COMPUTATIONAL FLUID DYNAMICS RESEARCH

ANNUAL REPORT

Prepared for

NASA CENTER OF RESEARCH EXCELLENCE
SCHOOL OF ENGINEERING
NORTH CAROLINA A&T STATE UNIVERSITY

by

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A. AREA SUMMARY

The focus of research in the CFD area is two-fold:

1. Develop new approaches for turbulence modeling so that high speed compressible flows can be studied for applications to entry and re-entry flows,

2. Perform research to improve CFD algorithm accuracy and efficiency for high speed flows.

Short-Range Plans

(1) Continued recruitment efforts with the objective of enticing two graduate students and two undergraduate students in Spring, 1993.

(2) Offering an advanced course in CFD at NCA&TSU in Fall 1993 if the enrollment is adequate. If only one or two students and faculty members are interested, efforts will be made to enroll in NCSU courses.

(3) Modeling of the pressure dilatation term as well as the compressible dissipation term and using the SPARK code to predict useful parameters such as the shear layer growth rate for compressible high speed turbulent flows.

(4) Development of efficient numerical algorithms for high speed flow fields. It is hoped that a new research associate can be hired in early 1993 to initiate research in this vital area.

(5) Continued association with the Theoretical Flow Physics Branch at the NASA Langley Research Center (LaRC). It is anticipated that Dr. Chandra and/or one faculty member and two students will spend most of 1993 summer at LaRC. Such an association enables faculty and students to (a) use the LaRC technical library; (b) interact with faculty and students from NCSU and other universities; and (c) interact with NASA and ICASE researchers and facilities on a daily basis.

(6) Development of algorithms for two-dimensional, three-dimensional, and axisymmetric radiation heat transfer for chemically reacting hypersonic flows.

B. AREA RESEARCH PROJECTS

Project Title: Turbulence Modeling for High Speed Compressible Flows
Principal Investigator: Dr. Suresh Chandra
Funding Amount: $25,000
Funding Source: NASA Langley Research Center
Duration: May 16, 1991 - December 31, 1992

C. AREA PROGRAM ACTIVITIES

During 1992, Dr. Chandra supervised the M.S. thesis work of one graduate student (Cheryl Sellers). Both Dr. Chandra and Ms. Sellers spent the bulk of the summer in 1991

and 1992 at NASA Langley Research Center (Theoretical Flow Physics Branch). Ms. Sellers focussed on studying compressibility effects in modeling turbulent high speed mixing layers. The accomplishments to date are:

(1) Incorporation of the extension of the compressibility dissipation model of Sarkar et al. of ICASE in the SPARK code using two-equation turbulence modeling.

(2) An extensive literature review to delineate work done or being done in the study of compressibility effects in turbulent shears flows.

(3) Comparison of results in (1) with the results of a large number of experimental and analytical studies.

(4) Presentation of a paper entitled "Study of Compressibility Effects in Turbulent Shear Flows" at the ASME Fluids Engineering Conference, June 22-23, 1992.

(5) Ms. Sellers defended her M.S. thesis on August 10, 1992. She has been admitted to the Ph.D. program in ME at the University of Illinois and has begun her doctoral studies this fall.

Additional Personnel

(1) For the period through October 1992, Dr. Chandra has been the only faculty member involved in CFD research. We have hired a full-time research associate beginning October 15. Dr. Gregory Elbert completed his Ph.D studies at Mississippi State University in early October and will initiate our effort in the areas of radiation heat transfer for hypersonic chemically reacting flows, thus complementing the turbulence modeling work for high speed flows.

(2) Mr. Kenneth Jones joined the ME Department in the of fall of 1992 as a tenure-track faculty member. He completed his Ph.D. studies at NCSU in late October. He is an asset to the CFD area in CORE by virtue of his experimental/analytical background in CFD research. Mr. Jones plans to apply for participation in one of the NASA/ASEE summer institutes in 1993 with the objective of becoming closely associated with appropriate NASA facilities and personnel. Dr. Chandra, Mr. Jones, and Dr. Elbert will work closely with Drs. Hassan and McRae of NCSU in accordance with the attached subcontract, which delineates the long-range research plan for the CFD area.

Educational Effort

1. A course in computational fluid dynamics is being offered by Dr. Chandra this fall. This course has a mix of undergraduate ME Seniors and graduate students.

2. Dr. Hassan A. Hassan will offer an advanced course in combustion and reacting flows at NCSU in spring. Some faculty members and graduate students in the CFD area at NCA&TSU will enroll in this course if their schedules permit.

Travel

1. NASA Orientation Conference - Washington, D. C.; March 24-25, 1992 (S. Chandra)

2. NASA Langley Research Center - Hampton, VA; April 21-24, 1992 (S. Chandra)

3. ASME - Fluids Engineering Conference, Los Angeles; June 20, 1992 (S. Chandra)
4. NASA Langley Research Center, Hampton, VA; November 16-19, 1992 (S. Chandra)

D. FACULTY AND STUDENT PARTICIPATION

Faculty Involved

Name & Title	Depart.	Ethic Background	Starting Date	Nature of Participation
S. Chandra Research Prof.	ME	Asian (U.S. citizen)	April 1992	CFD Group Coordinator Student Research Advisor
K. Jones Asst. Prof.	ME	White (U.S. citizen)	November 1992	Core Research Leader Student Research Advisor
G. Elbert Research Assoc.	ME	White (U.S. citizen)	October 1992	Core Research Leader Student Research Advisor
H. Hassan Prof. (NCSU)	Mech.&Aero.	Middle Eastern (U.S. citizen)	April 1992	Subcontractor (NCSU)
S. McRae Assoc. Prof. (NCSU)	Mech. & Aero.	White (U.S. citizen)	April 1992	Subcontractor (NCSU)

Student Involved

Name of Student	Classification/Major	Advisor	Graduation Date
Cheryl Sellers*	Graduate/M.E.	Chandra	August, 1992
Rafael Jones**	Undergraduate/M.E.	Elbert/ Chandra	December, 1992
Michael Gray**	Undergraduate/M.E.	Elbert/ Chandra	May, 1993
Stapleton Tabb	Undergraduate/M.E.	Chandra	December, 1993

* Currently a Ph.D.student in M.E.at the University of Illinois.
** Scheduled to begin graduate study in CFD at NCA&TSU upon graduation.

E. PROGRAM IMPACT AND FINANCIAL REPORT

Publications

1. Chandra, S., 1992, "Study of Compressibility Effects in Turbulent Shear Layers", ASME Fluids Engineering Conference, Los Angles, CA, June 21-23, Abstract published in "Fluids Engineering 1992 - Abstracts, FED-Vol. 133, ASME/Fluids Engineering Division, 1992".

2. Jones, K.M., DeJarnette, F. R., Griffith, W.C., and Yanta, W. J., 1992, "Boundary Layer Study on Nozzle Wall at Hypersonic Velocities", AIAA Paper No. 92-4013, presented at the AIAA 17th Aerospace Ground Testing Conference, Nashville, TN, July 6-8, 1992.

3. Sellers, C. and Chandra, S., "Compressibility Effects in Modeling Turbulent High Speed Mixing Layers", Accepted for Presentation at the 1993 ASME Forum on Turbulent Flows, Washington, DC, June 1993.

4. Elbert, G. J. and Cinnella, P., "Truly Two-Dimensional Algorithms for Radiative Non-equilibrium Flows", 13th International Conference on Numerical Methods in fluid Dynamics, Rome, Italy, July 1992.

5. Elbert, G. J. and Cinnella, P., "Axisymmetric Radiative Heat Transfer Calculations for Flows in Chemical Non-equilibrium", AIAA Paper 93-0139, 31st Aerospace Sciences Meeting, Reno, Nevada, January 1993.

6. Sellers, C., "Compressibility Effects in Modeling High Speed Turbulent Mixing Layers", M. S. Thesis, Department of Mechanical Engineering, North Carolina A&T State University, 1992.

Area Financial Report

Line Items	Allotments	Expenditure
1. Faculty Salaries (Chandra: 2.5 months) (Elbert: 2.5 months)	$31,375	$31,375
2. Student Wages	$ 6,000	$ 1,000
3. Fringe Benefits (24% of 1)	$ 7,530	$ 7,530
4. Indirect Costs (55% of 1 & 2)	$ 20,556	$ 17,806
5. Travel	$ 3,000	$ 2,962
6. Scientific Equipment	$ 52,519	$ 52,102
7. Contract Services	$ 2,000	$ 1,590
8. Subscriptions/Memberships	$ 600	$ 90
9. Books/Journals	$ 1,420	$ 990
10.Subcontract to NCSU	$ 37,153	$ 37,153
TOTAL	$162,153	$152,596

Equipment Purchased

The following equipment will be purchased in November 1992:

Vendor: Silicon Graphics, Inc.
Items: 3 IRIS INDIGO Model #W-RPC50
Unit Cost: $11,314.00
Totl Cost: $33,942.00

Vendor: Silicon Graphics, Inc.
Items: CD-ROM Update Media #M05-CD
Unit Cost: $ 1,967.89
Totl Cost: $ 1,967.89

Vendor: Parity Systems, Inc.
Items: 1 1.2 GB Inetrnal HD for the SGI R4000
               1 2.0 GB External DAT Drive for SGI R4000
Totl Cost: $10,399.66

Vendor: AMTEC Engineering, Inc.
Items: 3 Tecplot Release 5
Unit Cost: $ 530.00
Totl Cost: $ 1590.00

Vendor: DATAPRINT Inc.
Items: 1 HP Laserject IVm Model #C2021A
Totl Cost: $ 1759.00

F. SUBCONTRACT RESEARCH WORK AT NCSU UNDER GRANT NAGW-2924

1. Develop a New Approach for Turbulence Modeling

When employing a two-equation turbulence model, there is general agreement that one of the equations must be the equation governing the turbulent kinetic energy. The most popular second equation is based on the rate of turbulent kinetic energy dissipation or the characteristic turbulent frequency. Unfortunately, such equations do not account for certain mechanisms that are present when one examines the vorticity equation, namely, the effects of vortex stretching, which is a three-dimensional effect, and the production of vorticity term which is important when compressibility effects are important.

Because both TKE dissipation and turbulent frequency equations ignore the existence of above important effects, there has been general dissatisfaction with one equation or the other. There is one equation which governs the mean vorticity fluctuation, which is referred to as entropy, which can serve as a basis for the second equation in two-equation models. This equation has all the physics that exists in the vorticity equation and thus, may be an attractive alternative. Our goal is to pursue this approach.

2. Perform Research to Improve Computational Algorithm Accuracy and Efficiency

(a) Develop efficient numerical algorithms for high speed internal flow fields. This project involves the development of an efficient iteration strategy for solution of the Navier-Stokes equations. In three-dimensions, the governing equations are written in Newton's form and the Jacobian is partitioned and updated such that a Gauss-Seidel like iterative sequence is performed with forward and backward sweeps to approximately invert the Jacbian. Residual updating will be used to increase information transfer and quasi-Newton acceleration techniques will be applied. The resulting code will be applied to supersonic internal flows.

(b) Develop dynamic 3-D solution mesh algorithms. This task will involve the further development of a solution adaptive algorithm to include adaption of block grid interfaces and interiors. The algorithm presently only works for single block grids. The resulting code will be used to compute unsteady flows over complex aircraft shapes.

Other tasks will be performed in support of the effort at NCA&TSU at the direction of Dr. Suresh Chandra, CFD Coordinator.