DTIC FILE COPY

UNCLASSIFIED — MASTER COPY - FOR REPRODUCTION PUBLICATIONS

(2)

AD-A197 141

DTIC ELECTE JUL 1 8 1988 D H

REPORT DOCUMENTATION PAGE

Field	Entry
1b. RESTRICTIVE MARKINGS	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
3. DISTRIBUTION / AVAILABILITY OF REPORT	Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	
5. MONITORING ORGANIZATION REPORT NUMBER(S)	ARO 19392.19-EG-RW
6a. NAME OF PERFORMING ORGANIZATION	Univ. of Maryland, Dept. of Aerospace Engineer.
6b. OFFICE SYMBOL (If applicable)	
6c. ADDRESS (City, State, and ZIP Code)	College Park, MD 20742
7a. NAME OF MONITORING ORGANIZATION	U. S. Army Research Office
7b. ADDRESS (City, State, and ZIP Code)	P. O. Box 12211, Research Triangle Park, NC 27709-2211
8a. NAME OF FUNDING / SPONSORING ORGANIZATION	U. S. Army Research Office
8b. OFFICE SYMBOL (If applicable)	
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	DAAG29-83-K-0002
8c. ADDRESS (City, State, and ZIP Code)	P. O. Box 12211, Research Triangle Park, NC 27709-2211
10. SOURCE OF FUNDING NUMBERS	PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification)	Establishment of Center for Rotorcraft Education and Research
12. PERSONAL AUTHOR(S)	Alfred Gessow
13a. TYPE OF REPORT	Final
13b. TIME COVERED	FROM 11-22-82 TO 12-31-87
14. DATE OF REPORT (Year, Month, Day)	5-1-88
15. PAGE COUNT	23
16. SUPPLEMENTARY NOTATION	The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.
17. COSATI CODES	FIELD / GROUP / SUB-GROUP
18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	Helicopters; Rotorcraft, Aerospace, Education,

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Under a five-year contract with the U.S. Army Research Office, a Rotorcraft Center of Excellence was established in the Fall of 1982 at the University of Maryland. As one of the universities chosen for the program, Maryland had the responsibility to attract and involve a significant number of experienced faculty into the program; to develop and add to its graduate curriculum a number of specialized rotorcraft courses which cover the disciplines appplicable to rotorcraft design; to attract the best and brightest students into the program and motivate them into rotorcraft as a career; to upgrade and develop experimental facilities which meet the specialized needs of rotorcraft research; to blend faculty, students and facilities into a research combination which concentrated on leading-edge research areas; and finally, to disseminate widely the results of the research. The degree to which these responsibilities were met at the end of the contract period is summarized herein.

Field	Entry
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT	☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS
21. ABSTRACT SECURITY CLASSIFICATION	Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	
22b. TELEPHONE (Include Area Code)	
22c. OFFICE SYMBOL	

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE: UNCLASSIFIED

ARO 19392.19-EG-RW

Establishment of Center for Rotorcraft Education and Research

Final Report

Alfred Gessow

May 2, 1988

U.S. Army Research Office

Contract Number DAAG-29-83K-0002

Department of Aerospace Engineering
University of Maryland
College Park, Maryland

The Rotorcraft Center of Excellence at the University of Maryland

Introduction

The Center for Rotorcraft Education and Research (CRER) at the University of Maryland was established by the U.S. Army Research Office (ARO) in the Fall of 1982 as one of three Centers of Excellence, along with Georgia Institute of Technology and Rensselaer Polytechnic Institute, and is dedicated to the advancement of education and research in rotating wing aircraft technology. The Center has just completed an initial five-year term, and during this relatively short time has grown towards a level of maturity which significantly contributes towards the overall advancement of rotating wing aircraft technology.

Traditionally, the training required beyond a degree in Aerospace Engineering to pursue a career in rotating wing aircraft technologies has been placed mainly on industry through on-the-job training. In 1980, the U.S. Army's Vertical Lift Technology Review committee recognized this situation, and emphesized the need to train more specialists in these technologies. The committee ultimately recommended the establishment of a small number of centers of excellence in rotating wing aircraft technology among respected universities. This recommendation became a reality when the U.S. Army, through the ARO, conducted an open competition between universities. Under the direction of Professor Alfred Gessow, one of these Centers was formed at the University of Maryland. Now for the first time in the United States, and probably internationally, there are three major universities offering a complete spectrum of specialized graduate courses in the various rotorcraft disciplines. This has provided an immediate benefit to industry and government which now have an increasing number of M.S. and Ph.D. graduates available with specialized rotorcraft training.

At the University of Maryland, the Rotorcraft Center (CRER) is an integral part of the Department of Aerospace Engineering. Although the Department, as a whole, has many generic disciplinary research strengths (e.g. in aerodynamics, hypersonics, finite-element analyses, composite structures), a significant part of the Department's resources is devoted to the rotorcraft program. The objectives of CRER are to undertake research into rotorcraft problems from a multidisciplinary standpoint, as well as to provide graduate engineering education for those pursuing careers in the rotorcraft industry.

The People of CRER

Because of the somewhat unique multi-specialization required in rotorcraft engineering, the Center attracts and involves a significant number of experienced faculty in its rotorcraft program, most of whom have conducted previous rotorcraft research in industry or government. These faculty undertake research in addition to their developing and teaching graduate level courses which specialize in the disciplines applicable to rotorcraft design. At present, nine full-time faculty are actively involved in the research and teaching aspects of the rotorcraft program. In addition, a number of full-time research associates - all of whom specialize in rotorcraft engineering - significantly complement the research faculty. Adjunct and visiting faculty also contribute to both teaching and research aspects of the program.

The strong research and educational aspects of the Rotorcraft Program at the University of Maryland has correspondingly attracted high-caliber students who are motivated to pursue rotorcraft engineering as a career. At present, the total number of full-time rotorcraft graduate students at the Center has stabilized at around thirty. Currently, about 60% of the students are supported by the ARO through the prestigious U.S. Army Fellowship Program. A few students are supported with the assistance of the University's internal funds. The remainder are sponsored from other research grants and through educational leave programs from industry, the U.S. government and from foreign governments (e.g. France, Israel, Brazil, South Korea). A number of students have also received Vertiflite Fellowship awards from the American Helicopter Society.

Although office space is a scarce commodity on the campus, the University has refurbished a wing of an existing building to provide offices for all the rotorcraft students. In addition, the building houses a large seminar room, a small laboratory and a computer room which has access to all campus micro and mainframe computers. The daily interaction of the students in their offices provides a very productive learning atmosphere which complements the formal classroom and laboratory learning.

The various research studies at the Center are carried out by faculty, and by students under the direction of individual faculty. A significant part of the research faculty is composed of full-time research associates, who are all experienced rotorcraft researchers. In addition, three support engineers are responsible for providing technical support for the experimental research programs and computing facilities.

Research Thrusts

Because research conducted at the Center is not directed towards the development of a particular aircraft type, the scope is somewhat different from research conducted in industry and to some extent, from that in government laboratories. Fundamental research is undertaken in leading-edge technology areas which have longer term payoff possibilities and is directed towards improving the fundamental understanding of the aeromechanical processes which govern the behavior of rotating wing aircraft. Where possible, parallel theoretical and experimental projects are developed, with the experimental work aiding in the validation of the theory or revealing inherent limitations.

Ongoing research at the CRER focus on the important subdisciplines of rotating wing technology including dynamics, aerodynamics, aeroelasticity, structures and composite materials, flight mechanics and, of course, the complex interactions between these disciplines.

One of the major thrusts at the Center is in rotor dynamics and aeroelasticity, an area in which Maryland excels. Under the direction of Dr. Inderjit Chopra, the Center is actively investigating many complex dynamics problems, including aeroelastic stability, gust response, vibration and loads, and ground and air resonance. One of the topics which has received particular attention is the aeroelastic stability and response of rotors in forward flight, with emphasis on hingeless and advanced bearingless rotors. Through the sponsorship of NASA, the Center has also conducted research into the aeroelastic optimization of rotors to minimize vibration and blade stresses, and to maximize aeroelastic stability margins.

Another topic which has been the focus of considerable research at the Center is the dynamics of composite rotor blades. Composite materials, for example, are used extensively in the construction of blades and significant potential exists to tailor blade characteristics with these materials. Research at the Center has identified the significance of coupling terms on blade stability which result from stiffness-coupling created by non-balanced composite plies.

In a quest to reduce the inherent vibration on rotorcraft, the application of higher harmonic control (HHC) is another activity under investigation at the Center. To this end, a comprehensive analysis (including refined unsteady aerodynamic modeling) has recently been developed to predict the vibratory hub loads of a helicopter rotor system. The analysis is then used to compute optimum HHC control inputs and associated actuator power required to minimize these hub loads and the vibration levels.

Most of the rotor dynamics research is being done in close collaboration with outside organizations, particularly NASA and the Army. In all cases, theoretical developments in rotor dynamic analyses are supported by correlating predictions with experimental data obtained from a variety of sources, including rotor tests in the University's 8 by 11 foot Glenn L. Martin wind tunnel.

Rotor aerodynamics is another area of research which is being actively pursued at the Center. By virtue of their design, rotorcraft operate in a highly three-dimensional and unsteady aerodynamic environment, and as a result many important aerodynamic effects are difficult to predict and model accurately. For example, the rotor encounters transonic flow effects on the advancing blade, stalled conditions on the retreating blade and produces a complex trailed wake system which is a major source of three-dimensionality and unsteadiness.

Modeling of unsteady aerodynamics and dynamic stall effects on the rotor is one area of research which is receiving considerable attention. This research is conducted by Dr. Leishman is directed towards improving the predictive capabilities of the comprehensive rotor aeroelasticity codes which are also under development at the Center. Besides the modeling of unsteady stalled flow effects on the rotor, significant effort has been made to couple finite-difference type aerodynamic methods into the rotor aeroelasticity codes. Some of this work is being conducted in collaboration with ONERA of France.

Another area of aerodynamics research is directed towards providing an improved understanding of the interactional effects between the rotor and the fuselage. This research is being undertaken by Drs Leishman, Rand, Barlow and Jones. To complement the continued development at the Center of a theoretical analyses of this problem, an extensive experimental program is planned for 1988. These experiments will be performed in the Glenn L. Martin wind tunnel utilizing an in-house developed model rotor rig and a comprehensively (pressure) instrumented fuselage model (Fig. 1). There is a severe shortage of experimental data on this important interactional problem and this experiment should contribute to closing the existing gaps in our knowledge.

Other aerodynamics research that has been pursued by the Center include the understanding of unsteady blade tip vortex formation, which has been conducted over the last few years by Dr. Winklemann. Another important research area is the behavior of circulation controlled airfoils. This latter research has been pursued on both computational and experimental levels and has a direct relevance to the X-wing and NOTAR technology base. More recently, work has also been initiated by Dr. Leishman to study the behavior of swept tip rotor blades at high angles of attack corresponding to the retreating side of the rotor. A series of rotor tests with a variety of tip shapes will also be undertaken in the Glenn L. Martin wind tunnel during 1988.

Because of the importance of composite structures in rotorcraft design, the Center is pursuing an extensive theoretical and experimental research program in composite materials under the direction of Drs. Lee and Vizzini. In one such investigation, finite element modeling is used to accurately determine the characteristics of rotor blades undergoing axial, bending and torsional loading. The formulation takes into account finite rotation and warping, effects as well as variations in cross- sectional shape, taper, pre-twist, sweep and ply lay-up. Another investigation considers the failure mechanisms of composite materials, specifically, the effects of water absorbtion, elevated temperatures, and cyclic loading. All this research is supported by parallel experimental investigations.

This year marks the beginning of a new, vigorous research activity in rotorcraft flight mechanics and control at the Center. This is an area that has received considerably less attention from the rotorcraft research community than it should have, at a time when handling qualities and maneuverability may drive the design of the next generation of both civil and, in particular, military helicopters. Under the direction of Drs. Celi and Barlow, one of the main projects in this area will be the development of comprehensive analytical tools for the design of high-gain, digital flight control systems for highly maneuverable combat helicopters. Sponsored by the Army, and conducted jointly with the Systems Research Center at the University of Maryland, this project will also see a close cooperation with the Flight Research Division of the Royal Aircraft Establishment in Great Britain.

Besides developing its own research programs and experimental facilities, personnel from the Center also interact extensively with industry and government laboratories in research problems that are unique to the development of rotating wing aircraft. The objective here is to interchange ideas and results with other investigators in the field and to disseminate quickly and widely any results from the ongoing research programs.

As with most research programs, the most tangible results of Maryland's rotorcraft program are the research papers which present the research output and advances in knowledge to the rotorcraft community. Since the inception of the Center, over 45 papers have been accepted for publication in major technical Journals. In addition, some 65 papers have been published in Conference Proceedings, workshops and other meetings. In particular, in 1988 alone, five papers were presented by faculty and students at the Second International Conference on Rotorcraft Basic Research in February, seven papers were presented at the AIAA Structural Dynamics and Materials Conference in April, and another four papers will be presented at the AHS Annual Forum in June. Bearing in mind that the Center has only been established some five years, these accomplishments attest to the vitality and productivity of the faculty and student body.

The Center initiated and took a lead role in organizing the First International Conference on Rotorcraft Basic Research held in February 1985 at Triangle Park, NC. This year, the Center organized and hosted the Second Conference at the University of Maryland. This Conference was enormously successful, with some 30 papers being presented on fundamental rotorcraft research by leading investigators from throughout the world.

Other ways of exchanging information and stimulating research are through a seminar program, which averages about one meeting a week throughout the year. In these seminars, both in-house speakers and visitors from government and industry provide a useful input to supplement normal scheduled teaching.

Facilities

The rotorcraft program has also made possible the development of a number of experimental facilities which have been used at Maryland, and which will grow even more useful in the years ahead. A comprehensive rotor test rig has been developed for use in the University's Glenn L. Martin wind tunnel (Fig. 2 and 3). This rig can be used for hover and forward flight testing of rotors with various hub and blade configurations up to seven feet in diameter. The rig has remote collective and cyclic pitch controls plus remote shaft angle control. A six component hub balance which measures rotor aerodynamic loads is also part of the system. Blade and other rotating instrumentation are interfaced through a slip-ring system. This rotor rig provides a capability for carrying out a variety of aerodynamic and aeroelastic stability tests. The stability testing of the Integrated Technology Rotor (ITR) (Fig. 4) will be undertaken with this system, which is sponsored by the NASA/Ames Research Center.

The utility of the rotor rig has been greatly enhanced by the development of a real time data acquisition and analysis system which has been put in place to serve several laboratory experiments. The system is based on a HP 1000 computer for data analysis and display. There are more than 150 channels available for digitizing instrumentation outputs. This system is also linked to the university campus network of mini and mainframe computers, and will be complemented in the near future by the addition of a number of computer workstations purchased by the Aerospace Department.

A structural dynamics test facility has been developed which has a number of shakers and harmonic analyzers connected to the laboratory data acquisition system. The facility is used for the investigation of advanced testing techniques in the determination of helicopter fuselage frequencies, mode shapes and damping characteristics. A recent addition to the dynamics facility is a 10 foot diameter vacuum chamber (Fig. 5) which provides a capability to test rotors (Fig. 6) in the absence of aerodynamic loadings. In these tests, piezo-electric transducers are used to excite the various modes of blades vibration. This new facility is being developed with the assistance of Dr. Chandra and will become fully operational during 1988.

The increasing use of composite materials in rotorcraft has motivated the formation of the Composites Research Laboratory at the Center which is directed by Dr. Vizzini. This laboratory has a large automated autoclave and specialized test machines which are used for making and testing advanced composite materials. The autoclave (Fig. 7) is equipped with a microprocessor to provide automatic control of temperature and pressure during the cure process.

All the above experimental and computational facilities are supported with the assistance of research engineers, Messrs. Green, Samak and Ngo.

Education

Although a large effort at the Center is placed on research, there is also major emphasis on the formal teaching of rotorcraft courses. Five graduate level courses, as well as one undergraduate elective course, are included in the curriculum. These courses focus on the aerodynamics, dynamics, aerelasticity, stability and control, and design of rotorcraft. Because rotorcraft design requires a strong coupling of aeronautical disciplines, rotorcraft graduate students are required to take all five of these courses. Recently, increased emphasis has been placed on instruction in the preliminary design aspects of rotorcraft. This new course is taught by Mr. Stanzione and is supplemented by giving students hands-on experience with computer codes such as HESCOMP and VASCOMP. In addition, the increasing use of composite materials in rotorcraft has seen the development of two new graduate level courses in composites in which rotorcraft applications are featured.

After completing these courses, students are well prepared to undertake research in their selected discipline. Ultimately, these students leave the Center to move into industry or government laboratories with unique rotorcraft knowledge and skills. These give the student a significant head start over most entry-level engineers and scientists, and as a result they are more immediately useful to their employers. In the five years since the Center was established, 45 students have graduated with M.S. degrees and 14 will have obtained Ph.D. degrees by the end of 1988, all of whom are extensively trained in rotorcraft. It is clear that these students will be future leaders in the rotorcraft community.

Future Directions

For the last five years, funding for CRER has been largely provided by the ARO. However, the Center has obtained a sigificant number of research grants from Army, Navy, NASA and DOT sources. During this time, significant internal awards have been received from the University for the purchase of experimental equipment and to support graduate students. It is the intention of ARO that the Center become self sustaining by 1992. To this end, interaction with government and industry is being pursued with increasing vigor. The next few years, though, will be critical for the Center.

Over the last five years, CRER has proved its ability to significantly contribute to leading edge rotorcraft research. Unique theoretical and experimental facilities at the Center are now developed and operational and provide a significant resource for rotating wing research. The range and depth of rotorcraft courses developed have produced top-quality graduates who have unique skills in rotorcraft technologies. However, the Center must continue to expand its horizons to remain a viable resource to the rotorcraft community. To this end, we must expand our base of support to include a number of federal agencies and continue to establish joint research programs with government laboratories and industry. In particular, much more research is required to obtain a more comprehensive understanding the behavior of tilt rotor aircraft. Furthermore, the essential educational aspects of the program must be maintained so that graduates continue to be trained in the important rotorcraft disciplines. In order that top-quality students continue to be attracted to the program, efforts are underway to establish Fellowship support from industry.

The commitment made by the University and the U.S. Army has successfully established the Center to the point where payoffs in rotorcraft education and research capabilites are now being fully realized. The long term success of the Center necessitates that this momentum be continued with increasing vigor in the years to come.

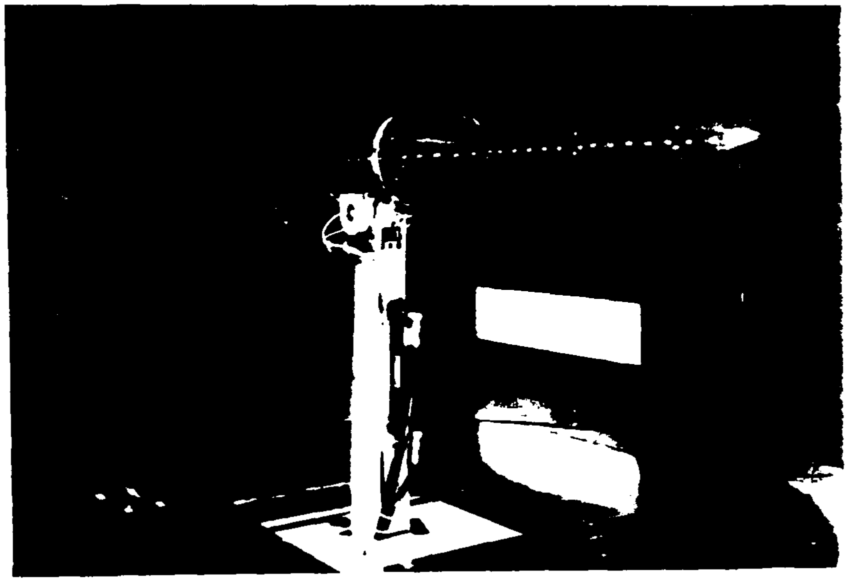

Fig. 1: Isolated fuselage model undergoing wind-tunnel tests in preparation for rotor/fuselage interaction experiments.

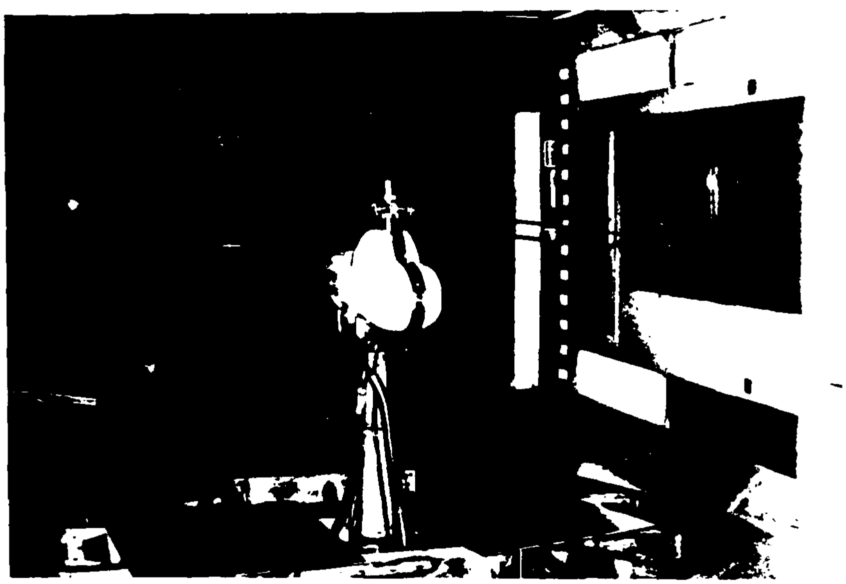

Fig. 2: Four-bladed articulated rotor system and composite fuselage shell in the Glenn L. Martin Wind Tunnel.

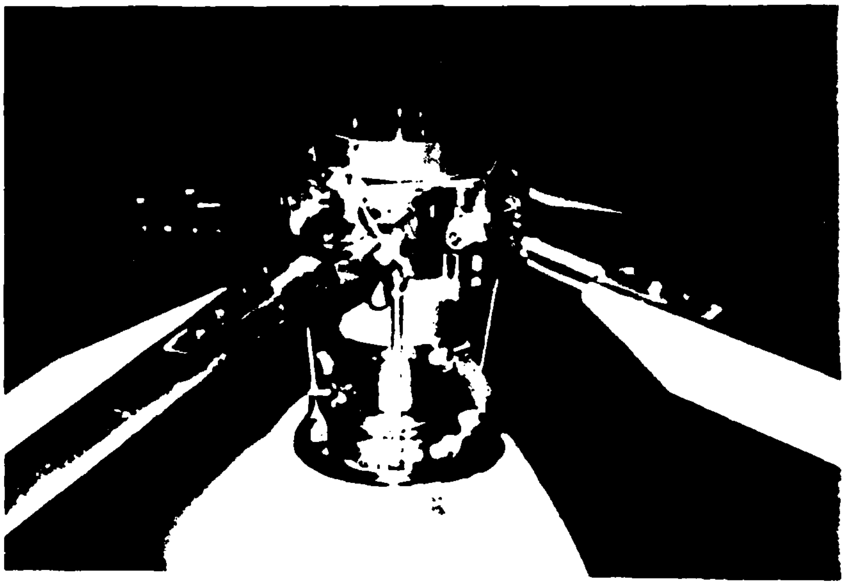

Fig. 3: Detail of the four-bladed articulated rotor system.

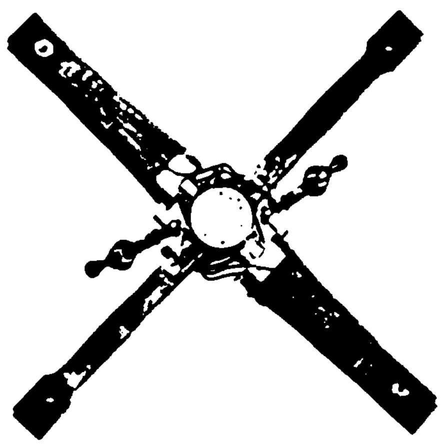

Fig. 4: The bearingless ITR rotor tested for NASA Ames.

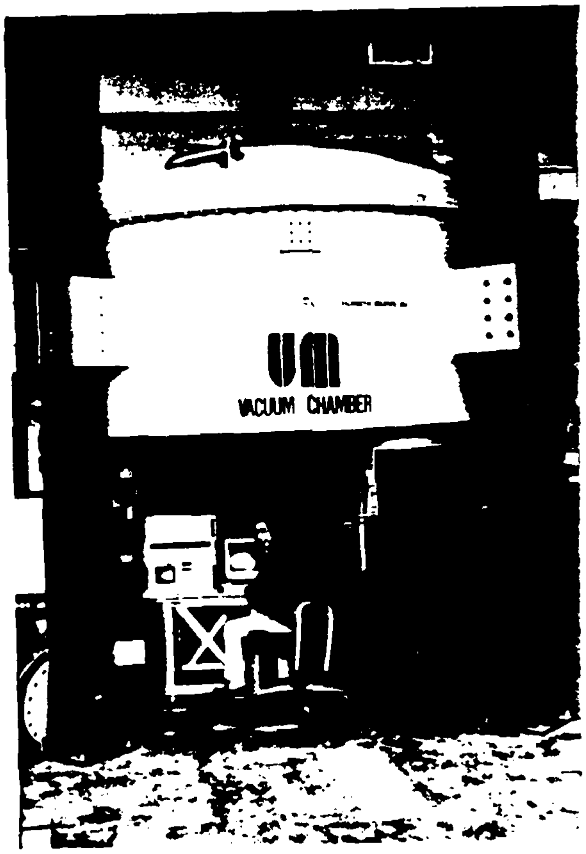

Fig. 5: The 10 foot vacuum chamber and computer controlled testing facility.

Fig. 6: A flexible diaphragm seals the base of the vacuum chamber and provides support for the rotor.

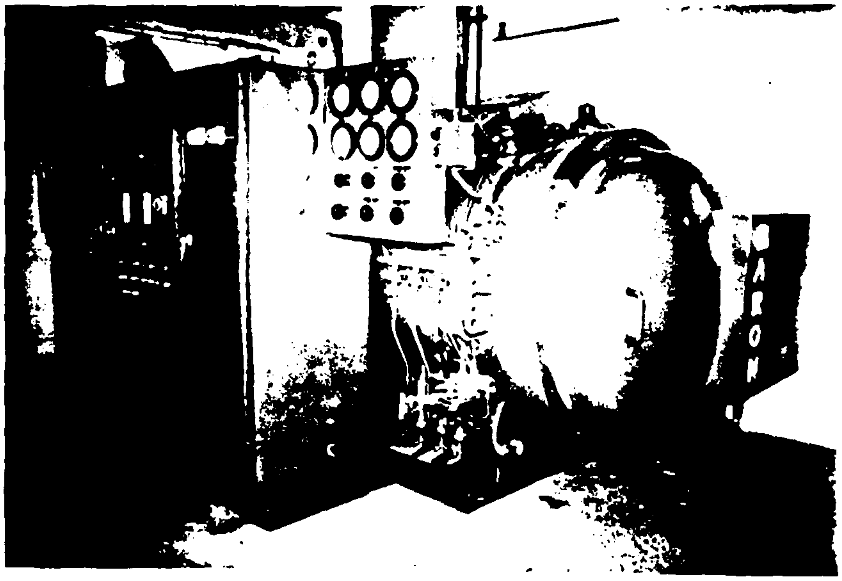

Fig. 7: Micro-computer controlled autoclave used for the manufacture of composite specimens.

Ph.D

Gunjit Bir -- with Advanced Rotorcraft Technology, Mountain View, California
Andrew L. Dull -- U.S. Army, West Point
Andrew Elliot -- McDonnell Douglas Helicopters
John Fish -- (May 1988)
Chang-Ho Hong -- University Professor in Korea
Jinseok Jang -- (May 1988)
Joon Lim -- (May 1988)
Brahamananda Panda -- with Kaman Corporation, Bloomfield, Connecticut
Vendatraman Raghavan -- (May 1988)

ROTORCRAFT DEGREES AWARDED

M.S.

Michael F. Ausserer -- USAF detailed to FAA
Vit Babuska -- with Von Karman Institute
Randal Barber -- CIA
John E. Bate -- with Sikorsky
Philippe Benquet -- Ministry of Defense, France
A.S. Elliot -- McDonnell Douglas Helicopters (completed his Ph.D.)
Roger Farley -- with NASA Goddard
Phillip Fine -- with U.S. Army
S. Fledel -- Israeli Air Force
David Haas -- now at Naval Ship Research Development Center (pursuing Ph.D. in Aerospace Engineering Department)
Jerry Higman -- with Patuxent Naval Air Center
C.H. Hong -- University Professor in Korea
J. Jang -- a Ph.D. student in Department of Aerospace Engineering
Mark Kammeyer -- with Naval Surface Weapons Center
K.C. Kim -- a Ph.D. student in Department of Aerospace Engineering
Y.H. Kim -- a Ph.D. student in Department of Aerospace Engineering
Joon Lim -- a Ph.D. student in Department of Aerospace Engineering
Dan Lopez -- a consultant
David Matuska -- with Sikorsky
Olympio Mello -- (May 1988)
Stephen K. Mouritsen -- with McDonnell Douglas Helicopters
Kevin Noonan -- with Aerostructures Directorate, NASA Langley
Hieu Ngo -- Helicopter Research Engineer, University of Maryland
Khahn Nguyen -- a Ph.D. student in Department of Aerospace Engineering
Shanmugan Paragiri -- at Glenn L. Martin Wind Tunnel, University of Maryland
Ramana Pidaparti -- a Ph.D. student at Purdue University
William Pogue -- (May 1988)
Aaron Salzberg -- Naval Research Lab
D.K. Samak -- an Engineer with the Department of Aerospace Engineering, University of Maryland
Michael Scardera -- with U.S. Air Force
Brian Schwiesow - with Bell Helicopter
Mark W. Scott -- with Sikorsky
Alan D. Stemple -- a Ph.D. student in Department of Aerospace Engineering
Frederick Tasker -- a Ph.D. student in Department of Aerospace Engineering
Agnes Todorov -- (May 1988)
Michael Torok -- a Ph.D. student in Department of Aerospace Engineering
Andrea Traversi -- with Eliotos Helicopters, Italy
James Wang -- a Ph.D. student in Department of Aerospace Engineering
Bernard Wunder -- with Patuxent Naval Air Center
John Vorwald -- with Naval Surface Weapons Center
David Yeh -- a Ph.D. student at Stanford University

Publications, Reports, and Presentations

Rotorcraft Publications

1. Bir, G.S. and Chopra, I., "Gust Response of Hingeless Rotors," Journal of the American Helicopter Society, Vol. 31, No. 2, April 1986, pp. 33-46.

2. Bir, G.S. and Chopra, I., "Prediction of Blade Stresses Due to Gust Loading," Vertica, Vol. 10, No. 3/4, October 1986, pp. 353-378.

3. Chopra, I., "Dynamic Analysis of Constant-Lift and Free-Tip Rotors," Journal of the American Helicopter Society, Vol. 28, No. 1, January 1983. pp. 24-33.

4. Chopra, I., "Aeroelastic Analysis of an Elastic Circulation-Controlled Rotor Blade in Hover," Vertica, Vol. 8, No. 4, December 1984, pp. 353-371.

5. Chopra, I., "Dynamic Stability of a Bearingless Circulation Control Rotor Blade in Hover," Journal of the American Helicopter Society, Vol. 30, No. 4, October 1985, pp. 40-47.

6. Fabunmi, J.A., "Extended Damping Models for Vibration Data Analysis," Journal of Sound and Vibration, Vol. 101, No. 2, July 1985, pp. 181-192.

7. Fabunmi, J.A., "Modal Constraints on Structural Dynamic Force Determination," Journal of the American Helicopter Society, Vol. 30, No. 4, October 1985, pp. 48-54.

8. Fabunmi, J.A., "Effects of Structural Modes on Vibratory Force Determination by the Pseudo Inverse Technique," AIAA Journal, Vol. 24 No. 3, March 1986, pp. 505-509.

9. Fabunmi, J.A., "Developments in Helicopter Ground Vibration Testing," Journal of the American Helicopter Society, Vol. 31, No. 3, July 1986, pp. 54-59.

10. Gessow, A., "Nikolsky Honorary Lecture: Understanding and Predicting Helicopter Behavior--Then and Now," Journal of the American Helicopter Society, Vol. 31, No. 1, January 1986, pp. 3-28.

11. Gessow, A. "The Ubiquitous Helicopter," AIAA Student Journal, Vol. 19, No. 4, March 1982.

12. Gessow, A. "The U.S. Army Centers of Excellence in Review," Vertiflite, Vol. 32, No. 7, Nov/Dec 1986, pp. 54-60.

13. Haas, D.J. and Lee, S.W., "A Nine Node Assumed Strain Finite Element for Composite Shells," Computers and Structures, Vol. 26, No. 3, 1987, pp. 445-452.

14. Hong, C.H. and Chopra, I., "Aeroelastic Stability Analysis of a Composite Blade," Journal of the American Helicopter Society, Vol. 30, No. 2, April 1985, pp. 57-67.

15. Hong, C.H., and Chopra, I., "Aeroelastic Stability Analysis of a Composite Bearingless Rotor Blade," Journal of the American Helicopter Society, Vol. 31, No. 4, October 1986, pp. 29-35.

16. Hong, C.H. and Chopra, I., "Flap-Lag-Torsion Aeroelastic Stability of a Circulation Control Rotor in Forward Flight," To be published in Journal of the American Helicopter Society,

17. Lee, S.W. and Kim, Y.H. "A New Approach to Finite Element Modeling of Beams with Warping Effect," International Journal for Numerical Methods in Engineering, Vol. 24, No. 12, 1987, pp. 2329-2342.

18. Panda, B. and Chopra, I., "Flap-Lag-Torsion Stability in Forward Flight," Journal of the American Helicopter Society, Vol. 30, No. 4, October 1985, pp. 30-39.

19. Panda, B. and Chopra, I., "Dynamic Stability of Hingeless and Bearingless Rotors in Forward Flight," Journal of Computers and Mathematics with Applications, Special Rotorcraft Issue, January 1986.

20. Panda, B. and Chopra, I., "Dynamics of Composite Rotor Blades in Forward Flight," Vertica, Vol. 11, No. 1/2, 1987, pp. 187-210.

21. Sivaneri, N.S. and Chopra, I., "Finite Element Analysis for Bearingless Rotor Blade Aeroelasticity," Journal of the American Helicopter Society, Vol. 29, No. 2, April 1984, pp. 42-51.

22. Sun, M., Pai, S.I., and Chopra, I., "Aerodynamic Force Calculations of an Elliptical Circulation Control Airfoil," AIAA Journal of Aircraft, Vol. 23, No. 9, September 1986.

23. Winkelmann, A.E. and Tsao, C.P., "A Color Video Display Technique for Flowfield Surveys," AIAA Journal, Vol. 23, No. 9, September 1985,

24. Leishman, J.G., "Validation of Approximate Indicial Functions For Two-Dimensional Subsonic Flow," University of Maryland Aerospace Engineering Department Report UMAERO-87-6, AIAA Journal of Aircraft, May 1988.

25. Leishman, J.G., "An Analytic Model for Airfoil Unsteady Drag Below Stall," AIAA Journal of Aircraft, March 1988.

26. Rand, O. and Gessow, A., "A Model for Investigation of Helicopter Fuselage Influence on Rotor Flow Fields," University of Maryland Aerospace Engineering Department Report UMAERO-87-13, accepted for publication in the Journal of Aircraft.

27. Haas, D. and Chopra, I., "Aeroelastic Characteristics of Swept Circulation Control Wings", accepted for publication Journal of Aircraft, 1988.

28. Jang, J. and Chopra, I., "Air and Ground Resonance of an Advanced Bearingless Rotor", accepted for publication Journal of the American Helicopter Society, 1988.

29. Dull, A.L. and Chopra, I., "Aeroelastic Stability of Bearingless Rotors in Forward Flight", accepted for publication Journal of the American Helicopter Society, 1988.

30. Raghavan V., Pai, S.I. and Chopra, I., "Circulation Control Airfoils in Unsteady Flow", accepted for publication Journal of the American Helicopter Society , 1988

31. Stemple, A.D. and Lee, S.W., "A Finite Element Model for Composite Beams with Arbitrary Cross-Sectional Warping," accepted for publication in AIAA Journal , May 1988.

32. Kim, K.C., Bir, G.S., and Chopra, I., "Helicopter Response due to Airplane's Vortex Wake," accepted for publication in Vertica, 1988.

33. Leishman, J.G., "Practical Modelling of Unsteady Airfoil Behaviour in Nominally Attached Two-Dimensional Compressible Flow," University of Maryland Aerospace Engineering Department Report UMAERO-87-2, submitted for publication in the Journal of the American Helicopter Society.

34. Leishman, J.G., Beddoes, T.S., "A Semi-Empirical Model for Dynamic Stall," UMAERO-87-24, submitted for publication in the Journal of the American Helicopter Society.

35. Leishman, J.G., "Modeling of Sweep Effects on Dynamic Stall Airloads," UMAERO-88-2, submitted for publication in the Journal of the American Helicopter Society.

36. Leishman, J.G., "Application of the Indicial Method to the Calculation of Lift and Moment during an Airfoil Vortex Interaction," UMAERO-87-28, submitted for publication in the Journal of Sound and Vibration.

37. Leishman, J.G., Nguyen, K.Q., "Modeling of Unsteady Aerodynamic Behavior in a Compressible Flow using Linear Systems Theory," UMAERO-88-3, submitted for publicationk in the AIAA Journal.

38. Rand, O. "A Model for Predicting Rotor/Fuselage Interactive Phenomena," University of Maryland Aerospace Engineering Department Report UMAERO-87-11, submitted for publication in the Journal of the American Helicopter Society.

39. Rand, O., "The Influence of Interactional Aerodynamics in Rotor/Fuselage Coupled Response," submitted to the Journal of the American Helicopter Society.

40. Celi, R., and Friedmann, P.P., "Rotor Blade Aeroelasticity in Forward Flight with an Implicit Aerodynamic Formulation," Paper AIAA-87-0921-CP, AIAA/ASME/ASCE/AHS 29th Structures, Structural Dynamics and Materials Conference, April 1987, Monterey, California, to appear in the AIAA Journal.

41. Celi, R. and Friedmann, P.P., "Aeroelastic Modeling of Swept Tip Rotor Blades Using Finite Elements," 43rd Annual Forum of the American Helicopter Society, St. Louis, Missouri, May 1987, accepted for publication in the Journal of the American Helicopter Society.

Papers in Conference Proceedings

42. Dull, A.L. and Chopra, I., "Aeroelastic Stability of Bearingless Rotors in Forward Flight," Proceedings of the 43rd Annual Forum of the American Helicopter Society, St. Louis, MO, May 1987, pp. 539-552.

43. Sivaneri, N.S. and Chopra, I., "Finite Element Analysis for Bearingless Rotor Blade Aeroelasticity," presented at the 38th Annual Forum of the American Helicopter Society, Anaheim, California, May 1982.

44. Chopra, I., "Aeroelastic Analysis of an elastic Circulation-Controlled Rotor Blade in Hover", presented at AIAA 24th SDM Conference, Lake Tahoe, Nevada, May 1983.

45. Hong, C.H. and Chopra, I., "Aeroelastic Stability Analysis of a Composite Blade", presented at 40th Annual Forum of the American Helicopter Society, Crystal City, May 1984.

46. Chopra, I., Dynamic Stability of a Bearingless Circulation Control Rotor Blade in Hover, presented at Second Decennial Specialists' Meeting on Rotorcraft Dynamics at Ames Research Center, Moffett Field, Calif. Nov. 1984.

47. Panda, B. and Chopra, I., "Flap-Lag-Torsion Stability in Forward Flight", presented at Second Decennial Specialists' Meeting on Rotorcraft Dynamics at Ames Research Center, Moffett Field, Calif., Nov. 1984.

48. Hong, C.H. and Chopra, I., "Aeroelastic Stability Analysis of a Bearingless Composite Blade in Hover", presented at International Conference on Rotorcraft Basic Research at Research Triangle Park, North Carolina, Feb. 1985.

49. Panda, B. and Chopra, I., "Dynamic Stability of Hingeless and Bearingless Rotors in Forward Flight", presented at International Conference on Rotorcraft Basic Research at Research Triangle Park, North Carolina, Feb. 1985.

50. Bir, G.S. and Chopra, I., "Gust Response of Hingeless Rotors," presented at 41st Annual Forum of the American Helicopter Society, Fort Worth, Texas, May 1985.

51. Bir, G.S. and Chopra, I., "Prediction of Blade Stresses Due to Gust Loading," presented at 11th European Rotorcraft Forum, London, England, Sept. 1985.

52. Kim, K.C., Bir, G.S. and Chopra, I., "Helicopter Response to an Airplane's Vortex Wake", presented at 12th European Rotorcraft Forum, Garmisch, Germany, Sept. 1986.

53. Chopra, I. and Hong, C.H., "Aeroelastic Stability of a Bearingles Circulation Control Rotor in Forward Flight", presented at 12th European Rotorcraft Forum, Garmisch, Germany, Sept. 1986.

54. Elliott A.S. and Chopra, I., "Hingeless Rotor Response to Random Gusts in Forward Flight," Proceedings of the AIAA Dynamics Specialists Conference, Paper AIAA-87-0954-CP, Monterey, California, April 1987, pp. 976-986.

55. Fabunmi, J.A., "Extended Damping Models for Vibration Data Analysis," Proceedings of the Second International Conference on Recent Advances in Structural Dynamics, Southampton, England, April 1984.

56. Gessow, A., "An Assessment of Current Helicopter Theory in Terms of Early Developments," Proceedings of the Conference on the Theoretical Basis of Helicopter Technology, Nanjing, China, November 6-8, 1985.

57. Haas, D. and Chopra, I., "Aeroelastic Characteristics of Swept Circulation Control Wings," Proceedings of the AIAA Dynamic Specialists Meeting, Paper AIAA-87-0920-CP, Monterey, CA, April 1987, pp. 717-729.

58. Kim, K.C., Desopper, A. and Chopra, I., "Dynamic Blade Response Calculations Using Improved Aerodynamic Modeling," Proceedings of the American Helicopter Society National Specialists Meeting on Aerodynamics and Aeroacustics, Arlington, Texas, February 1987.

59. Lim, J. and Chopra, I., "Design Sensitivity Analysis for an Aeroelastic Optimization of a Helicopter Blade," Proceedings of the AIAA Dynamics Specialists Conference, Paper AIAA-87-0923-CP, Monterey, CA, April 1987, pp. 1093-1102.

60. Jang, J. Chopra, I., "Air and Ground Ressonance of an Advanced Bearingless Rotor," Proceedings of the AIAA Dynamics Specialists Conference, Paper AIAA-87-0924-CP, Monterey, CA, April 1987, pp. 1068-1084.

61. Raghavan, V., Pai, S.I. and Chopra, I., "Circulation Control Airfoils in Unsteady Flow," Proceedings of the 43rd Annual Forum of the American Helicopter Society, St. Louis, MO, May 1987, pp. 35-48.

62. Jang, J. and Chopra, I., "Air Resonance of Bearingless Rotors in Forward Flight", Proceedings of the Second International Conference on Rotorcraft Basic Research, College Park, Maryland, Feb. 1988.

63. Nguyen, K. and Chopra, I., "Actuation Power Requirement for Higher Harmonic Control Systems", Proceedings of the Second International Conference on Rotorcraft Basic Research, College Park, Maryland, Feb. 1988.

64. Haas, D.J. and Chopra, I., "Flutter of Circulation Control Wings", Proceedings of 29th AIAA Structures, Structural Dynamics and Materials Conference, Williamsburg, Virginia, April 1988.

65. Tasker, F.A. and Chopra, I., "Assessment of Transient Testing Techniques for Rotor Stability Measurement", Proceedings of 29th Structures, Structural Dynamics and Materials Conference, Williamsburg, Virginia, April 1988.

66. Lim, J.W. and Chopra, I., "Stability Sensitivity Analysis of a Helicopter Rotor," Proceedings of 29th AIAA Structures, Structural Dynamics and Materials Conference, Williamsburg, Virginia, April 1988.

67. Rand, O., "The Influence of Interactional Aerodynamics in Rotor/Fuselage Coupled Response," Second International Conference on Rotorcraft Basic Research, College Park, Maryland, Feb. 1988.

68. Lim, J.W. and Chopra, I., "Aeroelastic Optimization of a Helicopter Rotor", Proceedings of 44th Annual Forum of the American Helicopter Society, Washington, D.C., June 1988.

69. Elliott, A.W., Leishman, J.G. and Chopra, I., "A Nonlinear Unsteady Aerodynamic Model for Rotorcraft Aeromechanical Analysis", Proceedings of 44th Annual Forum of American Helicopter Society, Washington, D.C., June 1988.

70. Stemple, A.D. and Lee, S.W., "A Finite Element Model for Composite Beams Undergoing Large Deflection with Arbitrary Cross-sectional Warping," Proceedings of the Second International Conference on Rotorcraft Basic Research, College Park, Maryland, Feb. 1988.

71. Fish, J.C. and Lee, S.W., "Tensile Strength of Tapered Composite Structures," Proceedings of 29th AIAA Structures, Structural Dynamics and Materials Conference, Williamsburg, Virginia, April 1988.

72. Kim, Y.H. and Lee, S.W., "A Large Deflection Finite Element Model of Beams with Arbitrary Cross-sectional Warping," Proceedings of ICES-88 Conference, Atlanta, Georgia, April 1988.

73. Leishman, J.G., "Representation of Sweep Effects on Dynamic Stall," Proceedings of the Second International Conference on Rotorcraft Basic Research, College Park, Maryland, Feb. 1988.

74. Celi, R., and Friedmann, P.P., "Rotor Blade Aeroelasticity in Forward Flight with an Implicit Aerodynamic Formulation," Paper AIAA-87-0921-CP, AIAA/ASME/ASCE/AHS 29th Structures, Structural Dynamics and Materials Conference, April 1987, Monterey, California, to appear in the AIAA Journal.

75. Celi, R. and Friedmann, P.P., "Aeroelastic Modeling of Swept Tip Rotor Blades Using Finite Elements," 43rd Annual Forum of the American Helicopter Society, St. Louis, Missouri, May 1987, accepted for publication in the Journal of the American Helicopter Society.

76. Celi, R. and Friedmann, P.P., "Structural Optimization With Aeroelastic Constraints of Rotor Blades With Straight and Swept Tips," Paper AIAA-88-2297-CP, AIAA/ASME/ASCE/AHS 29th Structures, Structural Dynamics and Materials Conference, Williamsburg, Virginia, April 1988.

77. Celi, R., "Effect of Hingeless Rotor Aeroelasticity on Helicopter Trim and Longitudinal Stability Using Quasilinearization," to be presented in the AIAA Atmospheric Flight Mechanics Conference, Minneapolis, Minnesota, August 1988.

78 Vizzini, A.J., "Prevention of Free-Edge Delamination via Edge Alteration," AIAA/ASME/ASCE/AHS 29th Structures, Structural Dynamics and Materials Conference, Williamsburg, Virginia, April 1988.

79. Pogue, W.R. and Vizzini, A.J., "The Effect of Structural Tailoring by Edge Alteration on Free-Edge Delamination," 44th Annual Forum of the American Helicopter Society, Washington, D.C., June 1988.

Other Presentations (Workshops, Seminars, etc.)

80. Chopra. I., "Aeroelastic Analysis of a Helicopter Blade Using Finite Element Theory," Finite Element Modeling Workshop, NASA Langley Research Center, Hampton, VA, February 1983.

81. Panda, B. and Chopra, I., "Aeroelastic Stability of a Composite Blade in Forward Flight", Presented at the Workshop on Dynamics and Aeroelastic Stability Modelling of Rotor Systems, Georgia Institute of Technology, Atlanta, Georgia, December, 1985, 10th Anniversary Special Issue of VERTICA, Vol. 11, No. 1, 1987, pp. 187-210.

82. Chopra, I., "Dynamics of Advanced Rotors," Invited Applied Mechanics Seminar, United Technologies Research Center, Hartford, CT, February 1985.

83. Chopra, I. and Hong, C.H., "Aeroelastic Stability of CCR in Forward Flight," Circulation Control Workshop, NASA Ames Research Center, February 1986.

84. Chopra, I., "Helicopter Dynamics Research at the University of Maryland," NASA/Industry Meeting on Design Analysis Methods for Vibrations Program, NASA Langley Research Center, Hampton, VA, December 1986.

85. Fish, J.C. and Lee, S.W., "Delamination in Tapered Composite Structures Under Tensile Loading," RPI Workshop on Composite Materials and Structures, Troy, NY, September 1986.

86. Gessow, A., "Helicopter Research Contributions in the 1940-1960 Time Period," Seminar presented at NASA Ames Research Center, August 1982.

87. Gessow, A., "Innovations in Rotorcraft Education," Panel discussion at the 40th Annual Forum of the American Helicopter Society, Washington, D.C., May 1984.

88. Gessow, A., Presentation of the American Helicopter Society 1985 Alexander Nikolsky Lecture, Seminar delivered at Princeton University, Princeton, NJ, February 1986.

89. Gessow, A., "Modern Developments in Helicopter Technology," Seminar delivered at the U.S. Army Ballistic Research Laboratory, Aberdeen, MD, February 1986 and at the Technion, Haifa, Israel, May 1987.

90. Kim, Y.H. and Lee, S.W., "A New Approach to Finite Element Modeling of Composite Helicopter Rotor Blades," Workshop on Dynamics and Aeroelastic Stability Modeling of Rotor Systems, Georgia Institute of Technology, Atlanta, GA, December 1985.

91. Panda, B. and Chopra, I., "Dynamics of Composite Rotor Blades is Forward Flight," Workshop on Dynamics and Aeroelastic Stability Modeling of Rotor Systems, Georgia Institute of Technology, Atlanta, GA, December 1985.

92. Salzberg, A.A., "Experimental Identification of Stiffness Coupling Terms for Composite Blade Spars," RPI Workshop on Composite Materials and Structures for Rotorcraft, Troy, NY, September 1986.

93. Stemple, A.D., Kim, Y.H. and Lee, S.W., "Finite Element Modeling of Composite Rotor Blades with Finite Rotation and Warping Effects", RPI Workshop on Composite Materials and Structures for Rotorcraft, Troy, NY, September 1986.

94. Chopra, I., "Dynamic Analysis of Advanced Rotor Systems", Second Technical Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems, Florida Atlantic University, Nov. 1987.

95. Elliott, A.S., Leishman, J.G. and Chopra, I., "A Nonlinear Unsteady Aerodynamic Model for Rotor Aeroelastic Analysis", Second Technical Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems, Florida Atlantic University, Nov. 1987.

96. Lim, J.W. and Chopra, I., "Stability Sensitivity Analysis for Aeroelastic Optimization of a Helicopter Rotor", Second Technical Workshop on Dynamics and Aeroelastic Stability Modeling of Rotorcraft Systems, Florida Atlantic University, Nov. 1987.

97. Fish, J.C. and Lee, S.W., "Edge Effects in Tapered Composite Structures," National Technical Specialists' Meeting on Advanced Rotorcraft Structures, Hampton, Virginia, October 1988.

98. Fish, J.C. and Lee, S.W., "Three-Dimensional Analysis of Combined Free Edge and Transverse Crack Tip Delamination," 9th ASTM Symposium on Composite Materials Testing and Design, Reno, Nevada, April 1988.