

- Reynolds capability (per meter): max. 100×10^6 in the 3D test section, max. 150×10^6 in the 2D test section.

A brief description of the facility is given below.

In its 30 years of service the tunnel has been used for more than 120 test programs, mostly for the national industry, among which the twin jet fighter IAR-93, the jet trainer IAR-99, the MIG-21 Lancer, the Polish jet fighter YRYDA, other aircraft projects, many missiles and a number of research and development projects.

In 1999 INCAS was admitted as a member of the Supersonic Tunnel Association, International (STAI).

Apart from the usual measurements of forces, moments and pressure distributions during the years there have been many special test programs like combustion base bleed tests, half model tests, parachute opening tests, intake tests with internal flow control, experimental studies on the use of jets for the reduction of drag on ogives and also for the control of vortex lift, studies on conical flows, dynamic derivatives measurements, tests of new balances and new visualisation techniques, development of a CTS system, tests on UAVs etc.

The whole experimental activity in the Trisonic Wind Tunnel is carried out according to the existing "Manual for Quality Assurance in the Trisonic Wind Tunnel".

In general the user supplies the models. However model design can be undertaken by I.N.C.A.S.

The actual model size will not only depend upon the type of test planned, but also on other factors such as maximum loads, starting loads, model weight, wind tunnel blockage and wall interference. The model shall be designed with a safety factor of four, based on the yield point strength of the material. The safety factor may be lowered, after consulting with the I.N.C.A.S. staff, depending upon the accuracy with which the loads are known and if it can be shown that in the case of a failure there will be no serious damage to any part of the facility.

The model should be designed with a concern for ease of installation on the balance. All removable parts should be doweled for accurate replacement. Enough clearance should be provided between the model and the sting to avoid any mechanical interference.

A tentative test programme, data reduction requirements, model drawings and a stress report must be discussed with the I.N.C.A.S. personnel at least 3 months prior to the scheduled date of start

for the tests. A detailed test programme should be agreed upon at least one month ahead of that time.

Description of the facility

The 1.2 m x 1.2 m wind tunnel is of the open circuit, blowdown type with a speed range from low subsonic ($M = 0.1$) to a maximum supersonic Mach number of 3.5. This range includes transonic Mach Numbers which are obtained through use of a perforated wall transonic test section. This transonic section is easily incorporated into the wind tunnel circuit when required.

For normal operation the control valve is manipulated to give a constant stagnation pressure and the stagnation temperature remains at approximately 20°C during a run. This latter is effected by causing the air to flow through a matrix of long steel tubes (18 mm diameter) at the outlet of the air storage. The mass of the tubing is about 200 tons and through its large thermal capacity this mass maintains outflowing air temperature to a value close to its initial value (approximately 20°C at all times).

The compressor plant delivers $400 \text{ m}^3/\text{min}$ of filtered, dry air at a maximum pressure of 20 bar and at about 20°C to the storage vessels. As a run is initiated, the air from the storage tanks flows into the settling chamber. This flow is regulated by the control valve to maintain the desired stagnation pressure in the settling chamber and the noise and turbulence levels are reduced to acceptably low values by baffles and screens. The air then accelerates in the nozzle to give the desired test section Mach Number. After the air has passed through the test section, it is slowed down in the variable and fixed diffusers and finally discharged through an exhaust silencer to atmosphere.

The available speed ranges of the wind tunnel are as follows:

- (1) Subsonic $0.1 \leq M \leq 0.75$
- (2) Transonic $0.7 \leq M \leq 1.4$
- (3) Supersonic $1.4 \leq M \leq 3.5$

In the subsonic and transonic ranges the wind tunnel can be run at any desired Mach Number. For the supersonic range, nozzle settings for nominal Mach Numbers of 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.8, 2.0, 2.25, 2.5, 2.75, 3.0, 3.25 and 3.5. are available.

A brief description of the various wind tunnel components is given below.

Compressor Plant

The compressor plant houses two Ingersoll Rand Centac C70 centrifugal compressors, their drive

motors and the air drying beds. An 2500 horsepower synchronous motor drives each compressor. The compressors are provided with constant mass flow and back pressure regulation. Finally a thermostatically controlled aftercooler maintains constant delivery temperature. The remaining moisture after cooling is removed from the air by passing it through one of two silica gel filled vessels. Air filters downstream of the dryers limit the maximum particle size in the air to five microns. The air is delivered into the tanks with an absolute humidity of less than 0.2 grams of water per Kg of air.

Storage Tanks

The three storage tanks connected in series have a total capacity of 1985 m³.

The tanks can be charged, from empty, to the maximum pressure of 20 bar in about 98 minutes.

A 13.5 m long thermal matrix consisting of two section of 18 mm diameter steel tubes is placed near the outlet of the storage vessels to keep the outflow at nearly constant temperature, thus limiting Reynolds Number variations during a run.

Pressure Control Valve

The pressure regulating system is a fully automatic, electro-hydraulic control system, incorporating feedback techniques.

On initiation of a run the control valve opens rapidly to a pre-selected initial position to fill the settling chamber with minimum air loss. As the desired settling chamber pressure is established the valve closes partially and then opens gradually during the useful part of the run to compensate for the fall in reservoir pressure.

If the valve reaches its maximum open position the run ends and the valve closes rapidly to avoid any further loss of air from the reservoir.

The control valve is capable of maintaining the selected settling chamber stagnation pressure within 0.5% of the set value during a run over the range of blowing pressures.

Settling Chamber

Flow stabilising devices (conical centrebody, cruciform web and two dished perforated baffles) which reduce the disturbed airflow downstream of the control valve to a nearly uniform velocity distribution, are placed in the settling chamber entry diffuser.

A 5 meter long section of the settling chamber was intended to contain a noise silencer but its installation has been postponed for the time being.

The flow straightening section is a cylindrical pressure shell containing five turbulence reducing screens perpendicular to the tunnel axis to provide a steady, uniform low turbulence flow at the entry to the contraction. The screens are seamless steel wire mesh attached at the periphery to a pre-formed wire rope and held in position by spring supports mounted outside the shell. These supports permit the screens to be initially pretensioned and allow them to deflect when the tunnel is operating to keep stresses at a reasonable level. An inner shell provides a smooth boundary for the air flow and the wire rope and clamps are contained between the inner and outer shells.

The settling chamber ends in a fixed contraction that reduces the section from a 4024 mm diameter to an outlet of 1778 mm x 1199 mm to match the inlet to the flexible nozzle section.

Flexible Nozzle Section

The 10 m long vertical side walls of the flexible nozzle section are parallel and 1.2 m apart. Each of the top and bottom flexible plates is supported by 15 hydraulic jacks. The flexible plates can be set for subsonic operation or to any of the calibrated supersonic contours between Mach 1.1 to 3.5. The flexible plates are set to match any of the desired contours with slope errors not exceeding +/- 0.05 deg.

Transonic Section

The transonic test section is inserted in tandem between the flexible nozzle and the variable diffuser section.

The basic transonic section is a cylindrical pressure shell approximately 4 m in length which contains the perforated wall test section, surrounded by the plenum chamber.

Two alternate and interchangeable perforated wall test sections are provided, for three-dimensional and two-dimensional testing respectively.

The three-dimensional transonic insert has been modified to allow very low porosity values (0.35% minimum) in order to provide interference-free results at Mach numbers near 1.0 .

Variable Diffuser

The variable diffuser is mounted on two carriages and can be withdrawn from the flexible nozzle section or the transonic section, to permit access to the model, its mounting sting and the pitch mechanism.

For transonic Mach Numbers less than unity and for subsonic testing, the Mach number is set by adjusting the diffuser second throat area.

With the transonic section in circuit, the four flaps at the front end of the diffuser are set to give the desired ejector section, thus determining the amount of flow through the perforated walls and plenum chamber. In the transonic range the top and bottom flaps are used during the run as Mach Number control flaps being servo-operated for the plenum pressure control, together with a servo-operated blow-off valve, under computer control.

In the supersonic range the variable diffuser acts as a flat walled convergent-divergent diffuser.

Model Support

The model support consisting of a pivoted sting assembly and a translating vertical strut, is housed in the upstream end of the variable diffuser section.

The rear part of the strut is fixed to the diffuser, while the main front part of the strut can be moved up and down by means of a ball lead screw, driven by a hydraulic motor and servo valve.

As the strut moves up or down it operates the pitch angle mechanism housed within the strut.

The sting assembly pivots about the pitch pin, changing the incidence of the model between -15 deg and +25 deg in steps or continuously, without appreciably altering the vertical position of the model.

Bent stings or modified pitch mechanisms allow increasing the incidence angle range.

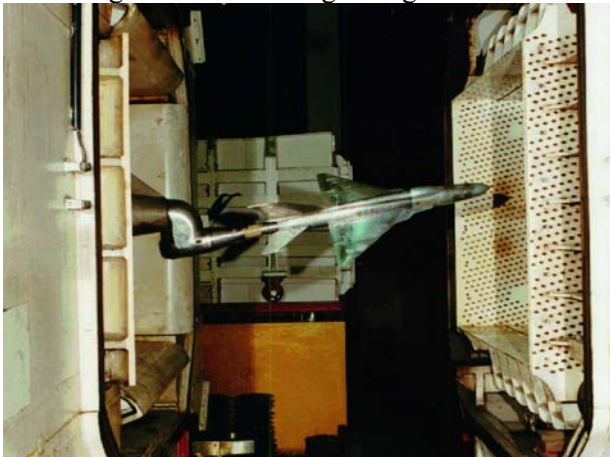


Fig. 2 . MIG-21 model

Fixed Diffuser and Outlet Silencer

The fixed diffuser is made in two parts. The front part is attached to the rear of the variable diffuser section and telescopes into the cylindrical part of the diffuser extension allowing the variable diffuser to move longitudinally and match with either the flexible nozzle or the transonic section outlet.

The air-flow passage transition from rectangular to circular cross-section is also made in this part. The

rear part of the diffuser extension is continued with the fixed diffuser, a concrete large area section and the outlet silencer.

Test Sections

At the downstream end of the flexible nozzle the top and bottom flexible walls become nearly parallel.

This part of the rectangular channel serves as the test section both in the supersonic and subsonic speed ranges, i.e. $1.4 \leq M \leq 3.5$ and $M \leq 0.75$ respectively. A pair of 750 mm diameter optical glass windows can be installed in the side walls for a Schlieren System.

The three dimensional insert, which permits testing models mounted on the strut support has a 1.2 m x 1.2 m flow channel, approximately 4 m in length and the effective test section is the downstream portion of this channel.

The walls are perforated by 10 mm holes inclined at 60 deg. The porosity of the walls may be adjusted at values continuously varying between 0.35% and 9.1% by means of pairs of perforated plates.

The slope of the top and bottom perforated walls can be varied from 2° convergence to 0.5° divergence. The cross flow through the walls and into the surrounding plenum chamber, which controls the Mach Number during a run, is determined by servo operated control flaps at the inlet of the variable diffuser and a blow-off valve piping.

Above the 3-D insert one can install a dorsal visualisation system (e.g. oil visualisation).

The two dimensional insert consists of perforated top and bottom parallel surfaces, 1.2 m apart. The side walls are convergent from the 1.2 m apart at the inlet to 0.48 m parallel through the test region. The model is mounted at both ends in circular sections of the vertical walls. Provision is made for remote pitching of the model by rotation of the circular sections and for readout of the pitch angle. A provision is also made for bringing out pressure instrumentation leads from the model.

A porous region on the side walls is provided with suction for removal of the boundary layer in the neighbourhood of the model roots.

The test section proportions permit testing of two dimensional wing models with a maximum chord of approximately 0.3 m and a span of 0.48 m .

Instrumentation

Force Measurements

Force and moment measurements (up to six components) are made with sting mounted internal strain gauge balances on any sting supported model. The capacities of the existing balances are shown below:

a) **2.00 MK XXVI TASK balance** with a 50.8 mm diameter and the following load capacity:

- normal force (at zero pitching mom.) 17800 N
- side force (at zero yawing mom.) 17800 N
- axial force 2670 N
- rolling moment 339 N.m
- pitching moment (at zero normal force) 1638 N.m
- yawing moment (at zero side force) 1356 N.m

b) **39 mm. diameter TEM balance** with the following load capacity (maximum single component loads, all others zero) :

- normal force 14000 N
- side force 9300 N
- axial force 2500 N
- rolling moment. 590 N.m
- pitching moment 435 N.m
- yawing moment 1000 N.m

c) **26 mm. diameter TEM balance** with the following load capacity:

- normal force 4670 N
- side force 2406 N
- axial force 711.5 N
- rolling moment. 19.2 N.m
- pitching moment 148.5 N.m
- yawing moment 65.5 N.m

Pressure Measurements

Pressure measurements are made with piezoresistive pressure transducers and force balance electro manometers installed in the model, wind tunnel walls or outside the tunnel. For a large number of pressure measuring points pressure scanning devices (scanivalves) are available. A detailed description of equipment is shown below:

- absolute pressure transducers with capacities from 4.14 bar to 13.8 bar and $\pm 0.05\%$ accuracy
- differential pressure transducer with a capacity of ± 1.03 bar and $\pm 0.05\%$ accuracy
- absolute pressure transducers with capacities from 0.69 to 6.9 bar and 0.25% accuracy ;
- differential pressure transducers with capacities from 0.34 bar to 13.8 bar and 0.25% accuracy.

Pressure distributions are determined using classical scanivalves and/or an electronic scanning device type ZOC 23B/32Px with 32 transducers of ± 50 psid capacity from Scanivalve Corporation.

Unsteady pressures are recorded using the miniature Kulite XCS-152-0.7 bar differential pressure transducers.

Transducers calibration is normally done by a secondary standard Texas Instruments 156 and periodically by a primary pressure standard Bell and Howel 6-201.

Schlieren System

The configuration of this system is the conventional "Z" arrangement with 30" diameter parabolic mirrors and additional plane mirrors to fold the system to enable it to fit with the ground position for the digital camera and light source units.

The Dorsal Visualization System

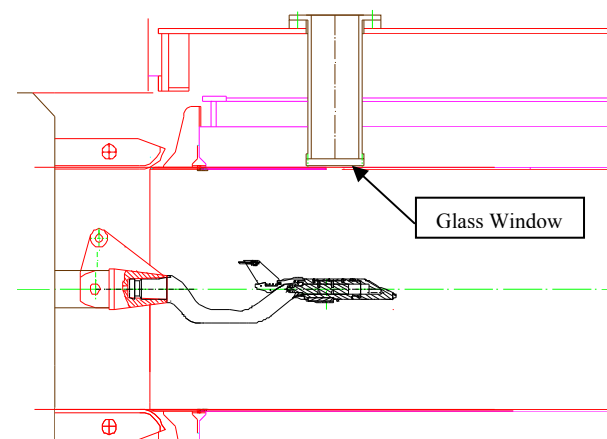


Fig. 3 . Dorsal Visualization System

The dorsal visualization system is based on a camera installed on top of the upper wall of the transonic 3D test section and allows the visualization of boundary layer separation and reattachment by means of a special paint applied on the model upper surface.

Hot Wire Thermoanemometry

The laboratory is provided with a DISA hot wire thermoanemometer with two measuring channels, each of them consisting of a 55M01 main unit, a 55M05 type power pack and a 55M11 booster adapter. The system contains also a 55H01 type traversing mechanism controlled by the 52B01 control unit and the 55D90 calibrating equipment consisting of the 55D45 nozzle unit, the 55D44 pressure control unit and the 55D46 pressure converter.

The system is provided with hot wire and hot film probes allowing measurements of mean and fluctuating velocities from a few cm/sec. to 350 m/sec (Mach = 1).

The Captive Trajectory Simulation system

A 3 degree of freedom CTS system allows the simulation of store trajectories in a vertical plane through the attachment pylon. The carrier aircraft model is fixed on the upper wall of the transonic test section and a robotic arm allows the horizontal and vertical movements of the store model and also the variation of its angle of attack.



Fig. 4 . Captive Trajectory Simulation system

The High Pressure Jets Equipment

The experimental apparatus available for the generation of high pressure jets includes a four stage, 225 bar air compressor, a group of air bottles with a total volume of 1 cubic meter, pipes, flexible ducts, control valves, pressure gauges etc.

Data acquisition system

The wind tunnel is equipped with a high speed, high accuracy data acquisition system controlled by a PC computer.

The data acquisition system has 64 analogue input channels with high accuracy instrumentation amplifiers and low-pass filters. The transducers are connected with high stability signal conditioners for RDT, thermocouples and strain gage.

The analogue to digital converter has a 12 bits resolution (1/4095) and maximum sampling speed up to 500,000 samples/sec.

The overall system accuracy (excluding transducers) is better than 0.1% .

The Data Acquisition System is based on an Industrial PC with a 14 slot chassis, P II Celeron

433 MHz, 64MB DIMM, 3.5 inch FDD, 20GB HDD, equipped with the following data acquisition and control modules:

- National Instruments AT-MIO-64E-3 data acquisition board with 64 analogue input channels, 12 bit A/D converter, max. speed 500,000 conversions per sec., 2 analogue outputs, digital inputs/outputs, counters / timers ;
- Keithley Metrabyte PIO - 96 digital input / output board.

The signal conditioners / amplifiers / filters are of the following types:

- MOXON SRC signal conditioners, constant voltage excitation 0 - 10 VDC (cont. adjustable), regulation : 0.005% FS, constant current excitation 1 - 50 mA (cont. adjustable), regulation : 0.01% FS, balance adjustment: 0.01% resolution;
- SCXI - 1120 National Instruments isolation amplifiers, gains: 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000, 0.15% gain accuracy, low - pass filters 4 Hz or 10 kHz, $\pm 5V$ output;
- SCXI - 1121 National Instruments isolation amplifiers with excitation, the same as SCXI-1120 plus: constant current 0.15 mA \pm 0.04% or 0.45 mA \pm 0.2%, max. load 10 k Ω , or constant voltage 3.333 V \pm 0.04% at 28 mA or 10 V \pm 0.2% at 14 mA;
- SCXI - 1141 National Instruments anti-aliasing filters, programmable cut-off frequency from 10 Hz to 25 kHz and programmable gain from 1 to 100.

The system software consists of on-line programs for Wind Tunnel control and data acquisition and extensive after run data reduction and presentation software.

The blow-down control system

The blow-down control system is controlled by computer and consists of the following sub-systems:

- the pressure regulating valve control subsystem
- the transonic Mach number control (top and bottom flaps and blow-off valve) subsystem
- the software protection against overloading the balance and sting
- the model angle of attack control subsystem
- the blow - down sequence control subsystem
- the Schlieren control subsystem
- the scanivalve control unit.

Performance

The number of runs per day will depend upon the configuration changes involved in a particular test programme and also on the length of the run chosen, i.e. the amount of air used in a run.

The period between runs for recharging will normally be approx. one hour, since the tanks are never fully exhausted.

Running experience has demonstrated that an overall average of at least six runs per day (including model rigging) may be expected.

The run times vary from 5 seconds to several minutes, depending on the test regime. Run time diagrams together with the Reynolds number envelopes for the 3D and 2D cases are shown in Figs. 5 and 6 .

The maximum Reynolds number capability of the tunnel is very high - up to 100 millions per meter in the 3D test section and up to 150 millions per meter in the 2D test section, provided that the balance, model and sting can resist the corresponding aerodynamic forces.

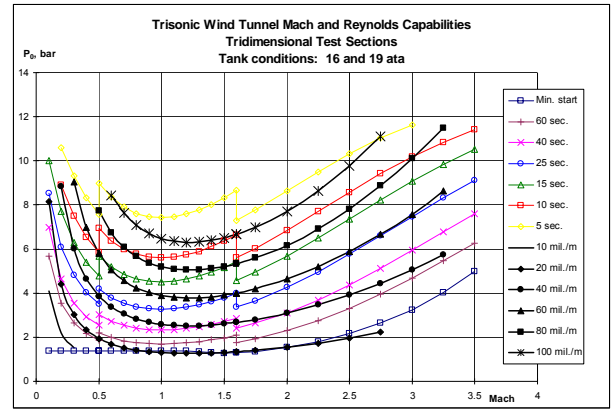


Fig. 5 . Mach - Reynolds Capability, 3D Test Sections

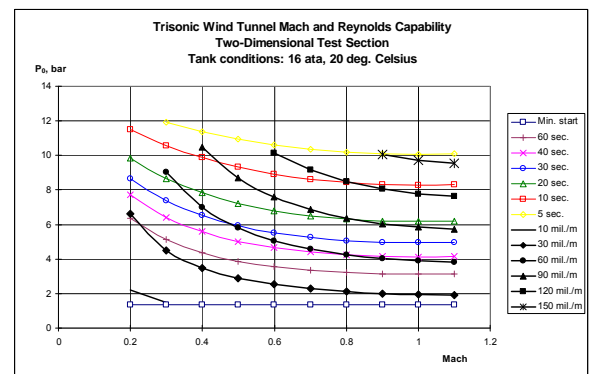


Fig. 6 . Mach - Reynolds Capability, 2D Test Section

This high Reynolds number capability was ensured by providing two maximum limits for the tank pressure - a high one (19 bar) for transonic 3D regime and a lower one (16 bar) for the rest.