DLRK 2022
DEUTSCHER LUFT- UND RAUMFAHRTKONGRESS
DGLR
27. - 29. SEPTEMBER 2022 – DRESDEN
„Luft- und Raumfahrt - gemeinsam forschen und nachhaltig gestalten“

CONCEPTUAL LOADS ASSESSMENT OF AIRCRAFT WITH FUSELAGE INTEGRATED LIQUID HYDROGEN TANK

Deutscher Luft- und Raumfahrtkongress 2022 – Dresden

im Deutsches Hygiene-Museum Dresden

Tobias Hecken – Institut für Aeroelastik
Philip Balack – Institut für Systemarchitekturen in der Luftfahrt
Michael Petsch – Institut für Bauweisen und Strukturtechnologie
David Zerbst – Institut für Faserverbundleichtbau und Adaptronik

DLR

Content

- Project description
- Project overall aircraft sizing workflow
- Conceptual flight and landing gear loads estimation
- Aircraft configuration
- Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen
- Outlook

Project description

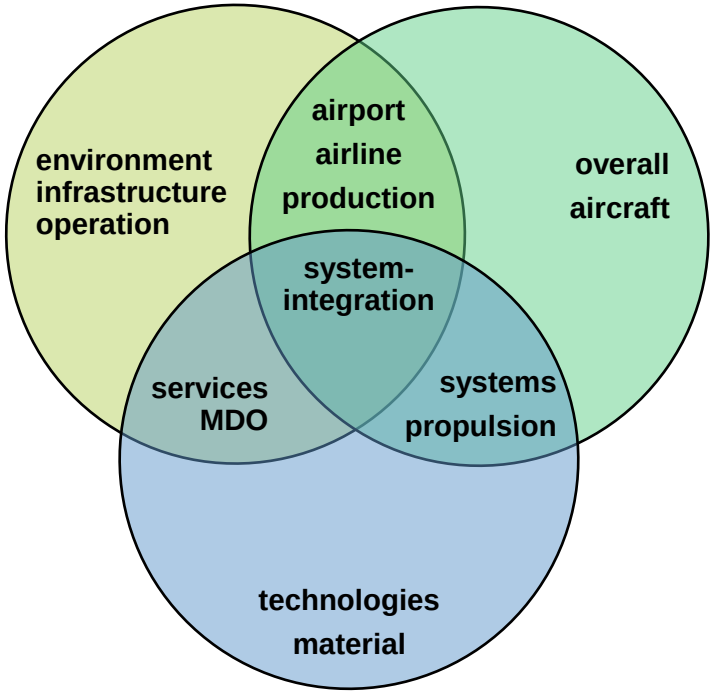
eXACT® EXploration of electric Aircraft Concepts and Technologies

DLR internal Project: 2020 – 2023, 20 DLR Institutes from 4 DLR divisions (energy, aviation, space, transport)

Conceptual study for environment-friendly flight

Goals:

- identify **aircraft concepts** and **enabling technologies** for climate neutral flight
  - propulsion system concepts considering batteries, fuel cells and hydrogen
- assess **future air transport systems** with respect to total energy, lifecycle, climate impact, society, infrastructure, values for stakeholders (airports, airlines, air traffic control), etc.

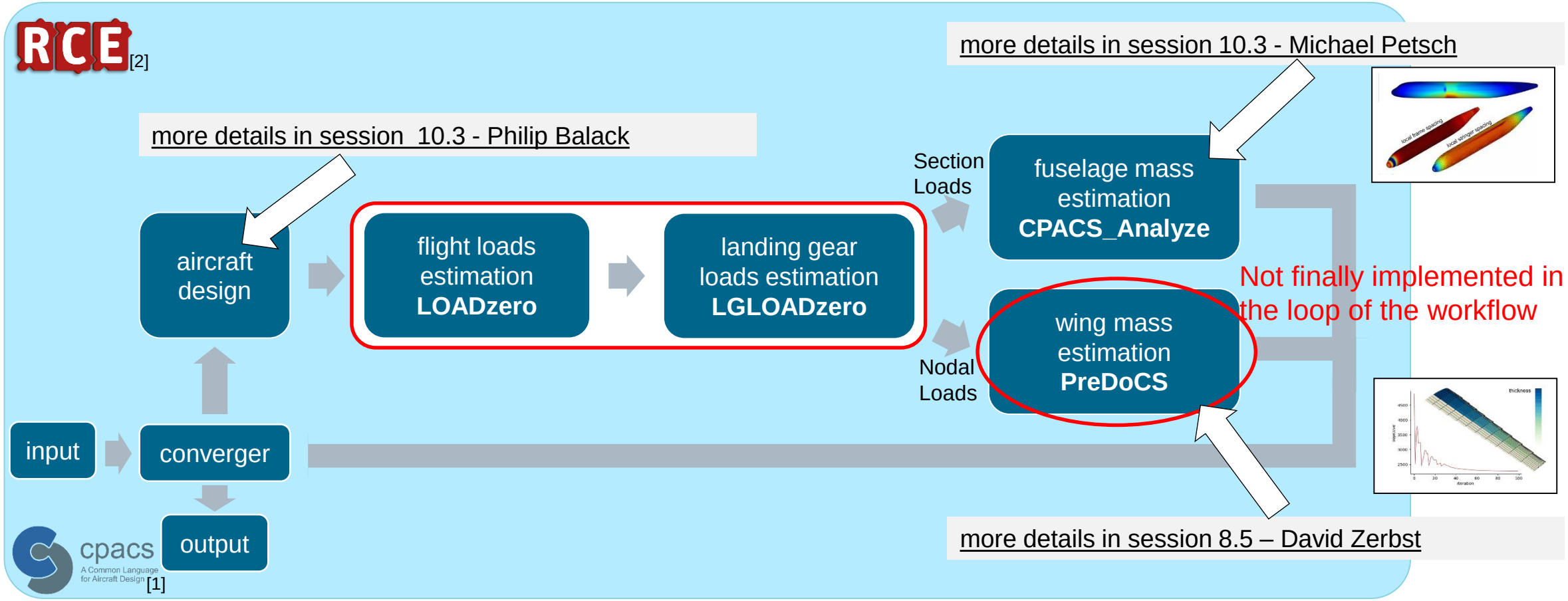


- green energy is the key for climate neutral and sustainable air mobility
- to this goal the aviation and energy sector have to collaborate together

DLRK September 2021 Bremen
A system level approach as applied in the framework of the DLR-internal project EXACT
Dr. Johannes Hartmann, Dr. Björn Nagel DLR Hamburg

Project overall aircraft sizing workflow

[1] M. Alder, E. Moerland, J. Jepsen and B. Nagel. Recent Advances in Establishing a Common Language for Aircraft Design with CPACS. Aerospace Europe Conference 2020, Bordeaux, France, 2020.
[2] Brigitte Boden, Jan Flink, Niklas Först, Robert Mischke, Kathrin Schaffert, Alexander Weinert, Annika Wohlan, and Andreas Schreiber. "RCE: an integration environment for engineering and science." SoftwareX 15 (2021): 100759. https://doi.org/10.1016/j.softx.2021.100759.



- a lower level of detail but high computational efficiency is required for fast overall aircraft design (OAD)

[3] Schrenk, O., “Ein einfaches Näherungsverfahren zur Ermittlung von Auftriebsverteilungen längs der Tragflügelspannweite”, Mittelung der Aerodynamischen Versuchsanstalt, Göttingen, 1940

Conceptual Flight Loads Estimation

CPACS File
(wing & fuselage data, massBreakdown)

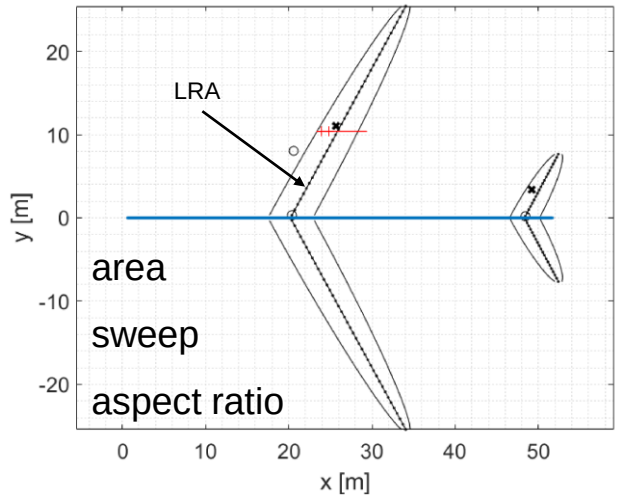
→ LOADzero →

CPACS File
(flight loads, mass model)

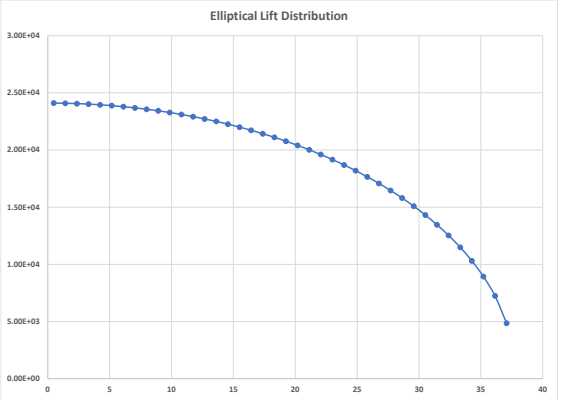
LOADzero for quick flight loads estimation (continuous development)

- minimal geometric inputs and flight conditions data
  - no difference of high/low wing & tail plane configuration
  - only one Mach number and equivalent air speed used – lack of definition of design speeds and altitudes
- setup of mass model for inertial loads
  - volumetric related masses (e.g. kerosene)
  - area related masses (e.g. structure)
  - point masses (e.g. engine, LG, LH2 tanks)
- setup of elliptical or Schrenk [3] lift distribution – stationary trimmed condition
  - winglet can be considered

Example: simple geometry definition



Example: elliptical lift distribution



Initial developer: G.P. Chiozzotto, former DLR employee
Developer: T. Hecken, DLR employee

[4] Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes CS-25, Amendment 11, European Aviation Safety Agency, 2011.
[5] Pratt K. H., “A Revised Formula for the Calculation of Gust Loads”, NACA TN-2964, 1953

Conceptual Flight Loads Estimation

CPACS File
(wing & fuselage data, massBreakdown)

→ LOADzero →

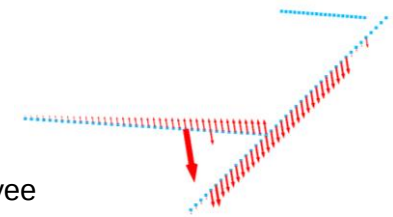
CPACS File
(flight loads, mass model)

LOADzero for quick flight loads estimation (continuous development)

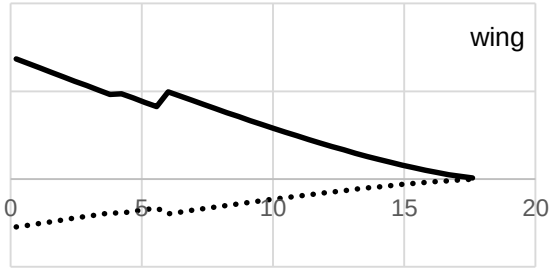
load cases in accordance to CS25 [4]

- manoeuvre load cases: quasi-static & symmetric, pos./neg.
- gust load cases: additional load factor/lift according to Pratt gust [5] for 1g cruise flight condition – encounters only main wing or also tail (acc. to load case)
- effective load acting is sum of aerodynamic and inertial forces & moments
  - no thrust load cases are considered
  - loads are distributed as nodal and/or section loads along the loads reference axis

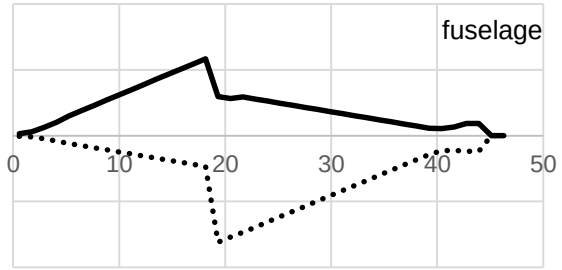
Example: nodal loads fz



Example: section loads fz



Example: section loads fz

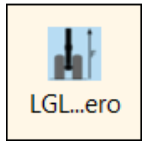


Initial developer: G.P. Chiozzotto, former DLR employee
Developer: T. Hecken, DLR employee

[4] Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes CS-25, Amendment 11, European Aviation Safety Agency, 2011.
[6] https://aviation-regulations.com/part/25

Conceptual Landing Gear Loads Estimation

CPACS File
(LG data, design masses, CoG, mass model)



CPACS File
(ground, landing loads)

LGLOADzero for quick ground and landing loads estimation

- minimal aircraft data
  - CoG and LG positions
  - design masses (MTOW, MLW; OEW, MZFW)
  - mass model used in LOADzero
  - tire data available
- setup of simplified landing gear model (wheel, axle, piston, bogie, …)
  - check of stability requirements of landing gears is done
  - no aerodynamic or thrust taken into account

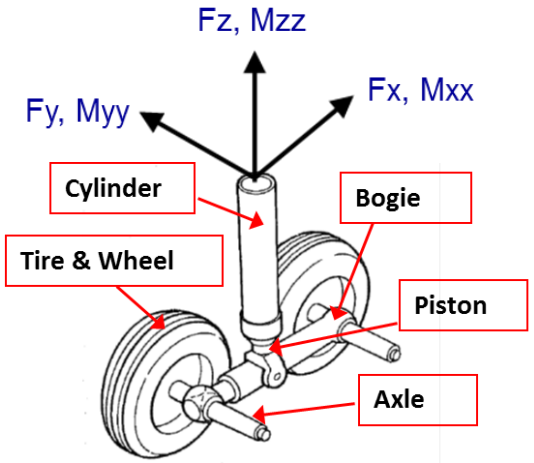
load cases in accordance to CS25 [4] & FAR25 [6]

- simulation of maximum static ground and landing gear load cases

➢ calculation of forces and moments of landing gears at attachment nodes

➢ calculation of nodal and section loads on LRAs
  - using mass model & overall force and moment equilibrium (accelerations) $\sum F = 0;\ \sum M = 0$

Simplified description of landing gear



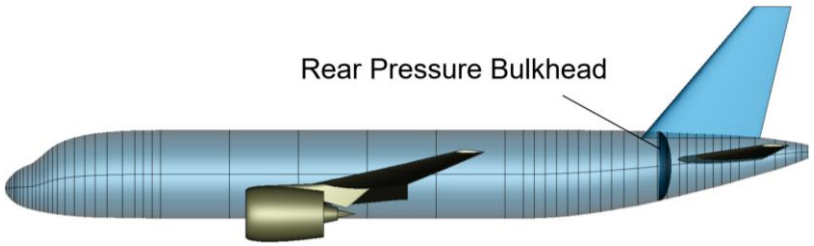
Developer: S. Cumnuantip, DLR employee
CO-Developer: T.Hecken, DLR employee

Aircraft configuration

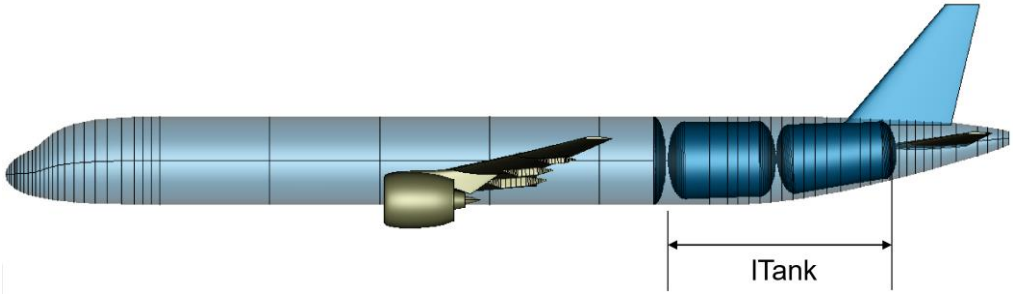
- fuel tanks require space with a margin for systems and maintenance
- typical integration of hydrogen tanks in the rear of the fuselage for manageable shifts in centre of gravity i.e. moderate tank size
- volumetric kerosene mass within wing due to LH2 is absent
- note: the wing is shifted due to CoG movement

TLARs	
design range	1500nm
design Mach number	0.78
PAX	250
payload	25000kg
wing span	36m
cruise altitude	10060m
engine	turbo fan

Reference configuration – D250-321TF-2040



Liquid Hydrogen (LH2) configuration – D250-TFLH2-2040

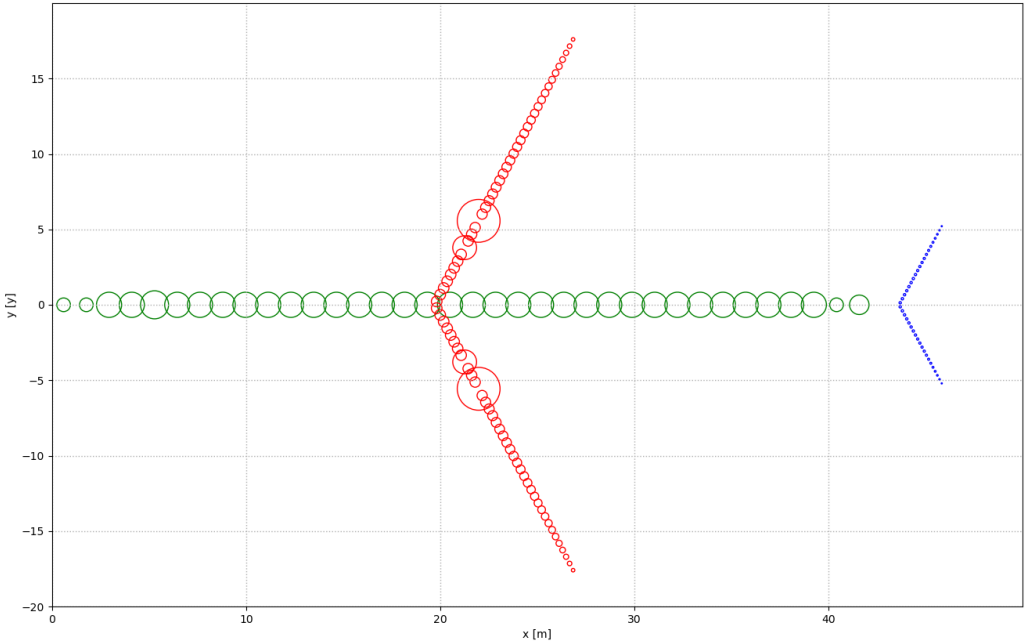


- How does the conceptual loads change when liquid hydrogen is used and LH2 tanks are integrated in the fuselage?

Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen

mass model for MTOM – design mission: 1500nm

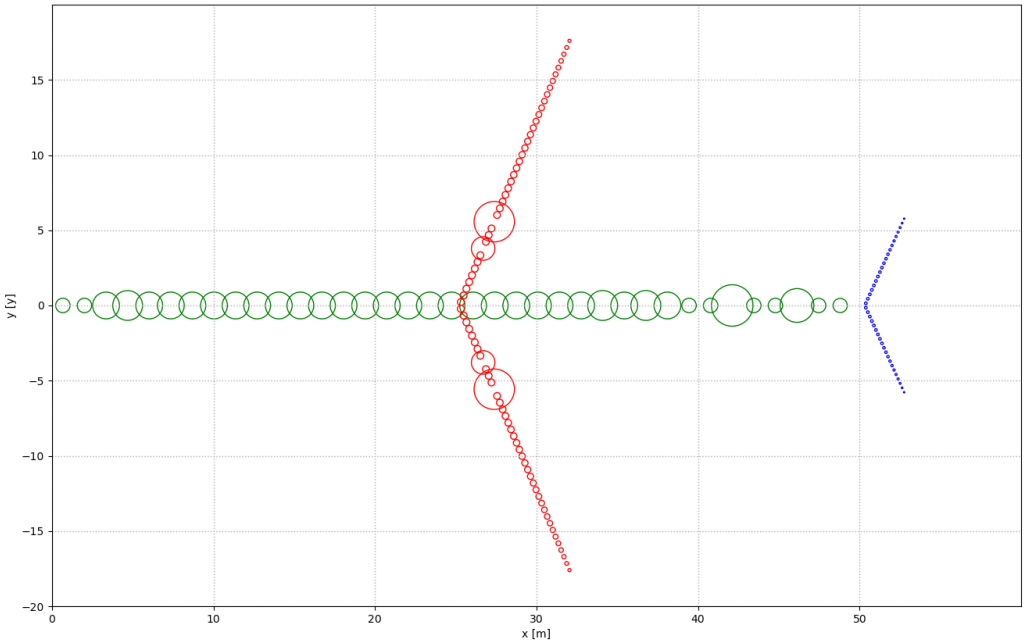
Reference configuration – D250-321TF-2040



fuselage length: 46.9 m
MTOM: 81305 kg
OEM: 47550 kg

fuel mass: 8755 kg
structure mass: 24275 kg
system mass: 5100 kg

Liquid Hydrogen (LH2) configuration – D250-TFLH2-2040



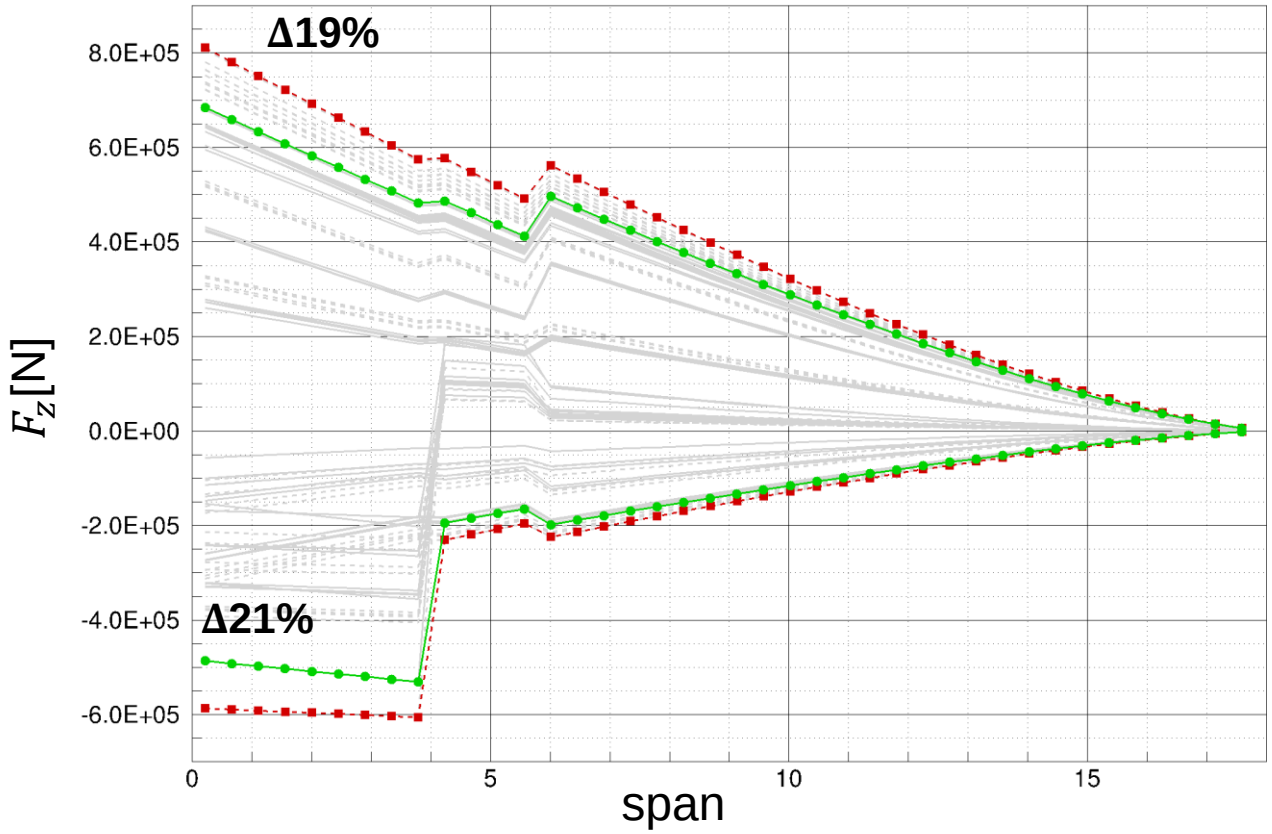
fuselage length: **53.5 m**
MTOM: 81313 kg
OEM: **53929 kg**

fuel mass: **2384 kg**
structure mass: 26600 kg
system mass: **9827 kg**

- LH2 concept has an impact on mass distribution

Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen

wing loads comparison



D250-321TF-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

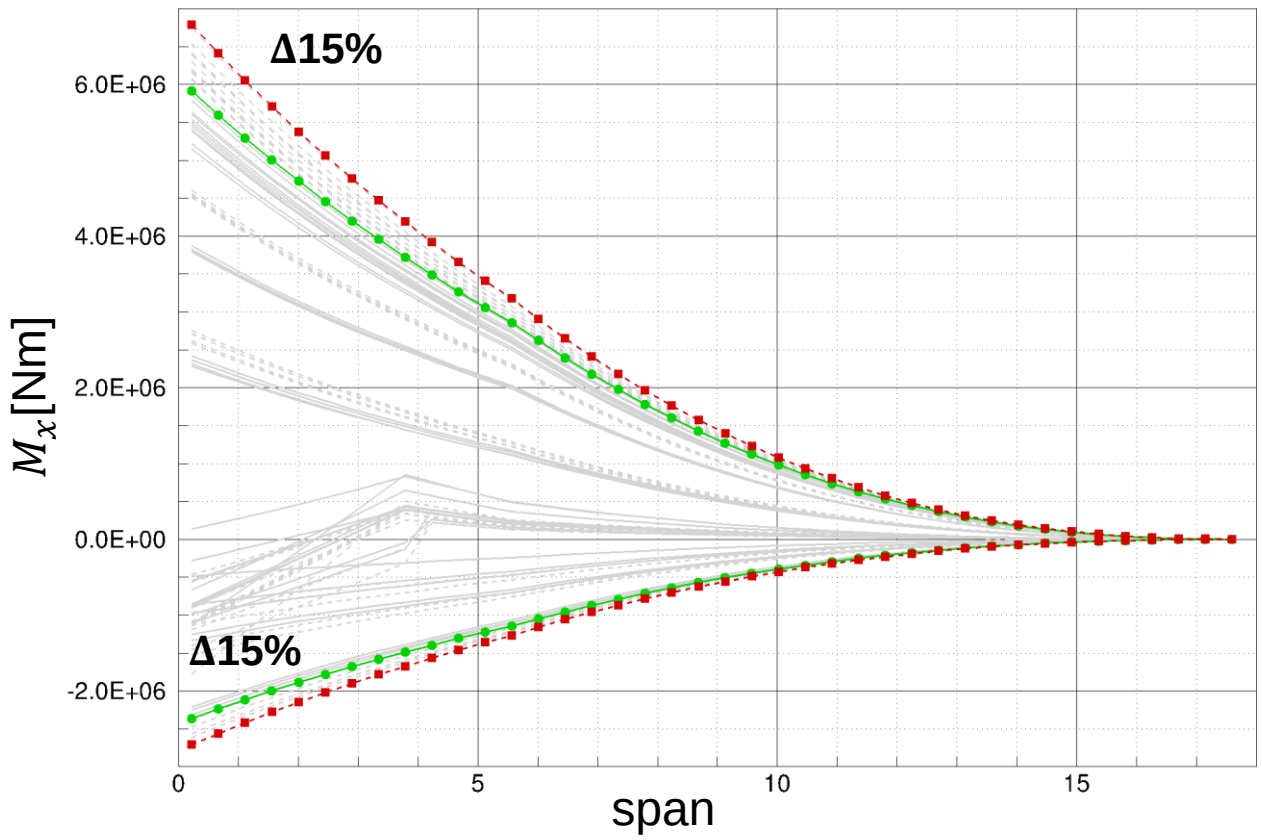
D250-TFLH2-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

- the missing fuel mass in the wing has the main impact on wing loads
- local higher landing gear loads

Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen

wing loads comparison



D250-321TF-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

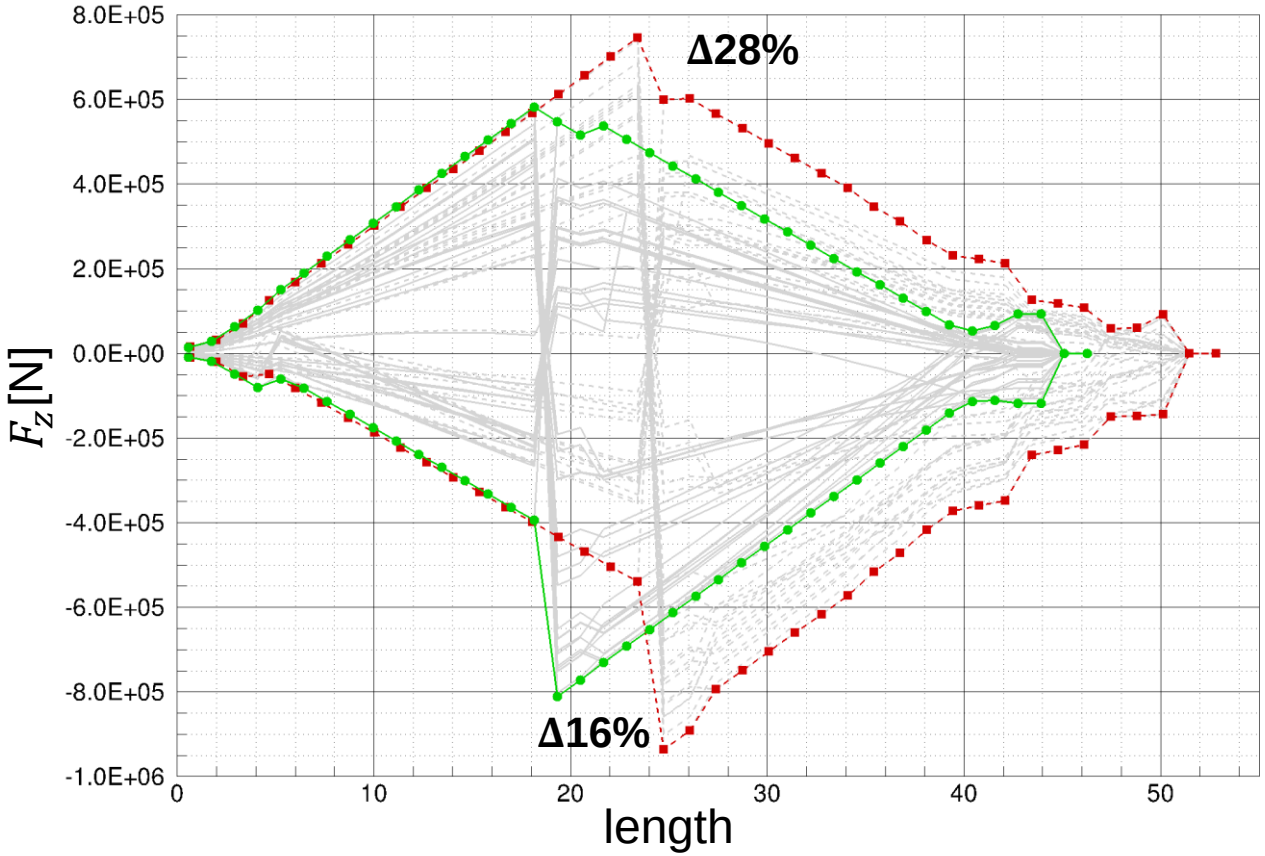
D250-TFLH2-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

- the missing fuel mass in the wing has the main impact on wing loads
- higher local landing gear loads no impact on wing bending moment at root

Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen

fuselage loads comparison



D250-321TF-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

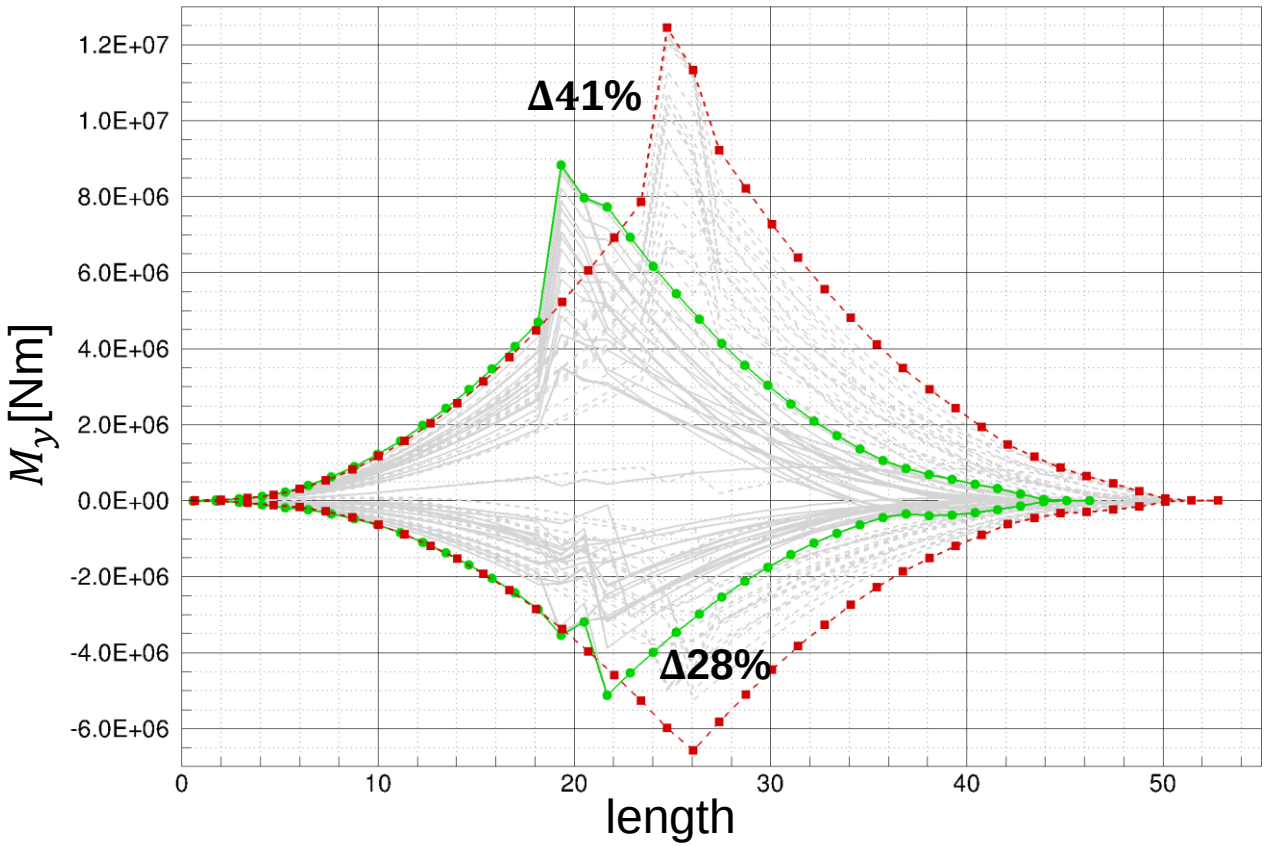
D250-TFLH2-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

- longer fuselage and LH2 tanks at the rear do have an impact on the fuselage loads

Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen

fuselage loads comparison



D250-321TF-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

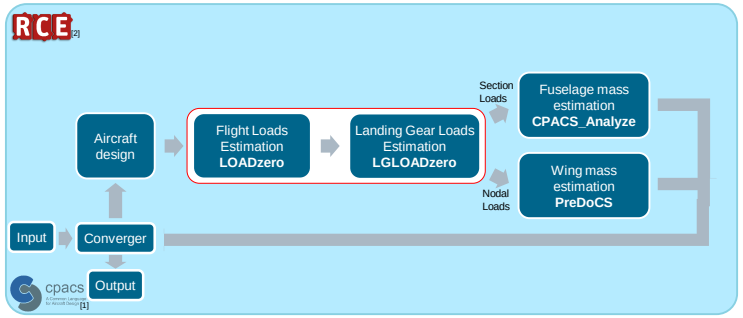
D250-TFLH2-2040

- max & min loads
- manoeuvre
- gust
- ground & landing

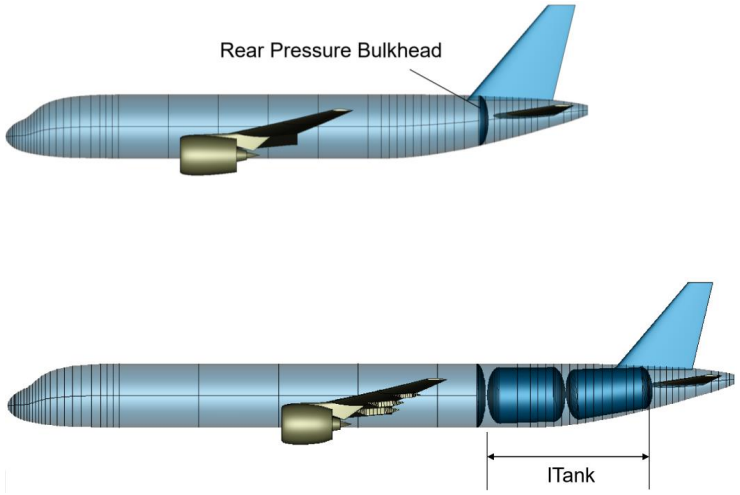
- longer fuselage and LH2 tanks at the rear do have an impact on the fuselage loads
- the higher wing loads influences also the fuselage loads

Summary

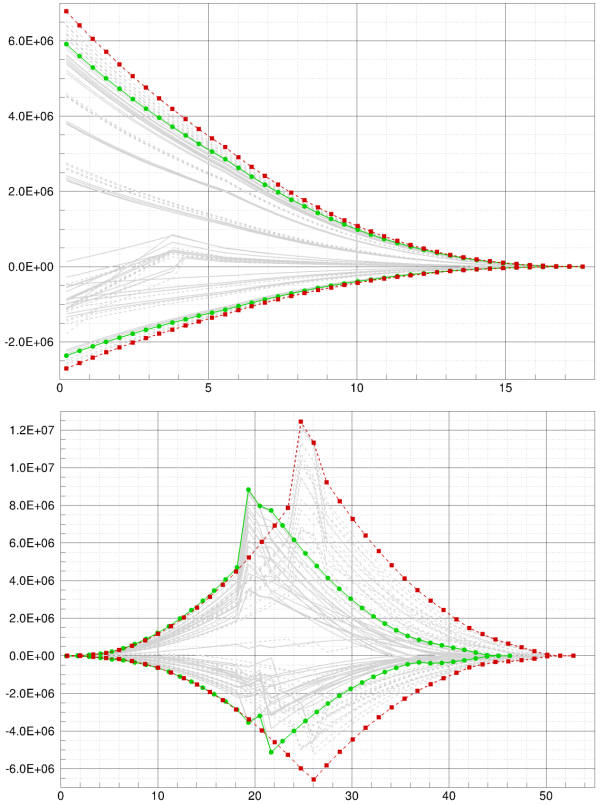
overall aircraft workflow



turbo fan with LH2 tank configuration



conceptual loads assessment



Outlook

- take wing mass estimation into account within in the framework for analyses
- investigation of more and different concepts

- comparison of conceptual loads with methods of higher fidelity

Impressum

Thank you for your attention

Topic: Conceptual Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen Tank

Date: 28.09.2022

Author: Tobias Hecken

Institute: Institute of aeroelasticity, Göttingen – www.dlr.de/ae

Contact: Tobias.Hecken@dlr.de

Mi. 28.09 16:50	**Öko-effiziente Flugzeugkonfi-gurationen**	**Hörsaal L2**
Comparison of Sustainable Regional Aircraft Concepts		
Georgi Atanasov – DLR		

Do. 29.09 16:20	**Neue Flugzeugent-wurfsmodelle**	**Hörsaal L2**
Semi-Physical Method for the Mass Estimation of Fuselage Carrying Liquid Hydrogen Fuel Tanks in Conceptual Aircraft Design		
Philip Balack – DLR		

Do. 29.09 17:10	**Neue Flugzeugent-wurfsmodelle**	**Hörsaal L2**
Analytical fuselage structure mass estimation using the PANDORA framework		
Michael Petsch – DLR		

Do. 29.09 12:15	**Fortschrittliche Strukturausle-gung**	**Raum S3 Q1**
Preliminary Design of Composite Wings Using Beam-based Structural Models		
David Zerbst – DLR		