Christos C. Chamis

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A notice written for the news report: "SAE Update (News for the Members of SAE)", Vol. 20, No. 4, April 2003, about Dr. Chamis becoming a Fellow of SAE (SAE = Society of Automotive/Aerospace Engineers) **Christos C. Chamis,** Senior Aerospace Scientist, NASA Glenn Research Center, for his pioneering contributions to the field of science and engineering in 3-D inelastic analysis, probabilistic structural analysis, structural tailoring, and high-temperature composite mechanics in which he developed computational methods and computer codes.

Selected Publications:

Christos C. Chamis (National Aeronautics and Space Administration Glenn Research Center, Cleveland, OH 44135, USA, Christos.C.Chamis@grc.nasa.gov), **"Polymer Composite Mechanics Review** — 1965 to 2006", Journal of Reinforced Plastics and Composites, July 2007, vol. 26, no. 10, pp. 987-1019,
doi: 10.1177/0731684407079419
ABSTRACT: The research and development in composite mechanics are reviewed from 1965 to 2006. The review covers micromechanics, macromechanics failure theories, impact resistance, structural analysis, plate and panel buckling, shell buckling, progressive fracture, containment, and probabilistic composite simulation. A few remarks are included about aerodynamic loads and a new all composite engine concept. Most of the sample cases are from the author's own research since this research covers all aspects of composites and since this avoids the permissions required by other authors when their results are included. References are cited as appropriate so that the reader can further look in any specific area.

C.C. Chamis, Design oriented analysis and structural synthesis of multilayered filamentary composites, Ph.D. thesis, Case Western Reserve University, Cleveland, Ohio, 1967

Chamis CC, Sendeckyj GP. Critique on theories predicting thermo-elastic properties of fibrous composites. J Compos Mater 1968;2(3):332–58.

Chamis, C. C., Buckling of Anisotropic Composite Plates, ASCE, pp. 2119-2139, October 1969.
Almroth's comments: A Galerkin solution is presented to the buckling problem for anisotropic plates with simple support and under different types of loading. Effects of membrane bending coupling are included and the reduced stiffness method of Reference A-7 is found to be a good approximation.

C. C. Chamis, "Buckling of anisotropic composite plates", ASCE J. Structural Div., Vol. 95, No. ST10, October 1969, pp. 2119-2139

Chamis C.C., 1969, Failure criteria for filamentary composites, Composite Materials: Testing and Design, ASTM STP 460: 336-351.

Christos C. Chamis, "Characterization and design mechanics for fiber-reinforced metals", NASA TN D-5784, 1970

Christos C. Chamis, "Design and Analysis of Fiber Composite Structural Components", Aerospace Structural Materials. NASA SP-227, 330 pages, published by NASA, Washington, D.C., 1970, p.217
(Abstract not available)

Chamis, C. C., Buckling of Boron/Aluminum and Graphite/Resin Fiber Composite Anisotropic Panels, Natl. Sampe Conf. on Space Shuttle Materials, 1971.
Almroth's comments: Theoretical results are presented for the buckling of single-ply rectangular plates. Buckling loads are given as functions of the fiber orientation.

Chamis, C. C., Theoretical Buckling Loads of Boron/Aluminum and Graphite/Resin Fiber Composite Anisotropic Plates, NASA TN D6572, December 1971.
Almroth's comments: Essentially the same as Reference A-14. A computer program listing is added.

Christos C. Chamis (NASA Lewis Research Center), "Computer Code for the Analysis of Multilayered Fiber Composites. Users Manual", NASA Technical note TN D-7013, Accession No. A053503, March 1971
ABSTRACT: A FORTRAN IV computer code for the micromechanics, macromechanics, and laminate analysis of multilayered fiber composite structural components is described. The code can be used either individually or as a subroutine within a complex structural analysis/synthesis program. The in-puts to the code are constituent materials properties, composite geometry, and loading conditions. The outputs are various properties for ply and composite; composite structural response, including bending-stretching coupling; and composite stress analysis, including comparisons with failure criteria for combined stress. The code was used successfully in the analysis and structural synthesis of flat panels, in the buckling analysis of flat panels, in multilayered composite material failure studies, and lamination residual stresses analysis.

Christos C. Chamis (NASA Lewis Research Center, Cleveland, Ohio), “Theoretical Buckling Loads of Boron/Aluminum and Graphite/Resin Fiber-Composite Anisotropic Plates.”, NASA Technical Note TN D-6572, December 1971, Accession Number: ADA309269,
Handle / proxy Url : http://handle.dtic.mil/100.2/ADA309269
ABSTRACT: Theoretical results are presented for the buckling of anisotropic plates. The plates are subjected to simple and combined in-plane loading. The plates are made from fiber composite material of boron/aluminum or high-modulus graphite/resin. The results are presented in nondimensional form as buckling load against fiber orientation angle for various plate aspect ratios. The results indicate that buckling loads of boron/aluminum plates are independent of fiber direction if the plate aspect ratios are greater than about 1, and moderately dependent when this ratio is less than about 1. In addition, the results indicate that the buckling loads are independent of aspect ratio for plates with aspect ratios greater than about 2. Boron/aluminum composite plates can resist buckling loads more efficiently than graphite/resin composites on a specific buckling stress basis. The numerical algorithm and a listing of the computer code used to obtain the results are included.

C.C. Chamis (NASA Lewis Research Center, Cleveland, Ohio), “Residual stresses in angleplied laminates and their effects on laminate behavior”, Metallurgical Society of AIME, International Conference on Composite Materials, 2nd, Toronto, Canada; United States; 16-20 Apr. 1978. 23 pp. 1978
ABSTRACT: NASA Lewis Research Center research in the field of composite laminate residual stresses is reviewed and summarized. The origin of lamination residual stresses, evidence of their presence, experimental methods for measuring them, and theoretical methods for predicting them are described. Typical results are presented which show the magnitudes of residual stresses in various laminates including hybrids and superhybrids, and in other complex composite components. Results are also presented which show the effects of lamination residual stresses on laminate warpage and on laminate mechanical properties including fracture stresses. Finally, the major findings and conclusions derived therefrom are summarized.

C. C. Chamis and G. T. Smith, 'Composite Durability Structural Analysis," NASA TM-79070, 1978.

Sinclair, J.H. and Chamis, C.C., "Compressive Behavior of Unidirectional Fibrous Composites," Compression Testing of Homogeneous Materials and Composites, STP 808, American Society for Testing and Materials, Philadelphia, PA, 1983.

Chamis, C.C. Simplified composites micromechanics equations for strength, fracture toughness, and environmental effects. NASA TM-83696, USA, 1984

Caruso, J.J. and C.C. Chamis, “Assessment of Simplified Composite Micromechanics Using Three-Dimensional Finite-Element Analysis”, J. Compos. Technol. Res., Vol/Issue 8, 1986, pp. 77- 83

Christos C. Chamis (NASA Lewis Research Center, Cleveland, Ohio 44135, USA), “Probabilistic structural analysis methods for space propulsion system components”, Probabilistic Engineering Mechanics, Vol. 2, No.2, June 1987, pp. 100-110, doi:10.1016/0266-8920(87)90021-X
ABSTRACT: NASA Lewis Research Center is currently developing probabilistic structural analysis methodology for select Space Shuttle Main Engine (SSME) components. This methodology consists of the following program elements: (1) composite load spectra, (2) probabilistic structural analysis methods, (3) probabilistic finite element theory - new variational principles, and (4) probabilistic structural analysis application. The methodology has led to significant technical progress in several important aspects of probabilistic structural analysis. The program and significant accomplishments to date are summarized in this

paper.

T. B. Irvine and C. A. Ginty, 'Progressive Fracture of Fiber Composites," Journal of Composite Materials, Vol. 20, March 1986, pp. 166-184.

P. L. N. Murthy and C. C. Chamis, Integrated Composite Analyzer (ICAN): Users and Programmers Manual, NASA Technical Paper 2515, March 1986.

L. Minnetyan, C. C. Chamis, and P. L. N. Murthy, "Structural Behavior of Composites with Progressive Fracture," NASA TM-102370, January 1990, 18 pp.

L. Minnetyan, P. L. N. Murthy, and C. C. Chamis, "Progression of Damage and Fracture in Composites under Dynamic Loading," NASA TM-103118, April 1990, 16 pp.

L. Minnetyan, P. L. N. Murthy, and C. C. Chamis, "Composite Structure Global Fracture Toughness via Computational Simulation," Computers k3 Structures, Vol. 37, No. 2, pp.175-180, 1990

L. Minnetyan, P. L. N. Murthy, and C. C. Chamis, "Progressive Fracture in Composites Subjected to Hygrothermal Environment," Proceedings of the 32nd SDM Conference (Part I), Baltimore, Maryland, April 8-10, 1991, pp. 867-877.

L. Minnetyan, C. C. Chamis, and P. L. N. Murthy, "Damage and Fracture in Composite Thin Shells," NASA TM-105289, November 1991

Minnetyan, L., Chamis, C., and Murthy, P. L. (1992). ''Structural behavior of composites with progressive fracture.'' J. of Reinforced Plastics and Compos., 11, 413–442.

Levon Minnetyan (1), James M. Rivers (1), Pappu L.N. Murthy (2) and Christos C. Chamis (2)
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"Structural durability of stiffened composite shells", AIAA Paper 92-2244-CP, 33rd AIAA Structures, Structural Dynamics and Materials Conference, 1992
ABSTRACT: The durability of a stiffened composite cylindrical shell panel is investigated under several loading conditions. An integrated computer code is utilized for the simulation of load induced structural degradation. Damage initiation, growth, and accumulation up to the stage of propagation to fracture are included in the computational simulation. Results indicate significant differences in the degradation paths for different loading cases. Effects of combined loading on structural durability and ultimate structural strength of a stiffened shell are assessed.

Michael E. Shiao, Galib H. Abumeri and Christos C. Chamis, "Probabilistic assessment of composite structures", Presented at the 34th Structures, Structural Dynamics and Materials Conference, La Jolla, CA, 19-23 Apr. 1993; sponsored by AIAA, ASME, ASCE, AHS, and ASC
ABSTRACT: A general computational simulation methodology for an integrated probabilistic assessment of composite structures is discussed and demonstrated using aircraft fuselage (stiffened composite cylindrical shell) structures with rectangular cutouts. The computational simulation was performed for the probabilistic assessment of the structural behavior including buckling loads, vibration frequencies, global displacements, and

local stresses. The scatter in the structural response is simulated based on the inherent uncertainties in the primitive (independent random) variables at the fiber matrix constituent, ply, laminate, and structural scales that describe the composite structures. The effect of uncertainties due to fabrication process variables such as fiber volume ratio, void volume ratio, ply orientation, and ply thickness is also included. The methodology has been embedded in the computer code IPACS (Integrated Probabilistic Assessment of Composite Structures). In addition to the simulated scatter, the IPACS code also calculates the sensitivity of the composite structural behavior to all the primitive variables that influence the structural behavior. This information is useful for assessing reliability and providing guidance for improvement. The results from the probabilistic assessment for the composite structure with rectangular cutouts indicate that the uncertainty in the longitudinal ply stress is mainly caused by the uncertainty in the laminate thickness, and the large overlap of the scatter in the first four buckling loads implies that the buckling mode shape for a specific buckling load can be either of the four modes.

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“Discontinuously Stiffened Composite Panel under Compressive Loading”, Journal of Reinforced Plastics and Composites, January 1995, vol. 14, no. 1, pp. 85-98, doi: 10.1177/073168449501400106
ABSTRACT: The design of composite structures requires an evaluation of their safety and durability under service loads and possible overload conditions. This paper presents a computational tool that has been developed to examine the response of stiffened composite panels via the simulation of damage initiation, growth, accumulation, progression, and propagation to structural fracture or collapse. The structural durability of a composite panel with a discontinuous stiffener is investigated under compressive loading induced by the gradual displacement of an end support. Results indicate damage initiation and progression to have significant effects on structural behavior under loading. Utilization of an integrated computer code for structural durability assessment is demonstrated.

Gotsis P.K., Chamis C.C., Minnetyan L., 1995, Effect of combined loads in the durability of a stiffened adhesively bonded composite structure, in: Proceedings of the 36th AIAA/ASME/ASCE/AHS/ ASC Structures, Structural Dynamics, and Material Conference, AIAA-95-1283-CP 2: 1083-1092.

Chamis C.C., Gotsis P.K., Minnetyan L., 1996, Damage progression in bolted composite structures, in: Proceedings of the 1995 USAF Structural Integrity Program Conference ASIP II: 663-679.

Gotsis P.K., Chamis C.C., Minnetyan L., 1996, Progressive Fracture of Fiber Composite Shell Structures Under Internal Pressure and Axial Loads, NASA TM-07234.

Christos C. Chamis (NASA Lewis Research Center, Cleveland, Ohio), “Probabilistic composite design”, in Composite materials: testing and design (thirteenth volume), edited by Steven J. Hooper, 1997, American Society for Testing and Materials, ISBN: 0-8031-2478-3
ABSTRACT: Probabilistic composite design is described in terms of a computational simulation. This simulation tracks probabilistically the composite design evolution from constituent materials, fabrication process, through composite mechanics and structural components. Comparisons with experimental data are provided to illustrate selection of probabilistic design allowables, test methods/specimen guidelines, and identification of in situ versus pristine strength. For example, results show that: in situ fiber tensile strength is

90 per cent of its prestine strength; flat-wise long-tapered specimens are most suitable for setting ply tensile strength allowables; a composite radome can be designed with a reliability of 0.999999; and laminate fatigue exhibits wide-spread scatter at 90 per cent cyclic-stress to static-strength ratios.

Gotsis P K, Chamis C C, Minnetyan. " Prediction of composite laminate fracture." Composite Science and Technology. 58. No. 7.1998. Pp 1137-1149

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(1) Sverdrup Technology, Inc., Lewis Research Center Group, Brookpark, OH, USA
(2) NASA Lewis Research Center, Cleveland, OH 44135-3191, USA
"Probabilistic evaluation of fuselage-type composite structures", Probabilistic Engineering Mechanics, Vol. 14, Nos. 1-2, January 1999, pp. 179-187, doi:10.1016/S0266-8920(98)00027-7
ABSTRACT: A methodology is developed to simulate computationally the uncertain behavior of composite structures. The uncertain behavior includes buckling loads, natural frequencies, displacements, stress/strain, etc., which are the consequences of the random variation (scatter) of the primitive (independent random) variables in the constituent, ply, laminate and structural levels. This methodology is implemented in a computer code IPACS (integrated probabilistic assessment of composite structures). A fuselage-type composite structure is analyzed to demonstrate the code's capability. The probability distribution functions of the buckling loads, natural frequency, displacement, strain and stress are computed. The sensitivity of each primitive (independent random) variable to a given structural response is also identified from the analyses.

C.C. Chamis, R.A. Aiello and P.L.N. Murthy, "Fiber composite sandwich thermostructural behavior: Computational simulation", (publisher and date not given, ProQuest-CSA)
ABSTRACT: Several computational levels of progressive sophistication /simplification are described to computationally simulate composite sandwich hygral, thermal, and structural behavior. The computational levels of sophistication include: (1) three-dimensional detailed finite element modeling of the honeycomb, the adhesive and the composite faces; (2) three-dimensional finite element modeling of the honeycomb assumed to be an equivalent continuous, homogeneous medium, the adhesive and the composite faces; (3) laminate theory simulation where the honeycomb (metal or composite) is assumed to consist of plies with equivalent properties; and (4) derivations of approximate, simplified equations for thermal and mechanical properties by simulating the honeycomb as an equivalent homogeneous medium. The approximate equations are combined with composite hygrothermomechanical and laminate theories to provide a simple and effective computational procedure for simulating the thermomechanical/thermostructural behavior of fiber composite sandwich structures.

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(2) Clarkson University, Potsdam, New York 13699, USA
"Future Experimental Methods Needed to Verify Composite Life-cycle Simulations", Recent Advances in Experimental Mechanics, Vol. 8., 2002, pp. 631-644, doi: 10.1007/0-306-48410-2_59
ABSTRACT: The future experimental methods needed for composite life-cycle are identified by computationally simulating the fracture of an integrally stiffened composite structure. The simulation describes events occurring during the fracture progression at all composite structure scales, the fracture modes that contribute to those events and the respective local failure mechanisms. The fracture modes in their respective scales provide opportunities to suggest future testing techniques to measure them. For example, energies emitted can be calibrated to identify non-destructive techniques to measure corresponding energies such as

acoustic, thermal and even optical. Successful testing methods can then be used to implement monitoring systems for in-service structural life-cycles.

Galib H. Abumeri (1) and Christos C. Chamis (2)
(1) QSS Group, Inc., Cleveland, Ohio
(2) Glenn Reseasrch Center, Cleveland, Ohio
"Probabilistic evaluation of advanced ceramic matrix composite structures", NASA/TM – 2003-212515, July 2003
ABSTRACT: The objective of this report is to summarize the deterministic and probabilistic structural evaluation results of two structures made with advanced ceramic composites (CMC): internally pressurized tube and uniformly loaded flange. The deterministic structural evaluation includes stress, displacement and buckling analyses. It is carried out using the finite element code MHOST1, developed for the 3-D inelastic analysis of structures that are made with advanced materials. The probabilistic evaluation is performed using the integrated probabilistic assessment of composite structures computer code IPACS2. The affects of uncertainties in primitive variables related to the material, fabrication process, and loadings on the material property and structural response behavior are quantified. The primitive variables considered are: thermo- mechanical properties of fiber and matrix, fiber and void volume ratios, use temperature, and pressure. The probabilistic structural analysis and probabilistic strength results are used by IPACS to perform reliability and risk evaluation of the two structures. The results will show that the sensitivity information obtained for the two composite structures from the computational simulation can be used to alter the design process to meet desired service requirements. In addition to detailed probabilistic analysis of the two structures, the following were performed specifically on the CMC tube: (1) predicted the failure load and the buckling load, (2) performed coupled non-deterministic multi-disciplinary structural analysis, and (3) demonstrated that probabilistic sensitivities can be used to select a reduced set of design variables for optimization.

C. C. Chamis (National Aeronautics and Space Administration, Glenn Research Center, Research and Technology Directorate, 21000 Brookpark Road, Cleveland, OH 44135-3191, USA), "Probabilistic simulation of multi-scale composite behavior", Theoretical and Applied Fracture Mechanics, Vol. 41, Nos. 1-3, April 2004, pp. 51-61, Special Issue: Mesofracture Mechanics: Current Approaches to Material Damage at Different Size and Time Scales, doi:10.1016/j.tafmec.2003.11.005
ABSTRACT: A methodology is developed to computationally assess the probabilistic composite behavior at all composite scales (from micro to structural) due to the uncertainties in the constituent (fiber and matrix) properties, in the fabrication process and in structural variables (primitive variables). The methodology is computationally efficient for simulating the probability distributions of composite behavior, such as material properties, laminate and structural responses. Byproducts of the methodology are probabilistic sensitivities of the composite primitive variables. The methodology has been implemented into the computer codes: Probabilistic Integrated Composite ANalyzer (PICAN) and Integrated Probabilistic Assessment of Composite Structures (IPACS). The accuracy and efficiency of this methodology are demonstrated by simulating the uncertainties in composite typical laminates and comparing the results with the Monte Carlo simulation method. Available experimental data of composite laminate behavior at all scales fall within the scatters predicted by PICAN. Multi-scaling is extended to simulate probabilistic thermo-mechanical fatigue and to simulate the probabilistic design of a composite redome in order to illustrate its versatility. Results show that probabilistic fatigue can be simulated for different temperature amplitudes and for different cyclic stress magnitudes. Results also show that laminate configurations can be selected to increase the redome reliability by several orders of magnitude without increasing the laminate thickness—a unique feature of structural composites.

Christos C. Chamis (1) and Galib H. Abumeri (2)
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(2)QSS Group, Inc., Cleveland, OH 44135, USA
"Probabilistic dynamic buckling of composite shell structures", Composites Part A: Applied Science and Manufacturing, Vol. 36, No. 10, October 2005, pp. 1368-1380, Special Issue Honouring Jack Vinson on his 75th Birthday, doi:10.1016/j.compositesa.2004.11.018
ABSTRACT: A computationally effective method is described to evaluate the probabilistic dynamic buckling of thin composite shells. The method is a judicious combination of available computer codes for finite element, composite mechanics and probabilistic structural analysis. The solution method is an incrementally updated Lagrangian. It is illustrated by applying it to a thin composite cylindrical shell subjected to dynamic loads. Both deterministic and probabilistic buckling loads are evaluated to demonstrate the effectiveness of the method. A universal plot is obtained for the specific shell that can be used to approximate buckling loads for different loading rates and different probability levels. Results from this plot show that the faster the rate, the higher the buckling load and the shorter the time. The lower the probability, the lower the buckling load for a specific time. Probabilistic sensitivity results show that the ply thickness, the fiber volume ratio, the fiber longitudinal modulus, dynamic load and loading rate are the dominant uncertainties in that order.

Christos C. Chamis (National Aeronautics and Space Administration Glenn Research Center, Cleveland, OH 44135, USA, Christos.C.Chamis@grc.nasa.gov), "Polymer Composite Mechanics Review — 1965 to 2006", Journal of Reinforced Plastics and Composites July 2007, vol. 26, no. 10, pp. 987-1019,
doi: 10.1177/0731684407079419
ABSTRACT: The research and development in composite mechanics are reviewed from 1965 to 2006. The review covers micromechanics, macromechanics failure theories, impact resistance, structural analysis, plate and panel buckling, shell buckling, progressive fracture, containment, and probabilistic composite simulation. A few remarks are included about aerodynamic loads and a new all composite engine concept. Most of the sample cases are from the author's own research since this research covers all aspects of composites and since this avoids the permissions required by other authors when their results are included. References are cited as appropriate so that the reader can further look in any specific area.

Gotsis P.K., Chamis C.C., David K., Abdi F., 2007, Progressive Fracture of Laminated Composite Stiffened Plate, NASA/TM-2007-214927.