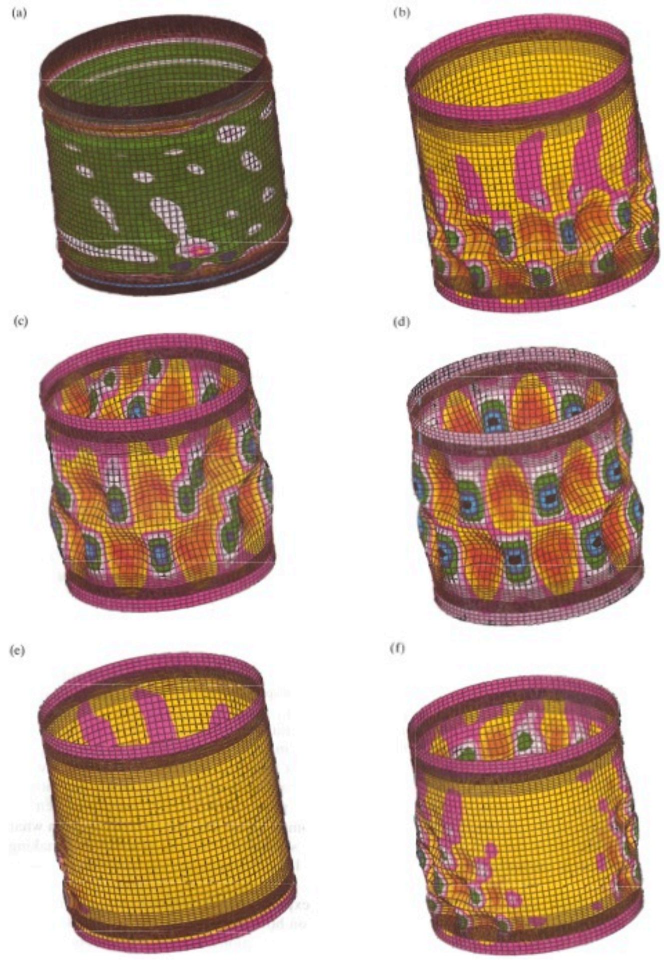
Dr. Charles C. Rankin



From:"On the solution of mode jumping phenomena in thin-walled shell structures" by Eduard Riks, Charles C. Rankin and Francis A. Brogan, Computer Methods in Applied Mechanics and Engineering, Vol. 136, 1996, pp. 59-92.

See:
http://0-www.worldcat.org.novacat.nova.edu/identities/lccn-no2002-30680
http://www.facebook.com/people/Charles-C-Rankin/1140678630

Charles Rankin should be promoted to Fellow mainly for his salient fundamental contributions over more than 30 years to the field of solid and structural mechanics of crucial significance to the aerospace industry as listed below. All of these contributions have been formulated by Charles and implemented into his general-purpose nonlinear static and dynamic finite element code called STAGS, widely used especially at NASA Langley Research Center. Note that Charles is no mere programmer implementing into a code the mechanics theories of others; he has developed these theories mainly by himself. Many of Charles' fundamental contributions are now finding their way (with Charles' cooperation) into the most widely used commercial structural computer programs such as MSC_NASTRAN, ANSYS and ABAQUS. In this way Charles' important original contributions will for the foreseeable future have a major impact on the aerospace industry. In the following paragraphs under Part I the numbers, [n], refer to the publications listed in Section 6.

I. Contributions to Technical Knowledge

I.1. Formulation of a finite-element-independent co-rotational theory and its implementation into the STAGS computer program in the 1980s [18, 29, 31, 33] that was original with Charles and that has just recently been and is now being introduced into widely used commercial computer codes. This method permits the simulation of highly nonlinear phenomena in thin-walled structures such as the reliable determination via Newton's method of far post-buckling static and dynamic equilibrium states of stiffened, composite shell structures universally used by the aerospace industry. Charles' unique co-rotational formulation avoids finite-element "lockup". It has been especially well received by the developers of commercial structural computer codes because it operates outside the finite element kernels that differ not only from code to code but also from finite element to finite element within each commercial software package. Unique to STAGS is an extension to large strain for various selected strain measures [5, 7], again in a process that is virtually independent of the details of the finite element kernal. A Google search with use of the string, "corotational finite element", produces about 74000 results, indicating that this original contribution of Charles has now become an important standard in computational mechanics the world over. Charles deserves promotion to Fellow Grade for this contribution alone. This work was in support of a multitude of NASA programs, including Space Shuttle solid rocket boosters, the Super Light Weight Tank effort, Aircraft Structural Integrity Program. This work has affected in the long run all projects that use STAGS, including also projects of the Navy and projects of the Air Force.

I.2. Formulation (with Eduard Riks) and implementation into STAGS of an arc-length method that permits the traversal of limit points from pre-buckling to post-buckling of imperfect shells under destabilizing loads [16, 21, 24, 25]. Charles optimized the solution stepping algorithm for the reliable determination of the nonlinear equilibrium state at each successive loading step. This strategy includes the unique ability to switch solutions paths and continue "in the path direction" of a particular buckling eigenvector in order to enable a more reliable and accurate investigation of post-buckling behavior. Charles' unique strategy permits the accurate prediction of "mode-jumping" [19, 23], a dynamic phenomenon in which a given post-buckled state evolves dynamically, at a given load level, into an entirely different, non-neighboring, post-buckled state. STAGS is the first general-purpose computer program to include these sophisticated formulations and strategies that are now finding their way into the major commercial codes. This work was supported the NASA, Navy, and Air Force, with impacts on the same projects mentioned under #1.

I.3. Formulation and implementation into STAGS of an algorithm to determine multiple bifurcation eigenvalues and eigenvectors from nonlinearly determined rather than from linearly determined pre-buckled equilibrium states. This original contribution by Charles is essential for the successful simulation of "mode jumping" [8, 19, 23], a phenomenon that is especially prominent in compressed stiffened thin shells of the type universally used by the aerospace industry. It is also essential for the determination of the behavior of an axially compressed imperfect stiffened cylindrical shell loaded well beyond its initial buckling load to ultimate failure in its far post-buckled state. This work supported all the projects mentioned under #1 and #2, since structural stability and solution beyond bifurcation has been the focus of work on STAGS from the beginning.

I.4. Formulation and implementation of a solution strategy that permits the successive introduction into a given nonlinear finite element model of a shell structure a sequence of buckling modal imperfections [8]. This strategy, original with Charles, is required in order to determine static and dynamic nonlinear post-buckled equilibrium states of thin shells with closely spaced bifurcation points in the nonlinear regime, for the determination of secondary and tertiary (and so on) equilibrium bifurcations, and for successful nonlinear continuation beyond these secondary and tertiary bifurcations [8, 13]. This very complex nonlinear behavior is typical of extremely light-weight stiffened thin shell structures such as the huge external tank of the Space Shuttle and optimally designed aircraft fuselages. Charles' unique strategy is crucial if the ultimate failure of such thin shell structures is to be determined reliably. Numerous comparisons in the literature between test and the theory implemented in STAGS demonstrate the accuracy of predictions by STAGS. This work supported and aided the projects mentioned in #1 and #2.

I.5. Formulation and implementation of a strategy that permits successive smooth transitions from static to transient and from transient to static analyses of a given structure during execution of a sequence of nonlinear computer runs sometimes required for the complete determination of the ultimate failure of a thin shell structure [8]. A crucial aspect of this strategy is the use of advanced static arc-length methods to enable the reliable return to a converged nonlinear static equilibrium state from a nonlinear transient state by means of appropriate load relaxation. This work originated with the NASA requirements to determine and correlate far-postbuckling test results with STAGS analyses. These enhancements benefited most of the projects listed in #1 and #2.

I.6. Formulation and implementation of a strategy that permits the simulation of unzipping of a through crack in a shell possibly with multiple crack tips and turning of a crack during loading [9, 26, 28, 30]. This unique and sophisticated strategy requires the use of a combination of advanced arc-length procedures and load-relaxation return to nonlinear static equilibrium, all done seamlessly in STAGS without user intervention. STAGS is the only code to report the actual energy release rate during the entire crack growth process. This crack tip behavior simulation capability, originally unique to STAGS, is crucial for solution of the problem of fatigue failure and catastrophic delamination in composite and metallic aircraft fuselages [2, 4, 9, 15]. Charles' formulations are now finding their way into ABAQUS, primarily via Charles' service on the ABAQUS Fracture Customer Review Team (Item No. 2 in Section 5). The Aircraft Structural Integrity Program (ASIP from NASA) funded and benefited from the enhancements mentioned in this section. These benefits have spread to a multitude of projects that succeeded ASIP.

I.7. Formulation and implementation of a "sandwich" finite element that efficiently accounts for soft, shear-deformable cores and stiff face sheets [11, 36]. The STAGS sandwich element makes clever use of existing shell elements for the face sheets, and adds a separation between the face sheets. The space is filled with an 8-node solid element whose displacement field is taken from the face sheets; this process allows for a very high order resolution of the dominant shear field between the face sheets. An additional important aspect of the sandwich element is that one is able to raise the through-the-thickness order by stacking phantom face sheets within the core to provide a more flexible displacement field. Phantom face sheets are shell elements with no stiffness, with a displacement field driven by the core shear field. This project came from NASA's advanced composite effort.

I.8. The development of unique nonlinear material models in separate "material modules" which are independent of the rest of the software. This formulation makes it straightforward to introduce into large commercial finite element codes various composite-response progressive failure models that include many different failure threshold and growth criteria [14, 22, 28]. Notable among these models created by Charles is the simulation of composite fatigue delamination in a mixed-mode setting [2] and advanced decohesion finite elements for the simulation of composite delamination [4]: an initial version implemented into STAGS in 1999 and revised and improved since then. These sophisticated models have been implemented in ABAQUS. This project was generated by the need to streamline and simplify STAGS updates, and as such, benefited the advanced composite efforts of NASA.

II. Contributions through Application of Technical Knowledge
The new technical knowledge created by Dr. Charles Rankin has been implemented into the STAGS computer program by Dr. Rankin and his associates. STAGS is widely used by NASA. Parts of the STAGS technology have been and are being incorporated into commercial software packages such as ABAQUS, MSC-NASTRAN and ANSYS. STAGS has been used by NASA and others to solve practical problems involving the Space Shuttle External Tank, the prediction of fracture in aging aircraft pressurized fuselages (Aircraft Structural Integrity Program – ASIP), and countless other projects. Even after many years of intensive use, STAGS has a continually increasing degree of use. For example, Dr. Rankin is co-author of at least four papers presented at the 53rd AIAA Structures, Structural Dynamics and Materials Conference held in Honolulu, Hawaii in April 2012.

III. Contributions through Leadership and Management of Technical Resources
The development of the STAGS computer program at Lockheed (now Lockheed Martin) was a team effort led by Dr. Rankin from 1983 to 2003. Included on Dr. Rankin's team at Lockheed Martin were Francis A. Brogan, Gary Stanley, Bryan Hurlbut, Bill Loden, Lyle Swensen, and Larry Chien. Dr. Rankin was responsible for raising money to support these STAGS team members. He wrote proposals, negotiated contracts, and ran NASA, Air Force, and Navy contracts during those years. Every year he wrote performance reviews for the people he led and provided work for. As a member of the Rhombus Consultants Group, Dr. Rankin continues to develop the STAGS computer program, writing proposals and negotiating contracts with NASA Langley Research Center. Other members of the STAGS development team have included Dr. Tony Ingraffea and Dr. Wash Wawrzynek and others at the Cornell Fracture Group and Dr. Norm Knight at the NASA Langley Research Center.

IV. Service to the Aerospace Profession
Dr. Rankin has served continuously for the last 10 years on the AIAA Structures Technical Committee. During this time he has attended at least 20 AIAA Structures TC meetings. He has served as technical session chair or co-chair at one or more sessions at AIAA SDM Conferences every year during his tenure on the AIAA Structures TC. He has reviewed over 300 extended abstracts submitted to the AIAA for SDM conferences during his tenure on the Structures TC. He has served for eight years on the NASA Engineering and Safety Center (NESC) Structures Technical Discipline team. He is a member of the ABAQUS Fracture Customer Review Team, which reviews contributions to the field of failure and proposes solutions and schedules for current unsolved problems. Dr. Rankin continues to serve in all the capacities mentioned above. Whenever NASA or other STAGS users have questions he always takes time to answer them and even introduces special capabilities into STAGS that improve the applicability and predictive capability of STAGS for the specific case.

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2. PROFESSIONAL RECORD (Begin with the first position after college)

UNIVERSITY OF CALIFORNIA, Berkeley, CA 1970–1971: Postdoctoral fellowship, research in molecular dynamics.

UNIVERSITY OF SOUTHERN CALIFORNIA, Los Angeles, CA 1968–1970: Postdoctoral fellowship, research in theoretical chemistry.

LOCKHEED-MARTIN ADVANCED TECHNOLOGY CENTER, Palo Alto, CA 1972–1981: Associate

Research Scientist Dr. Rankin developed software for structural dynamic analysis, generating models and calculating dynamic response for pre- and post-test correlation of re-entry vehicles subjected to severe dynamic loads.

1981–1987: Research Scientist Dr. Rankin developed software for computational structural mechanics applications: finite element and finite difference methods. He conducted numerical and analytical research in structural mechanics with special emphasis on nonlinear and transient response. He conducted research addressing the collapse of fabricated shells that resulted in the development of an element-independent large rotation formulation and a very sophisticated, advanced nonlinear solution algorithm toolkit for finite element applications.

1987–2003: Staff Scientist, Senior Staff Scientist Dr. Rankin developed software for computational structural mechanics applications via finite element methods. He conducted numerical and analytical research in structural mechanics with special emphasis on nonlinear and transient response. Most recent work addressed branching to alternate solution paths near bifurcation points, secondary bifurcation, modeling cracks influenced by geometric nonlinearities and local curvatures (including crack extension and turning as a function of system response), the consistent linearization of the element-independent large rotation formulation, and the development of advanced nonlinear solution algorithms for static and dynamic finite element applications. Principal investigator for the residual strength determination and structural analysis code development tasks for the NASA-sponsored Aircraft Structural Integrity Program (ASIP) that was launched after the Aloha Airlines incident.

1983–2003: Principal Investigator--STructural Analysis of General Shells (STAGS) Dr. Charles Rankin inherited management of the STAGS development contract from NASA in 1983. Work on STAGS up to that time had been continuing at LMSC under NASA sponsorship for over a decade. During the 1980's, Dr. Rankin implemented the element-independent, large rotation algorithm which has by now found its way into most of the widely-used nonlinear finite element codes. Dr. Rankin and his LMSC/LMMS colleagues have established a strong working relationship with Dr. Eduard Riks of TU Delft (in the Netherlands). Using Dr. Riks' state-of-the-art solution control algorithms in the STAGS program, Dr. Rankin and his colleagues have made STAGS second to none for solving complex nonlinear response problems, including excursions into the far-post-buckled regime. Dr. Rankin coordinated and participated strongly in accelerated efforts on the STAGS program in a subtask of the Computational Structural Mechanics Testbed Contract NAS1-18444 (1992)--under which he and his colleagues introduced into the program crack definitions, estimates of the total energy release during crack extension, both by Virtual Crack Extension (VCE) and by node release, and a much-improved solution algorithm to deal with structures containing damage.

From 1993 to 1995, Dr. Rankin directed and participated strongly in work on Task 21 of the Task Assignment Contract NAS1-19241, Mission Systems & Operations Analysis of the NASA Space Station Freedom, Advanced Concepts (MSOA). In these endeavors, he and his colleagues implemented user crack input definitions, surface-to-surface (pad) and point-to-surface (general) contact elements and algorithms, and prototype solid elements. He also directed and worked on energy release rates for separate crack opening modes and on least squares loading and fastener elements.

In 1994 and 1995, Dr. Rankin coordinated the integration of STAGS with FRANC3D-- the fracture code developed by Cornell to simulate curvilinear cracks in complex, stiffened shells. In FRANC3D, STAGS plays the role of the analysis engine in response to models generated as a function of the current crack orientation and geometry. Merging these codes and maintaining their compatibility as all parts are enhanced continues to be a large scale project involving very close coordination between the Cornell Fracture Group, NASA Langley Research Center, and Lockheed-Martin Advanced Technology Center.

In 1995, Dr. Rankin implemented the first algorithm to simulate crack extension using the Crack Tip Opening Angle (CTOA) in the STAGS program. After the MSOA efforts, Dr. Rankin has continued to direct and participate strongly in ongoing STAGS development work under Contract NAS1-2015, Task 7—introducing much better solution strategies, automated crack extension, plane strain plasticity, plastic fasteners, user stiffness, line contact, and a much, much faster linear equation solver into the program. Directing and participating in work under Contract NAS1- 19242. Dr. Rankin has also helped streamline the user input to STAGS and has devoted considerable attention and effort to the improvement of user documentation and the user interface in general. These efforts have also focused on the development and exploitation of STAGS-system software for post-processing of computed results--including the development of a stand-alone graphics engine that produces Adobe-readable pdf-formatted files that can be parsed on any computer.

Dr. Rankin retired from Lockheed in 2003.

RHOMBUS CONSULTANTS GROUP, INC., PALO ALTO, CALIFORNIA
2003–Date: Consulting Specialist. Dr. Rankin extended corotation to work with large strain, and he continues to update STAGS functionality to reflect the needs of its customers. Beginning in 2005, Rhombus participated in two Small Business Innovative Research (SBIR) projects dealing with fatigue and delamination growth in layered composites, in which Rhombus upgraded and transitioned STAGS capability to Simulia's ABAQUS code. Work continues today in fatigue and delamination, nonlinear geometric response, and other nonlinear material behavior.

3. TECHNICAL HONORS AND AWARDS

1. Phi Beta Kappa and Phi Eta Sigma, American Physical Society, AIAA. (1968)

2. Lockheed-Martin Productivity Improvement Award (PIP), for superior performance, 1993.

3. Lockheed-Martin Certificate of Appreciation, 1996, FAA-NASA Symposium on Continued Airworthiness for work on widespread fatigue damage in airliner fuselages.

4. Lockheed-Martin Productivity Improvement Award (PIP), 1997, for longstanding support of the STAGS code, including mentoring new users on best STAGS use practices.

5. NASA LaRC Group Achievement Award, 1997, Aging Aircraft Structural Integrity Program, for work on crack propagation due to widespread fatigue and other causes.

6. NASA Group Achievement Award, "Advanced Subsonic Technology Aging Aircraft Program Team," at NASA LaRC: for exemplary achievement in developing NDE techniques and structural integrity analysis methodologies to enhance the safety and extend the life of high time airplanes. (1999)

7. Special NASA Award "Turning Goals into Reality" for valuable contributions to NASA Airframe Structural Integrity Team and exceptional progress toward Aviation Safety (1997).

8. Dr. Rankin received multiple NASA Engineering and Safety Center (NESC) Certificates of Appreciation for eight consecutive years of service on the NESC Structures Technical Discipline Team. This team examines safety-critical problems in a variety of structures of great importance to NASA, including the Space Shuttle External Tank, for example. Work continues on this Team at the present time. Award dates 2004-2011

9. NASA Group Achievement Award for work on the Space Shuttle Program External Tank Intertank Stringer Cracking Investigation Team. (2012)

4. EDUCATIONAL BACKGROUND

UNIVERSITY OF CHICAGO, Chicago, IL 1968 Ph.D., Molecular Physics.

UNIVERSITY OF NORTH CAROLINA, Chapel Hill, NC 1964 B.S., Chemistry.

LOCKHEED TECHNICAL COURSE: Basic Optics, rest of “education” learned on the job.

5. SERVICE TO AIAA AND OTHER PROFESSIONAL SOCIETIES

1. Dr. Rankin served continuously for the last ten years on the AIAA Structures Technical Committee, either as a “friend” or as a member. During this time he has attended at least 20 AIAA Structures Technical Committee (TC) meetings.

2. He has served as a reviewer of over 300 AIAA extended abstracts submitted to the AIAA for the AIAA Structures, Dynamics and Materials (SDM) conferences that Dr. Rankin attends each year.

3. He has served as technical session chair or co-chair for one or more technical sessions at AIAA SDM Conferences every year during his tenure on the AIAA Structures TC.

4. He has served as a reviewer of many journal papers.

5. He has served three times on a board for evaluation of a student’s defense of a PhD dissertation or MS thesis.

5. Dr. Rankin is a member of the ABAQUS Fracture Customer Review Team, wherein contributions to the field of failure are discussed, and proposed solutions and schedules are generated (2003-Present).

6. He has served as a member of the NESC Space Shuttle Program External Tank Intertank Stringer Cracking Investigation Team (2011)

7. He participated in the International Workshop on Structural Integrity of Aging Airplanes, 1992

8. He has served eight years on the NASA Engineering and Safety Center (NESC) Structures Technical Discipline Team (2004-Present)

9. He has served the Sierra Club as a leader of long hikes for many years.

6. PUBLICATIONS, PATENTS AND OTHER PUBLIC CONTRIBUTIONS

1. “Use of GENOPT and BIGBOSOR4 to obtain optimum designs of multi-walled inflatable spherical and cylindrical vacuum chambers”, (with David Bushnell), AIAA 53rd Structures, Structural Dynamics and Materials Conference, Honolulu, Hawaii, April 2012

2. “Simulation of Composite Fatigue Delamination in a Mixed-Mode Setting,” with Bryan Hurlbut, presented at the 2011 Simulia (ABAQUS) Customer Conference (2011).

3. “Use of GENOPT and BIGBOSOR4 to Obtain Optimum Designs of an Axially Compressed Cylindrical Shell with a Composite Truss-Core Sandwich Wall,” with David Bushnell, presented at the 52nd AIAA SDM Conference, Paper #2011-1811 (2011).

4. “Advanced Decohesion Elements for the Simulation of Composite Delamination,” with Marc Regelbrugge & Bryan Hurlbut, presented at the 2010 Simulia (ABAQUS) Customer Conference (2010).

5. “The Use of Shell Elements for the Analysis of Large Strain Response,” presented at the 48th AIAA SDM Conference, Paper #2007-2384 (2007).

6. “Design Equations & System Implications of Thin Film Membrane Mirrors & Windows,” with Jason Lindler & Eric Flint, presented at the 48th AIAA SDM Conference, Paper #2007-1815 (2007).

7. “Application of Linear Finite Elements to Finite Strain Using Corotation,” presented at the 47th AIAA SDM Conference, Paper #2006-1751 (2006).

8. “Difficulties in Optimization of Imperfect Stiffened Cylindrical Shells,” with David Bushnell, presented at the 47th AIAA SDM Conference, Paper #2006-1943 (2006).

9. “Residual Strength Calculations of Stiffened Metal Panels Containing Cracks,” with Eduard Riks, presented at the 46th AIAA SDM Conference, Paper #2005-2007 (2005).

10. “Optimum design of Stiffened Panels with Sub-stiffeners,” with David Bushnell, presented at the 46th AIAA SDM Conference, Paper #2005-1932.

11. “Finite Element Modeling of the Buckling Response of Sandwich Panels,” with Cheryl Rose, David Moore and Norman Knight, presented at the 43rd AIAA SDM Conference, Paper #2002-1517 (2002).

12. “Optimization of Perfect and Imperfect Ring and Stringer-Stiffened Cylindrical Shells with PANDA2 and Evaluation of the Optimum Design with STAGS,” with David Bushnell, presented at the 43rd AIAA SDM Conference, Paper #2002-1408 (2002).

13. “Tools for the Evaluation of the Residual Strength of Cracked Pressurized Fuselage Shells,” with Eduard Riks, presented at the 42nd AIAA SDM Conference, Paper #2001-1325 (2001).

14. “Controlling Nonlinear Procedures During Progressive Failure Analysis,” with N. Knight & F. Brogan,

presented at the 41st AIAA SDM Conference, Paper #2000-1460 (2000).

15. “On the Simulation of Crack Propagation in Pressurized Fuselages,” with E. Riks, presented at the 41st AIAA SDM Conference, Paper #2000-1594 (2000)

16. “Modeling and Nonlinear Structural Analysis of a Large-Scale Launch Vehicle,” with Richard Young, J. of Spacecraft & Rockets, Vol. 36, No. 6, pp. 804-811 (1999).

17. “Line-to-Line Contact Behavior of Shell Structures,” with W. Loden, L. Swenson, and L. Chien, presnted at the 40th AIAA SDM Conference, Paper #99-1237 (1999).

18. “On the Choice of Best Possible Corotational Element Frame,” presented at the 3rd International Conference on Computational Mechanics at Atlanta, GA. (1998)

19. Optimization of Stiffened Panels in which Mode Jumping Is Accounted For,” with D. Bushnell, presented at the 38th AIAA SDM Conference, AIAA Paper 97-1141, (1997)

20. “Modeling and Nonlinear Analysis of a Large Scale Launch Vehicle under Combined Thermal & Mechanical Loads,” with R. D. Young, presented at the 37th AIAA SDM Conference, AIAA Paper No. 1996-1551, (1996).

21. “Computer Simulation of the Buckling Behavior of Thin Shells Under Quasi Static Loads,” with E. Riks, Archives of Computational Methods in Engineering, Vol. 4, No. 4, pp 325-351 (1997).

22. “Nonlinear Response and Residual Strength of Damaged Stiffened Shells Subjected to Combined Loads,” with James Starnes, Vicki Britt, and Cheryl Rose. Presented at the 37th AIAA SDM Conference, Paper #1996-1555 (1996).

23. “On the Solution of Mode Jumping Phenomena in Thin-Walled Shell Structures,” with E. Riks and Francis A. Brogan, Comp. Meth. Appl. Mech. Eng., Vol 136, pp 59-92 (1996).

24. “Simulation of Propagating Instabilities in Structures using the STAGS Finite Element Code,” with W. Loden, presented at the AMD-MD Summer Conference, UCLA, (1995)

25. “Computer Simulation of Dynamic Buckling Phenomena under Quasi Static Loads,” with E. Riks, J. Starnes, and A. Waters, (published where and when?).

26. “The Buckling Behavior of a Central Crack in a Plate under Tension,” with E. Riks, Eng. Fracture Mechanics, pp 529-548, 1992.

27. “Applications of the USA-STAGS-CFA Code to Nonlinear Fluid-Structure Interaction Problems in Underwater Shock of Submerged Structures,” Proceedings of the 60th Shock and Vibration Symposium, Vol. 1, Virginia Beach, VA, Nov. 1989, pp 121-138.

28. “Damage Propagation in Stiffened Fuselage Shells Containing Cracks,” presented at International Workshop on Structural Integrity of Aging Airplanes, April, 1992.

29. “Finite Rotation Analysis and Consistent Linearization Using Projectors,” with B. Nour-Omid, Comp. Meth. Appl. Mech. Eng., Vol. 93, pp 353-384, January, 1991.

30. “Bulging Cracks in Pressurized Fuselages: A Procedure for Computation,” with E. Riks and F. A. Brogan, in Analytical and Computational Models of Shells, A. K. Noor, T. Belytschko and J. Simo eds., American Society of Mechanical Engineers, New York, 1989.

31. “The Use of Projectors to Improve Finite Element Performance,” with Bahram Nour-Omid, Computers & Structures, Vol. 30, pp 257-267, October, 1988.

32. “Analysis of Structural Collapse by the Reduced Basis Technique Using a Mixed Local-Global Formulation,” with P. Stehlin, LMSC-F035663, Lockheed Palo Alto Research Laboratory, Palo Alto, CA, May, 1986, presented at the 27th AIAA/ASME/ASCE Structures, Structural Dynamics, and Materials Conference, San Antonio, May, 1986.

33. “An Element-Independent Corotational Procedure for the Treatment of Large Rotations,” with F. A. Brogan, ASME J. Pressure Vessel Technology, pp 165-174, May, 1986

34. B. O. Almroth & Charles C. Rankin, “Imperfection Sensitivity of Cylindrical Shells,” in Recent Advances in Engineering Mechanics and their Impact on Civil Engineering Practice, Vol. II, pp 1701-1704, Proceedings of the Fourth Engineering Mechanics Division Specialty Conference, Eds. W.F. Chen and A.D.M Lewis, Published by the American Society of Civil Engineers (New York, 1983)

35. “A Semi-Implicit Dynamic Relaxation Algorithm for Static Nonlinear Structural Analysis,” with K. C. Park, in “Research in Structural and Solid Mechanics – 1982,” compiled by J. M. Housner and A. K. Noor, NASA CP-2245, pp. 1-24.

36. “Transient Response of Soft Bonded Multilayered Shells,” with C. J. Bonner, D. W. Lindow, and P. G. Underwood, AIAA Journal, Vol. 13, No. 3, pp 350-356, l975.

37. “Classical S-Matrix for Linear Reactive Collisions of H + Cl,” with W. H. Miller, J. Chem. Phys., pp 3150, 1971.

38. “Quantum Solution of Collinear Reactive systems: H + Cl,” with J. C. Light, J. Chem. Phys., pp 1701, 1969.

39. “Relaxation of a Gas of Harmonic Oscillators,” with J. C. Light, Journal of Chemical Physics, pp 1305, 1967.

40. “Statistical Theory of Chemical Kinetics: Application to Neutral Atom Molecule Reactions,” with J. C. Light and P. Pechukas, J. Chem. Phys., pp 794, 1966.

41. “Transient Response of Soft Bonded Multilayered Shells,” with C. J. Bonner, D. W. Lindow, and P. G. Underwood, presented at the 15th SDM conference, AIAA Paper No. 1974-342, 1974..

42. “STAGS Example Problems Manual,” with N. F. Knight, NASA CR-2006-214281, March 2006.

43. “The Computational Structural Mechanics testbed Structural Element Processor ES5: STAGS Shell Element,” with F. A. Brogan, NASA CR-4358, May 1991.

44. “Controlling Progressive Failure Analyses using Artificial Viscous Damping,” with N. F. Knight and F. A. Brogan, AIAA Paper 2001-1180.

45. “Enhancements to the STAGS Computer Code,” with P. Stehlin and F. A. Brogan, NASA CR-4000, November 1986.

46. “STAGS Computational Procedure for Progressive Failure Analysis of Laminated Composite Structures,” with N. F. Knight and F. A. Brogan, International Journal of Non-Linear Mechanics, Vol. 37, No. 4-5, pp. 833-849 (2002).

47. “Sandwich Modeling with an Application to the Residual Strength Analysis of a Damaged Compression Panel,” with E. Riks, International Journal of Non-Linear Mechanics, Vol. 37, No. 4-5, pp. 897-908 (2002).

48. “Sandwich Modeling with an Application to the Residual Strength Analysis of a Damaged Compression Panel,” with E. Riks, AIAA Paper No. 2001-1323, April 2001.

49. “Numerical Aspects of Shell Stability Analysis”, with E. riks and F. A. Brogan, in Computational Mechanics of Nonlinear Response of Shells, W. B. Kratzir and E. Onate (eds), Springer-Verlag, Berlin, pp. 125-151, 1990.

50. “110 Mount Element,”, with W. C. Perry, Lockheed report LMSC-D062175, 1985.

51. “Enhanced Analysis Capability in USA/STAGS,” with T. L. Geers, J. A. Derutz, G. M. Stanley, and W. C. Perry, Lockheed Report No. LMSC-D877665, 1983.

52. “Compuational Tools for Stability Analysis,” with E. Riks, AIAA Paper No. 1997-1138, presented at the 41st SDM, 1997.

53. “Application of the Thurston Bifurcation Solution strategy to Problems with Modal Interaction,” with F. A. Brogan, AIAA Paper No. 1988-2286.

54. “Consistent Linearization of the Element-Independent Corotational Formulation for the Structural Analysis of General Shells,” Lockheed Report No. LMSC-F202439, March 1987.

55. “Some Computational Tools for the Analysis of through Cracks in stiffened Fuselage Shelss,” with F. A. Brogan and E. riks, Computational mechanics, Vol. 13, pp. 143-156, 1993.

56. “An Element-Independent Corotational Procedure for the Treatment of Large Rotations,” with F. A. Brogan, in Collapse Analysis of Structures, L. Sobel and K. Thomas (eds), pp. 85-100, ASME PVP Vol. 84, (1984).

57. "STAGS User Manual – Version 5.0," with F. A. Brogan, W. A. Logan, H. D. Cabiness, Rhombus Consultants Group, Inc. January 2005. Previously released as LMSC-P032594.

58. "Formulation of Improved Plasticity Calculations in the STAGSC-1 and NICE-SPAR Computer Codes," with G. Stanley and J. Deruntz, Lockheed Report No. LMSC-F183026, 1987.

59. "Improved Plasticity and Imperfections in the STAGSC-1 Computer Code –Phase 2: Implementation," with F. A. Brogan, Lockheed Report No. LMSC-F386402, 1990.

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EIGHT 2012 STAGS TESTIMONIALS FROM USERS OF STAGS

STAGS testimonial from John E. Atwell, NSWCCD, Bethesda, MD, February 1, 2012:

The finite element analysis program STAGS has been used by the Naval Surface Warfare Center, Carderock Division, for the past 30 years. STAGS is an invaluable tool used in the design and evaluation of submarine structures. STAGS soon became orphaned and lost support in the engineering community as ABAQUS and other programs gained prominence. However it remains a key part of the NAVSEA submarine design criteria. STAGS was recently resurrected for use on a new submarine design, but did not have large model support. When I contacted Charles about upgrading STAGS, he was very generous with his time in working with me to make the necessary changes. Through this process I gained a cordial working relationship with Charles and he was always very responsive to any questions I had about the inner workings of STAGS. He was also very quick to fix any bugs that were found. After several months of modifications we finally brought STAGS into the 21st century.

Along with our in house FEMAP-to-STAGS translator, we now have the ability to create more complex models that we only dreamed of 5 years ago.

STAGS has been proven to match ABAQUS in analysis capabilities and also has some non-linear buckling capabilities that ABAQUS is unable to achieve. STAGS has the ability to perform a bifurcation buckling analysis from a non-linear stress state. This means that you can load a model so that the material is in a non-linear area of the stress/strain curve, and determine the bifurcation buckling load of that model using the plastic tangent modulus of the material at the load state rather than the elastic modulus of the material. ABAQUS does not have this capability; it can only perform a bifurcation analysis using the elastic modulus of the material.

STAGS was also recently used on the buckling analysis of a full surface ship. The highlighted buckling areas were in complete agreement with the actual buckling seen on the real ship. This is something that was previously not achievable with the tools we had at our disposal. We look forward to the continued use of STAGS and working with Dr. Rankin.

John Atwell
Senior Structural Engineer, NSWCCD
Bethesda, MD

From Dale Berry at SIMULA (February 27, 2012):

I work for SIMULIA, a Dassault Systemes division providing simulation software. Our main product is Abaqus which is heavily used in commercial industry as a bread-and-butter nonlinear solver, including for buckling. My association with Charles began nearly 10 years ago when Boeing began pushing us to enhance the capabilities in Abaqus for composite progressive fracture. We formed a Fracture Customer Review Team to align the needs of the aerospace industry with needs in other industries. We were quickly introduced to Charles Rankin who joined the team along with researchers from Boeing, Intel, ExxonMobil, NASA, National Industute of Aeronautics, Alstom, and others.

Charles' impact was substantial on the workings of the team and on the evolution of Abaqus as a tool for composites simulation now used heavily at Boeing, Airbus and others. Charles was very interested in transferring the legacy of technology in STAGS into a COTS product like Abaqus and has provided us with guidance on development of new techniques involving both VCCT and cohesive models for fracture. He has also provided input into the base solver technology for instability problems. For example, Abaqus has long contained an arc-length control RIKS feature although the implementation and bifurcation path following strategies in STAGS are more advanced. He has also provided substantial support to evaluating and validating the large strain, large rotation formulations in Abaqus for shell buckling problems. His direct involvement has helped advance and strengthen the overall capability of Abaqus in shell buckling simulation for commercial applications.

I hope this is helpful although it is not specifically what you were looking for. I would personally and wholeheartedly endorse your nomination of Charles as an AIAA Fellow.

Thank you, Dale Berry

STAGS testimonial by Michael Jacoby, Lockheed Martin Missiles & Space, March 4, 2012

I have been a STAGS user since the late 1980s, initially using the code for thin shell buckling problems, and the structural analysis of cryogenic pressure vessels for space-borne instrument applications.

Back then, there was no other tool available for the reliable solution of these types of problems. Over the years, Dr. Rankin has continually extended the capability of STAGS, through the development of advanced algorithms, such as co-rotation and arclength-based solution methods. In many cases, the technology embedded in STAGS has led to wide-spread adoption in other structural analysis tools, such as Nastran and Abaqus. Dr. Rankin continues to develop and further extend STAGS capabilities to this day, most recently incorporating a Lanczos eigensolver into the code.

As one of many examples of the types of problems enabled by Dr. Rankin and STAGS, I was recently asked to investigate the buckling and post-buckling behavior of a thin-wall composite cylinder under the influence of substantial shear loadings, with the inclusion of significant initial imperfections. This is an extremely challenging problem; STAGS made it relatively straightforward. Through a combination of eigenvalue analysis and nonlinear statics analysis, I was able to predict the structural response of the cylinder far into the post-buckled regime. To bolster confidence in the predictions, testing was performed, which matched the predicted response to within approximately 10% right up to the ultimate failure load! This remarkable agreement built confidence that the structure would survive its harsh loading environment, and ultimately led to the success of the mission.

In addition to developing STAGS, Dr. Rankin has provided me with invaluable engineering advice and helped guide my physical intuition in the behavior of complex structures. He has always been willing to help with difficult problems. His boundless enthusiasm, comraderie, and good humor is infectious. He has served as an excellent mentor to me over our years of collaboration.

I heartedly endorse Dr. Rankin's election to AIAA Fellow Grade.

Sincerely,
Michael Jacoby

February 7, 2012

From Dawn C. Jegley, NASA Langley Research Center:

I have been using the STAGS computer code for approximately 25 years for analysis of composite aerospace structures. STAGS nonlinear and bucking analyses capabilities made it the best choice for many of these projects. The ability to include geometric imperfections, extensive post-buckling analysis and failure progression analysis have been key factors in selecting STAGS over this time. Some examples of projects for which I have used STAGS include:

Transverse Shearing in Thick Laminates 1985-1990
NASA Structural Efficiency Studies 1988-2006
NASA Advanced Composites Technology Program (ACT), 1990-2000
NASA 21st Century Aircraft Technology Project (TCAT) 2001-2005
NASA Subsonic Fixed Wing Program (SFW) 2006-2009
NASA Environmentally Responsible Aviation Program (ERA) 2009-present

The size and complexity of the structures analyzed ranged from small coupons with details such as cutouts through a complete 40-foot long composite wing structure. STAGS was the primary analytical tool in some cases and was used to double check results from other codes in other cases.

Over the years, I have contacted Dr. Rankin numerous times with questions and have always gotten a quick response with suggestions for better ways to model certain features and finding errors in models. New capabilities have been implemented based on user needs.

STAGS is the primary code I use for analysis. I do more management these days than hands-on research, however, STAGS is still my code of choice. I have published many papers over the years in which the value of STAGS was demonstrated through the test-analysis correlation.

Dr Rankin's contribution to the advancement of the understanding of structural behavior and our ability to predict it is invaluable and I fully support the suggestion that he be granted the rank of Fellow in AIAA.

Sincerely,
Dawn C. Jegley
Structural Mechanics and Concepts Branch
NASA Langley Research Center

From Andrew Lovejoy, NASA Langley Research Center:

Charles Rankin STAGS Testimonial

I have used the STAGS finite element code on numerous occasions in the past 15 years for my work at NASA Langley Research Center as both a contractor and now as a civil servant. As part of the Shell Buckling Knockdown Factor program at NASA, STAGS has been an important asset, both due to its capabilities and for providing additional solutions to add confidence in the structural predictions. Without the added analyses from STAGS, a deficiency in an analytical method for the analysis of fluted-core composite cylinders may not have been discovered. It was due to having solutions from three finite element codes (Abaqus, NASTRAN and STAGS) that allowed me to discover what was causing the difference in buckling load that was predicted from the analytical solution and the finite element solutions. From November, 2010 to February, 2011, I used STAGS to evaluate the intertank stringer cracks on the Space Shuttle External Tank in preparations for the STS-133 launch. During that investigation, I worked very closely with Charles, and he developed a method to more easily map the pressure loads to the tank surface. While previously we had to generate a functional representation and incorporate it in a pressure subroutine, Charles' new method used the tabulated pressure data directly to interpolate the pressure data loading to the integration points. This improvement resulted in a more efficient and easy method to apply the flight pressure loads to the external tank. This method can easily be adapted to use tabular data to apply thicknesses for the elements, which will eliminate the need to write a wall subroutine as is currently done. Elimination of the wall routine will save tremendous amounts of time both in initial model development and analysis. For example, the portion of the external tank that was used in the STS-133 investigation had thousands of lines of code to apply the tabular thickness data to skins and stringers, which took many days to write and check for accuracy. Charles' new method can use the same tabular data that was used to develop the subroutine, and directly apply thickness information to the integration points, which saves time and reduces the likelihood of an error that could occur when the data is programmed manually. I also used STAGS to evaluate the response of a Space Shuttle Derived Heavy Lift Vehicle tank due to blast loading that resulted from an abort scenario. I used STAGS because of the ease with which I could represent the time-dependent blast pressures as a function in a pressure subroutine to apply pressure to the structure. These are just a few of examples of how STAGS has been extremely useful for my work, and Charles has always been responsive when help was required.

Andrew Lovejoy

From Mike Nemeth, NASA Langley Research Center (Mike's comments are in bold face):

1. Name(s) of the project(s) in which STAGS played a role

    My top project was the structural verification of the Space Shuttle Superlightweight External Tank.

The studies are documented in the J. Spacecraft and Rockets.

2. Dates of your STAGS use during each project
1994-1998

3. Unique capability/capabilities of STAGS that led to success
During that time, STAGS had the most robust and reliable nonlinear collapse algorithm for structural instability issues associated with thin-walled shells.

4. Quality and timeliness of help that you received from Dr. Rankin during your application(s) of STAGS
Whenever we found program errors, Dr. Rankin fixed them immediately.
Whenever modeling issues arose, Dr. Rankin supplied expert opinion at no charge to NASA.

5. Overall impact of STAGS on your project(s)
The use of STAGS greatly reduced the risk of flying a substantially thinner shell structure for the first time. The project would have certainly been delayed significantly, costing millions of dollars to the taxpayers.

6. Any other comments that you feel are appropriate
I believe that STAGS was the "pathfinder" for nonlinear structural analysis. It appears to have stimulated commercial finite element code developers into providing similar nonlinear analysis capabilities.

From Robert Thornburgh, Army Research Laboratory at NASA Langley Research Center:

Over the past nine years I have used the STAGS analysis code to study buckling of structures ranging from small test articles to helicopter structures to the Space Shuttle External Tank. While other commercial finite-element codes have taken over most structural analysis, STAGS remains the standard by which shell buckling and nonlinear structural analysis are compared in the research community. As a researcher, I have found that the ability to define shell units in the input deck to be an extremely powerful timesaving feature. One can model seemingly complex test articles in less than an hour, which might take upwards of a week to model in PATRAN. In addition, Dr Rankin saw very early the importance of including geometric imperfection in shell-buckling models and incorporated numerous methods for modeling imperfection in STAGS. Another feature that is of extreme importance in the research environment is the ability to customize STAGS. Dr Rankin built STAGS with a modular code, which makes incorporating user-modified subroutines a very simple process. This can save a researcher tremendous amounts of time by programmatically solving complex modeling issues. Dr Rankin has always been eager to receive feedback on the use of STAGS, and on several occasions spent large amounts of time investigating technical questions that I had encountered with STAGS. I believe that much of what has been learned over the past several decades about shell stability and nonlinear structural deformation has been facilitated by Dr Rankin's STAGS analysis code and that STAGS will continue to be a part of structural research efforts for years to come.

Dr. Robert P. Thornburgh
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STAGS testimonial from Rick Young (NASA Langley), February 29, 2012

Verified Damage Tolerance and Residual Strength Prediction Methodology for Built-Up Metallic Structures with Damage, 1990-2000.

NASA Airframe Structural Integrity Program (1990-1992), the Aging Aircraft Element of NASA's Advanced Subsonic Technology Program (1992-1998), and the Structural Integrity Element of the Inherently Reliable Systems Program (1999-2000). All of these programs included an extensive test and analysis program to develop a verified residual strength prediction methodology for built-up metallic structures with damage and subjected to combined internal pressure and mechanical loads. Advanced technology was developed that has been used by U.S. airline operators and aircraft manufacturers to safely and economically extend the life of high time airplanes in the commercial and military transport fleet. The developed analysis methodologies implemented in the STAGS code represented the most accurate procedure available in the world at the time for predicting the residual strength of metallic aircraft structure with damage. The accomplishments of the team (NASA, Lockheed, and university partners) were recognized by NASA Group Achievement Awards in 1996 and 1999, and a NASA "Turning Goals into Reality" award in 1999. The team developed high-fidelity modeling and nonlinear analysis procedures required to predict the complex nonlinear response of built-up structures, and also to conduct research to increase the understanding of the complex response of structures with damage. Unique capabilities of the STAGS code included specialized modeling of cracks, computation of stress intensity factors using a modified crack closure technique, the Crack-Tip-Opening-Angle (CTOA) elastic-plastic fracture criterion for crack extension, and load relaxation to re-establish equilibrium after crack extension. The CTOA fracture criterion was later incorporated into the commercially available ABAQUS structural analysis code. The residual strength prediction methodology for built-up structures using STAGS was successfully applied to predict or simulate the nonlinear fracture response of fuselage panels tested in NASA's Aircraft Structural Integrity Program. The methodology was transferred to industry (Douglas Aircraft, the Boeing Company, and Lockheed Marietta) and was successfully applied to predict the response of commercial aircraft structure, generally providing test/analysis differences of less than 10%. The residual strength prediction methodology using STAGS was used by Boeing Phantom Works for a DC-9 aft bulkhead test, and Boeing Wichita, for residual strength of KC-135 fuselage panels. The methodology also influenced the general approach to damage tolerant design and analysis. The Boeing Company used STAGS to conduct nonlinear parametric analyses and update Boeing's damage tolerance design guide for stiffened panels. The improved modeling and analysis methods for computing the nonlinear response of stiffened structure with damage were transferred to Lockheed Marietta during the High Speed Research (HSR) program, and later applied to improve life predictions and refine inspection schedules for Strategic Airlift Aircraft (C-5). The historical industry approach of apply compounding knockdown factors to account for the effect of curvature and stiffening elements in stiffened shells with damage was replaced by parametric nonlinear analyses of detailed models. One such knockdown factor was the bulging factor to account for the effect of curvature on the response of a shell with a crack.

Nonlinear Structural Analysis Methodology for Shuttle Superlightweight Tank, 1996-2000.
A team of NASA Langley researchers applied the STAGS code to develop the first accurate high-fidelity nonlinear analyses of the Shuttle's Superlightweight fuel tank to include the effects of initial geometric imperfections, in addition to extremely complex geometry and loading conditions, on the nonlinear response of the shell. The unique capabilities of STAGS included high-quality shell elements, transition elements to enable mesh refinement in select regions, geometric nonlinear capability, an arc-length path following algorithm, and a sparse matrix solver. In addition, user-written subroutines were utilized extensively to model the complex geometry, detailed thickness maps of chem-milled panels, and spatial temperature and pressure distributions for cryogen-filled vessels under flight loads. These analyses were able to predict a short-wavelength response phenomena that was characterized by growth in the local deflection amplitude as applied loads are increased. The nonlinear analysis approach using STAGS improved the design approach used by Marshall Space Flight Center and Michoud Assembly Facility, that was previously based on linear bifurcation analyses modified by historical "knock-down" factors. The results of the analyses using STAGS formed the basis for a new approach for designing complex thin-walled shell structures with nonlinear response and collapse characteristics, correlated very well with full-scale ground tests for the original tank, established stability margins of safety for the new tank, and provided Marshall with the confidence to reduce the weight of the new Superlightweight tank design by an additional 200 pounds. The Marshall Structures and Dynamics Laboratory Deputy Director stated that the nonlinear shell analysis saved the program several full-scale structural tests, reducing costs and schedule significantly. The STAGS nonlinear shell analysis code and modeling techniques were transferred to Marshall and Michoud personnel, and adopted as the method for doing shell analysis at Marshall. The body of work at the time represented one of the most complex, large-scale nonlinear shell analyses ever conducted on a flight vehicle and has been recognized by a NASA Group Achievement Award.

Quality and timeliness of help received from Dr. Rankin
For approximately 10 years, 1990-2000, I was involved at NASA in defining development tasks for the STAGS finite element code. Dr. Rankin's expertise in structural mechanics and computational methods, and knowledge of the internal workings of the STAGS code were invaluable during the definition and execution of code development, AND in the application of the STAGS code for research purposes. Dr. Rankin was instrumental in guiding the long-term development of STAGS to enable solving complex computational problems of national importance. Working with a large complex code, Dr. Rankin was able to implement new features to add capability, while simultaneously advancing computational efficiency and maintaining the computational integrity necessary to solve difficult nonlinear problems. In addition to adding solution capability, Dr. Rankin was diligent in advancing pre-processing and post-processing capability of the STAGS code and in updating user manuals, both enhancing the usability of the code. Since the code had a limited user base and was under continuing development, it was not uncommon to experience bugs in new or old code, or simply have user errors while applying the STAGS code to perform research. In these situations, Dr. Rankin was happy to accept test cases displaying problems, and prompt to provide a problem resolution or work around. Often prompt support from the code developers was critical to completing NASA's research in a timely manner. In addition, the quality of the support, from technical and personal perspectives, was always superior. Dr. Rankin was able to dig into the application problem being studied to provide expert advice. Simultaneously, Dr. Rankin's good nature helped establish personal friendships with many users. These relationships based on technical and personal respect contributed significantly to being able to work as a team to solve complex research problems.

Overall impact of STAGS on the projects:
The STAGS code didn't have all the bells and whistles of some commercially available codes, but it had specific capabilities that allowed it to be uniquely successful for research in structural mechanics. Complete access to the source code and the code developers were both critical in being able to tailor code execution and output and develop new computational methodologies in a research environment.
The overall impact of STAGS had several dimensions: the methodologies developed and the STAGS code were directly transferable to industry use, many algorithms developed and refined within the STAGS code were eventually implemented in commercially available software packages, and last but not least, the analysis results generated using the STAGS code increased the understanding of the complex response of structures with damage and/or geometrically nonlinear deformation. In addition to these engineering advances, I believe that the users of the STAGS code, through exercising the code, and interacting with other users and the code developers, also develop significantly as professionals, much more so than if they were turning the crank by running a commercial code.

Other Comments:
In my personal and professional interactions with Dr. Rankin, I found him to be brilliant, passionate, generous, humble, and gracious; all appropriate traits for an AIAA fellow.

From Rick Young, NASA Langley Research Center
