



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, Pockelsstrasse,
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



AERnova



SMR
Engineering &
Development



RWTH AACHEN
UNIVERSITY



Technion



Aim of the conference and workshop

Conference and workshop are primarily organised as the final events of the running EU project COCOMAT demonstrating its results. The scientific community and industry in general are invited to attend. Both events aim to promote discussion and an exchange of information between scientists and engineers in the field of buckling, postbuckling and collapse behaviour of composite structures.

The **conference** aims at presenting scientific achievements from the COCOMAT project. In addition, papers with recent results on the same topic but from outside the project are as well presented.

Within the **workshop** new fast design tools and improved commercial tools, developed by COCOMAT, are demonstrated.

The present conference follows the *1st Int. Conference on Buckling and Postbuckling Behaviour of Composite Laminated Shell Structures* which was held in Eilat, Israel, 1-2 March 2004. There the achievements of the COCOMAT forerunner project POSICOSS were highlighted.

Topics

New achievements in the following topics of buckling, postbuckling and collapse behaviour of composite laminated shell structures are presented:

- Experimental methods and results
- Degradation models
- Failure criteria
- Advanced finite element tools for certification
- Fast design tools
- Influence of imperfections
- Structural optimisation
- Design guidelines

All topics will focus on curved panels and shells (unstiffened and stiffened ones) under various states of loading.

EU project COCOMAT

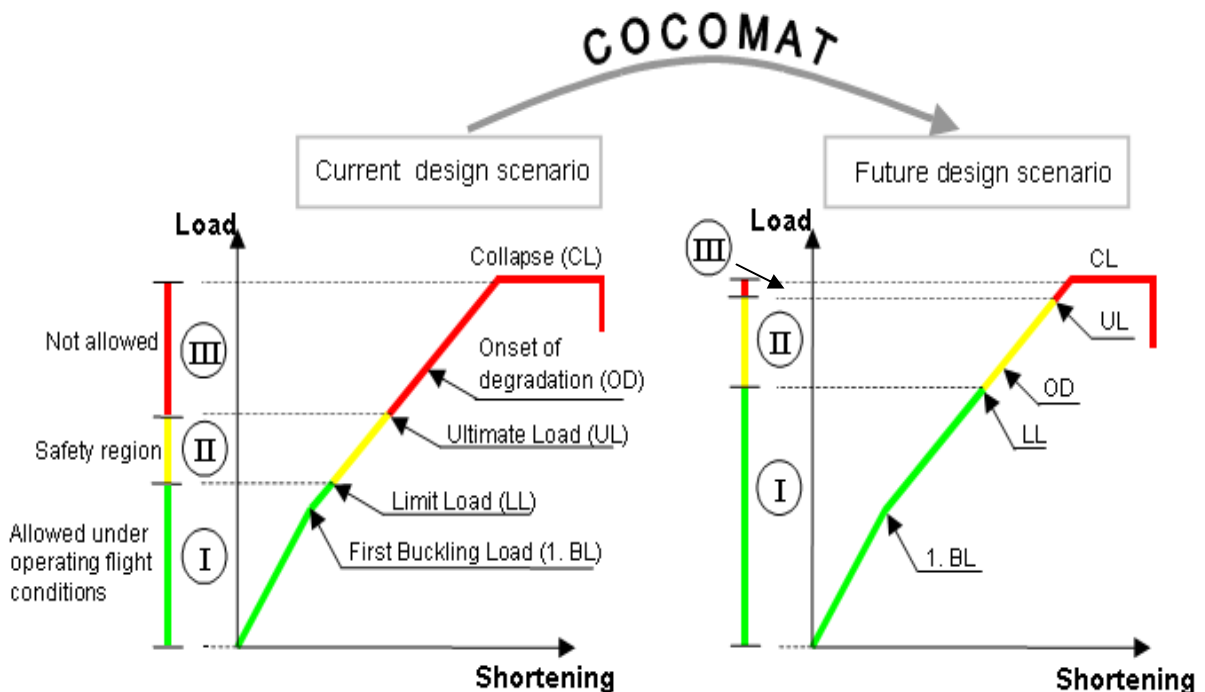
The EU project COCOMAT (Improved MATerial Exploitation at Safe Design of COMposite Airframe Structures by Accurate Simulation of COLLAPSE) is a Specific Targeted Research Project within the 6th Framework Programme. It started 2004 and will be finished in October 2008.

COCOMAT aims to exploit considerable reserves in the capacities of composite aircraft panels by accurate simulation of collapse. The main objective of COCOMAT is a future design scenario for composite curved stiffened panels which are understood as parts of real aircraft structures (cf. figure below).

The project results comprise of an experimental data base, improved slow certification tools, fast design tools as well as design guidelines.

More details can be found at www.cocomat.de.

COCOMAT builds up on the finished EU project POSICOSS (*Improved POstbuckling Simulation for Design of Fibre COMposite Stiffened Fuselage Structures*), which developed fast procedures for buckling and postbuckling analysis of fibre composite stiffened panels of fuselage structures, created experimental data bases and derived design guidelines.



Current and future design scenario for stiffened CFRP panels

Committees

Chairman

Prof. Richard Degenhardt, DLR, Braunschweig, D and PFH Göttingen, D

E-mail: richard.degenhardt@dlr.de

Mobile phone: +49 162 269 2474

Conference Secretariat / Local arrangements

E-mail: cocomat@dlr.de

Organisation Committee

Mrs Doris Ries, DLR, D

Mrs Ursula Schönyan, DLR, D

Mrs Karen Scott, DLR, D

Mrs Marita Greef, DLR, D

Mr Dirk Wilckens, DLR, D

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Dr Rolf Jarlas, FOI, Stockholm, S

Prof. Werner Wagner, UKA, Karlsruhe, D

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Prof. Rolands Rikards, RTU, Riga, Latvia

Prof. Hans-G. Reimerdes, RWTH, Aachen, D

Prof. Haim Abramovich, TECHNION, Haifa, IL

Prof. Tanchum Weller, TECHNION, Haifa, IL

Mr Giuseppe Pagnano, Agusta-Westland, Varese, I

Mr Felix Rebollo Arribas, AERNNOVA, Miñano, E

Dr Zaira Marioli-Riga, HAI, Schimatari, GR

Mrs Gila Ghilai, IAI, Tel Aviv, IL

Mr Pawel Chojnacki, PZL, Swidnik, PL

Dr Claudine Bon, SAMTECH, Angleur, B

Dr Silvio Merazzi, SMR, Bienne, CH

List of presentations

	No.	Country	Authors	Title
Keynote presentations	1	Germany	J. Szodruch (DLR, DGLR, EAG, ACARE)	Future Aircraft Technologies – The European Strategic Research Agenda
	2	Germany	P. Linde (Airbus)	Overview of Test Prediction and Damage Simulation of Composite Aircraft Structures
	3	Germany	R. Degenhardt, D. Wilckens, K. Rohwer, R. Zimmermann, J. Teßmer (DLR)	Improved Material Exploitation of Composite Airframe Structures by Accurate Simulation of Collapse - The COCOMAT project
	4	Netherlands	E. Riks (SMR)	Evolution of analysis tools
	5	Netherlands	J. Arbocz, J.de Vries (TU Delft)	Looking for alternate ways to define Knockdown Factors
	6	Germany	J. Tessmer (DLR)	Structural Mechanics in the Design Process of Composite Aircraft Structures
	7	USA	M. Hillburger (NASA)	Developments in Shell Buckling Analysis, Design and Testing
	8	Germany	R. Cuntze	Formulations of Failure Conditions – Isn't it basically just Beltrami and Mohr-Coulomb?
	9	Germany	A. Rittweger, S. Christianson, H. Öry (EADS Astrium Space)	Dimensioning of Orthotropic Stiffened CFRP Shells of Large Launch Vehicle for Load Introduction and Stability
	10	Netherlands	A. Calvi (ESA)	E.C.S.S. Buckling handbook
	11	Germany	M. Schagerl (Airbus)	HSB - A Handbook for Fundamentals and Methods for Aeronautical Design and Analyses
	12	Germany	C. Hühne, R. Rolfes (L)	Multiscale Approach for Determination of Stiffness and Strength of Textile Composites
COCOMAT partners	13	Germany	R. Degenhardt, D. Wilckens, K. Rohwer, M. Kepke, B. Hildebrandt, A. Zipfel (DLR)	Buckling and collapse tests using advanced measurement systems
	14	Germany	D. Wilckens, R. Degenhardt, K. Rohwer, J. Tessmer (DLR), P. Bürmann (Airbus)	IBUCK - A fast simulation tool for the design of CFRP aerospace structures
	15	Italy	A. Caruso, V. Pietroni, Mr. E. Masiero (Agusta-Westland), R. Degenhardt (DLR)	Material properties, design of structures and degradation models
	16	Spain	J. A. Araico, I. de Zarate Alberdi, F.R. Arribas (Aernnova)	FEM Simulation of Potted-Ends on Compression Loaded Graphite-Epoxy Test Specimens
	17	Spain / Israel	H. Abramovich, T. Weller (TECHNION), I. de Zarate (Aernnova)	Experimental results on buckling and postbuckling behavior of panels - An overview
	18	Greece	C. Vrettos, E. Karachalios, Z. Marioli-Riga, C. Bisagni, P. Cordisco, O. de Zarate Alberdi, A. Caruso (HAI, POLIMI, Aernnova, Agusta)	Non-Linear analysis of stiffened composite boxes under combined loading
	19	Israel	G. Ghilai, E. Feldman and A. David, Israel Aerospace Industries, (IAI)	COCOMAT Guidelines for design & analysis of CFRP stiffened panels for buckling & postbuckling
	20	Poland	M. Zeglen, P. Chojnacki, J. Ogiela (PZL)	Polish Aviation Works PZL-Swidnik – participation, results and experiences from COCOMAT project
	21	Belgium	M. Bruyneel, B. Colson, J. Delsemme, P. Jetteur, P. Morelle, A. Remouchamps (SAMTECH)	Exploiting semi-analytical sensitivities from linear and nonlinear finite-element analyses for composite panel optimization
	22	Switzerland	M. Doreille, S. Merazzi (SMR)	Post-buckling analysis of composite structures with B2000++
	23	Australia	A. Orifici, R.S. Thomson, R. Degenhardt (DLR), C. Bisagn (Politecnico di Milano), J. Bayandor (CRC-ACS)	An analysis tool for design and certification of postbuckling composite aerospace structures
	24	Australia	A. Orifici, I. Herszberg, A. Kotler, R. Thomson, J. Bayandor (CRC-ACS), H. Abramovich, T. Weller (TECHNION)	Failure in skin-stiffener sections under postbuckling loads
	25	Australia	A. Orifici, S. Lauterbach, H. Abramovich, R. Thomson, W. Wagner, C. Balzani (CRC-ACS, TECHNION, Uni. Karlsruhe)	Analysis of damage sensitivity and collapse in postbuckling fibre-reinforced multi-stiffener panels
	26	Sweden	R. Jarlas (FOI)	A benchmark example for collapse analysis of stiffened composite panels
	27	Germany	C. Balzani, W. Wagner (University Karlsruhe)	Numerical Treatment of Damage Propagation in Axially Compressed Composite Airframe Panels
	28	Italy	P. Cordisco, C. Bisagni (POLIMI)	Cyclic buckling of composite boxes
	29	Latvia	K. Kalnins, R. Rikards, J. Auzins (Riga Technical University), C. Bisagni (Politecnico di Milano), H. Abramovich (TECHNION)	Metamodelling methodology for post-buckling simulation of composite stiffened structures with physical validation
	30	Latvia	R. Rikards, K. Kalnins (Riga Technical University), R. Degenhardt (DLR)	Overview of slow computational and fast simulation tools
	31	Germany	H. Reimerdes, S. Büsing (RWTH)	Failure and Failure Progression in the Skin-Stiffener Interface in Composite Specimens
	32	Germany	S. Büsing, H. Reimerdes, T. Möcker (RWTH)	Simulation of Postbuckling Experiments with a Fast Design Tool
	33	Germany	S. Büsing, H. Reimerdes (RWTH)	A Strip Element with Interface Layer for the Prediction of Delamination in Buckled Composite Panels
	34	Israel	H. Abramovich, C. Bisagni and P. Cordisco (TECHNION, Politecnico di Milano)	Effect of cyclic post-buckling loads on CFRP panels
	35	Israel	H. Abramovich, T. Weller (TECHNION)	Repeated Buckling and Postbuckling Behaviour of Laminated Stringer Stiffened Composite Panels with and without Damage
	36	Israel	H. Abramovich, T. Weller (TECHNION)	Buckling and Postbuckling Behaviour of Laminated Composite Stringer Stiffened Curved Panels under Axial Compression-Experiments and Design

	No.	Country	Authors	Title
Others	37	UK	C. A. Featherston, D. Kennedy, S. Qu (Cardiff University)	Multi-level postbuckling optimum design of aerospace structures
	38	UK	C. Völlmecke, M. A. Wadee (Imperial College London)	Nonlinear buckling of uniaxially compressed delaminated composite panels
	39	UK	C. Williamson, S. J. Lord (QinetiQ)	Damage prediction and its effect on post-buckled wing design
	40	UK	Hongtao Wang, J. G. A. Croll (University College London)	Finite element validation of a lower-bound design method for optimising buckling capacities of FRP shells
	41	UK	J. E. Herencia, P. M Weaver, M. I. Friswell (Uni. Bristol)	A fast optimization technique for preliminary sizing of anisotropic composite stiffened panels
	42	Italy	C. Meola, G. Carlomagno, M. Valentino, C. Bonavolontà (Uni Naples)	Non destructive evaluation of impact damage in CFRP with infrared thermography and squid
	43	Netherlands	T. Rahman, E.L. Jansen (TU Delft)	Finite element based coupled mode initial post-buckling analysis of a composite cylindrical shell
	44	Portugal	N. Silva, D. Camotim, N. Silvestre (TU Lisbon), R. Degenhardt (DLR)	Application of generalised beam theory to the study of the stability behaviour of laminated CFRP cylindrical stiffened panels
	45	Austria	M. Oberuggenberger, J. King (University of Innsbruck)	Buckling and collapse of shell structures: sensitivity analysis
	46	Israel	V. Weissberg, T. Genosar, G. Ghilai (IAI)	Instability and collapse of sandwich shells; representing a/c wing skins
	47	Australia	M. C. W. Lee, R. S. Thomson, R. Degenhardt, D. W. Kelly (UNSW)	A stochastic study on the robustness of a stiffened composite structure
	48	Australia	Z. Mikulik, R. S. Thomson, D. W. Kelly, B. G. Prusty (CRC-ACS)	Assessment of fracture mechanics based methodologies to predict skin-to-stiffener debonding in a postbuckling compression panel
	49	China	C.L. Wu (ASRI)	Buckling Behaviour of Composite Laminated Corrugated Panel with Sinusoidal Profile First Part: Equivalent Stiffness Terms
	50	China	H. Wang, X. Sun (ASRI), A. Büschel, W. Wagner (UKA), R. Degenhardt, K. Rohwer (DLR)	Empirical formula for the critical perturbation load
	51	Belgium	C. Brauner, Y. Radovic, Jean-Pierre Delsemme, P. Jetteur (SAMTECH)	Advanced non linear failure analysis of a reinforcement composite curved beam with delamination and ply degradation
	52	Germany	J. Orf, L. Kärger, R. Degenhardt, A. Bethge (DLR)	The influence of imperfections on the buckling behavior of unstiffened CFRP-cylinders
	53	Germany	A. Wetzel (Ferchau), J. Baaran (DLR)	Residual strength prediction of impacted composite sandwich structures
	54	Germany	P. Steinmüller, R. Degenhardt, K. Rohwer (Airbus, DLR)	Investigations of axially loaded unstiffened CFRP cylindrical shells subject to single perturbation loads
	55	Germany	C. Mittelstedt, M. Beerhorst (PFH Göttingen, Airbus)	Closed-form buckling analysis of omegastringer-stiffened composite panels considering periodic boundary conditions
	56	Germany	C. Mittelstedt, M. Schagerl (PFH Göttingen, Airbus)	The Windenburg problem revisited: Buckling and minimum stiffness requirements for composite plates with reinforced edges
	57	Germany	W. Rust, M. Kracht (FH Hanover, CADFEM)	Recent experiences in load analysis of aircraft fuselage panels
	58	Germany	G. Schuhmacher, M. Wagner, A. Hörmann, F. Daoud (EADS-MAS)	Optimisation of Composite Aircraft Structures in Consideration of Postbuckling Behaviour
	59	Germany	C. Hühne, R. Rolfes (LUH Hannover)	Probabilistic approach to determine the lower limit of buckling load of composite shells
	60	Germany	T. Möcker, F. Goetz, J. Marsolek (Abaqus D), S. Kraschin (Bishop GmbH - Aeronautical Engineers), P. Linde, W. Wohlers (Airbus)	Abaqus FEM Analysis of the Postbuckling Behaviour of Composite Shell Structures
	61	Germany	J. Pontow, D. Dinkler (TU Braunschweig)	Evaluation of the perturbation sensitivity of composite laminated shells
	62	USA	F. Abdi, D. Huang (Alpha STAR Corporation)	Progressive fracture of stitched stiffened composite shear panels in the post buckling range
	63	USA	C. C. Chamis (NASA)	Dynamic Buckling of Thin Composite shells
	64	Italy	B. Gambino (Alenia)	Methodology to analyze postbuckling behaviour for multispar configuration structures
Not presented				
	65	China	Hao Wu, Ying Yan (Beihang University)	A parametric study for the design of stiffened composite panel

Conference programme – overview sessions

Time	3 rd September (Day 1)	Time	4 th September (Day 2)	Time	5 th September (Day 3)
9.00	Registration				
10.45	R. Degenhardt Welcome	8.30 - 10.00	Keynote lectures	8.30 - 10.00	Keynote lectures
11.00 - 12.30	Keynote lectures	10.30 - 12.10	Semi-analytical concepts	10.30 - 12.10	Structure tests
					Unstiffened structures II / Analysis and validation II
13.30 - 15.10	COCOMAT - Workpackage summaries	12.10 - 15.00	COCOMAT Workshop	13.10 - 14.50	Degradation II
15.40 - 17.40	COCOMAT - Achievements of the PhD students (Fast simulation tools, tests)	15.00 - 17.00	Analysis and validation I	15.20 - 17.00	Keynote lectures: Design handbooks
18.00	Transfer University - Dinner	17.15	Transfer University - DLR		
18.30-22.30	Conference Dinner (Dornse) 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)	18.00 - 20.00	DLR - Technical visiting tour (Finger food available)	17.00	End of Conference
		20.00	Transfer DLR - Hotels		
					Conference Venue: Technical University of Braunschweig, Pockelsstrasse 4 (Altgebäude), Braunschweig, Germany

Conference programme - 7 -

Time 3rd September (Day 1)

Conference Venue:
Technical University of Braunschweig,
Pockelsstrasse 4, Braunschweig, Germany

from

9.00 *Registration and morning coffee*

10.45 R. Degenhardt (DLR, PFH) Welcome / Organisation aspects

Session A Chair: Prof. Martin Wiedemann (DLR)
Keynote lectures

11.00	J. Szodrich (DLR, DGLR, EAG, ACARE) Future Aircraft Technologies – The European Strategic Research Agenda	1
11.30	P. Linde (Airbus) Overview of Test Prediction and Damage Simulation of Composite Aircraft Structures	2
12.00	R. Degenhardt, D. Wilckens, K. Rohwer, R. Zimmermann, J. Teßmer (DLR) Improved Material Exploitation of Composite Airframe Structures by Accurate Simulation of Collapse - The COCOMAT project	3

12.30 *Buffet lunch*

Session A1 Chair: Dr Hans von den Driesch (EU)
COCOMAT - Workpackage summaries

13.30	R. Jarlas (FOI) A benchmark example for collapse analysis of stiffened composite panels	26
13.50	A. Caruso, V. Pietroni, Mr. E. Masiero, (Agusta-Westland), R. Degenhardt (DLR) Material properties, design of structures and degradation models	15
14.10	R. Rikards, K. Kalnins (Riga Technical University), R. Degenhardt (DLR) Overview of slow computational and fast simulation tools	30
14.30	H. Abramovich, T. Weller (TECHNION), I. de Zarate (Aernnova) Experimental results on buckling and postbuckling behavior of panels - An overview	17
14.50	G. Ghilai, E. Feldman and A. David, Israel Aerospace Industries, (IAI) COCOMAT Guidelines for design & analysis of CFRP stiffened panels for buckling & postbuckling	19

15.10 *Coffee break*

Session A2 Chair: Prof. Chiara Bisagni (Politecnico di Milano)
COCOMAT - Achievements of the PhD students (Fast simulation tools, tests)

15.40	A. Orifici, R.S. Thomson, R. Degenhardt (DLR), C. Bisagni (Politecnico di Milano), J. Bayandor (CRC-ACS) An analysis tool for design and certification of postbuckling composite aerospace structures	23
16.00	K. Kalnins, R. Rikards, J. Auzins (Riga Technical University), C. Bisagni (Politecnico di Milano), H. Abramovich (TECHNION) Metamodeling methodology for post-buckling simulation of composite stiffened structures with physical validation	29
16.20	P. Cordisco, C. Bisagni (Politecnico di Milano) Cyclic buckling of composite boxes	28
16.40	D. Wilckens, R. Degenhardt, K. Rohwer, J. Tessmer (DLR), P. Bürmann (Airbus) IBUCK - A fast simulation tool for the design of CFRP aerospace structures	14
17.00	S. Büsing, H. Reimerdes (RWTH) A Strip Element with Interface Layer for the Prediction of Delamination in Buckled Composite Panels	33
17.20	C. Balzani, W. Wagner (University Karlsruhe) Numerical Treatment of Damage Propagation in Axially Compressed Composite Airframe Panels	27

18.00 *Transfer University - Dinner location*

18.30- **Conference Dinner (Dornse)** see page 14 of the Handout

22.30 **Dinner speech: Prof. Joachim Block (ROSETTA Lander - a challenging mission to the origins of the solar system)**

Session B Chair: Prof. Michael Sinapius (DLR)**Keynote lectures**

8.30	<i>M. Hillburger (NASA)</i> Developments in Shell Buckling Analysis, Design and Testing	7
9.00	<i>A. Rittweger, S. Christianson, H. Öry (EADS Astrium Space)</i> Dimensioning of Orthotropic Stiffened CFRP Shells of Large Launch Vehicle for Load Introduction and Stability	9
9.30	<i>R. Cuntze</i> Formulations of Failure Conditions – Isn't it basically just Beltrami and Mohr-Coulomb?	8

10.00 Coffee break**Session B1a Chair: Dr Jan Tessmer (DLR)****Semi-analytical concepts**

10.30	<i>S. Büsing, H. Reimerdes, T. Möcker (RWTH)</i> Simulation of Postbuckling Experiments with a Fast Design Tool	32
10.50	<i>C. Mittelstedt, M. Beerhorst (PFH Göttingen, Airbus)</i> Closed-form buckling analysis of omegastringer-stiffened composite panels considering periodic boundary conditions	55
11.10	<i>N. Silva, D. Camotim, N. Silvestre (TU Lisbon), R. Degenhardt (DLR)</i> Application of generalised beam theory to the study of the stability behaviour of laminated CFRP cylindrical stiffened panels	44
11.30	<i>C. Mittelstedt, M. Schagerl (PFH Göttingen, Airbus)</i> The Windenburg problem revisited: Buckling and minimum stiffness requirements for composite plates with reinforced edges	56
11.50	<i>M. Bruyneel, B. Colson, J. Delsemme, P. Jetteur, P. Morelle, A. Remouchamps (SAMTECH)</i> Exploiting semi-analytical sensitivities from linear and nonlinear finite-element analyses for composite panel optimization	21

Session B1b Chair: Prof. Murray Scott (CRC-ACS)**Degradation I**

24	<i>A. Orifici, I. Herszberg, A. Kotler, R. Thomson, J. Bayandor (CRC-ACS), H. Abramovich, T. Weller (TECHNION)</i> Failure in skin-stiffener sections under postbuckling loads	24
31	<i>H. Reimerdes, S. Büsing (RWTH)</i> Failure and Failure Progression in the Skin-Stiffener Interface in Composite Specimens	31
38	<i>C. Völlmecke, M. A. Wadee (Imperial College London)</i> Nonlinear buckling of uniaxially compressed delaminated composite panels	38
42	<i>C. Meola, G. Carlomagno, M. Valentino, C. Bonavolontà (Uni Naples)</i> Non destructive evaluation of impact damage in cfrp with infrared thermography and squid	42
48	<i>Z. Mikulik, R. S. Thomson, D. W. Kelly, B. G. Prusty (CRC-ACS)</i> Assessment of fracture mechanics based methodologies to predict skin-to-stiffener debonding in a postbuckling compression panel	48

12.10-15.00

COCOMAT Workshop

Demonstration of the improved simulation tools

(Buffet lunch in parallel)



**POSSCOSS
Workshop Hamburg,
2005**

**Session B2a Chair: Dr Rolf Jarlas (FOI)****Analysis and validation I**

15.00	<i>J. A. Araico, I. de Zarate Alberdi, F.R. Arribas (Aernnova)</i> FEM Simulation of Potted-Ends on Compression Loaded Graphite-Epoxy Test Specimens	16
15.20	<i>M. Doreille, S. Merazzi (SMR)</i> Post-buckling analysis of composite structures with B2000++	22
15.40	<i>C.L. Wu (ASRI)</i> Buckling Behaviour of Composite Laminated Corrugated Panel with Sinusoidal Profile First Part: Equivalent Stiffness Terms	49
16.00	<i>W. Rust, M. Kracht (FH Hanover, CADFEM)</i> Recent experiences in load analysis of aircraft fuselage panels	57
16.20	<i>B. Gambino (Alenia)</i> Methodology to analyze postbuckling behaviour for multispar configuration structures	64
16.40	<i>T. Möcker, F. Goetz, J. Marsolek (Abaqus D), S. Kraschin (Bishop GmbH - Aeronautical Engineers), P. Linde, W. Wohlers (Airbus)</i> Abaqus FEM Analysis of the Postbuckling Behaviour of Composite Shell Structures	60

Session B2b Chair: Prof. Haim Abramovich (TECHNION)**Unstiffened structures I**

59	<i>C. Hühne, R. Rolfes (LUH Hannover)</i> Probabilistic approach to determine the lower limit of buckling load of composite shells	59
63	<i>C. C. Chamis (NASA)</i> Dynamic Buckling of Thin Composite shells	63
61	<i>J. Pontow, D. Dinkler (TU Braunschweig)</i> Evaluation of the perturbation sensitivity of composite laminated shells	61
43	<i>T. Rahman, E.L. Jansen (TU Delft)</i> Finite element based coupled mode initial post-buckling analysis of a composite cylindrical shell	43
52	<i>J. Orf, L. Kärger, R. Degenhardt, A. Bethge (DLR)</i> The influence of imperfections on the buckling behavior of unstiffened CFRP-cylinders	52
40	<i>Hongtao Wang, J. G. A. Croll (University College London)</i> Finite element validation of a lower-bound design method for optimising buckling capacities of FRP shells	40

17.15 **Transfer University - DLR**18.00 - 20.00 **DLR - Technical visiting tour** (Finger food available) see page 15 of the Handout20.00 **Transfer DLR - Hotels**

Time 5th September (Day 3)

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9.00	<i>J. Arbocz, J.de Vries (TU Delft)</i> Looking for alternate ways to define Knockdown Factors 5
9.30	<i>C. Hühne, M. Vogler, G. Ernst, R. Rolfes (Leibnitz University Hannover)</i> Multiscale Approach for Determination of Stiffness and Strength of Textile Composites 12
10.00	Coffee break
Session C1a Chair: Prof. Werner Wagner (Uni Karlsruhe)	
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10.50	<i>H. Abramovich, T. Weller (TECHNION)</i> Buckling and Postbuckling Behavior of Laminated Composite Stringer Stiffened Curved Panels under Axial Compression-Experiments and Design 36
11.10	<i>H. Abramovich, T. Weller (TECHNION)</i> Repeated Buckling and Postbuckling Behavior of Laminated Stringer Stiffened Composite Panels with and without Damage 35
11.30	<i>M. Zeglen, P. Chojnacki, J. Ogiela (PZL)</i> Polish Aviation Works PZL-Swidnik – participation, results and experiences from COCOMAT project 20
11.50	<i>R. Degenhardt, D. Wilckens, K. Rohwer, M. Kepke, B. Hildebrandt, A. Zipfel (DLR)</i> Buckling and collapse tests using advanced measurement systems 13
12.10	Buffet lunch
Session C2a Chair: Prof. H. Reimerdes (RWTH Aachen)	
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13.10	<i>C. Brauner, Y. Radovicic, Jean-Pierre Delseemme, P. Jetteur (SAMTECH)</i> Advanced non linear failure analysis of a reinforcement composite curved beam with delamination and ply degradation 51
13.30	<i>A. Wetzel (Ferchau), J. Baaran (DLR)</i> Residual strength prediction of impacted composite sandwich structures 53
13.50	<i>A. Orifici, S. Lauterbach, H. Abramovich, R. Thomson, W. Wagner, C. Balzani (CRC-ACS, TECHNION, Uni. Karlsruhe)</i> Analysis of damage sensitivity and collapse in postbuckling fibre-reinforced multi-stiffener panels 25
14.10	<i>F. Abdi, D. Huang (Alpha STAR)</i> Progressive fracture of stitched stiffened composite shear panels in the post buckling range 62
14.30	<i>C. Williamson, S. J. Lord (QinetiQ)</i> Damage prediction and its effect on post-buckled wing design 39
14.50	Coffee break
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	<i>P. Steinmüller, R. Degenhardt, K. Rohwer (Airbus, DLR)</i> Investigations of axially loaded unstiffened CFRP cylindrical shells subject to single perturbation loads 54
	<i>C. Vrettos, E. Karachalios, Z. Marioli-Riga, C. Bisagni, P. Cordisco, O. de Zarate Alberdi, A. Caruso (HAI, POLIMI, Aernnova, Agusta)</i> Non-Linear analysis of stiffened composite boxes under combined loading 18
	<i>V. Weissberg, T. Genosar, G. Ghilai (IAI)</i> Instability and collapse of sandwich shells; representing a/c wing skins 46
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13.50	<i>A. Orifici, S. Lauterbach, H. Abramovich, R. Thomson, W. Wagner, C. Balzani (CRC-ACS, TECHNION, Uni. Karlsruhe)</i> Analysis of damage sensitivity and collapse in postbuckling fibre-reinforced multi-stiffener panels 25
14.10	<i>F. Abdi, D. Huang (Alpha STAR)</i> Progressive fracture of stitched stiffened composite shear panels in the post buckling range 62
14.30	<i>C. Williamson, S. J. Lord (QinetiQ)</i> Damage prediction and its effect on post-buckled wing design 39
14.50	Coffee break
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	<i>C. A. Featherston, D. Kennedy, S. Qu (Cardiff University)</i> Multi-level postbuckling optimum design of aerospace structures 37
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15.50	<i>A. Calvi (ESA)</i> E.C.S.S. Buckling handbook 10
16.20	<i>M. Schagerl (Airbus)</i> HSB - A Handbook for Fundamentals and Methods for Aeronautical Design and Analyses 11
16.50	R. Degenhardt Closing words
17.00	End of Conference

COCOMAT workshop - Exhibitors

University Karlsruhe, Inst. für Baustatik
Kaiserstr.12, 76131 Karlsruhe, Germany
Tel, +49 721 608 2280, ww@bs.uni-karlsruhe.de



Politecnico di Milano
Dipartimento di Ingegneria Aerospaziale
Via La Masa 34, 20158 Milano, Italy
Tel, +39 02 23998390, Chiara.Bisagni@polimi.it



**POLITECNICO
DI MILANO**

Riga Technical University, Institute of Materials and Structures
Kalku Iela 1, LV-1658 Riga, Latvia
Tel, +371 708 9124, rikards@latnet.lv



RWTH Aachen, Institut für Leichtbau
Wuellnerstr. 7, 52062 Aachen, Germany
Tel, +49 241 8096830, hg_reim@ilb.rwth-aachen.de



Technion – Israel Institute of Technology, Faculty of Aerospace Engineering
Technion City, 32000 Haifa, Israel
Tel, +972 4 8292303, haim@aerodyne.technion.ac.il



CRC-ACS - Cooperative Research Centre for Advanced Composite Structures Limited
506 Lorimer Street, Fishermans Bend, Victoria, 3207, Australia
Tel, +61 3 9676 4900, m.scott@crc-accs.com.au



SMR S.A.

P.O. Box 4014, 2500 Bienne 4, Switzerland

Tel, +41 32 345 2121, merazzi@smr.ch



Samtech, Liège Science Park

Rue des Chasseurs-Ardennais, 8, 4031 Angleur, Belgium

Tel, +32 4361 6963, claudine.bon@samcef.com



DLR, Institute of Composite Structures and Adaptive Systems

Lilienthalplatz 7, 38108 Braunschweig, Germany

Tel, +49 531 295 3059, richard.degenhardt@dlr.de



Abaqus Deutschland GmbH

Elisabethstraße 16, 52062 Aachenv, Germany

Tel, +49 241 474 01 0, www.simulia.com



Private University of Applied Sciences Göttingen

CFK-Valley Stade Campus

Airbusstr. 6, 21684 Stade, Germany

Tel, +49 41 41 / 7967-0, www.pfh.de

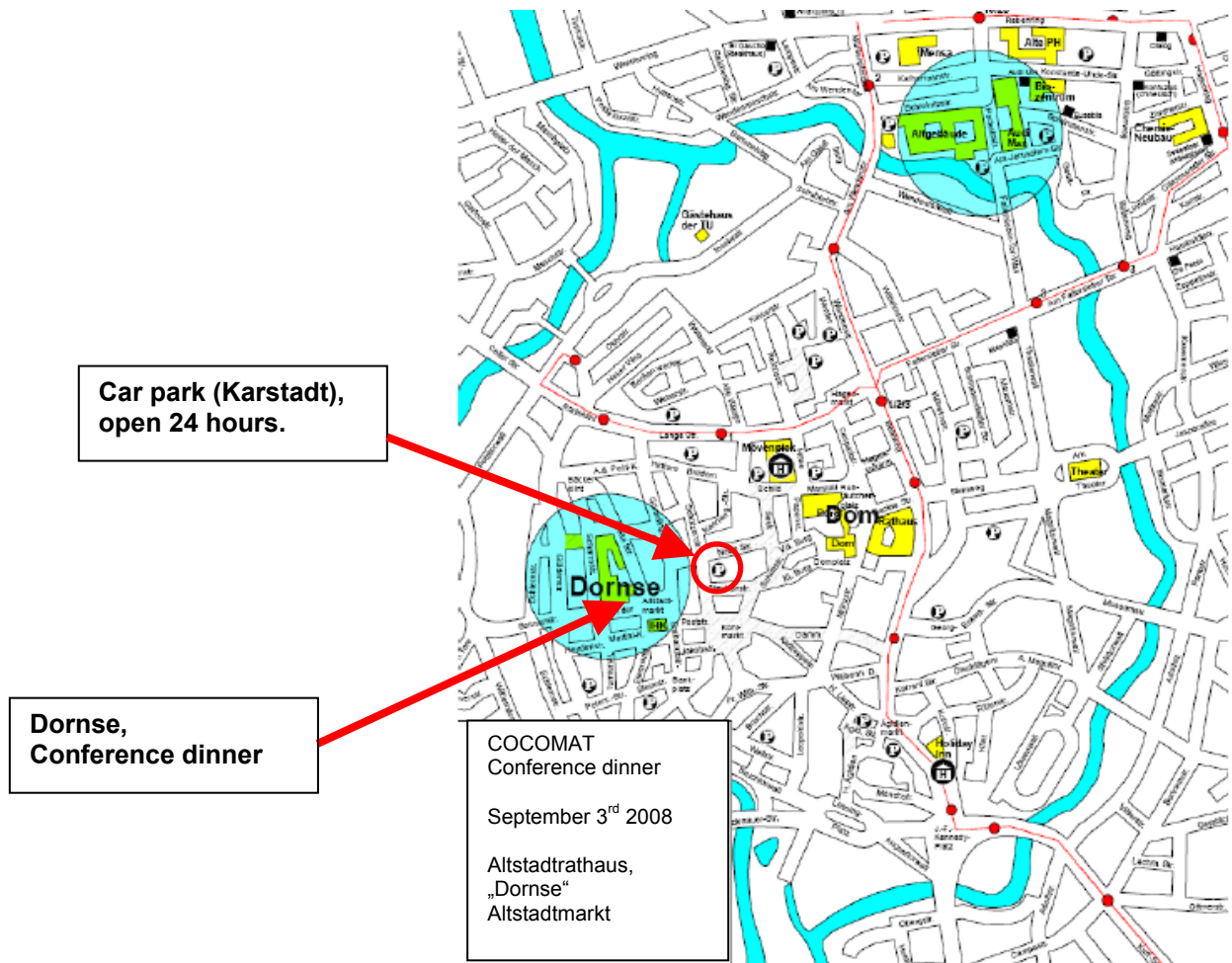


Conference dinner, 3rd September 2008 – Agenda

- 18.00 Transfer University - Dinner location (Dornse)
- 18.30 Reception
- 19.30 Welcome by
- Prof. Richard Degenhardt (Conference Chairman)
- Carsten Lehmann (Chief City Councilor of the City of Braunschweig)
- 20.00 Dinner
- 21.00 Dinner speech:
Prof. Joachim Block (ROSETTA Lander - a challenging mission to the origins of the solar system)
- 21.45 COCOMAT awards
- 22.30 End

Location: Dornse (Altstadtrathaus), Altstadtmarkt (see also page 56)

Car park: Karstadt (see map below), this is the only car park which is open 24 hours.



DLR – Technical visiting tour, 4th September 2008

Location: DLR Braunschweig

Institute of Composite Structures and Adaptive Systems

Day: 4 September 2008

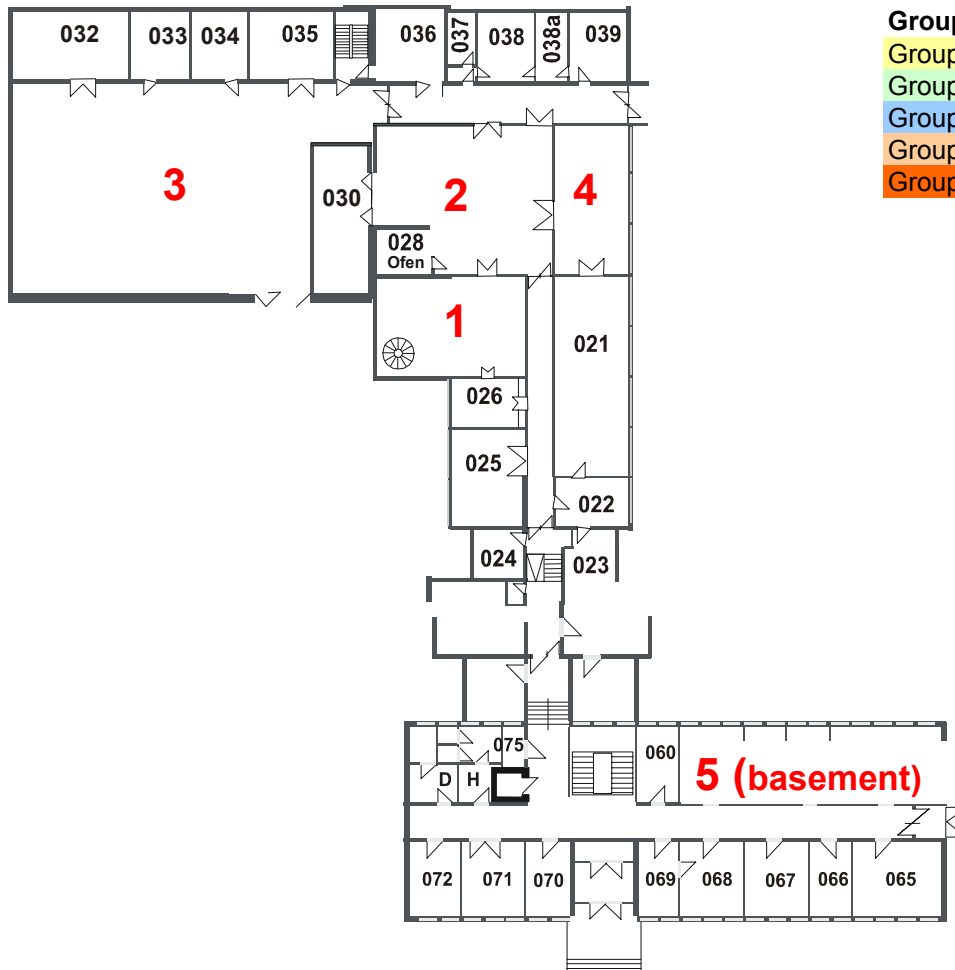
Agenda

17.15 Transfer University - DLR

18.00 DLR - Technical visiting tour (Finger food available)

20.00 Transfer DLR - Hotels

No.	Station	Presenter	Time / Group				
			18.00	18.20	18.40	19.00	19.20
1	Buckling test facility	Prof. R. Degenhardt	Group 1	Group 2	Group 3	Group 4	Group 5
2	Composite technology (microwave, induction technology, demonstration parts)	Mr M. Kleineberg, Mr M. Podkorytov, Mr T. Ströhlein, Mr S. Niemann	Group 2	Group 3	Group 4	Group 5	Group 1
3	Testing field	Mr D. Hartung	Group 3	Group 4	Group 5	Group 1	Group 2
4	Adaptive systems	Mr R. Keimer	Group 4	Group 5	Group 1	Group 2	Group 3
5	Ultrasonic testing field	Dr W. Hillger	Group 5	Group 1	Group 2	Group 3	Group 4



Group leaders:

Group 1: Mrs T. Führer

Group 2: Mrs J. Orf

Group 3: Mr T. Wille

Group 4: Mr J. Wölper

Group 5: Mr A. Szewieczek

Abstracts

The full extended abstracts can be downloaded at www.cocomat.de.

Session A	Chair: Prof. Martin Wiedemann (DLR)
Keynote lectures	
3rd September, 2008	Time: 11.00

No. 1

Title: Future Aircraft Technologies – The European Strategic Research Agenda

Authors: J. Szodruch (DLR, DGLR, ACARE)

Contact: Tel. +49 (0)2203 601 3677

Abstract:

Passenger air traffic will increase by 5% annually within the next 20 years. The resulting challenges for the entire air transport system have been discussed within ACARE, the European Advisory Council for Aeronautics, and the major goals are quantified in the Vision 2020. This document is by now the most important and widely accepted strategic guideline, valid for all the aeronautical research activities in Europe and is further detailed in the Strategic Research Agenda. The growth of air traffic will induce major challenges for the capacity of air traffic management systems and the environment. Especially the environmental impact of air traffic was discussed within international reports about the global climate change, such as IPCC. On the one hand it is necessary to improve air transport to fulfil the ACARE goals within the several disciplines like material and structures, system, propulsion and aerodynamics and on the other hand the multidisciplinary work requires improvement, in order to increase the efficiency of the air transport system. From the research point of view also the long term effect of today's scientific work must be considered to enable an emission neutral flight in future.

No. 2
Title: Overview of Test Prediction and Damage Simulation of Composite Aircraft Structures
Authors: P. Linde (Airbus)
Contact: peter.linde@airbus.com

Abstract:

The steady increase of composite parts in civil aircraft over the last three decades have recently been followed by a radical increase in weight percentage composites in the structure. In the most recent long range aircraft under development by both Boeing and Airbus, most major structure components not only of the wings but also of the fuselage now consist of composites. This necessitates an increased use of efficient structural simulation capabilities. One important aspect of this is the virtual testing of shear compression panels at Airbus which here will be presented. Having served well for Glare during the A380 development, it is currently undergoing a considerable development to extend its capacity to composites. Summarized under the designation SIMULation of Panels in AirCRAFT, "SIMULPAC", this platform has served a major role in the initial A350 developments; in the first designs, during virtual testing the configuration of new components and for predictions of the first real shear compression panels. The second aspect to be presented here is the damage modelling of composites to be used in detailed simulations and in parts of the above virtual panel tests. Here will be focused on the mesoscopic approach, in which damage is simulated for each ply. The plies may be "layers" in a layered shell or be modelled by separate continuum shell elements. Here, an overview at the three failure modes: fibre rupture, matrix cracking and delamination will be given. Finally, a view into topics of interest over the next years will be presented.

No. 3
Title: Improved Material Exploitation of Composite Airframe Structures by Accurate Simulation of Collapse - The COCOMAT project
Authors: R. Degenhardt, D. Wilckens, K. Rohwer, R. Zimmermann, J. Teßmer (DLR)
Contact: richard.degenhardt@dlr.de

Abstract:

European aircraft industry demands for reduced development and operating costs, by 20% and 50% in the short and long term, respectively. Contributions to this aim are provided by the completed project POSICOSS and the running follow-up project COCOMAT, both supported by the European Commission. As an important contribution to cost reduction a decrease in structural weight can be reached by exploiting considerable reserves in primary fibre composite fuselage structures through an accurate and reliable simulation of postbuckling and collapse. The POSICOSS consortium developed fast procedures for postbuckling analysis of fibre composite stiffened panels, created comprehensive experimental data bases and derived design guidelines. COCOMAT builds up on the POSICOSS results and considers in addition the simulation of collapse by taking degradation into account. The main objective is a future design scenario for composite stiffened panels which allows the exploiting of considerable reserves in primary fibre composite fuselage structures. The results comprise an extended experimental data base, degradation models, improved certification and design tools as well as design guidelines. The paper deals with the main objectives of the project COCOMAT and selected project results.

Session A1	Chair: Dr Hans von den Driesch (EU)
COCOMAT – Work Package Summaries	
3rd September, 2008	Time: 13.30

No. 26

Title: A benchmark example for collapse analysis of stiffened composite panels

Authors: R. Jarlas (FOI)

Contact: rolf.jarlas@foi.se

Abstract:

Eight different Finite Element implementations used by the partners within the COCOMAT consortium have been used to simulate the behaviour of curved stiffened composite panels loaded in compression. The aim has been to define a suitable benchmark example and compare the abilities of the different Finite Element codes to simulate the structural behaviour in the post-buckling range. The benchmark example will be defined and presented together with the results and conclusions. It was found that the results obtained with an imperfection-free model were sensitive to differences in the finite element implementation. On the other hand, when a realistic geometry-imperfection was introduced it was found that the load-shortening curve varied in a fairly narrow band depending on the program used. Comparing the curves from the analysis with the experimental data it is not possible to say that one program or method is superior to the others, or that any program gives poor or inaccurate results compared to the others. The partners observed lack of convergence in some case and found that understanding of how damping parameters and time-steps should be chosen were very important.

No. 15

Title: Material properties, design of structures and degradation models

Authors: A. Caruso, V. Pietroni, Mr. E. Masiero, S. Poggi (Agusta-Westland), R. Degenhardt (DLR)

Contact: a.caruso@it.agusta.com

Abstract:

This paper is focused on the material properties obtained for different kind material, test results on stiffened strips to study the development of degradation, the development of degradation models based on the test results obtained and the design of stiffened CFRP panels which are needed for buckling tests. In the first part material properties are presented of the specimens with and without damages, manufactured of the material IM7/8552 UD, 985-GT6-135 and IM7/8552. The second part shows test results on small structures (e.g. stiffened strips or plates) and gives an overview of degradation models which were developed based on these tests. The last part shows the 6 panel designs which are validation panels and industrial panels. They were selected for testing out of 85 panels designed in COCOMAT.

No. 30
Title: Overview of slow computational and fast simulation tools developed during the project COCOMAT
Authors: R. Rikards, K. Kalnins (Riga Technical University), R. Degenhardt (DLR)
Contact: rikards@latnet.lv

Abstract:

The paper overviews the progress achieved by the European Commission funded project COCOMAT1 work package devoted to the development of improved simulation procedures for collapse of composite airframe structures, which take degradation into account. It has been identified by industrial applications that very accurate, but necessarily slow tools are required for the final certification, whereas reliable fast tools reducing design and analysis time by an order of magnitude, will allow for an economic design process. Twelve industrial and academic partners have been involved in the extension of commercial analysis software such as SAMCEF, B2000, ABAQUS, MSC.MARC, MSC.NASTRAN and improvement of in-house tools. In general, structural degradation has been implemented as growth of skin-stringer separation and delamination in the stiffened composite structures. Interlaminar fracture growth criteria have been implemented by means of Virtual Crack Closure Technique (VCCT) and Virtual Crack Extension (VCE) Method. Furthermore stress/strain based failure criteria such as Hashin, Puck and Maximum Stress have been introduced to model initiation and progression of the ply damage. Finally, all developed tools have been validated by means of the experimental results obtained from the other work packages within the COCOMAT1 project. Among the validation experiments were: double cantilever beam, end-notched flexure and mixed mode stiffener specimens together with stiffened panel and box structures with pre-existing and industrially pre-selected damage.

No. 17
Title: COCOMAT - Experimental results on buckling and postbuckling behaviour of panels- An overview
Authors: H. Abramovich, T. Weller (TECHNION), I. de Zarate (Aernnova)
Contact: haim@aerodyne.technion.ac.il

Abstract:

The COCOMAT project is trying to establish a future design scenario for composite stiffened panels which allows the exploiting of considerable reserves in primary fiber composite fuselage structures. Within its framework an extended experimental data base, degradation models, and improved certification and design tools as well as design guidelines were established. The present paper deals with the experimental results on buckling and postbuckling of laminated composite curved stringer - stiffened panels axially compressed. Two of the partners tested also boxes formed by two curved panels and two straight panels, under combined torsion and axial compression, and pure torque. The experimental work comprised of testing the panels under repeated buckling for less than 2000 cycles and testing of panels with artificial and impact damage under cycling loading. The degradation due to cycling loading and the artificial and induced damage was experimentally investigated.

No. 19
Title: COCOMAT Guidelines for design & analysis of CFRP stiffened panels for buckling & postbuckling
Authors: G. Ghilai, E. Feldman and A. David, Israel Aerospace Industries, (IAI)
Contact: gghilai@iai.co.il

Abstract:

One of the most important goals of the COCOMAT EU R&D project is the generation of a formulated set of guidelines, which can be applied when buckling or post buckling of stiffened CFRP panels are considered. Issues of concern for composite materials are addressed, such as prediction of onset of damage and propagation of defects during buckling and post buckling, under static and cyclic loading. The design and analysis guidelines are the result of a good cooperation between partners from industry, universities and research centers, and are based on extensive theoretical and experimental research performed within the COCOMAT project. The analysis guidelines cover FE types and meshing, damage mechanisms, degradation models, recommendations regarding interface elements at damage zone and ply failure models. Comparison between various analysis codes is also provided. Lessons learned concerning testing of structures in the buckling regime are presented. Sensitivity of conventional design to damage of various sizes has been investigated, and conclusions are drawn regarding design criteria. Two structural applications are also presented, where some of the above mentioned guidelines were implemented at IAI.

Session A2	Chair: Prof. Chiara Bisagni (POLIMI)
COCOMAT – Achievements of the PhD students (Fast simulation tools, tests)	
3rd September, 2008	Time: 15.40

No. 23

Title: An analysis tool for design and certification of postbuckling composite aerospace structures

Authors: A. Orifici, R.S. Thomson (CRC-ACS), R. Degenhardt (DLR), C. Bisagni (Politecnico di Milano), J. Bayandor (RMIT)

Contact: a.orifici@crc-accs.com.au

Abstract:

In aerospace, carbon fibre-reinforced polymer (CFRP) materials and postbuckling skin-stiffened structures are key technologies that have been used to improve structural efficiency. However, the application of composite postbuckling structures in aircraft has been limited as today's analysis tools cannot accurately predict structural collapse in compression. In this work, a finite element analysis tool for design and certification of aerospace structures is presented, which predicts collapse by taking the critical damage mechanisms into account. The tool incorporates a global-local analysis technique for predicting interlaminar damage initiation, and degradation models to capture the growth of a pre-existing interlaminar damage region, such as a delamination or skin-stiffener debond, and in-plane ply damage mechanisms such as fibre fracture and matrix cracking. The analysis tool has been applied to single- and multi-stiffener fuselage-representative composite panels, in both intact and pre-damaged configurations. This has been performed in a design context, in which panel configurations are selected based on their suitability for experimental testing, and in an analysis context for comparison with experimental results as representative of aircraft certification studies. For all cases, the tool was capable of accurately capturing the key damage mechanisms contributing to final structural collapse, and suitable for the design of next-generation composite aerospace structures.

No. 29

Title: Metamodelling methodology for post-buckling simulation of composite stiffened structures with physical validation

Authors: K. Kalnins, R. Rikards, J. Auzins (Riga Technical University), C. Bisagni (Politecnico di Milano), H. Abramovich (TECHNION)

Contact: kasisk@latnet.lv

Abstract:

The metamodelling methodology has been proposed for postbuckling simulation of stiffened composite structures that takes material degradation into account. Proposed methodology for elaboration of the fast simulation procedure for axially or torsionally loaded stiffened composite structures is based on response surface methodology (RSM) and design and analysis of computer experiments (DACE). Numerical analyses have been parametrically sampled by means of ANSYS/LS-DYNA probabilistic design toolbox extracting the load-shortening response curves. These response curves were approximated using piece-wise uniform metamodelling identifying the skin and the stiffener buckling loads as well as recognising the buckling and postbuckling stiffnesses ratios. Different

parametric and non parametric polynomial functions were used for metamodeling. Three stiffened panel design's together with two closed box structure metamodels have been trained and validated with the tests performed within the COCOMAT1 project. An investigation was performed to obtain the behaviour of stiffened composite shells in the presence of predetermined degradation, in regions between the outer skin and stiffeners. Preselected degradation scenarios have been elaborated based on industrial certification requirements and the worst case scenario approach. Parametric studies over a wide range of damage sizes and sites were carried out to study the effects of the material softening parameters on overall postbuckling behaviour. The resulting design procedure provides an effective optimal design tool for preliminary study of the composite stiffened structures with the material degradation restrains in addition to optimum weight design guidelines over the buckling/postbuckling load ratios.

No. 28

Title: Cyclic buckling of composite boxes

Authors: P. Cordisco and C. Bisagni (Politecnico di Milano)

Contact: cordisco@aero.polimi.it, chiara.bisagni@polimi.it

Abstract:

Buckling tests results obtained on two boxes, manufactured by Agusta/Westland, and made of CFRP curved stringer stiffened panels are here presented. Tests on boxes were performed both statically and cyclically under combined axial compression and torque. The effect of different application sequences of combined loading is derived. Moreover, the influence of repeated post-buckling combined loads is investigated in terms of global behaviour (stiffness, buckling loads and post-buckling deformed shapes), in terms of local behaviour (strain distribution) and in terms of collapse modalities (collapse load, failure area). Then, finite elements analyses are performed using ABAQUS/Explicit. Results show, from one hand, the reliability of these structures to safely operate in the post-buckling field, even when the buckling load is reached thousands of times during the operative life, and, from the other hand, the capability of dynamic explicit simulations to well describe the behaviour of aeronautical stiffened structures.

No. 14

Title: IBUCK - A fast simulation tool for the design of CFRP aerospace structures

Authors: D. Wilckens, R. Degenhardt, K. Rohwer, J. Tessmer (DLR), P. Bürmann (DLR)

Contact: dirk.wilckens@dlr.de

Abstract:

IBUCK is a fast semi-analytical model to investigate the buckling and post-buckling behaviour of stringer-stiffened panels. The model consists of the skin and stiffeners in longitudinal direction. The load case considered is axial compression. The large out of plane displacements are covered through nonlinear strain-displacement relations. In order to approximate the buckling and post buckling deformation pattern, trigonometric functions are considered for local as well as for global, stringer based buckling. First, a linear buckling eigenvalue analysis is carried out and a combination of buckling eigenmodes is chosen as imperfection. Then the load history is started and the Fourier

coefficients are determined by minimizing the energy at each load level. The arc-length method is used to solve the equations.

No. 33

Title: A Strip Element with Interface Layer for the Prediction of Delamination in Buckled Composite Panels

Authors: S. Büsing, H. Reimerdes (RWTH)

Contact: buesing@ilb.rwth-aachen.de

Abstract:

An element for the prediction of delamination is presented, that is based on the combination of two shells with an interface layer. This interface layer enables the calculation of stresses between the shells, which are the input for a failure criterion indicating the onset of delamination between the shells. The element is implemented into a tool for the postbuckling simulation of composite stiffened panels, which is based on the discretisation of the structure by strip elements, while the buckling and postbuckling behaviour are described by trigonometric functions. As less degrees of freedom are necessary compared to a finite element formulation, the computational effort is reduced. Implementing the strip element with interface layer into this tool enables the prediction of the onset of delamination during the postbuckling analysis. To demonstrate the applicability of the element, portions of a composite stiffened panel are analysed, where the element is used to model the combination of skin and stiffener foot to indicate onset of skin-stiffener separation.

No. 27

Title: Numerical Treatment of Damage Propagation in Axially Compressed Composite Airframe Panels

Authors: C. Balzani, W. Wagner (University Karlsruhe)

Contact: claudio.balzani@bs.uni-karlsruhe.de

Abstract:

This paper presents an approach for the simulation of stringer-stiffened composite airframe panels under axial compression based on the finite element method. Layered shear-elastic shell elements allowing for an arbitrary stacking sequence and a variable location of the reference plane along the thickness are used to model the pre- and postbuckling response of the composite. Transverse shear locking effects are reduced via the well-known assumed natural strains (ANS) approach. A ply discount model with constant knock-down factors is employed to account for ply failure which can occur as fiber fracture, matrix cracking, or fiber-matrix shear failure. Delamination, and particularly debonding of the stiffener from the skin, is modeled via so-called interface elements in which the cohesive zone approach is implemented. A special cohesive law is presented which is history-dependent in order to prevent restoration of cohesion. A penalty contact formulation avoids the interpenetration of the crack faces. A numerical validation example with experimental evidence highlights the performance and applicability of the proposed model.

Session B	Chair: Prof. Michael Sinapius (DLR)
Keynote Lectures	
4th September, 2008	Time: 8.30

No. 7

Title: Developments in Shell Buckling Analysis, Design and Testing

Authors: M. Hilburger (NASA)

Contact: mark.w.hilburger@nasa.gov

Abstract:

High-performance aerospace shell structures are inherently thin-walled because of weight and performance considerations and are often subjected to destabilizing loads. Thus, buckling is an important and often critical consideration in the design of these structures and reliable, validated design criteria for thin-walled shells are needed, especially for shells made of advanced composite materials. Shell-buckling design criteria have a history steeped in empiricism. From approximately 1930 to 1967, many shell-buckling experiments were conducted on metallic shells. Typically, the experiments yielded buckling loads that were substantially lower than the corresponding analytical predictions, which were based on simplified linear bifurcation analyses of geometrically perfect shells with nominal dimensions and idealized support conditions. The primary source of discrepancy between corresponding analytical predictions and experimental results is attributed to small deviations from the idealized geometry of a shell, known as initial geometric imperfections. Empirical design factors, known as "knockdown" factors, were determined from these test data and were to be used in conjunction with linear bifurcation analyses for simply supported shells to adjust or "knockdown" the unconservative analytical prediction. This approach to shell design remains prominent in industry practice, as evidenced by the extensive use of the NASA space vehicle design recommendations. Recent advancements in digital computers, high-fidelity structural analysis tools and testing technologies are enabling the development of a new shell buckling design philosophy, namely, analysis-based knockdown factors. Key enabling technology developments and their implementation in ongoing NASA Shell Buckling Knockdown Factor development activities are presented in this lecture. In addition, the development of a refined shell-buckling preliminary-design criteria that is based on high-fidelity nonlinear finite-element analyses that include the effects of a manufacturing-process-specific geometric imperfection signature is presented.

No. 9

Title: Dimensioning of Orthotropic Stiffened CFRP Shells of Large Launch Vehicle for Load Introduction and Stability

Authors: A. Rittweger, S. Christianson, H. Öry (EADS Astrium Space)

Contact: Andreas.Rittweger@astrium.eads.net

Abstract:

The dimensioning of an orthotropic stiffened cylindrical CFRP shell subjected to load introduction of concentrated axial loads using rapid analytical methods is presented. The dimensioning considers required constraints in the force flux distribution, strength of the

laminate, general instability, panel instability (from ring frame to ring frame) and local instability. The rapid analytical methods allow for mass optimization. The final design is confirmed by detailed FE analysis. A comparison of the FE analysis with the analytical results is shown.

No. 8

Title: Formulations of Failure Conditions – Isn't it basically just Beltrami and Mohr-Coulomb?

Authors: R. Cuntze

Contact: Ralf_Cuntze@t-online.de

Abstract:

Strength Design Verification demands for reliable failure conditions. Such a condition is the mathematical formulation of a failure curve or a failure surface. Existing conditions often map a course of multi-axial test data by one global equation not taking into account that data may belong to more than one failure mode. This means, it is located in a mode interaction domain and extrapolations out of the mapping domain may lead to erroneous results. Driven from the shortcomings of such a 'global fitting' the author looked for a 'failure mode-related fitting'. The author termed this procedure the Failure Mode Concept (FMC), [Cun04]. The derived phenomenological, engineeringlike, stress-based strength failure conditions for onset of fracture are invariant-based. These are applied for a wide variety of materials: Brittle and ductile isotropic materials, brittle unidirectional laminae, and brittle woven fabrics. The materials might possess a dense or a porous consistency. More than other theories (e.g. for UD material [Chr98, Has 80]) the FMC utilizes a strict failure mode thinking as well as the application of material symmetry-related invariants which are dedicated to a volume change or a shape change or to material internal friction the homogenized material element may experience. The choice of the material symmetry-related invariants for the formulation of a distinct stress condition can be based on Beltrami's strain energy density formulation ("At onset of yielding a material possesses a distinct strain energy". This strain energy is composed of two portions, the dilatational energy and the distortional energy, [Bel885]1) and on Mohr-Coulomb ("Fracture is determined by the stresses in the fracture plane", [Mor00]7), if material friction has to be considered. Some essential conclusions may be drawn from the investigations: °Very different but similar behaving materials can be basically treated with the same strength condition. This makes us to check in the dimensioning phase - in case of a new material - whether available information from results of a similar behaving material may be used. °The FMC has proven to be a helpful tool in simply fitting the course of various multi-axial material strength test data, and it finally can capture several failure modes in one pseudo-global failure condition avoiding the shortcomings of the usual 'global fitting' strength conditions. °It is applicable to brittle/ductile, dense/porous, isotropic/anisotropic materials, if a failure mode can be identified. °More representative multi-axial strength test data should be available, even for some standard materials.

Session B1a	Chair: Dr Jan Tessmer (DLR)
Semi-analytical concepts	
4th September, 2008	Time: 10.30

No. 32

Title: Simulation of Postbuckling Experiments with a Fast Design Tool

Authors: S. Büsing, H. Reimerdes, T. Möcker (RWTH)

Contact: buesing@ilb.rwth-aachen.de

Abstract:

An analysis procedure for the simulation of the postbuckling behaviour of composite stiffened panels is presented, that is based on the discretisation of the structure by strip elements. Only one element in longitudinal direction of the structure is necessary, as the buckling and postbuckling behaviour are described by trigonometric functions. Compared to a finite element discretisation, less degrees of freedom are used, which reduces the computational effort. Next to an overview of the underlying theory, the application of the approach is presented. Numerical results for two curved stiffened panel configurations loaded by axial compression are presented in terms of buckling load and buckling pattern, postbuckling behaviour as well as an estimation of global buckling load. In order to demonstrate the applicability of the approach, the numerical data is compared to results that were determined by experiments.

No. 55

Title: Closed-form buckling analysis of omegastringer-Stiffened composite panels considering Periodic boundary conditions

Authors: C. Mittelstedt, M. Beerhorst (PFH Göttingen, Airbus)

Contact: christian.mittelstedt@airbus.com

Abstract:

In this contribution, a closed-form solution for the buckling loads of composite plates under compression that are longitudinally stiffened by omega-stringers is described. The analysis is based on rather simple trigonometric and polynomial shape functions for the buckling mode of the plate while the stringers are introduced into the analysis model by employing equivalent rotational springs at the plate edges. Furthermore, the exact elasticity solution for the buckling problem of an elastically restrained composite plate is shortly discussed, and a set of generic buckling curves using non-dimensional characteristic quantities is presented that can be used in a handbook-like manner in day-to-day engineering practice. Accompanying finite element simulations show that the closed-form approach is very reliable for typical aircraft composite fuselage configurations and as such can be used with confidence in engineering practice.

No. 44
Title: On the use of generalised beam theory to assess the buckling and post-buckling behaviour of laminated CFRP cylindrical stiffened panels
Authors: N. M. F. Silva, D. Camotim, N. Silvestre (TU Lisbon), R. Degenhardt (DLR)
Contact: nunosilva2000@yahoo.com.br

Abstract:

The paper presents the application of a novel fast numerical tool, based on Generalised Beam Theory (GBT), to perform buckling and post-buckling analyses of laminated CFRP panels. GBT is a beam theory developed for prismatic thin-walled members (*e.g.*, columns, beams or panels), which takes into account both global and local deformations. One of its main features is the fact that the cross-section is discretised into deformation modes with clear mechanical meanings (*e.g.*, global bending, distortional, local-plate, shear and transverse extension deformation modes) – this (i) allows for a better understanding of the member structural behaviour and (ii) makes it possible to perform analyses with very few d.o.f. (by preselecting a set of deformation modes). No stiffness degradation is taken into consideration and the material is deemed linear elastic and orthotropic. One presents numerical results concerning the local buckling and post-buckling behaviour of stiffened CFRP cylindrical panels, including one that was experimental and numerically investigated in the context of the COCOMAT project. The panel deformed configurations and buckling loads obtained with GBT are validated through the comparison with either experimental data or values yielded by shell finite element analyses carried out in the code ABAQUS.

No. 56
Title: The windenburg problem revisited: buckling and minimum stiffness requirements for composite plates with reinforced edges
Authors: C. Mittelstedt, M. Schagerl (PFH Göttingen, Airbus)
Contact: christian.mittelstedt@airbus.com

Abstract:

In this contribution, the buckling behaviour of symmetrically laminated orthotropic rectangular composite plates under uniform compression is investigated. The plates under consideration are simply supported at the loaded transverse edges as well as at one of the unloaded longitudinal edges. The remaining unloaded edge is free but reinforced by a flange of arbitrary cross-section. For the corresponding linear buckling problem, the exact elasticity solution is derived from the underlying governing partial differential equation in conjunction with the boundary conditions at the plate edges. The resultant transcendental equation is used to compute a set of generic buckling curves employing nondimensional characteristic quantities for the plate and the flange. Beside the computation of the buckling load, an important design criterion for such reinforced plates is the determination of a certain threshold value for the bending stiffness EI of the flange such that the plate buckles locally while the flange itself remains more or less straight and in its original position. This specific value for EI (which is commonly referred to as minimum stiffness $\min EI$) is determined in a closed-form analytical manner, and a design criterion for practical purposes is proposed.

No. 21
Title: Exploiting semi-analytical sensitivities from linear and nonlinear finite-element analyses for composite panel optimization
Authors: M. Bruyneel, B. Colson, J. Delsemme, P. Jetteur, P. Morelle, A. Remouchamps (SAMTECH)
Contact: michael.bruyneel@samcef.com

Abstract:

The optimization of fuselage composite stiffened panels (see [1]) is the general framework of the research and development work described in this paper. More precisely, we consider a specific application and the associated optimization problem, where the design parameters are composite ply thicknesses for skins and stiffeners. The objective is the minimization of the total weight while optimization constraints involve reserve factors for both buckling and collapse analyses. The two most innovative features of this work are precisely related to the numerical simulations for the evaluation of buckling and collapse reserve factors – and their sensitivities – by means of linear and nonlinear finite element analyses respectively. The first part of this paper deals with convergence issues of the optimization process that may occur due to the inherent complexity of the evolution of buckling modes over different designs. We first highlight that this can be avoided when enough buckling modes are taken into account in the linear analysis, since this maintains the structure sensitive to design restrictions. Furthermore, we also illustrate the fact that a better convergence speed can be achieved if a large number of those buckling modes are considered for the optimization (see [2]). The second part is dedicated to the computation of semi-analytical sensitivities in nonlinear finite element analyses. General computational schemes were deduced and implemented for the computation of sensitivities for most structural responses (displacements, stresses ...). However a more demanding effort was required for evaluating the sensitivity of the collapse reserve factor. In this paper we show that a formula based on Riks' continuation method proves to be efficient in this framework. The above computational schemes were successfully integrated in SAMCEF Linear, SAMCEF Mecano and BOSS quattro, the latter being the multidisciplinary optimization platform of SAMTECH. They were further demonstrated on the optimization of an industrial test case. In particular, our aim is to show that, when semi-analytical sensitivities are available as a direct result of the FE analyses, the computational time of the optimization dramatically decreases with respect to that of approaches based on numerical perturbation (finite differences), which is a significant step forward and allows the engineers to tackle more complex problems. The presentation of the associated results concludes this paper.

Session B1b	Chair: Prof. Murray Scott (CRC-ACS)
Degradation I	
4th September	Time: 10.30

No. 24

Title: Failure in skin-stiffener sections under postbuckling loads

Authors: A. Orifici, H. Abramovich, I. Herszberg, A. Kotler, T. Weller, R. Thomson, J. Bayandor (CRC-ACS, TECHNION, RMIT)

Contact: a.orifici@crc-accs.com.au

Abstract:

An experimental and numerical investigation was performed into the damage mechanisms and failure loads in skinstiffener sections. In the experimental investigation, thin strips consisting of a skin and single stiffener were cut from a range of various fuselage-representative panels. There were seven panel designs, which involved changes in geometry, lay-up, material, stiffener shape and the use of co-curing or secondary bonding to join the skin and stiffener. A total of 203 thin strip sections were cut from these panels and tested to failure. The sections were loaded in two test rigs that aimed to simulate the various symmetric and antisymmetric loads on skin-stiffener interfaces in a postbuckling panel. Five failure modes were observed, corresponding to the first damage event occurring at different locations: stiffener bend, stiffener blade, core region under the stiffener, flange edge, and skin. In general, there was good repeatability of the experimental results, particularly when classified according to failure mode, though there was a significant degree of variability in some results. For the numerical analysis, two-dimensional finite element models were analysed, and strength criteria applied in order to predict the initiation of interlaminar damage. In general, the numerical predictions gave good comparison with the experiment in terms of the critical damage locations and initiation loads, which were within the experimental scatter. Discussion is given on the sensitivity of the specimen designs, and how the twodimensional analysis approach has been applied to large fuselage-representative structures.

No. 31

Title: Failure and Failure Progression in the Skin-Stiffener Interface in Composite Specimens

Authors: H. Reimerdes, S. Büsing (RWTH)

Contact: hg_reim@ilb.rwth-aachen.de

Abstract:

Thin-walled stiffened structures are widely used in aerospace structures. Loaded in compression or shear, those structures tend to buckle. Even after first buckling of the skin, the load can still be increased until failure of the stiffeners. Initiation of stiffener failure in a composite stiffened panel may be delamination or debonding of stringer foot and skin. Therefore, prediction and simulation of skin-stiffener separation is of particular interest. In this paper, the results of Pull-off tests on specimens representing a strip of a stiffened composite panel are presented, that were carried out in order to investigate failure load and failure mode of the skin-stiffener connection. Two sets of specimens were

investigated, that differ in layup and stiffener type. Furthermore a tool is presented, that uses a special element. This element is based on a high order theory for the investigation of sandwich structures. It consists of two shells connected by an adhesive layer. A degradation model is implemented into the adhesive layer, which accounts for failure by introducing a damage parameter, that reduces the stiffness of the adhesive layer gradually up to complete decohesion. This tool is applied to simulate the Pull-off tests, and the results are compared to those of the experiments.

No. 38

Title: Nonlinear buckling of uniaxially compressed delaminated composite panels

Authors: C. Völlmecke, M. A. Wadee (Imperial Colledge London)

Contact: cv05@imperial.ac.uk

Abstract:

A geometrically nonlinear plate model has been developed to investigate the buckling behaviour of laminated composite panels under uniaxial compression each with a pre-existing centrally located delamination patch. A Rayleigh–Ritz procedure based on trigonometric out-of-plane displacement functions is used in conjunction with minimum energy principles to describe the mechanical behaviour of the plates. The in-plane displacements are determined via von Kármán's compatibility equation by applying restrained edges at the boundary of the delaminated patch. Different delamination configurations are studied with the critical buckling loads and eigenvectors being determined using linear analysis. Conclusions are drawn relating the delamination parameters to the buckling load and response, and the results are validated by comparing against previous research. The model is then investigated in the postbuckling range and this gives an indication of the residual capacity of the panels after the instability. Future model developments are also briefly discussed including the possibility of modelling delamination propagation.

No. 42

Title: Non destructive evaluation of impact damage in cfrp with infrared thermography and squid

Authors: C. Meola, G. Carlomagno, M. Valentino, C. Bonavolontà (Uni Naples)

Contact: carmeola@unina.it

Abstract:

Carbon Fibre Reinforced Polymer (CFRP) materials generally respond with hidden damage to an impact event. If undetected such damage may lead to unexpected structures collapse, and to catastrophic effects if the damaged structure is an aircraft's part. Thus, it is important to detect the hidden damage at an incipient stage. The attention of the present paper is focused on the use of two different non-destructive techniques, such as Lock-in Thermography (LT) and Eddy Current (EC) using SQUID (Superconducting Quantum Interference Device) as magnetic probe. CFRP specimens impacted at different energy in the range from 1.8 up to 19.3 J have been analyzed. Both techniques are capable of discovering also the slight damage caused by the lowest energy impact; in addition, the LT technique supplies also information about the propagation of the damage through the material thickness.

No. 48

Title: Assessment of fracture mechanics based methodologies to predict skin-to-stiffener debonding in a postbuckling compression panel

Authors: Z. Mikulik, R. S. Thomson, D. W. Kelly, B. G. Prusty (UNSW, CRC-ACS)

Contact: z.mikulik@crc-acs.com.au

Abstract:

This paper addresses the accuracy of two fracture mechanics methodologies to predict skin-to-stiffener debonding in a postbuckled composite compression panel. The first methodology uses the MSC.Nastran finite element (FE) software with the Crack Tip Element (CTE) approach, while the second uses the Abaqus FE software and the Virtual Crack Closure Technique (VCCT). The accuracy of the CTE and the VCCT methodologies is established by comparing the numerical predictions to data from tests on large stiffened panels. Both numerical models over-predicted the load-displacement behaviour. The disagreement in stiffness considerably influenced the capability of the FE model to predict the onset and growth of stiffener debonding. It was found that use of the appropriate modelling strategy, damping factor and degree of mesh refinement at the crack tip were important to obtain accurate results.

Session B2a	Chair: Dr Rolf Jarlas (FOI)
Analysis and validation I	
4th September	Time: 15.00

No. 16

Title: FEM Simulation of Potted-Ends on Compression Loaded Graphite-Epoxy Test Specimens

Authors: J. Ansótegui Araico, I. de Zarate Alberdi, F.R. Arribas (Aernnova)

Contact: joseba.ansotegui@aernnova.com, inigo.ortizdezarate@aernnova.com, felix.rebollo@aernnova.com

Abstract:

The interesting effects of simulating the real potted-ends commonly used on testing thin-walled compression-loaded graphite-epoxy specimens are presented. Test specimen FE models with boundary conditions simulated with the typical rigid constrains (SPCs) and identical models accounting for the real potted-ends (geometry and material) have been compared and results, supported by experimental data, are discussed. The comparison study is based on the characteristics parameters that define the global structural response of the typical thin-walled compression members, i.e. pre-buckling stiffness, first buckling load, collapse load and deformed shape. It was clearly appreciable that finite element models simulating the real potted ends (potting geometry and material) lead to a more accurate simulation of the global response than models simulating the boundary condition at loaded ends with the typical rigid constrains (SPCs).

No. 22

Title: Post-buckling analysis of composite structures with B2000++

Authors: M. Doreille, S. Merazzi (SMR)

Contact: merazzi@smr.ch

Abstract:

The paper gives an overview on the current state of the development of the B2000++ fast tool for post-buckling analysis of composite panels, one of the objectives of the COCOMAT project. The developments comprise a static non-linear finite element continuation solver (Riks or Crisfield), an artificial damping procedure, a line search technique to improve the convergence of the Newton algorithm, as well as an implicit dynamic non-linear solver with linear multi-step time integration and variable time step size controlled by a local time integration error estimation. An efficient and robust family of elements, specifically shell elements with Assumed Natural Strain and Enhanced Assumed Strain to reduce locking, automatic selection between 5 or 6 degrees of freedoms per nodes for proper handling of shell intersections, is described. If the material is linear the elements feature pre-integration through the thickness of linear materials to reduce the cost for evaluating the element first and second variations. The element also features an intra-laminar progressive damage with the LaRC04 failure criteria for damage initiation and the Bažant crack band model for damage evolution. However, the Bažant crack band model requires elements with very small size and is thus costly. The solvers and elements are implemented in the B2000++ finite element simulation environment,

which provides fast sparse linear solvers and finite element assemblers running on multi-core CPU's, thus resulting in short analysis response times, particularly for post-buckling analysis of composite panels. Validation of the developments is illustrated by comparative analysis of several stiffened panels.

No. 49

Title: Buckling Behaviour of Composite Laminated Corrugated Panel with Sinusoidal Profile First Part: Equivalent Stiffness Terms

Authors: C.L. Wu (ASRI)

Contact: Wucunli@yahoo.com

Abstract:

This paper deals with equivalent stiffness techniques, as a corrugated panel is approximated by an anisotropic plate. The extending classical laminate theory is applied to the cross section of a corrugated plate with sinusoidal profile. The membrane, bending and membrane-bending coupling stiffness terms of a corrugated plate are derived in the form of analysis formulas. The accuracy of the formulas is validated through test data of a composite wing box with corrugated spar webs. It is found that relative errors of computational results vs. test gauge results are less than 6% as the formulas are used to obtain the equivalent stiffness terms. The results show encouraging agreement.

No. 57

Title: Recent experiences in load analysis of aircraft fuselage panels

Authors: W. Rust, M. Kracht (FH Hanover, CADFEM)

Contact: wilhelm.rust@mbau.fh-hannover.de

Abstract:

Experiences in modelling and development of methods for the nonlinear finite element analysis of the loading behaviour of aircraft fuselage panels are presented. Simulations were performed using panels with especially developed aircraft like boundary conditions. Detection of maximum load is influenced by the way the load is applied in connection with appropriate imperfections. The problem of finding the correct load path in the vicinity of bifurcation points is discussed. Presented solutions include standard perturbation by single force imperfections, empirically proved displacement difference method and the eigenvalue tracking method. A material model for mesomarc coupling of nonlinear panel and barrel analysis is presented which introduces nonlinear effects into a coarse meshed FE barrel model for preliminary design purposes.

No. 64
Title: Methodology to analyze postbuckling behaviour for multispar configuration structures

Authors: B. Gambino (Alenia)

Contact: bgambino@aeronautica.alenia.it

Abstract:

A based finite element procedure for predicting failure of reinforced composites multispar structures in postbuckling range is described. A finite element model is used to evaluate internal forces and post-processing software is developed to extract loads between skins and spar caps. Separate failure criteria are applied to evaluate debonding in the skin spar cap interface area. In order to show the weight saving due to postbuckling a trade study is presented.

No. 60
Title: Abaqus FEM Analysis of the Postbuckling Behaviour of Composite Shell Structures

Authors: T. Möcker, F. Goetz, J. Marsolek (Abaqus D), S. Kraschin (Bishop GmbH - Aeronautical Engineers), P. Linde, W. Wohlers (Airbus)

Contact: Torsten.MOECKER@3ds.com

Abstract:

A parametric For the design of stiffened composite shell structures the knowledge of the structural response in the postbuckling region is an important topic. Accordingly, tools are required that enable an accurate and reliable prediction of the postbuckling behaviour. In this paper it is shown how the finite element code ABAQUS can be used for this purpose. When performing finite element simulations, a large amount of time is often needed to build up the finite element model - in particular if the model consists of several parts with complex geometries. For this reason the pre-processing tool ABAQUS /CAE provides an interface which allows the user to automate repetitive tasks. Based on this interface, a tool simplifying the pre- and post processing of shell structures stiffened by stringers and frames was developed by ABAQUS Deutschland for the company Airbus. Next to a summary of the abilities of this tool, the main focus of this paper is on discussing several modelling techniques that are used to enable a realistic idealisation of the physical problem and on presenting simulation results for an exemplary structure. Based on this example, the influence

Session B2b	Chair: Prof. Haim Abramovich (TECHNION)
Unstiffened structures I	
4th September	Time: 15.00

No. 59

Title: Probabilistic approach to determine the lower limit of buckling load of composite shells

Authors: C. Hühne, R. Rolfes (Leibnitz University Hannover)

Contact: c.huehne@isd.uni-hannover.de

Abstract:

The discrepancy between the analytical determined buckling load of a perfect cylindrical shells and experimental test results is traced back to imperfections. The most frequently used guideline for the design of cylindrical shells, the NASA SP-8007, proposes the deterministic calculation of a knockdown factor for the buckling load with respect to the ratio of radius and wall-thickness, which turned out to be very conservative in numerous cases and which is not intended for composite shells. In order to be able to determine a lower bound for the buckling load of an arbitrary type of shell, probabilistic design methods have been developed. The measured imperfection patterns are described with a double Fourier series whereas the Fourier coefficients characterize the random distribution. In this paper, a probabilistic analysis of the buckling load is performed regarding the Fourier coefficients as random variables. The Finite Element code ABAQUS is used to determine the non-linear buckling load and a Monte Carlo simulation is executed. The probabilistic approach is realized for a set of six composite shells. The results indicate that also non-traditional imperfections like loading imperfections have to be considered for a reliable lower limit of the buckling load.

No. 63

Title: Dynamic buckling and post buckling of composites shells

Authors: C. C. Chamis (NASA)

Contact: Christos.C.Chamis@nasa.gov

Abstract:

A computationally effective method has been developed and is described to evaluate the dynamic buckling and post buckling of thin composite shells. The method is a judicious combination of available computer codes for finite element, composite mechanics and incremental structural analysis. The solution method is an incrementally updated Lagrangian.

No. 61

Title: Evaluation of the perturbation sensitivity of composite laminated shells

Authors: J. Pontow, D. Dinkler (TU Braunschweig)

Contact: j.pontow@tu-bs.de

Abstract:

The perturbation sensitivity and its influence on the limit loads of shells are widely discussed phenomena. Both phenomena may be classified with respect to the type of perturbation. As perturbations influence the stability of shells, the identification of unfavourable perturbations is essential. The perturbation energy concept enables to identify unfavourable non-initial perturbation loads and to evaluate the perturbation sensitivity of fundamental states by the perturbation energy. This measure is also the basis for a load-level-specific optimisation of the perturbation sensitivity. Hence, the present paper discusses the perturbation sensitivity of unstiffened composite laminated cylindrical shells consisting of unidirectional layers by means of the perturbation energy concept.

No. 43

Title: Finite element based coupled mode initial post-buckling analysis of a composite cylindrical shell

Authors: T. Rahman, E.L. Jansen (TU Delft)

Contact: T.Rahman@tudelft.nl

Abstract:

In this paper a multi mode finite element implementation of Koiter's initial post-buckling theory with the inclusion of the pre-buckling nonlinearity is presented. The implementation is done in a general purpose finite element code. Using this implementation a coupled mode initial post-buckling analysis of an axially loaded composite cylindrical shell is carried out with a small number of representative modes. For coupled mode asymmetric imperfection sensitivity analysis the most imperfection sensitive path of the structure is obtained in the frame of minimum path theory and the imperfection sensitivity analysis is done by varying the imperfection amplitude in that specific direction. Single mode perturbation analysis results show a reasonable agreement with semi-analytical results. Coupled mode analysis results also compare well with fully nonlinear analysis for sufficiently small imperfection amplitudes.

No. 52

Title: The influence of imperfections on the buckling behavior of unstiffened CFRP-cylinders

Authors: J. Orf, L. Kärger, R. Degenhardt, A. Bethge (DLR)

Contact: jana.orf@dlr.de

Abstract:

The objective of this work was the investigation of several imperfections concerning their influence on the buckling behaviour of thin-walled circular cylindrical CFRP (carbon fibre reinforce plastics) shells subjected to compression. For that purpose ten cylinders were manufactured, measured in different ways and axially loaded. Based on the information of several measurements, ten deterministic numerical models were generated and their exactness was proofed with statistical tests. In consideration of further imperfections a probabilistic analysis using Monte Carlo method was performed. That investigation came to the conclusion, that the imperfection of the load has an enormous influence on the buckling behaviour.

No. 40

Title: Finite element validation of a lower-bound design method for optimising buckling capacities of FRP shells

Authors: Hongtao Wang, J. G. A. Croll (University College London)

Contact: hongtao.wang@ucl.ac.uk

Abstract:

The buckling loads of thin FRP laminated shells are sensitive to initial geometric imperfections. A large number of geometric and material variables prohibit the traditional lower-bound experimental design methodology for isotropic shells from being applied to composite shells. As an alternative, a so-called “reduced stiffness method” (RSM) has been applied to the lower-bound buckling analysis of FRP laminated shells. The RSM analysis has shown that the classical critical mode which gives the lowest reduced stiffness critical load is often different from the mode giving the minimum classical critical load. This paper presents a series of finite element numerical experiments to test the validity of the RSM. By examining the effects of initial imperfections in the form of the recognised classical critical modes, it is shown that the RSM provide a reliable lower-bound method for buckling design of FRP shells.

Session C	Chair: Prof. Klaus Rohwer (DLR)
Keynote lectures	
5th September	Time: 8.30

No. 4

Title: On the Purpose and Limitations of Buckling Analysis/ Evolution of analysis tools

Authors: E. Riks (SMR)

Contact: eduard.riks@mac.com

Abstract:

The discussion in this presentation is restricted to mechanical systems that are conservative or quasi-conservative. By quasi conservative we mean that the notion of conservatism holds as long as the changes of state occur infinitely slow. If changes of state occur with a finite rate of deformation, dissipative forces may come into play. Classic elastic stability theory studies the behaviour of engineering structures under the influence of their service loads with a special focus on the determination of the (maximum) load these structures can carry. This maximum load is determined by geometrical effects that result from the state of deformation and not (in the first place) by material failure mechanisms. It is important to realize that the classical theory is restricted to quasi static loading conditions. The load carrying capacity in this setting is reached at the deformation state at which any further increase of the loading will result in the destruction of the structure. The state where this change is about to occur is called the collapse state, the limit state, or the state of loss of stability. The theory categorizes these states also as (proper) limit points and unstable bifurcation points. In early applications of the theory, the actual collapse process - called snap through or snap buckling - was not deemed to be of particular interest and simply not considered. It should be added that the analytical tools in those days were not capable of solving the nonlinear partial differential equations of motion so that this transient phenomenon could be calculated. In fact, most applications remained restricted to the solution of the quasi-nonlinear buckling equations that arise when the pre-buckling state can be taken to be a linear function of the load intensity. Thus before the age of "computational mechanics", in the beginning of the 20th century, applications of stability theory remained restricted to problems that exhibited an initially linear pre-buckling state. This state of affairs did not change with the appearance of the perturbation theory of elastic stability conceived by Koiter. A mile stone in the development of the concept of buckling, this development offered a considerable gain in understanding of the way stability is lost or maintained at a bifurcation point. It explained the consequences of these properties for the behaviour of structures loaded into the neighborhood of such a point. It also provided a systematic derivation of an ordered sequence of linearized equations that determine the shape of the most important bifurcations that can be encountered. However, with the analytical means available at that time, these equations were no more accessible to computation than the well established linearized buckling equations. As a consequence, applications of Koiter's general theory remained also restricted to problems with a linear pre-buckling state. It was the advent of the computer and the surge of the numerical treatment of the classical theories of solid mechanics that gradually offered possibilities in computation that nobody would or could have dreamed of before. This revolution opened an approach in the solution of nonlinear equations that removed the necessity to restrict the analysis to initial linear behaviour. It

also removed the restriction to “static analysis only”. This means that the traditional assessment of the load carrying capacity on the basis of a quasi static loading process can presently be amended by transient analysis and even replaced by it. Moreover, these advances have now also paved the way to consider non classical definitions of stability loss. In particular, buckling induced by transient loading of short duration is presently studied as a possible potential critical loading case for certain buckling problems that are encountered in practice.

No. 5

Title: Looking for alternate ways to define Knockdown Factors

Authors: J. Arbocz (TU Delft)

Contact: J.Arbocz@tudelft.nl

Abstract:

A probability-based analysis method for predicting buckling loads of compression-loaded laminated composite shells is presented, and its potential as a basis for a new shell-stability design criterion is demonstrated and discussed. In particular, a database containing information about specimen geometry, material properties, and measured initial geometric imperfections for a selected group of laminated-composite cylindrical shells is used to calculate new buckling-load "knockdown factors". These knockdown factors are shown to be substantially improved and hence much less conservative than the corresponding deterministic knockdown factors that are presently used by industry. The probability integral associated with the analysis is evaluated by using two methods; that is, by using the exact Monte Carlo method and by using an approximate first-order second-moment method. A comparison of the results from these two methods indicates that the first-order second-moment method yields results that are conservative for the shells considered. Furthermore, the results show that the improved, reliability-based knockdown factor presented always yields a safe estimate of the buckling load for the shells examined.

No. 12

Title: Multiscale Approach for Determination of Stiffness and Strength of Textile Composites

Authors: C. Hühne, M. Vogler, G. Ernst, R. Rolfes (Leibnitz University Hannover)

Contact: c.huehne@isd.uni-hannover.de

Abstract:

Textile composites describe a broad range of polymer composite materials with textile reinforcements, from woven and non-crimp commodity fabrics to three dimensional textiles. In a general manner textile composites are based on textile preforms manufactured by some textile processing technique and on some resin infiltration and consolidation technique. Due to the complex three-dimensional structure of textile composites, experimental determination of strength parameters is not an easy procedure. Especially the through-thickness parameters are hardly to obtain. Therefore, in addition to real material testings, virtual material testings are performed by use of an information-passing multiscale approach. The multiscale approach consists of three scales and is based on computation of representative volume elements (RVE's) on micro-, meso- and macroscale. The micromechanical RVE enables to determine stiffness and strength

parameters of unidirectional fiber bundle material. Further, statistical distribution of fibers is investigated. The homogenized material parameters at microscale are used as input data for the next scale, the mesoscale. In the mesomechanical RVE, fiber architecture, in particular fiber undulations and the influence of through-thickness reinforcements, are studied. The obtained stiffnesses and strengthes are used as input for the macroscale. On macroscale, structural components are calculated. On each scale, numerical results are compared with experimental test data for validating the numerical models.

Session C1a	Chair: Prof. Werner Wagner (Uni. Karlsruhe)
Structure Tests	
4th September	Time: 10:30

No. 34

Title: Effect of cyclic post-buckling loads on CFRP panels

Authors: H. Abramovich (TECHNION), C. Bisagni, P. Cordisco (Politecnico di Milano)

Contact: haim@aerodyne.technion.ac.il, chiara.bisagni@polimi.it,
cordisco@aero.polimi.it

Abstract:

Experimental results obtained on four carbon fiber composite stiffened curved panels subjected to static and cyclic compression and shear loadings are discussed. Two of the four panels presented an initial delamination obtained with Teflon inserts between stringers and skin. Panels were assembled in two closed boxes using flat aluminum plates. This solution allows the application of shear on each panel by applying torque on the box. The first box was obtained using undamaged panels, while the second one assembling damaged panels. Results are described in terms of axial load vs. shortening curve, torque vs. rotation curve, deformed shape and strain measurements. Boxes were subjected to a cyclic post-buckling torque, allowing the investigation of the effect of cyclic buckling in terms of global and local behavior. The obtained results show that this kind of structures can well work in the post-buckling field even if during their operative life the buckling load is reached thousands of times.

No. 36

Title: Buckling and Postbuckling Behavior of Laminated Composite Stringer Stiffened Curved Panels under Axial Compression-Experiments and Design

Authors: H. Abramovich, T. Weller (TECHNION)

Contact: haim@aerodyne.technion.ac.il

Abstract:

The design of aerospace structures places great emphasis on exploiting the behavior and on mass minimization of such panels to reduce lifecycle costs. An optimum (minimum mass) design approach based on initial buckling, stress or strain, and stiffness constraints, typically yields an idealized structural configuration characterized by almost equal critical loads for local and overall buckling. This, of course, results in little postbuckling strength capacity and susceptibility to premature failure. However, an alternative optimum design approach can be imposed to achieve lower mass designs for a given loading by requiring the initial local buckling to occur considerably below the design load and allowing for the response characteristics known to exist in postbuckled panels, i.e. capability to carry loads higher than their initial buckling load. To meet the requirements of low structurally weight, advanced lightweight laminated composite elements are increasingly being introduced into new designs of modern aerospace structures for enhancing both their structural efficiency and performance. In recognition of the numerous advantages that composites offer, there is a steady growth in replacement of metallic components by composite ones in marine structures, ground transportation, robotics, sports and other

fields of engineering. In light of the above discussion, it has been suggested that permitting postbuckling to take place under ultimate load of fuselage structures, i.e. alleviation of design constraints, may provide a means for meeting the objectives for the design of next generation aircraft, where the demand is reduction of weight without prejudice to cost and structural life (see paper Vision 2020 of the European Community). This approach has been undertaken in an experimental study (Improved POSTbuckling Simulation for Design of Fibre COMposite Stiffened Fuselage Structures - POSICOSS project) as a part of an ongoing effort on design of low cost low weight airborne structures initiated by the 5th European Initiative Program. It was aimed at supporting the development of improved, fast and reliable procedures for analysis and simulation of postbuckling behavior of fiber composite stiffened panel of future generation fuselage structures and their design. Within the POSICOSS project, the Technion performed a long test series, on curved laminated composite stringer stiffened panels under axial compression, shear load introduced by torsion and combined axial compression and shear. The buckling and postbuckling behavior of these panels was recorded till their final collapse. The first part of this test series, dealing with panels PSC1-PSC9 was reported in the literature. The results of the tests with panels BOX1-BOX4, which deal with two identical panels, combined together by two flat non-stiffened aluminum panels, to form a torsion box, thus enabling application of shear tractions, through introduction of torsion, and combined axial compression and shear, were also reported. The present manuscript is aimed at describing the buckling and postbuckling behavior, test results and relevant numerical studies of another four panels, AXIAL1-AXIAL4, having J type stringers of the configurations. Based on the whole experimental work carried out within the framework of the POSICOSS project and employing one of the fast tools developed by the TECHNION, the effective width method modified for laminated composite panels, design guidelines were formulated and presented.

No. 35

Title: Repeated Buckling and Postbuckling Behavior of Laminated Stringer Stiffened Composite Panels with and without Damage

Authors: H. Abramovich, T. Weller (TECHNION)

Contact: haim@aerodyne.technion.ac.il

Abstract:

The performances of the air transport sector as a whole have almost reached a stage of leveling off. New breakthrough design concepts and technologies are needed to introduce a new era of air flight. Air transport demands are predicted to double in the next 10 – 15 years and triple in 20 years time. Involved with it, both the European and American aeronautical industries expect an operating cost reduction of 20% in the mean period followed by a further reduction of 50% in the long run. During its normal service life, a fuselage, which is composed of many curved laminated composite stringer stiffened panels, may experience a few hundreds of buckling-postbuckling cycles. Although it is well recognized that CFRP stiffened structures are capable of withstanding very deep post-buckling, yielding collapse loads equal to three - four times their buckling load, there exists scarce knowledge in the literature about the effects of repeated buckling on the global behaviour of the panels composing such fuselages. Very few results are available on how repeated buckling under combined loading influences the non-linear behaviour of aluminium cylindrical shells and CFRP aeronautical panels and their collapse modes, and on how far into the post-buckling region it is possible to increase loading without losing structural safety. Therefore, in light of the above, it is the aim of the present manuscript, to

contribute to the basic understanding and knowledge of the above topic, by summarizing the experimental and numerical results that were experienced and obtained within the COCOMAT consortium, during the years 2003-2008. Three laminated composite curved stringer stiffened panels, COCOMAT1, COCOMAT3 and COCOMAT4 were tested under repeated buckling. These panels were manufacture without nominal initial damage. The first panel had stringers similar to those used in the previous program, POSICOSS , while the other two had stringers with no drop-off layers .The panel COCOMAT2, a twin of COCOMAT3 and COCOMAT4, was tested under a static load to provide a reference point. To investigate the influence of damage on the repeated buckling of the panels, another five panels were tested, COCOMAT 7 till COCOMAT 9, COCOMAT 12 and COCOMAT 13. All these panels contained prescribed initial debonding of the three central stringers of the panel. Various damage sizes were introduced to amplify the phenomena. In parallel, in addition to the normal delaminations, impact was applied on the panels in the vicinity of the artificial delaminations, yielding additional damage to the panel. All of the panels were first tested under 2000 cycles with an axial compression load ranging from 0 to 1.5 of the first experimental detected buckling load, then followed by additional cycling in the range of 60k cycles. No degradation corresponding to the first 2000 cycles was detected. Numerical calculations, employing the ABAQUS FE code were performed. Comparisons were made between the experimental results and the corresponding theoretical/numerical ones.

No. 20

Title: Polish Aviation Works PZL-Swidnik – participation, results and experiences from COCOMAT project

Authors: M. Zeglen, P.Chojnacki, J. Ogiela (PZL)

Contact: marzena.zeglen@pzl.swidnik.pl, Chojnacki@pzl.swidnik.pl

Abstract:

The paper presents PZL-Świdnik activity in COCOMAT project with special focus on test activity. PZL-Swidnik performed various kind of tests beginning from characterization composite material properties investigation Then small undamaged and pre-damaged simple stiffened specimens were tested applying cyclic compressive loads. For final static buckling and cyclic compressive tests undamaged and pre-damaged composite stiffened panels were used. Each step of activity is detailed described and documented by acquired data, movies and pictures. The investigated material properties and small specimens test results were used for numerical analyses which showed predicted localization of first cracks and load level during final stiffened panels tests. Pre-test numerical computation results were compared with real test results. Finally PZL-Swidnik performed numerical computation using existing tools. The results were compared with test results. The paper also explains why PZL-Swidnik is interested in such projects like COCOMAT.

No. 13

Title: Buckling and collapse tests using advanced measurement systems

Authors: R. Degenhardt, D. Wilckens, K. Rohwer, M. Kepke, B. Hildebrandt, A. Zipfel (DLR)

Contact: richard.degenhardt@dlr.de

Abstract:

In the current design scenario for CFRP aircraft structures, the load carrying capacity of the structures is not fully exploited as the reserves in the post buckling area are not taken into account in the design process. This is difficult since degradation has to be considered in the simulation of the post buckling behaviour of the structures. In order to cover these effects, simulation procedures taking material degradation into account are developed in the running EU project COCOMAT, which have to be validated with experimental results. The present work focuses on the tests of 12 stringer-stiffened CFRP panels with a special interest on the skin-stringer separation. The load case considered here is axial compression under quasi-static loading. Half of the panels were undamaged and the other half were pre-damaged. In order to study the influence of degradation a part of the panels were also subjected to cyclic loading which means in this case repeated quasi-static loading. The tests were conducted in the DLR buckling test facility. Several advanced measurement systems, which have been proved to be suitable to monitor the deformation pattern of the panel as well as failure in the skin-stringer connection have been applied. The High-Speed ARAMIS System, which is based on photogrammetry, allows the full scale measurement of the deformations up to 4000 pictures per second. This is needed because the buckling scenario – even under static loading – is a highly dynamic process. The use of thermography allows detecting skin-stringer separation already during the experiment. Due to the local deformations, the structure is slightly heated in the damaged areas. As an additional method, piezo patches were placed at different positions of the structure to send and receive Lamb-Waves, the results of which indicate damages.

Session C1b	Chair: Dr Silvio Merazzi (SMR)
Unstiffened structures II / Analysis and validation II	
5th September	Time: 10.30

No. 50

Title: Empirical formula for the critical perturbation load

Authors: H. Wang (ASRI), A. Büschel (UKA), R. Degenhardt, K. Rohwer (DLR), W. Wagner (UKA), X. Sun (ASRI)

Contact: why623@hotmail.com, richard.degenhardt@dlr.de

Abstract:

Aerospace industry demands for significantly reduced development and operating costs. The use of composite materials promises to reduce structural weight and contributes so to this objective. However, for the design of unstiffened cylindrical shells the NASA SP-8007 design guideline from 19681 has to be applied. This guideline provides knock-down factors for the buckling loads depending only of the R/t (radius/thickness). The values are rather conservative and the structural behaviour of composite material is not considered adequately. Advanced thin-walled cylindrical shell structures under compression are therefore penalized if the knock-down factor based on this design guideline must be applied. One proposal for an improved design guideline is the Single-Perturbation-Load approach². This concept assumes that a single perturbation load, which is larger than the critical perturbation load, is leading to the worst imperfection. A Finite-Element calculation of an arbitrarily cylinder under axial compression and a perturbation load leads directly to the design load. A reduction of this buckling load by a knock-down factor from the NASA SP 8007 is not needed any more. However, the knowledge of the critical perturbation load is required. This paper presents investigations to develop an empirical formula for the critical perturbation load for metallic structures. It is the basis for the development of a formula for composite structures.

No. 54

Title: Investigations of axially loaded unstiffened CFRP cylindrical shells subject to single perturbation loads

Authors: P. Steinmüller, R. Degenhardt, K. Rohwer (Airbus, DLR)

Contact: mail@patrick-steinmueller.de

Abstract:

As the pressure on cost efficiency increases, the demand for a low structural weight grows. This can be achieved by using a lightweight design or/and materials with a high strength/stiffness to weight – ratio. Unstiffened cylindrical shells made out of Carbon Fibre Reinforced Plastic (CFRP) are one example of a very weight efficient structure in terms of axial load carrying capacity. These structures are critical in loss of stability, which occurs in form of snap through. As imperfections trigger the buckling, cylindrical shells never reach their theoretical buckling load. The large sensitivity to imperfection is a result of post-buckling modes, which can be reached with a very low amount of bending energy only. Geometrical- (shape, radius and height) and load- (additional bending or non-uniform compression) imperfections are the most important divergences according to

many authors. Hühne [1] showed by test and numerical analyses, that for both loading and geometrical imperfections loss of stability initiate with a single buckle. Therefore, unification of imperfection sensitivity is allowed. A local indentation is as well a realistic, worst and stimulating geometrical imperfection at the same time [5]. The knockdown factor (KDF, ρ) is defined to the ratio between the buckling loads of the imperfect and perfect cylinders. Due to absent of a robust and reliable method, the well-known standard NASA SP-8007 from 1968 [2] is still frequently used to find ρ . Nevertheless, to use this lower band of test results is the simplest and most conservative way at the same time. It can be shown, why to do so impede lightweight design. The SP-8007 orthotropic KDF is in the region of the one for isotropic material and does not take into account the stacking sequence properly. This factor mainly depends on the R/t-ratio and is independent of material stiffness. However, Table 1 highlights, that just by changing the stacking sequence, the KDF can change dramatically. In addition, even the same design tested twice can result in two largely different buckling loads. When Z30 is analysed with different real measured geometrical imperfections, the results show KDFs between 0.68 and 0.95. It can be shown as well with numerical analyses that the differences between Z26 and Z09 are not coming from different shapes. A short explanation of the selected lay-ups listed in Table 1 shall be given. The cylinder Z26 has a buckling load near the optimum for a $[\pm\alpha/\pm\beta]$ lay-up. In order to investigate the relevance of the stacking sequence for the new concept, for Z09 and Z10 the lay-up has been reversed and swapped. Z30 has the optimum buckling load for a laminate with five $[\pm\alpha]$ double layers. Here ρ means the ratio between the test and ABAQUS results and for Z30 the value is based on the second test result. Within ABAQUS, a non-linear solution with perfect geometry has been used. The stacking sequence direction is always from in- to outside the cylinder and the effective free length $L=510\text{mm}$.

No. 18

Title: Non-Linear analysis of stiffened composite boxes under combined loading

Authors: C. Vrettos, E. Karachalios, Z. Marioli-Riga, C. Bisagni, P. Cordisco, O. de Zarate Alberdi, A. Caruso (HAI, Politecnico di Milano, AGUSTA)

Contact: karachalios.evaggelos@haicorp.com

Abstract:

The work presented herein concerns the numerical simulation of a closed stiffened composite box subjected to compression followed by torsion loading up to failure. The objective is to validate the numerical model and detect any deficiencies of the modelling procedure. For the purpose of numerical correlation between the FE model and the experiment, a series of quantities are plotted versus the load progression: strains, displacements, deformation plots and load – displacement curves. The physical test article also contains artificial stringer – skin debondings realised via Teflon film. The energy release rates are calculated at the debonding front using a specially developed software tool. The FE model is generally stiffer than the actual structure but the numerical results are in a reasonable level of agreement with the experimental data. Finally, it was observed that the modelling of the potted part of the test article has a strong impact on the stiffness of the FE model.

No. 46
Title: Instability and collapse of sandwich shells; representing a/c wing skins
Authors: V. Weissberg, T. Genosar, G. Ghilai (IAI)
Contact: vweisbrg@iai.co.il

Abstract:

The instability and the failure mode of nearly cylindrical sandwich shells, loaded in torsion, were investigated by theoretical calculation, Finite Element Analysis and finally verified by two parametric test specimens. Limited studies on composite wing boxes have been reported (Ref. 1-3), but they are all for solid laminate skins and none for thin composite sandwich shell skins. The purpose of this work was to develop analysis methodology for the prediction of instability (buckling) and collapse (failure) of light weight sandwich shells. The results are to be used in the design of GA (general aviation) structures. In order to achieve this goal it was necessary to answer several questions.

Session C2a	Chair: Prof. H. Reimerdes (RWTH Aachen)
Degradation II	
5th September	Time: 13.10

No. 51

Title: Advanced non linear failure analysis of a reinforcement composite curved beam with delamination and ply degradation

Authors: C. Brauner, Y. Radovicic, Jean-Pierre Delsemme, P. Jetteur (SAMTECH)

Contact: christian.brauner@samcef.com

Abstract:

In the design of composite structures, one of the main challenges is to deal with delamination. In fact, delamination appears mainly near edges, junction, macro defects or zones of external loading because of the three-dimensional state of stress which occurs in these regions. In this report it is shown how to simulate a failure of a reinforcement composite curved beam which is according to the ASTM norm 6415. The geometries and material data are given by the company AIRBUS. This article based on a benchmark which was done in the past to show the capabilities of the software SAMCEF to AIRBUS. The FE model of the test case was crated as parameterized model. It is a four point bending test witch takes into account the following aspects: large displacements, flexible rigid contacts between the cylinders and the specimen, a bilinear material behaviour (Different young modules for tensile and compression), delamination between 5 different plies and ply degradation.

No. 53

Title: Residual strength prediction of impacted composite sandwich structures

Authors: A. Wetzel (Ferchau), J. Baaran (DLR)

Contact: wetzel.anja@web.de

Abstract:

The paper presents two methods for predicting the in-plane compression strength of impact damaged sandwich structures. For developing these methods uniaxial in-plane compression tests of impact damaged unsymmetrical sandwich coupons are conducted. The specimens were made of two CFRP face sheets of different thickness and an embedded honeycomb core. Low velocity impacts from 1 J up to 15 J caused varying amounts of core and face sheet damage and a dent in the impacted face sheet. While increasing the in-plane compression in the residual strength tests, the dent grew in depth and transverse to the loading direction until final failure of the impacted face sheet occurred. This phenomenological observation is reproduced in computational simulations. The simulations use either an efficient finite element model or a semi-analytical Ritz approach including non-linear displacement-strain relations and progressive damage growth in the core. For the latter stress-based failure criteria and stiffness degradation models are applied. Residual strength criteria are developed depending on the numerical solver. The comparison of simulation and test results demonstrates that the presented methods are able to predict the damage tolerance of unsymmetrical sandwich structures.

For damages due a high-energy impact the simulations show that the face sheet damage has to be included in the model. Including the face sheet damage into the semi-analytical model increases the computational time tremendously. Therefore, the semi-analytical model should be used only for impact damages with negligible face sheet damage.

No. 25

Title: Analysis of damage sensitivity and collapse in postbuckling fibre-reinforced multi-stiffener panels

Authors: A. Orifici, S. Lauterbach, H. Abramovich, R. Thomson, W. Wagner, C. Balzani (CRC-ACS, TECHNION, University Karlsruhe)

Contact: a.orifici@crc-accs.com.au

Abstract:

A carbon fibre-reinforced polymer (CFRP) multi-stiffener panel was analysed under postbuckling loads until collapse in both intact and pre-damaged configurations. An analysis tool was applied that included an approach for predicting interlaminar damage initiation and degradation models for capturing interlaminar damage growth and in-plane damage mechanisms. Analysis of the panel in the intact configuration predicted collapse due to fibre fracture in the stiffeners close to the panel clamps, which agreed well with results from experimental testing. A pre-damaged configuration was proposed that used three Teflon-generated skin-stiffener debonds. An analysis of this configuration showed that crack growth in the skin-stiffener interfaces from the Teflon debonds was not predicted to occur, which agreed with observations from experimental testing. A parametric study was conducted to investigate the effect of the skin-stiffener damage parameters such as length, width and location on the crack growth and collapse behaviour of the panel. It was found that the sensitivity of the panel design to the damage parameters was dependent on the postbuckling mode shape or displacement pattern, and particularly the extent to which this influenced the conditions at the crack front. More broadly, the analysis tool was shown to be capable of capturing the critical damage mechanisms leading to collapse in postbuckling for CFRP stiffened structures.

No. 62
Title: Progressive fracture of stitched stiffened composite shear panels in the post buckling range
Authors: F. Abdi, D. Huang (Alpha STAR Corporation)
Contact: fabdi@alphastarcorp.com

Abstract:

Progressive damage and fracture of stitched J-Stiffened composite panels under shear loading is evaluated via computational simulation. The objective of this paper is to demonstrate the postbuckling range application of a new multi-scale methodology that scales up constituent material properties, stress and strain limits to the structure level, to evaluate the overall damage and fracture propagation for stitched laminates. Stiffened panels with different lay-up configurations are simulated for various damage stages, including damage initiation, growth, accumulation, and progression to fracture. Postbuckling analysis is also included to evaluate progressive fracture characteristics after local buckling of the skin. Results are compared with experimental data from the literature (Figure 1). It was determined that: 1) Postbuckling effects have a significant influence on the ultimate collapse load of quasi-isotropic stiffened shear panels; 2) Computational simulation without considering the postbuckling mode over predicts the collapse load by approximately 35 percent and the stiffness is over predicted by 7.6 percent.; 3) It was found that ply configuration significantly affects the strength of stitched composite panels under shear loading; 4) Damage volume and/or damage energy can be used to evaluate the overall degradation stages of a structure; and 5) Computational simulation provides an effective means for parametric design investigations of stiffened and stitched composite structures.

No. 39
Title: Damage prediction and its effect on post-buckled wing design
Authors: C. Williamson, S. J. Lord (QinetiQ)
Contact: cwilliamson@QinetiQ.com, sjlord@QinetiQ.com

Abstract:

Over the last few years there has been an increase in the use of laminated carbon fibre reinforced plastics (CFRPs) in military and civil aerostructures, mainly due to their superior specific strength and stiffness. Reducing the extent of mechanical fasteners by co-curing, co-bonding or secondary bonding the stiffeners to the skin offers the possibility of significantly lighter structures and lower production costs. Additionally, stiffened composite structures have been shown to be able to support load beyond initial local skin buckling. However, the confidence in composite structure designs which allow buckling has yet to be widely adopted, predominately due to the unpredictability of their degradation during post-buckle loading. This unpredictability stems from a number of complicated failure mechanisms and how they are affected by buckling mode-switching behaviour. This paper discusses prediction methods of structural buckling and damage modelling in postbuckling stiffened composite structures under uniaxial compression. Good agreement has been obtained with experimental results. Implications of the effect of in-service damage on postbuckled panels are then discussed. The work has provided confidence in the use of a promising tool for future design as well as suggesting how post-buckled design can be used in the optimisation of future aerostructures.

Session C2b	Chair: Dr Kaspars Kalnis (RTU)
Optimisation	
5th September	Time: 13.10

No. 47

Title: A stochastic study on the robustness of a stiffened composite structure

Authors: M. C. W. Lee (UNSW), R. S. Thomson (CRC-ACS), R. Degenhardt (DLR), D. W. Kelly (UNSW)

Contact: merrill.lee@student.unsw.edu.au

Abstract:

COCOMAT is an ongoing four year European Commission project aimed at exploiting the large reserve of strength in composite structures through more accurate prediction of collapse. As part of the research program, curved stiffened composite panels of various designs have been manufactured and tested in compression. In the current pool of experiments it is possible to observe the scatter in results caused by manufacturing defects and material variations. In order to gain more insight into the results, a stochastic framework has been developed where variations are introduced into the finite element analyses and the effects measured. An issue arises as to what the stochastic boundaries should be, and the how this affects the final result. In a bid to understand how the stochastic method can be useful in future analyses a design criterion, robustness, has been used. A qualitative measure of robustness in the form of a Robust Index has been derived so that comparisons between the results achieved can be made.

No. 37

Title: Multi-level postbuckling optimum design of aerospace structures

Authors: C. A. Featherston, D. Kennedy, S. Qu (Cardiff University)

Contact: FeatherstonCA@cardiff.ac.uk

Abstract:

Mass optimisation of aircraft structures consisting of stiffened panels subject to buckling requires consideration of the often substantial postbuckling reserves of strength available. Due to the level of complexity involved in optimising structures such as the wings and fuselage of an aircraft, this process can be undertaken most efficiently using a multilevel approach. The software Viconopt MLO has been developed to achieve such an approach, acting as an interface between the exact strip software VICONOPT and the finite element analysis programme MSC/NASTRAN. This paper describes the extension of this multi-level approach to cover postbuckling optimum design.

No. 58

Title: Optimisation of Composite Aircraft Structures in Consideration of Postbuckling Behaviour

Authors: G. Schuhmacher, M. Wagner, A. Hörmann, F. Daoud (EADS-MAS)

Contact: Gerd.Schuhmacher@eads.com

Abstract:

The structural design of an airframe is determined by multidisciplinary criteria (stress, fatigue, buckling, control surface effectiveness, flutter and weight etc.). Several thousands of structural sizes of stringers, panels, ribs etc. have to be determined considering hundreds of thousands of requirements to find an optimum solution, i.e. a design fulfilling all requirements with a minimum weight or minimum cost respectively. The design process involves various groups of the airframe manufacturer and its suppliers, and requires the application of complex analysis procedures to show compliance with all design criteria. Traditionally the conceptual design of an aircraft is determined by the design group as well as the stress group of the airframe manufacturer or its supplier. This is done by generating an initial design based on the designers experience which is then analyzed by the stress group in order to determine the stress and buckling reserves for a few selected load cases. Based on experience and fully stressed design methods the structural sizes are modified, until the strength criteria are satisfied.

No. 41

Title: A fast optimization technique for preliminary sizing of anisotropic composite stiffened panels

Authors: J. E. Herencia, P. M Weaver, M. I. Friswell (Uni. Bristol)

Contact: j.e.herencia@bristol.ac.uk

Abstract:

A fast optimization technique is presented for preliminary sizing of anisotropic composite stiffened panels. The optimization consists of two steps. At the first step, a representative skin-stiffener assembly (superstiffener) of the composite stiffened panel is optimized using continuous optimization of lamination parameters under strength, local and global buckling and practical design constraints. For computational efficiency, buckling constraints are provided in terms of closed form solutions and conservatism is partially removed by considering the skin-stiffener interaction. At the second step, a genetic algorithm is used to identify the actual superstiffener's laminates. The fitness function in the genetic algorithm is formed by the first step constraints, instead of the traditional lamination parameter distance. Studies will be conducted for certain loading conditions and geometries to examine the optimisation process as well as the effect of the constraints on the skin and stiffener geometry and final lay-up.

No. 45

Title: Buckling and collapse of shell structures: sensitivity analysis

Authors: M. Oberguggenberger, J. King (University of Innsbruck)

Contact: michael.oberguggenberger@uibk.ac.at

Abstract:

This article addresses the issue of buckling failure of shell structures. We argue that a good understanding of the shell behaviour near the limit state can and should be addressed through sensitivity analysis, that is, the assessment of the impact of individual input parameters (loads, material constants, geometry) or sets of input parameters on the failure of the structure. A major challenge in most applications lies in the fact that high computational costs have to be faced. Methods have to be developed that admit assertions about the sensitivity of the output with as few computations as possible. This article presents a number of sensitivity indices based on Monte Carlo simulation techniques. We developed these methods in a project from aerospace engineering with light weight shell structures. We believe that the methods will be useful in composite laminated structures, where equally high computational costs are the rule. A thorough understanding of the sensitivities of a structure can ultimately serve as a robust basis for design guideline.

Session D	Chair: Mrs Gila Ghilai (IAI)
Design handbooks	
5th September	Time: 15.20

No. 6

Title: Structural Mechanics in the Design Process of Composite Aircraft Structures

Authors: J. Tessmer (DLR)

Contact: jan.tessmer@dlr.de

Abstract:

Innovative composite technologies call for fast and reliable methods in structural mechanics for the design of safe and high performance aircraft structures. Providing high fidelity simulation methods is therefore an important demand to the research community. Starting with the manufacturing process, multi-physical modelling is necessary for optimal manufacturing processes. Also, accurate material models, failure criteria and degradation approaches have to account for intelligent industrial manufacturing technologies. On this basis an accurate prediction of the load bearing capacity up to collapse can be derived. It is a goal, to account for these models and methods already in the early design stage, therefore giving clear guidance within design handbooks for their practical use. Finally, this approach should allow for competitive aircraft development.

No. 10

Title: E.C.S.S. Buckling handbook

Authors: A. Calvi (ESA)

Contact: adriano.Calvi@esa.int

Abstract:

The objective of the ECSS E-HB-32-24 Buckling Handbook (BH) is to merge the information necessary for proper evaluation of buckling loads, including the robustness of this evaluation and the related margins, both for structures and structural elements of space systems. An outline of the draft issue of the proposed handbook, with a synopsis of each section, has been developed and is presented herein. The so called "Public Review" of the BH is presently foreseen beginning of 2009 with the aim of raising formal comments from the aerospace community to be later on processed by the BH Working Group. The Public Review will be conducted via the "ECSS Book Shelf" which is the electronic repository for the ECSS non-normative documentation. The ECSS Book Shelf is a "wiki" i.e. a collection of web pages designed to enable anyone who accesses it to contribute or modify content, using a simplified mark-up language. Comments on the proposed handbook are solicited from the scientific community and industry.

No. 11
Title: HSB - A Handbook for Fundamentals and Methods for Aeronautical Design and Analyses
Authors: M. Schagerl (Airbus)
Contact: martin.schagerl@airbus.com

Abstract:

The lecture presents the project of the Handbook Structure-Analysis (HSB). The HSB is issued by the Industry-Committee for Structure-Analysis (IASB), which was founded in 1968. Currently the IASB counts more than 30 active members from aeronautical industries, research and academic institutions, and civil and military authorities. The content of the HSB is updated continuously. The latest version of the HSB has 2300 pages and covers topics on definitions, materials, joints, static analyses, static stability, static strength, fatigue and damage tolerance, and vibrations. Typically the HSB is applied in different development phases of aeronautical products, e.g. preliminary and final design of structural dimensions, definition of structure tests, agreement of methods with suppliers, basis for the choice of materials or basis for the qualification of materials for suppliers. The HSB is not for sale and is intended only for the use of selected recipients, which are identified by the issuing committee IASB.

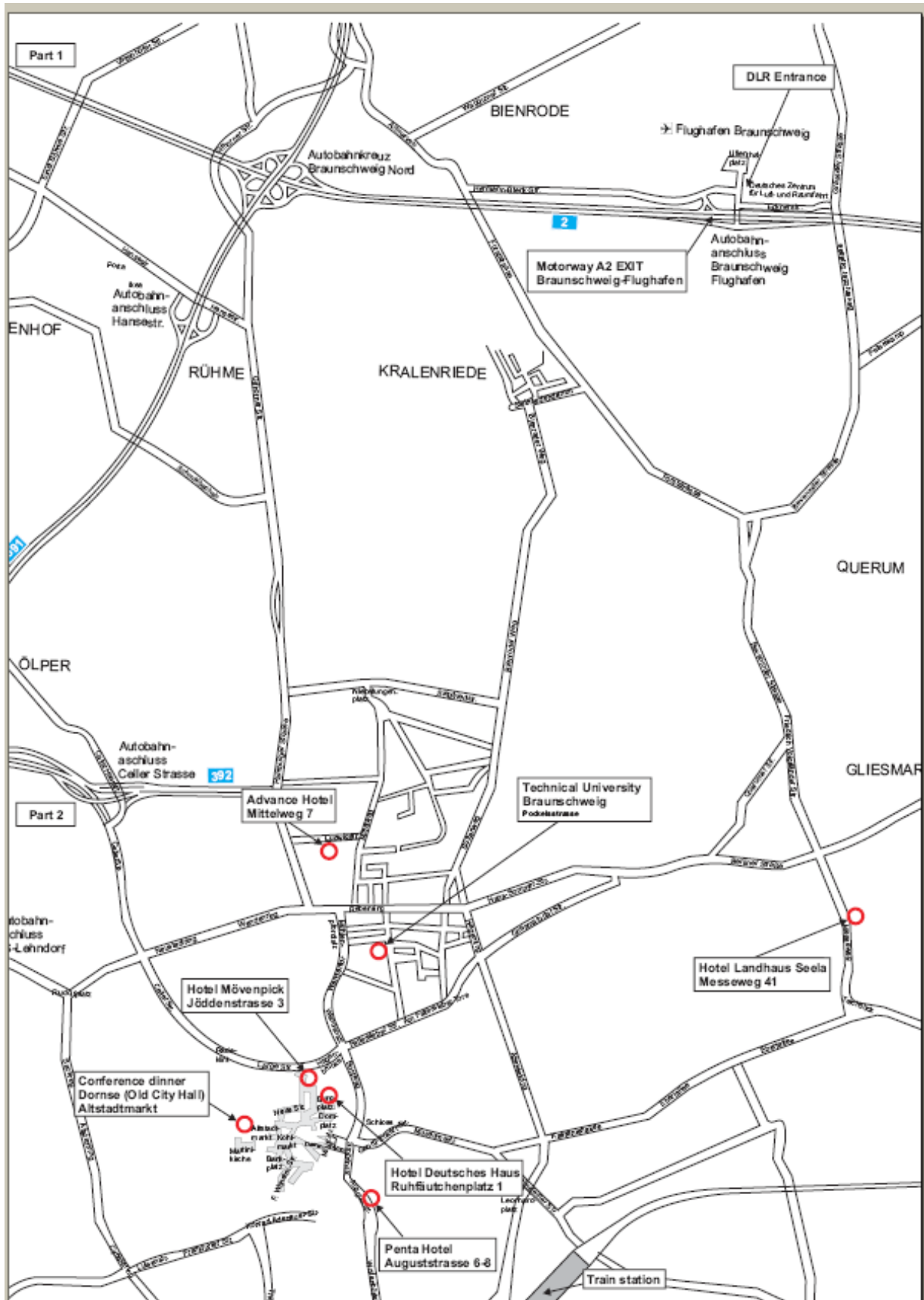
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No. 65
Title: A parametric study for the design of stiffened composite panel
Authors: Hao Wu, Ying Yan (Beihang University)
Contact: wuhao1212@foxmail.com

Abstract:

A parametric study is conducted for the design of stiffened composite panel (SCP). A SCP with two stiffeners, loaded under uniaxial compression load is studied, where effects of stiffener thickness and distance on the critical buckling behaviour of the SCP are investigated. It is illustrated that stiffener has an effect of boundary condition on the skin, and an optimal structural efficiency exists when this effect is significant enough. The boundary condition effect makes the whole SCP buckles as local skin buckling and its critical buckling behaviour is dominated by the local skin buckling with the lowest critical buckling load. The parametric study provides designer with comprehension of the stiffener/skin enhancement in the buckling behaviour of the SCP, serving for the design of SCP in the future.

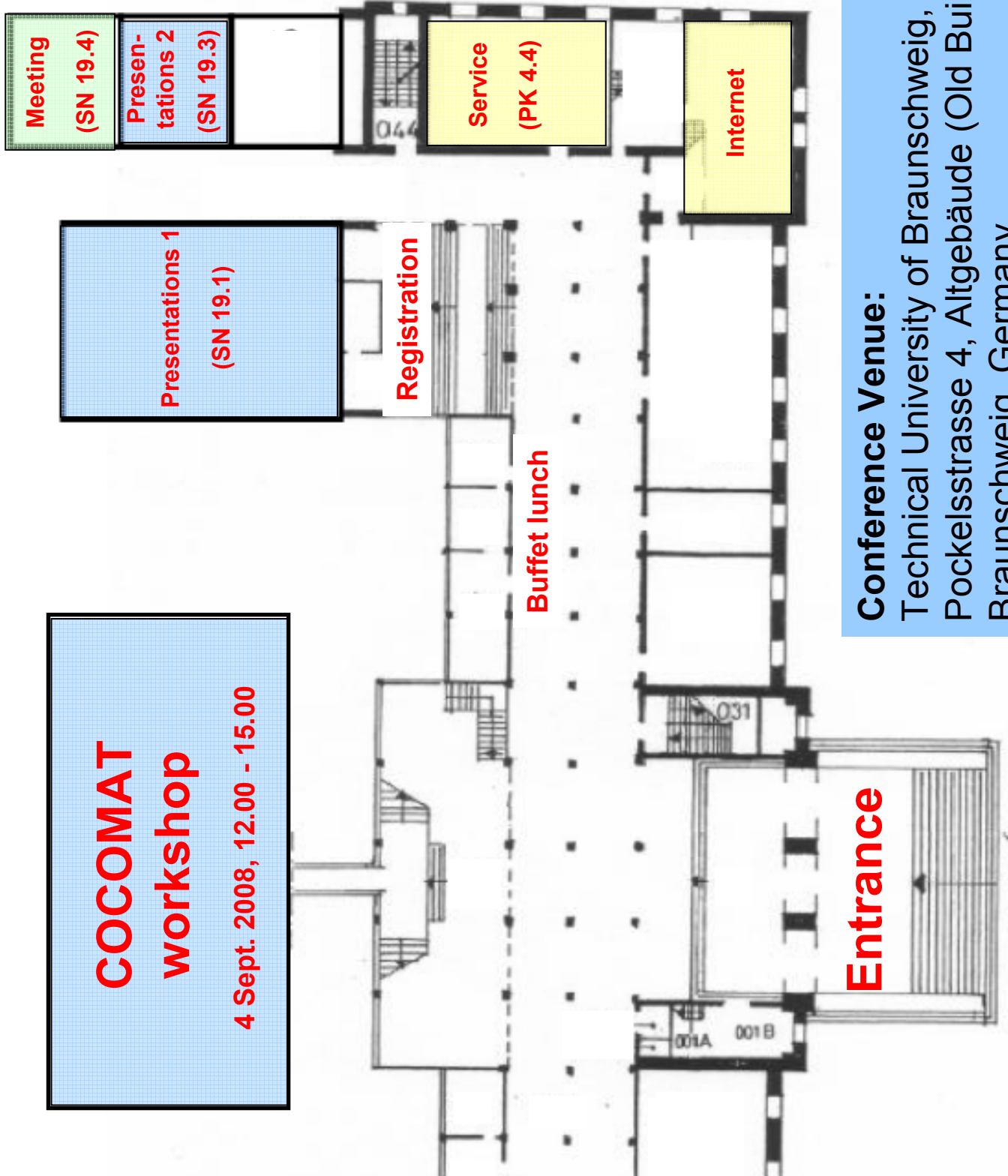
Braunschweig – city map (location of the conference, hotels, dinner event and DLR)



Technical University Braunschweig - map



Conference building - room plan



Conference Venue:
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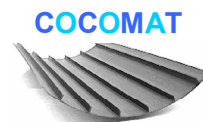
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COCOMAT consortium

www.cocomat.de



Deutsche Gesellschaft für Luft- und Raumfahrt Lilienthal-Oberth e.V. (German Society for Aeronautics and Astronautics)

www.dglr.de



Private Fachhochschule Göttingen (Private University of Applied Sciences Göttingen)

www.pfh.de



Technical University of Braunschweig

www.tu-bs.de



City of Braunschweig

www.braunschweig.de



Composite Technology Center Stade



CFK Valley Stade

www.cfk-valley.com



SAMTECH S.A.

www.samcef.com



AIAA – American Institute of Aeronautics and Astronautics

www.aiaa.org

