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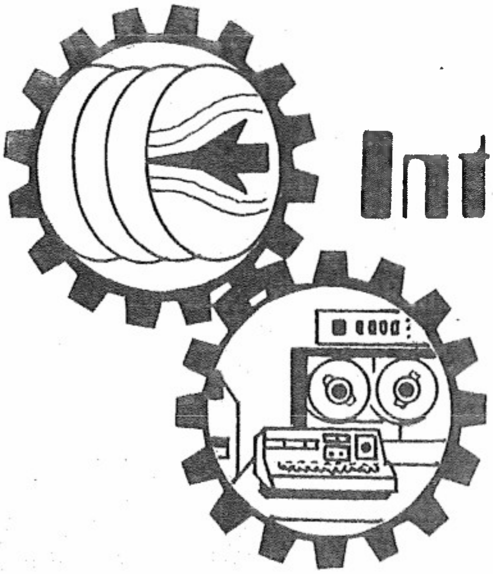

Integrating Wind Tunnels And Computers

VOLUME I

SPONSOR: AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

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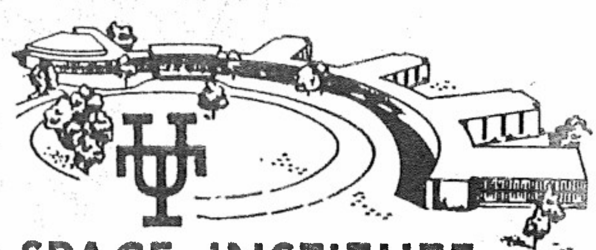

SPACE INSTITUTE

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

The Summer Design Study Group at the University of Tennessee Space Institute studied the status of integration of computers with wind tunnels. The study was begun with a series of presentations made to the group by industry, government, and university workers in the field. The background of the individuals making the presentation covered a broad spectrum of viewpoints and experience from computer design, theoretical analysis, computational aerodynamics, wind tunnel technology, and flight vehicle design. Each of the speakers had in-depth discussions with the Design Group as a whole or with one or more of the three

panels: (1) Experimental Methods, (2) Computational Fluid Dynamics, and (3) Computer Systems. An extensive literature survey and review was undertaken. The Design System as it progressed focused primarily on the following aspects:

(a) exploration of the present state of computational fluid dynamics and its impact on the design cycle and computer requirements for future developments in this field;

(b) the increase in productivity and efficiency which experimental facilities can achieve by a close integration with computers;

(c) improvements in simulation quality of wind tunnels possible in conjunction with computer control;

(d) research experiments necessary to provide a better understanding of the physics of fluid flow and to assist in the modeling of these phenomena for computational methods, with primary emphasis on turbulent flows.

A Steering Committee, whose membership represented a spectrum of specialized talents from universities and governmental agencies, assisted the Technical Director in delineating the scope of the study. The Study Group met twice with this Steering Committee.

It is believed that the principal objective of the study, namely that of providing a meaningful education experience was achieved, and that, furthermore, the results will be of interest to the sponsor.

The reference documentation and bibliography are presented in Volume II.

VOLUME I

EXECUTIVE SUMMARY

USAF/OSR/ASEE

SUMMER DESIGN STUDY PROGRAM

on the

INTEGRATION OF WIND TUNNELS AND COMPUTERS

by

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Project Administrator

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Tullahoma, Tennessee

AFOSR Grant No. 77-3289 August 1977

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ABSTRACT

The Summer Design Study Group at the University of Tennessee Space Institute studied the status of integration of computers with wind tunnels. The study was begun with a series of presentations made to the group by industry, government, and university workers in the field. The background of the individuals making the presentation covered a broad spectrum of viewpoints and experience from computer design, theoretical analysis, computational aerodynamics, wind tunnel technology, and flight vehicle design. Each of the speakers had in-depth discussions with the Design Group as a whole or with one or more of the three panels:

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COMMENTS BY THE STEERING COMMITTEE

This report is the result of an unusual educational experiment: a set of young people in academic positions ranging from mathematics to engineering spent the summer months at UTSI for the purpose of arriving at a common point of view on the interrelations between computers and wind tunnels. Their task was not easy; they had to become fast experts in a field of strongly held and divergent opinions. A large amount of factual information presented by lecturers from the engineering and computing communities had to be absorbed, put into context, and synthesized into a coherent picture. We feel that this task was well accomplished and that their report will prove useful to others in understanding the relative rolls of, and constructive relationships between, computers and wind tunnels. We take this opportunity to commend the members for their quick assimilation of facts and philosophies about a complex relationship, and for the long hours they devoted to preparing their report, resulting in a very respectable contribution. The task would have been much more difficult, if not impossible, without Professor Bernard Marschner, whose untiring efforts to coordinate and guide the study were crucial for its success. Last but not least, the contribution of Dr. Robert Young, Associate Dean of the University of Tennessee Space Institute, should be acknowledged. He was the guiding spirit in getting the study under way and in providing the appropriate academic setting for its execution.

Hans W. Liepmann, Chairman
Steering Committee
November 14, 1977

1.0 INTRODUCTION

Early discussions between individuals of the University of Tennessee Space Institute and the Arnold Engineering Development Center indicated the desirability of a Summer Design Study involving some subject of interest to AEDC. These discussions resulted in a contract between the University of Tennessee Space Institute, the Air Force Office of Scientific Research, and the American Society for Engineering Education. The contract was for a study of the interaction between wind tunnels and computers and the potential result of these interactions on productivity and on the design cycle of air vehicles. In conjunction with ASEE, the University of Tennessee Space Institute proceeded with advertising and the selection of the Summer Faculty. Brief resumes of these individuals are given in an appendix to Volume I. Likewise, UTSI in conjunction with AEDC and its operating contractor, ARO, Inc., secured the services of an individual with experience both in aerodynamics and in computer systems for the position of Technical Director. AFOSR in conjunction with UTSI selected a Steering Committee to provide overall guidance for the Summer Design Study.

The study objectives were refined in joint discussions between UTSI, the Technical Director, and the Steering Committee. These objectives are summarized in Section 2.0. The Technical Director outlined for approval of the Steering Committee the methodology to be used in meeting these design objectives, and this outline is presented in Section 3.0. The period of the Design Study was from June 13 through August 19, 1977. The individuals of the Study Group were invited for a briefing and a site visit prior to the beginning of the program. The Technical Director met several times with local AEDC people and UTSI and arrived at UTSI two weeks before the beginning of the program in order to prepare a schedule of events and make the necessary arrangements for speakers. The detailed schedule and a copy of the announcements for speakers are presented as appendices to Volume I.

It was necessary to review the fields of wind tunnel testing and computational fluid dynamics in order to understand better how computers and wind tunnels can be used, independently and interactively, to the benefit of aerodynamic design and testing. In the material in Volume II there is a fair amount of tutorial material that may be omitted if the reader is current in the field. The Study Group has attempted to concentrate on those areas in the timely generation of the design data in which the computer can most probably effect significant improvement.

2.0 OBJECTIVES

The following objectives guided the Design Study. These objectives were arrived at in guidance meetings between the Technical Director and the Steering Committee before the study began.

1. To provide a design study experience on a realistic and pertinent engineering subject for the faculty participants.
2. To ascertain the current status of experimental aerodynamic facilities and test methods and the current status of aerodynamic computational methodologies and computer systems.
3. To prepare an estimate of future developments in experimental and computational aerodynamics consistent with projected design needs, with special emphasis on the impact of the next generation of experimental and computational facilities.
4. To explore means of obtaining and improving aerodynamic data by developing concepts for integrated use of computers and wind tunnels.
5. To prepare the faculty participants to make future contributions in the area of experimental and computational aerodynamics.

3.0 METHODOLOGY

As a result of guidance from the Steering Committee and from review of previous design study reports, the following methodology for the conduct of the study was developed:

1. A review would be made of current literature in the following three areas:
   a. Experimental facilities and methodology for wind tunnel testing of advanced military air vehicles.
   b. State of the art in computational fluid mechanics and aerodynamics.
   c. Design trends of computer architecture and computer implementation techniques as they pertain to computational aerodynamics and wind tunnel testing.
2. Material would be presented by contributors in the three fields under consideration to aid in the understanding of computational and experimental aerodynamics.
3. A brief written assessment of the current status of the three areas would be prepared.
4. A written estimate would be made of future trends, capabilities, and limitations for the interaction between computational aerodynamics, experimental aerodynamics, and advanced computer design implementation.
5. Study participants would present reviews of current technical reports in the three areas.

4.0 STEERING COMMITTEE

A Steering Committee appointed by AFOSR to provide advice and guidance to the Summer Design Study Group consisted of the following individuals:

1. Dr. Hans W. Liepmann, Chairman--Director, Graduate Aeronautical Laboratories
   California Institute of Technology
   Pasadena, CA 91125

2. Dr. Gary T. Chapman-------------Aerodynamics Research Branch, Code FAR
   NASA-Ames Research Center
   Moffett Field, CA 94035

3. Dr. Wilbur Hankey---------------Air Force Flight Dynamics Laboratory
   Wright-Patterson AFB, OH 45433

4. Dr. David McIntyre--------------Air Force Weapons Laboratory/AD
   Kirtland AFB, NM 87117

5. Dr. Richard Seebass-------------Department of Aerospace Engineering
   University of Arizona
   Tucson, AZ 85721

5.0 DISCUSSION OF INVESTIGATION

The Summer Design Study Group performed no new research, experiments, or calculations. The group of twelve university faculty members devoted ten weeks to the intense study of the present and future interaction of computers and wind tunnels; this report represents a comprehensive review of the subject. The study results are based on (1) oral and written presentations by a diverse group of technical specialists from the field of experimental and computational aerodynamics and from the computer industry, and (2) a thorough literature search and an active reading and review program of a large number of technical reports in the field. One of the challenges encountered by the Study Group was to assimilate this huge body of information and condense it down to a modest number of specific areas for discussion and recommendation. The areas which were most thoroughly explored are discussed below.

In order to determine the effect of integration of computers and wind tunnels it was necessary to review the activity, performance, and usefulness of the existing test facilities in order to see what impact the computer could make.

The investigation of wind tunnels focused considerable emphasis on simulation accuracy and methods as well as a means for possible improvement. The Study Group also considered the need to investigate more details of the physics of the flow, which would help in understanding the simulation criteria, and the need to provide input for the mathematical modeling of certain parts of the physics of the flow for computational fluid dynamics. Another area of computer impact was in improving the design cycle efficiency by closed-loop application to tunnel flow controls, model controls, intelligent walls, and data collection and analysis. Further increased efficiency in the use of wind tunnels could be obtained by integration of computers in test plan optimization and in comparing computer code results with the data output from the wind tunnel in "real time" to affect the conduct of a test.

In the course of this study, it became evident that certain fundamental cross purposes were involved (i.e., quantitative versus qualitative productivity). The driving function for production wind tunnels is "productivity," namely data points per hour, data points per man-hour, data points per dollar; all sorts of quantitative measures seem to be the driving function. Test directors, contractor operators, and Air Force Project Officers understand and pursue this quantitative measure. It becomes clear that very often this quantitative measure works to the detriment of qualitative data taking. Performing calibration and flow-field investigations in existing facilities with the aim of improving the utility of the facility is difficult since this type of investigation appears not to carry the same weight as amassing of production data points (i.e., those for a system development).

Another fact emerged during the study of existing facilities: it is apparently more desirable, perhaps even easier, and certainly more technically rewarding, to pursue the design, development, and construction of new facilities than to study and design modifications to existing wind tunnels for the purpose of improving quality of flow. It is very difficult to obtain funding and priority for this sort of modification work. Likewise, in the development of new instrumentation, new balances, and new flow-measuring devices, the driving function is the word "productivity" (and again, productivity is a quantitative, not a qualitative term). A better motivating goal would be "efficiency" (that is, more meaningful data, not more data).

In reviewing the situation for the setting of a single or finite number of tunnel parameters or a single or finite number of model parameters, one finds that the accuracy or precision of present instrumentation is probably at least an order of magnitude better than the accuracy of simulation of the test being conducted in the wind tunnel. The closed-loop integration of a computer with tunnel and model setting devices would certainly have an impact on speeding up the productivity of existing facilities. This effort, however, would have very little impact on the simulation accuracy of the test being conducted in the wind tunnel. There clearly remains a problem in terms of deficiencies in tunnel flow simulation qualities such as velocity and Mach number irregularities, variations in flow angle, and disturbances which affect the model testing (e.g., noise and vibration). When separation and boundary-layer transition are important, Reynolds number simulation is necessary; usually this cannot be achieved in existing tunnels, but requires extrapolation based on experience derived from previous tests and flight comparisons. Consequently, good results are still a very empirical art. It is not unusual to review data in which accuracies of one drag count are a goal. While repeatability and point setting of tunnel parameters are achievable, at present the simulation accuracy is about an order of magnitude worse than one drag count. Despite this fact, one drag count seems to be a presently unattainable goal. Tests have often been run where the corrections applied to the measured data were as large as 20 percent of the measured value. The corrections by and large are based on empirical data, experience, intuition, and long-term use of the tunnel by the test conductor. It appears unrealistic to ask for accuracy of one count in drag and then to apply numerous corrections for wind tunnel wall interference, flow angularity, uncertainty in transition point, nonsimulation of Reynolds number, nonsimulation of engine effects, sting deflection effects, etc., for approximately 50 counts of drag.

A look at the present wind tunnels indicates a need for an understanding of some of the basic phenomena such as Reynolds number effects on separation and transition in order to support progress in the field of computational fluid dynamics. The review of this area leads one to believe that considerable progress is needed and is possible. A continuing modest level of support for fundamental research-type wind tunnel investigations is needed.

Another conceptual area which was reviewed extensively was the intelligent wall wind tunnel, which offers the promise of significant reductions in wind tunnel wall interference. Many researchers are pursuing this development; however, the level of effort is still quite modest, and the diversity of approaches is quite varied. The mechanical variations of the wall boundaries have indicated several different mechanical approaches. Likewise, various computational schemes for calculating the far flow field and performing the matching are under investigation. The work necessary in the area of instrumentation and wind tunnel adjustments suitable for three-dimensional testing indicates that a considerable period of research and development will be in the offing. It is not believed that computer control of the ultimate device will be limited by computer technology.

The field of computational fluid dynamics (CFD) was reviewed in broad scope by the Summer Study Group. This effort emphasized the assessment of what presently can be accurately computed, and it resulted in the isolation of many areas where additional work is necessary. Computational fluid dynamics (CFD) is a relatively new field and does not have the extensive background of a large number of active researchers and facilities supporting the problem, as does its counterpart, experimental fluid dynamics. However, practically every major computer installation involved in aerodynamic research is being used to develop CFD with a corresponding proliferation of methods and solution algorithms. Some of these efforts are commendable, but as with any new tool, some applications are fundamentally incorrect and reflect the relative immaturity of CFD. Discussions with aircraft manufacturers indicated opposing views on the usefulness of CFD. (Those manufacturers having management with strong experimental background tend to discount the value of this field.) Nonetheless, CFD is being implemented by all, and the design process is being accomplished with more efficiency. There is a definite trend within the aerospace community toward optimizing design tradeoffs by way of computation prior to the validation phase of wind tunnel experiments. The cut-and-try experimental method of aerodynamic design is being supplanted by design by analysis, and the future of CFD is bright indeed. But it is unlikely that CFD will ever totally replace the function of wind tunnel experimentation. Aerodynamic phenomena are simply too complex to permit digital representation.

It is expected that the blend of CFD with wind tunnels will be complementary, with each tool aiding the other, each providing answers to specific design questions, and each generating problems for the other technique to solve. We must take positive steps to encourage increased cooperation between computational fluid dynamics and wind tunnel technology.

The availability of the existing large computers to the community of researchers is extremely limited and is probably delaying the understanding of this field considerably. Attacks on the three-dimensional problem will require computing power in excess of the presently available sequential machines. The availability of a new generation of machines (presently being marketed) which introduces architectural variations can contribute to early work in the three-dimensional area. Again, however, these machines (e.g., the Cray I, Star 100, and Illiac IV) are available only on a limited basis to a limited number of researchers.

The computer panel functioned in a support role to the other panels. In carrying out this role the panel worked on quantifying the computer requirements for the various applications and then examined the situation in the computer field in order to determine the availability of computers to fulfill the requirements. In every case (with the single exception of the large computer required for CFD), either available computers or new computers with normal growth expectations could fill the requirement. And for this requirement the architectural variations that have been studied and the prototypes already built, coupled with the rapid increase in component performance optimized for a three-dimensional class of problems could be designed and built with vector performance of 10^3 megaflops at this time. However, such a machine should be built only at such a time as a number of analytical simulation studies, algorithm developments, and software developments are completed and thoroughly understood.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Many recommendations and conclusions, as well as summary positions, are given in the main text of Volume II. Not all of the recommendations are repeated here; rather, a number of the recommendations are combined and reorganized and presented in a more over-all summary fashion. The reader is referred to Volume II for the supporting material for the various conclusions.

1. *It was definitely concluded that for the foreseeable future the roles of computers and wind tunnels will be complementary. It is expected that the computer will play a greater role in the process of design by analysis in the future; however, that role will be one of supplementing the wind tunnel. The combination of numerical computation, verified by critical experiments in the wind tunnel, will greatly improve the design process.*

2. *The pacing item for progress in computational fluid dynamics is an understanding of the physics of fluid flow with turbulence. A continuing level of effort in fundamental studies of turbulence is necessary for progress in the derivation of physically reasonable and consistent turbulence models.*

3. *There is a continuing need for a few moderately sized, high quality wind tunnels (along with support personnel) completely dedicated to basic research and free to operate without production-oriented goals. These research tunnels are needed for conducting controlled experiments, primarily to study basic phenomena and discover new facts which ultimately will lead to a better understanding of complicated viscous flow problems. This work will result in improved correlation among individual wind tunnels*

free flight, and computational codes, and will lead to a more compact and efficient design cycle.

4. The production wind tunnels should receive attention in the area of improving flow quality. A higher priority should be given to the correction of flow irregularities presently existing in the production wind tunnels. This will be a long-term and continuous effort which will require a considerable expenditure of funds in order to raise the overall simulation quality of the flow within the wind tunnel test section.

5. A continuing effort in the development of noninterfering techniques for flow parameter measurements, for the determination of flow conditions, and for the determination of model attitudes and positions should be vigorously pursued. The minicomputer can play a significant role in improving these types of conditions. Also, a group of minicomputers in a distributive network can play a role in the wind tunnel and test model closed-loop control mode.

6. It is believed that the technique of adaptive walls, coupled with the computer operating in a closed-loop mode, can have a significant impact on improving the simulation quality of wind tunnels. The adaptive or corrective wall research should be pursued and continued at an increased level of activity; in particular, a strong coordinating organization between the sponsoring agencies and the individuals conducting the work should be set up on a rather formalized basis for the next several years. The most difficult problems are concerned with the measurement of flow variables near the wall and the mechanisms used for adjusting the wall boundaries. The use of a relatively large computer is a vital necessity but is within the state of the art in computers.

7. The real-time availability of a modern large-scale computer during the conduct of wind tunnel tests on which the design computer program results could be used for comparison with test results would improve the design process by verifying numerical optimization and by allowing the examination of only critical areas. At a minimum, planning should be begun for remote terminals with graphics capabilities connected to the aircraft designer's computer for access from the tunnel control room.

8. In the area of computational fluid dynamics, efforts should be made to give researchers in the field an easier access to some of the very large sequential machines presently installed in the United States. A freer access to the machines for computational work will improve the understanding of the mathematics, numerical methods, and fluid mechanics in this field by allowing more of the researchers access to suitable machines.

9. Parallel to this effort in numerical experimentation, serious consideration and support should be given to the mathematical aspects of computational fluid dynamics. This work will pace the development of methods of solutions and greatly affect the subsequent choice of computer architectures.

10. The efforts to conduct design studies on future machines which have special abilities for the solving of three-dimensional time-averaged Navier-Stokes (Reynolds) equations should be pursued. These design studies should include a significant amount of simulation activity and a rather complete development of the software; this is particularly true of the operating system. Proposed vectorized architectures should be simulated on existing host machines, and a large number of timing studies of

various architectures should be made to assist in setting the critical design parameters of a large-scale computing system.

11. Various investigators examining advanced architectural concepts such as the class of machines of the multiple instruction, multiple data (MIMD) type should be encouraged, as should individuals pursuing software developments for presently conceived parallel, or pipelining machines. In particular, considerable effort should be given to the area of developing vectorizing software in order to make this class of machine more user oriented. Otherwise, computational fluid dynamicists will need the additional skills of computer scientists.

APPENDIX I

SUMMER DESIGN STUDY PANEL MEMBERS

Panel 1: Experimental Methods in Acquisition of Aerodynamic Data	Source of Highest Degree	Organization	Area of Interest
*Collins, Frank G.	University of California-Berkeley	Aerospace Engineering UTSI Tullahoma, TN 37388	Aerospace Engineering
Garcia, Sal R.	Texas A & M University	Maritime Systems Engrg. Moody College Galveston, TX 77553	Engineering Systems
Jones, Michael	North Carolina State Univ.	School of Engineering UT-Chattanooga Chattanooga, TN 37401	Mechanical Engineering
Tirres, Carlos	Air Force Institute of Technology	Engineering Division Motlow State Community College Tullahoma, TN 37388	Aerospace Engineering

Panel 2: Computational Methods in Acquisition of Aerodynamic Data	Source of Highest Degree	Organization	Areas of Interest
*Cheng, Sin-I	Princeton University Princeton, NJ 08540	Princeton University Department of Aerospace Engineering	Aerospace Engineering
Chambless, Donald A.	Tulane University	Auburn University at Montgomery Mathematics Department Mongtomery, AL 36117	Mathematics
Jacocks, James L.	University of Tennessee Space Institute	Senior Engineer PWT/ARO, Inc. Arnold AFS, TN 37389	Aerospace Engineering
Sahai, Vireshwar	Virginia Polytechnic Institute	Tenn. Tech. University Engineering Science Dept. Cookeville, TN 38501	Engineering Mechanics

APPENDIX I CONCLUDED

Panel 3: Computer Developments for Support of Acquisition of Aerodynamic Data	Source of Highest Degree	Organization	Areas of Interest
*Hornfeck, William A.	Auburn University	Electrical Engineering Program Gannon College Erie, PA 16501	Electrical Engineering
Broome, Lesunda Eugene	University of Houston	Mathematics Dept. Moody College Galveston, TX 77553	Mathematics
Cunningham, James R.	University of Florida	School of Engineering UT-Chattanooga Chattanooga, TN 37401	Chemical Engineering
Dick, Gregory M.	Stanford University	University of Pittsburgh, Johnstown Division of Engineering Technology Johnstown, PA 15904	Electrical Engineering
Technical Director			
Marschner, Bernard W.	California Institute of Technology	Department of Computer Science Colorado State University Fort Collins, CO 80523	Computer Systems/ Computer Analysis
Project Administrator			
Young, Robert L.	Northwestern University	Associate Dean The University of Tennessee Space Institute Tullahoma, TN 37388	Mechanical Engineering

APPENDIX II

SPEAKERS FOR THE AFOSR-ASEE-UTSI-AEDC SUMMER STUDY DESIGN PROGRAM

Name	Organization	Title
Dr. Charles H. Weaver	UTSI	Welcome of Participants & Observers
Dr. Leith Potter Mr. Ross Roepke	ARO, Inc. USAF/AEDC	Introduction of AEDC & ARO Personnel
Dr. Bernard Marschner	UTSI	Outline of Program Objectives
Dr. James Wu	UTSI	Introductory Lecture on Theoretical Background on Fluid Mechanics
Dr. Trevor Moulden	UTSI	Introduction to Concepts of Boundary Layer, Turbulence, and Separation
Dr. J. Leith Potter	ARO, Inc.	Aerodynamic Problems in the Development of Air Vehicles across the Speed Regimes
Dr. Sam Pate Dr. Michael High	ARO, Inc.	Status of the Art in the Acquisition of Aerodynamic Data by Experimental Methods
Dr. Kenneth Kimble	UTSI	Introductory Lecture on Numerical Methods and Background in Solutions of Partial Differential Equations
Dr. Kenneth Kimble	UTSI	Current Methods, Problems, and Progress on Finite Differences and Finite Elements for the Numerical Solution of Partial Differential Equations
Dr. Bernard Marschner	UTSI	Overview of Computer Architecture Concepts
Dr. John Adams	ARO, Inc.	Computational Aerodynamics
Dr. Wendell Norman	ARO, Inc.	New Approaches to Experimental Aerodynamics Facilities
Mr. R. O. Dietz	USAF/AEDC	Facility Planning Briefing
Dr. James Xerikos	McDonnell-Douglas	Computational Experimental Aerodynamic Testing

APPENDIX II CONTINUED

Name	Organization	Title
Dr. Virgil Sandborn	Colorado State University	Limitations in Measure & Analysis in Non-Equilibrium Flows including Separation
Dr. Larry DaCosta	Boeing Aircraft Corp.	Computational and Experimental Aerodynamic Data in the Design of Aircraft
Dr. V. L. Peterson	NASA/Ames Research	Status of Advanced Techniques in Computational Aerodynamics and the next major step
Dr. F. Ronald Bailey	NASA/Ames Research	Future Computer Capabilities
Mr. Dick McHugh	Control Data Corp.	New Computer Architectural Concepts for Super Computers
Mr. Thomas Wachowski	Institute for Advanced Computation	Overview of the Institute for Advanced Computation
Dr. Raimo Hakkinen	McDonnell-Douglas	Experiences in Experimental & Computational Aerodynamics
Dr. Richard Hendrickson Dr. Charles Puglisi Dr. Richard Russell	CRAY Research	CRAY I Vector Processor and Future Developments
Mr. Wayne Brubaker	Goodyear Aerospace Corp.	Parallel Processing--An Approach to Large Scale Numerical Problem Solution in Real-Time
Mr. Jack Patterson	Lockheed-Marietta	Comparison of Computer-Aided Aerodynamics with Wind Tunnel-Generated Aerodynamics
Dr. D. H. Lawrie	University of Illinois	Techniques and Effectiveness of Programming Strategies for High Speed Computers
Mr. Joe McKay	BMDATC-P	PEPE Architecture
Mr. Hiram Martin	Systems Development Corp.	FORTRAN Compiler for Parallel Processing
Mr. Sam Dougherty	ARO, Inc.	Flow Quality
Mr. Andy Anderson	ARO, Inc.	Accuracy of Wind Tunnel Results

Name	Organization	Title
Dr. Thomas Weeks	Wright-Patterson Air Force Base	"Reynolds Number, Separation, and Intelligent Wall Work at Air Force Flight Dynamics Laboratory
Dr. George Paul	IBM, New York	"Scientific Computing, Vector Processing, and Outlook."
Dr. W. Michael Farmer	UTSI	"Laser Velocimetry"
Dr. James O. Hornkohl	UTSI	"Laser Velocimetry"
Dr. William Heiser	AEDC	"Procurement Philosophy"

SUMMARY OF THE 1977 USAF/OSR/ASEE SUMMER DESIGN STUDY PROGRAM ON THE INTEGRATION OF WIND TUNNELS AND COMPUTERS

by

Frank G. Collins
Associate Professor of Aerospace Engineering
The University of Tennessee Space Institute
Tullahoma, Tennessee 37388

The Summer Design Study Group, which consisted of a group of eleven university faculty members under the direction of a technical director and a project administrator, devoted ten weeks to the intensive study of the present and future interaction of computers and wind tunnels. This paper represents a summary of the results of the study.[1] No new research, experiments, or calculations were performed by the group. The study results were based on (1) oral and written presentations by a diverse group of technical specialists from the field of experimental and computational aerodynamics and from the computer industry, and (2) a thorough literature search and an active reading and review program of a large number of technical reports in the field. The areas which were most thoroughly explored and the conclusions arrived at are discussed below.

In order to determine the effect of integration of computers and wind tunnels it was necessary to review the activity, performance, and usefulness of the existing test facilities in order to see what impact the computer could make.

The investigation of wind tunnels focused considerable emphasis on simulation accuracy rather than test repeatability. In the future there will be less incremental testing and more reliance upon absolute measurements. Simulation improvements were seen as necessary to reduce the development time and eliminate design based upon geometrically similar vehicles.

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The technology for simulation improvement is, in general, at hand but needs to be implimented.

The Study Group considered the need to investigate more details of the physics of the flow, which would help in understanding the simulation criteria, and the need to provide input for the mathematical modeling of certain parts of the physics of the flow for computational fluid dynamics. Another area of computer impact was in improving the design cycle efficiency by closed-loop application to tunnel flow controls, model controls, intelligent walls, and data collection and analysis. Further increased efficiency in the use of wind tunnels could be obtained by integration of computers in test plan optimization and in comparing computer code results with the data output from the wind tunnel in "real time" to affect the conduct of a test.

In the course of this study, it became evident that certain fundamental cross purposes were involved (i.e., quantitative versus qualitative productivity.) The driving function for production wind tunnels is "productivity," e.g., data points per hour. It becomes clear that very often this quantitative measure works to the detriment of qualitative data taking.

Another fact emerged during the study of existing facilities: it is apparently more desirable, perhaps even easier, and certainly more technically rewarding, to pursue the design, development, and construction of new facilities than to study and design modifications to existing wind tunnels for the purpose of improving quality of flow. Likewise, in the development of new instrumentation, the driving function is the "productivity" while a better motivating goal would be "efficiency" (that is, more meaningful data, not more data.)

In reviewing the situation for the setting of a finite number of tunnel and model parameters, one finds that the accuracy or precision of present instrumentation is probably at least an order of magnitude better than the accuracy of simulation of the test being conducted in the wind tunnel. The closed-loop integration of a computer with tunnel and model setting devices.

would certainly have an impact on the productivity of existing facilities but would have very little impact on the simulation accuracy of the test being conducted in the wind tunnel. There clearly remains a problem in terms of deficiencies in tunnel flow simulation qualities.

Reynolds number simulation is necessary; usually this cannot be achieved in existing tunnels, but requires extrapolation based on experience derived from previous tests and flight comparisons. Consequently, good results are still a very empirical art. Accuracies of one drag count are usually the goal but at present the simulation accuracy is about an order of magnitude worse than one drag count and the goal is presently unattainable.

There is a continuing need for an understanding of some of the basic flow phenomena such as separation, transition, and turbulence in order to support progress in the field of computational fluid dynamics. Considerable progress is needed and is possible, and a continuing modest level of support for fundamental research-type wind tunnel investigations is needed.

Another conceptual area which was reviewed extensively was the intelligent wall wind tunnel, which offers the promise of significant reductions in wind tunnel wall interference. Many researchers are pursuing this development; however, the level of effort is still quite modest, and the diversity of approaches is quite varied. Several different mechanical approaches and far field computational schemes are under investigation. The work necessary in the area of instrumentation and wind tunnel adjustments suitable for three-dimensional testing indicates that a considerable period of research and development will be in the offing. It is not believed that computer control of the ultimate device will be limited by computer technology.

The field of computational fluid dynamics (CFD) was reviewed in broad scope by the Summer Study Group. This effort emphasized the assessment of what presently can be accurately computed, and it resulted in the isolation of many areas where additional work is necessary. Computational fluid dynamics (CFD) is a relatively new field and does not have the extensive background of active researchers and facilities supporting the problem, as does its counterpart, experimental fluid dynamics. However, practically every major computer installation involved in aerodynamic research is being used to develop CFD with a corresponding proliferation of methods and solution algorithms. Some of these efforts are commendable, but as with any new tool, some applications are fundamentally incorrect and reflect the relative immaturity of CFD. Although there are opposing views by the aircraft manufacturers on the usefulness of CFD, nonetheless it is being implemented by all and the design process is being accomplished with more efficiency.

There is a definite trend toward optimizing design tradeoffs by way of computation prior to the validation phase of wind tunnel experiments. The cut-and-try experimental method of aerodynamic design is being supplanted by design by analysis, and the future of CFD is bright indeed. But it is unlikely that CFD will ever totally replace the function of wind tunnel experimentation. Aerodynamic phenomena are simply too complex to permit digital representation.

It is expected that the blend of CFD with wind tunnels will be complementary, with each tool aiding the other, each providing answers to specific design questions, and each generating problems for the other technique to solve. Positive steps should be taken to encourage increased cooperation between computational fluid dynamics and wind tunnel technology.

The availability of the existing large computers to the community of researchers is extremely limited and is probably delaying the understanding of this field considerably. Attacks on the three-dimensional problem will require computing power in excess of the presently available sequential machines. The availability of a new generation of machines (presently being marketed) which introduces architectural variations can contribute to early work in the three-dimensional area. Again, however, these machines are available only on a limited basis to a limited number of researchers.

The Study Group worked on quantifying the computer requirements for the various applications and then examined the situation in the computer field in order to determine the availability of computers to fulfill the requirements. In every case (with the single exception of the large computer required for CFD), either available computers or new computers with normal growth expectations could fill the requirement. For the CFD requirement the architectural variations that have been studied and the prototypes already built, coupled with the rapid increase in component performance, optimized for a three-dimensional class of problems, could be designed and built with vector performance of 10^3 megaflops at this time. However, such a machine should be built only at such a time as a number of analytical simulation studies, algorithm developments, and software developments are completed and thoroughly understood.

The following is a brief summary of the recommendations and conclusions made by the Study Group.

1. For the foreseeable future the roles of computers and wind tunnels will be complementary. The computer will play a greater role in the process of design by analysis in the future while critical wind tunnel experiments will be needed to verify computational procedures.

2. The pacing item for progress in computational fluid dynamics is an understanding of the physics of fluid flow with turbulence.

3. There is a continuing need for a few moderately sized, high quality research wind tunnels for conducting controlled experiments, primarily to study basic phenomena and discover new facts which ultimately will lead to a better understanding of complicated viscous flow problems.

4. A higher priority should be placed upon improving the siumlation quality of production wind tunnels. This will be a long-term and continuous effort which will require a considerable expenditure of funds.

5. A continuing effort in developing noninterfering techniques for flow and model measurements should be vigorously pursued. The minicomputer can play a significant role in utilizing

these types of techniques. Also, a distributive network of minicomputers can play a role in the wind tunnel and test model closed-loop control mode.

6. The technique of adaptive walls, coupled with the computer operating in a closed-loop mode, can have a significant impact on improving the simulation quality of wind tunnels. The adaptive wall research should be pursued and continued at an increased level of activity. The most difficult problems are concerned with the measurement of flow variables near the wall and the mechanisms used for adjusting the wall boundaries. The use of a relatively large computer is a vital necessity but is within the state of the art in computers.

7. The real-time availability of a modern large-scale computer during the conduct of wind tunnel tests on which the design computer program results could be used for comparison with test results would improve the design process by verifying numerical optimization and by allowing the examination of only critical areas.

8. Efforts should be made to give researchers in computational fluid dynamics an easier access to some of the very large sequential machines presently installed in the United States.

9. Serious consideration and support should be given to the mathematical aspects of computational fluid dynamics. This work will pace the development of methods of solutions and greatly affect the subsequent choice of computer architectures.

10. The efforts to conduct design studies on future machines which have special abilities for the solving of three-dimensional time-averaged Navier-Stokes (Reynolds) equations, including the proposed vectorized architectures, should be pursued. These design studies should include a significant amount of simulation activity and a rather complete development of the software.

11. Various investigators examining advanced architectural concepts or pursuing software developments for presently conceived parallel or pipelining machines should be encouraged. Considerable effort should be given to the area of developing vectorizing software in order to make this class of machine more user oriented.

APPENDIX

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