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ABSTRACT

A small supersonic wind tunnel (The NAL 0.2m Supersonic Wind Tunnel) was built at the National Aerospace Laboratory, Japan in 1995. The test section is 0.2m×0.2m in cross section and 0.4m long. Mach number can be set to any value from 1.5 to 2.5 by its flexible plate nozzle. Total pressure can be up to 0.15MPa and total temperature is around 330K. This tunnel has two unique points. The main structure and compressor were designed to be available at cryogenic temperatures. The contraction ratio to the test section is about 28, and the boundary layer suction device is mounted at the contraction, in order to establish low turbulent flow.

Key Words:wind tunnel, supersonic flow, high Reynolds number, cryogenic wind tunnel

概　要

1995年に小型超音速風洞（航技研0.2m超音速風洞）が航空宇宙技術研究所に新たに作られた。測定部は断面が0.2m×0.2mで長さが0.4mである。マッハ数は可変ノズルにより1.5から2.5までの任意の値に設定できる。総圧は0.15MPaまでで，総温は約330Kである。本風洞は主構造材と圧縮機が低温で使えるように設計されていることと，測定部面積に対する縮流比は約28もあり，境界層吸い取り装置が縮流部に設け，流れの低乱化を図っていることの二つの特徴を持つ。

1. Introduction

The NAL 0.2m Supersonic Wind Tunnel was built in 1995 to provide a new small supersonic wind tunnel for Near Future Aircraft Technology (NFAT) research at NAL and to acquire the technology needed for the high-Reynolds-number supersonic wind tunnel. (See Fig. 1.) This tunnel is the first continuous supersonic wind tunnel with an axial-flow compressor in Japan. It is also the first case in which cryogenic wind tunnel technology was adopted for supersonic application, which is very important for the high-Reynolds-number wind tunnel with supersonic flow. However, some parts of the tunnel will still not be available at cryogenic temperatures. The flow quality must be good in the supersonic as well as in the other flows. Technology for noise and turbulence reduction was used.

2. Tunnel Description

2.1 Performance Characteristics of the NAL 0.2m SWT

The NAL 0.2m SWT can operate with dry air or cryogenic nitrogen gas. Operation with dry air is currently available. Cryogenic operation will be available in future because it was designed as a cryogenic wind tunnel. The tunnel structure was designed and the materials were selected for cryogenic operation at pressures up to 0.5MPa. The main components of the tunnel including the compressor are available at cryogenic temperatures. The temperature of the tunnel can be as low as 100K. The tunnel pressure can range from 0.05 to 0.5MPa. Although it can operate at peak performance at cryogenic temperatures, the performance at present is limited as shown in Fig.2

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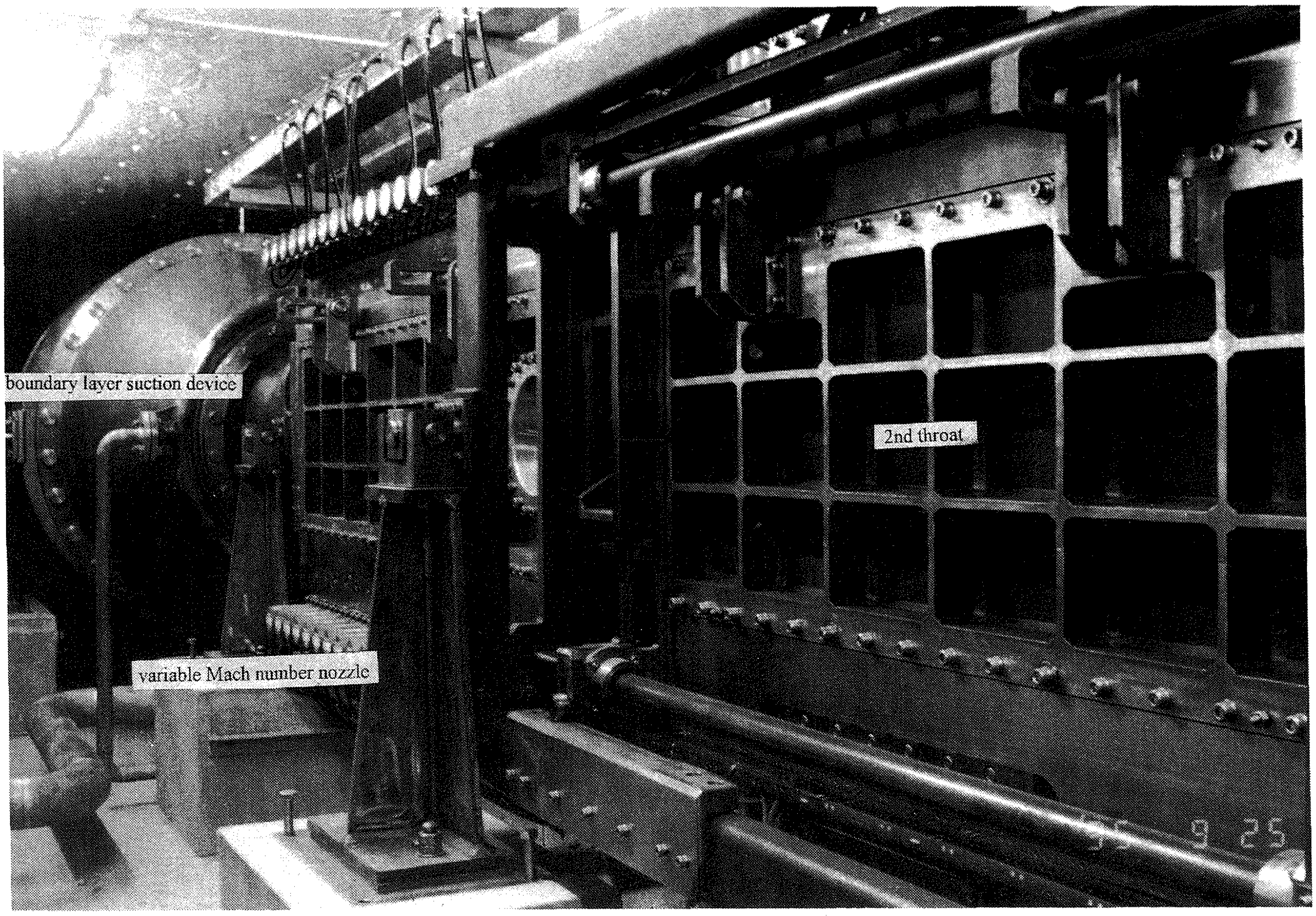

Fig.1 The NAL 0.2m Supersonic Wind Tunnel

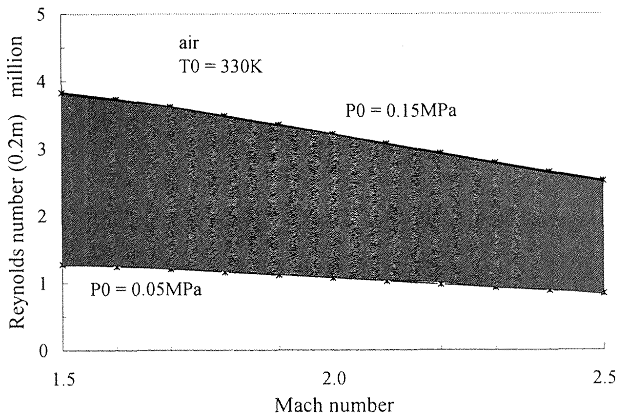

Fig.2 Reynolds number vs. Mach number (Current Performance)

and Table 1.

Replacing the compressor drive motor and the cooler with 2MW units is expected to allow the tunnel to operate at pressures up to 0.3MPa. After the tunnel is equipped with the liquid nitrogen supply and cryogenic nitrogen gas exhaust systems, it will be able to operate at cryogenic temperatures with the replacement of some electric devices and jacks at the flexible nozzle and the second throat. The final performance is shown in Fig.3 and Table 2.

Table 1 Current performance

Current performance (air operation only)	
Mach number	1.5 to 2.5 in supersonic flow
	0.55 to 0.8 in subsonic flow
Total temperature	330K
Total pressure	0.05 to 0.15MPa
Drive motor	550kW(continuous)
	750kW(for 15 minutes)

2.2 Tunnel Circuit

The tunnel centerline is 9.3m × 2.2m and it is also 1m above the base line as shown in Figs.4 and 5. The method of supporting the tunnel was designed to avoid large stresses due to thermal expansion. Only one point at the compressor is fixed. The centerline passing through the compressor axis can move only along the line. The other tunnel components can move

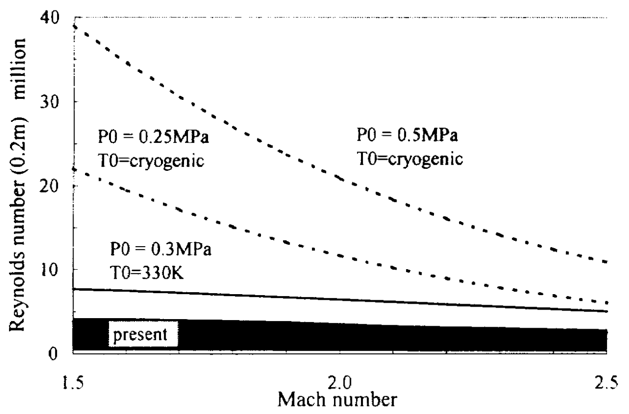

Fig.3 Reynolds number vs. Mach number after Power-Upgrade

Table 2 Future Power-Upgrade

Future Power-Upgrade (air and nitrogen gas operation)	
Mach number	1.5 to 2.5 in supersonic flow
	0.55 to 0.8 in subsonic flow
Total temperature	100K to 330K (depends on Mach number)
Total pressure	0.05 to 0.3MPa in air operation
	0.1 to 0.5MPa in cryogenic operation
Drive motor	up to 2MW

on the 1m-high horizontal plane with the specially designed supports shown in Fig.1. The special tunnel components are the gas exhaust section between the 3 rd and 4th corners and the two liquid nitrogen injection ports just downstream of the compressor and the second throat. The exhaust section is used to adjust the tunnel pressure. The liquid nitrogen injection port downstream of the compressor currently supplies dry air to the tunnel. The boundary layer suction device is mounted on the contraction component to delay the transition of the boundary layer on its wall. The test section can be moved downward when a model is installed in it. The whole circuit is in a cold box that is thermally insulated for cryogenic operation as shown in Fig. 6. The box can also reduce the noise level at the outside operator position.

2.3 Test Section and Variable Mach Number Nozzle

The variable Mach number nozzle is designed to make the test section length 0.4m long. The Mach number can be set to any value from 1.5 to 2.5 in 0.01 steps. The flexible plates are contoured vertically by 18 pairs of motor-drive actuators as shown in Fig.7. The position of each actuator is controlled by a computer and the contour can be changed during tunnel operation. The plate material is SUS317 because of its high fracture toughness and rustlproof characteristic. Each roughness R_{max} at 8 points on the four walls around the nozzle throat measures 0.7μm at most. A pair of 160mm-diameter Schilieren windows is located at the center of the test section range on the side walls. Three 0.3mm static pressure orifices are located in a vertical line 155mm upstream of the center of the window on each side wall. One of six orifices will be selected to determine the test section Mach number after initial measurements. A sting support system is mounted downstream from the test section. It can move vertically to keep the model at the center of the test section during operation at a selected angle of attack. It can also move vertically in the range of -60mm and 60mm. It can rotate through an angle of attack in the range -14° to 14°.

2.4 Settling Chamber

A 20.6° half-diffuse angle diffuser is located at the settling chamber inlet. Two screens are installed in it to avoid boundary layer separation and also to make the exit flow more uniform. A 40mm long honeycomb is installed in the settling chamber ,whose cells are 1/ 8 inch in diameter. It is made of an aluminum alloy and is mounted with stainless wires to avoid thermal stress. Screen sizing and arrangement are based on the test results shown in reference 1. The flow speed in the settling chamber is in the same range as in the tunnel in reference 1. Two farthest upstream screens are 20 in mesh number with 0.27mm diameter wires. The other two are 50 in mesh number with 0.112mm diameter wires. The space among the three upstream are 150mm and the space between the two downstream is 60mm. The farthest downstream 308mm long parallel pipe section causes the vorticity disturbance to decrease naturally.

2.5 Contraction

The contraction ratio to the test section area is 28.3. The contour is designed at Mach number 1.5 according to the Thwaites paper (reference 2) for axisymmetric flow. The contraction length is determined from the computed results of the equivalent

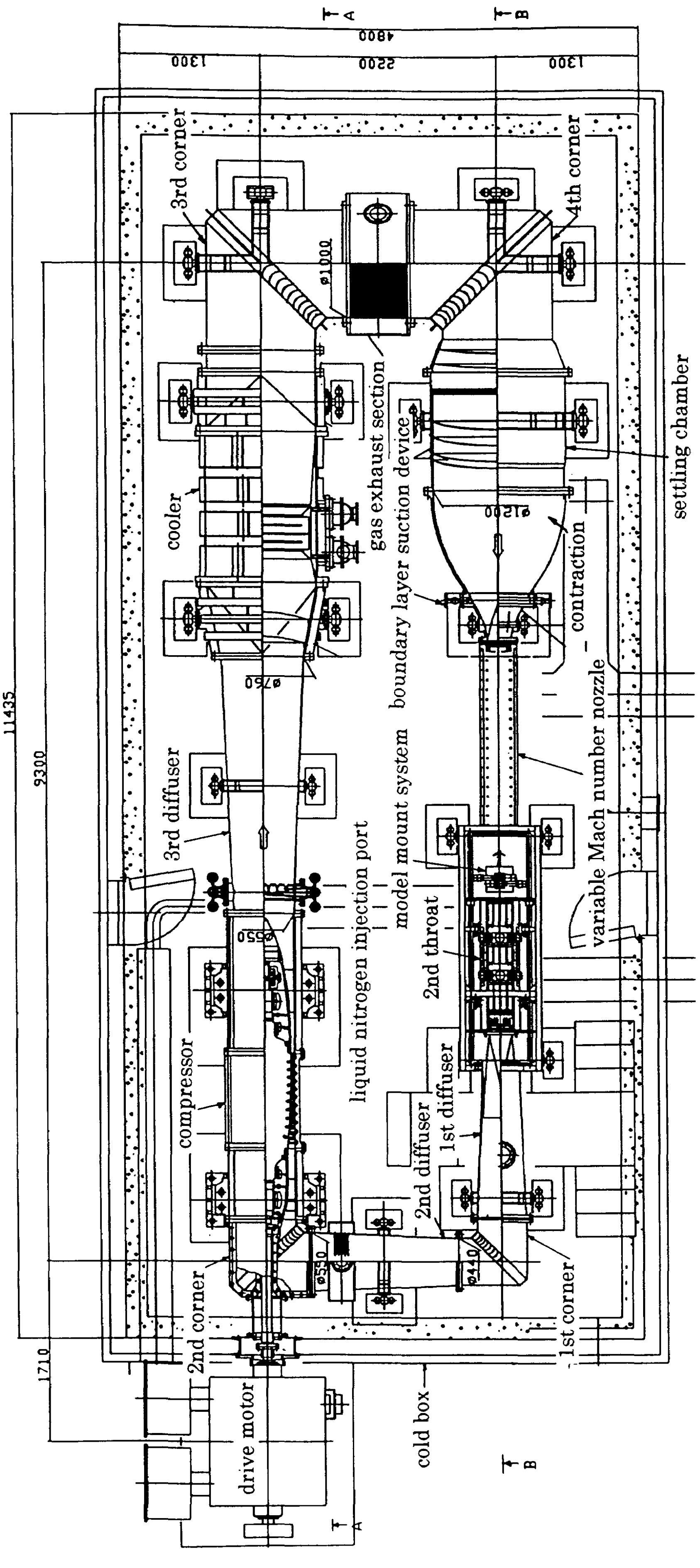

Fig.4 Tunnel Circuit (Plan View)

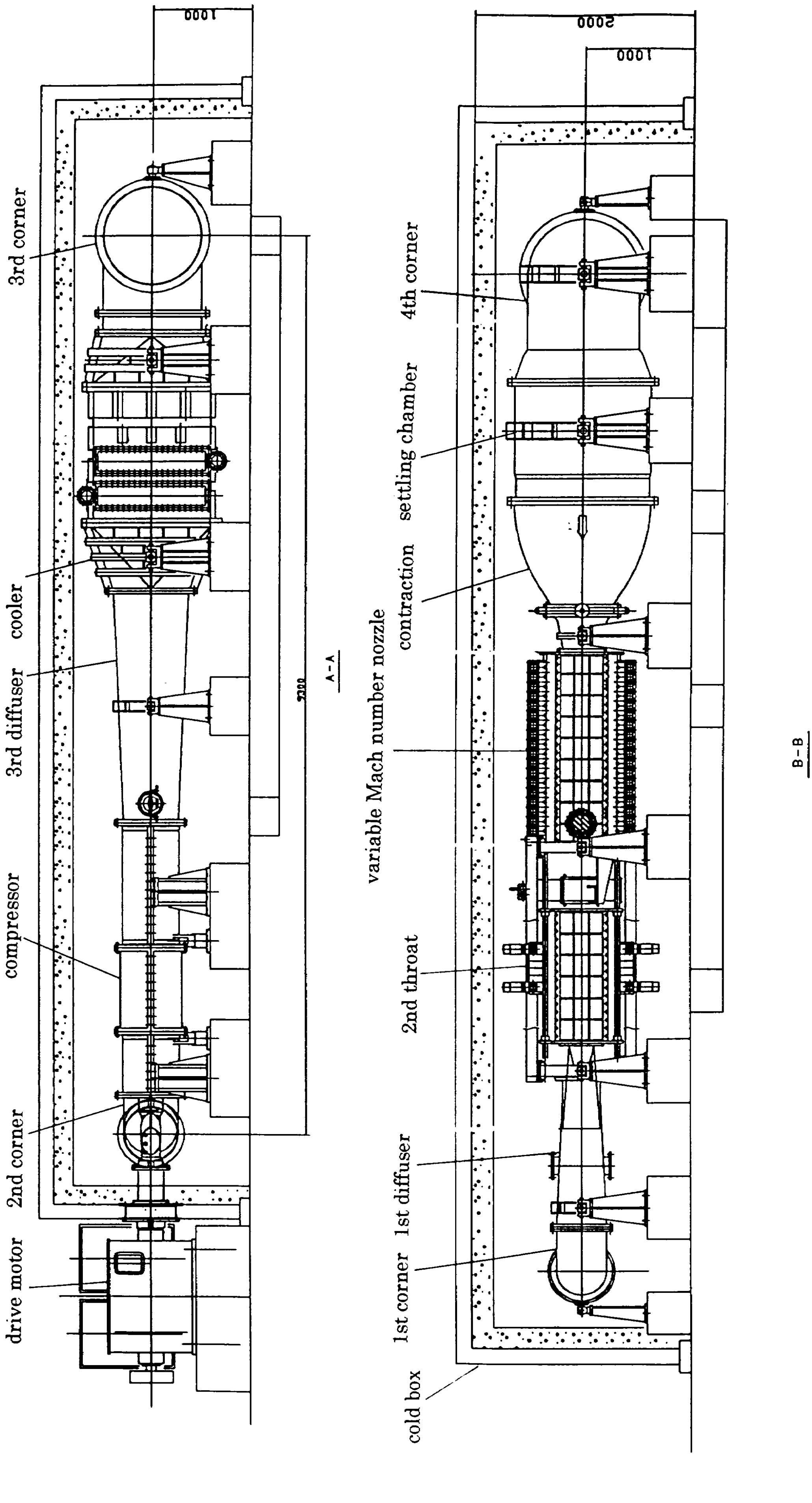

Fig.5 Tunnel Circuit (Side View)

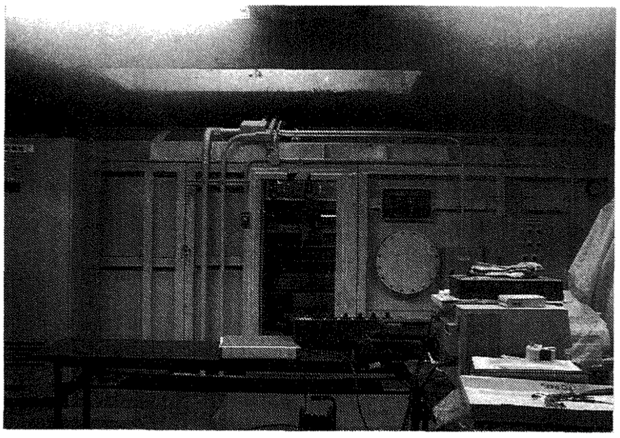

Fig.6 Cold Box

plane flow to the contraction in flow rate. The round settling chamber transfers to the rectangular nozzle inlet in a transition region that is 0.35m long. The boundary layer suction device is located immediately upstream of the transition region. The suction plate is 60mm wide rigimesh. The nozzle inlet is 0.2m wide and 0.3m high. The round part surface is polished and the transition part surface is polished to a mirror-finish.

2.6 Second Throat

Pressure recovery is expected to be achieved in the 0.35m rectangular parallel channel. The cross area of the channel can be adjusted with two pairs of jacks mounted on the ceiling and floor during the tunnel operation. To improve the pressure recovery performance, the contoured walls can be further adjusted by independent operation of the two pairs of jacks. The parallel channel works as expected according to the shakedown test results.

2.7 Cooler

A cooler is located downstream of the compressor. The gas temperature at the inlet is around 470K in air operation at 330K in total temperature. It is made of SUS304 for cryogenic operation. The water inside can be purged completely with pure nitrogen gas before cryogenic operation. The purge system has already been installed. The cooler can remove the heat flux from the flow up to 750kW at present. The room for increasing the cooler capacity remains immediately downstream of the cooler.

2.8 Gas Exhaust Section

The nitrogen gas exhaust section is located between the 3rd and 4th corners. The section is connected to vacuum pumps at present to control the pressure by exhausting dry air inside the tunnel. The section is also connected through a valve to the gas-return section between the 1st and 2nd corners. This bypass is used to avoid compressor surges. In particular, the valve is initially open in case of high Mach numbers larger than 2.0. It is closed after the flow rate passing the compressor is large enough. The section will be connected to an outside stack through a control valve for cryogenic operation in the future. The round plate inside the section has many small holes on it, through which gas passes.

2.9 Liquid Nitrogen Injection Ports

Two liquid nitrogen injection ports are just downstream of the compressor and the second throat. The port downstream of the compressor supplies dry air to the tunnel at present. The port will be used mainly in cryogenic operation to avoid damage to the compressor blades by liquid nitrogen particles. Only a small amount of liquid nitrogen will be injected at the other port. Neither port is connected to any liquid nitrogen supply system.

2.10 Compressor and Drive Motor

The tunnel structure was designed to be available at 0.5MPa at cryogenic temperatures. The 10-stage axial-flow compressor was also designed to meet this application. The pressure ratio is set by the flow rate and drive motor speed up to 8400rpm. The compressor performance is shown in Fig.8. A portion of the performance was examined and the obtained results are plotted in the figure. The bearing system of the compressor was also designed to be available for cryogenic operation.

The drive motor is a two-pole 550kW induction motor. Its speed ranges from 3600 to 8400 rpm. The speed fluctuation is less than 0.01%. The output of the motor can be increased to 750kW for 15 minutes.

2.11 Cold Box

The whole tunnel circuit is in a cold box that is thermally insulated inside. The ceiling and side walls are thermally insulated with 0.1m thick glass fiber plates. The floor is not insulated yet. The insulation

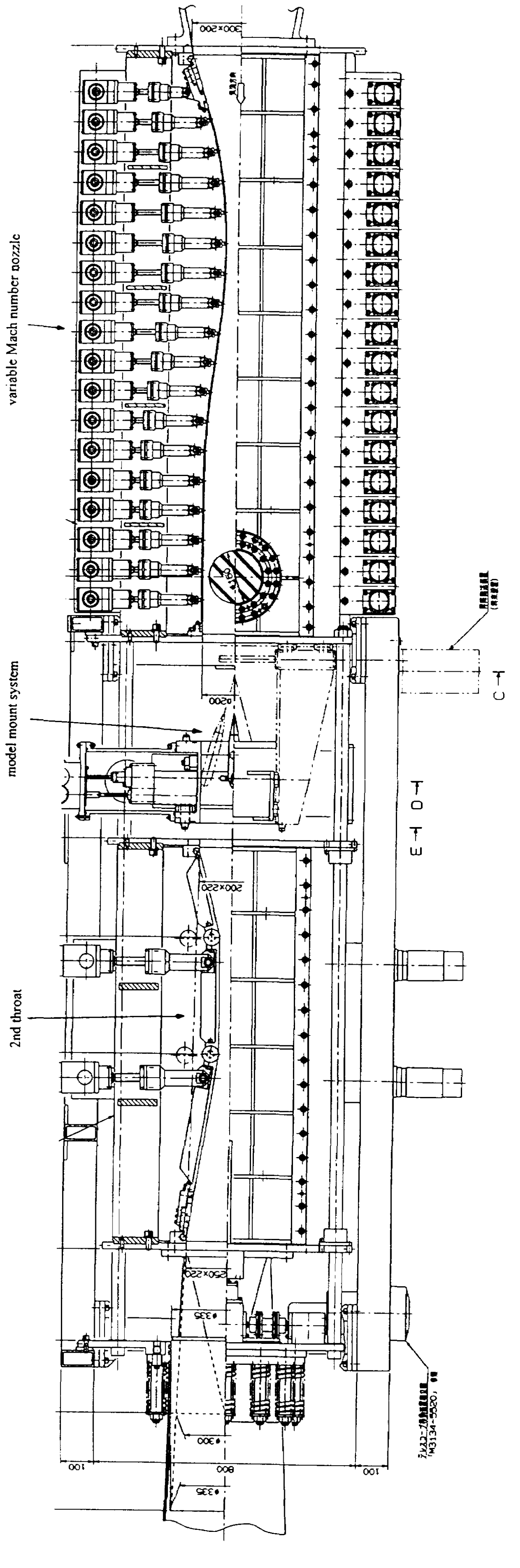

Fig.7 Test Section and Variable Mach Number Nozzle

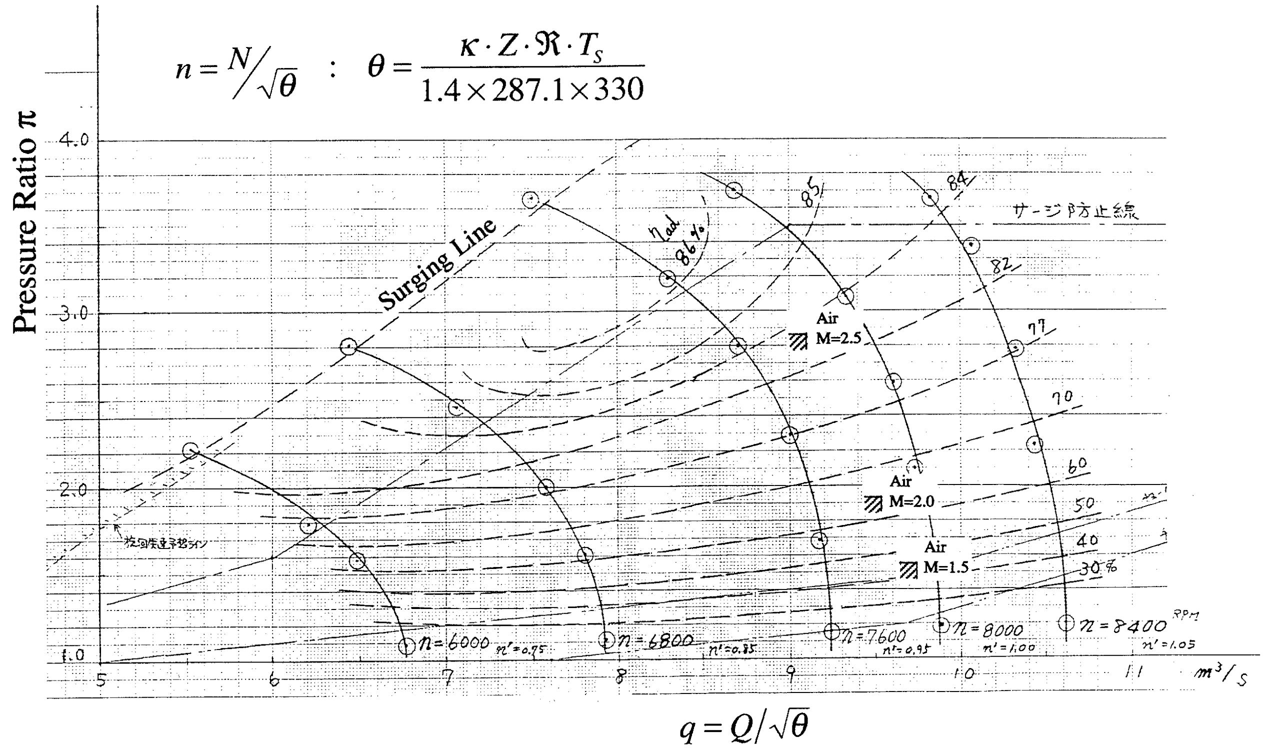

Fig.8 Compressor Performance

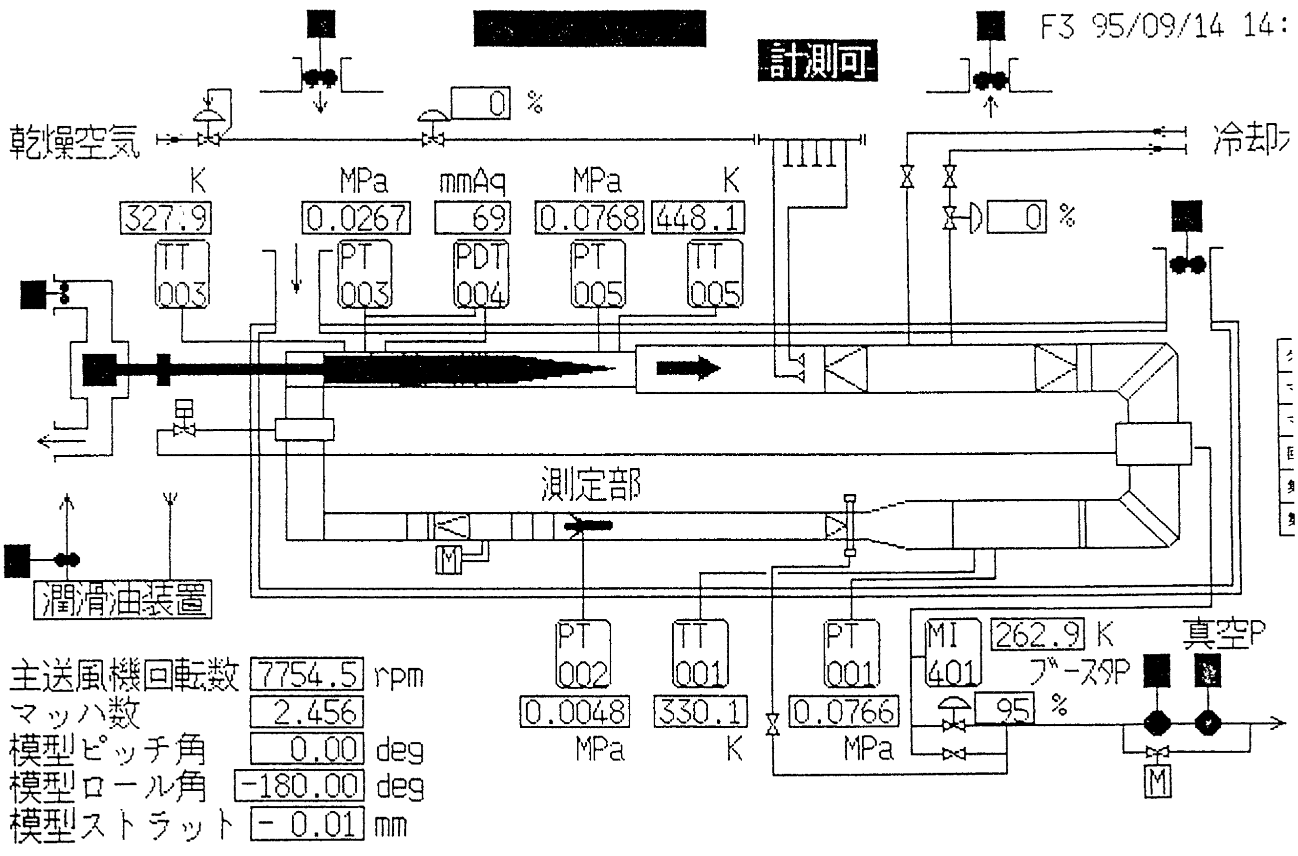

Fig.9 Monitored Tunnel Status Display

thickness will be doubled for future cryogenic operation. The box is airtight up to a 0.01MPa pressure difference between the outside and inside. The box also reduces the noise level at the operator position outside.

2.12 Control

One researcher can operate the tunnel by himself. Total pressure and temperature and compressor speed are automatically controlled. A computer constantly indicates the appropriate operation to the researcher on a display. When changing the test Mach number, the computer contours the flexible nozzle plates and varies the second throat area, thereby setting the correct compressor speed automatically. The status of the tunnel operation is indicated at all time, as shown in Fig. 9.

3. Future Plans

3.1 Initial Measurement

Flow uniformity and steadiness will be measured on the central vertical plane in the test section. In addition, the pressure fluctuation on the 10° cone model and noise levels at several points in the tunnel circuit will be measured with microphones. Turbulence at the test section will be measured with hot-wire anemometry.

3.2 Checkout of Actuators and Electric Devices at Cryogenic Temperatures

A duplicate pair of the jack system at the nozzle will be examined at cryogenic temperatures. The test model was fabricated to improve lubrication at cryogenic temperatures. The electric devices will be also examined at the same time. An endurance test will be conducted which corresponds to 10 years of operation.

3.3 Cryogenic Operation and Power-up

The tunnel was designed to operate at cryogenic temperatures. Some parts are not available for use. In particular, the gas exhaust and liquid nitrogen supply systems are not yet complete. But the technology for building these is available because it is the same as that of the NAL 0.1m cryogenic wind tunnel. A major difference from the transonic cryogenic wind tunnel is the very large amount of injected liquid nitrogen compared with the tunnel flow rate. The ratio of liquid nitrogen to the mass flow rate in the test section will be up to about 30% at M=2.5. Although compressor blade damage by the liquid nitrogen particles can be avoided by using the downstream port, the particles must vaporize completely before they reach the test section.

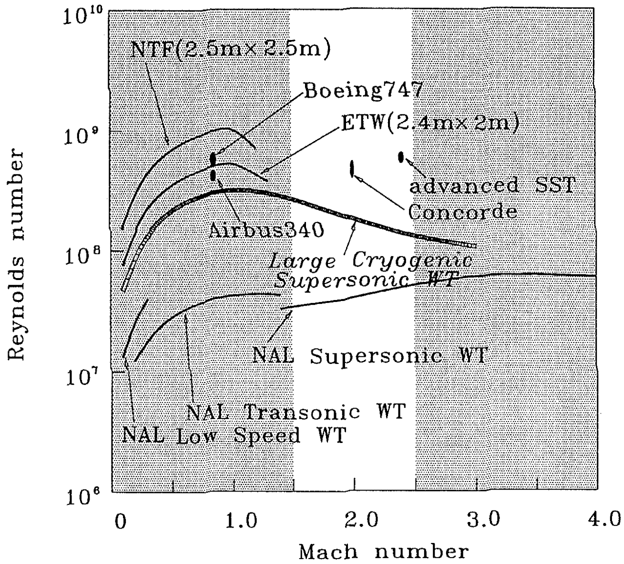

Fig.10 Reynolds Number vs. Mach number for Large Cryogenic Supersonic Wind Tunnel

The increase of the power of the motor drive to 2 MW is very attractive for researchers studying the boundary layer transition if the flow quality is good. But the flow quality has not been examined yet . The increase of power increases the noise level as much as the mass flow rate. The plan for increasing the power will be decided after measuring the noise level in the present powered tunnel.

3.4 A Cryogenic High Reynolds Number Wind Tunnel Plan

A supersonic wind tunnel for high-Reynolds-number testing is needed worldwide, although transonic wind tunnels for the same purpose have been constructed using cryogenic technology. A large cryogenic wind tunnel was investigated at NAL. The tunnel designed in the investigation has two test sections for transonic and supersonic flows. The test section is 1.25m × 1.25m. The flow speed ranges from 0.2 to 3 in Mach number and total pressure and temperature range from 0.1 to 0.5MPa and 90 to 330K, respectively. The maximum attainable Reynolds number is shown in Fig.10. The 0.2m supersonic wind tunnel is also a pilot facility for the larger tunnel.

4. Concluding Remarks

The NAL 0.2m Supersonic Wind Tunnel built in 1995 and its features were described. The main features are tunnel components available at cryogenic temperatures, the large contraction ratio of 28.3, the carefully designed settling chamber and contraction, and the boundary layer suction device and highly polished contraction surface. The cryogenic availability is needed for a high-Reynolds-number supersonic wind tunnel. The other features are needed for a quiet low supersonic wind tunnel. Tests for measuring the flow noise and turbulence in this tunnel will be carried out. The results will be useful for improving the flow quality.

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