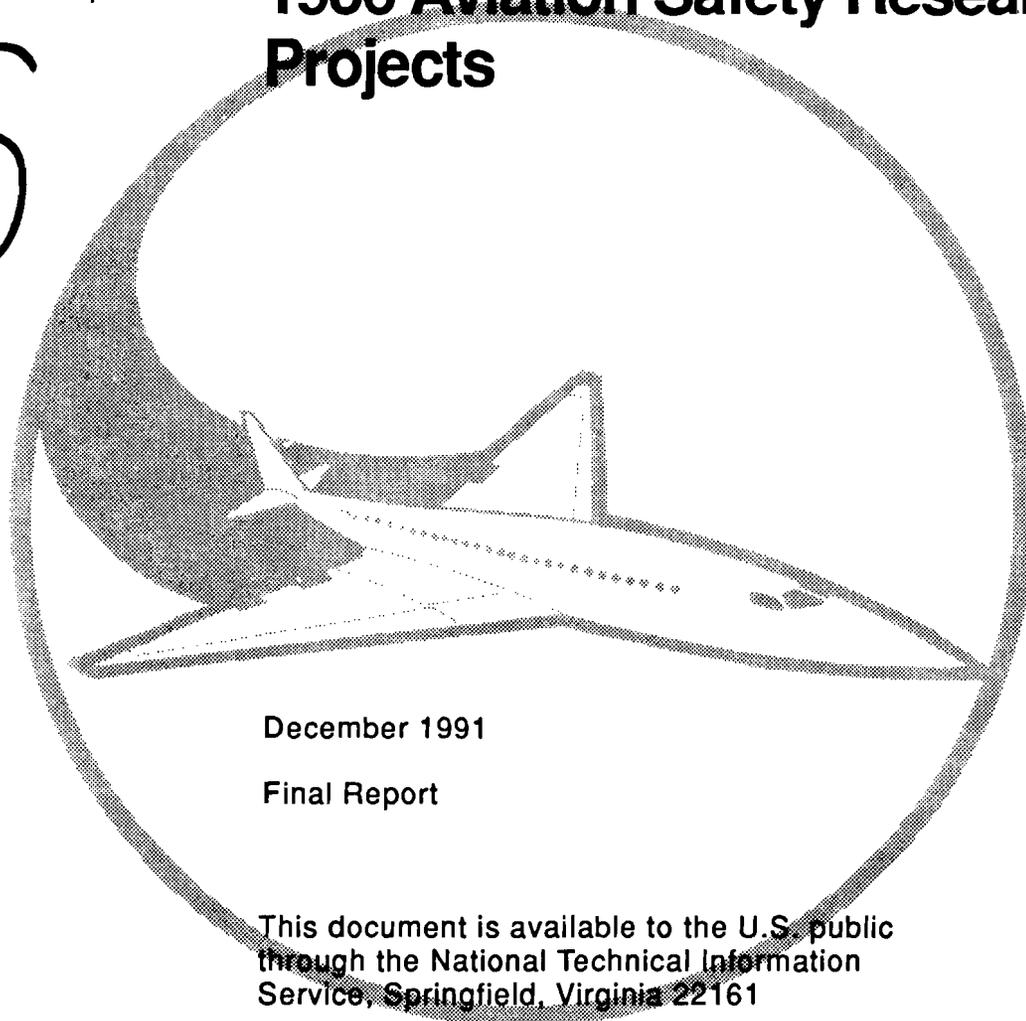


DOT/FAA/CT-91/4

FAA Technical Center  
Atlantic City International Airport  
N.J. 08405

# Wichita State University 1986 Aviation Safety Research Projects

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December 1991

Final Report

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U.S. Department of Transportation  
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16. Abstract <p>The proposal which the National Institute for Aviation Research (NIAR) at the Wichita State University (WSU) submitted to the Federal Aviation Administration (FAA) on May 23, 1986, proposed aviation safety research efforts in four areas: crashworthiness; electro-impulse deicing; stall/spin prevention; software reliability.</p> <p>Specific research topics were selected on the basis of a review of FAA research interests, the specialized expertise of WSU research interests, and discussions held with FAA personnel at the FAA Technical Center in Atlantic City and at WSU. The research carried out under this contract is now complete.</p> <p>In addition to the research activities undertaken during the period of this contract, the NIAR has completed construction on a 74,000-square-foot building which houses the activities and laboratories of the institute. Extensive equipment has been purchased as part of this contract and is now housed in the institute building. Moreover, the FAA support for equipment has been used to match State of Kansas equipment grants and has resulted in several well equipped laboratories.</p> <p>This research has involved 13 faculty members and 14 students. The NIAR is now positioned for sustained research as well as advanced training of graduate students in wide range of technical disciplines related to aviation safety. Publications resulting from their research efforts are listed by area.</p>					
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## EXECUTIVE SUMMARY

The proposal which the National Institute for Aviation Research (NIAR) at The Wichita State University (WSU) submitted to the Federal Aviation Administration (FAA) on May 23, 1986, suggested aviation safety research efforts in four areas:

Crashworthiness  
Electro-Impulse De-Icing  
Stall/Spin Prevention  
Software Reliability

Specific research topics within each of these four areas were selected on the basis of a review of FAA research interests, specialized expertise of WSU research investigators, and discussions with FAA personnel held at the FAA Technical Center in Atlantic City and at WSU. The research carried out under this contract is now complete.

In addition to the research activities undertaken during the period of this contract, the NIAR has completed construction on a 74,000- square-foot building which houses the activities and laboratories of the institute. Extensive equipment has been purchased as part of this contract and is now housed in the institute building. In several instances, the FAA support for equipment has been used to obtain matching State of Kansas equipment grants. The result is several jointly-funded, well-equipped laboratories.

This research has involved 13 faculty members and 14 students. Publications resulting from their research efforts are listed by area. The NIAR is now positioned for sustained research of significance to the FAA, as well as advanced training of graduate students in a wide range of technical disciplines related to aviation.

## INTRODUCTION

Aviation and aeronautical research in the United States stands today at a crossroads. It has been estimated that interdisciplinary efforts in propulsion, materials, aerodynamics, structures, and avionics could by the turn of the century make obsolete virtually all significant civil and military aircraft operational today (both fixed and rotary wing). Furthermore, the preeminence of American aviation technological development is being seriously threatened by foreign competition. The revitalization of aeronautical research and aviation technology capabilities has been defined as an important national priority.

Accompanying these technological advancements is an increasing necessity to improve the safety of aircraft and flight operations. Use of composite materials in structures requires different approaches to structural design, particularly with regard to energy absorbing properties. The advanced electronic systems now in use increase the vulnerability of control and navigational systems to electromagnetic and other interference. Application of other emerging technologies produces similar problems. An aggressive program of research is needed to assure the continual safety of flight.

The Wichita State University, with a unique location in the heart of the nation's aircraft industry and with a distinguished 50-year history of aeronautical research to build on, is in a favorable position to assist in meeting this national challenge. A new advanced technology research center has been developed to enhance its aeronautical research capabilities and to use more effectively the significant faculty and industrial resources that already exist on The Wichita State University campus and in the Wichita, Kansas, industrial community.

The development of The Wichita State University National Institute for Aviation Research involves the major expansion of research capabilities in key areas of emerging high priority need to the nation's aviation industry. When fully developed the institute will have new laboratory facilities, state-of-the-art equipment, instrumentation and computers, and research faculty and graduate students involved in projects significant to maintaining world leadership in aviation technology.

This research is part of an integrated plan for research in the area of aviation safety of interest to the Federal Aviation Administration. Research projects were conducted in four areas: crashworthiness, electro-impulse deicing, stall/spin prevention, and software reliability. Results of the WSU/FAA research have been disseminated by means of site visits to appropriate FAA facilities; symposia sponsored by the institute with university, government, and industry participation; and technical reports issued by the institute and jointly with the FAA.

## BACKGROUND.

The Wichita State University has a long and distinguished record in aviation education and research, dating from the 1930s. The location of The Boeing Military Airplane Company, Cessna Aircraft Company, Beech Aircraft, and Gates Learjet Corporation in the Wichita area has served to nourish the development of strong programs in aviation-related areas. Virtually all of these companies use the wind tunnel laboratories at The Wichita State University in the development of their products.

Many other aircraft, not produced in Wichita, have also been tested at WSU. Companies which have used the WSU research facilities include Boeing-Vertol, Bell Helicopter, Ling Temco Vought, and Fairchild-Republic. Graduates of the WSU Aeronautical Engineering program are employed at every major airplane and helicopter company in the United States, and with the National Aeronautical and Space Administration, the FAA, the U.S. Army, the U.S. Navy, and U.S. Air Force laboratories.

Since 1976, the university has received more than \$18 million in government and industry support for aviation research and training. NASA, FAA, and the Army have been major grant sources, funding numerous aeronautical research projects in the College of Engineering in the last two decades. The lengthy tradition of wind tunnel aviation research at The Wichita State University has been augmented in recent years by increased expertise in structures, materials science, propulsion, and systems research areas which are complemented by a sophisticated university digital computing center.

In 1968, the university inaugurated its first engineering doctoral program in aeronautical engineering. This program has been expanded to include other engineering specialties including mechanical, electrical, and industrial engineering. New doctoral programs in chemistry, applied mathematics, and human factors psychology have also been initiated.

In the fall of 1985, The Wichita State University created what is now the National Institute for Aviation Research. This institute consists of three centers: Center for Basic and Applied Research, Center for Aviation Safety Research, and Center for Productivity Enhancement.

## WSU/FAA PROJECT SUMMARY

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Project Number	Project Area	Principal Investigator
<b>1. Crashworthiness</b>		
1.1	Energy Absorption Mechanisms	Horn
1.2	Computational Crash Dynamics Analysis	Horn
<b>2. Electro-Impulse De-Icing</b>		
		Zumwalt
<b>3. Stall/Spin Prevention</b>		
3.1	Stall/Spin Flight Simulation	Nagati
3.2	Stall/Spin Aerodynamic Data	Snyder
<b>4. Software Reliability</b>		
4.1	Aviation Software Reliability	Suchenek
4.2	Software Reliability Assessment in Aviation System	Fard / Zheng

## PROJECT SUMMARIES

### CRASHWORTHINESS: ENERGY ABSORPTION MECHANISMS

WALTER J. HORN, Ph.D. AND MASSUD ROUHI, M.S.

**SUMMARY.** Energy absorption mechanisms of metal and composite structures were studied by conducting comparisons of the post-buckling behavior of metallic and composite plates with centrally located cutouts. The post-buckling characteristics of aluminum, graphite/epoxy, and graphite/PEEK square flat panels with centrally located circular holes were studied. The stability, post-buckling, ultimate strength, and energy absorption behavior of 0.08-inch-thick aluminum panels were compared to that of composite plates with a stacking sequence of [-45/0/45/90/-45/45/-45/45], for hole diameter to panel width ratios of 0, 0.2, 0.4, 0.5, and 0.7. A post-buckling test fixture was designed and developed to examine compressive buckling, post-buckling, and failure mechanisms of the panels.

Experimental results indicate that both the metallic and composite panels have significant post-buckling strengths and load-carrying capabilities well beyond their initial buckling load with similar mode shapes of the buckling and post-buckling deformations. However, the presence of a circular cutout reduces the post-buckling strength of the plate but could actually increase the critical buckling load.

The results of an analytical study of this structural response, using the nonlinear capability of the MSC/NASTRAN finite element computer code, were compared with the experimental measurements. Agreement between experimental results and finite element analyses was good. The energy absorption capability of panels was found to be a function of the plate thickness and the diameter of the centrally located hole.

**DESCRIPTION OF LABORATORY.** The Impact Dynamics Laboratory was developed concurrently with construction of the new Institute for Aviation Research building. The building was completed December 1, 1989. On August 31, 1990, the NIAR took possession of VIA Systems (Carmel, CA) Horizontal Impact Test Sled (HITS). Initial trials runs of the HITS by VIA Systems were successful.

The HITS facility (see figure 1) has an overall length of 90 feet with a usable track length of 77 feet. The HITS is designed to accelerate a 3000-pound payload to 55 miles per hour for an average departure acceleration of 1.65gs.

The VIA HITS consists of four major subsystems: decelerator, carriage, track, and propulsion (see figures 2-4). The decelerator is an all mechanical device which absorbs energy by virtue of a steel strap undergoing continuous plastic deformation as the impacting carriage causes it to pull through a series of rollers. By adjusting the stance of the decelerator and/or changing the shape of the steel bands, it is possible to regulate the force levels and tailor the pulse to set specifications (i.e., the characteristic triangular pulse specified in the R.F.P. of 25 g/200 msec). The carriage is a 655-pound, dual probe vehicle

with a maximum allowable pitch moment of 3,150,000-inch pounds. The track provides guidance for the carriage and mounting facilities for the propulsion and decelerator systems. The propulsion system is a compressed air, dual piston motor system. The payload weight and required velocity level determines which motor, 4.25-inch-diameter or 7.5-inch-diameter, is used.

In conjunction with the HITS installation and acceptance, other projects and purchases designed to enhance the operation of the laboratory were completed.

Using KTEC (Kansas Technology Enterprise Corporation) state matching funds, the NIAR signed a purchase agreement in October 1990 with DSP Technology (Fremont, CA), for a data acquisition system (DAS) and operating software (see figure 5). This is an expandable, 48-channel, 100-Kilosample/sec per channel system capable of storing data from a 1.2-second trace. An AT-386 class computer was purchased to act as DSPT's DAS System Controller. FAA experts from the Civil Aeromedical Institute (CAMI) facility in Oklahoma City were consulted prior to instrumentation selection. KTEC funding was also used to purchase dummies and a high speed vision system (see figure 6).

Electrical power for the HITS and HITS control room was installed by the WSU physical plant. Signal control lines for the HITS were also installed. These control lines are necessary for the operation of the HITS and monitoring of the HITS subsystems (i.e., pressure levels of the HITS propulsion system). Additional equipment such as pressure transducers and digital display units were purchased to further facilitate monitoring of the HITS propulsion system.

Payload handling will be easily accomplished due to the purchase of a 1-ton capacity material handling gantry/hoist/trolley system. Payload weight measurements will be accomplished with a 1-ton capacity crane scale.

PUBLICATIONS: "A Comparison of the Post-Buckling Behavior of Metallic and Composite Plates with Centrally Located Cutouts," NIAR Report 89-11, with M. Rouhi.

GRADUATE STUDENT: Massud Rouhi.

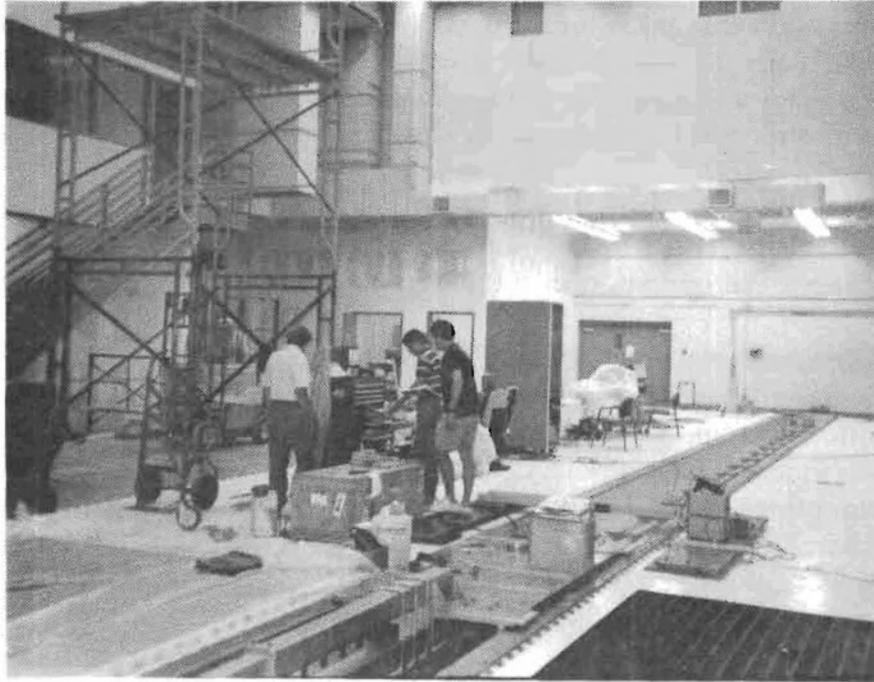


FIGURE 1. IMPACT DYNAMICS LABORATORY

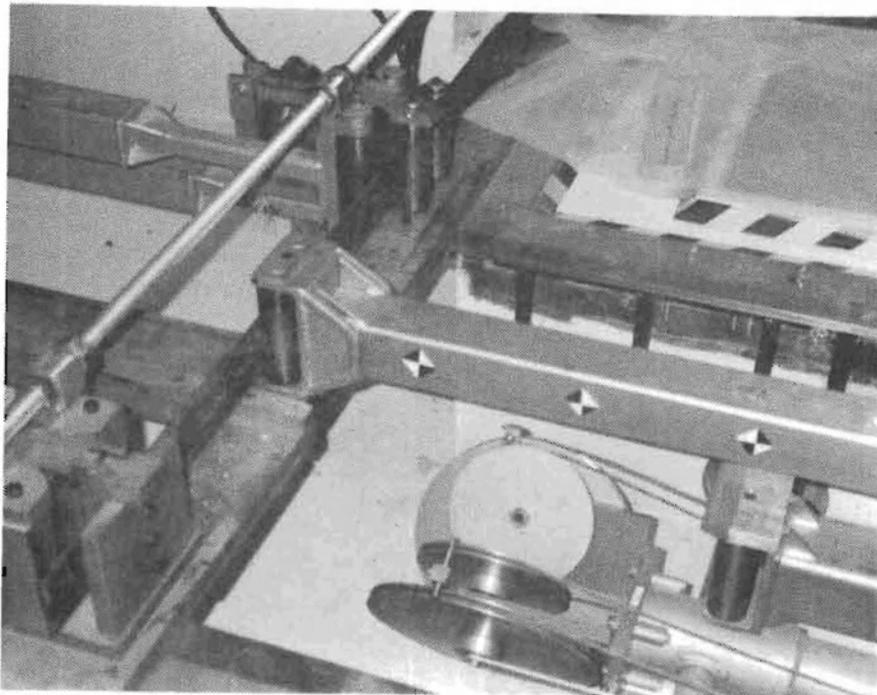


FIGURE 2. IMPACT DYNAMICS DECELERATOR

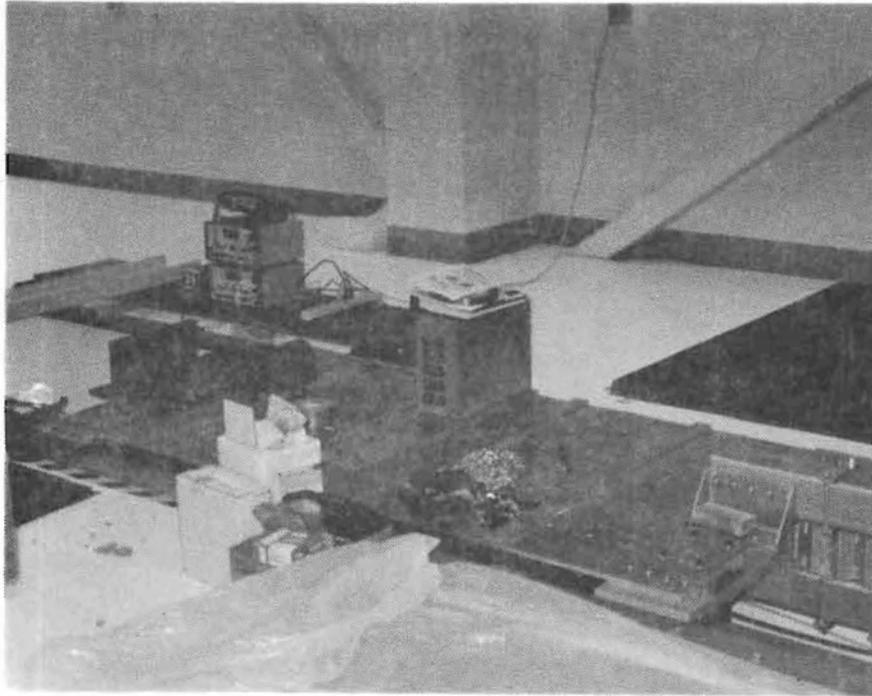


FIGURE 3. IMPACT DYNAMICS CARRIAGE

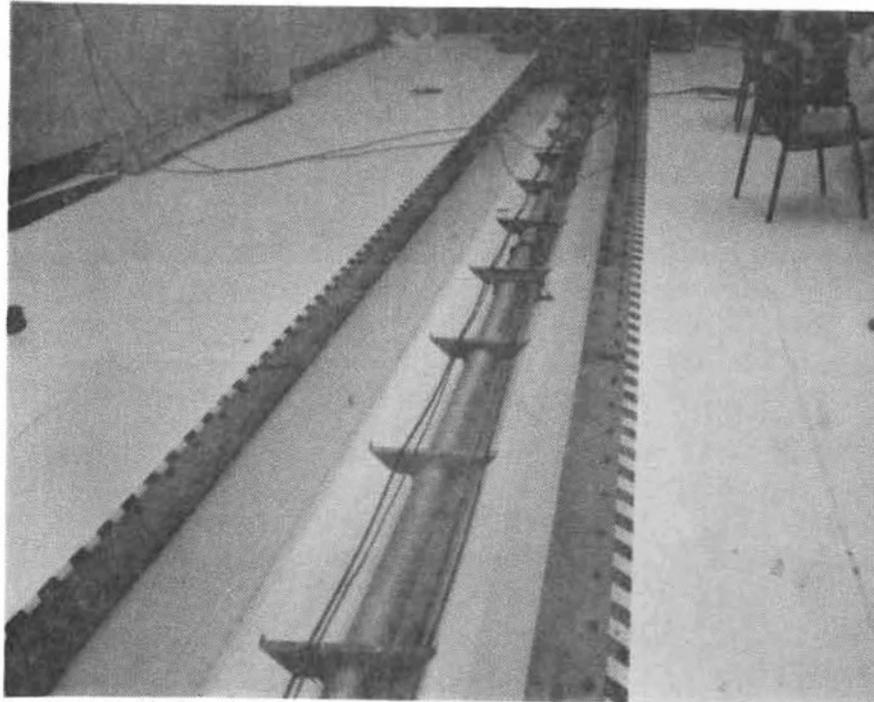


FIGURE 4. IMPACT DYNAMICS TRACK

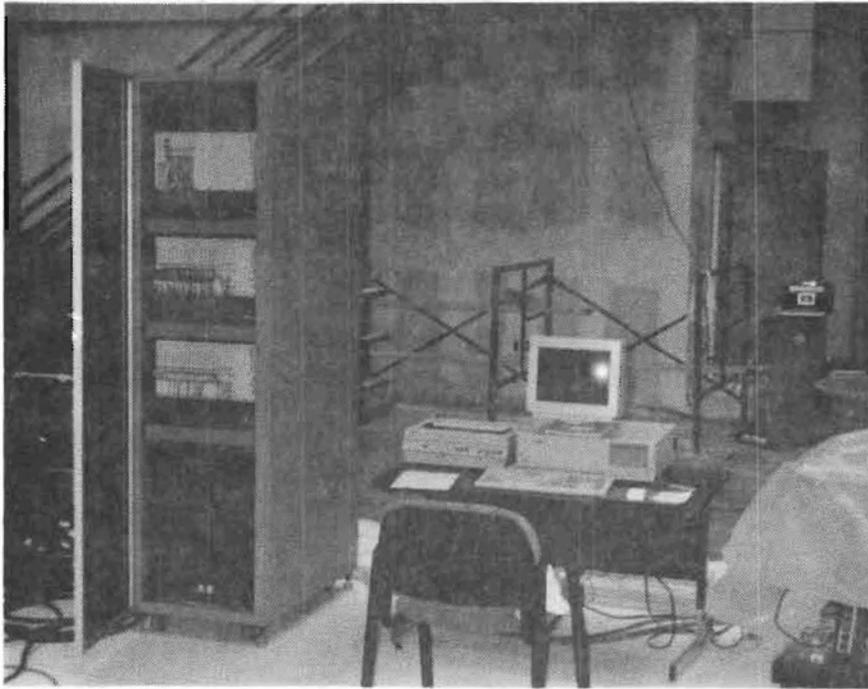


FIGURE 5. DSP DATA ACQUISITION SYSTEM

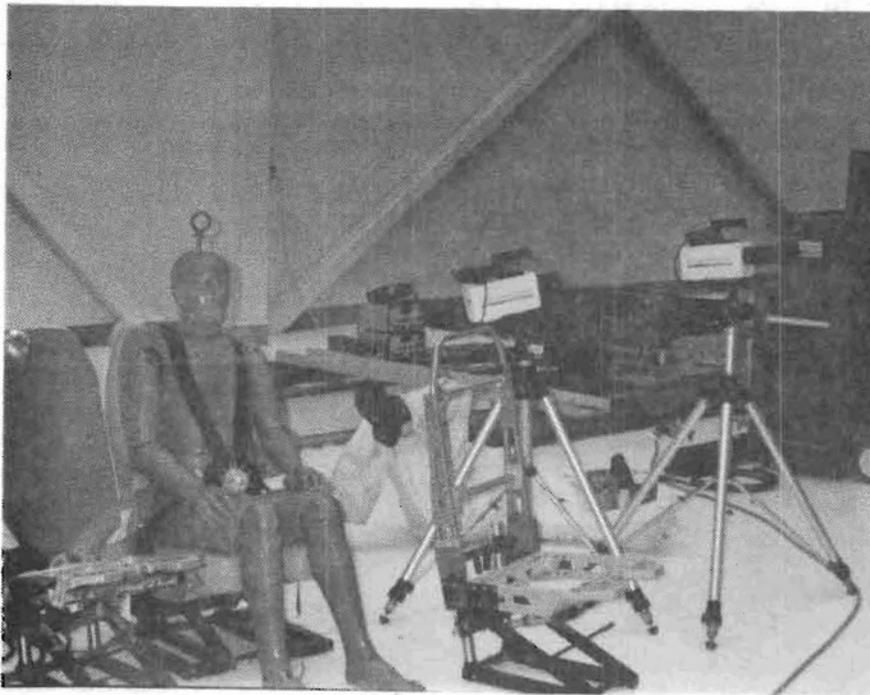


FIGURE 6. DUMMY AND VISION SYSTEM

**CRASHWORTHINESS: COMPUTATIONAL CRASH DYNAMICS ANALYSIS**  
**WALTER J. HORN, Ph.D. AND DAN L. CRISTMORE, M.S.**

**SUMMARY.** The purpose of this research effort was to develop analytical capability to predict the crashworthiness characteristics of composite aircraft. An extensive literature survey of previous crashworthiness research work indicated that the computer code, KRASH, was probably the best suited for modification. The code is a hybrid code and thus requires a great deal of input data that are typically generated by structural tests. In an effort to make this code useful at the preliminary design stage, modifications were investigated which could be incorporated into KRASH so that the crashworthiness of the vehicle could be evaluated without the requirement for structural testing. A finite element method was investigated for inclusion in the code to generate the nonlinear stiffness matrix for the beam elements in KRASH. This is normally an experimentally determined input. Recommendations were presented for the modification of the computer code to accommodate the nonlinear analysis of the vehicle.

A preliminary assessment of the effect of composite materials on the crashworthiness of aircraft structures was conducted using the KRASH code. The influence of composite material mechanical properties such as anisotropy, ultimate strength, torsional stiffness, and nonlinearity on the dynamic response was investigated. Very minor influence on the vehicle responses were observed for the range of parameters investigated.

**PUBLICATIONS:** "Computational Crash Dynamics," NIAR Report 89-19, with D.L. Christmore.

**GRADUATE RESEARCH ASSISTANTS:** Dan L. Christmore.

## DEICING: ELECTRO-IMPULSE DEICING

GLEN W. ZUMWALT, Ph.D.

**SUMMARY.** In previous development work on Electro-impulse Deicing (EIDI), questions about fatigue life and electromagnetic interference had not been adequately answered. These both relate directly to aircraft safety and are of great concern to the Federal Aviation Administration. In view of the increasing use of composite materials in aircraft, it was necessary that both aluminum and composite materials be included in the testing. The FAA's Mr. Charles Masters, Aircraft Icing Program Manager, provided technical guidance. Professor Glen W. Zumwalt was the Wichita State University Project Director.

Tests were performed on two aluminum wing leading edge models (see figures 7 - 8) and one composite leading edge model. The aluminum models were identical except for skin thickness. Both were 6 feet long with ribs at 1.5-foot intervals. They were made at the Cessna plant in Wichita to make this a test of a typical production quality wing section. The composite model had been made earlier by the Learfan Aircraft Company. It was a Kevlar composite leading edge of 38 inch span. These were all fitted with EIDI coils (see figures 9 - 10) and soft aluminum doublers were bonded to the inner wing surfaces opposite the coils. The models were placed in a cold box for the fatigue tests. Coils were impulsed at four spanwise positions for each metal model and two positions for the composite model. A total of 15,000 impulses were delivered to each metal wing coil position, and 20,000 impulses to the composite wing coil positions. The impulse energy levels were those previously determined to be needed for effective deicing.

Damage was limited to coil beam mounting brackets and end closure ribs which were peculiar to these test models. No changes could be detected for the composite model.

Electromagnetic interference tests used the same models as the fatigue tests. Tests in a shielded room revealed that EIDI is well shielded by an aluminum wing, but in a composite wing every component of the system must be individually shielded to meet emission standards. More work is suggested to effect good shielding for the EIDI in composite structures.

**PUBLICATIONS:** "Electro-Impulse Deicing - A Status Report," AIAA Aerospace Services Meeting, Reno, Nevada, January 1988.

"Electro-Impulse Deicing," FAA Report, DOT/FAA/CT-88/27, September 1988.

"Fatigue and Electromagnetic Interference Test for Electro-Impulsed Deicing," SAE Technical Paper Series, April 1989.

**GRADUATE RESEARCH ASSISTANT:** J. Schwartz.

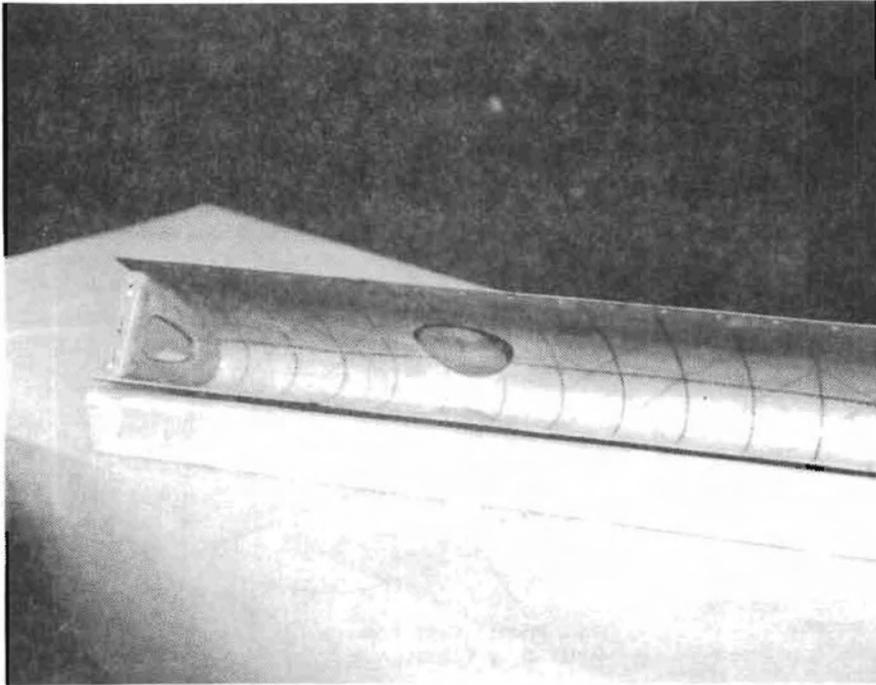


FIGURE 7. INSIDE VIEW OF COMPOSITE MODEL

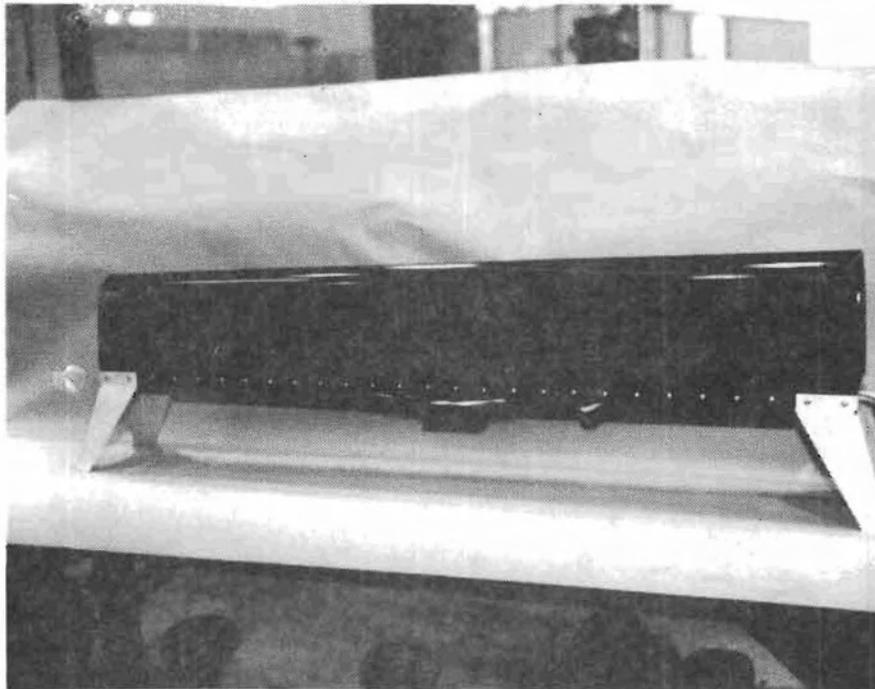


FIGURE 8. COMPOSITE LEADING EDGE MODEL (NON-PROTECTED)

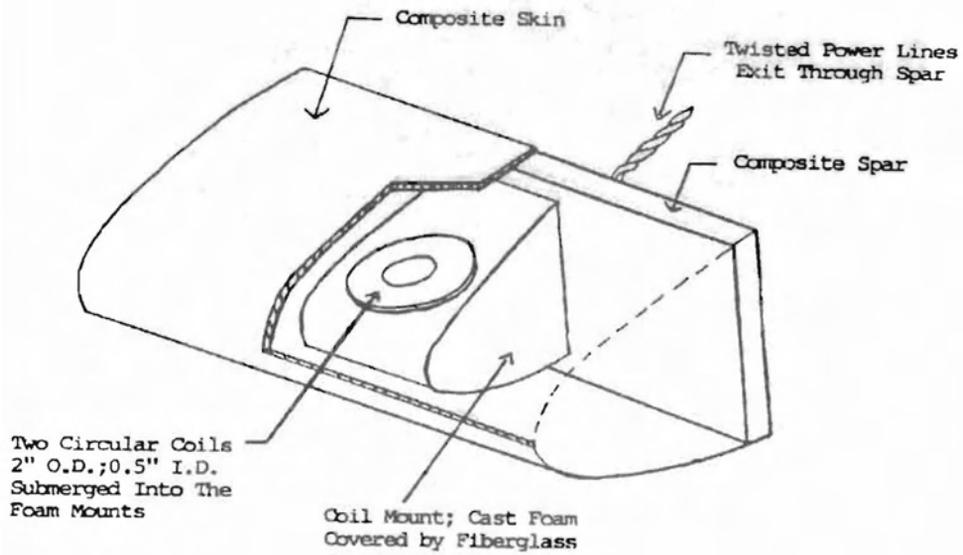


FIGURE 9. COIL MOUNTING METHOD

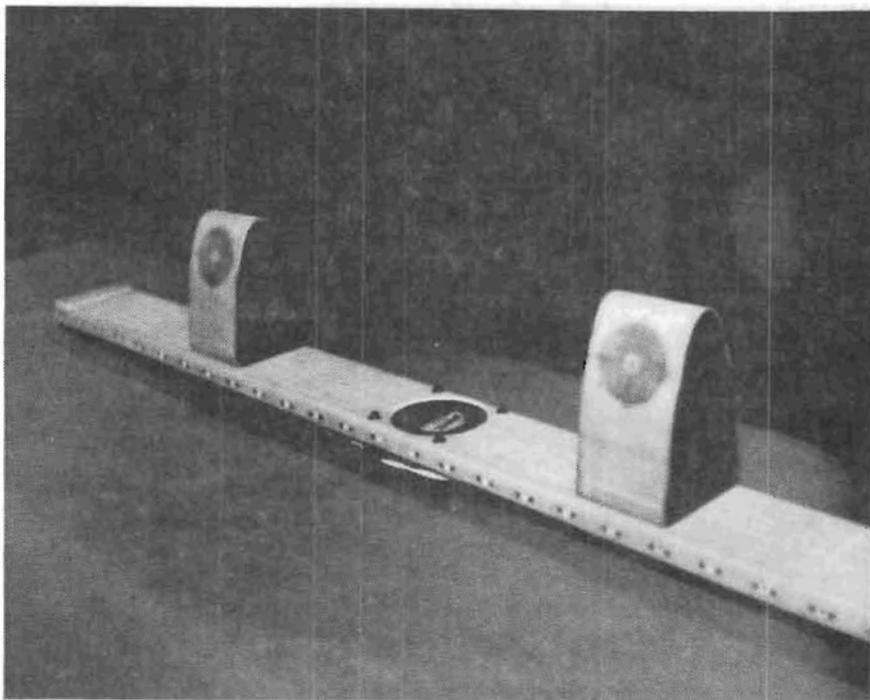


FIGURE 10. SPAR AND COIL FOR COMPOSITE MODEL

**STALL/SPIN PREVENTION: AERODYNAMIC DATA**  
**MELVIN H. SYNDER, Ph.D.**

**SUMMARY.** The purpose of this project was to develop a bank of aerodynamic data, including high angle-of-attack aerodynamic characteristics of 2-D airfoils and characteristics of 3-D wings and of complete airplanes beyond the stall. To fill gaps in available literature, flow visualization studies and wind tunnel tests were conducted. Also, a flow visualization laboratory was established to study wing stall and anti-stall devices.

The flow visualization laboratory is in operation. A bank of 2-D high angle-of-attack airfoil data has been compiled. The 3-D data have been acquired; water tunnel and wind tunnel reflection plane tests have been performed and continue. Data obtained indicated that movable leading-edge control surfaces show promise toward the goal of controlled flight beyond the stall.

**DESCRIPTION OF LABORATORY.** The NIAR water tunnel (built by FluidDyne of Minneapolis Minnesota) is shown in the figures 11, 12 and 13. It is a recirculating water tunnel with a test section 2 x 3 x 6 feet long. Aircraft models (or other shapes) are sting mounted in the test section by means of a C-strut. The models may be yawed or pitched using a remote control. Tunnel speed may be varied from 0 to 1 feet per second (producing Reynolds numbers per foot up to  $9.0 \times 10^4$ ). Angles of yaw and pitch and water velocity are indicated on digital readouts.

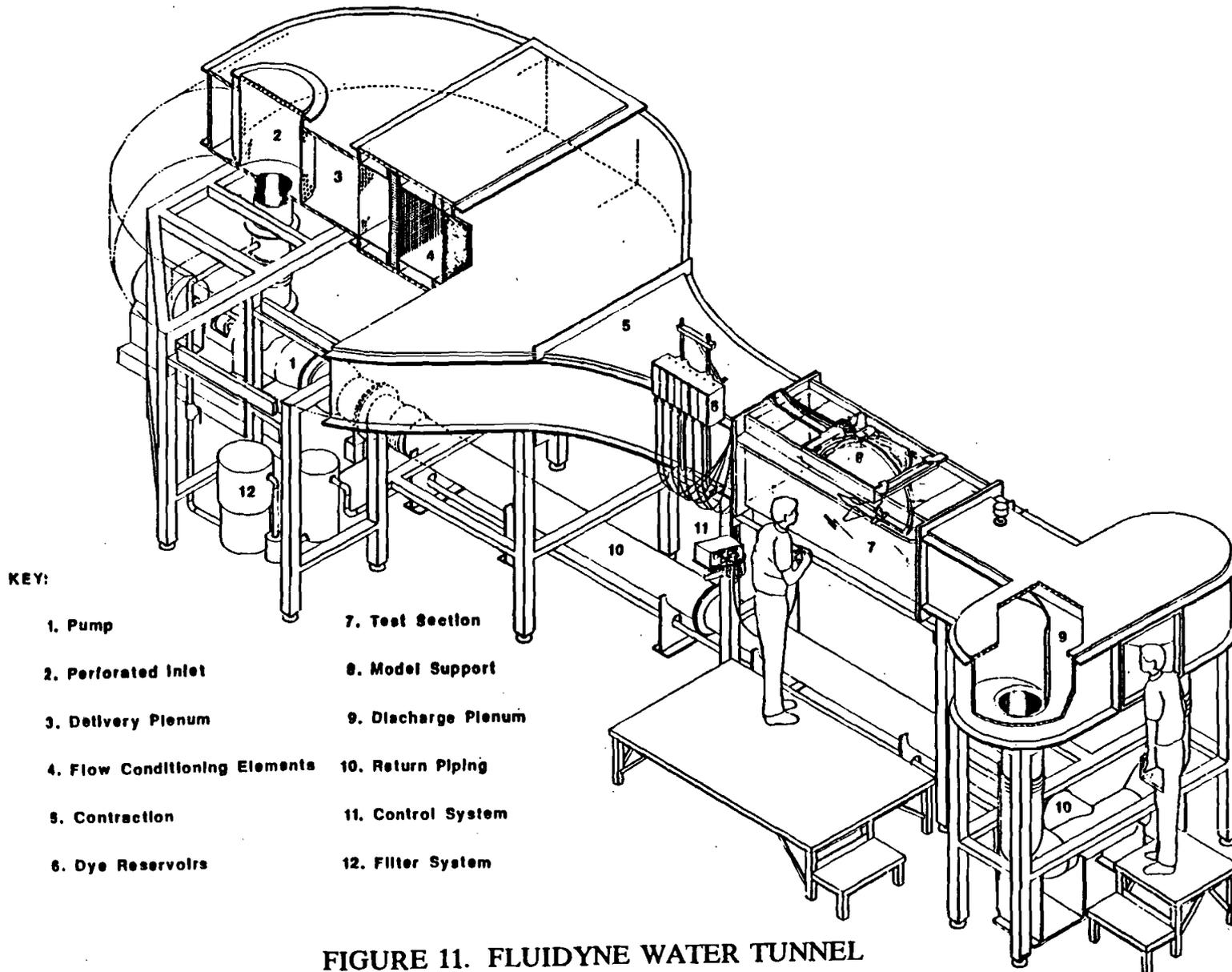
The test section is plexiglas and models may be viewed from either side, the bottom, or from downstream. Flow is visualized by introducing colored water (colored by food dye) from ports in the model. Data are taken using a video camrecorder or conventional still cameras.

Since installation, a number of improvements have been made on the water tunnel. The model mount door has been counter weighted and dampened for the operator's safety. An alternate model mount has been fabricated to make it possible to test reflection-plane wings. The dye system, originally gravity driven, has been pressurized to make it easier to control the dye flow rate. A sidewall disk mount has been fabricated so that unsteady flow effects of dynamic stalling of the model may be simulated.

**PUBLICATIONS.** "Flow Visualization in the New WSU Water Tunnel," Abstract for AIAA Techfest, presented November 14, 1987.

"Stall/Spin Aerodynamic Data," FAA report DOT/FAA/CT-88/29, September 1988.

**GRADUATE RESEARCH ASSISTANT.** Wang Yong.



**FIGURE 11. FLUIDYNE WATER TUNNEL**

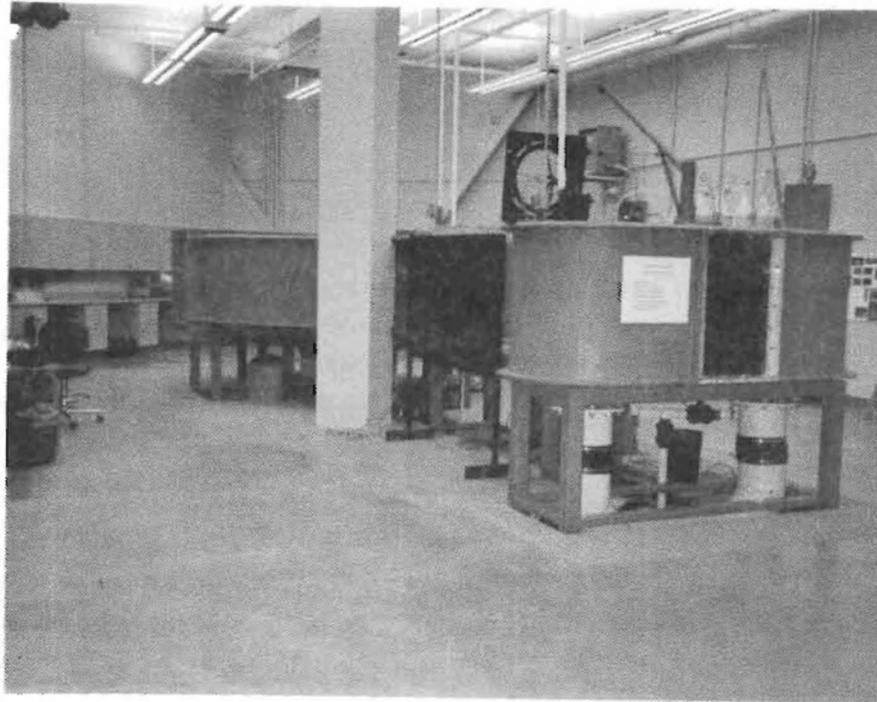


FIGURE 12. FLOW VISUALIZATION LABORATORY

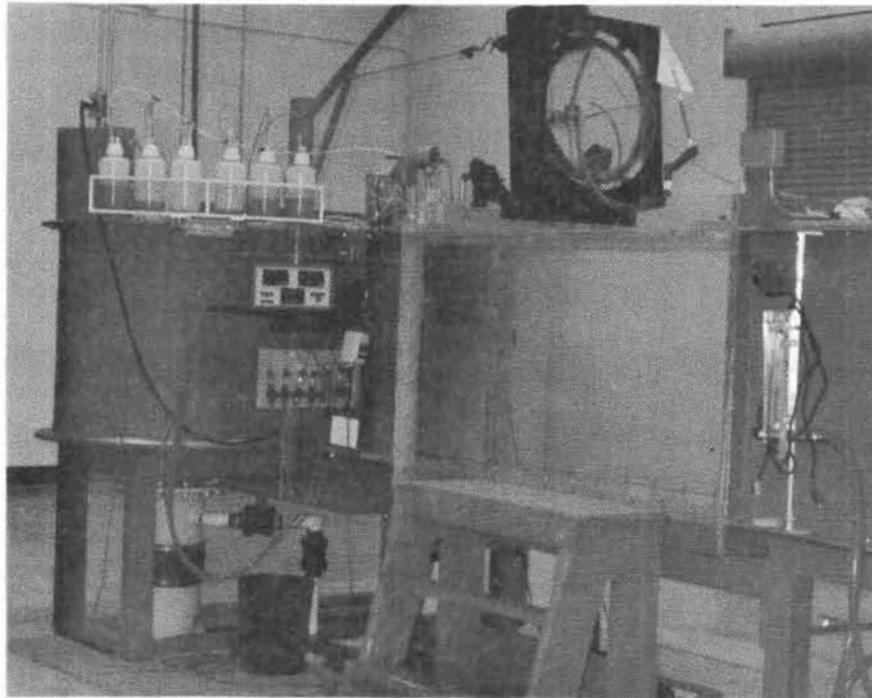


FIGURE 13. FLOW VISUALIZATION LABORATORY

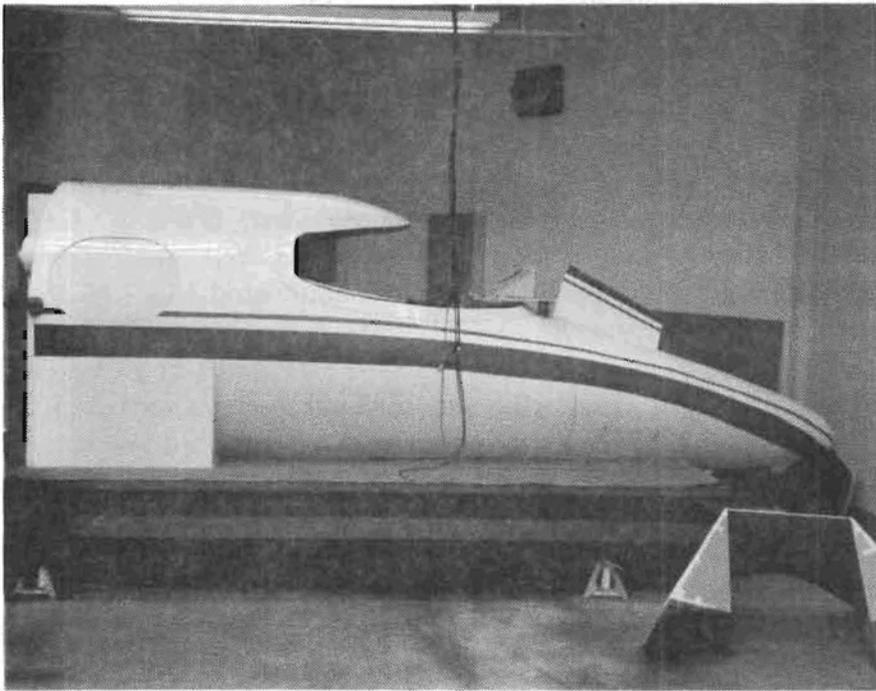


FIGURE 14. LEAR COCKPIT

## SOFTWARE RELIABILITY: A RECONSTRUCTION OF RUNS OF INTERACTIVE REAL-TIME PROGRAMS

MAREK A. SUCHENEK, Ph.D.

**SUMMARY.** The purpose of this project was to design a software debugging system. The system supports the debugging process of real-time concurrent programs by the reconstruction of their runs. The main goal of the first phase of the project was the design and implementation of a debugging system (see figure 15) which adopts the method of tracing and trapping for the purpose of testing real-time software of distributed microprocessor avionics systems. These systems consist of a number of microprocessor subsystems communicating with each other via a MIL-STD-1553 bus. An in-circuit emulator provides subjective non-invasive control of the tested system. A simulator in the debugging system simulates realistic environment of the tested software. Users provide break points for the tested software and corresponding service subroutines in which correct CPU contexts will be stated. For breaking and re-starting runs of the tested system, the clocks of the debugging system synchronize the emulation and simulation environment.

**DESCRIPTION OF LABORATORY.** The single tested element is called an IEEE 1553 subsystem. The 1553 subsystem's CPU is VME bus SYS68K CPU-29XB with microprocessor (12.5 MHz) installed. The 1553 subsystems communicate with each other through a MIL-STD-1553B bus. Each subsystem is connected to a MIL-STD-1553B bus through the standard autonomous interface DTI-1151. A programmable in-circuit emulator MV68020 is embedded. The emulator reconstructs the behavior of SYS 68K CPU-29XB's microprocessor on the basis of monitoring the 1553 subsystem's local bus. An emulator probe replaces the CPU's microprocessor and enables a controlled execution (25 MHz) of the 1553 subsystem CPU's programs. The board DDC Bus-65517 enables a simulation of the remaining 1553 subsystems and tested software environment. The central clock of the debugging system accumulates the elapsed net time of emulation. It is implemented by a single VME board microcomputer SYS 68K/CPU-6A. The synchronization of breaking and re-starting runs of the 1553 subsystem is obtained by cooperations of central clock and simulator clock. The VAX 8650 is used as a supervising system. The information of break points and service subroutines can be input through the user terminal of VAX 8650. The object codes are generated by a crossassembler and sent to the emulator via Ethernet.



**PUBLICATIONS.** "Non-monotonic Derivations Which Preserve Pragmatic Truth," Proceedings of the International Symposium on Methodologies for Intelligent Systems. Ed. Zbigniew Ras and Maria Zemankova. Oak Ridge, TN, 1987, pp. 69-74.

"Forcing Versus Closed World Assumptions," Methodologies for Intelligent Systems. New York: North-Holland, 1987, pp. 453-60.

"Two Applications of Model-Theoretic Forcing to Lipski's Model of Data Base with Incomplete Information," *Fundamental Informaticae* 12 (1989) pp. 269-288.

"Using the Hot Bench Laboratory for Testing, Measurement, and Validation of 1553 Bus Related Software," (A copy included in the FAA Digital Validation Handbook.)

"Non-Invasive Testing of Real-Time Avionic-Microprocessor Systems," *Microprocessing and Microprogramming: The Euromicro Journal*, (August 1989) pp. 665-671.

"Minimal Models for Closed-World Data Bases, in Methodologies for Intelligent Systems," Ras, Zibgniew (ed.) 1989. North-Holland. pp. 515-552.

"A Syntactic Characterization of Minimal Entailment, in Logic Programming," Lusk, Ewing and Overbeek (eds.) Proceedings of the North American Conference. 1989. The MIT Press. pp. 81-91.

"General Indefinite and Maybe Information in Relational Databases," *Information Processing '89 G-X-Ritter* (Ed.), Elsevier Science. B>B. (North Holland) August 1989. San Francisco, CA. pp. 809-814.

"A Syntactic Characterization of Minimal Entailment, in Logic Programming," North American Conference on Logic Programming Cleveland, OH. Oct. 1989.

"Minimal Models for Closed World Data Bases," International Symposium on Methodologies for Intelligent Systems" Charlotte, NC. Oct. 1989.

"General Indefinite and Maybe Information in Relational Databases," *Information Processing '89*, San Francisco, CA. August 1989.

**GRADUATE RESEARCH ASSISTANT.** Xitong Zheng.

## SOFTWARE RELIABILITY: SOFTWARE RELIABILITY ASSESSMENT IN AVIATION SYSTEMS

XITONG ZHENG, Ph.D. AND N. FARD, Ph.D.

**SUMMARY.** System reliability depends on the reliability of both the software and hardware system. Hardware reliability theories based on probability functions are well defined, and many models have contributed to the high reliability of complex hardware systems. Reliability models for software are not well developed and differ from hardware models in several important ways. Software reliability models assume no wearout, therefore there is no bathtub hazard rate curve, and software failure is the result of design error. Redundancy in the software may not be effective. Reliability does not increase by the use of two identical units since the same errors exist in both sets of software. After the removal of an identical error, it is fixed and it should never again cause the system to fail. Classification of the errors according to various cases of errors and the type of information obtained are most effective in determining appropriate models.

A literature search was conducted to study different approaches in software reliability assessment. The result of this research indicates that the historical research in this field is mostly after 1970. There are different assumptions and time units selected from reliability evaluation models. Some authors have chosen calendar time and some others CPU time. There is no disagreement on software reliability growth, however. Detected faults are removed, which leads to fewer faults in a program and higher reliability as the usage time increases.

Software reliability models may be classified in terms of the required type of data, time unit, failure rate assumption, probability distribution of time to failure, or number of failures per unit time.

## CONCLUDING REMARKS

The WSU/NIAR and FAA projects and facility development described previously mark the initiation of joint University-FAA aviation safety research efforts. The FY-1986 efforts were agreed to by the WSU/NIAR and the FAA in a manner to coalesce and nurture each organization's priority research interests. The WSU/NIAR is developing and enhancing its abilities and capabilities to respond to present and future research needs of government and industry. In FY-1989, an International Aircraft Operator Information System research contract was initiated between WSU/NIAR and the FAA to provide a data base and automated computer hardware/software system which will facilitate and enhance the distribution of Airworthiness Directives as well as the communication concerning aircraft owners/operators and other pertinent information within the FAA. Future aviation safety research tasks (ie., aging aircraft, aircraft crashworthiness/structural airworthiness, and human factors) will heavily utilize the facilities, research faculty, and graduate students of the NIAR.

It is anticipated that the joint aviation industry, academia, and government research efforts, which the NIAR is fostering, will have a positive contributory effect in furthering the United States' preeminence in the international civil aviation system.