AERO – AIRCRAFT DESIGN AND SYSTEMS GROUP

Aircraft Preliminary Sizing Tools @ Aero

SAS → OPerA → PreSTo → further Tool Chain

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Contents

- *Aircraft Design* Lecture
- Goals
- **SAS** - Simple Aircraft Sizing
- **OPeRA** - Optimization in Preliminary Aircraft Design
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- Further Processing in a Tool Chain
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**Aircraft Design Lecture**

**General remarks**

- Lecture is based on methods from:
  - Loftin, Torenbeek, Roskam, Raymer, …
  - Datcom, …
  - many own additions

- 16 design steps (see Fig.)

- Emphasis on *preliminary sizing* with *matching chart*:
  - Jet: $T/W = f (m/S)$
  - Prop: $P/W = f (m/S)$

- Lecture in this format since 1998:
  - More than 1000 students taught
  - many student reports and theses produced

- Spreadsheet for preliminary sizing is in service for many years: http://FE.ProfScholz.de

- Preliminary sizing spreadsheet has been used for:
  - tutorials, examinations
  - projects, theses
**Aircraft Design Lecture**

**Contents**

- **Preliminary sizing**
  - Matching chart
  - \((L/D)_{\text{max}}\) estimation with „wetted aspect ratio“
  - Fuel calculation with fuel fractions

- **Cabin & fuselage**
  - Seats abreast optimum
  - Baggage and cargo volume check
  - Cross section optimization
  - Cabin surface estimation
  - Ditching check: waterline & door sill
  - Exit type and location: check

- **Wing**
  - Wing parameters found for best operational characteristics

- **High Lift**
  - High lift geometry found from trial & error procedure
  - \(C_{L,\text{max}}\) found from Datcom

- **Empennage I**
  - Sizing from tail volume
Aircraft Design Lecture

- **Mass and CG**
  - Mass from three methods
    - Roskam (OEW distributed about A/C main components)
    - „Modified Raymer“ (mass from one key parameter)
    - Torenbeek (well proven)
  - CG determination and wing position correction
  - Loading diagramm (mass versus CG position) for all sensible load cases established

- **Empennage II (stability & control power)**
  - Horizontal tail
  - Vertical tail

- **Landing gear (parameters selected)**
  - tip over stability
  - clearance (engine, tail, L/G retraction)
  - Flotation with COMFAA.exe

- **Drag**
  - Drag from two methods:
    - wetted area
    - skin friction drag, pressure drag
    - wave drag, interference drag

- **Design evaluation:**
  - Direct Operating Coast, DOC
  - Method: Association of European Airline

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**Diagram:**

- Natural stability limit (linear)
- Minimum stability (linear)
- Control limit
- CG range (Dxpayload)
- CG range (polynomic)
- CG range (polynomic)

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**Diagram:**

- Direct Operating Costs
  - Depreciation
  - Interest
  - Insurance
  - Fuel
  - Maintenance
  - Zara
  - Fees and charges
Goals

• Give full computer support for the Aircraft Design lecture by Prof. Scholz / Hamburg
• Start tool with nothing but requirements
• Never ask the user for data without giving proper support
• Provide straightforward and fast solutions (⇒ PreSTo)
• Give the best support (didactics, methods, statistics database, …)
• Keep user in the loop
• Include expert knowledge in simple „if-then“ checks and provide answers with red / green buttons
• Provide simple, traceable optimization capabilities at different expert levels
• Provide aircraft data for 3D-plots and three-view-drawings
• Couple to higher order tools for further investigation
SAS – Simple Aircraft Sizing

For Jets and CS-25:
- **SAS Classic**: The tool used for more than a decade with more than 1000 students.
  - Requirements: Payload, Range, Take-Off & Landing Field Length, Mach Number.
  - Key Parameters: Glide Ratio, SFC, BPR, max. Lift Coefficients, mass ratios, …
- **SAS Matching**: By automatically adjusting the ratio $V/V_{md}$, the location of the cruise line is optimized in the matching chart.
- **SAS Optimization**: An evolutionary optimization algorithm is fitted to SAS Matching.

For Jets / Props and other Certification Base:
- SAS Jet – CS-23
- SAS Prop – CS-25
- SAS Prop – CS-23
- SAS VLA
- SAS Ultra Light
- …
OPerA – Optimization in Preliminary Aircraft Design

The Aircraft Modeled in Excel:
- Automatic Design: Cabin Design, Wing, Empennage, Landing Gear, …
- Mass Estimation, Drag Estimation
- SFC estimation
- DOC Calculation with Added Values

Optimization
1. Optimus® and Excel connected via Add-In
2. Optimization directly in Excel with VBA:
   - DOE Diagonal
   - Differential Evolution (DE)
OPerA – Optimization in Preliminary Aircraft Design

Optimus® and Excel connected via Add-In
OPeRA – Optimization in Preliminary Aircraft Design

Program Structure

- 15 iteration loops
- 20 optimization variables
- About 230 input variables
- About 150 geometry parameters
OPeRA – Optimization in Preliminary Aircraft Design

Optimus ®

Example of an active workflow window in Optimus ®
PreSTo – Aircraft Preliminary Sizing Tool

Screen Shots
PreSTo Control Center and Database

PreSTo - Aircraft Preliminary Sizing Tool

Version 1.0

http://PreSToProfScholz.de

Aircraft Name:
FD 728

Description:
Redesign

PreSTo Control Center – Start page
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
PreSTo Control Center and Database

[Diagram showing data flow and modules]
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
PreSTo Control Center and Database

PreSTo is an Excel spreadsheet based on Prof. Dieter Scholz' aircraft design lecture. This tool allows the user to quickly design an aircraft and optimise it, starting from the basic requirements such as number of passengers, range or cargo mass to continue with the main parts: fuselage, wing, tail, landing gear. Besides, masses and position of CG also Direct Operating Costs (DOC) are calculated. Further analysis in the area of e.g. flight dynamics or CFD is enabled with the connection to CEASiOM. PreSTo further connects to PIADO and CATIA.

For further information, documentation and downloads see: http://PreSTo.ProfScholz.de

PreSTo is a project by:
Aero - Aircraft Design and Systems Group
Department for Automotive and Aeronautical Engineering
Hamburg University of Applied Sciences (HAW Hamburg).

GPL
Free Software

PreSTo is free software, you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, License Version 3.

PreSTo is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.
See the GNU General Public License for more details.

http://www.gnu.org/licenses/
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
PreSTo Control Center and Database

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R</td>
<td>2550 [km]</td>
</tr>
<tr>
<td>2</td>
<td>n_pax</td>
<td>99 [-]</td>
</tr>
<tr>
<td>3</td>
<td>m_cargo</td>
<td>0 [kg]</td>
</tr>
<tr>
<td>4</td>
<td>M_CR</td>
<td>0.81 [-]</td>
</tr>
<tr>
<td>5</td>
<td>S_LFL</td>
<td>1420 [m]</td>
</tr>
<tr>
<td>6</td>
<td>V_APP</td>
<td>135 [km/h]</td>
</tr>
<tr>
<td>7</td>
<td>S_TOFL</td>
<td>1463 [m]</td>
</tr>
<tr>
<td>8</td>
<td>n_E</td>
<td>2 [-]</td>
</tr>
</tbody>
</table>

PreSTo Control Center – Database
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots

Preliminary Sizing

User open und close Chapters with + / - sign

Preliminary Sizing – Start page
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots

Preliminary Sizing

User may select data based on **statistics**

User may select data based on **pop up hints**

Preliminary Sizing – **General statistics**
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Preliminary Sizing

\[ E_{\text{max}} = k_E \sqrt{\frac{A}{S_{\text{wet}} / S_W}} \]

Buttons starts statistics database

White: User input data
Gray: System calculated data

Estimation of max. glide ratio, \( E_{\text{max}} \)

Choose: factor \( k_E \)

<table>
<thead>
<tr>
<th>Relative wetted area</th>
<th>( S_{\text{wet}} / S_W )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect ratio</td>
<td>( A )</td>
</tr>
<tr>
<td>Max. glide ratio</td>
<td>( E_{\text{max \ chosen}} )</td>
</tr>
</tbody>
</table>

\( E_{\text{max}} \) calculated

Statistical database

Suggestion
Screen Shots
Cabin & Fuselage

User input and results are checked.
Green means „ok“
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Cabin & Fuselage

Cross section dimensions (from Economy Class)
Automatic calculation

☑ Automatic optimization

Change this …

… to minimize this:

- $d_{f,o} = 4.01$ [m]
- $t_{floor} = 0.136$ [m]
- $h_{f,o} = 3.72$ [m]
- $w_{f,o} = 4.33$ [m]

Optimize cross section parameters such that the equivalent outer diameter is a minimum. This will lead to a minimum wetted area of the fuselage and hence a minimum skin friction drag.
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Cabin & Fuselage

Alternative seat arrangement:

Seat rail
Container
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Cabin & Fuselage

Seat layout
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Cabin & Fuselage

Seat layout comparison:
Airbus original and PreSTo

A330-300 designed in PreSTo

A330-300 from Airbus
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots

Wing

Taper ratio suggestion

User support with experience from industry and academia presented with respect to current design
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots

Wing

Preview of wing parameters
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
High Lift

Final statement in high lift preliminary design

Available increase of lift coefficient due to highlift devices

\[ \Delta C_{L,\text{max,High lift}} = 1.985 \]

Required increase of lift coefficient

\[ \Delta C_{L,\text{max,required}} = 1.757 \]

Highlift is sufficient

Wing plan view

Preview of high lift parameters
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots

High Lift

Display of calculated Datcom data and Automatic readout of parameters with respect of actual design point

SUBSONIC MAXIMUM LIFT OF HIGH-ASPECTED-RATIO WINGS

ACCORDING TO DATCOM FIGURE 4.1.3.4-21a

Designpoint

- $\Delta y = 1.4$
- $\Delta y = 1.6$
- $\Delta y = 1.8$
- $\Delta y = 2$
- $\Delta y = 2.2$
- $\Delta y = 2.4$
- $\Delta y > 2.5$

$C_{L_{\text{max}}}/C_{L_{\text{max}}}$ vs. $\phi_{LE}$
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Tailplane I

Preview of tail parameters

Horizontal stabilizer

Fin

Rudder
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots

Tailplane I

Showing design parameters with respect to established practice

RAYMER Horizontal tail position suggestion

- above this line OK if no pitch-up tendency of wing
- under this line OK for Subsonic
- Best position for HT under this line
- Design point

Design point
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Tailplane II

Horizontal tailplane sizing diagram

Required CG range
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Landing Gear

Engine ground clearance due to landing gear length

Engine 1 bank angle is OK
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots

Landing Gear

Calculating sill height – an important parameter for airport compatibility
PreSTo - Aircraft Preliminary Sizing Tool

Screen Shots
Landing Gear

Calculation of ACN values
Aircraft
Classification
Number

COMFAA is integrated into PreSTo:
- automatic input of data
- COMFAA results stored in PreSTo
PreSTo - Aircraft Preliminary Sizing Tool

Data Export / Visualization
CEASIOM

FD 728 from PreSTo in
ACBuilder from CEASIOM

ATR 72 from PreSTo in
ACBuilder from CEASIOM
PreSTo - Aircraft Preliminary Sizing Tool

Data Export / Visualization

CEASIOM

FD 728 from PreSTo in
ACBuilder from CEASIOM
shown in the style of a
three-view drawing
PreSTo - Aircraft Preliminary Sizing Tool

Data Export / Visualization

CEASIOM

ATR 72 from PreSTo in SUMO from CEASIOM

ATR 72 from PreSTo
with surface and volume mesh generated by SUMO from CEASIOM
PreSto - Aircraft Preliminary Sizing Tool

Data Export / Visualization
Catia

ATR 72 from PreSto in Catia
built with parametric model
PreSTo - Aircraft Preliminary Sizing Tool

Data Export / Visualization
Catia

FD 728 from PreSTo in Catia built with parametric model
PreSTo - Aircraft Preliminary Sizing Tool

Data Export / Visualization
Catia

FD 728 from PreSTo in Catia
automatically generated three-view drawing
derived from parametric model

*Parametric_Aircraft.CATProduct*
Drawing generated on: 03.04.2011
Scale: 1:250
PreSTo - Aircraft Preliminary Sizing Tool

Data Export / Visualization
PrADO (Preliminary Aircraft Design and Optimization)

ATR 72 - Jet from PreSTo in PrADO
This is not done automatically done!
PreSTo - Aircraft Preliminary Sizing Tool

Data Export / Visualization

**CPACS** (Common Parametric Aircraft Configuration Schema)

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<cpacs xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="cpacs_schema.xsd">
  <header>
    <name>FD 728</name>
    <description>Redesign</description>
    <creator>Standard</creator>
    <timestamp>2012-01-24T23:34:28</timestamp>
    <version>1.0</version>
    <cpacsVersion>1.6</cpacsVersion>
  </header>
  <updates>
    <update>
      ...
    </update>
  </updates>
</cpacs>
```
Further Tool Chain

Computerised Environment for Aircraft Synthesis and Integrated Optimisation Methods

SUMO
ActBuilder
Geometry Weight Propulsion
Neocass: Beam, plate VLM, DLM
Stiffness, modes

CFD: VLM, DLM
AMBER Data fusion, sampling
Coefficients

FCSDT

USAF Digital DATCOM

Tornado

JSBSim

X-Plane

FlightGear
Further Tool Chain

Diamond SIMULATION

D-SIM-42

Diamond DA - 42

FDM in Matlab/Simulink
PreSTo Homepage / Download

http://PreSTo.ProfScholz.de

Download PreSTo-Cabin

PreSTo Documentation

PreSTo-Cabin
Module 2: Cabin and Fuselage Layout supports the sizing and the interactive step-by-step design of the cabin in some detail. Based on cabin parameters, the fuselage general dimensions are found.

PreSTo-Cabin is now available as "PreSTo-Cabin 1.0.xls"
This file is set up for the Airbus A320.

Please make sure:
- ...to use Excel 2003 or a more recent version (unfortunately PreSTo is incompatible with Open Office),
- ...to allow Excel to use macros (you will be asked upon opening the program).

PreSTo-Cabin 1.0.xlsx Changed on: 17 January 2011, Size: 2.9M
This file is set up for the Fairchild Dornier 728 Cabin data extracted from:
FairchildDornier728_3View_and_Cabin.jpg Size: 96K

PreSTo-Cabin 1.0 A330.xlsx Changed on: 22 April 2011, Size: 2.9M
This file is set up for the Airbus A330. Compare cabin data from Airbus with the PreSTo layout:
A330_Cabin_layout.jpg Size: 395K

Try out PreSTo-Cabin yourself. Your feedback is welcome!

PreSTo Documentation

PreSTo-Cabin Documentation 10-11-15.pdf Changed on: 17 February 2011, Size: 1.8M
Conclusions and Outlook

- **SAS, OPerA and PreSTo** support manual basic **aircraft design** and **optimization**
- **Interfaces** are provided to **higher order tools**
  - CEASIOM
  - PrADO
- **Visualization** of the aircraft is done with outside tools:
  - CEASIOM
    - ACBuilder
    - SUMO
  - Catia
- **Next steps:**
  - Finish SAS, OPerA and PreSTo
  - Offer for download:  [http://SAS.ProfScholz.de](http://SAS.ProfScholz.de)  [http://PreSTo.ProfScholz.de](http://PreSTo.ProfScholz.de)
- **Further research based on „Aircraft Preliminary Sizing Tools @ Aero” :**
  - Boxwing Aircraft
  - „Smart Turboprop”
  - Braced Wing Aircraft
Contact

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http://SAS.ProfScholz.de
http://OPerA.ProfScholz.de
http://PreSTo.ProfScholz.de