12:53:52 OCA PAD INITIATION - PROJECT HEADER INFORMATION | 01/19/96

Active

Project #: E-16-N06 Cost share #: Rev #: 0
Center # : 10/24-6-R8563-0A1 Center shr #: OCA file #:
Work type : RES
Contract#: NAG3-1754 Mod #: INITIATION Document : GRANT
Prime #: Contract entity: GTRC

~~Subprojects ? : N~~ CFDA:
Main project #: E-20-W70 PE #:

Project unit: AERO ENGR Unit code: 02.010.110
Project director(s):
MCGEE O G AERO ENGR (404)894-2204

Sponsor/division names: NASA / LEWIS RESEARCH CTR, OH
Sponsor/division codes: 105 / 011

Award period: 950531 to 960530 (performance) 960830 (reports)

| Sponsor amount | New this change | Total to date |
|---|---|---|
| Contract value | 44,644.91 | 44,644.91 |
| Funded | 44,644.91 | 44,644.91 |
| Cost sharing amount | | 0.00 |

Does subcontracting plan apply ?: N

Title: 3-D AEROELASTIC ANALYSIS OF MISTUNED BLADED-DISK ASSEMBLIES

## PROJECT ADMINISTRATION DATA

OCA contact: Anita D. Rowland 894-4820

| Sponsor technical contact | Sponsor issuing office |
|---|---|
| JOHN LUCERO (5230)<br>(216)433-2684 | IRENE CIERCHACKI<br>(216)433-2781 |
| NASA LEWIS RESEARCH CENTER<br>21000 BROOKPARK ROAD<br>STRUCTURAL DYNAMICS BRANCH<br>MAIL STOP 23-3<br>CLEVELAND, OHIO 44135 | SAME<br><br>PROCUREMENT DIVISION<br>MAIL STOP 500-309 |

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): Y
Defense priority rating : supplemental sheet
Equipment title vests with: Sponsor GIT X
1260.408
Administrative comments -
E-16-N06 ACCOUNT SET-UP TO COMPLETE TRANSFER OF PI TO AE.

PROJECT CLOSEOUT - NOTICE

Closeout Notice Date 08-SEP-1997

Project Number E-16-N06 Doch Id 46253

Center Number 10/24-6-R8563-0A1

Project Director MCGEE, OLIVER

Project Unit AERO ENGR

Sponsor NASA/LEWIS RESEARCH CTR, OH

Division Id 3391

Contract Number NAG3-1754 Contract Entity GTRC

Prime Contract Number

Title 3-D AEROELASTIC ANALYSIS OF MISTUNED BLADED-DISK ASSEMBLIES

Effective Completion Date 30-MAY-1997 (Performance) 30-AUG-1997 (Reports)

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| Closeout Action: | Y/N | Date Submitted |
|---|---|---|
| Final Invoice or Copy of Final Invoice | Y | |
| Final Report of Inventions and/or Subcontracts | Y | |
| Government Property Inventory and Related Certificate | Y | |
| Classified Material Certificate | N | |
| Release and Assignment | N | |
| Other | N | |

Comments

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| Distribution Required: | |
|---|---|
| Project Director/Principal Investigator | Y |
| Research Administrative Network | Y |
| Accounting | Y |
| Research Security Department | N |
| Reports Coordinator | Y |
| Research Property Team | Y |
| Supply Services Department | Y |
| Georgia Tech Research Corporation | Y |
| Project File | Y |

NOTE: Final Patent Questionnaire sent to PDPI

Main Proj# E-20-W70
Sub proj. #. E-16-N06
#1

ANNUAL SUMMARY OF WORK IN PROGRESS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
FACULTY AWARDS FOR RESEARCH (FAR)

| | |
|---|---|
| Award Number: | NASA Grant NAG3-1571 |
| Principal Investigator: | Oliver G. McGee III, Ph.D. |
| Amount of Support: | $73,103 (FY#2) |
| Period of support: | February 15, 1994 to October 14, 1995 |
| No cost extension: | October 15, 1995 to May 30, 1997 |
| Date of request: | August 8, 1997 |
| Requested Amount for FY#3: | $77,610 |
| Proposed period of support: | October 1, 1997 to October 14, 1998 |
| Project Title: | **Nonlinear Dynamic Analysis of Disordered Bladed-Disk Assemblies** |

5832

**Summary of Ongoing and Future Research Effort**

In a effort to address current needs for efficient, air propulsion systems, we have developed some new analytical predictive tools for understanding and alleviating aircraft engine instabilities which have led to accelerated high cycle fatigue and catastrophic failures of these machines during flight. A frequent cause of failure in jet engines is excessive resonant vibrations and stall flutter instabilities. The likelihood of these phenomena is reduced when designers employ the analytical models we have developed. These prediction models will ultimately increase the nation's competitiveness in producing high performance jet engines with enhanced operability, energy economy, and safety.

The objectives of our current threads of research in the final year are directed along two lines. First, we want to improve the current state of blade stress and aeromechanical reduced-ordered modeling of high bypass engine fans. Specifically, a new reduced-order iterative redesign tool for passively controlling the mechanical authority of shroudless, wide chord, laminated composite transonic bypass engine fans has been developed. Second, we aim to advance current understanding of aeromechanical feedback control of dynamic flow instabilities in axial flow compressors. A systematic theoretical evaluation of several approaches to aeromechanical feedback control of rotating stall in axial compressors has been conducted. Attached are abstracts of two papers [1,2] under preparation for the 1998 ASME Turbo Expo in Stockholm, Sweden sponsored under Grant No. NAG3-1571.

Our goals during the final year under Grant No. NAG3-1571 is to enhance NASA's capabilities of forced response of turbomachines (such as NASA FREPS). We will continue our development of the reduced-ordered, three-dimensional component synthesis models for aeromechanical evaluation of integrated bladed-disk assemblies (i.e., the disk, non-identical blading, etc.). We will complete our development of component systems design optimization strategies for specified vibratory stresses and increased fatigue life prediction of assembly components, and for specified frequency margins on the Campbell diagrams of turbomachines. Finally, we will integrate the developed codes with NASA's turbomachinery aeromechanics prediction capability (such as NASA FREPS).

ANNUAL SUMMARY OF WORK IN PROGRESS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
FACULTY AWARDS FOR RESEARCH (FAR)

Award Number: NASA Grant NAG3-1571
Principal Investigator: Oliver G. McGee III, Ph.D.
Project Title: **Nonlinear Dynamic Analysis of Disordered Bladed-Disk Assemblies**

**Summary of Ongoing and Future Research Effort** (cont.)

Full documentation of the proposed work (i.e., computer program modulation, and nondimensional tables, graphical charts, and visualizations of dynamical response information) in annual performance reports, NASA technical memorandums and reports, and journal articles will be the primary form of deliverables.

A final year timetable of effort is proposed.

Under the sponsorship of NASA Grant No. NAG3-1571 during fiscal year #2, the principal investigator attended one international conference, one continuing education international workshop in turbomachinery technologies. These include:

1. Turbomachinery Aerodynamics, Whittle Laboratory, University of Cambridge Program for Industry, University of Cambridge Board of Continuing Education, Cambridge, ENGLAND, June 1996.

2. ASME International Gas Turbine and Aeroengine Congress and Expositions, Birmingham, England, June 1996.

During the final year #3, the travel budget of the principal investigator includes a planned attendance to one international conference - the ASME International Gas Turbine and Aeroengine Congress and Expositions, Stockholm, Sweden, June 1998, and two visitations in the Fall 1997 and Summer 1998 to NASA Lewis Research Center in Cleveland, Ohio.

## REFERENCES


1. McGee, O.G., and Fang, C., "Vibration Response and Flutter Control of Laminated Composite Transonic Bypass Engine Fans," *ASME Turbo Expo'98, Structural Dynamics Committee, ASME Journal of Engineering for Gas Turbine Engines and Power* (to be submitted, 1997).

2. McGee, O.G., Graf, M., and Frechette, L., "Theoretical Evaluation of Aeromechanical Feedback Control of Rotating Stall in Axial Compressors," *ASME Turbo Expo'98, Turbomachinery Committee, ASME Journal of Turbomachinery*, (to be submitted, 1997).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
FACULTY AWARDS FOR RESEARCH (FAR)
BUDGET REQUEST FOR FUNDS IN FISCAL YEAR 3

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PI NAME: Dr. Oliver G. McGee III — DATE of REQUEST 8-8-97
NASA GRANT NO. NAG3-1571 — YEAR of FAR AWARD 1994

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October 1, 1997 - October 1, 1998

| | NASA |
|---|---|
| DIRECT LABOR | |
| Prin. Inv. Prof. O.G. McGee | |
| 1 mos., 100% @ $77,200/9 mo. acad. yr. | 8,578 |
| 9 mos., 10% @ $77,200/9 mo. acad. yr. | 7,720 |
| Graduate Research Associate | |
| 9 mos., 50% @ $2,000/mo. | 9,000 |
| Graduate Research Associate | |
| 9 mos., 50% @ $2,000/mo. | 9,000 |
| Undergraduate Research Assistant | |
| 6 mos., 50% @ $1,000/mo. | 3,000 |
| **Subtotal Salary & Wages** | **$37,298** |
| FRINGE BENEFITS | |
| Retirement @ 24.7% of $37,298 Fac. Sal. | 9,213 |
| Graduate Tuition & Fees @ $2,178/Qtr. | wc |
| **Subtotal Fringe Benefits** | **$9,213** |
| **Subtotal Personnel** | **$46,511** |
| TRAVEL | |
| Two Domestic-NASA Center | 1,500 |
| One International Meeting | 3,000 |
| **Subtotal Travel** | **$4,500** |
| OTHER DIRECT COSTS | |
| Materials and Supplies | 1,000 |
| Reports and Publications | 1,300 |
| Communications (fax, phone, postage) | 125 |

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
FACULTY AWARDS FOR RESEARCH (FAR)
BUDGET REQUEST FOR FUNDS IN FISCAL YEAR 3 (cont)

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PI NAME: Dr. Oliver G. McGee III — DATE of REQUEST 8-8-97
NASA GRANT NO. NAG3-1571 — YEAR of FAR AWARD 1994

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October 1, 1997 - October 1, 1998

| | NASA |
|---|---|
| OTHER DIRECT COSTS (cont) | |
| Secretarial Services | 2,000 |
| Computer Resources (non auditable) ............ | wc |
| **Subtotal Other Direct Costs ...................** | **$4,425** |
| **TOTAL DIRECT COSTS .............................** | **$55,436** |
| INDIRECT COSTS | |
| 40% of $55,436 (Direct Costs)................. | 22,174 |
| **TOTAL COSTS ..................................** | **$77,610** |

Addendum: Description of Travel Expenses

1. 1998 ASME/IGTI Aeroengine Congress and Exposition
   Destination: Stockholm, Sweden
   Purpose: Presentation of Research Papers, ASME/IGTI Structural Dynamics and Turbomachinery Committees.
   Dates: June 1998
   Estimated Expenses:

| | |
|---|---|
| Airfare | 1500 |
| Registration | 500 |
| Hotel (5 days) | 700 |
| Meals (5 days) | 300 |

2. VISITATIONS TO NASA LEWIS RESEARCH CENTER
   Destination: Structural Dynamics Branch
   Cleveland, Ohio
   Purpose: Site visits and presentation/discussion of research progress and results. Cost of visitation includes that of the P.I. and Under-represented Minority Student Personnel.
   Dates: Fall 1997, Summer 1998
   Estimated Expenses:

| | |
|---|---|
| Airfare | 800 |
| Hotel (3 days) | 300 |
| Meals | 200 |

# Vibration Response and Flutter Control of Laminated Composite Transonic Bypass Engine Fans

O.G. McGee[1]
School of Aerospace Engineering, School of Civil & Environmental Engineering
Georgia Institute of Technology, Atlanta, Georgia U.S.A.

C. Fang
School of Aerospace Engineering
Georgia Institute of Technology, Atlanta, Georgia U.S.A.

A new reduced-order iterative redesign tool for passively controlling the mechanical authority of shroudless, wide chord, laminated composite transonic bypass engine fans has been developed. A frequent cause of fatigue failure of these composite fans is stall flutter and/or excessive resonant vibration response. The primary design strategy is to reduce the likelihood of fan resonance and flutter using a Campbell diagram. In off-design operation, the frequency margins of the lower flex-torsion modes of transonic fans may be dangerously close to integral order resonant and empirical stall flutter boundaries. In addition, designers must guard against any low order modes that exhibit a significant amount of coupled flex-torsion response near the tip regions of the fan. Such flex-torsion coupling derives from the large hub slope typical of high bypass engines inlets and/or the blade's fiberous composite mold construction and any associated flex warpages attributed to ply misorientations and/or fiber nonuniformities. An important design question for composite fans is whether it is advantageous to employ passive control techniques of composite tailoring and shape optimization to separate the modes via prescribed frequency margins based on past experience, to provide flex-torsion stall flutter protection using empirical values of reduced frequencies, and to control the flex-torsion vibratory response.

The present design strategy addresses this question by controlling the mechanical strength of a recently developed transonic bypass fan by identifying optimally permissible symmetric angle-ply orientations of the fiberous composite layup, and by determining an optimum distribution of blade thickness between the hub and mean radius of the fan. The primary design goals are to alleviate low integral order resonant and stall flutter characteristics, to control twist-flex vibratory response in the fundamental mode, and to ensure the mechanical strength integrity of the fiberous composite blade construction under steady centrifugal tension and gas bending stresses. Baseline and optimally-restructured Campbell diagrams and design sensitivity calculations are presented. Optimum design histories of ply lay-ups and nondimensional constraints (i.e., frequency margins, reduced frequencies, twist-flex vibratory response, first-ply failure principal stress limits, and thickness distribution) show that a proper choice of composite tailoring and shape optimization produces a feasible Campbell diagram well within the specified response and empirical stall flutter boundaries. An additional development offered shows that the present three-dimensional, reduced-ordered, energy-based model is equally efficient and accurate in its description of the response of composite fans, when its performance is compared to a conventional three-dimensional, cyclic-symmetric fan analysis employing a widely distributed, general-purpose finite element software package.

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[1] Currently on leave as a Martin Luther King, Jr. Visiting Scientist in the MIT Gas Turbine Laboratory.

# Theoretical Evaluation of Aeromechanical Feedback Control of Rotating Stall in Axial Compressors

O.G. McGee [1]
School of Aerospace Engineering, School of Civil & Environmental Engineering,
Georgia Institute of Technology, Atlanta, Georgia 30332-0150

M. Graf
Pratt & Whitney, Government Engines & Space Propulsion,
West Palm Beach, FL 33410-9600

L. Frechette
Gas Turbine Laboratory,
Massachusetts Institute of Technology, Cambridge, MA 02139

A systematic theoretical evaluation of several approaches to aeromechanical feedback control of rotating stall in axial compressors has been conducted. Previous proof of concept studies have established that compression systems employing aeromechanical feedback can be stabilized against aerodynamic instabilities, resulting in significant gains in system operating range. The control schemes developed in the present work utilize static pressure sensing and local structural actuation for dynamic compensation. These methods damp the small amplitude, traveling wave flowfield disturbances that have been observed as rotating stall precursors for a class of axial compressors. The following aeromechanical control methodologies were examined: (1) dynamic fluid injection upstream of the compressor, (2) variable compressor inlet and exit duct geometries, (3) flexible compressor casing wall providing control of tip clearance flow processes, and (4) dynamically restaggered inlet guide vanes and rotor blades. Throughout emphasis has been placed on delineating a general methodology for evaluation of aeromechanical feedback control strategies and quantifying the performance of the different methods examined. The present study shows that the two most effective aeromechanical controls are the use of dynamic flow injection upstream of the compressor and variable compressor exit duct geometry. The primary metric of evaluation has been the maximum achievable positive characteristic slope for a set of optimized aeromechanical control parameters. The results show that a proper choice of dynamic compensation affects the ability to stabilize compression systems.

An additional issue addressed has been to show that an analysis of the linearized equations of motion including aeromechanical feedback and an alternate approach based on a disturbance-energy corollary lead to fundamentally equivalent descriptions of the physical mechanisms associated with stall inception in the presence of aeromechanical control. Based on the disturbance-energy concept, a new metric has been proposed which measures the overall effective characteristic slope of compression systems with aeromechanical feedback.

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[1] Currently on leave as a Martin Luther King, Jr. Visiting Scientist in the MIT Gas Turbine Laboratory.