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DEVELOPMENT OF THE UNIVERSITY OF TEXAS AT ARLINGTON AERODYNAMICS RESEARCH CENTER

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Abstract

The Aerodynamics Research Center (ARC) of the University of Texas at Arlington (UTA) was developed to provide modern test facilities for supporting research and educational programs in experimental aerodynamics, aerothermodynamics and propulsion. When fully operational, the experimental simulation capabilities of the Center will span the complete flight spectrum from low to hypersonic speeds. The primary emphasis of the research conducted at the ARC is directed towards increased understanding of fundamental fluid dynamic phenomena. A secondary goal is the generation of experimental data bases to support development and validation of computational fluid dynamics codes. In this endeavor, the ARC works closely with UTA's Computational Fluid Dynamics Center.

The test facility capabilities, facility development programs, and experimental research programs in progress at the ARC are described in this paper.

Introduction

The Aerodynamics Research Center occupies a 1000 square meter laboratory complex housing the experimental test facilities, supporting control room, a central computer room for data processing, model shop, instrumentation lab, and adjoining staff office complex. The principal laboratories consist of the Low Speed Wind Tunnel Lab; High Speed Aerodynamics Lab, containing transonic, supersonic, and hypersonic wind tunnels; and the Aeropropulsion Lab. The test labs are equipped with microprocessor-based facility control and data acquisition systems, and contain modern optical flow visualization and diagnostics capability as well as standard force, pressure, and heat transfer measurement systems.

The operation of the test facilities is supported by a large central air compressor system that was obtained from the U.S. Army Aeroflightdynamics Lab at the NASA-Ames Research Center. The compressor provides dry air at a pressure level of 200 atm and a flow rate of 57,000 ℓ/min. The compressor, along with two smaller back-up units, is located in a 200 square meter building adjoining the main laboratory building.

A diagram of the test facility complex is shown in Fig. 1, and the anticipated flight simulation capability (Mach number - Reynolds number performance map) is presented in Fig. 2. Currently, the low-speed wind tunnel, transonic tunnel, and shock tube are fully operational. Initial operation of the hypersonic shock tunnel is anticipated during the Summer of 1988, and the supersonic tunnel construction is scheduled for 1989. Completion of the aeropropulsion lab test facilities is anticipated for 1990.

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Experimental Test Facilities

Low Speed Wind Tunnel Lab

The low speed wind tunnel (Fig. 3) is a conventional closed-circuit, continuous-flow tunnel with a 0.61 x 0.91 m test section and a speed range of 0 to 50 m/sec. It is equipped with an Aerolab 6-component pyramidal strain-gage balance system, and a three-component sting balance. Both closed and open-jet test sections are available. A modified test section designed for propulsion/airframe integration research is also available that can incorporate either ejector nozzles or a Tech Development Model 602 (GE CF-6) engine simulator to provide the simulated propulsion system flow field. Operation of the tunnel is supported by a Hewlett-Packard HP-85 computer control and data acquisition system, and an Aerolab smoke flow visualization system. The low speed wind tunnel is primarily used for both senior level and graduate research programs in all facets of low-speed aerodynamics and propulsion/ airframe integration.

High Speed Aerodynamics Lab

The High-Speed Aerodynamics Lab contains four test facilities; a transonic Ludwieg tube tunnel, supersonic Ludwieg tube tunnel, hypersonic shock tunnel, and a small shock tube for basic research in high-temperature gasdynamics and sensor development and calibration.

High-Reynolds Number, Transonic, Ludwieg Tube Wind Tunnel (HIRT)

The HIRT tunnel was originally developed at the Air Force Arnold Engineering Development Center (AEDC) to investigate the potential of the Ludwieg tube concept for the National Transonic Facility.[1,2] The tunnel was donated to UTA in 1978, and following an extensive development of the supporting compressor system, pneumatic control system, and computer control and data acquisition system, was placed into operation in January 1984.[3] The capabilities of the tunnel include a Mach number range of 0.5 to 1.2, with a corresponding Reynolds number range of $4(10)^7$ to $40(10)^7$ per meter. A unique capability of the HIRT tunnel is the ability to independently vary Mach and Reynolds numbers over the full operating range of the tunnel. The test section employs a conventional AEDC porous wall design with a

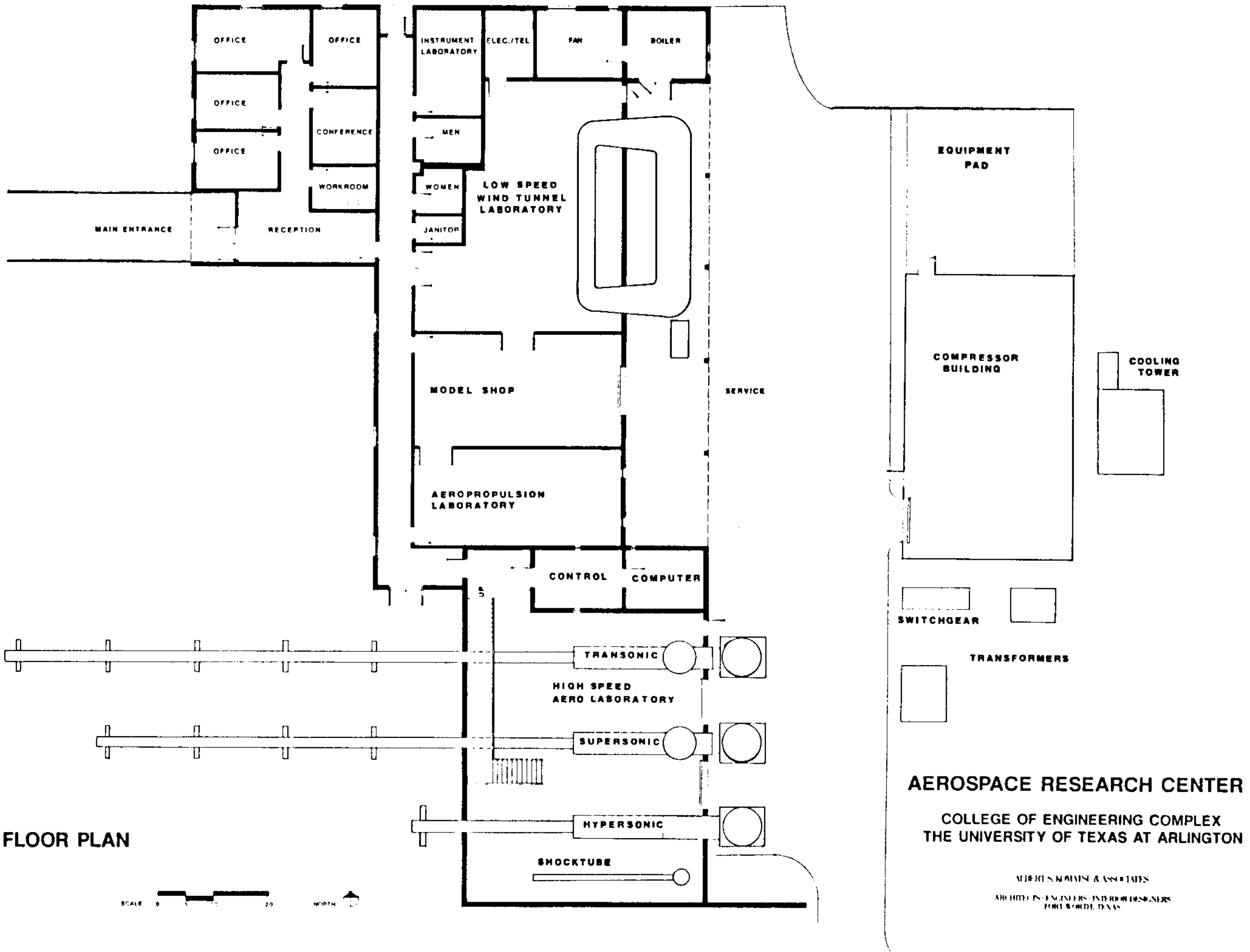

Fig. 1. UTA Aerodynamics Research Center - Test Facility Complex

rectangular cross section measuring 18.5 x 23.2 cm, and is 64 cm long. The porous walls minimize shock wave reflections from the tunnel walls as well as provide for substantial alleviation of tunnel wall interference effects. The porous wall design also allows acceleration to low supersonic Mach numbers with a fixed-area-ratio convergent nozzle.

The Ludwieg tube tunnel (Figs. 4,5) operates on an expansion wave principle. The charge tube is 36 cm in diameter and 34 m long, and can be pressurized to a maximum pressure level of 45 atm. The tunnel flow is initiated by opening a pneumatic-actuated, sliding-sleeve valve located downstream of the diffuser. The resulting expansion wave propagates upstream into the charge tube, thus initiating the flow through the nozzle and test section. A steady flow of about 120 msec duration is obtained as the expansion wave travels upstream through the 34 m charge tube, reflects, and returns to the test section. The transonic tunnel has excellent flow quality, with a nominal variation of test section Mach number of about 0.5 percent, and a background turbulence level of about 1.0 percent[1] (as measured by rms fluctuation pressure coefficients on a standard calibration model). This is lower by a factor of almost two than that of comparable AEDC or NASA transonic tunnels. Operation of the tunnel is supported by a microprocessor-based, computer control and data acquisition system. Provisions are also underway to add optical windows to the test section, and a program to develop laser holographic interferometry capability is being carried out in conjunction with the Optics Laboratory of the Electrical Engineering Department.

Supersonic Ludwieg Tube Wind Tunnel

The supersonic wind tunnel (Fig. 6) is currently under development, and will utilize a variable area nozzle, test section and diffuser system donated to UTA by the LTV Aerospace and Defense Company in conjunction with a spare charge tube and starting valve obtained from AEDC with the transonic Ludwieg tube tunnel. The nozzle is based on the unique AMRAD® flexible plate nozzle concept, and provides continuous Mach number variation over a range from 1.5 to 4, with Reynolds number capabilities of up to $20(10)^7$ per meter. The steady flow time will be about 80 msec. The test section size is 15 x 15 cm, and can be configured as a closed test section for aerodynamic testing, or as a semi-open jet test section for propulsion inlet testing. An inlet mass flow throttle system can be installed in the diffuser downstream of the test section to provide inlet capture ratio variation. Optical windows are located in the side walls of the test section.

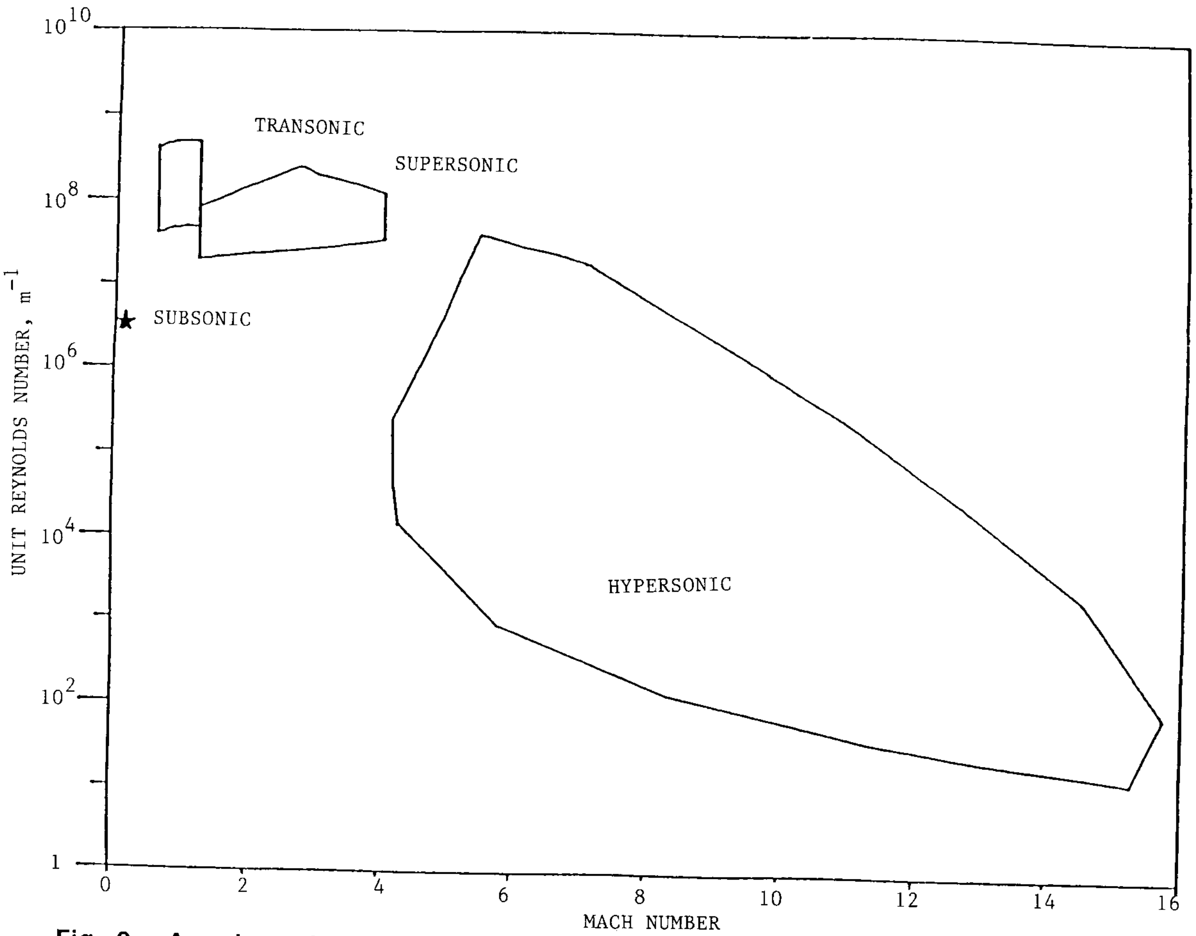

Fig. 2. Aerodynamics Research Center - Experimental Simulation Capability

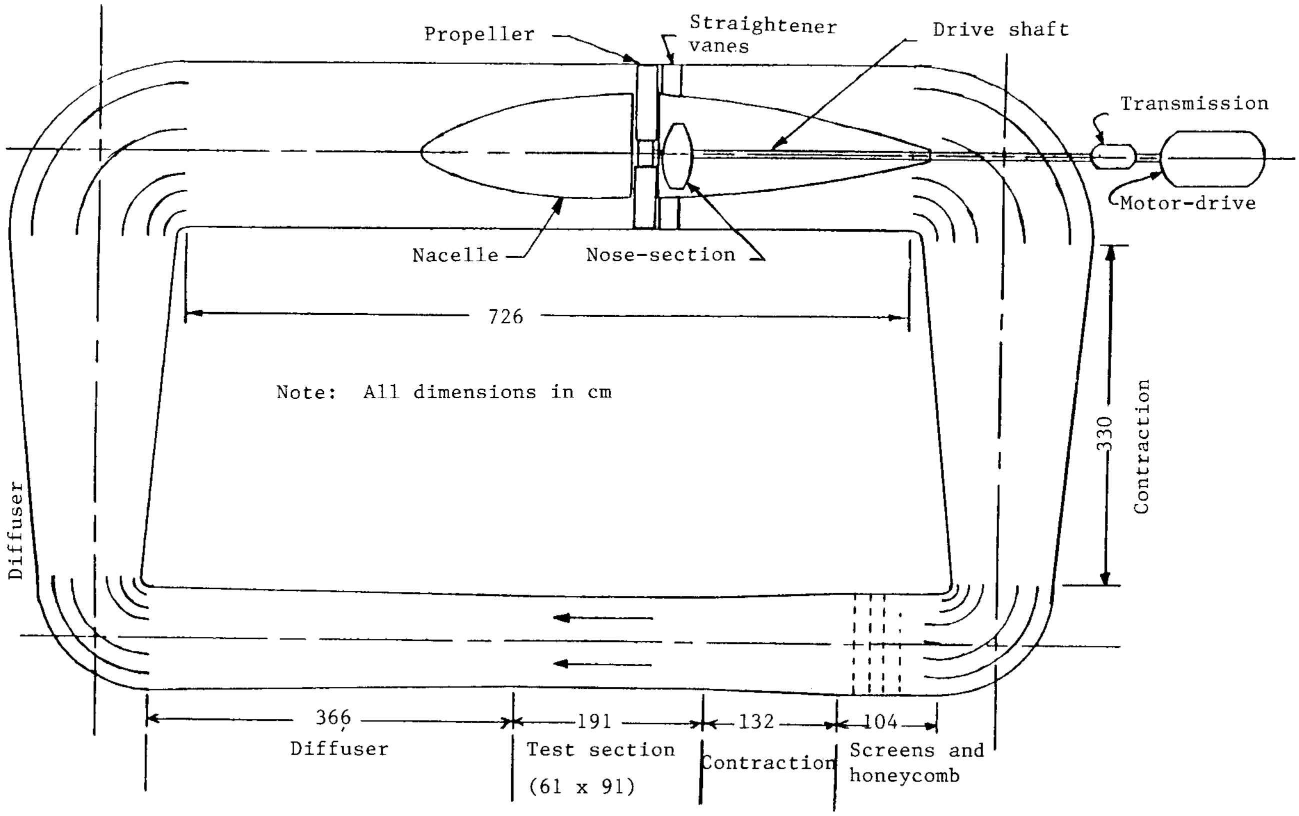

Fig. 3. Low Speed Wind Tunnel

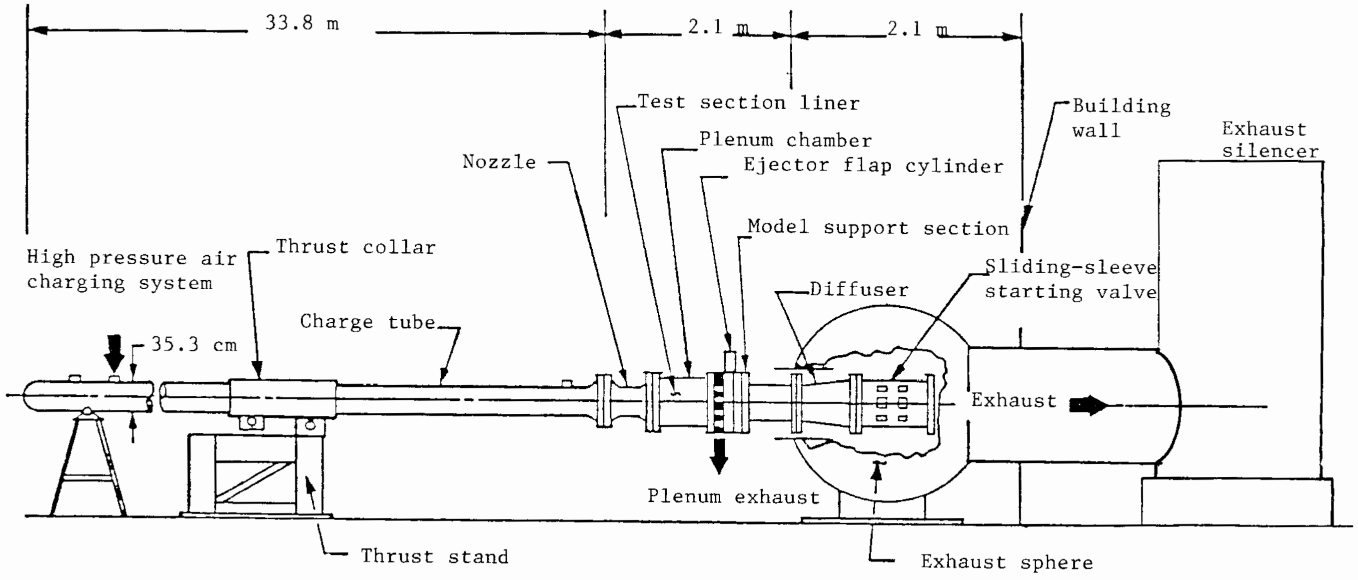

Fig. 4. Elevation View - Transonic Ludwieg Tube Wind Tunnel

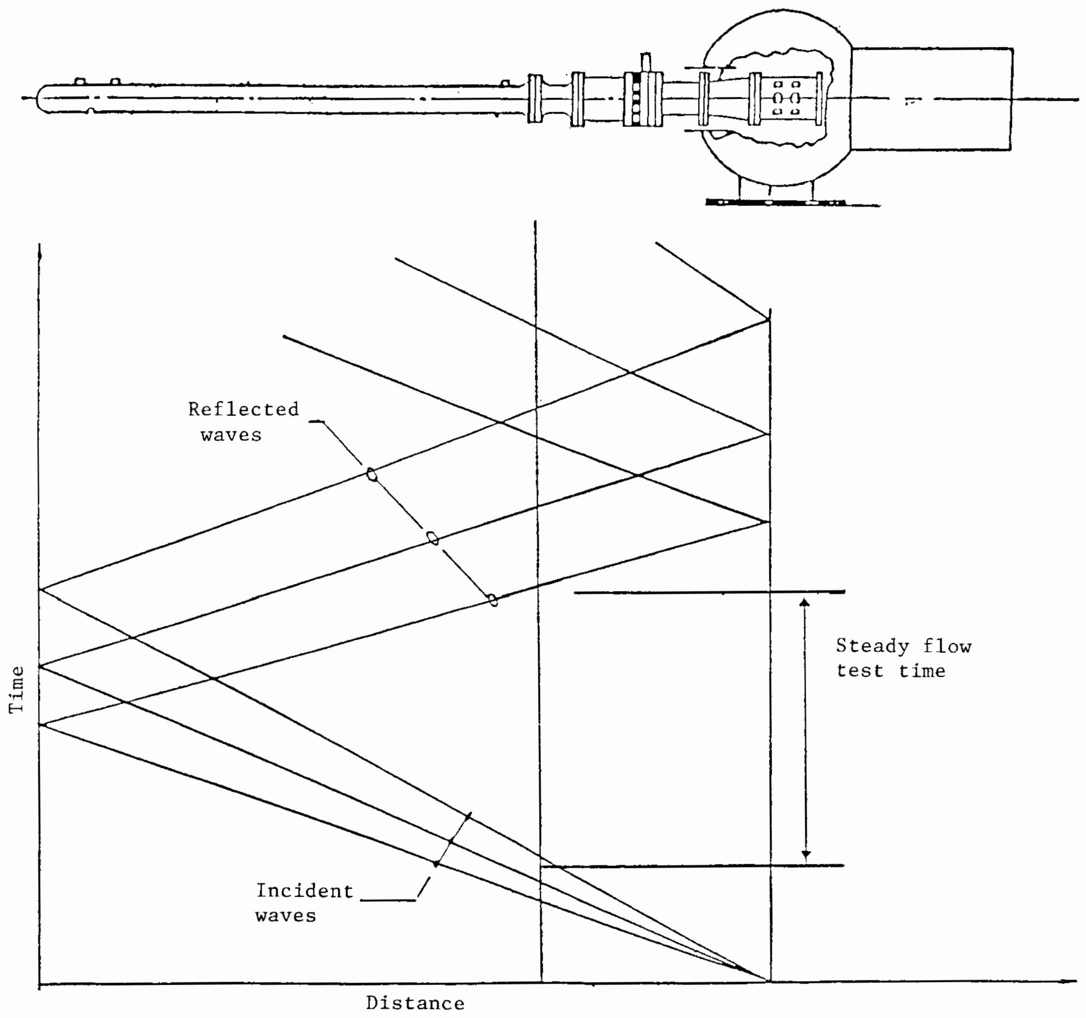

Fig. 5. Ideal Wave Diagram for Transonic Ludwieg Tube Wind Tunnel

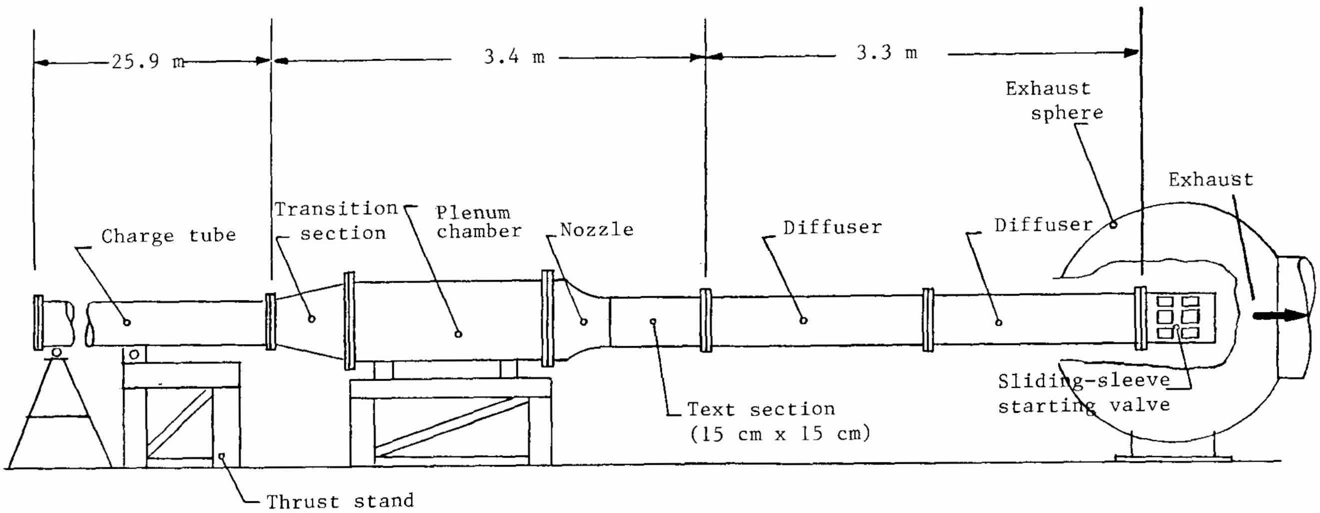

Fig. 6. Elevation View of Supersonic Ludwieg Tube Wind Tunnel

Hypersonic Shock Tunnel

The hypersonic shock tunnel (Fig. 7) is in the final stages of development, and is anticipated to achieve operational status during the Summer of 1988. The shock tunnel will utilize either a Mach 8 contoured nozzle coupled to a 20 cm diameter test section, or a conical nozzle with interchangeable throat inserts to provide a Mach number range from 5 to 16. The conical nozzle mates to a 33 cm diameter test section. Both nozzle/test section assemblies and the corresponding diffuser sections were donated to UTA by the LTV Aerospace and Defense Company.[4] These components will be coupled to a high-pressure (400 atm), helium-air shock tube driver and appropriate vacuum system being developed at UTA. The driver is 3 m in length and 15 cm in diameter, whereas the driven tube is 8.25 m in length and 15 cm in diameter. Initial operation in the "equilibrium" mode (Fig. 8) is planned, which should provide run times in the 4-6 msec range. The anticipated altitude simulation capability of the facility is shown in Fig. 9. These calculations are based on equilibrium nozzle flow calculations,[5] although finite-rate chemistry calculations of the nozzle expansion[6] indicates that the upper limit of tunnel operation for equilibrium flow will probably be about Mach 8-10, depending on pressure level. Both test sections contain optical windows, and flow visualization capability via schlieren and holographic interferometry will be provided as well as standard pressure, force and heat transfer instrumentation.

A study is also underway to investigate the feasibility of providing the capability of performing isolated propulsion nozzle and nozzle/airframe integration experiments in the hypersonic shock tunnel. Several novel concepts that would provide a high-temperature propulsive nozzle flow to a centerbody located within the hypersonic aerodynamic nozzle are being investigated. An important criteria is to provide realistic simulation of both the nozzle pressure ratio and the proper stagnation enthalpy ratio of the propulsive and external aerodynamic flow fields.

Shock Tube Facility

The shock tube facility employs a conventional pressure-driven tube with a driver/driven tube area ratio of 4. The tube is capable of operation in either the conventional or reflected mode of operation. It was developed at UTA[7] to support basic research in high-temperature gasdynamics and sensor development. Existing instrumentation includes conventional thin-film heat sensors, high-response pressure transducers, and a Hewlett-Packard two-channel digital storage oscilloscope for data acquisition. This system will soon be supplemented with a microprocessor computer control and data acquisition system, as well as additional sensor instrumentation.

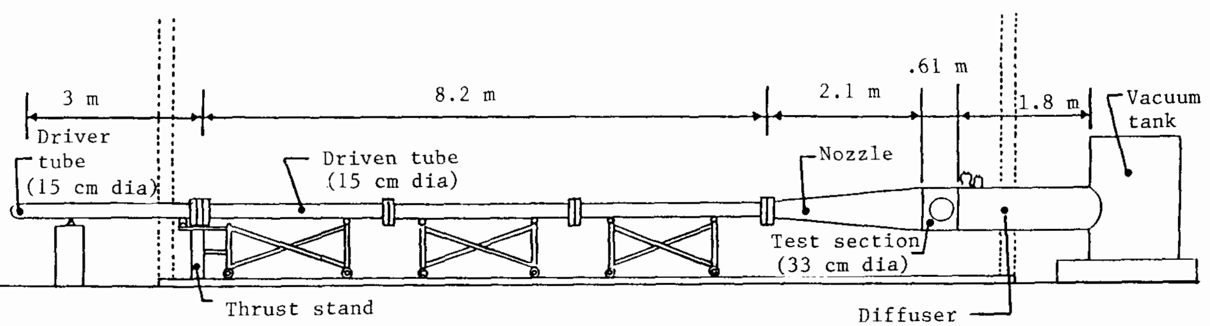

Fig. 7. Elevation View of Hypersonic Shock Tunnel

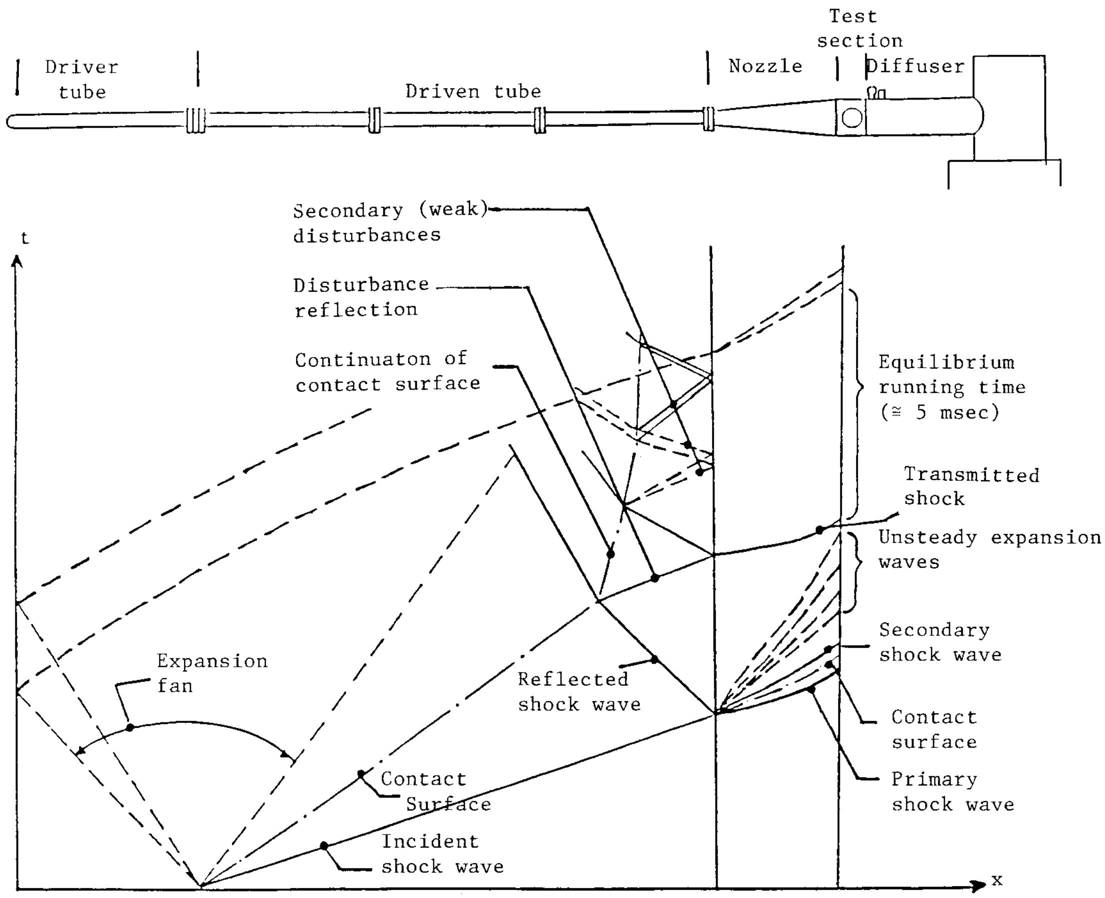

Fig. 8. Wave Diagram for Hypersonic Shock Tunnel (Equilibrium Operating Mode)

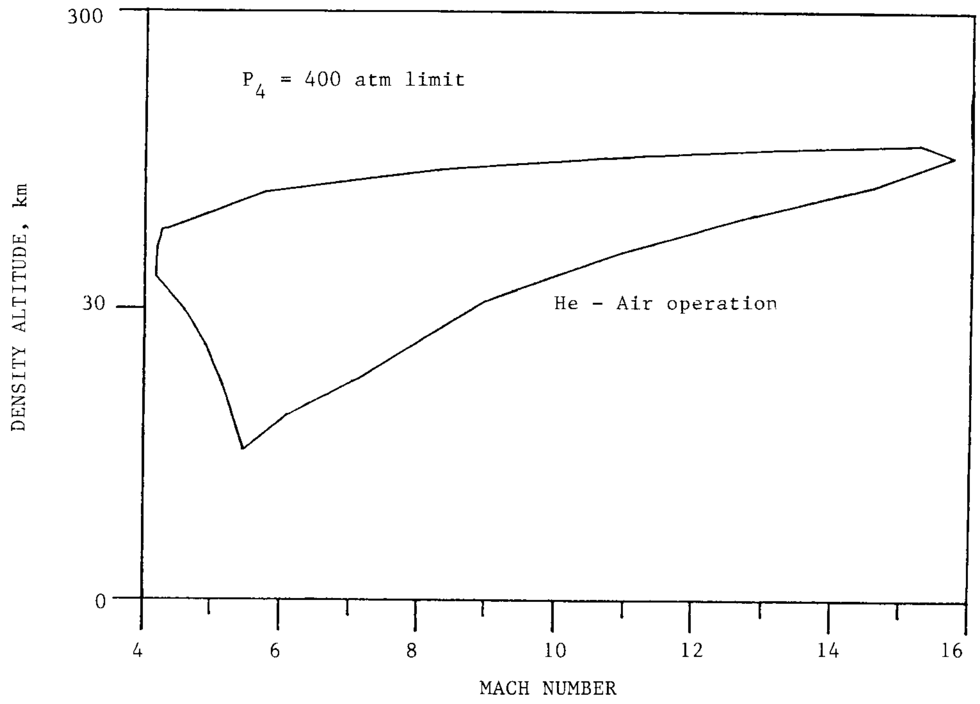

Fig. 9. Hypersonic Shock Tunnel - Density Altitude vs Mach Number

Aeropropulsion Lab

The third major component of the laboratory complex will be the Aeropropulsion Lab. The major test facility of this lab will employ a Thermal Dynamics F-5000 2 MW DC electric arc heater obtained from Arnold Engineering Development Center. The heater was developed as part of the LORHO program[8] conducted at AEDC to develop arc heaters and MHD accelerators for application to hypersonic test facility development, and provides a continuous source of heated nitrogen or simulated air at temperatures ranging from 2000-5000 K with pressure levels up to 20 atm (Fig. 10). Development of the facility to operational status will require a 2 MW rectifier, high-pressure cooling water system, high-pressure N_2 supply system, and vacuum system. Current plans for the facility include

(1) research in aerodynamic heating and material erosion

(2) use of the arc heater as a supersonic combustion ramjet simulation facility by coupling the heater exhaust through a "direct-connect" nozzle to provide simulated SCRJ inlet flow-fields

(3) use of the arc heater to simulate the exhaust from the SCRJ for propulsion nozzle and nozzle/airframe integration studies, and

(4) adding a Magnetohydrodynamic (MHD) accelerator channel downstream of the supersonic nozzle to investigate the feasibility of achieving high-enthalpy flow simulation without encountering large-scale departures from chemical equilibrium in the nozzle expansion.

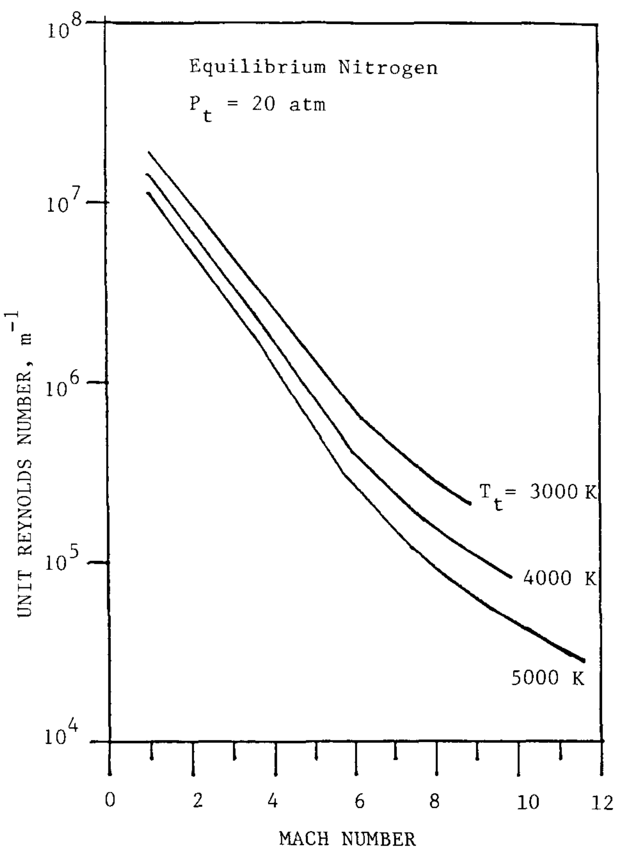

Fig. 10. Performance of Proposed Aerodynamic Heating Facility

Support Facilities

Central Data Acquisition/Processing

A centrally-located control room with adjoining computer room is located directly between the High-Speed Aerodynamics Lab and the Aeropropulsion Lab. The central data acquisition system for the High-Speed Aerodynamics Lab involves an extended-capability IBM PC/XT located in the control room driving a remotely-located DSP Technology High-Speed Data Acquisition System that is transportable between the various test facilities. The DSP Technology system provides 48-channels for data acquisition (pressure transducer, strain-gage, or thermocouple input) and 16 output channels for facility control. The system is based on a sample-and-hold concept, and provides simultaneous sampling of all 48 channels at a frequency of 100 KHz/channel. The system provides 12-bit accuracy, with a dedicated variable-gain amplifier and A/D converter for each channel (Fig. 11). The digitized data signals are stored directly into RAM modules during a test run, and transmitted back to the control room for data processing upon completion of the run. The computer resources of the Center also include an IBM-9000 and a Masscomp Model MC5500 for data processing support, enhanced graphics display, and supporting analysis. A Hewlett-Packard Model 54201A 300 MHz, two-channel digitizing oscilloscope and accompanying HP Model 45 Vectra PC are also available for selected measurement and recording of very-fast transient signals.

Optical Flow Diagnostics

Optical flow visualization and diagnostics will be an integral part of the experimental fluid dynamics research conducted at the ARC. A high-power pulsed ruby laser is available for conventional schlieren and interferometry studies using film recording, and a new pulsed Nd:YAG laser holographic interferometry system that uses photorefractive crystals as the storage media is being developed by the UTA Optics Lab[9,10] for use in optical flow diagnostics. A diagram of the system is shown in Fig. 12. The advantage of this approach is in the elimination of the necessity of film processing and the ability to streamline data transfer directly from the photorefractive crystals into a data acquisition system for digital processing. Laser light screen and surface flow visualization techniques are also being refined for use in the high-speed test facilities.

Central Compressor System

The central compressor system is located in an adjoining 200 square meter building, and consists of a Clark CMB-6 3000 psi compressor, an Ingersoll-Rand 15T2 1000 psi compressor, and a Kellogg-American DB-462 200 psi compressor. All three compressors are connected to appropriate driers, and deliver air to a central distribution panel located in the High Speed Aerodynamics Lab. From there, the air is regulated and distributed throughout the laboratory complex to the appropriate test facilities. The Clark compressor, together with the accompanying 1200 HP drive system, intercoolers, after coolers and twin-tower drier was a gift from the U.S. Army Aeroflightdynamics Lab at NASA-Ames Research Center. UTA provided the motor starter and switchgear, storage tanks, and cooling tower required to complete the system.

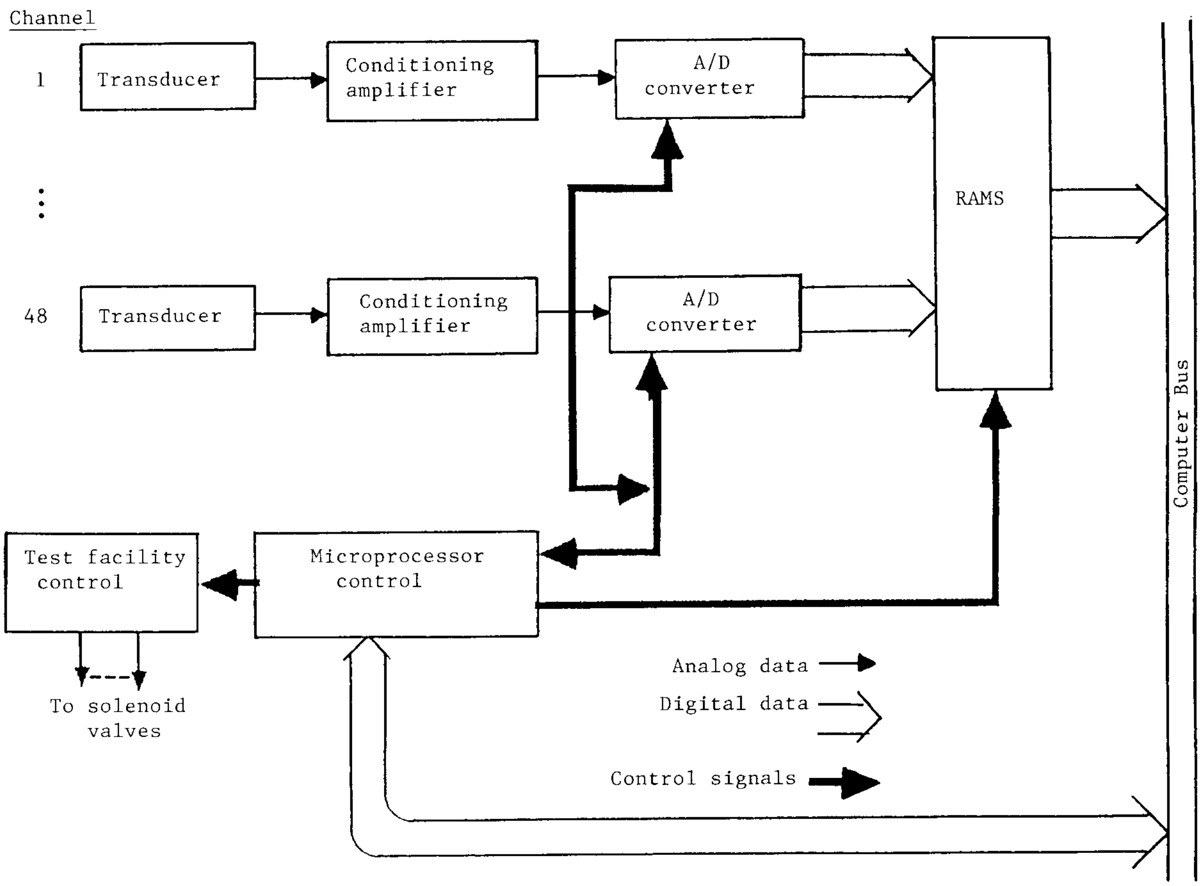

Fig. 11. Block Diagram-High Speed Data Acquisition/Control System

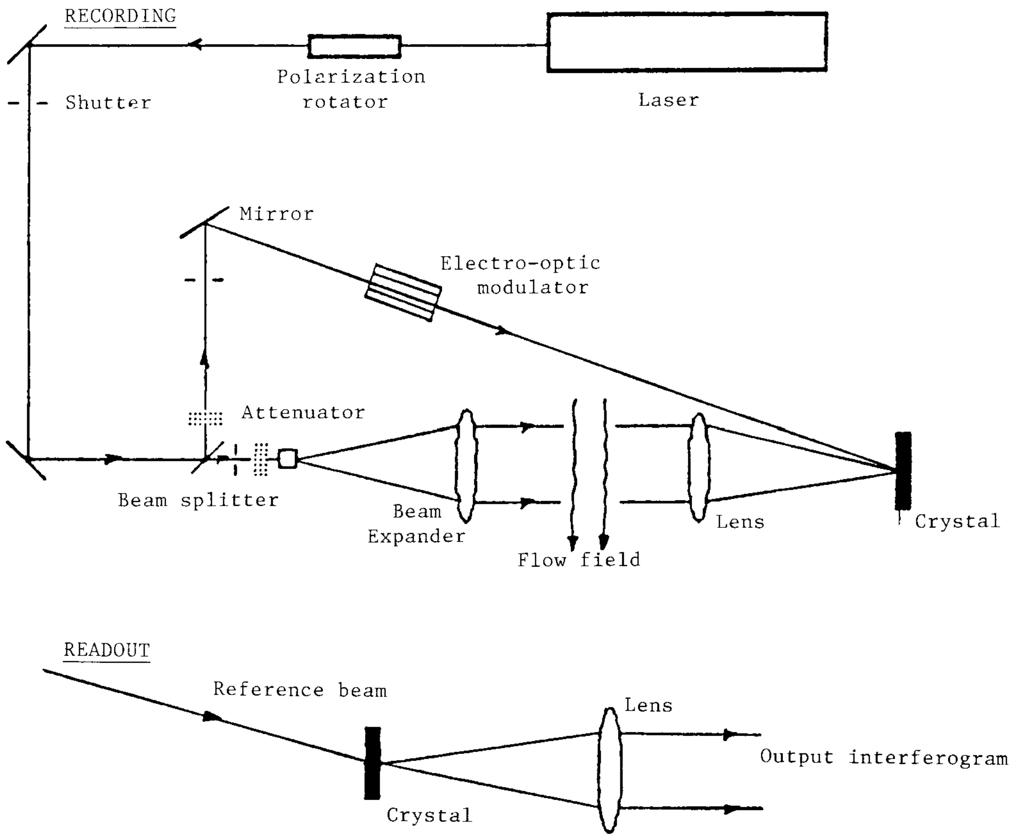

Fig. 12. Holographic Interferometry System Incorporating Photorefractive Crystals as Recording Media

Model Shop

A small model shop containing precision lathes, mills, drill presses, etc. is available on-site for fabrication of models and supporting tunnel hardware. In addition, extensive machine-shop capabilities are available at the Texas Engineering Experiment Station located at Texas A&M University for machining jobs beyond the capability of the Aerodynamics Research Center.

Instrumentation Lab

An instrumentation lab equipped with modern electronic diagnostic and calibration equipment to support instrumentation sensor development, calibration, and repair is available on-site; and is, like the model shop, supported by more extensive capabilities at the Texas Engineering Experiment Station.

Research Programs

Current and pending research programs at the ARC are summarized in Table 1. These programs are focused towards:

(1) research leading to improved understanding of a variety of fundamental fluid dynamic phenomena associated with low-speed, transonic, and hypersonic flight
(2) development and application of new diagnostic techniques, and
(3) test facility development.

With completion of the supersonic Ludwieg tube tunnel, and the propulsion/aerodynamic heating simulation facilities, it is anticipated that those facilities will lead to further research programs in high-speed aerodynamics.

Concluding Remarks

The Aerodynamics Research Center provides a unique capability for university-level research in experimental aerodynamics, with simulation capabilities that will cover the complete flight spectrum from low to hypersonic speeds. The test facilities have not only enhanced UTA's research and educational program at the graduate level, but are also impacting the quality of laboratory instruction at the undergraduate level by introducing students to modern techniques widely used in government and industry laboratories.

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Table 1. Current and Pending Research at the ARC

Program	Facility*	Sponsor
1. **Experimental Fluid Dynamics Research**		
• Investigation of entrainment and lift enhancement of a two-dimensional powered-lift concept	LSWT	UTA
• Experimental simulation of transonic vortex-airfoil interactions	TWT LSWT	ARO
• Effect of rotor tip shape on vortex diffusion and blade-vortex interaction	TWT	Bell Helicopter
• Unsteady, high-α, transonic aerodynamics	TWT	General Dynamics (pending)
• Hypersonic shock/boundary layer interaction	HST	NASA-LaRC (pending)
2. **Diagnostic Techniques**		
• Measurement of hypersonic near-body flow fields and boundary layers	ST	General Dynamics
• Visualization of unsteady transonic flow fields by holographic interferometry using photorefractive crystals	TWT	ARO
3. **Test Facility Development**		
• Hypersonic shock tunnel development	HST	UTA
• Supersonic Ludwieg-tube tunnel development	SST	UTA
• Hypersonic propulsion nozzle test facility development	HST	General Dynamics
• Arc heater facility development	APL	U.T. System (pending)
• MHD-augmented, continuous-flow hypersonic test facility	APL	DARPA,UT System (pending)

*LSWT - Low Speed Wind Tunnel
TWT - Transonic Wind Tunnel
SST - Supersonic Wind Tunnel
HST - Hypersonic Shock Tunnel
ST - Shock Tube
APL - Aero Propulsion Lab

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