Improved Material Exploitation of Composite Airframe Structures by Accurate Simulation of Collapse – The COCOMAT project

R. Degenhardt, D. Wilckens, K. Rohwer, R. Zimmermann, J. Teßmer
3 -5 September 2008, Braunschweig, Germany
Outline

1. The EC 6th Framework Programme
2. Forerunner projects (interaction, results)
3. Consortium
4. Structures considered, what is collapse
5. Overall objective, kind of degradation, main results
6. Examples of results
7. Summary
The EC 6th Framework Programme
Integrating and strengthening the European Research Area

**Work Programme:**

**Priority 4:** Aeronautics and Space

**Area:** Strengthening competitiveness

**Objective:** Reduction of aircraft development and operating costs by 20% and 50% in the short and long term, respectively.

**COCOMAT** contributes to this aim by:

**Instrument:** Specific Targeted REsearch Project (STREP)

**Goal:** Reducing structural weight at safe design by exploitation of considerable reserves in primary fibre composite fuselage structures through accurate simulation of collapse
Forerunner projects - Interaction

Group for Aeronautical Research and Technology in EURope
Action Group 25: Postbuckling and Collapse Analysis

GARTEUR AG 25

Improved MATerial Exploitation
at Safe Design of COMposite Airframe Structures
by Accurate Simulation of COLLapse

COCOMAT

POSICOSS

Year 2000 2001 2002 2003 2004 2005 2006 2007

Improved POSTbuckling
SIMulation for Design of Fibre
COMposite
Stiffened Fuselage
Structures
COCOMAT Consortium

Large industries

AGUSTAWESTLAND

AERinnova

E

GR

IL

PL

SMEs

Samtech

SMR Engineering & Development

Research establishments

DLR

FOI

CRCACS

AUS

Universities

RWTH AACHEN UNIVERSITY

Universität Karlsruhe (TH)

Technion

RTU

D

D

D

IL

LV
COCOMAT considers **curved CFRP panels** which are understood as **parts of a fuselage section**.

**Next generation** –
All composite fuselage structure
What is collapse
(Example: Axially compressed curved stiffened CFRP panel)
COCOMAT – Main objective (1)

Current design scenario

Future design scenario

Load

Shortening

Not allowed

Safety region

Allowed under operating flight conditions

Collapse (CL)

Onset of degradation (OD)

Ultimate Load (UL)

Limit Load (LL)

First Buckling Load (1. BL)

1. BL

CL

UL

OD

LL

I

II

III

COCOMAT
Fast and accurate simulation of the collapse load of stringer stiffened CFRP curved panels with taking degradation and cyclic loading into account, in addition to geometrical nonlinearity.

cyclic loading = repeated static loading
Kind of degradation

Failure propagation will be taken into account

- Skin-stringer separation is considered as the most important and dangerous mode and is investigated in any case.

- Delamination in the stringer blade was also observed in the POSICOSS project and is considered.

- Delamination in the skin is be considered as less important case, however, is also taken into account.
# Work plan

<table>
<thead>
<tr>
<th>WP 1: Benchmarking on collapse analysis of undamaged and damaged structures with existing tools</th>
</tr>
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<tbody>
<tr>
<td>WP 2: Material characterisation, damage investigation and design of structures for static and cyclic tests</td>
</tr>
<tr>
<td>WP 3: Development of improved simulation procedures for collapse</td>
</tr>
<tr>
<td>WP 4: Manufacture, inspection and testing by static and cyclic loading of undamaged panels from WP2</td>
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<tr>
<td>WP 5: Manufacture, inspection and testing by static and cyclic loading of pre-damaged panels from WP2</td>
</tr>
<tr>
<td>WP 6: Design guidelines and industrial validation</td>
</tr>
<tr>
<td>WP 7: Management and exploitation</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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</thead>
</table>

COCOMAT – Main results

Some details:

- Personnel resources: 716 person-months
- Total costs: 6.7 Mio Euros
- EC funding: 4.0 Mio Euros
## Experimental data base

<table>
<thead>
<tr>
<th>Workpackage</th>
<th>Kind of structure</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP 2.1</td>
<td>Characterisation of material properties</td>
<td>Specimens GFRP layer</td>
</tr>
<tr>
<td>WP 2.2</td>
<td>Investigation of degradation by tests and development of degradation models</td>
<td>Stiffened strips</td>
</tr>
<tr>
<td>WP 4</td>
<td>Manufacture, inspection and testing by static and cyclic loading of undamaged panels</td>
<td>Panels</td>
</tr>
<tr>
<td>WP 5</td>
<td>Pre-damaged panels</td>
<td>Panels</td>
</tr>
</tbody>
</table>
Simulation Tools

Analysis

<table>
<thead>
<tr>
<th>Fast tools</th>
<th>Slow tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools with analytical and semi-analytical approach</td>
<td>Commercial FE tools (e.g. SAMCEF, NASTRAN, ABAQUS, etc.)</td>
</tr>
</tbody>
</table>

- For design process
- For certification
Outline

1. The EC 6th Framework Programme
2. Forerunner projects (interaction, results)
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4. Structures considered, what is collapse
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6. Examples of results
7. Summary and conclusions
WP 1 - Benchmarking - Example

Not correct because
1) Degradation is not considered
2) Sensitive for modelling of the lateral boundary conditions

Collapse
WP 2 - Material properties, degradation models and panel designs

- Material properties: - IM7/8552 UD
  - 985-GT6-135 UD
  - 950-GF3-5H-1000 carbon fabric

- Degradation models (experiments and mechanical models)
- Designed panels which should be manufactured and tested
  (85 designed, 6 selected)
WP 3 - Improved simulation procedures for collapse - Slow certification tools

Degradation models
- Stress based
  - Tsai Hill, Maximum stress, Minimum strain, Puck
- Fracture based
  - VCCT energy release rates

Commercial software's
- ABAQUS
- MARC
- NASTRAN
- SAMCEF

In-house software's
- FEAP
- STRIPE
WP 3 - Improved simulation procedures for collapse - Fast design tools
## WP 4 / WP 5 Buckling tests until collapse

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Manufacturer - Tester</th>
<th>AERNNOVA - DLR</th>
<th>PZL</th>
<th>AGUSTA - POLIMI</th>
<th>IAI - TECHNION</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Design 1</td>
<td>Design 2</td>
<td>Design 3</td>
<td>Design 5</td>
<td>Design 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compression</td>
<td>Compression</td>
<td>Combined shear+ compression</td>
<td>Compresssion</td>
<td>Shear</td>
</tr>
<tr>
<td>WP 4: Manufacture, inspection and testing by static and cyclic loading of undamaged panels from WP2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 4.2: Buckling tests until collapse by static loading</td>
<td>2</td>
<td>1</td>
<td>1 *</td>
<td>2 *</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Task 4.3: Cyclic buckling tests</td>
<td>2</td>
<td>1</td>
<td>2 *</td>
<td>2 *</td>
<td>2</td>
<td>4 *</td>
</tr>
<tr>
<td>WP 5: Manufacture, inspection and testing by static and cyclic loading of pre-damaged panels from WP2</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Task 5.3: Buckling tests until collapse by static loading</td>
<td>2</td>
<td>1</td>
<td>1 *</td>
<td>2 *</td>
<td>1</td>
<td>2 *</td>
</tr>
<tr>
<td>Task 5.4: Cyclic buckling tests</td>
<td>2</td>
<td>1</td>
<td>2 *</td>
<td>4 *</td>
<td>2</td>
<td>4 *</td>
</tr>
<tr>
<td>Sum</td>
<td>8</td>
<td>4</td>
<td>6 *</td>
<td>10</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

*) Model which consists of two combined panels (better shear introduction)
WP 4 - Test Panel P29 – Load shortening curve with Thermography
WP 4 - Panel P29 – Load shortening curve

Load [kN] vs. Shortening [mm]

1. 0 to 20
2. 20 to 80
3. 80 to 100
4. 100 to 120

Images 1 to 6 correspond to the load shortening stages.
WP 4 – Panel P29 – Measurements after collapse

ARAMIS

Thermography\(^1\)

Ultrasonic inspection

\(^1\)In co-operation with Institut für Kunststoffprüfung und Kunststoffkunde Universität Stuttgart
Strain gages (# 7 & 8) readings vs. axial compression (after 50k cycles).

Development of the buckling pattern as a function of axial compression:
(a) under 91.8 kN, (b) under 113.8 kN, (c) under 197.9 kN, (d) under 226 kN,
(b) (e) under 229.2 kN (f), (g), (b) damage after collapse under 229.2 kN
Comparison Test and Simulation

Selected highlights
Partner: RWTH

- A 1D-element with adhesive layer, linear softening model and a mixed mode fracture criterion has been developed.
- The approach was validated with simulations of DCB, ENF and MMB tests.

Comparison of test results and simulations

MMB test
Partner: University of Karlsruhe

FE tool for composites:

- Delamination / skin-stringer separation: Cohesive interface elements
- Ply failure: Shell elements with Tsai-Wu or Hashin criteria (optional) and ply discount model for degradation
- Applicability proven by various simulations
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Partner: CRC-ACS

DLR panel (D1), comparison with panel after cyclic loading (producing pre-damage)\(^1\)

Aernnova panel (D2), comparison with intact panel test\(^1\)\(^2\)

• Improved post-buckling analysis of composite with the B2000++ finite element simulation environment
  □ New fast and robust family of shell elements with finite rotation with 5 or 6 degrees of freedom and pre-integration of the material equations, Assumed Natural Strain and Enhanced Assumed Strain to reduce locking.
  □ New parallel static and dynamic non-linear FEM solvers.

Dynamic post-buckling analysis of industrial panel
Partner: RTU

DCB test for rib stiffened panel

Ultrasonic inspection of COCOMAT tested panels
Partner: DLR

Simulation of DLR Design 1 panel
Reduction of E->0.1%
Max Strength of the adhesive layer 48 MPa

DLR Design 1 panel – UMAT implicit
Simulate buckling and post buckling with adhesive and ply degradation.

Simulation of Skin-Stringer separation

**Partner: SAMTECH**

**SAMCEF by Samtech**
Partner: POLIMI
Tests and analyses of pre-damaged panels

- Zone A
- Zone B
- Zone C

Damaged areas

Tsai-Wu failure

Graph:
- Torque [kNm] vs. Rotation [deg]
- FE - Damaged box
- SN4

Heatmaps for Zones A, B, C

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Conventional design is not too sensitive to damage size.

Even with detached or completely absent central stringer, the buckling and collapse loads do not change dramatically.
WP 6 – IAI contribution - structure for industrial validation

- Composite Stiffened Panel for A/C Stabilizer.
- Carbon/Epoxy Stiffened skin structure.
- Industrial validation, both analytical and experimental, for the section bounded by Ribs A & B.
- Test specimen has been manufactured by IAI and tested by TECHNION.

Different (from COCOMAT)
manufacturing process:
cobonded stiffeners instead of cocured ones.

Different (from COCOMAT)
material:
250°F per IAI MS instead of COCOMAT 350°F IM7/8552
Summary

Current Industrial Practice

Total Load/Collapse Load

POSICISS 2004

Collapse Load

Onset of Degradation

First Buckling Load

Total Load/Collapse Load

COCOMAT 2008

Total Load/Collapse Load

Defects up to 2" size allowed

Allowed under operating flight conditions

Safety region

Not allowed

Ultimate Load (UL)

Limit Load (LL)

Edge Shortening

Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Institute of Composite Structures and Adaptive Systems
2nd Int. Conference on Buckling and Postbuckling Behaviour of Composite Laminated Shell Structures with COCOMAT’Workshop

3–5 September 2008

Organiser:
DLR (German Aerospace Center), Institute of Composite Structures and Adaptive Systems, Braunschweig, Germany

Conference Venue:
Technical University of Braunschweig, D湖erstrasse, Braunschweig, Germany

www.cocomat.de

COCOMAT is a running EU project and stands for: Improved MAterial Exploitation at Safe Design of Composite Airframe Structures by Accurate Simulation of COllapse
# Programm

<table>
<thead>
<tr>
<th>Time</th>
<th>3rd September (Day 1)</th>
<th>Time</th>
<th>4th September (Day 2)</th>
<th>Time</th>
<th>5th September (Day 3)</th>
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<tbody>
<tr>
<td>9.00</td>
<td>Registration</td>
<td>10.45</td>
<td>R. Degenhardt Welcome</td>
<td>8.30 - 10.00</td>
<td>Keynote lectures</td>
</tr>
<tr>
<td>10.45</td>
<td>R. Degenhardt Welcome</td>
<td>11.00 - 12.30</td>
<td>Keynote lectures</td>
<td>8.30 - 10.00</td>
<td>Keynote lectures</td>
</tr>
<tr>
<td>11.00 - 12.30</td>
<td>Keynote lectures</td>
<td>10.30 - 12.10</td>
<td>Semi-analytical concepts</td>
<td>10.30 - 12.10</td>
<td>Structure tests</td>
</tr>
<tr>
<td>12.10 - 15.00</td>
<td>COCOMAT - Workpackage summaries</td>
<td>13.10 - 15.00</td>
<td>COCOMAT Workshop</td>
<td>13.10 - 14.50</td>
<td>Degradation II</td>
</tr>
<tr>
<td>15.40 - 17.40</td>
<td>COCOMAT - Achievements of the PhD students (Fast simulation tools, tests)</td>
<td>15.00 - 17.00</td>
<td>Analysis and validation I</td>
<td>15.20 - 17.00</td>
<td>Keynote lectures: Design handbooks</td>
</tr>
<tr>
<td>18.00</td>
<td>Transfer University - Dinner</td>
<td>18.00 - 20.00</td>
<td>DLR - Technical visiting tour (Finger food available)</td>
<td>17.00</td>
<td>End of Conference</td>
</tr>
<tr>
<td>18.30-22.30</td>
<td>Conference Dinner (Dornse)</td>
<td>20.00</td>
<td>Transfer DLR - Hotels</td>
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</table>

1) Welcome by Mr. Lehmann (Chief city councilor of the City of Braunschweig)
2) Dinner speech: Prof. Joachim Block (ROSETTA Lander - a challenging mission to the origins of the solar system)

Conference Venue: Technical University of Braunschweig, Pockelstrasse 4 (Altgebäude), Braunschweig, Germany
COCOMAT
Improved MATerial Exploitation
at Safe Design of Composite Airframe Structures by
Accurate Simulation of COmposite I llaysia

Specific Targeted Research Project (2004-2007) funded by the European Community
Thematic Priority 4 - Aeronautics and Space

2nd International Conference on
Buckling and Postbuckling Behaviour of
Composite Laminated Shell Structures
with
COCOMAT Workshop
3-5 Sept 2008

List of participants:
1. DLR
2. AGUSTA
3. AERONNOVA
4. Hellenic Aerospace Industry
5. Israeli Aircraft Industries
6. FZL, Stuttgart
7. SANTECH
8. SMIS
9. CRC-ACS - Cooperative Research Centre for Advanced Composite Structures Limited
10. FOI - Swedish Defence Research Agency
11. Karlstads University
12. Politecnico di Milano
13. Bوها, Technion University
14. RWTH Aachen
15. Technion