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„Luft- und Raumfahrt - gemeinsam forschen und nachhaltig gestalten“

Semi-Physical Method for the Mass Estimation of Fuselages carrying Liquid Hydrogen Fuel Tanks in Conceptual Aircraft Design

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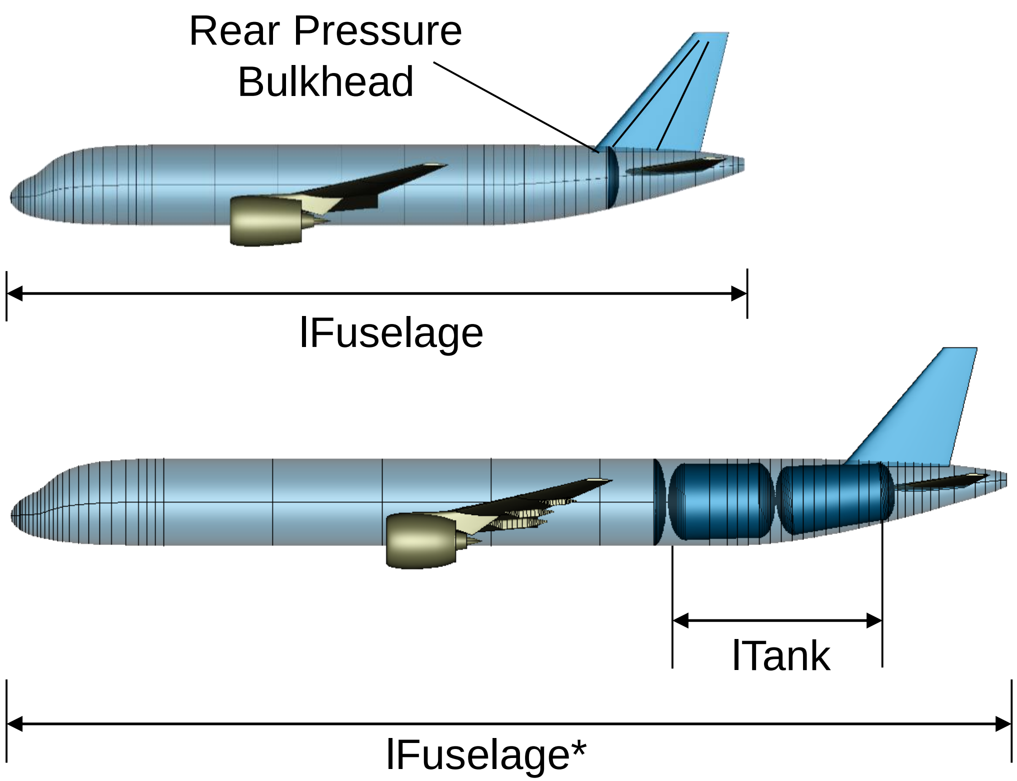
Integration of Hydrogen Tanks in the Fuselage

- Typical integration of hydrogen tanks in the rear of the fuselage for manageable shifts in center of gravity i.e. moderate tank size
- Fuel tanks require space with a margin for systems and maintenance



How does the fuselage mass change when a fuel tank is integrated?

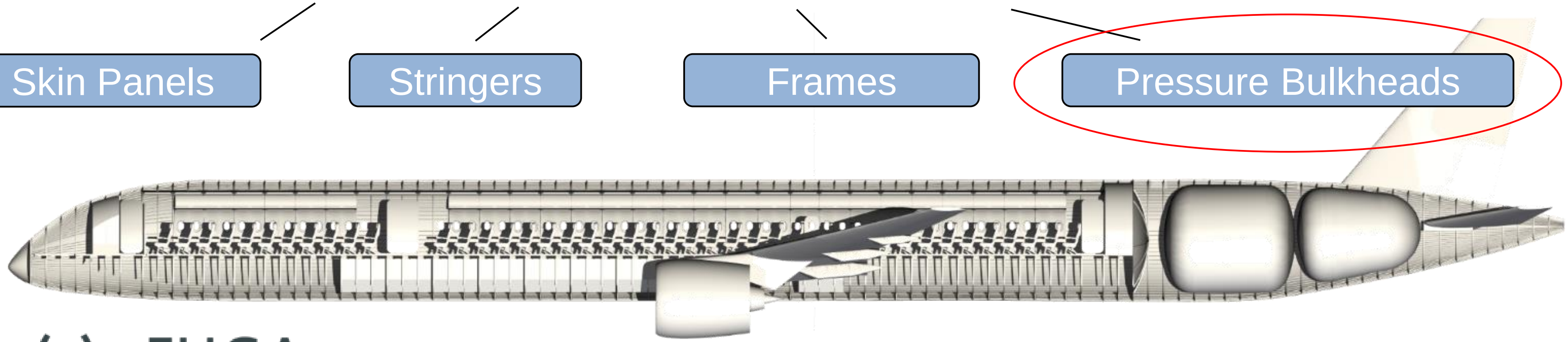
Typical Fuselage Mass Estimation in Overall Aircraft Design

- **Literature [1] gives an empirical relationship for the fuselage mass:**
  - $m_{Fuselage} = f\left(l_{Fuselage}, d_{Fuselage}, k_{Factors}\right)$
  - k-Faktors:
    - $k_{Pressurization}$: Fuselage pressurization
    - k_{Engine}: Location of the engine i.e. wing-mounted or fuselage-mounted
    - k_{Wing}: Wing type i.e. low-wing or high-wing
    - $k_{LandingGear}$: Location of the main landing gear i.e. wing-mounted, fuselage-mounted
- **Advantage:**
  - Good database
  - Valid for different aircraft configurations
  - Useful for the design of conventional aircraft
- **Disadvantage:**
  - Not so useful for configurations where the structure of the fuselage differs from conventional aircraft

Breakdown of Fuselage Structure Components

Primary Fuselage Structure / Shell

- Skin Panels
- Stringers
- Frames
- Pressure Bulkheads



FUGA
Fuselage Geometry Assembler

Secondary Fuselage Structure

- Cabin Floor
- Doors
- Windows
- Floor Support Structure
- Windshield
- Cargo Hold Structure
- Wheel Bays
- Attachment structures for Wing, Tail and Landing Gear

- The secondary fuselage structure typically makes up 35-45% of the total mass
- The target is to estimate primary and secondary structure independently

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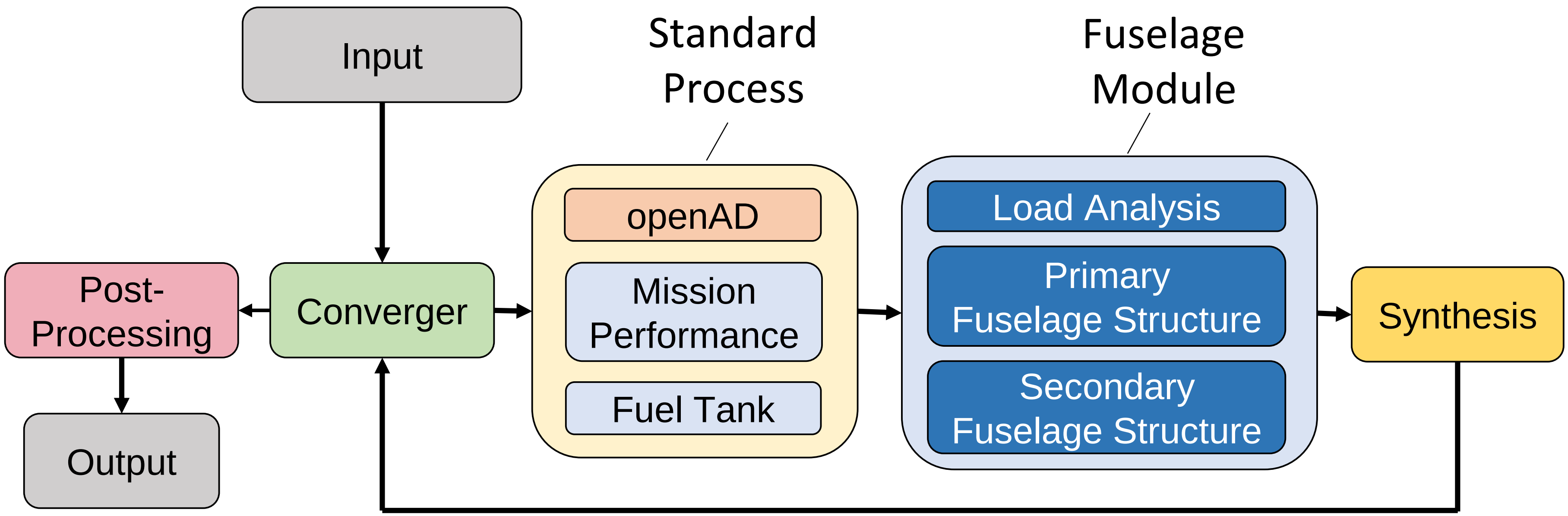
Overall Aircraft Design Workflow with Semi-Physical Method



- Fully automatic, iterative design workflow
- Minimum +15 Minutes compared to workflow without fuselage module

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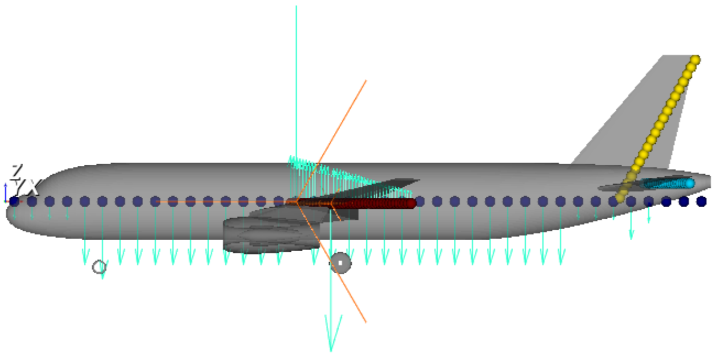
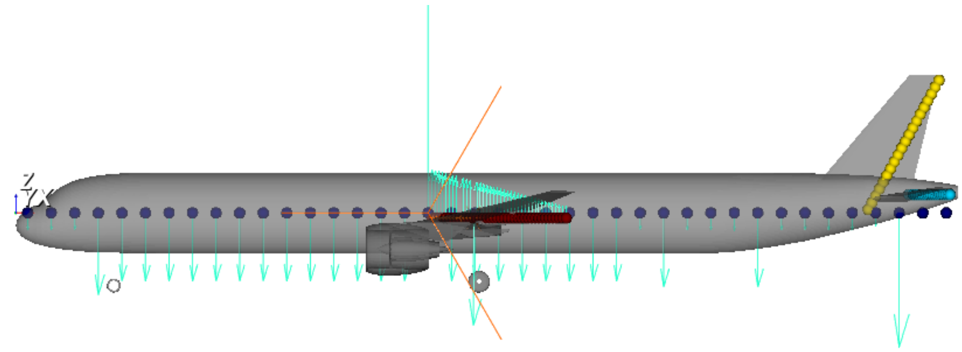
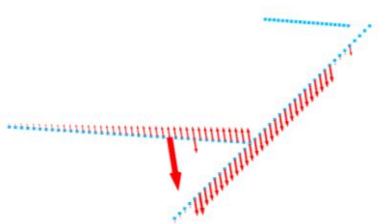
Load Estimation with Tools of DLR-AE

See presentation of Tobias Hecken (Conceptual Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen Tank)

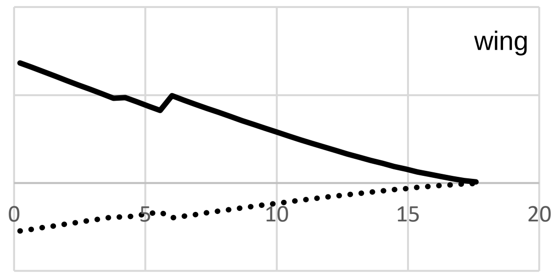




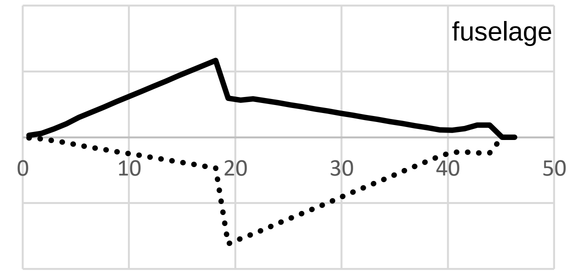
Example: nodal loads fz



Example: section loads fz



Example: section loads fz

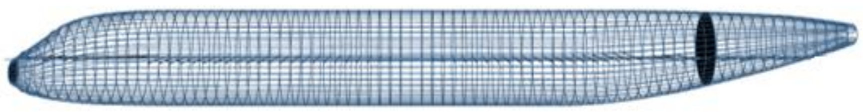


- Load cases for trimmed flight with critical centers of gravity
- Flight and ground loads estimation

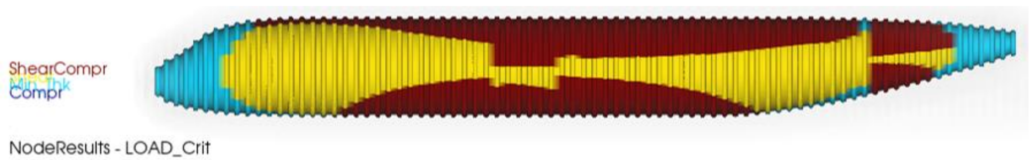
Primary Fuselage Structure with Tools of DLR-BT

See presentation of Michael Petsch (Analytical fuselage structure mass estimation using the PANDORA framework)

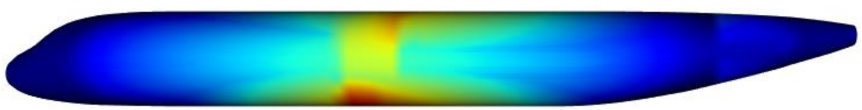
- **Components calculated/estimated in *PANDORA*:**
  - Skin Panels
    - Analytical method
  - Stringers
    - Fixed Skin-to-Stringer Ratio
  - Frames
    - Fixed pitch



Stringer and Frame Distribution



Critical Loadtypes



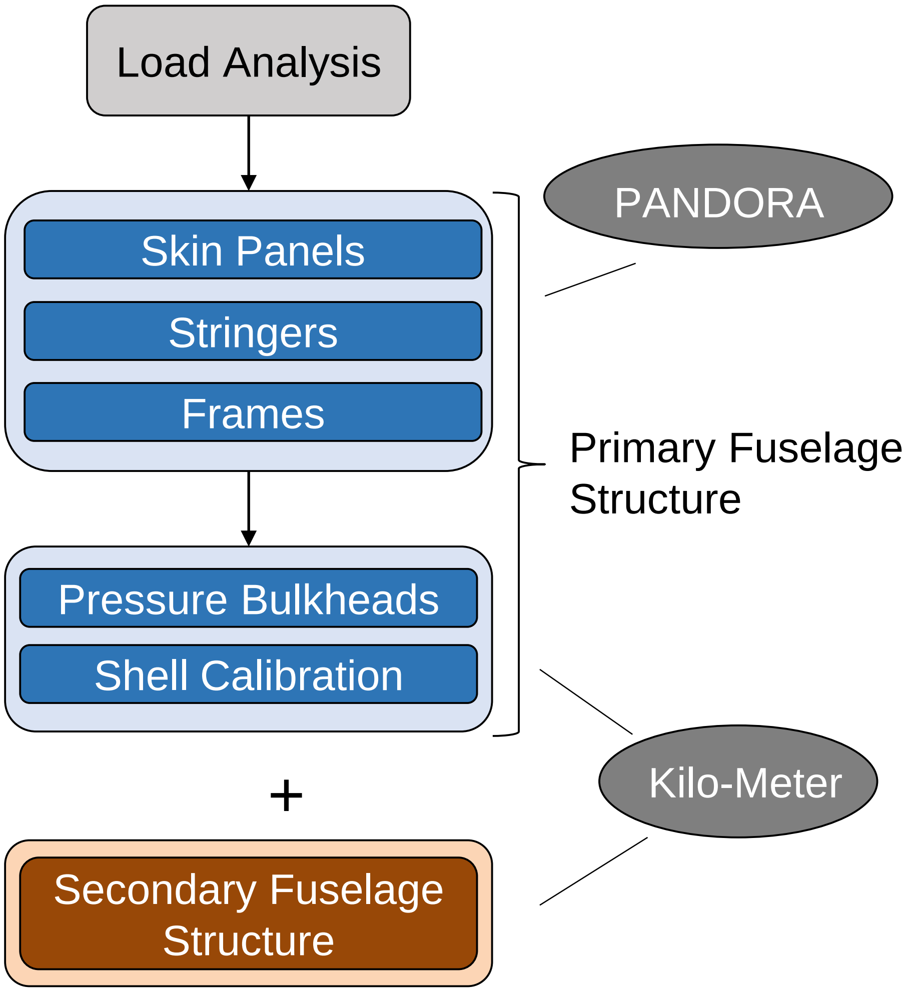
Skin Panels Thickness Distribution

- **Sensitivities:**
  - Load Distribution
  - Cabin Pressure
- **Simplifications:**
  - Ideal circular cross-section
  - No consideration of load paths

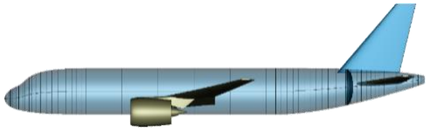
Secondary Fuselage Structure

Functionality of the tool *Kilo-Meter*:

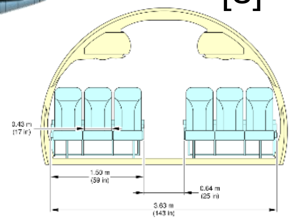
- Implementation of an empirical formula from Torenbeek [2] to estimate the mass of the pressure bulkheads
    - Built-in sensitivity for increased pressure bulkhead size due to a „full“ cross-section
- Empirical formula from Torenbeek [2] to estimate the mass of the secondary fuselage structure
    - Assumption:
        - *The secondary fuselage mass scales primarily with the cabin area*
    - The formula was therefore adapted in order to account for changes in cabin length instead of fuselage length



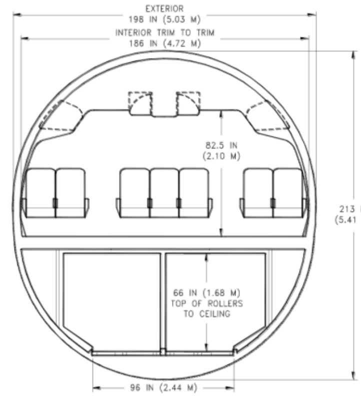
Use Case: Short/Medium Range



Single-Aisle Cross-Section



[3]



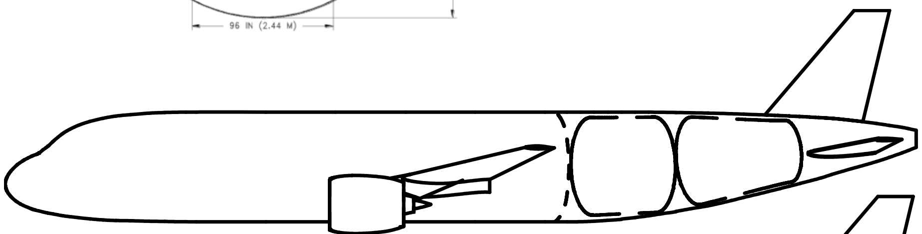
[4]

7Abreast Cross-Section

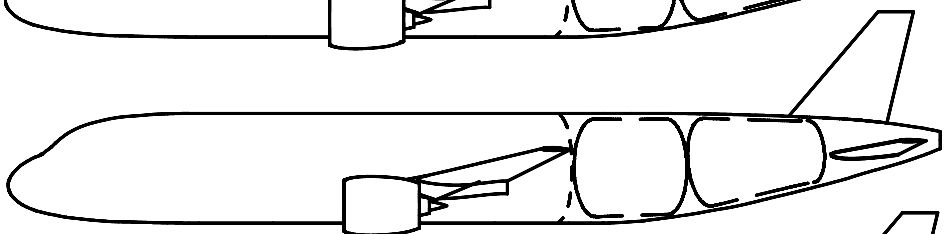
A design change in fuselage cross-section is required for weight and balance reasons

Complete redesign for each range

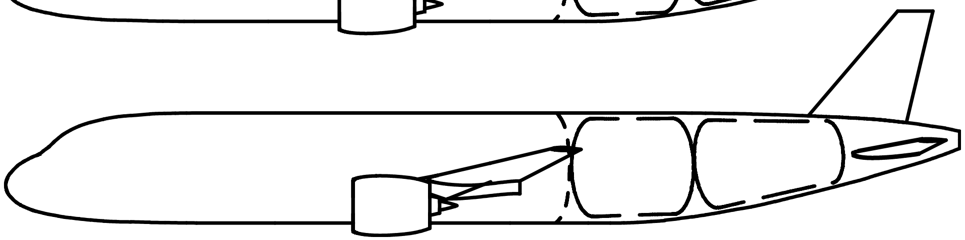
-10% Range



Designrange = 2900nm

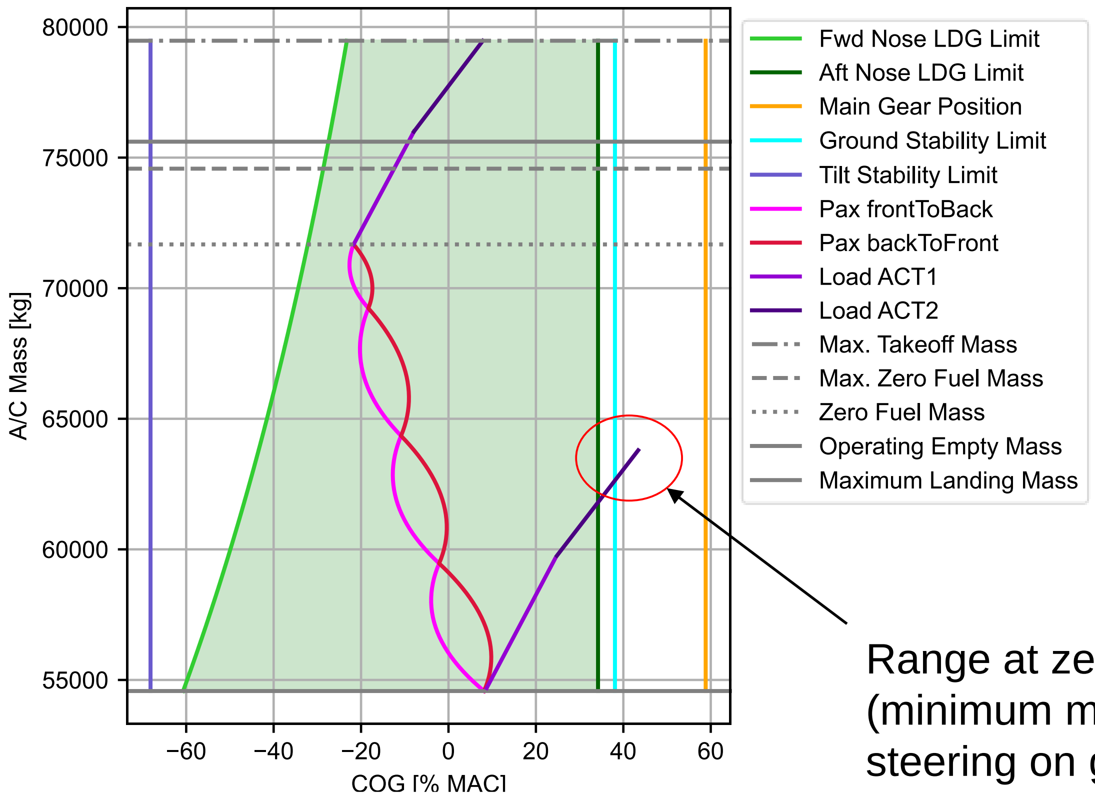


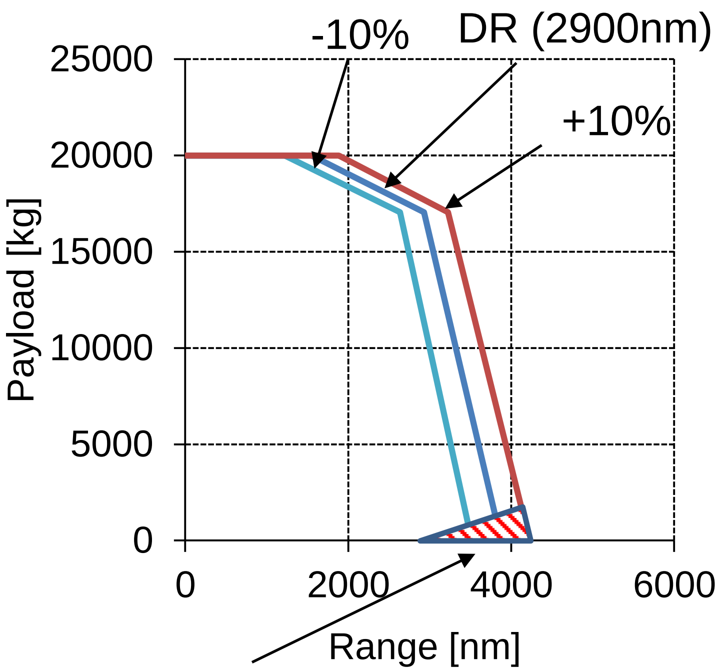
+10% Range



lFus/dFus ≈ 9

Side Note: Weight & Balance Issues





Range at zero payload is limited (minimum mass on nose landing gear for steering on ground)

- Ferry range is not operable
- Restrictions on typical operations are small and therefore acceptable

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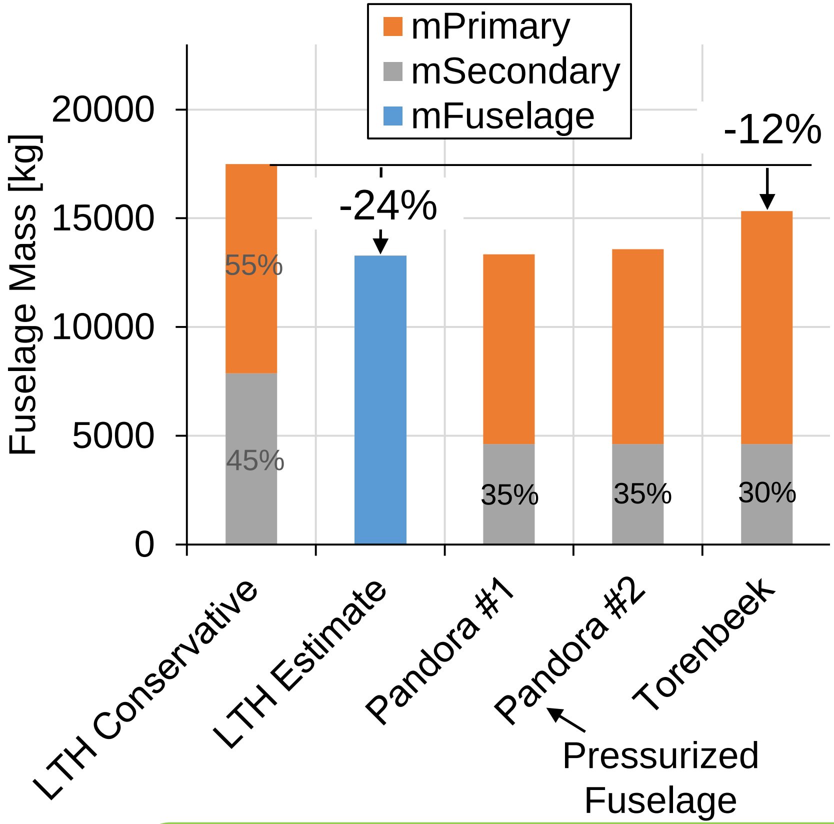
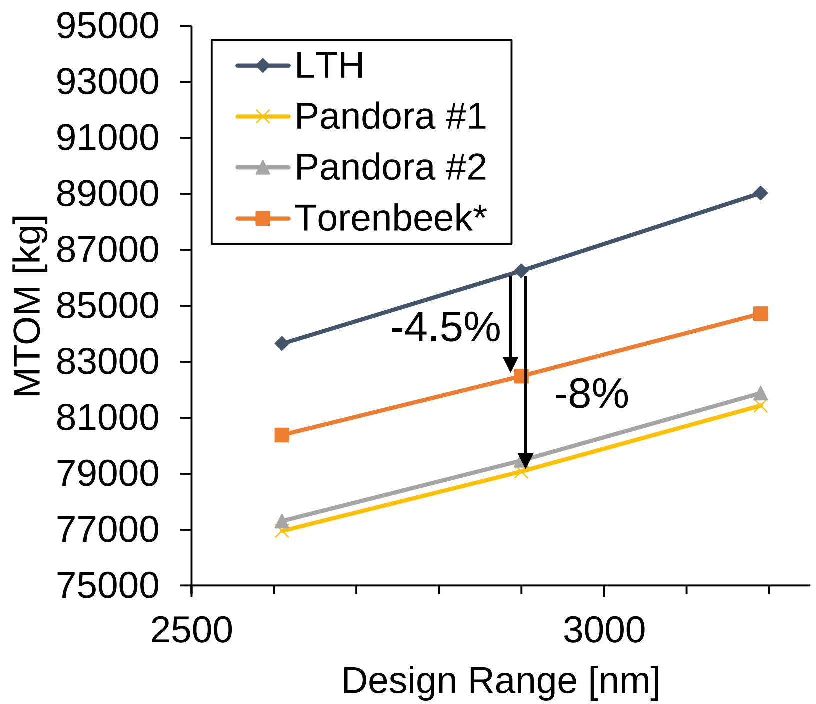
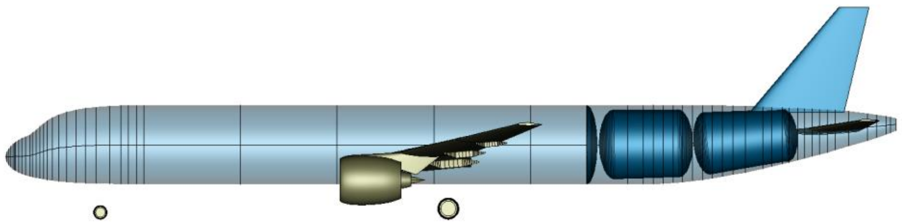
Use Case: Results of the Mass Estimation Methods





- 40% „reduction“ of secondary structure mass (2900nm)
- Double digit reductions in fuselage structure mass for both the semi-empirical (Pandora) and the empirical* method (Torenbeek)

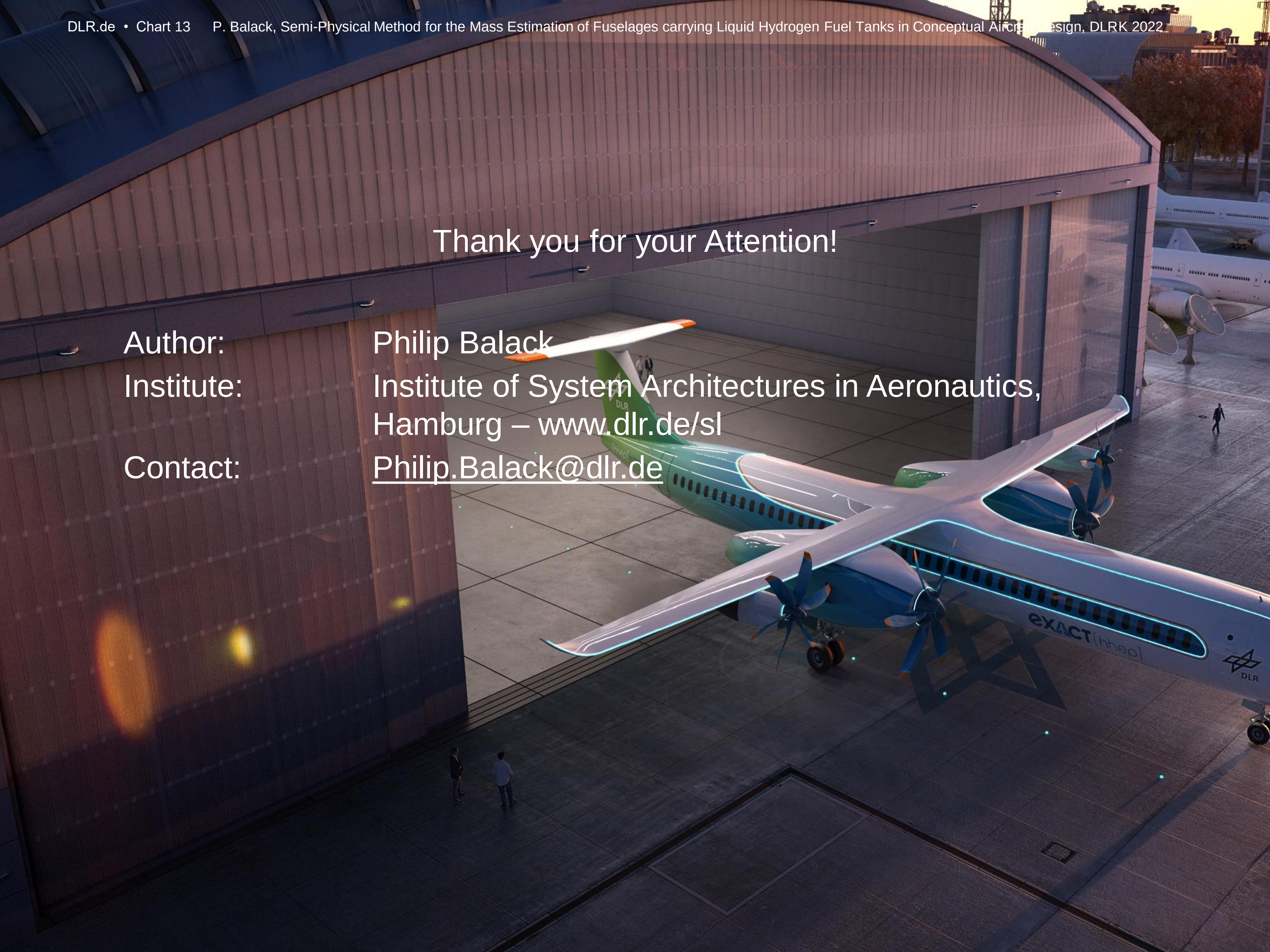
Summary and Outlook



- Collaboration between 3 DLR institutes with regard to interfaces in CPACS
- Setup of a semi-physical method

Future Activities

- Refine Analytical Sizing of Stringers and Frames according to local conditions
- Assess mass penalty due to reinforced frame connecting the VTP to the fuselage
- Use the method to update the fleet of hydrogen aircraft in EXACT



Thank you for your Attention!

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Bibliography

[1] Luftfahrttechnisches Handbuch – Ausgabe 2017

[2] Torenbeek, E., Advanced aircraft design. Conceptual design, analysis, and optimization of subsonic civil airplanes, Wiley, Chichester, 2013.

[3] A320 Airport Characteristics Aiport and Maintenance Planning, Airbus S.A.S., 2017

[4] 767 Airplane Characteristics for Airport Planning, Boeing Commercial Airplanes, 2021