Deutsches Zentrum
für Luft- und Raumfahrt

DGLR

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

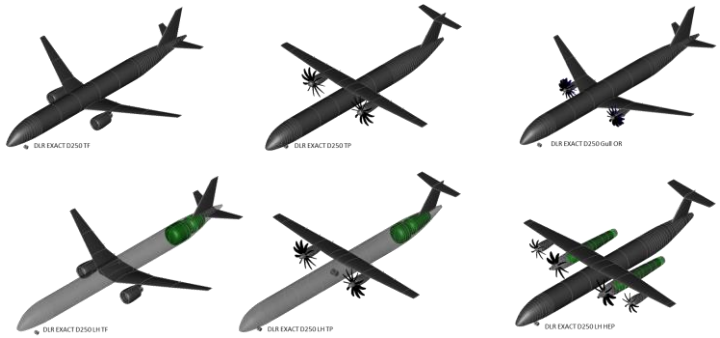
eXACT®

Analytical fuselage structure mass estimation using the PANDORA framework

Michael Petsch, D. Kohlgrüber, C. Leon, D. Schwinn, E. Wegener
DLR-BT Stuttgart

September, 29th 2022

EXACT Project MDO Workflow



- Description of aircraft configurations:

  CPACS[1] (Common Parametric Aircraft Configuration Schema)

  cpacs
  A Common Language for Aircraft Design

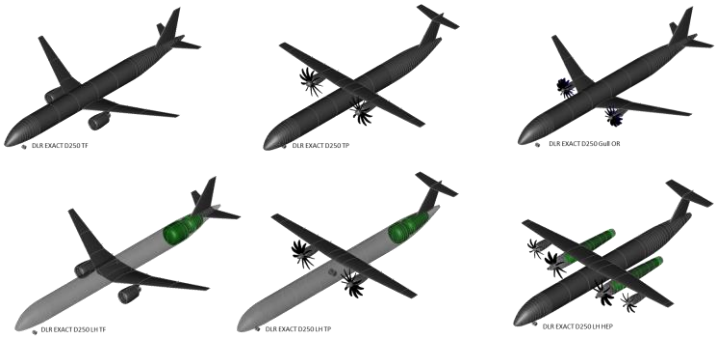
- MDO workflow:

  RCE [2] (Remote Component Environment)

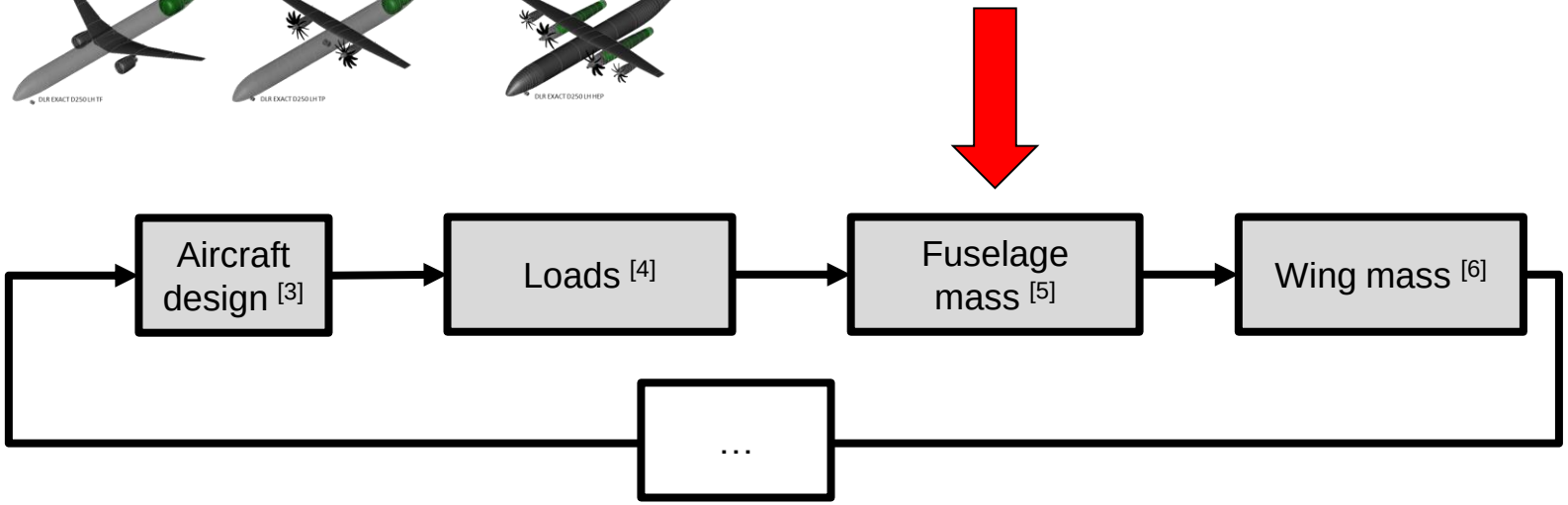
[1] M. Alder, E. Moerland, J. Jepsen and B. Nagel. Recent Advances in Establishing a Common Language for Aircraft Design with CPACS.
Aerospace Europe Conference 2020, Bordeaux, France, 2020.

[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

EXACT Project MDO Workflow



PANDORA (DLR-BT)

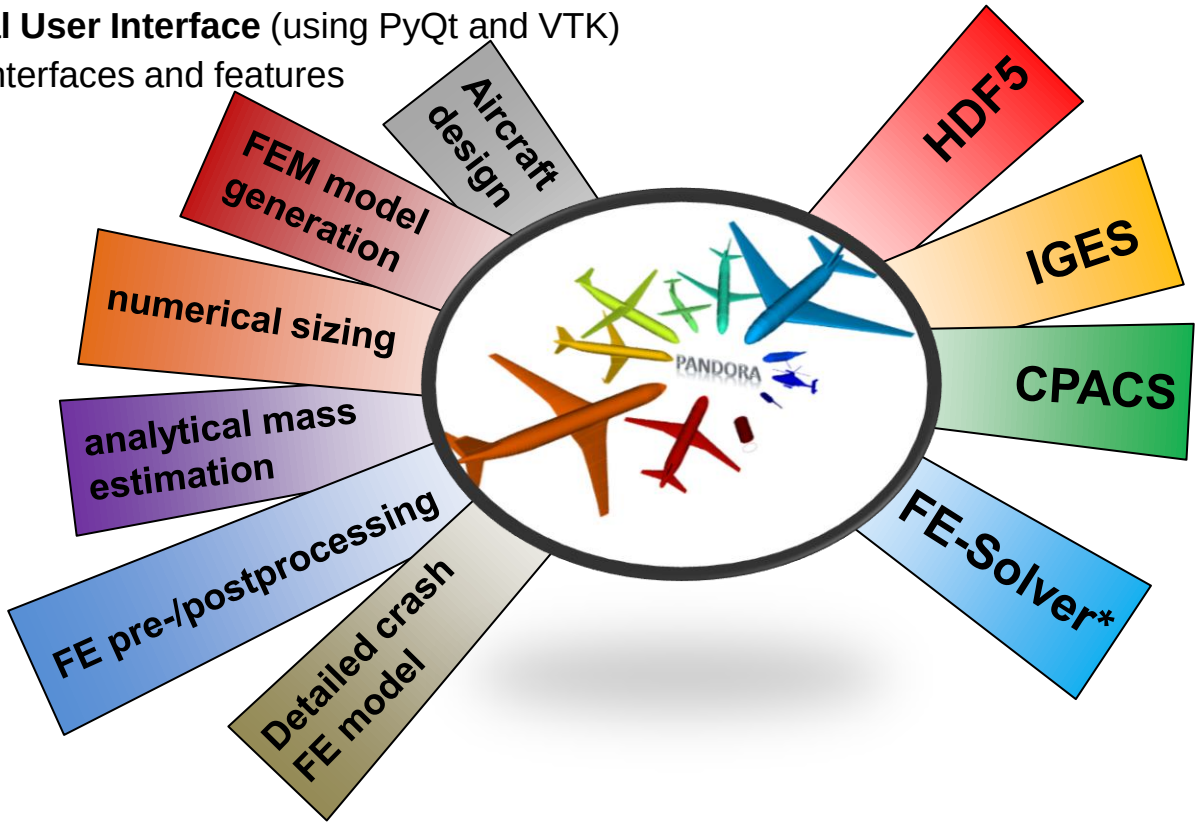


[3] Philip Ballack – „Semi-Physical Method for the Mass Estimation of Fuselages carrying Liquid Hydrogen Fuel Tanks in Conceptual Aircraft Design"
[4] Tobias Hecken – „Conceptual Loads Assessment of Aircraft with Fuselage Integrated Liquid Hydrogen Tank"
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, "PANDORA - A python based framework for modelling and structural sizing of transport aircraft", EASN-CEAS, Glasgow, Scotland, 2018.
[6] David Zerbst – "Preliminary Design of Composite Wings Using Beam-based Structural Models"

PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **Python** based framework in development since 2016
- Framework to join all tool developments (at DLR-BT)
- **Graphical User Interface** (using PyQt and VTK)
- Multiple interfaces and features

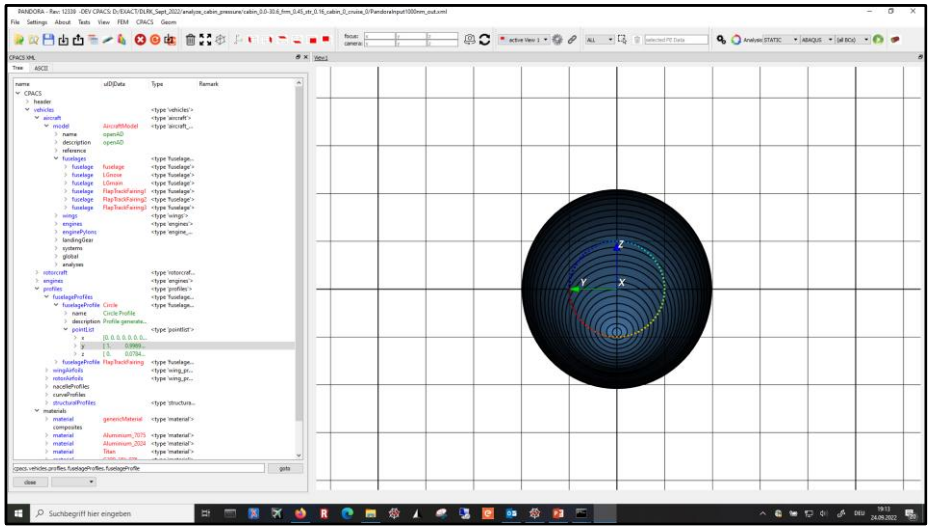


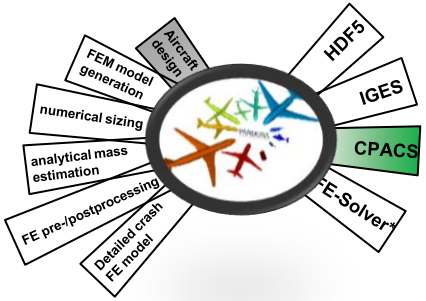
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, "PANDORA - A python based framework for modelling and structural sizing of transport aircraft", EASN-CEAS, Glasgow, Scotland, 2018.
[*] ANSYS, B2000++, VPS, LS-DYNA,…

PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **Aircaft design features:**
  - visualize/check CPACS data



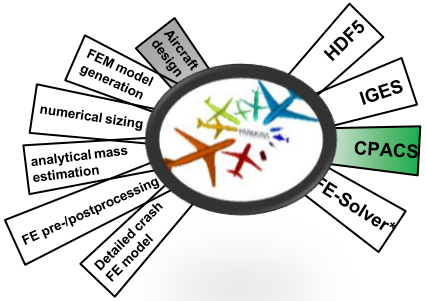


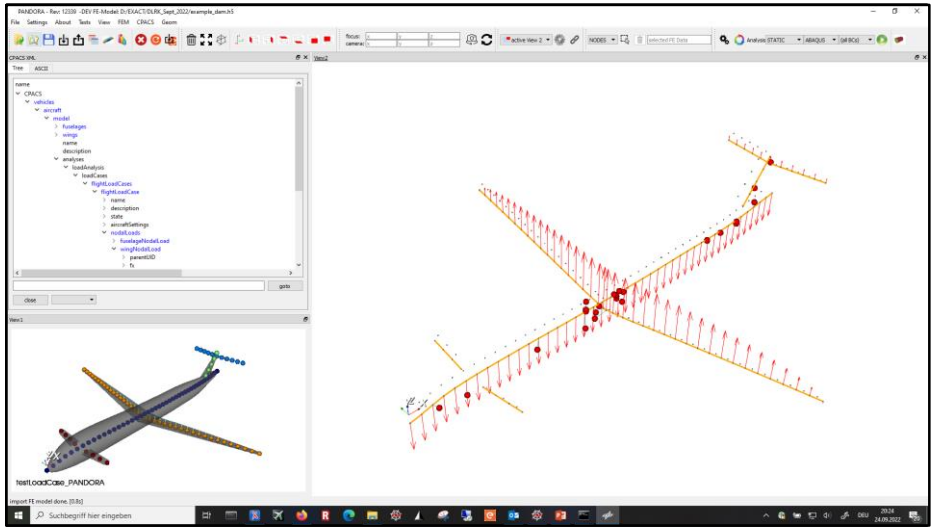
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **Aircaft design features:**
  - define/edit aircraft shape
  - define/edit fuselage structure
  - set inital loads, thickness, cross-sections,…



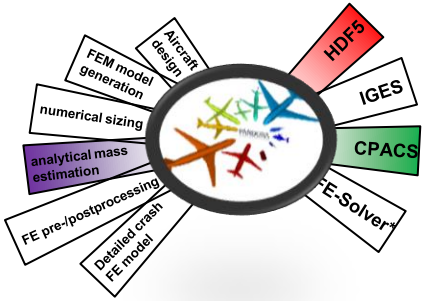


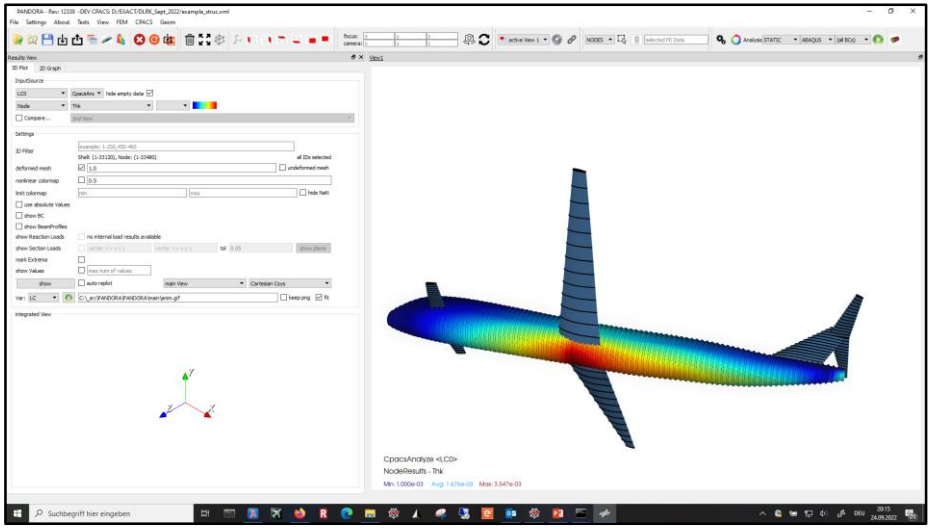
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **Analytical mass estimation**
  - using CPACS definition
  - runtime <1min



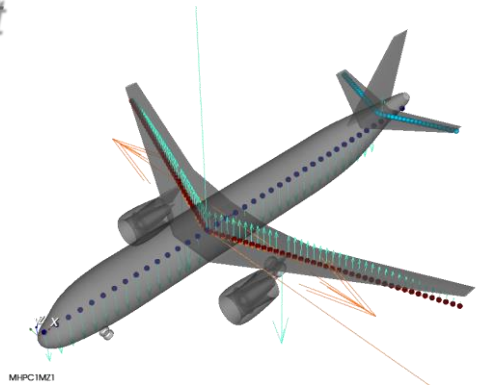


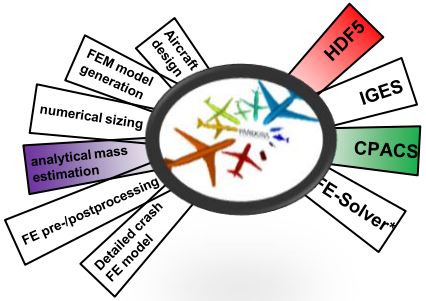
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

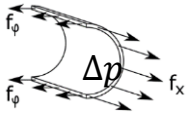
Parametric Numerical Design and Optimization Routines for Aircraft

- **Analytical mass estimation**
  - using CPACS definition
  - runtime <1min



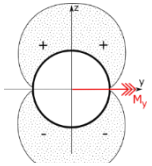


Internal pressure Δp
Barlow's formula



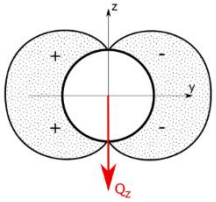
Normal force N_x

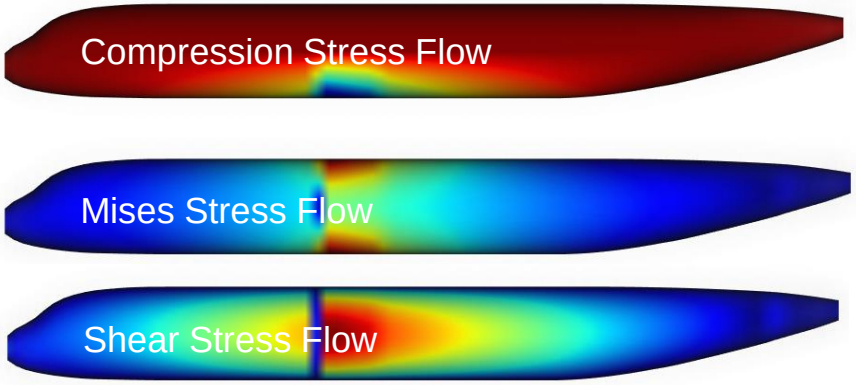
Bending moment M_y, M_z



Transverse force

Torsional moment M_T



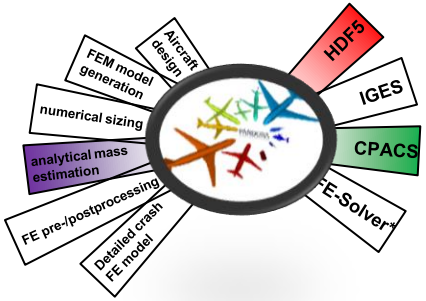


[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **Analytical mass estimation**
  - using CPACS definition
  - runtime <1min



$$f_v = \sqrt{f_x^2 + f_\varphi^2 - f_x f_\varphi + 3g_\varphi^2} < \sigma_{p0,2} * t$$

$$\sigma_{cr,Druck} = \frac{\eta \pi k_c E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

$$\sigma_{cr,Schub} = \frac{\eta \pi k_s E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

$$\frac{\sigma_{Druck}}{\sigma_{cr,Druck}} + \left(\frac{\sigma_{Schub}}{\sigma_{cr,Schub}}\right)^2 = 1$$

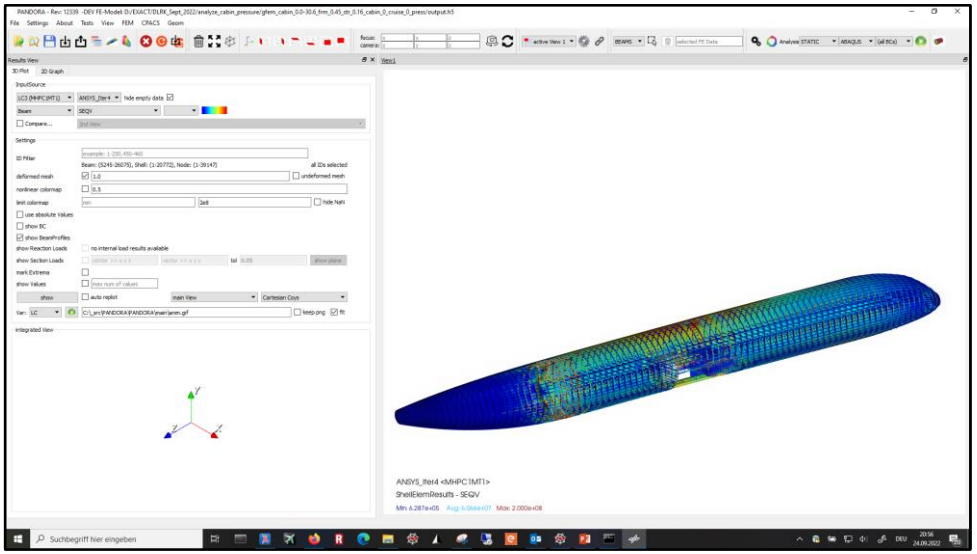
Skin: thickness sized with safety factor
Stringer: smeared using skin-stringer-ratio
Frames: estimated by default profile like A320

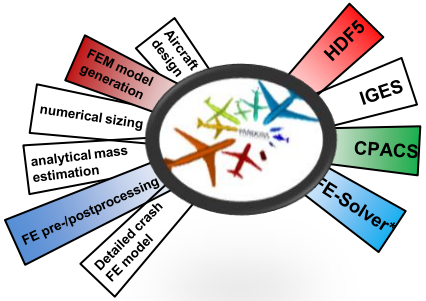
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **FE model generation**
  - using CPACS definition
  - automatic model generation
  - interactive FE pre-/post-processing



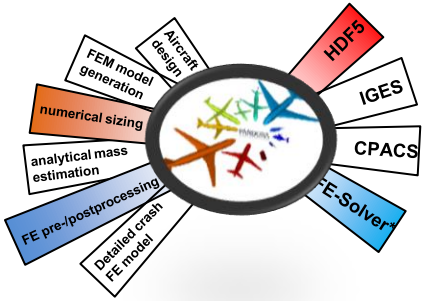


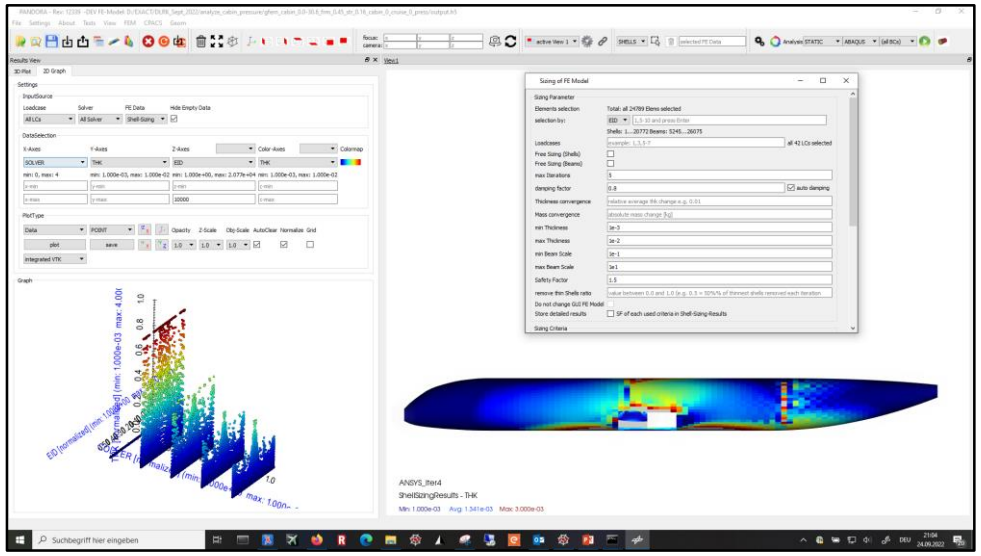
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

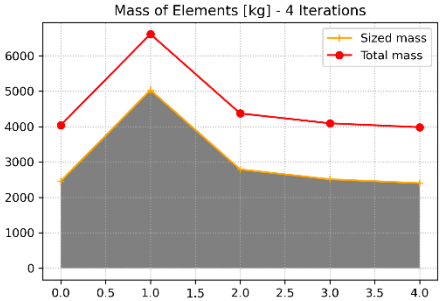
PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **numerical FE sizing**
  - interface for different solver
  - different sizing criteria (strength, buckling,…)
  - interactive FE pre-/post-processing





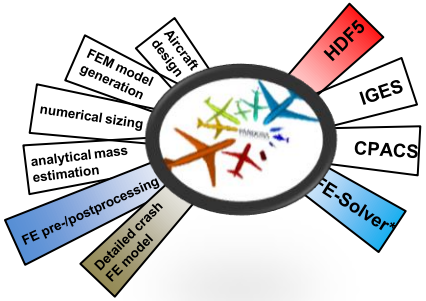


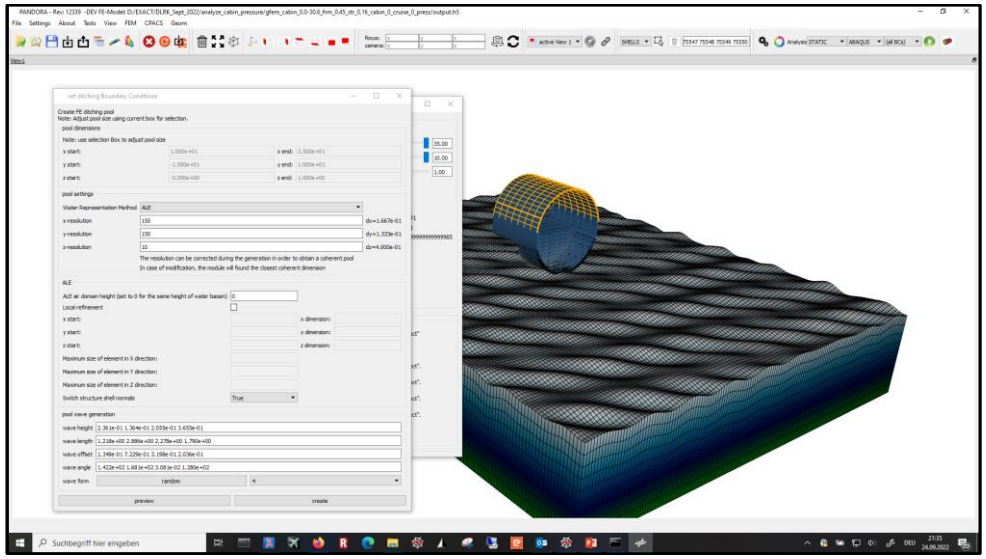
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

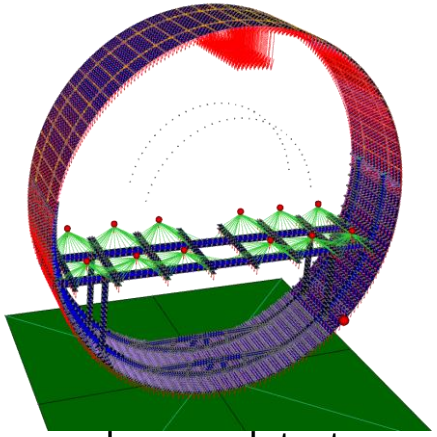
PANDORA [5] Tool at DLR-BT (continuous development)

Parametric Numerical Design and Optimization Routines for Aircraft

- **detailed FE model generation**
  - Automatic or user defined model refinement
  - cooperation with [7] at DLR-BT in crash topics







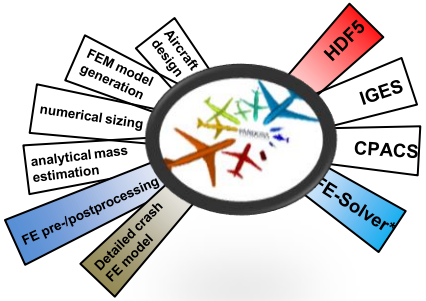
drop crash test

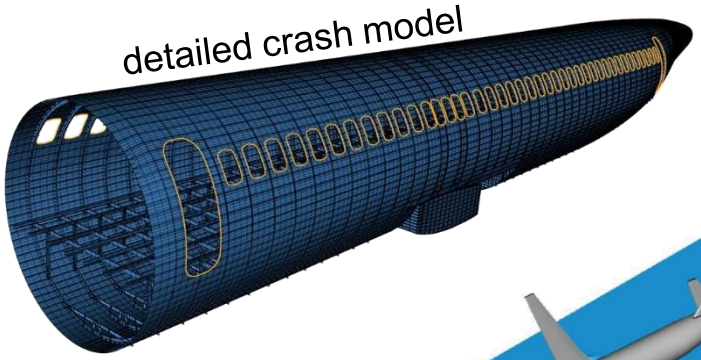
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.
[7] Paul Schatrow – „Methodenentwicklung für die Gesamtflugzeug-Crashsimulation“

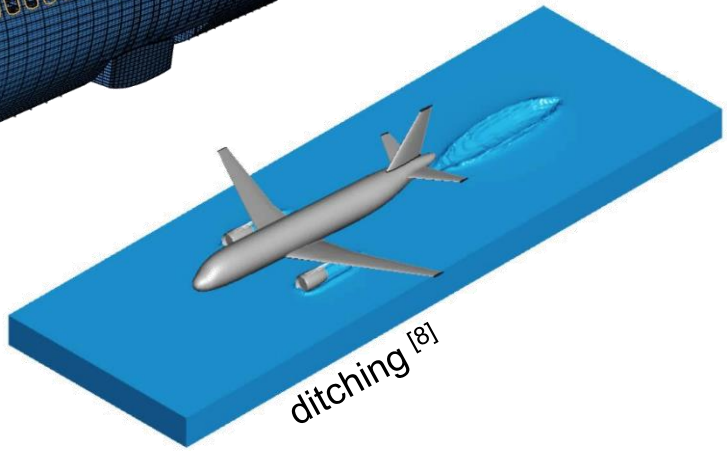
PANDORA [5] Tool at DLR-BT (continuous development)

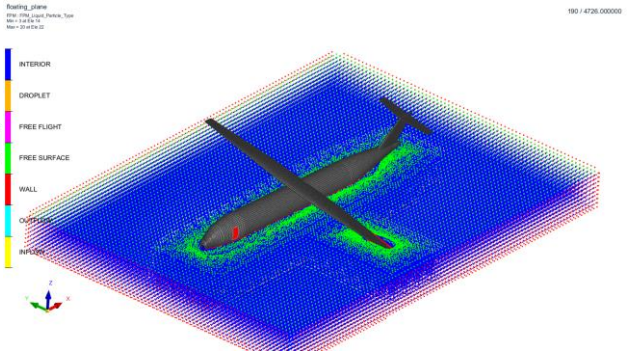
Parametric Numerical Design and Optimization Routines for Aircraft

- **detailed FE model generation**
  - Automatic or user defined model refinement
  - cooperation with [7] at DLR-BT in crash topics







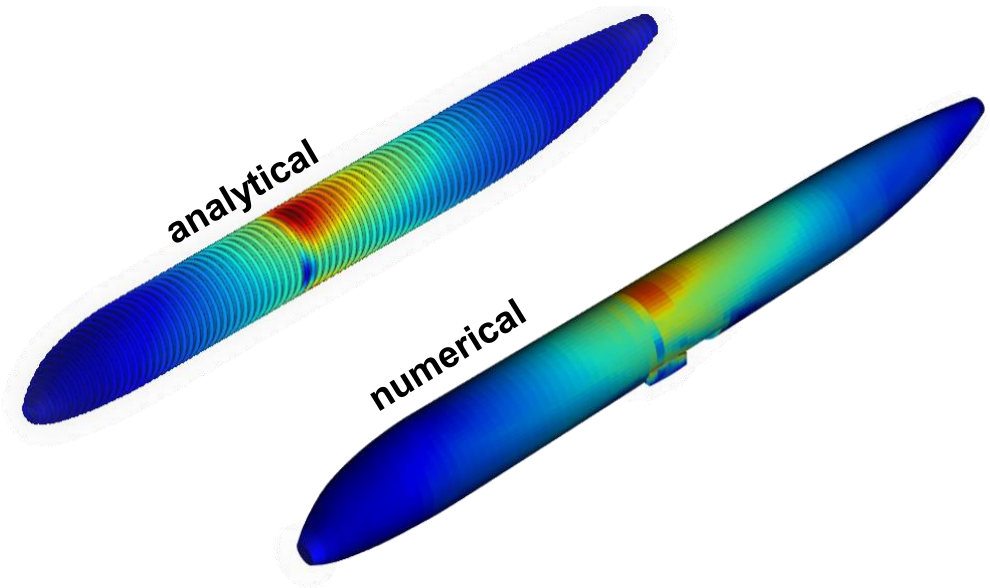


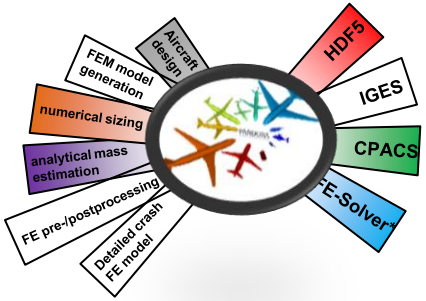
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.
[7] Paul Schatrow – „Methodenentwicklung für die Gesamtflugzeug-Crashsimulation“
[8] C. Munoz, M. Petsch, D. Kohlgrüber, M. Pedelaborde-Augas, „Automatic tool-based pre-processing of generic structural models for water impact simulations in the aircraft pre-design”, EASN-CEAS, Virtual, 2021

PANDORA [5] Tool at DLR-BT (continuous development)

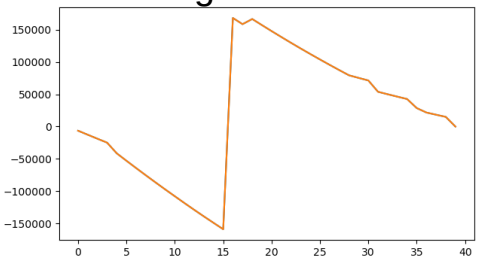
Parametric Numerical Design and Optimization Routines for Aircraft

- **analytical** vs **numerical** mass estimation
  - exemplary **mises stress** for loadcase „GHNC1OE2“





fuselage cutload FZ

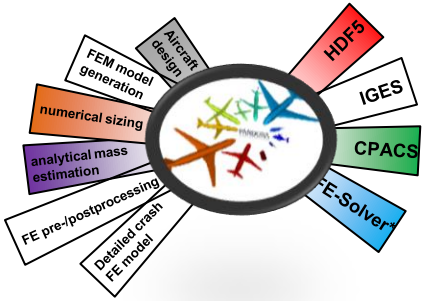


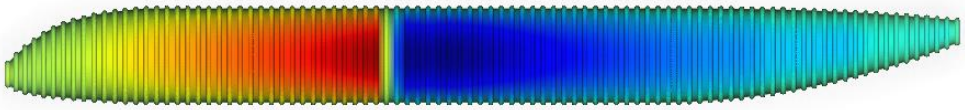
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

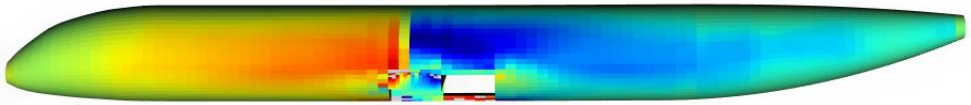
Parametric Numerical Design and Optimization Routines for Aircraft

- **analytical** vs **numerical** mass estimation
  - exemplary **shear stress** for loadcase „GHNC1OE2“



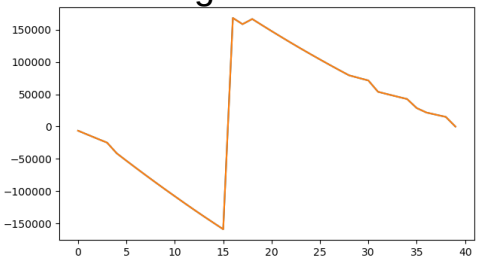


analytical



numerical

fuselage cutload FZ

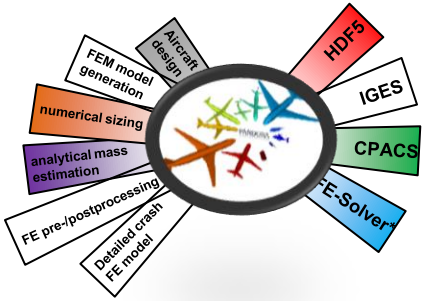


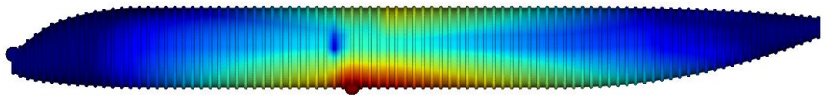
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

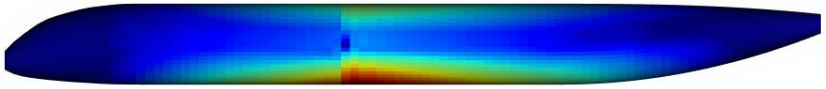
Parametric Numerical Design and Optimization Routines for Aircraft

- **analytical** vs **numerical** mass estimation
  - skin thickness without cabin pressure

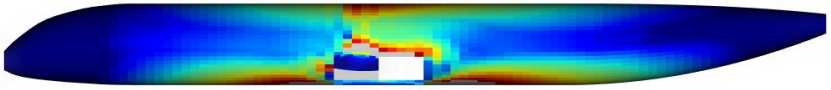




analytical
Skin mass: 2322 kg
Runtime: ~1min



numerical (no details)
Skin mass: 2495 kg
Runtime: ~1h



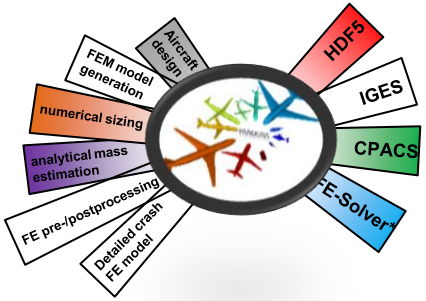
numerical
Skin mass: 2611 kg
Runtime: ~1h

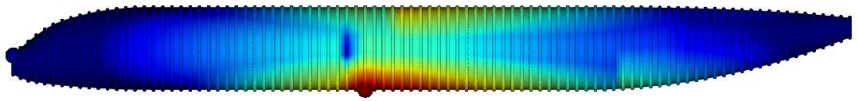
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

PANDORA [5] Tool at DLR-BT (continuous development)

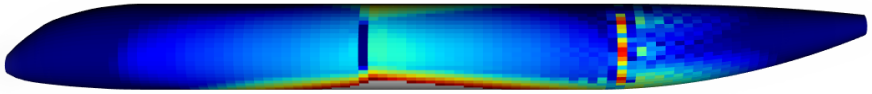
Parametric Numerical Design and Optimization Routines for Aircraft

- **analytical** vs **numerical** mass estimation
  - skin thickness with cabin pressure

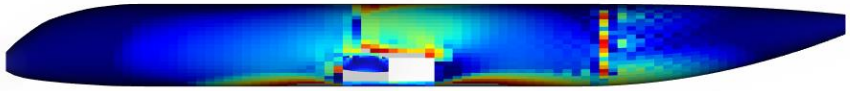




analytical
Skin mass: 2218 kg
Runtime: ~1min



numerical (no details)
Skin mass: 2248 kg
Runtime: ~1h



numerical
Skin mass: 2400 kg
Runtime: ~1h

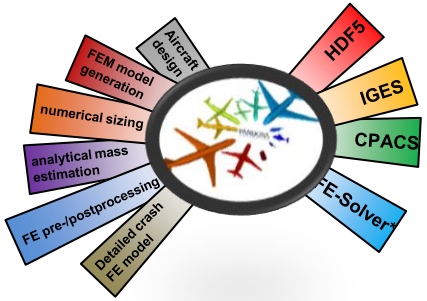
[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

Summary

- analytical mass estimation results good for preliminary design
  - **+/- 10% compared to numerical sizing**
  - runtime ~1min vs ~1h and numerical is less stable
  - some calibrations useful for next steps:
    - with numerical results (high-/low-wing)
    - with real aircraft data

- MDO Process:
  - **CPACS**[1]
  - **RCE**[2]

- **PANDORA**[5] enviroment at DLR-BT Stuttgart



[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

[5] M. Petsch, D. Kohlgrüber and J. Heubischl, “PANDORA - A python based framework for modelling and structural sizing of transport aircraft”, EASN-CEAS, Glasgow, Scotland, 2018.

eXACT®

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

Michael Petsch, D. Kohlgrüber, C. Leon, D. Schwinn, E. Wegener
DLR-BT (Institute of Structures and Design)
Stuttgart, Pfaffenwaldring 38-40
Michael.Petsch@dlr.de

DLR