Dieter Scholz:
Summary of the AeroLecture on 2024-05-23

Raj Nangia:
The Drive for Sustainability Inspires Unconventional Thinking on New Aircraft Designs

- *No lecture notes are distributed because the pictures are not free of copyright.*
- *Instead, a list of publications written by Raj Nangia is made available. See below.*
- *These are the notes taken during the lecture by Dieter Scholz*

Introduction

Aviation is now flying for 120 years with kerosene since 1903, Wright Brothers – and half of this time I [Raj Nangia] was part of it.

Aviation entered sustainability debate in 2000: LH2, Cryoplane, … but most well-established certification requirements continue to be in place. LH2 aircraft must be as safe as kerosene aircraft.

Use of technologies:

- Very short range: battery
- short ranges: battery / hybrid / fuel cell powered
- up to 400 nm: electric rail travel; example: England-France
- up to 2000 nm: LH2 powered
- beyond 3000 nm: Sustainable Aviation Fuel, SAF.

The "hot cakes" are the existing aircraft. Life of pax aircraft is 30 years! It takes this long to replace the fleet.

Solutions (will be detailed later):

- air-to-air refuelling
- wake surfing (formation flying)

General Remarks from Flight Physics

Efficiency parameters in use: L/D & M*L/D

Breguet Range Parameter: X = V*L/D / SFC or M*L/D / SFC

L/D, some numbers:

- 21 for A330
- 22+ for A350 & B787
- Car: 100
- Rail: 1000
- Sailplane: 70

M*L/D, some numbers:

- ⇨ 1990: on average 15
- ⇨ today: M*L/D: up to 18.7

M*L/D is amazingly a rather constant value through history. L/D is increasing a little, but M goes down a little. This leaves M*L/D a rather constant value. Will M*L/D increase much more in the future? (Maybe not)

Large Span as a Solution

This requires braced wings and maybe also folding wing tips.

Airbus project: AlbatrossONE: Aeroelastic wing. Idea: gust load alleviation with spring loaded wingtips that move up in an updraft. So, the benefit is from a large span wing that limits the otherwise high loads (root bending moment) with gust load alleviation.
https://www.airbus.com/en/innovation/disruptive-concepts/biomimicry/wings/albatrossone

Aspect Ratio (AR) for passenger aircraft
have grown up to 11.

NASA / Boeing X-66A (https://de.wikipedia.org/wiki/Boeing_X-66A)
Full scale research aircraft
short/medium rage
with AR = 12 …14
span up to 52 m (ICAO Code letter D), L/D = ?
Another idea: Wide Body, Joint Wing. The problem is in wing buckling, L/D up to 23.

Blended Wing Body (BWB)

USAF / NASA: Blended Wing Body, research planed as (only) a scaled X-Aircraft
Problems with this project (as seen by Raj Nangia):

- ⇨ Passenger cabin completely enclosed.
- ⇨ Evacuation not solved. Where are the exits?
- ⇨ Vertical fin not on body, but on wing tips. This is rather problematic!
- ⇨ Jets on top of the aft body. in the location of the boundary layer of the big flat fuselage. Not good for engines.
- ⇨ Claim: L/D = 23 or 24. Is that realistic?

See also: https://doi.org/10.5281/zenodo.6515774, https://doi.org/10.48441/4427.442

Efficiency via Operations

- ⇨ Civil air to air refuelling (EU Research in Framework Program FP7)
- ⇨ Wake surfing (formation flying) (NATO AVT 279)
- ⇨ Reference: Please see Ray Nangia's evening lecture in Hamburg 2012
  https://www.fzt.haw-hamburg.de/pers/Scholz/dglr/hh/poster_2011_03_31_Air-to-Air_Refuelling.pdf
  https://www.fzt.haw-hamburg.de/pers/Scholz/dglr/hh/text_2011_03_31_Air-to-Air_Refuelling.pdf

Air-to air refuelling has come a long way: Cartoon 1909 in satire magazin "Punsh" (https://en.wikipedia.org/wiki/Punch_(magazine))
This has a 20% to 30% fuel advantage when flying over a range of 6000 nm.
Can also be done with small aircraft flying over a range of 3000 nm.
Airbus manages military automatic refuelling with A310 and A330. So, it should also work automatically with passenger aircraft.

Wake / vortex surfing, also known as **close formation flying**: 10% advantage on trailing aircraft (if it is an equally sized aircraft). If a smaller is following even higher fuel savings are possible.

Energy Alternatives Considering 1.5 °C Temperature Increase (Max.)

General remark: Energy can only be transformed, this never to 100% efficiency.
Required is by all means: De-carbonise aviation --- quickly!
But keep this in mind:

- ⇨ safety comes before de-cabonisation
- ⇨ certification comes before de-cabonisation
- ⇨ crashworthiness comes before de-cabonisation

How Mature is LH2 in Aviation (With Fuel Cell and Electric Motors)?

- ⇨ Today flown: 400 kW (RR "Spirit of Innovation"
- ⇨ But: would need to replace kerosene turbofan: 9 MW (single aisle benchmark)
- ⇨ Hydrogen atoms love oxygen. Hydrogen can blow up
- ⇨ Critical is also nitrogen
- ⇨ Hydrogen leads to material embrittlement
- ⇨ LH2 can cause boiling expanding vapour explosion (BLEVE)
- ⇨ Ignition on contract with water (rain)
- ⇨ Internal heat during liquefaction, boil-off leads to over-pressure
- ⇨ LH2-certification: problem with aircraft stability & control
- ⇨ Fuel in conventional wing tanks (together with tail tank) is used to manage CG; not possible with LH2. Example of CG control with fuel: Concorde.
- ⇨ No wing box use for LH2 (dry wing)
- ⇨ LH2: Still 90% MTOW at landing

- ⇨ Centre tank (kerosene): It took 18 years, several accidents (1996, 2002, 2006, 2008) and rule-making to get this simple addition of functionality to an accepted and safe state. Extrapolate this to the use of LH2!
- ⇨ Only two LH2 flying aircraft have been built in aviation history. The two aircraft did not perform a take-off on LH2 (only used in cruise)
- ⇨ 1.) Martin B-57 Canberra, USA, LH2 trials, 1955 (https://simpleflying.com/martin-b-57b-hydrogen-powered-flights-1950s)
- ⇨ 2.) TU 155 (https://en.wikipedia.org/wiki/Tupolev_Tu-155)

LH2 Fundamentals and Literature Review

LH2 3 times lighter 4 time bulkier.
History: Book by Brewer (https://www.amazon.de/dp/0849358388)
History: Cryoplane project:

https://www.fzt.haw-hamburg.de/pers/Scholz/dglr/hh/text_2001_12_06_Cryoplane.pdf
https://www.fzt.haw-hamburg.de/pers/Scholz/dglr/hh/text_2004_02_26_Cryoplane.pdf

Recent single aisle investigations by HAW Hamburg, ILF at TU Braunschweig:

http://GF.ProfScholz.de

Fuel cell and electric motors: 1 MW heat generation. Heat exchangers needed to transfer the energy into the environment.

Airbus ZEROe and Beyond

Airbus ZEROe project. Very little information released to the public. It seems, Airbus only releases information to the public of things that will not be used anymore. Otherwise, you cannot understand, why the things published have such state.

https://doi.org/10.5281/zenodo.4301103

Airbus Transcontinental LH2 Concepts: Aft part of the fuselage is used by LH2 tanks. Passengers sit in front of the wing. Has anyone calculated the shift of CG? Probably not. It may not work.

Unconventional Concepts

Asymmetrical Aircraft:

https://en.wikipedia.org/wiki/Asymmetrical_aircraft

Blohm-Voss BV 141: gondola for observer on the wing (asymmetric aircraft):

https://en.wikipedia.org/wiki/Blohm_&_Voss_BV_141

Rutan model 202, Boomerang (asymmetric aircraft):

https://en.wikipedia.org/wiki/Rutan_Boomerang

Double fuselage aircraft (leads to substantial reduction in wing bending):

https://en.wikipedia.org/wiki/Twin-fuselage_aircraft

H2Fly (double fuselage aircraft for LH2) by DLR and University of Ulm:

https://www.h2fly.de

https://en.wikipedia.org/wiki/DLR_HY4

LH2 Wisdom

Keep in mind for LH2:

- ⇨ Each engine needs its own LH2 tank
- ⇨ LH2 tanks need to be well contained
- ⇨ LH2 tanks need to be well separated from passengers
- ⇨ LH2 tanks may not obstruct exits

Design of an aircraft with twin fuselage (one fuselage for passengers, one fuselage for LH2 tank)

- ⇨ CFD on done on such aircraft configuration.
- ⇨ wing root bending moments are of the same order of magnitude as conventional aircraft.
- ⇨ asymmetry components.
- ⇨ also investigated: forward swept wing concept.

Oblique wing aircraft

Anti-symmetric oblique wing aircraft (R.T. Jones)

Summary (What will we see in the future?)

- ⇨ SAF (but very low overall energy efficiency and too much surface of the earth is needed to make SAF for aviation available)
- ⇨ Truss braced wing aircraft like Boeing X-66a
- ⇨ BWB maybe on long ranges
- ⇨ Maybe LH2, because it has no carbon emissions, but:
    - LH2 aircraft have a problem with fuel storage on long range
    - LH2 is dangerous. It needs a split between passenger cabin and LH2 tank
    - Raise Technology Readiness Level (TRL) of LH2 aircraft. Not ready to be built yet! (https://en.wikipedia.org/wiki/Technology_readiness_level)

From the Q&A

https://group.apus-aero.com
https://group.apus-aero.com/zero-emission
https://www.haute-innovation.com/magazin/mobilitaet/wasserstoff-flugzeug

Compressed hydrogen in the wings.

Further reading recommended by Raj Nangia related to this evening lecture:

NANGIA, Raj, 2018-11-06. Highly Efficient Civil Aviation, Now via Operations - AAR & Challenges. In: *SAE Aerospace Systems and Technology Conference 2018 (ASTC 2018)*, London, UK. Available from: https://doi.org/10.5281/zenodo.11388466.

NANGIA, Raj, HYDE, Les, COOPER, Jonathan. 2023-07-09. Developing Certifiable Liquid Hydrogen "Gondola" Airliner, Design Innovations & Challenges. In: *Aerospace Europe Conference 2023 – Joint 10th European Conference for Aerospace Sciences (EUCASS) and 9th conference of the Council of European Aerospace Societies (CEAS)*, Lausanne, Switzerland. Available from: https://doi.org/10.5281/zenodo.11388886

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The Drive for Sustainability Inspires Unconventional Thinking on New Aircraft Designs

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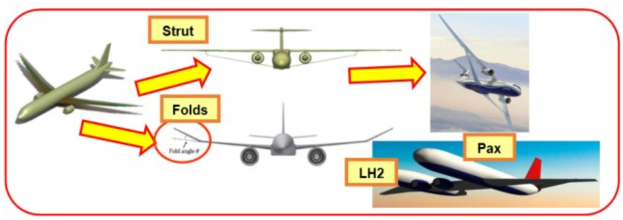
Date: **Thursday 23 May 2024, 18:00**
Location: **HAW Hamburg, Berliner Tor 5, Hörsaal 01.10**



With growing realisation of environmental issues and sustainability, we need to minimise reliance on fossil fuels. A “realistic” vision of aircraft development scenario for 2050 and beyond is imagined to be four-fold: battery-electric for very short ranges, hybrid - hydrogen fuel cells for short ranges, Liquid Hydrogen (LH2) for the medium ranges, and Sustainable Aviation Fuel (SAF) for the longer ranges with air-to-air refueling and formation flying.

For improving flight efficiency of airliners, ideas are towards increasing the wing aspect ratio to 14 and beyond, overcoming the adverse structural effects. Strut or truss braced wings are being considered as in the NASA X-66. Another unconventional idea is to use flared folding wingtips that cope with gusts. Such ideas will be discussed.

Using LH2 fuel requires a great deal of unconventional thinking. LH2 being (a) cryogenic with low energy density and (b) potentially explosive, presents a challenge for designing a safe, efficient, and certifiable aircraft. The over-arching constraint is that the LH2 fuel system must be segregated from the passengers – no obstruction of exits and compliant with emergency landing requirements.

Dr Raj Nangia graduated from University of London with BSc and PhD in Aeronautical Engineering and has worked on several UK and International aircraft projects: Hawker Siddeley Gnat Trainer, Hawk, Concorde, Harrier, & ASTOVL Developments, EAP, Typhoon, Advanced SST, Blended Wing bodies, Civil & Military Intake Developments, HALE & UCAV's and currently Tempest.

He has published 150+ papers & presentations, several with international authors at international aerospace conferences.

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