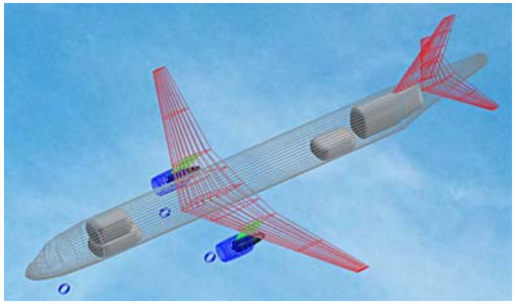
Hochschule für Angewandte Wissenschaften Hamburg
*Hamburg University of Applied Sciences*

**AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)**

# Hydrogen as Future Fuel Used in Minimum Change Derivatives of the Airbus A321



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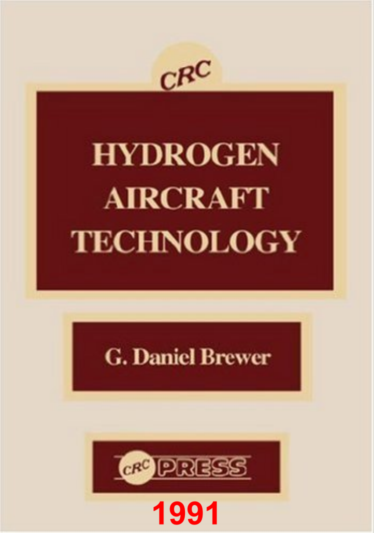
# Abstract

A new concept of a passenger aircraft using hydrogen as fuel is presented. Due to the future depletion of fossil fuels and growth of aviation within the next years, the aeronautical industry must get ready now for a realistic solution. Many projects were conducted for hydrogen-fueled aircraft designs in the past, however all the effort was focused on an expensive totally new aircraft design. In this work, research is based on the Airbus A320 with a requirement for 1510 NM range at 19.3 t maximum payload. Goal is to redesign the aircraft under the premise of minimum change and minimum costs. Hydrogen as the new energy carrier will be stored at cryogenically temperatures. Still it needs more tank volume. This extra volume is best generated with an aircraft stretch leading to an increase of aircraft length. A minimum change option would be to simply use A320 seating in an A321, using the additional space for the new hydrogen fuel tanks. Unfortunately, the additional volume on its own is not sufficient. Therefore, three different hydrogen-fueled versions are developed. 1.) The A321-HSO stretched beyond the length of the A321. 2.) The A321-HWO with A321 fuselage and additional under-wing podded hydrogen fuel tanks. 3.) A321-H19O with A321 fuselage and A319 cabin. All three versions were designed and optimized in OPerA, the in-house conceptual design and optimization program based on a genetic algorithm. Objective function for the optimization are minimum Direct Operating Costs (DOC). Assumed is a price for hydrogen, energy-equivalent to kerosene and estimated for 2030 to be 1.12 USD/kg. All three versions stayed in feasible dimensions. The weight of the aircraft is decreased between 3.4% (A321-H19O) and 0.7% (A321-HSO). Depending on the version considered, the DOC of the aircraft is increased by 20% to 30%. Hydrogen aircraft do not show CO2 emissions, releasing only water vapor, NOx and particles into the air. However, water emitted at altitude can form cirrus clouds. This effect on global warming is presently not fully understood. The result: If fossil fuels get near to depletion and kerosene gets so scarce that the price of hydrogen matches that of kerosene, passenger air transport remains available with hydrogen-fueled minimum change conversions of existing aircraft types.

**Hydrogen as Future Fuel Used in Minimum Change Derivatives of the Airbus A321**

# Content

# Literature / Previous Projects



CRC
HYDROGEN
AIRCRAFT
TECHNOLOGY

G. Daniel Brewer

CRC PRESS

1991

2012: Dan BREWER (93)
[1], [2]

FINAL TECHNICAL REPORT
(PUBLISHABLE VERSION)

CONTRACT N°: G4RD-CT-2000-00192

PROJECT N°: GRD1-1999-10014

ACRONYM: CRYOPLANE

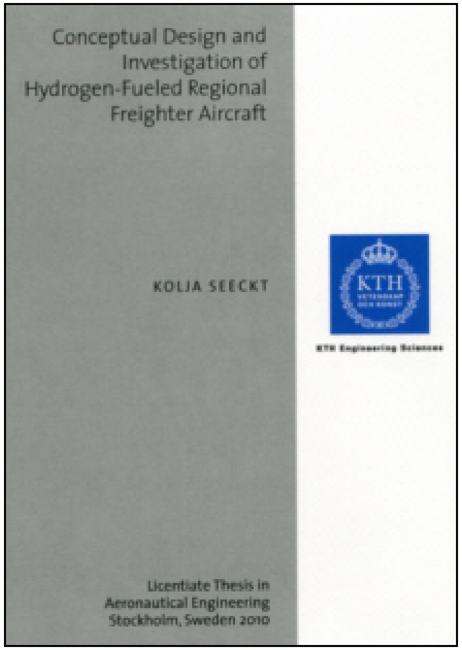
TITLE: Liquid Hydrogen Fuelled Aircraft – System Analysis

PROJECT CO-ORDINATOR : Airbus Deutschland GmbH

WESTENBERGER, Andreas: Liquid Hydrogen Fuelled Aircraft – System Analysis, CRYOPLANE / Final Technical Report, 2003 [3]

**Green Freighter**
**HAW Hamburg** (lead)
TU Braunschweig (IFL)
Airbus, Hamburg
Bishop GmbH
09/2006 to 04/2010

Federal Ministry
of Education
and Research



Conceptual Design and
Investigation of
Hydrogen-Fueled Regional
Freighter Aircraft

KOLJA SEECKT

KTH

KTH Engineering Sciences

Licentiate Thesis in
Aeronautical Engineering
Stockholm, Sweden 2010

SEECKT, Kolja:
**Conceptual Design and Investigation of Hydrogen-Fueled Regional Freighter Aircraft**.
Stockholm, KTH, Licentiate Thesis, 2010 – In cooperation with **HAW Hamburg**. [4]

# Motivation

## The Availability of Energy is Important!

- Depletion of fossile fuels => aviation energy carrier instead of aviation fuel

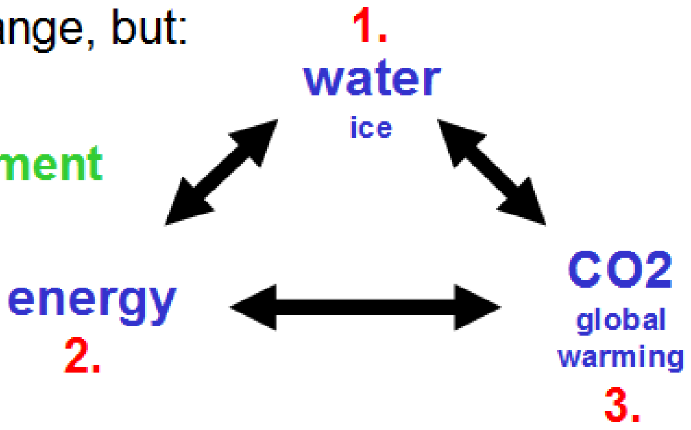
- The **search** for the aviation energy carrier of the future **is ongoing**:

| | |
|---|---|
| # biofuel, synthetic fuel, drop-in fuel | *advantage*: aircraft stay the same |
| # batteries | *advantage*: direct use of electricity |
| # **hydrogen** | *advantage*: **best known technology** |

- Current focus: CO2, Global Warming, Climate Change, but:
- **There are more issues than CO2**
- **Needed: Balanced look with Life Cycle Assessment**
- **Ensure:**

  **Future availability of energy in aviation !**

  (or tell your kids the party is over)



**1.**
**water**
**ice**

**energy**
**2.**

**CO2**
**global warming**
**3.**

SCHOLZ, DLRK 2012 [5]

# Motivation

## Note the Scale of the Energy Consumption in Aviation!

- **Global energy consumption in aviation** (2009):
  - 230 Mtoe (million ton oil equivalent) per year
  - with 0.8 t/m³ this is 9.1 m³/s (flow of a smaller tributary of the river Elbe; *p.t.o.*)
  - with heating value, *H* = 41.9 MJ/kg this is 300000 MW or 300 nuclear power plants (simple energy comparison)

- How does this relate to **biofuel production**?

**BIOREFLY Project**

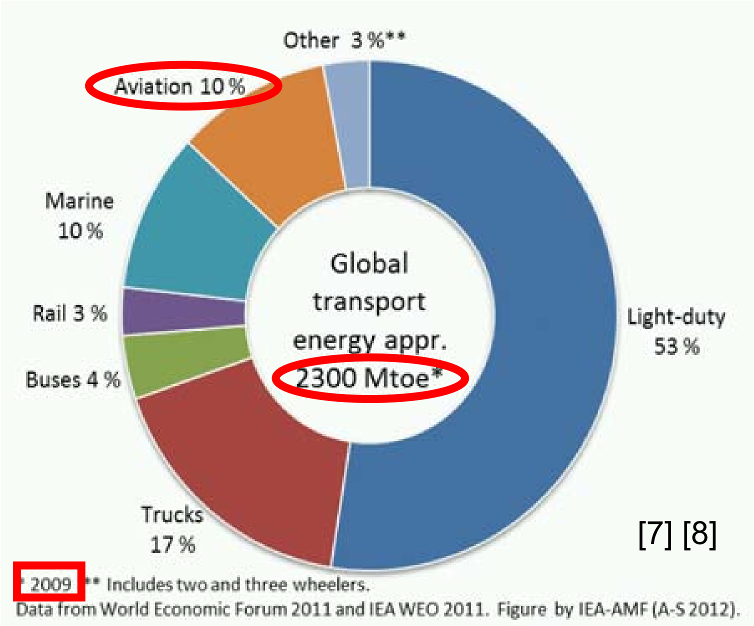
2,000 TON/Y INDUSTRIAL SCALE DEMONSTRATION BIOREFINERY ON LIGNIN-BASED AVIATION FUEL

by 2018

SEVENTH FRAMEWORK PROGRAMME

This [6] is 0.00087 % of global energy consumption in avaition.

- Clearly, after peak oil (2050?) there will be **more than one energy carrier** in aviation => necessary. **Hydrogen** must be one of these energy carriers! Or we won't make it.

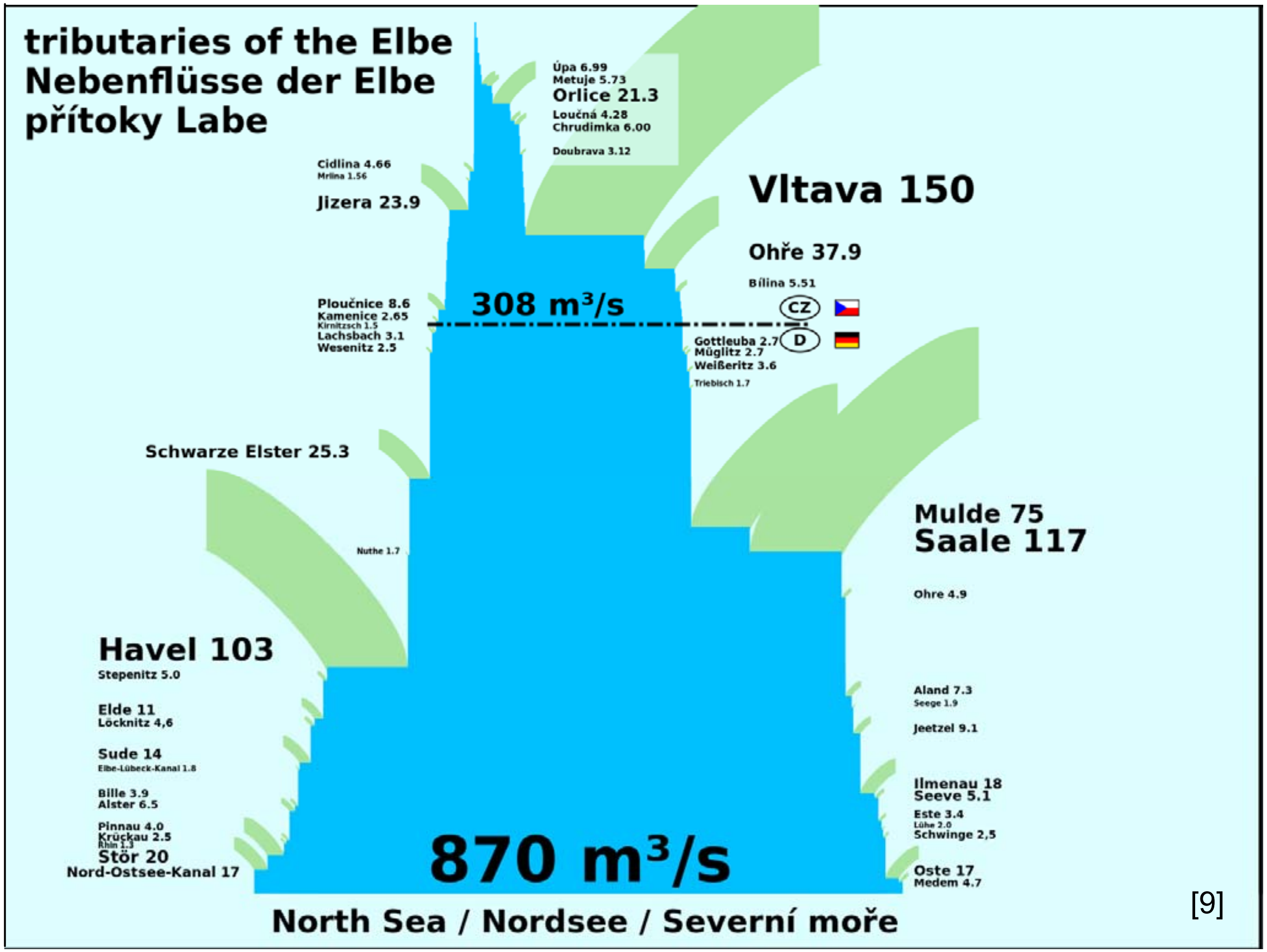


[7] [8]

* 2009 ** Includes two and three wheelers.
Data from World Economic Forum 2011 and IEA WEO 2011. Figure by IEA-AMF (A-S 2012).

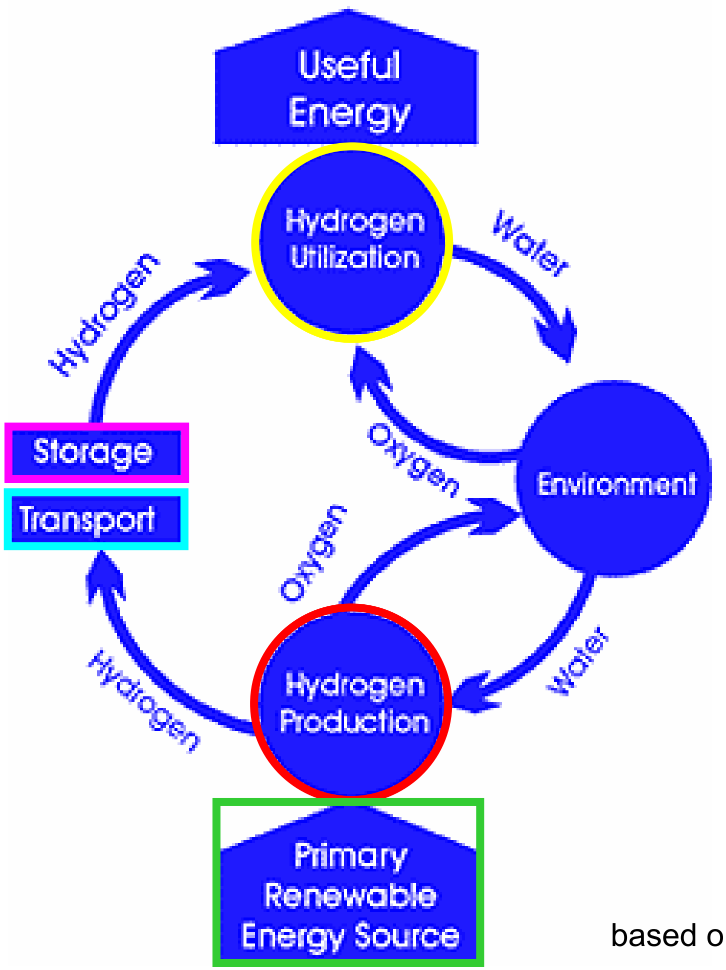
# Note the Scale of the Energy Consumption in Aviation!

**Global aviation fuel consumption** **9.1 m³/s** is roughly Hamburg's water discharge into the Elbe:



[9]

# Hydrogen Life Cycle



based on [10]

## Hydrogen Production …

### … with Natural Gas Steam Reforming

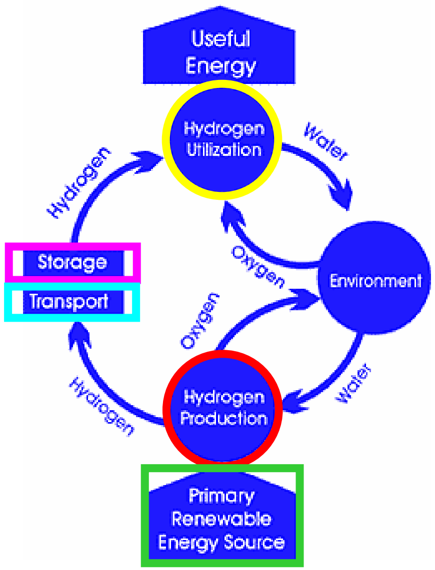
Hydrocarbons are catalytically splitted in the presence of a steam with a temperature near 900 °C. A gas is produced (syngas) mainly consists of **hydrogen** and CO.

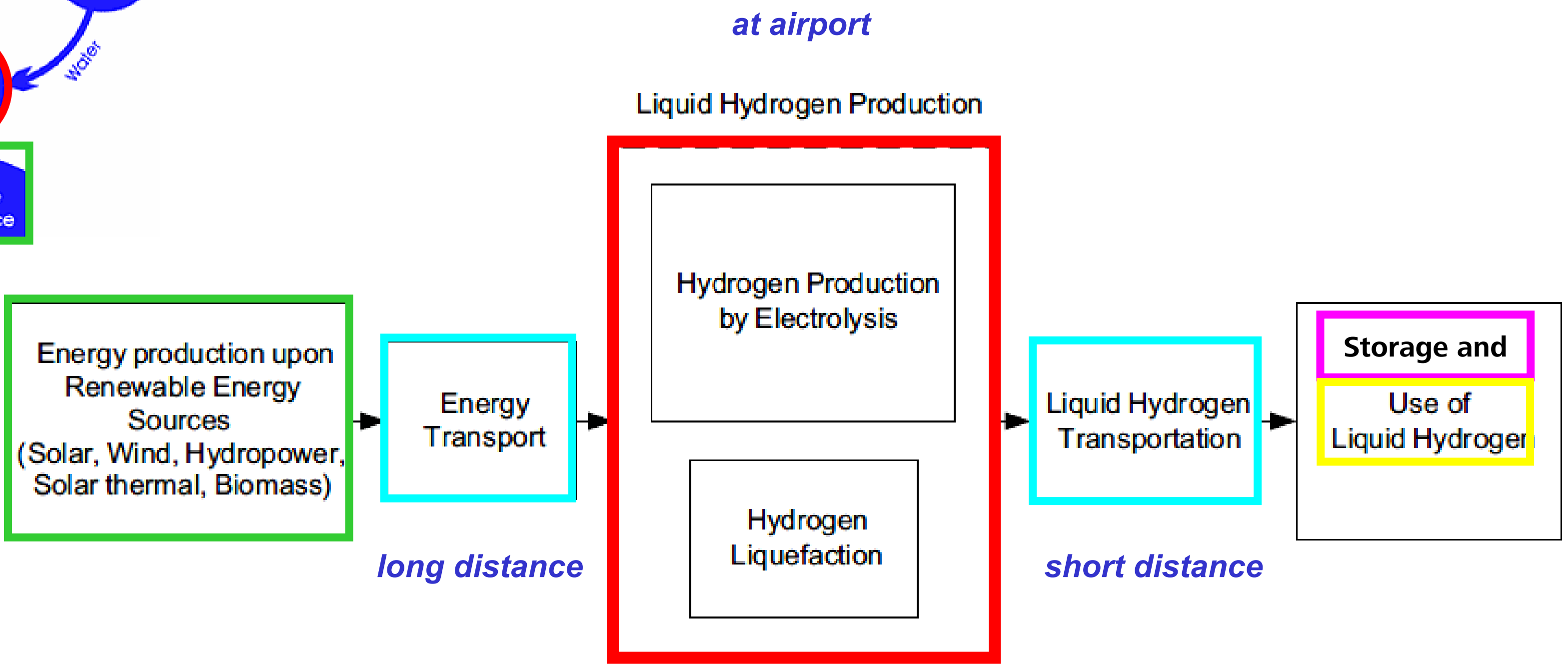
Inexpensive. Used in 97 % of the cases.

### … with Renewable Energy

# Solar energy using photovoltaics
# Solar thermal energy
# Wind power source
# Hydro power source
# Biomass energy source (Biomass gasification)

# Hydrogen Life Cycle





*at airport*

Liquid Hydrogen Production

Hydrogen Production by Electrolysis

Hydrogen Liquefaction

Energy production upon Renewable Energy Sources (Solar, Wind, Hydropower, Solar thermal, Biomass)

Energy Transport

*long distance*

Liquid Hydrogen Transportation

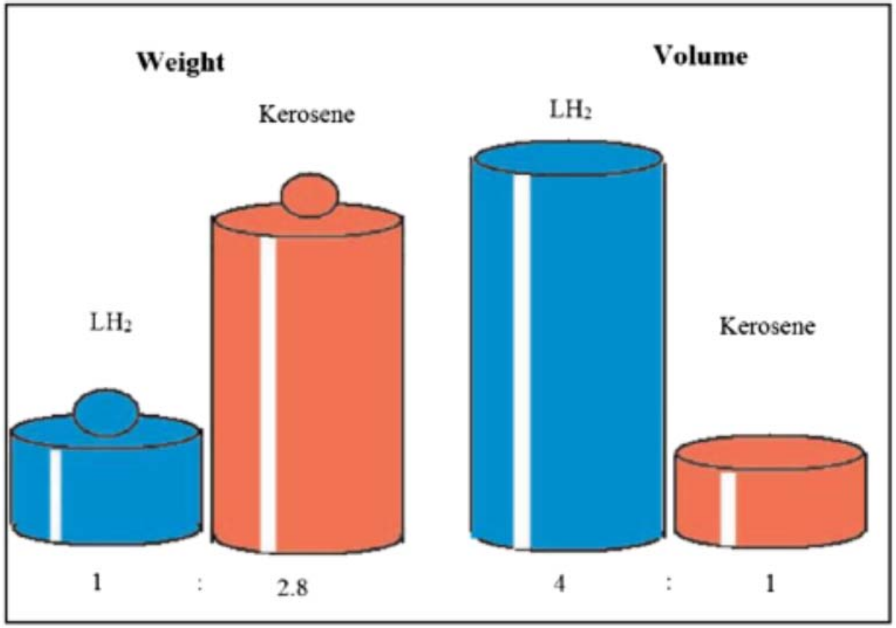
*short distance*

**Storage and**

Use of Liquid Hydrogen

# Characteristics of Hydrogen – Important for Aircraft Design

- **Comparison at equal energy:**

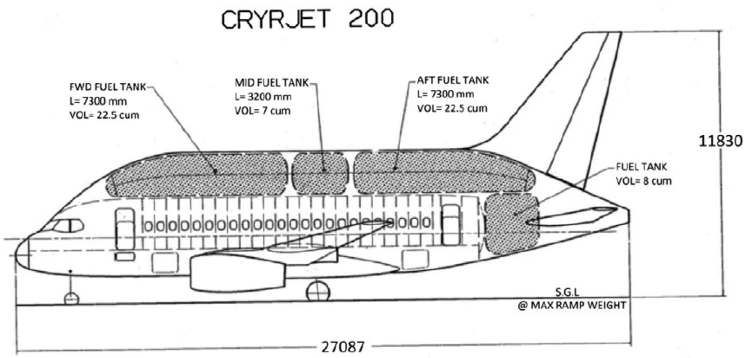


- **Boil-off**
- **Hydrogen embrittlement** (Wasserstoffversprödung) **of materials**

# Hydrogen Aircraft Configurations

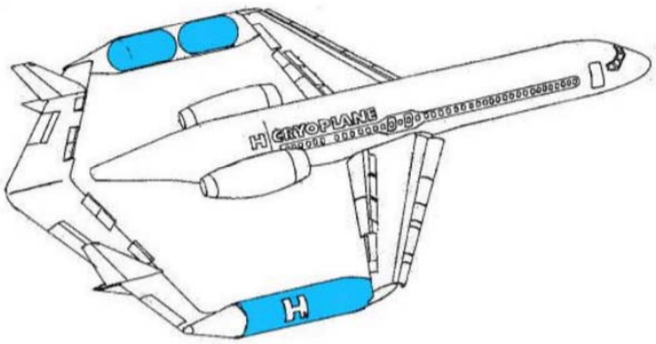
- The selection of a type of **aviation energy carrier** needs to be seen **together with** the resultant **aircraft configuration**!

WESTENBERGER, Andreas: Liquid Hydrogen Fuelled Aircraft – System Analysis. CRYOPLANE, Final Technical Report, 2003 [3]

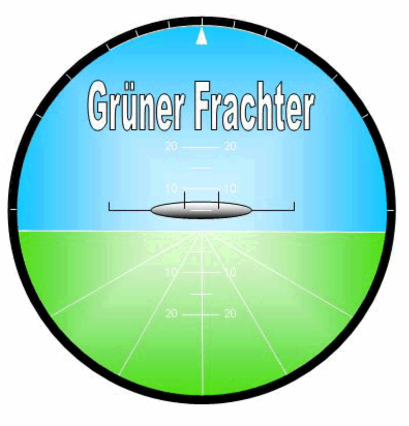


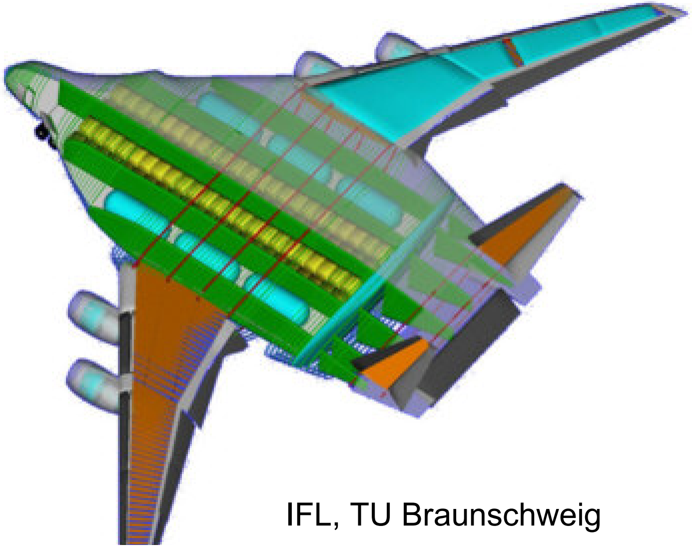
# Introduction

WESTENBERGER, Andreas:
Liquid Hydrogen Fuelled Aircraft –
System Analysis. CRYOPLANE, Final
Technical Report, 2003 [3]

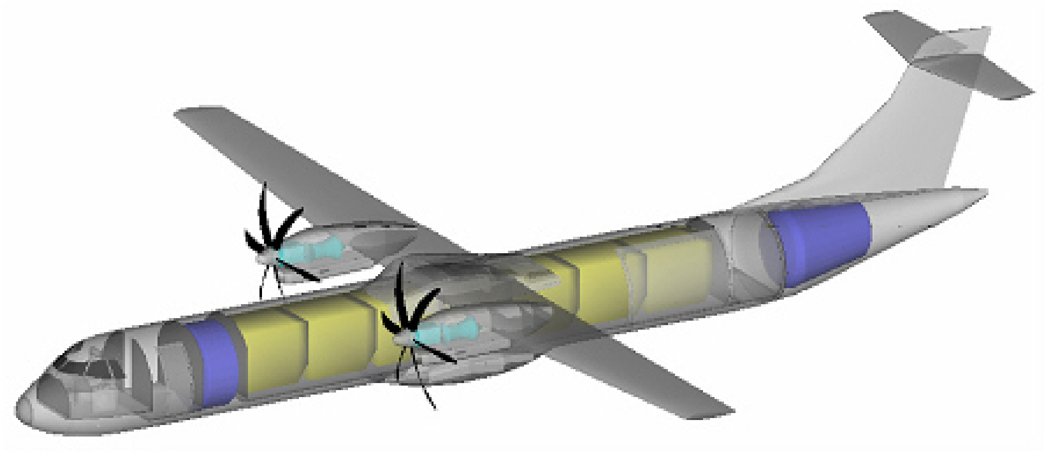


# Introduction

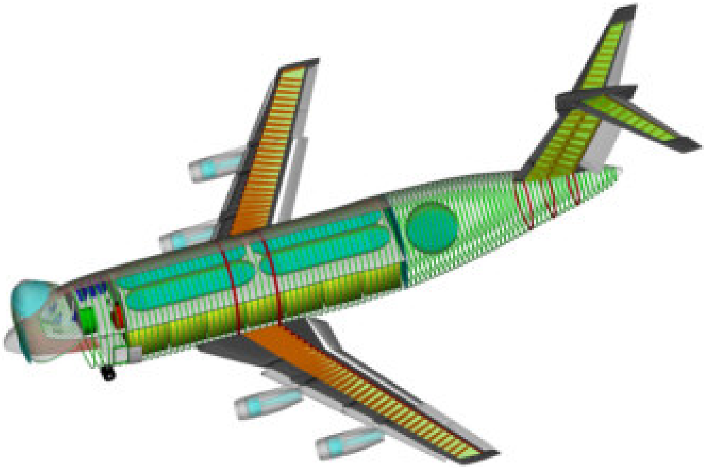




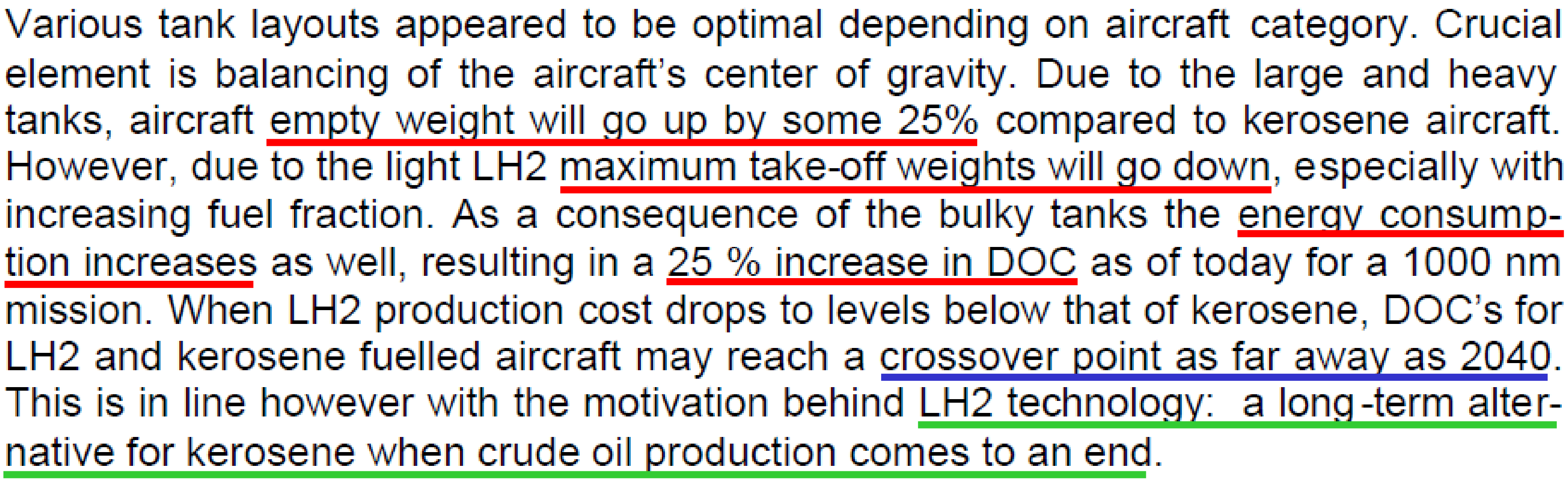
IFL, TU Braunschweig



AERO, HAW Hamburg



# Findings from CRYOPLANE



Various tank layouts appeared to be optimal depending on aircraft category. Crucial element is balancing of the aircraft's center of gravity. Due to the large and heavy tanks, aircraft empty weight will go up by some 25% compared to kerosene aircraft. However, due to the light LH2 maximum take-off weights will go down, especially with increasing fuel fraction. As a consequence of the bulky tanks the energy consumption increases as well, resulting in a 25 % increase in DOC as of today for a 1000 nm mission. When LH2 production cost drops to levels below that of kerosene, DOC's for LH2 and kerosene fuelled aircraft may reach a crossover point as far away as 2040. This is in line however with the motivation behind LH2 technology: a long-term alternative for kerosene when crude oil production comes to an end.

# Erkenntnisse aus dem Projekt "Grüner Frachter"

**Vorteile von LH2:**

- **Fliegen bleibt auch nach dem Ende fossiler Kraftstoffe möglich**!
- Bereits heute ist die **LH2-Technologie im Flugzeug bekannt** und anwendbar.
- Die Verbrennung von Wasserstoff ist **umweltfreundlicher** als die von Kerosin.
- Wasserstoff ist leichter als Kerosin – aber Tanks schwer. MTOW sinkt leicht. **Induzierte Widerstand sinkt**.

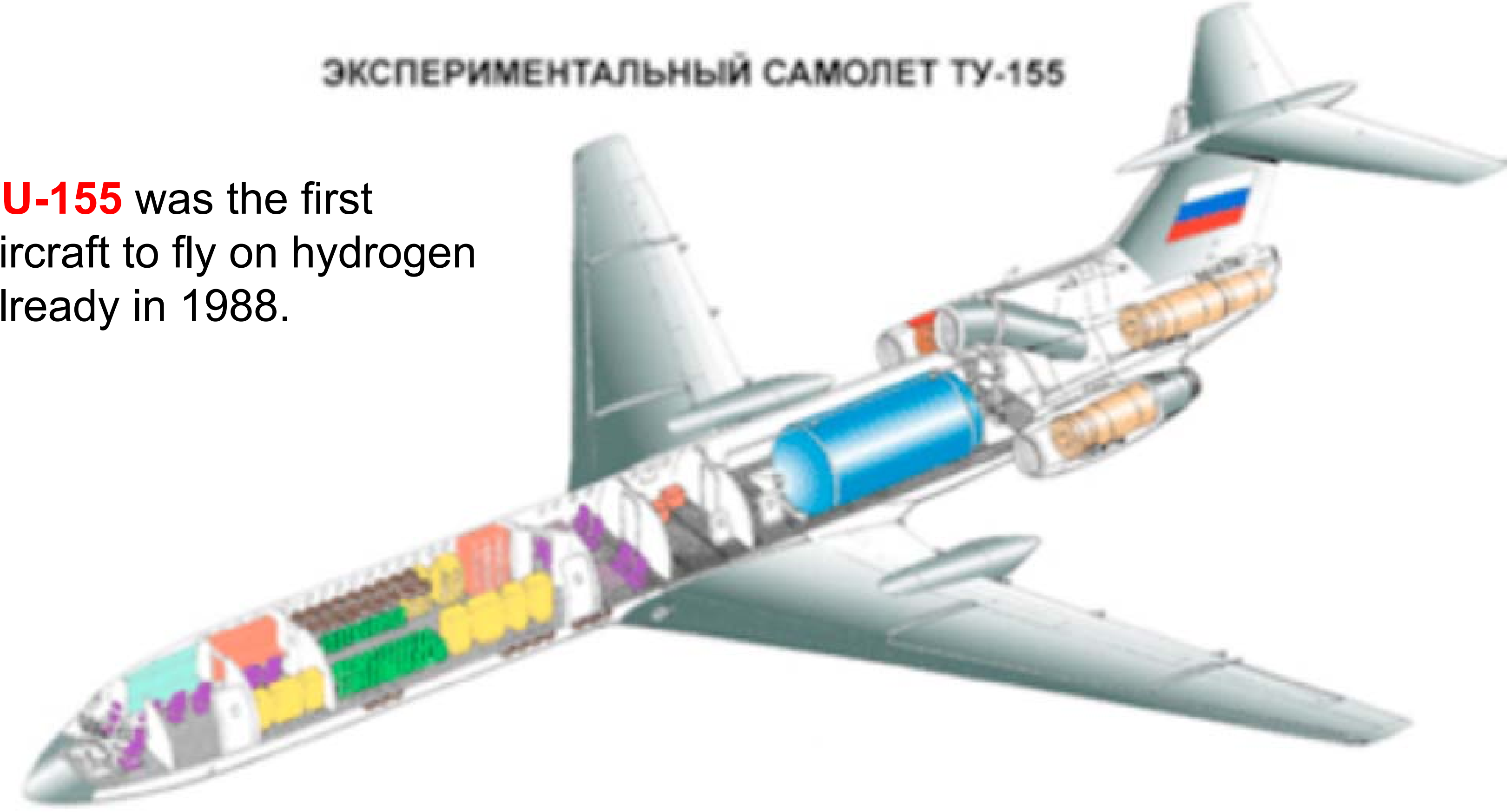
**Nachteile von LH2:**

- **Herkömmliche Flugzeuge können nicht genutzt werden.**
- Es ist eine **neue Infrastruktur am Flughafen erforderlich**: Wasserstoffproduktion, Wasserstoffverflüssigung
- Um die gleiche Nutzlast über die gleiche Reichweite zu transportieren müssen größere Unterbringungsräume für die (nahezu) zylindrischen LH2-Tanks gefunden werden. LH2-Flugzeuge sind aufgrund der großen Tanks größer und zeigen damit einen **höheren Nullwiderstand**.
- Alle untersuchten LH2-Flugzeugkonfigurationen haben leicht **höhere Betriebskosten**.
- Trotz der Isolierung der Tanks, erwärmt sich der Wasserstoff und wird teilweise wieder gasförmig.
  - # Im Flug kann dieser Wasserstoff verbraucht werden.
  - # **Am Boden** würde der Druck im Tank steigen und **Wasserstoff müsste abgeblasen werden**.
- Ein betanktes Flugzeug kann also nicht einfach so auf dem Vorfeld stehen gelassen werden. **Eine Betankung ist erst kurz vor dem Start sinnvoll.** Der Flugbetrieb muss diesen Umstand berücksichtigen und wird damit etwas weniger flexibel.

**Doch, können – siehe dieser Vortrag!**

## LH2-Technology already Tested in Aviation

**TU-155** was the first aircraft to fly on hydrogen already in 1988.



[11]

## Hydrogen's Show Stopper in Aviation

**Hydrogen**'s show stopper in aviation is the necessary **big investments**

1.) in new aircraft

2.) in new airport infrastructure
   - * liquid hydrogen production
   - * new refueling equipment at airports

**In contrast**:
**Drop-in fuel** (biofuel, synthetic fuel) needs **no investment in the aviation system**

1.) same aircraft

2.) same airport infrastructure
   - * no extra production fascility at airport
   - * same refueling equipment

## Hydrogen's Show Stopper in Aviation

**Hydrogen**'s show stopper in aviation is the necessary **big investments**

1.) in new aircraft

*Can we reduce the investment by using modified existing aircraft for the new energy carrier hydrogen?*

2.) in new airport infrastructure
  * liquid hydrogen production
  * new refueling equipment at airports

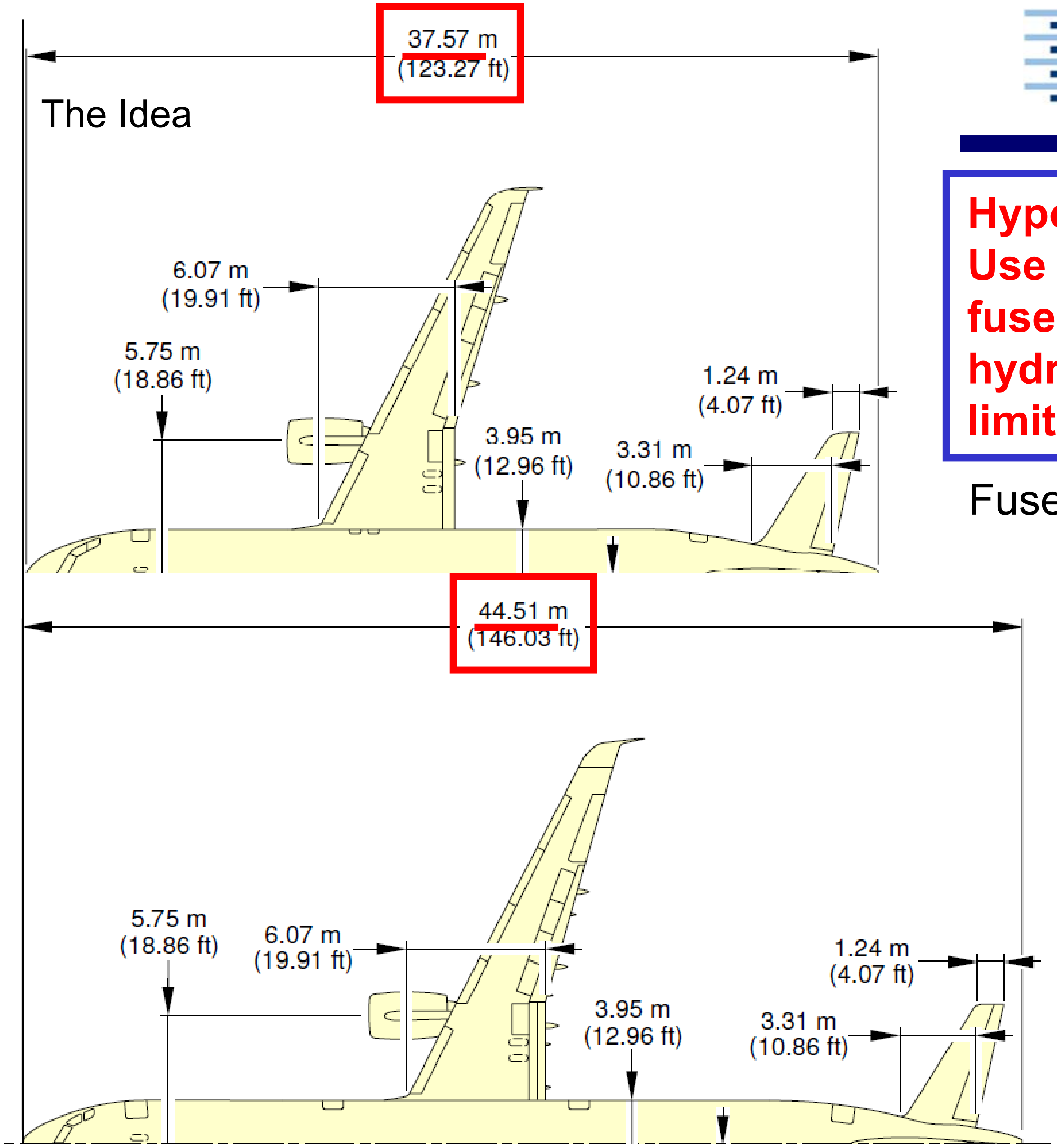
**In contrast**:

**Drop-in fuel** (biofuel, synthetic fuel) needs **no investment in the aviation system**

1.) same aircraft

2.) same airport infrastructure
  * no extra production fascility at airport
  * same refueling equipment

# The Idea



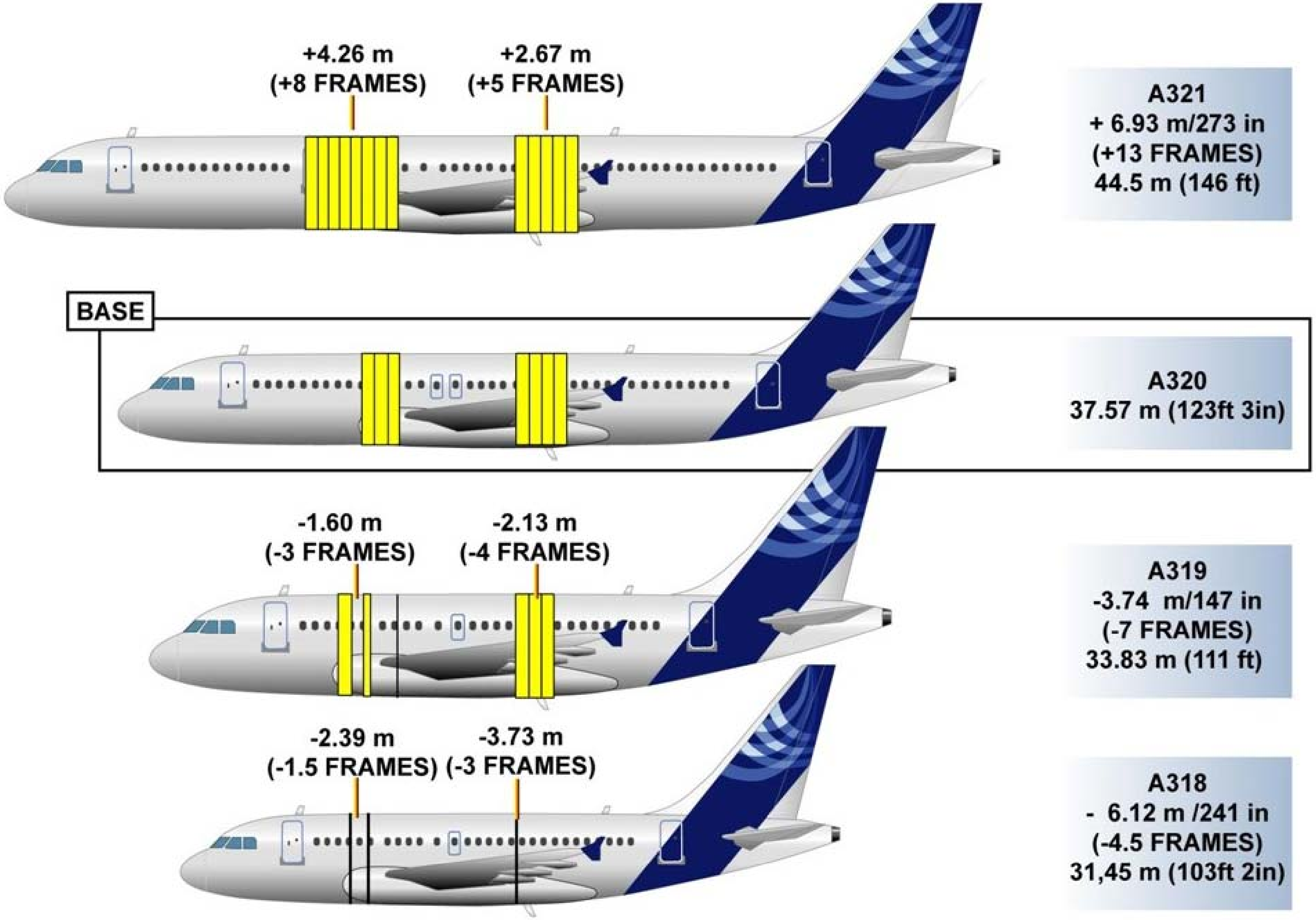
**Hypothesis:**
**Use an existing (longer) fuselage to integrate the hydrogen tanks to limit investment!!!**

Fuselage Length Compared:

**A320**

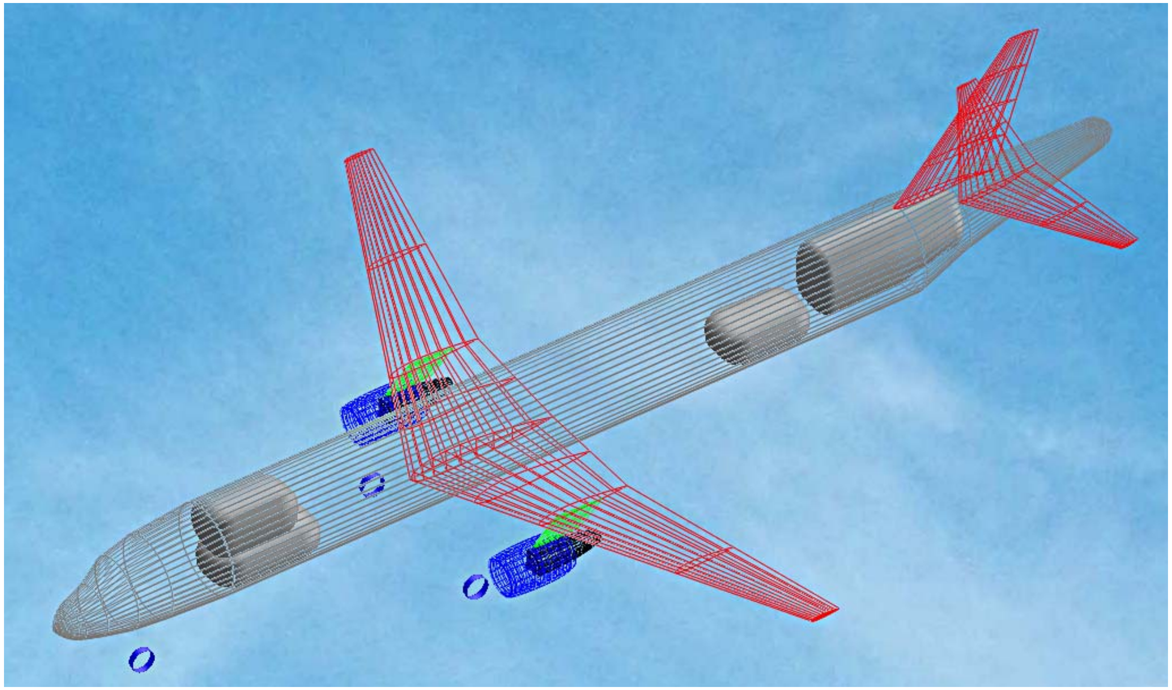
**A321**

# A320 Family



Dimensions of the A320 family (Airbus Technical Data)

## Hydrogen Storage in the Fuselage (Front and Rear)

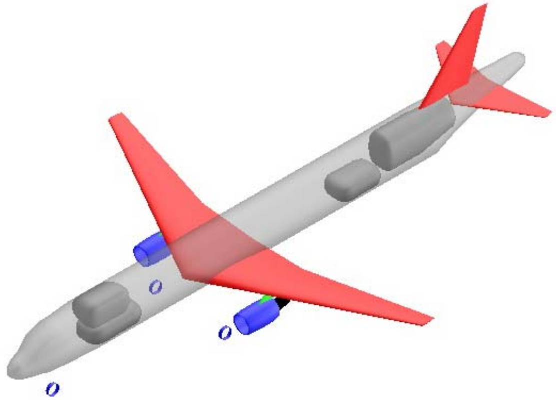


Distribution of the tank in the front and in the back to **balance CG**.

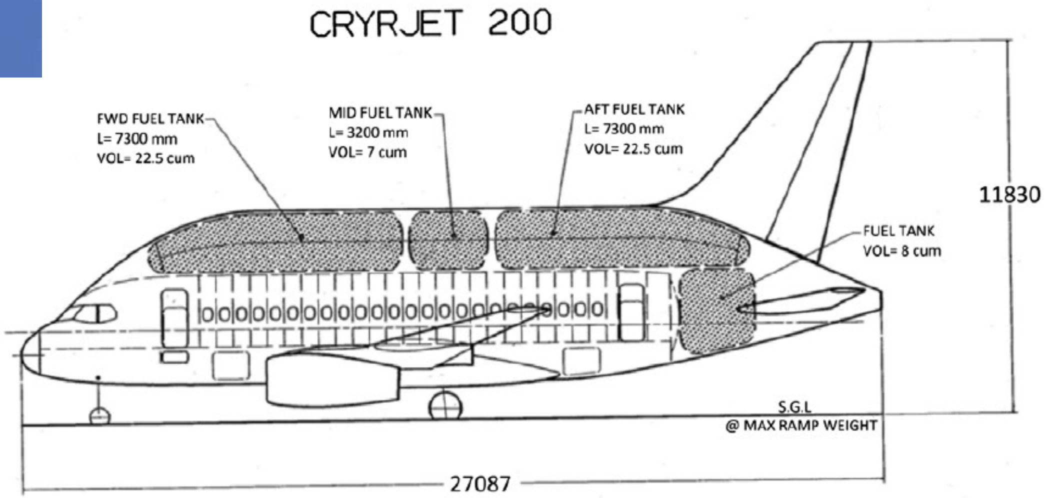
Two tanks forward and two tanks aft.
Assume no double **tank failure**
or aircraft robust against CG shift.

**Use of** some portion of the front and aft **cabin**.

**Use of** an even bigger protion of front and aft **cargo compartment**.



# Hydrogen Storage over the Fuselage (Not Selected for this Project)



# Trade-Off for Tank Location in Fuselage

Not compatible with fuselage stretch.

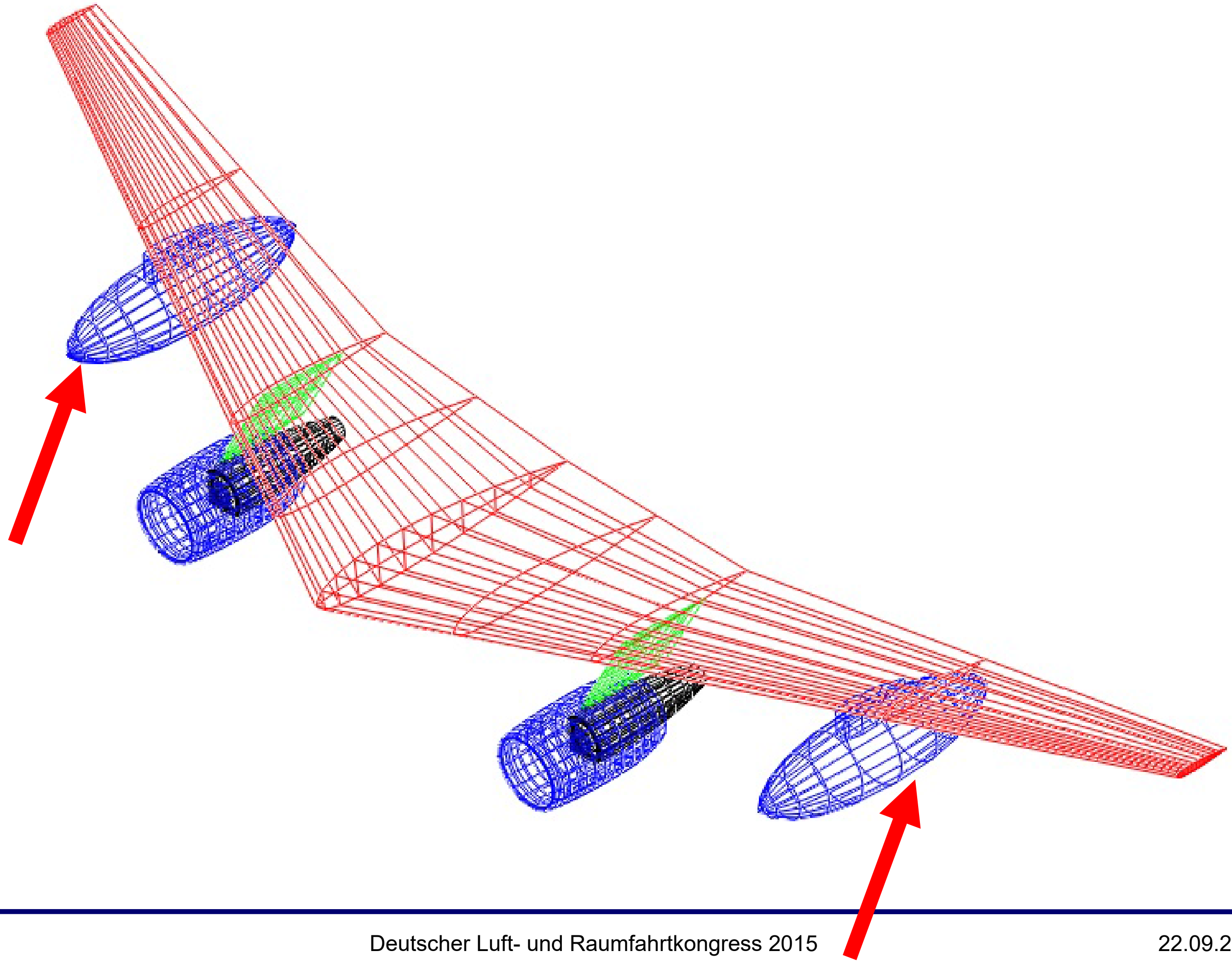
| | CONFIGURATION | |
|---|---|---|
| FEATURE | Over the fuselage | Front and Rear |
| Access for crew and passengers | 3[†] | 1 |
| Surface to volume considerations | 1 | 3 |
| Control of C.G. | 2 | 3 |
| Security in case of damage | 3 | 2 |
| Drag Increase | 1 | 3 |
| Weight increase | 2 | 2 |
| Manufacturing process consideration | 1 | 3 |
| **TOTAL** | **13** | **17** |

[†] 3 is High; 2 is Medium; 1 is Low

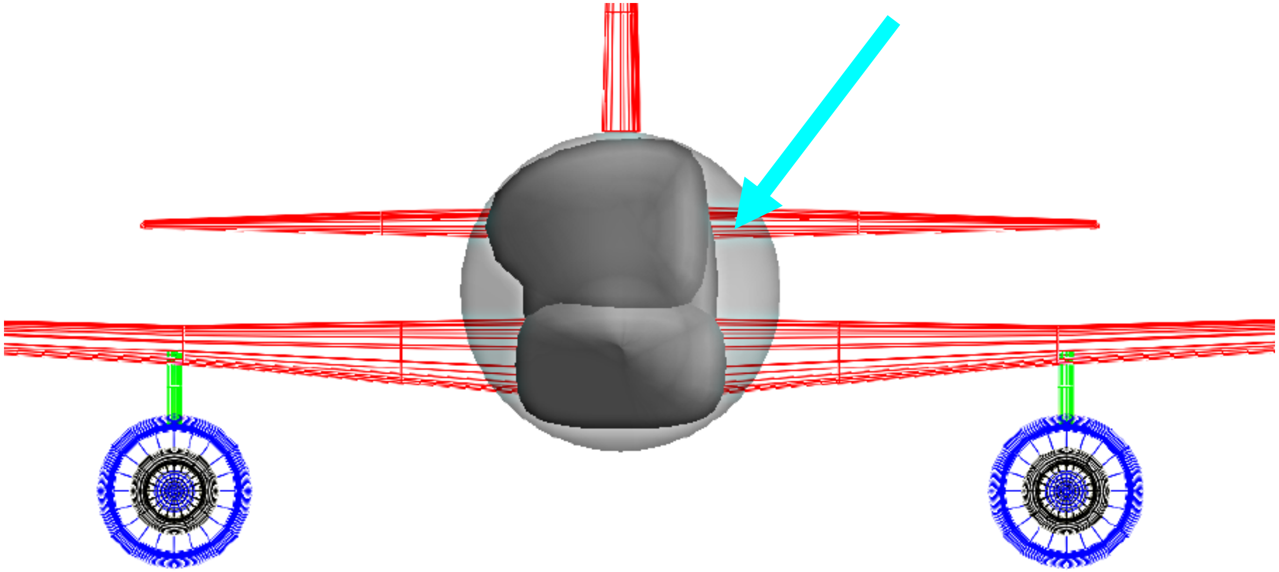
**Scoring Model**

**The winner!**

# Additional (!) Hydrogen Storage in Underwing Pods



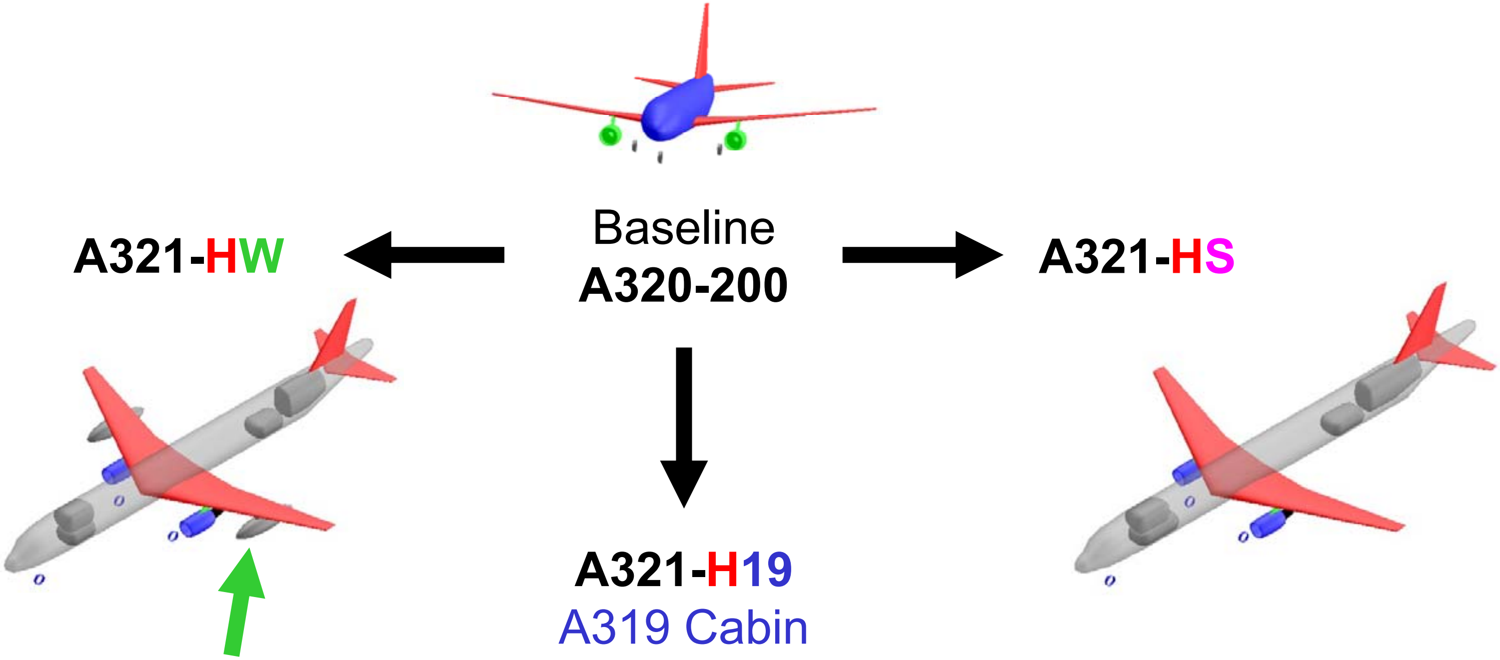
## Passage Way for Cockpit Crew to Reach the Cabin



- For certification: No need for passage way (Roskam)
- Passage way selected here for convenience. But: Reduces tank volume in the front tank.

  Leads to longer fuselage

# Overview of Aircraft Configurations in this Study



Baseline
**A320-200**

**A321-HW**

**A321-HS**

**A321-H19**
A319 Cabin

**H**: LH2 Aircraft
**W**: A321 with addtional hydrogen tanks under wing
**S**: A321 with additional stretch (to give more volume for LH2 tanks)
**19**: A321 filled only with 156 (instead of 180) one-class passengers (more room left for LH2 tanks). Same payload & range kept

# Baseline: Airbus A320

## Baseline Aircraft: A320

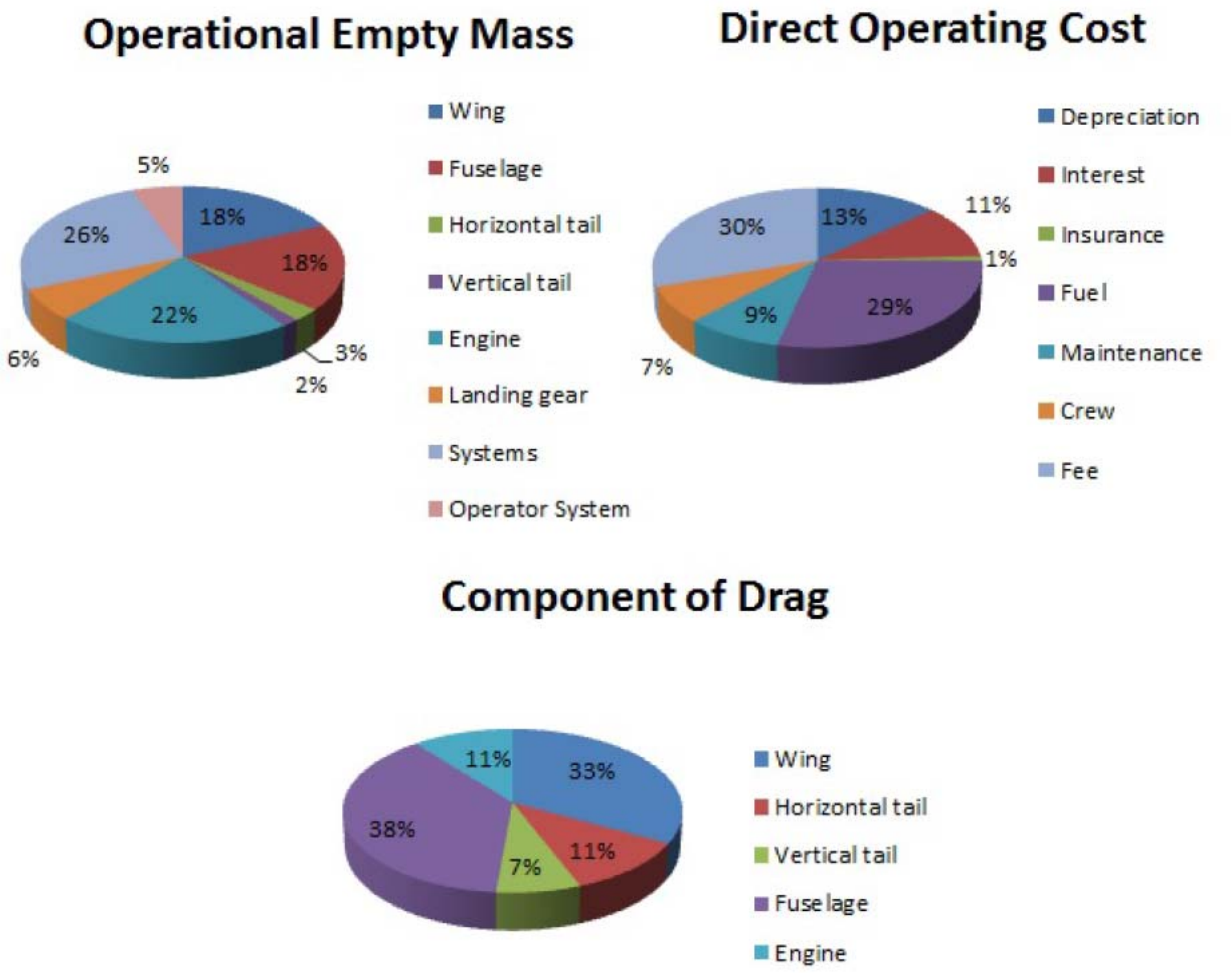
List of fundamentag aircraft and cabin variables with the values of the reference aircraft

| Parameter | Value |
|---|---|
| $m_{MPL}$ [kg] | 19256 |
| $R_{MPL}$ [NM] | 1510 |
| $M_{CR}$ | 0.76 |
| $s_{TOFL}$ [m] | 1767.8 |
| $s_{LFL}$ [m] | 1447.8 |
| $n_{PAX}$ | 180 |
| $m_{PAX}$ [kg] | 93 |
| $SP$ [in] | 29 |

## Calculation tool adapted and used: OPerA – Optimization in Preliminary Aircraft

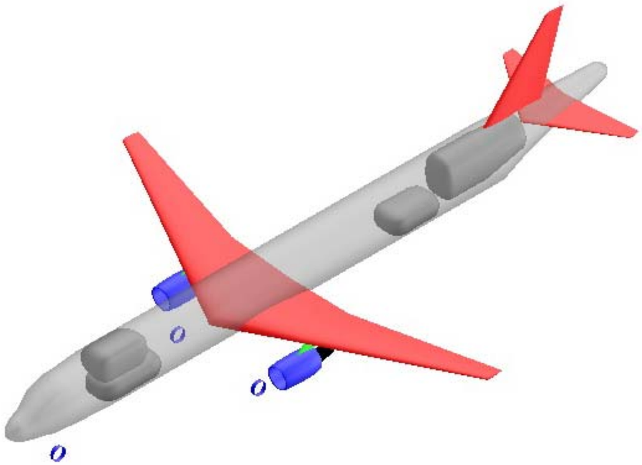
| Parameter | Name | Value A320-200 |
|---|---|---|
| Landing field length [m] | $s_{LFL}$ | 1448 |
| Take-off field length [m] | $s_{TOFL}$ | 1768 |
| Max. lift coefficient, landing | $C_{L,max,L}$ | 3.14 |
| Max. lift coefficient, take-off | $C_{L,max,TO}$ | 2.82 |
| Mass ratio, max landing to max take-off | $m_{ML}/m_{MTO}$ | 0.88 |
| Aspect ratio | $A$ | 9.5 |
| Number of engines | $n_E$ | 2 |
| Number of passengers | $n_{PAX}$ | 180 |
| Number of seats abreast | $n_{SA}$ | 6 |
| Wing sweep at 25 % chord [°] | $\varphi_{25}$ | 25 |
| Taper ratio | $\lambda$ | 0.213 |
| Position of the vertical tail in case of cruciform config. | $z_H/b_V$ | 0.56 |
| Minimum distance from engine to wing over nacelle diam. | $z_{P,min}/D_N$ | 0.15 |
| By-Pass ratio | $BPR$ | 6 |
| Mach number, cruise | $M_{CR}$ | 0.76 |
| Seat pitch [m] | $SP$ | 0.74 |
| Aisle width [m] | $w_{aisle}$ | 0.51 |
| Seat width [m] | $w_{sear}$ | 0.51 |
| Armrest width [m] | $w_{armrest}$ | 0.051 |
| Sidewall Clearance (at armrest) [m] | $s_{clearence}$ | 0.015 |

# Baseline: Airbus A320



**Breakdown of the OEW, DOC and Drag Component for the A320-200**

# Comparison of A321-HS with A320-200



| | Length [m] | Mass of tank [kg] | Mass of fuel [kg] |
|---|---|---|---|
| **Rear upper tank** | 4.14 | 581.6 | 1600 |
| **Rear lower tank** | 5.24 | 315.4 | 1225 |
| **Back upper tank** | 6.92 | 1385 | 2874.4 |
| **Back lower tank** | 4.16 | 249.3 | 967.8 |
| **Total [kg]** | | 2531.3 | 6667.2 |

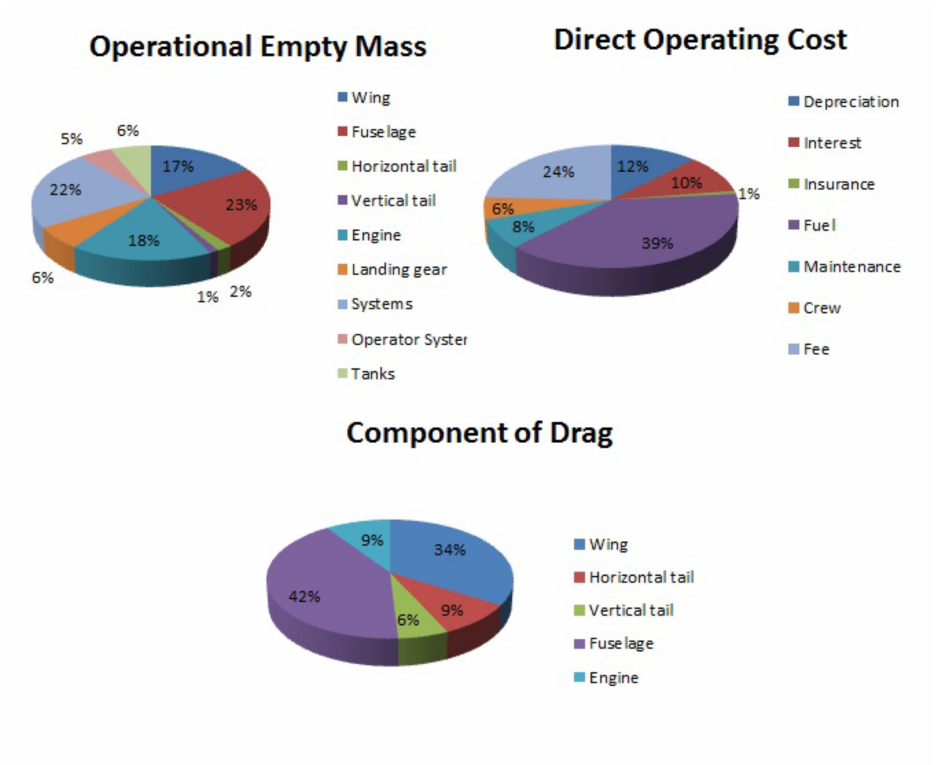
Details of the tanks for the A321-HS

| Parameter | A321-HS | Variation (A320) |
|---|---|---|
| $m_{MTO}$ [kg] | 73578 | +1.8 |
| $m_{OE}$ [kg] | 47658 | +18.6 |
| $m_F$ [kg] | 6664 | -48.0 |
| $DOC$ (AEA) [€/NM/t] | 1.68 | +26.7 |
| $DOC$ (TUB) [€/NM/t] | 1.49 | +29.3 |
| $l_F$ [m] | 49.4 | +28.8 |
| $S_W\,[m^2]$ | 131.1 | +9.0 |
| $b_{W,geo}$ [m] | 35.3 | +4.4 |
| $A_{W,eff}$ | 9.5 | 0 |
| $\varphi_{25}$ [°] | 25 | 0 |
| $\lambda$ | 0.21 | 0 |
| $E_{max}$ | 17.6 | +0.4 |
| $T_{TO}$ [kN] | 103.9 | -5.0 |
| $BPR$ | 6 | 0 |
| $SFC$ [kg/N/s] | 5.79E-06 | -65.0 |
| $h_{CR}$ [ft] | 37706 | -3.0 |
| $m_{MTO}/S_W\,[kg/m^2]$ | 560.7 | -6.6 |

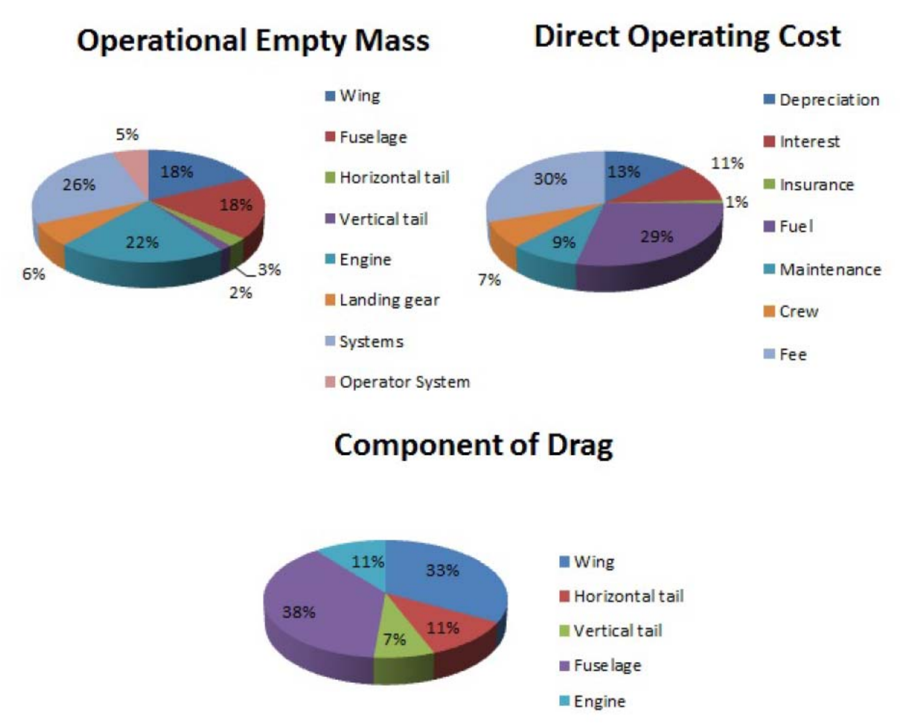
energy up 46 %

A321: $l_F$ = 44.5 m
Delta: 4.9 m

# Aircraft Design for Hydrogen



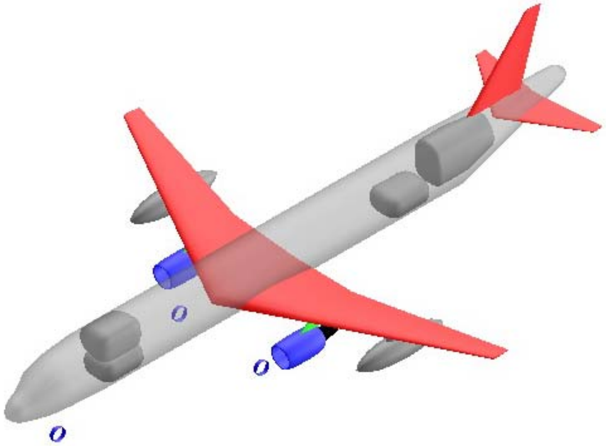
**A320-200**



**A321-HS**

**Breakdown of the OEW, DOC and Drag Component**

# Comparison of A321-HW with A320-200



| | Length [m] | Mass of tank [kg] | Mass of fuel [kg] |
|---|---|---|---|
| **Rear upper tank** | 3.5 | 484.7 | 1333.5 |
| **Rear lower tank** | 3.5 | 207.7 | 805.3 |
| **Back upper tank** | 3.5 | 692.4 | 1300 |
| **Back lower tank** | 3.5 | 207.7 | 805.3 |
| **Wing tanks** | 6 | 880 | 2345 |
| **Total [kg]** | | 2472.5 | 6589.1 |

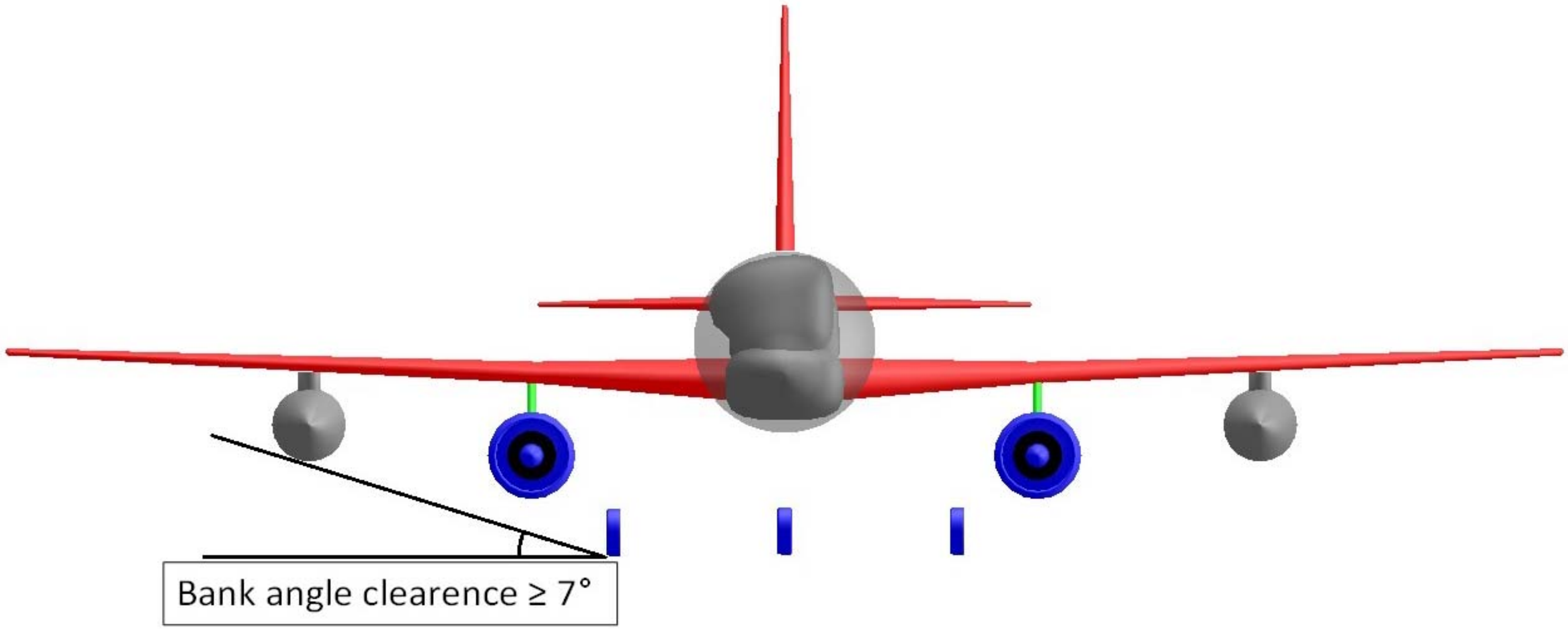
Details of the tanks for the A321-HW

| Parameter | A321-HW | Variation (A320) |
|---|---|---|
| $m_{MTO}$ [kg] | 70716 | -2.2 |
| $m_{OE}$ [kg] | 44871 | +11.6 |
| $m_F$ [kg] | 6588 | -48.6 |
| $DOC$ (AEA) [€/NM/t] | 1.63 | +23.3 |
| $DOC$ (TUB) [€/NM/t] | 1.45 | +25.9 |
| $l_F$ [m] | 45.2 | +18.0 |
| $S_W$ [$m^2$] | 126.1 | +4.8 |
| $b_{W,geo}$ [m] | 34.6 | +2.4 |
| $A_{W,eff}$ | 9.5 | 0 |
| $\varphi_{25}$ [°] | 25 | 0 |
| $\lambda$ | 0.21 | 0 |
| $E_{max}$ | 16.9 | -3.9 |
| $T_{TO}$ [kN] | 99.8 | -8.8 |
| $BPR$ | 6 | 0 |
| $SFC$ [kg/N/s] | 5.82E-06 | -64.8 |
| $h_{CR}$ [ft] | 36720 | -5.6 |
| $m_{MTO}/S_W$ [$kg/m^2$] | 560.7 | -6.6 |

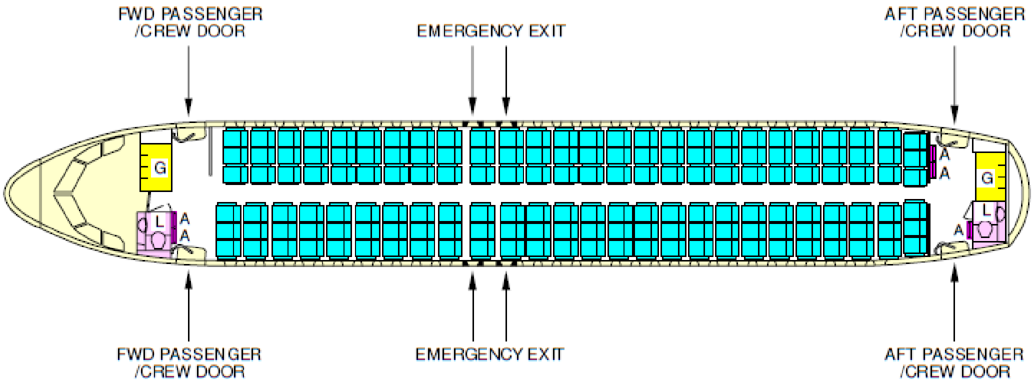
energy up 44 %

A321: $l_F$ = 44.5 m
Delta: 0.7 m

# Aircraft Design for Hydrogen

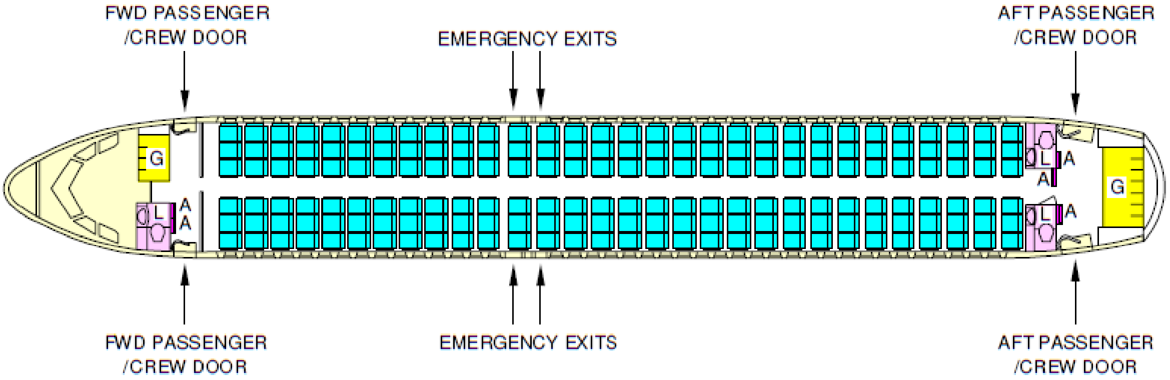


Bank angle clearence for the wing tanks of A321-HW



| ITEM | DESIGNATION | |
|---|---|---|
| G | 🟨 GALLEY | (2) |
| L | ▨ LAVATORY | (2) |
| A | 🟪 ATTENDANT SEAT | (5) |

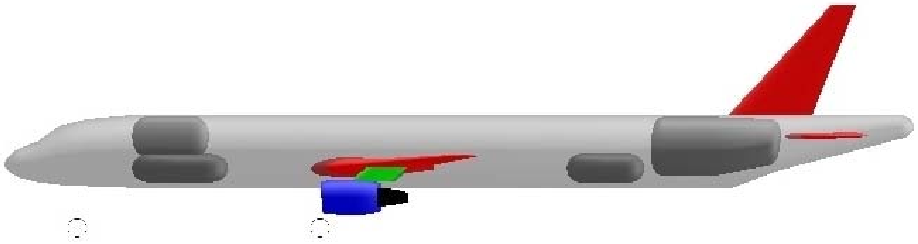
🟦 156 SEATS ALL TOURIST CLASS
28/30 in PITCH. 6 ABREAST. 3.3

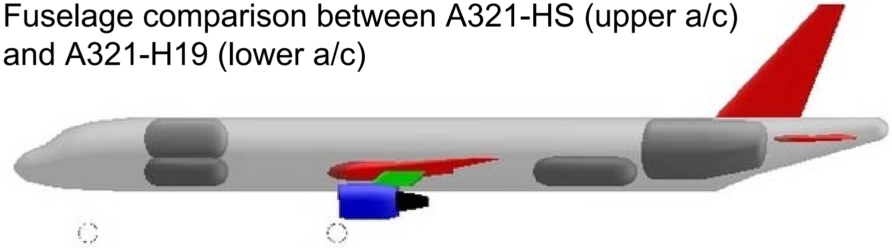


| ITEM | DESIGNATION | |
|---|---|---|
| G | 🟨 GALLEY | (2) |
| L | ▨ LAVATORY | (3) |
| A | 🟪 ATTENDANT SEAT | (5) |

🟦 180 SEATS ALL TOURIST CLASS
28/29 in PITCH. 6 ABREAST. 3.3

# Comparison of A321-H19 with A320-200





Fuselage comparison between A321-HS (upper a/c) and A321-H19 (lower a/c)

| | Length [m] | Mass of tank [kg] | Mass of fuel [k |
|---|---|---|---|
| **Rear upper tank** | 4.36 | 612.5 | 1685 |
| **Rear lower tank** | 4.36 | 262.5 | 1017 |
| **Back upper tank** | 6.54 | 1312.5 | 2462 |
| **Back lower tank** | 5.47 | 329.5 | 127 |
| | **Total [kg]** | 2517 | 6442 |

Details of the tanks for the A321-H19

| Parameter | A321-H19 | Variation (A320) |
|---|---|---|
| $m_{MTO}$ [kg] | 70916 | -1.9 |
| $m_{OE}$ [kg] | 45208 | +12.5 |
| $m_F$ [kg] | 6443 | -49.7 |
| $DOC$ (AEA) [€/NM/t] | 1.78 | +34.9 |
| $DOC$ (TUB) [€/NM/t] | 1.61 | +39.8 |
| $l_F$ [m] | 46.2 | +20.5 |
| $S_W\,[m^2]$ | 126.5 | +5.1 |
| $b_{W,geo}$ [m] | 34.7 | +2.5 |
| $A_{W,eff}$ | 9.5 | 0 |
| $\varphi_{25}$ [°] | 25 | 0 |
| $\lambda$ | 0.21 | 0 |
| $E_{max}$ | 17.6 | +0.3 |
| $T_{TO}$ [kN] | 100.2 | -8.4 |
| $BPR$ | 6 | 0 |
| $SFC$ [kg/N/s] | 5.82E-06 | -64.8 |
| $h_{CR}$ [ft] | 37676 | -3.1 |
| $m_{MTO}/S_W\,[kg/m^2]$ | 560.7 | -6.6 |

energy up 41 %

A321: $l_F$ = 44.5 m
Delta: 1.7 m

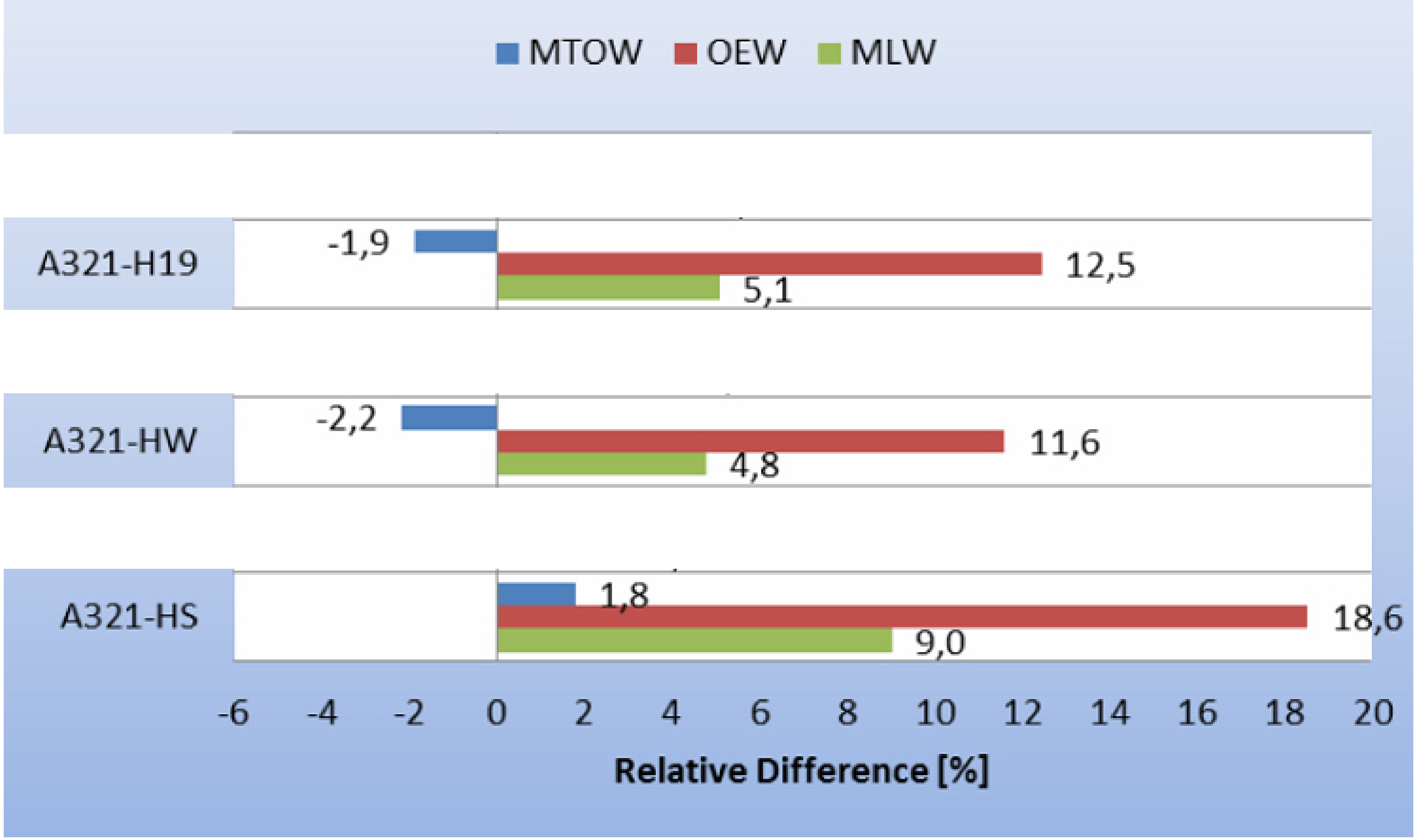
**If DOC are based on A319:**
**DOC (AEA) +17%**
**DOC (TUB) +21%**

# Overall Comparison

| | A320-200 | A321-HS | A321-HW | A321-H19 |
|---|---|---|---|---|
| $l_F$ [m] | 38.4 | 49.4 | 45.2 | 46.2 |
| $m_{MTO}$ [kg] | 72274 | 73578 | 70716 | 70916 |
| $m_{OE}$ [kg] | 40199 | 47658 | 44871 | 45208 |
| $m_{ML}$ [kg] | 63457 | 69164 | 66473 | 66661 |
| $m_F$ [kg] | 12819 | 6664 | 6588 | 6443 |
| $E_{max}$ | 17.5 | 17.6 | 16.9 | 17.6 |
| $T_{TO}$ [kN] | 109.4 | 103.9 | 99.8 | 100.2 |
| $BPR$ | 6 | 6 | 6 | 6 |
| $SFC$ [kg/N/s] | 1.65E-05 | 5.79E-06 | 5.82E-06 | 5.82E-06 |
| $m_T$ [kg] | - | 2531 | 2473 | 2517 |
| $n_{PAX}$ | 180 | 180 | 180 | 156 |
| $DOC$ [€/NM/t] | 1.32 | 1.68 | 1.63 | 1.78 |
| $DOC$ [€/NM/t] | 1.15 | 1.49 | 1.45 | 1.61 |

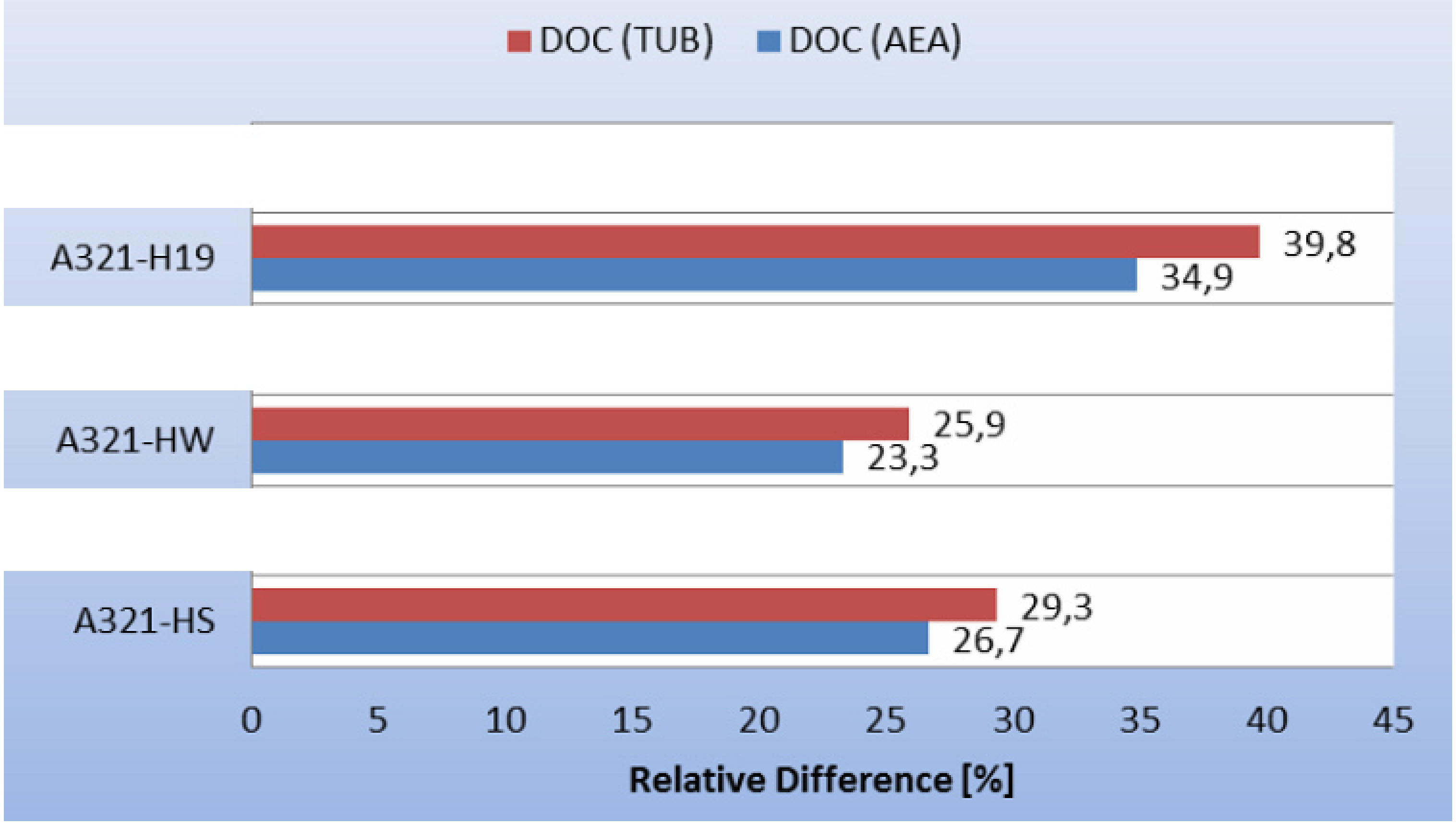
A321: $l_F$ = 44.5 m

# Overall Comparison



Comparison of MTOW, OEW, MLW related to the original A320-200

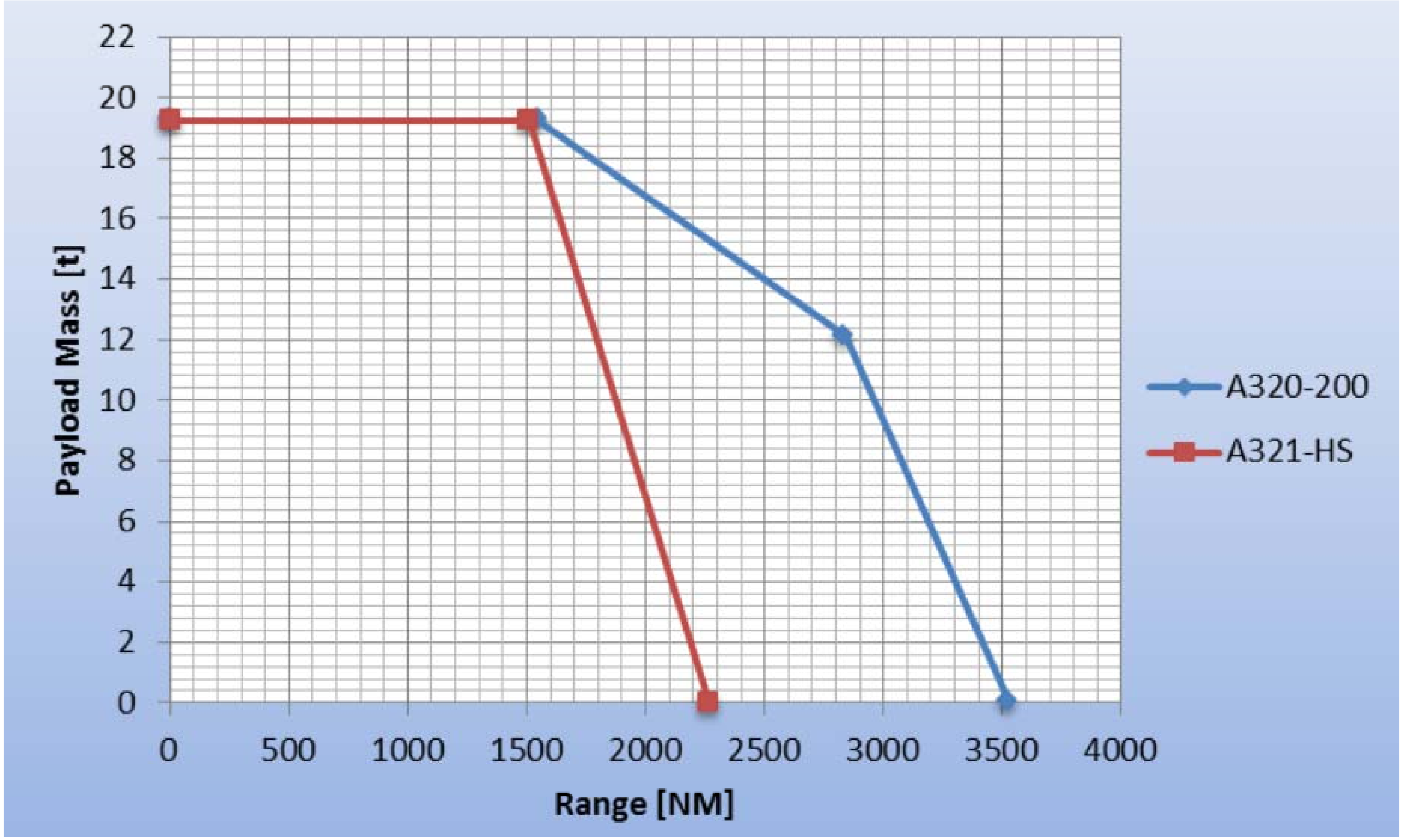
# Overall Comparison



**If DOC are based on A319:**
**DOC (AEA) +17%**
**DOC (TUB) +21%**

Comparison of DOC related to the original A320-200

# Overall Comparison



Payload-Range diagram comparison between a kerosene and a hydrogen-fueled aircraft

# Conclusions

News where at one time distributed via Newpapers –
- then via Newspapers and Radio,
- then via Newspapers and Radio and TV,
- then via Newspapers and Radio and TV and Interent,
- …

We will say: Aircraft flew at one time with Kerosene –
- then with Kerosene and Drop-In Fuel,
- then with Kerosene and Drop-In Fuel and Hydrogen,
- …

The question will NOT be one or the other energy carrier?, but
**what mixture of energy carriers for the aviation system?**

# Hydrogen as Future Fuel Used in Minimum Change Derivatives of the Airbus A321

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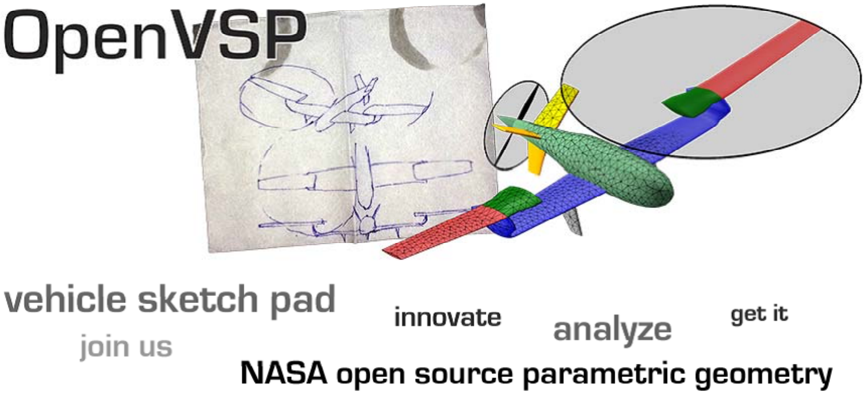
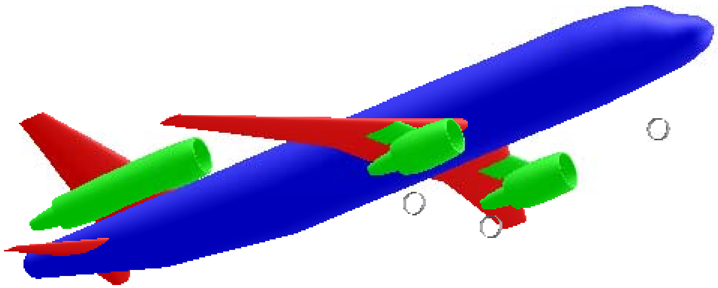
http://AERO.ProfScholz.de

# **Aircraft Sketches** Done with **OpenVSP** (NASA) and **OpenVSP-Connect** (HAW Hamburg)



**www.openVSP.org**

**OpenVSP.ProfScholz.de**



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**This presentation is strongly based on the coauthor's thesis**:

DIB, Leon: *The Aviation Fuel and the Passenger Aircraft for the Future – Hydrogen*. Master Thesis. Hamburg University of Applied Sciences, Aircraft Design and Systems Group (AERO), 2015. – Download: http://library.ProfScholz.de

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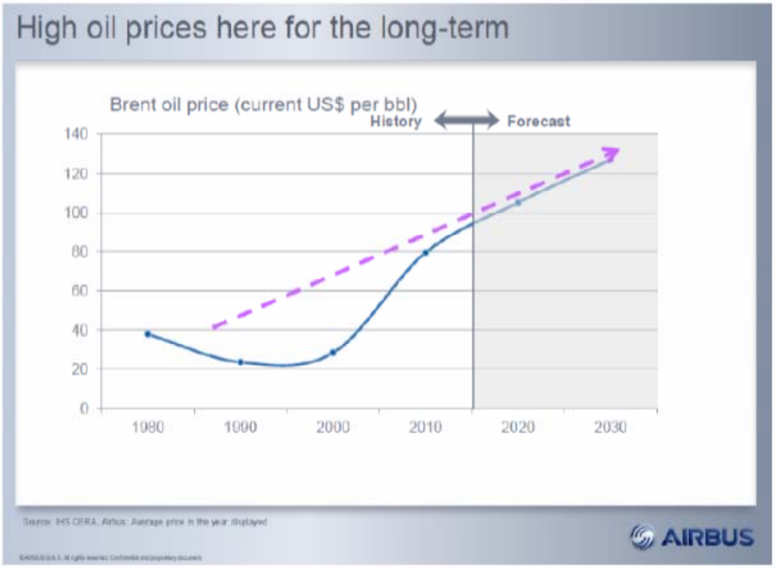
# Backup Slide

## Price Increase of Kerosene

Aircraft Design &
Aero Structures

- The increase of kerosene price in the future is predicted by Airbus to be linear: 2 US$/bbl/year
- Barrel: 1bbl (US) = 159 l; 1,3 US$/€; 0,8 kg/l
- Future fuel price: current fuel price (2013: 0,53 €/kg) plus price increase



High oil prices here for the long-term

Source: IHS CERA, Airbus: Average price in the year displayed

0.012 €/kg/year

J. Leahy. *Navigating the Future.* Global Market Forecast 2012-2031. Airbus, 2012

D. Scholz

05.11.2013

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