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Initial

SUBJECT Report of a visit to Pasadena and Moffett Field, May 13 - 21, 1952.

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ISSUED TO Internal

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1. U.S. Navy Symposium on Aeroballistics, Pasadena, May 13-15, 1952.

1.1 The Symposium consisted of 4 technical sessions and an all day visit to N.O.T.S., Inyokern. The texts of papers, together with the discussions, are to be distributed later to the participating organizations. Some remarks concerning papers of particular interest to ourselves at present are given below, together with additional references.

1.2 Aerodynamic interference of the parent aircraft and air-launched missiles. Two papers were given on the above subject. The first,

> "some aerodynamic interference effects of the parent aircraft on air-launched missiles" by M.W. Hunter and R.W. Luce of the Douglas Aircraft Co.(BuAer Project Sparrow) * dealt with theoretical and experimental work on launching of Sparrow missiles from XF3D aircraft, the missiles being underslung, and located alternatively at 6.5, 8.5 and 12.5 ft. from the a/c centerline. It was found that, due to flow induced by the aircraft wing, the missiles would rotate in pitch and roll after launching. The calculated wing induced angle of attack amounted to about 5° max. and this caused serious missile rotation in pitch, necessitating a 0.1 sec. arming delay in order to ensure aircraft safety.

* Additional references:

J.C. Stamper, R.W. Luce — Interim report on an examination of the effects on launching of the Sparrow II missile of the aerodynamic interference between the airplane wing, launching pylon and missile. Douglas Aircraft Co. Rep. SM14120, 26 Oct. 1951

J.C. Stamper, R.W. Luce, E.J. Velton — Effects of aerodynamic interference of a parent aircraft on the Sparrow II missile. Douglas Aircraft Co. Rep. SM14383 (To be published)

Douglas Aircraft Co. Rep. SM 14334 -Subsonic Sparrow Tunnel tests.

From the point of view of rolling motion, a shorter delay would have been satisfactory.

At 5000 ft. altitude, M = 0.91, the missile rotated in pitch at 100°/sec, using a short launcher. The rate of rotation was reduced to ¼ using 1 ft. launching rails and eliminated with 3 ft. rails.

At 20000 ft. altitude, M = 0.7, the rotation in pitch amounted to 25°/sec. (standard launcher).

The above results were in general agreement with wind tunnel tests carried out at NACA Langley over transonic speed range.

In the discussion of this paper Dr. MacPhail suggested that in order to avoid pitching motion the missile wings could be preset to compensate for the wing induced angle of attack. This apparently was not considered by Douglas Aircraft Co., the wings being presumably locked during the propulsion phase.

The second paper:
"The effect of missile jet discharges on the aerodynamics of the launching aircraft" by J. Goldsmith, U.A.C., BuAer Project,* dealt with the problem of jet-wing interference and was based on simulated, small scale, wind-tunnel tests. A maximum increase in lift amounting to $\Delta C_L = 0.04$ was observed on a half wing with jet located at 15% chord above the wing. On the basis of calculations for a 17000 lb. a.u.w. aircraft

* Additional references:

J. Goldsmith, J.L. Moulton — Effect of missile jet blast on the aerodynamics of the launching aircraft. U.A.C. Research Dept. Report No. 95438-10, 1-4-52.

carrying a 2000 lb. missile it was suggested that dangerous rates of aircraft roll may result with a missile climbing at a suitable, slow rate. However, it was felt that the extreme example quoted (very light aircraft and a heavy missile) was rather unrealistic and that there was as yet no proof that the problem was a serious one in practice. Moreover, the calculations were based on wind tunnel data averaged out for positions of jet nozzle up to six wing chords ahead of the wing - again a rather doubtful procedure.

1.3 "Thrust axis control of supersonic nozzles by jet shock interference" by G.F. Hausmann and J.T. Corso, U.A.C., Project Meteor.

This paper dealt with control of rockets and boosters in accelerated flight at low velocities, at which external aerodynamic control surfaces are ineffective. As an alternative to jet-vane controls (as used in V2 and difficult to arrange in view of high temperatures), deflection of supersonic jet inside the nozzle by means of small, high pressure gas jets discharging into the nozzle was proposed and experimentally investigated. It gave very satisfactory results (large side thrust components) and a complete control system was proposed using four equally spaced orifices and a tubular high pressure gas container.

1.4 Aerodynamic data on cruciform missile configurations.

A series of six papers dealt with various aspects of the above subject, including wing-body-tail interference and aero-elastic effects for movable wing and fixed wing designs. Extensive tunnel results (C.A.L. and A.D.L.) were compared with theoretical estimates, in some cases at angles of attack reaching 25°.

It is the writer's impression that in the present stage of development of cruciform missiles there is enough fundamental (general and detailed) data available for aerodynamic design purposes and that therefore further work on such projects should be restricted to tests of specific designs.

1.5 The final session of the Symposium was devoted to hypersonics and papers dealing with hypersonic tunnels, flight of ultra-speed ($M \approx 15$) pellets, relaxation phenomena, etc., were presented. Some progress has been made with operation of small hypersonic tunnels and reliable boundary layer measurements are now being obtained at large Mach Numbers. However, the difficulties of operation and design of hypersonic tunnels of any size running at high temperatures and stagnation pressures, are still immense and a large proportion of effort is devoted to tunnel development rather than testing.

1.6 Visit to U.S. Naval Ordnance Test Station, Inyokern.

The main activities of N.O.T.S. are the development of solid propellant rocket weapons and open-air range testing of rocket projectiles and missiles. The Terrier range was inspected and a demonstration round of 2.75" FFAR (Folding Fin Aircraft Rocket) was seen fired from a 6° ramp, boosted to 750 ft./sec. The rocket was said to attain 3000 ft./sec. velocity and 7500 yards range.

The new, enclosed, atmospheric shooting range was visited. It is 480 ft. long and about 30 x 40 ft. in cross-section. The large cross-sectional area is provided in order to accomodate models which are unstable, particularly at transonic speeds. Over 20 photographic stations are installed, two cameras being mounted at each station, their optical axis making an angle of about 90°, as indicated in fig. 1. Wide-angle cameras cover the whole trajectory and six exposures (on one plate) are taken by each camera with the aid of a timed flashing unit. The photographs, as indicated in fig. 1, are taken by reflected light and a bright background is obtained with Scotchlite reflectors. The flashes are triggered by projectile passing lightscreens before each photographic station. It is claimed that the projectile position can be determined to within 0.0001 in. from the negatives - however, no satisfactory explanation was given of the method to achieve this high order of accuracy.

2. Visit to the Jet Propulsion Laboratory, May 16, 1952.

2.1 A brief visit was paid to JPL[x] and their two supersonic tunnels, 12" and 20" square, were seen. From the point of view of accuracy of measurements and instrumentation, the JPL tunnels are probably the best in the U.S.A. Both tunnels are fitted with flexible nozzles (the larger one has a completely automatic jacking system) which appear completely satisfactory and operate over a very wide Mach No. range (up to 4.9 in 20 in. tunnel). The 12 in. tunnel is driven by 4000 h.p. compressors and 16000 h.p. is used for 20 in. tunnel (60 p.s.i. at M = 4.9). A 3-component strain gauge balance is used in the 12 in. tunnel and a mechanical 6-component balance, mounted on solid flexures and using hydraulic pick-ups is mounted in the 20 in. tunnel. Pressures are measured on multi-tube, silicone oil manometers connected to a low reference pressure and manifolds are arranged so that no fluid will enter the pressure lines in case of vacuum failure or sudden decrease of tunnel pressure.

2.2 The flexible nozzle design is similar in both tunnels and consists of a solid steel plate with integral lugs to which jacks are attached with pins[xx], see fig. 2. This design is highly satisfactory but not free from transverse distortion of the plate, due to effects of edges and lack of lug support at edges,

x Discussions were held with:
Dr. Louis Dunn, Director
Mr. Frank Goddart, Head, Wind Tunnel Section
Mr. Barnett, i/c 12" Tunnel
Mr. Howard, i/c 20" Tunnel

xx For details see "Design and operation of a 12 in. supersonic wind tunnel" by A.E. Puckett, I.Ae.Sc. Preprint 160, 1948 the transverse deflection amounting to some 0.005 in. However, this has no adverse effect on flow distribution.

As regards the aerodynamics of nozzle design, a difficulty was encountered in matching theoretical design profile and shape obtainable with the flexible wall. The nozzles were designed with a straight profile downstream of the throat and therefore a discontinuity in curvature occured where the concave profile started. The flexible wall produced of course a continuous curvature and as a result a shock and expansion system was observed at the beginning of the test
Except for this region the flow distribution was however satisfactory.

2.3 In the Wind Tunnel Section of JPL a total of about seventy people are employed, with about 20 professionals. About 70% of tunnel time is devoted to specific project tests while 30% is reserved for coping with breakdowns and fundamental work.

2.4 Basic research on skin friction and heat transfer on a flat plate, using a direct friction force measuring technique, is in progress in the JPL tunnels.

3. Visit to N.A.C.A. Ames Aeronautical Laboratory, May 19 and 21, 1952

3.1 The object of this visit was to discuss the design of large, high speed wind tunnels and wind tunnel testing technique at transonic speeds.* In addition, several high speed and hypersonic tunnels were inspected and their features discussed. Some of the tunnels installed at Ames Lab. are listed below. The total installed power (at present) amounts to 110000 h.p.

* General discussions were held with Dr. Henry J. DeFrance, Director and Mr. Bioletti, Assoc. Director.

10 x 14 in.^{2} Hypersonic Tunnel - open circuit	
6 x 6 ft.^{2}, $M \doteq 2$, Supersonic Tunnel, Sliding Block nozzle	closed circuit
16 ft. dia. $M \leq 1$, H.S. Tunnel, converted to slotted W.S.	closed circuit
1 x 3 ft.^{2}, Supersonic Tunnel, Flexible nozzle	closed circuit
12 ft. dia., variable density, H.S. Tunnel	closed circuit
1 x 3 ft.^{2}, Free flight supersonic tunnel	Driven from 12 ft. dia. tunnel used as air resevoir (6 at. pressure)
1 x 3 ft.^{2}, Supersonic Tunnel	Driven from 12 ft. dia. tunnel used as air resevoir (6 at. pressure)

3.2 <u>10 x 14 in.^{2} Hypersonic Tunnel</u>

The drive arrangement of this tunnel is unusual and, as shown in fig. 3, consists of centrifugal compressors at intake giving 6 at. and Fuller pumps in parallel with aircraft type superchargers connected to the diffuser. The tunnel circuit is "open" and diffuser flow is split by means of boundary layer scoops (on two walls only), which collect low total head air, compressed by Fuller pumps. The main tunnel flow passes through aircraft type turbo-superchargers driven by 6 at. air from the intake compressor.

The nozzle blocks are fixed and, in order to change Mach Number, they are rotated about the exit to obtain suitable throat gap. Apparently this crude method of Mach No. variation produces satisfactory flow down to $M = 2.5$ or 3.

The diffuser proper has a variable throat and the tunnel is started with both nozzle and diffuser widely open, i.e., at an effective low Mach No.

Although referred to as "hypersonic", this is essentially a supersonic tunnel limited by both pressure ratio and temperature available (350°F max.) to Mach No. of about 6. It has been mostly used for force and pressure distribution tests on bodies of revolution.

3.3 1 x 3 ft.^{2} Free Flight Tunnel

This is a semi-continuous, open circuit tunnel which runs off the 12 ft. dia. tunnel used to store 600000 ft.^{3} of air at 6 at. A throttle valve is used to vary Reynolds No. The free flight tunnel has solid nozzle blocks for M = 2 and 3 and a long (about 18 ft.) working section instrumented with 4 photographic and timing stations. The models are fired upstream from 20 or 37 mm gun and are trapped upstream of the nozzle throat in a butt. For fin-stabilized models sabot technique is used and, by using light models, muzzle velocities up to 8000 ft./sec. are obtained from conventional guns. The use of extra long barrels in order to increase muzzle velocity and 3 in. caliber guns is considered. Electronic chronograph equipment good to 0.1 msec. has been developed for this tunnel. For boundary layer studies on models a 13 in. dia. field of view interferometer is available.

The Ames people are very pleased with their Free Flight Tunnel and consider it a really useful piece of equipment. In addition to drag and interferometer data they are able to obtain lift and pitching moment data by observing oscillations of initially yawed models, with different C.G. positions.

3.4 6 x 6 ft.^{2} Supersonic Tunnel

Drive: 51000 h.p. slip-ring induction motor driving 8 stage axial compressor, 2.1 max. pressure ratio. Compressor casing splits in half and can be rolled away for inspection of blades.

Nozzle: is of the asymmetric, sliding block type and covers $1.2 < M < 2.0$. Best flow distribution is obtained at M = 1.4, the flow curvature being appreciable above and below this

Mach No. The models are therefore mounted with span vertical (i.e. in the two-dimensional plane).

Working Section — is equipped with 50 in. dia., 5.5 in. thick glass schlieren windows. They were poured by Corning and polished by Tinsley.

Balances — used in this tunnel are of the internal model, strain gauge type. Force readings are obtained from a printer which is driven by a photocell mounted on a lead screw and made to follow the galvo spot. In future it is intended to use punch cards in conjunction with IBM machines, both balance readings and reduction coefficients being punched in the cards.

3.5 <u>1 x 3 ft^2 Supersonic Tunnel (closed circuit)</u>

Drive — 4 Carrier blast-furnace, centrifugal compressors.

Nozzle — Variable Mach No., flexible plate, lugs integral, with plate (similar to JPL design?). Manufactured by Baldwin-Southwark, together with automatic cam driver controls for Mach No. setting. The nozzle is highly unsatisfactory due to distortion of plate after machining and low accuracy of the automatic jack-setting system. In effect, it is mostly used at M = 1.5 and jacks are operated, if necessary, individually.

Working section — size was chosen in 1942, when it was intended for two-dimensional work. When the tunnel first run in July 1945, it was the largest supersonic in the U.S.A.

3.6 <u>Unitary Plan: 8 ft. Tunnel Project</u>[x]

[x] Discussions were held with Mr. Parsons, Assoc. Director, i/c Unitary Plan and Mr. Huntsberger, i/c 8 ft Tunnel Project.

3.6.1 The so-called 8 ft. Tunnel Project comprises three wind tunnels covering Mach No. range from 0 to 3.5 and driven from one 180000 h.p. motor group. The approximate layout of the installation is shown diagramatically in fig. 5, and a brief description is given below. The installation occupies an area of about 800 x 500 ft.^{2} and the estimated cost is $27 million. It is to be completed in 1954.

3.6.2

<u>Drive</u>

4 G.E. 45000 h.p. slip ring, wound rotor induction motors. Speed regulation by liquid rheostats. Double ended shaft fitted with couplings.

3.6.3

<u>Transonic tunnel</u>, 11 x 11 ft.^{2} working section

3 stage, 1.43 pressure ratio axial compressor. 2.5 at. max.

$0 < M \leq 1.4$.

Nozzle and working section: flexible plate nozzle to produce supersonic velocities and used undeflected at $M < 1$, fig. 4. The flexible plate is of non-uniform cross section to take elastic curve corresponding to the required nozzle profile and is operated by a single jack. The plate is fixed at the exit and pivoted at the intake end, as shown diagrammatically in fig. 4. The flexible nozzle section is followed by slotted working section, 11 x 11 ft.^{2} and 22 ft. long. Longitudinal, constant width slots on all four sides are envisaged, but the design of w.s. is not yet frozen. Subsonically, the slotted w.s. provides freedom from blockage interference, while supersonically it should attenuate reflected model shocks. The design of slotted w.s. is further discussed under 3.6.7.

3.6.4 <u>Supersonic Tunnel, Low M,</u> 9 x 7 ft.^{2} w.s.

3.5 pressure ratio, axial compressor
2 at. max. (at M > 1.6)
1.4 ≤ M ≤ 2.6
Nozzle: asymmetrical, sliding block type
W.S. : rectangular, in order to provide freedom from shock interference for high incidence model tests.

3.6.5 <u>Supersonic Tunnel, High M,</u> 8 x 6 ft.^{2} W.S.

Compressor drive as above, see fig. 5
2 at. max.
M ≤ 3.5
In spite of the low compressor pressure ratio, design Mach Nos. up to 3.5 are achieved by means of a diffuser injector which by-passes the tunnel w.s. In this way compressor characteristics (low pressure ratio, large mass flow) are matched to the tunnel requirements (high pressure ratio, small mass flow). The injector is arranged on two opposite walls of the diffuser and has adjustable flaps. Although total head of the injector air does not differ, except for the cooler loss, from the tunnel air total head, the injector accelerates the diffuser boundary layer and thus improves diffuser efficiency. The full scale injector design is based on small scale, pilot experiments.

Nozzle: flexible plate, multi-jack type. Although this type of nozzle construction is not liked in Ames labs, it is the only practicable one in this tunnel size and Mach No. range. The sliding-block type nozzle becomes excessively long at high M.

3.6.6 <u>Miscellaneous data</u>

a. The aerodynamic design of compressors was done at Ames Labs. and they are being manufactured by Newport News Naval Shipyards, Va. Both compressors have vertically split casings which can be rolled away on site for inspection. The casings are made sufficiently stiff so that on parting the bending sag does not exceed 0.005 in.

Rotor blades are machined at Ames whereas stator blades are manufactured outside in cast steel. The most serious problem encountered in compressor design was sealing and lubrication of 3.5 pressure ratio compressor bearing, which operates at 450°F. Even small amounts of oil in the air could not be tolerated on account of schlieren windows and cooler contamination.

b. A rather unorthodox design was evolved for expansion joints, which are required to provide several inches of movement. The expansion joint, as indicated in fig. 6, consists of a toroidal rubber tube which seals on flanges attached to the tunnel duct. Again, some of the expansion joints are subjected to high temperature and flanges in contact with rubber have to be internally cooled.

c. The use of one compressor and cooler in the two supersonic tunnel circuits necessitates the provision of two movable, cascaded tunnel corners, as indicated in fig. 5.

d. The tunnels' ducts are made of at least one inch thick steel plate. The welding specification does not call for a complete X-ray survey of welds (which, in any case, would be difficult to make in inaccessible, cascaded corner sections), but requires taking of random sample radiographs. The tunnels are to be proof-tested pneumatically to 25% over the design, maximum pressure.

e. The tunnels' centreline is located 20 ft. above ground level, which enables the working section to be conveniently located at the second floor level. However, excavations are required to house coolers, which are some 70 ft. in diameter.

f. The question of Reynolds Number was briefly discussed and it was agreed that in general 2 million was minimum and 4 million desirable, but that it was not necessary to exceed this value. At the same time, 6 ft. was considered the minimum tunnel size one should have for convenience of working inside the working section.

g. The following approximate cost figures were quoted:

Drive (complete except foundations)	- 30$/h.p.
Nozzles (variable, any type)	- 1$/lb. plus
Shell	- 0.4$/lb.

As regards the design and draughting effort, it amounted roughly to 50 man-years at Ames and perhaps 100 man-years outside (excepting drive design). It is envisaged that some 200 people will be required to operate the 8 ft. Tunnel Project installation.

h. One difficulty particular to the Moffet Field installation, is the requirement of earthquake-proof foundations.

i. In order to control compressor surging on starting and stopping of the tunnel, consideration is given to control air mass flow rate by operating nozzles during these periods.

3.6.7 Development of Transonic Tunnel Technique *

Work on transonic tunnel working section design started at Ames after theory of slotted, blockage-free tunnels was developed at Langley and preliminary tests confirmed theoretical predictions. However, it was felt at Ames that the slot design problem was unnecessarily complicated by Langley's simultaneous requirements of

a. "Deblocking" W.S. subsonically,
b. Producing unifrom supersonic flow and
c. Attenuating reflected shock interference

and it was therefore decided to drop requirement b. and use instead a simple flexible plate nozzle to produce supersonic flow. (see 3.6.3. and fig. 4).

Pilot tests on slotted working sections were carried out in 5 x 5 in^2 continuous and 2 x 2 ft.^{2} blowdown tunnels and no difficulties were expected in extrapolating results to full scale (11 x 11 ft.^{2} tunnel).

* Discussion with Mr. J. Spiegel and Mr. J. Anderson

Subsonically, fair agreement was obtained between the predicted and actual blockage-free slot configuration for square tunnel. With 16 slots per tunnel wall, 3 to 4% of slot area eliminated blockage. Parallel, constant width slots were used, as indicated in fig. 7.

Supersonically, it was not possible to eliminate completely reflected shock disturbances, which consisted of a shock-expansion region, but, with a suitable slot configuration, the intensity of both compression and expansion.. regions was reduced. These tests were carried out by pressure plotting NACA Research Model (RM) 12, for which detailed transonic data is available from free flight tests. No information could be obtained concerning zig-zag baffles fittedin the slots for shock attenuation, a development on which, according to previous reports, Ames Labs. were working. Most of this work was apparently being carried out by the United Aircraft Co.

As regards the shock attenuation problem, it was felt that in general due to shock-boundary layer interaction on the tunnel walls complete elimination of reflected disturbances was impossible to achieve and it was envisaged that b.l. suction might be required to obtain better results.

In addition to velocity (or pressure) distribution tests, the pressure drop across the slots was measured and it was intended to scale up the slot design on the basis of constant resistance to flow. It thus appears that the slot design procedure is inconsistent in that it is based on potential flow theory (blockage free sections) and then modified on the basis of viscous flow characteristics. So far these two aspects of the slot design were not correlated.

The Ames design of the slot-diffuser junction is different from the Langley's version, as shown in fig. 7. The slotted w.s. is parallel-walled and the slots terminate in an abrupt step. A slight fairing is provided at the diffuser entry, its cross-section being bigger than the tunnel w.s. area to accomodate the low energy, slot airflows. In spite of this rather crude design, the pressure ratio required for the Ames slotted sections is not excessive and amounts to about 1.2 at M = 1.3.

It appears that in general great use is made at Ames of pilot tunnel results, not only for the determination of working section geometry but also for such details as design and location of model struts and incidence gear. The tunnel flow was found very sensitive to the latter at slightly supersonic velocities.

4. Miscellaneous Notes

4.1 Half-model tunnel testing

Half-model technique was discussed in connection with tests carried out in Moffett Field's 12 ft. dia. and 3 x 1 ft.^{2} continuous tunnels.

In the 12 ft. high speed tunnel no b.l. separation plate or spacers were used, the models being mounted directly on the tunnel floor on a turntable. The tunnel b.l. displacement thickness was about 0.25 in. The drag was corrected for frictional drag of the turntable, separately measured (model off). Good agreement was obtained between half-model and full model tests.

In the 3 x 1 ft.^{2} supersonic tunnel tests were being made on wings on a half model of fixed wing missile. In view of the large model incidence range, the model body was mounted on a reflection plate away from the tunnel wall and wing alone was connected to the balance. The set up was somewhat similar to our own.

4.2 Sabot design

Two different designs of sabot for shooting of cruciform, finned models were seen at Ames and N.O.T.S. establishments.

Lucite sabots, fig. 8, are used in the Ames Free Flight Tunnel (see 3.3). They are machined integrally from a lucite bar and are not protected at the base from powdor gases.

A metal split sabot, fig. 8, is used at Inyokern. The two halves are held togethor in the gun by means of a rectangular, copper bar.

4.3 Provision of Wind Tunnel balances

A visit was paid to the Sandberg-Serrell Corporation, Consulting Engineers, Pasadena, to examine the possibilities of ordering wind tunnel balances from them.

Mr. Serrell was responsible for the design of balances for the 10 ft. Galcit tunnel, the Co-operative W.T., and, between 1946 and 1948, was in charge of instrumentation of the J.P.L. 20 in. supersonic tunnel. He also did balance design studies for A.E.D.C. Since 1948, when Sandberg-Serrell Co. was formed, Mr. Serrell was engaged on the following designs: flexible nozzle, test section and balance for 13 x 15 in.^{2} Aberdeen Supersonic Tunnel, J.P.L. 20 in. tunnel flexible nozzle, flexible nozzles (M = 1.6 and 3.5) for A.E.D.C. 16 ft. tunnels, internal model strain gauge balances.

The above experience appears to be very worthwhile, particularly in view of the generally known excellence of some of the equipmont (e.g. J.P.L. 20 in. tunnel balance and instrumentation). Sandberg-Serrell Co. are interested in orders for design of wind tunnel equipment, but usually do not handle manufacture, although, if necessary, will obtain tenders and assumo responsibility for calibration of the equipment. It was agreed that quotations will be obtained from Sandberg-Serrell Co. for a 6-component balance for 10 x 10 in.^{2} supersonic tunnel.

4.4 <u>Visit to University of California, Berkeley</u>

A short visit was paid to the Mechanical Engineering Dept. and the Low Pressure Wind Tunnel Project. The latter installation is well known from literature and is impressive in that very high vacuum is being maintained without difficulty in a large vessel which surrounds the tunnel working section and contains (remotely operated) instrumentation. The tunnel is driven by 5 steam ejectors mounted in series and can be supplied with different gases from high pressure bottles. Heat transfer and drag of simple bodies is measured in Mach No. range up to 5 and Re. Nos. from 10 to 1000. Precision manometers of the optical projector, counter type, very similar to the ones built by ourselves, are being used (with butane phthalate).

4.5 <u>Visit to Statham Laboratories, Los Angeles</u>

A short visit was paid to the manufacturers of transducers in use in our H.S.A.L. in order to learn of any new instrument developments. Apart from a miniature (3/8 in. dia.) pressure pick-up (type P81), which is not in production yet, no new instruments applicable to wind tunnel testing were seen.

JL/ELP

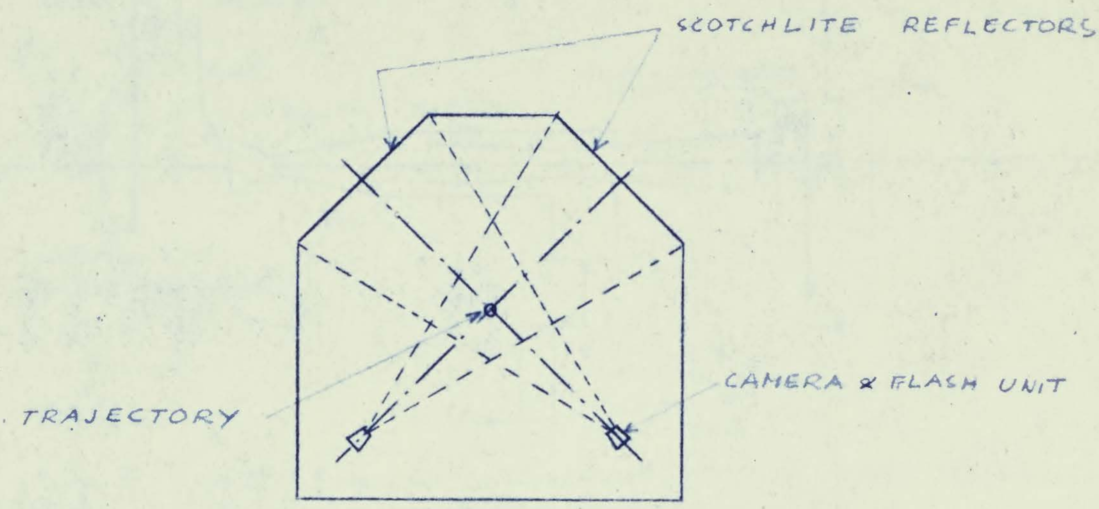

FIG. 1 SCHEMATIC OF N.O.T.S. BALLISTIC RANGE

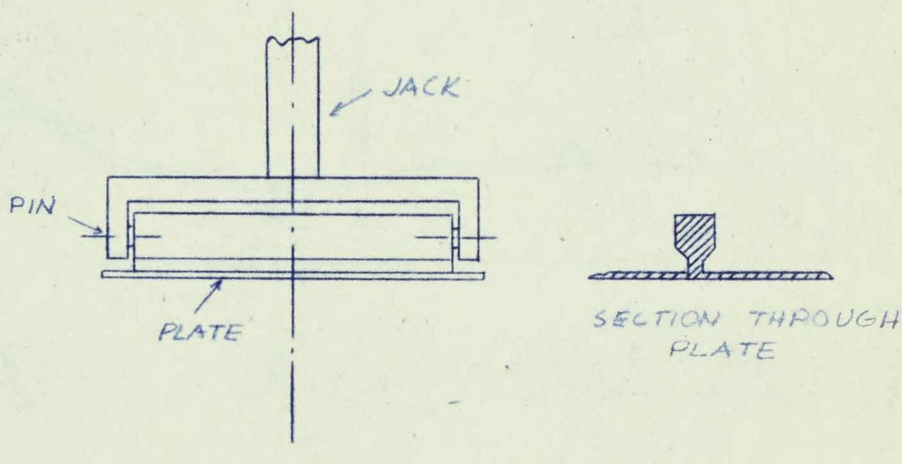

FIG. 2 JPL SUPERSONIC NOZZLE FLEXIBLE PLATE

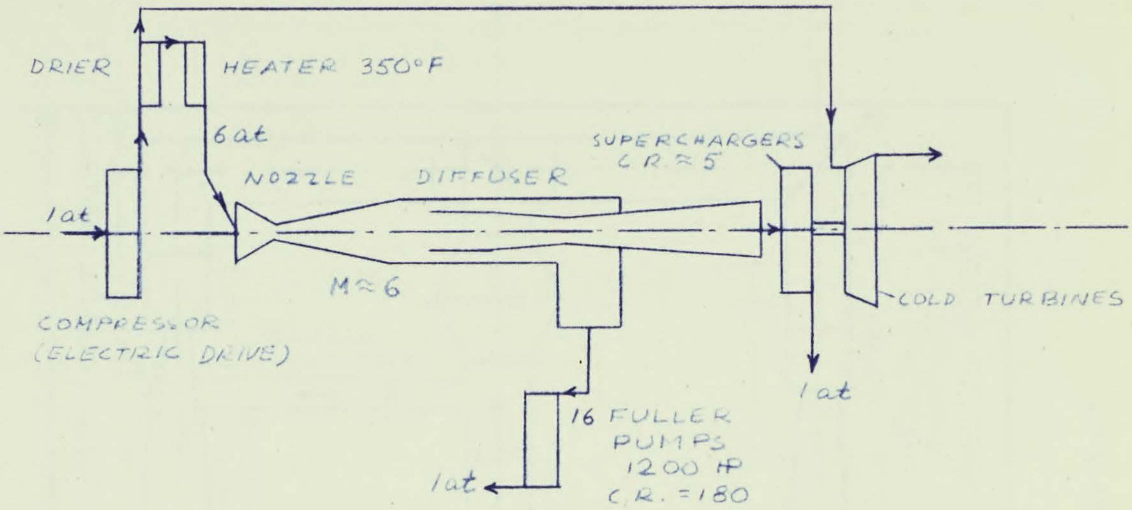

FIG. 3 SCHEMATIC OF $10 \times 14\ in^2$ HYPERSONIC TUNNEL DRIVE

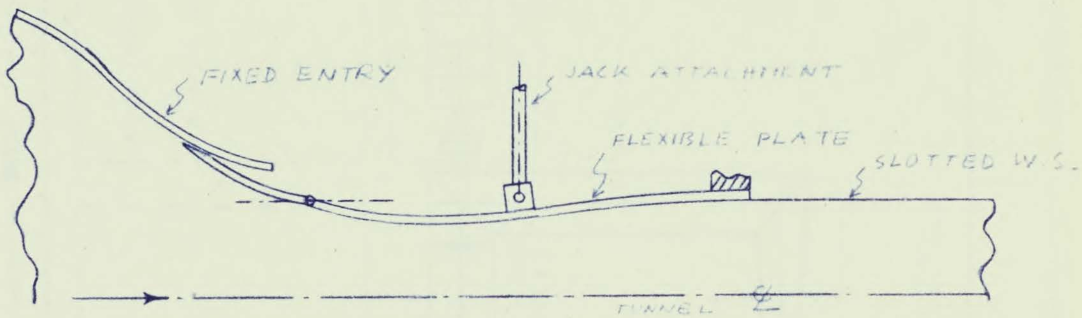

FIG. 4 FLEXIBLE NOZZLE, $11 \times 11\ ft^2$ TRANSONIC TUNNEL

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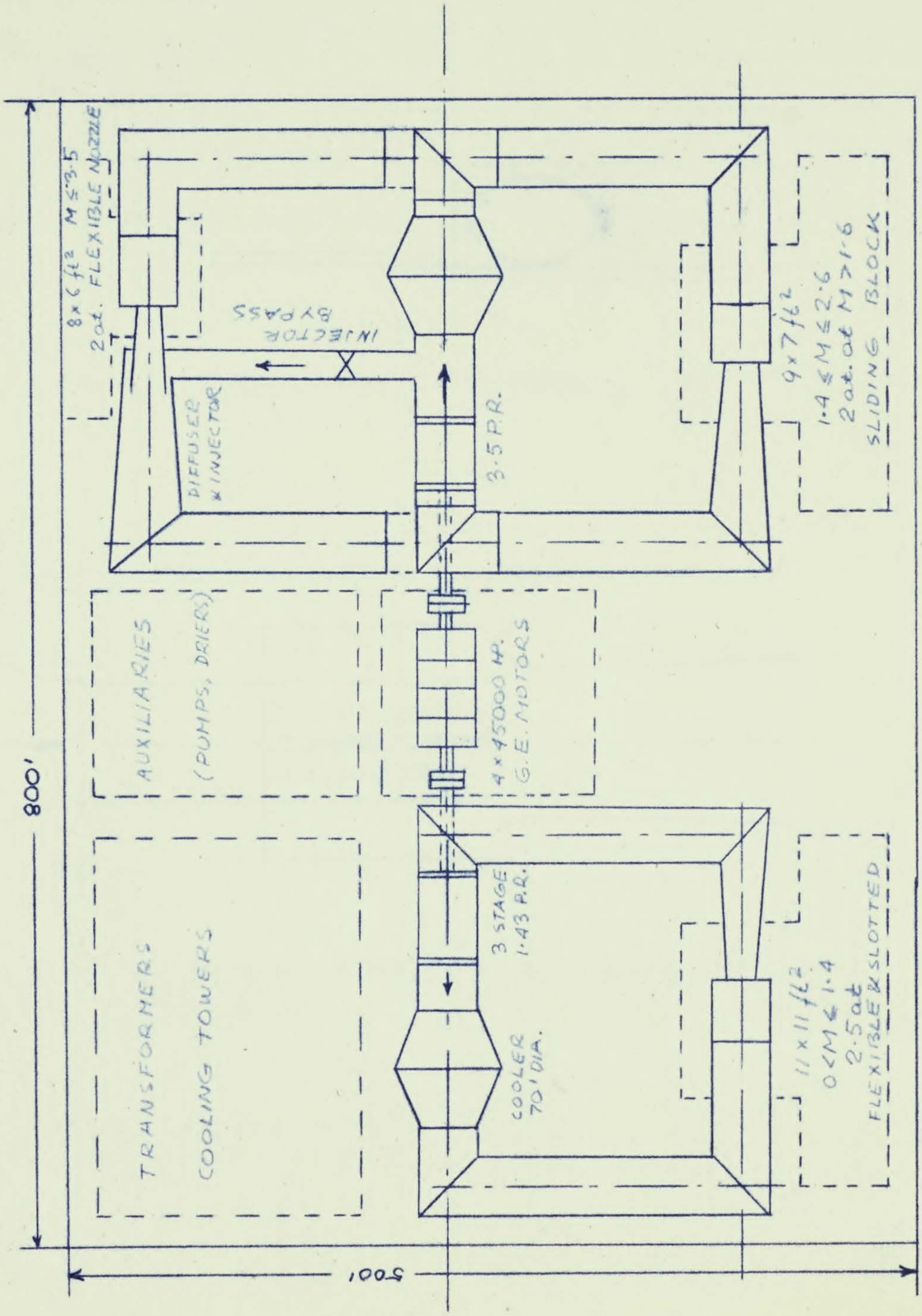

FIG.5 8 ft. TUNNEL PROJECT - APPROXIMATE LAYOUT

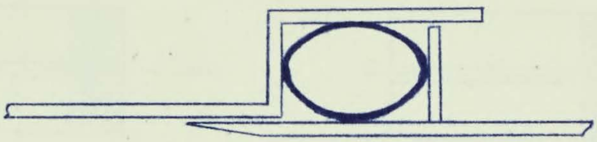

FIG. 6 PNEUMATIC EXPANSION JOINT

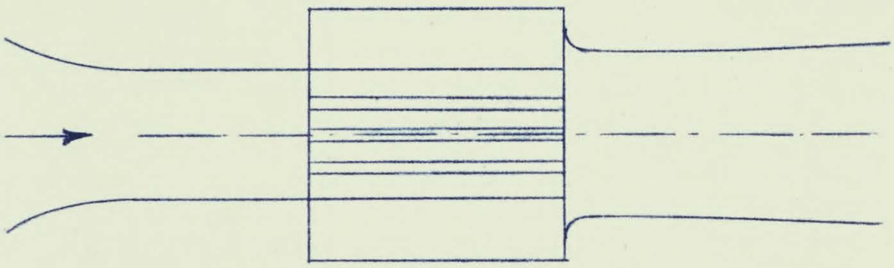

FIG. 7 PILOT SLOTTED WORKING SECTION