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LANGLEY'S TWO-DIMENSIONAL RESEARCH FACILITIES — CAPABILITIES AND PLANS

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SUMMARY

In recent years there has been a renewed interest in the development of a wide variety of advanced airfoils and a systematic documentation of airfoil characteristics in the subsonic-transonic flight regime. In 1973, the National Aeronautics and Space Administration (NASA) responded to the resurgence of interest in systematic airfoil research by establishing a comprehensive airfoil program. This program included provisions for the rehabilitation of existing facilities, the exploration of new test techniques, and the development of new test facilities.

This paper describes the current capabilities and the forthcoming plans for Langley's two-dimensional research facilities. The characteristics of the Langley facilities are discussed in terms of Reynolds number, Mach number, and angle-of-attack capabilities. Comments are made with regard to the approaches which have been investigated to alleviate typical problem areas such as wall boundary effects. Because of the need for increased Reynolds number capability at high subsonic speeds, a considerable portion of the paper deals with a description of the 20- by 60-cm two-dimensional test section of the Langley 0.3-meter transonic cryogenic tunnel which is currently in the calibration and shakedown phase.

INTRODUCTION

As pointed out in reference 1, for many years Langley Research Center placed a strong emphasis on the combined application of aerodynamic theory and two-dimensional experimental facilities in the development of advanced airfoils. In the 1950's and 1960's, however, with the extensive emphasis on the three-dimensional aspects of swept wings, supersonic flight, and the minimization of component interference, airfoil research was virtually nonexistent.

Interest in airfoil research was rekindled when the development of supercritical and other advanced airfoils demonstrated that additional performance gains could be realized by the application of new airfoil design concepts. In response to this renewed interest, Langley began, in about 1968, to upgrade its airfoil test capability. The purpose of this paper is to present an overview of Langley's current two-dimensional test capability and to indicate the additional capabilities planned for the near future.

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SYMBOLS

c	model chord
M	Mach number
P_t	stagnation pressure
q	dynamic pressure
R_c	Reynolds number based on model chord
T_t	stagnation temperature
t/c	thickness-to-chord ratio
α	angle of attack

DISCUSSION

Several facilities will be discussed in this paper. In the area of low-speed research, the continuous-flow Langley low-turbulence pressure tunnel provides essentially the same outstanding high Reynolds number capability that it provided during the 1940's. In the area of high-speed research, three facilities are described. The Langley 6- by 19-inch transonic tunnel was developed as a pilot airfoil facility and is currently dedicated to the study of wall effects and the develcpment of test techniques. The Langley 6- by 28-inch tunnel provides a high-speed, moderate Reynolds number capability. The Langley 0.3-meter transonic cryogenic tunnel, Langley's newest two-dimensional facility, is currently under development and will provide a high Reynolds number capability with unique operating envelopes.

A detailed description of the characteristics of these facilities and an indication of Langley's current and projected two-dimensional programs follow.

Langley Low-Turbulence Pressure Tunnel

The Langley low-turbulence pressure tunnel (LTPT) is described in references 2 and 3, and the Reynolds number envelope is shown in figure 1. (The Reynolds number for this and all subsequent figures is based on a typical model chord for the particular facility.) A sketch of the LTPT is presented in figure 2. Even though the LTPT was constructed over 30 years ago, it still fulfills a very important requirement in that it adequately covers both the regions of interest for general aviation aircraft and the high-lift landing and take-off conditions for a wide variety of aircraft. With its 10-atm capability it provides a Reynolds number of about 30×10^6 at a Mach number of about 0.25. Another desirable characteristic of the LTPT is that its large test section (0.08 by 0.19 m (3 by 7.5 ft)) provides a large model chord capability. The photograph shown in figure 3 illustrates the comparatively large two-dimensional test section with a 0.6-m (2-ft) chord model installed. There are obvious advantages of the large chord model when considering model accuracy and multielement airfoil testing. The LTPT is a continuous-flow facility that operates from very low velocities up to a Mach number of about 0.35 and is designed to provide the capability for exceptionally good flow quality.

The research programs conducted in the LTPT are varied. Under the current programs, there is a considerable amount of effort being placed on the development of new, general aviation airfoil concepts and the low-speed assessment of supercritical sections. The development of the general aviation airfoils is discussed in reference 4. Renewed attention is being placed on laminar flow research. A photograph of a passive laminar flow airfoil for the LTPT is shown in figure 4.

Insofar as projected program extensions, the LTPT with its large model chord and low-speed, high Reynolds number capability will continue to be Langley's prime facility for the development of high-lift, multielement systems. At present the improvements which are scheduled for this facility include the installation of a fast pressurization system and a computer-driven wake-survey apparatus. Modifications will be made to provide additional improvements to restore the flow to its original high quality and to provide stagnation temperature control.

In order to provide Langley with a valid and useful high-lift development capability, provisions are being made to incorporate a sidewall boundary-layer control system and a new high load balance system. The new boundary-layer control system will provide control by blowing through slots in the sidewalls. The data shown in figure 5 illustrate the typical effects of this type of sidewall control on the lift characteristics of a multielement airfoil. Section lift coefficients are plotted against angle of attack. The three different cases shown are the lift near the wall without blowing (lower curve), the lift at midspan without blowing (middle curve), and the lift at the midspan and near the wall with blowing (top curve). It is obvious from the two lower lift curves that, without blowing, the flow across the airfoil is not two dimensional. With blowing (top curve), the sidewall boundary layer is apparently energized, resulting in uniform flow across the airfoil.

An additional improvement scheduled for this facility is a suction system for application of active laminar-flow control to airfoils.

Langley 6- by 19-Inch Transonic Tunnel

The Langley 6- by 19-inch transonic tunnel (ref. 5) was placed in operation in 1970 and represented one of the first steps in reestablishing Langley's airfoil research facilities. Its Reynolds number envelope is shown in figure 6. The Langley 6- by 19-inch tunnel is a blowdown to atmosphere type with a Mach number range of 0.5 to 1.2. It is a low Reynolds number facility with no independent control of Mach number and Reynolds number. The photograph shown in figure 7 presents exterior and interior views of the tunnel. The vertical test section as shown in the interior view lends itself to simple, inexpensive modifications. This facility is currently dedicated to the development of new two-dimensional testing methods and techniques. Two current programs of this type are the solid flexible wall studies and the parametric slotted wall interference studies. A sketch illustrating the parametric slotted wall study is shown in figure 8. Descriptions of the wall interference studies which have been conducted in this tunnel are presented in references 6 and 7. The Langley 6- by 19-inch tunnel will continue to be used for the development of refined transonic wall configurations.

Langley 6- by 28-Inch Transonic Tunnel

The Langley 6- by 28-inch transonic tunnel is described in reference 8. A plot of the Reynolds number - Mach number envelope is shown in figure 9, and a photograph of the tunnel is shown in figure 10. The tunnel, which is shown on the upper level in the photograph, was placed in operation in 1974. It is a blowdown type, operating over a Mach number range of 0.3 to 1.2 and a stagnation pressure range of 1.2 to 6 atm. The pressure capability provides a low to moderate Reynolds number capability with independent Mach number and Reynolds number control. The tunnel, with its transonic and 15×10^6 Reynolds number capability, is dedicated to a wide range of airfoil research. Current tunnel programs include the development of supercritical airfoils, supercritical propellers, and rotor aircraft airfoils. The rotorcraft airfoil studies are particularly extensive and figure 11 shows a photograph of some of the models which have already been tested. The rotorcraft program is discussed in more detail in reference 9.

Projected programs for the Langley 6- by 28-inch transonic tunnel include the development of high-speed general aviation airfoils and dynamic stall research. The facility will be updated in the near future with the addition of a sidewall boundary-layer suction system incorporated in the model turntables. The projected programs also include plans to provide an oscillating airfoil system. This system will enhance the dynamic stall research effort in addition to providing for oscillating airfoil studies.

Langley 0.3-meter Transonic Cryogenic Tunnel

Langley's newest two-dimensional research facility is the 20- by 60-cm test section of the Langley 0.3-meter transonic cryogenic tunnel (TCT). A more complete description of the basic 0.3-meter TCT is presented in reference 10. The Reynolds number - Mach number envelope for the two-dimensional test section is presented in figure 12, and a photograph of the facility in figure 13. As indicated on figure 13, the test section is located in the top leg and the flow is clockwise. The tunnel is a fan-driven, continuous-flow tunnel which utilizes the cryogenic pressure tunnel concept. The test medium is gaseous nitrogen which provides a temperature range varying from about 77 K (-320° F) to about 327 K (130° F). The photograph indicates the nitrogen injection station and the exhaust stacks. The cryogenic temperature capability provides a multiple increase in Reynolds number of about six over that at ambient temperature. The reduced temperature capability, combined with the 5-atm capability, results in a very high Reynolds number at relatively low model loading. For example, to achieve this Reynolds number in a conventional pressure tunnel of the same size would require a stagnation pressure of about 30 atm. The operating envelope shown in figure 12 indicates that a Reynolds number of about 50×10^6 can be obtained at a Mach number of about 0.85. The tunnel with its unique pressure and temperature capability provides independent control and assessment of Mach number, Reynolds number, and aeroelastic effects: An example of this attractive capability is shown in figure 14. This figure represents a dynamic pressure - Reynolds number envelope for a 15-cm (6-in.) chord model at a Mach number of 0.80. The conditions which define the outer boundaries of this envelope are the horizontal pressure lines and the diagonal temperature cuts. Conventional pressure tunnels operate along the ambient temperature line, and increases in Reynolds number are accomplished by increasing the stagnation pressure. This obviously results in large increases in dynamic pressure q and model loading. The addition of the temperature parameter expands the envelope, and a large range of either pure Reynolds number studies (horizontal cuts) or pure aeroelastic studies (vertical cuts) can be accomplished with just one model. For example, at a stagnation pressure P_t of 5 atm, a pure Reynolds study could be made at Reynolds numbers from about 8 to 50×10^6. The ability to conduct pure aeroelastic studies or maintain a constant shape over a wide Reynolds number range may become extremely important in the assessment of airfoils having thin, highly cambered trailing edges. As shown in figure 15, the tunnel features removable model modules. In this photograph, the plenum lid and test-section ceiling have been removed and the module is in the raised position. The photograph in figure 16 is a top view looking down into the test section with the model module installed in the test position. This removable feature and the duplicate module assemblies will allow for the complete preparation of a model during the test of another model. The cryogenic tunnel incorporates computer-driven angle-of-attack and momentum-rake systems. The momentum rake (shown in the photograph in fig. 16) is programmed to traverse automatically through the wake, to determine the boundaries of the wake, and then to step through the wake at a prescribed rate and number of steps.

The Langley 0.3-meter transonic cryogenic tunnel is currently being utilized to extend cryogenic wind-tunnel technology and to develop a unique airfoil research capability. Studies are being conducted to develop cryogenic test techniques, define minimum operating temperatures, and support the development of the National Transonic Facility. Progress is being made toward the development of an airfoil research capability. Shakedown and calibrations are nearing completion, preliminary blockage tests have been conducted, and an NACA 0012 correlation model has been tested through the entire operating envelope. An assessment of the slotted walls and sidewall boundary-layer effects is in progress. In addition, work is being conducted to develop a preliminary sidewall boundary-layer control system.

Some of the plans which are projected for the new cryogenic facility are briefly described. The new classes of airfoils illustrated in figure 17, such as the supercritical, peaky, and the new thick spanloader concepts will be assessed up to Reynolds numbers of 50×10^6. The unique test envelope will be used to evaluate highly cambered fighter airfoil concepts. Factors which affect Reynolds number sensitivity will be assessed and documented. The high Reynolds number experimental results will be used to evaluate and contribute to transonic viscous flow theories and to provide guidance in the utilization of conventional airfoil facilities. Plans are now being made to provide the tunnel with an advanced data-acquisition and tunnel-control system and a study is currently underway to update the current sidewall boundary-layer control system.

CONCLUDING REMARKS

It was mentioned previously that in order to provide an exact two-dimensional test capability, it was essential to control the unnatural tunnel-wall boundary effects and model-wall boundary-layer interactions as well as test at the correct Mach and Reynolds numbers. Throughout this paper it was indicated that the wall problems are being addressed in all of the Langley facilities. Progress is being made, but the alleviation of the various tunnel wall problems, particularly those at high Mach number and high lift coefficients, will require a considerable amount of research and tunnel refinements.

With regard to the Mach number and Reynolds number test capability, figure 18 summarizes Langley Research Center's current capabilities. This summary chart represents the flight Reynolds number design conditions for several classes of aircraft. In addition, it illustrates the test capabilities of the Langley facilities. The general aviation design envelope, shown in the low Mach number, low Reynolds number corner of the figure, has not changed drastically over the past several decades. The transport-cargo aircraft design trend, however, has changed dramatically, and the large transport-cargo types, such as the B-747 and C-5, tend to establish the upper requirement for two-dimensional design considerations. The attack helicopter design point represents a typical, higher Mach number design requirement. It will be noted from the figure that the Langley low-turbulence pressure tunnel still very adequately covers the general aviation requirements and that the Langley 6- by 28-inch tunnel fulfills the high Mach number helicopter requirement. The addition of the Langley 0.3-meter transonic cryogenic tunnel with its Reynolds number capability of 50×10^6 will eliminate the large gap which previously existed for the large transport-cargo class of aircraft. It is interesting to note that upper tunnel capabilities encompassed by the Langley low-turbulence pressure tunnel and Langley 0.3-meter transonic cryogenic tunnel envelopes are achieved in continuous-flow facilities. It can be seen from this figure that for Mach number and Reynolds number requirements, the Langley airfoil facilities provide the test capabilities required to adequately simulate the design flight condition for modern aircraft and rotorcraft.

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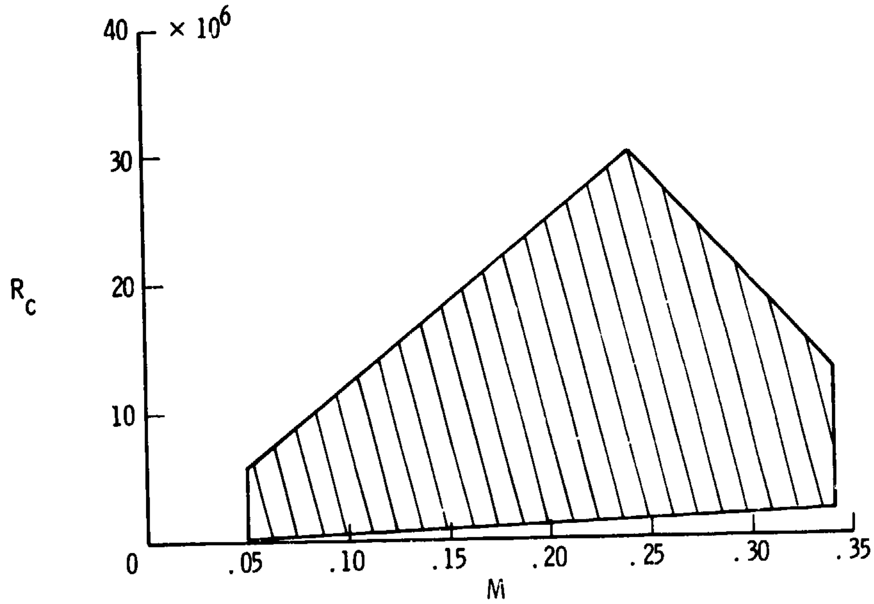

Figure 1.- Reynolds number envelope for Langley low-turbulence pressure tunnel.

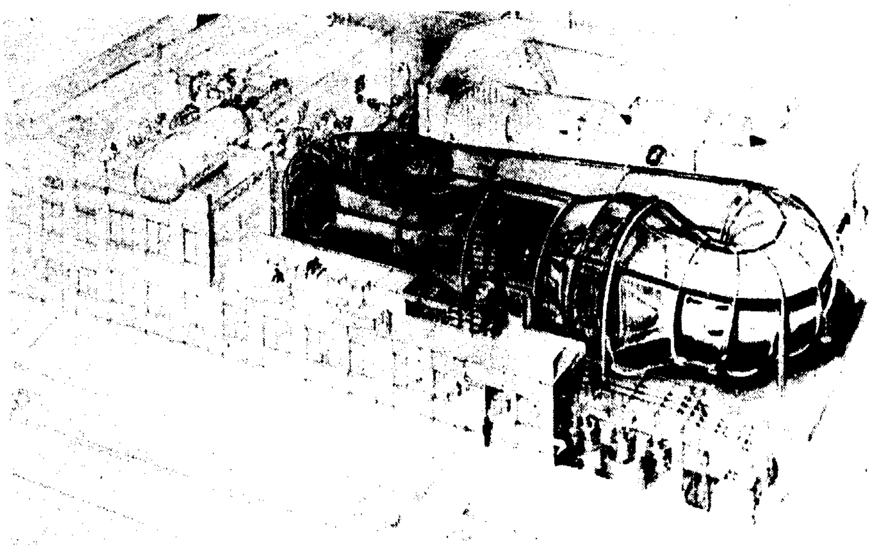

Figure 2.- Langley low-turbulence pressure tunnel.

Figure 3.- The 60.96-cm (24-in.) model installed in Langley low-turbulence pressure tunnel test section.

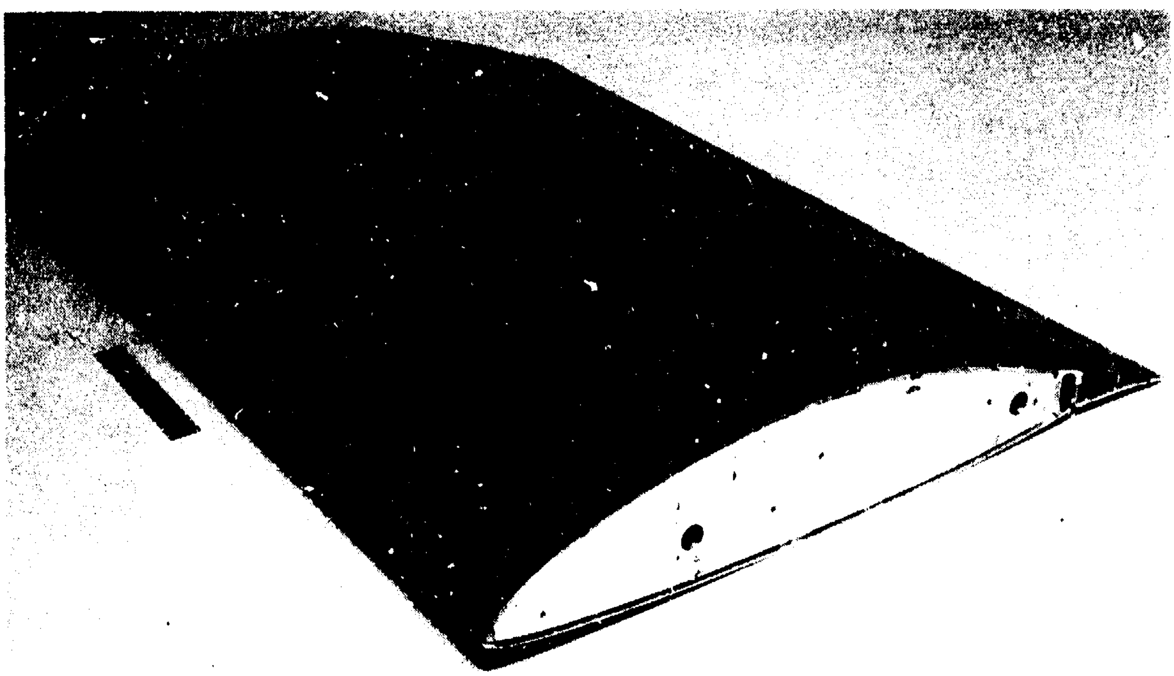

Figure 4.- Passive laminar flow airfoil for Langley low-turbulence pressure tunnel.

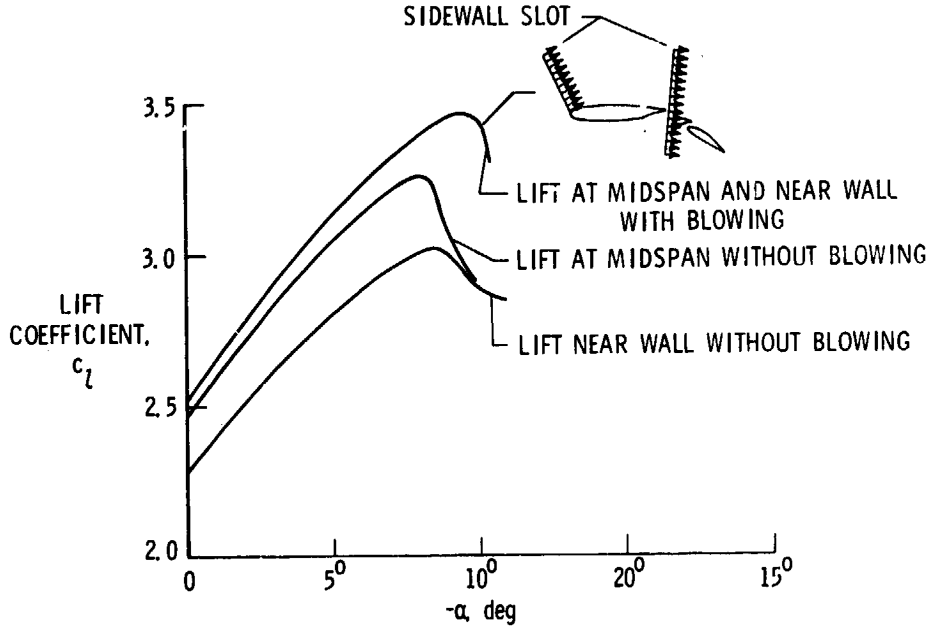

Figure 5.- Typical effects of boundary-layer control on lift characteristics.

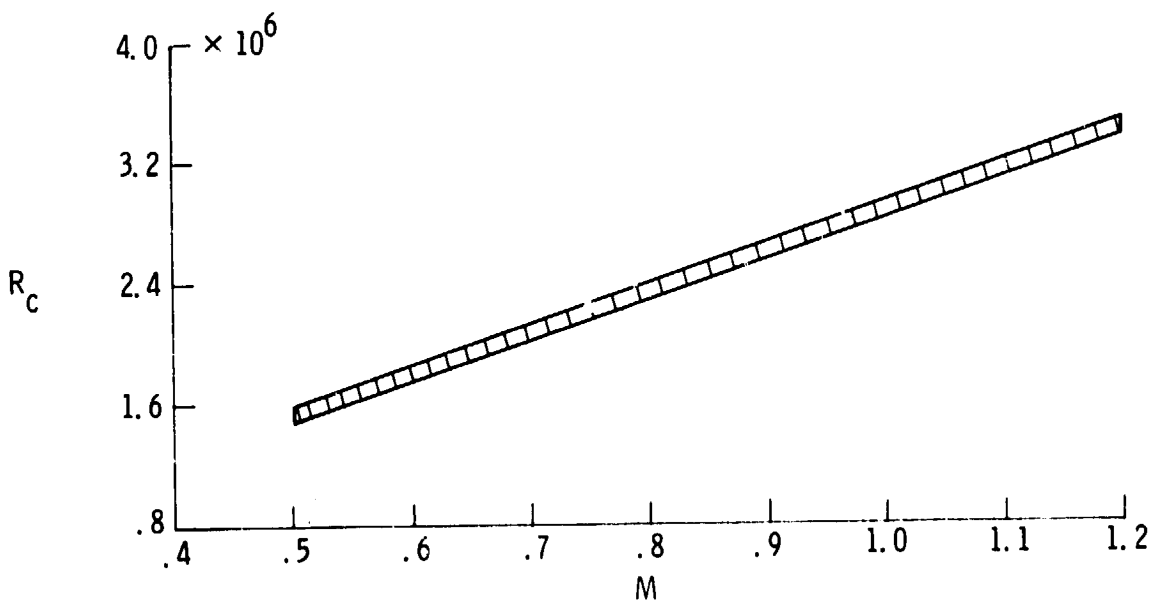

Figure 6.- Reynolds number envelope for Langley 6- by 19-inch transonic tunnel.

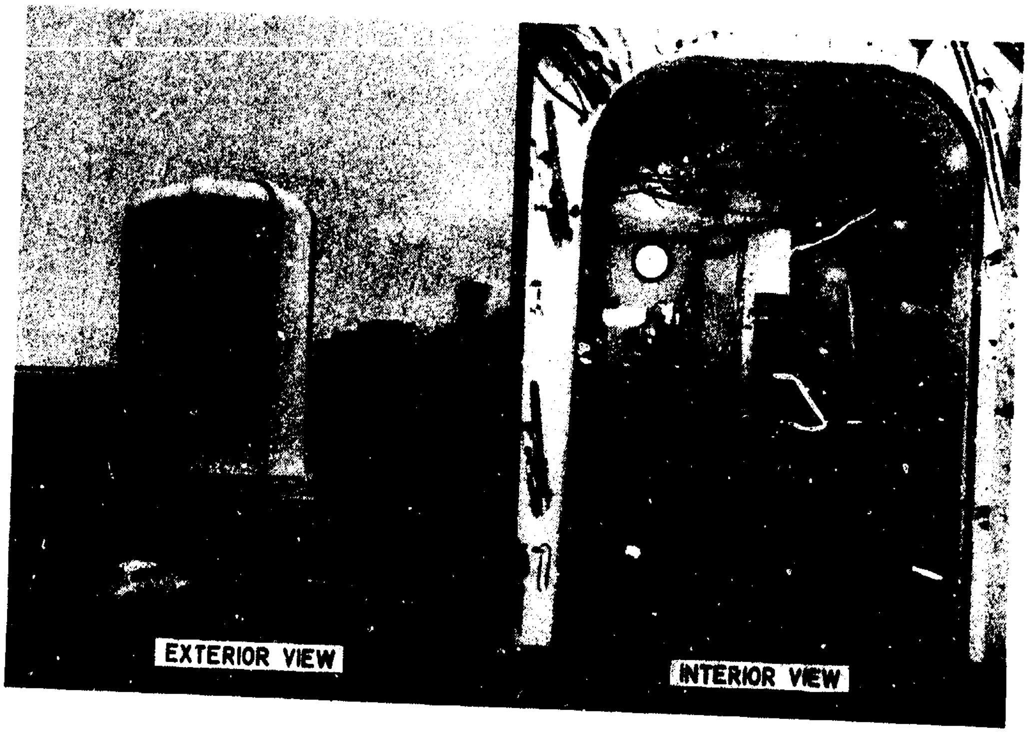

Figure 7.- Langley 6- by 19-inch transonic tunnel.

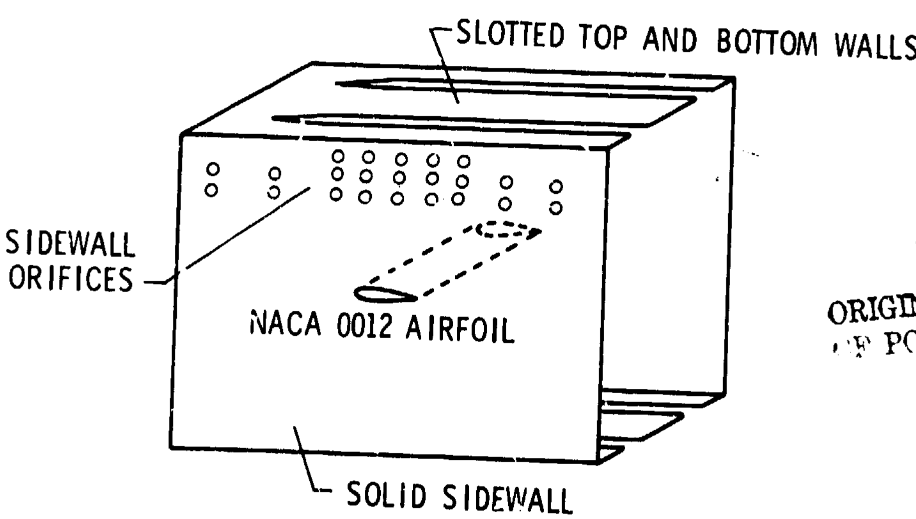

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Figure 8.- Parametric slotted wall study for Langley 6- by 19-inch transonic tunnel.

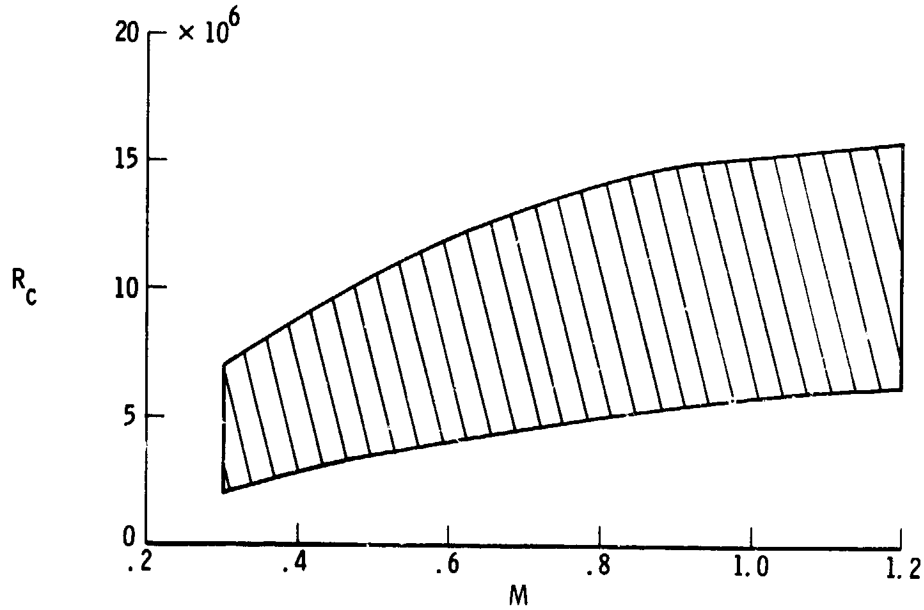

Figure 9.- Reynolds number envelope for Langley 6- by 28-inch transonic tunnel.

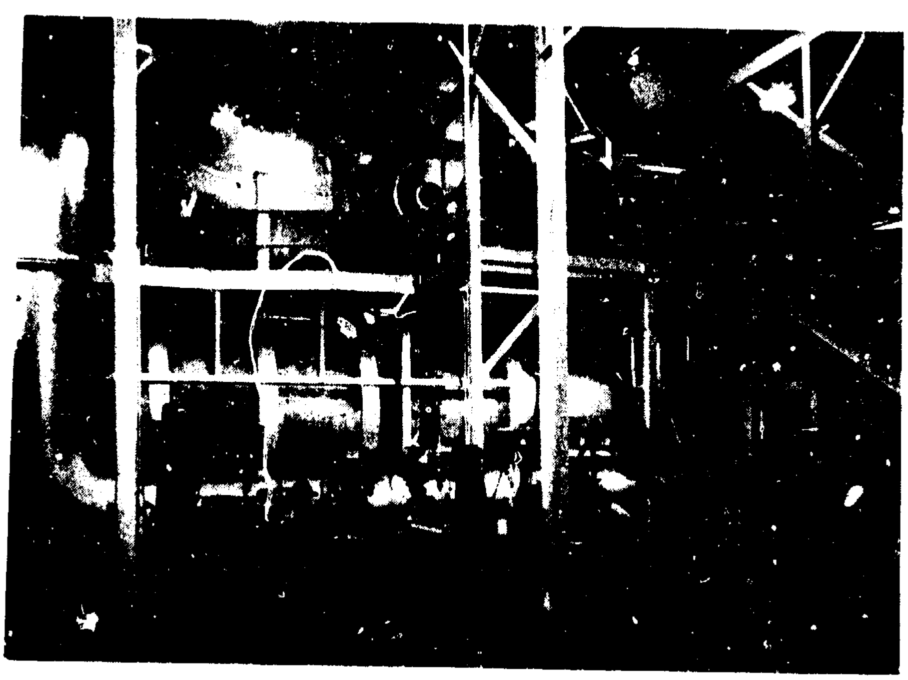

Figure 10.- Langley 6- by 28-inch transonic tunnel.

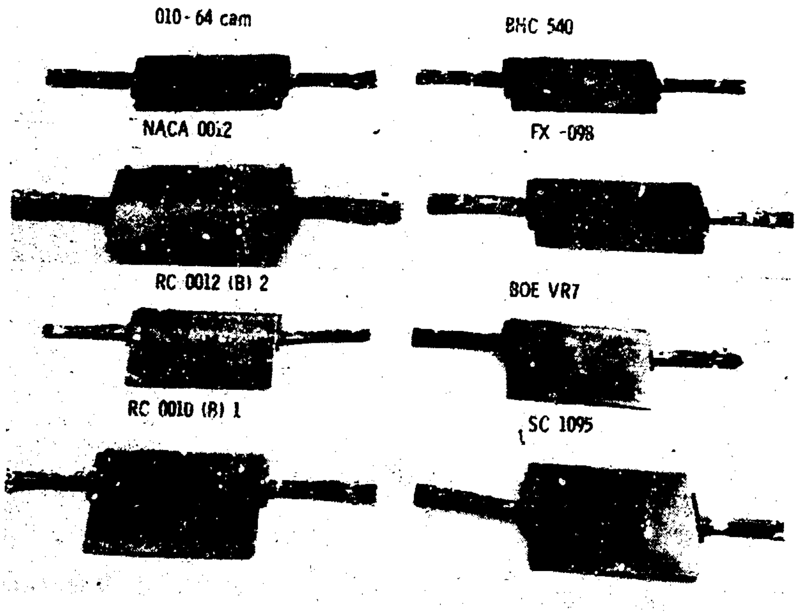

Figure 11.- Rotorcraft airfoil development models tested in Langley 6- by 28-inch transonic tunnel.

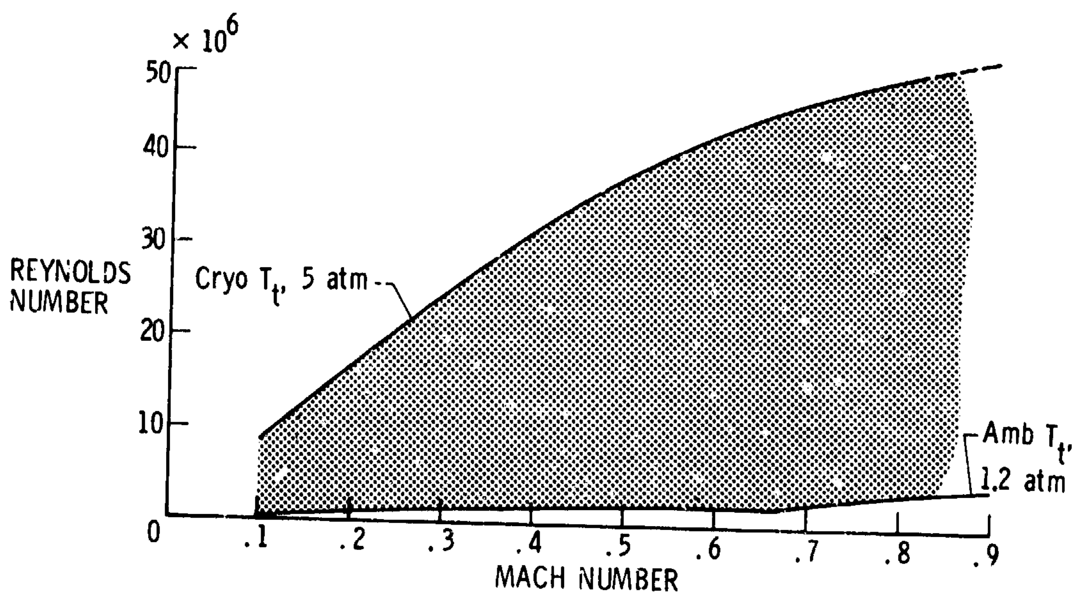

Figure 12.- Reynolds number envelope for two-dimensional test section in Langley 0.3-meter transonic cryogenic tunnel.

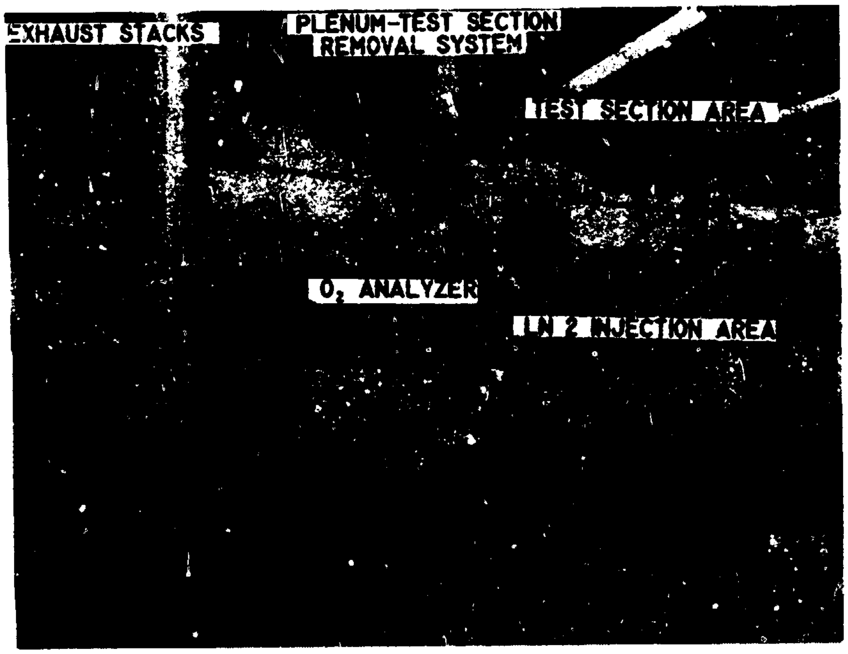

Figure 13.- Two-dimensional test section of Langley 0.3-meter transonic cryogenic tunnel.

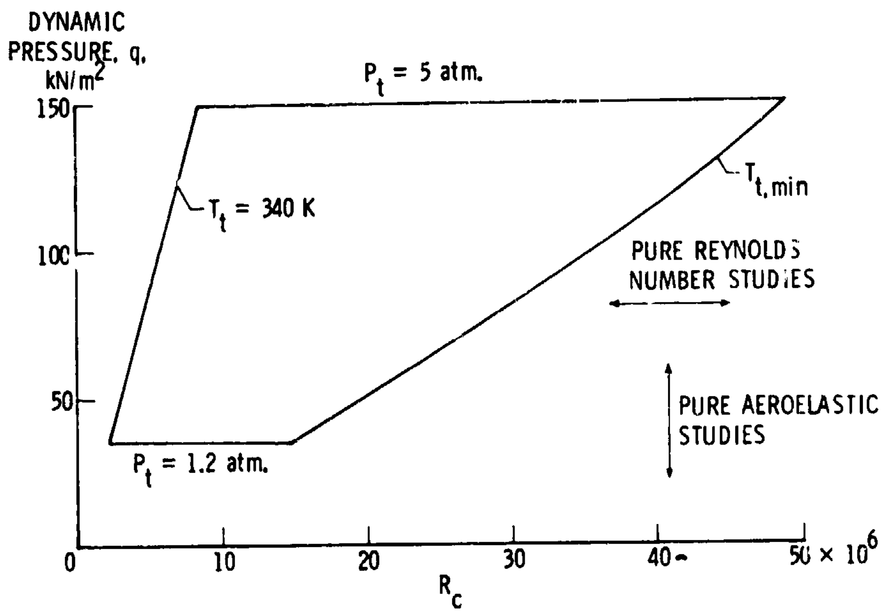

Figure 14.- Reynolds number - dynamic pressure envelope for two-dimensional test section in Langley 0.3-meter transonic cryogenic tunnel at M = 0.80 and c = 15 cm.

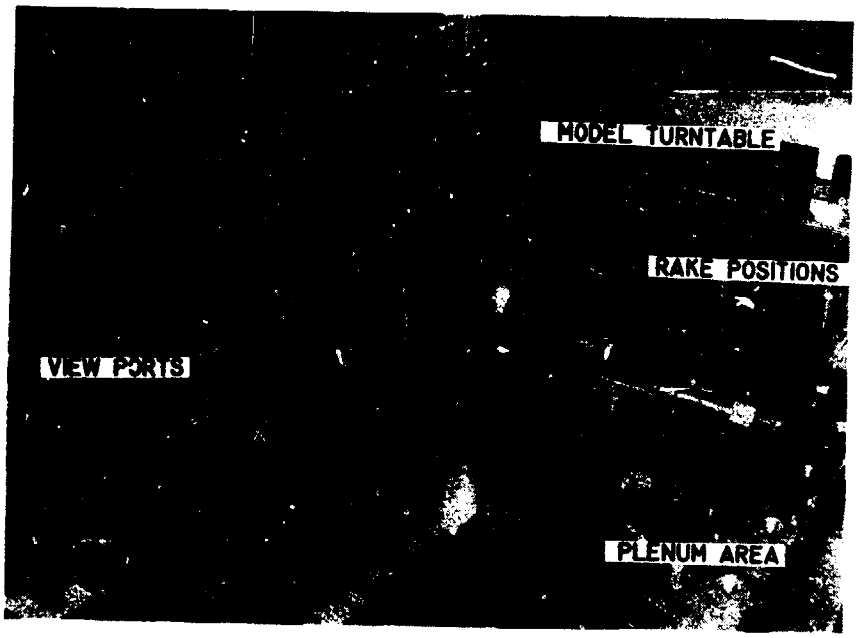

Figure 15.- Model modules in Langley 0.3-meter transonic cryogenic tunnel.

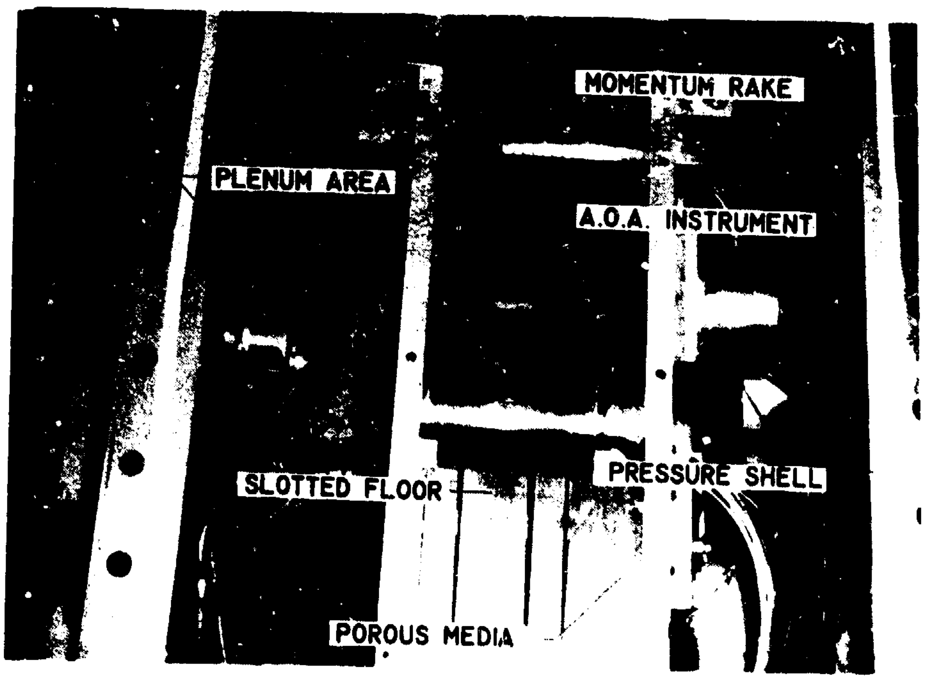

Figure 16.- Top view of two-dimensional test section in Langley 0.3-meter transonic cryogenic tunnel.

INVESTIGATION	AIRFOIL	t/c	c, in.
BLOCKAGE	0012-64	0.12	3
	0012-64	0.12	5
	0012-64	0.12	7
	0012-64	0.12	9
WALL BOUNDARY CORRELATION	0012	0.12	6
	65-213	0.13	6
	SCW	0.10, 0.14	6
	9510	0.11	6
FIGHTER		0.08	6
SPANLOADER		0.20	6
SURFACE FINISH		0.20	6

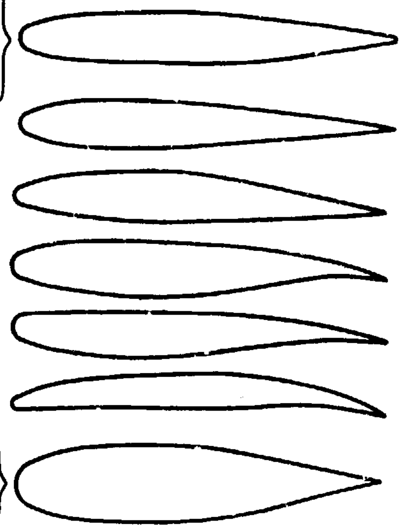

Figure 17.- Two-dimensional airfoil research program for Langley 0.3-meter transonic cryogenic tunnel.

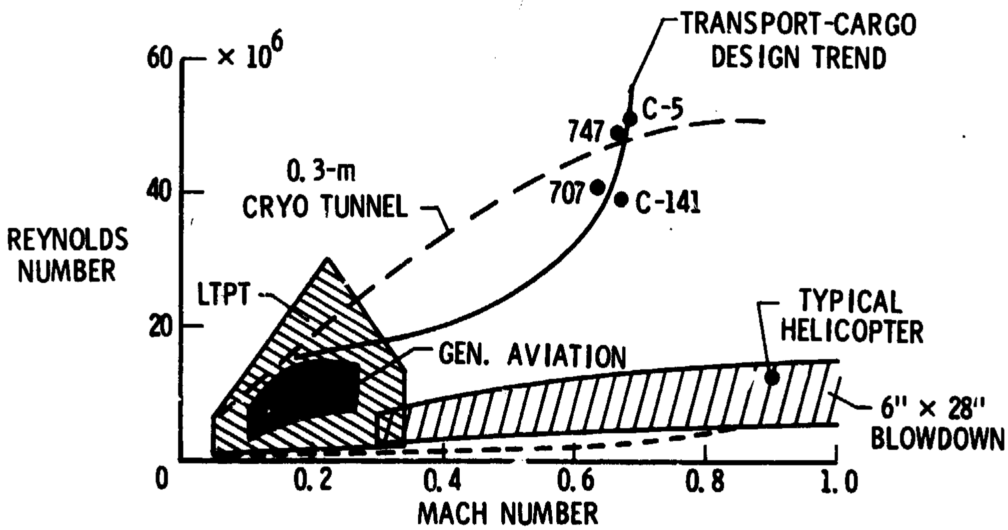

Figure 18.- Langley airfoil test capability.