3rd Int. Conference on

Buckling and Postbuckling Behaviour of Composite Laminated Shell Structures

with

DESICOS[1] Workshop

25-27 March 2015

Final program

Status: 19 March 2015

Organiser:

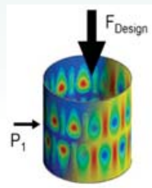
DLR (German Aerospace Center), Institute of Composite Structures and Adaptive Systems, Braunschweig, Germany

Conference Place:

Technical University of Braunschweig, Pockelsstrasse 4, Braunschweig, Germany

www.desicos.eu

1 **DESICOS is a running EU project and stands for:**
New Robust **DESI**gn Guideline for Imperfection Sensitive **CO**mposite Launcher **S**tructures



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Keynote speakers

1) **Prof. Hansjörg Dittus** (DLR, Member of executive board, responsible for space)
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2) **Prof. JN Reddy** (Texas AM University)
Refined theories and finite element models for the analysis of laminated composite structures: An overview

3) **Dr. Mark Hilburger** (NASA, Senior researcher)
Recent Developments in the Analysis and Testing of Large-Scale Buckling-Critical Cylinders

4) **Dr. Jochen Albus** (Airbus, Senior expert)
Parametric Instability of Pressurized Propellant Tanks

5) **Dr. Peter Linde** (Airbus)
Structural Modelling and Simulation of Aircraft Composite Structures; State of the Industry

6) **Prof. Andreas Rittweger** (DLR, Head of the Institute of Space Systems)
Pre-Dimensioning of Launch Vehicles due to Booster Load Introduction based on Semi-Analytical Methods

7) **Prof. Jan Blachut** (University of Liverpool)
Composite spheroidal shells under external pressure

8) **Prof. Brian Falzon** (Royal Academy of Engineering - Bombardier Chair in Aerospace Composites, Queen's University Belfast)
Modelling damage in thin-walled composite structures

9) **Prof. Christian Hühne** (DLR, Institute of Composite Structures and Adaptive Systems, Head of department Composite Design)
Single perturbation load approach – From the initial idea until today

10) **Dr. habil. Christian Mittelstedt** (SOGETI High Tech GmbH, Hamburg)
Recent developments in the rapid and efficient closed-form analytical modeling of buckling problems in composite lightweight engineering

11) **Dr. Tobias Wille** (DLR, Institute of Composite Structures and Adaptive Systems, Head of department Structural Mechanics)
Challenges in Structural Mechanics of Composite Structures

12) **Prof. Ralf Cuntze** (retired)
Reliable strength design verification - Fundamentals, requirements and some hints

13) **Dr. John Hart-Smith** (retired)
The use of simple strain-energy concepts to debunk the classical thin-shell buckling analyses for once and for all

Aim of the conference and workshop

Conference and workshop are primarily organised as the final events of the running EU project DESICOS demonstrating its results. The scientific community and industry in general are invited to attend. Both events aim to promote discussion and 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 DESICOS project. In addition, papers with recent results on the same topic but from outside the project are as well accepted.

Within the ***workshop*** new software related to improved simulation of composites, improved design tools or test structures developed within DESICOS but also outside the project, are presented and demonstrated.

History
The present conference follows the two conferences from the past:
1st Int. Conference on Buckling and Postbuckling Behaviour of Composite Laminated Shell Structures Eilat, Israel, 1-2 March 2004, demonstrating results from the EU project POSICOSS, www.cocomat.de.

2nd Int. Conference on Buckling and Postbuckling Behaviour of Composite Laminated Shell Structures Braunschweig, Germany, 5-7 September 2008, demonstrating results from the EU project COCOMAT, www.cocomat.de.

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

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

All topics shall focus on various Composite Laminated Shell Structures under different states of loading.

EU project DESICOS

The running EU project DESICOS (New Robust DESIgn Guideline for Imperfection Sensitive COmposite Launcher Structures) is a Level 1 Project within the 7th Framework Programme. It started February 2012 and will be finished in July 2015.

DESICOS aims to exploit considerable reserves in the capacities of imperfection sensitive composite launcher structures by applying the Single Perturbation Load Approach (SPLA), which assumes that a large enough disturbing load leads to the worst realistic geometric imperfection, combined with a Specific Stochastic Approach to take into account load imperfection, thick-ness imperfection, etc. Currently, imperfection sensitive shell structures prone to buckling are designed according to the NASA SP 8007 guideline using the conservative lower bound curve. The guideline dates from 1968, and the structural behaviour of composite material is not considered appropriately, in particular since the imperfection sensitivity and the buckling load of shells made from such materials depend on the lay-up design. NASA SP 8007 design guidelines allows designing only so called "black metal" structures. Therefore there is a high need for a new precise and fast design and testing approach.

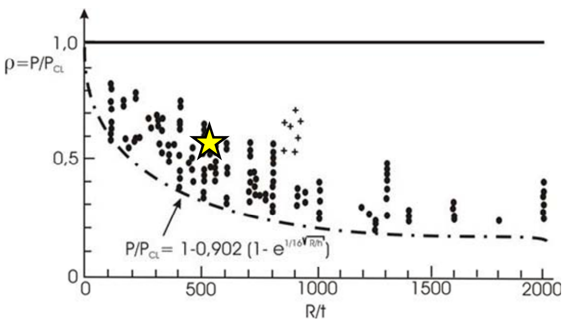
The project results comprise an experimental data base, new design approaches for imperfection sensitive structures and new design recommendations.

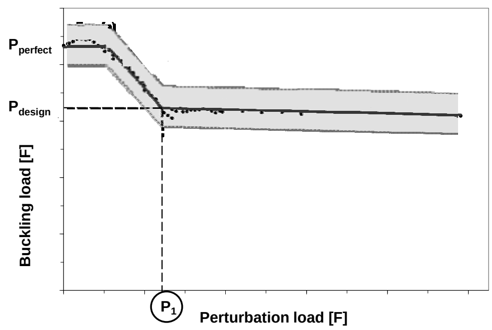
More details can be found at www.desicos.eu.

Current design scenario: (NASA SP 8007)

DESICOS

Future design scenario: Single Perturbation Load Approach (SPLA) + Stochastic Approach





$$P_{design} = P_{perfect} * \rho_{NASA}$$

ρ_{NASA} = Knock down factor NASA SP-8007

- Depends only on radius and thickness
- Potential of composite material can not be considered appropriately

$$P_{design} = P_{perfect} * \rho_1 * \rho_2$$

ρ_1 = Knock down factor *SPLA*

ρ_2 = Knock down factor *Stochastic Approach*

- Approach applicable to any material
- Potential of composites fully exploited

Committees

Chairman
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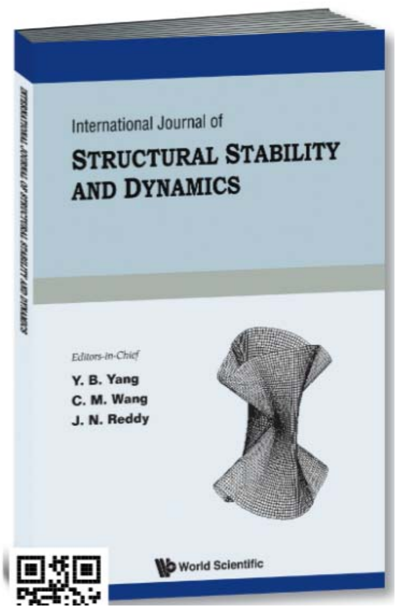
Prof. Klaus Rohwer, DLR, Braunschweig, D
Prof. Andreas Rittweger, DLR, D
Dr Rolf Zimmermann, DLR, Braunschweig, D
Prof. Zafer Gürdal, Skoltech, Russia
Prof. Mostafa M. Abdalla, TU-Delft, NL
Dr Martin Ruess, TU-Delft, NL
Prof. Eelco Jansen, Leibniz University, Hannover, D
Prof. Raimund Rolfes, Leibniz University, Hannover, D
Prof. Murray Scott, CRC-ACS, Melbourne, AUS
Prof. Ganga Prusty, CRC-ACS, Melbourne, AUS
Dr Rodney Thomson, CRC-ACS, Melbourne, AUS
Prof. Chiara Bisagni, TU-Delft, Delft, NL
Dr Kaspars Kalnins, RTU, Riga, Latvia
Prof. Hans-G. Reimerdes, RWTH, Aachen, D
Prof. Haim Abramovich, TECHNION, Haifa, IL
Mr. Patrice Blanchard, ASTRIUM-F, F
Mr. Jesus Gomez, ASTRIUM-D, D
Dr. Jochen Albus, ASTRIUM-D, D
Mr. Avi Wieder, GRIPHUS, Haifa, IL

Publications

Conference handout:
Will contain all short abstracts giving an overview

Conference CD:
Will contain all extended abstracts

Special issue
Selected presentations of high quality will be published in a special issue of the Int. Journal of Structural Stability and Dynamics.



List of presentations

	No	Country	Authors	Title
Keynote speakers	A01	Germany	Hansjörg Dittus (DLR, Member of executive board, responsible for space)	Reusability – DLR´s new R&D-programme for launch technologies
	A02	Germany	Ralf Cuntze	Reliable strength design verification - Fundamentals, requirements and some hints
	A03	USA	Mark Hilburger (NASA, Senior researcher)	Subscale and Full-Scale Testing of Buckling-Critical Launch Vehicle Structures
	A04	Germany	Andreas Rittweger (DLR, Head of Institute of Space Systems)	Pre-Dimensioning of Launch Vehicles due to Booster Load Introduction based on Semi-Analytical Methods
	A05	Germany	Christian Hühne (DLR, Head of department Composite Design)	Single perturbation load approach – From the initial idea until today
	A06	USA	JN Reddy (Texas AM University, USA)	Refined theories and finite element models for the analysis of laminated composite structures: An overview
	A07	Germany	Peter Linde (Airbus)	Structural Modelling and Simulation of Aircraft Composite Structures; State of the Industry
	A08	Australia	John Hart-Smith	The use of simple strain-energy concepts to debunk the classical thin-shell buckling analyses for once and for all
	A09	Germany	Tobias Wille (DLR, Head of department Structural mechanics)	Challenges in Structural Mechanics of Composite Structures
	A10	Germany	Christian Mittelstedt (Sogeti)	Recent developments in the rapid and efficient closed-form analytical modeling of buckling problems in composite lightweight engineering
	A11	UK	Jan Blachut (University of Liverpool)	Composite spheroidal shells under external pressure
	A12	Germany	Jochen Albus (Airbus, Senior expert)	Parametric Instability of Pressurized Propellant Tanks
	A13	UK	Brian Falzon (Royal Academy of Engineering - Bombardier Chair in Aerospace Composites, Queen's University Belfast)	Modelling damage in thin-walled composite structures
ESICOS partners	B01	Germany	R. Khakimova, S. Castro, R. Degenhardt, D. Wilckens, M. Kepke, B. Hildebrandt, F. Odermann (DLR, PFH)	Buckling experiments on imperfection sensitive thin-walled structures using additional perturbation loads
	B02	Germany	R. Khakimova, R. Degenhardt (DLR)	Assessment of the Single Perturbation Load Approach on composite conical shells
	B03	Germany	R. Wagner, C. Hühne (DLR)	Numerical investigation on experimental buckling loads of unstiffened cylindrical composite shells with varying ratio of radius/wall thickness
	B04	Germany	D. Degenhardt, M. Hilburger, S. Castro, R. Khakimova, R. Degenhardt (DLR, NASA, Embraer, PFH)	Buckling studies under non-uniform loading
	B05	Germany	C. Wolff, D.Wilckens (DLR)	Testing and Modelling of impact damaged orthotropic stiffened CFRP-Panels
	B06	Germany	D. Wilckens, F. Odermann (DLR)	Buckling and Post Buckling of Stiffened CFRP Panels under Compression and Shear
	B07	Germany	S. Freund, A. Sauerbrei, R. Zimmermann (DLR)	Multilevel Skin Buckling Analysis using Hierarchical Metamodels
	B08	Germany	F. Odermann, M. Geier (DLR)	Buckling tests of unstiffened cylindrical composite shells under dynamic axial pulse loading
	B09	Germany	F. da Cunha, T. Wille, R. Degenhardt, M. Sinapius (DLR)	Structural Robustness Assessment of Thin-Walled Composite Structures in the Postbuckling Regime
	B10	Germany	R. Degenhardt (DLR, PFH)	New Robust Design Guideline for Imperfection Sensitive Composite Launcher Structures - The DESICOS project
	B11	Australia	J. Kepple, M. Herath, G. Pearce, G. Prusty, R. Thomson (CRC-ACS, University of New South Wales, Advanced Composite Structures Australia)	Stochastic analysis of imperfection sensitive composite cylinders using realistic imperfection models
	B12	Germany	S. Castro, R. Khakimova , G. Ziegmann, D. Degenhardt, R. Degenhardt, Mark Hilburger (PFH, DLR, TU Clausthal, Sogeti, NASA)	Simulation of geometric imperfections and uneven edges in thin-walled cylinders
	B13	France	P. Blanchard (Airbus)	WP 5 Contribution to improved design guidelines
	B14	Italy	C. Bisagni (Politecnico di Milano)	Overview of FP7 Project DAEDALOS - Dynamics in Aircraft Engineering Design and Analysis for Light Optimized Structures
	B15	Nether-lands	K. Liang, M. Ruess (TU-Delft)	New robust knock-down factors for the stiffened cylinder

	No	Country	Authors	Title
DESICOS partners	B16	Netherlands	M. Ruess (TU-Delft)	WP 3 Development of new design methods
	B17	Germany	E.L. Jansen, T. Rahman, R. Rolfes (Uni. Hannover, TNO DIANA BV)	Towards mode selection criteria for multi-mode initial postbuckling analysis of composite cylindrical shells
	B18	Germany	A. Meurer, M. Dannert, R. Rolfes (Leibniz University Hannover)	New Design Approach for Axially Compressed Composite Cylindrical Shells combining the Single Perturbation Load Approach and Probabilistic Analyses
	B19	Germany	E. Jansen, H. Abramovich, R. Rolfes (Leibniz University Hannover, TECHNION)	Improving the vibration correlation technique for shells using analysis tools
	B20	Germany	S. G. P. Castro, C. Mittelstedt, F. A. C .Monteiro, M. A. Arbelo , R. Degenhardt, G. Ziegmann (PFH, DLR, TU Clausthal. Sogeti)	A semi-analytical approach for linear and non-linear analysis of unstiffened laminated composite cylinders and cones under axial, torsion and pressure loads (PFH, DLR, TU Clausthal, Sogeti)
	B21	Germany	S. G. P. Castro, R. Zimmermann, C. Mittelstedt, M. A. Arbelo , R. Khakimova, M. W. Hilburger, R. Degenhardt (PFH, Embraer, DLR, NASA)	Non-linear buckling response of unstiffened laminated composite cylinders using different geometric imperfections
	B22	Germany	S. G. P. Castro, M. A. Arbelo , R. Degenhardt, G. Ziegmann (PFH, DLR, TU Clausthal. Sogeti)	Single perturbation load approach: new definition for P1 and explaining the constancy of the buckling load
	B23	Brazil	M. Arbelo,K. Kalnins,O. Ozoliņš,S. Castro,R. Degenhardt (ITA, RTU, DLR)	Buckling of imperfection sensitive shell structures: experimental characterization of the knock-down factor using the Multiple Perturbation Load Approach
	B24	Italy	C. Bisagni (Politecnico di Milano)	WP 2 - Material characterization and design of structures for buckling tests
	B25	Italy	M. Alfano, C. Bisagni (Politecnico di Milano)	Reliability assessment of buckling response of axially compressed sandwich composite shells with and without cut-outs
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	B27	Latvia	K. Kalnins (Riga Technical University)	WP 1 Benchmarking
	B28	Latvia	K. Kalnins, E. Skukis, O. Ozolins, M. A. Arbelo (RTU, PFH)	Experimental determination of the buckling load of composite cylindrical shells using Vibration Correlation Technique
	B29	Germany	L. Friedrich, A. Dafnis, H. Reimerdes, K. Schröder (RWTH Aachen)	Influence of load application on the collapse load of imperfection sensitive shell structures
	B30	Germany	L. Friedrich, H. Reimerdes, K. Schröder (RWTH Aachen)	Advanced sizing strategies for preliminary design of orthotropic grid stiffened shell structures
	B31	Israel	H. Abramovich, D. Govich and A. Grunwald (TECHNION)	Curved panels buckling prediction using the Vibration Correlation Technique
	B32	Israel	H. Abramovich (Technion)	WP 4 - Manufacturing and buckling tests
Other speakers	C01	Spain	M. A. Castillo-Acero, C. Cuerno-Rejado, M. A. Gómez-Tierno (Aernnova, UPM)	Highly Orthotropic Panels Structural Stability, Farrar and Bloch Waves Theory
	C02	Greece	V. K. Mantzaroudis, D.G. Stamatelos (Hellenic Air Force Academy)	Closed-form local skin buckling solution for orthotropic and anisotropic stiffened panels braced with omega stringers
	C03	Germany	C. Schillo, D. Krause (TU Hamburg Harburg)	Experimental and numerical study regarding the influence of traditional and non-traditional imperfections on the buckling load of unstiffened cylindrical CFRP shells
	C04	Germany	T.Ungwattanapanit, H. Baier (TU Munich)	Weight optimization using equivalent static loads of postbuckled, stiffened panels made by steered-fiber laminates
	C05	Russia	T. Le-Manh, Z. Gurdal, M. Abdalla (Skoltech, TU-Delft)	Nonlinear buckling of tapered composite plates in isogeometric analysis framework
	C06	UK	A. Al-Azzawi, J. McCrory, L.F. Kawashita, C.A. Featherston, R. Pullin and K. M. Holford (Cardiff university)	Buckling and postbuckling behaviour of glare laminates containing splices and doublers: experimental and numerical investigations
	C07	Iran	H. Assaee (Shiraz University of Technology)	Application of different versions of finite strip Method as fast tools for buckling analysis of Composite stiffened shells
	C08	Germany	T. A. Schmid Fuertes, H.-G. Reimerdes (Airbus, RWTH Aachen)	Buckling and post-buckling analyses of circular composite cylinders under axial compression using a semi-analytical approach
	C09	France	P. Le Grognec, K. Sad Saoud (Mines Douai)	Analytical and numerical analysis of the elastic/plastic local/global buckling and postbuckling of composite structures
	C10	USA, Italy	E. J. Barbero, A. Madeo, G. Zagari, R. Zinno, G. Zucco (West Virginia University, University of Calabria)	Imperfection sensitivity analysis of composite cylindrical shells using Koiter's method
	C11	Denmark	S. R. Henrichsen, E. Lindgaard, E. Lund (Aalborg University)	Discrete material buckling optimization of laminated composite structures considering "worst" shape imperfections
	C12	Germany	A. Köllner, C. Völlmecke (TU-Berlin)	Buckling and post-buckling behaviour of delaminated composite struts

	No	Country	Authors	Title
Other speakers	C13	USA	M. Schultz, L. Oremont, M. Hilburger (NASA)	Experimental and analytical characterization of fluted-core sandwich composite structures
	C14	UK, China	J. Croll, M. Wang (Uni. College London, China Uni. of Petroleum)	Lower Bound Buckling Loads for Design of Laminate Composite Cylinders
	C15	Poland	L. Czechowski (Lodz University of Technology)	Analysis of dynamic buckling of FGM plate under pulse of heat flux and compression force
	C16	Poland	T. Kubiak (Lodz University of Technology)	Numerical model of postbuckling behaviour of GFRP beams subjected to pure bending
	C17	Poland	A. Gliszczynski, T. Kubiak (Lodz University of Technology)	Load-carrying capacity of thin-walled composite beams subjected to pure bending
	C18	India	K.C. Gopalakrishnan, R. Ramesh Kumar (Government Engineering College, CET and GEC Barton Hill, Thriruvananthpuram)	Delamination of secondary bonding around cuts in a compressively loaded CFRP skinned sandwich structure
	C19	UK	A. Watson, B. Wang, S. Wang, C. Harvey (Loughborough University)	Couple Instabilities of Stiffened Panels with Multiple Stiffener Sizes
	C20	Germany	M.J. Weber, P. Middendorf (Airbus, TU Stuttgart)	Semi-analytical global and panel buckling of composite grid-stiffened cylindrical shells
	C21	UK	P. Weaver (University of Bristol)	Imperfection-insensitive shells using variable stiffness composites
	C22	Belgium, Japan	J.P. Delsemme, M. Bruyneel, Ph. Jetteur, B. Magneville, T. Naito, Y. Urushiyama (SAMTECH, Honda)	Progressive damage modeling in composite: from aerospace to automotive industry
	C23	Ukraine	V.M.Trach, N.P.Semenyuk, A.V.Podvornyi, N.B.Zhukova (National University of Water Management and Nature Resources Use, Timoshenko Institute)	On the method of calculation of buckling and postbuckling behavior of laminated shells with small arbitrary imperfections
	C24	Australia	John-Hart Smith	A necessary correction of the classical analyses for buckling of circular arches, rings, and tubes
	C25	UK	Zia R. Tahir, P. Mandal (University of Manchester)	Effect of Asymmetric Meshing on the Buckling Behaviour of Composite Cylindrical Shells under Axial Compression
	C26	USA	M. Brojan, D. Terwagne, R. Lagrange, P. Reis (Uni. of Ljubljana, ULB, MIT)	Wrinkling of thin spherical shells on elastic substrates
	C27	India	T. Rajanna, Sauvik Banerjee, Yogesh M. Desai, D.L. Prabhakara (Indian Institute of Technology) Sahyadri College of Engineering)	Stability behaviour of composite laminates with and without cut-out under non-uniform edge loads
	C28	Switzerland	F. Runkel, A. F. Arrieta, P. Ermanni (ETH Zurich)	Structural Tailoring for Enhanced Bending-Twist Coupling through Elastic Instability
	C29	Slovenia	B. Brank, A. Stanić, B. Hudobivnik (University of Ljubljana)	Simulations of surface wrinkling of bi-layer composite
	C30	Poland	R. J. Mania (Lodz University of Technology)	Buckling and post-buckling of FML compressed open cross section profiles
	C31	China	Zhang Guofan, Sun Xiasheng (ASRI)	A fast approach on postbuckling analysis of composite stiffened structures
	C32	Germany	T. Kühn, H. Pasternak, C. Mittelstedt (EADS EFW, TU Cottbus, Sogeti)	Closed-form local buckling analysis of shear-deformable composite laminated beam structures
	C33	Germany	A. Baucke, C. Mittelstedt (HAW, Sogeti)	Influence of bending-twisting-coupling on the buckling behaviour of composite laminated plates – a new look at an old problem
	C34	Poland	A. Muc, P.D. Pastuszak (Cracow University of Technology)	Remarks on buckling analysis of composite plates and shells
	C35	Poland	A. Muc, P. Kędziora (Cracow University of Technology)	Buckling enhancement of laminated structures with piezoelectric actuators
	C36	Austria	B. Goller, H. Haller (INTALES)	Industrial Branching analysis and assessment of the structural load carrying behaviour of composites in the post buckling regime
	C37	India	Aditi Sharma (Rajalakshmi Engineering College)	Design, fabrication and testing of hybrid nano composite structures
	C38	Switzerland	L. Thomas, S. Merazzi (SMR)	Finite element buckling analysis of skin-stiffener anisogrid fuselage structures
	C39	Japan	A.Takano (Kanagawa University)	Discussion for statistical methods on buckling knockdown factor
	C40	Germany	M. Klein (GOM)	How Optical 3D Metrology supports Component Design and the Optimization of Numerical Simulations

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with DESICOS Workshop

25-27 March 2015, Braunschweig, Germany, www.desicos.eu

25th March (Day 1)

8.30	*Registration*
9.45	*R. Degenhardt - Welcome*
10.00 - 12.00	Keynote lectures
13.00 - 14.40	DESICOS - Workpackage summaries
	Online-session: access via www.ifarlink.aero
15.10 - 17.30	DESICOS - Achievements of the PhD students - New design concepts
18.00	*Transfer to Dinner*
18.30 - 22.30	**Conference Dinner (at Dornse)** 1) Welcome by Mrs. Annegret Ihbe (Mayoress of the City) 2) Dinner speech: Prof. Joachim Block (ROSETTA Lander - a challenging mission to the origins of the solar system)
22.45	*Transfer to hotels*

26th March (Day 2)

8.00	*Registration*		
8.30 - 10.00	Keynote lectures		
10.30 - 12.30	Improved theories / concepts	Damaged structures	Design and analysis
12.10 - 15.00	**DESICOS Workshop** (Demonstration of improved tools, designs, testing)		
15.00 - 17.30	Semi-analytical concepts	Experiments	Design and analysis
18.00	*Transfer to DLR*		
18.30 - 20.30	DLR visiting lab tour		
20.45	*Transfer to hotels*		

27th March (Day 3)

8.00	*Registration*	
8.30 - 10.00	Keynote lectures	
10.30 - 12.10	Experiments	Design and analysis
13.00 - 14.20	New concepts	Design and analysis
15.00 - 16.30	Keynote lectures	
16.30	*R. Degenhardt - Closing remarks*	
16.35	*End of Conference*	

25th March 2015 (Day 1)

9.00	***Registration***
9.45	R. Degenhardt (DLR, PFH) Welcome
	Keynote lectures Chair: Martin Wiedemann (DLR)
10.00	*Hansjörg Dittus (DLR, Member of executive board, responsible for space)* Reusability – DLR´s new R&D-programme for launch technologies
10.30	*Mark Hilburger (NASA, Senior researcher)* Subscale and Full-Scale Testing of Buckling-Critical Launch Vehicle Structures
11.00	*Andreas Rittweger (DLR, Head of Institute of Space Systems)* Pre-Dimensioning of Launch Vehicles due to Booster Load Introduction based on Semi-Analytical Methods
11.30	*Peter Linde (Airbus)* Structural Modelling and Simulation of Aircraft Composite Structures; State of the Industry
12.00	***Buffet lunch***
	DESICOS - Workpackage summaries Chair: Eelco Jansen (Leibniz University Hanover)
13.00	*R. Degenhardt (DLR, PFH)* DESICOS - New Robust Design Guideline for Imperfection Sensitive Composite Launcher Structures
13.25	*K. Kalnins (Riga Technical University)* WP 1 - Benchmarking
13.40	*C. Bisagni (Politecnico di Milano, TU-Delft)* WP 2 - Material characterization and design of structures for buckling tests
13.55	*M. Ruess (TU-Delft)* WP 3 - Development & application of improved design approaches
14.10	*H. Abramovich (Technion)* WP 4 - Manufacturing and buckling tests
14.25	*P. Blanchard (Airbus)* WP 5 - Contribution to improved design guidelines
14.40	***Coffee break***
	Public websession, Register for free at http://goo.gl/6cWRwR DESICOS - Achievements of the PhD students: New design concepts Chair: Chiara Bisagni (TU-Delft)
15.10	R. Degenhardt (DLR, PFH), Chiara Bisagni (TU-Delft) Welcome
15.20	*K. Liang, M. Ruess (TU-Delft)* New robust knock-down factors for the stiffened cylinder
15.40	*A. Meurer, M. Dannert, R. Rolfes (Leibniz University Hannover)* New Design Approach for Axially Compressed Composite Cylindrical Shells combining the Single Perturbation Load Approach and Probabilistic Analyses
16.00	*S. G. P. Castro, C. Mittelstedt, F. A. C .Monteiro, M. A. Arbelo , R. Degenhardt, G. Ziegmann (PFH, DLR, TU Clausthal. Sogeti)* A semi-analytical approach for linear and non-linear analysis of unstiffened laminated composite cylinders and cones under axial, torsion and pressure loads
16.20	*M. Alfano, C. Bisagni (Politecnico di Milano, TU-Delft)* Reliability assessment of buckling response of axially compressed sandwich composite shells with and without cut-outs
16.40	*L. Friedrich, H. Reimerdes, K. Schröder (RWTH Aachen)* Advanced sizing strategies for preliminary design of orthotropic grid stiffened shell structures
17.00	*R. Khakimova, R. Degenhardt (DLR)* Assessment of the Single Perturbation Load Approach on composite conical shells
17.20	*J. Kepple, M. Herath, G. Pearce, G. Prusty, R. Thomson (CRC-ACS, University of New South Wales,* Stochastic analysis of imperfection sensitive composite cylinders using realistic imperfection models
17.40	Discussion
17.50	End
18.00	***Transfer to dinner***
18.30 - 22.30	**Conference Dinner (Dornse)** **Agenda: see page 16** **1) Welcome by Mrs. Annegret Ihbe (Mayoress of the City of Braunschweig)** **2) Dinner speech: Prof. Joachim Block (ROSETTA Lander - a challenging mission to the origins of the solar system)**
22.45	***Transfer to hotels***

26th March 2015 (Day 2)

Keynote lectures
Chair: Saullo Castro (Embraer)

8.30 *Christian Hühne (DLR, Head of department Composite Design)*
Single perturbation load approach – From the initial idea until today

9.00 *JN Reddy (Texas AM University, USA)*
Refined theories and finite element models for the analysis of laminated composite structures: An overview

9.30 *John Hart-Smith*
The use of simple strain-energy concepts to debunk the classical thin-shell buckling analyses for once and for all

10.00 ***Coffee break***

	Room 1 Semi-analytical concepts Chair: David Gao (Australian National University)	Room 2 Damaged structures / Buckling with piezos / FGM Chair: Marc Schultz (NASA)	Room 3 Design and Analysis Chair: Kaspars Kaknins (RTU)
10.30	*V. K. Mantzaroudis, D.G. Stamatelos (Hellenic Air Force Academy)* Closed-form local skin buckling solution for orthotropic and anisotropic stiffened panels braced with omega stringers	*A. Köllner, C. Völlmecke (TU-Berlin)* Buckling and post-buckling behaviour of delaminated composite struts	*B. Goller, H. Haller (INTALES)* Industrial Branching analysis and assessment of the structural load carrying behaviour of composites in the post buckling regime
10.50	*T. Kühn, H. Pasternak, C. Mittelstedt (EADS EFW, TU Cottbus, Sogeti)* Closed-form local buckling analysis of shear-deformable composite laminated beam structures	*K.C. Gopalakrishnan, R. Ramesh Kumar (Government Engineering College, CET and GEC Barton Hill, Thriruvananthpuram)* Delamination of secondary bonding around cuts in a compressively loaded CFRP skinned sandwich structure	*T. Rajanna, Sauvik Banerjee, Yogesh M. Desai, D.L. Prabhakara (Indian Institute of Technology) Sahyadri College of Engineering)* Stability behaviour of composite laminates with and without cutout under non-uniform edge loads
11.10	*M. A. Castillo-Acero, C. Cuerno-Rejado, M. A. Gómez-Tierno (Aernnova, UPM)* Highly Orthotropic Panels Structural Stability, Farrar and Bloch Waves Theory	*J.P. Delsemme, M. Bruyneel, Ph. Jetteur, B. Magneville, T. Naito, Y. Urushiyama (SAMTECH, Honda)* Progressive damage modeling in composite: from aerospace to automotive industry	*T. Kubiak (Lodz University of Technology)* Numerical model of postbuckling behaviour of GFRP beams subjected to pure bending
11.30	*H. Assaee (Shiraz University of Technology)* Application of different versions of finite strip Method as fast tools for buckling analysis of Composite stiffened shells	*A. Muc, P. Kędziora (Cracow University of Technology)* Buckling enhancement of laminated structures with piezoelectric actuators	*B. Brank, A. Stanić, B. Hudobivnik (University of Ljubljana)* Simulations of surface wrinkling of bi-layer composite
11.50	*T. A. Schmid Fuertes, H.-G. Reimerdes (Airbus, RWTH Aachen)* Buckling and post-buckling analyses of circular composite cylinders under axial compression using a semi-analytical approach	*L. Czechowski (Lodz University of Technology)* Analysis of dynamic buckling of FGM plate under pulse of heat flux and compression force	*A. Watson, B. Wang, S. Wang, C. Harvey (Loughborough University)* Couple Instabilities of Stiffened Panels with Multiple Stiffener Sizes

12.10-15.00

DESICOS Workshop see page 17

(Demonstration of improved tools, designs, testing)

(Buffet lunch + coffee in parallel)

26th March 2015 (Day 2)

	Room 1 **Improved theories / concepts** Chair: Theodor-Andres Schmid Fuertes (Airbus)	**Room 2** **Experiments** Chair: J. Gomez (Airbus Defence & Space)	**Room 3** **Design and Analysis** Chair: T. Rajanna (Indian Institute of Technology Bombay)
15.00	*J. Croll, M. Wang (Uni. College London, China Uni. of Petroleum)* Lower Bound Buckling Loads for Design of Laminate Composite Cylinders	*M. Brojan, D. Terwagne, R. Lagrange, P. Reis (Uni. of Ljubljana, ULB, MIT)* Wrinkling of thin spherical shells on elastic substrates	*E. J. Barbero, A. Madeo, G. Zagari, R. Zinno, G. Zucco (West Virginia University, University of Calabria)* Imperfection sensitivity analysis of composite cylindrical shells using Koiter's method
15.20	*E.L. Jansen, T. Rahman, R. Rolfes (Uni. Hannover, TNO DIANA BV)* Towards mode selection criteria for multi-mode initial postbuckling analysis of composite cylindrical shells	*M. Schultz, L. Oremont, M. Hilburger (NASA)* Experimental and analytical characterization of fluted-core sandwich composite structures	*A. Muc, P.D. Pastuszak (Cracow University of Technology)* Remarks on buckling analysis of composite plates and shells
15.40	*S. G. P. Castro, M. A. Arbelo , R. Degenhardt (PFH, DLR)* Single perturbation load approach: new definition for P1 and explaining the constancy of the buckling load	*H. Abramovich, D. Govich and A. Grunwald (TECHNION)* Curved panels buckling prediction using the Vibration Correlation Technique	*R. J. Mania (Lodz University of Technology)* Buckling and post-buckling of FML compressed open cross section profiles
16.00	*V.M.Trach, N.P. Semenyuk, A.V. Podvornyi, N.B. Zhukova (National University of Water Management and Nature Resources Use, Timoshenko Institute)* On the method of calculation of buckling and postbuckling behavior of laminated shells with small arbitrary imperfections	*A. Al-Azzawi, J. McCrory, L.F. Kawashita, C.A. Featherston, R. Pullin and K. M. Holford (Cardiff university)* Buckling and postbuckling behaviour of glare laminates containing splices and doublers: experimental and numerical investigations	*T.Ungwattanapanit, H. Baier (TU Munich)* Weight optimization using equivalent static loads of postbuckled, stiffened panels made by steered-fiber laminates
16.20	*F. da Cunha, T. Wille, R. Degenhardt, M. Sinapius (DLR)* Structural Robustness Assessment of Thin-Walled Composite Structures in the Postbuckling Regime	*K. Kalnins, E. Skukis, O. Ozolins, M. A. Arbelo (RTU, PFH)* Experimental determination of the buckling load of composite cylindrical shells using Vibration Correlation Technique	*P. Le Grognec, K. Sad Saoud (Mines Douai)* Analytical and numerical analysis of the elastic/plastic local/global buckling and postbuckling of composite structures
16.40	*E. Jansen, H. Abramovich, R. Rolfes (Leibniz University Hannover, TECHNION)* Improving the vibration correlation technique for shells using analysis tools	*L. Friedrich, A. Dafnis, H. Reimerdes, K. Schröder (RWTH Aachen)* Influence of load application on the collapse load of imperfection sensitive shell structures	*A. Gliszczynski, T. Kubiak (Lodz University of Technology)* Load-carrying capacity of thin-walled composite beams subjected to pure bending
17.00	*John-Hart Smith* A necessary correction of the classical analyses for buckling of circular arches, rings, and tubes	*Aditi Sharma (Rajalakshmi Engineering College)* Design, fabrication and testing of hybrid nano composite structures	*P. Weaver (University of Bristol)* Imperfection-insensitive shells using variable stiffness composites
17.20		*M. Arbelo, K. Kalnins, O. Ozoliņš, S. Castro, R. Degenhardt (ITA, RTU, DLR)* Buckling of imperfection sensitive shell structures: experimental characterization of the knock-down factor using the Multiple Perturbation Load Approach	*A. Takano (Kanagawa University)* Discussion for statistical methods on buckling knockdown factor
18.00	***Transfer to DLR***		
18.30 - 20.30	**DLR - Technical visiting tour** **(Finger food available)**	**Agenda: see page 21**	
20.45	***Transfer to hotels***		

27th March 2015 (Day 3)

Keynote lectures
Chair: Mark Hilburger (NASA)

8.30 *Ralf Cuntze*
Reliable strength design verification - Fundamentals, requirements and some hints

9.00 *Jochen Albus (Airbus, Senior expert)*
Parametric Instability of Pressurized Propellant Tanks

9.30 *Jan Blachut (University of Liverpool)*
Composite spheroidal shells under external pressure

10.00 ***Coffee break***

	Room 1 **Experiments** Chair: Haim Abramovich (TECHNION)	**Room 2** **Design and Analysis** Chair: Christian Mittelstedt (Sogeti)
10.30	*R. Khakimova, S. Castro, R. Degenhardt, D. Wilckens, M. Kepke, B. Hildebrandt, F. Odermann (DLR, PFH)* Buckling experiments on imperfection sensitive thin-walled structures using additional perturbation loads	*R. Wagner, C. Hühne (DLR)* Semi-analytical probabilistic sensitivity analysis for unstiffened cylindrical composite shells under compression
10.50	*D. Wilckens, F. Odermann (DLR)* Buckling and Post Buckling of Stiffened CFRP Panels under Compression and Shear	*T. Ludwig, S. Merazzi (SMR)* Finite element buckling analysis of skin-stiffener anisogrid fuselage structures
11.10	*C. Wolff, D.Wilckens (DLR)* Testing and Modelling of impact damaged orthotropic stiffened CFRP-Panels	*S. G. P. Castro, R. Zimmermann, C. Mittelstedt, M. A. Arbelo , R. Khakimova, M. W. Hilburger, R. Degenhardt (PFH, Embraer, DLR, NASA)* Non-linear buckling response of unstiffened laminated composite cylinders using different geometric imperfections
11.30	*F. Odermann, M. Geier (DLR)* Buckling tests of unstiffened cylindrical composite shells under dynamic axial pulse loading	*S. Castro, R. Khakimova , G. Ziegmann, D. Degenhardt, R. Degenhardt, Mark Hilburger (PFH, DLR, TU Clausthal, Sogeti, NASA)* Simulation of geometric imperfections and uneven edges in thin-walled cylinders
11.50	*C. Schillo, D. Krause (TU Hamburg Harburg)* Experimental and numerical study regarding the influence of traditional and non-traditional imperfections on the buckling load of unstiffened cylindrical CFRP shells	*D. Degenhardt, M. Hilburger, S. Castro, R. Khakimova, R. Degenhardt (DLR, NASA, Embraer, PFH)* Investigation on the effects of non-uniform loading on the buckling of thin-walled cylindrical shells

12.10 ***Buffet lunch***

27th March 2015 (Day 3)

	Room 1 **New concepts** Chair: Dimitris Stamatelos (Hellenic Air Force Academy)	Room 2 **Design and Analysis** Chair: Tomasz Kubiak (Lodz University of Technology)
13.00	*A. Baucke, C. Mittelstedt (HAW, Sogeti)* Influence of bending-twisting-coupling on the buckling behaviour of composite laminated plates – a new look at an old problem	*T. Le-Manh, Z. Gurdal, M. Abdalla (Skoltech, TU-Delft)* Nonlinear buckling of tapered composite plates in isogeometric analysis framework
13.20	*M.J. Weber, P. Middendorf (Airbus, TU Stuttgart)* Semi-analytical global and panel buckling of composite grid-stiffened cylindrical shells	*S. R. Henrichsen, E. Lindgaard, E. Lund (Aalborg University)* Discrete material buckling optimization of laminated composite structures considering “worst” shape imperfections
13.40	*Zhang Guofan, Sun Xiasheng (ASRI)* A fast approach on postbuckling analysis of composite stiffened structures	*Zia R. Tahir, P. Mandal (University of Manchester)* Effect of Asymmetric Meshing on the Buckling Behaviour of Composite Cylindrical Shells under Axial Compression
14.00	*S. Freund, A. Sauerbrei, R. Zimmermann (DLR)* Multilevel Skin Buckling Analysis using Hierarchical Metamodels	*F. Runkel, A. F. Arrieta, P. Ermanni (ETH Zurich)* Structural Tailoring for Enhanced Bending-Twist Coupling through Elastic Instability
14.20	*C. Bisagni (Politecnico di Milano, TU-Delft)* Overview of FP7 Project DAEDALOS - Dynamics in Aircraft Engineering Design and Analysis for Light Optimized Structures	*M. Klein (GOM)* How Optical 3D Metrology supports Component Design and the Optimization of Numerical Simulations

14.40 ***Coffee break***

Keynote lectures
Chair: Mariano Arbelo (ITA)

15.00	*Christian Mittelstedt (Sogeti)* Recent developments in the rapid and efficient closed-form analytical modeling of buckling problems in composite lightweight engineering
15.30	*Brian Falzon (Royal Academy of Engineering - Bombardier Chair in Aerospace Composites, Queen’s University Belfast)* Modelling damage in thin-walled composite structures
16.00	*Tobias Wille (DLR, Head of department Structural mechanics)* Challenges in Structural Mechanics of Composite Structures
16.30	R. Degenhardt Closing words
16.35	**End of Conference**

Conference dinner, 25 March 2015 – Agenda

18.00 Organised bus transfer: University - Dinner location (Dornse)

18.30 Reception

19.30 Welcome by
- Prof. Richard Degenhardt (Conference Chairman)
- Welcome by Mrs. Annegret Ihbe (Mayoress of the City of Braunschweig)

20.00 Dinner

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

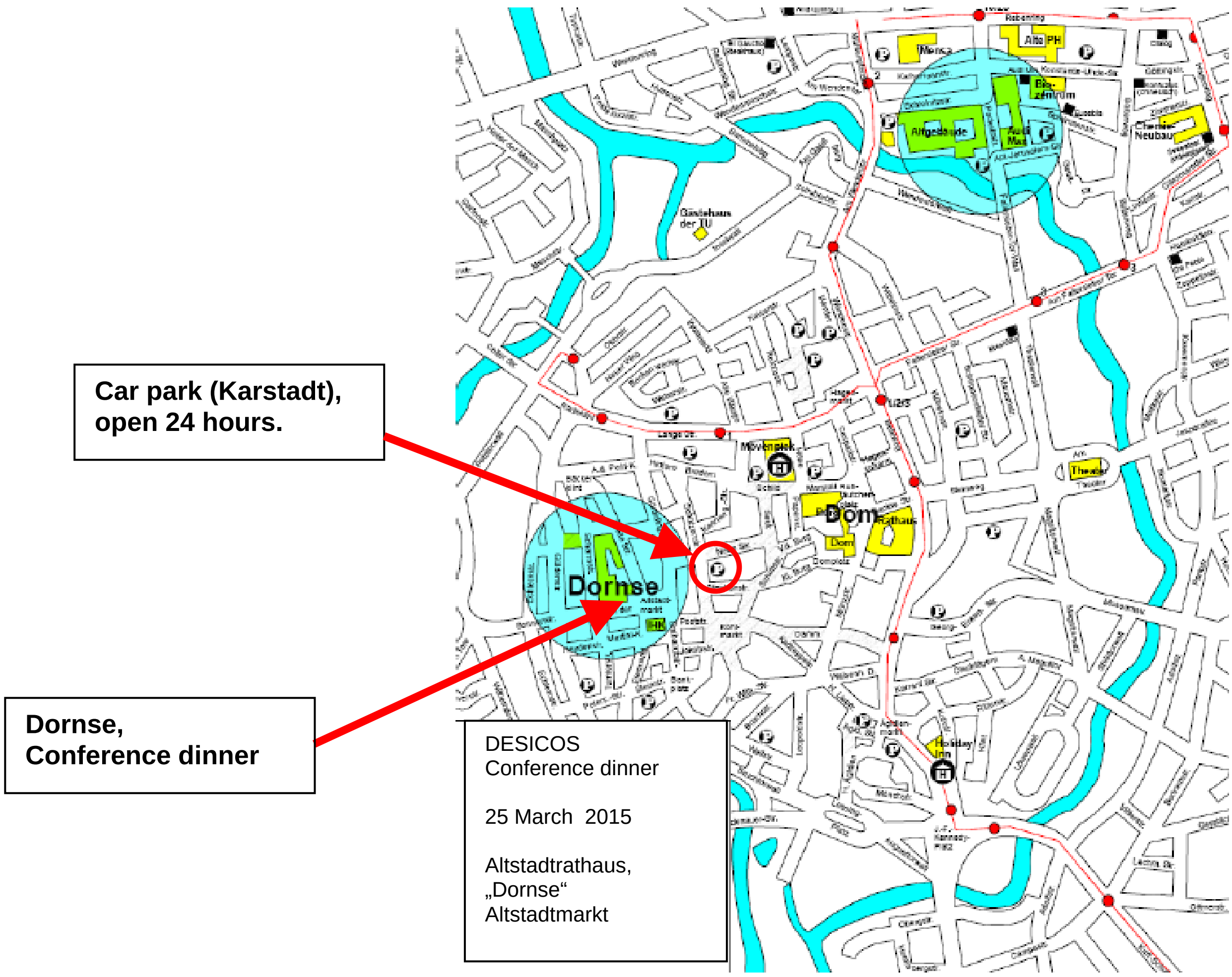
21.45 DESICOS awards

22.45 End

22:45 Organised bus transfer to hotels

Location: Dornse (Altstadtrathaus), Altstadtmarkt, 38100 Braunschweig

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



DESICOS workshop

Objective

Within the ***workshop*** new software related to improved simulation of composites, improved design tools or test structures developed within DESICOS but also outside the project, are presented and demonstrated.

Date / location

26 March 2015, 12.00 -15.00
Embedded in the conference, see page 18

Exhibitors

Booth 1	**Demonstration of**
RWTH Aachen University Institute of Structural Mechanics and Lightweight Design Wuellnerstr. 7, 52062 Aachen, Germany Tel, +49 241 8096830, office@sla.rwth-aachen.de www.sla.rwth-aachen.de	Improved software

Booth 2	**Demonstration of**
Technion **Israel Institute of Technology** Faculty of Aerospace Engineering Technion City, 32000 Haifa, Israel Tel, +972 4 8292303, haim@aerodyne.technion.ac.il http://www.technion.ac.il/en/	Software to calculate the collapse of stringered stiffened composite panels using the effective width method

Booth 3	**Demonstration of**
Riga Technical University Institute of Materials and Structures Kalku Iela 1, LV-1658 Riga, Latvia Tel, +371 708 9124, kaspars.kalnins@rtu.lv http://www.rtu.lv/en/	Improved software

Booth 4	Demonstration of
PFH- Private University of Applied Sciences Göttingen Composite Engineering Campus Stade Airbusstr. 6, 21684 Stade, Germany Tel, +49 41 41 / 7967-0, degenhardt@pfh.de www.pfh.de	- Fast software for the buckling of composite structures using the Ritz-method - Study courses in Composite Engineering (Bachelor and Master)

Booth 5	Demonstration of
Leibniz Universität Hannover Institute of Structural Analysis Appelstr. 9A, 30167 Hannover, Germany Tel, +49 (0)511 762 2992, e.jansen@isd.uni-hannover.de www.uni-hannover.de **TNO DIANA BV** Delftechpark 19a, 2628 XJ Delft, The Netherlands Tel, +31 (0)88 3436200, info@tnodiana.com www.tnodiana.com	Special Finite Element Tools for Nonlinear Buckling and Vibration Analysis

Booth 6	Demonstration of
ESAComp – Componeering Inc. Itamerenkatu 8 FI-00180 Helsinki, Finland Tel. +358 9 4342 1550, harri.katajisto@componeering.com http://www.esacomp.com/	Quick and clean tool for the design of composite cylinders including non-linear buckling analysis with imperfections

Booth 7 SIEMENS **Siemens PLM Software,** Liège Science Park Rue des Chasseurs-Ardennais, 8, 4031 Angleur, Belgium Tel, +32 4 361 69 75, jean-pierre.delsemme@siemens.com www.siemens.com/plm	**Demonstration of**
	LMS Samtech Samcef embedded in NX 10: - Scalability (from designers trough analysis) - Multi-CAD support with editing and idealization capabilities - Extensive modeling function: mesh, LBC's - Connection to Laminate modeler & Laminate manufacturing tools (Catia CPD, Siemens Fibersim) - Customization (NX Open) - Powerful linear and nonlinear finite element analysis - Robust & Validated damage model of composite material - Element library and BCs available (contact, plasticity, ..)

Booth 8 **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-acs.com.au http://www.crc-acs.com.au/	**Demonstration of**
	Improved software for stochastic analysis

Booth 9 **Dassault Systemes Deutschland GmbH** Elisabethstr. 16, 52062 Aachen, Germany Tel, +49 241474010, simulia.info@3ds.com http://www.3ds.com/products-services/simulia	**Demonstration of**
	SIMULIA Software Portfolio

Booth 10 **DLR – German Aerospace Center** **Institute of Composite Structures and Adaptive Systems** Lilienthalplatz 7, 38108 Braunschweig, Germany Tel, +49 531 295 3059, richard.degenhardt@dlr.de www.dlr.de/fa/en/	**Demonstration of** - Composite test structures - Manufacturing process - Whole aircraft design framework software - Damage detection and analysis

Booth 11 **INTALES GmbH -- Engineering Solutions** Innsbrucker Str. 1, 6161 Natters, Austria Tel., +43 512 546111 15, goller@intales.com www.intales.com/	**Demonstration of** - Software for optimizing lightweight structures - Approach is applicable to large and complex FE-models with multiple load cases - Optimization method is integrated into ABAQUS - It can be used for models involving different kinds of elements, like shell elements including layered composite, sandwich or isotropic (metallic) shell sections, and also fastener elements - Efficient data management by using an SQLITE database

Booth 12 **SMR S.A.** P.O. Box 4014, 2500 Bienne 4, Switzerland Tel, +41 32 345 2121, merazzi@smr.ch	**Demonstration of** B200 Software Portfolio

Booth 13 **GOM Gesellschaft für Optische Messtechnik mbH** Mittelweg 7-8, 38106 Braunschweig, Germany Tel.: +49 531 39029, m.mueller@gom.com	**Demonstration of** ARAMIS measurement system

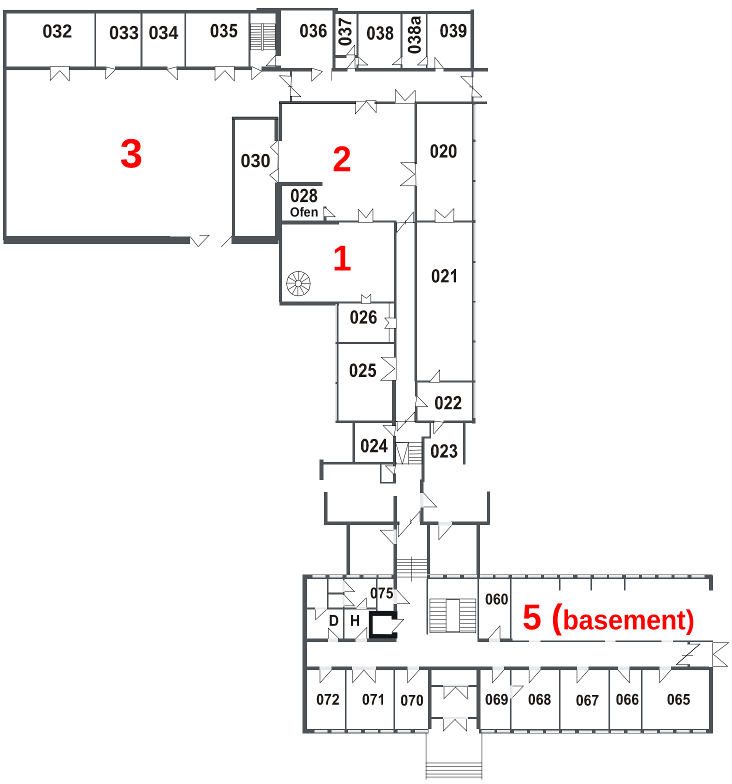
DLR - Technical visiting tour

Location: DLR Braunschweig
Institute of Composite Structures and Adaptive Systems
Day: 26 March 2015

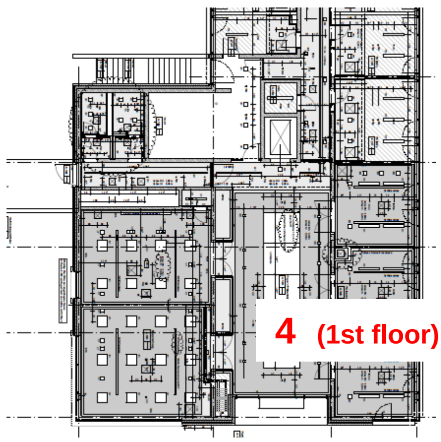
Agenda

18.00 Transfer University - DLR
18.40 DLR - Technical visiting tour (Finger food available)
20.45 Transfer DLR - Hotels

No.	Station	Presenter	Time / Group				
			18.40	19.00	19.20	19.40	20.00
1	Buckling test facility	Mr. Dirk Wilckens	Group 1	Group 2	Group 3	Group 4	Group 5
2	Composite technology	Mr. Phillipp Hillmer	Group 2	Group 3	Group 4	Group 5	Group 1
3	Testing field	Mr. Steffen Opitz / Mr. Falk Odermann	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	Ulltrasonic testing field	Mr A. Szewieczek	Group 5	Group 1	Group 2	Group 3	Group 4



Group leaders:
Group 1: Mrs. Caroline Wolff
Group 2: Mrs. Regina Khakimova
Group 3: Mr. David Degenhardt
Group 4: Mr. Sebastian Freund
Group 5: Mr. Ronald Wagner



Abstracts

The full extended abstracts can be downloaded at www.desicos.eu.

Keynote lectures	
Room 1	**Chair: Martin Wiedemann (DLR)**
25th March, 2015	**Time: 10.00**

No. A01

Title: Reusability – DLR´s new R&D-programme for launch technologies

Authors: Hansjörg Dittus (DLR, Member of executive board, responsible for space)

Contact: hansjoerg.dittus@dlr.de

Abstract:

Launch vehicles are the crucial issue for every space application. Thus, to come up with a suitable competitive and efficient European system is of strategic interest within the European member states. The decision of the ESA ministerial council to develop a new European ARIANE 6 launch vehicle and the recent efforts of private launch providers in the United States of America aim to further improve technologies and know-how already in use. We believe that going forward the most promising step beyond this could be to re-employ rocket components, e.g. engines or even whole stages. With this in mind, DLR, the German Aerospace Center, has initiated a new R&D program to recover and re-use launch vehicles as far as is technically possible. The present situation is that European launch vehicles are produced for single use only. A first step within DLR´s new research program would be to fully recover rocket hardware that has been launched and to analyze the degradation of the entire launch system including failure mechanisms during extensive post-flight inspections. This is of course a priority in order to efficiently refine re- usable systems and components for the future. Moreover, to utilize lightweight structures for rocket tank components and rocket engines to a greater extent is foreseen as serving an additional benefit. In practice, DLR will now initiate a project to analyze structural loads during launch and ascent of a sounding rocket. The intended health monitoring system will enable an insight into the buckling behavior of the structure. Starting in 2017 DLR aims to continue launching its experimental sounding vehicles every 2 years.

No. A03

Title: Recent Developments in the Analysis and Testing of Large-Scale Buckling-Critical Cylinders

Authors: Mark Hilburger (NASA, Senior researcher)

Contact: mark.w.hilburger@nasa.gov

Abstract:

NASA's Shell Buckling Knockdown Factor Project (SBKF), was established in the spring of 2007 by the NASA Engineering and Safety Center (NESC) in collaboration with NASA's Constellation Program and Exploration Systems Mission Directorate. The SBKF project has the goal of developing improved (i.e., less-conservative, robust), shell buckling design factors (a.k.a. knockdown factors) and design and analysis technologies for launch vehicle (LV) structures. Preliminary design studies indicate that implementation of these new knockdown factors can enable significant reductions in mass and control mass-growth in these vehicles and can help mitigate some of the typical LV development and performance risks. In particular, the new design technologies are expected to reduce the reliance on testing, provide high-fidelity estimates of structural performance, reliability, robustness, and enable increased payload

capability. The lecture will summarize the SBKF objectives, approach towards developing and validating new technologies, and provide a look towards the future of design, analysis and testing of the next generation of buckling-critical launch vehicle structures. In addition, this lecture will present results from recent buckling test efforts at NASA on two different orthogrid-stiffened metallic cylindrical shell test articles. The first test article was a subscale 8-foot-diameter stiffened cylinder subjected to a uniform compression load. The second test article was a 27.5-ft-diameter Space Shuttle External Tank-derived cylinder and was subjected to combined internal pressure and axial compression.

No. A04

Title: Pre-Dimensioning of Launch Vehicles due to Booster Load Introduction based on Semi-Analytical Methods

Authors: Andreas Rittweger (DLR, Head of Institute of Space Systems)

Contact: Andreas.Rittweger@dlr.de

Abstract:

Launchers like Ariane 5 or Ariane 6 (PPH configuration) are subjected to large load introduction due to the Booster loads. These Booster loads lead to high stress concentration, which is decaying in circumferential and axial direction. The decaying of the warping stresses is not limited to the vicinity of the load introduction point, it is effective over large parts of the launcher. The decaying behavior is depending on the design of the shell structures itself, mainly influenced by the orthotropic stiffening. The warping force fluxes, which are transmitted to the adjacent structures, have to be limited to avoid overloading of tank structures or overloading of bonded connections to the solid booster motor case (composite motor cases). At the beginning of the development the design of the structure has to be defined to meet mass and cost targets. The work out of the design and the dimensioning is based on optimization studies. A huge number of investigations with respect to different configurations, design concepts, dimensioning of orthotropic stiffening and weight optimization is carried out. In order to manage the huge amount of variables and analyses, rapid methods for the dimensioning are requested. In case of axisymmetric shells analytical methods, based on Fourier transformation of the differential equations of the shell, are available. Orthotropic stiffened shell segments can be considered in a smeared manner, as well as ring frames can be taken into account as discrete members. In case of non-axisymmetric shells (by non-axisymmetric stiffening) analytical shell panel elements based on the shear field theory have been developed, which allow together with stringer and ring frame elements a rapid analysis of complex stiffened structures. Based on studies for Ariane 5 and Ariane 6 Booster load introduction the rapid analysis methods and approaches for stress and stability analysis are presented. It turned out that they allow a significant quicker solution compared to the Finite- Element method without losing accuracy.

No. A07

Title: Structural Modelling and Simulation of Aircraft Composite Structures; State of the Industry

Authors: P. Linde (Airbus)

Contact: peter.linde@airbus.com

Abstract:

The last years have seen steady progress in the area of numerical simulation of the mechanical behavior of aircraft composite structures. The introduction into service of the recent long range aircraft Airbus A350 XWB and the Boeing 787 have been accompanied by worldwide intensive research in this area, with many and useful findings and improvements as a result. This contribution will provide an overview of industrial work in development and research in the composites modelling and simulation areas performed at Airbus. A brief introduction to the role of modelling and simulation in the development of an aircraft is followed by a glance into the

area of virtual testing, which have increased in importance due to more complex materials and design. In order for virtual testing to work reliably high demands are placed on both elements and damage models, for which an overview of recent work is given. Different types of shell elements used are discussed in an overview, starting with the “laminated” classical shell, followed by the continuum shell. As a more advanced supplement Airbus has worked on a solid like shell, enabling full material models, and performed an implementation. The damage behaviour for composite structures are here divided into continuum and discrete models. The most common models used are the continuum damage models. These are used both for in-ply damage and intra-ply damage. For these damage mechanisms, several failure criteria have been studied, in industry cooperation as well as within the frame of a benchmarking process that is introduced. More recently, first experience has been gathered with discrete damage modelling, or partition of unity, in the frame of element formulations. For composites this has focused on in-ply damage. A brief view on the formulations used and first work is given. Finally, for applications, the above discussed work has been partly implemented in the modelling and simulation of aircraft parts, such as stiffened panels. A brief view on the effect of progressed elements and damage models is given in selected examples. Finally, a summary, conclusion and recommendation for future research is given.

DESICOS – Work Package Summaries	
Room 1	Chair: Eelco Jansen (Leibniz University Hanover)
25th March, 2015	Time: 13.00

No. B10

Title: DESICOS - New Robust Design Guideline for Imperfection Sensitive Composite Launcher Structures

Authors: Richard Degenhardt (DLR, PFH)

Contact: richard.degenhardt@dlr.de

Abstract:

The running EU project DESICOS (New Robust DESIgn Guideline for Imperfection Sensitive COmposite Launcher Structures) is a Level 1 Project within the 7th Framework Programme. It started February 2012 and will be finished end of July 2015. DESICOS aims to exploit considerable reserves in the capacities of imperfection sensitive composite launcher structures by applying the Single Perturbation Load Approach (SPLA), which assumes that a large enough disturbing load leads to the worst realistic geometric imperfection, combined with a Specific Stochastic Approach to take into account load imperfection, thick-ness imperfection, etc. Currently, imperfection sensitive shell structures prone to buckling are designed according to the NASA SP 8007 guideline using the conservative lower bound curve. The guideline dates from 1968, and the structural behaviour of composite material is not considered appropriately, in particular since the imperfection sensitivity and the buckling load of shells made from such materials depend on the lay-up design. NASA SP 8007 design guidelines allows designing only so called "black metal" structures. Therefore there is a high need for a new precise and fast design and testing approach. The project results comprise an experimental data base, new design approaches for imperfection sensitive structures and new design recommendations. More details can be found at www.desicos.eu.

No. B27

Title: WP 1 - Benchmarking

Authors: K. Kalnins (Riga Technical University)

Contact: kaspars.kalnins@sigmanet.lv

Abstract:

Within the DESICOS project the Work package-1 was designed to address and to harmonise the issues once dealing with the finite element modelling aspects for imperfection sensitive cylindrical shells. In particularly attention has been paid for studying the literature references which provide sufficient data for the experimentally tested and thoroughly measured benchmark examples. The knowledge of best practice and reference setting collected during benchmark effort was transferred for other work packages as an approved technique, which gives robust and reliable results of the finite element analyses for the selected user case studies. Initial a matrix for selection of FE benchmark cases was proposed to systemise available references in following categories: data provided by DESICOS partner – (availability), type of structure (stiffened/non-stiffened cone`s, cylinder`s), provided/tested material properties, experimental data curve availability, initial FE verification by authors and etc. Such propose was thought to give better justification of selected benchmark, and initially identify the shortage of information

which would delay a latter verification stage. Literature has been extensively extended by partner PFH, resulting in collecting and examining of almost 300 articles on buckling of shell structures. An extend list has been listed in references section and publicly at DESICOS webpage: http://www.desicos.eu/Publications.html. As following task was to focus on modelling aspects with the respect to the Single Perturbation Load Approach (SPLA). An influence of the finite element mesh density, boundary conditions, implicit solver parameters as dumping parameters, explicit solver settings etc., on the buckling behaviour. SPLA technique realization in the case of finite element analyses was studied to simulate as accurate as possible side load application, close to the real experiment behaviour. Several load introduction scenarios has been compared in order to obtain most successful numerical implementation technique. Finally a benchmarking was conducted by all involved partners of selected non-stiffened cylinder Z15 - originally tested by DLR. Predefined modelling settings was incorporated among partners in selected FE tools to conduct reliable and robust buckling analyses. This exercise allowed to compare the abilities of those tool`s and to assess the efficiency – like calculation time, curve fitting etc. Two types of structures were studied in this task, perfect shell (perfect shell geometry) and shell containing imperfection from ultrasound thickness distribution inspection. Restrictions of the nominal ply thickness, element size, boundary conditions and general loading principles was considered. Therefore FE analyses results of selected benchmark structure conducted by different finite element codes served as a guide for entire DESICOS project on modelling of selected down-scaled launcher structures..

No. B24

Title: WP 2 - Design of test structures

Authors: C. Bisagni (Politecnico di Milano, TU-Delft)

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Abstract:

Workpackage 2 consists of two Tasks. The first Task is focused on the identification of material properties for the structures that will be analyzed in Workpackage 3 and tested in Workpackage 4. It consists in the manufacturing and testing of specimens in order to characterize the specific composite material properties under static loading. The second Task regards the design of imperfection sensitive structures that are manufactured and tested in Workpackage 4. The design develops from the consideration of the benchmark results and benefits from the significant expertise of the industrial partners in designing advanced metallic and composite structures. The availability of the testing equipment and the manufacturing capabilities are also taken into account. The selected structures are scaled-down versions of real parts of the European Launcher Vehicle ARIANE 5. In particular, the following structures are scaled and designed to be manufactured and tested: the sandwich cylindrical shells of the Dual Launch System (SYLDA) and of the Interstage Skirt Structure (ISS), the metallic cylindrical shell of the Liquid Hydrogen Tank (RLH2), the aluminum alloy stiffened structure of the Jupe AVant Equipée (JAVE) and two versions of the conical shell of the Vehicle Equipment Bay (VEB), one in laminate composite and one in sandwich.

No. B16

Title: WP 3 - Development & application of improved design approaches

Authors: M. Ruess (TU-Delft)

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Abstract:

The development and application of improved design rules for imperfection sensitive composite launcher structures lies at the heart of the EU-DESICOS project with the aim to enrich the well-established NASA SP 8007 guideline, dating back to 1968, by novel concepts tailored to the potential of nowadays laminate composites. Based on the high level of sophistication of numerical analysis tools for buckling of thin-walled structures various design, modeling and analysis concepts were tested and further developed. The applied approaches include deterministic, stochastic and combined methods to reveal the performance of stiffened and unstiffened cylinder and conical shell structures with regard to improved design loads compared to the existing guidelines which are based on comprehensive cylinder buckling test series. Besides a number of numerical baseline studies considering single perturbations of the perfect structure, sensitivity analyses with respect to material properties, imperfections, boundary conditions and holes the development of design rules, their applicability and range of validity is addressed. Furthermore, the reliability and usability of the single-perturbation load approach as a simple design load case in combination with a stochastic approach is discussed and evaluated. All developments have been verified with benchmark studies and compared to test results. In addition to the recommendations and advice of an existing buckling handbook for space structures the extensive numerical testing has provided further insight to modeling and analysis aspects for laminate composite shell structures.

No. B32

Title: WP 4 - Manufacturing and buckling tests

Authors: H. Abramovich (Technion)

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Abstract:

The 4th workpackage of the DESICOS project, WP4, has two main tasks: Task 4.1 is dedicated to manufacture and non-destructive inspections of the structures designed and calculated in WP2, like sandwich and laminated composite cylindrical shells, metal cylindrical shells, aluminum stringered stiffened structures (JAVE) and sandwich and laminated composite cones; Task 4.2 consists of testing the specimens manufactured and inspected in the previous task. The various partners involved in this task, will use their state-of-the-art buckling test facilities, while employing modern measurement systems like ARAMIS or Laser based systems to measure and monitor the behavior of the various structures during loading and at the buckling and post-buckling regions. The initial geometric imperfections for all the tested specimens will be measured, prior to testing, yielding a large data base to be used for further evaluation and comparison of the experimental and numerical predictions. The Vibration Correlation Technique (VCT) will be used on some of the specimens, to obtain non-destructive predictions of their first static buckling load. The SPLA method, which implies using a small lateral force to simulate geometric imperfections, will be applied on the tested specimens, to assess its applicability and its efficiency to simulate the "worst" initial geometric imperfection, thus leading to an improved lower bound buckling for imperfection sensitive composite type structures.

No. B13

Title: WP 5 - Contribution to improved design guidelines

Authors: P. Blanchard (Airbus)

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Abstract:

DESICOS Project is oriented to provide less conservative methods for buckling prediction of cylindrical and conical shells. How this goal could be reached will be evaluated at the end of the Project. Moreover, DESICOS is a way to explore or re visit, compare, evaluate, select different approaches, tools, numerical strategies, etc. This includes the SPLA (single load perturbation approach) and MPLA (multiple load perturbation approach) whose concept has been deeply investigated in framework of DESICOS. One of the most important goals of the project is the generation of a set of guidelines. The design and analysis guidelines are the result of a good cooperation between the universities and research centers partners, and the partner from industry. They are based on extensive theoretical and experimental research performed within DESICOS project. This oral session will present the scheme followed to go from academic results to results applicable in industrial context, and will highlight some issues the industrial partner would like to be answered for the guidelines.

DESICOS – Achievements of the PhD students: New design concepts	
Room 1	**Chair: Prof. Chiara Bisagni (TU-Delft)**
25th March, 2015	**Time: 15.10**

No. B15

Title: New robust knock-down factors for the stiffened cylinder

Authors: K. Liang, M. Ruess (TU-Delft)

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Abstract:

Cylindrical shells, which exhibit high buckling imperfection sensitivities, are commonly used in the design of rocket launcher structures. The NASA guideline SP-8007 provides some knock-down factors which rely on lower-bound curves from experimental data to determine the load carrying capability of these cylindrical shell in 1968. Many recent researches have indicated that the knock-down factors from the NASA SP-8007 guideline are inclined to produce very conservative estimations for the buckling load of imperfect shells, due to the limitations of computational power and experimental skills forty-six years ago. This study presents a new robust design, which was first introduced in the proposal of an EU project-DESICOS, for imperfection sensitive stiffened cylinders. The knock-down factors produced by this new design are proposed by a combination of a deterministic study based on the single perturbation load approach (SPLA) and a stochastic study using Monte Carlo simulations. The real geometric imperfection measured from the unstiffened cylinders can be directly introduced into the smeared model of the stiffened cylinder where the stiffeners need not be modeled and the effect of stiffeners are taken into account using a general shell stiffness..

No. B18

Title: New Design Approach for Axially Compressed Composite Cylindrical Shells combining the Single Perturbation Load Approach and Probabilistic Analyses

Authors: A. Meurer, M. Dannert, R. Rolfes (Leibniz University Hannover)

Contact: a.meurer@isd.uni-hannover.de

Abstract:

In the recent time, various different approaches to obtain design loads for cylindrical shells have been proposed to overcome the overly conservativeness of the broadly applied NASA-SP 8007. Straight-forward deterministic approaches like the Single Perturbation Load Approach lack the ability to account for various unknown imperfections in the real manufactured specimen. The design loads obtained by probabilistic approaches include these uncertainties and yield a design of known reliability. However, they share the disadvantage to rely on adequate knowledge of the distribution of imperfections. To overcome the costly production of specimen and measurements of geometric imperfections, a new approach is proposed. This Probabilistic Perturbation Load Approach accounts for the influence of various uncertain non-traditional imperfections while at the same time being independent from geometric imperfection measurements.

No. B20

Title: Cyclic buckling of composite boxes

Authors: S. G. P. Castro, C. Mittelstedt, F. A. C .Monteiro, M. A. Arbelo , R. Degenhardt, G. Ziegmann (PFH, DLR, TU Clausthal. Sogeti)

Contact: castrosaullo@gmail.com

Abstract:

A semi-analytical model for the non-linear analysis of simply supported, unstiffened laminated composite cylinders and cones using the Ritz method and the Classical Laminated Plate Theory is proposed. A matrix notation is used to formulate the problem using the Donnell's and the Sanders' non-linear equations. The approximation functions proposed are capable to simulate the elephant's foot effect, a common phenomenon and a common failure mode for cylindrical and conical structures under axial compression. Axial, torsion and pressure loads can be applied individually or combined, and solutions for linear static, linear buckling and non-linear buckling analyses are presented and verified using a commercial finite element software. The presented non-linear buckling analyses used perturbation loads to create the initial geometric imperfections, showing the capability of the method for arbitrary imperfection patterns. The linear stiffness matrices are integrated analytically and for the conical structures an approximation is proposed to overcome the non-integrable expressions.

No. B25

Title: Reliability assessment of buckling response of axially compressed sandwich composite shells with and without cut-outs

Authors: M. Alfano, C. Bisagni (Politecnico di Milano, TU-Delft)

Contact: michela.alfano@polimi.it

Abstract:

The objective of the running EU project DESICOS (New Robust DESign Guideline for Imperfection Sensitive COmposite Launcher Structures) is to formulate an improved shell design methodology in order to meet the demand of aerospace industry for lighter structures. Within the project, this paper discusses the development of a reliability-based probabilistic methodology through the combination of the Stress-Strength Interference Method and the Latin Hypercube Method with the aim to predict the bucking response of three sandwich composite cylindrical shells, assuming a loading condition of pure compression. The three shells are made of the same material, but have different stacking sequence and geometric dimensions. One of these shells includes also the presence of three circular cut-outs. Different types of sources of input imperfections are taken into account: uncertainty of longitudinal Young's modulus and of orientation of the laminae, geometric imperfections and boundary imperfections. The methodology enables a first assessment of the structural reliability and of the imperfection sensitivity of the three sandwich composite shells through the calculation of reliability buckling factor for a specified level of probability. This factor depends on the requirements of reliability level, on the number of adopted samples and on the assumptions made in modeling the input imperfections. In particular, the influence of the imperfections is here evaluated separately and in combination. The main advantage of the developed procedure is the versatility that allows it to be applied to the buckling analysis of both laminated composite shells and sandwich composite shells including different types and different models of imperfections.

No. B30

Title: Advanced sizing strategies for preliminary design of orthotropic grid stiffened shell structures

Authors: L. Friedrich, H. Reimerdes, K. Schröder (RWTH Aachen)

Contact: friedrich@ilb.rwth-aachen.de

Abstract:

Thin walled integrally stiffened shell structures are frequently used in primary structures of space launcher vehicles. These structures are prone to buckle and thus fail due to a loss of structural stability. It has to be distinguished between two major modes of instability, namely a global buckling of the entire structure and a local buckling of skin sections, longitudinal as well as circumferential stiffeners. Due to the large number of design variables when designing an

integrally stiffened shell structure, the preliminary design of these structures is a demanding problem. To allow an efficient preliminary design, advanced sizing strategies have to be developed. For this purpose, analytical methods to allow assessing the local as well as global instability of the integrally stiffened shell structure are employed. Within this contribution, sizing strategies basing on closed form efficient analytical methods are introduced and applied to identify proper designs of integrally orthotropic stiffened shell structures.

No. B02

Title: Assessment of the Single Perturbation Load Approach on composite conical shells

Authors: R. Khakimova, R. Degenhardt (DLR)

Contact: Regina.Khakimova@dlr.de

Abstract:

The importance of taking into account geometric imperfections for cylindrical and conical thin-walled structures in buckling had been already recognized a long time ago. In spite of extensive recent research on buckling of imperfect shells, such structures are still today generally designed at the preliminary design phase according to the NASA SP-8007 for cylinders and the NASA SP-8019 for truncated cones. Both guidelines date from 1960’s and they are based on a lower bound curve which does not consider important mechanical characteristics of laminated composite shells. New design approaches that allow taking full advantage of using composite materials are required. Nowadays, with the everyday increasing computational power, it becomes easier to consider imperfections in numerical simulations. However, in the early design stage the real geometric imperfection pattern of a new type of structure is not available. The Single Perturbation Load Approach (SPLA), a design method developed by Hühne, is a deterministic approach where a lateral load is applied prior to axial compression, stimulating a single dimple. This study attempts to assess the SPLA applied to truncated conical shells: its applicability and limitations.

No. B11

Title: Stochastic analysis of imperfection sensitive composite cylinders using realistic imperfection models

Authors: J. Kepple, M. Herath, G. Pearce, G. Prusty, R. Thomson (CRC-ACS, University of New South Wales, Advanced Composite Structures Australia)

Contact: jendi.kepple@gmail.com

Abstract:

The important role of imperfections on decreasing the buckling load of structural cylinders has been investigated by scientists and engineers for the past century, yet there is currently no method that is able to thoroughly investigate and replicate realistic imperfections for a full account of possible buckling loads. This drawback impairs optimized design as shell designers are restrained to using an outdated and conservative lower-bound design philosophy that relies on empirical data from 1968. Modern manufacturing methods and materials such as high-strength, high-stiffness composites require new, optimized design measures to take full advantage of their greater efficiencies. Even when identical lay-ups, material and shell geometries are used, these cylinders exhibit a large scatter in buckling load levels due to imperfections introduced in their manufacturing process. Stochastic analyses can optimize and improve the robust design and reliability of such cylinders through accurate prediction of the range of conceivable buckling loads by realistic simulation of structural imperfections. A stochastic procedure which realistically models imperfection sensitive composite cylindrical shells is investigated in this paper. Monte-Carlo simulations of axially compressed cylinders are performed to show the combined effect of geometric and thickness imperfections on the scatter of the buckling load.

Keynote lectures	
Room 1	**Chair: Saullo Castro (Embraer)**
26th March, 2015	**Time: 8.30**

No. A05

Title: Single perturbation load approach – From the initial idea until today

Authors: Christian Hühne (DLR, Head of department Composite Design)

Contact: Christian.Huehne@dlr.de

Abstract:

Thin-walled cylindrical shells are prone to buckling. Imperfections which are defined as deviations from the perfect geometrical shape or homogeneous loading distribution can reduce the buckling load significantly compared to that of the perfect shell. For the design of unstiffened cylindrical shells mostly the NASA SP-8007 guideline is used, which recommends reducing the buckling load of the perfect shell using a knock-down factor. Existing knock-down factors are conservative and structural behaviour of composite material is not considered. The history of the developed Single Perturbation Load Approach (SPLA) is presented which delivers less-conservative knock-down factors and considers the physical properties of composite material. A probabilistic approach is used to examine the reliability of the SPLA for test shells with traditional geometric imperfections. Inhomogeneous loading distribution along the circumference causes also a reduction of the load carrying capability of thin-walled cylinders. The advanced Single-Perturbation Load Approach (α-SPLA) takes also these non-traditional imperfections into account. Based on test results the α-SPLA is validated. A probabilistic approach is used to examine the reliability of the α-SPLA for test-shells with traditional and non-traditional imperfections.

No. A06

Title: Refined theories and finite element models for the analysis of laminated composite structures: An overview

Authors: JN Reddy (Texas AM University, USA)

Contact: jnreddy@exchange.tamu.edu

Abstract:

In this lecture an overview of various theories used to model the structural behavior of laminated plates and shells is presented and the author's recent research on the development of a robust shell element and its application to nonlinear and post-buckling analysis of composite and functionally graded shells is presented. In particular, the classical, first-order, third-order, and layerwise theories and their finite element models are reviewed. Numerical examples showing the relative accuracy of various theories will be presented. In addition, the speaker's recent work on the development of laminated composite shells for large deformation analysis of plates and shells will be discussed and its use in the solution of several benchmark problems will presented.

No. A08

Title: The use of simple strain-energy concepts to debunk the classical thin-shell buckling analyses for once and for all

Authors: John Hart-Smith

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Abstract:

The error in the classical prediction of the buckling stress of a longitudinally compressed unpressurized cylindrical shell, whereby the prediction is twice as high as the bulk of the test data, is shown here to result from failure to properly understand the concept of strain energy. The classical failure to identify the correct buckling mode for rings and long cylindrical tubes subjected to external pressure can be explained the same way. This fatal error in the classical analyses, one of many, is seen to be due to the neglect of the strain energy stored in the compressed shell immediately prior to buckling. The consequence of this omission from buckling analysis is shown to be that the membrane stresses created during buckling were predicted to add to the resistance to buckling from bending deformations when, in fact, they contributed nothing to the buckling resistance. Buckling is resisted by bending stresses alone, because the membrane strain energy increments associated with the portions of the shell that buckle in one direction are nullified by the increments of strain-energy from the buckling in the other direction. The pre- buckling strain energy is alternatively increased and decreased. This is not apparent when the pre-buckling strain energy is neglected. The purpose of this paper is to create awareness that specific corrections applied to the classical thin-shell buckling analyses can enable them to all agree with test data without needing to invoke hypothetical imperfections in the test articles to achieve agreement between test and theory.

Semi-analytical concepts	
Room 1	Chair: David Gao (Australian National University)
26th March, 2015	Time: 10.00

No. C02

Title: Closed-form local skin buckling solution for orthotropic and anisotropic stiffened panels braced with omega stringers

Authors: V. K. Mantzaroudis, D.G. Stamatelos (Hellenic Air Force Academy)

Contact: dimitrisstamatelos@yahoo.com

Abstract:

In the present contribution a novel fast design tool is developed to enable the calculation of critical buckling loads of large structural components comprising stiffened composite panels. In more detail the development of analytical, closed form solutions for the local buckling problem of composite plates, stiffened with equidistant omega stringers, is performed. The skin local buckling problem of a stiffened plate is treated as the buckling of the skin segment enclosed by two consecutive stringers. In this case, the effect of the stringers to the skin is modeled by applying appropriate elastic restrains, as boundary conditions. The elastic restrains are derived and determined considering the bending and torsional stiffness of the stringers. The solution of the skin local buckling problem is obtained utilizing the Rayleigh-Ritz method. Additionally, the developed closed form solution is extended to the interesting case of anisotropic stiffened panels. Finally, the validation of the analytical results is obtained comparing them with the respective numerical, where a satisfactory correlation is achieved.

No. C32

Title: Closed-form local buckling analysis of shear-deformable composite laminated beam structures

Authors: T. Kühn, H. Pasternak, C. Mittelstedt (EADS EFW, TU Cottbus, Sogeti)

Contact: Christian.Mittelstedt@sogeti-hightech.de

Abstract:

This paper discusses a novel closed-form analytical approach for the local flange buckling analysis of thick-walled beams with close-profile cross-sections under shear and compression loads. The web and the flanges of the beams are assumed with symmetric stacking sequences. Based on a discrete plate analysis approach the flange under consideration is idealized as a plate that has two rotationally restrained edges wherein the rotational restraints depend on the properties of the web of the beam. For the restraint stiffness that is taken to represent the remainder of the beam's cross-section, straightforward closed-form approximate solutions can be postulated. The buckling analysis as well as the calculation of the restraint stiffness is based on first-order shear deformation theory in order to account for transverse shear effects as they become relevant in moderately thick composite laminates. In order to derive a closed- form solution for the critical buckling load, adequate sets of shape functions are postulated for the buckling deflections as well as for the rotations of the laminate cross-section in the buckled state. The buckling condition is then derived from the principle of minimum elastic potential of the laminated plate in the buckled state. It will be shown that the employed shape functions allow for a very reliable determination of the local buckling modes of the flanges of composite beams and the corresponding critical buckling loads in a fully closed-form analytical approximate manner.

No. C01

Title: Highly Orthotropic Panels Structural Stability, Farrar and Bloch Waves Theory

Authors: M. A. Castillo-Acero, C. Cuerno-Rejado, M. A. Gómez-Tierno (Aernnova, UPM)

Contact: miguelangel.castillo@aernnova.com

Abstract:

This paper presents the studies developed to design and manufacture structural highly orthotropic panels. They aim to provide the capabilities required for highly orthotropic structures that enable morphing. These panels are highly deformable in one given direction and in the perpendicular one must be compliant to sustain the internal loads per certification stiffness and strength requirements. Neither classic orthotropic or regular cellular solids theories are strictly applicable on their study. A combination of computational method, Matlab coded, to size panels for stability and classic structural beam theory is studied. Then, non-linear FEM models, in displacements and material, are developed for an aerospace control surface application, resulting in Bloch wave panel behavior alike. A sample panel is sized and 3D modeled, and then produced using additive layer manufacturing process to demonstrate the initial stages of a validation and verification campaign.

No. C07

Title: Application of different versions of finite strip Method as fast tools for buckling analysis of Composite stiffened shells

Authors: H. Assaee (Shiraz University of Technology)

Contact: assaee@sutech.ac.ir

Abstract:

In this paper a fast tool based on finite strip approach is represented for buckling analysis of composite laminated shell structures. The developed tool is applicable for various types of stiffeners in axial (i.e. stringer) or hoop directions (i.e. rib). Moreover, it can deal with arbitrary shapes of stiffeners as well as various arrangements. The loading on stiffened cylindrical shells may be axial compression, external pressure, torsion or a combination of mentioned loads. In this paper four elements are introduced in the formulation as curved and flat finite strips as well as two types of finite rings. In the formulation of developed approach Classical laminated shell theory (CLST) and Sanders-Koiter strain- displacement relations are used. It is noted that in developed fast tool only the cross section of the prismatic shell structure is required to be modeled in the tool. The results are compared to those` obtained by FEM approach and results available in open literatures. The comparison of results revealed that the developed fast tool can predict the precise buckling load as well as buckling mode shape of composite stiffened cylindrical shells with very low number of degrees of freedom and also with a simple and fast modeling approach.

No. C08

Title: Buckling and post-buckling analyses of circular composite cylinders under axial compression using a semi-analytical approach

Authors: T. A. Schmid Fuertes, H.-G. Reimerdes (Airbus, RWTH Aachen)

Contact: theodor-andres.schmid-fuertes@airbus.com

Abstract:

Cylindrical shells are very common structural elements in the aerospace industry. Subjected to axial compression they are prone to buckling. The predicted theoretical buckling load is in general not achieved in practice. It is a common understanding that this behaviour is explained by the sensitivity to (geometrical) imperfections. In this paper a formulation of a non-linear

shell theory that includes geometrical imperfections is presented. The problem is solved using a semi-analytical approach. The achieved linear and non-linear buckling results as well as post-buckling equilibrium paths are compared to experimental and numerical results reported in the literature.

Damaged structures / Buckling with piezos / FGM	
Room 2	Chair: Marc Schultz (NASA)
26th March, 2015	Time: 10.00

No. C12

Title: Buckling and post-buckling behaviour of delaminated composite struts

Authors: A. Köllner, C. Völlmecke (TU-Berlin)

Contact: anton.koellner@tu-berlin.de

Abstract:

In the work presented the buckling and post-buckling behaviour of composite struts under uniaxial compression is investigated. Herein, a geometrically nonlinear model described in Ref. 1 is extended to composite materials comprising only four generalized coordinates. By minimizing the total potential energy of the system, critical buckling loads for varying lengths and depths of delaminations are determined analytically. Equilibrium paths and bifurcation diagrams are furthermore evaluated numerically using AUTO-07p2 whilst system parameters are varied. The outcome of the work provides detailed information about the influence of delaminations on the buckling behaviour of composite struts.

No. C18

Title: Delamination of secondary bonding around cuts in a compressively loaded CFRP skinned sandwich structure

Authors: K.C. Gopalakrishnan, R. Ramesh Kumar (Government Engineering College, CET and GEC Barton Hill, Thriruvananthpuram)

Contact: rameshkumar9446@gmail.com

Abstract:

CFRP skinned sandwich structures in the form of cylinder or cone with very thin skin thickness of 0.5mm and different diameters in the range of 1000 to 5000 mm with stubby to slender configurations that are designed to bear compressive loads are widely used in launch vehicles. To overcome honeycomb core shear failure, around the reinforced cutouts and other low margin areas are locally potted. Reinforcements are originally provided as a part of primary bonding during curing. Finally, the basic design was qualified with an expected mode of failure of separation of the skin from the core, forcing generally for a buckling induced fiber breakage. However, as being observed in certain stray incidents the shell is locally damaged by hitting during transportation. Under such case the skin is reinforced to avoid local buckling following a room temperature cured process that is defined as secondary bonding. Interfacial debond growth between honeycomb core and skin is generally very complex in nature not only due to geometric and material nonlinearity but also the oscillatory singularity nature of stress and displacement field in the vicinity of the debond tip. It was reported in literature that debond growth does not occur until the debond region has buckled and the growth is governed by the peel mode of fracture. Author's recent studies on the comparison of test data on the delamination growth, mode of failure and fracture load of the sandwich panel with prediction using cohesive zone element showed good agreement. In the present study, cohesive zone model analyses are carried out considering tested properties on mode–I and mode-II delamination fracture toughness values and interfacial tensile strength of sandwich adapter under axial compression and prediction of critical debond load with test data shows a good agreement. Further, reinforcement around the hole bonded with room temperature curable adhesive having low lap shear strength (as a part of repair scheme) is considered for the study to assess the buckling induced peel stress at the debond front. The study is useful in the design of composite structure where need for a secondary bond for reinforcement is a mandatory.

No. C22

Title: Progressive damage modeling in composite: from aerospace to automotive industry

Authors: J.P. Delsemme, M. Bruyneel, Ph. Jetteur, B. Magneville, T. Naito, Y. Urushiyama (SAMTECH, Honda)

Contact: jean-pierre.delsemme@siemens.com

Abstract:

In this paper we will review the progressive damage modeling implemented in finite element code SAMCEF. Starting from simplified formulations used during the European projects COCOMAT and ALCAS with main results of panel buckling, post-buckling and also skin-stringer separation and ply failure, the results of more advanced models recently obtained in cooperation with Honda R&D will be presented. These models rely on better understanding of progressive damages and specially the shear behavior of UD ply. In a second time, a detailed description of that model and parameter identification procedure will be given. Finally, some industrial applications will be presented.

No. C35

Title: Buckling enhancement of laminated structures with piezoelectric actuators

Authors: A. Muc, P. Kędziora (Cracow University of Technology)

Contact: olekmuc@mech.pk.edu.pl

Abstract:

In this paper, dynamics, electromechanical couplings, and control of piezoelectric laminated cylindrical shells and rectangular plates are investigated. It is assumed that the piezoelectric layers are distributed on the top and bottom surfaces of the structures. The geometric design variables of the piezoelectric patches, including the placement and sizing of the piezoelectric sensor/actuators (S/As), are processed. The results of numerical examples provide some meaningful and heuristic conclusions for practical design.

No. C15

Title: Analysis of dynamic buckling of FGM plate under pulse of heat flux and compression force

Authors: L. Czechowski (Lodz University of Technology)

Contact: leszek.czechowski@p.lodz.pl

Abstract:

The paper concerns an analysis of dynamic buckling of functionally graded material plates under interaction of heat flux loading with huge power and compression force, applying finite element method. The materials of investigated structure as well as their properties are varying in each layer across the plate thickness formulated by the power law distribution. The rectangular pulse of heat flux was applied evenly to whole ceramic surface. The analysis was conducted in the ANSYS 14.5 software. The duration of heat flux loading equal to a period of natural fundamental flexural vibrations of given structures has been taken into consideration. The duration of compression force was stable throughout time simulation. To involve large deflections of structures, the Green-Lagrange nonlinear-displacement equations and the incremental Newton-Raphson algorithm have been used. An assessment of dynamic response of a plate was carried out on base of Budiansky-Hutchinson criterion. The studies have been conducted for different volume fraction distributions applying different compression force and heat flux loading. The calculation results in function of the heat flux and force vs. maximal plate deflection have been presented and discussed.

Design and Analysis	
Room 3	Chair: Kaspars Kaknins (RTU)
26th March, 2015	Time: 10.00

No. C36

Title: Industrial Branching analysis and assessment of the structural load carrying behaviour of composites in the post buckling regime

Authors: B. Goller, H. Haller (INTALES)

Contact: goller@intales.com

Abstract:

Buckling is mostly the driving failure mode for the sizing process of light weight structures. As this failure mode is in principal a nonlinear phenomenon which may cause tremendous load redistribution which leads to a change of the equilibrium state, the investigation becomes more complex especially for large structures. In industrial projects the sizing process commonly is done using numerical analysis like the Finite Element Method for complex structures. This leads frequently to large models with a large number of degrees of freedom and to large equilibrium systems which need computational time. The determination of the critical points along an equilibrium load path of a structure needs to be done carefully and is therefore quite time consuming. In an industrial environment, commercial codes are usually employed for the structural analysis and hence the access of the stiffness matrix and its extension and modification for performing a branching analysis is not possible. Therefore, an alternative strategy has been established where the workflow of the commercial FE-codes is taken as boundary condition. This adaptation to the ABAQUS solver has been programmed in order to automate this process and to reduce the analysis time. In this presentation, the determination of the load path of an industrial structure including the identification of Null-eigenvalues including a strategy for mode tracking will be presented.

No. C27

Title: Stability behaviour of composite laminates with and without cutout under non-uniform edge loads

Authors: T. Rajanna, Sauvik Banerjee, Yogesh M. Desai, D.L. Prabhakara (Indian Institute of Technology)

Contact: t.rajanna@gmail.com

Abstract:

The objective of the present work is to investigate the influence of non-uniform in-plane loads on vibration and buckling behaviour of laminated plates with and without cutout under different edge conditions. Towards this, a nine node heterosis plate element having five degrees of freedom (u, v, w, θx and θy) at boundary nodes and four degrees of freedom (u, v, θx and θy) at central node is developed by employing the effects of shear deformation and rotary inertia. The one advantages of this type element is that, it behaves better even for extreme thin plate configuration. The effect of different parameters, such as, cutout sizes, ply-orientations, aspect ratios of plate, boundary conditions and variety of non-uniform edge loads on buckling are considered in this study. It is shown that cutout sizes under different non- uniform loads and boundary conditions have a remarkable effect on the buckling behaviour of composite laminates.

No. C16

Title: Numerical model of postbuckling behaviour of GFRP beams subjected to pure bending

Authors: T. Kubiak (Lodz University of Technology)

Contact: tomasz.kubiak@p.lodz.pl

Abstract:

The papers deals with numerical calculations of thin-walled composite laminate beams with closed cross-section subjected to pure bending. A thin-walled beams with square cross-section made of eight layers GFRP laminate have been taken into consideration. FEM model have been prepared using four node multi-layered shell elements governed by first order shear deformation theory. Linear buckling analysis and nonlinear static analysis including large displacements have been performed. A Newton-Rapson algorithm have been employed. The FEM calculations have been conduct using Ansys® software. Three following layer arrangement were considered: [45/-45/0/0]S, [45/-45/45/0]S and [45/-45/45/0/0/-45/45/-45]T. The influence of number of load steps and geometrical initial imperfection on course of equilibrium paths have been checked. The results of calculations have been compared with experimentally performed four-point bending tests. Comparing results of tests and numerical calculations it was observed that: in some cases the deflection of beams not correspond to the bifurcation buckling mode correspond to the lowest buckling mode: the geometrical imperfection corresponds to higher buckling mode should be taken into consideration to obtain similar postbuckling equilibrium paths from tests and FEM calculations. As it is well known the buckling load and failure load for real structures depend on course of equilibrium paths. Taking above into account Author of this paper try to show some problems in obtaining numerical calculations results similar to experimental tests.

No. C29

Title: Simulations of surface wrinkling of bi-layer composite

Authors: B. Brank, A. Stanić, B. Hudobivnik (University of Ljubljana)

Contact: bbrank@fgg.uni-lj.si

Abstract:

Surface wrinkling of a bi-layer elastic composite composed of thin and stiff film and soft and thick substrate plays an important role in morphogenesis of many biological systems. In classical design of structures, it is mostly regarded as a failure mechanism. Nevertheless, inspired by examples from Nature, we can learn and discover a way to harness such phenomenon in a controlled and orderly way. Today surface wrinkling is already utilized as an enabling mechanism for a variety of advanced technological applications, including fabrication of tunable optics, micro-lens arrays, smart adhesives, tunable hydrophobic/hydrophilic surfaces, fabrication of micro-scale gears, thin film metrology, etc.. The basic mechanics behind this mechanical instability phenomenon rests upon the mismatch between the stiffness of the film and the substrate. When sufficiently large, compressive stresses may induce bifurcation from the state of homogeneous deformation, by relieving the stress locally to minimize the system's strain energy. More precisely, due to energetically more favorable bending over compression in the film, the substrate locally deforms as a solid, but the film mostly bends. This effect becomes even more evident as the film gets thinner. The correlation between the characteristic wavelength λ (and amplitude a), depth d of the pattern and the emerging pattern itself, depends on the geometrical and physical parameters of the system, i.e. film thickness, elastic material properties of the film and the substrate, and external stress activation, which can be governed, e.g. via swelling, thermal or mechanical activation. For simulation of surface wrinkling of a bi-layer elastic composite by the finite element method, one needs a reliable 3d-solid or solid-shell element. It should be volumetric-locking-free at finite deformations of quasi-incompressible hyperelastic materials and shear-locking-free when its thickness is limiting to a very small number. A good candidate that is able to comply with the above requirements is the enhanced assumed strain 3d-solid (brick) finite element. It was used for non-linear static and dynamic buckling analyses of a hyperelastic thick spherical shell composed of very thin film and very thick substrate. For static analysis, an extremely robust path-following method is needed in order to be able to simulate the surface wrinkling phenomenon. For dynamic analysis the results depend on the applied time stepping scheme. The standard Newmark as well as the energy conserving/decying implicit time stepping schemes were used. Some types of analyses were successful in predicting wrinkling buckling pattern of the thin surface film of composite structure, while some others failed the task. Necessary ingredients for successful computation of this kind of mechanical instability phenomenon will be presented and discussed at the conference.

No. C19

Title: Couple Instabilities of Stiffened Panels with Multiple Stiffener Sizes

Authors: A. Watson, B. Wang, S. Wang, C. Harvey (Loughborough University)

Contact: A.Watson@lboro.ac.uk

Abstract:

The panel analysis exact finite strip code, VICONOPT, is utilised to analyse a stiffened panel with multiple stiffener sizes subject to axial compression. Introducing more than one size of stiffener complicates the buckling behaviour of the panel with the addition of one or more torsional buckling modes. If a panel has two sizes of ‘T’ shaped stiffeners alternating across the width of the panel then the possible buckling mode shapes will fall into four different categories. These are skin initiated buckling (mode A); torsional buckling of the small stiffener (mode B); torsional buckling of the large stiffener (mode C) and overall buckling (mode D). A plot of buckling stress versus buckling half wavelength shows a curve with four minima. If mode A is critical then this will have the lowest stress value. Mode D typically has the largest value. Postbuckling behaviour of the stiffened panels is predicted by using the finite element programme MARC. The paper shows buckling stress versus buckling half-wavelength plot for a panel and shows that buckling modes can combine at the same wavelength to reduce buckling stability. Higher eigenvalues are examined and show that different modes do combine where buckling stresses are similar. It is seen that for particular wavelengths different modes become critical. Boundary conditions influence the long wavelength modes significantly. To establish a high quality postbuckling model that allows for simply supported loaded ends usually results in the use of rigid body elements. It is shown that these elements can over estimate true overall buckling stress values. Postbuckling results presented show a significant reduction in peak load without the use of rigid body elements. It is suggested that use of rigid body elements will not identify the correct postbuckling path even if the local mode is correctly identified.

Improved theories / concepts	
Room 1	Chair: Theodor-Andres Schmid Fuertes (Airbus)
26th March, 2015	Time: 15.00

No. C14

Title: Lower Bound Buckling Loads for Design of Laminate Composite Cylinders

Authors: J. Croll, M. Wang (Uni. College London, China Uni. of Petroleum)

Contact: j.croll@ucl.ac.uk

Abstract:

Over a period of more than 45 years, an extensive research programme has allowed a series of very simple propositions, relating to the safe design of shells experiencing imperfection sensitive buckling, to be recast in the form of a series of lemmas. These are briefly summarised and their practical use illustrated in relation to the prediction of safe lower bounds to the imperfection sensitive buckling of axially loaded, fibre reinforced polymeric, laminated cylinders. With a fundamental aspect of the approach, sometimes referred to as the reduced stiffness method, being the delineation of the various shell membrane and bending stiffness (or perhaps more appropriately energy) components contributing to the buckling resistance, the method will be shown to also provide a powerful way of making rational design decisions to optimise the use of fibre reinforcement.

No. B17

Title: Towards mode selection criteria for multi-mode initial postbuckling analysis of composite cylindrical shells

Authors: E.L. Jansen, T. Rahman, R. Rolfes (Uni. Hannover, TNO DIANA BV)

Contact: e.jansen@isd.uni-hannover.de

Abstract:

The objective of the present work is to investigate the influence of non-uniform in-plane loads on vibration and buckling behaviour of laminated plates with and without cutout under different edge conditions. Towards this, a nine node heterosis plate element having five degrees of freedom (u, v, w, θx and θy) at boundary nodes and four degrees of freedom (u, v, θx and θy) at central node is developed by employing the effects of shear deformation and rotary inertia. The one advantages of this type element is that, it behaves better even for extreme thin plate configuration. The effect of different parameters, such as, cutout sizes, ply-orientations, aspect ratios of plate, boundary conditions and variety of non-uniform edge loads on buckling are considered in this study. It is shown that cutout sizes under different non- uniform loads and boundary conditions have a remarkable effect on the buckling behaviour of composite laminates.

No. B22

Title: Single perturbation load approach: new definition for P1 and explaining the constancy of the buckling load

Authors: S. G. P. Castro, M. A. Arbelo , R. Degenhardt, G. Ziegmann (PFH, DLR, TU Clausthal. Sogeti)

Contact: castrosaullo@gmail.com

Abstract:

The single perturbation load approach is a deterministic analysis method applied in the determination of design loads for imperfection sensitive structures. As verified by Hühne et al., imperfection sensitive cylindrical structures when subjected to axial compression will exhibit a progressively decreasing load carrying capacity for growing imperfection amplitudes up to a threshold, where the buckling load remains nearly constant. The method was named single perturbation load because a unitary lateral load is used to create the geometric imperfection, and the threshold perturbation load beyond which the buckling load is nearly constant is called P1. The aim of the present paper is to summarize what has been presented by Castro et al., explaining the constancy of the buckling load and giving a precise definition for the threshold perturbation load P1.

No. C23

Title: On the method of calculation of buckling and postbuckling behavior of laminated shells with small arbitrary imperfections

Authors: V.M.Trach, N.P.Semenyuk, A.V.Podvornyi, N.B.Zhukova (National University of Water Management and Nature Resources Use, Timoshenko Institute)

Contact: trach-vm@ukr.net

Abstract:

In the present paper the variant of computational methods of stability and initial postbuckling behavior of isotropic shells which are offered in Ref.1-3 is generalized with respect to laminated composite shells. Using methods of the asymptotic analysis of the Timoshenko-Mindlin theory the relationships for calculation of shells with the small geometrical imperfections of the arbitrary shape are produced . On the basis of obtained equations the technique of calculation of a non-linear pre-buckling state, limiting loads and bifurcation, and also initial postbuckling behavior of laminated cylindrical shells at an axial compression are worked out. The results of calculation of boron-plastic shell are represented. The features of transformation of the interacting modes of imperfections are researched.

No. B09

Title: Structural Robustness Assessment of Thin-Walled Composite Structures in the Postbuckling Regime

Authors: F. da Cunha, T. Wille, R. Degenhardt, M. Sinapius (DLR)

Contact: fribeirosc@hotmail.com

Abstract:

In this work, the novel structural robustness design strategy and the energy-based structural robustness index are employed to assess stiffened composite shells in the post-buckling regime. Firstly, a deterministic parametric study is carried out varying the skin-thickness and spacing between stringers. Secondly, a probabilistic assessment is carried out. As result, the potential benefits of the novel structural robustness design strategy is discussed by analyzing stiffened composite shells under compressive loading in both deterministic and probabilistic contexts.

No. B19

Title: Improving the vibration correlation technique for shells using analysis tools

Authors: E. Jansen, H. Abramovich, R. Rolfes (Leibniz University Hannover, TECHNION)

Contact: e.jansen@isd.uni-hannover.de

Abstract:

The availability of a Vibration Correlation Technique (VCT) for nondestructive determination of buckling loads of cylin- drical shells has obvious advantages. Earlier, a semi-empirical VCT approach has been developed and applied successfully for the prediction of the buckling load of closely stiffened aluminum shells. In the present paper, a possibility to support and improve the estimates of this semi-empirical VCT approach by means of the application of analysis tools is proposed. Two semi-analytical models with different levels of complexity will be used for this purpose. In the two approaches employed, both the nonlinear effect of the static state and the nonlinear effect of the geometric imperfections are represented. These two methods form the basis of an extension of the existing semi-empirical Vibration Correlation Technique for shells, to a VCT in which vibration measurements and analysis tools are combined. In the present work, an integated approach is developed, in which the VCT is supported by these analysis tools.

No. C24

Title: A necessary correction of the classical analyses for buckling of circular arches, rings, and tubes

Authors: John-Hart Smith

Contact: leonard.john.hart_smith@verizon.net

Abstract:

The study of the buckling of circular arches, rings, and tubes of finite and infinite length under radial and hydraulic external pressure has been confused by general acceptance of a physically incorrect mathematical interpretation of the plausible and almost certainly correct notion that the process of buckling was inextensional. One unrecognized consequence of this is that the accepted elliptical (n = 2) mode for the buckling of rings and long tubes violates the requirements of equilibrium. A related consequence is that true first buckling mode (n = 1) has always been portrayed as merely a rigid-body motion, and not a buckling mode at all. This resulted from the addition of fictitious tangential displacements to the actual radial displacements that varied cyclically around the circumference in order to enforce the absence of membrane hoop strains around the circumference. The true interpretation of the inextensibility condition is shown here to be the absence of in-plane displacements, not in-plane strains. Variable hoop stresses are needed to match the circumferentially variable distance from the skin to the centroid of the shell over which the constant pressure acts. This reinterpretation of the inextensibility criterion applies to all shell buckling problems, not just this class. The author's new analyses correct all of these errors in the prior art, including the glaring inconsistency between the buckling stress for a 359.9999999999999-deg arch (buckling stress coefficient k = 0) and a 360-deg. ring (k = 0 3). His new analyses also confirm that the correct first buckling mode has only one wavelength around the circumference, not the two predicted by the classical analyses. Experimental confirmation of the correctness of the n = 1 mode is provided from published literature on research about submarines. The author has found no experimental evidence to support the existence of the generally accepted n = 2 buckling mode. Another difficulty in the classical analyses concerns the expressions for the changes in curvature as a function of the displacements. The most widely accepted equations, those by Love, contain errors that were corrected by Lamb over a century ago. This issue is fully explained here, by hand calculations, which is made possible by the simplicity of this one-co-ordinate problem. It is harder to validate the correct analyses when the situation is more complex. Again, it is found that the problems with the closed- form analyses have been replicated in the finite-element analyses, which also need correcting.

Experiments	
Room 2	Chair: H. Assaee (Shiraz University of Technology)
26th March, 2015	Time: 15.00

No. C26

Title: Wrinkling of thin spherical shells on elastic substrates

Authors: M. Brojan, D. Terwagne, R. Lagrange, P. Reis (Uni. of Ljubljana, ULB, MIT)

Contact: miha.brojan@fs.uni-lj.si

Abstract:

We present results of an experimental analysis of the morphology of wrinkling patterns of thin spherical shells constrained to soft elastic substrates. Our experimental hemispherical samples are fabricated using rapid prototyping techniques and consist of a thin-stiff shell adhered to a soft-thick substrate, both made out of silicone-based rubbers. Pressurizing an inner spherical air cavity enables us to compress our samples, thereby morphing the outer thin shell from its initially smooth configuration into a post-buckling wrinkled state. A variety of patterns can be found depending on the combination of geometric and material properties of the samples. During loading/unloading cycle we observe experimentally the hysteretic behavior due to the series of multiple snap-buckling events that must occur on the initially smooth spherical shell for each of the individual wrinkling unit to form. We focus our attention on the specific pattern mode of hexagonal-like dimples, which we characterize by analyzing their surface profile using a digital 3D scanner. Through digital image processing, we skeletonize these patterns by identifying the location of dimple minima and remarkably accurately describe the network of ridges via spherical Voronoi tessellation. By drawing analogies with the packing of particles on curved surfaces, we find that our system relaxes stresses both by out-of-surface buckling through the formation of arrays of dimples, and by simultaneously developing topological defects in these patterns. We also derive analytical expressions to accurately predict the total number of wrinkling units, their characteristic size, an average coordination number and approximately the number of non-hexagonal wrinkling units.

No. C13

Title: Experimental and analytical characterization of fluted-core sandwich composite structures

Authors: M.Schultz, L. Oremont, M. Hilburger (NASA)

Contact: marc.r.schultz@nasa.gov

Abstract:

As composite materials gain wider acceptance for aerospace primary structure, experimental-characterization and analysis methods must evolve, especially if new or underutilized composite structural concepts are to be successfully implemented. One such potentially underutilized concept is the fluted-core sandwich composite, which consists of facesheets separated by angled web members, and has a number potential advantages over traditional-core (honeycomb, foam, etc.) sandwich composites. However, fluted-core sandwich composites also exhibit a number of behaviors not seen with traditional-core sandwich composites. For example, stable local buckling that can lead to material failure can occur in the facesheets between webs. Additionally, in the direction perpendicular to the webs, the effective transverse-shear stiffness is largely determined by the bending stiffnesses of the facesheets and the webs and is much lower than in the direction parallel to the webs. These local buckling and transverse-shear behaviors can have a large influence on material failure and global buckling, respectively. Thus it is important to accurately characterize and model these behaviors. A

discussion of experimental characterization and analysis methods that interrogate these behaviors will be given in the proposed presentation.

No. B31

Title: Curved panels buckling prediction using the Vibration Correlation Technique

Authors: H. Abramovich, D. Govich and A. Grunwald (TECHNION)

Contact: abramovich.haim@gmail.com

Abstract:

The Vibration Correlation Technique (VCT) for experimentally nondestructive determination of buckling loads of thin walled structures is applied for the prediction of the buckling load of stringer stiffened curved panels manufactured both from aluminum and laminated composite material. The modal behavior of the panels was investigated by exciting the structures using the modal hammer method. Natural frequencies of the panels were recorded as a function of the applied axial compression load. Unlike, shell structures which present a non-stable post buckling behavior, the stringer stiffened panels show a stable post buckling behavior, enabling the measurement of the natural frequencies up to the actual experimental buckling load. A comparison between the modal behavior of compressed plate like structures and shell ones was performed, showing areas of applicability for the VCT approach to predict buckling of thin walled structures.

No. C06

Title: Buckling and postbuckling behaviour of glare laminates containing splices and doublers: experimental and numerical investigations

Authors: A. Al-Azzawi, J. McCrory, L.F. Kawashita, C.A. Featherston, R. Pullin and K. M. Holford (Cardiff university)

Contact: Al-AzzawiAS@cardiff.ac.uk

Abstract:

A 3D finite element model using cohesive elements and continuum (bulk) material damage models was developed to examine the progressive damage and failure behaviour of Glare™ Fibre Metal Laminate (FML) specimens subject to compressive loading. Specimens were either ‘pristine’ or contained manufacturing defects in typical features such as splices and doublers. In particular, the initiation and growth of delamination at the inter-laminar interfaces and the onset of plasticity during buckling have been examined. Load eccentricity and geometric imperfections were incorporated in an explicit dynamic nonlinear analysis implemented in the software Abaqus/Explicit. A series of specimens with and without artificial delaminations were tested under compression for validation. Tests were monitored using Digital Image Correlation (DIC) for visualisation of full-field displacements and strains whilst Acoustic Emission (AE) monitoring enabled detection and location of the onset and progression of damage. Results for Glare 4B specimens incorporating longitudinal and transverse delaminations into both splice and doubler geometries are presented. Good correlation between test and predicted results is observed.

No. B28

Title: Experimental determination of the buckling load of composite cylindrical shells using Vibration Correlation Technique

Authors: K. Kalnins, E. Skukis, O. Ozolins, M. A. Arbelo (RTU, PFH)

Contact: kaspars.kalnins@sigmanet.lv

Abstract:

The current research focuses on experimental determination the buckling load by non-destructive assessment of modal response drift due to incremental compression stresses and its influence in estimation of buckling load. Such a methodology is known as Vibration Correlation Technique (VCT) and has a potential for estimation of limit load for axially loaded structures from the set of self-frequency measurements. For particular study a finite element eigenvalue analysis involving axially loaded state of the structure was compared with modal tests of axially loaded cylinders. A set of cylinders has been manufactured with the radius/thickness ratios of 400 and made from UD carbon fiber prepreg Unipreg© 100g/m2. The total thickness of six ply unbalanced laminate is 0.626 mm. A whole prototyping procedure was performed at RTU prototyping laboratory. Obtained vibration results from set of three identical cylinders confirmed the trend required for identification of the buckling load. However it has been noted that sensitivity of obtained results highly dependent on technique applied for excitation of the structure. Therefore a set of recommendations for further study has been proposed.

No. B29

Title: Influence of load application on the collapse load of imperfection sensitive shell structures

Authors: L. Friedrich, A. Dafnis, H. Reimerdes, K. Schröder (RWTH Aachen)

Contact: friedrich@ilb.rwth-aachen.de

Abstract:

Shell buckling experiments are mostly conducted in a displacement controlled manner i.e. the displacement at the loaded shell edge is increased by means of a hydraulic piston and the load applied is measured as reaction force. In contrast to this, real structures, such as primary structures of space launcher vehicles, are loaded in a force controlled manner. Within this contribution, the effect of the kind of load application on the collapse load of imperfection sensitive shell structures is investigated. For this purpose, the effect mentioned is studied numerically by performing dynamic explicit force controlled buckling computations for shells featuring geometrical imperfections. Subsequently, these results are compared to displacement controlled shell buckling computations of the same kind of shell structure. In order to validate the corresponding results, a test rig designed to apply axial compressive forces in a force controlled manner is developed and presented within this contribution.

No. C37

Title: Design, fabrication and testing of hybrid nano composite structures

Authors: Aditi Sharma (Rajalakshmi Engineering College)

Contact: aditisharma1992@gmail.com

Abstract:

Five (20cm x 20cm) panels of unidirectional glass fibre reinforced plastic of 1000 gsm with natural fibre and carbon nano particles were designed to take up direct and bending loads. Fabrication was done using manual hand lay-up process and compression moulding techniques. The fabrication of each laminate comprises of different fibre orientations. After the fabrication process, the laminates are cut to various sizes, according to ASTM Standards for testing purposes. The fabricated composite were tested mainly by direct and bending loads from which the tensile, bending and impact strengths were evaluated. The testing was done by ASTM method. The test results indicated that inclusion of a natural fibre has reduced the weight and increased the strength of the composite material. By the addition of carbon nano particles (less than a gram), it is found that the tensile strength has increased by 23%. The orientation where 45° is in the topmost and bottom layer, the laminate fails quickly for tensile test. For compression test, the specimen just bends not breaks. The orientation where 90° is in the topmost and bottom layer, the laminate has good tensile strength but weak compressive

strength. This composite material can be used for the work floor area where a tool drop will not crack or fail the material, in the places connecting the fuselage and the leading edge of the wing, in high temperature exposure areas, like the inner wall of the combustion chamber, turbine blades, propeller blades, etc.

No. B23

Title: Buckling of imperfection sensitive shell structures: experimental characterization of the knock-down factor using the Multiple Perturbation Load Approach

Authors: M. Arbelo, K. Kalnins, O. Ozoliņš, S. Castro, R. Degenhardt (ITA, RTU, DLR)

Contact: arbelom@gmail.com

Abstract:

This work presents an experimental study to compare the effects on the buckling load of imperfection sensitive cylindrical shell structures using the “Multiple Perturbation Load Approach” (MPLA) and the “Single Perturbation Load Approach” (SPLA). A benchmark case is developed using a composite cylindrical shell with a radius over thickness ratio of 400. An experimental test setup is set to provide reliable results. The knock-down factor on the buckling load using one, two and three perturbation loads distributed along the surface of the cylinder is characterized, presented and discussed in this paper. The experimental result shows that lowest knock-down factor are achieved when the number of perturbation loads is increased.

Design and Analysis	
Room 3	Chair: T. Rajanna (Indian Institute of Technology Bombay)
26th March, 2015	Time: 15.00

No. C10

Title: Imperfection sensitivity analysis of composite cylindrical shells using Koiter's method

Authors: E. J. Barbero, A. Madeo, G. Zagari, R. Zinno, G. Zucco (West Virginia University, University of Calabria)

Contact: antoniomadeo81@gmail.com

Abstract:

The novel methodology for imperfection sensitivity analysis, presented in [1] is here applied for the evaluation of limit load of composite cylindrical shells. Koiter's perturbation method is used to calculate the imperfection paths emanating from mode interaction bifurcations while the Monte Carlo method is used to tests a large number of modes and all possible interactions among them. The computational cost is low because of the efficiency of Koiter's method. The demands of Koiter's method for accurate evaluations of higher order derivatives of the potential energy are met by a mixed, corotational element.

No. C34

Title: Remarks on buckling analysis of composite plates and shells

Authors: A. Muc, P.D. Pastuszak (Cracow University of Technology)

Contact: olekmuc@mech.pk.edu.pl

Abstract:

In this work, numerical and experimental results encountered in the buckling phenomena and modes of different composite laminated plates and shells are discussed. Differences in the estimations of buckling loads for the classical Love-Kirchhoff (L-K) and the first order transverse shear deformation theory are compared. Various specimens were tested both numerically and experimentally, i.e. plates, cylindrical, spherical, torispherical shells having multilayered composite or sandwich structure. In addition, the buckling problem of repaired steel shells, with the use of multilayered composites is discussed. The external loads in the form of uniform pressure or compressive forces are also considered.

No. C30

Title: Buckling and post-buckling of FML compressed open cross section profiles

Authors: R. J. Mania (Lodz University of Technology)

Contact: Radoslaw.Mania@p.lodz.pl

Abstract:

The subject of the paper is the nonlinear static buckling and post-buckling analysis of thin-walled profiles made of fibre metal laminate materials. These profiles are subjected to axial uniform compression. Short profiles of open cross- section and flat walls are considered (channel shape, Z-shape and hat shape profiles). The choice of these shapes results from their presence in airplane fuselage as ribs, stiffeners or stringers. The tendency to decrease the total weight of flying apparatus leads to thinner members which strength is determined in many cases by buckling load. For verification and comparison reasons the problem was defined for

plate profile model on the basis of two theories – the asymptotic Koiter theory for conservative systems and the first order deformation theory where all nonlinear terms of strain tensor were considered. The computations were performed with the application of the Analytical Numerical Method (Koiter formulation) and the Finite Element Method. Different sequences of aluminium layers and glass fibre reinforced composite layers were considered. The numerical results of both analytical approaches were compared with experimental data of intensive laboratory investigation.

No. C04

Title: Weight optimization using equivalent static loads of postbuckled, stiffened panels made by steered-fiber laminates

Authors: T.Ungwattanapanit, H. Baier (TU Munich)

Contact: ungwattanapanit@tum.de

Abstract:

Thanks to state-of-the-art manufacturing technics available today, in-plane, steered fiber paths as opposed to conventional straight fiber patterns can be manufactured by the likes of Automated Fiber Placement (AFP), among other methods. Continuous fiber angle variation at the ply level causing variable-stiffness laminates can be optimized to increase stiffened panel performances e.g. pre- & post-buckling stability through optimal bending stiffness distribution, or reduction of stress concentration around cutouts. Weight optimization of a postbuckled fuselage window section made by steered-fiber laminates is conducted. Critical bifurcation buckling load, max. transverse displacement, and max. failure index are selected as design constraints. The optimization with nonlinear responses is facilitated by Equivalent Static Loads Method, in which the original design problem is transformed into an iterative procedure of well-established, linear sub-optimization problems. The most attractive feature of this approach is that highly efficient gradient-based optimization is now possible through design sensitivities determined by linear analyses. Optimal solutions as well as computational efficiency comparison of the presented Equivalent Static Loads method for nonlinear response Structural Optimization (ESLSO), genetic algorithm (GA), and adaptive response surface-based optimization procedure are described in details.

No. C09

Title: Analytical and numerical analysis of the elastic/plastic local/global buckling and postbuckling of composite structures

Authors: P. Le Grognec, K. Sad Saoud (Mines Douai)

Contact: philippe.le.grognec@mines-douai.fr

Abstract:

This paper is devoted to the buckling and post-buckling analysis of various elastic/plastic structures. A general analytical procedure is first presented, which gives rise to closed-form solutions for the critical loadings and the associated buckling modes of geometrically simple structures under uniform uniaxial or biaxial compressive stress states. Then, numerical tools are developed so as to deal with the post-buckling behavior in finite elastoplasticity. Arc- length methods are used in order to cope with possible snap-through or snap-back phenomena up to advanced post- critical states. Branch-switching techniques are also implemented and allow one to derive not only primary but also secondary true elastoplastic bifurcation loads and to bifurcate on the desired equilibrium branches in an incremental way. Several problems are then addressed both analytically and numerically, for illustration purposes. The case of cylindrical shells under various loadings is first considered (secondary modes are obtained under axial compression). Finally, the local/global buckling and post-buckling of sandwich structures is investigated. This problem also leads to secondary modes due to modal interaction.

No. C17

Title: Load-carrying capacity of thin-walled composite beams subjected to pure bending

Authors: A. Gliszczynski, T. Kubiak (Lodz University of Technology)

Contact: 159141@edu.p.lodz.pl

Abstract:

The paper deals with estimating load capacity of thin-walled composite beams with C-shaped cross-section subjected to pure bending. The discussed beams were made of eight-layer GFRP laminate. The analysis have been performed on six different quasi-isotropic layer arrangement. To designate load capacity of analysed structures the ANSYS program based on finite element method were employed. The proposed numerical correspond to condition of the experimental tests. The four point bending tests were conducted. The obtained results were compared with the results of the experiment. Estimates of load capacity were based on the following failure criteria: Tsai-Wu criterion, Maximum Stress criterion and Hoffman criterion.

No. C21

Title: Imperfection-insensitive shells using variable stiffness composites

Authors: P. Weaver (University of Bristol)

Contact: Paul.Weaver@bristol.ac.uk

Abstract:

The imperfection sensitivity of cylindrical panels under compression loading can be reduced and practically eliminated using appropriate stiffness tailoring techniques. Shells that are designed using spatially varying stiffness properties, i.e. with variable angle-tow (VAT) laminae, give their laminates variable-stiffness properties over the surface co-ordinates. Techniques including Advanced Fibre Placement (AFP) and Continuous Tow Shearing (CTS) are possible manufacturing routes. By using a modelling approach, i.e. an asymptotic model of non-linear shell behaviour combined with a genetic algorithm, the post-buckling stability can be maximised with respect to VAT design variables. Results for optimized straight-fibre and VAT shells are presented in comparison with quasi-isotropic (QI) designs. In the straight-fibre case, small improvements in the post-buckling stability are shown to be possible but at the expense of the buckling load. On the other hand, in the VAT case, considerable improvements in the post-buckling stability are obtained and drops in axial stiffness and load associated with buckling are reduced to negligible levels. The improvements are shown to be a result of a favourable redistribution of membrane stress prior to buckling combined with a stable localisation of the buckling mode. The asymptotic results are compared with non-linear finite-element analyses and are found to be in good agreement. Potential future multi-objective optimisation studies are discussed.

No. C39

Title: Discussion for statistical methods on buckling knockdown factor

Authors: A. Takano (Kanagawa University)

Contact: atakano@kanagawa-u.ac.jp

Abstract:

Many investigations for statistical method on buckling knockdown factor are published. They required the information for initial imperfections in advance and the information is used to probabilistic method. However, in the actual design phase, the information for initial imperfections is difficulty to obtain in advance because it means that test production, measurement, and buckling test is required before actual production. In addition, these investigations use "descriptive statistics", i.e., they didn't distinguish "sample" and "population" and it requires enough samples to assume no difference between population and sample. On the

other hand, "inferential statistics" strictly distinguish the "sample" and "population". "Inferential statistics" is able to predict the buckling load for the population by using small sample. Simply comparing the test and analytical results and using inferential statistics enables prediction of buckling load for the population and it does not require the information of imperfection. However, the method requires the "population with unchangeable average and deviations". It means that significant difference imperfection between the population and new products, for example, due to difference manufacturing process and accuracy, induce significant difference of buckling load. Advantage and disadvantage of these two methods is discussed and possibility for new methods that is combined these two methods is also discussed.

Keynote lectures	
Room 1	**Chair: Chair: Mark Hilburger (NASA)**
27th March, 2015	**Time: 8.30**

No. A02

Title: Reliable strength design verification - Fundamentals, requirements and some hints

Authors: Ralf Cuntze

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Abstract:

Industry is faced to accelerate the development time. Therefore, reliable design tools are searched which are simply applicable in Pre-Dimensioning and in Design Verification. For instance, reliable stress states and reliable failure conditions are demanded such as Strength Failure Conditions (SFCs). In this paper preferably discussed shall be SFCs for composites. The generation of SFCs, most often termed failure criteria, is based on some fundamentals and must consider theoretical and practical requirements. This paper considers them and further respects most of the DESICOS 'topics accepted from outside the project'. The provided Lessons Learnt mainly stem from the author's contributions to the World-Wide-Failure-Exercises-I and -II (1993-2013) on UD materials. 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 may lead to an erroneous Margin of Safety. 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). The derived stress-based SFCs for Onset of Fracture are invariant-based. They can be applied for a variety of materials: Brittle and ductile behaving isotropic materials, and brittle composites. The materials might possess a dense or a porous consistency. The FMC applies material symmetry and invariants which are dedicated, following Beltrami, to a volume change (dilatational energy) or a shape change (distortional energy), the homogenized material element of the solid may experience. Due to Mohr-Coulomb, further material friction (energy) must be considered for brittle behaving materials. Interaction is required in the case that several modes are activated by the present stress state. There are several sources of error that happen to occur, i.e. in the WWFE, the quality of the test data in the tests, the evaluation of raw test data, and placing of non-compatible test data in a common graph of different test series.

No. A12

Title: Parametric Instability of Pressurized Propellant Tanks

Authors: Jochen Albus (Airbus, Senior expert)

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Abstract:

Pressurized propellant tanks might become dynamically unstable with detrimental dynamic responses if a dynamic excitation leads to a coupling of pressure oscillations (especially due to the response of axisymmetric modes) with very low damped ovalizing modes. This phenomenon can be described and identified as the so-called parametric instability. During the dynamic qualification test campaign of the Ariane 5 Cryogenic Upper Stage ESC-A, a parametric instability was observed for sinusoidal tests under certain test conditions with low static pressure in the propellant tank. The parametric instability was identified and an analytical simulation was performed that confirmed the instability. During flight, harmonic excitations might occur due to pressure oscillations within the solid rocket booster. However, the application of the analytical model on flight conditions indicates that the flight behavior will be stable. This was confirmed by results from additional tests. This paper describes the phenomenon of the parametric instability of pressurized propellant tanks and presents an analytical methodology to assess the risk of the occurrence of a parametric instability.

No. A10

Title: Recent developments in the rapid and efficient closed-form analytical modeling of buckling problems in composite lightweight engineering

Authors: Christian Mittelstedt (Sogeti)

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Abstract:

Besides the advanced computational resources that are nowadays available there is still a significant interest in the development of efficient and rapid closed-form analysis methods that can be used in practical lightweight engineering work especially in fields such as predesign, optimization, conceptual and parametric studies, and the like. This keynote lecture will present a selective overview of closed-form analysis methods the author has developed with co-workers in the field of buckling and postbuckling of thin-walled composite structures during the last few years. Their derivation, theoretical background, and constraints in terms of general applicability will be discussed, and their efficiency and accuracy will be highlighted.

Experiments	
Room 1	Chair: Haim Abramovich (TECHNION)
27th March, 2015	Time: 10.30

No. B01

Title: Buckling experiments on imperfection sensitive thin-walled structures using additional perturbation loads

Authors: R. Khakimova, S. Castro, R. Degenhardt, D. Wilckens, M. Kepke, B. Hildebrandt, F. Odermann (DLR, PFH)

Contact: Regina.Khakimova@dlr.de

Abstract:

Thin walled conical structures are widely used in aerospace, offshore, civil and other engineering fields and industries. The aerospace industry is always looking for new methods and materials to make air- and spacecrafts more efficient. Besides cost effectiveness, practicality and safety the main aspect is the weight reduction. The running EU project DESICOS (New Robust DESIgn Guideline for Imperfection Sensitive COmposite Launcher Structures) contributes to lighter and cheaper structures by new alternative design procedures for imperfection sensitive composite launcher structures, exploiting the worst imperfection approach efficiently. For most relevant architectures of cylindrical and conical launcher structures (monolithic, sandwich - without and with holes) 12 partners develop new design methods which will be validated by tests of structures designed and manufactured within the project. The Single Perturbation Load Approach (SPLA), an alternative design method developed by Hühne, is a deterministic approach where a lateral load is applied prior to axial compression, stimulating a single dimple. To validate this method, several CFRP cylindrical and conical shells were manufactured and tested at DLR.

No. B06

Title: Buckling and Post Buckling of Stiffened CFRP Panels under Compression and Shear

Authors: D. Wilckens, F. Odermann (DLR)

Contact: dirk.wilckens@dlr.de

Abstract:

In this contribution, the buckling and post buckling behaviour of stiffened CFRP panels with open profile stringers is treated. This study comprises experimental analysis under in-plane loading conditions such as axial compression, shear and the combination of both. The structure is loaded with different load ratios until the early post buckling regime without damaging the structure and finally loaded until collapse under compression or shear loading. Load shortening data, strain gauges and DIC measurements are available for the interpretation of the structural response and for the validation of numerical models. The test shells represent a design for a low loaded forward fuselage section utilizing a low skin thickness and large stringer pitch.

No. B05

Title: Testing and Modelling of impact damaged orthotropic stiffened CFRP-Panels

Authors: C. Wolff, D.Wilckens (DLR)

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Abstract:

In the present contribution, the residual strength behaviour of stiffened CFRP shells under axial compression loading is discussed. In this context, two stiffened CFRP panels are pre-damaged by impact and tested under axial compression until collapse. The panels without damage were tested before in order to obtain a reference result. Two different impact scenarios are investigated on a T- and a J-stringer stiffened panel, respectively. The damaged area is assessed by ultra-sonic (US) inspection. Load shortening data, strains as well as full field displacements are recorded during the test. Additionally to the experiments, the structural behaviour is simulated for the undamaged and damaged structures using the commercial FE-code Abaqus. The US inspection results of the impacted areas are transferred into the FE-models, and the stiffness and strength of affected elements are degraded accordingly. The numerical results are compared to the experimental findings. Through this approach, the influence of both impact scenarios on the structural behaviour of stiffened CFRP shells is assessed by test and simulation.

No. B08

Title: Buckling tests of unstiffened cylindrical composite shells under dynamic axial pulse loading

Authors: F. Odermann, M. Geier (DLR)

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Abstract:

The development of launcher systems for space applications faces engineers with problems regarding dynamic loads on thin walled structures. Often the design of these structures is based on static or linear assumptions incorporating a large factor of safety since the effects of dynamic loads are not yet fully understood. One critical aspect, the dynamic buckling phenomenon, addresses the stability behavior of thin walled structures under short term transient, pulse or oscillating loads. As experimental investigations on columns and panels already exist in some fields, the experimental test methods for the investigation of unstiffened cylindrical shells need to be improved in order to attain more accurate results. Within this presentation, a novel test method to investigate the buckling behavior of unstiffened circular cylindrical composite shells under static and dynamic axial pulse loads with constant boundary conditions is presented. To this, a brief overview of the existing test methods is given and the potential for further development is pointed out. The novel test method is described along with its new dedicated test facility, measurement systems and test procedures. Finally, test results of a cylindrical composite shell under static and dynamic axial compressive loads are presented.

No. C03

Title: Experimental and numerical study regarding the influence of traditional and non-traditional imperfections on the buckling load of unstiffened cylindrical CFRP shells

Authors: C. Schillo, D. Krause (TU Hamburg Harburg)

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Abstract:

In order to develop a reliability based design approach for unstiffened cylindrical CFRP shells, the influences of different kinds of uncertainties related to the development process need to be identified and a statistical database of representative CFRP specimens needs to be established. Knowing these uncertainties, the corresponding sensitivity of a model prediction, as well as the effect of negligence of certain parameters during the design process can be quantified. The experimental part of this study aims at contributing to a probabilistic design approach through a statistical characterization of two nominal identical sets of CFRP cylinders. Two cylindrical tubes with a radius to thickness ratio of 142 are manufactured using the filament winding process and are cut into 11 specimens that are tested in compression. All cylinders are optically measured in the mounted state to identify geometric imperfections which are characterized using power spectral analysis. During each compression test, occurring load imperfections are measured using a multi-axial load cell and a high-speed camera documents the onset and

development of buckling. Additional tests are carried out with some of the cylinders using a very rigid mounting to quantify the influence of boundary conditions. In the subsequent analysis, finite element models with varying degree of detail are used to reproduce test data and each model uncertainty is identified using EN 1990 Annex D. It is found that for the chosen setup and manufacturing process, geometric imperfections and simplifications for boundary conditions play a minor role in improving the predictive quality of the model. A mayor influence has the consideration of the measured load imperfections.

Design and Analysis	
Room 2	Chair: Thorsten Kühn (EADS EFW)
27th March, 2015	Time: 10.30

No. B03

Title: Numerical investigation on experimental buckling loads of unstiffened cylindrical composite shells with varying ratio of radius/wall thickness

Authors: R. Wagner, C. Hühne (DLR)

Contact: ronald.wagner@dlr.de

Abstract:

Thin-walled unstiffened cylindrical composite shells are prone to buckling. The structural behavior of these shells responds really sensitive to initial geometric imperfections, which occur during the manufacturing process of an unstiffened composite cylinder. Geometric imperfections like small dimples cause a deviation from the perfect geometrical shape of a cylinder and can reduce the buckling load significantly. Scattering of material and geometric parameters as well as an inhomogeneous loading causes also a reduction of the load carrying capability of these cylinders. Research's mainly investigated the influence of geometric imperfections on the buckling load and ignored the other sources of imperfections. In this paper the before mentioned imperfections and their effects on the buckling load of cylindrical shells are investigated using a semi-analytical probabilistic sensitivity analysis. With this method the structural response behavior of the cylindrical shells is evaluated in order to identify imperfections which are most critical in terms of stability behavior. The study is performed for shells with equal material und geometric parameters but different laminate stacking and the imperfections are classified into different degrees of priority using indices. The purpose of this paper is to identify imperfections which are most critical on the stability behavior of unstiffened cylindrical composite shells to show where to spend resources for the largest improvement of future guidelines for imperfection sensitive composite launcher structures.

No. C38

Title: Finite element buckling analysis of skin-stiffener anisogrid fuselage structures

Authors: T. Ludwig, S. Merazzi (SMR)

Contact: tludwig@smr.ch

Abstract:

Buckling analysis of anisogrid skin-stiffener structures with the Finite Element (FE) method requires FE models of high fidelity. Reasons are the small size and the non-rectangular shape of the skin bays, and the large number of interconnected blade stiffeners. In the EU-FP7 Project PoLaRBEAR, different FE modelling techniques were evaluated, to select those with the best trade-off between accuracy, robustness, and computational effort. These techniques were implemented in a fully parametric modelling tool. Results for first buckling and post-buckling with the B2000++ research FE code are presented for a range of panel designs under axial compression and shear loads, and compared to orthogrid designs.

No. B21

Title: Non-linear buckling response of unstiffened laminated composite cylinders using different geometric imperfections

Authors: S. G. P. Castro, C. Mittelstedt, M. A. Arbelo , R. Degenhardt, R. Khakimova, M. W. Hilburger, G. Ziegmann (PFH, DLR, NASA, TU Clausthal)

Contact: castrosaullo@gmail.com

Abstract:

The important role of geometric imperfections on the decrease of the buckling load for thin-walled cylinders had been recognized already by the first authors investigating the theoretical approaches on this topic. However, there are currently no closed-form solutions to take imperfections into account already during the early design phases. Since 1970s a considerable number of experimental and numerical investigations have been conducted to develop new stochastic and deterministic methods for calculating less conservative KDFs. Among the deterministic approaches many suggest the use of different geometric imperfection patterns in order to investigate the imperfection sensitivity but there is no consensus about which imperfection pattern is the correct one. The present study will investigate the effect of five different imperfection patterns on the non-linear buckling response of unstiffened laminated cylinders with the aim to bring about general directives that can be used as future reference.

No. B12

Title: Simulation of geometric imperfections and uneven edges in thin-walled cylinders

Authors: S. Castro, R. Khakimova , G. Ziegmann, D. Degenhardt, R. Degenhardt, Mark Hilburger (PFH, DLR, TU Clausthal, Sogeti, NASA)

Contact: castrosaullo@gmail.com

Abstract:

Many studies available in the literature state the importance role of geometric imperfections and asymmetric loads on the buckling behavior of thin-walled cylinders. The lack of publications treating in details how such imperfections should be mapped into the finite element model motivated the development of the current study. Dummy data samples will be used such that the reader will be able to follow and reproduce each step in order to learn the main pitfalls and caveats that arise when treating measured data. The geometric imperfections are realized into the finite element model by applying proper translations for each node into the perfect finite element mesh, and the load imperfections are realized using gap elements, which are a particular case of contact elements with one-to-one nodal contact, hence eliminating the burden or contact searches.

No. B04

Title: Investigation on the effects of non-uniform loading on the buckling of thin-walled cylindrical shells

Authors: S. G. P. Castro, C. Mittelstedt, M. A. Arbelo , R. Degenhardt, R. Khakimova, M. W. Hilburger, G. Ziegmann (PFH, DLR, NASA, TU Clausthal)

Contact: david.degenhardt@dlr.de

Abstract:

Future launchers are expected to be lighter and produced more cost efficient. Today's space structures are already very lightweight designs and according to the current guidelines the reserve capacities are fully exploited. In order to further reduce the weight a deeper understanding of the structural behavior is needed. For the reliable determination of a less conservative design buckling load, knowledge of worst and realistic imperfections is required. This paper focusses in more detail on non-uniform loading as one relevant part among many different imperfections, aiming a deeper understanding of the buckling phenomenon influenced by this kind of disturbance. In addition, this study forms the basis for appropriate buckling test activities on a metallic shell. The non-uniformity is simulated by a thin shim between the cylinder and the loading. For the loading process different modelling strategies are studied. Finally, it provides detailed parametric studies defining appropriate shim geometries and positions to be used in the tests to be performed.

New concepts	
Room 1	Chair: Dimitris Stamatelos (Hellenic Air Force Academy)
27th March, 2015	Time: 13.00

No. C33

Title: Influence of bending-twisting-coupling on the buckling behaviour of composite laminated plates – a new look at an old problem

Authors: A. Baucke, C. Mittelstedt (HAW, Sogeti)

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Abstract:

The preliminary design of lightweight structures requires the analysis of many different design configurations under numerous load cases. In order to reduce the involved computational time and effort especially in the conceptual phases and preliminary design stages, there is still a huge interest in the development of closed- form analytical methods that enable a rapid and efficient analysis of given structural parts. This contribution is devoted to the linear buckling analysis of symmetrically laminated composite plates under uniform uniaxial compression explicitly accounting for bending-twisting-coupling. As is well-known, exact closed-form analytical methods for the buckling analysis are only available for purely orthotropic laminates. As a consequence the influence of bending-twisting-coupling that is generally present in practically relevant laminated plates is often neglected. Since this leads to non-conservative allowable compressive loads in all cases, there is a need to reduce the bearable linear buckling load by a suitable knock-down factor when one refers to reference solutions for purely orthotropic laminates. Up to now these knock-down factors have been developed and validated for discrete representative laminates in terms of material combination and lay-up only. It is, however, much more preferable to employ a non-dimensional laminate description using non-dimensional elastic parameters, as these are applicable for any material combination with arbitrary stacking sequence and as a consequence the results are of a generic and universal nature. This contribution outlines the development of a knock-down factor describing the influence of bending-twisting-coupling on the buckling behavior of composite laminated plates using non-dimensional parameters. The linear buckling load is determined by the use of the Rayleigh-Ritz method for the linear buckling problem using a series expansion. The obtained results have been verified with accompanying finite-element-analysis and conditioned in order to provide a useful method for the determination of the knock-down factor for bending-twisting-coupling. The method that is going to be presented in this contribution is of a purely closed- form analytical nature and yet of high accuracy in order to describe the influence of bending-twisting-coupling. Further, it is very easy to apply and thus feasible for application in engineering practice.

No. C20

Title: Semi-analytical global and panel buckling of composite grid-stiffened cylindrical shells

Authors: M.J. Weber, P. Middendorf (Airbus, TU Stuttgart)

Contact: markus.weber@airbus.com

Abstract:

Structural stability is one, or the most design driving criterion for aerospace structures. The accurate prediction of the various forms of buckling becomes especially important when seeking a minimum weight design. The grid-stiffened structures, with the isogrid and orthogrid being the most popular forms, provide a large design space to investigate, but also exhibit a complex behaviour in terms of structural stability. This paper focuses on buckling of the panel as a whole by presenting and comparing semi-analytical methods for global and panel buckling, where the latter takes the discrete nature of the stiffening structure into account. Results are presented for parameter studies of the composite cylindrical grid-stiffened shell including mechanical effects from panel curvature, stiffener eccentricity, and material orthotropy. The results show panel buckling to occur at significantly lower loads compared to global buckling, with a magnitude depending on the very specific geometry and kind of applied loads.

No. C31

Title: A fast approach on postbuckling analysis of composite stiffened structures

Authors: Zhang Guofan, Sun Xiasheng (ASRI)

Contact: michaelzgf@163.com

Abstract:

Stiffened composite panel is the typical thin wall structure applied in aerospace industry, and its main failure mode is buckling subjected to compressive loading. In this paper, an approach using Finite Element Method to investigate post-buckling behavior of stiffened composite structures under compression was developed, which was verified through multi levels of specimens from coupon to panel. The modeling strategies and analysis method for post-buckling simulation were introduced, under the consideration of progressive damage including interlaminar failure and intralaminar failure, and the models of delamination simulation using cohesive element and Multi-Point constraints were also described in detail as well. Then, the numerical results of the coupon specimen and the stiffened panel are obtained by FE simulations. A thorough comparison were accomplished by comparing the load carrying capacity and key position strains of the specimen numerically predicted by FE models with the data observed in the tests, and the comments were also given. The comparison indicates that the FEM approach which adopted developed methodology could meet the demand of engineering application in predicting the post-buckling behavior of intact stiffened structures in aircraft design stage.

No. B07

Title: Multilevel Skin Buckling Analysis using Hierarchical Metamodels

Authors: S. Freund, A. Sauerbrei, R. Zimmermann (DLR)

Contact: sebastian.freund@dlr.de

Abstract:

Within design processes, shorter design cycles are required while the quality or performance of a product must be increased. These requirements can be fulfilled by a shift to virtual product design which reduces the number of manufacturing trials and structural testing. Yet, even in an early design phase, the simulations in the virtual product design must be of high accuracy. This improves the starting point when entering detailed design and thus reduces the number of design iterations in the costly detailed design phase. The buckling analysis of thin-walled stiffened structures made of carbon fiber reinforced plastics (CFRP) is carried out in various ways. Firstly, analytical, closed-from methods are used as fast analysis method. In order to compensate their lack in accuracy, many costly structural tests are performed to enhance these analytical methods with empirical data. Another method is the usage of high-DOF FEM-models. Compared to analytical methods, they can be more accurate but require high computation times, thus are not applicable in a multidisciplinary design and optimization process. To describe the buckling behavior of those structures, metamodels are an approach to overcome the drawbacks of the methods mentioned above. Once they are established,

metamodels are cheap in terms of numerical costs and can describe the initial analysis model in a considerable accuracy. One key challenge is to introduce an appropriate parametrization of the panel structure. It should be able to describe all influential design variations and especially exploit the advantages of CFRP. On the other hand, the number of design parameters must be minimized to reduce the time required for the metamodel creation and to increase the accuracy in respect to the limited amount of sample points given. In addition to classical metamodels, hierarchical metamodels are developed to com- bine sample points from analysis methods of different fidelity. This methodology enriches a plurality low-fidelity sample points with a limited amount of high-fidelity sample points. The low-fidelity target function is of low accuracy but little cost in terms of computation time or expense, while the high-fidelity target function is of high accuracy but very high costs. For the buckling analysis, several levels of fidelity exist. There are closed-form solutions based on simplified model assumptions. A more accurate method are numerical calculations based on models of different discretization and accuracy. The most accurate representation can be obtained from test results, which is not covered here. In this work, the creation process of metamodels using universal kriging and hierarchical kriging for the analysis of first buckling of CFRP panels are discussed. It describes the buckling analysis methods used and discusses a suitable parameter space. Next, the creation of universal and hierarchical kriging models will be pointed out. Lastly both types of kriging models for the buckling analysis are created and the performance of hierarchical kriging models is evaluated and discussed.

No. B14

Title: Overview of FP7 Project DAEDALOS - Dynamics in Aircraft Engineering Design and Analysis for Light Optimized Structures

Authors: C. Bisagni (Politecnico di Milano, TU-Delft)

Contact: C.Bisagni@tudelft.nl

Abstract:

The “Dynamics in Aircraft Engineering Design and Analysis for Light Optimized Structures” (DAEDALOS) project aimed to develop methods and procedures to determine dynamic loads by considering the effects of dynamic buckling, material damping and mechanical hysteresis during aircraft service. Advanced analysis and design principles were assessed with the scope of partly removing the uncertainty and the conservatism of today’s design and certification procedures. To reach these objectives a DAEDALOS aircraft model representing a mid-size business jet was developed. Analysis and in-depth investigation of the dynamic response were carried out on full finite element models and on hybrid models. Material damping was experimentally evaluated, and different methods for damping evaluation were developed, implemented in finite element codes and experimentally validated. They include a strain energy method, a quasi-linear viscoelastic material model, and a generalized Maxwell viscous material damping. Panels and shells representative of typical components of the DAEDALOS aircraft model were experimentally tested subjected to static as well as dynamic loads. Composite and metallic components of the aircraft model were investigated to evaluate the benefit in terms of weight saving.

Design and Analysis	
Room 2	Chair: Tomasz Kubiak (Lodz University of Technology)
27th March, 2015	Time: 13.00

No. C05

Title: Nonlinear buckling of tapered composite plates in isogeometric analysis framework

Authors: T. Le-Manh, Z. Gurdal, M. Abdalla (Skoltech, TU-Delft)

Contact: t.le@skolkovotech.ru

Abstract:

Nonlinear buckling and postbuckling of tapered composite plates subjected to uniaxial load are investigated in this work using NURBS-based (Non-Uniform Rational B-Spline) isogeometric analysis. Governing equations of laminated composite plates are derived under first-order shear deformable framework and von-Karman nonlinearity. Finite element mesh in C1 continuity is obtained by using quadratic NURBS element. The thickness of each lamina is defined as a linear interpolation from a set of control thickness parameters which are assigned along control points. Geometric imperfection described as initial transverse deviation is intentionally applied. Riks method is employed in nonlinear analysis. Numerical results including isotropic and composite plates of uniform and tapered thickness are carried out to verify the theory and describe the applicability of the approach.

No. C11

Title: Discrete material buckling optimization of laminated composite structures considering "worst" shape imperfections

Authors: S. R. Henrichsen, E. Lindgaard, E. Lund (Aalborg University)

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Abstract:

Robust design of laminated composite structures is considered in this work. Because laminated composite structures are often thin walled, buckling failure can occur prior to material failure, making it desirable to maximize the buckling load. However, as a structure always contains imperfections these must be included into the optimization, otherwise the imperfection sensitivity of the structure can be increased through optimization. To minimize the imperfection sensitivity of the structure the so-called Recurrence Optimization is applied. This approach uses a sequence of laminate optimizations and "worst" shape imperfection optimizations to design robust composite structures. The approach is demonstrated on an U-profile where the imperfection sensitivity is monitored, and based on the example it can be concluded that robust designs can be obtained.

No. C25

Title: Effect of Asymmetric Meshing on the Buckling Behaviour of Composite Cylindrical Shells under Axial Compression

Authors: Zia R. Tahir, P. Mandal (University of Manchester)

Contact: ziartahir@uet.edu.pk

Abstract:

This paper presents a numerical study on buckling and post buckling behaviour of Campsite (CFRP) cylindrical shells under axial compression using asymmetric meshing technique (AMT). AMT is a perturbation method to introduce disturbance without changing geometry,

boundary conditions or loading conditions. Asymmetric meshing affects predicted buckling load, buckling mode shape and post-buckling behaviour. AMT was employed in both axial direction and circumferential direction of the shell model separately using three different techniques, first by changing the shell element size and varying the total number elements, second by varying the shell element size and keeping the total number of elements constant, and third by varying the shell elements size using bias ratio and keeping the total number of elements constant. Use of AMT showed changes in buckling load values of up to 7% compared to symmetric meshing with small amplitude of asymmetry, which further increases with increase in magnitude of asymmetry in meshing. The major conclusions from this study are: different techniques of AMT have relatively less influence on predicted buckling load and significant influence on load displacement curve behaviour in post buckling; AMT in axial direction and AMT in circumferential direction have different influence on buckling load, buckling mode shape and load displacement curve in post-buckling; the effect of AMT is different for different lay-up orientations in shells having same L/R and R/t.

No. C28

Title: Structural Tailoring for Enhanced Bending-Twist Coupling through Elastic Instability

Authors: F. Runkel, A. F. Arrieta, P. Ermanni (ETH Zurich)

Contact: runkelf@ethz.ch

Abstract:

For lightweight structures, buckling as the instability response due to an external loading is a design criterion. Under the condition that the overall system performance in the postbuckling regime is maintained, a structure may be allowed to buckle locally. This results in a change in effective stiffnesses of the structure which commonly is considered a drawback. However, taking advantage of the effects resulting from local buckling, instabilities can be utilized to realise novel functionality for lightweight systems. In this paper, the use of instability of structurally tailored compliant elements for aeroelastically aided shape adaptation of wing structures featuring a NACA 0012 profile and a wing box comprised by two spars is investigated. Exploiting the potential of anisotropic materials, one spar of the wing box is designed as the compliant component such that buckling occurs as a prescribed load level is reached. The instability affects the bending-twist coupling of the wing due to shear centre relocation caused by the change in geometry of the spar. This morphing is achieved passively without the need of external actuators. Hence, such a compliant system with strategically positioned variable stiffness components reduces structural complexity while providing global morphing due to a change in effective stiffnesses of the structure.

No. C40

Title: How Optical 3D Metrology supports Component Design and the Optimization of Numerical Simulations

Authors: M. Klein (GOM)

Contact: M.Klein@gom.com

Abstract:

The development and manufacturing of a modern flight vehicle is an extremely complex process and demands careful balance and compromise between safety, technical abilities, design, available technologies and costs. Consequently, in aerospace development different technologies and engineering disciplines are consolidated, such as aerodynamics, propulsion, materials science, structural design and manufacturing. GOM invites you to a presentation which will show different applications from the aerospace industry using optical 3D metrology covering topics from smaller scale measurement such as coupon- and element testing up to evaluation of sub-components deformation behavior and validation of FE models.

Keynote lectures	
Room 1	Chair: Christian Mittelstedt (Sogeti)
27th March, 2015	Time: 15.00

No. A11

Title: Composite spheroidal shells under external pressure

Authors: Jan Blachut (University of Liverpool)

Contact: em20@liverpool.ac.uk

Abstract:

Spheroidal shells are formed by an ellipse being rotated about its axis. Within spheroidal shells one distinguishes prolate and oblate geometries. Complete spheroids are usually split into two halves giving hemispherical or ellipsoidal domes. As such spheroidal shells are seen nearly in all engineering fields ranging from on land, in the sea, and in the air. They are found to work under a variety of loading profiles and the construction material of the wall until fairly recently has been metal. One of specific applications is related to spheroidal shells being loaded by external pressure or in some instances loaded by under pressure (vacuum). Hence buckling performance of FRP spheroids is timely and of prime interest. Bifurcation, collapse and First Ply Failure pressures have been obtained for a range of CFRP spheroidal shells under static external pressures. Comparisons of the load carrying capacities are made for like-for-like geometries. It is shown that some prolate ellipsoids can be stronger, for up to 70% than the equivalent spheres. The effect of boundary conditions in the equatorial plane on the buckling strength is assessed for the diameter-to-wall- thickness ratio ranging from 100 to 500. Regions where the strength (FPF) rather than asymmetric bifurcation control the failure have been identified. Small perturbations in ply orientations, $\pm 5^{o}$, have been introduced in order to assess their influence on the buckling strength. Both symmetric and asymmetric stacking with respect to the mid-plane have been analysed (including random stacking). Initial shape imperfections positioned at the apex of a hemispherical head have been examined. The latter aimed at assessing the sensitivity of buckling pressure to deviations from perfect geometry. Results have been obtained for the lower-bound approach based on the local flattening using the increased-radius.

No. A13

Title: Modelling damage in thin-walled composite structures

Authors: Brian Falzon (Royal Academy of Engineering - Bombardier Chair in Aerospace Composites, Queen's University Belfast)

Contact: b.falzon@qub.ac.uk

Abstract:

A high-fidelity composite damage model is presented and applied to predict low-velocity impact damage, compression after impact (CAI) strength and crushing of thin-walled composite structures. The simulated results correlated well with experimental testing in terms of overall force-displacement response, damage morphologies and energy dissipation. The predictive power of this model makes it suitable for use as part of a virtual testing methodology, reducing the reliance on physical testing.

No. A09

Title: Challenges in Structural Mechanics of Composite Structures

Authors: Tobias Wille (DLR, Head of department Structural mechanics)

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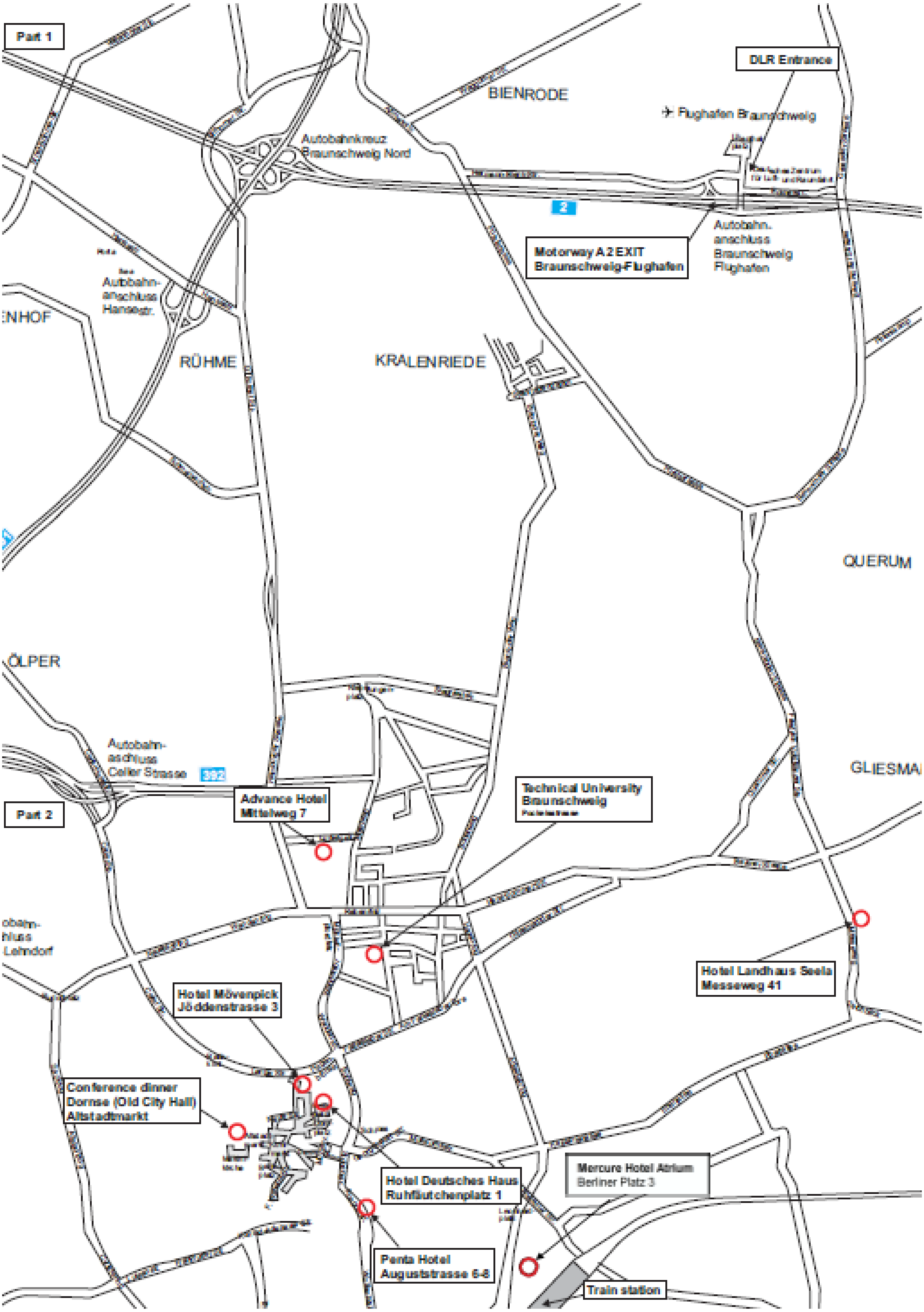
Abstract:

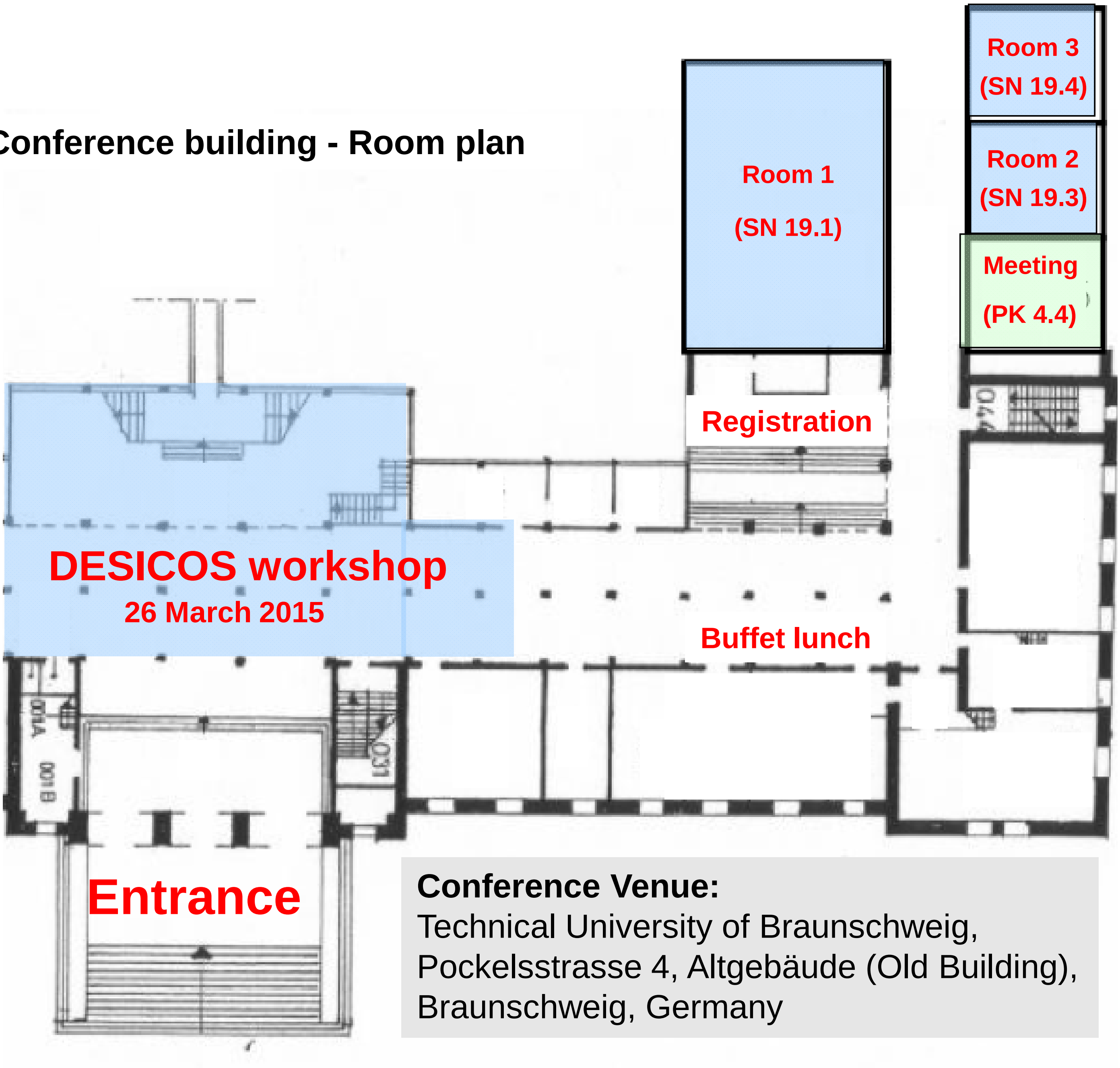
In order to improve energy efficiency of transport systems achieving weight savings is one of the key issues. This could be obtained in particular by combining optimal structural design with high-performance materials such as composites or hybrid materials. Yet, in general their lightweight potential is still not fully exploited for many industrial applications. Due to the complex behavior a strong effort on phenomenological investigation from material up to structural level is required taking into account various particularities such as conditioning or cycling or statistical spread. Effective procedures and tools are needed to identify most relevant effects and parameters, which are to be considered from the preliminary up to the detailed design phase. Manufacturing requirements have to be taken into account in order to enable an efficient and robust production with minimal ramp-up time. Therefore, an holistic approach is increasingly demanded, which considers requirements from both, various design stages and disciplines. Moreover, its integration within a whole life cycle analysis is aimed evaluating aspects from material development via part manufacturing, assembly, inspection, actual operation and maintenance up to final recycling or disposal. Within the department Structural Mechanics main focus is laid upon research and development of reliable and efficient methods as well as software tools for analyzing composite structures. The aim is to provide fast numerical tools available at an early development stage within a concurrent/ integrated engineering concept. Further, detailed analysis methods for process simulation, impact, damage analysis, fatigue or residual strength are integrated within an overall CAE process. Special methods for simulation based design and life cycle analysis are developed for composite structures for aerospace, automotive and wind energy industry. In conjunction, the experimental validation of new methods is of special interest as the department provides and develops unique test facilities.

Map - Braunschweig – (conference, hotels, dinner, DLR)



Map - University

Conference building - Room plan



Conference Venue:
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Braunschweig, Germany

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