Radical changes in the aircraft design process through software technology

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Outline

• Traditional aircraft design

• Software enabled aircraft design

• Projects at the German Aerospace Center (DLR)

• Software-Tools

• Built with Qt
Traditional aircraft design
Conceptual design

Sketchpad

SAC Bomber ~ At the onset
Conventional construction, materials, technology

Canard ±25° travel

Vertical inlets

April 1955: Estimated weight 650,000 lb
July 1956: Estimated weight 700,000 lb

Floating panels
(Ejected at subsonic speeds)

4 Engines
JP-4 fuel and HEP

Elevons
Flaps
Conceptual design
Handbook formulae

- Collection of simple Equations
- Particularly useful for traditional designs
- Based on simplified physics or empirics
- Rough estimates for e.g.:
  - Amount of lift
  - Structural loads
  - Total mass
  - Tank size

**Forces in a Climb**

- $F = \text{Thrust}$
- $L = \text{Lift}$
- $D = \text{Drag}$
- $W = \text{Weight}$
- $m = \text{aircraft mass}$
- $a = \text{acceleration}$

Equations:

- **Vertical**
  - $F \sin(c) - D \sin(c) + L \cos(c) - W = m a_v$
- **Horizontal**
  - $F \cos(c) - D \cos(c) - L \sin(c) = m a_h$

Definition of Excess Thrust:

- $F - D = F_{ex}$

Vertical
- $F_{ex} \sin(c) + L \cos(c) - W = m a_v$

Horizontal
- $F_{ex} \cos(c) - L \sin(c) = m a_h$
Preliminary design
Models + Wind tunnel experiments

Wright Brothers (1901)
Detailed design
Prototypes + Test flights

X-1 (1946)

Rockwell XVF-12 (1981)

X-15 (Neil Armstrong, 1960)

X-29 (1984)
Software-enabled aircraft design
Software-aided design: unconventional designs

• Building aircraft prototypes is time consuming and expensive

• Software allows to:
  
  • Find strengths and weaknesses of new designs
  
  • Simulate, if all requirements can be met
  
  • Explore many different concepts
  
  • Simulate even unconventional aircraft designs accurately where no human experience is available
Software-aided design: conventional designs

- Improve fuel efficiency
- Squeeze the margins
- Improve reliability and safety
- No low hanging fruits anymore → Optimization software explores the whole design space for a few percent improvement
Design projects at the DLR
The German Aerospace Center (DLR)
Project FrEACs

• The aircraft of tomorrow

• Unconventional designs:
  • Blended Wing Body
  • Strut-braced wing

• Track uncertainties throughout whole simulation chain
Project Digital-X

- Complete Simulation of aircraft and helicopters
- Very high accuracy / small errors
- Development of a new CFD simulation code
- Optimize aircraft to improve fuel efficiency
- Flying the virtual aircraft prior to the first flight
- Use HPC systems used for simulations
Project Mephisto

• Simulation of unmanned combat aircraft (drones)

• Novel flap and aileron concepts

• Explore new stealth materials

• Compute and minimize probability of detection
Software Tools
Aerodynamics simulation (CFD)

- High precision flow simulation
- HPC architectures
- Computation time: hours – days!
Simulation of the aircraft structure

- Simulation of mechanical loads
- Estimation of the aircraft structure’s mass
- Simulation of wing deformation / deflection by loads
- Changes solution of the CFD simulations
Engine simulation

• High precision simulation of aircraft engine

• Estimation of engine behavior (efficiency, thrust, speed)

• Airflow simulation

• Combustion

• Aeroacoustics

• Engine design optimization
Aircraft dynamics and control

- Simulation of aircraft movements
- Estimates forces during a maneuver
- Allows to estimate, whether aircraft behaves as planned
- Active control simulation
RCE – Workflow-driven Integration Environment

• **Software framework** to integrate and solve multidisciplinary design analysis and optimization (MDAO) problems

• Provides a **workflow management** for coupling simulation codes in a **graphical user interface**

• **Create** and **execute** workflows easily

• Provides secure and uniform access of data in a **distributed environment** (also at different sites)

• Connection to **HPC facilities** possible
RCE – Workflow-driven Integration Environment RCE
Distributed Multidisciplinary, Multi-Level Aircraft Design

Distributed Multidisciplinary, Multi-Level Optimization Chain

**CFD mesh generation for loads Centaur**
20 min
5 min

**objective function assembly (fuel burn) CFAsm**
<1 min
96 CPUs
6 hr

**aerodynamic RANS CFD for mission TAU + ANSYS**
45 min
192 CPUs

**parameter application to aerodynamic shape Aeropartan**
<1 min

**parameter application to structure shape Aeropartan**
<1 min

**CFD mesh generation for performance Centaur**
20 min
5 min

**structural FEM model shape update DELIS**
5 min
45 days
60 it.

**design parameter update (subplex) Pyranha**

**start**

**end**

**converged?**

no

yes

**<1 min**
RCE – Workflow-driven Integration Environment RCE
Built with Qt
GTlab – Gas Turbine Laboratory

Interactive, cross platform simulation and design environment for aircraft engines and gas turbines.
Built with Qt
Built with Qt
PreDesign

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October 19, 2016
DLR.de
Built with Qt

**TiGL – Geometry generation**

- Central *geometry* library used by many simulation tools in DLR for *aircraft design*
- **Multipurpose**
- **Multilanguage** – Python, C/C++, MATLAB, Java, FORTRAN
- **Multiplatform** – Win, Linux, OS X, Android (experimental)
- **Open Source** , Apache 2.0
- Based on CAD kernel OpenCASCADE
Built with Qt
TiGL – Platform independent Geometry Viewer
**Built with Qt**

**DataFinder** – Data store for simulation results

- Data management software
- Storage of all simulation data
- Tag based data search
- WebDAV backend
- Implemented in Python + Qt
- Open Source
Built with Qt

DataFinder – Data store for simulation results
Wrap up
The Digital Aircraft Vision

Full flight envelope coverage:  
- CFD mostly done near cruise point
- Attached flow
- Separated flow, unsteady

Configurations:
- Clean
- Airbrakes deployed
- High lift

- 50 flight points
- 100 mass cases
- 10 a/c configurations
- 5 maneuvers
- 20 gusts (gradient lengths)
- 4 control laws

~ 20,000,000 simulations

Engineering experience for current configurations and technologies

~ 100,000 simulations
Wrap-up

• Software technology, HPC hardware and algorithms have large impact on aircraft design

• Software is used in all phases of aircraft design

• Still major challenge: Simulation of the virtual aircraft