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LOADS AND AEROELASTICITY DIVISION RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR FY 1986 AND PLANS FOR FY 1987

JAMES E. GARDNER AND S. C. DIXON

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Langley Research Center
Hampton, Virginia 23665-5225

LOADS AND AEROELASTICITY DIVISION
RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR FY 1986 AND PLANS FOR FY 1987

SUMMARY

The purpose of this paper is to present the Loads and Aeroelasticity Division's research accomplishments for FY 86 and research plans for FY 87. The work under each branch (technical area) will be described in terms of highlights of accomplishments during the past year and highlights of plans for the current year as they relate to five year plans and the objectives for each technical area. This information will be useful in program coordination with other government organizations, universities, and industry in areas of mutual interest.

ORGANIZATION

The Langley Research Center is organized by directorates as shown on figure 1. Directorates are organized by divisions and offices. The Loads and Aeroelasticity Division of the Structures Directorate consists of five branches as shown on figure 2. This figure lists the key people in the division which consists of 66 NASA civil servants, nine members of the Army Aerostructures Directorate, USAARTA, Army Aviation Systems Command located at Langley Research Center, and one member of the Air Force. Recent changes in key people include the loss of Jerry Newsom from the Aeroservoelasticity Branch to NASA Headquarters (Technical Assistant to the Administrator) and the assignments of Rodney Ricketts as Assistant Head of the Thermal Structures Branch and Bill Cazier as Assistant Head of the Configuration Aeroelasticity Branch. Each branch represents a technical area and disciplines under the technical areas are shown on the figure. All of the Army personnel work on the Rotorcraft Aeroelasticity and Rotorcraft Structural Dynamics disciplines.

The division conducts analytical and experimental research in the five technical areas to meet technology requirements for advanced aerospace vehicles. The research focuses on the long range thrusts shown in figure 3. The Configuration Aeroelasticity Branch (CAB), Unsteady Aerodynamics Branch (UAB), and Aeroservoelasticity Branch (ASEB) all work in the area of Prediction and Control of Aeroelastic Stability and Response of Aircraft and Rotorcraft. The Aerothermal Loads Branch (ALB) and the Thermal Structures Branch (TSB) work the areas of Lightweight, Hot Structures for High Speed Vehicles (Aeronautics) and Aerothermal Structures and Materials Technology for Space Transportation Systems (Space).

RESEARCH PHILOSOPHY

The basic philosophy and motivation of the Loads and Aeroelasticity Division research program can be captured in selected quotes from some leaders in Aerospace Research and Development. In his 13th Von Karman lecture on Aeroelasticity (ref. 1), I. E. Garrick related the following: "Von Karman's sense of humor, which was remarkably appropriate to a given occasion, has become legendary. Recognizing that the poor structures engineer was usually held accountable for structural integrity, he quipped, 'The aerodynamicist assumes everything but the responsibility.'"

"It has been gratifying to me to observe that in major aerospace industry the aeroelastician is no longer the stepchild he once was. From an almost parochial isolated specialist, he is now the generalist who tends to pull together the separate efforts in structures, aerodynamics, stability and control, and propulsion, even in early design stages. Yet, there are still human problems such as one-way communications and barriers between departments as well as physical problems that are often so recondite and difficult that aeroelastic problems may slip through the cracks."

In his Wright Brothers Lectureship in Aeronautics on Optimization (ref. 2), Holt Ashley observed: "Further mention will be made in what follows of the keen disappointment felt by many specialists because their theories have received so little practical application. This phenomenon is frequently attributed to a reluctance by developmental engineers to adopt unfamiliar and untried methods of analysis."

In an appraisal of a study of hypersonic airframe structures, (ref. 3), Rene' Miller stated: "The cost effectiveness of .... (Thermal) Structural Concepts is greatly dependent on solutions to the detailed design problems. In fact, it is likely that these detailed design problems as demonstrated in the X-15 program will prove to be the pacing item in the development of Hypersonic Aircraft."

The Loads and Aeroelasticity Division program is aimed at producing the data and analysis methods required by those who are accountable for the structural integrity of aerospace vehicles; to provide the detailed design data and methods for the pacing item of development of hypersonic vehicles - cost effective thermal structures; to continue to pull together those separate efforts that ought to (or must) be considered as a single task to preclude aeroelastic problems from slipping through the cracks; and to alleviate the reluctance by developmental engineers to adopt unfamiliar and untried methods by making them both familiar and proven.

FACILITIES

The Loads and Aeroelasticity Division has two major facilities available to support its research as shown in figure 4.

The Transonic Dynamics Tunnel (TDT) is a Mach 0.2 to 1.2 continuous flow, variable-pressure wind tunnel with a 16-foot-square test section which uses a Freon-12 test medium primarily for dynamic aeroelastic testing. This unique facility is used primarily by the Configuration Aeroelasticity Branch. Semi-span, side-wall mounted models and full-span cable-mounted models are used for aeroelastic studies of fixed wing aircraft. The Aeroelastic Rotor Experimental System (ARES) test stand is used in the tunnel to study the aeroelastic effects on rotors. A General Rotor Aeroelastic

Laboratory, located nearby, is used to setup the ARES test stand in preparation for entry into the TDT and for rotorcraft studies in hover. A modernization of the TDT Data Acquisition System is underway. A major CofF activity for density increase has recently been completed. The upgraded facility can now operate at dynamic pressures up to 600 psf. The maximum Reynolds number is about 10 x 10^6/ft. The replacement cost for this facility is $63M.

The Aerothermal Loads Complex consists of five facilities which are operated by the Aerothermal Loads Branch to carry out their research. The 8-Foot High Temperature Tunnel (8' HTT) is a unique hypersonic Mach 7 blowdown wind tunnel with an 8' diameter test section (uniform temperature test core of 4') that uses products of combustion (methane and air under pressure) as the test medium. The tunnel operates at dynamic pressures of 250 to 1800 psf, temperatures of 2400 to 3600°R and Reynolds numbers of 0.3 to 2.2 x 10^6/ft. The tunnel is used to test 2-D and 3-D type models to determine aerothermal loads and to evaluate new high temperature structural concepts. A major CofF item is underway to provide alternate Mach number capability and oxygen enrichment for the test medium. This is being done primarily to allow the tunnel to test models that have hypersonic air breathing propulsion applications. The replacement cost for the tunnel is $45M.

The 7-Inch High Temperature Tunnel (7" HTT) is a nearly 1/12 scale of the 8' HTT with basically the same capabilities as the larger tunnel. It is used primarily as an aid in the design of larger models for the 8' HTT and for aerothermal loads test on subscale models. The 7" HTT is currently being used to evaluate various new systems for the 8' HTT. The replacement cost for the tunnel is $0.8M.

The three Aerothermal Arc Tunnels (20 MW, 5 MW and 1 MW) are used to test models in an environment that simulates the flight reentry envelope for high speed vehicles such as the Space Shuttle. The amount of usable energy to the test medium in these facilities is 9 MW, 2 MW, and 1/2 MW. The 5 MW is a three phase AC arc heater while the 20 MW and 1 MW are DC arc heaters. Test conditions such as temperature, flow rate, and enthalpy vary greatly since a variety of nozzles and throats are available and since model sizes are different (3" diameter to 1' x 2' panels). The replacement cost for these arc tunnels is $24M.

FY 86 ACCOMPLISHMENTS

Configuration Aeroelasticity Branch

The Configuration Aeroelasticity Branch conducts research (figure 5) to determine, analytically and experimentally, effective means for predicting and reducing helicopter vibrations and to evaluate the aeroelastic characteristics of new rotor systems; to develop the aeroelastic understanding and prediction capabilities needed to apply new aerodynamic and structural concepts to future flight vehicles and to determine and solve the aeroelastic problems of current designs. This work is more clearly identified in figure 6 which shows the five year plan of the three disciplines and their expected results.

The Configuration Aeroelasticity FY 86 accomplishments listed below are highlighted by figures 7 through 12.

Aircraft Aeroelasticity:
- Unanticipated Flutter Characteristics of New Composite A-6 Wing Identified in TDT Tests
- Unusual Instability Boundary for DAST ARW-2 Found to be Narrow Transonic Response Region
- Adaptive Flutter Suppression System Evaluated in TDT Tests
- Active Flexible Wing Model Successfully Tested in TDT

Rotorcraft Aeroelasticity:
- Langley Blackhawk Rotor Design Shows Performance Improvements Over Existing Rotor

Rotorcraft Structural Dynamics:
- Sensitivity Analysis Implemented in NASTRAN for Helicopter Airframe Optimization to Reduce Vibrations

Each highlight is accompanied by descriptive material.

Unsteady Aerodynamics Branch

The Unsteady Aerodynamics Branch conducts research (figure 13) to produce, apply, and validate through experiments a set of analytical methods for predicting steady and unsteady aerodynamic loads and aeroelastic characteristics of flight vehicles--with continued emphasis on the transonic range and emerging emphasis on high angle-of-attack maneuvering subsonic and supersonic conditions. This work is more clearly identified in figure 14 which shows the five year plan of the three disciplines and their expected results.

The Unsteady Aerodynamics FY 86 accomplishments listed below are highlighted by figures 15 through 18.

Theory Development and Design Methods:
- New Algorithm for Unsteady Transonic Small-Disturbance Equation Gives Order of Magnitude Increase in Computational Efficiency
- Approximate Factorization Algorithm Enables Supersonic Unsteady Aerodynamics Calculations
- Fuselage Aerodynamic Interference Effects Predicted on RAE Wing Unsteady Loading

Experiments:
- Laminar Flow Observed on Supercritical Airfoil at High Reynolds Numbers

Each highlight is accompanied by descriptive material.

Aeroservoelasticity Branch

The Aeroservoelasticity Branch conducts research (figure 19) to develop methodologies for the analysis and synthesis of multifunctional active control systems and conceives, recommends, and provides technical support for experiments to validate the methodologies. Mathematical models needed to support NASA projects are used to verify the theoretical developments and their computer implementations. This work is more clearly identified in figure 20 which shows the five year plan of the three disciplines and their expected results.

The Aeroservoelasticity FY 86 accomplishments listed below are highlighted by figures 21 through 25.

Analysis and Design Methods:
- New Method for Approximating Unsteady Aerodynamics for Aeroservoelasticity Computations
- Automated Transonic Aeroelasticity Analysis Program Developed

Applications and Validations:
- ARW-2 Wing Tip Accelerations Correlates With Surface Pressure Shock Movement
- Active Control of Shock Induced Oscillations
- Active Flexible Wing Wind-Tunnel Test Program

Each highlight is accompanied by descriptive material.

Aerothermal Loads Branch

The Aerothermal Loads Branch conducts research (figure 26) to develop and validate solution algorithms, modeling techniques, and integrated finite element solutions for fluid-thermal-structural analysis; to identify and understand flow phenomena and flow/surface/structure interaction parameters required to define detailed aerothermal loads for structural design via analysis and test; and to define methods for testing in high enthalpy flow environments including the capability for testing air breathing engines at hypersonic speeds. This work is more clearly identified in figure 27 which shows the five year plan of the three disciplines and their expected results.

The Aerothermal Loads Branch FY 86 accomplishments listed below are highlighted by figures 28 through 32.

Experiments:
- Shock Impingement on a Cylindrical Leading Edge - Augmented Heating Rate Measurements
- Protective Shroud Successfully Removed at Mach 6.7 in LaRC 8' High Temperature Tunnel

Analysis:
- Combined Indicators Required for Viscous Flow
- Integrated Fluid-Thermal-Structural Algorithm Demonstrated for Nonlinear Thermal Stress-Strain Analysis

Facilities and Test Techniques:
- Compact Analyzer Controls Oxygen Enrichment Level During Combustion Process with Fast Response

Each highlight is accompanied by descriptive material.

Thermal Structures Branch

The Thermal Structures Branch conducts research (figure 33) to develop and validate concepts for aerospace structures whose design is significantly controlled by the thermal excursions of the operating environments of aerospace vehicles. Systems studies in concert with the Space Systems Division or High-Speed Aerodynamics Division help to identify structures and materials technology needs. Structural concepts are then developed, analyzed, fabricated, and tested to verify the required technology advances. This work is more clearly identified in figure 34 which shows the five year plan of the three major disciplines and their expected results. Thermal structures experimental needs are currently in the definition stage. Static testing of small components is currently being done with the support of contractors, ADFRF, and the Aerothermal Loads Branch.

The Thermal Structures FY 86 accomplishments listed below are highlighted by figures 35 through 38.

Propulsion Structures:
- Cooled Hypersonic Engine Strut

Airframe Structures:
- Leaktight Honeycomb Joint Design for 900°F Service Environment
- Multiwall Insulating Blatter for Cryogenic Tank

Analysis and Synthesis Methods:
- Sizing and Optimization Language

Each highlight is accompanied by descriptive material.

PUBLICATIONS

The FY 86 accomplishments of the Loads and Aeroelasticity Division resulted in a number of publications. The publications are listed below by organization and are identified by the categories of journal publications, formal NASA reports, conference presentations, contractor reports, tech briefs, and patents.

DIVISION OFFICE

Formal NASA Reports

1. Dixon, S. C.; Tenney, D. R.; Rummler, D. R.; Wieting, A. R.; and Bader, R. M.: Structures and Materials Technology Issues for Reusable Launch Vehicles. NASA TM-87626, October 1985.

2. Hanson, P. W.: Aeroelasticity at the NASA Langley Research Center - Recent Progress, New Challenges. NASA TM-87660, December 1985.

3. Gardner, J. E.; and Dixon, S. C.: Loads and Aeroelasticity Division Research and Technology Accomplishments for FY 1985 and Plans for FY 1986. NASA TM-87676, January 1986.

Conference Presentations

4. Dixon, C. S.; Tenney, D. R.; Rummler, D. R.; Wieting, A. R.; and Bader, R. M.: Structures and Materials Technology Issues for Reusable Launch Vehicles. Presented at the IEEE 18th Annual Electronics and Aerospace Systems Conference (EASCOM 85), October 29, 1985, Washington, DC.

CONFIGURATION AEROELASTICITY BRANCH

Formal NASA Reports

5. Kehoe, M. W.; Cazier, F. W., Jr.; and Ellison, J. F.: Ground Vibration Test of the Laminar Flow Control JetStar Airplane. NASA TM-86398, October 1985.

6. Cazier, F. W., Jr., and Kehoe, M. W.: Ground Vibration Test of F-16 Airplane With Modified Decoupler Pylons. NASA TM-87634, April 1986.

7. Cole, S. R.: Divergence Study of a High-Aspect Ratio, Forward-Swept Wing. NASA TM-87682, June 1986.

8. Cazier, F. W., Jr.; and Kehoe, M. W.: Flight Test of a Decoupler Pylon for Wing/Store Flutter Suppression. NASA TM-87767, July 1986.

9. Cazier, F. W., Jr.; and Kehoe, M. W.: Flight Test of Passive Wing/Store Flutter Suppression. NASA TM-87766, August 1986.

10. Mantay, W. R.; and Yeager, W. T., Jr.: Aeroelastic Considerations for Torsionally Soft Rotors. NASA TM-87687, AVSCOM TR 86-B-1, August 1986.

Conference Presentations

11. Cole, S. R.: Divergence Study of a High-Aspect Ratio, Forward-Swept Wing. Presented at the AIAA 24th Aerospace Sciences Meeting, January 6-9, 1986, Reno, Nevada. AIAA Paper No. 86-0009.

12. Cazier, F. W., Jr.; and Kehoe, M. W.: Flight Test of A Decoupler Pylon for Wing/Store Flutter Suppression. Presented at the AIAA 3rd Flight Testing Conference and Technical Display, April 2-4, 1986, Las Vegas, Nevada. AIAA Paper No. 86-9730.

13. Cazier, F. W., Jr.; and Kehoe, M. W.: Flight Test of Passive Wing/Store Flutter Suppression. Presented at the Joint Technical Coordinating Group for Munitions Development 1986 Aircraft/Stores Compatibility Symposium, April 8-10, 1986, Wright-Patterson AFB, Ohio. In Proceedings.

14. Halwes, D. R.; and Cline, J. H.: Total Rotor Isolation System (TRIS) Flight Test Results. Presented at the AHS 42nd Annual Forum and Technology Display, June 2-4, 1986, Washington, DC. In Proceedings.

Contractor Reports

15. Reed, W. H., III: An Airfoil Flutter Model Suspension System to Accommodate Large Static Transonic Airloads. (NAS1-17686 Dei-Tech, Inc.) NASA CR-177998, October 1985.

16. Halwes, D. R.; and Nicks, C. O.: Six Degree-of-Freedom "LIVE" Isolation System Tests - Part 1: Interim Report. (NAS1-16969 Bell Helicopter Textron.) NASA CR-177928, April 1986.

Tech Briefs

17. Halwes, D. R. (Bell Helicopter Textron, Inc.): Six-Degree-of-Freedom Total Rotor Isolation System. NASA Tech Brief LAR-13581.

UNSTEADY AERODYNAMICS BRANCH

Journal Publications

18. Williams, M. H.; Bland, S. R.; and Edwards, J. W.: Flow Instabilities in Transonic Small-Disturbance Theory. AIAA Journal, Volume 23, No. 10, October 1985, p. 1491-1496.

19. Runyan, H. L.; and Tai, H.: Application of a Lifting Surface Theory for a Helicopter in Forward Flight. Vertica, Volume 10, Nos. 3/4, 1986, p. 269-280.

20. Batina, J. T.: Unsteady Transonic Flow Calculations for Two-Dimensional Canard-Wing Configurations. Journal of Aircraft, Volume 23, No. 4, April 1986, p. 290-298.

21. Batina, J. T.: Unsteady Transonic Flow Calculations for Interfering Lifting Surface Configurations. Journal of Aircraft, Volume 23, No. 5, May 1986, p. 422-430.

22. Berry, H. M.; Batina, J. T.; and Yang, T. Y.: Viscous Effects on Transonic Airfoil Stability and Response. Journal of Aircraft, Volume 23, No. 5, May 1986, p. 361-369.

Formal NASA Reports

23. Runyan, H. L.; and Tai, H.: Compressible, Unsteady Lifting-Surface Theory for a Helicopter Rotor in Forward Flight. NASA TP-2503, December 1985.

24. Batina, J. T.: Unsteady Transonic Flow Calculations for Wing-Fuselage Configurations. NASA TM-87707, March 1986.

25. Gallman, J. W.; Batina, J. T.; and Yang, T. Y.: A Computational Transonic Flutter Boundary Tracking Procedure. NASA TM-87708, March 1986.

26. Gibbons, M. D.; Whitlow, W., Jr.; and Williams, M. H.: Nonisentropic Unsteady Three Dimensional Small Disturbance Potential Theory. NASA TM-87726, April 1986.

27. Whitlow, W., Jr.; Hafez, M. M.; and Osher, S. J.: An Entropy Correction Method for Unsteady Full Potential Flows With Strong Shocks. NASA TM-87769, June 1986.

28. Seidel, D. A.; and Batina, J. T.: User's Manual for XTRAN2L (Version 1.2): A Program for Solving the General-Frequency Unsteady Transonic Small-Disturbance Equation. NASA TM-87737, July 1986.

Conference Presentations

29. Yates, E. C., Jr.: Problems and Progress in Aeroelasticity for Interdisciplinary Design. Presented at the Recent Trends In Aeroelasticity, Structures, and Structural Dynamics, February 6-7, 1986, Gainesville, Florida.

30. Batina, J. T.: Unsteady Transonic Flow Calculations for Wing-Fuselage Configurations. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0862-CP.

31. Gallman, J. W.; Batina, J. T.; and Yang, T. Y.: A Computational Transonic Flutter Boundary Tracking Procedure. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0902-CP.

32. Gibbons, M. D.; Whitlow, W., Jr.; and Williams, M. H.: Nonisentropic Unsteady Three-Dimensional Small Disturbance Theory. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0863-CP.

33. Smith, G. E.; Whitlow, W., Jr.; and Hassan, H. A.: Unsteady Transonic Flows Past Airfoils Using the Euler Equations. Presented at the AIAA 4th Applied Aerodynamics Conference, June 9-11, 1986, San Diego, California. AIAA Paper No. 86-1764-CP.

34. Whitlow, W., Jr., Hafez, M. M.; and Osher, S. J.: An Entropy Correction Method for Unsteady Full Potential Flows With Strong Shocks. Presented at the AIAA 4th Applied Aerodynamics Conference, June 9-11, 1986, San Diego, California. AIAA Paper No. 86-1768-CP.

35. Edwards, J. W.: Application of Potential Theory Computations to Transonic Aeroelasticity. Presented at the 15th Congress of the International Council of the Aeronautical Sciences (ICAS), September 7-12, 1986, London, England. Paper No. ICAS-86-2-9.1.

36. Yates, E. C., Jr.; and Chu, L-C.: Static Aeroelastic Effects on the Flutter of Supercritical Wing. Presented at the 63rd Meeting of the AGARD Structures and Materials Panel Specialists' Meeting on Static Aeroelastic Effects on High-Performance Aircraft, September 28 - October 3, 1986, Athens, Greece. Proceedings pending.

37. Yates, E. C., Jr.; and Whitlow, W., Jr.: Development of Computational Methods for Unsteady Aerodynamics at the NASA Langley Research Center. Presented at the 63rd Meeting of the AGARD Structures and Materials Panel Workshop on Future Research on Transonic Unsteady Aerodynamics and Its Aeroelastic Applications, September 28 - October 3, 1986, Athens, Greece.

Contractor Reports

38. Ehlers, F. E.; Weatherill, W. H.; and Yip, E. L.: Development and Application of Algorithms for Calculating the Transonic Flow About Harmonically Oscillating Wings. (NAS1-16297 Boeing Commercial Airplane Company.) NASA CR-172376, October 1984 (Released 1985).

AEROSERVOELASTICITY BRANCH

Formal NASA Reports

39. Arbuckle, P. D.; Sliwa, S. M.; Roy, M. L.; and Tiffany, S. H.: FIT: A Computer Program That Interactively Determines Polynomial Equations for Data Which Are a Function of Two Independent Variables. NASA TM-86413, October 1985.

40. Dunn, H. J.: UNAERO: A Package of FORTRAN Subroutines for Approximating Unsteady Aerodynamics in the Time Domain. NASA TM-86392, October 1985.

41. Eckstrom, C. V.: Prediction of Wing Aeroelastic Effects on Aircraft Lift and Pitching Moment Characteristics. NASA TM-87631, November 1985.

42. Wieseman, C. D.: A Method to Stabilize Linear Systems Using Eigenvalue Gradient Information. NASA TP-2479, November 1985.

43. Eckstrom, C. V.: Flight Measurements of Surface Pressures on a Flexible Supercritical Research Wing. NASA TP-2501, December 1985.

44. Eckstrom, C. V.: Loads Calibrations of Strain Gage Bridges on the DAST Project Aeroelastic Research Wing (ARW-2). NASA TM-87677, March 1986.

Conference Presentations

45. Eckstrom, C. V.: Prediction of Wing Aeroelastic Effects on Aircraft Lift and Pitching Moment Characteristics. Presented at the Navy Aircraft Flight Loads Technology Transfer Conference, October 16-17, 1985, Washington, DC. Proceedings pending.

46. Newsom, J. R.: Aeroservoelasticity Studies for NASP. Presented at the First National Aero-Space Plane Technology Symposium, May 20-22, 1986, Hampton, Virginia. Paper No. 116, NASA CP-1007.

47. Gilbert, M. G.: A Sensitivity Method for Integrated Structural Active Control Law Design. Presented at the NASA Langley/VPI&SU Symposium on Sensitivity Analysis in Engineering, September 25-26, 1986, Hampton, Virginia. NASA CP pending.

48. Eckstrom, C. V.: Prediction of Wing Aeroelastic Effects on Aircraft Lift and Pitching Moment Characteristics. Presented at the 63rd Meeting of the AGARD Structures and Materials Panel Specialists' Meeting on Static Aeroelastic Effects on High-Performance Aircraft, September 28 - October 3, 1986, Athens, Greece.

49. Murrow, H. N.: Measurements of Atmospheric Turbulence. Presented at the NASA Langley Workshop on Atmospheric Turbulence Relative to Aviation, Missile, and Space Programs, April 2-4, 1986, Hampton, Virginia. NASA CP pending.

50. Weisshaar, T. A.; Newsom, J. R.; Gilbert, M. G.; and Zeiler, T. A.: Integrated Structure/Control Design - Present Methodology and Future Opportunities. Presented at the 15th Congress of the International Council of the Aeronautical Sciences (ICAS), September 7-12, 1986, London, England. Paper No. ICAS 86-4.8.1.

51. Murrow, H. N.: A Summary of Atmospheric Turbulence Data (In-Situ Measurements) in the U.S.A. Presented at the AGARD Structures and Materials Panel Workshop on the Flight of Flexible Aircraft in Turbulence, September 29 - October 2, 1986, Athens, Greece. Proceedings pending.

Contractor Reports

52. Hajela, P.: Optimal Airframe Synthesis for Gust Loads. (NAG1-579 University of Florida.) NASA CR-178047, February 1986.

Tech Briefs

53. Arbuckle, P. D.; Sliwa, S. M.; Tiffany, S. H.; and Roy, M. L.: FIT: A Computer Program That Interactively Determines Polynomial Equations for Data Which Are a Function of Two Independent Variables. NASA Tech Brief LAR-13457.

AEROTHERMAL LOADS BRANCH

Journal Publications

54. Swann, R. T.; Wood, G. M., Jr.; Brown, R. D.; Upchurch, B. T.; and Allen, G. J.: Non-Catalytic Surfaces for Metallic Heat. Progress in Astronautics and Aeronautics, Volume 96, Thermal Design of Aeroassisted Orbital Transfer Vehicles, edited by H. F. Nelson, 1985, p. 538-558.

55. Macaraeg, M. G.: The Effect of Power-Law Body Forces on a Thermally Driven Flow Between Concentric Rotating Spheres. Journal of the Atmospheric Sciences, Volume 43, No. 3, February 1, 1986, p. 302-304.

56. Macaraeg, M. G.: Numerical Experiments of Axisymmetric Flow in a Nonuniform Gravitational Field. AIAA Journal, Volume 24, No. 9, September 1986, p. 1483-1487.

57. Macaraeg, M. G.; and Streett, C. L.: Improvements in Spectral Collocation Discretization Through a Multiple Domain Technique. Applied Numerical Mathematics, Volume 2, No. 2, April 1986, p. 95-108.

Formal NASA Reports

58. Macaraeg, M. G.: Application of CFD to Aerothermal Heating Problems. NASA TM-87670, January 1986.

59. Macaraeg, M. G.; and Streett, C. L.: A Spectral Multi-Domain Technique With Application to Generalized Curvilinear Coordinates. NASA TM-87701, March 1986.

60. Lewis, B. W.; Brown, K. G.; Wood, G. M., Jr.; Puster, R. L.; Paulin, P. A.; Fishel, C. E.; and Ellerbe, D. A.: Mass Spectrometric Gas Composition Measurements Associated With Jet Interaction Tests in a High-Enthalpy Wind Tunnel. NASA TM-87642, June 1986.

61. Streett, C. L.; and Macaraeg, M. G.: Preconditioning for First-Order Spectral Discretizations. NASA TM-87619, August 1986.

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62. Macaraeg, M. G.: Applications of CFD to Aerothermal Heating Problems. Presented at the AIAA 24th Aerospace Sciences Meeting, January 6-9, 1986, Reno, Nevada. AIAA Paper No. 86-0232.

63. Singh, J. J.; Sprinkle, D. R.; and Puster, R. L.: A New On-Line Technique for Natural Gas Calorimetry. Presented at the Institute of Gas Technology Second Annual Symposium on "Natural Gas Energy Measurement", April 30-May 2, 1986, Chicago, Illinois. In Proceedings, Section 4, p. 1-25.

64. Thornton, E. A.; Dechaumphai, P.; Vemaganti, G.; and Wieting, A. R.: Finite Element Approach for Prediction of Aerothermal Loads. Presented at the AIAA/ASME 4th Joint Fluid Mechanics, Plasma Dynamics and Lasers Conference, May 12-14, 1986, Atlanta, Georgia. AIAA Paper No. 86-1050.

65. Macaraeg, M. G.; and Streett, C. L.: Spectral Multiple Domain Technique With Application to Generalized Curvilinear Coordinates. Presented at the INRIA Sixth International Symposium on Finite Element Methods in Flow Problems, June 16-20, 1986, Antibes, France. In Proceedings, p. 231-238.

Tech Briefs

66. Singh, J. J.; Sprinke, D. R.; and Puster, R. L.: New Method for Determining Heats of combustion of Gaseous Hydrocarbons. NASA Tech Brief LAR-13528.

THERMAL STRUCTURES BRANCH

Journal Publications

67. Shideler, J. L.; Webb, G. L.; and Pittman, C. M.: Verification Tests of Durable Thermal Protection System Concepts. Journal of Spacecraft and Rockets, Volume 22, No. 6, November - December, 1985, p. 598-604.

68. Sawyer, J. W.: Effect of Stitching on the Strength of Bonded Composite Single Lap Joints. AIAA Journal, Volume 23, No. 11, November 1985.

69. Prabharan, R.; and Sawyer, J. W.: A Photoelastic Investigation of a Symmetric Four Point Bend Shear Test for Composite Materials. Composite Structures Journal, Volume 5, No. 3, 1986, p. 217-231.

70. Taylor, A. H.; Cerro, J. A.; and Jackson, L. R.: Analytical Study of Reusable Flight-Weight Cryogenic Propellant Tank Designs. Journal of Spacecraft and Rockets, Volume 23, No. 2, March - April 1986, p. 149-157.

Formal NASA Reports

71. Royster, D. M.; Davis, R. C.; Shinn, J. M.; Bales, T. T.; and Wiant, H. R.: Fabrication and Evaluation of Superplastically Formed/Weld-Brazed Corrugated Compression Panels with Beaded Webs. NASA TP-2512, November 1985.

72. Sawyer, J. W.: Experimental Evaluation of Mechanical Joints in 2-Dimensional Carbon-Carbon Material at Room and Elevated Temperatures. NASA TM-87648, February 1986.

73. Shore, C. P.: Review of Convectively Cooled Structures for Hypersonic Flight. NASA TM-87740, May 1986.

Conference Presentations

74. Sawyer, J. W.: Experimental Evaluation of Mechanical Joints in 2-Dimensional Carbon-Carbon Material at Room and Elevated Temperatures. Presented at the Seventh JANNAF Rocket Nozzle Technology Meeting, November 13-15, 1985, Monterey, California. Proceedings pending.

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FY 87 PLANS

The FY 87 plans for the Loads and Aeroelasticity Division are broken out by each of the branches (technical areas) and selected highlights of proposed FY 87 milestones are presented.

Configuration Aeroelasticity Branch

For FY 87 the Configuration Aeroelasticity Branch (CAB) will continue its broadly based research program on dynamic and aeroelastic phenomena of aircraft and rotorcraft as summarized in figure 39.

A large portion of this work is associated with tests in the Langley Transonic Dynamics Tunnel (TDT) with companion theoretical studies. Research studies are planned for both rotorcraft and airplanes. The rotorcraft studies will use the aeroelastic rotor experimental system (ARES). Rotorcraft work will focus on applications of advanced aerodynamic and structural methodology to new rotor concepts. Airplane focused studies include such items as adaptive active flutter suppression, aeroelastic tailoring, and empennage buffet. In addition, to research studies, an aeroelastic verification test is planned for the new wing for the A-6 airplane.

Work will continue in the area of prediction of helicopter vibration characteristics by using finite element modeling procedures. Studies involving the major airframe manufacturers will be continued.

Significant progress in the development of a new data acquisition, display, and control system for the TDT is expected. The installation of the wiring to connect the system to the various stations to be served will be completed. The system will be ready for off-line operation near the end of the year.

Selected highlights of proposed FY 87 milestones are listed below and are shown by figures 40 through 43.

Aircraft Aeroelasticity:
- Aircraft Aeroelasticity
- Upgrading the Data Acquisition System for the Langley Transonic Dynamics Tunnel

Rotorcraft Aeroelasticity:
- Rotorcraft Dynamics and Aeroelasticity

Rotorcraft Structural Dynamics:
- A National Capability to Analyze Vibration as Part of Helicopter Structural Design

Each highlight is accompanied by descriptive material.

Unsteady Aerodynamics Branch

For FY 87 there will be continuing activity in developing finite-difference algorithms to solve nonlinear, unsteady fluid flow equations for application to aeroelastic analysis (Figure 44). A major effort will be to complete the development and validation of the CAP-TSD (Computational Aeroelasticity Program-Transonic Small Disturbance) code. The code significantly improves the efficiency of aeroelastic calculations and is capable of treating complete vehicle geometries, including the effects of multiple lifting surfaces, fuselages, and wing stores. A three-dimensional full potential code will be developed to assess the advantages of full potential vs. transonic small disturbance theory. Work will be initiated to apply Euler and Navier-Stokes codes to problems in unsteady aerodynamics and aeroelasticity. Navier-Stokes calculations will be performed for correlation with unsteady pressures measured at Reynolds numbers up to 35 million.

The experimental program will include two wind tunnel tests, the completion of a model design, and the acquisition of a research facility. One test will be conducted to measure unsteady pressures on interfering lifting surfaces while one surface is undergoing unsteady motions. A wing/oscillating canard configuration will be used for the test. The other test will be a canard alone high angle of attack dynamic test. A benchmark aeroelastic model will be designed. A low cost facility for basic unsteady aerodynamic and aeroelastic studies will be acquired. The facility also can be used to test the aeroelastic and unsteady aerodynamic characteristics of new and novel flight vehicle configurations.

Selected highlights of proposed FY 87 milestones are listed below and are shown by figures 45 through 47.

Theory Development and Design Methods:
- Development of Complete Aircraft Transonic Aeroelasticity Code

Experiments:
- Wind Tunnel Test to Measure Wing/Canard Interference Effects on Unsteady Pressure
- Basic Aeroelastic and Unsteady Aerodynamic Research Facility

Each highlight is accompanied by descriptive material.

Aeroservoelasticity Branch

There are several efforts planned for FY 87 in each of the three major areas of analysis methods, design methods, and applications and validations (figure 48).

In the analysis methods area, the renewed area of research in static aeroservoelasticity will continue. Both linear and nonlinear methods will be investigated. There will be a focus on development of optimal sensitivity analysis for both analysis and control law synthesis. This development will provide the basis for integrated structure/control design methodology.

In the applications and validations area, control laws for the active flexible wing model will be tested and analytical results compared with experimental data. Data from the ARW-2 wind-tunnel test will continue to be analyzed. Aeroservoelastic analyses of the oblique wing aircraft, both in the subsonic and supersonic speed range, will begin. The development of aerothermoservoelasticity analysis methods will begin with application to the National Aero-space Plane Program.

Reporting will begin on results of the spanwise gradient measurements of atmospheric turbulence.

Selected highlights of proposed FY 87 milestones are listed below and are shown by figures 49 through 51.

Analysis and Design Methods:
- Functional Integration Technology (FIT) Team Participation
- Integrated Aero/Thermal/Elastic Analysis

Applications and Validations:
- Perform Aeroservoelastic Analysis of the RSRA/X-Wing Aircraft

Each highlight is accompanied by descriptive material.

Aerothermal Loads Branch

For FY 87, there will be a continuing level of activity in all three disciplines as summarized in figure 52.

Experiments - The major thrusts of the thermal loads research effort for FY 87 consists of three specific tasks: 1) complete tests to establish a design and code validation data base of aerothermal loads for a blunt leading edge model with an impinging shock and for other generic hypersonic vehicle local configurations; 2) obtain gap heating results for a curved surface subject to a pressure gradient across the surface; 3) characterize the 2-D turbulent boundary layer in the 8' HTT.

Analysis - The major thrust for the ALB analytical effort in FY 87 consists of two specific tasks: 1) continued development and validation of finite element methodology for the prediction of aerothermal loads to complement and supplement the experimental effort including implementation and evaluation of 3-D viscous analysis and adaptive/unstructured grid refinement strategies; 2) continue development and validation of the integrated fluid-thermal-structural analysis capability as a tool to design and evaluate structural concepts for super/hypersonic vehicles including implementation of an internal cooling model. Major efforts will be devoted to completing finite element analyses of a blunt leading edge with an impinging shock and a compression corner utilizing adaptive/unstructured mesh strategies.

Facilities and Test Techniques - The facilities effort involves the safe and efficient operation and the expansion of the test capabilities of the high energy facilities of the Aerothermal Loads Branch.

A major effort for facilities development is support of the modification (FY 87 CofF) to the the 8' HTT which will make it a unique national research facility for testing air-breathing propulsion systems for very high-speed aircraft and missiles. In support of this effort, the 7" HTT will be used to investigate alternate modes of oxygen injection and to develop propulsion testing support structures. Recertification of the combustor pressure vessel is schedule for this year.

FY 87 testing in the 8' HTT will include a U.S. Army Transpiration Cooled Radom model, the Curved Surface Test Apparatus Chine Gap Heating Model, a Survey of the 2-D Turbulent Boundary Layer on the Panel Holder, a Second Generation Curved Metallic TPS Model, and a Swept Leading Edge Model.

Selected highlights of the proposed FY 87 milestones are listed below and are shown in figures 53 through 56.

Experiments:

- Aerothermal Loads Experimental Program

Analysis:

- 2-D Flow Over a Compression Corner - Finite-Element Navier-Stokes Code Validation
- Shock-On-Lip Analysis

Facilities and Test Techniques:

- Oxygen Enrichment and Alternate Mach Number Modification to the 8'High Temperature Tunnel

Each highlight is accompanied by descriptive material.

Thermal Structures Branch

There are several major research activities for FY 87 which collectively represent a concerted thrust to advance the state of the art in thermal structures (figure 57).

Systems studies will continue to identify structural technology needs and to assess various concepts proposed to meet these needs. Emphasis will be on The National Aerospace Plane and Super/Hypersonic Transport vehicles although efforts will continue in support of future space transportation systems with an emphasis on earth-to-orbit vehicles. Work on airframe structure will transition from titanium concepts developed for a Mach 5 airplane to actively cooled and carbon-carbon structures for use on high speed vehicles.

Work on TPS will be focused on: Solving the gap flow problem for superalloy metallic concepts, with tests of the modified curved surface TPS model scheduled for late FY 87; completion of tests of the 1 ft. x 2 ft. ACC panel with analysis of results for the gap heating at panel edges; and a new effort looking at heat pipes and active cooling for stagnation heating regions such as leading edges. The latter effort will consist of analytical studies and preliminary designs followed by detailed design, fabrication, and test of selected hardware components in FY 87.

In the area of propulsion structures, work will continue on the scramjet fuel injector strut, with fabrication expected to be completed by mid CY 87 and tests starting in late CY 87. Work on cowl lip cooling will be initiated with an analytical study of the effects of variations of geometries and heating rates on concept designs. Low level-of-effort contractor studies will continue on a ramjet indirect cooling system for use on a Mach 5 class cruise airplane, and a missile/scramjet engine structure program.

Analytical efforts will continue to focus on enhanced thermal structural analysis, with a focus on radiation heat transfer, and documentation of programs developed in-house for conceptual design studies.

Selected highlights of the proposed FY 87 milestones are listed below and are shown in figures 58 through 60.

Propulsion Structures:
- Analysis of Scramjet Engine Strut

Airframe Structures:
- Cryogenic Tank Thermal Analysis for Use in Advanced Hypersonic Aircraft and Space Transportation Systems

Analysis and Synthesis Methods:

Each highlight is accompanied by descriptive material.

CONCLUDING REMARKS

This publication documents the FY 1986 accomplishments, research and technology highlights, and FY 1987 plans for the Loads and Aeroelasticity Division.

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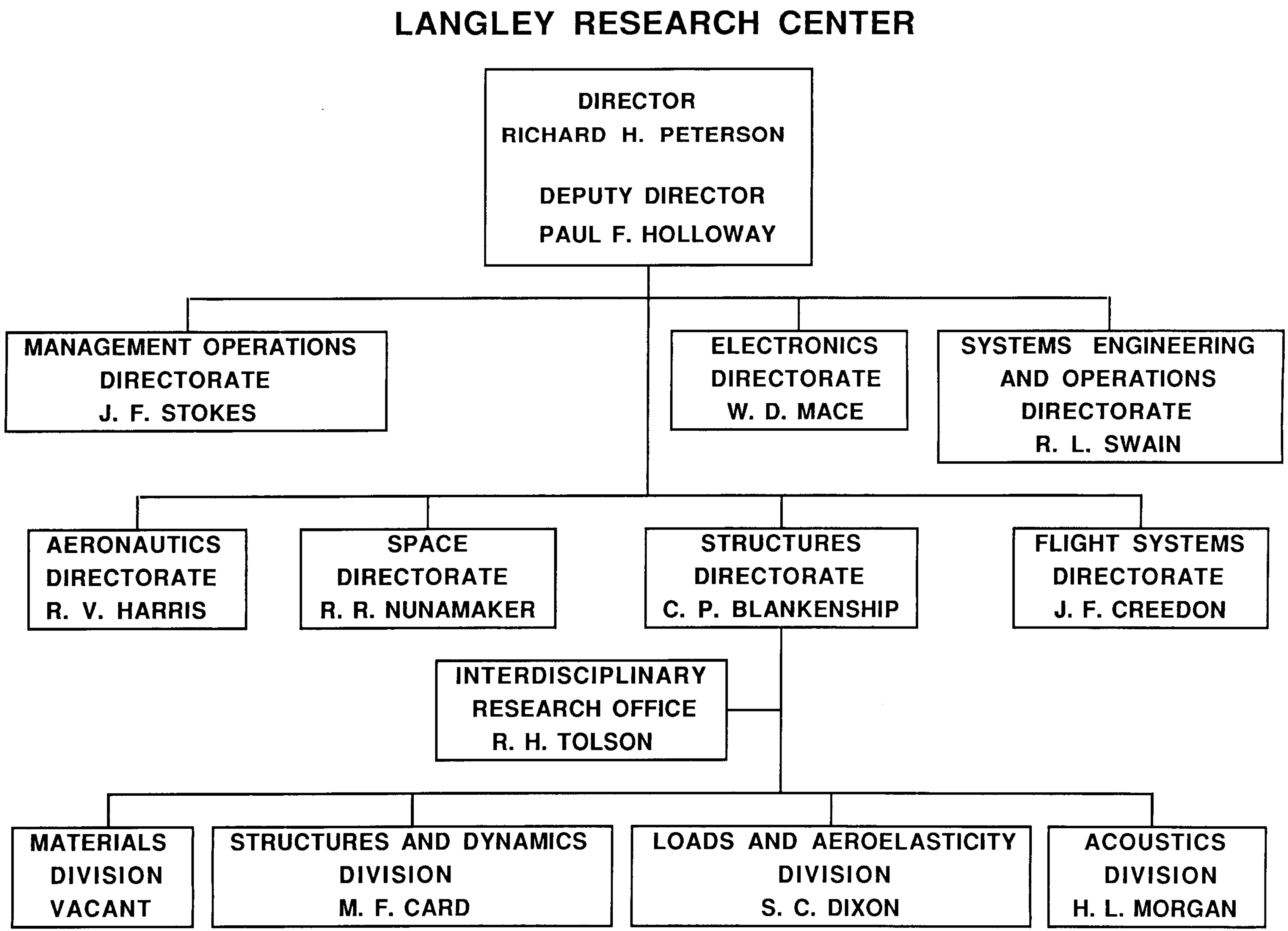
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MATERIALS DIVISION VACANT
STRUCTURES AND DYNAMICS DIVISION M. F. CARD
LOADS AND AEROELASTICITY DIVISION S. C. DIXON
ACOUSTICS DIVISION H. L. MORGAN

FIGURE 1.

LOADS AND AERONELASTICITY DIVISION
5

CHIEF: SIDNEY C. DIXON
ASSISTANT CHIEF: IRVING ABEL
TECHNICAL ASSISTANT: JAMES E. GARDNER

CONFIGURATION AEROELASTICITY
13 + 10*

HEAD: ROBERT DOGGETT
ASST: BILL CAZIER

- AIRCRAFT AEROELASTICITY
- ROTORCRAFT AEROELASTICITY
- ROTORCRAFT STRUCTURAL DYNAMICS

UNSTEADY AERODYNAMICS
11

HEAD: JOHN EDWARDS

- THEORY DEVELOPMENT
- DESIGN METHODS
- EXPERIMENTS

AEROSERVOELASTICITY
9

HEAD: VACANT

- ANALYSIS METHODS
- DESIGN METHODS
- APPLICATIONS AND VALIDATIONS

AEROTHERMAL LOADS
13

HEAD: ALLAN WIETING

- EXPERIMENTS
- ANALYSIS
- FACILITIES AND TEST TECHNIQUES

THERMAL STRUCTURES
15

HEAD: DONALD RUMMLER
ASST: RODNEY RICKETTS

- PROPULSION STRUCTURES
- AIRFRAME STRUCTURES
- ANALYSIS AND SYNTHESIS METHODS

TOTAL NASA - 66

* TOTAL ARMY - 9

* TOTAL AF - 1

FIGURE 2.

LOADS AND AEROELASTICITY DIVISION

LONG RANGE THRUSTS

AERONAUTICS

- AEROELASTIC STABILITY AND RESPONSE OF AIRCRAFT AND ROTORCRAFT
- LIGHTWEIGHT, HOT STRUCTURES FOR HIGH SPEED AIRCRAFT

SPACE

- AEROTHERMAL STRUCTURES & MATERIALS TECHNOLOGY FOR STS

FIGURE 3.

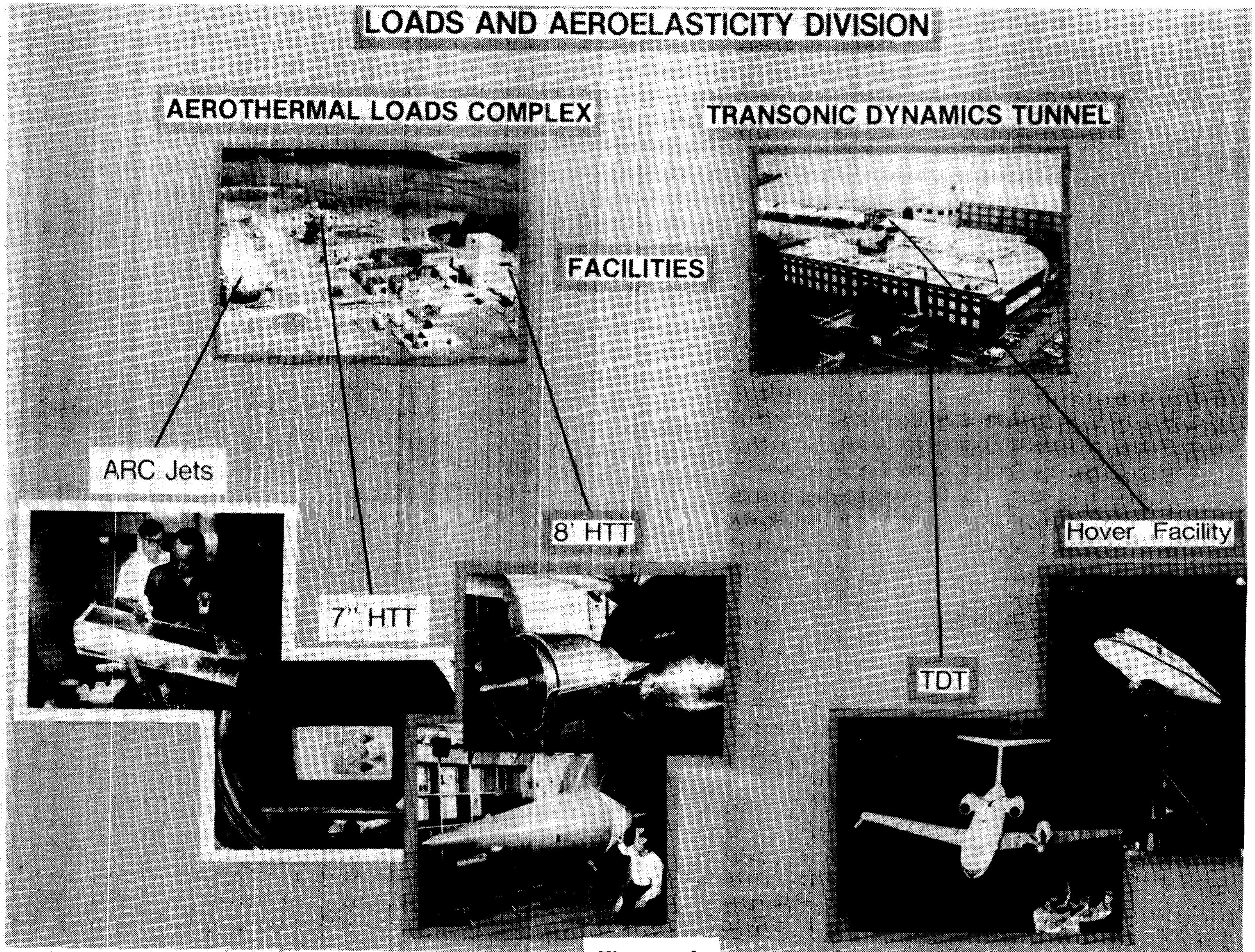
LOADS AND AEROELASTICITY DIVISION
AEROTHERMAL LOADS COMPLEX
TRANSONIC DYNAMICS TUNNEL
FACILITIES
ARC Jets
7" HTT
8' HTT
TDT
Hover Facility

Figure 4.

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L-84-10,997

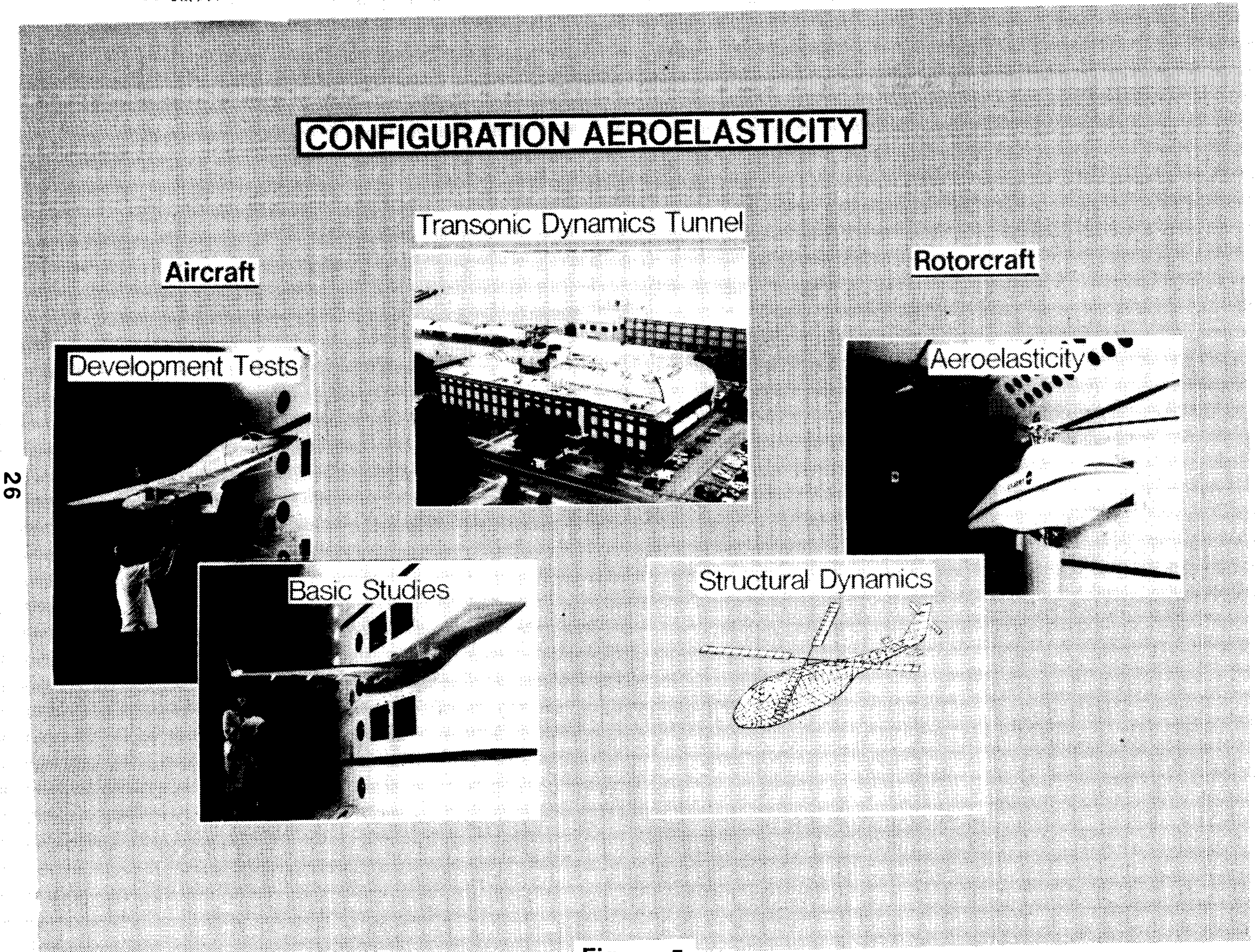

Figure 5.

CONFIGURATION AEROELASTICITY

FIVE YEAR PLAN

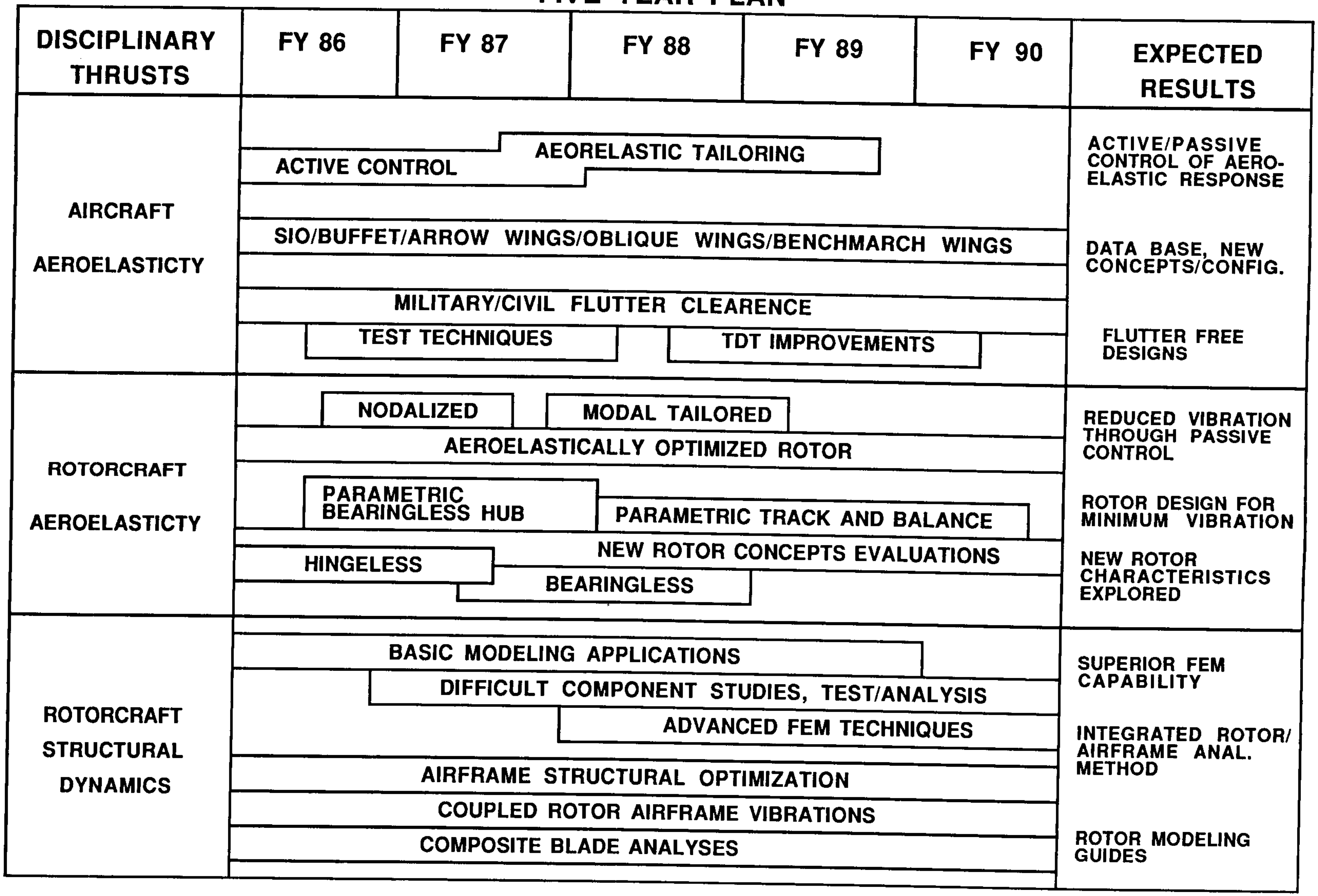

FIGURE 6.

UNANTICIPATED FLUTTER CHARACTERISTICS OF NEW COMPOSITE A-6 WING IDENTIFIED IN TDT TESTS

Stanley R. Cole and Jose A. Rivera
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-63-21

Research Objective - Because the A-6 Intruder airplane is an important part of the Navy's air arm and will be used for many years to come, a new composite-structure wing to improve fatigue characteristics and to remove flutter placards for certain external store configurations is being developed. To verify that the new design has acceptable flutter speeds, an experimental study was undertaken to determine the transonic flutter characteristics.

Approach - A 1/4-size dynamically scaled aeroelastic model was tested in the Langley Transonic Dynamics Tunnel (TDT) to determine the flutter characteristics of the wing with and without external stores. The store configurations to be studied were selected from those expected to be used most commonly and to have the most impact on flutter. A photograph of the semi-span model mounted in the wind tunnel is shown in figure 7(b). The aerodynamic effects of the fuselage on the wing were accounted for by using a rigid fuselage fairing. The model wing was attached to the wall through a specially designed fixture that simulated the wing-fuselage attachment flexibility.

Accomplishment Description - A total of eight configurations were tested at transonic Mach numbers. An aggregate number of 14 flutter points was obtained. The tests of the clean wing, both with and without pylons, showed that the flutter characteristics of the basic wing were satisfactory. The flutter boundary was well outside the airplane planned operating envelope. The flutter characteristics of some of the key external store configurations were not satisfactory and were quite different from what had been predicted by analysis prior to the test. Some illustrative flutter results are shown on the figure for a configuration with a 300-gallon fuel tank mounted on each of the two inboard pylons. Also included is the calculated flutter boundary. Aerodynamic forces on the tanks were not included in this analysis because they were thought to have a second order effect. The experimental data show an almost constant dynamic pressure flutter boundary, whereas the analytical data show a typical transonic "bucket-like" boundary. To aid in further understanding these experimental results, flutter tests were conducted with the large fuel tanks replaced by "pencil" stores that were thin streamlined bodies having the same inertial properties as the fuel tanks. As shown in the figure, these data have a Mach number effect as predicted analytically. These results indicate that store unsteady aerodynamics play an important role in the flutter mechanism for the new A-6 wing design.

Significance - Wind-tunnel flutter tests are conducted as early as possible in the design process to ensure that any flutter deficiency can be identified early when the cost in dollars and in time to fix the problem is minimum. In addition, wind-tunnel tests such as these reduce the extent of very costly flight flutter testing. In this instance, a flutter deficient design was identified early in the design process and efforts are already underway to modify the design.

Future Plans - Although the wing of the model was destroyed during the wind-tunnel tests, sufficient data were obtained to understand the flutter characteristics and modify the structural design to have acceptable flutter properties. Additional wind-tunnel tests are planned for CY 1987 using a new model that incorporates the design changes.

Figure 7(a).

UNANTICIPATED FLUTTER CHARACTERISTICS OF NEW COMPOSITE A-6 WING IDENTIFIED IN TDT TESTS

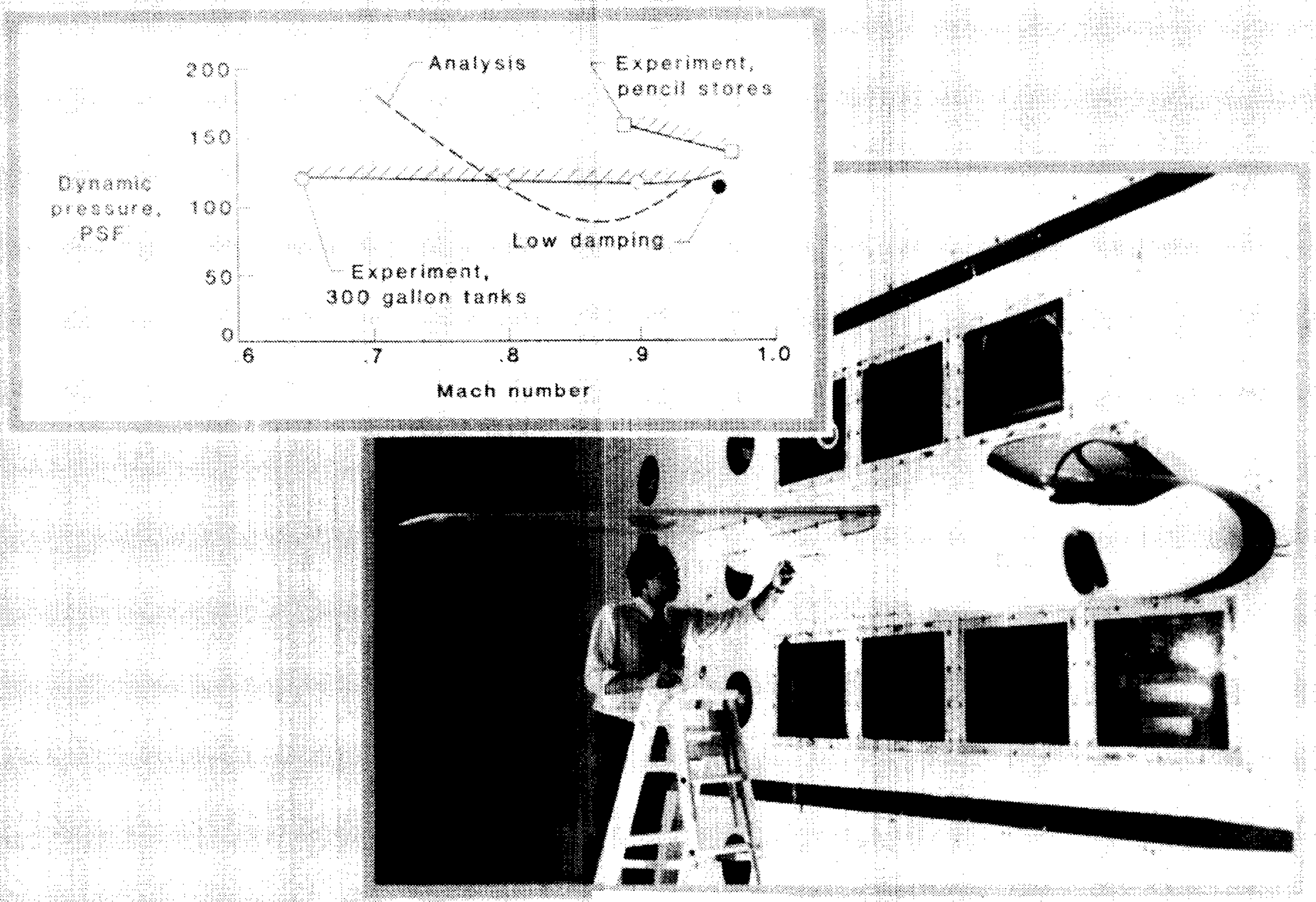

Figure 7(b).

UNUSUAL INSTABILITY BOUNDARY FOR DAST ARW-2 FOUND TO BE NARROW TRANSONIC RESPONSE REGION

Maynard C. Sandford, Clinton V. Eckstrom, and David A. Seidel
Configuration Aeroelasticity, Aeroservoelasticity, and Unsteady Aerodynamics Branches
Extensions 2661, 3834, and 4236

RTOP 505-63-21

Research Objective - The objective of this research is to investigate further an unusual transonic instability encountered in a previous test of the second DAST aeroelastic research wing (ARW-2) in the Langley Transonic Dynamics Tunnel (TDT).

Approach - During previous tests in 1983, what appeared to be a wing first-bending mode instability was encountered using a subcritical response technique at dynamic pressures well below the predicted classical flutter boundary. This instability occurred at nearly constant Mach number of 0.9 and covered an extreme range of dynamic pressures from 50 psf to above 300 psf. It was sensitive to wing angle-of-attack. Because this instability exhibited similar characteristics to that known as shock induced oscillations (SIO), it was decided that a second test in the TDT would be worthwhile to explore in more detail this unusual instability.

Accomplishment Description - The test in January 1986 found no "hard flutter" conditions. These tests showed that the previously identified instability boundary could be penetrated at $\alpha = 0°$. Penetration tests at three dynamic pressure levels of about 80, 160, and 310 psf near the critical Mach number indicated that wing motion increases proportionately with dynamic pressure. This wing motion was comprised mainly of the first bending mode which had a wind-off frequency of 8.2 Hz. Typical results of the normalized wing tip motion are shown in figure 8(b). The wing tip motion rises rapidly at M = 0.90, reaches a maximum near M = 0.93, and decreases rapidly at M = 0.95. Frequency response plots shown in the figure for several Mach numbers illustrate vividly the rapid rise in the wing first bending mode near 10 Hz over a narrow transonic Mach number range. Tufts were installed on the wing and indicated visually large regions of flow separation near the trailing edge of both the upper and lower surfaces above M = 0.90. Wing angle-of-attack effects were observed but the effects exhibited no consistent pattern. A worthwhile note, at a dynamic pressure of 325 psf, M = 0.92 and $\alpha = -1°$, the wing tip experienced peak-to-peak deflections of about six inches (a 50-percent increase over the corresponding deflection for $\alpha = 0°$), and required use of the tunnel emergency stop system.

Significance - This investigation has provided additional information which will provide a better understanding of the mechanisms involved in the dynamic response characteristics of advanced configurations at transonic speeds, thus contributing markedly to the flight safety of these configurations.

Future Plans - Complete data analysis and publish results in formal NASA papers.

Figure 8(a).

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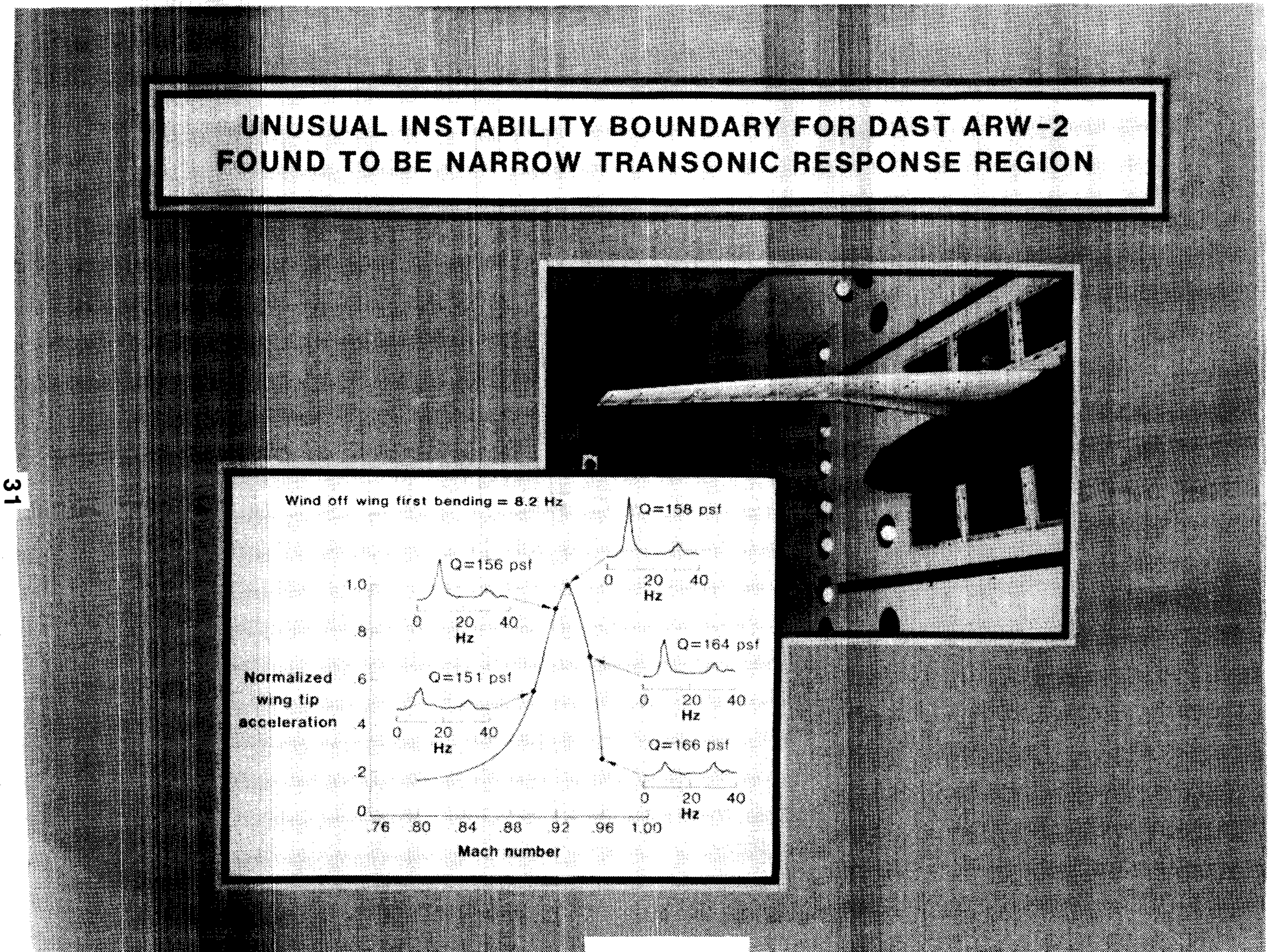

Figure 8(b).

ADAPTIVE FLUTTER SUPPRESSION SYSTEM EVALUATED IN TDT TESTS

F. W. Cazier, Jr. and Moses G. Farmer
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-63-21

Research Objective - Because modern fighter aircraft carry a large variety of external wing-mounted stores, in some instances it is necessary to placard the operational envelope because of flutter. One approach to avoiding this restriction is to use an active control system to suppress flutter. Such a system operates by sensing wing or store motion and feeding back these signals through appropriate control laws to drive control surfaces to produce forces and moments to suppress flutter. Adaptive control systems are particularly attractive for this application because no knowledge of the store configuration being flown is required. Adaptive control systems continually measure system response due to control inputs and continually update control laws based on these measurements.

Approach - Recently, a 1/4-scale, cable-mounted F-16 aeroelastic model equipped with an Adaptive Flutter Suppression System (AFSS) was tested in the Langley Transonic Dynamics Tunnel (TDT) in a joint USAF/NASA/General Dynamics test. A photograph of the model is shown in figure 9(b) along with a sketch illustrating the AFSS operation. Accelerometers were used to measure wing motion. The AFSS digital computer was located in the control room. Computer generated signals were sent to the flaperons to provide a continuous low amplitude random excitation to the model. The resultant wing motion was measured and a mathematical representation of the model was determined by using an analysis implemented on the digital computer. Using this derived mathematical model a control law was then developed to suppress flutter.

Accomplishment Description - Flutter data, AFSS off and AFSS on, were obtained for three flutter critical store configurations. System-on testing began below the flutter boundary and proceeded above the system-off flutter boundary. The adaptive control law would update approximately four times per minute. Although this update rate is too slow for practical airplane applications, it was adquate for the purposes of this study. Mach number and dynamic pressure were increased until maximum test conditions were achieved or until a control law was developed which could not suppress flutter (at which time control was switched automatically to a previously tested non-adaptive control law which acted as a "flutter stopper"). The maximum demonstrated improvement in flutter dynamic pressure was approximately 22 percent. Although this improvement was significant, it was less than that demonstrated by the non-adaptive control law used as the backup for safety purposes.

Significance - Adaptive flutter suppression with no predetermined control laws or knowledge of store configuration has been successfully demonstrated on a full-span, "free-flying" model. Data obtained during this initial study will provide an invaluable foundation upon which to build future studies.

Future Plans - A second wind-tunnel test with significantly faster computers and more advanced software is scheduled in 1987. Ejection of stores to rapidly create a flutter-critical condition will be performed during this test series.

Figure 9(a).

NASA
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ADAPTIVE FLUTTER SUPPRESSION EVALUATED IN TDT TESTS

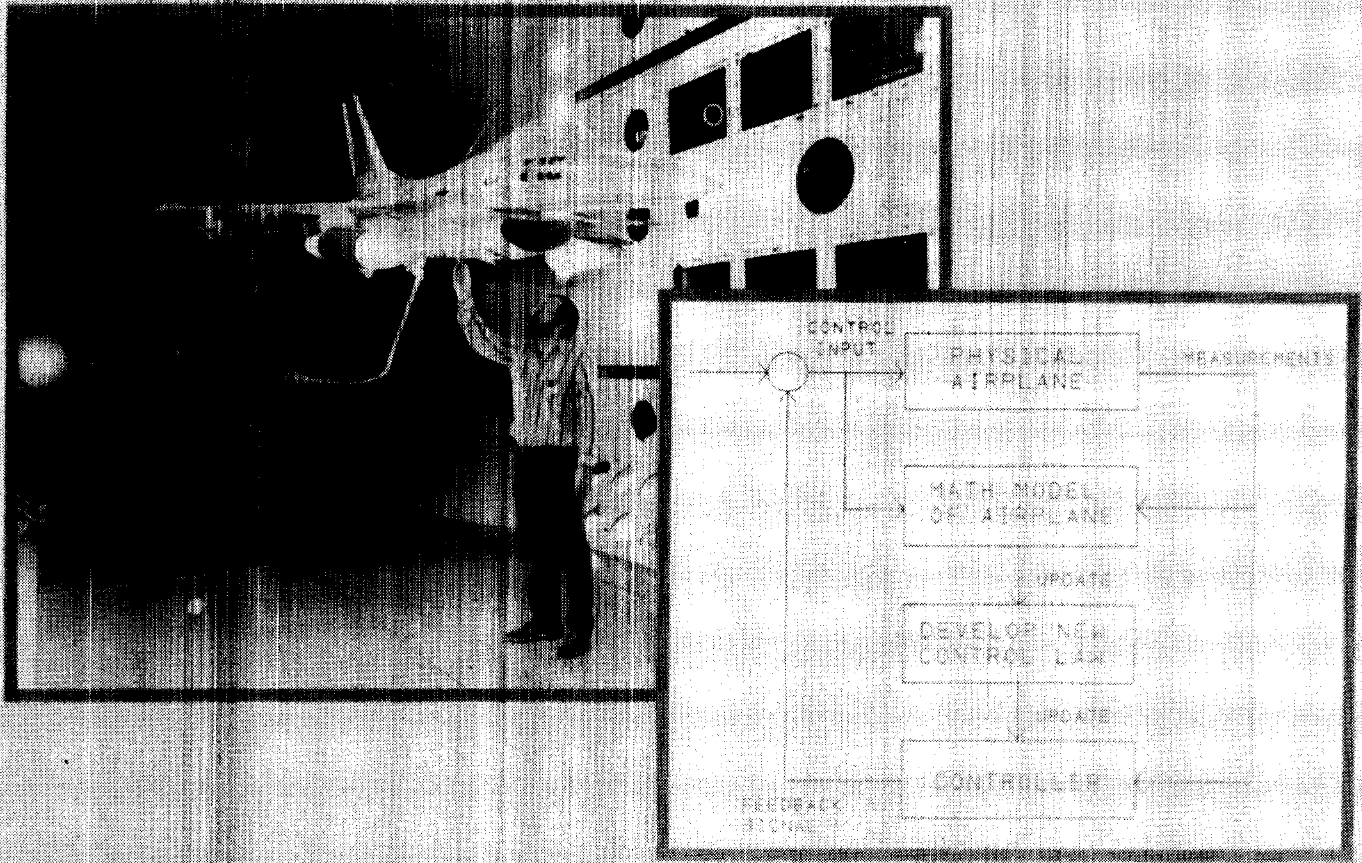

Figure 9(b).

ACTIVE FLEXIBLE WING MODEL SUCCESSFULLY TESTED IN TDT

Maynard C. Sandford and Stanley R. Cole
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-63-21

Research Objective - Utilizing wing flexibility to provide control power is a technological concept that would be a useful capability for an advanced high performance fighter vehicle. This concept would use multiple active control surfaces to provide variation in the wing shape for roll and maneuver load control. In addition the active surfaces could be used for flutter suppression. The objective of the present tests of an active flexible wing was to obtain a database of measured static aerodynamic forces and moments due to multiple control surface deflections.

Approach - The active flexible wing model was designed and built by Rockwell International. The 1/6-scale, full-span configuration was tested in the Langley Transonic Dynamics Tunnel (TDT) as part of a cooperative program with AFWAL. This model was mounted to a tunnel sting arrangement which allowed the complete model freedom to roll about an axis near the sting centerline. Model loads were measured using a six-component balance. A hydraulic brake located on the sting at the rear of the model was used to prevent roll motion throughout most of these early tests. The complete model system is shown mounted in the wind tunnel in figure 10(b). The wings of the model were aeroelastically tailored to obtain the desired wing structural stiffness properties. The model had eight large control surfaces, two each on the leading and trailing edges of both wing panels.

Accomplishment Description - All objectives of this wind-tunnel test entry were successfully accomplished. Data for calculating roll control effectiveness of each control surface were obtained by moving the surfaces through their allowable deflection ranges at various tunnel conditions. Maneuver load control data were obtained at several tunnel conditions by measuring model loads for various combinations of control surface deflections and model angle of attack. Also, control system transfer functions were measured at several tunnel conditions. All of these data were obtained with the model hydraulic roll brake on to prevent roll motion. In addition, the model was flutter cleared throughout the test operating envelope. At the conclusion of these tests, the model hydraulic roll brake was released and the model roll capability was thoroughly checked out. The hydraulic safety brake design worked quite satisfactorily. This brake will be used during a second test entry for model safety in the event that the roll control laws prove to be inadequate.

Significance - Data were obtained during this first wind-tunnel test entry for evaluating the capabilities of flexible wing control and its application to an advanced fighter vehicle concept. These data will be used to design control laws for active control of rolling maneuvers, maneuver loads, and loads due to gusts.

Future Plans - Control laws will be developed by NASA and Rockwell and implemented on digital computers. Experimental evaluation of these roll control concepts will be made in a second TDT entry, scheduled for early CY 1987. In addition, the model will be modified to measure pressure distributions on the wing before the second entry.

Figure 10(a).

NASA
L-86-5915

ACTIVE FLEXIBLE WING MODEL SUCCESSFULLY TESTED IN TDT

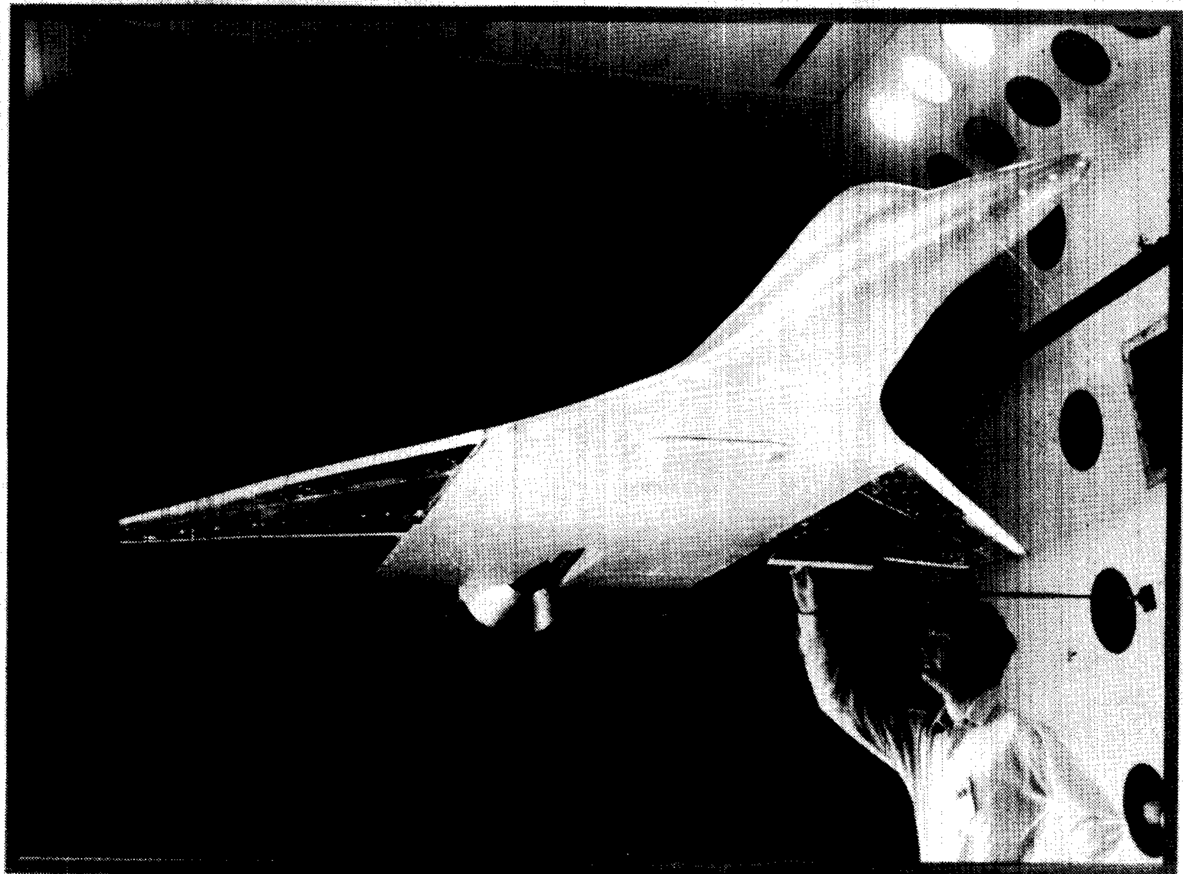

Figure 10(b).

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LANGLEY BLACKHAWK ROTOR DESIGN SHOWS PERFORMANCE IMPROVEMENTS OVER EXISTING ROTOR

William T. Yeager, Jr., Maj. Robert G. Cramer, Jr., Matthew L. Wilbur, Jeffrey D. Singleton, and Wayne R. Mantay
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-61-51

Research Objective - A planned U.S. Army program to upgrade the UH-60 (Blackhawk) helicopter includes the design and qualification of new main rotor blades to improve performance. (This upgrade may also include replacing the existing engines.) Performance improvements are expected in hover and in forward flight throughout the operational envelope. As part of this effort a model of an advanced rotor blade that was designed at the U.S. Army Aerostructures Directorate using technology which optimized blade planform, airfoil section, twist, and solidity was tested in the Langley Transonic Dynamics Tunnel (TDT). Tests such as these reduce the development risk by providing comparative data between a candidate advanced rotor and the baseline rotor. In addition, because of the parametric nature of the data, they provide a synergistic data base that can be used in evaluating analytical methods and in the development of other advanced rotor systems.

Approach - The TDT was chosen for these tests because of its unique ability to use Freon-12 as a test medium which allows closer simulation of a full-scale aerodynamic environment than is possible in air. This simulated aerodynamic environment was critical to the evaluation of the advanced rotor blade design. The tests involved 1/6-size aeroelastically scaled models of both the existing Blackhawk rotor and the advanced rotor. Each of the model rotors were tested at various rotor tasks defined by aircraft gross weight and propulsive force requirements at forward speeds up to approximately 170 knots. At each test condition, measurements of main-rotor torque were made to evaluate differences in performance between the two rotors.

Accomplishment Description - Some illustrative performance results from this investigation are shown in figure 11(b) for a nominal design condition used by the Army, namely, 4000 feet altitude and 95°F ambient temperature. Similar results were obtained for other temperature and altitude conditions. The data indicate improvements in performance for the advanced blade at all forward speeds for the two gross weight conditions presented. Although the data are not shown here, the advanced rotor also showed performance improvements in hover. Both the experimental hover and forward-flight performance results are also in agreement with analytical predictions (not shown in figure) made before the wind-tunnel test with the analyses used in the advanced rotor blade design process.

Significance - The improvements in performance obtained for the advanced blades are substantial: about 5-percent increase in hover efficiency and 20-percent power reduction for cruise. These tests have generated considerable interest in government and industry. The data could form the foundation for a flight demonstration program which could then determine the blades to be used for the growth Blackhawk helicopter. Furthermore, should the Army decide to re-engine the Blackhawk as part of the upgrade, these data will be invaluable in sizing the new engine.

Future Plans - Results will be documented in a NASA formal publication. Additional testing will be done to investigate the role of blade dynamics in reducing fixed-system vibration, without sacrificing rotor performance improvements already gained.

Figure 11(a).

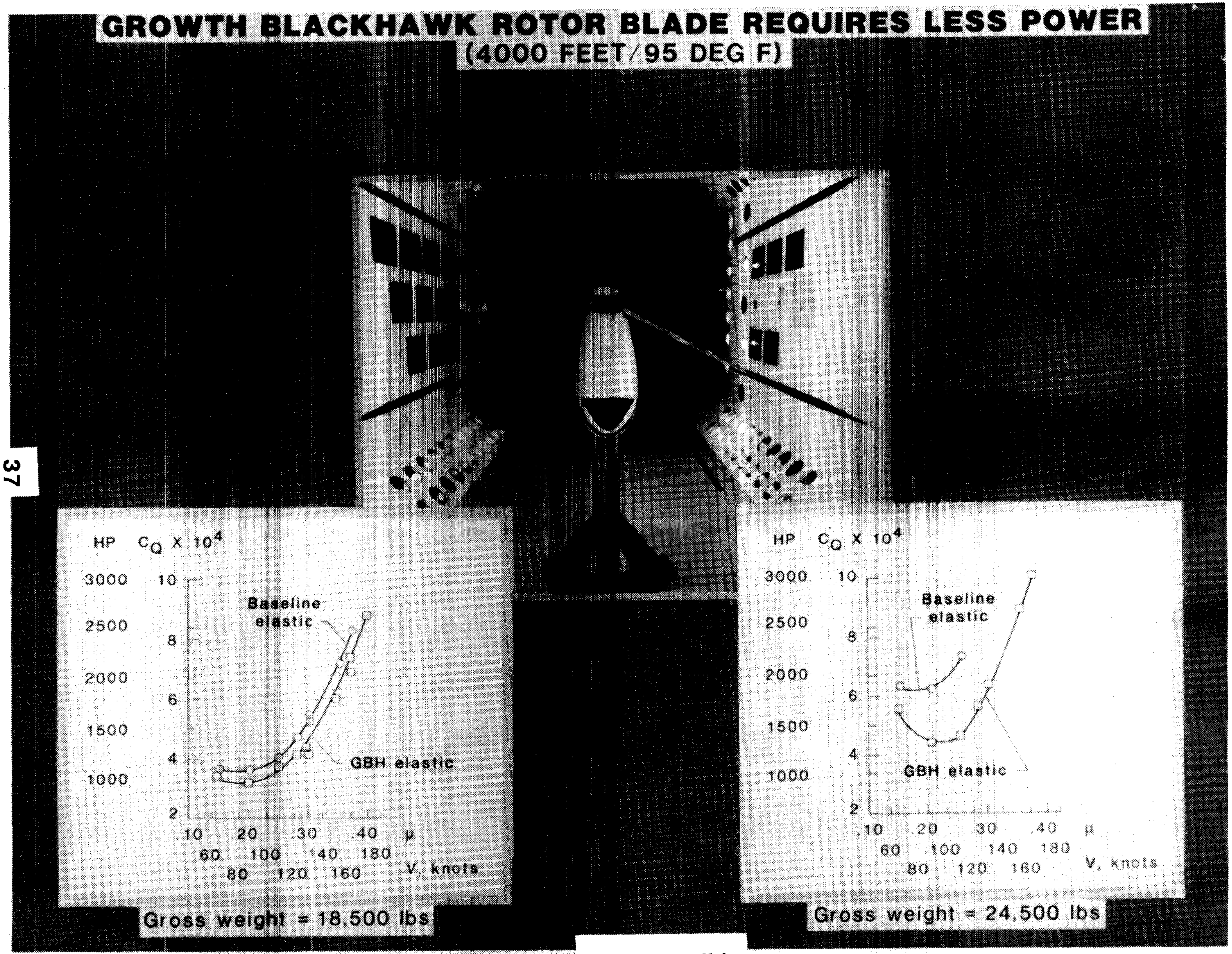
GROWTH BLACKHAWK ROTOR BLADE REQUIRES LESS POWER
(4000 FEET/95 DEG F)
HP
$C_Q \times 10^4$
3000
2500
2000
1500
1000
10
8
6
4
2
Baseline elastic
GBH elastic
.10
.20
.30
.40
μ
60
80
100
120
140
160
180
V, knots
Gross weight = 18,500 lbs
HP
$C_Q \times 10^4$
3000
2500
2000
1500
1000
10
8
6
4
2
Baseline elastic
GBH elastic
.10
.20
.30
.40
μ
60
80
100
120
140
160
180
V, knots
Gross weight = 24,500 lbs

Figure 11(b).

SENSITIVITY ANALYSIS IMPLEMENTED IN NASTRAN FOR HELICOPTER AIRFRAME OPTIMIZATION TO REDUCE VIBRATIONS

T. S. Murthy
PRC Kentron Inc.
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-63-51

Research Objective - Vibration continues to be a problem in helicopters despite considerable efforts to reduce it. The problem has been attacked by the use of active and passive vibration control devices, by design changes in the main rotor system, and by changes in airframe design. Often these solutions, particularly the use of vibration control devices, involves significant weight penalties. Although there have been several studies on rotor blade optimization for vibration attenuation, airframe optimization is a relatively new research topic and has only recently been addressed. Airframes are designed to satisfy strength, vibration and performance requirements. The selection of the best airframe that meets all the requirements, in particular the vibration requirement, is a difficult task. It would appear that structural optimization tools, properly brought to bear by the design engineer, would go a long way toward achieving the goal of a low vibration helicopter. The objective of the present study is to develop practical computational procedures for optimization of helicopter structures subjected to steady-state vibratory loads.

Approach - In-house research work was recently initiated to develop several key elements needed for optimization of airframes. The elements of the approach are: (1) formulating design sensitivity analysis procedures, (2) implementing sensitivity analysis in a general purpose finite element analysis program, (3) interfacing sensitivity analysis with an optimizer, (4) applying analysis to simple and complex finite-element models of airframes, and discussing optimization problems, methods, and results with engineers in the helicopter industry to ensure relevancy of research.

Accomplishment Description - Design sensitivity analysis for constraints on steady-state forced response have been formulated and implemented in MSC/NASTRAN as a new solution sequence to augment the already existing sensitivity analyses for statics and normal modes. Numerical results were obtained for a "stick" finite element model of the AH-1G helicopter airframe are shown in figure 12(b). The results indicate that the stiffness in the tailboom region should be increased to reduce vibration levels in the cockpit area of the fuselage for the case shown. The distribution of element strain energy densities (not shown in figure) in the airframe was found to be similar to the distribution of sensitivity coefficients, thus also indicating that the stiffness in the tailboom region be increased to control the forced response in the cockpit.

Significance - This work represents the completion of a necessary first step in developing a structural optimization procedure applicable to reducing vibrations of helicopter airframes.

Future Plans - Continue the overall research study by including damping effects in the sensitivity analysis, mating sensitivity analysis with an optimizer, and initiating applications to realistic structural problems.

Figure 12(a).

SENSITIVITY ANALYSIS IMPLEMENTED IN NASTRAN FOR HELICOPTER AIRFRAME OPTIMIZATION TO REDUCE VIBRATIONS

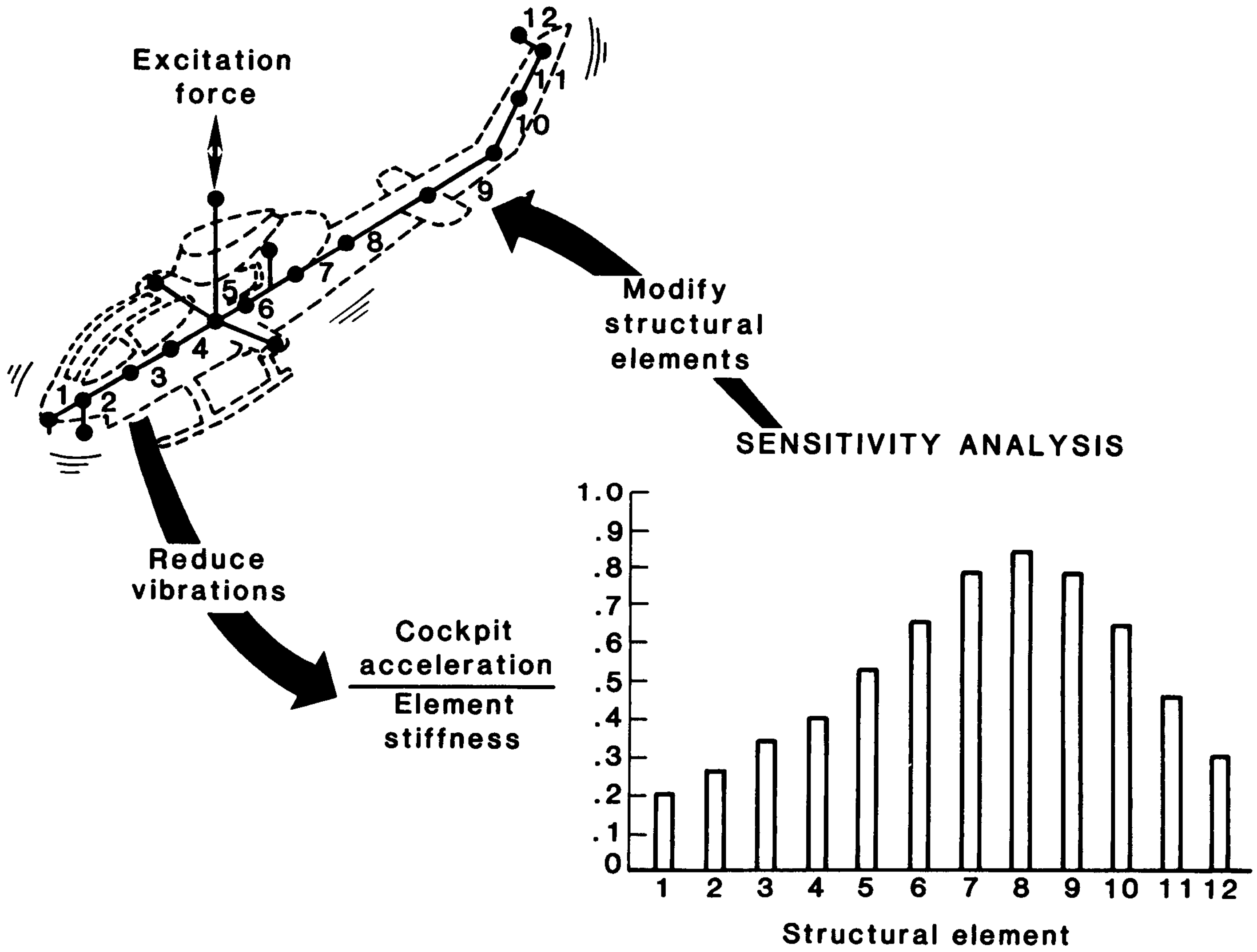

Figure 12(b).

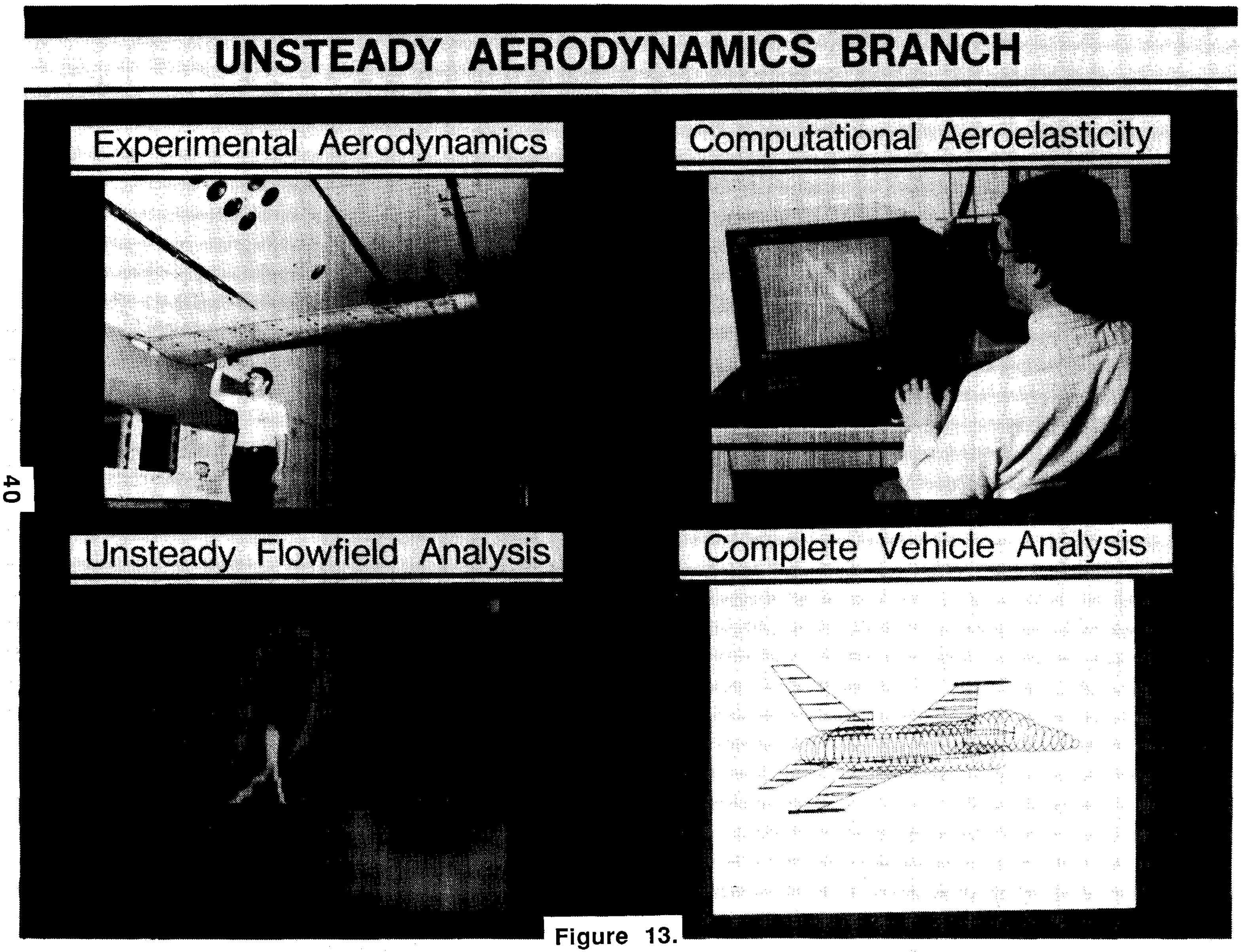

Figure 13.

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UNSTEADY AERODYNAMICS
FIVE YEAR PLAN

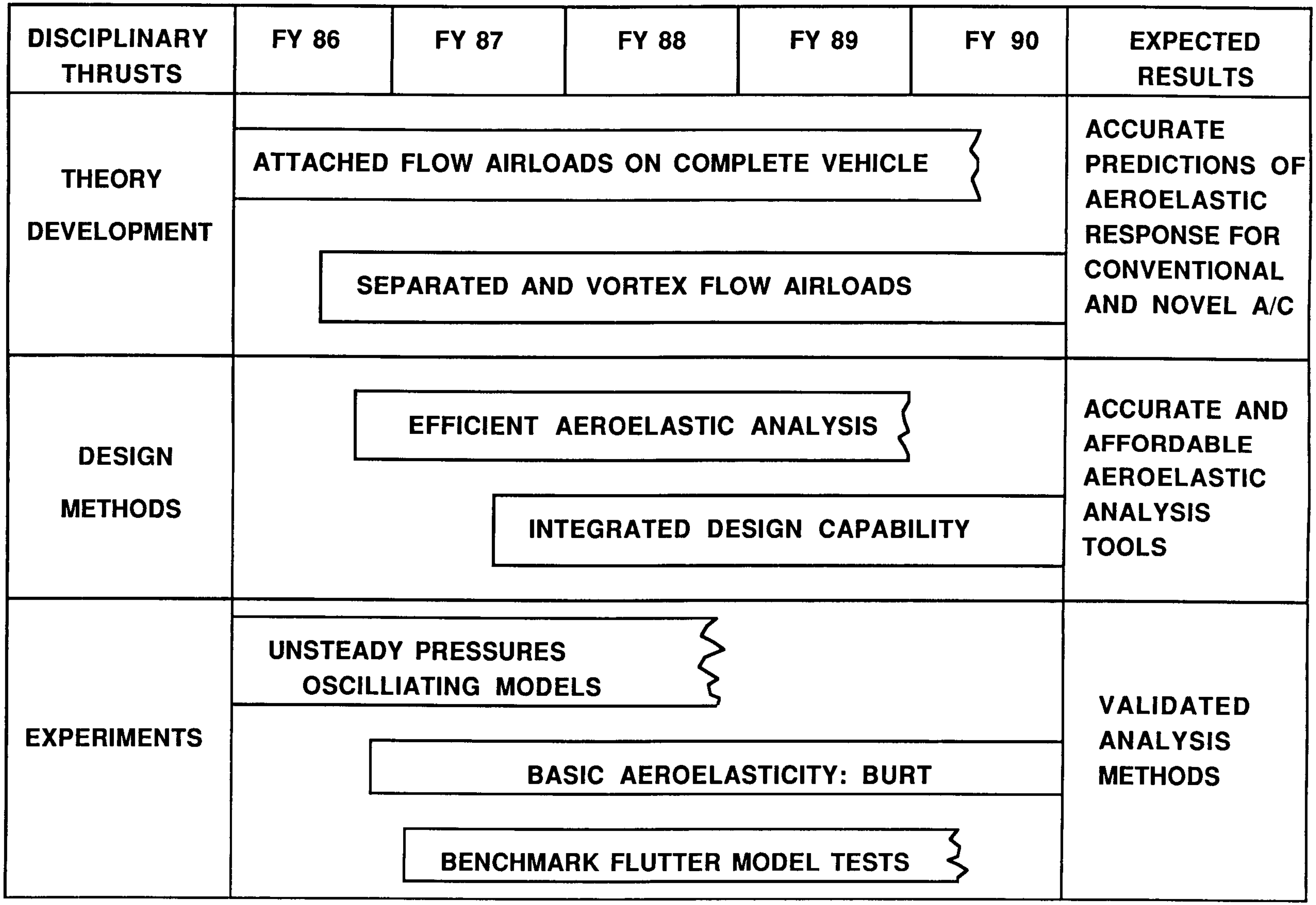


Figure 14.

NEW ALGORITHM FOR UNSTEADY TRANSONIC SMALL-DISTURBANCE EQUATION GIVES ORDER OF MAGNITUDE INCREASE IN COMPUTATIONAL EFFICIENCY

John T. Batina
Unsteady Aerodynamics Branch
Extension 4236

RTOP 505-63-21

Research Objective - The objective of the research was to develop an approximate factorization (AF) algorithm for solution of the unsteady transonic small-disturbance equation that is more efficient in comparison with the alternating- direction implicit (ADI) algorithm.

Approach - The ADI algorithm, which is implemented within the XTRAN3S code, is inefficient for application to practical wings of moderate to high sweep and taper, because of a severe numerical stability restriction. A new AF algorithm was developed to remove the stability restriction and hence allow calculations to be performed at greatly reduced computational expense.

Accomplishment Description - Calculations were performed for the F-5 wing at $M = 0.9$ to assess the accuracy and efficiency of the new algorithm. The wing has an aspect ratio of 3.16, a leading edge sweep angle of 32°, and a taper ratio of 0.28. The upper left of figure 15(b) shows the stability boundary for the ADI algorithm which indicates that calculations must be performed for very small time steps ($\Delta t < 0.017$) for the algorithm to be numerically stable. This severe stability restriction typically results in thousands of time steps required to obtain a converged steady solution. The AF algorithm, however, is unconditionally stable and hence calculations may be performed with any time-step size. A comparison of the convergence histories of the two algorithms is shown in the upper right of the figure. The AF algorithm provides a converged steady-state solution in approximately one-tenth the total number of time steps that the ADI algorithm requires. The AF algorithm gives similar improvements in computational expense for subsequent unsteady calculations required for flutter analysis. A comparison of chordwise unsteady pressures at the wing midsemispan is shown in the lower left of the figure. The calculations were performed for the rigid wing pitching harmonically with a reduced frequency of $k = 0.14$. The ADI results were obtained with 2292 steps/cycle of motion whereas the AF results were obtained with only 200 steps/cycle.

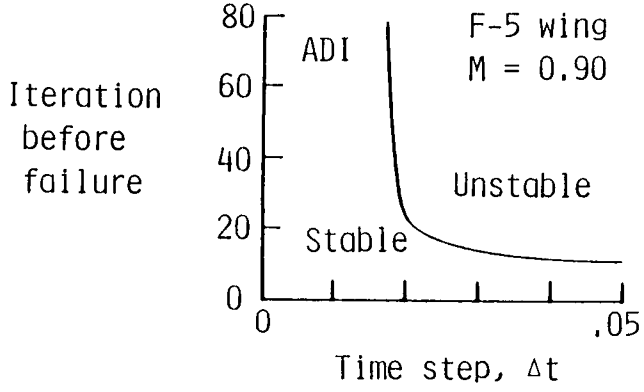
Significance - As shown in the lower left of the figure, the two sets of calculated unsteady pressures are very similar and both sets compare well with the experimental data. The computational cost summary for the two algorithms, shown in the lower right of the figure, indicates that the AF algorithm gives a significant decrease in cost in comparison with the ADI algorithm.

Future Plans - The research was conducted as part of an effort to develop alternative solution algorithms for improved numerical stability. Further comparisons will be made to assess the accuracy and efficiency of the new AF algorithm. A paper on the basic features of the method will be presented at the 25th Aerospace Sciences meeting, AIAA paper 87-0109.

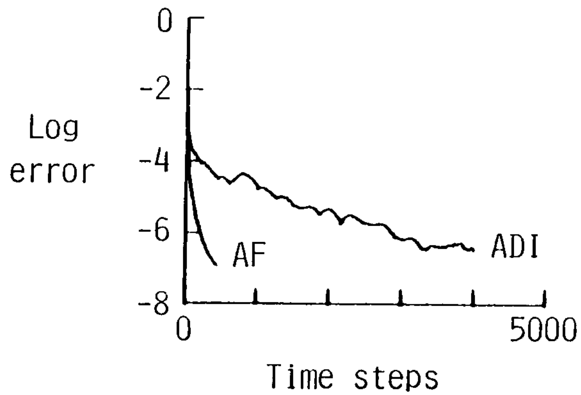
Figure 15(a).

NEW ALGORITHM FOR UNSTEADY TRANSONIC SMALL-DISTURBANCE EQUATION GIVES ORDER OF MAGNITUDE INCREASE IN COMPUTATIONAL EFFICIENCY

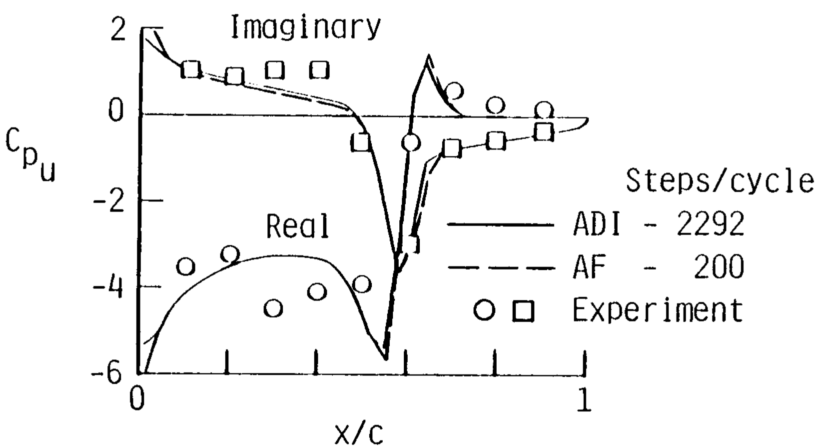
- STABILITY RESTRICTION WITH ADI
  - AF algorithm unrestricted



- IMPROVED CONVERGENCE WITH AF



- UNSTEADY PRESSURES FOR k = 0.14



- DECREASE IN COMPUTATIONAL EXPENSE

Cost Summary

	Steady	Unsteady
ADI	$2000	$3600
AF	$200	$600

Figure 15(b).

APPROXIMATE FACTORIZATION ALGORITHM ENABLES SUPERSONIC UNSTEADY AERODYNAMIC CALCULATIONS

John T. Batina
Unsteady Aerodynamics Branch
Extension 4236

RTOP 505-63-21

Research Objective - The research was performed to assess a new approximate-factorization (AF) algorithm for application to unsteady aerodynamic cases with supersonic freestream conditions.

Approach - The AF algorithm solves the unsteady nonlinear small-disturbance potential equation for transonic flow. It was developed as a more efficient solution procedure than the alternating-direction implicit algorithm of the XTRAN3S code. To date, the XTRAN3S code has been unsuccessful for supersonic freestream applications.

Accomplishment Description - Calculations were performed at a freestream Mach number of $M = 1.1$ to assess the ability of the new AF algorithm to treat cases with supersonic freestream flow. Results were obtained for the F-5 wing planform, as shown in the upper left of figure 16(b), and chordwise pressure distributions are presented at the wing mid-semispan. The wing has a full-span aspect ratio of 3.16, a leading edge sweep angle of 32°, and a taper ratio of 0.28. The upper right of the figure shows a comparison of steady pressure distributions calculated using the AF algorithm with the experimental data. For this case, there is a shock wave at the trailing edge and, in general, the AF steady pressures agree well with the experiment. Comparisons of unsteady pressure distributions are shown in the lower portion of the figure with upper surface results plotted on the left and lower surface results plotted on the right. The calculations were performed for the rigid wing pitching harmonically with a reduced frequency of $k = 0.116$. The AF unsteady pressures agree well with the experimental data along both the upper and lower wing surfaces.

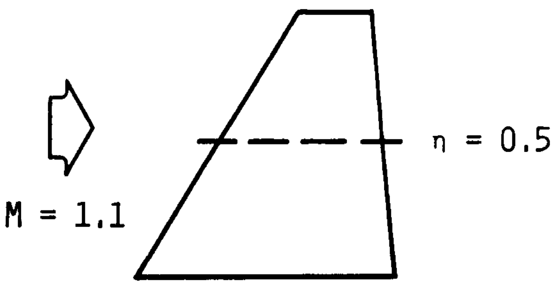
Significance - As indicated by the good agreement between calculation and experiment shown in the chart, the AF algorithm provides an accurate solution for supersonic freestream cases.

Future Plans - The research was conducted as part of a larger effort directed toward developing computational methods of predicting unsteady flows about aircraft configurations with emphasis on the flutter critical transonic speed range. A paper will be published on initial application to supersonic cases in 1987.

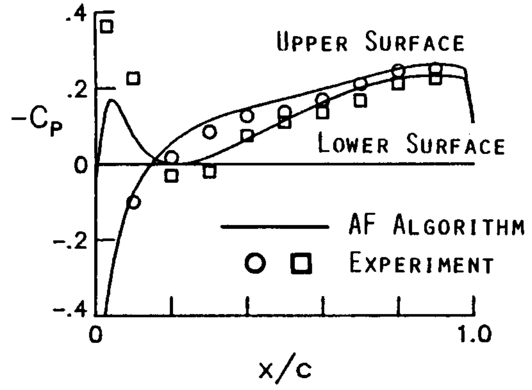
Figure 16(a).

APPROXIMATE FACTORIZATION ALGORITHM ENABLES SUPERSONIC UNSTEADY AERODYNAMIC CALCULATIONS

- F-5 WING PLANFORM



- STEADY PRESSURES AGREE WELL WITH EXPERIMENT



- UNSTEADY PRESSURES AGREE WELL WITH EXPERIMENT

RIGID WING PITCHING AT k = 0.116

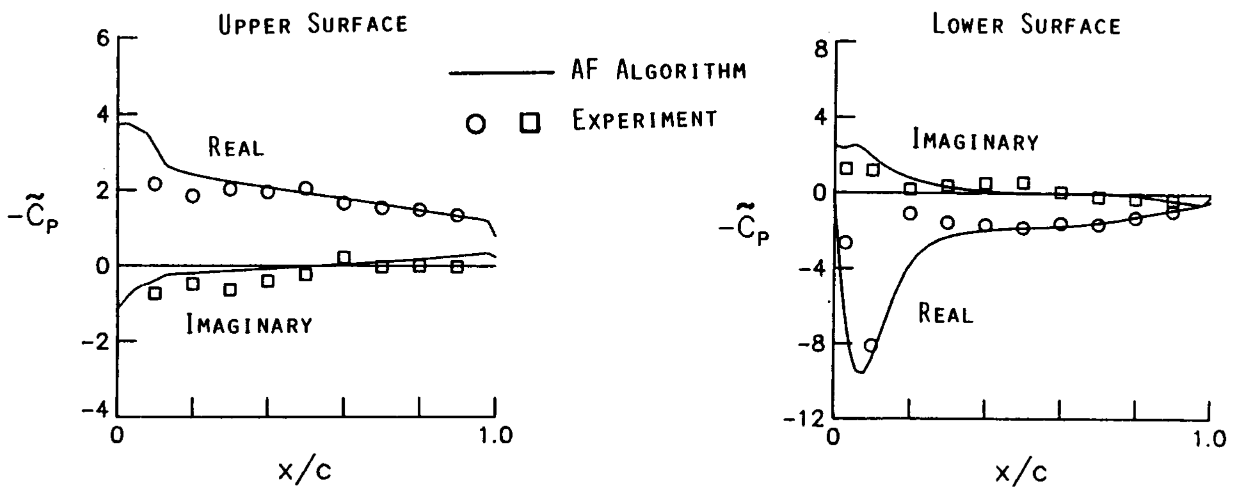


Figure 16(b).

FUSELAGE AERODYNAMIC INTERFERENCE EFFECTS PREDICTED ON RAE WING UNSTEADY LOADING

John T. Batina
Unsteady Aerodynamics Branch
Extension 4236

RTOP 505-63-21

Research Objective - The research was performed to determine the effects of fuselage aerodynamic interference on the unsteady wing loading of a transport type wing-fuselage configuration.

Approach - The three-dimensional finite-difference code XTRAN3S provides a time-marching solution to the unsteady, transonic, small-disturbance equation. In this study, the XTRAN3S code was used to assess fuselage aerodynamic interference effects by obtaining parallel results with and without the fuselage included in the calculation.

Accomplishment Description - Calculations were performed for a transport-type wing-fuselage model that was tested in the Royal Aircraft Establishment (RAE) 8 Ft. x 6 Ft. Transonic Wind Tunnel. The wing has an RAE 101 airfoil section, a leading edge sweep angle of 37°, an aspect ratio of 6.0, and a taper ratio of one-third. The fuselage is a sting-mounted axisymmetric body of revolution with fineness ratio (length/maximum diameter) of 7.66. The freestream Mach number was $M = 0.91$ and the mean angle of attack was 1.0°. Unsteady sectional lift and moment coefficients for the wing oscillating in its first bending mode at a reduced frequency of $k = 0.25$ are shown in figure 17(b). These coefficients are plotted as real (in-phase) and imaginary (out-of-phase) components of the spanwise wing loading. The unsteady coefficients are largest in the outboard region of the wing since the wing motion is largest at the tip. The effect of fuselage aerodynamic interference is generally largest inboard towards the wing-fuselage junction as expected. The interference effect attenuates along the span and is negligible outboard near the wing tip.

Significance - The capability permits the modeling of wing-fuselage configurations for transonic aeroelastic analyses and allows the prediction of fuselage aerodynamic interference effects on transonic unsteady airloads and flutter characteristics of wings.

Future Plans - The research was conducted as part of a larger effort directed toward developing computational methods of predicting unsteady transonic flows about complete aircraft configurations.

Figure 17(a).

RAE WING UNSTEADY LOADING DUE TO WING FIRST BENDING MODE

• $M = 0.91$, $\alpha = 1°$, and $k = 0.25$

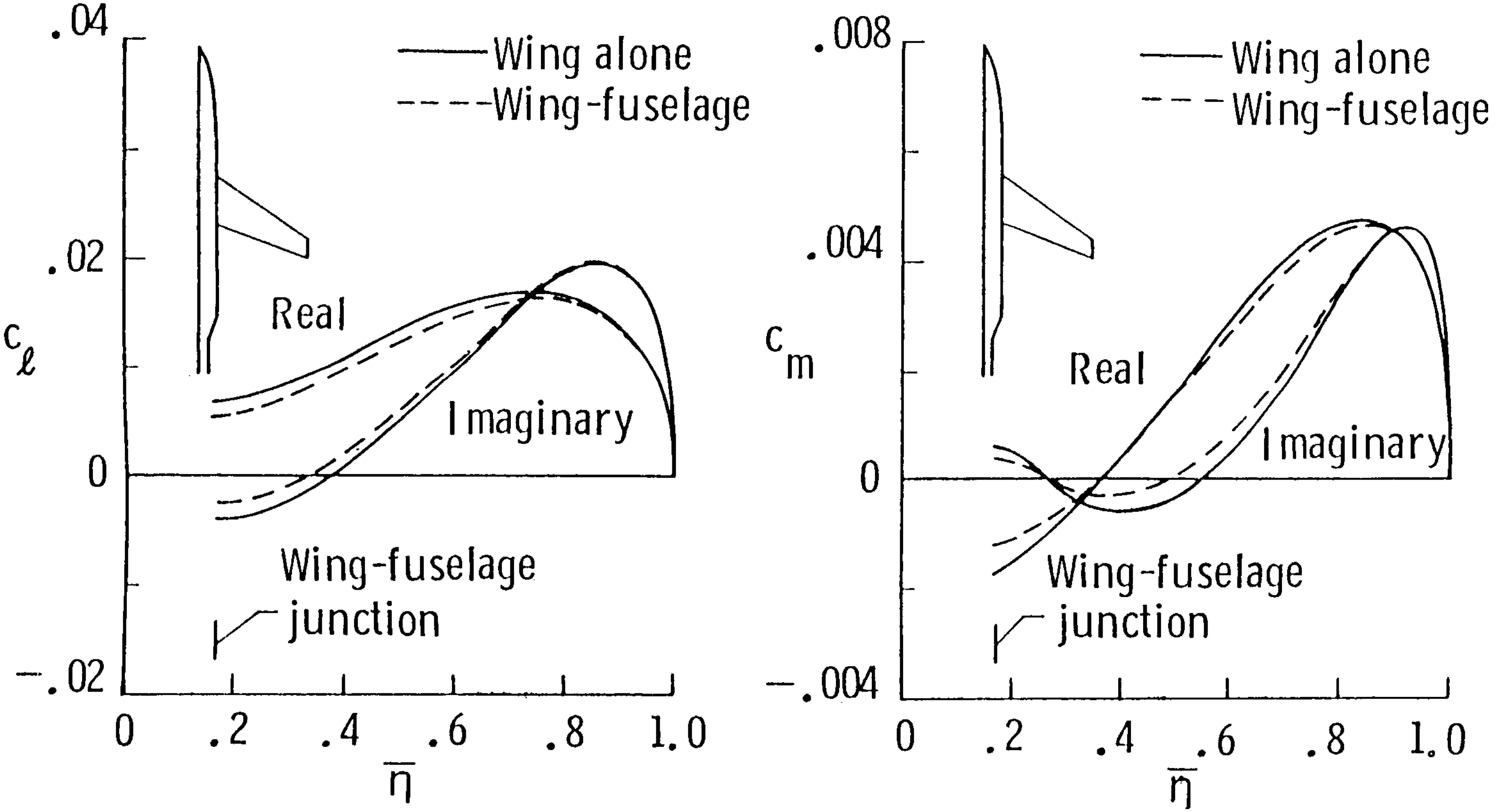


Figure 17(b).

LAMINAR FLOW OBSERVED ON SUPERCRITICAL AIRFOIL AT HIGH REYNOLDS NUMBERS

Robert W. Hess and David A. Seidel
Unsteady Aerodynamics Branch
Extension 4236

RTOP 505-63-21

Research Objective - This research was conducted to obtain a data base of unsteady transonic pressures for a wide range of Reynolds numbers and to develop instrumentation techniques for measuring unsteady pressures at cryogenic temperatures.

Approach - Unsteady transonic pressures were measured on a 14 percent thick supercritical airfoil at cryogenic temperatures. The tests were conducted in Langley Research Center's 0.3-meter Transonic Cryogenic Tunnel at free stream Mach numbers (M) between 0.65 and 0.74 and at Reynolds numbers based on airfoil chord (Rc) between 6 million and 35 million. Steady and unsteady pressures were measured for airfoil mean angles of attack (α) between -2 degrees and +3 degrees and for unsteady airfoil pitch angles (pitch axis at 35 percent chord) between 0.25 degrees and 1 degree. The frequency of oscillation was varied from 5 Hertz to 60 Hertz. Pressures were measured with 43 transducers--27 on the upper surface, 16 on the lower surface--that were specially designed to operate at cryogenic temperatures.

Accomplishment Description - Figures 18(b) and 18(c) show measured data for fixed angles of attack of 0 and 2 degrees at M = 0.72 and Rc = 35 million. The left side of each figure shows the time histories of measured pressures at five transducer locations. The locations, x/c (percent chord) = 0.14, 0.26, 0.46, 0.62, 0.75, are shown as the solid symbols on the right side of each figure. The pressure signals have been amplified by a factor of 10, and the transducers' sensitivities are shown in the figures. In Figure 18(b) (α = 0 degrees), the pressure time histories show the characteristics of a turbulent boundary layer at all transducer locations. Figure 18(c) (α = 2 degrees) shows that the pressure is quiescent at x/c = 0.14 and 0.26. At x/c = 0.46, the effect of shock movement is observed. At x/c = 0.62, shock movement is observed, and turbulent flow is apparent. The most obvious difference between the two flow conditions is the slightly more favorable pressure gradient and the presence of a shock wave at α = 2 degrees.

Significance - These results provide data to help validate methods for predicting unsteady pressures. This requires a knowledge of where transition occurs, and this research provides insight into where this occurs. Transition was observed to occur much further aft than was expected.

Future Plans - The data will be used for CFD code validation. Current efforts are aimed at correlating the measured data with Navier-Stokes calculations.

Figure 18(a).

TIME HISTORIES OF UNSTEADY PRESSURES

$M = 0.72$, $\alpha = 0^{\circ}$, $Rc = 35 \times 10^{6}$

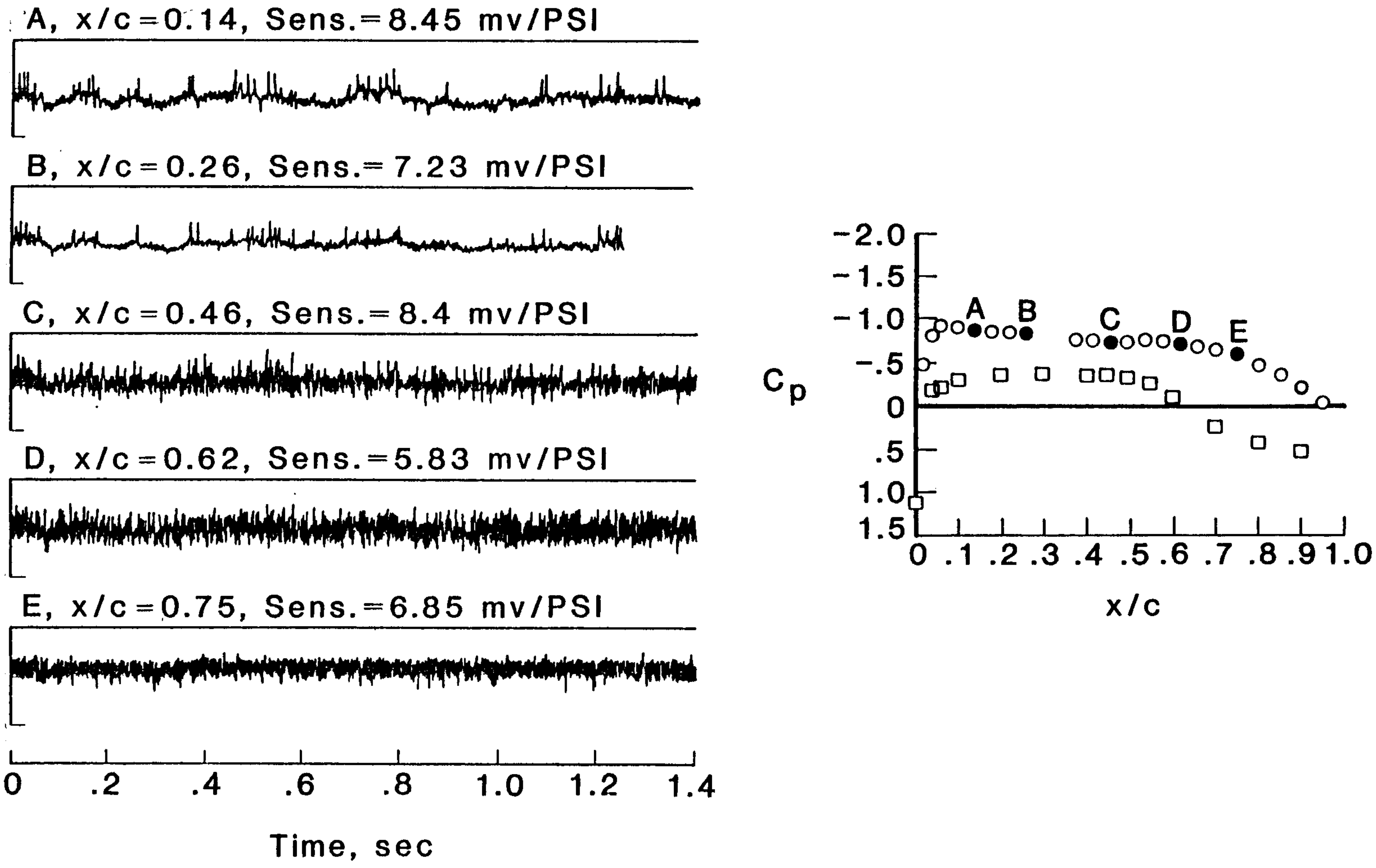


Figure 18(b).

TIME HISTORIES OF UNSTEADY PRESSURES

$M = 0.72$, $\alpha = 2^{o}$, $Rc = 35 \times 10^{6}$

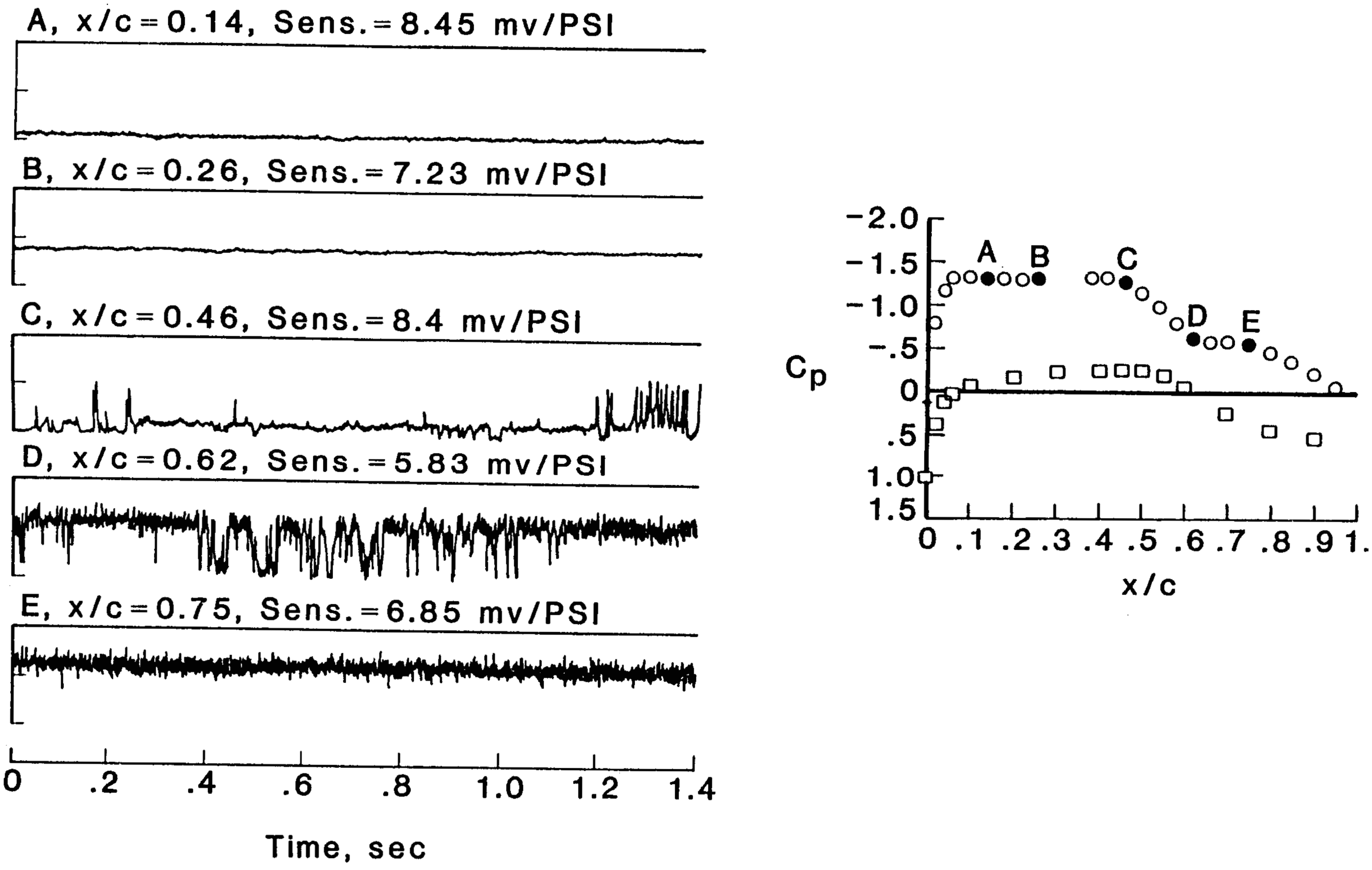


Figure 18(c).

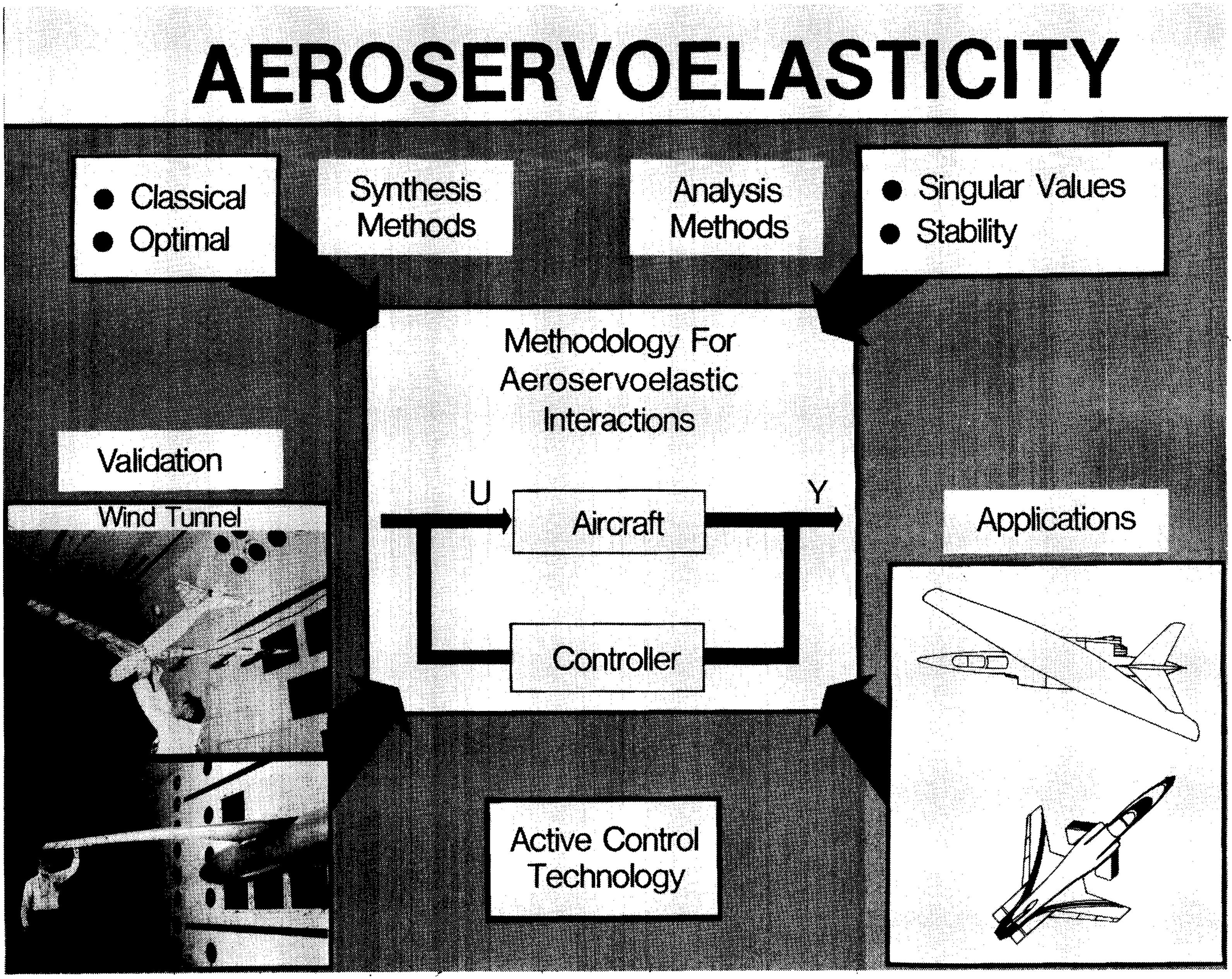

AEROSERVOELASTICITY
● Classical
● Optimal
Synthesis Methods
Analysis Methods
● Singular Values
● Stability
Methodology For Aeroservoelastic Interactions
U
Aircraft
Y
Controller
Validation
Wind Tunnel
Applications
Active Control Technology

Figure 19.

AEROSERVOELASTICITY

FIVE YEAR PLAN

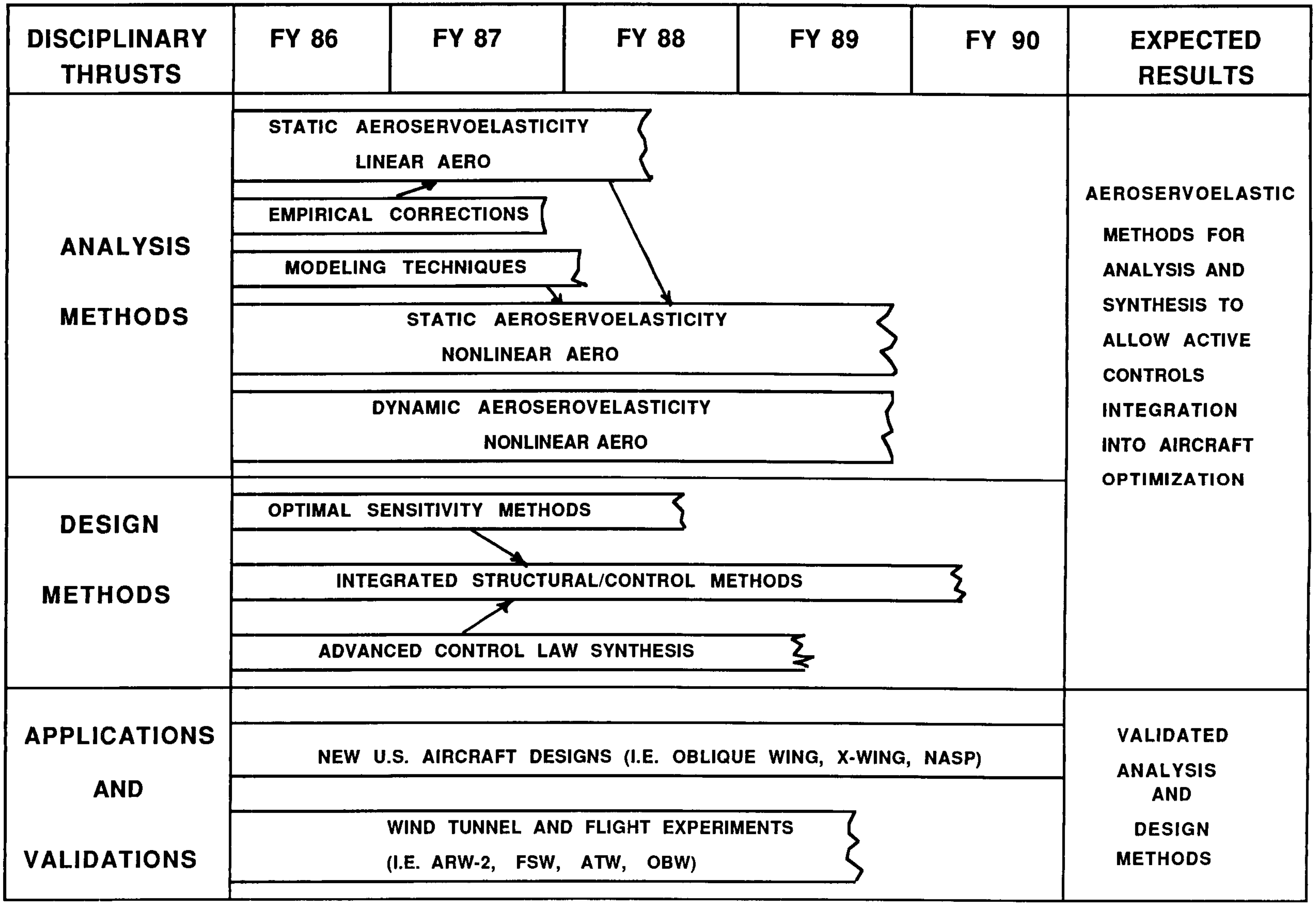


Figure 20.

NEW METHOD FOR APPROXIMATING UNSTEADY AERODYNAMICS FOR AEROSERVOELASTICITY COMPUTATIONS

Sherwood H. Tiffany and William M. Adams, Jr.
Aeroservoelasticity Branch, LAD and Analytical Methods Branch, GCD
Extensions 3323 and 3975

RTOP 505-63-21

Research Objective - The research objective is to develop a method for approximating unsteady aerodynamics with rational functions which reduces the number of differential equations necessary to represent a flexible aircraft in flight and to provide analytical results for comparison with other existing methods.

Approach - The basic formulation of the rational function approximations to unsteady aerodynamics which allows a significant reduction in the number of differential equations of motion for a flexible aircraft was originally developed by Dr. Mordechay Karpel (GRANT NGL 05-02-043). His method used a gradient-based nonlinear programming technique to best select the coefficients of the rational terms, and had a fixed set of constraints for all aerodynamic elements, and required normalization of the aerodynamic tabular data. The approach used to modify and generalize his original method was to (1) allow flexibility in selecting the constraints; (2) use a nongradient nonlinear optimizer which avoids problems arising from numerical computations of gradients; and (3) use a measure of relative error which eliminates the necessity of normalizing the original tabular values of aerodynamic data.

Accomplishment Description - Two existing methods and the new method are included in a unified software system which allows easy selection of the method which best suits a particular application. All formulations have the same modeling capability and employ the same nongradient nonlinear optimizer as well as the same system analysis techniques. Results presented on figure 21(b) show that the new method decreases the number of differential equations by over 50%, for the same approximate error, as compared to two existing methods.

Significance - Reducing the number of differential equations when approximating unsteady aerodynamics significantly decreases the computer time and cost for aeroservoelasticity analysis computations, as well as allowing larger problems to be analyzed. The flexibility in selecting modeling constraints results in more realistic models, and the use of a nongradient optimizer avoids numerical complications arising from the computation of gradients.

Future Plans - Plans are to document the method in a NASA TP; write a users guide for the unified software system; perform additional analysis comparisons using the approximations; and add several options that will increase the efficiency of the computations, thereby reducing the computational costs.

Figure 21(a).

NEW METHOD FOR APPROXIMATING UNSTEADY AERODYNAMICS FOR AEROSERVOELASTICITY COMPUTATIONS

<u>PROBLEM:</u> LARGE NUMBER OF DIFFERENTIAL EQUATIONS NECESSARY TO MINIMIZE THE ERROR WHEN APPROXIMATING UNSTEADY AERODYNAMICS WITH RATIONAL FUNCTION APPROXIMATIONS

<u>SOLUTION:</u> NEW METHOD DEVELOPED WHICH DECREASES THE NUMBER OF DIFFERENTIAL EQUATIONS BY OVER 50% COMPARED TO EXISTING METHODS

<u>BENEFIT:</u> DECREASED COMPUTER TIME AND COST FOR AEROSERVOELASTICITY COMPUTATIONS

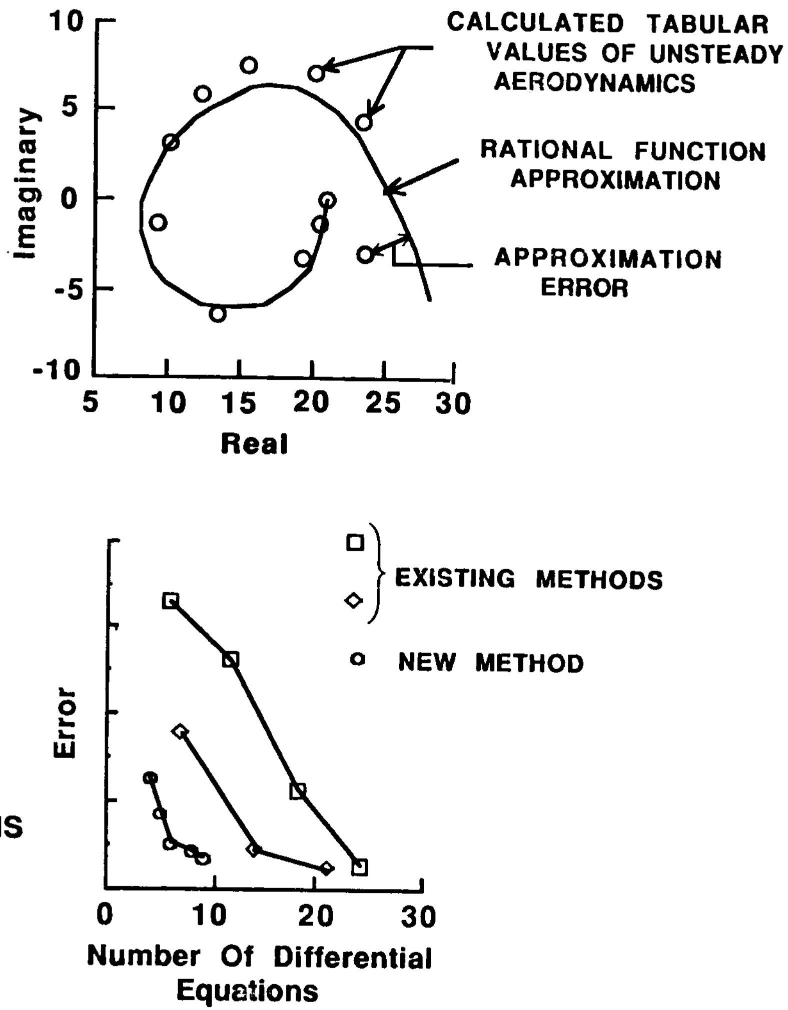


Figure 21(b).

AUTOMATED TRANSONIC AEROELASTICITY ANALYSIS PROGRAM DEVELOPED

Michael A. Armistead
Aeroservoelasticity Branch
Extension 3834

RTOP 505-63-21

Research Objective - The research objective is to develop an automated capability for performing transonic static aeroelastic analyses on a flexible three dimensional wing and to provide results for comparison with experimentally measured data for the ARW-2 wing.

Approach - The basic methodology for performing transonic static aeroelastic analyses was previously developed by W. Whitlow, Jr. and R. Bennett (AIAA Paper 82-0689). The method used sequential iterative calculations between the VPS32 vector computer (for FLO22 aerodynamic calculations) and the Cyber computer (for calculation of the structural deformation). The process of transferring files between computers and evaluating intermediate results for a converged solution was time consuming in terms of computer time, users time, and calendar time. The approach to simplify and reduce these times was to (1) run both programs on the VPS32 computer, (2) automate file manipulation in the runstream definition, (3) add logic to evaluate intermediate results and automatically exit the iterative loop when the convergence criteria is met, and (4) provide a restart capability so that if the user wants to perform additional iterations it is not necessary to start from the beginning.

Accomplishment Description - Program improvements were implemented and checked to assure that results were comparable with those from the original method. The new program was used to calculate transonic aeroelastic characteristics for the ARW-2 right semispan configuration tested previously in the NASA Langley Transonic Dynamics Tunnel (TDT). Results presented on figure 22(b) show computed pressure coefficients for both a rigid wing and a flexible wing (to show the calculated aeroelastic effect) and measured pressure coefficients for the flexible ARW-2 wing. The calculated pressure coefficients agree well with the measured data although the computed location of the recompression shock is slightly further aft when compared with measured data. Also shown are computed and measured wing vertical deflections which are also in close agreement.

Significance - Automating the computational method resulted in significant time savings to the user. Instead of requiring days to obtain a typical aeroelastic solution, the new program can obtain the same results in a few hours. The program is much more practical for producing computed results for a large matrix of flight or wind tunnel test conditions.

Future Plans - A users guide for the program will be written. The ability to handle control surface deflections, and boundary layer thickness in determining the wing shape will be included. Additional comparisons with ARW-2 test measurements will be made.

Figure 22(a).

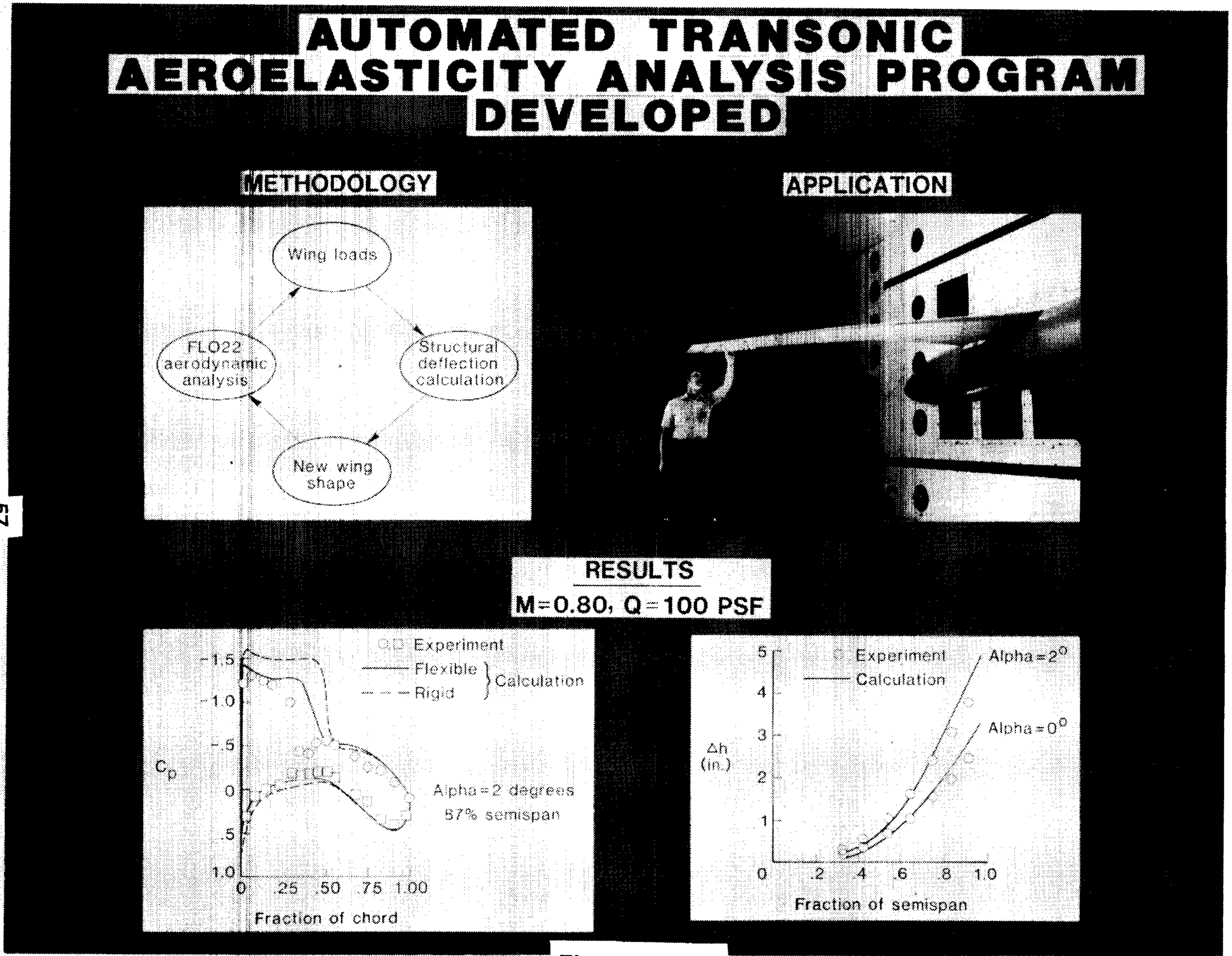


Figure 22(b).

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ARW-2 WING TIP ACCELERATION CORRELATES WITH SURFACE PRESSURE SHOCK MOVEMENT

Clinton V. Eckstrom, David A. Seidel and Maynard C. Sandford
Aeroservoelasticity, Unsteady Aerodynamics and Configuration Aeroelasticity Branches
Extensions 3834, 4236, and 2661

RTOP 505-63-21

Research Objective - The objective was to investigate characteristics of unsteady wing motions experienced in the transonic speed region by the ARW-2 wing as tested in the Langley Transonic Dynamics Tunnel (TDT).

Approach - During a test of the ARW-2 right semispan in TDT during September 1983 an unusual wing first bending mode response was encountered at dynamic pressures well below the predicted classical flutter boundary. The onset of this unusual response was encountered at a nearly constant Mach Number of 0.90 over the dynamic pressure range from 50 psf to above 300 psf. During this initial test series the wing oscillatory response onset boundary was identified but the response characteristics were not further explored. Therefore a second series of tests were performed to investigate the wing response characteristics in the response region.

Accomplishment Description - The second series of tests were accomplished in January 1986 during which testing continued past the previously identified boundary for onset of the wing response. No "hard flutter" conditions were found. Wing surface pressure measurements were evaluated and it was determined that significant changes in the wing recompression shock location were occurring on both the upper and lower wing surface at the same frequency as the wing response motion as measured by the wing accelerometers. Typical results obtained at the test condition where the largest amplitude response occurred are shown on figures 23(b) and 23(c). The test item sketch shows locations on the wing from which accelerometer and surface pressure measurements are presented. The wing tip accelerometer record shows response to a large amplitude burst of wing motion which was primarily in the wing first bending mode which had a wind-off frequency of 8.2 Hz. Two times are noted on the accelerometer record. They are times for a half cycle of motion for which the shock locations were most forward and aft for that oscillatory motion cycle. Four typical unsteady pressure measurements from the wing upper surface at the spanwise location noted on the test item sketch are also presented to show how local pressures were varying with time. The sinusoidal pressure variation at the wing leading edge ($X/C = .025$) results from angle of attack variations associated with the motion of the outboard portion of the wing. This effect is also evident at $X/C = .41$. Further aft along the chordline the large amplitude pressure variations at $X/C = .68$ are due to the shock moving back and forth across the orifice location. The more random oscillatory pressure trace recorded at $X/C = .91$ is indicative of separated flow. The wing upper surface pressure profile variations for the two selected times illustrates the large change in shock location that was occurring.

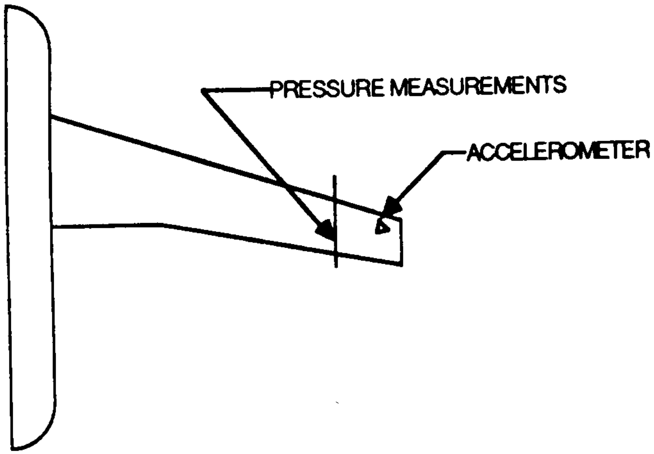
Significance - This investigation has provided insight into the local wing surface pressure variations associated with the unusual unsteady wing motions encountered while testing the ARW-2 wing in TDT.

Future Plans - Complete data analysis for other test conditions and publish results in formal NASA publications.

Figure 23(a).

ARW-2 WING TIP ACCELERATION CORRELATES WITH SURFACE PRESSURE SHOCK MOVEMENT

TEST ITEM



MACH NUMBER = 0.92
DYNAMIC PRESSURE = 325 PSF
ANGLE OF ATTACK = -1 DEGREE

WING TIP ACCELERATION RECORD

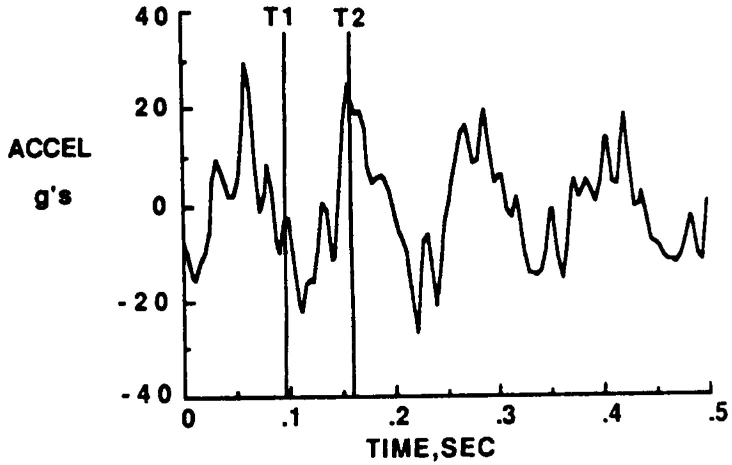
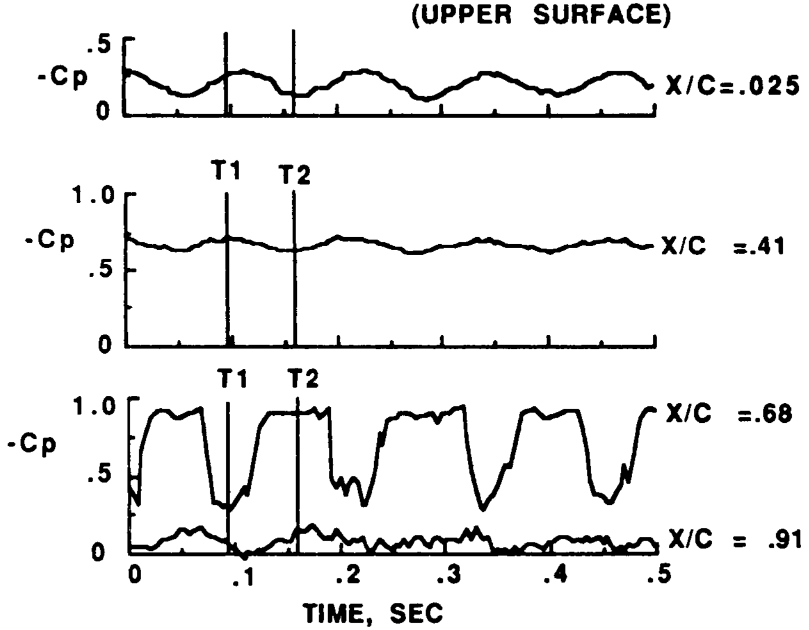


Figure 23(b).

ARW-2 WING TIP ACCELERATION CORRELATES WITH SURFACE PRESSURE SHOCK MOVEMENT

UNSTEADY PRESSURE MEASUREMENTS



PRESSURE PROFILE VARIATION

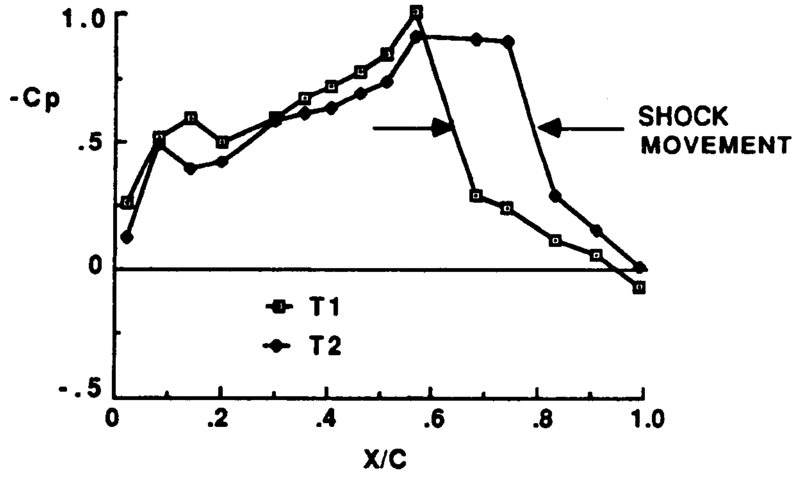


Figure 23(c).

ACTIVE CONTROL OF SHOCK INDUCED OSCILLATIONS

William M. Adams, Jr. and Sherwood H. Tiffany
Analytical Methods Branch, GCD and Aeroservoelasticity Branch, LAD
Extensions 3975 and 3323

RTOP 505-63-21

Research Objective - The objective of this research is to experimentally demonstrate active suppression of shock induced oscillations of the ARW-2 right semispan in the Transonic Dynamics Tunnel (TDT).

Approach - The approach consists of: (a) Apply Fast Fourier Transform techniques to estimate transfer functions at several test points by utilizing experimental data from the September 1983 tunnel test in TDT, (b) Develop a scheduled (as a function of Mach number and/or dynamic pressure) control law which adds damping in the critical mode and satisfies robustness constraints, and (c) Test control law performance in the second ARW-2 test in TDT.

Accomplishment Description - A control law was developed and tested which used compensated acceleration feedback to drive an outboard control surface. The control law was designed to add damping in the critical mode thereby suppressing an "apparent" instability predicted based on extrapolating damping trends observed in the earlier wind tunnel test. This second entry showed that, although the damping in the critical mode became very small and reached a minimum near a Mach number (M) of 0.92, no divergent instability occurred. Figures 24(b) and 24(c) show the control law added significant damping in the critical mode for all test conditions through M = 0.90. The control law also added damping at M = 0.92 for lower dynamic pressure (Q) test conditions (Q = 100 to 151 psf), but not for higher Q test conditions (Q = 211 to 323 psf). Two circumstances contributed to the decreased effectiveness of the control law at M = 0.92 and the higher Q test conditions. The first was the flow over the wing became separated and turbulent in the region of the control surface as M increased, and second the control law was scheduled to increase in frequency at which damping was added as a function of both Q and M. Although the frequency of the wing oscillation initially increased with M and Q, it decreased to approximately 10 Hz at M = 0.92 and Q = 323 psf. This frequency was considerably below the 12.28 Hz frequency of peak effort that was designed for at this test condition.

Significance - Oscillations of this type have occurred for several aircraft and, in some cases, have made it necessary to restrict their flight envelopes. This test demonstrated that damping could be increased by active control even when flow was essentially separated in the region of the control surface. Thus it may be possible to employ active controls to remove or reduce flight envelope restrictions for this type of oscillation.

Future Plans - Additional analysis will be made of the data recorded during the tests and a paper will be written which describes the results. Potential benefits due to alternate choices for sensor configuration will be investigated. Approximate methods of combining aerodynamic forces due to the shock with those generated by use of linear potential theory aerodynamic codes will be explored.

Figure 24(a).

ACTIVE CONTROL OF SHOCK INDUCED OSCILLATIONS

ARW-2 ACCELEROMETER PEAK-HOLD RESPONSES

(Q = 100 TO 151 PSF)

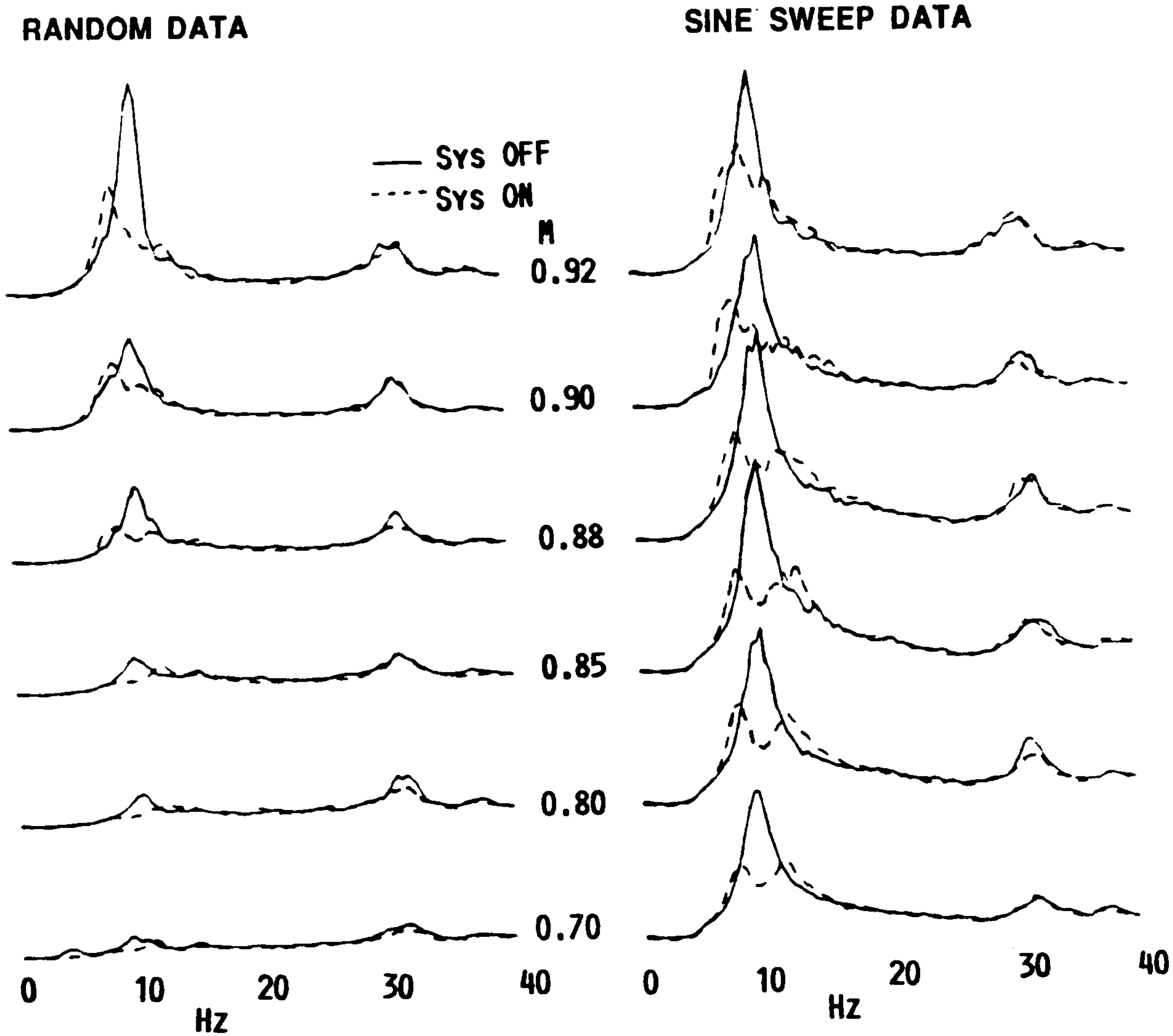


Figure 24(b).

ACTIVE CONTROL OF SHOCK INDUCED OSCILLATIONS

ARW-2 ACCELEROMETER PEAK-HOLD RESPONSES

(Q = 211 TO 323 PSF)

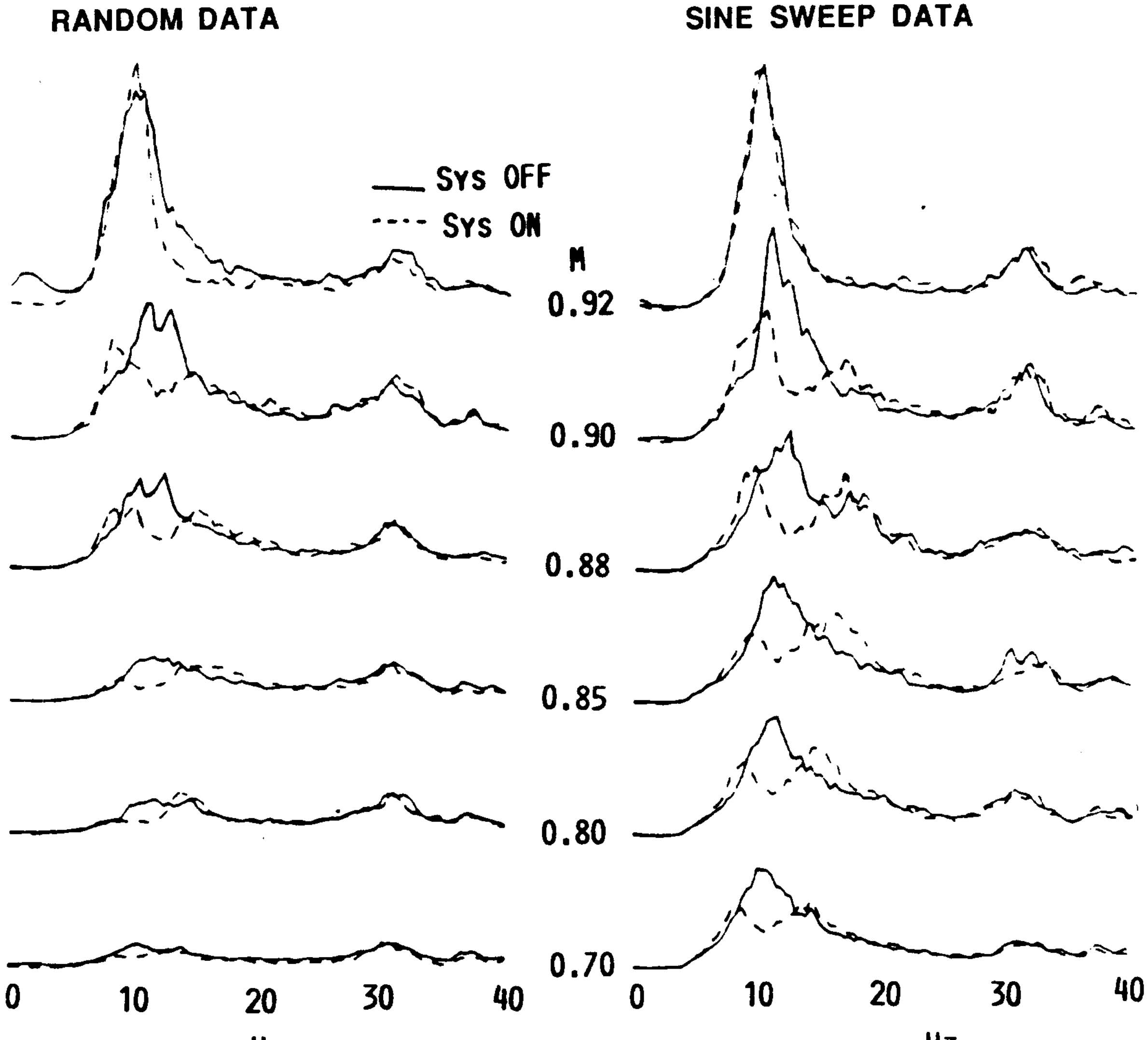


Figure 24(c).

ACTIVE FLEXIBLE WING WIND TUNNEL TEST PROGRAM

Boyd Perry, III
Aeroservoelasticity Branch
Extension 3323

RTOP 505-63-21

Research Objective - The objective of the present work is to synthesize and test an active roll control system for the Active Flexible Wing wind tunnel model shown in figure 25(b). The research is conducted jointly by the Aeroservoelasticity Branch and the Configuration Aeroelasticity Branch.

Approach - The Active Flexible Wing concept was developed by Rockwell International, who designed and built the wind tunnel model. The model is aeroelastically scaled with a span of about nine feet and is mounted on a sting in such a manner that the model is free to roll. The model has two leading-edge and two trailing-edge control surfaces on each wing panel. The figure indicates the approach taken. There are two wind tunnel entries in the program, both in the LaRC Transonic Dynamics Tunnel. As indicated by the arrows, data reduction and other analytical activities occur after the first tunnel entry and are necessary in preparation for the second.

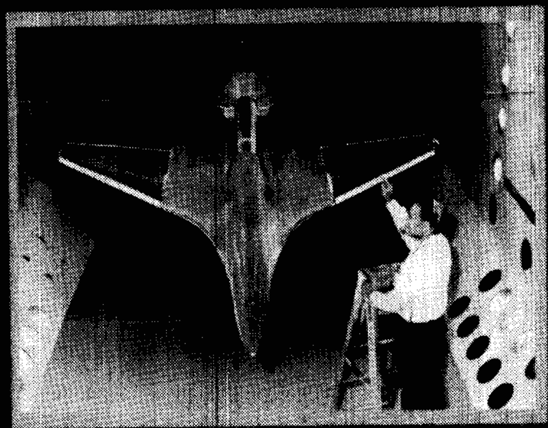
Accomplishment Description - The first entry was conducted in early 1986 and yielded a data base of static forces and moments due to control surface deflections. Using this data base, a new method was developed and employed to derive correction factors so that analytical predictions of control surface effectiveness matched the measured value. The plot in the upper-right corner of the figure illustrates the comparison with experiment of the uncorrected and corrected analytical predictions. Using these corrections, control laws for active roll control have been synthesized at two dynamic pressures at a Mach number of 0.90. The table in the lower right corner indicates the predicted performance of the synthesized control laws and compares them with design goals. Linear analysis predicts that the control laws exceed minimum gain and phase margin (GM and PM) goals and "beat" the time-to-90-degrees-roll-angle goal.

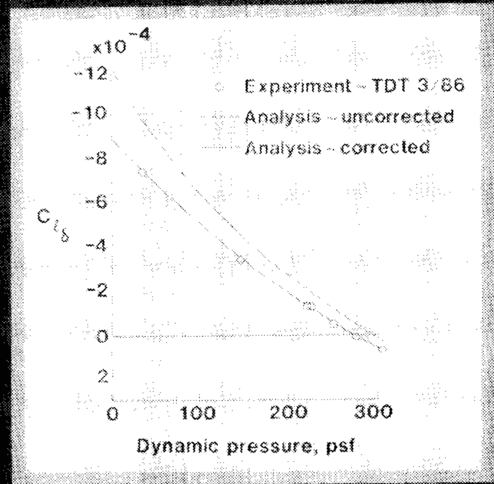
Significance - Im synthesizing control laws it is important to have an accurate mathematical model of the airplane. The new method for obtaining correction factors, and the use of the correction factors, assures that the control-surface-effectiveness portion of the math model is as accurate as possible.

Future Plans - As indicated by the arrow returning to the model, the control laws will be tested on the model during the second tunnel entry, scheduled for early 1987. This entry will provide the opportunity to compare the analytically-predicted closed-loop performance of the model-plus-active-roll-control-system with the measured experimental performance. Agreement between analysis and experiment will verify that the analytical methods were correct; disagreement will point towards areas where improvements in the analytical methods are required.

Figure 25(a).

ACTIVE FLEXIBLE WING WIND TUNNEL TEST PROGRAM





	Q (PSF)	GM (DB)	PM (DEG)	Time to 90 (SEC)
(Goal)	All	6.0	45	.38
	150	9.8	77	.29
	250	11.1	82	.30

Figure 25(b).

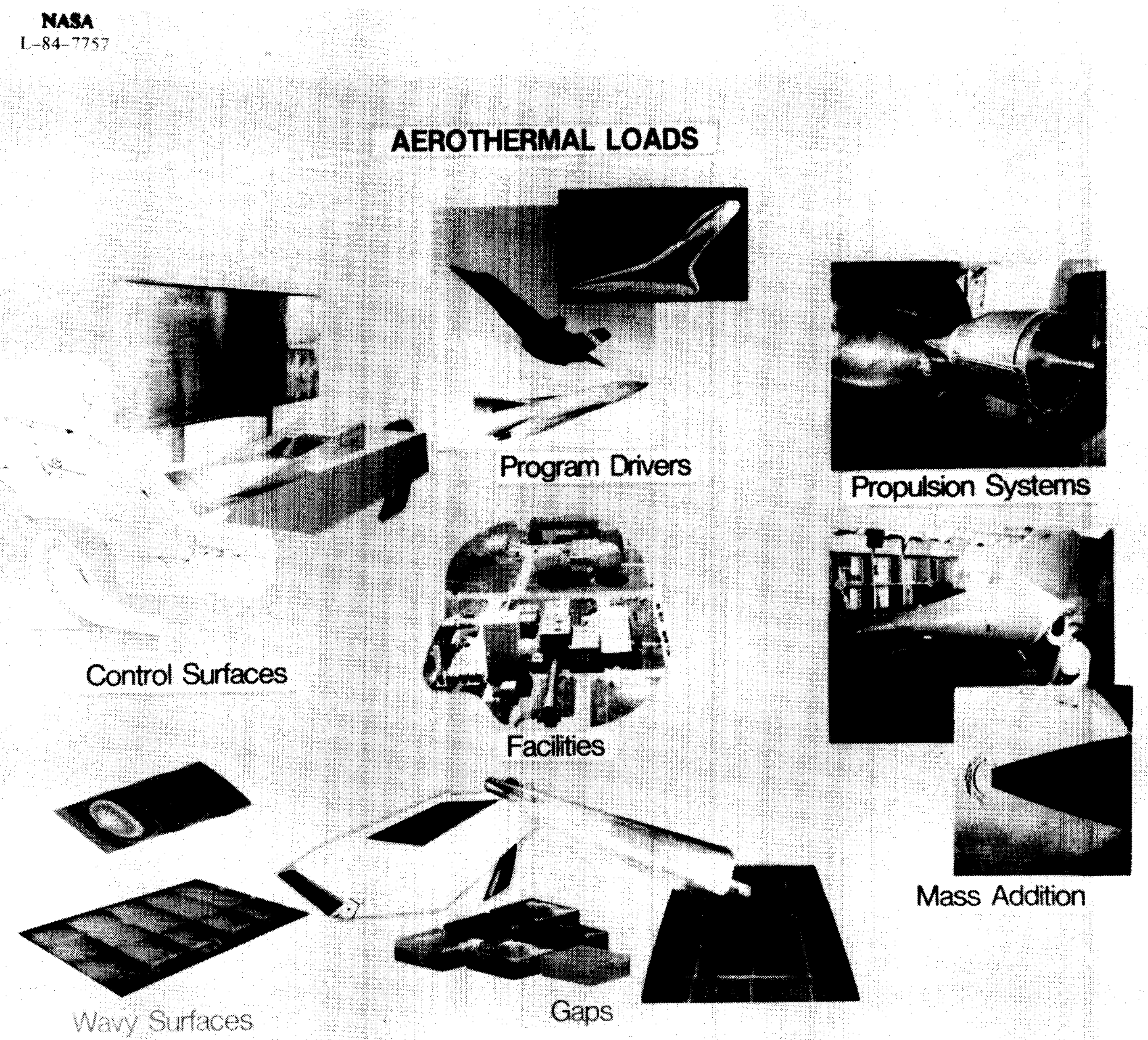

NASA
L-84-7757
AEROTHERMAL LOADS
Program Drivers
Propulsion Systems
Control Surfaces
Facilities
Mass Addition
Wavy Surfaces
Gaps

Figure 26.

AEROTHERMAL LOADS
FIVE YEAR PLAN

DISCIPLINARY THRUSTS	FY 86	FY 87	FY 88	FY 89	FY 90	EXPECTED RESULTS
EXPERIMENTS	GAPS/WAVY SURFACES/ PROTUBERANCES					DETAILED DESIGN DATA BASE
	COMPRESSION/AXIAL CORNER FLOWS					
	SHOCK-SHOCK/SHOCK BOUNDARY LAYER					VALIDATED CODES
	MASS ADDITION FLOW EFFECTS					
	NASA/INDUSTRY/DOD COOPERATIVE STUDIES					
ANALYSIS	EULER ALGORITHMS					INTEGRATED ANALYSIS CAPABILITY
	NAVIER-STOKES COMPRESSIBLE VISCOUS FLOW ALGORITHM					
	ADAPTIVE TECHNIQUES					
	INTEGRATED FLUID-THERMAL-STRUCTURAL					
FACILITIES AND TEST TECHNIQUES	FACILITY OPERATION, MAINTENANCE, AND ENHANCEMENT					EFFICIENT RELIABLE FACILITIES AND TEST TECHNIQUES
	HIGH TEMPERATURE INSTRUMENTATION					
	8' HTT MODIFICATION/AIR BREATHING PROPULSION					

Figure 27.

SHOCK IMPINGEMENT ON A CYLINDRICAL LEADING EDGE AUGMENTED HEATING RATE MEASUREMENTS

Allan R. Wieting
Aerothermal Loads Branch
Extension 3423

RTOP 506-40-21

Research Objective - Impinging shock waves interacting with the bow shock of a blunt leading edge produce strongly augmented leading edge heating rates. The magnitude of the heating augmentation is a function of the flow conditions and the location of the shock interaction with respect to the leading edge centerline. Several types of shock interaction types are possible but the most severe is the Type IV interaction (shown in the schematic on figure 28(b)) which occurs when the impinging shock interacts with the bow shock in a narrow region below the leading edge centerline and forms a supersonic jet that conducts high energy flow directly to the leading edge surface. Shock interactions that occur above and below this narrow region form shear layers that interact with the cylinder with decreasing severity as the location of the interaction moves away from the critical region. Flow configurations of this type occur on hypersonic engine inlets, where, for engine efficiency, it is desirable to have the forebody compression shock incident on the engine cowl (a condition referred to as "shock-on-lip"). Therefore, the current research is focused on detailed determination of these local heating rates as input to the structural design of the structure and the active cooling systems required.

Approach - The LaRC 8' High Temperature Tunnel (8' HTT) and the Calspan 48" Shock Tunnel were used to define the heating and pressure loads on a 3" diameter cylindrical leading edge (with a dense population of instrumentation) with an incident shock formed by a wedge shock generator. Detailed measurements were made over a range of Mach Numbers, Reynolds Numbers, shock strengths, and shock interaction locations.

Accomplishment Description - The heating rate distributions for flows between Mach 6 and 8 have been defined for several Reynolds Numbers, shock strengths, and shock interaction locations. Data for the heating rate distribution (normalized by the no-shock stagnation heating rate) over the surface of the cylinder for Mach 8.0 flow using a 12.5 degree wedge shock generator with the shock positioned to produce a Type IV interaction is shown at the left of the figure. The peak heating rate is a factor of ten higher than the no-shock case. Also, the locus of peak heating rates for the range of shock interaction locations is shown at the right of the figure (including data for a sphere due to Edney).

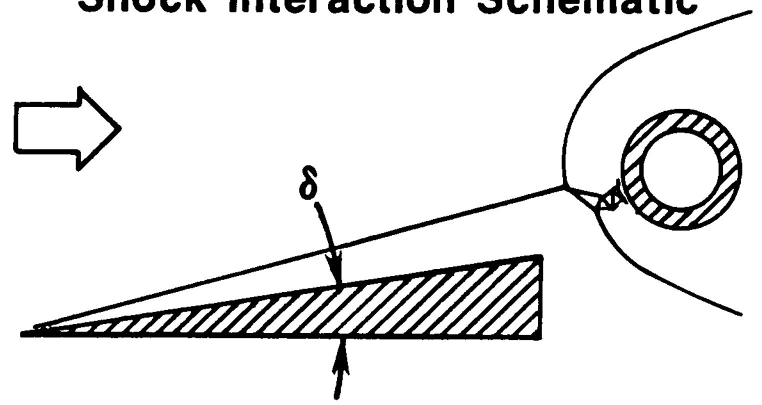
Significance - Accurate definition of local heating loads such as these are essential for the design of safe minimum weight structures and active cooling systems for hypersonic vehicles.

Future Plans - Extend the data base to higher Mach Numbers (up to 19) and Reynolds Numbers. Investigate the effect of leading edge and shock sweep on the induced loads.

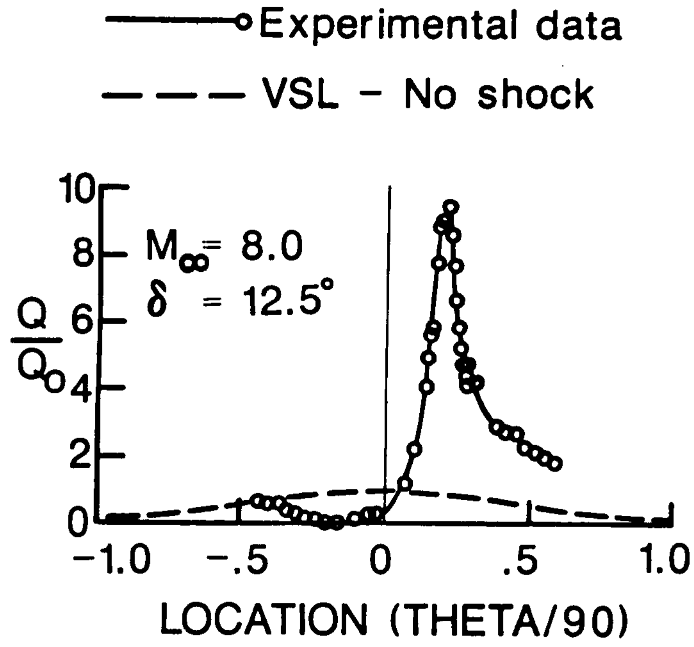
Figure 28(a).

SHOCK IMPINGEMENT ON A CYLINDRICAL LEADING EDGE AUGMENTED HEATING RATE MEASUREMENTS

Shock Interaction Schematic



Normalized Heating Rate Distribution



Locus of Peak Heating

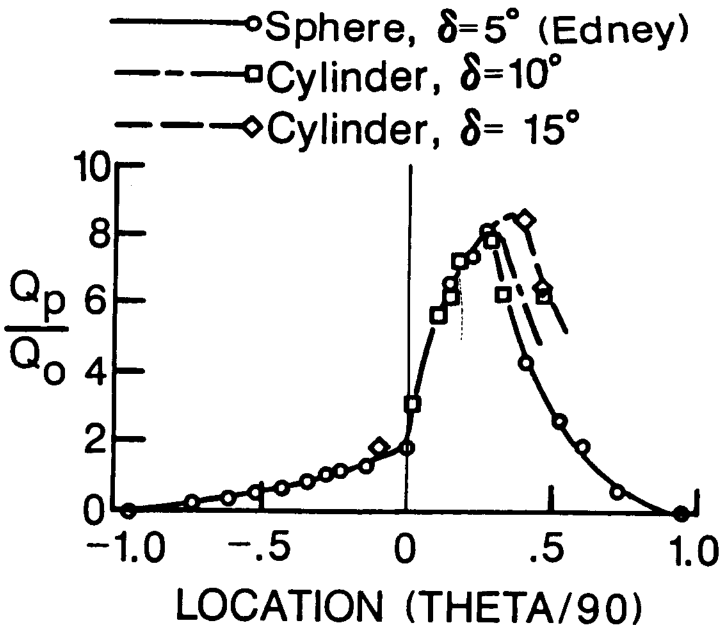


Figure 28(b).

PROTECTIVE SHROUD SUCCESSFULLY REMOVED AT MACH 6.7 IN LaRC 8' HIGH TEMPERATURE TUNNEL

Kristopher K. Notestine and L. Roane Hunt
PRC Kentron Inc. and Aerothermal Loads Branch
Extensions 3168 and 3423

RTOP 506-43-31

Research Objective - The Army Strategic Defense Command (SDC) is developing viable interceptor weapon systems that must protect forebody radomes during portions of the flight trajectory when the aerothermodynamic loads are most severe and when rain or debris impact is most likely. Consequently, the basic design parameters of the various protective concepts must be verified by suitable testing. Therefore, the present concept, consisting of shroud petals that must be removed during flight to expose the forebody radome, was tested in the 8' HTT to obtain transient pressure loads and petal release trajectories for design optimization.

Approach - A simulated forebody protected by a series of shroud petal sets was designed and fabricated by the McDonnell Douglas Astronautics Company (MDAC) to function in the 8' HTT at a Mach number of 6.7 and a dynamic pressure of 600 psf. Six shroud configurations consisting of various petal orientations and release angles were tested with and without insulation inserts designed to suppress shock interaction effects. The forebody was instrumented with twenty high frequency pressure transducers for high resolution recording of loads during petal release. High speed movie and video cameras were used to document petal trajectory.

Accomplishment Description - All six configurations were successfully tested providing transient pressure data corresponding to selected design variations. A typical shroud petal removal sequence is shown in figure 29 (b). Picture frame (1) shows the petal configuration intact prior to release. The subsequent selected frames capture the four petal release with a 5 ms time interval between frames. As the petals open and release, the insulation insert disintegrates and is dispersed to expose the forebody. The sketch in the lower left of the figure illustrates the assumed shock pattern that produces the transient surface pressure histories shown in the lower right. The surface peak pressure loads without foam insulation were up to 7 times the steady-state forebody pressure. The peak pressure with foam was reduced in magnitude and duration indicating the effectiveness of insulation to reduce shock loads on the radome.

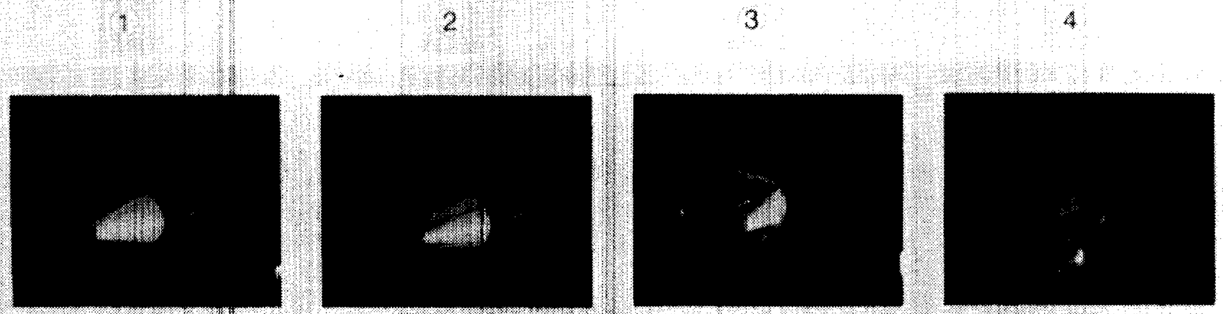
Significance - Generally, the peak pressures measured on the forebody during petal release agreed with design predictions. Pressure levels were higher under the petals than under the petal seams. The foam insulation attenuated the pressure load. All of the designs had good petal clearance and symmetry relative to the forebody during removal.

Future Plans - Representatives of SDC and MDAC have expressed interest in proof testing of a full-scale model of the final design in the 8' HTT.

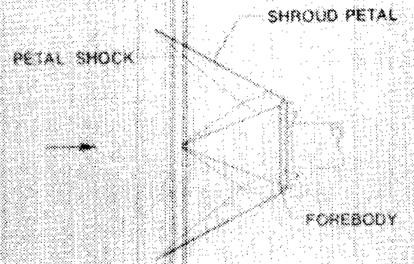
Figure 29(a).

NASA
L-86-10,170

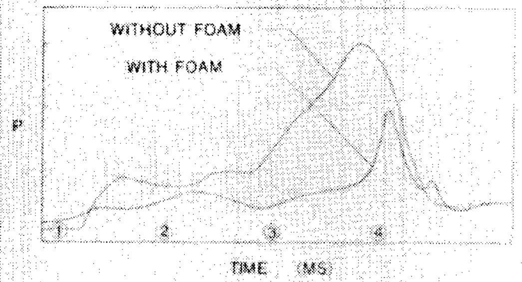
PROTECTIVE SHROUD SUCCESSFULLY REMOVED AT MACH 6.7 IN LaRC 8' HIGH TEMPERATURE TUNNEL



SHROUD PETAL REMOVAL SEQUENCE



TRANSIENT SHOCK PATTERN



SURFACE PRESSURE HISTORY

Figure 29(b).

COMBINED INDICATORS REQUIRED FOR VISCOUS FLOW

Kim S. Bey
Aerothermal Loads Branch
Extension 4441

RTOP 506-43-31

Research Objective - Develop efficient finite element methods for the accurate prediction of aerodynamic heating using automatic mesh refinement to add elements in regions of sharp gradients.

Approach - A crude finite element mesh is generated using PATRAN. A steady-state solution is obtained for this crude mesh using the two-step Taylor-Galerkin algorithm on the VPS-32. The mesh is then refined based on gradients of the flow variables so that elements are added in regions with shocks and boundary layers. This process continues until the mesh is sufficient to capture sharp gradients.

Accomplishment Description - A mesh enrichment strategy for quadrilateral elements has been added to the Taylor-Galerkin code. The strategy is to divide a quadrilateral whose indicator is larger than a given tolerance into four quadrilaterals by simple bisection. In the computations, regions of refined element are transitioned to regions of unrefined elements using triangular elements. The choice of a refinement indicator for capturing shocks is second derivatives of any flow variable, since all are discontinuous across the shock. A combination of indicators is required for capturing the boundary layer. Figure 30(b) shows an example of automatic mesh refinement for the problem of axisymmetric flow over a hemispheric cylinder. The initial mesh which contains 360 elements is so crude that any indicator gives a globally refined mesh for the first refinement. The results of second refinement using the individual and combined indicators of velocity and temperature shows that an indicator on velocity is needed to refine the boundary layer along the body while an indicator on temperature is needed in the stagnation region. Many more refinements are needed to accurately capture the features of the boundary layer and the stagnation point heating.

Significance - Although experience in using this procedure for the prediction of aerodynamic heating is limited, the technique offers the potential for solving complex flow problems without a prior knowledge of the detailed flow field, thereby relieving the researcher of the burden of generating a mesh specifically designed to capture the flow physics and eliminating the time consuming task of regenerating a mesh based on solutions obtained from inadequate meshes.

Future Plans - The refinement strategy will be applied to the hemispheric cylinder and to 2D flow over a three inch diameter cylinder to predict the aerodynamic heating. A strategy to unrefine elements is needed to remove elements that are not needed as the gradients are sharpened by successive refinements.

Figure 30(a).

COMBINED INDICATORS REQUIRED FOR VISCOUS FLOW

Example : Hemispheric Cylinder

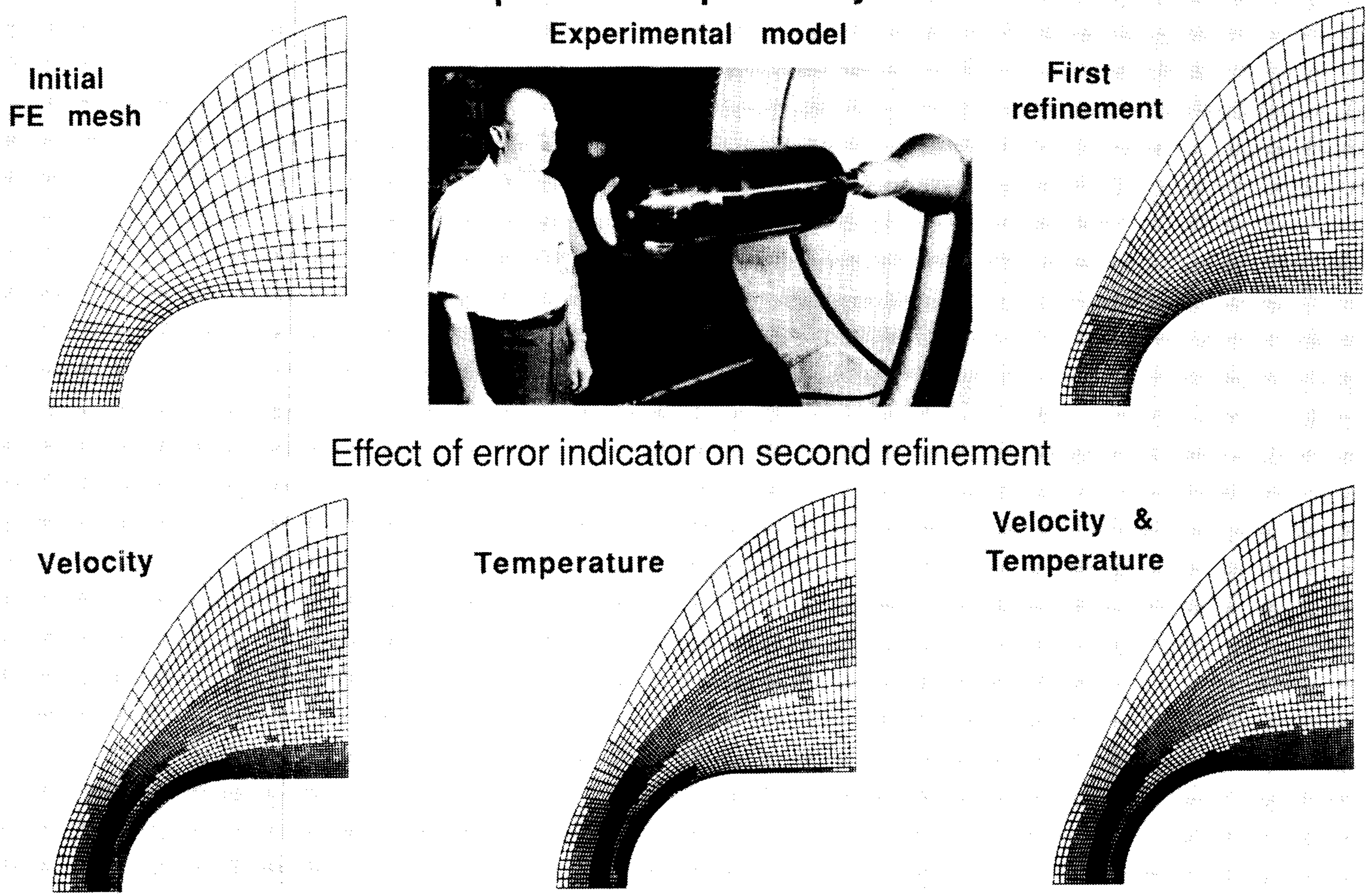


Figure 30(b).

INTEGRATED FLUID-THERMAL-STRUCTURAL ALGORITHM DEMONSTRATED FOR NONLINEAR THERMAL AND STRESS-STRAIN ANALYSIS

Pramote Dechaumphai
Old Dominion University
Extension 3423

RTOPS 506-40-21 and 506-43-31

Research Objective - The objective of this research is to develop a fully integrated fluid-thermal-structural (I F-T-S) analysis capability, that utilizes a single model and possibly a single algorithm for all three disciplines to simultaneously compute the coupled aerothermo-structural response of a structure.

Approach - Finite element theory is the targeted methodology for the integrated analysis capability, since it was clearly the method of choice in thermal and structural analysis. A team of world class investigators was assembled on grants and contracts to aid in the development of the integrated analysis capability with the early emphasis on computational fluid dynamics (CFD). Now as the finite element CFD capability begins to mature, the integration of the disciplines is being addressed.

Accomplishment Description - Accomplishments to date have shown that finite element analysis of CFD problems is a viable alternative to the more classical approaches and can offer some advantages such as unstructured gridding for adaptive refinement in complex flow fields. A Taylor-Galerkin algorithm, developed for the CFD analysis, has also been applied to a linear thermal-structural analysis. Figure 31(b) shows the results of extending the capability even further by exploiting the algorithm for nonlinear thermal-structural analyses of a 3" diameter stainless steel cylindrical leading edge with shock interaction as shown. The linear analysis results, constant material thermal properties and temperature independent linear stress-strain relations, predict a maximum surface temperature of 2425° R and a stress level, -337 ksi, beyond the yield stress of the material. The nonlinear analysis results, with temperature dependent material thermal properties and temperature dependent nonlinear stress-strain relations (illustrated by two temperature curves), predict a maximum surface temperature of 1641° R and a stress level, -144 ksi, within the operating range of the material.

Significance
An I F-T-S analysis capability is essential for designing safe minimum weight super/hypersonic vehicles. The accurate determination of aerothermal loads on these vehicles and their thermal and structural response are coupled through the surface temperature and in some cases through the deformed shape of the body. The capability of including nonlinear thermal-structural models in the I F-T-S analysis has been demonstrated with this problem.

Future Plans - Development of the I F-T-S analysis capability will continue with focus on three major areas: Development of finite element CFD methodology including algorithms, adaptive refinement, local error estimates improved accuracy and improved efficiency; Development of efficient coupling strategies for the three disciplines; and Expansion of analysis capability to include real gas effects, equilibrium and nonequilibrium chemistry effects, turbulence, mass addition, wall catalysis, etc.

Figure 31(a).

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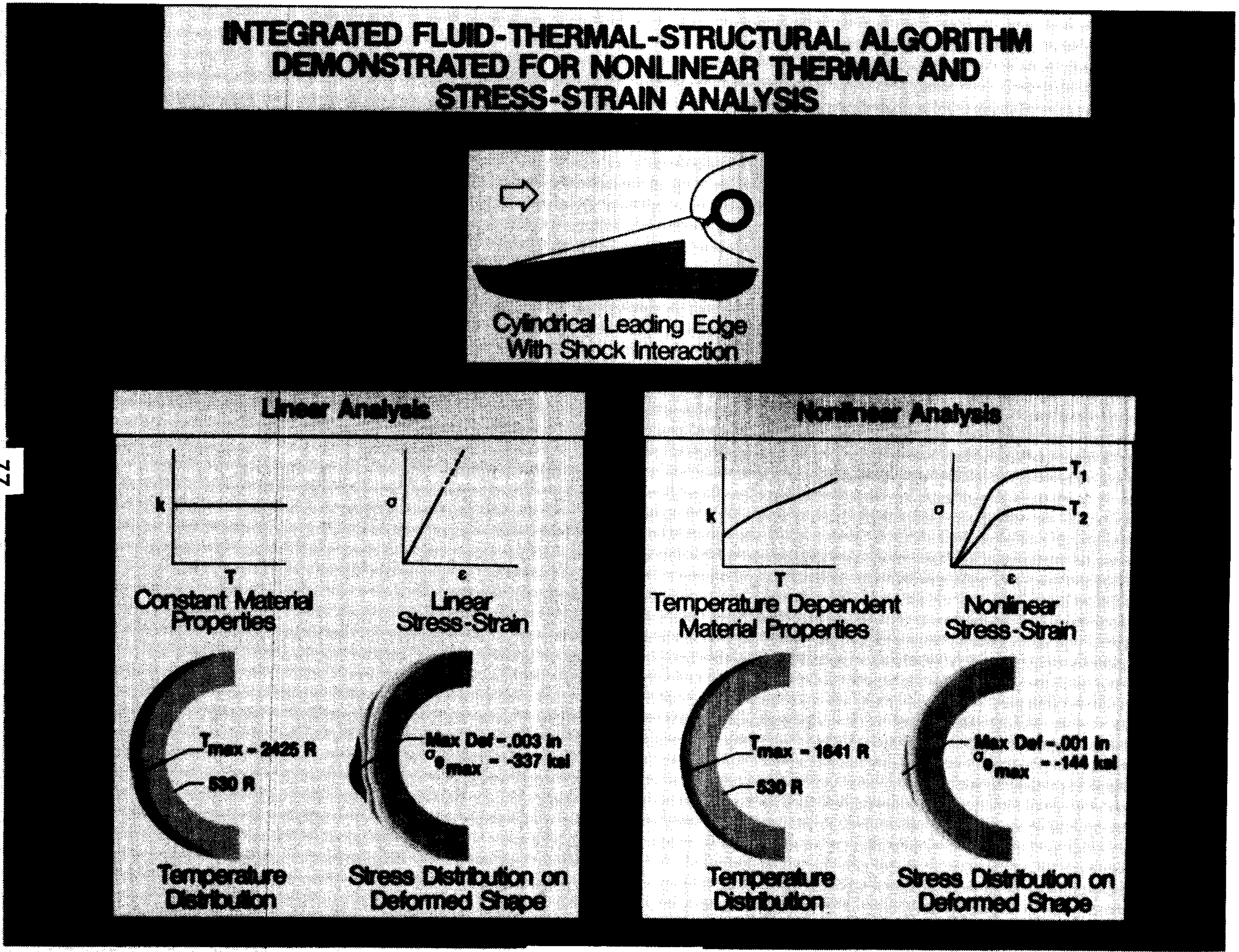


Figure 31(b).

COMPACT ANALYZER CONTROLS OXYGEN ENRICHMENT LEVEL DURING COMBUSTION PROCESS WITH FAST RESPONSE

Richard L. Puster and Dr. Jag J. Singh
Aerothermal Loads Branch and Instrument Research Division
Extensions 3115 and 3907

RTOP 505-63-81

Research Objective - Future engine tests in the 8-Foot HTT which uses combustion products as its test medium, require oxygen enrichment to duplicate the oxygen content of air for propulsion tests, as illustrated in the upper left of figure 32(b). The purpose of the present study was to demonstrate that oxygen content could be measured precisely and used in the automatic control of the oxygen enrichment level to simulate air.

Approach - The system illustrated in the lower left was thoroughly tested in the laboratory prior to installation in the 7" HTT (a 1/12.8 scale model of the 8'-HTT). The essential elements of the system are a sampling probe, a pressure regulator to keep the inlet pressure at one atmosphere, a heater to raise the gas temperature to 300° C, and the zirconia sensor. The zirconia sensor has a heater to keep its temperature at 800° C, and it produces a voltage potential that is proportional to the difference in oxygen concentration across the hot sensor; reference air is on the other side of the sensor. The voltage from the analyzer is used by a controller/CPU which provides both oxygen content data readout and automatic control of an oxygen control valve supplying liquid oxygen (LOX) to the wind tunnel combustor.

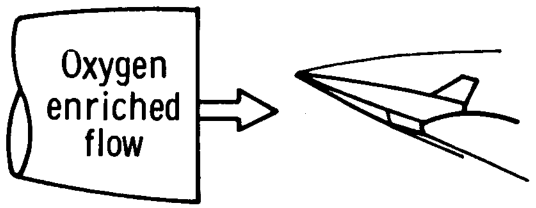
Accomplishment Description - The combustion gas was sampled continuously with either a fixed probe or moveable probe mounted in the test section. A typical histogram of the oxygen control process is shown in the upper right of the figure. Initially, the system shows a decrease in oxygen level from 21 percent (air) to 5 percent as the combustion process is established. The oxygen content was then manually controlled to a level near the desired 21 percent control point for air simulation. The system was then switched to the automatic model, and it achieved a 21 percent level in less than 1/2 second, and thereafter, updated it every 1/5 second. The sensitivity of the servo/pneumatic controller was optimized to allow fast approach and stability for all oxygen levels. New set points of 24 percent and 18 percent were manually entered and the system switched to automatic model to demonstrate its stability. Other perturbations such as switching between probes gave equally good results. The gas sampling system lends itself to miniaturization to about 2-cubic inches for installation in test models.

Significance - The system can be used in the 8-Foot HTT or other facilities for automatic real-time control of the Oxygen content assuring accurate and a proper test media as well as enhanced facility productivity and flexibility.

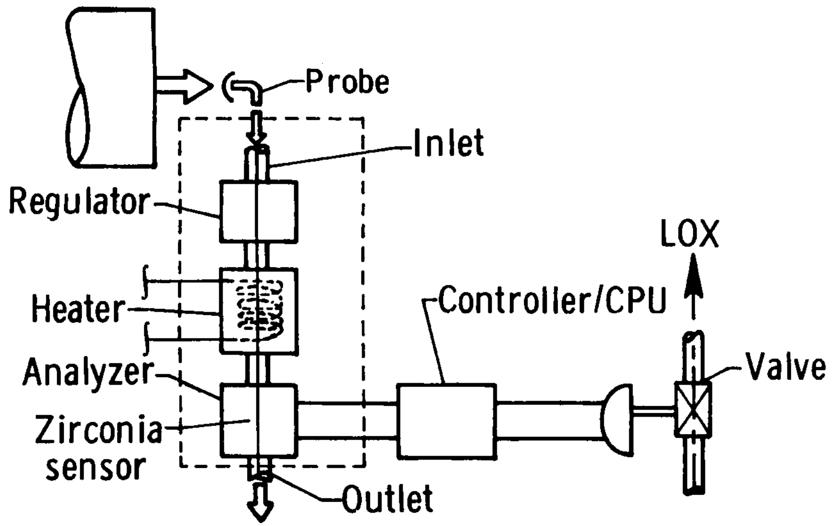
Future Plans - A similar system will be designed and built for use in the 8-Foot HTT.

Figure 32(a).

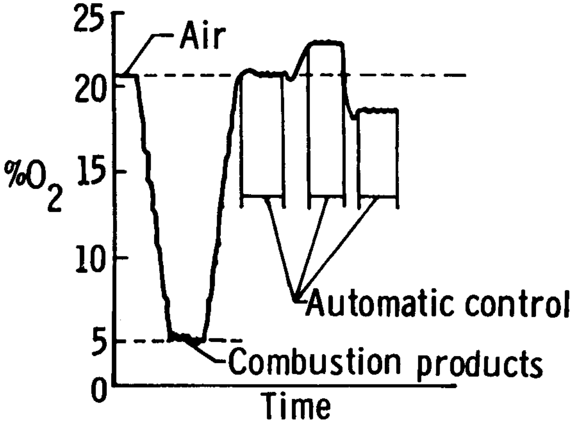
COMPACT ANALYZER CONTROLS
OXYGEN ENRICHMENT LEVEL DURING COMBUSTION PROCESS



Engine test in 8' HTT



O_2 analyzer test in 7-inch HTT



O_2 control histogram

- Compact - 2 in^3
- Real time - 0. 2s update
- Enhanced facility productivity and flexibility

Benefits

Figure 32(b).

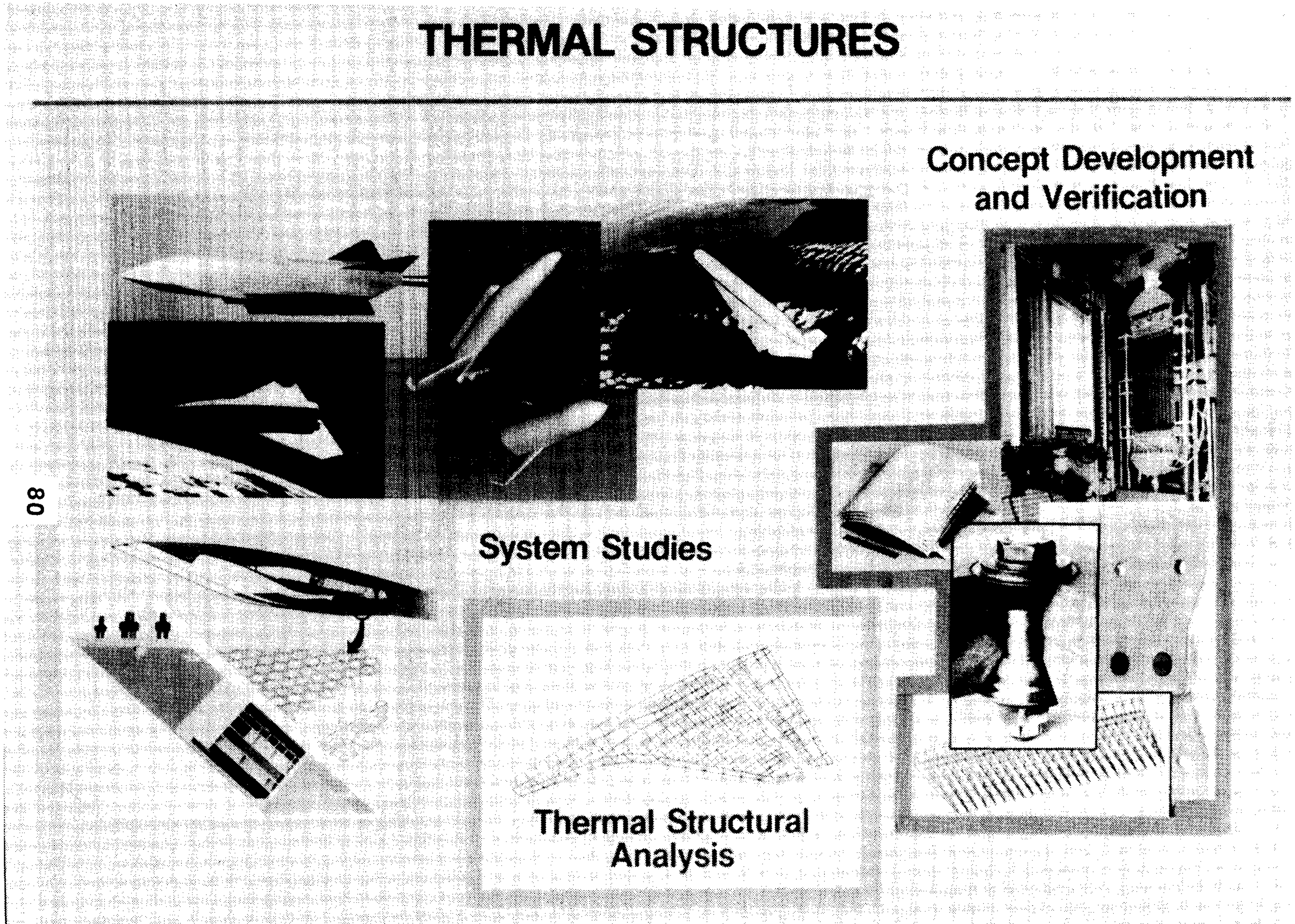

THERMAL STRUCTURES
Concept Development
and Verification
System Studies
Thermal Structural
Analysis

Figure 33.

THERMAL STRUCTURES

FIVE YEAR PLAN

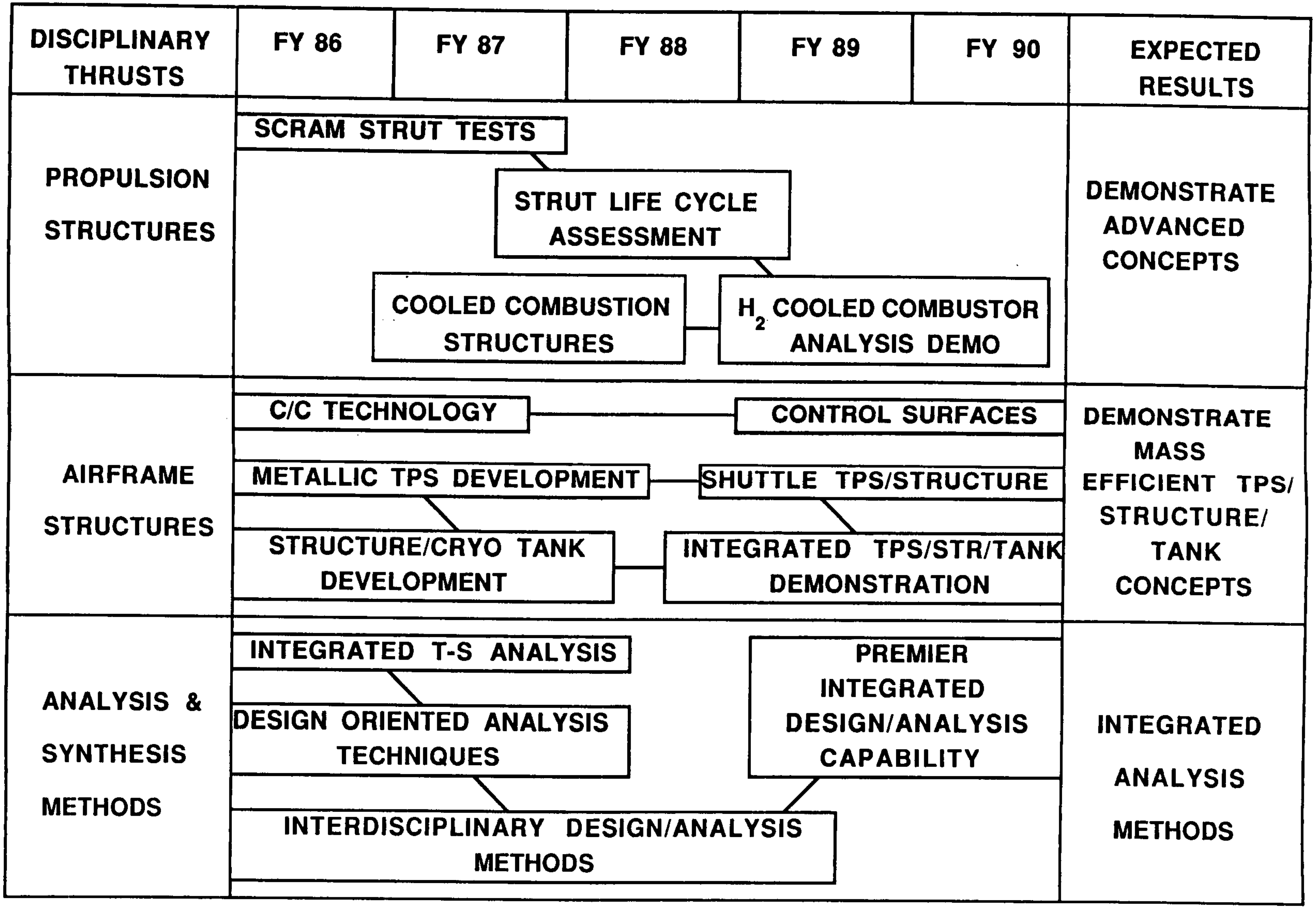


Figure 34.

COOLED HYPERSONIC ENGINE STRUT

Robert R. McWithey
Thermal Structures Branch
Extension 4201

RTOP 505-62-81

Research Objective - In the 1960's, Langley sponsored a comprehensive study involving the design, fabrication and testing of a scramjet Hypersonic Research Engine (HRE). Although the results of the study confirmed the suitability of the basic approach for scramjet engines, the coolant requirements for the HRE exceeded the heat capacity of the available hydrogen fuel, and the fatigue life was far shorter than desired. The problems stemmed, in part, from the annular design and high compression ratio of the HRE which resulted in large areas being exposed to an intense heating environment. Findings of the HRE study and additional studies led to the Langley 3-dimensional, fixed geometry airframe-integrated scramjet engine concept as shown in figure 35(b). In-house and industry design studies produced viable designs for the Langley integrated scramjet with cooling requirements that permit engine operation to Mach numbers of 9-10 without additional hydrogen for engine cooling. However, the design studies indicated the need for advances in fabrication and material technology to achieve reasonable structural life. Advanced fabrication studies (conducted during the 70's) were successful in indicating methods to improve fatigue life. Therefore, the objective of the present research is to successfully incorporate the results of these previous studies into the fabrication of a flightweight fuel injection strut.

Approach - The detailed thermo/structural design of the fuel injection strut was conducted in-house and under contract to AiResearch Manufacturing Company. Strut fabrication is being performed by AiResearch under contract to NASA Langley. Additional fabrication studies are included in the present contract to determine strut fabrication and assembly procedures. After delivery to Langley, the strut will be subjected to static loading and heating tests, and to aerothermal tests that will simulate the environment produced by flight conditions. Successful completion of these tests will establish the validity of the thermo/structural design for the Langley integrated scramjet engine.

Accomplishment Description - Detailed design studies have been conducted by the contractor. However, initial attempts to fabricate the strut were unsuccessful, and fabrication studies became a major part of the current effort. Parts for the strut have been successfully fabricated and several partial-length struts completely assembled. NDT and pressure tests on the partial-length struts indicated several deficiencies in braze management and structural strength. Additional fabrication studies are planned to correct these deficiencies.

Significance - Successful fabrication and tests of the fuel injection strut will be the first validation of the thermo/structural design of the Langley integrated scramjet engine concept and will partially provide the necessary data base for fabrication of future scramjet engines.

Future Plans - Delivery of the strut is scheduled in FY 87. Aerothermal tests on the strut will be conducted in a Langley propulsion tunnel in FY 88. Ultimately, a hydrogen-cooled engine module representing the Langley scramjet engine and incorporating the fuel injection strut will be tested in the 8-Foot High Temperature Tunnel.

Figure 35(a).

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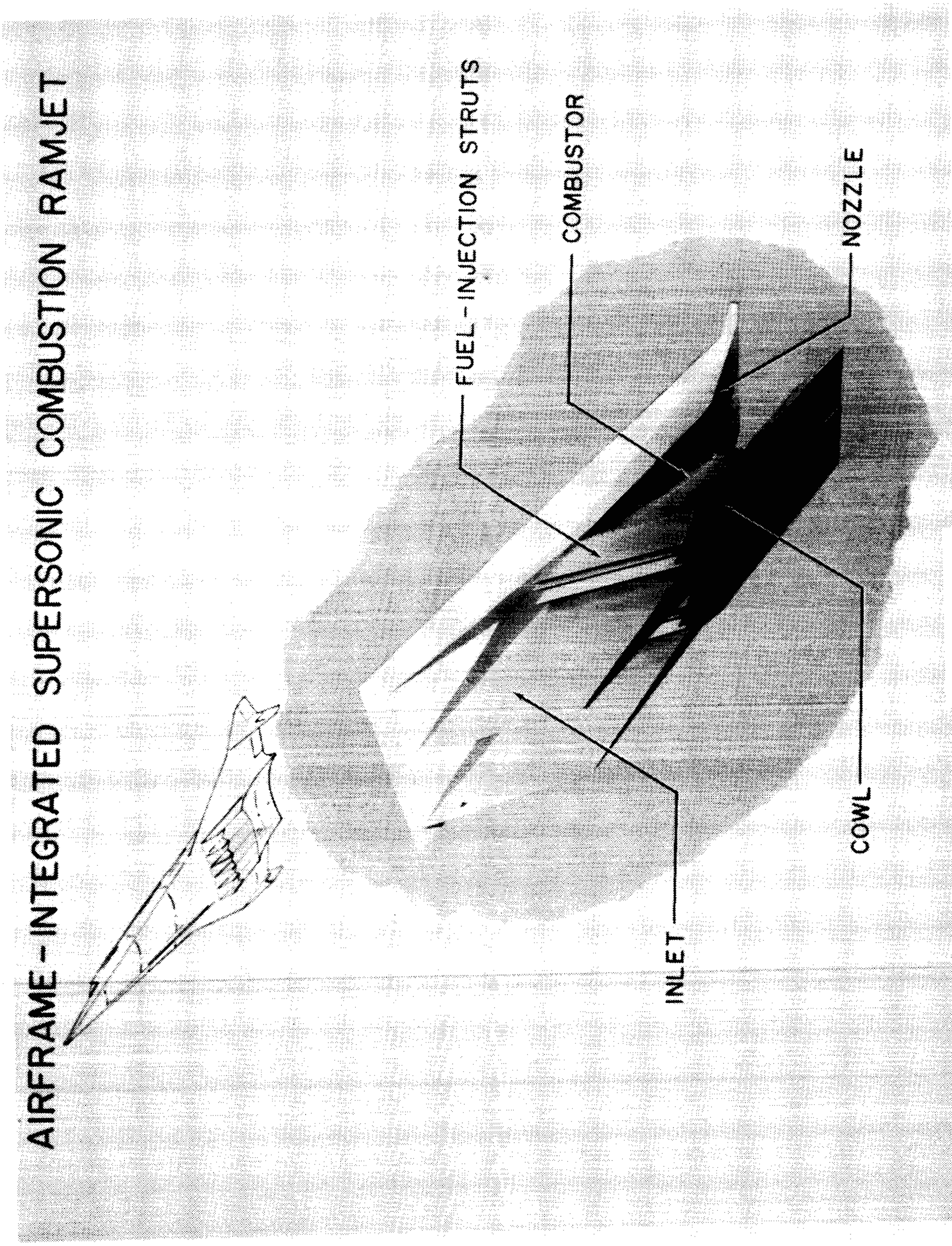


Figure 35(b).

LEAKTIGHT HONEYCOMB JOINT DESIGN FOR 900°F SERVICE ENVIRONMENT

A. H. Taylor
Thermal Structures Branch
Extension 4142

RTOP 506-43-31

Research Objective - The structural mass fraction of future cryogenically fueled high speed aircraft can be significantly reduced by utilizing efficient titanium honeycomb-core sandwich structural concepts with thin gage superplastically formed sine-wave webs solid-state diffusion-bonded (SSDB) to the spar, rib or frame caps. The program goals for the advanced honeycomb concept include a 900°F operating temperature for 2500 flight hours, without exceeding a creep strain of 0.2%, and a cycle life of 50,000 cycles for aeroinertial loads at a 40 ksi stress level in the structural material. Leaktight containment of the cryogenic propellants is probably the most ambitious goal. It is required because the operating temperature of 900°F is above the auto-ignition temperature of most known fuels.

Approach - Because there are no known sealants for these joints, welding of the structure is the intuitive solution to providing leaktight joints. The fabrication and joining of the honeycomb structure is a pacing technology for this structural concept. First, for use temperatures in the 900°F range, there are no known adhesive or brazing alloys. Furthermore, diffusion bonding is not feasible because high fabrication pressures and temperatures would require an unacceptably heavy core to prevent it from crushing during the process. Therefore, liquid interface diffusion (LID) bonding was selected for the core to face sheet fabrication process.

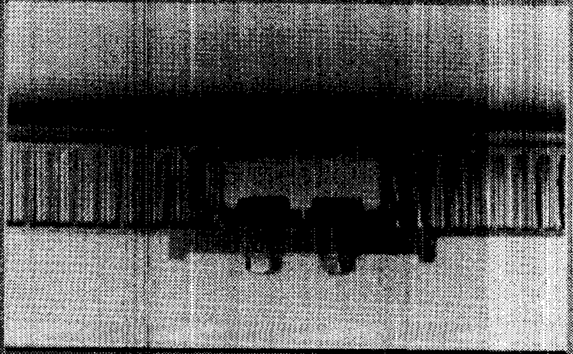
Accomplishment Description - LID bonded titanium honeycomb core sandwich welded joints matured over a several year period to the concept are shown in figure 36(b). The LID process is used to join the face sheets and core of the basic panel. The periphery of each panel is padded up by chemically milling the center to 1/2 the joint thickness. A thin channel is spot welded to the core prior to the LID cycle and the flanges are concurrently LID and SSD bonded to the lower and upper face sheets, respectively. This closeout forms a barrier to prevent gas or liquid permeation of the core. The joint is accomplished by mechanically attaching the inner face sheets to the rib or spar cap. The outer face sheet is fabricated to a smaller dimension than the inner face sheet in order to provide a gap for access to the mechanical attachments. The resulting gap on the outer surface is then filled with a plate which is electron beam welded in place to complete the joint. The static and fatigue test results indicate the honeycomb joint design has an endurance limit of nearly 40 ksi for 50,000 cycles and can withstand static loads nearing the yield strength of the material or ultimate strength of the mechanical fasteners.

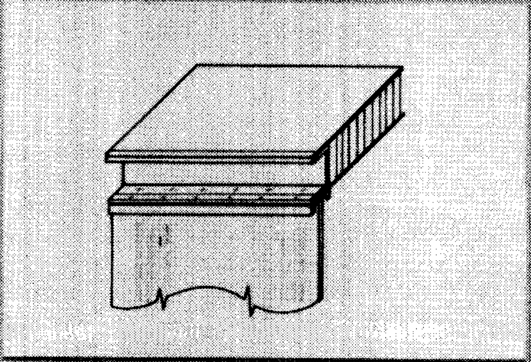
Significance - The demonstrated static room temperature performance of the honeycomb core sandwich structure and panel joint concept is the initial step for this structural concept to provide leaktight containment for cryogenic liquids.

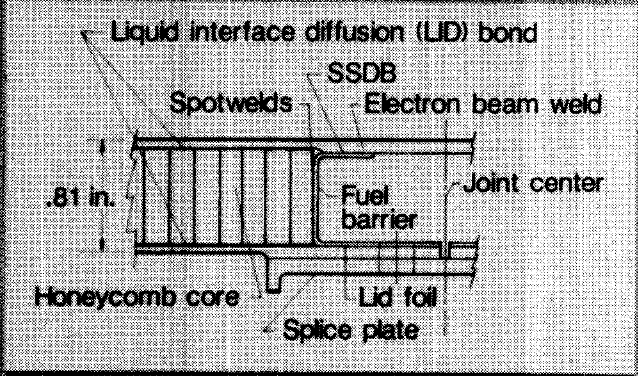
Future Plans - Testing of the LID bonded honeycomb panel and panels with joints at elevated temperatures is currently in progress at Ames DFRF to verify the panel and panel joint performance in the anticipated flight thermomechanical environment.

Figure 36(a).

TITANIUM HONEYCOMB JOINT CONCEPT







- Joint concept developed & LID process verified
- Fatigue/static tension goals met during tests
- Panels being thermal tested at DFRF

Figure 36(b).

MULTIWALL INSULATING BLADDER FOR CRYOGENIC TANK

Max L. Blosser
Thermal Structures Branch
Ext. 4295

RTOP 506-43-31

Research Objective - Efficient insulation systems are needed for cryogenic tanks of future hypersonic vehicles. An insulating bladder consisting of evacuated, titanium multiwall insulation has been proposed. The objective of this study is to investigate the feasibility of a multiwall insulating bladder.

Approach - At least two critical issues have been identified: ability of the foil gauge metal to maintain a vacuum for an acceptable lifetime, and ability of the multiwall to transmit the pressure and inertial loads from the cryogenic liquid to the tank structure. Investigation of vacuum integrity will require fabrication of new test specimens and complicated tests. However, the through-the-thickness compressive strength of multiwall could be addressed using in-house analysis and available test specimens. An existing finite-element model was modified to predict the compressive strength of multiwall, and available multiwall TPS specimens were tested in compression.

Accomplishment Description - As shown in figure 37(b), multiwall consists of alternate layers of dimpled and flat titanium foil. The through-the-thickness strength of multiwall depends almost entirely on the dimpled sheets. The flat sheets merely restrain the dimpled sheets from spreading laterally. The analysis, therefore, focused on predicting the maximum load which can be carried by the dimpled sheet. For the thicknesses considered, the maximum load is limited by buckling of the dimpled sheet. The dimpled sheet geometry is characterized by three dimensions: height, pitch, and thickness. The height is the vertical distance between the crests of the upper and lower dimples. The pitch is the lateral distance between adjacent dimples. The thickness refers to the thickness of the sheet material before forming the dimples.

A small section of a dimpled sheet was modeled using the Engineering Analysis Language (EAL) finite-element computer program. This model was used to calculate the elastic buckling load of the dimpled sheet. The model was parametrically varied to investigate a variety of dimpled sheet geometries. Starting from a set of base values, each of the three characteristic dimensions was independently varied to determine the sensitivity of the maximum load to changes in dimpled sheet geometry. The figure shows the results of these calculations for variations in the geometric parameters normalized by their base values. The maximum load is very sensitive to pitch and height. Therefore, large compressive loads may be carried by thin sheets with the appropriate pitch and height.

Several specimens, available from the multiwall thermal protection system program, were tested in compression. However, these specimens were not designed to carry through-the-thickness loads and the dimples were not well aligned between layers. Consequently, the specimens failed at less than half the predicted load. Although the magnitudes of the maximum loads did not agree well, the variation in geometry produces similar trends in both analysis and tests.

Significance - Hypersonic vehicles will require very efficient cryogenic insulation systems. The multiwall cryogenic insulation system has the potential to meet this need. This study has shown that multiwall will likely be able to carry the required pressure loads at a light weight. The sensitivity curves provide one of the tools necessary to optimize the multiwall insulation for comparison with other cryogenic insulation systems.

Future Plans - Better specimens are needed to verify the structural analysis. Tests must be conducted to investigate the vacuum integrity of the system. This work will be continued if resources are provided.

Figure 37(a).

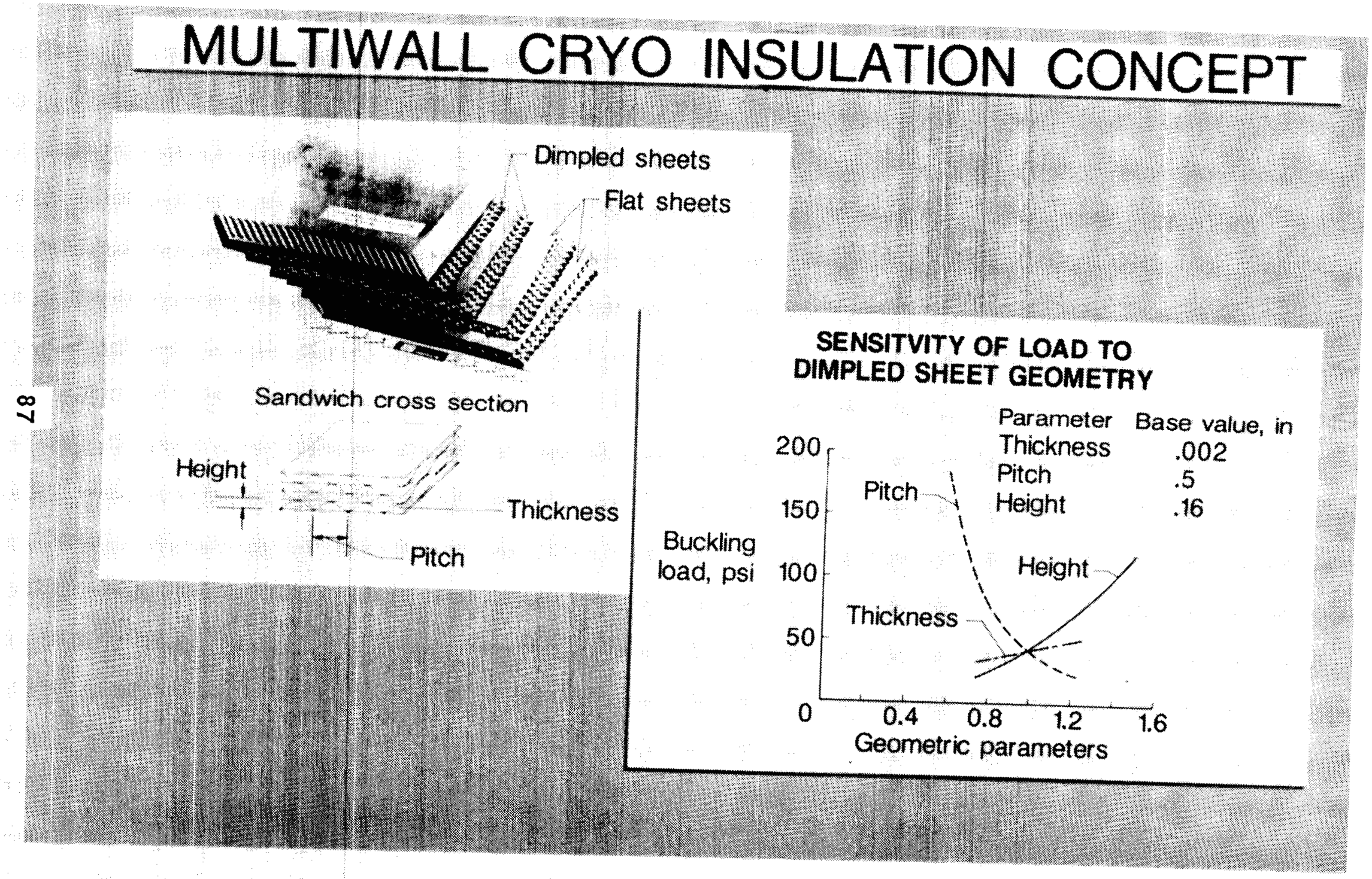

MULTIWALL CRYO INSULATION CONCEPT
Dimpled sheets
Flat sheets
Sandwich cross section
Height
Thickness
Pitch
SENSITVITY OF LOAD TO
DIMPLED SHEET GEOMETRY
Parameter Base value, in
Thickness .002
Pitch .5
Height .16
Buckling load, psi
0
50
100
150
200
Pitch
Height
Thickness
0.4
0.8
1.2
1.6
Geometric parameters

Figure 37(b).

SIZING & OPTIMIZATION LANGUAGE (SOL)

Stephen J. Scotti
Thermal Structures Branch
Extension 4296

RTOP 506-43-31

Research Objective - The performance of advanced vehicles is dependent on the proper interaction of the various aerospace disciplines contributing to the vehicle design. Also, within a given discipline (such as structures), there are various elements which must be properly integrated to arrive at a design with optimum performance. The objective is to develop an new, general method to perform such an integration task.

Approach - The development of a high level computer language which has built-in features to facilitate error-free modeling and optimization was chosen as the approach to meet the research objective. The availability of the MYSTRO compiler development system at Langley made this approach feasible. The initial version of the language has the structure to perform simple sizing and multi-level optimization. The output of the language compiler is FORTRAN to facilitate debugging of the compiler code and to allow coupling to existing FORTRAN software. An existing optimization routine, Automated Design Synthesis (ADS), is used to perform the actual optimization when solving problems.

Accomplishment Description - An initial version of the computer language, called Sizing and Optimization Language (SOL), has been developed. It consists of approximately 10000 lines of Pascal code which was written over a two month time period. Initially, each piece of code in the compiler was exercized to remove simple logic errors, and several classic optimization problems were successfully solved using SOL. Some combined sizing and optimization problems were also successfully solved uncovering only a few bugs in the compiler in spite of its size. The use of the MYSTRO development system is believed to have reduced the possibility for compiler bugs significantly.

Figure 38(b) illustrates the use of SOL to solve an integrated thermal/structural problem. The object is to design an evacuated multiwall cryogenic tank insulation. The requirements are that the multiwall sandwich resist the 20 psi tank pressure without buckling and that the weight of the sandwich plus the liquid hydrogen boiloff (due to aerodynamic heating) are minimized. The height and pitch (h and p) of the dimple spacing, and the thickness (t) of the dimpled sheets are the design variables which control the sandwich buckling resistance. A correlation to a parametric finite element study of sandwich buckling has been developed for the SOL model. The boiloff of the cryogenic fuel is determined by solving for the heat flux through the panel assuming a constant radiation equilibrium outer skin temperature due to aeroheating and an internal skin temperature due to the hydrogen heat sink. The parameters h,p, and t determine the thermal resistance of the sandwich using the method of reference 4. This heat transfer problem was solved as an optimization problem where the heat flux through each layer was constrained to be equal to the heat flux through the entire panel. The multiwall design problem was then solved as an optimization problem (which included the nested heat transfer problem) minimizing the sandwich plus boiloff weight while still satisfying the buckling constraint. A geometry constraint forcing p/h to be less than 4.5 was added because of the bounds of the buckling correlation. The results are shown in the accompanying figure. The optimum is constrained by both the buckling and geometry ($p/h < 4.5$) constraints. These results show that the range of the buckling data should be expanded to the higher p/h values found to be important in reducing boiloff.

Significance - The advantages of SOL include the following: the simplicity and flexibility in the description of the problem; and the extensive checking for common modeling mistakes by the compiler.

Future Plans - An initial version of a high level computer language (SOL) to solve interdisciplinary problems has been developed. The present version of SOL will be documented in a users/reference manual to allow distribution to other potential users. The feedback from use of SOL to solve practical problems will be used to generalize the modeling capability in SOL to handle a wider range of problems in integrated design.

Figure 38(a).

SIZING & OPTIMIZATION LANGUAGE (SOL)

- High-level computer language
- Built-in multi-level optimization
- Structured model-refinement capability
- Fortran output, extensive error checking

EXAMPLE APPLICATION

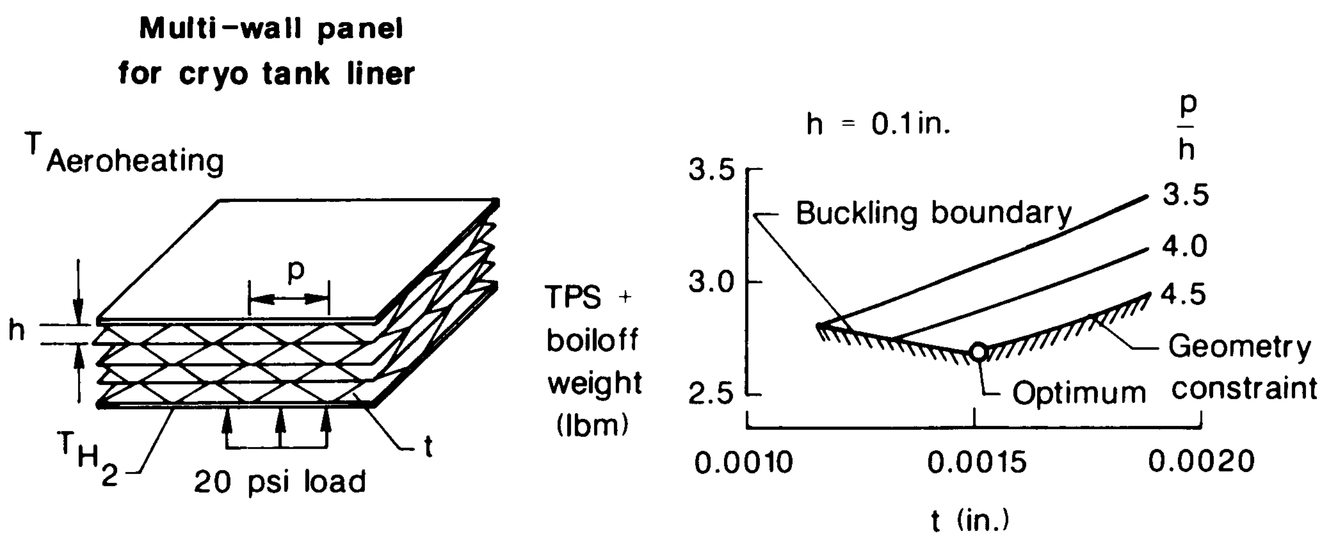


Figure 38(b).

CONFIGURATION AEROELASTICITY BRANCH

FY 87 PLANS

0 COMPLETE ADAPTIVE ACTIVE FLUTTER SUPPRESSION STUDY

0 COMPLETE SECOND PHASE IN EVALUATION OF ACTIVE FLEXIBLE WING CONCEPT

0 COMPLETE WIND-TUNNEL AND RPV BUFFET TESTS ON TWIN VERTICAL TAIL CONFIGURATION

0 COMPLETE STUDY OF VIBRATION/ STABILITY/PERFORMANCE OF TAILORED BEARINGLESS ROTOR

0 INITIATE TRACK AND BALANCE SENSITIVITY STUDIES - THEORY EXPERIMENT CORRELATION

0 ADD BEARINGLESS HUB ANALYTICAL MODEL TO CAMRAD CODE

0 COMPLETE FINITE-ELEMENT ANALYSIS AND EXPERIMENTAL CORRELATION FOR BOEING MODEL 360 AND BELL ACAP

0 COMPLETE CORRELATION STUDIES FOR AH-1G COUPLED ROTOR-AIRFRAME ANALYSIS

0 COMPLETE BREADBOARD DEMONSTRATION OF VIBRATION CONSTRAINED OPTIMIZATION FOR ROTORCRAFT

0 NEW DAS FOR TDT OPERATIONAL FOR OFF-LINE USE

Figure 39.

AIRCRAFT AEROELASTICITY

Frank W. Cazier, Jr.
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-63-21

Research Objective - The primary objectives in Aircraft Aeroelasticity research area are (1) to determine and solve aeroelastic problems of current designs, and (2) to develop the aeroelastic understanding and prediction capabilities needed to apply new aerodynamic and structural concepts to future flight vehicles.

Approach - The types of research included in the Aircraft Aeroelasticity area are illustrated in figure 40(b). This research is a combination of experimental and complementary analytical studies. The experimental work focuses on the use of the Langley Transonic Dynamics Tunnel (TDT) which is specifically designed to meet the unique needs of aeroelastic testing. On occasion flight research programs are undertaken when it is necessary to simulate important parameters that cannot be accurately accounted for in ground-based facilities. Quite often the research is a cooperative effort with other government agencies and/or industry.

Status/Plans - Work for the coming year includes a variety of activities. Several will be mentioned here by way of illustration. A flutter clearance study of the new wing for the A-6 airplane will be conducted in the TDT using a sidewall mounted model. This model will be tested with and without several combinations of external stores to verify that the new design is free from flutter throughout the operating envelope. Work will be continued for two studies associated with the use of active controls to favorably change aeroelastic response. One is an adaptive flutter suppression endeavor, whereas the other is a study of the use of active controls along with aeroelastic tailoring of the structure to enhance roll control characteristics. Studies of self-induced oscillations are also planned , as is an empennage buffet response investigation of a modern fighter configuration.

Figure 40(a).

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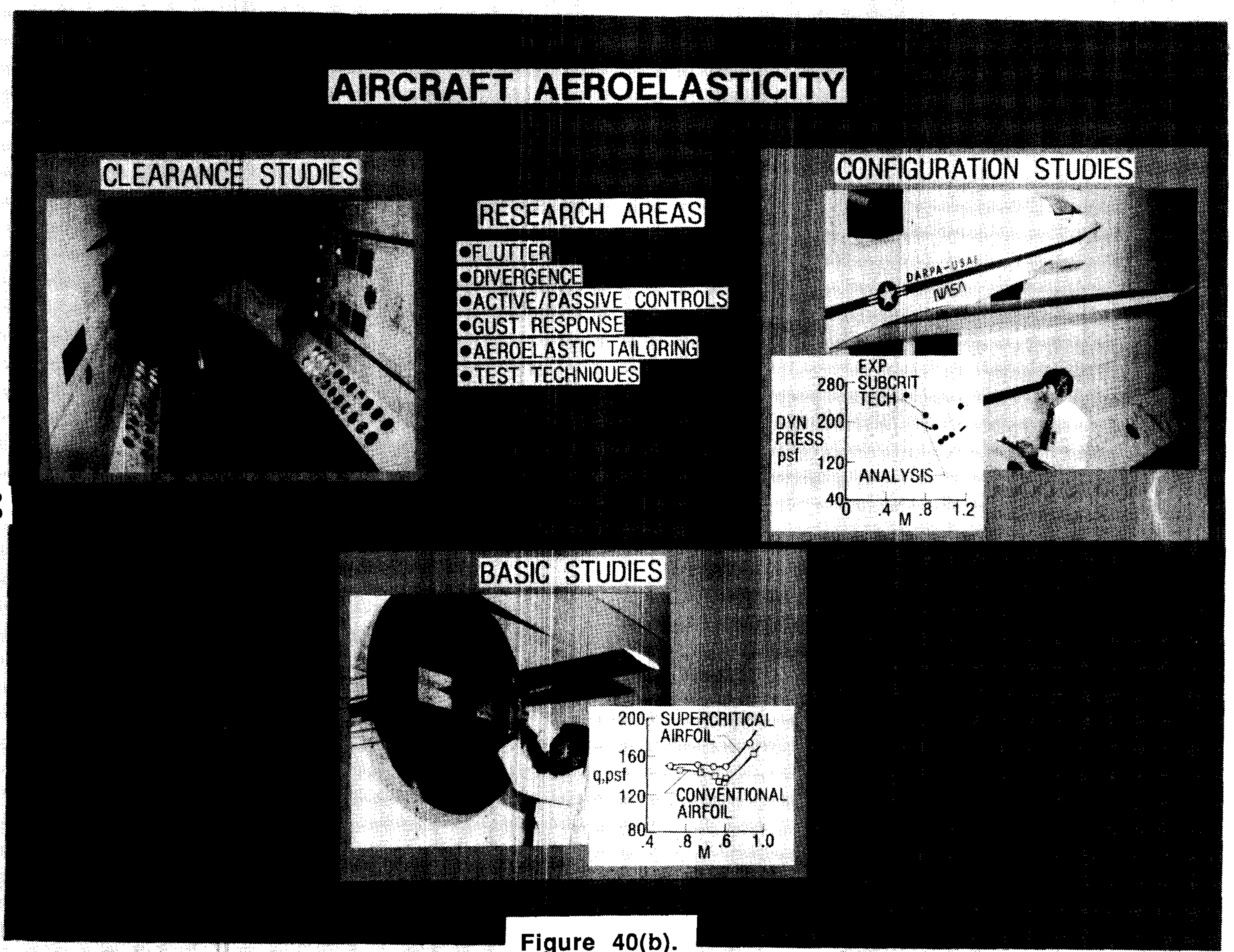

Figure 40(b).

UPGRADING THE DATA ACQUISITION SYSTEM FOR THE LANGLEY TRANSONIC DYNAMICS TUNNEL

Bryce M. Kepley
Configuration Aeroelasticity Branch
Extension 2661

Research Objective - The objective is to increase the productivity of the Langley Transonic Dynamics Tunnel (TDT) by replacing the existing computer-controlled data acquisition, display and control system with a new system that takes advantage of technological advances that have been made since the original system was designed over ten years ago. The new system will provide increased reliability, more flexibility, more data channels, faster data rates,design and enhanced real time analysis as compared to the present system.

Approach - The conceptual design of the new system was developed by a Langley in-house team. The system consists of there central processor units which interface with an analog front-end that can accommodate 192 data channels. The three computer configuration provides the flexibility needed to perform multiple tasks. The configuration of the analog front-end provide for support of multiple tests. The new system is configured to support tests in the General Rotor Aeroelastic Laboratory (hover facility) ajacent to the TDT building. This facility is not on the present system.

Status/Plans - The development of this system is proceeding on schedule. All major hardware components have been acquired and are now in place as shown in figure 41(b). The design of the required software is essentially complete, and a considerable amount of software has been written. The system is expected to be ready for off-line operational use near the end of fiscal year 1987.

Figure 41(a).

INSTALLATION OF NEW DAS FOR TDT PROCEEDING ON SCHEDULE

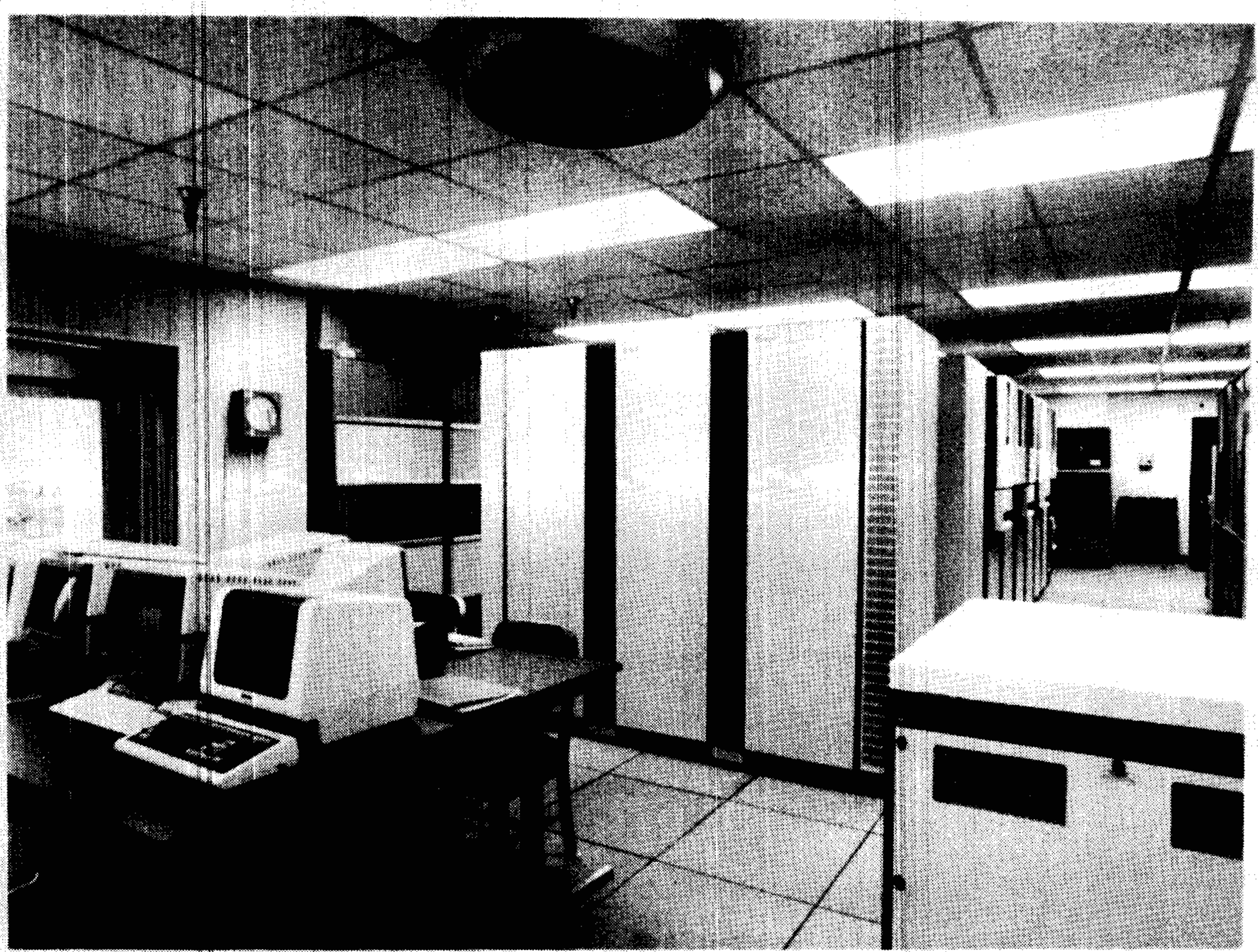

Figure 41(b).

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ROTORCRAFT DYNAMICS AND AEROELASTICITY

Wayne R. Mantay
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-61-51

Research Objectives - The triad of research objectives in this area are (1) to conduct research in aeroelasticity, aerodynamics and dynamics of rotors; (2) to support design of advanced performance helicopters in the areas of loads, vibration and aeroelastic stability; and (3) to develop the experimental and analytical techniques necessary to extend TDT capabilities to future research opportunities, such as bearingless rotors.

Approach - This research area is a joint effort of the Loads and Aeroelasticity Division and the U.S. Army Structures Laboratory which is co-located at the NASA Langley Research Center. The work is a combination of experimental studies, tests in the TDT and the General Rotor Aeroelastic Laboratory (hover facility), and analytical studies. The Aeroelastic Rotor Experimental System (ARES) is a key test bed in the experimental studies. The in-house civil service research is supported and supplemented by industry contracts and university grants.

Status/Plans - Research during this year will address a variety of topics such as aeroelastic stability of hingeless rotors, rotor gust response, rotor optimization evaluations, advanced rotor track and balance characteristics, and a variable speed rotor concept. One example project, namely, the tailored bearingless rotor study, is illustrated in figure 42(b). An Army/NASA contract has been signed with Bell Helicopter to provide for the design and fabrication of aeroelastcially tailored model rotor blades for testing in the Langley Transonic Dynamics Tunnel (TDT). The five sets of blades include two baseline rotors, one with government-designed advanced aerodynamics in terms of plan-form, airfoil selection, and twist. The three remaining rotors will have improved blade dynamics using the Bell "nodalization" method. One of the three "nodalized" blade sets will also have Bell-designed advanced aerodynamics. The primary purpose of this effort is to determine what effect, if any the nodalization" method has on rotor blades with advanced aerodynamics. All five blade sets will be tested on the ARES model in the TDT using a Bell model bearingless rotor hub. Rotor performance as well as rotor and fixed-system loads will be measured for all rotors over a wide range of test conditions.

Figure 42(a).

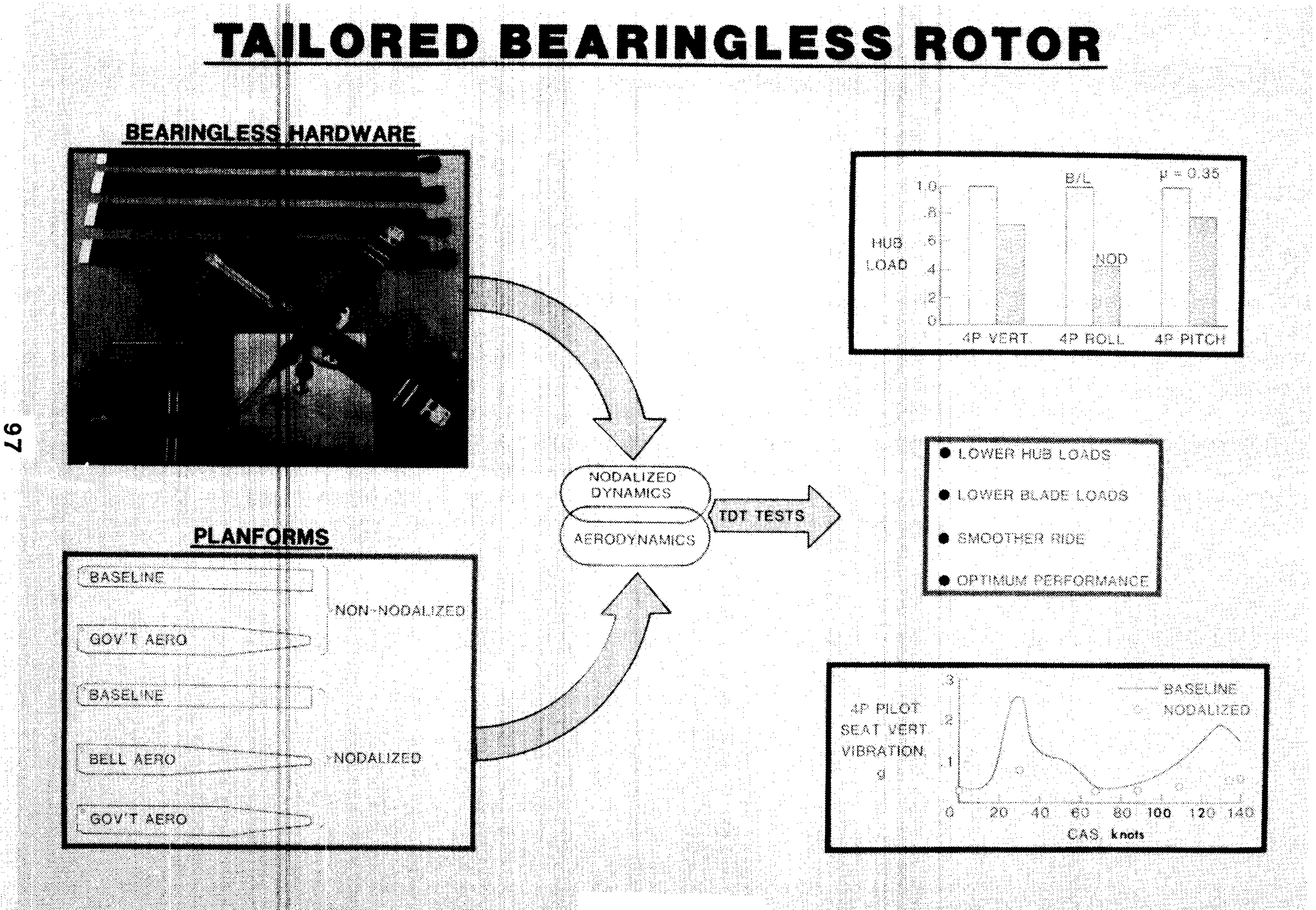

TAILORED BEARINGLESS ROTOR
BEARINGLESS HARDWARE
PLANFORMS
BASELINE
GOV'T AERO
NON-NODALIZED
BASELINE
BELL AERO
GOV'T AERO
NODALIZED
NODALIZED DYNAMICS
AERODYNAMICS
TDT TESTS
HUB LOAD
1.0
.8
.6
.4
.2
0
B/L
NOD
μ = 0.35
4P VERT
4P ROLL
4P PITCH
● LOWER HUB LOADS
● LOWER BLADE LOADS
● SMOOTHER RIDE
● OPTIMUM PERFORMANCE
4P PILOT SEAT VERT VIBRATION, g
.3
.2
.1
BASELINE
NODALIZED
0
20
40
60
80
100
120
140
CAS, knots

Figure 42(b).

A NATIONAL CAPABILITY TO ANALYZE VIBRATION AS PART OF HELICOPTER STRUCTURAL DESIGN

Raymond G. Kvaternik
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-61-51

Research Objective - Helicopters are prone to vibrations which can seriously degrade both service life and ride quality. With only a few exceptions vibrations problems have not been identified and attacked until the flight test and operational stages. There is now a recognized need to account for vibrations during the analytical phases of design. The advent of modern methods of computer analysis has provided the opportunity to achieve such a capability. The objective is to emplace in the United States a superior capability for design analysis of helicopter vibrations (figure 43(b)).

Approach/Status/Plans - Three meetings of the company participants have been held during which representatives from each company reported on the research tasks that they have underway. At the most recent meeting the following items, not necessarily all complete, were reported on: plan for conducting vibration measurements and formulating special finite-element models of difficult components of the AH-1G helicopter, results and experiences from forming a finite-element model of the D292 (ACAP) airframe with results from ground vibration test (Bell); results and experiences from calculating the flight vibrations of the AH-1G helicopter and correlating with existing flight test data, results and experiences from conducting a ground vibration test of the Model 360 helicopter airframe (Boeing Vertol); results and experiences from conducting a ground vibration test of the AH-64 and correlating with results from a finite-element analysis (McDonnell Douglas Helicopter Company); and results and experiences from conducting a ground vibration test of the UH-60 and correlating the results from a finite-element analysis (Sikorsky).

For the coming year, efforts will be placed on documenting the studies completed to date and completing the UH-60, D292, and Model 360 test and analysis correlation. In addition, a new study by Bell will focus on determining the effects of difficult components on the vibration characteristics of metal airframes with emphasis on developing means for properly accounting for the effects of such components in finite-element models.

Figure 43(a).

DESIGN ANALYSIS METHODS FOR VIBRATIONS (DAMVIBS) PROGRAM

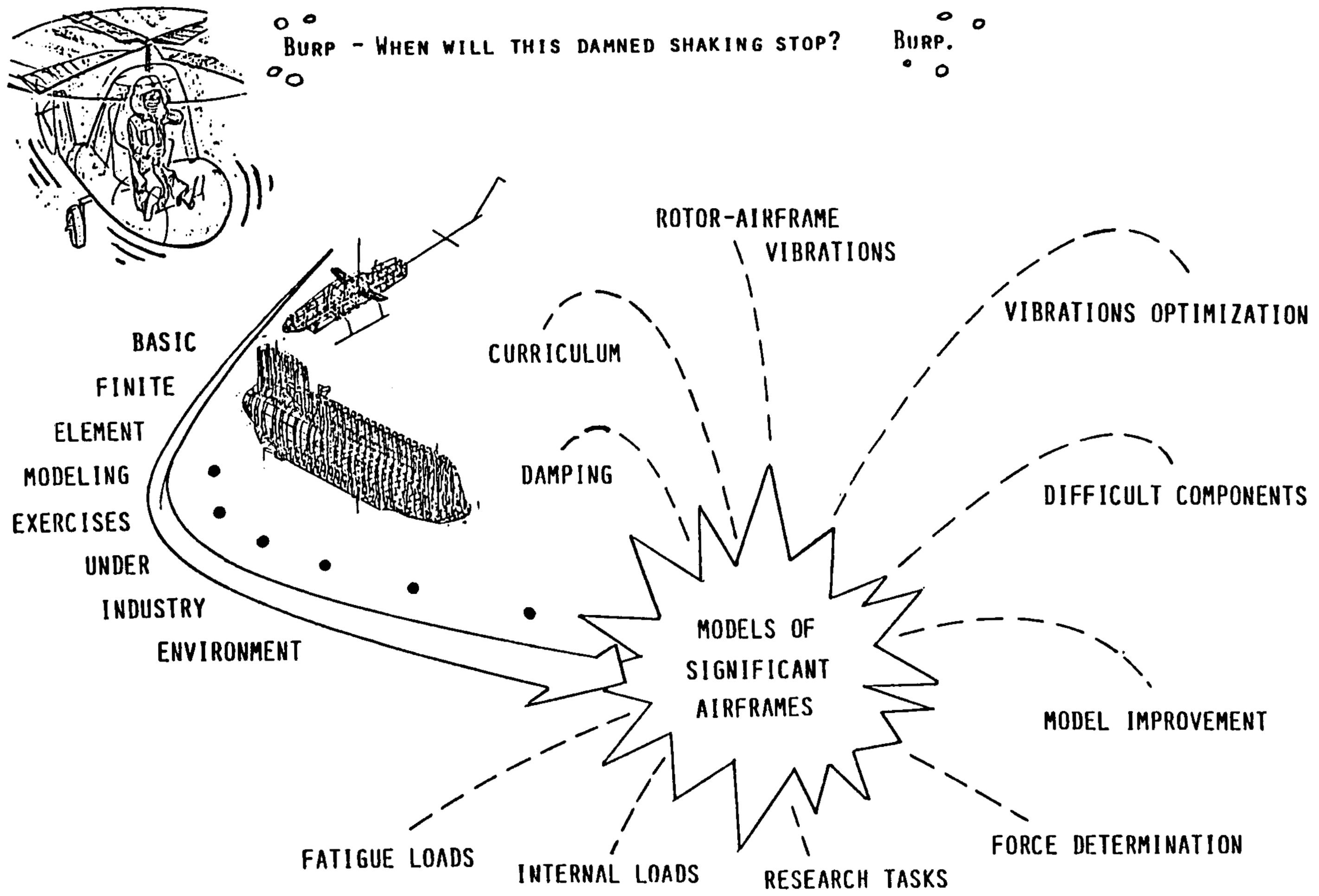


Figure 43(b).

UNSTEADY AERODYNAMICS BRANCH

FY 87 PLANS

0 COMPLETE DEVELOPMENT, CHECKOUT, AND RELEASE OF CAP-TSD

- CONTINUE NASA LANGLEY/AFWAL COOPERATIVE EFFORT

0 DEVELOP 3-D APPROXIMATE FACTORIZATION FULL POTENTIAL CODE

0 EXPERIMENTAL PROGRAM

- CLIPPED DELTA WING/CANARD INTERFERENCE TEST
- CANARD-ALONE HIGH-ALPHA DYNAMIC TEST
- DESIGN BENCHMARCH AEROELASTIC MODEL

0 PROCURE BASIC UNSTEADY RESEARCH FACILITY (BURT)

Figure 44.

DEVELOPMENT OF COMPLETE AIRCRAFT TRANSONIC AEROELASTICITY CODE

John T. Batina
Unsteady Aerodynamics Branch
Extension 4236

RTOP 505-63-21

Research Objective - The objective of the research is to develop a computer code for transonic aeroelastic analysis of realistic complete aircraft configurations.

Approach - A time-accurate approximate factorization (AF) algorithm has been developed for solution of the unsteady small-disturbance equation for transonic flow. The new algorithm is very efficient for transonic unsteady aerodynamic and aeroelastic analyses when compared with the alternating-direction implicit algorithm of the Air Force/Boeing XTRAN3S code. A new computer code is subsequently being developed to fully exploit the computational efficiency and superior stability characteristics of the AF algorithm. The new code is called CAP-TSD which is an acronym for Computational Aeroelasticity Program - Transonic Small Disturbance.

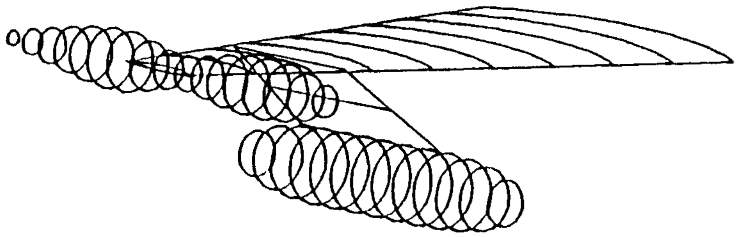
Status/Plans - The CAP-TSD code has been developed to allow the treatment of complete aircraft configurations including canard, wing, tail, fuselage, and control surfaces. Options to include pylons, stores, and nacelles have also been recently included. The present capability has the option of half-span modeling for symmetric cases or full-span modeling for the treatment of antisymmetric mode shapes or asymmetric geometries such as an oblique wing. Several of the configurations which are being modeled using CAP-TSD are shown in figure 45(b). These configurations illustrate various components which are modeled. Code development is currently nearing completion and applications are being performed for validation. The applications include isolated wing as well as complete aircraft geometries at subsonic and supersonic freestream conditions.

Figure 45(a).

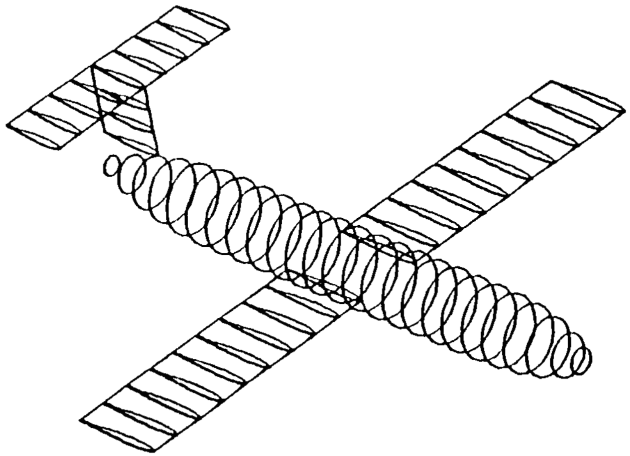
C-2

COMPLETE AIRCRAFT MODELING WITH CAP-TSD

- NLR F-5 WING/TIPTANK/PYLON/STORE



- DFVLR WING/FUSELAGE/TAIL



- F-16 AIRCRAFT

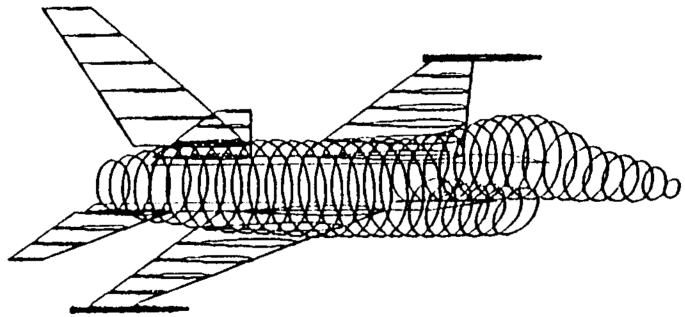


Figure 45(b).

WIND TUNNEL TEST TO MEASURE WING/CANARD INTERFERENCE EFFECTS ON UNSTEADY PRESSURES

Robert W. Hess and David A. Seidel
Unsteady Aerodynamics Branch
Extension 4236

RTOP 505-63-21

Research Objective - The objective of this research is to measure unsteady aerodynamic pressures on interfering lifting surfaces while one surface is undergoing unsteady motions.

Approach - Unsteady pressures will be measured on a wing/canard configuration. Both surfaces have clipped delta wing planforms and 6 percent thick circular arc airfoils, as shown in figure 46(b). The canard location will be fixed, while the wing can be placed in either of two locations. This will allow the distance between the two surfaces to vary. The wing also can be placed in five vertical positions to keep it in plane with the canard when the canard is at angle of attack.

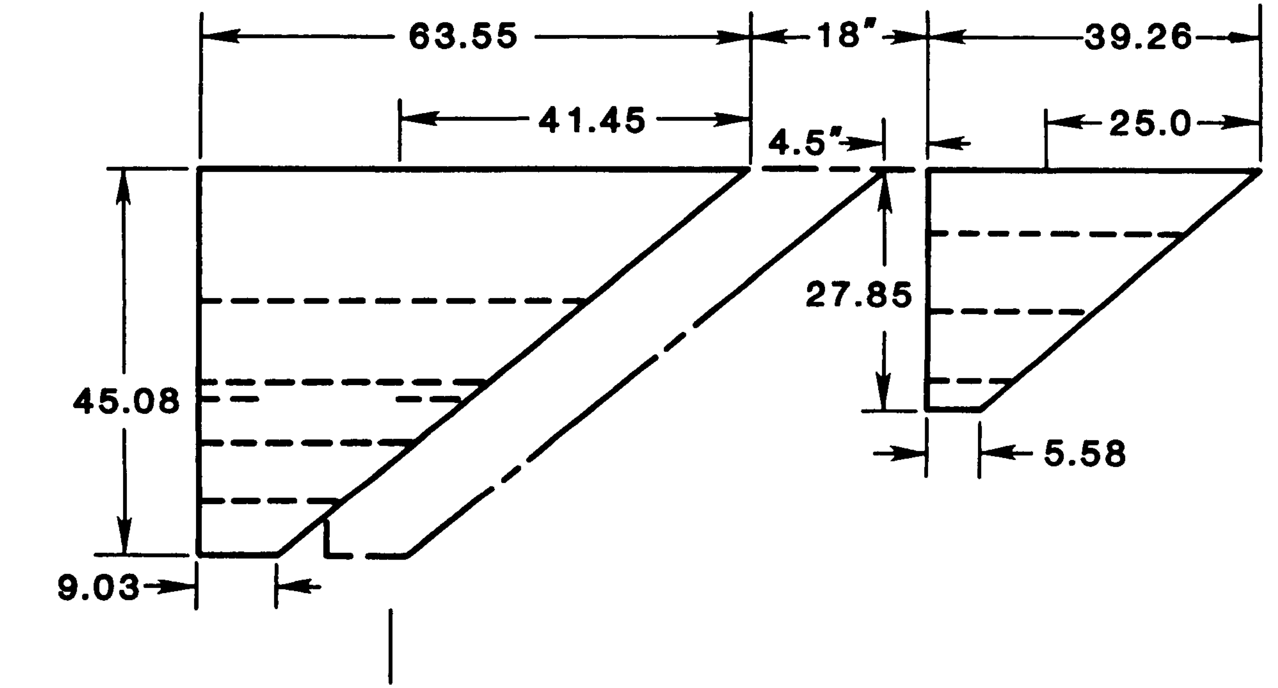
The wing angle of attack can vary between 0 and 8 degrees. The canard mean angle of attack can vary between 0 and 50 degrees and can be oscillated at amplitudes up to 20 degrees and frequencies up to 40 Hertz. The wing is instrumented with five accelerometers and 75 static and dynamic pressure ports along four chordwise rows on the upper and lower surfaces. The canard is instrumented with five accelerometers and 70 static and dynamic pressure ports along three chordwise rows on the upper and lower surfaces. Flow visualization techniques will be used to examine the flow field around the wing and canard and to visualize the interference effects.

Status/Plans - A wind tunnel test of the wing/canard configuration is planned for the summer of 1987 in the Transonic Dynamics Tunnel. The wing and the canard have been fabricated and are undergoing instrumentation installation and checkout. The model drive/support system and a splitter plate are being fabricated. A vapor generator for flow field visualization has been designed and fabricated. The vapor generator is being optimized for maximum particle generation.

Figure 46(a).

WING/CANARD TEST CONFIGURATION

● Clipped delta planforms



● 6% circular arc airfoil sections

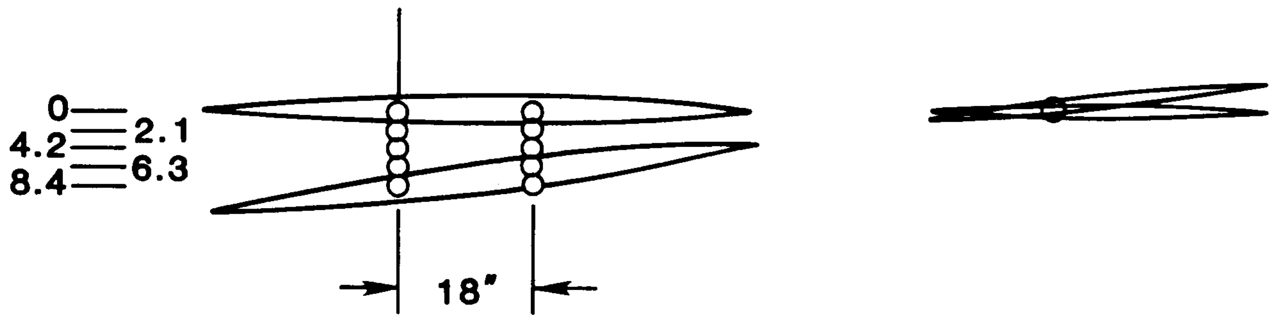


Figure 46(b).

BASIC AEROELASTIC AND UNSTEADY AERODYNAMIC RESEARCH TUNNEL

David A. Seidel
Unsteady Aerodynamics Branch
Extension 4236

RTOP 505-63-21

Research Objective - This effort is aimed at acquiring a low-cost facility for basic unsteady aerodynamic and aeroelasticity studies. In addition, the tunnel can be used to test the aeroelastic and unsteady aerodynamic characteristics of new and novel flight vehicle configurations.

Approach - A joint effort is underway to procure a low turbulence Basic Unsteady Research Tunnel (BURT). The effort is being supported by three branches within the Loads and Aeroelasticity Division--the Unsteady Aerodynamics Branch, the Configuration Aeroelasticity Branch, and the Aeroservoelasticity Branch. The tunnel will be capable of testing both rigid and aeroelastically scaled models. Instrumentation will be acquired to provide tunnel control, to measure pressures on models and in flow fields, and to provide flow visualization.

Status/Plans - The tunnel size and speed requirements have been determined to allow aeroelastic and unsteady aerodynamic tests of scaled models. The test section will be approximately 4ft. x 4ft. with a maximum freestream velocity of 225 mph. At sea level conditions, this results in a maximum Mach number of 0.3, dynamic pressure of 130 pounds per square foot, and Reynold's number of 2.1 million per foot. A request for proposals is scheduled to be released during the third quarter of FY 1987. Tunnel acquisition is expected to be completed during the first quarter of FY 1988. Tunnel instrumentation required for testing will be procured in the same time frame.

Figure 47.

AEROSERVOELASTICITY BRANCH

FY 87 PLANS

0 TEST CONTROL LAWS FOR AFW MODEL AND COMPARE ANALYTICAL RESULTS WITH EXPERIMENTAL DATA

0 DEVELOP A NONLINEAR SIMULATION MODEL INCLUDING UNSTEADY AERO FOR A FLEXIBLE ACTIVELY-CONTROLLED AIRCRAFT

0 COMPLETE SOFTWARE DEVELOPMENT FOR DIRECT DIGITAL CONTROL LAW DESIGN USING OPTIMIZATION TECHNIQUES INCLUDING TIME RESPONSE CONSTRAINTS

0 COMPLETE DATA ANALYSIS FOR ARW-2 WIND TUNNEL TEST

0 INTEGRATE CONTROL SURFACE AND BOUNDARY LAYER CAPABILITY INTO TRANSONIC AEROELASTIC ANALYSIS

0 APPLY AN INTEGRATED ACTIVE CONTROL/STRUCTURAL TAILORING DESIGN METHOD TO AN OBLIQUE WING CONFIGURATION

0 PERFORM SUBSONIC AND SUPERSONIC DYNAMIC ASE STABILITY ANALYSIS OF THE OBLIQUE WING AIRCRAFT

0 PERFORM ASE STABILITY ANALYSES OF STOPPED ROTOR X-WING AIRCRAFT

Figure 48.

FUNCTIONAL INTEGRATION TECHNOLOGY (FIT) TEAM PARTICIPATION

Tom Zeiler
PRC Kentron Inc.
Extension 3169

RTOP 505-63-21

Research Objective - The objective of the FIT team activity is to develop methodologies for integrated modeling, analysis, and design of aircraft dynamics. The desired results of these activities are twofold: an improvement in the effectiveness of piloted simulation as a preliminary design phase tool, and; the analysis and design (aeroservoelastic tailoring, task-tailored control design, etc.) of integrated aircraft dynamics (flutter, low-speed flying qualities, etc.). The FIT methodologies are to be merged with those of ACIG (Aircraft Configuration Integration Group) in the future to produce methodologies for comprehensive integrated design of aircraft. The role of ASEB in the FIT team is the development of the aeroservoelastic model and the analysis and design of aeroservoelastic characteristics.

Approach - The approach of the FIT team has been to develop an integrated, nonlinear dynamics model (structures, aerodynamics, controls, and engines) of an existing vehicle (the F-18). This model is to be used in batch simulation with ACSL (Advanced Continuous Simulation Language) and will be the basis of the real-time simulation model. To this end, ASEB has taken a NASTRAN structural model obtained from MCAIR and has converted it into EAL (Engineering Analysis Language) to take advantage of certain computational and data management capabilities of EAL. Also, an ISAC (Integrated Structures, Aerodynamics, and Control) model of the F-18 has been developed for the generation of unsteady aerodynamic loads and aeroservoelastic analysis. Shown in figure 49(b) is the ISAC model with structural nodes included. The vertical fin and rudder are shown separated from the body and with dihedral removed for the purposes of display.

Status/Plans - Free vibration analysis of the structural model has been accomplished with satisfactory results. Modal data obtained have been used to calculate nonlinear interaction effects between rigid body motion and flexible motion. These interactions, commonly neglected in segregated structural and flight dynamics work, are being included in the FIT team's integrated dynamics model. The structural modal data are also being provided as input to ISAC for the computation of generalized unsteady aerodynamic forces. The computation of these forces for incorporation into the FIT dynamics model has begun. Computation of generalized unsteady aerodynamic forces with ISAC will continue so as to build up a table of forces for a range of flight conditions. The structural model will be used to obtain load coefficients for calculating flight loads from ACSL simulation studies. There will also be a study made of the effects of the nonlinear rigid body/flexibility interaction upon the calculated loads. Future plans also include the development of sensitivities of dynamic behavior to structural parameters (e.g. mass, stiffness).

Figure 49(a).

FUNCTIONAL INTEGRATION TECHNOLOGY (FIT) TEAM PARTICIPATION

GOAL IS TO PRODUCE HIGH FIDELITY INTEGRATED REAL TIME NONLINEAR PILOTED SIMULATIONS FOR USE IN AIRCRAFT PRELIMINARY DESIGN PHASE INCLUDING CONTROLS, STRUCTURES, AERODYNAMICS, AND ENGINES.

- o ASEB SPECIFYING STRUCTURAL AND UNSTEADY AERODYNAMIC INTERFACES IN EQUATION OF MOTION DEVELOPMENT
- o ASEB PERFORMING STRUCTURAL AND AERODYNAMIC CALCULATIONS OF F-18 AIRCRAFT FOR VERIFICATION OF METHODOLOGY

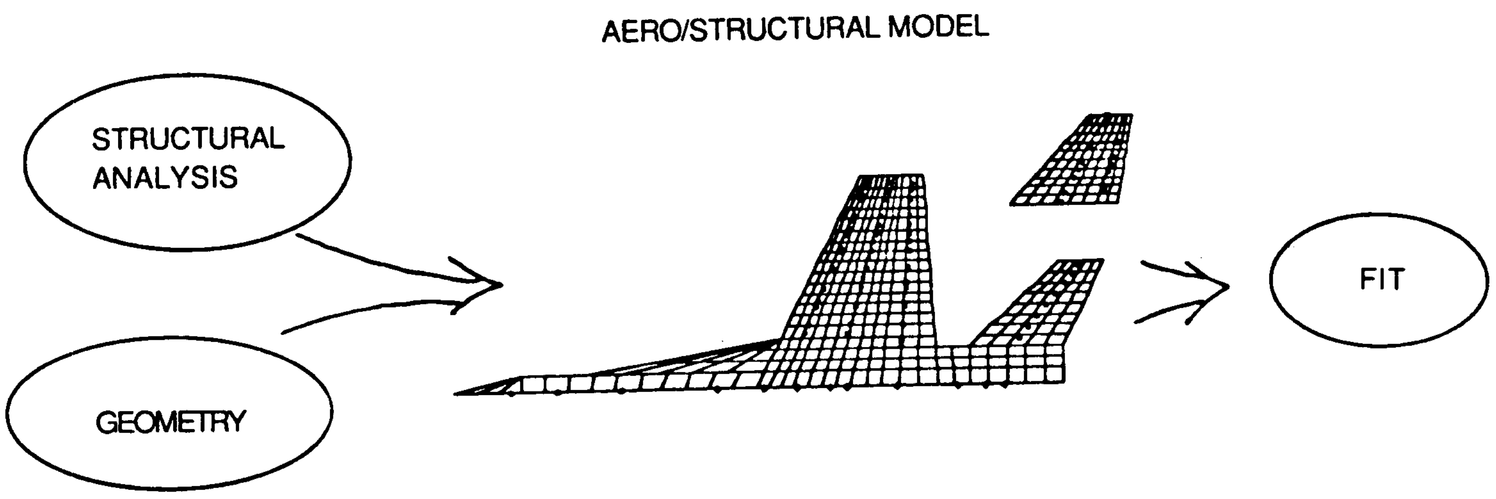


Figure 49(b).

INTEGRATED AERO/THERMAL/ELASTIC ANALYSIS

C. V. Spain, T. Pototzky, and D. Soistmann
PRC Kentron Inc.
Extension 3169

RTOP 505-63-21

Research Objective -The rigorous mission requirements imposed on advanced aerospace vehicles will drive the designs toward very efficient structures (i.e., reduced weight). The combination of reduced weight and efficient aerodynamic shape (i.e., thin wing) for hypersonic flight has the potential to result in a relatively flexible structure. The flexible structure, high temperature, high Mach number and high dynamic pressure operating conditions provide for a severe aerothermoelastic (both static and dynamic) environment. The objectives of this research is to develop the analytical capability of determining aerothermoelastic characteristics and help resolve associated problems on hypersonic vehicles of national interest. The capability to predict quasi-steady state thermal and aerodynamic loads, deformations and required control settings for trim at selected flight conditions will enhance the design and analysis process.

Approach - The problem requires that the equilibrium between aerodynamic loading, thermal loading, qravity, inertial loading, deformed shape of the structure, and control settings be solved for at a given flight condition. Figure 50(b) depicts the current concept of the iterative method. The most suitable state-of-the art hypersonic aerodynamic programs will be selected to provide pressure distributions and heating rates. The elastic structural analysis will be performed with the Engineering Analysis Language and the thermal structural analysis with the SPAR Thermal Analyzer. The process involves predicting a rigid body trim condition, and updating deformations (due to aerodynamic, thermal, gravity and inertial loading) and control settings until equilibrium is achieved.

Status/Plans - Aeroelastic trim conditions for symmetric configurations at subsonic speeds have been determined using EAL and a modified version of a kernel function code by Atlee M. Cunningham, Jr., of General Dynamics. An aeroelastic trim method for a nonsymmetric aircraft at subsonic and supersonic speeds is also complete using the same analytical tools. Maneuver conditions can include straight and level, steady climb/descent, pull-up/push-over and level, climbing or descending turns. Critical to the integrated aero/thermal/elastic analysis is the availability of aerodynamic and aerothermal codes for hypersonic flight. The Aerodynamic Preliminary Analysis System II (APAS) is under study as a possible tool for predicting pressures and heating rates for hypersonic flight.

Figure 50(a).

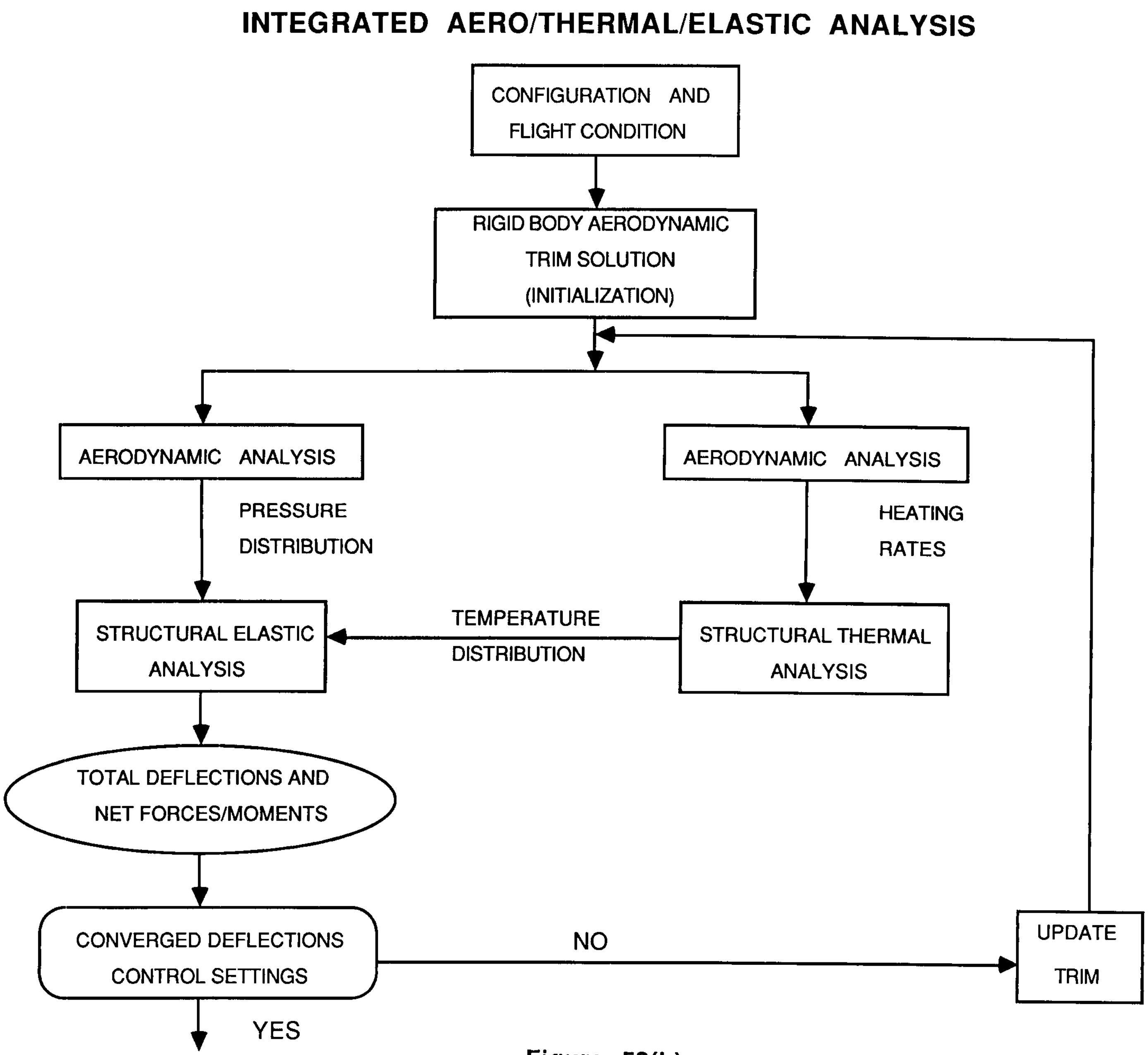

INTEGRATED AERO/THERMAL/ELASTIC ANALYSIS
CONFIGURATION AND FLIGHT CONDITION
RIGID BODY AERODYNAMIC TRIM SOLUTION (INITIALIZATION)
AERODYNAMIC ANALYSIS
PRESSURE DISTRIBUTION
AERODYNAMIC ANALYSIS
HEATING RATES
STRUCTURAL ELASTIC ANALYSIS
TEMPERATURE DISTRIBUTION
STRUCTURAL THERMAL ANALYSIS
TOTAL DEFLECTIONS AND NET FORCES/MOMENTS
CONVERGED DEFLECTIONS CONTROL SETTINGS
NO
UPDATE TRIM
YES

Figure 50(b).

PERFORM AEROSERVOELASTIC ANALYSIS OF THE RSRA/X-WING AIRCRAFT

Michael G. Gilbert
Aeroservoelasticity Branch
Extension 2388

RTOP 505-61-51

Research Objective - The X-Wing rotor concept is a new development in the design of high speed vertical takeoff and landing aircraft. In this concept, the rotor blades of a conventional helicopter are stopped during high speed forward flight and act as two forward-swept and two aft-swept wings offering an enhanced forward speed capability. A technology demonstration flight test program is being conducted to verify the concept using the Rotor Systems Research Aircraft (RSRA) with an X-Wing rotor. The Aeroservoelasticity Branch of Langley Research Center is acting as a consultant to the RSRA/X-Wing program office in the area of stopped rotor aeroelasticity including interactions with the RSRA flight control systems. This work is being performed in cooperation with Sikorsky Aircraft Co., the RSRA/X-Wing prime contractor, and Northrop Aircraft Co., the fixed-wing flight control system subcontractor. Langley analyses to date have shown significant changes in unaugmented aircraft short period dynamics due to static aeroelastic deformations of the forward-swept X-Wing blades, with the short period predicted to be unstable around 230 knots at sea level.

Approach - Several aeroelastic models of the RSRA/X-Wing aircraft have been developed for the analysis of the longitudinal and lateral flight dynamics of the vehicle. These models are based on a normal vibration mode description of the vehicle structural dynamics which were provided by Northrop Aircraft Co. and unsteady aerodynamic force predictions calculated at LaRC using a doublet lattice aerodynamics program. The harmonic unsteady aerodynamic data as a function of reduced frequency k is approximated in the Laplace transform domain for arbitrary motion and the equations of motion are formulated in state-space for compatibility with control system analyses. Static aeroelastic analyses are performed using a modal residualization procedure on the modal equations directly with $k=0.0$ aerodynamic data.

Status/Plans - The state-space aeroelastic models of the RSRA/X-Wing aircraft longitudinal and lateral dynamics will be combined with the existing and proposed RSRA flight control law definitions once they are received from the contractor. These models will be used to verify overall vehicle aeroservoelastic stability and control system performance prior to the first X-Wing flight of the vehicle. The modal based static aeroelastic analysis procedure described above will be validated against wind tunnel test results of an aeroelastic 1/6th scale X-Wing model mounted on a rigid RSRA model which was tested during November 1986 at United Technologies Research Center in Hartford Conn. Further validation of the full scale predicted results is planned using a direct structural influence coefficient approach and a linear steady aerodynamics code.

Figure 51.

AEROTHERMAL LOADS BRANCH

FY 87 PLANS

0 COMPLETE EXPERIMENTAL DATA BASE FOR SHOCK IMPINGEMENT ON A CYLINDRICAL LEADING EDGE

0 CONTINUE DEVELOPMENT OF DETAILED AEROTHERMAL LOADS DATA BASE FOR GENERIC HYPERSONIC VEHICLE COMPONENTS

0 COMPLETE ANALYSIS OF SHOCK IMPINGEMENT ON A CYLINDRICAL LEADING EDGE

0 COMPLETE ANALYSIS OF 2-D FLOW OVER A COMPRESSION CORNER

0 CHARACTERIZE THE 2-D TURBULENT BOUNDARY LAYER ON THE 8' HTT PANEL HOLDER

0 CONTINUE DEVELOPMENT AND VALIDATION OF 2-D AND 3-D FINITE ELEMENT NAVIER-STOKES CODES

0 CONTINUE DEVELOPMENT AND VALIDATION OF ADAPTIVE REFINEMENT TECHNIQUES FOR UNSTRUCTURED FINITE ELEMENT GRIDS

0 CONTINUE DEVELOPMENT AND VALIDATION OF INTEGRATED FLUID-THERMAL-STRUCTURAL ANALYSIS CODES

0 DEVELOP AND VALIDATE AN INTERNAL COOLING MODEL FOR THE INTEGRATED FLUID-THERMAL-STRUCTURAL ANALYSIS CODE

0 CONTINUE OXYGEN ENRICHMENT AND ALTERNATE MACH NUMBER MODIFICATION OF THE 8' HIGH TEMPERATURE TUNNEL

0 INVESTIGATE ALTERNATE MODES FOR OXYGEN INJECTION AND DEVELOP PROPULSION TESTING SUPPORT SYSTEMS IN THE 7" HIGH TEMPERATURE TUNNEL

Figure 52.

AEROTHERMAL LOADS EXPERIMENTAL PROGRAM

George C. Olsen
Aerothermal Loads Branch
Extension 2325

RTOP 506-43-31

Research Objective - The objective of the research is to develop a data base of detail local aerothermal loads for geometry configurations common to all hypersonic flight vehicles. The data base will provide the detailed loads required for design of the structure and it's active cooling systems as well as supplying detailed data for validation of analytical codes.

Approach - Design a family of generic configuration experiments representative of critical configurations found on most hypersonic vehicles as illustrated on figure 53(b). These include a shock-on-lip configuration typical of hypersonic scramjet engine inlets, corner flow configurations encountered in engines and on airframes, leading edges with impinging shocks, control surfaces with span- and chord-wise gaps and shock interactions, shock/boundary layer interactions, and compression surfaces. The models will be extensively instrumented to capture the locally intense heating rates and pressure distributions. These tests will consider a range of sweep angles, impinging shock strengths, and Mach and Reynolds numbers flows. The tests will be conducted in the NASA LaRC 8' High Temperature Tunnel (8' HTT) and the Calspan Shock Tunnels.

Status/Plans - The initial tests of the shock-on-lip configuration in the 8' HTT have been completed and additional tests in the Shock Tunnel are underway to increase the Mach Number and Reynolds Number range of the data. Results of tests at Mach = 8 have shown peak heating rates increased by a factor of ten by an impinging shock (12.50 turning angle). Swept leading edge model design has been initiated.

Figure 53(a).

AEROTHERMAL LOADS EXPERIMENTAL PROGRAM

DESIGN AND CODE VALIDATION DATA BASE

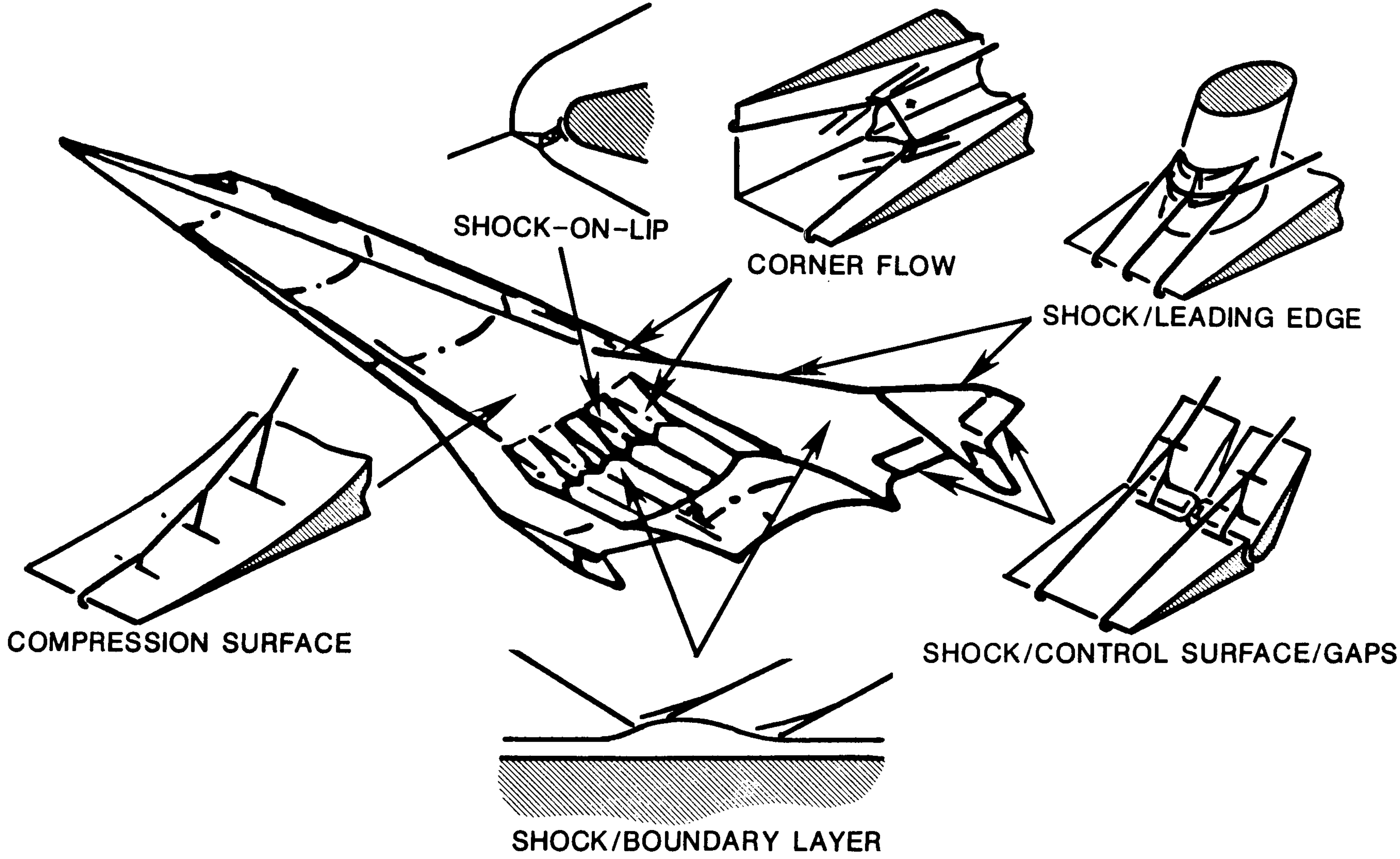


Figure 53(b).

2-D FLOW OVER A COMPRESSION CORNER - FINITE-ELEMENT NAVIER-STOKES CODE VALIDATION

Gururaja Vemaganti
Old Dominion University
Extension 3155

RTOP 506-43-31 and 506-40-21

Research Objective - The long range objective of this work is the validation of analytical codes by comparison of their results with high quality experimental data. There are two phases to the effort, the first is validation of the finite element Navier-Stokes code and its algorithm on a classical graded mesh. The second is validation of the code on an adaptive/unstructured mesh.

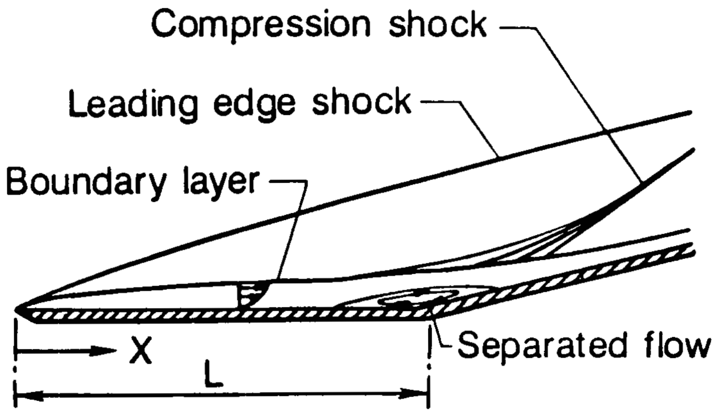
Approach - Analytically model Mach 11.68 flow over an 18" sharp leading edge flat plate with a 15° 2-D compression corner (physical model and flow conditions shown in figure 54(b)) utilizing a classical graded mesh with points clustered in the boundary layer region. Compare the predicted results with the experimental data of Holden collected in the Calspan 48" shock tunnel. Evaluate the accuracy of the predictions and the sensitivity with respect to the mesh spacing and adjustable parameters for artificial viscosity. Model the same problem using adaptive/unstructured mesh refinement strategies that automatically modify the grids to concentrate the mesh in locations of high gradients as determined by monitoring selected flow field parameters as the solution develops. Compare the resulting solution to the best graded mesh solution for accuracy and economy of computer resources.

Status/Plans - A graded mesh solution has been accomplished and effects of artificial viscosity evaluated. Skin friction and wall heating rate distributions from the analysis, shown on the figure, correlate closely with the experimental values up to flow separation and after reattachment. The analysis did not resolve the separated flow region because of the relatively course mesh in that region. Computations on the graded mesh where expensive. Computations using the adaptive/unstructured mesh refinement strategies are planned with the intention of improving the solution quality, especially in the stagnation region, without increasing the computational costs.

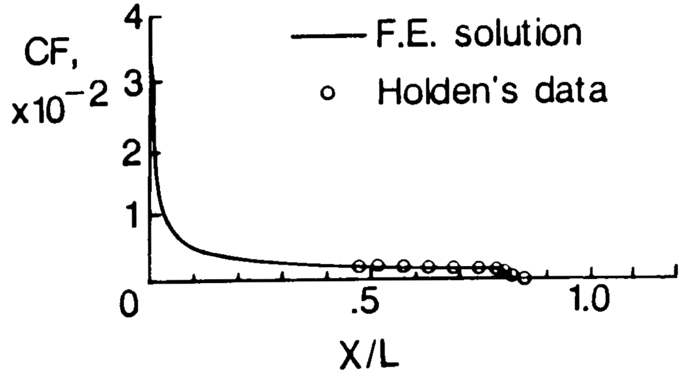
Figure 54(a).

2-D FLOW OVER A COMPRESSION CORNER – FINITE-ELEMENT NAVIER-STOKES CODE VALIDATION

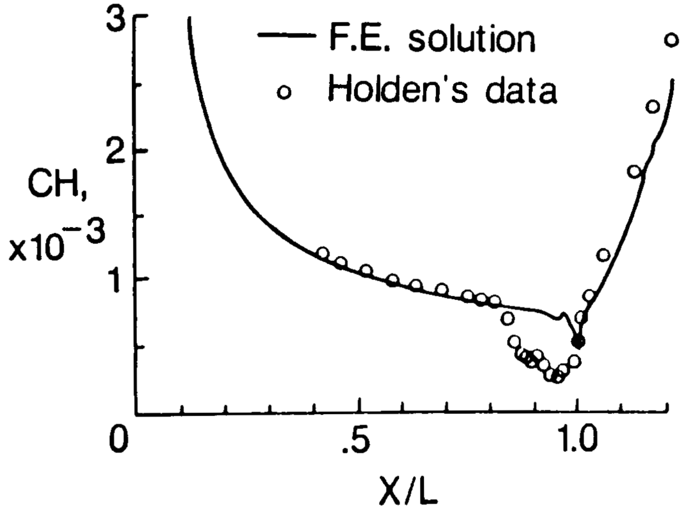
Physical Model



Skin Friction Distribution



Wall Heating Rate Distribution



- Flow conditions
  - o $M = 11.68$
  - o $T_\infty = 116$ R
  - o $T_W = 535$ R
  - o $Re/ft = 1.7 \times 10^5$
- Graded mesh costly
- Adaptive/unstructured mesh to be used

Figure 54(b).

SHOCK-ON-LIP ANALYSIS

Allan R. Wieting
Aerothermal Loads Branch
Extension 3423

RTOP 506-43-31 and 506-40-21

Research Objective - Develop an analytical code capable of efficiently modeling the complex viscous shock interactions such as the shock-on-lip configuration of a hypersonic scramjet engine inlet. The code must be capable of capturing complex shock interactions without a prior knowledge of their exact location and accurately predict surface heating rates, pressures, and skin frictions.

Approach - A finite element Navier-Stokes fluid analysis code, under development for several years, will be employed. The code will be used in conjunction with an adaptive/unstructured grid strategy that automatically refines the grid in the critical regions by sensing large gradients in the developing flow field solution. The ability of the codes to work on unstructured grids will be exploited to provide high accuracy predictions with reasonable computer resources. Several variations of adaptive strategies and sensors are under investigation. These analytical tools will be validated against a detailed experimental data base under development.

Status and Plans - The available analytical codes and adaptive strategies are currently being validated for leading edge flow without an incident shock. They are being tuned for highly accurate prediction of wall heating rates and then will be applied to the shock interaction problem.

Figure 55.

OXYGEN ENRICHMENT AND ALTERNATE MACH NUMBER MODIFICATION TO THE 8' HIGH TEMPERATURE TUNNEL

Carl R. Pearson
Aerothermal Loads Branch
Extension 3423

Research Objective - The 8' HTT is to be modified to provide a unique national facility for testing hypersonic air-breathing propulsion systems. The modified facility, which can accommodate free standing engines, will complement existing lower speed Air Force facilities by providing true flight simulation for Mach numbers from 4 to 7 over a wide range of altitudes.

Approach/Accomplishments - An oxygen enrichment system that will restore the free molecular oxygen concentration of the methane-air combustion-heated test stream to the proper level (approx. 21%) will be added to the facility. A system to supply hydrogen at near cryogenic temperatures will be installed to provide fuel for the propulsion systems. Supplemental nozzles will be provided for testing at Mach numbers of 4 and 5. These nozzles will be coupled with a mixer which will reduce the temperature of the test stream and increase the mass flow to provide the correct flow conditions for the lower Mach numbers. In addition, various existing tunnel components will be refurbished and updated to increase facility productivity. One of these modifications will be the replacement of the present air-film/water-cooled throat of the Mach 7 nozzle with air transpiration cooled components which should improve the performance and increase the life of he nozzle. Other separate but related projects include a new high speed Data Acquisition System for collecting, reducing to engineering units, and storing the experimental data and a Host computer system for data reduction, manipulation, and display.

Status/Plans - The schedule for completion of the modifications is shown in figure 56(b). The major construction phase is in progress with a nine month construction down time scheduled to begin 6/88. Prior to the down time aerothermal loads tests will continue to be conducted in the facility and the newly installed data acquisition system will be checked out and calibrated. A twelve month tunnel checkout and calibration period will follow the down time and propulsion testing is scheduled to begin in 3/90.

Figure 56(a).

SCHEDULE FOR 8-FOOT HTT MODIFICATION

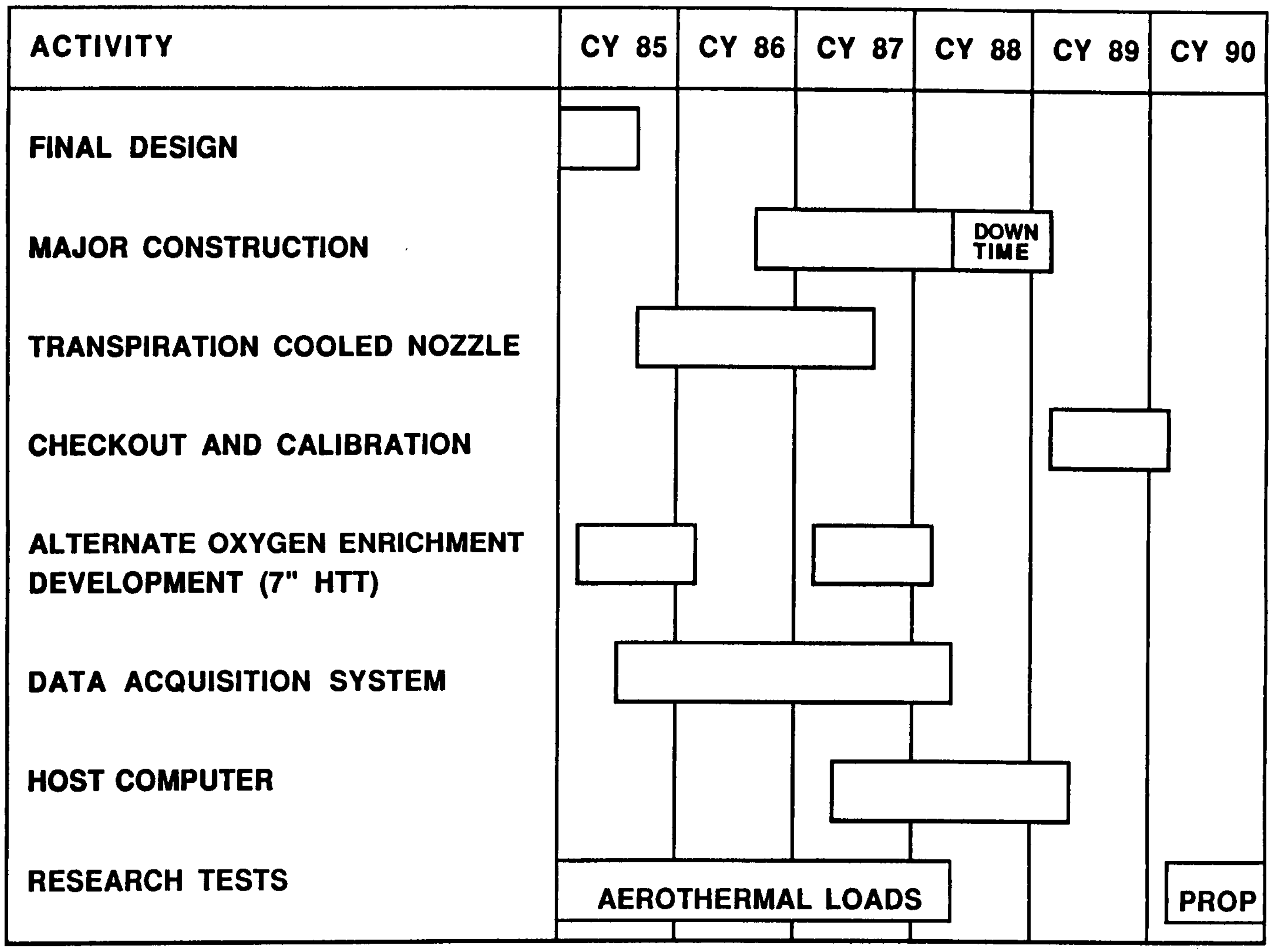


Figure 56(b).

THERMAL STRUCTURES BRANCH

FY 87 PLANS

0 UPGRADE COOLED STRUCTURES WEIGHT ESTIMATION METHODOLOGY

0 INITIATE STUDY OF CARBON/CARBON FOR CONTROL SURFACES

0 DETERMINE APPLICATION LIMITS OF HEAT PIPES FOR LEADING EDGES

0 INCORPORATE RADIATION INTO HIERARCHICAL FINITE ELEMENTS

0 DETERMINE THERMAL EFFECTS FOR AEROELASTIC STUDIES

0 TEST SCRAMJET STRUT IN COMBUSTION FACILITY

0 TEST CURVED TPS TO RESOLVE GAP HEATING ISSUES

Figure 57.

ANALYSIS OF SCRAMJET ENGINE STRUT

Robert R. McWithey and Carl J. Martin
Thermal Structures Branch and PRC Kentron Inc.
Extension 4201, 4147

RTOP 506-43-31

Research Objective - Airbreathing hypersonic vehicles require the use of hydrogen-fueled scramjet engines for propulsion above Mach 5-8. Prior research led to the development of a scramjet engine configuration utilizing a fuel injection strut with a geometry shown in figure 58(b). These struts are subjected to high external pressures and heat loads due to aerodynamic and combustion effects and must be cooled actively by the hydrogen fuel. In order to study methods for cooling this engine structure, a flightweight strut is being fabricated under contract by AiResearch Manufacturing Company. Upon completion, the strut will be aerothermally tested in Langley's hypersonic engine test facilities. The maximum Mach number, total temperature, and pressure achievable in the test facility are shown in the figure. The objectives of these tests are to demonstrate the thermal and structural integrity and verify various design concepts of the scramjet engine strut under simulated flight conditions. At present, analyses are being conducted to determine strut temperatures and stresses resulting from the tunnel test operating conditions.

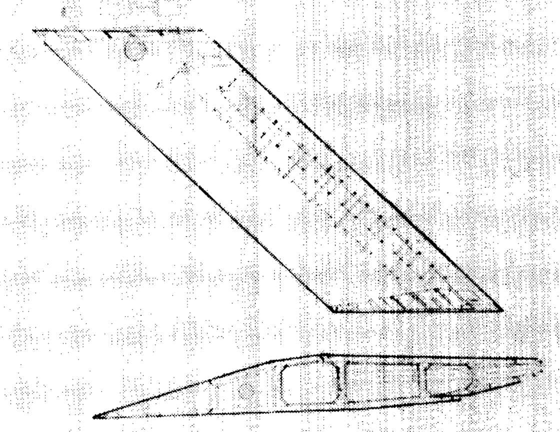
Approach - Performances of the leading edge impingement cooling scheme and the pin-fin thermal protection system have been evaluated using a combination of the latest empirical equations and EAL thermal finite-element analyses. The structural temperatures and hydrogen coolant flow in the strut were analyzed using a detailed two-dimensional thermal finite-element model of the scramjet strut. Various structural finite-element models have been used to investigate thermal stresses and stresses due to pressure loadings. These analyses have been performed using the maximum mission loads as well as the loads and constraint conditions predicted for testing. The maximum structural loading occurs during the transient unstart.

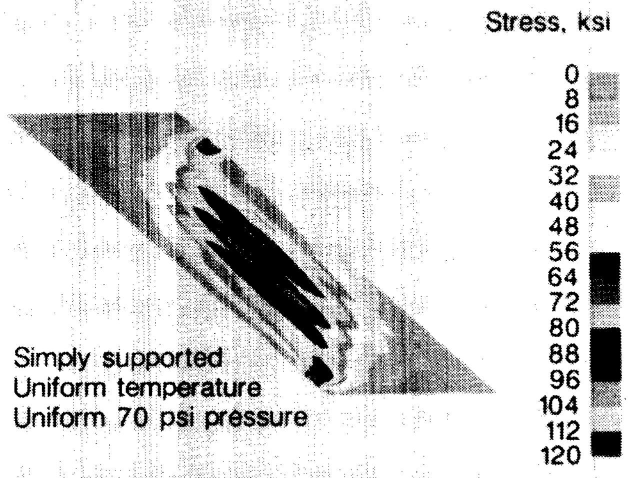
Status/Plans - The present analytical work is nearly complete, and some results are shown on the facing page. The highest heat fluxes occur at the leading edge which is cooled by impinging hydrogen. The temperature distribution in the leading edge at the design heating and cooling rates is shown in the figure. The maximum temperature of 1360 R is well within the capability of the Nickel 201 TPS and provides for an adequate cycle life. The engine unstart phenomenon will be duplicated during testing, but the stress distribution will be altered slightly due to differences in support conditions. However, the stress levels predicted during testing (shown in the figure) are of the same magnitude as those in the design case.

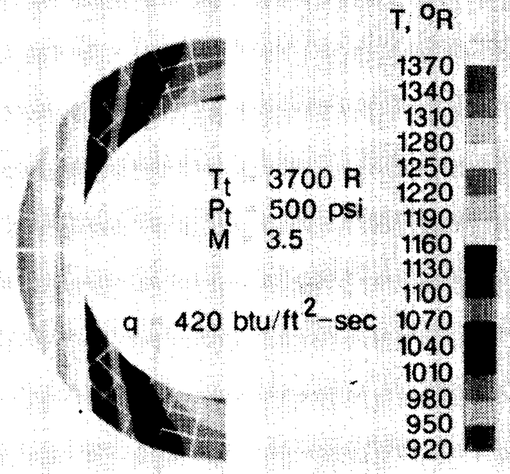
An instrumented full size copper aerothermal model of the strut is being constructed and will provide more detailed heating rate, temperature, and pressure distributions at the tunnel operating conditions. This testing is necessary since instrumentation on the flightweight strut is limited. These data will be used to refine the thermal and structural loadings of the various analytical models of the scramjet engine strut. Also, a stainless steel model of the strut is being fabricated for static and dynamic structural testing in the laboratory. The combination of testing and analytical work will provide important understanding of the thermal and structural loads the flightweight scramjet strut will be subjected to during testing.

Figure 58(a).

SCRAMJET ENGINE STRUT ANALYSIS







- Strut design adequate for testing–thermal, structural
- Steel/copper model being constructed for proof tests
- Analysis of as–built strut in progress

Figure 58(b).

CRYOGENIC TANK THERMAL ANALYSIS FOR USE IN ADVANCED HYPERSONIC AIRCRAFT AND SPACE TRANSPORTATION VEHICLES

James C. Robinson
Thermal Structures Branch
Extension 2291

RTOP 506-43-31

Research Objective - The objective of this research is to develop a cryogenic tank analysis for evaluation of tank design options and determination of temperature distributions in a cryogenic tank for thermal stress evaluation. The analysis will use a finite-element thermal mode l that includes external heating to the tank, conduction in the tank insulation system, internal radiation, simplified phase-change and fuel boil-off, and the effects of pressure and fuel use rate.

Approach - A study will be conducted in three phases: 1) develop analytical models of a cylindrical tank and a double-bubble tank (shown in figure 59(b)); 2) verify the double-bubble modeling methodology by comparing analytical results to experimental results; 3) using verified methodology, analyze a cylindrical tank to evaluate parameters of interest. The models will represent the heat transfer in a tank cross-section. The liquid hydrogen is assumed to be at a uniform temperature throughout and the gas above the liquid is assumed to vary in temperature in the vertical direction only. Some of the parameters to be studied include insulation distribution, effects of tank pressure control on boil-off, and the effect of pumping gas, as well as liquid, to the engines.

Status/Plans - The double-bubble model has been created and is being verified. In the figure, some tank inner and outer surface temperatures are shown for a typical flight trajectory. The outer surface temperature profile was applied to the tank both experimentally and analytically. Analytical predictions for the inner surface temperature are in poor to good agreement with the measured temperatures depending on the duration of heating. The inclusion of a reasonable approximation of the effects of boil-off and evaluation of the heat removed from the system when excess boil-off is dumped overboard is under way. Upon completion of the comparison with the experimental results for the double-bubble tank, the cylindrical tank model will be completed and parametric studies undertaken.

Figure 59(a).

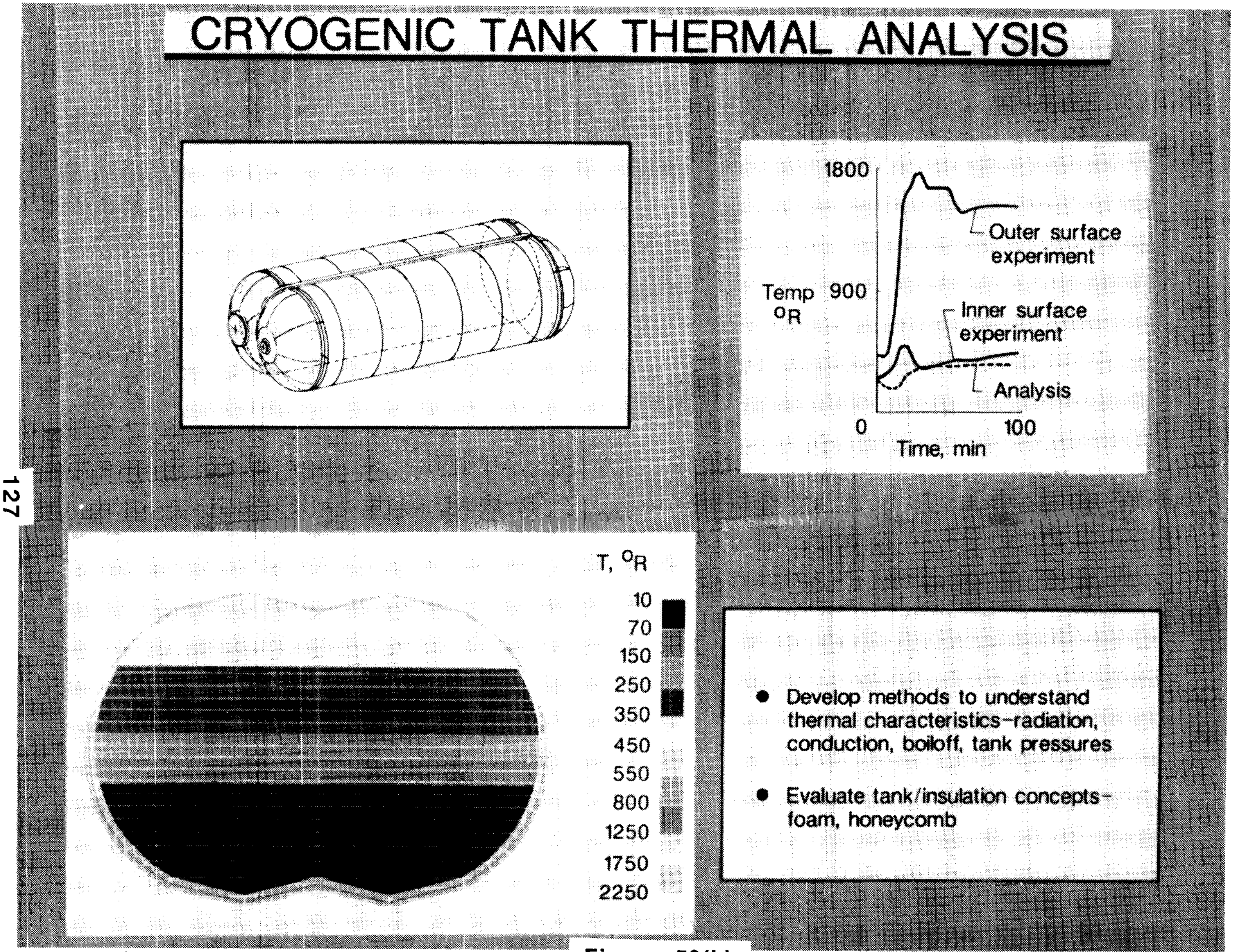

CRYOGENIC TANK THERMAL ANALYSIS
1800
Temp
°R
900
0
100
Time, min
Outer surface experiment
Inner surface experiment
Analysis
T, °R
10
70
150
250
350
450
550
800
1250
1750
2250
• Develop methods to understand thermal characteristics–radiation, conduction, boiloff, tank pressures
• Evaluate tank/insulation concepts–foam, honeycomb

Figure 59(b).

IMPROVED THERMAL ANALYSIS METHODS

James C. Robinson
Thermal Structures Branch
Extension 2291

RTOP 506-43-31

Research Objective - Advanced high speed vehicles operating in the atmosphere are subjected to extreme aerodynamic heating resulting in very high structural temperatures and temperature gradients. The presence of the gradients and high rates of radiation heat transfer require large analytical models for evaluation. Analysis using present methods may not be feasible. The objective of this effort is to improve thermal analysis methodology to make these analyses feasible.

Approach - Research will be conducted under grant by the Universities of Washington and West Virginia. The UWA grant will investigate improving the efficiency of radiation viewfactor analysis. The UWV grant will investigate improving the efficiency of transient thermal analysis by developing transform methods suitable for nonlinear transient thermal analyses and solution-error estimation techniques.

Status/Future Plans - Under the UWA grant, Dr. Ashley F. Emery is developing efficient radiation viewfactor calculation techniques by applying some methodology for *hidden line* algorithms developed by David Hedgely (Ames-Dryden Flight Research Facility) for viewfactor analysis and implementing a "defined accuracy" algorithm which allows the analyst to select an accuracy level desired for viewfactors, thus allowing the analyst to select a level of accuracy and computational effort commensurate with the accuracy required. In addition, Dr. Emery plans to investigate optimal meshing schemes for improving the accuracy of the resulting temperatures.

Under the UWV grant, Dr. Kumar K. Tamma is developing efficient transient thermal analysis techniques by the use of transform methods to obviate the need for time-marching algorithms in transient thermal analysis. Present efforts are directed toward demonstrating the applicability of the method for two-dimensional problems incorporating nonlinearities due to temperature-dependent material properties and thermal radiation. Additional efforts are under way to develop estimates of the accuracy of a given solution after the solution has been completed.

The methods developed will be implemented in the SPAR Thermal Analyzer under a contract that is part of the NASA Computational Structural Mechanics program.

Figure 60.

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16. Abstract

The purpose of this paper is to present the Loads and Aeroelasticity Division's research accomplishments for FY 86 and research plans for FY 87. The work under each Branch (technical area) will be described in terms of highlights of accomplishments during the past year and highlights of plans for the current year as they relate to five year plans for each technical area. This information will be useful in program coordination with other government organizations and industry in areas of mutual interest.

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