source: Andreas Malm –The rise of Steam Power and the Roots of Global Warming

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  - **Development of the swept-wing jet passenger aircraft**
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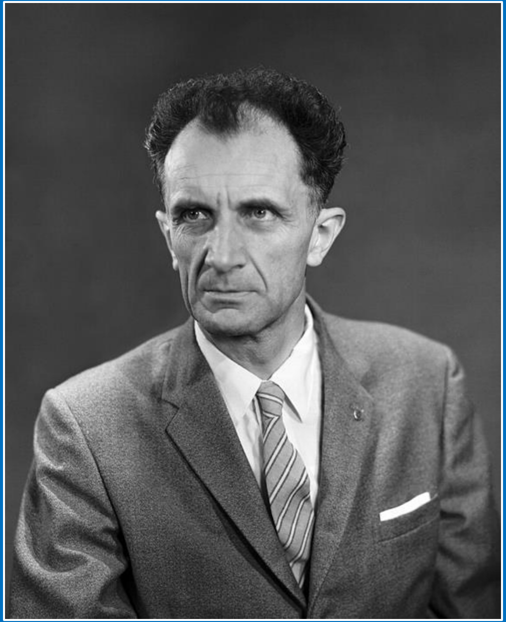
World War 2: Introduction of Swept-Wing fighter



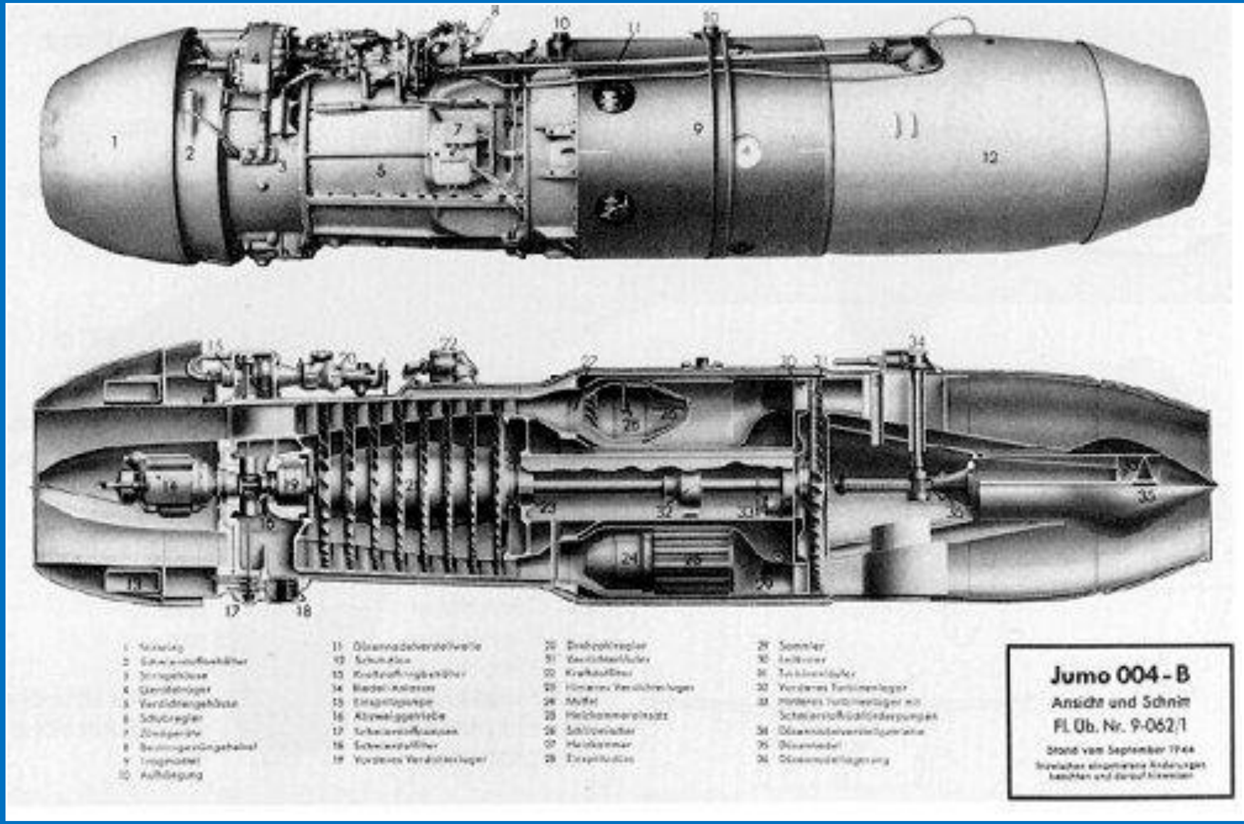
North American P-51 Mustang
- Packard (Rolls Royce) Merlin 60 engine
- Straight, laminar flow wing, AR 5.83
- Max Speed 710 km/hr (M 0.58)
- Service ceiling 41.900 ft
- Range 2260 km
- First flight October 1940

Adolf Busemann
- 1935 Volta Congress
  Swept-Wing Concept
- May 1945 Braunschweig
  Swept-wing test results
- 1947 Operation Paperclip
  moved to USA

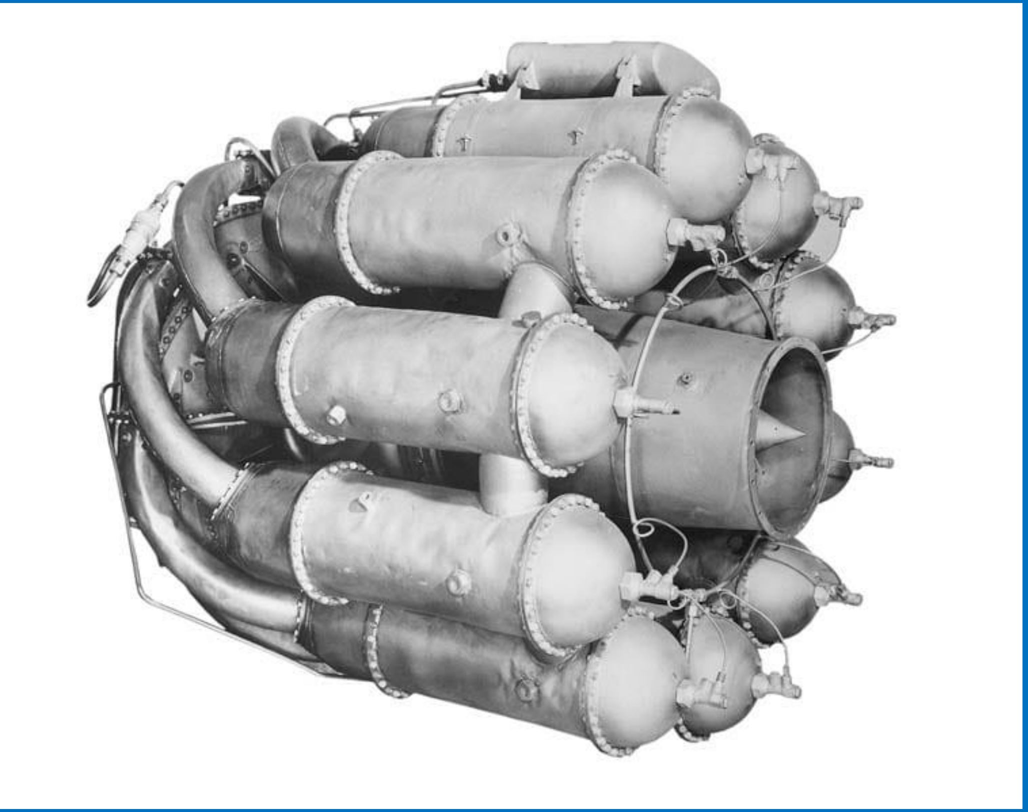
Messerschmitt Me 262
- 2 Jumo 4 axial-flow gas turbines
- Swept wing, 18,5°, AR 7.32
- Max Speed 870 km/hr (M 0.73)
- Service ceiling 37.600 ft
- Range 1050 km
- First flight April 1941

The Me 262 burned 7-10 times more fuel per hour, but at a much higher speed

World War 2: Introduction of Gas Turbine Engine
Junkers Jumo 004 axial and Whittle W.1 radial gas turbines



Jumo 004 overhaul time 10-20 hours. Over 6.000 Jumo 004s were built between 1944 and 1945



RR Welland overhaul time 180 hours. 167 Wellands were produced between 1943 and 1946

Source: K. von Gersdorf - Flugmotoren und Strahltriebwerke

From Swept Jet Bomber to turbofan passenger aircraft

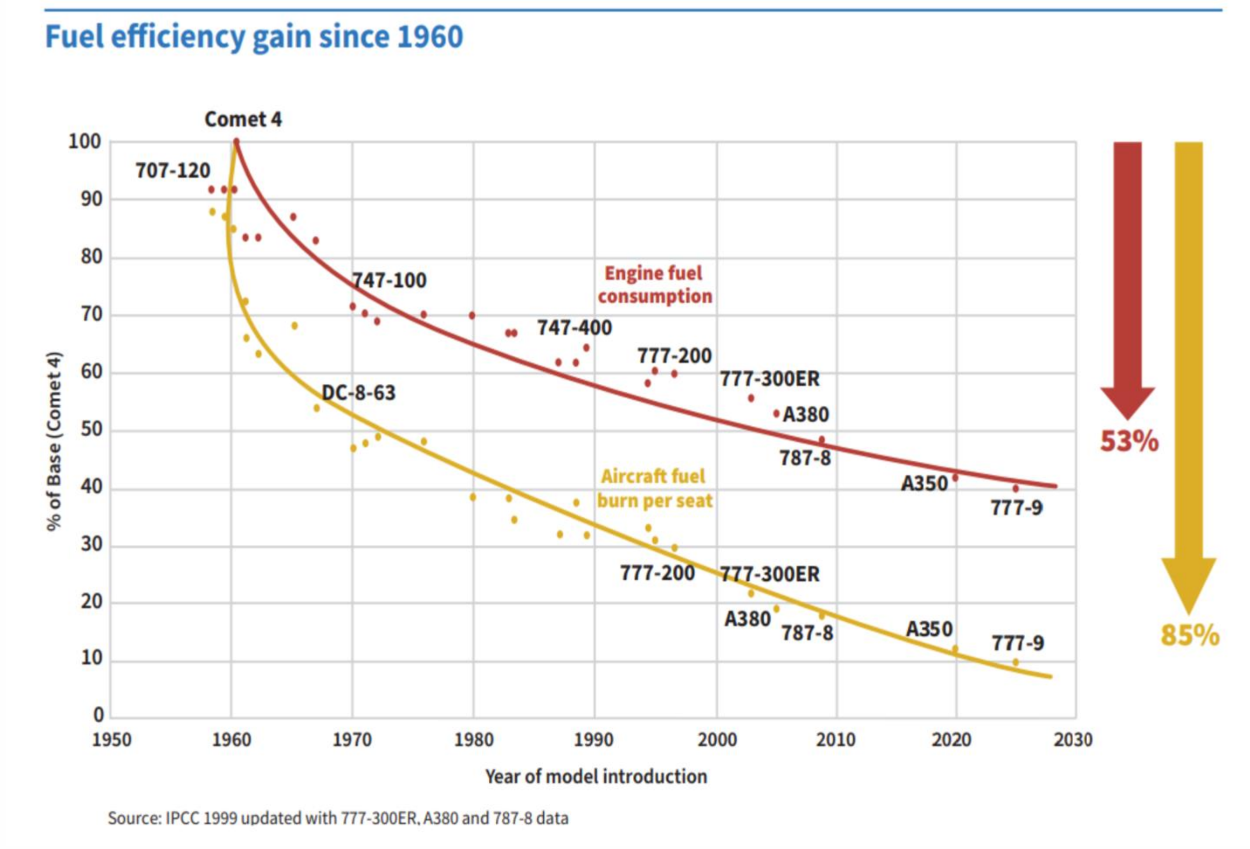
B-47 Stratojet

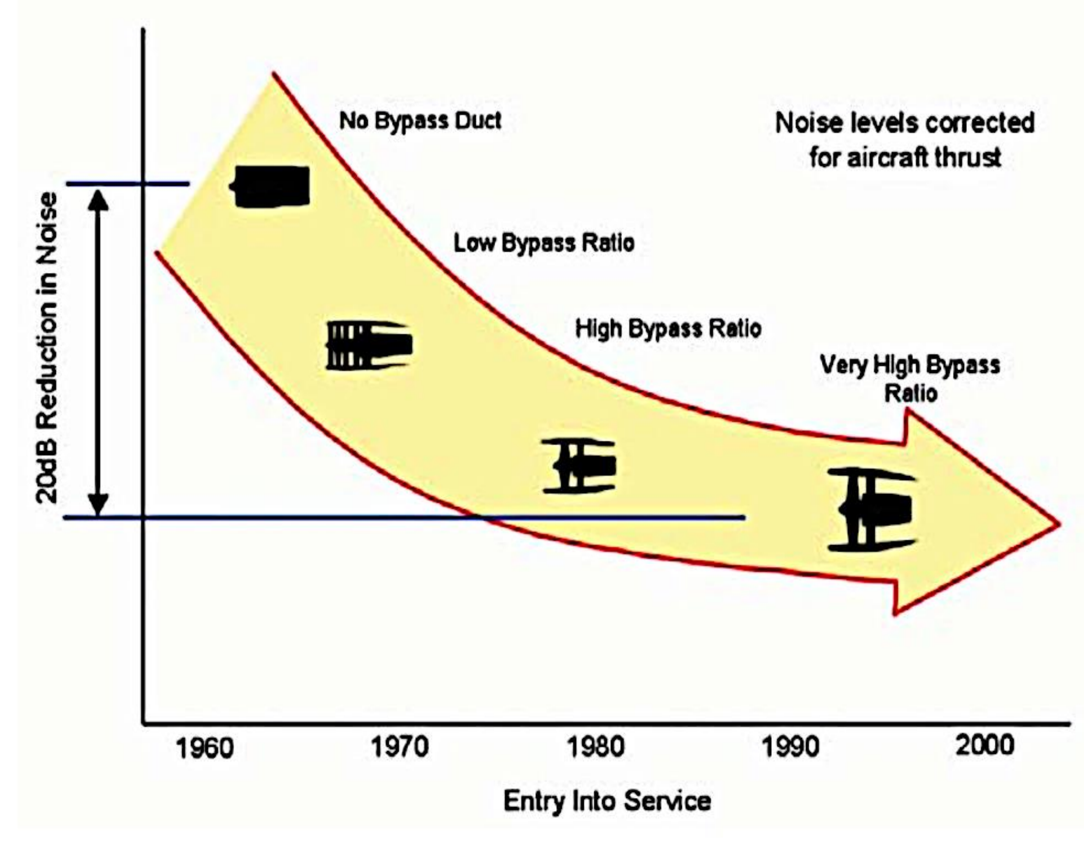
- 6 GE J47-GE-25 Turbojet engines
- Swept wing, 35°, AR 9.4
- Maximum speed 977 km/hr (M 0.85)
- Payload 11,340 kg
- Service ceiling 40,500 ft
- Combat range 5200 km
- First flight Dec 1947

Boeing 707

- 4 Pratt & Whitney JT3C-6 turbofans
- Swept wing, 35°, AR 7.2
- Cruise speed 950 km/hr (Mach 0.85)
- 137-173 passengers
- Service ceiling 42,000 ft
- Range 5600 km
- First flight Dec 1957

Development of (jet) fuel consumption and noise





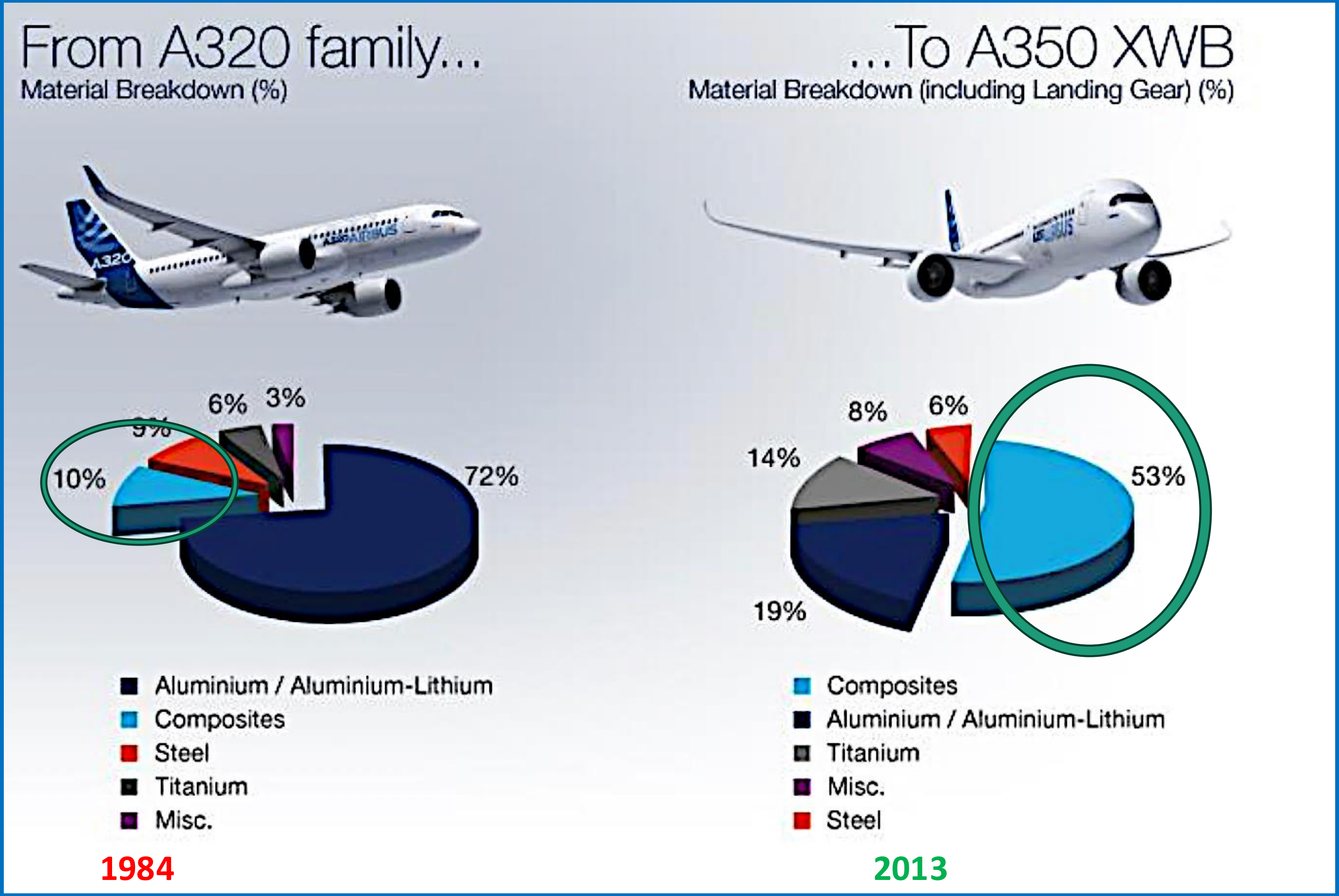
The engines size/fan diameter increased also. Requiring more distance from wing to ground

Engine fan diameter

1960: B737-200	JT8D	BPR 0	125 cm
1976: A320 ceo	CFM56	BPR 6	152 cm
2013: A320 neo	CFM Leap A1	BPR 11	195 cm

Sources: IPCC 1999 updated and N.T. Birch 2020 Vision. The prospects for Large Civil Aircraft Propulsion

Weight reduction with composites



Source: Airbus

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1967 Airbus

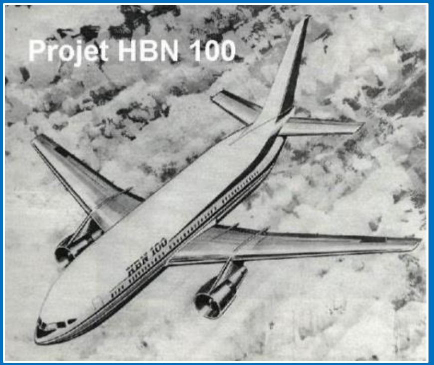
Toulouse or not “To Lose” that is the question

- **1960s** French and UK 200-seater airliner plans:
  - Sud Aviation: Galion,
  - BAC: BAC 2-11,
  - HSA/Breguet/Nord Aviation: HBN 100

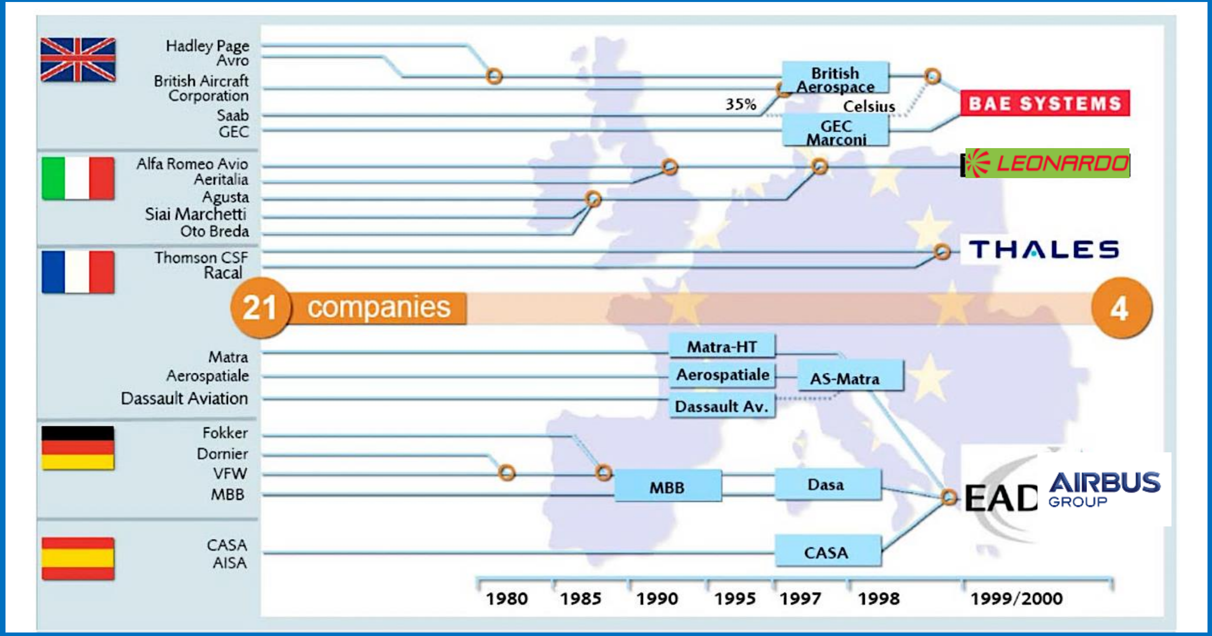
- **July 1967** France, Britain and Germany ministers agreed to take appropriate measures for the joint development and production of an “**airbus.**” (FR 37.5 %, UK 37.5%, GE 25%). Rogier Béteille became technical director of A300 Programme.

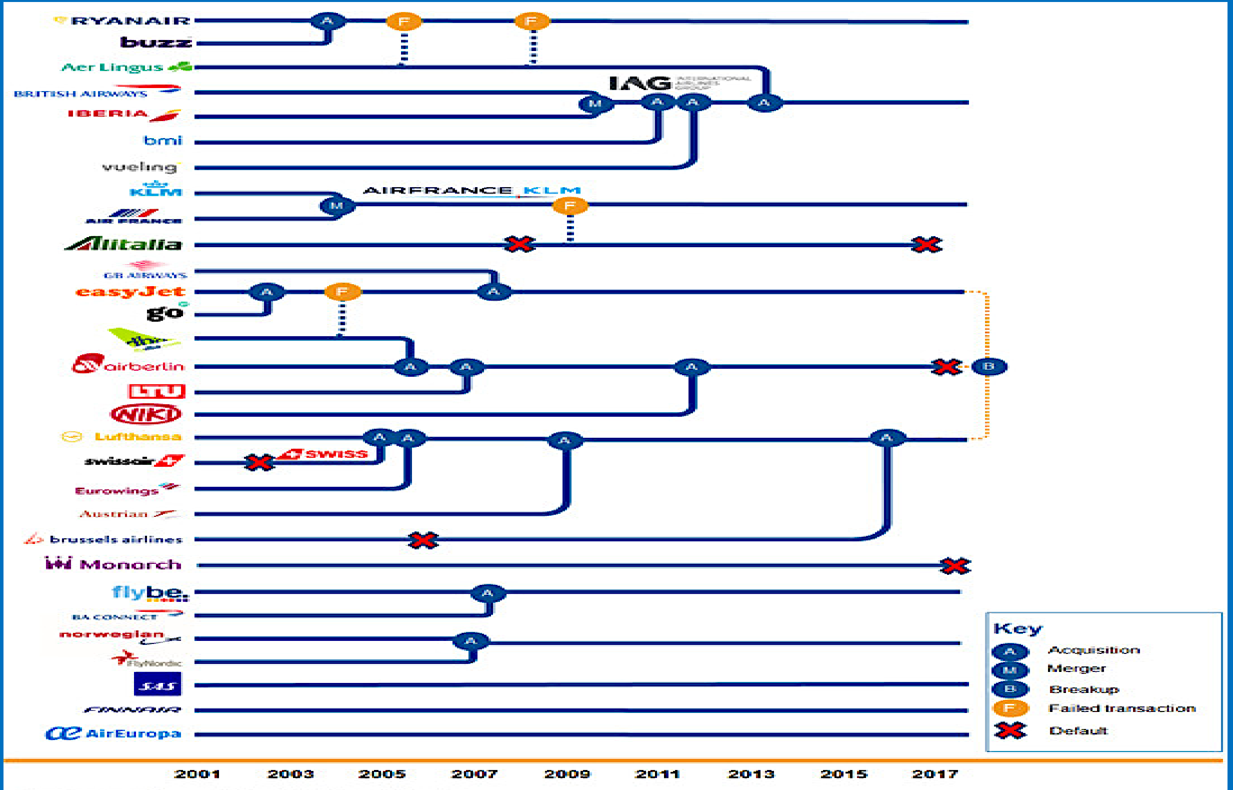
- **Dec 1968** Britain announced to pull out. (Airbus Brexit). GE proposed to step up to 50% if FR did the same. HSA needed £35 million for tools to design and build the wings. GE provided the loan.

- **May 1969 Paris Airshow** A300 born as partnership (GIE) of Sud Aviation, HSA and Deutsche Airbus. A300B 300 passengers, 5000 km range

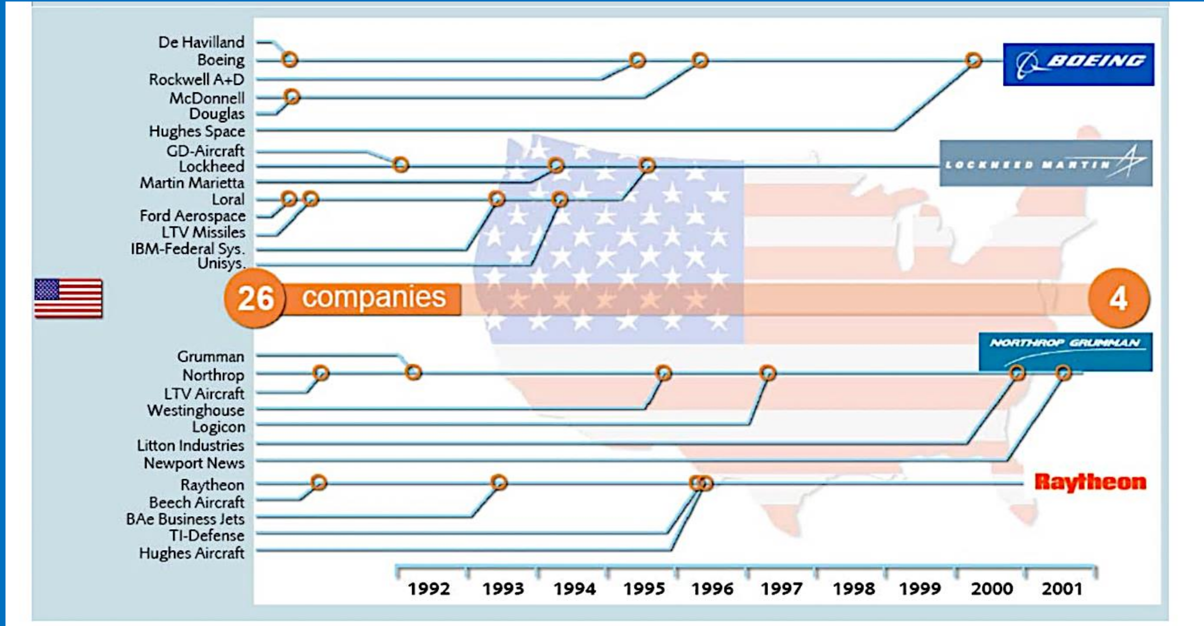


Aerospace Industry and Airline Consolidation

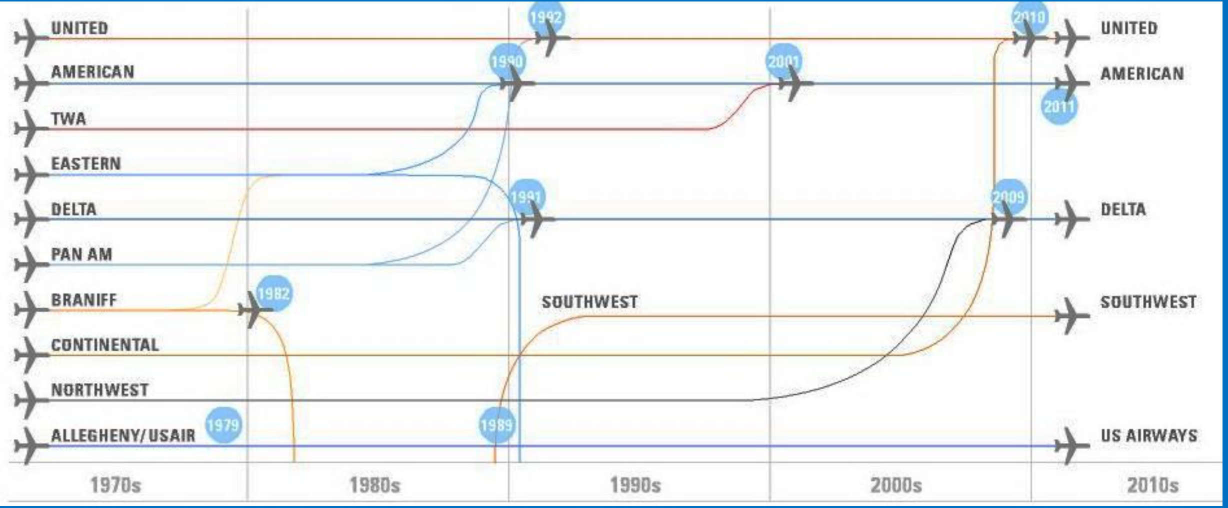




Source: Scope presentation, consideration of deals involving controlling stakes

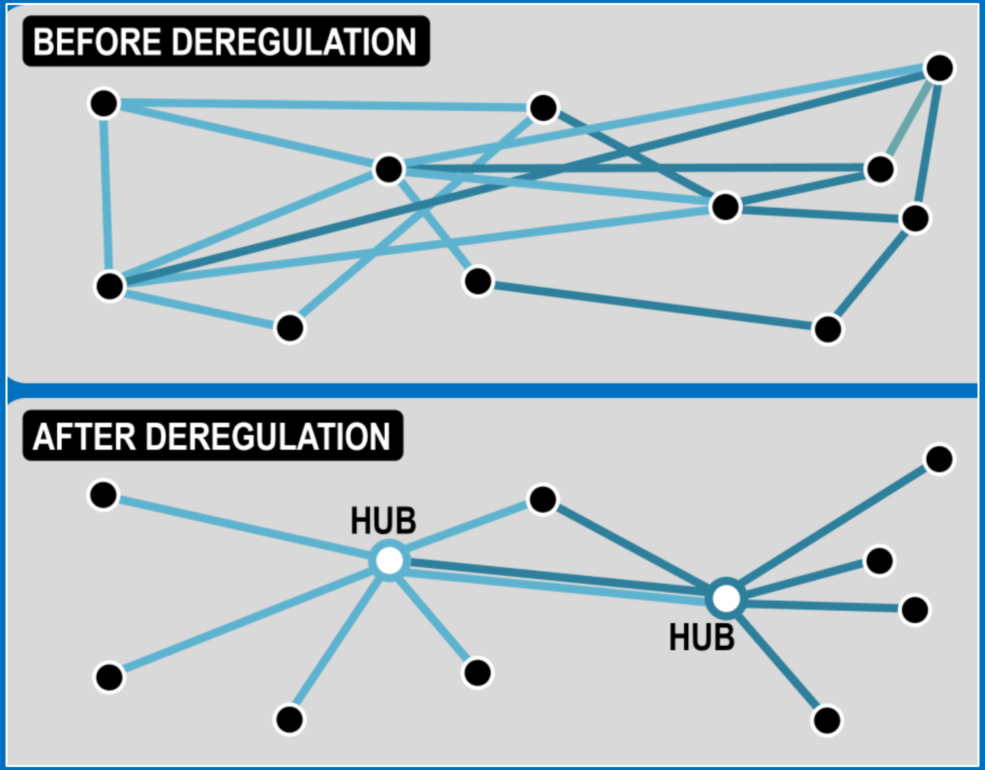


Source: EADS.



Deregulation, Hub and Spoke, Alliances and Code-sharing

1978 USA Airline Deregulation
1987 European Airline Deregulation



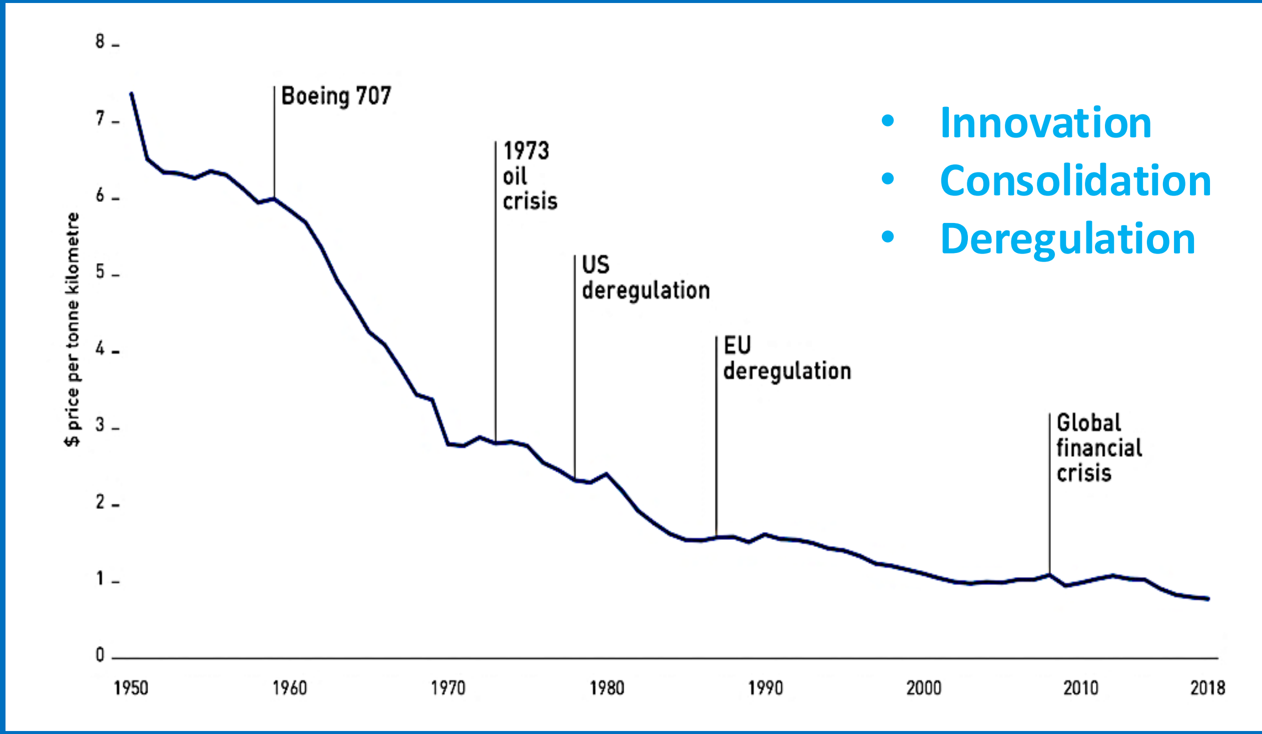
Airline Alliances

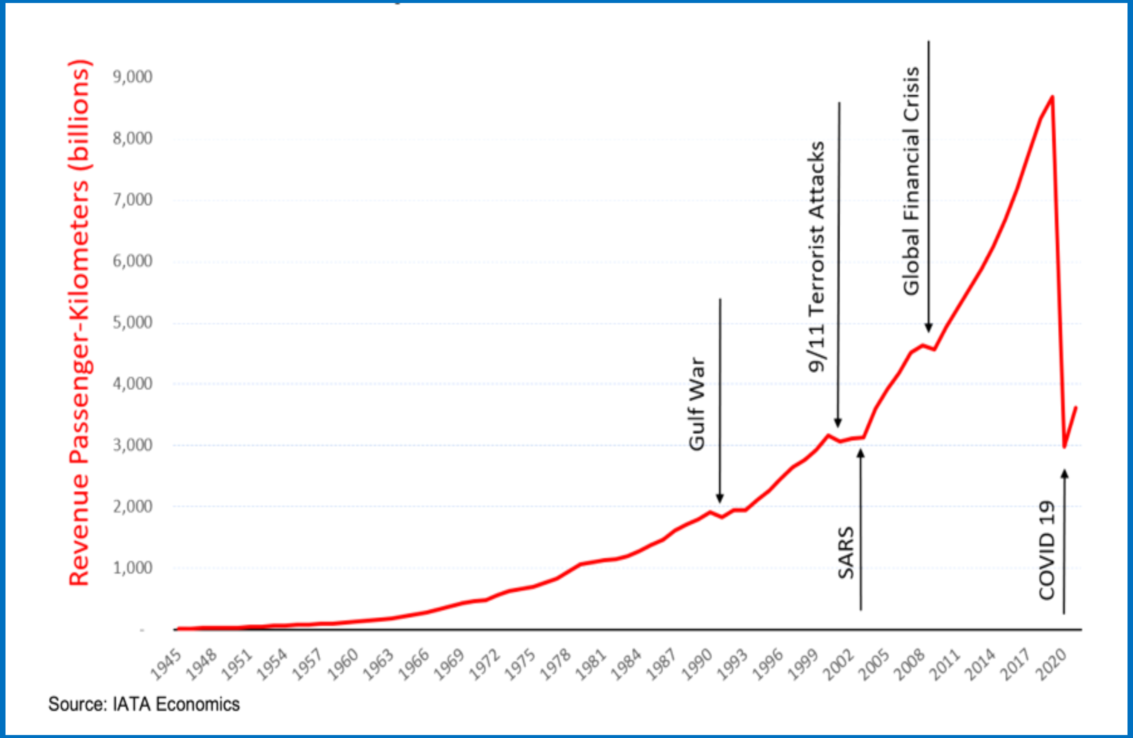
	oneworld	SkyTeam	STAR ALLIANCE
	1999	2000	1997
Members	15	19	26
Destinations	998	1058	1289
Countries	175	169	192

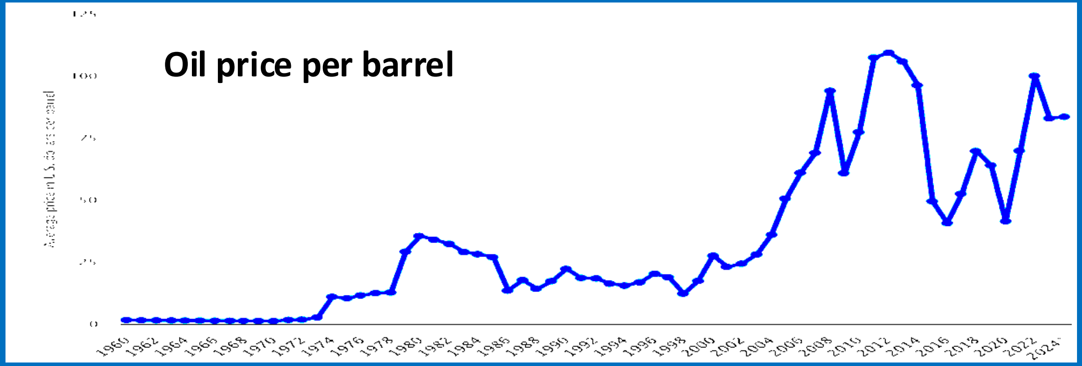
Code Sharing

Flight	Departure Time
QR 149 Qatar Airways	07:50
IB 7902 Iberia / Operated by Qatar Airways 149	07:50
LA 5315 LATAM Airlines / Operated by Qatar Airways 149	07:50
MH 9249 Malaysia Airlines / Operated by Qatar Airways 149	07:50
UL 3421 SriLankan Airlines / Operated by Qatar Airways 149	07:50
VA 6083 Virgin Australia / Operated by Qatar Airways 149	07:50
WY 6307 Oman Air / Operated by Qatar Airways 149	07:50

Development of Jet Air Transport costs and production
(Ticket price and RPK growth from 1960-2020)





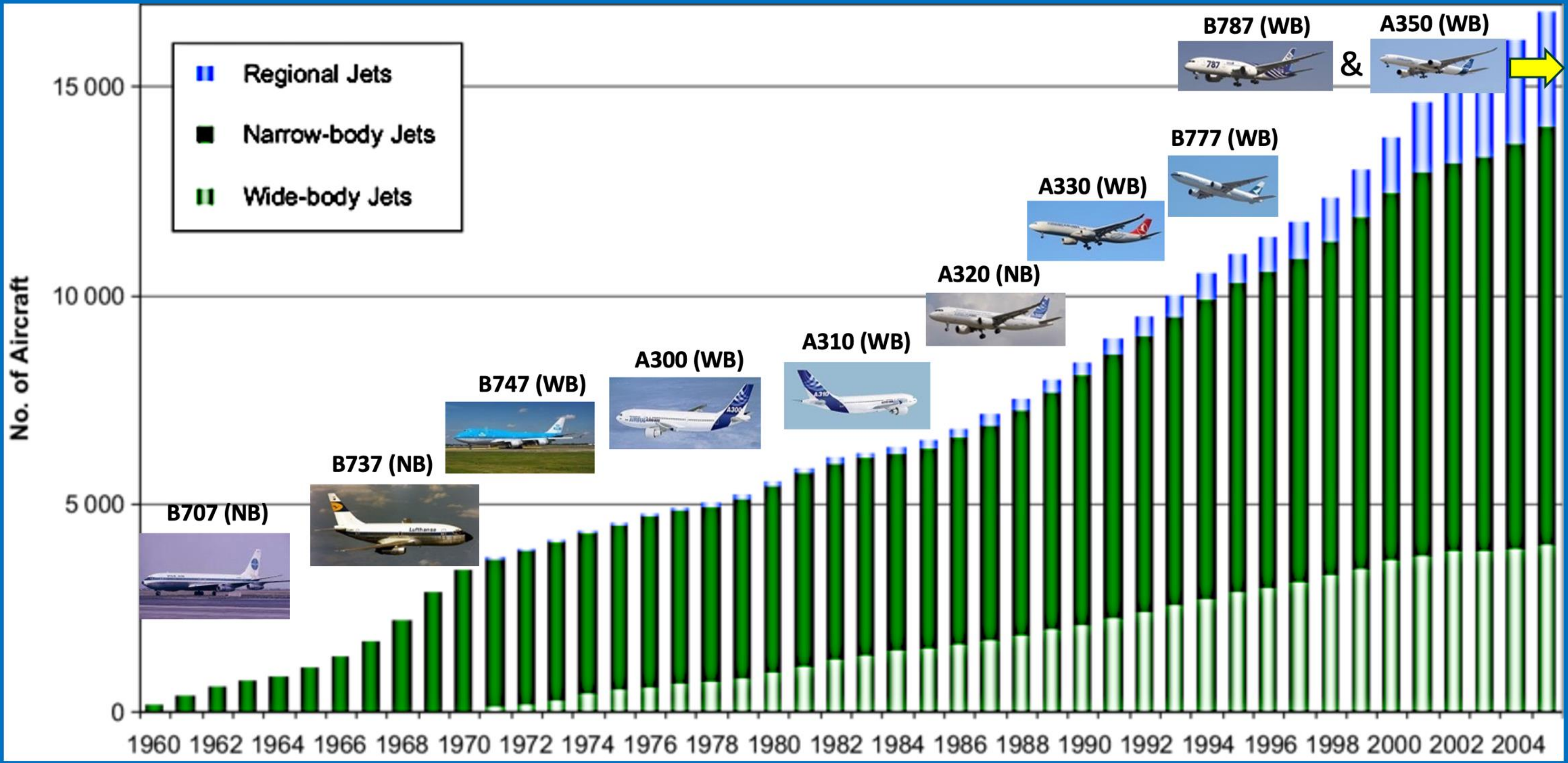


- In the 1980s about 80% were business passengers
- In 2023 about 90% were passengers for Leisure and Visiting Friends and Relatives (VFR)

Sources: ICAO 2019, IATA and Statista

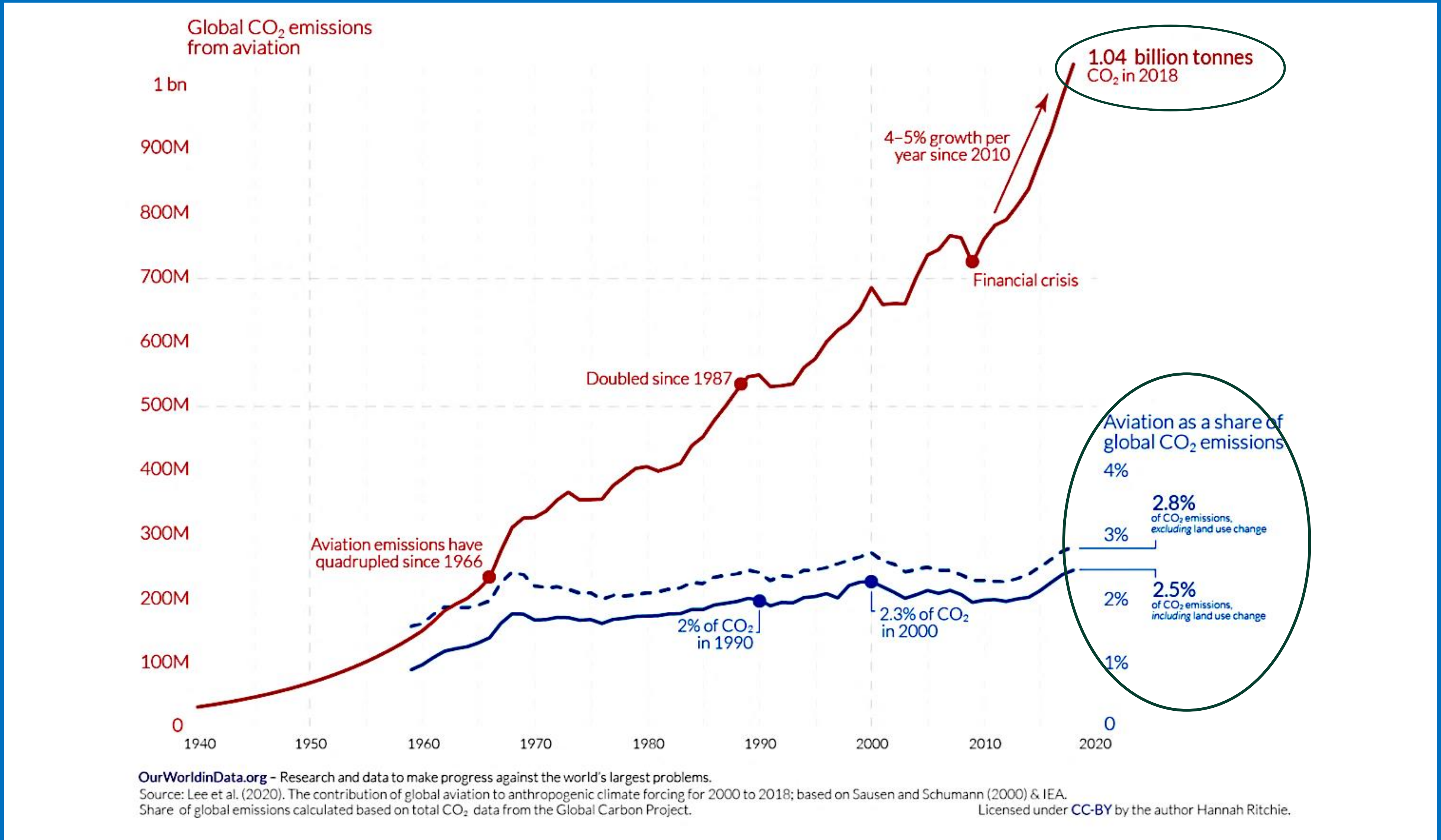
Development of the global airline jet fleet

(Boeing and Airbus examples)



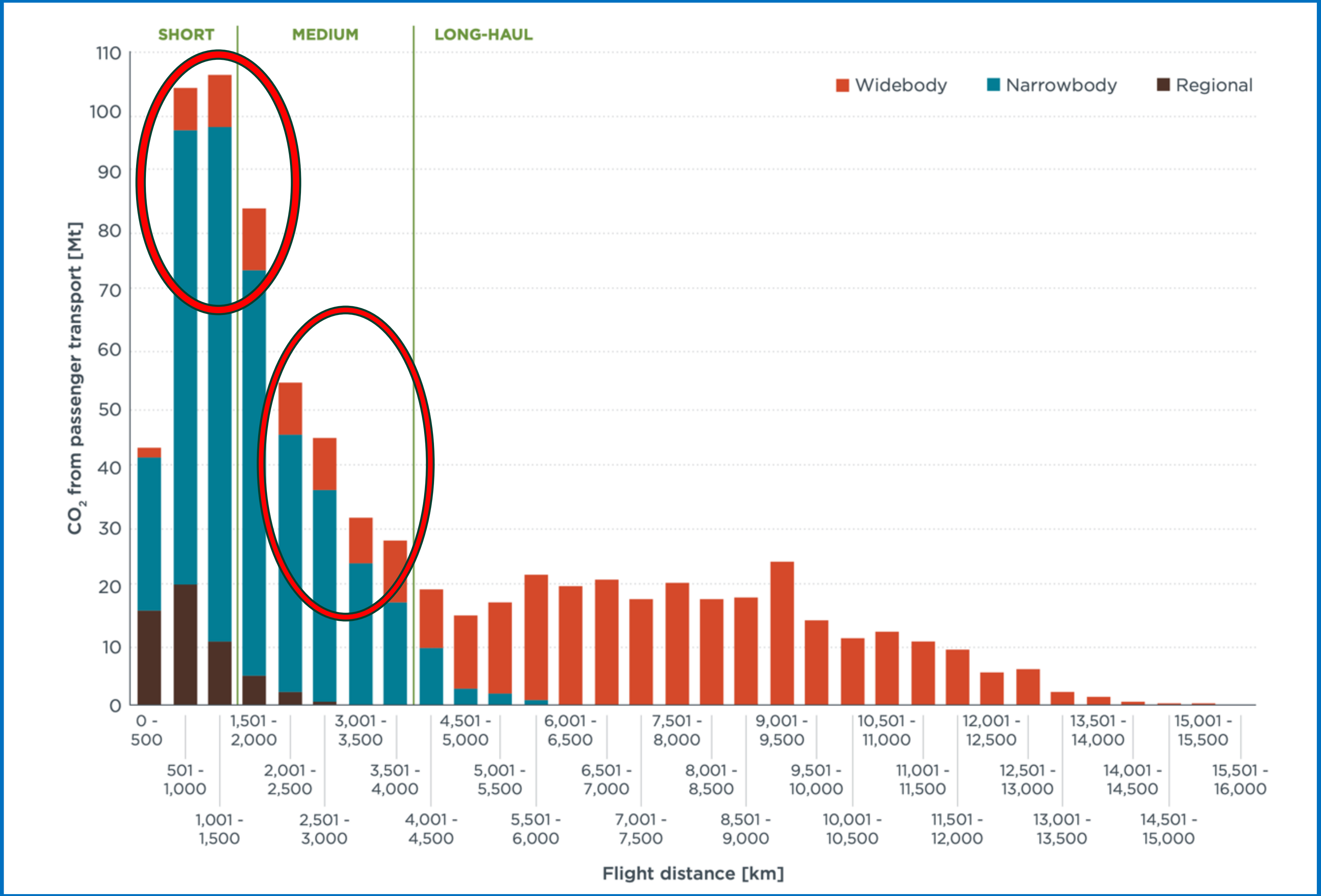
Source: J. Kilpi - Fleet composition of commercial jet aircraft 1952–2005

Global CO_2 Emissions from Aviation



Source: Hannah Ritchie – Global Carbon dioxide emissions from aviation One World in data

CO_2 Emissions by stage length (2019)



CO_2 per segment

- **In 2019 about 7.5% of the Short/Medium Range RPKs are produced with Wide Body aircraft.**
- **The reason: airport slot limitations**

Source: ICCT CO2 Emissions from Commercial Aviation 2013, 2018 and 2019

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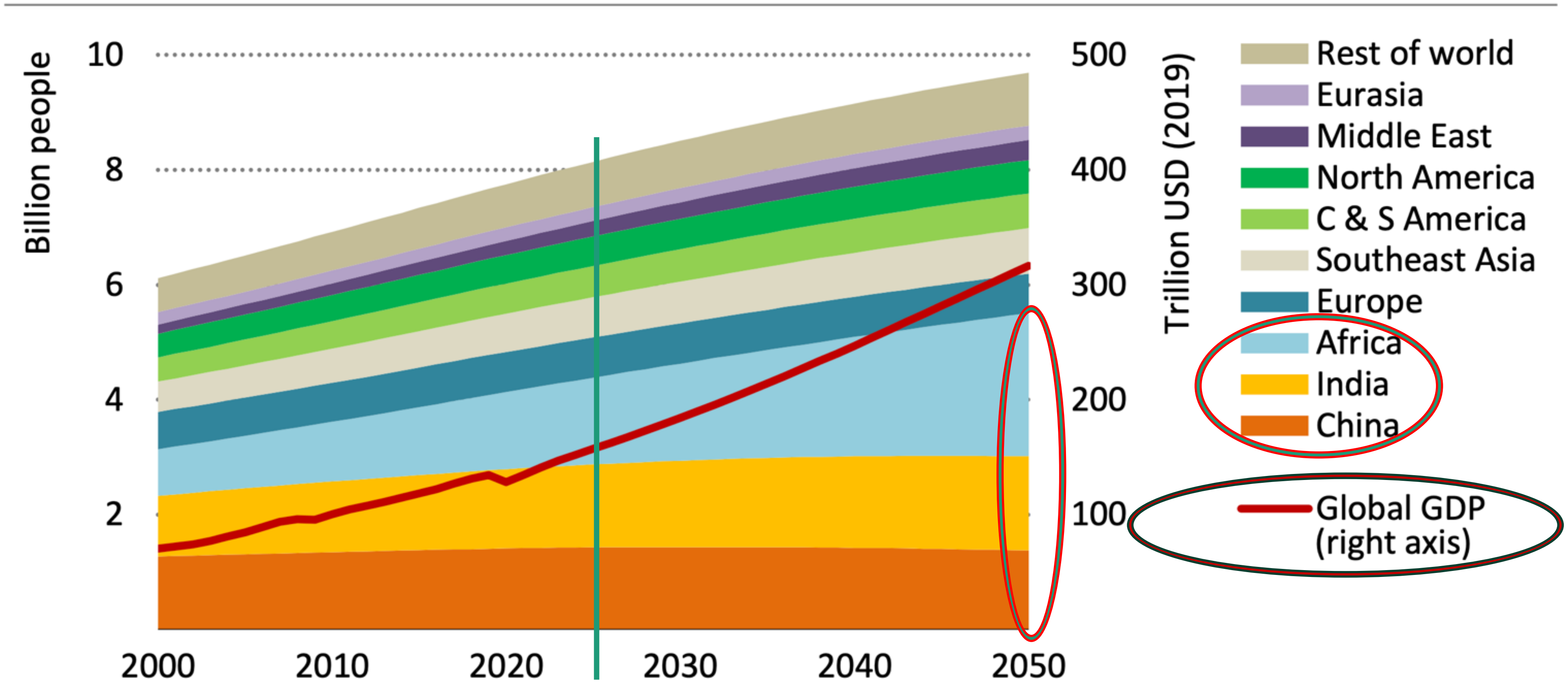
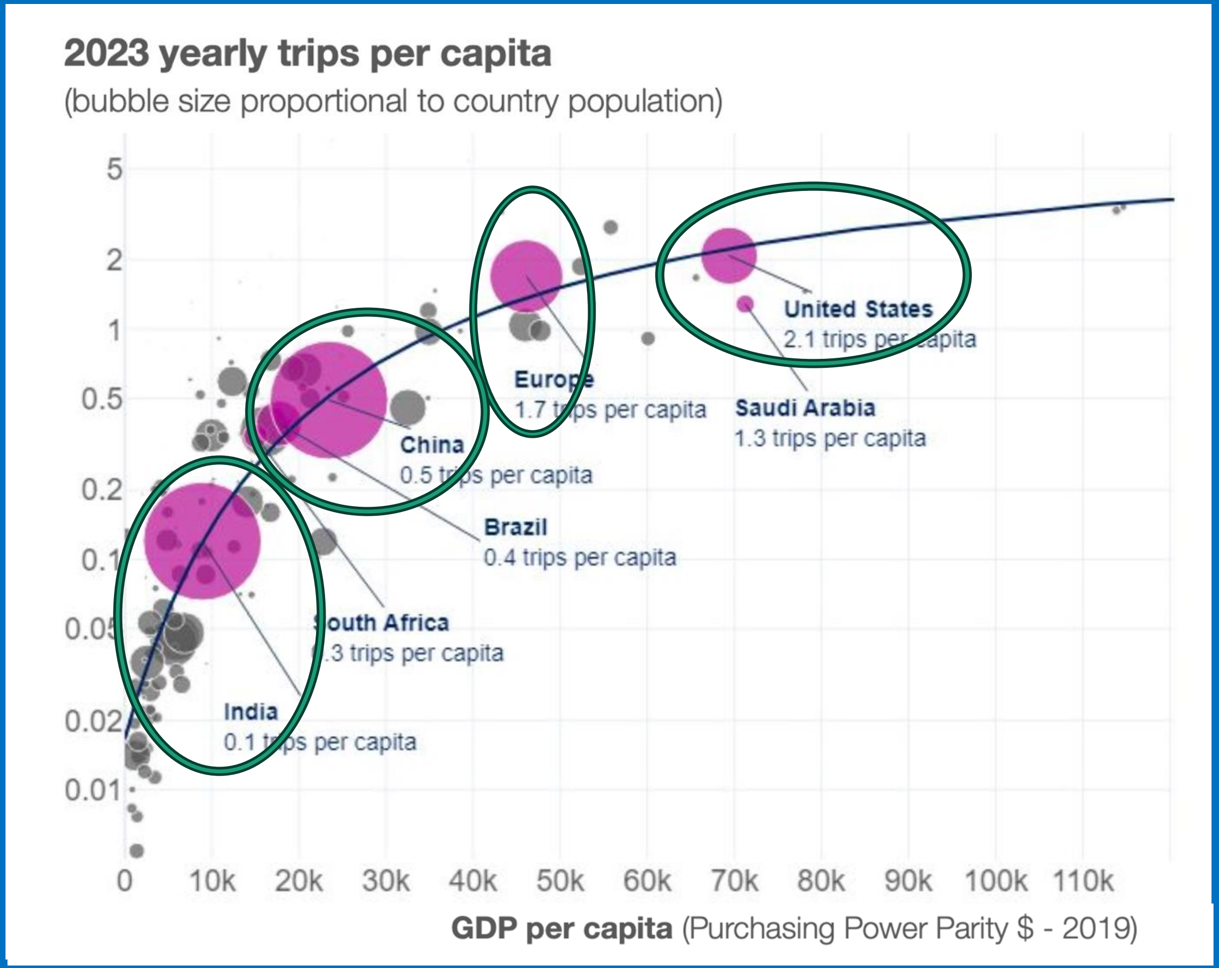
World Population by Region and Gross Domestic Product (GDP)

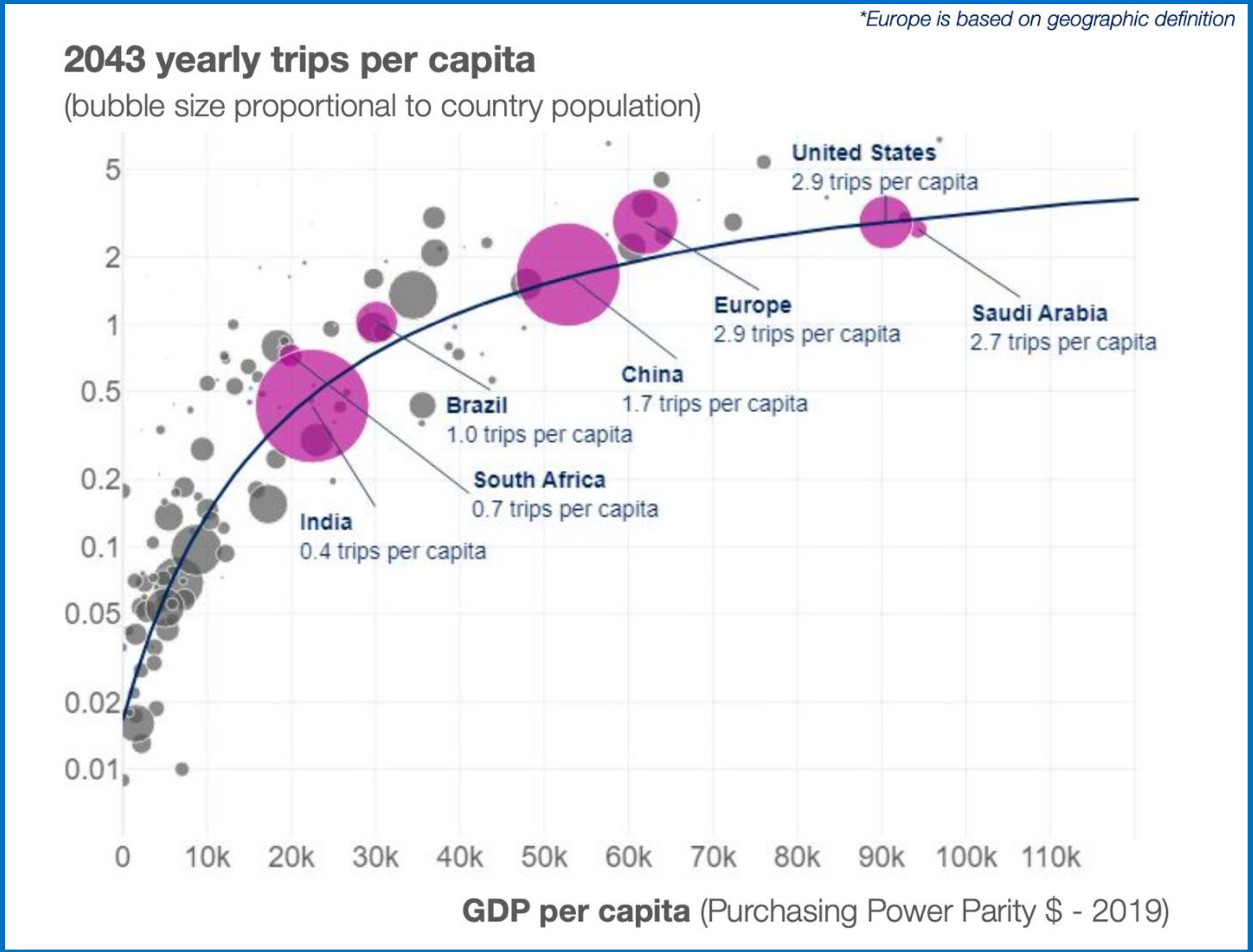


By 2050, the world's population expands to 9.7 billion people and the global economy is more than twice as large as in 2020

Source: IEA Net Zero by 2050. A Roadmap for the Global Energy Sector

Yearly air trips per capita as function of GDP/Cap (2023-2043)



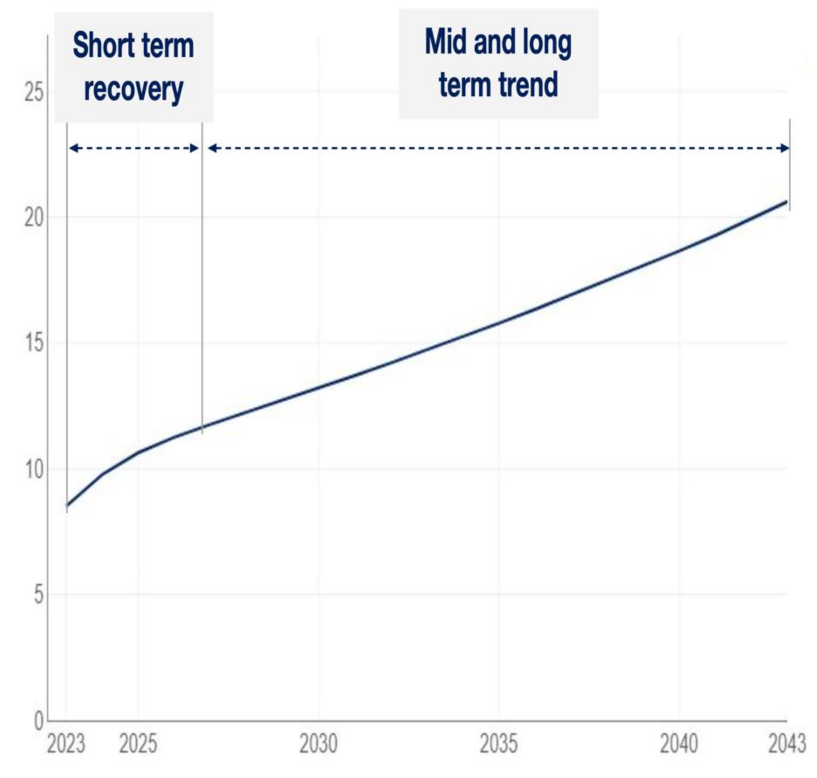


80% of the world population has never flown

Source: Airbus GMF 2024

IATA Forecasted RPK and Passenger Growth 2023-2043

(CAGR = Compound Annual Growth Rate)



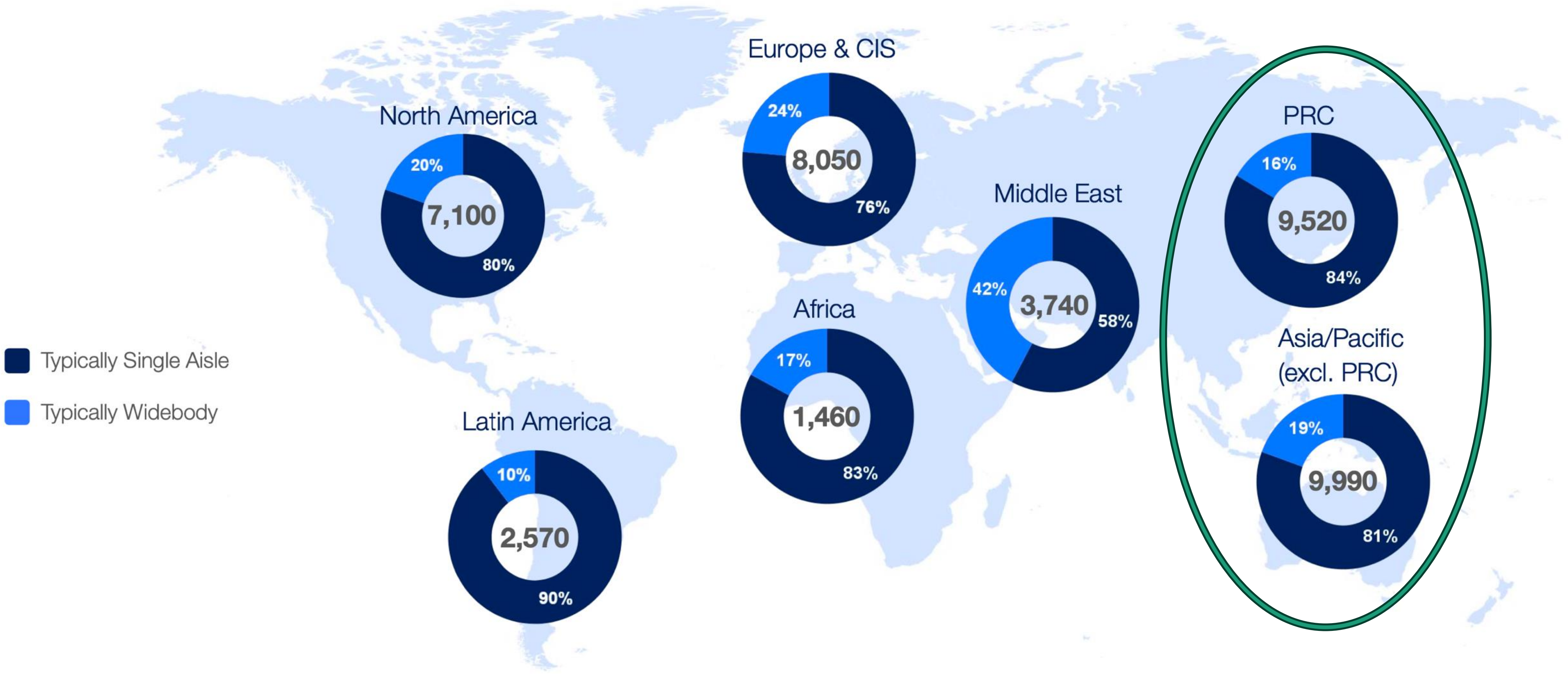
Region	CAGR (2023 – 2043)	Additional passengers by 2043, million
Africa	3.7%	182
Asia Pacific	5.1%	2,609
Europe	2.3%	662
Middle East	4.1%	314
North America	3.0%	763
Latin America	3.0%	200
World	**3.8%**	**4,138**

8-20 Trillion RPK growth

Source: Airbus GMF 2024 & IATA Global Outlook for Air Transport, December 2024

Demand for 42,430 new aircraft between 2024 and 2043

Source Airbus GMF
Notes: Passenger aircraft (≥ 100 seats) & Freighters (≥ 10 tons payload) | Figures rounded to nearest 10



AIRBUS

Airbus State-of-the-Art Narrow-body (SA) and Wide-body aircraft (TA)

Aircraft type	Pax	Empty Weight (kg)	Range (km)	Cruise Speed (km/hr)
Airbus A321 neo (SA)	206-245	50.000	7.400	830 (M.78)
Airbus A350 XWB (TA)	315-480	150.000	16.000	900 (M.85)

(A321neo/A350 XWB: Wing Sweep Angle 25/32°, Wing Aspect Ratio 10.5/9.6)

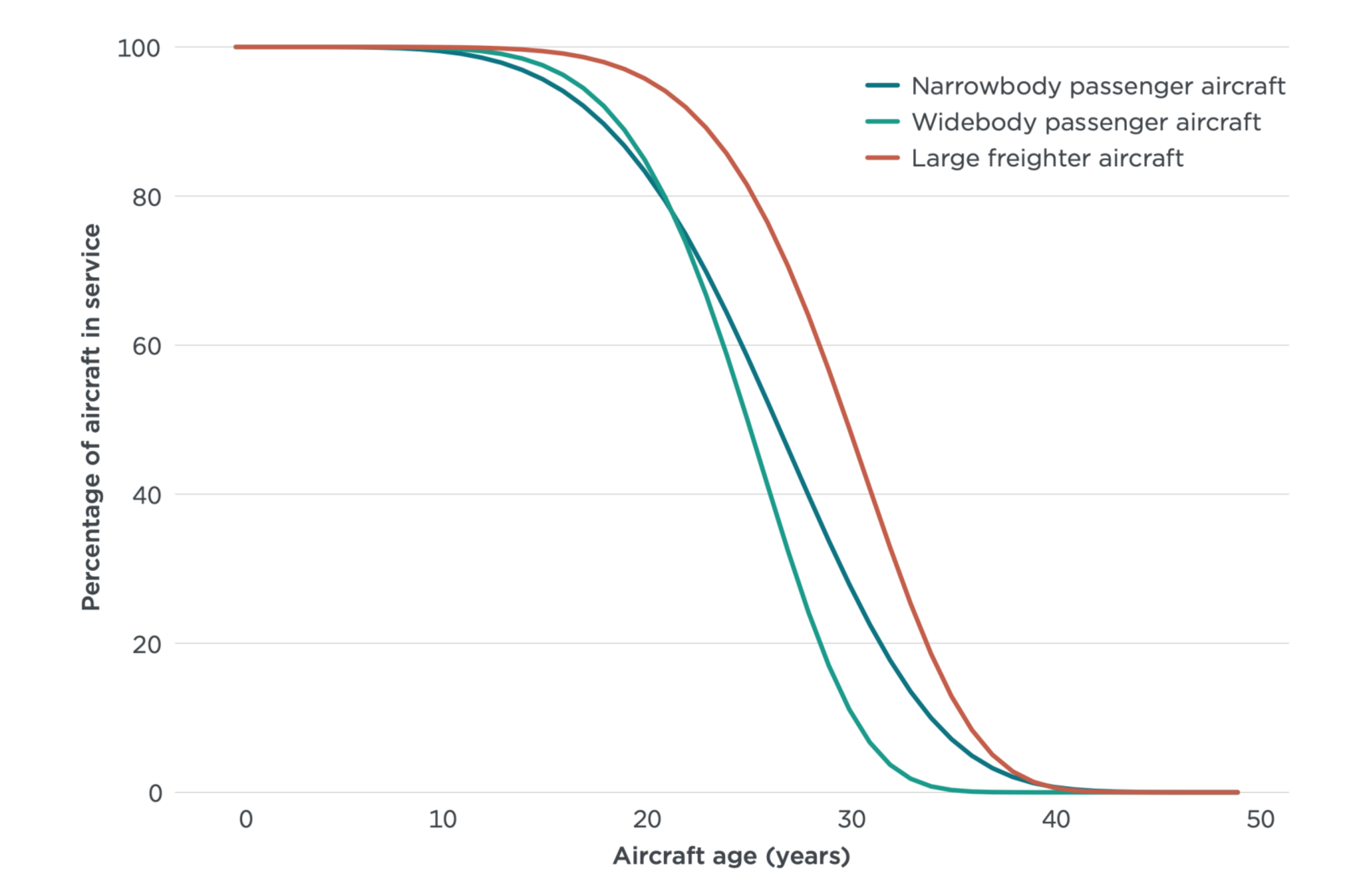
Source: Wikipedia

Airbus A320 neo and A350 XWB deliveries and orders 2024
(production/supply chain limitations!)

A320 neo Family
3.765 built (602 in 2024)
Is 50 per month!
Backlog 7.204 (12 years)

A350 XWB Family
642 built (57 in 2024)
Is 5 per month!
Backlog 702 (12 years)

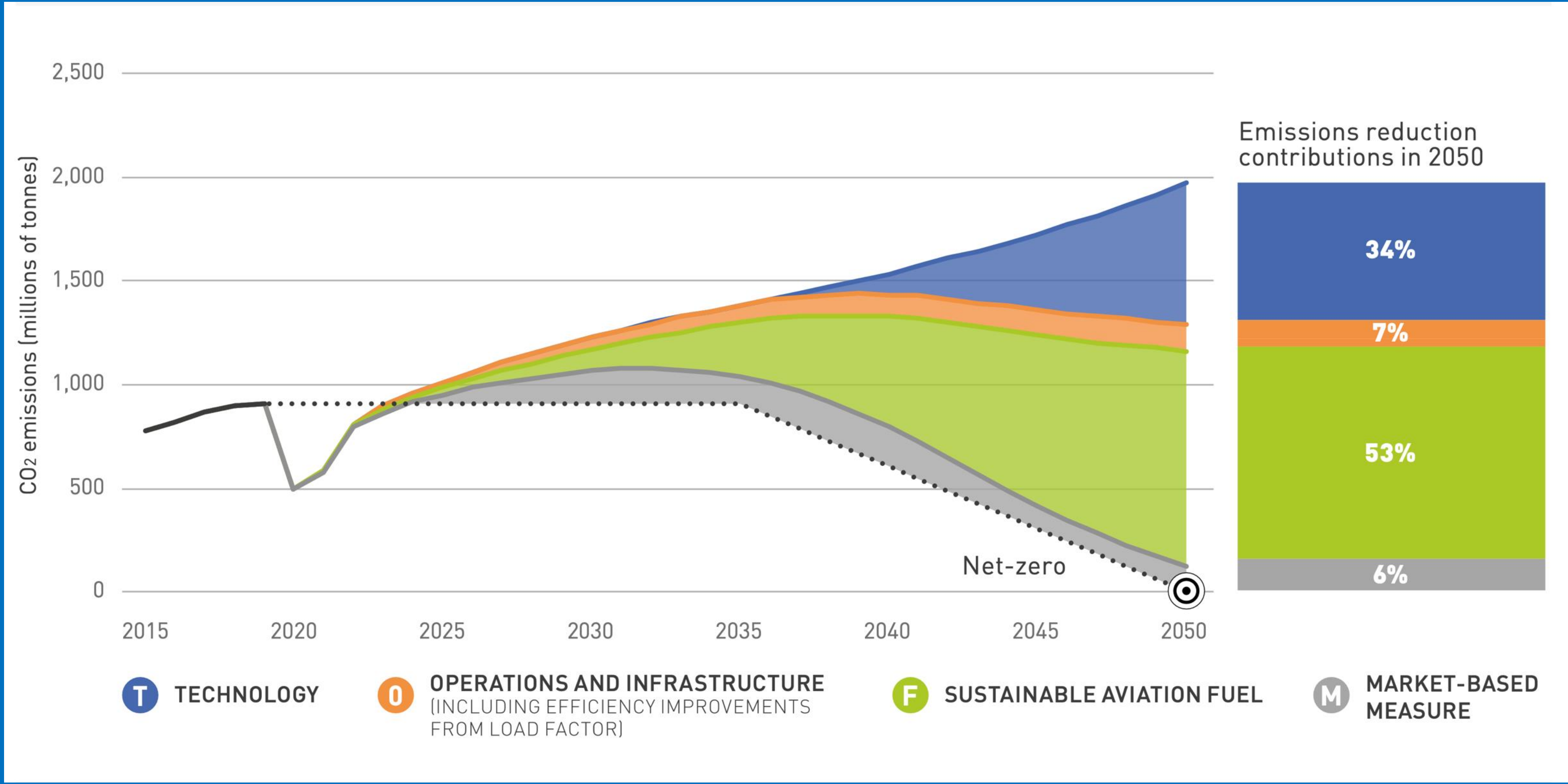
Aircraft Service Life by class



The A321neo and A350 aircraft ordered today, will still fly in 2055!

Source: International Council on Clean Aviation ICCT

How to get to net-zero CO_2 in 2050?



Source: ATAG Waypoint 2050, Scenario 3. Aspirational and Aggressive Technology Perspective

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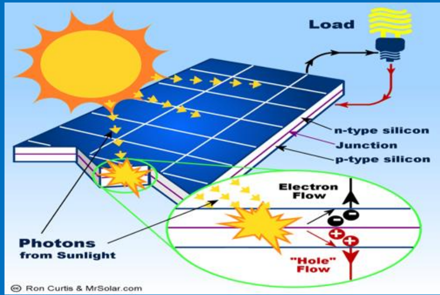
Most efficient use of solar energy

300 million years ago, solar energy allowed the forming of coal, gas and oil.

The basis of the cheap fossil fuels of today!



Solar energy can nowadays provide clean green electricity through:

- Solar panels
- Wind turbines
- Hydropower turbines

The most efficient use of the green electricity is through:

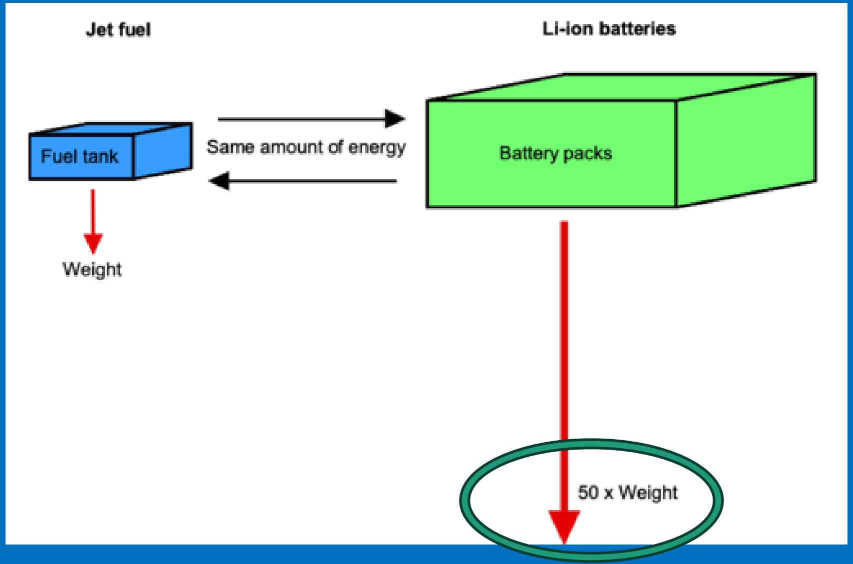
- Direct use or via batteries
- Followed by hydrogen
- Followed by Power to Liquid Sustainable Aviation Fuel SAF

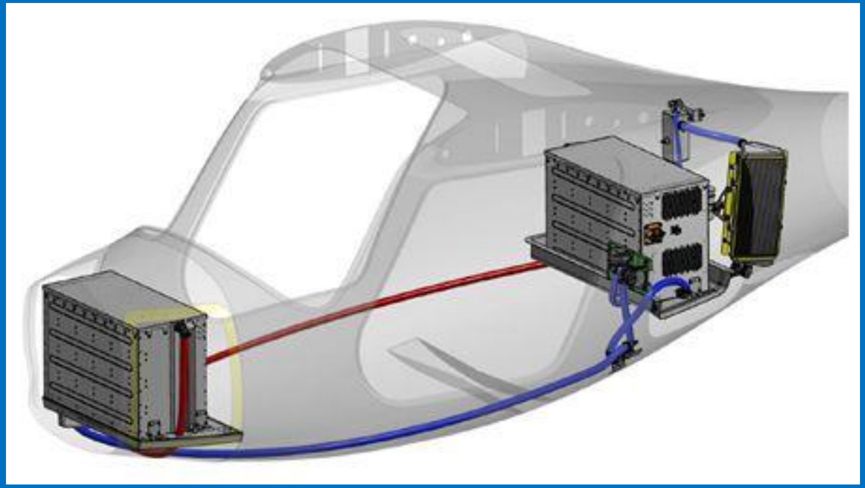
But there are serious issues ….

Source: Wikipedia

Electric Aviation Battery Issues

Electric aviation can not provide a significant contribution to net-zero CO_2 in 2050!





Pipistrel Velis Electro the only aircraft certified (2020)

- Max payload 172 kg (2 people)
- Composite, Wing Aspect Ratio 12
- Max flight duration 50 minutes
- Liquid-cooled electric engine 77 hp/57.6 kW
- 2 liquid-cooled Li-Ion 345 VDC, 11 kWh batteries
- Charging time 30-100% in 2 hours
- Limited battery operational temperature range (-10 - +40°C)
- 100 Pipistrel Velis's sold in 30 countries

Cancelled battery-powered aircraft

Airbus E-Fan

- 2 people
- Li-Ion battery 29 kWh, 250 VDC, 3 hours recharge time
- Endurance 60 minutes
- 1 built, flew over English Channel in 2015
- Project stopped in 2017

NASA X-57 Maxwell

- 2 people, (Wing AR 15)
- Li-Ion battery 460 VDC, 70 kWh
- Endurance 60 minutes
- Project cancelled in 2023

LILIUM GmbH

- Lilium Jet 5 people
- 250 km range , 250 km/hr cruise speed, 10.000 feet
- Lilium spent US$ 1.6 Billion
- Insolvent Nov 2024

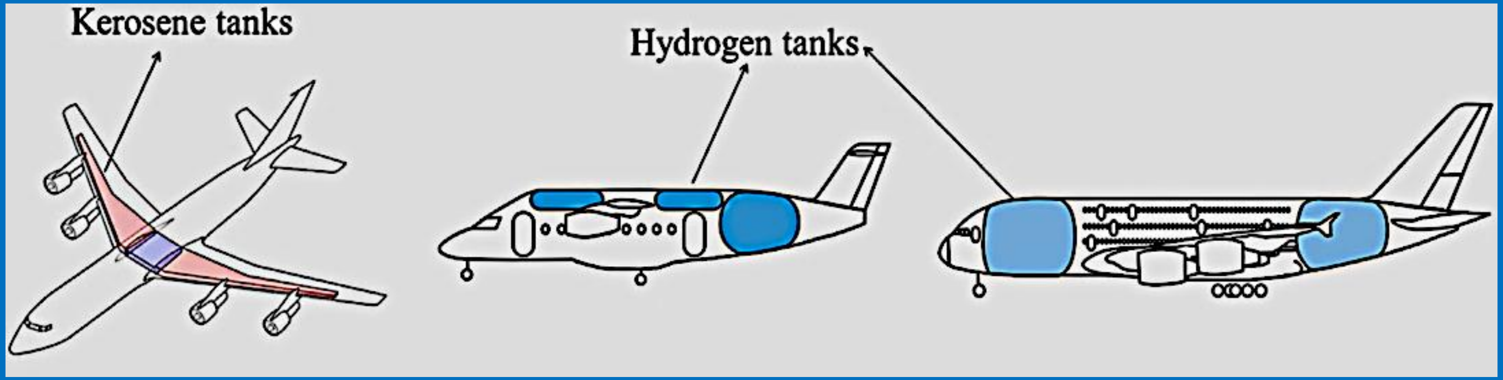
VOLOCOPTER GmbH

- 4 people
- Range 27 km, flight time 27 minutes
- Over 500 Million Euro spent
- Insolvent Dec 2024

(Liquid) Hydrogen as Zero CO2 Aviation Fuel Issues

LH2 might only provide a very limited contribution to net-zero CO2 aviation in 2050!

- LH2 has 3 times the energy per kilogram compared to kerosene
- LH2 however needs 4 times the volume compared to kerosene
- LH2 cannot be stored in the A/C wing (LH2 tanks in fuselage)



- LH2 has to be stored at minus 253 degrees Celsius
- Thermal management and leak management
- Lack of worldwide LH2 production capacity
- Lack of worldwide airport infrastructure for kerosene and LH2
- Safety and Certification of aircraft and ground infrastructure

Source: A. Baroutaji cs – Comprehensive investigation on hydrogen and fuel cell technology in aviation and the aerospace sector. Cartoon: Tom Baxter/Gary Larson

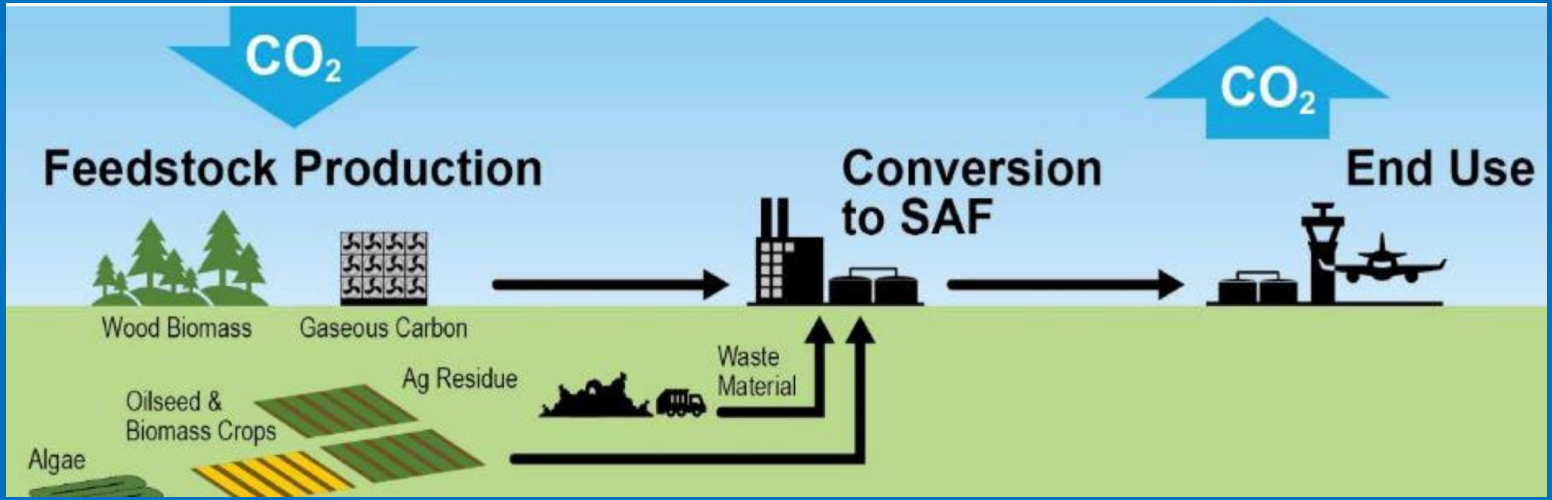
Cancelled Hydrogen Aircraft Projects

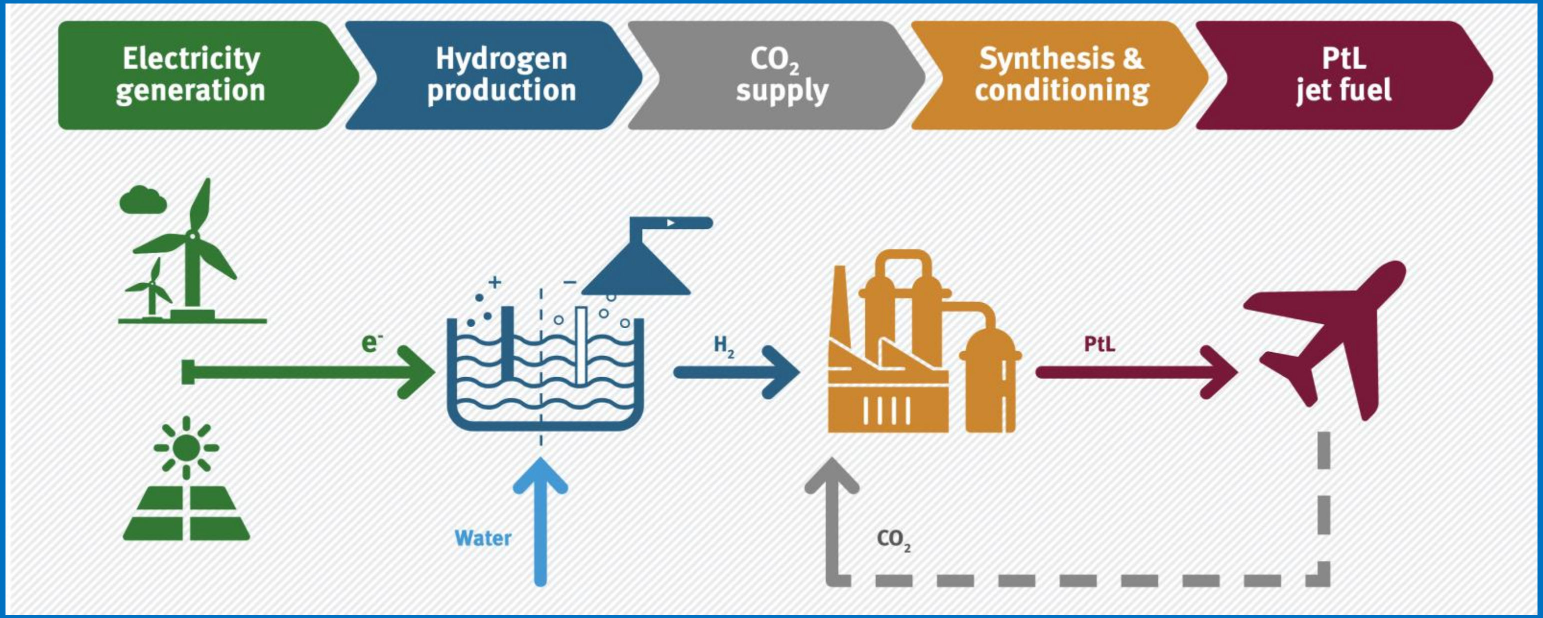
APUS 2i
- Founded 2014
- 1 pilot 4 passengers, 900 km
- Investment 40 Meuro
- Roll out 6 September 2024
- Insolvent March 2025

Universal Hydrogen
- Founded in 2020 by Paul Eremenko cs
- 40 passengers, 900 km
- 2023 first flight with Dash 8 with one H2/fuel cell engine
- Raised 100 million US$ investor money
- Went bankrupt in June 2024

Airbus ZEROe
- Announced 2020, 100 pax, range 1850 km
- Podded fuel cell/hydrogen tank/engine
- Planned EIS 2035
- Investment 1,7 Billion Euro
- Stopped Febr 2025

Sustainable Aviation Fuel (SAF)





Bio-based SAF

Need for large quantity of bio material. Competition with food production!

Synthetic SAF (PtL)

Need for large quantity of green electricity for electrolysis and carbon capture

Recent NASA-DLR flight tests showed that SAF produces 50-70 % less contrails as fossil-based kerosene

Source: USA SAF Grand Challenge Roadmap, Ludwig Boelkow System Technik LBST and Voigt cs - Cleaner burning aviation fuels can reduce contrail cloudiness

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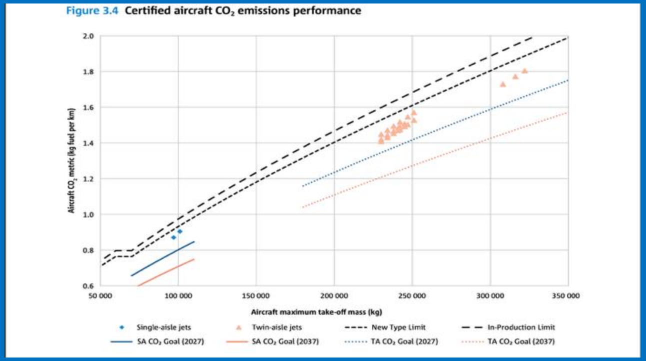
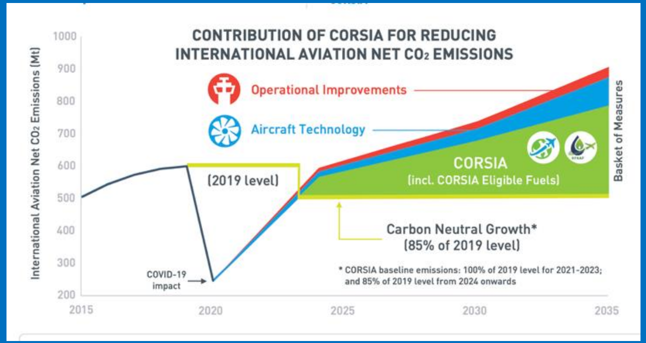
Regulatory and Market-based measures

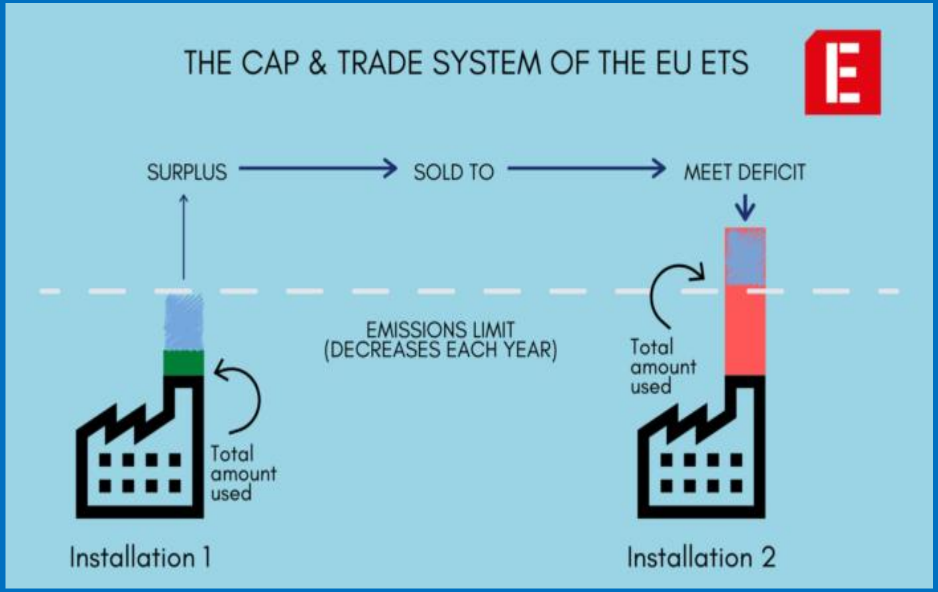
- ICAO CO2 Emission Standards
- ICAO CORSIA Requirements
- EU Emissions Trading Scheme (ETS)
- EU ReFuelEU Requirements
- EU Energy Taxation Directive (ETD)
- Airport Taxes (today 29€ per flight at Schiphol)
- Value Added Tax

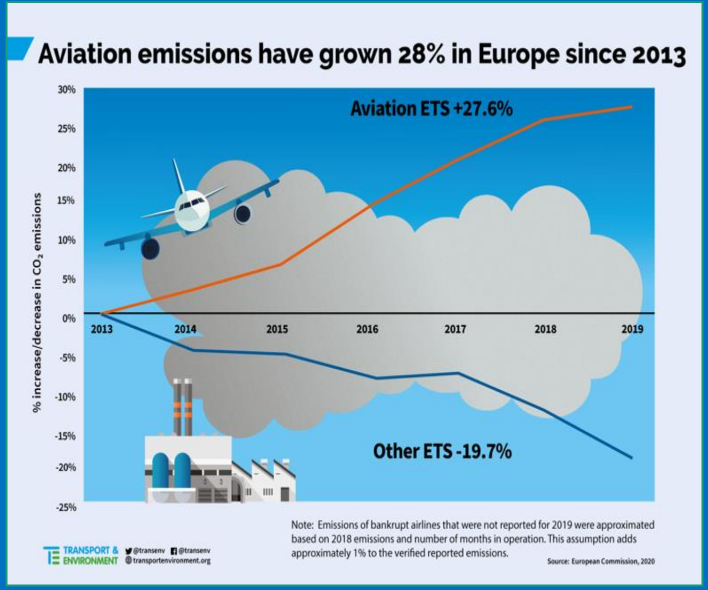


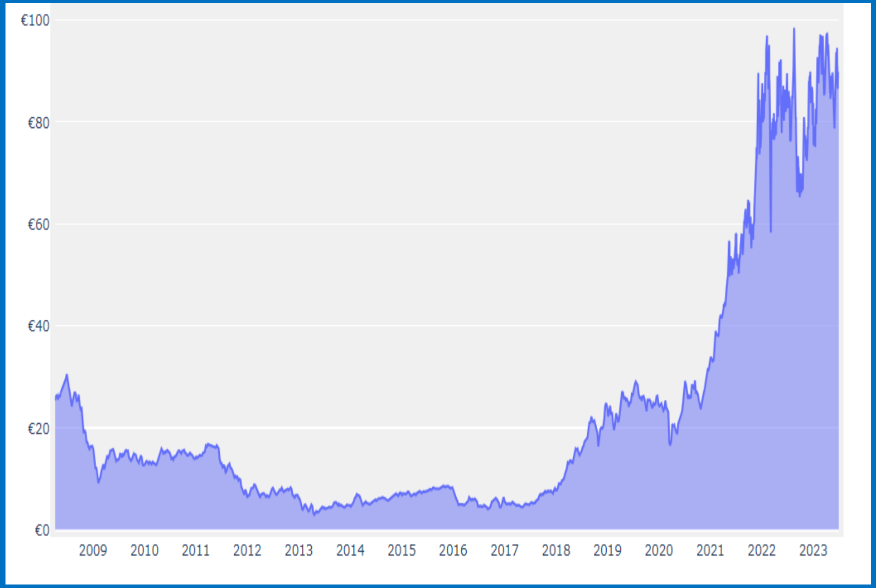


Source: Destination 2050 – A route to net-zero European Aviation and EASA European Aviation Environmental Report 2025

2005: EU Emissions Trading System (ETS)
(“Cap and Trade”)



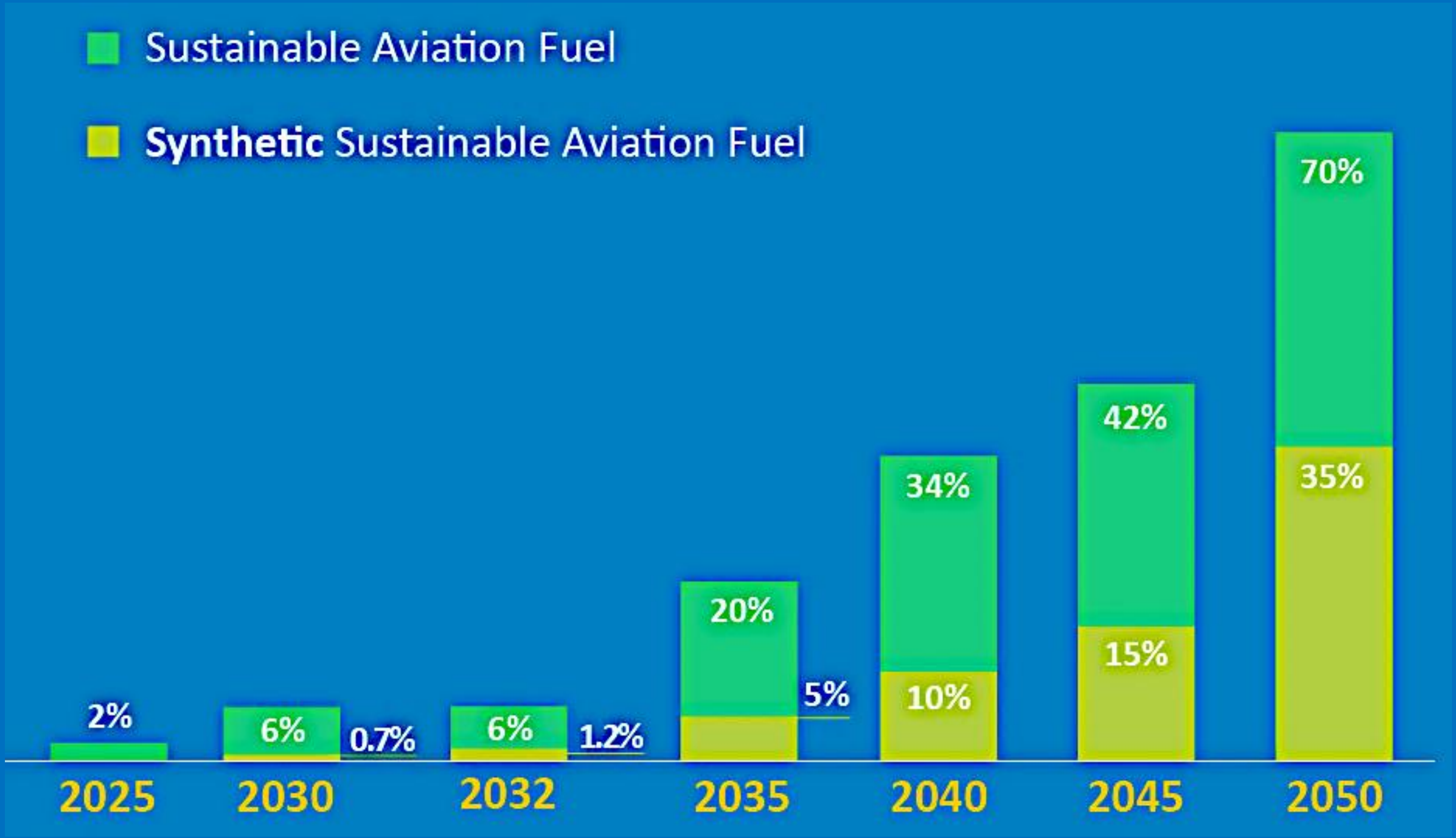




- The EU “Green Deal Fit for 55” has as target CO2 reduction of 55% by 2030 and 100% in 2050
- Every CO2 emitting organisation got a (yearly 4.3-4.4% decreasing) Cap and an ETS free allowance to start
- Free allowances will be phased out by 2026

- Aviation is part of ETS since 2012
- Airlines have to buy CO2 allowances on the free market
- The CO2 price on the market has risen from 25€ in 2020 to 90€ per Tonne CO2 in 2024

2023: EU ReFuelEU Aviation (drop-in SAF)



Big reliance on ramping up SAF production

- Production needs to go from 100 million liters today to at least 449 billion liters in 2050.
- SAF will contribute around 65% of the emissions reductions needed in 2050.

IATA FLY NET ZERO

- In 2023 Air France-KLM used 80.000 Tons SAF (96 million litres)
- Air France-KLM has committed itself to 10% SAF in 2030

Source: EASA/ReFuelEU/KLM

ETS/ReFuelEU/SAF Issues and Consequences

ETS cost evolution:

- In 2019 the European Airlines paid € 1.7 Billion ETS, (with a € 27 Billion jet fuel tax exemption).
- In 2030 for Air-France KLM the ETS tax will reach €430 million per year (10 times the 2019 ETS tax)

SAF availability and cost

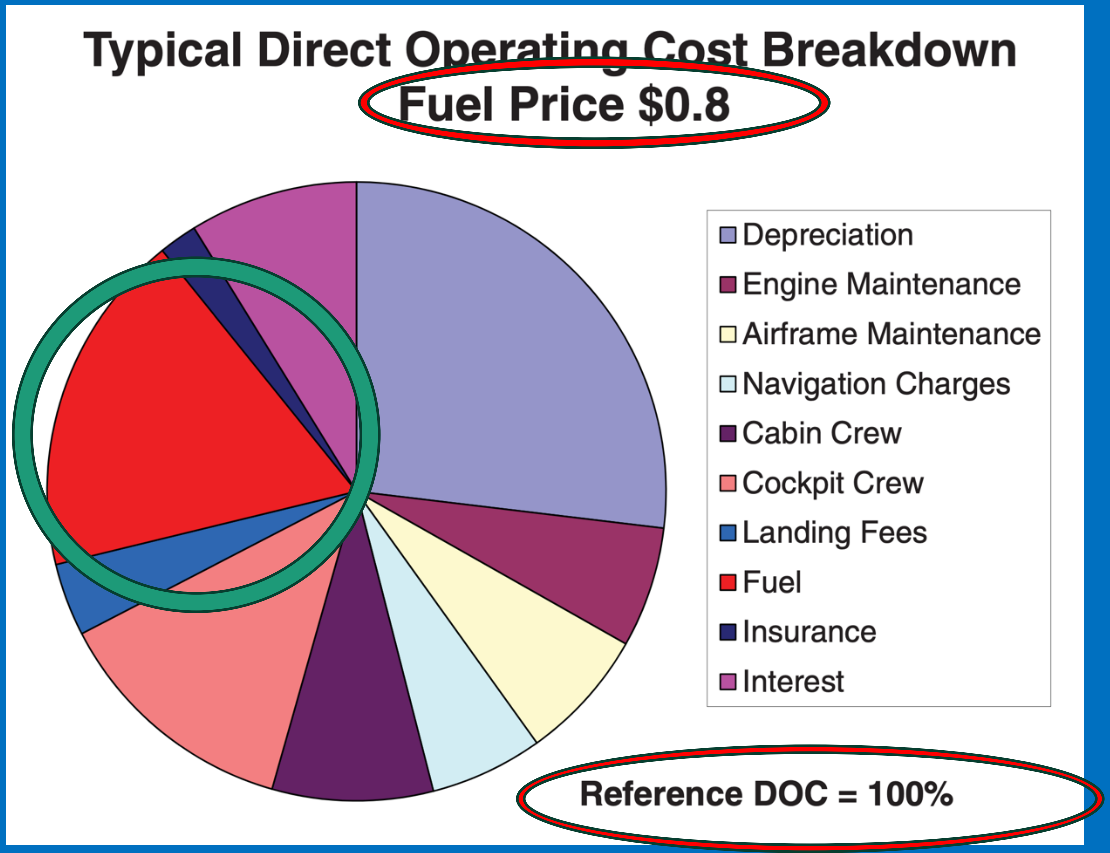
- Uncertainty of enough bio-based SAF (enough biomaterials)
- Uncertainty of enough green electricity to produce the Power-to-Liquid SAF (for electrolysis to produce the hydrogen and for the Carbon Capture)
- Power-to-Liquid SAF may be 4-8 times more expensive than fossil-based kerosene
- Long-term SAF commitments and investment "chicken and egg"

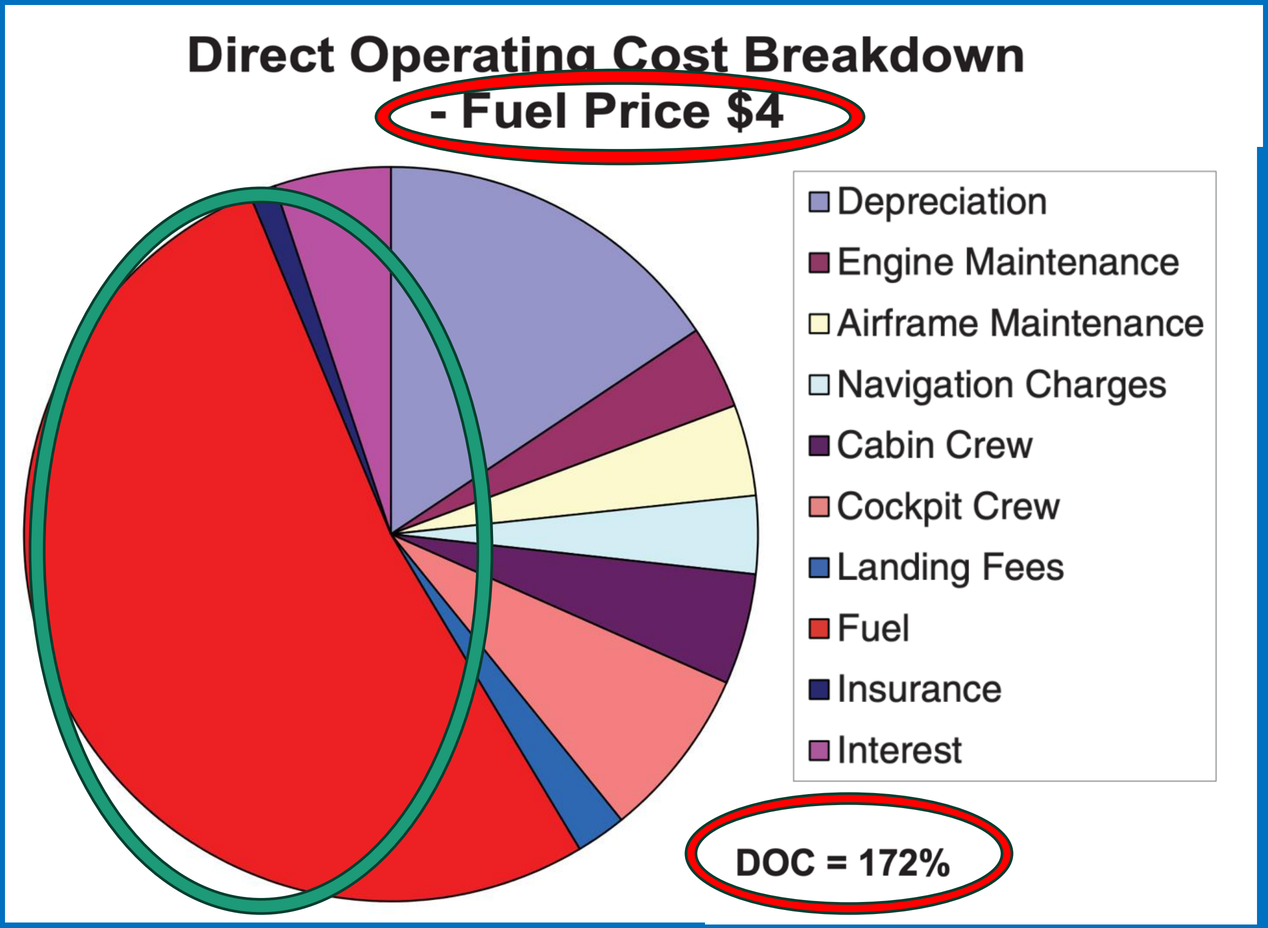
In 2050, due to ETS and ReFuelEU the airline industry may face significantly:

- *Higher fares (15-70%)*
- *Lower travel demand (10-40%)*

Sources: CE Delft - Taxes in the Field of Aviation and their Impact and ChatGPT

Effects Fuel Price on DOC of A320 type aircraft





An increase of DOC with 72% results in an increase of the Ticket price with 72%!

Source: J. A. Jupp - The design of future passenger aircraft – the environmental and fuel price challenges

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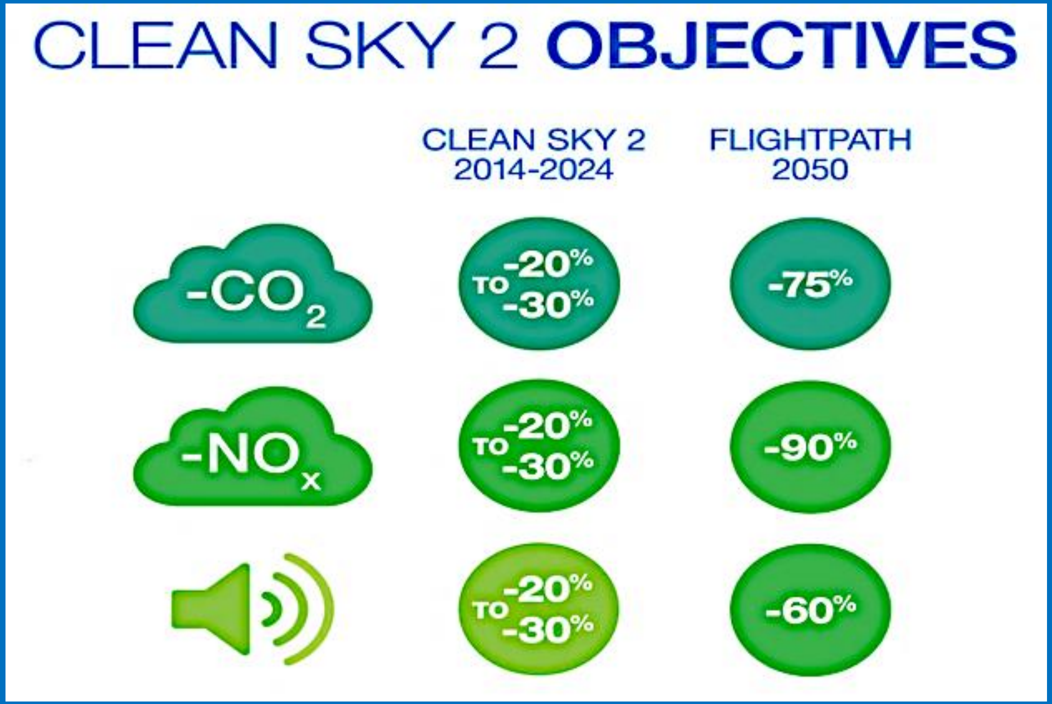
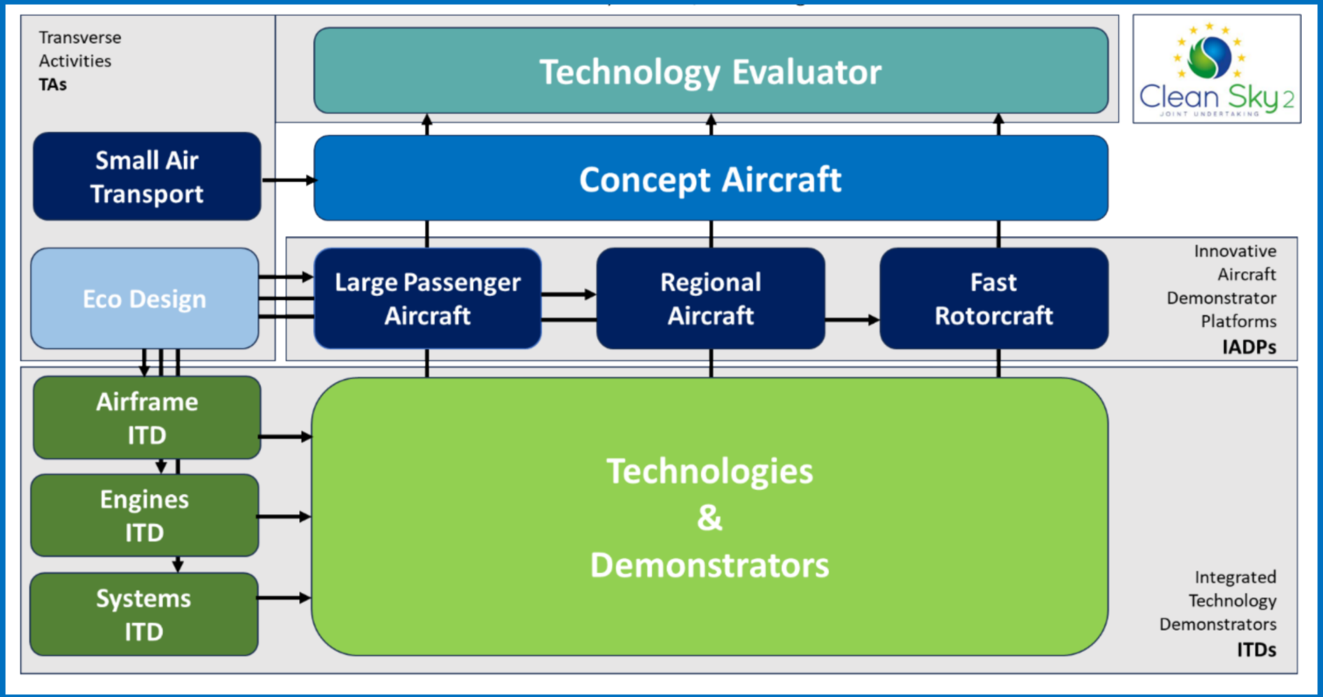
- Introduction
- Growth forecast and CO_2 Emission consequences
- General measures to reduce CO_2 Emissions
- **Technology developments and new, optimal aircraft**
  - **Technology Development/EU Clean Sky 2/EU Clean Aviation**
  - More fit-for-purpose (range/size/speed) aircraft
- US FAA/NASA/MIT Boeing and JetZero developments
- Summary and Conclusions

EU Clean Sky 2 Objectives and Structure

- **Objectives: Developing *Environmentally Friendly aircraft* as well as a *strong Competitive European Aircraft Industry and Supply Chain***
- **Budget around 4 Billion Euro for 2014-2024, roughly *50% paid by Industry* and *50% paid by the European taxpayer***





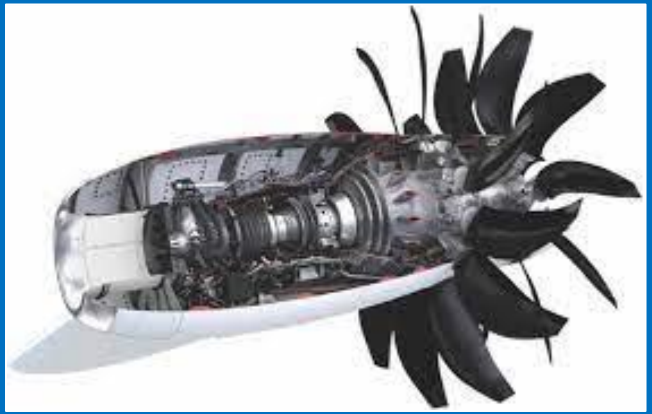
- **Vehicle Innovative Aircraft Demonstrator Platforms (IADPs)**
- **Large Systems Integrated Technology Demonstrators (ITDs)**

Source: Clean Sky 2

EU Clean Sky Large Passenger Aircraft Flagships

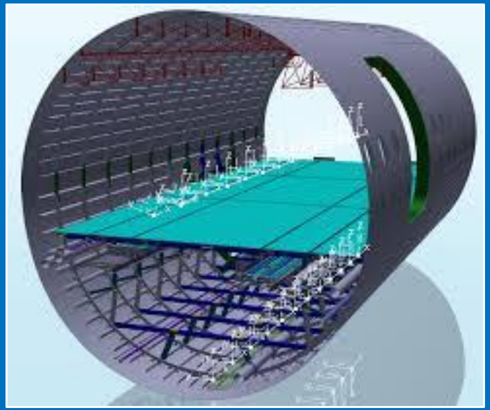
Breakthrough Laminar Aircraft Demonstrator in Europe (BLADE)

- 9-meter wing extension (A340)
- Natural Laminar Flow (NLF)
- Wing sweep 20° (from 30°)
- Mach 0.75 (from 0.82)
- 10% drag reduction



SAFRAN Open Rotor

- Counter Rotating OR
- Fan diameter 3.9 m
- 20% fuel burn reduction



Multi Function Fuselage Demonstrator (MFFD)

- 8 Meter fuselage section
- Thermo-Plastic Materials
- Robot/Cobot production
- 1000 kg weight reduction
- Production 70-100 per month
- DLR-Fraunhofer cooperation

Disruptive Cockpit (DisCo)

- Workload reduction
- Autonomous systems
- Single Pilot Operations
  - 5% COC reduction
  - Worldwide 80.000 new pilots short at the end of 2032!

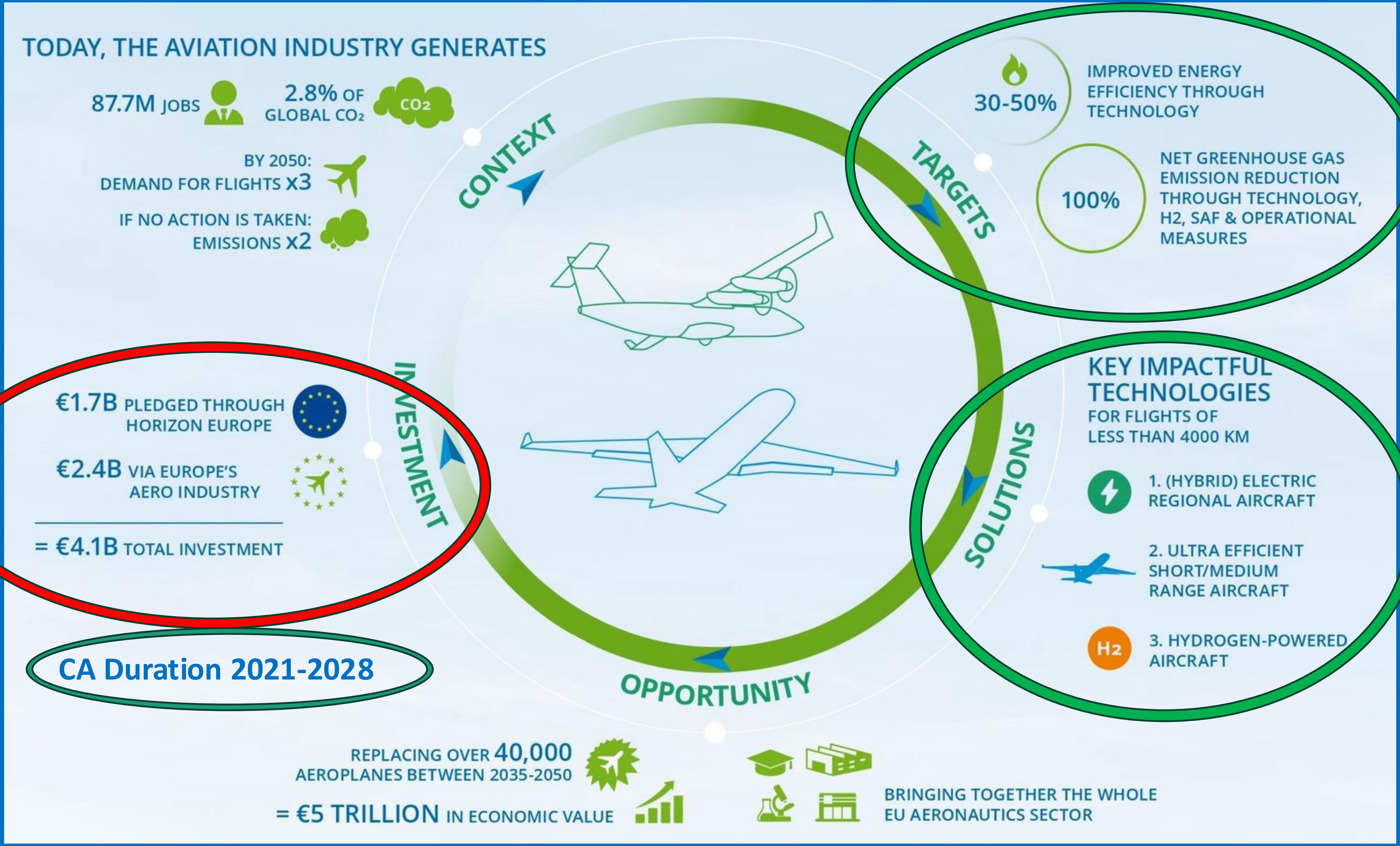
Aircraft Concepts

The current fleet divided into several market segments:

- **Mainliners (4)** (covering **Long Range** and **SMR**),
- **Regional aircraft (3)** (different mission targets),
- **Small Air Transport (1)** (19 seats)
- **Business Jets (1)**,
- **Fast Rotorcraft (2)**

Source: J-F Brouckaert CS2 Presentation ICAS Stockholm 2022

EU Clean Aviation (CA) Targets and Budgets



2025: EU Clean Aviation Running Projects

Ultra-efficient Regional Aircraft

Combining Innovative Airframe, Novel Systems & HE power train

HE-ART
2.150-2.850 MW Multi Hybrid Electric propulsion system for regional AiRcrafT
ROLLS-ROYCE (*)

AMBER
2250 MW Multi Power train InnovAtive DeMonstrator for hyBrid-Electric Regional Application
GE AVIO (*)

TheMa4HERA
Thermal Management Solutions for the Hybrid Electric Regional Aircraft
HONEYWELL (*)

HECATE
Hybrid ElectriC regional Aircraft distribution Technologies
COLLINS (*)

HERWINGT
Hybrid Electric Regional Wing Integration Novel Green Technologies
AIRBUS (*)

HERFUSE
Hybrid-Electric Regional FUSelage & Empennages
LEONARDO (*)

ODE4HERA
Open Digital Environment for Hybrid-Electric Regional Architectures
DLR (DEUTSCHES ZENTRUM FUR LUFT – UND RAUMFAHRT)

Ultra-efficient Short Medium Range

Combined powerplant & Airframe efficiency

HEAVEN
Ultrafan – Hydrogen & hybrid gas turbine design
ROLLS-ROYCE (*)

SWITCH
Sustainable Water-Enhanced-Turbofan (WET) Comprising Hybrid-electrics
MTU AERO (*)

OFELIA
Open fan engine demonstrator incl. gas turbine design hybridisation for Environmental Low Impact of Aviation
SAFRAN (*)

UP WING
Ultra Performance Wing
AIRBUS (*)

FASTER-H2
Fuselage H2 integration & Ultra efficient empennage
AIRBUS (*)

COMPANION
Common Platform and Advanced INstrumentation ReadIness for ultra efficient propulsion demonstration
AIRBUS (*)

AWATAR
Advanced Wing MATuration And integration
ONERA (OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES)

Hydrogen Powered

Novel concepts with H2 direct burn & fuel cell based propulsion

CAVENDISH
Hydrogen and dual fuel combustion technologies
ROLLS-ROYCE (*)

HYDEA
Hydrogen engine integration in flying platform
GE AVIO (*)

NEWBORN
NExt generation high poWer fuel cells for airBORNe applications
HONEYWELL (*)

H2ELIOS
HydrogEn Lightweight & Innovative tank for zerO-emisSion aircraft
ACITURRI (*)

FLHYing Tank
Liquid hydrogen load bearing tank for commuter
PIPISTREL (*)

HYPoTrade
Hydrogen Fuel Cell Electric Power Train Demonstration
PIPISTREL (*)

TROPHY
Technological Research On Propulsion by HYdrogen
SAFRAN

FAME
Fuel cell propulsion system for Aircraft Megawatt Engines
AIRBUS (*)

HEROPS
Hydrogen-Electric ZeRo Emission Propulsion System
MTU AERO ENGINES AG

Support Action

CLAIM
Clean Aviation Support for Impact Monitoring
DLR (DEUTSCHES ZENTRUM FUR LUFT – UND RAUMFAHRT)

Transversal Projects

CONCERTO
Construction Of Novel CERTification methOds and means of compliance for disruptive technologies
DASSAULT (*)

HERA
Hybrid-Electric Regional Aircraft Architecture and technology integration
LEONARDO (*)

SMR ACAP
SMR Aircraft architecture and technology integration Project
AIRBUS (*)

ECARE
European Clean Aviation Regional Ecosystem/synergies with regions

(*) Consortium Leader

Source: Clean Aviation

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    - **More fit-for-purpose aircraft design (range/speed & airport capacity)**
- US FAA/NASA/MIT Boeing and JetZero developments
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New aircraft: Finding the optimum

(Passenger demands, Airlines, Airports, ATC and Environment)

Passenger demands

- Low ticket price
- Direct flights with high enough frequency
- Seat pitch/comfort
- Environment (flight shame?)

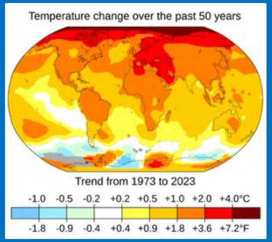
Airlines

- Competitiveness and shareholder value
- Maximum range flexibility
- High speed (productivity)
- Minimal Aircraft Direct Operating Cost
- Limited number of aircraft types
    - Maintenance
    - Training of flight and cockpit crew

Air Space, Airports and ATC

Aircraft Industry

- Certification/safety/noise
- Competitiveness
    - Aircraft acquisition cost
    - Aircraft Direct Operating Cost
- Shareholder value
- Limited number of aircraft types
- Maximum number of sold aircraft per type

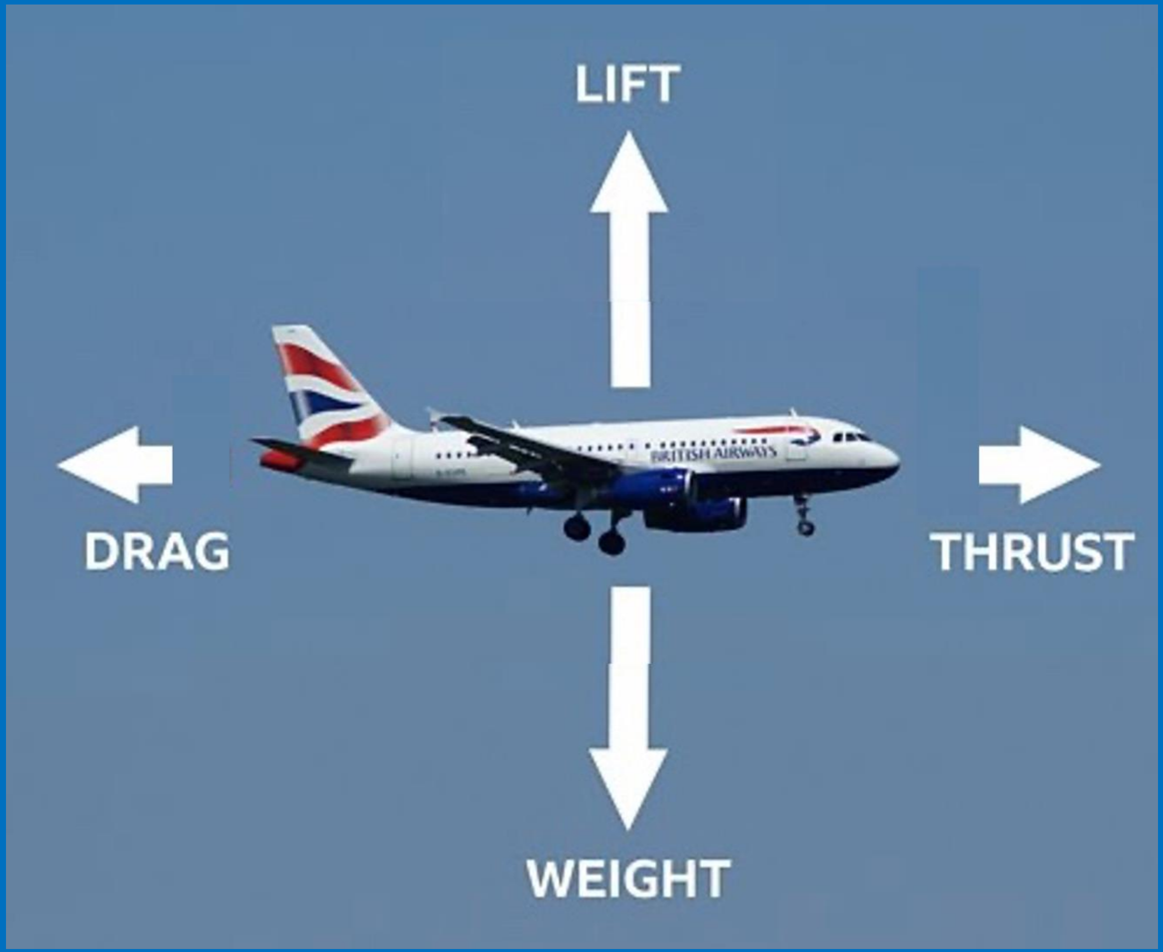


Environment/emissions

- Global Warming

What should be the Top Level Requirements for the new aircraft?

Relation Range, Speed and Fuel consumption



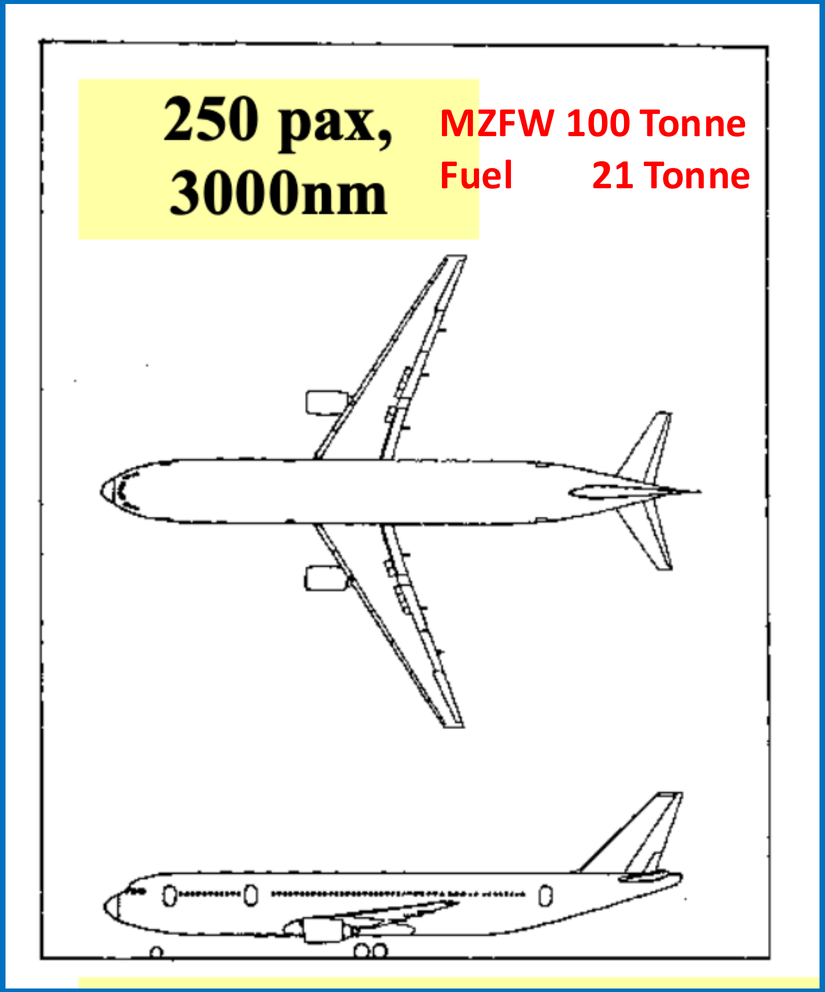
Snowball effects!!

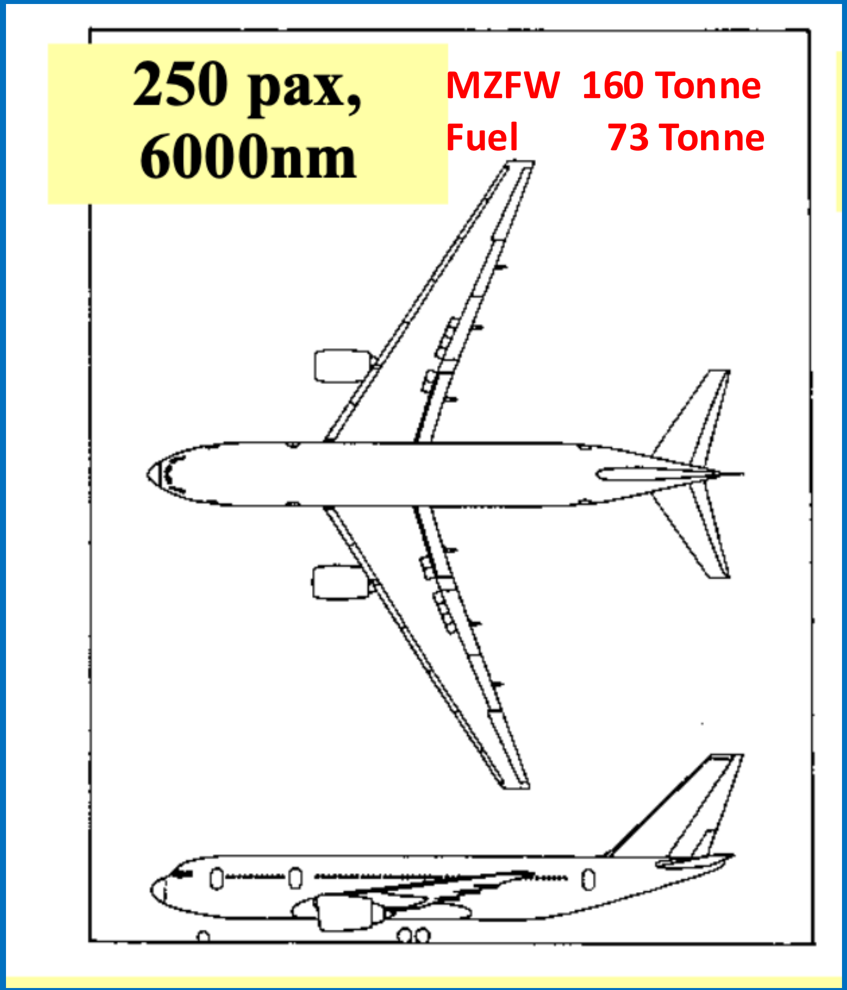
- **Greater design range means:**
  - More fuel capacity required
  - Larger/Heavier wing, stronger undercarriage
  - Stronger and heavier engines
- **Higher speed means:**
  - More drag and more fuel consumption
  - Stronger and heavier engines
- **More weight means:**
  - More lift required
  - Resulting in more drag
  - Resulting in more required thrust
  - Resulting in **higher fuel consumption**

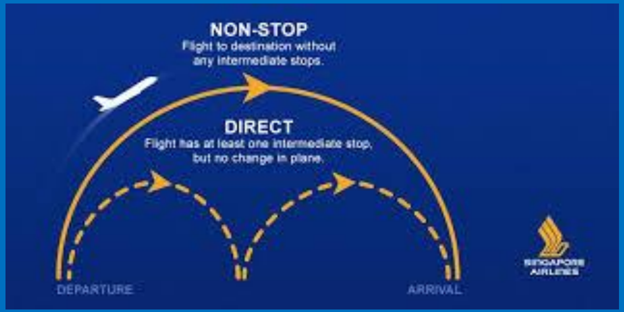
Note: Lift/weight can be 20 times the thrust/drag

Effect of range on fuel burn per passenger km

(250 passengers, 3000-6000 nm, M 0.85, with and without ISO)







Increased range with same payload leads to:

- Increased fuel, fuel tank volume and mass
- Heavier wing/tail and undercarriage
- Increased drag, thrust and heavier engines
- Increased fuel burn and emissions

MINIMIZE THE SNOWBALL!

For a 3000 nm range, the aircraft designed for 6000 nm, would burn 32.5 tonne of fuel! This is 50% more!

Source: R. Nangia - A Vision for Highly Fuel-Efficient Commercial Aviation, Eucass 2007

Distance of the World's 10 busiest air routes (2024)

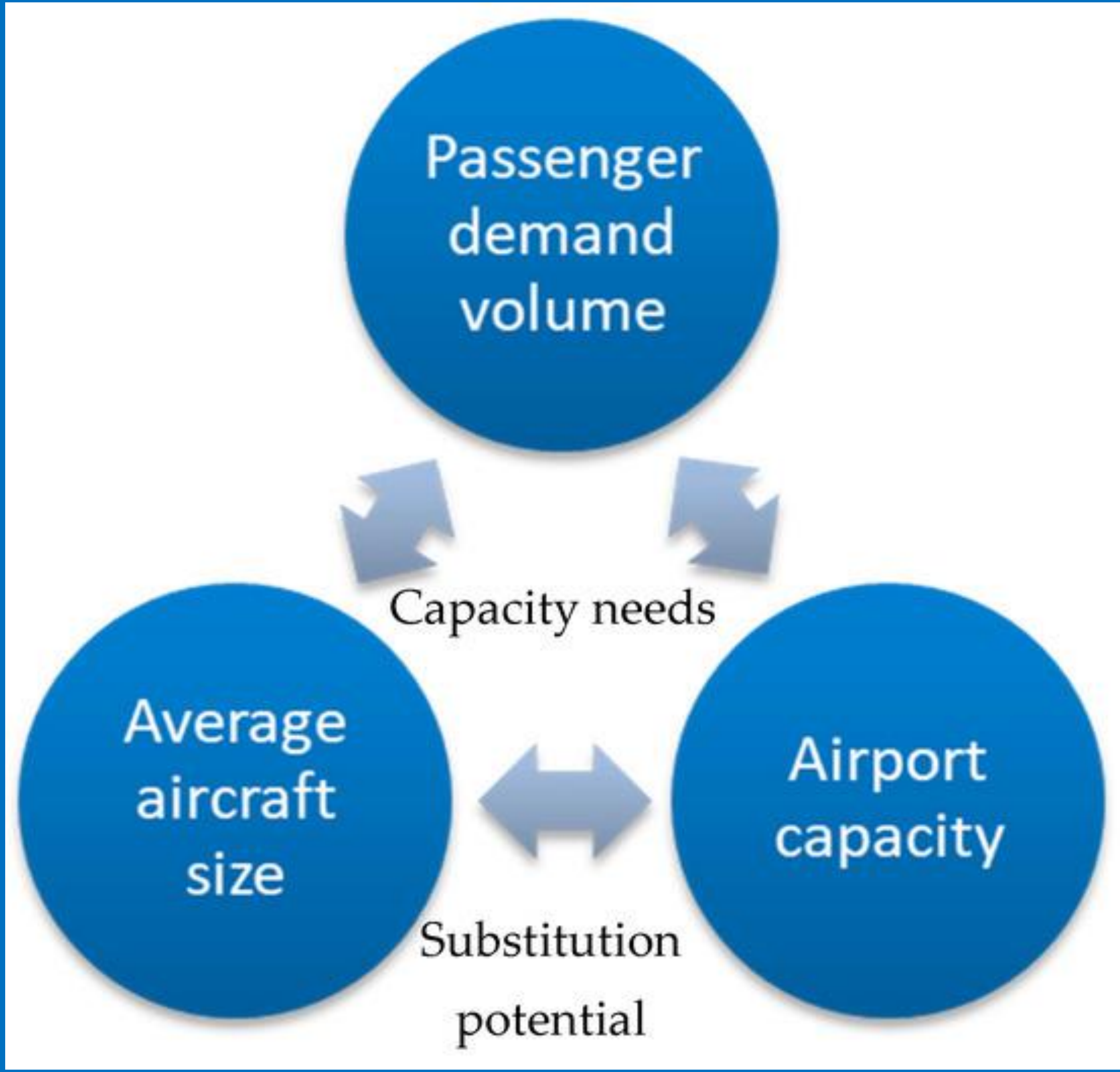
Rank	Departing	Arriving	Distance (km)	2024[1] (Nr Pass)	2023[2] (Nr Pass)
1	Jeju	Seoul–Gimpo	449	14,183,719	13,728,786
2	Sapporo	Tokyo–Haneda	835	11,931,572	11,936,302
3	Fukuoka	Tokyo–Haneda	889	11,335,551	11,264,229
4	Hanoi	Ho Chi Minh City	1171	10,631,435	10,883,555
5	Sydney	Melbourne	705	9,217,377	9,342,312
6	Jeddah	Riyadh	857	8,700,415	7,902,142
7	Tokyo–Haneda	Naha	1573	8,033,641	7,982,218
8	Mumbai	Delhi	1150	7,963,686	7,276,430
9	Beijing–Capital	Shanghai–Hongqiao	1081	7,714,758	8,355,225
10	Guangzhou	Shanghai–Hongqiao	1176	7,010,321	7,162,999

From a distance point of view an aircraft with 2000-4000 km range seems to be more than sufficient!

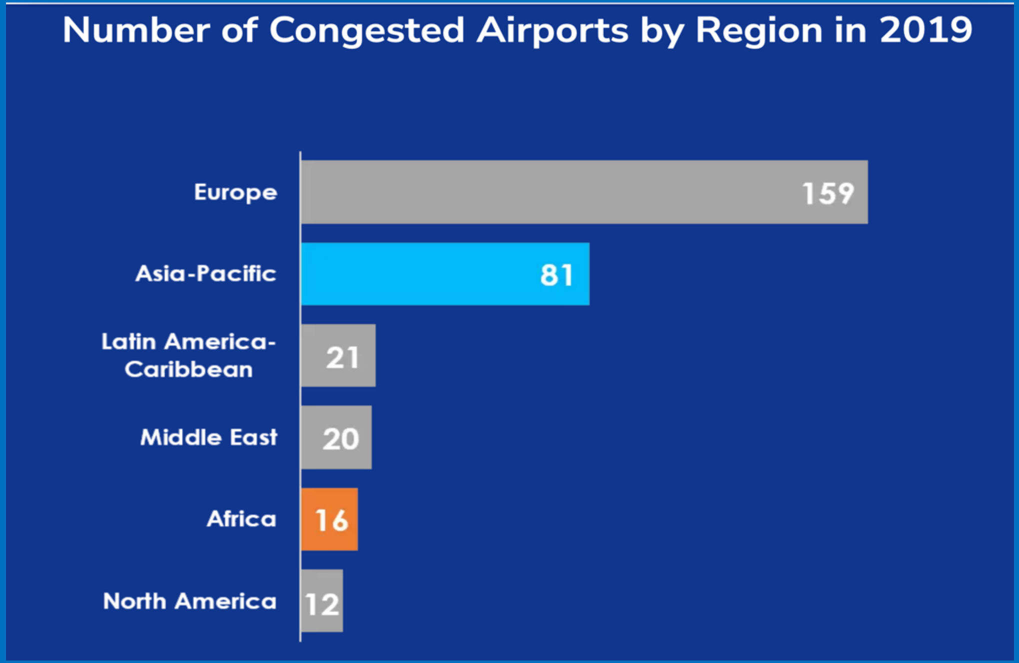
MINIMIZE THE SNOWBALL!

Source: Wikipedia

Airport capacity restrictions effects

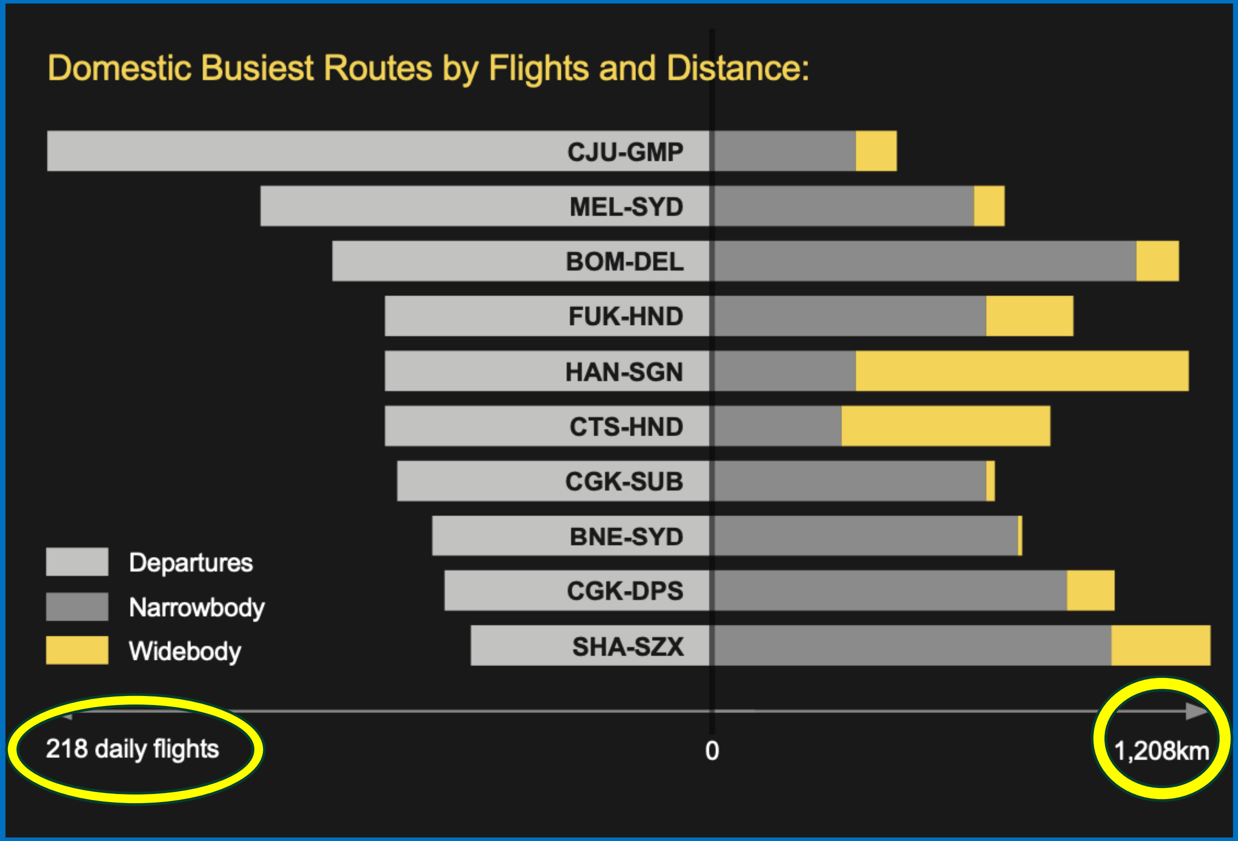


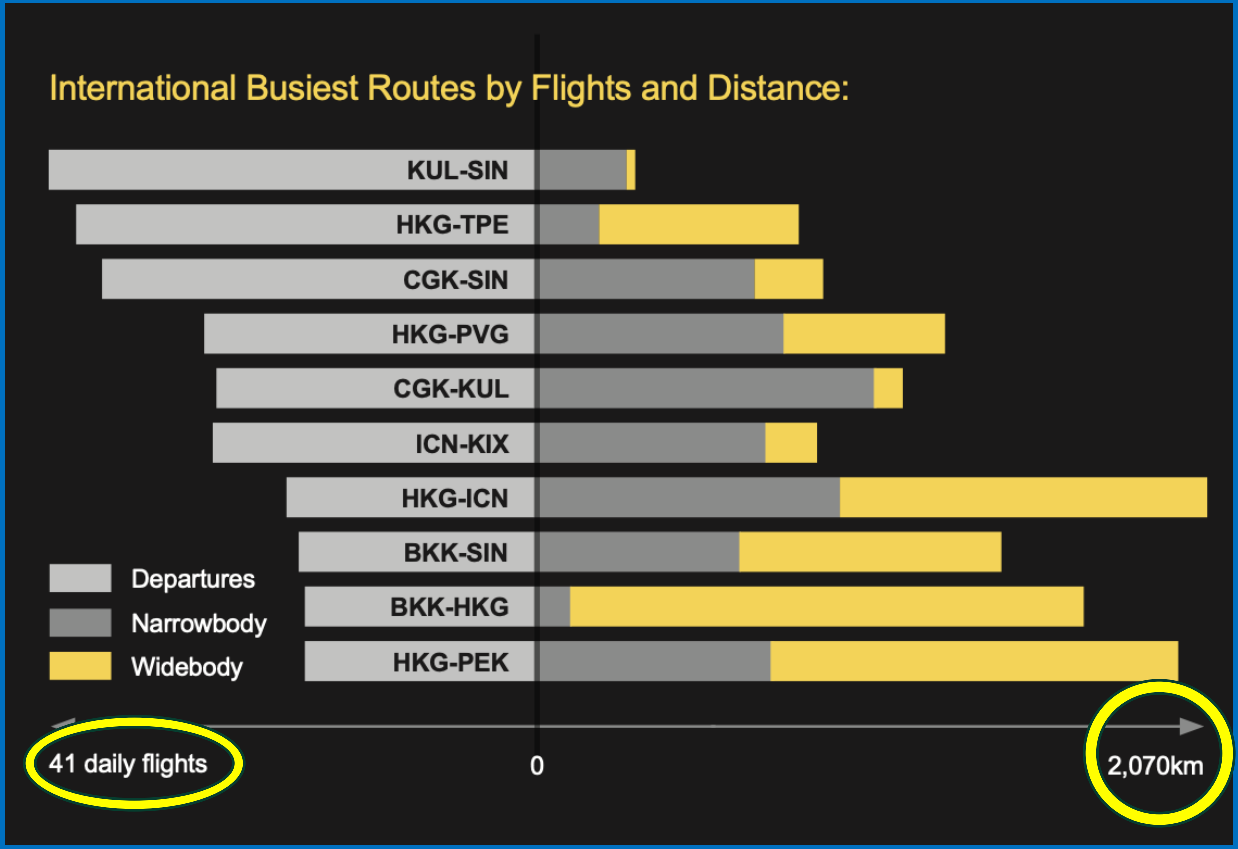
- Airport slot-capacity limits constrain the passenger volume growth (with Narrow-Body Short-Medium Range Aircraft as the A321neo/B737Max)
- So, Wide-Body aircraft (as the A350 and B777/787) have to be used to enable further passenger growth at slot-capacity limited airports



Source: DLR, ACI – Future Airport Slot Policy and the Airline Industry

2019: Airport capacity constraints in Asia: Distances and Frequencies with Narrow-Body and Wide-Body Aircraft

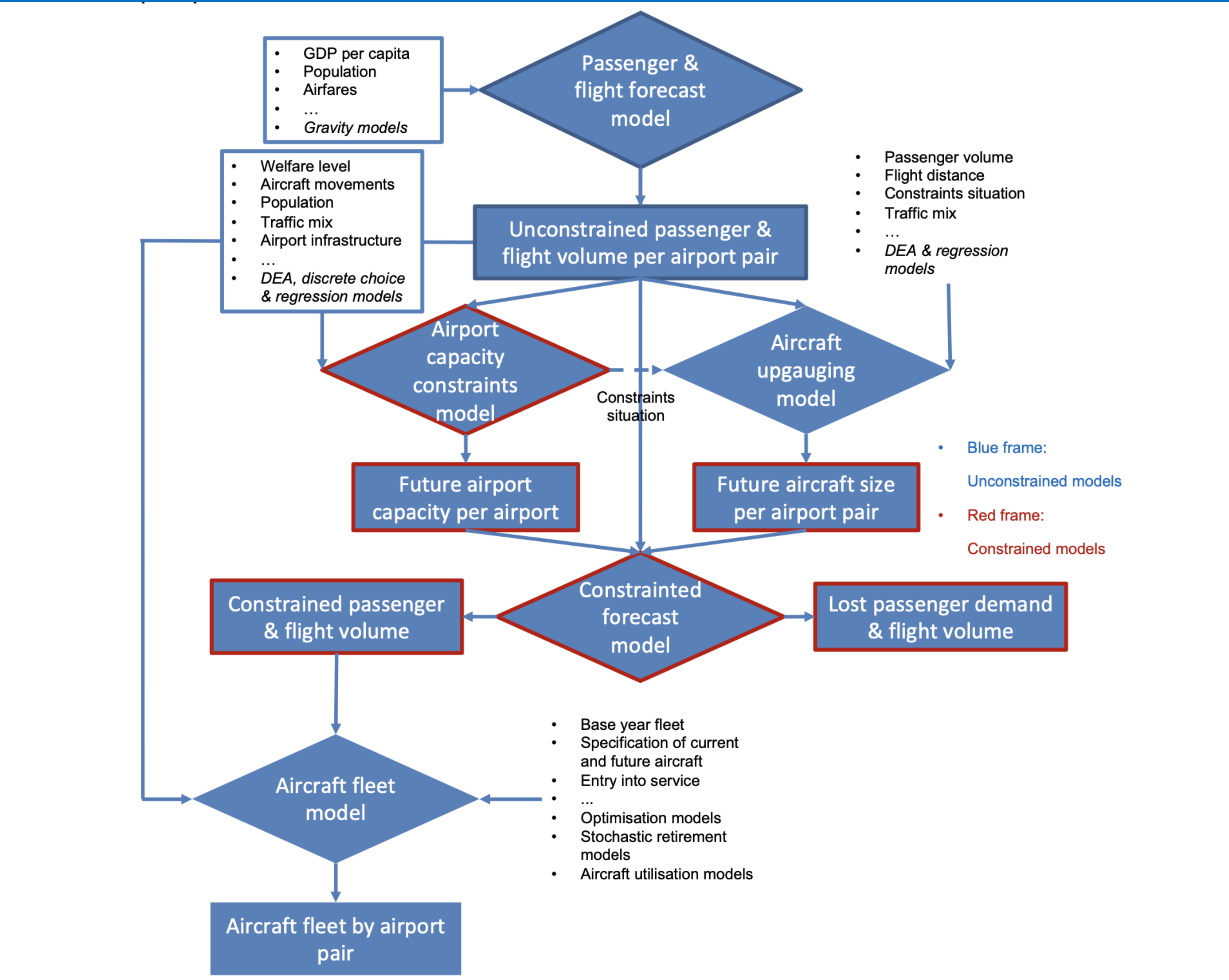




CGK=Jakarta, PVG=Shanghai, ICN=Inchon, KIX=Kansai, CJU=Jeju, GMP=Gimpo, FUK=Fukuoka, HND=Haneda, CTS=New Chitose, BNE=Brisbane, DPS=Denpasar, SZX=Shenzhen, BOM=Bombay, DEL=Delhi

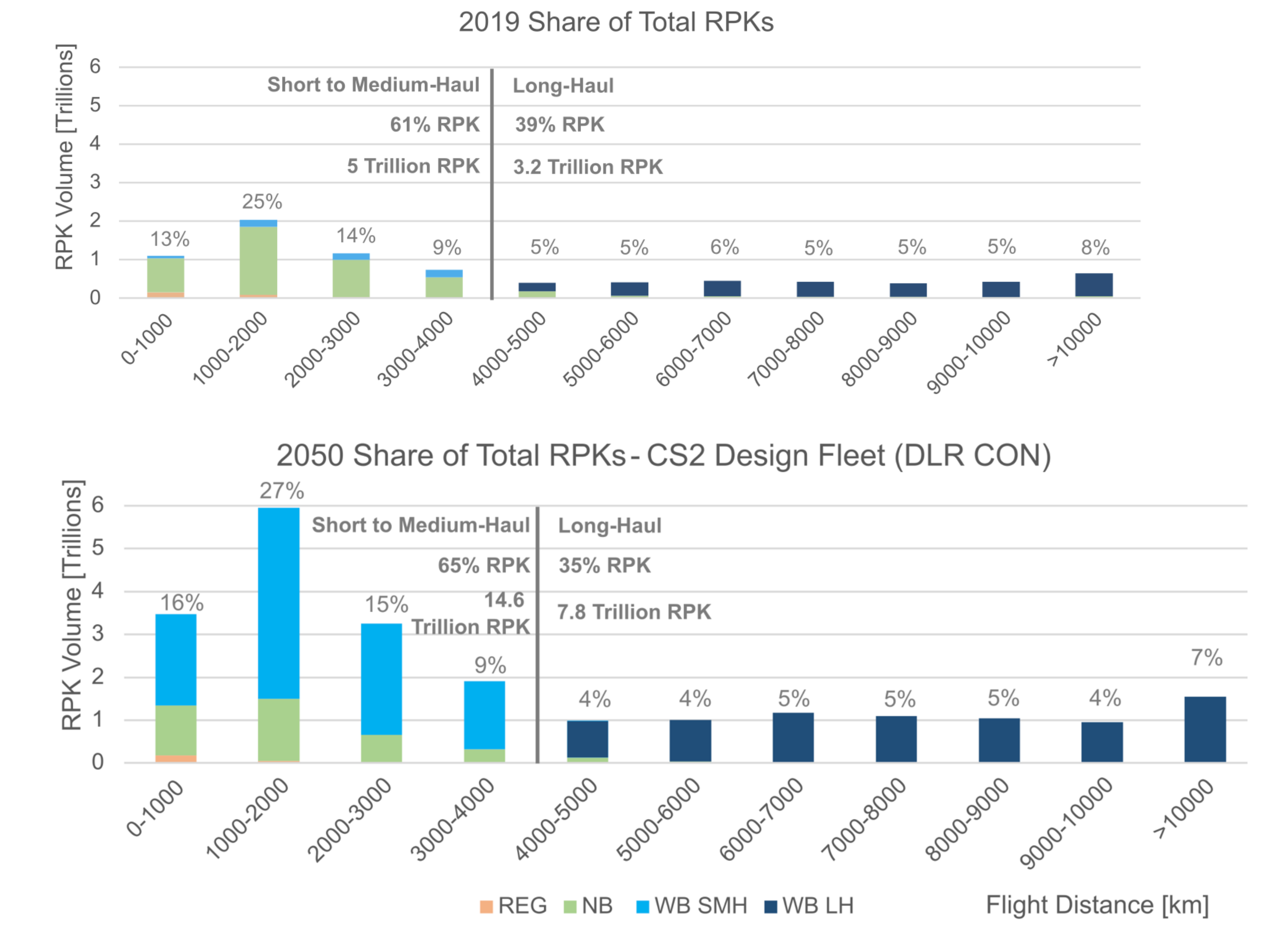
Source: AOG Busiest Routes 2019

DLR Fleet Forecast Model for EU JU Clean Sky 2



Source: CS2 Technology Evaluator Final Global Assessment 2024

DLR forecasted growth in *RPK volume* for NBs, WBs < 4000 km and WBs >4000 km range (constrained)

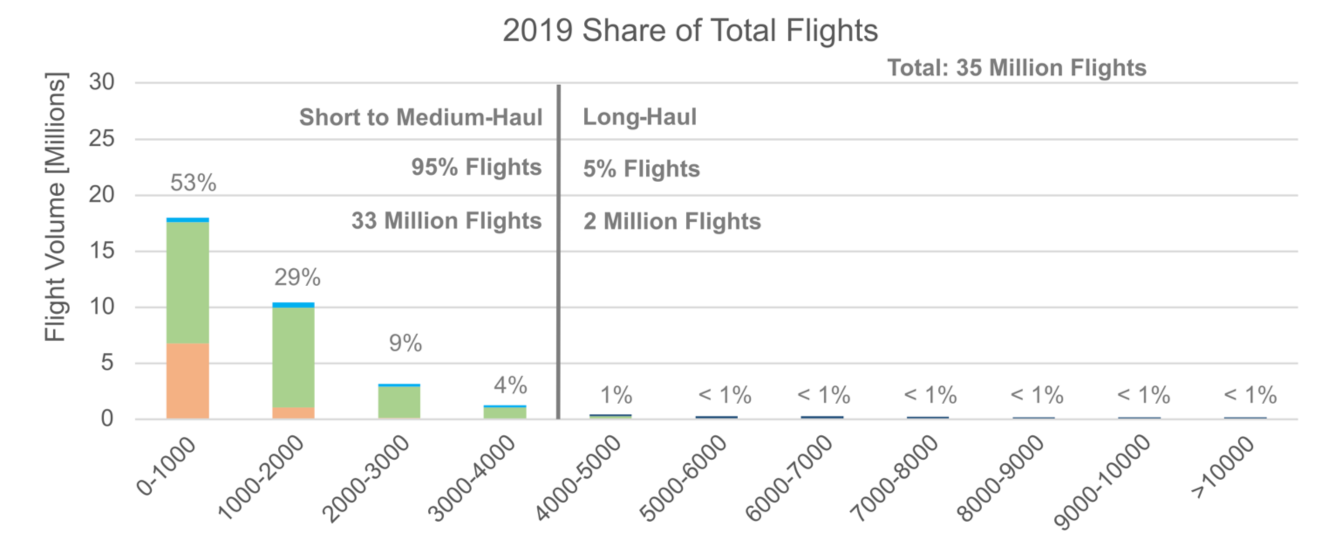


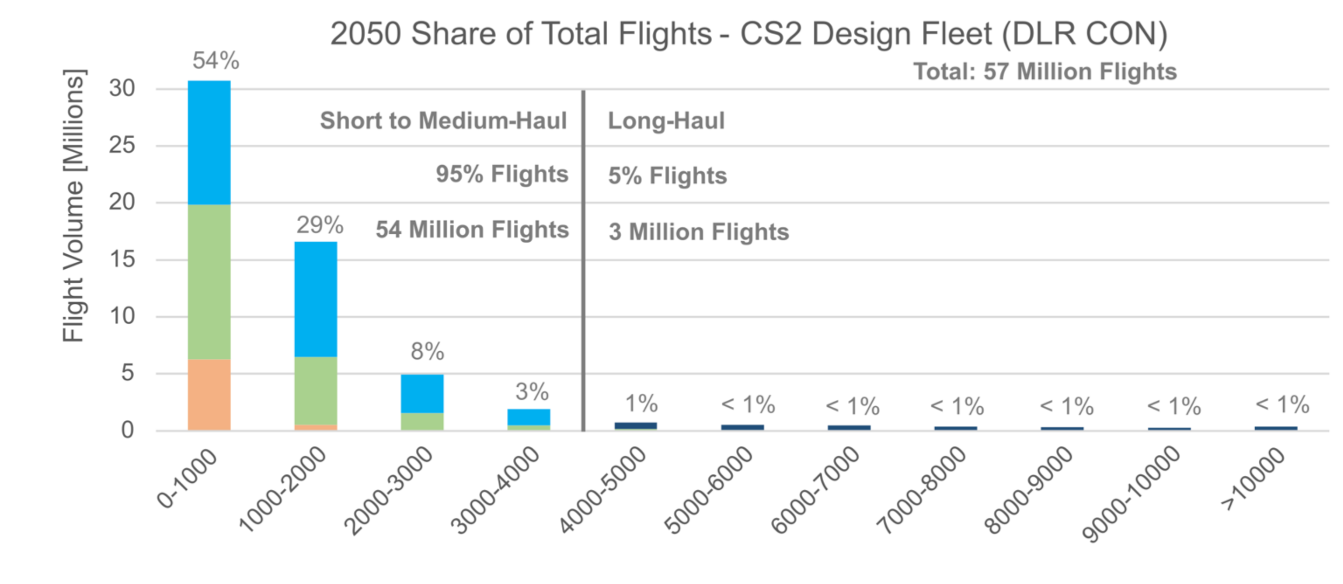
In 2019 the RPK share of wide bodies on distances <4000 km was only 7.5%

Because of the airport runway slot capacity limits this RPK share is forecasted to grow to 48% in 2050!

Source: CS2 Technology Evaluator Final Global Assessment 2024

DLR forecasted growth in *Flights volume* for NBs, WBs < 4000 km and WBs >4000 km range (constrained)



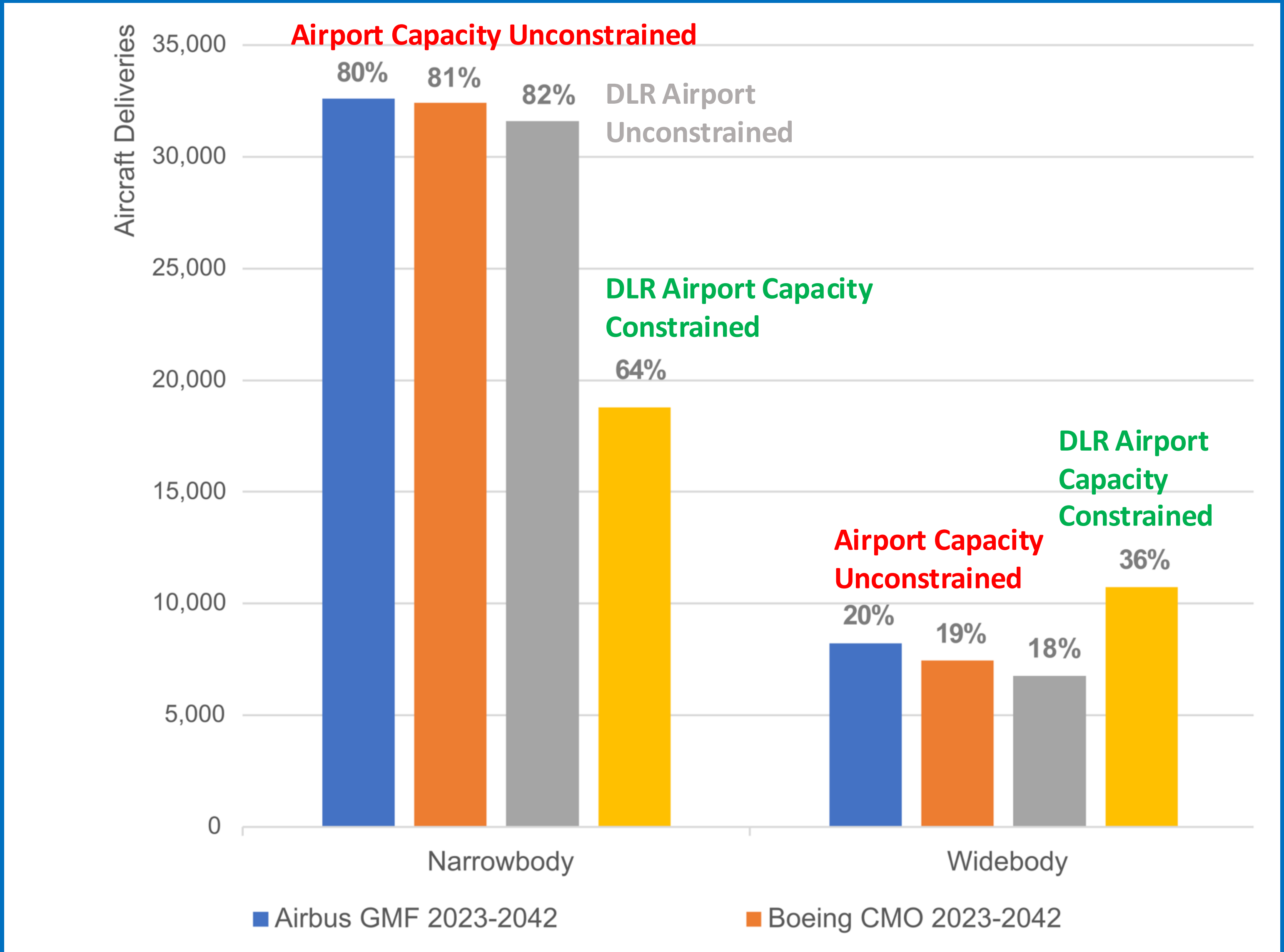


In 2019 the number of flights with wide bodies on distances <4000 km was about 4%

Because of the Airport runway slot capacity limits this flights percentage is forecasted to grow to 45%

Source: CS2 Technology Evaluator Final Global Assessment 2024

Airbus GMF, Boeing CMO (airport unconstrained) versus DLR Unconstrained and DLR Airport Constrained *Aircraft Delivery Forecast for 2042*



For the unconstrained case the forecasts of Airbus, Boeing and DLR are equal. Confidence in the DLR model!

Taking Airport Capacity constraints into account:

- Less Narrow Bodies
- More Wide Bodies

Source: CS2 Technology Evaluator Final Global Assessment 2024

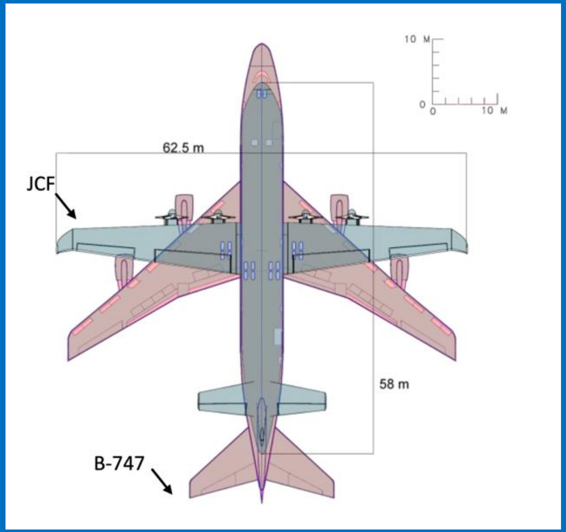
Case for a Short-Range Wide-Body Airliner

- Over 20% of the flights of wide-body aircraft are shorter than 4000 km
- The **increasing slot/capacity limitations of the global airports** forces the airlines into the use of **wide-body airliners for short-range** continental routes
  - The main region for this use is Asia-Pacific
  - But more and more also in Europe and the USA (United Airlines flew 3600 domestic flights with wide-body aircraft on 34 routes (2023))

- The share of Revenue Passenger Kilometres (RPKs) by Wide Bodies for Short-Medium Range operations is expected to increase from 7.5% in 2019 to 48% in 2050. The **existing wide-body airliners, like e.g. the A350 and B787,** are however designed for **long-range** operations. The are **heavy and operate at high Mach Numbers (Mach 0.85).**

- ***A new Short-Range Wide-Body aircraft with a range of 4000 km and a cruise Mach number of 0.7 could help to reduce the growing airport capacity problem with greatly reduced fuel-burn/CO2 emissions and airport noise***

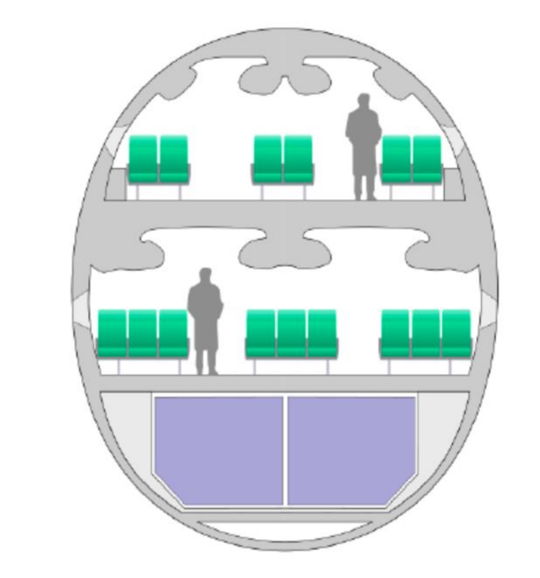
2015: TU-Delft Jumbo City Flyer

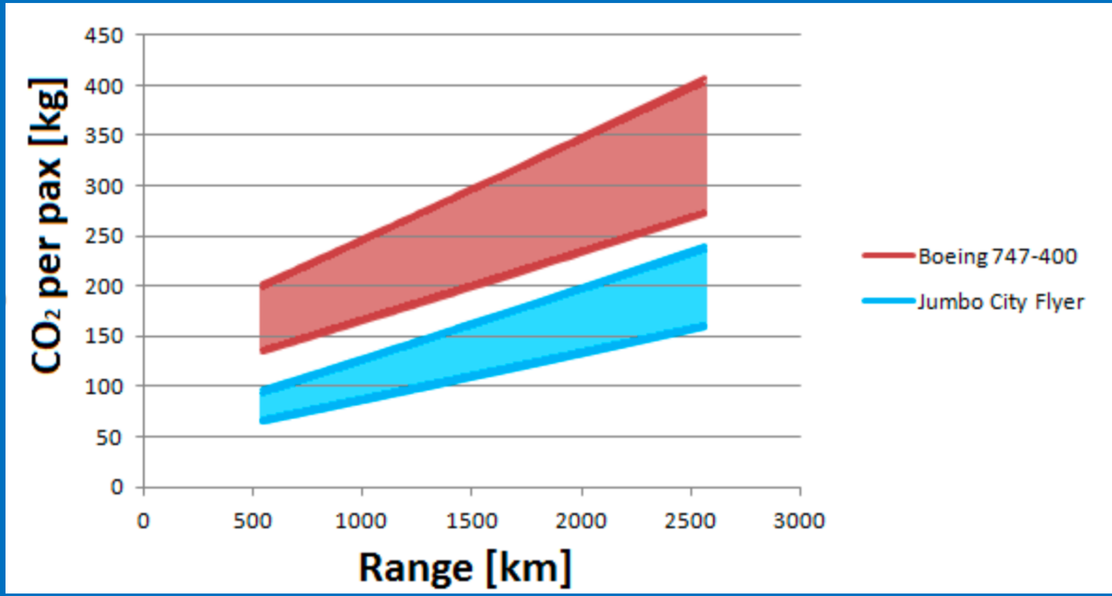


General JCF data

- 500 passengers
- Cruising speed 685 km/hr
- Design Range 2500 km
- Cruising altitude 27000 ft
- Payload 68.7 tonne

- CO2 per pass km
  - 540 km 81 kg (-52%)
  - 1250 km 122 kg (-47%)
  - 1990 km 165 kg (-43%)





Source: A. Rao & G. Eitelberg – Jumbo City Flyer

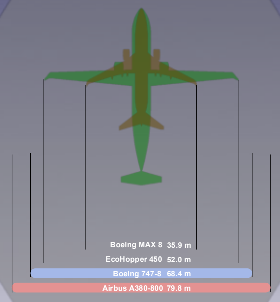
2019: BSc Design Exercise Study EH450

EcoHopper 450

A short term solution for a sustainable future in aviation

Disrupting aviation

In the past few decades, the growth of global commercial aviation has shown no signs of slowing down. The effects of aviation on global warming, air quality and noise pollution contribute to the demand for more sustainable aviation. The EcoHopper 450 is designed with these three concerns in mind. As a short term, cost-effective alternative for intra-continental flights, the EcoHopper 450 will serve the short-range, high-demand market.



Ambitious goals

The strive for sustainability was formulated using three driving requirements, all with respect to current state-of-the-art aircraft.

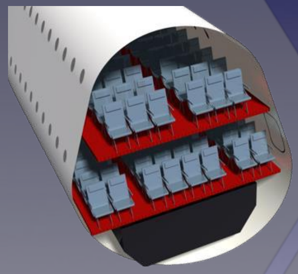
- A reduction of 10% in operating costs.
- A reduction of 10% in fuel consumption.
- Decreased NO_x and CO_2 emissions.
- One noise class lower.

Specifications

Range: 1,400 km
Passenger count: 450
Cruise speed: 790 km/h
Cruise altitude: 9 km
Wing span: 52 m
Length: 55 m
Empty mass: 89.0 t
Max. mass: 155.0 t

Fuel: -25%
Noise: -5dB
CO_2: -29%
$: -14%

Seating configuration



Novel technologies

The aircraft is equipped with novel technologies to meet the requirements:

- Electric taxiing
- Self-powered braking
- Bleedless architecture
- Innovative wing design
- Ultra-high bypass engines
- Composite strut

Source: TU-Delft LR BSc Design Exercise “Bigger is Better”

Will the Short-Range Wide-Body aircraft be realized?

- A Short-Range WB aircraft will **cannibalise the Long-Range WB aircraft market**
  - All short-range missions can be flown with long-range aircraft!
  - Less Long-Range Wide-Bodies (eg A350s and B777/787s) will be produced!

- Developing, certifying and producing a new aircraft requires **significant investment costs and time and involves significant risk**
  - Airbus A350 costed 11 billion €, 9 years development time, 3 years delay
  - Boeing B787 costed 32 billion $, 7 years development time, 3 years delay

- With ***no competition there is no commercial incentive!*** The only argumentation is environmental: a ***significant reduction of CO2 emissions***

- ***"The Environment versus Shareholder Value (and airline/lessor flexibility)"***

Boeing 737 Max and Airbus A320 Neo successors (Clean Sheet of Paper: Entry into Service 2037-2038)

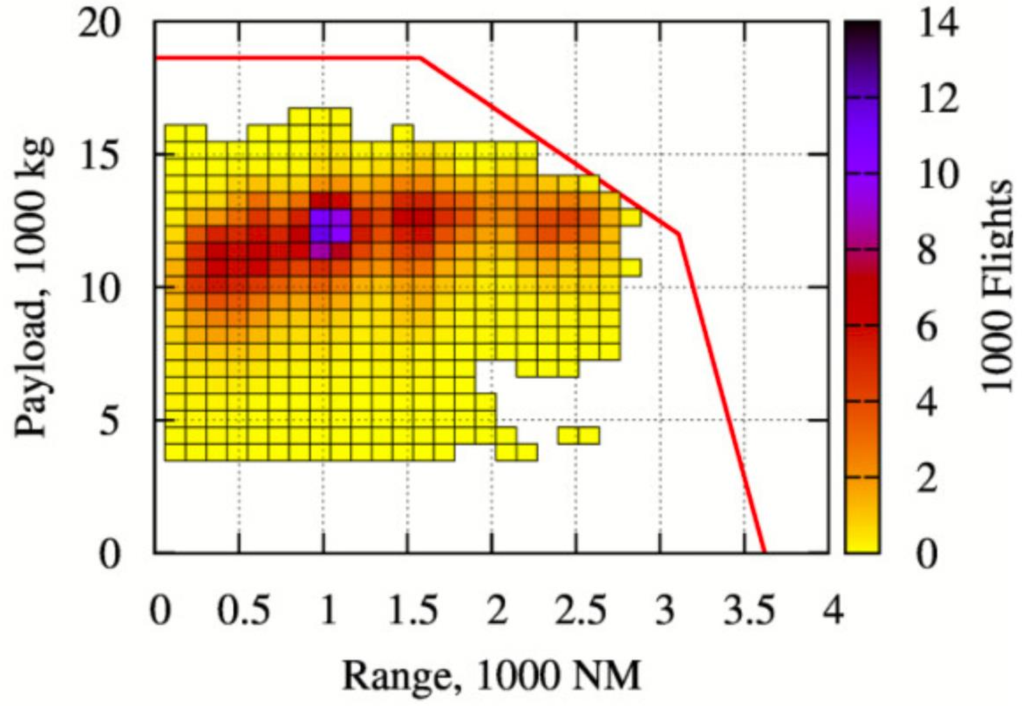
Aluminium airframe from 1967

Aluminium airframe from 1984

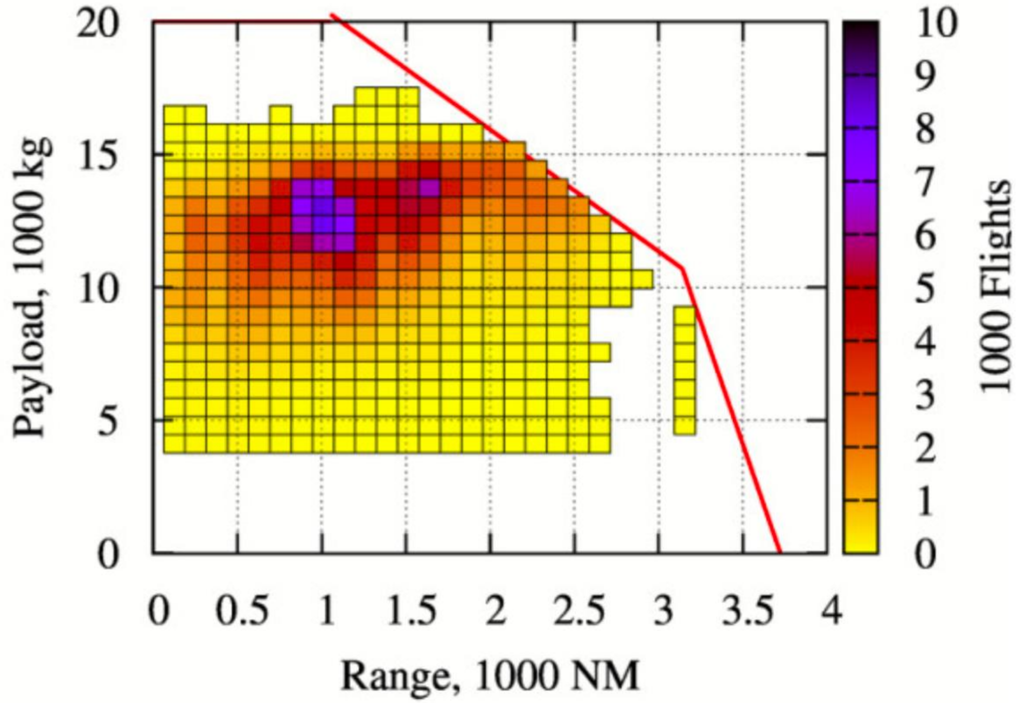
What determines the speed (M 0.78) and Design Range (7400 km)?

Shareholder value or the Environment? Is this the CO2 emissions optimum?

Annual number of flights and payload-range diagram



A320-200



B737-800

For most of the flights a design for a design range of max 4000 km) and a payload of 15000 kg would be sufficient!

Source: M. Husemann, K. Schaefer and E. Stumpf, “Flexibility within flight operations as an evaluation criterion for preliminary aircraft design,“

Effects on flight duration of lower speeds
(Flight from Amsterdam to Madrid 1500 km)

A320 Mach 0.78 = 830 km/hr: 1 hour 48 min

EH450 Mach 0.72 = 790 km/hr: 1 hour 54 min

JCF Mach 0.57 = 685 km/hr: 2 hours 11 min

For short-medium range flights the longer flight duration seems acceptable for the passenger

However, it might mean that less flights per day could be made. This is negative for the airlines

A320 Neo Successor Concepts

2019 Airbus Albatros one - Scale model flight test. Wing Aspect Ratio 18

- Dec 15, 2023 France (Conseil pour la Recherche Aéronautique Civile - CORAC) decided to provide funds for RDT&E to develop a A320 Neo family successor
- **French Budget 300 M€ per year for 2024, 2025 and 2026**
- A320 Neo Successor planned Entry Into Service mid 2030s

2022 EU CS2 U-HARWARD - Ultra High Aspect Ratio Wing Advanced Research and Designs Wing Aspect Ratio 15-20

2023 ONERA Project Gullhyver: RISE Open Rotor, TTBW with Aspect Ratio of 20, 200 seats, 7500 km (Hydrogen but also usable for SAF)

2025 Clean Aviation Project AWATAR

Project Leader ONERA

- 36 months duration (2025-2027)
- 14.7 M€ funding, (13.2 M€ from EU CA)

- 250 passengers, 3700 km range
- Ultra-thin, Very High Aspect Ratio, Strut-Braced, dry wing
- Open Rotor, hydrogen propulsion
- Natural Laminar Flow
- Advanced Ice protection

- OEMs: Airbus and Dassault
- Res. Establ.: ONERA, DLR and NLR
- Unis: TU-Delft and Uni Montpellier
- 3 Wind tunnels
  - European Transonic Wind tunnel ETW
  - ONERA S2MA
  - Collins Icing Wind tunnel
- EASA involvement

Source: EU Clean Aviation

Will the Shorter-Range Lower-Speed aircraft be realized?

- Over 10 years production backlogs for A321neo/B737Max
- An extra aircraft type causes extra maintenance and pilot training
- For Airbus/Boeing a new airliner development causes extra costs and risks
- There is no competitive necessity, lower speed is negative for airline productivity
- With ***no competition there is no commercial incentive!*** The only argumentation is sustainability/environmental: a ***significant reduction of CO2 emissions***
- ***"Sustainability versus Shareholder Value (and airline/lessor flexibility)"***

Content

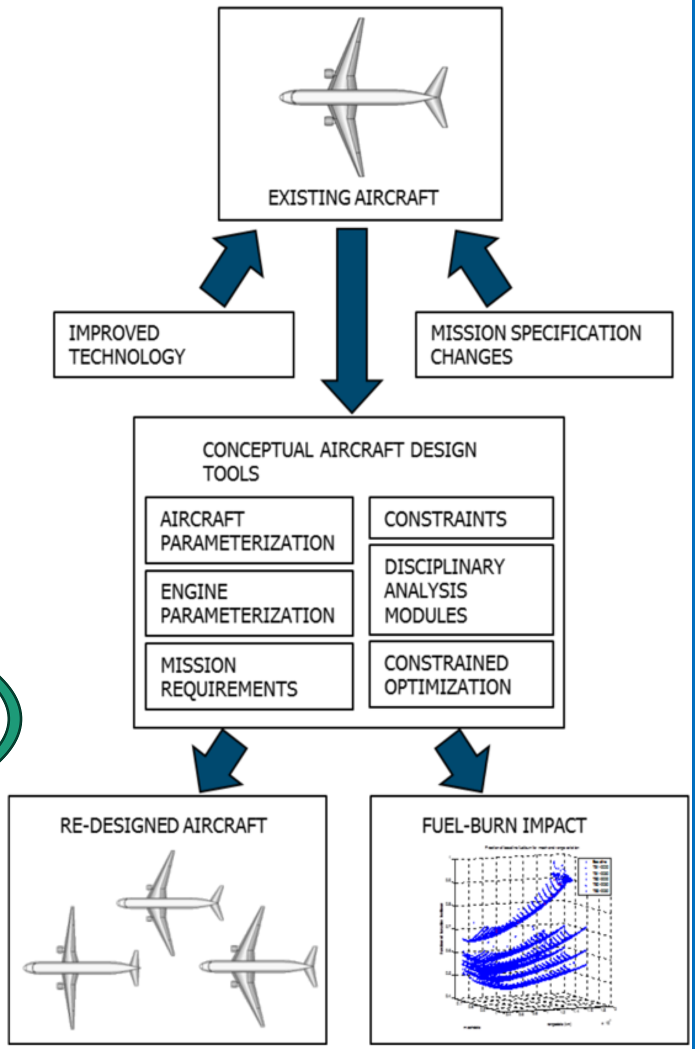
- Introduction
- Growth forecast and CO_2 Emission consequences
- General measures to reduce CO_2 Emissions
- Technology developments and new, optimal aircraft
- **US FAA/NASA/MIT/Boeing and JetZero developments**
- Summary and Conclusions

FAA ASCENT – Project 10 – Aircraft Technology Modelling and Assessment Phase 1

(ASCENT is the FAA-NASA-MIT-Wash State University DOD funded "Aviation Sustainability Center")

- Some emerging world views and scenarios in ASCENT 10 (particularly the "High R&D" and "Environmental Bounds" worldviews) call for innovative solutions
- **Mission specification changes are operational improvements**, including aircraft and engine redesign, that can lead to significant fuel savings
  - **Cruise Speed Reduction (CSR)**
  - Changes to Payload/Range capabilities
  - Maximum allowable span
- PARTNER P43, investigated system-level economic implications using our best tools at the time. **CSR was found to be beneficial with all operational costs included.**
- **Improved tools** (SUAVE) and system-level analyses are now available to refine the quality of our predictions

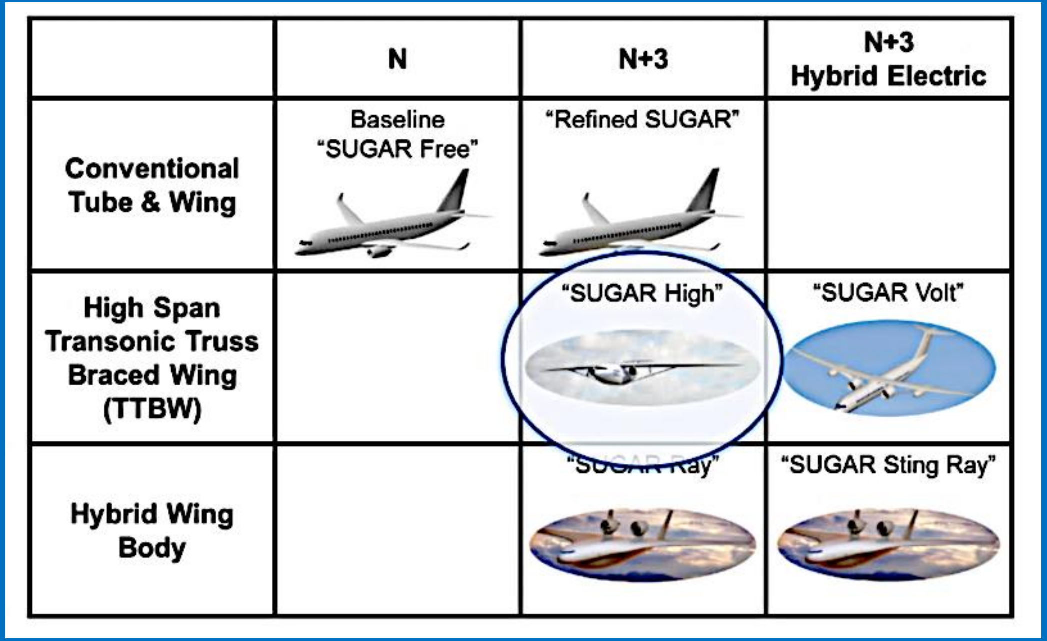
SUAVE



Source: FAA Lazlo Windhoffer – Spring 2017 Annual Advisory Board Presentation

NASA Subsonic Ultra Green Aircraft Research (SUGAR)

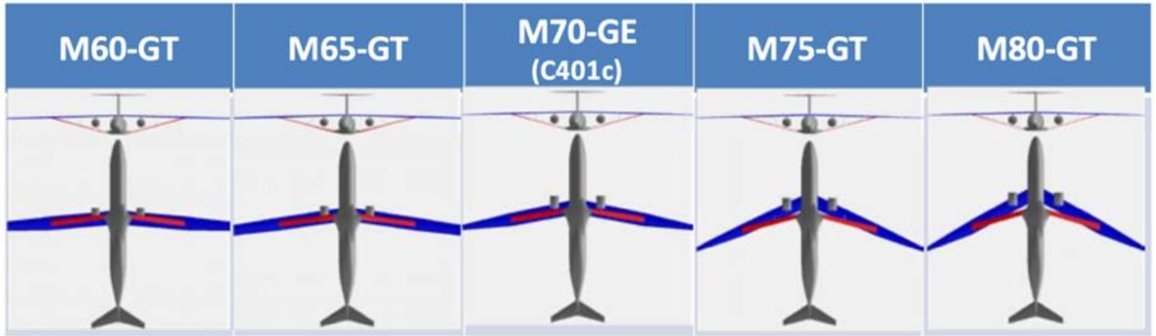
- Phase 1: 2008-2010 Concept studies
- Phase 2/3/4: 2010-2018 thin Truss-Braced Wing and Hybrid Electric Power studies
- *High Aspect Ratio of the wing (20)*
- *Room for a large size engine*
- *154 pax, 6500 km range*



	N	N+3	N+3 Hybrid Electric
Conventional Tube & Wing	Baseline "SUGAR Free"	"Refined SUGAR"	
High Span Transonic Truss Braced Wing (TTBW)		"SUGAR High"	"SUGAR Volt"
Hybrid Wing Body		"SUGAR Ray"	"SUGAR Sting Ray"

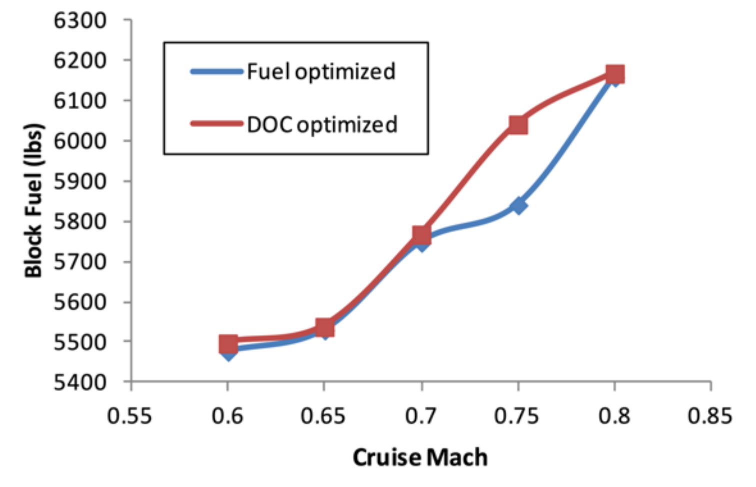
Source: NASA

NASA SUGAR Variants: Mach 0.6-0.8
(Effects of speed on fuel burn)



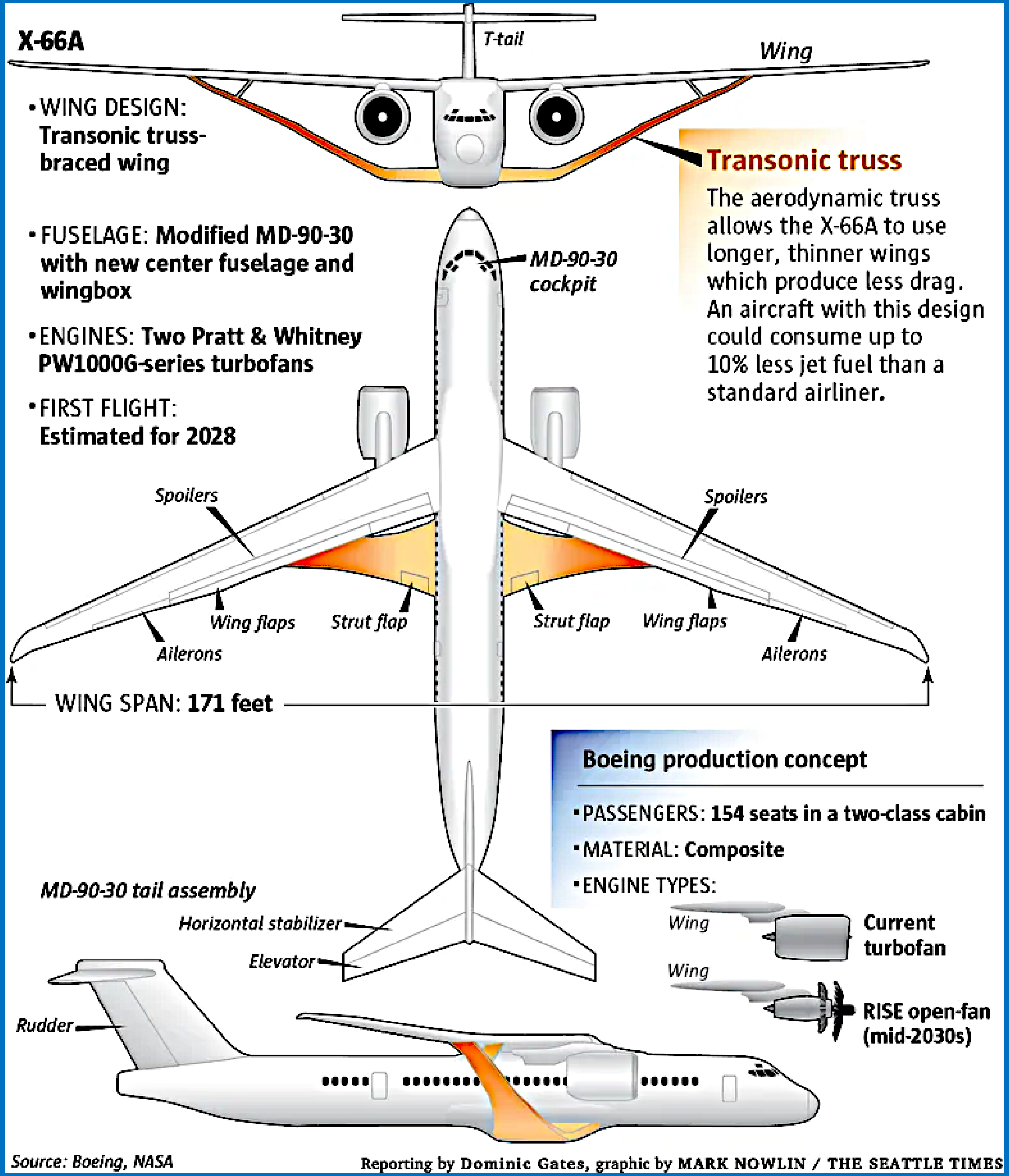
	Units					
Cruise Mach Number		**0.60**	**0.65**	**0.70**	**0.75**	**0.80**
TOGW	lb	126,900	128,000	129,700	132,500	144,600
OEW	lb	74,500	75,700	76,900	78,300	85,900
Payload	lb	30,800	30,800	30,800	30,800	30,800
Passengers/Class		154/Dual	154/Dual	154/Dual	154/Dual	154/Dual
Range	nm	3,500	3,500	3,500	3,500	3,500
Block Fuel (900nm range)	lb	5,290	5,320	5,520	5,880	6,840
Block Time (900nm range)	hr	3.0	2.8	2.7	2.6	2.5
Wing Area	ft^2	1,130	1,150	1,150	1,180	1,320
Wing Span	ft	149	150	150	152	161
Wing Aspect Ratio		19.55	19.55	19.55	19.55	19.55
Wing Sweep	deg	3.76	4.31	5.40	6.56	17.23
Wing t/c		0.148	0.121	0.107	0.107	0.107
Strut t/c		0.198	0.155	0.156	0.100	0.100
Jury t/c		0.119	0.196	0.121	0.195	0.122
Start of Cruise L/D		25.6	25.0	24.6	22.9	19.8
Thrust per engine	lb	17,620	17,780	19,220	20,950	24,990

- Payload 30.800 lbs
- 154 Passengers
- Design Range 6500 KM
- SUGAR base was Mach 0.7
- For 1670 Km the Block Fuel is:
  - M 0.8 6840 lbs
  - M 0.6 5290 lbs (23% less) with a 1/2 hour longer flight (3 hrs instead 2.5 hrs)



Source: D. P. Wells – Cruise Speed Sensitivity for Transonic Truss-Braced Wing

NASA-Boeing X-66A



- Announced: Jan 2023
- Mach 0.8 (why?), 52 m wing span, Wing Sweep Angle of 20° and an Aspect Ratio 20
- Fuel 30% better than B737Max and A320neo
- Planned first flight: 2028
- NASA funding: 425 Million US$ over 7 years
- Boeing/partners: 725 Million US$
- Aero-elasticity as well as crosswind take-off and landing are important issues
- Stopped: April 2025

Source: NASA/Boeing

JetZero Blended Wing Body

- 30-50% less fuel/CO2 per tonne km/pass-km
- USAF Tanker version, 9000 km range
- *Aug 2023: USAF gave JetZero a 235 M$ contract for full-scale demonstrator in 2027*
- March 2024 1/8 scale model flight
- CFM LEAP or P&W 1000G engines
- Composite airframe/Noise shielding
- Alaska Airlines interest in 250 pax version
- United Airlines invests in JetZero
- Delta Air Lines is partner to JetZero

Source: JetZero

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Summary and Conclusions

- Forecast for 2050: a 2-3 times global RPK demand (China and India)
- ICAO and the IATA agreed on net-zero CO_2 emission in 2050
- There is a limit on airport slot capacity, resulting in an increased use of wide-body aircraft for short-medium ranges
- Electric and LH2 propulsion will play a very minor role in 2050
- Important elements of the solution to enable net-zero CO_2 air transport in 2050:
    - *Large-scale use of green Sustainable Aviation Fuels (PtL eFuel)*
    - *New competitive & low-CO_2 emission SMR Narrow-Body and Short-Range Wide-Body aircraft (design/operational range <4000 km and Cruise Mach number of max 0.7).*
- **Start NOW and EIS of the new aircraft can be in 2035!**