TRAINING CENTER FOR EXPERIMENTAL AERODYNAMICS

TECHNICAL MEMORANDUM 9

TURBOMACHINERY LABORATORY

by

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The seven facilities at T.C.E.A. in support of its programme of teaching and research were formerly in operation at the NASA Center at Langley Field.

This equipment comprises a subsonic and supersonic calibration-duct, a subsonic, a transonic and a supersonic cascade tunnel, and a low-speed and a high-speed rotor test stand.

These facilities, not all of which are yet installed and in working condition, are located on the groundfloor of the building formerly housing the large Eiffel wind tunnel (see fig. 1).

A new disposition is planned in view of the foreseen development (fig. 1 bis).

A detailed description of the main items (including a statement of its present condition and the present plans for its improvement and restoration) and of their ancillary equipment is given below. Equipment missing to bring the high-speed tunnels up to an operating state is also listed.

In addition to these facilities, a water compressor, obtained from Fluid Dynamics Research Laboratory, Wright Field, is expected within a few months.
I. LOW SPEED FACILITIES

These facilities are in a running state and are being used for instruction and research.

The equipment, which is installed in a single room, consists of:

1. The low-speed instrument calibration duct, L-4.
2. The low-speed cascade tunnel, C-1.
3. The low-speed rotor test stand, R-1.

1. Low-speed instrument calibration duct, L-4 (fig. 2).

Purpose: calibration and development of instruments for flow survey.

Description: It is essentially a small wind tunnel having a circular test section, 8 inches in diameter. It has a non-return arrangement with atmospheric intake and exhaust.

It is driven by an axial-flow fan powered by a 75 HP d.c. motor, fed from an M.G. set described below.

The maximum velocity is about 400 ft/sec.

It is equipped with four instrument ports, and a set of hand-driven instrument carriages allowing translation and rotation in one or two directions.

2. Low-speed cascade tunnel, C-1 (Fig. 3).

Purpose: Development of blade section, and investigation of primary and secondary flows in cascade.
Description: The tunnel has a rectangular test section 5 x 20 inches. It has a non-return arrangement with atmospheric intake and exhaust.

It is driven by a centrifugal blower, powered by a 25 HP d.c. motor, fed from an M.G. set.

The maximum stream velocity is about 130 ft/sec.

The tunnel can be equipped with both solid and porous side walls in the test section (the latter, for boundary-layer removal). Slots in the side walls, ahead of the test section complete the boundary-layer removal system.

Top and bottom walls are porous and deformable.

Usually, sets of 7 blades are used. The inlet direction to the blades can be changed by steps, using triangular insert plates. The blade spacing can be changed by steps. The blade angle of attack can be changed continuously.

Auxiliaries: A 60 HP suction blower is used for boundary-layer removal. Independent control of the amount of suction is provided for each porous wall or slot. The tunnel is equipped with two instrument carriages, one giving a translation parallel to the cascade alignment, and a rotation around an axis parallel to blade height, the other one giving the same translation and rotation, plus translation parallel to the blade height and parallel to the blade chord.

A new carriage, remotely actuated is on the drawing board.

Instrumentation: Consist of sets of combined pitot-static and directional probes. Betz manometers, electrical manometers, and pressure gauge are used.

Hot-wire probes are being developed.
3. **Low-speed rotor test stand, R-1 (fig. 4).**

**Purpose:** At the moment, study of low-speed single rotor performance, such as investigation of blade loadings, tip clearance losses, correlation with cascade data. To be modified later to allow complete stage study.

**Description:** The machine has in its actual configuration, a rotor tip diameter of 28 inches, hub diameter of 22 inches. It has a non-return arrangement with atmospheric intake and exhaust.

It is driven by a 75 HP d.c. motor fed from an M.G. set. The maximum r.p.m. is 3,600 corresponding to a maximum tip speed of 440 ft/sec.

It is equipped with 4 instrument ports in front and behind the rotor.

Continuous r.p.m. control is supplemented by a throttling valve in the exhaust pipe. Blade number and angle of attack can be changed.

**Instrumentation:** is the same as for the low speed cascade tunnel.

**Planned modification:** it is planned to fit I.G.V. (inlet guide vanes) and a stator to allow stage study.

Other hub configurations will be used also to allow greater tip to hub ratios.

Ultimately, another test section will be fitted. Axial velocity will be provided by an axial flow fan and the existing motor. The rotor will be driven by an independent motor, this providing a wide range of flow coefficient. I.G.V. and stator will be fitted.
5. **Power supply for the low speed facilities.**

The three facilities are fed by the same M.G. set, consisting of a 325 HP AC motor driving two 150 HP generators.

Speed control in the tunnel is obtained by action on both tunnel motor and generator excitation.

This arrangement allows the operation of two of the tunnels independently at the same time.

4. **Water compressor, R-3.**

**Purpose:** Visualization of flow phenomena occurring in axial-flow turbomachinery such as tip clearance flow, rotating stall propagation, blade row interference.

**Description:** Is essentially a three stage axial flow pump using water as a working fluid. It is of the closed circuit type. Constant hub and tip diameters are maintained throughout (hub dia.: 8.3 inches - tip dia.: 11.4 inches).

The test pump is driven by a 2 HP variable speed D.C. motor, with a maximum r.p.m. of 400. A booster pump, driven by a 3 HP motor makes up line losses.

A butterfly throttle valve is provided in the circuit. Instruments ports are available for survey behind any blade rows.

A system for injecting a colored tracer is built-in.

Blade setting angle and blade row spacing are variable.

**Instrumentation:** Will have to be developed at the Center.
II. HIGH SPEED FACILITIES

With the exception of the high speed rotor-test stand R-2, these facilities are not yet installed.

The equipment consists of:

1. A high-speed instrument calibration wind tunnel, S-4.
2. A transonic cascade wind tunnel, C-2.
3. A supersonic cascade wind tunnel, C-3.

This equipment is stored in individual cubicles, in building A, adjoining the low-speed facilities hall.

1. **High speed instrument calibration wind tunnel, S-4.**

**Purpose:** Calibration and development of flow surveying instruments in the compressible regime, subsonic and supersonic. The dimensions (see below) of the test section make it usable for other purposes than instrument calibration.

**Description:** The tunnel has two alternative test sections, one subsonic and one supersonic.

The **subsonic test section** (fig. 5) is rectangular 8 x 15 inches and is equipped with a variable diffuser, which is remotely controlled. It has instruments ports on the side walls. Two of them can be replaced by glass windows.

The **supersonic test section** (fig. 6) is square 8 x 8 inches. It is of the variable Mach number, slinding block nozzle type. The range covered is from $M = 1.3$ to 2.7. The sliding block mechanism is actuated
by a remote controlled motor.

The test section is equipped with a glass window and 2 instrument ports. One of them can be replaced by a glass window. In this configuration, a Schlieren system can be used.

**Present State**: The tunnel is stored, dismantled in its cubicle. It is complete, from the inlet pipe to the settling chamber to the exhaust pipe and can thus be linked to any suitable air supply.

**Air Supply and Ancillaries**, such as exhausters are missing at the moment.

2. **High speed cascade wind tunnel C-2** (Fig. 6).

**Purpose**: obtain high speed cascade data for optimum compressor and turbine design in the compressible range. It is suitable to provide data for fundamental investigations of the effect of cascade parameters on high speed performance and operating range.

**Description**: The test section is rectangular, 7 x 20 inches. The Mach number range is from 0.3 to 1.2. The tunnel has a variable area remote controlled nozzle, and is equipped with a top slotted wall and a bottom deformable porous wall, with provision for boundary-layer suction.

The quantity of air required varies as a function of Mach number, stagger angle and number of blades. Representative quantities are:

- **Maximum flow**: approximately 70 lbs/sec. air at 15 psig.
- **Normal operating quantities**: 45 lbs/sec. at 8 psig.
Side walls are equipped with slots. The test section side walls are either glass wall, for Schlieren system use or porous for boundary-layer removal.

The whole test section is rotating, providing for continuous variation of stagger angles. The blades, usually 7 of them, are inserted, in plates, with a fixed angle of attack. Series of blades are available.

The tunnel is suitable for testing compressor and turbine bladings. Provision is made for testing of impulse blades.

Independent control of suction, for each wall or slot, is realized by means of remote controlled valves.

Survey instrumentation: A remote controlled instrument carriage is available for wake survey. It provides a translation parallel to the cascade alignment and a rotation around an axis parallel to blade height. Probe position can be adjusted span-wise.

Instruments available include combined pitot-static directional probes and temperature probes.

Present state: The tunnel is stored, dismantled in its cubicle. It is complete, from the inlet pipe to the settling chamber to the exhaust pipe and can thus be linked to any suitable air supply.

3. Supersonic cascade tunnel, C-3 (fig. 7).

Purpose: to determine optimum shapes for transonic and entirely supersonic blades as well as to investigate shock-wave boundary-layer interaction.
Description: The tunnel has a rectangular test section, 6 x 10 inches. It is equipped with asymmetrical nozzle blocks for $M = 1.5, 1.8, 2.0, \text{ and } 2.25$.

Air flow requirements: 30 lbs/sec. at 15 psig.

45 lbs/sec. at 45 psig.

Present state: The tunnel is stored, dismantled in its cubicle. It is complete, from the inlet pipe to the settling chamber to the exhaust pipe and can thus be linked to any suitable air supply.

Air supply: is missing at the moment.

No boundary-layer removal is provided.

Glass side walls allow the use of a Schlieren system. As in C-2, the whole test section is rotating for continuous variation of stagger angle.

The tunnel is suitable for testing of compressor and turbine blading. Provision is made for testing of impulse blades.

Survey instrumentation: A remote controlled instrument carriage is built in for wake survey. It provides a translation parallel to the cascade alignment. Rotation of the probes around an axis parallel to the blade height is made by hand at the moment.

Air Supply for S-4, C-2, and C-3.

As stated above, the air supply system for these tunnels is missing. The most economic solution is to have a common single supply. Originally at Langley, these facilities were run at atmospheric
11. pressure, but it is proposed to make some structural modifications to the tunnels and to operate them at low pressure, thus lowering the power requirement to some 2000 Kw.

Exhausters of a total power of 500 Kw are required for air evacuation and boundary layer control.

4. High speed rotor test stand.

Purpose: Actually suitable to obtain fundamental information on axial flow compressors in the compressible range from experiments on a single rotor, or a single stage.

Description: The stand consists of a closed test loop which can be operated at various pressures and with gases other than air.

Rotor tip diameter is 16" hub diameter 12". Maximum rotor tip speed is 1000 ft/sec., max. r.p.m. 17,500.

It is driven by a 250 HP D.C. motor fed by the M.G. set used for the low-speed equipment, but this time, with the two generators coupled in parallel. Speed is controlled by acting on the generators' excitation.

Flow is controlled by means of a combined drum-butterfly valve, remotely actuated.

The test section has glass window and instrument ports aft and fore the single rotor.
The whole cover of the test section can rotate (including the instrument supports) allowing to survey the wake at different circumferential positions. The driving motor is of the dynamometer type. A pressure type torque measuring device is available.

Instruments available include combined pitot-static and directional probes, temperature and total pressure rakes.

This piece of equipment was used in the early investigation on supersonic rotors. The medium was Freon gas.

State of equipment: The test stand is now complete, with its auxiliaries, and the run-in tests are about to start.

Tunnel instrumentation is not yet fully realized. A remote controlled instrument carriage and several manometers are on order.

Two high speed rotors are available for testing.

A complete stage for research on tip losses is on the drawing board.
<table>
<thead>
<tr>
<th>FACILITY</th>
<th>TEST SECTION</th>
<th>SPEED RANGE</th>
<th>POWER</th>
<th>SPECIAL FEATURES</th>
<th>CONDITION</th>
<th>MISSING ELEMENTS (excluding power supply)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>Low-speed instrument calibration duct</td>
<td>Circular dia. : 5&quot;</td>
<td>up to 400 ft/sec.</td>
<td>75 HP D.C. motor</td>
<td>Operating</td>
<td>Flexible top and bottom walls. Boundary-layer suction on all walls. Variable incidence and stagger angles, and variable blade spacing.</td>
</tr>
<tr>
<td>C-1</td>
<td>Low-speed cascade tunnel</td>
<td>Rectangular 5&quot; x 20&quot;</td>
<td>up to 130 ft/sec.</td>
<td>25 HP D.C. motor</td>
<td>Operating</td>
<td>Flexible top and bottom walls. Boundary-layer suction on all walls. Variable incidence and stagger angles, and variable blade spacing.</td>
</tr>
<tr>
<td>R-1</td>
<td>Low-speed rotor test stand</td>
<td>Circular Hub dia. : 22&quot; tip dia. : 28&quot;</td>
<td>Tip speed up to 440 ft/sec.</td>
<td>75 HP D.C. motor</td>
<td>Operating</td>
<td>Equipped with adjustable exhaust valve.</td>
</tr>
<tr>
<td>9-3</td>
<td>Multi-stage water compressor</td>
<td>Circular Hub dia. : 6.3&quot; tip dia. : 11.4&quot;</td>
<td>Tip speed up to 38 ft/sec.</td>
<td></td>
<td>On order</td>
<td>Instrumentation.</td>
</tr>
<tr>
<td>S-4</td>
<td>High-speed instrument calibration wind tunnel</td>
<td>Rectangular Subsonic: 8&quot; x 15&quot; and Supersonic: 8&quot; x 8&quot;</td>
<td>( M &lt; 1 ) and ( 1.2 &lt; M &lt; 2.7 )</td>
<td>Variable diffuser. Sliding block nozzle.</td>
<td></td>
<td>Dryer, exhausters. Modification necessary to work below atmospheric pressure. Instrumentation (Schlieren and pressure measuring devices - Instrument carriages).</td>
</tr>
<tr>
<td>C-2</td>
<td>High-speed cascade wind tunnel</td>
<td>Rectangular 7&quot; x 20&quot;</td>
<td>( 0.3 &lt; M &lt; 1.2 )</td>
<td>Variable area nozzle. Top wall slotted. Bottom wall porous and flexible. Boundary-layer suction on bottom and side walls. Variable incidence and stagger angles, and variable blade spacing.</td>
<td>Stored dimethyl. No power supply available. Driven with driving motor required.</td>
<td>As for S-4, plus boundary-layer suction device (ejector or exhauster).</td>
</tr>
<tr>
<td>C-3</td>
<td>Supersonic cascade tunnel</td>
<td>Rectangular 6&quot; x 10&quot;</td>
<td>( M = 1.5, 1.8, 2.0 ) and 2.25.</td>
<td>4 asymmetrical nozzle blocks Variable stagger angle.</td>
<td>As for S-4.</td>
<td></td>
</tr>
</tbody>
</table>
T.C.E.A. EXPERIMENTAL FACILITIES.

Fig1. TURBOMACHINERY LABORATORY

Low Speed Wind Tunnels.  L4, C1, R1.
High Speed Wind Tunnels.  S4, C2, C3.
High Speed Rotor Test Stand.  R2.
High Pressure Air Supply.  H.P.A.S.
Hypersonic Tunnel.  H1.

Operational.  [Blank Box]
To be Installed.  [Filled Box]
Fig. 1 bis. TURBOMACHINERY LABORATORY.

PLANNED DISPOSITION. Ground Floor.
High Speed Equipment Installed.

High Speed Wind Tunnels. S4, C2, C3.
High Speed Rotor Test Stand. R2.
Hypersonic Tunnel. H1.
High Pressure Air Supply. H.P.A.S.
Motor Generator Set. M.G.
Motor Compressor Set. M.C.
Exhausters. Exh.
Cooling Tower. C.T.
Master Control. M Cont.
Local Control. L.C.
T.C.E.A. EXPERIMENTAL FACILITIES.

Fig. 1bis. TURBOMACHINERY LABORATORY.

PLANNED DISPOSITION. First Floor.

Water Compressor R3.
Figure 2

Low speed instrument calibration duct - L-4

Power: 75 HP D.C. motor driving an axial flow fan.
Test section: circular, 8" diameter.
Maximum velocity: 440 ft/sec.
Speed control: Continuous by control of both motor and feeding generator excitation.
Low speed cascade tunnel - C-1

Power: 25 HP D.C. motor driving a centrifugal blower.
Test section: rectangular 20" x 5".
    solid and porous side walls - additional slots -
    porous and deformable top and bottom walls.
Speed control: continuous by control of both motor and feeding
generator excitation.
Maximum velocity: 130 ft/sec.
Number of blades: usually 7

Inlet flow direction blade, angle of attack and spacing variable.
Suction blower for boundary layer removal, with independent control for
each wall or slot.
Low speed rotor test stand - R-1

Power : 75 HP D.C. motor
Rotor configuration : hub diameter 22"
tip diameter 28"
Maximum rpm : 3,600
Maximum tip speed : 440 ft/sec.
Speed control : continuous by control of both motor and feeding generator excitation. Blade number and angle of attack variable. The test stand is equipped with an exhaust throttling valve.
Figure 5

Subsonic configuration - S-4

Rectangular test section 15" x 8"
Variable, remote controlled diffuser.
Figure 5 bis

Supersonic configuration - S-4

Squared 5" x 5" test section
Variable Mach number, sliding block type, remote controlled
Mach number range: 1.3 to 2.7
Air supply 30 lbs/sec. at 15 psig
    45 lbs/sec. at 45 psig required
Glass window for Schlieren system.
High speed cascade tunnel - C-2

Rectangular test section 7" x 20"
Variable nozzle type
Mach number range 0.3 to 1.2
Typical air flow requirements: Max 70 lbs/sec. at 15 psig
                             Normal 45 lbs at 8 psig
Variable stagger angle and angle of attack
Built in survey apparatus
Glass window for Schlieren system.
Figure 7

**Supersonic cascade tunnel - C-3**

Rectangular test section 6" x 10"
Asymmetrical nozzle blocks for M = 1.5, 1.8, 2.0 and 2.5
Air flow requirements : 30 lbs/sec. at 15 psig
45 lbs/sec. at 45 psig.
Variable stagger angle
Built-in survey apparatus.
Figure 8

High speed rotor test stand - R-2

Closed loop variable density, variable medium tunnel
Hub diameter 12"
Tip diameter 16"
Maximum tip speed 1000 ft/sec.
Power: 250 HP dynamometer motor, driven by an MG set
Speed control: by action on generator excitation.
A description of the facilities at TCEA for research in the field of turbomachinery is given. Both low and high speed equipment is available. The low speed facilities include an instrument calibration duct, a cascade tunnel and a rotor test stand now in operation. A multistage water compressor will be added soon.

(over)

1. Low speed facilities.
2. High speed facilities.

I. CHAUVIN, Jacques
II. TCEA TM 9.
<table>
<thead>
<tr>
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<tr>
<td>étage sera installé prochainement.</td>
<td>Of the high speed facilities, a high speed rotor test stand is in operation, and an instrument calibration tunnel, a high speed cascade tunnel, a supersonic cascade tunnel have yet to be installed.</td>
</tr>
<tr>
<td>Les souffleries à hautes vitesses comprennent une soufflerie d'étalonnage, une soufflerie à grille d'aubes à haute vitesse, une soufflerie supersonique à grille d'aubes, non encore installées, et une installation d'essai pour rotor qui sera mise en route début 1961.</td>
<td>For each tunnel, the technical data's, the range of utilisation, the instrumentation and the planned modifications are given.</td>
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<td>Pour chaque tunnel, on donne les caractéristiques techniques, le domaine d'utilisation, les instruments de mesure disponibles et les perfectionnements envisagés.</td>
<td>Copies disponibles au CFAE, Rhode-St-Genèse, Belgique.</td>
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Copies available at TCEA, Rhode-St-Genèse, Belgium.
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