TECHNICAL REPORT NO. 54

COMBUSTOR REQUIREMENTS FOR PROJECT PV704

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1. INTRODUCTION

Combustion equipment is required for Project PV.704. In order that the significance and context of these combustors may be appreciated, the general layout of the aircraft is given in Fig. 1 - 3.

Fig. 1 is a plan and section drawing of the aircraft. It is 35.3 ft. in diameter; stands about two feet off the ground, measures 7.7 ft. from the lower surface to the canopy; is approximately symmetrical in section and is expected to weigh about 20,000 lb. with 5,700 lb. fuel. The maximum fuel is 13,120 lb. giving a maximum weight of 27,322 lb.

Six Armstrong Siddeley Viper turbo-jets - 1,900 lb. thrust, 22 inch overall diameter, 525 lb. weight each - are mounted radially in the wing, exhausting inward; and used as gas generators to drive a pair of contra-rotating compressors by means of a radial in-flow turbine. (See the section cutaway Fig. 2).

The eight foot diameter compressors, (Fig. 3) which rotate slowly by comparison with conventional turbo-jets, draw air from the upper and lower intakes (Fig. 2) and force it radially out through the wing between the Viper engines. Some of the air thrown out by the compressors is directed back to feed the Viper engines (Fig. 4).

The air is diffused in the wing to a high pressure at the flame holders (Fig. 1) where fuel may be added to augment the thrust, and is then exhausted through pneumatically controlled shutters or gills (Fig. 5) which direct the jet as it exhausts all around the aircraft periphery; either to raise the aircraft vertically off the ground or to propel it in forward flight. This control of the exhaust direction enables the jets to be used for manoeuvring and stabilizing the aircraft in all flight conditions, so that separate additional controls are not required to cater for vertical take-off and hovering. Thus, for instance, to pull up the nose of the aircraft the pilot will control the shutters by means of a conventional stick control to direct the jet out of the top of the wing top of the wing in the rear sector and thrust the tail down, or to roll he will similarly direct the jet from the top of one wing and from the bottom of the other. For stabilizing, the main rotors and a diaphragm are used to sense when the aircraft pitches in a gust and use is made of the jet controls to correct it. Stabilization through the controls is essential on this aircraft since the centre of gravity is in the middle of the wing at half the chord from the leading edge, whereas the aircraft would only be stable without using the controls if the

1. INTRODUCTION (continued)

centre of gravity were about at the quarter chord position. The change in jet direction as the aircraft pitches, performs the same function as the fixed stabilizer of a conventional aircraft.

In operation, to take-off, all the shutters on the top of the wing are closed and the shutters on the bottom are opened wide. Without adding fuel to augment it, a total of about 20,000 lb. thrust is produced by the jets pointing downward all around the wing together with the central nozzle; however, this jet-around-wing configuration produces a powerful take-off of ground cushion so that the lift on the aircraft is, in fact, increased to possibly 30,000 lb., and the aircraft rises to about 17 ft. (Fig. 7) where the ground cushion effect falls off rapidly. For vertical take-off the thrust must be greater than the weight and thus without afterburning the fuel capacity will be restricted to approximately 3,500 lb: with afterburning, however, approximately 30,000 lb. thrust can be produced. However, it is envisaged that transition to forward flight will normally be from the ground cushion. By operating a transition control the pilot leans the jets backwards gradually, to accelerate the aircraft, and raises the nose; with the thrust less than the weight, the aircraft can accelerate and rise into free air a short distance from the starting point.

In forward flight ram pressure is collected into the air intake which progressively increases the afterburning pressure ratio and thermal efficiency. For supersonic speed augmentation will always be necessary and because of the large mass of air the impellers can handle, a very large thrust and high top speed is possible. The large installed thrust also leads to a high thrust to weight ratio which makes a very high ceiling possible. The efficiency of the airframe at supersonic speed appears good and that of the engine reasonable, so that a long supersonic cruise range is also forecast.

For landing, a fully vertical descent will usually be made, with or without thrust augmentation from a hot main jet. Transition to the landing condition from in-flight is similar to the take-off transition. The nose is raised and the jets transferred to the undersurface and leaned forward collectively to rapidly slow the aircraft down; as the speed falls close to zero the nose is lowered and the aircraft brought down into the ground cushion. The pilot must then close the throttle to reach the ground.

2. INFLUENCE OF COMBUSTOR PRESSURE DROP

The 20,000 lb. static thrust quoted without afterburning is 1.75 times the thrust which the Viper gas generators would give if used as direct 'jet-lifters' or thrusting engines: this augmentation being due to converting the relatively small mass flow high velocity jet into a large mass flow low velocity jet with fundamental improvement of static thrust efficiency. It will be appreciated that the 'cold' static thrust obtained in this way is very sensitive to internal pressure losses and that the introduction of a combustor into this low energy flow is a possible source of prohibitive loss. The presence of the combustor in the duct is, however, unavoidable since the cardinal feature of the design is not merely to have a high mass flow for vertical take-off but to make use of the large mass flow at high speed where with high ram pressure ratio available, burning fuel in the main duct will provide a very large installed thrust; and so to combine the vertical take-off feature with an aircraft of outstanding supersonic performance. This approach is illustrated by the chart Fig. 10 (showing how the power required to produce a given static thrust reduces as the 'jet' mass flow increases) on which is indicated that at some point internal ducting of the jet becomes possible and high 'ram-jet' thrust can be obtained.

Thus the prime consideration for combustor design is that of low loss. In calculating performance the following loss factor has been assumed.

$$\frac{\Delta p}{q} = 2 + 1.3\,(T_c/T_e - 1)$$ where

q = entry dynamic head

T_c = chamber exit temperature

T_e = chamber entry temperature

It is hoped that a combustor design matching this low pressure drop requirement and giving satisfactory combustion efficiency over the required range of conditions can be achieved. In any case some relaxation of the required flight envelope will be preferable to increased pressure drop.

11 August 8 A9

set for 1 segment
req'd 1st May/June 58
1 complete set Aug 58

3. GENERAL REQUIREMENT

The general requirement is for the design, test and development of a suitable sample combustor with associated fuel system and for the delivery of one aircraft set of combustors by August 1958 with the extra requirement for an additional eight (one outer wing segment) by the earliest possible date in advance of the complete set. The aircraft set would include all ignition equipment, fuel pumps, valves, etc. associated with the combustion equipment.

The general layout of the outer wing showing the space available for combustion equipment is shown in the attached drawing. A brief specification for the combustor follows.

4. COMBUSTOR SPECIFICATION

4.1 Pressure Loss

The desired pressure loss factor for the combustor may be expressed as

$$\frac{\Delta P}{q} = 2.0 + 1.3\ (T_c/T_e - 1)$$

4.2 Fuel

Kerosine or wide-cut gasoline.

4.3 Total Temperature Rise

A uniform temperature profile within ± 100°C is required at the combustor exit plane. (not defined) ℄ of shutter plate

Maximum continuous total temperature at exit = 1200°K

Maximum 5 minutes rating = 1500°K

(N.B. Future development may necessitate up-rating).

4.4 Operating Conditions

A flight envelope is given in Fig. 8, and the approximate variation of inlet temperature and pressure with flight Mach number and altitude in Fig. 6 and 7. Maximum fuel flow requirements may be determined from the limiting speed line shown. The combustor inlet Mach number is given in Fig. 9. It should be noted that in the critical operating condition

4.4 Operating Conditions (continued)

$M_\infty = 0.8$ at 35,000 ft. the pressure temperature product $p_a t_b$ is lower than for any other comparable combustion equipment.

4.5 Combustion Efficiency

The contractor is requested to submit an estimate of combustion efficiency and stability limit variation for the range of inlet temperature and pressures, for a combustion system designed to this specification.

4.6 Weights Estimate

The contractor is requested to submit a provisional weight estimate for the combustion equipment, including all associated equipment such as ignition plugs, wires, control boxes and switches, fuel pumps, lines, etc. The combustor itself is understood to include all structural insulation, the provision of which will be the contractor's responsibility because of its intimate connection with the combustor design.

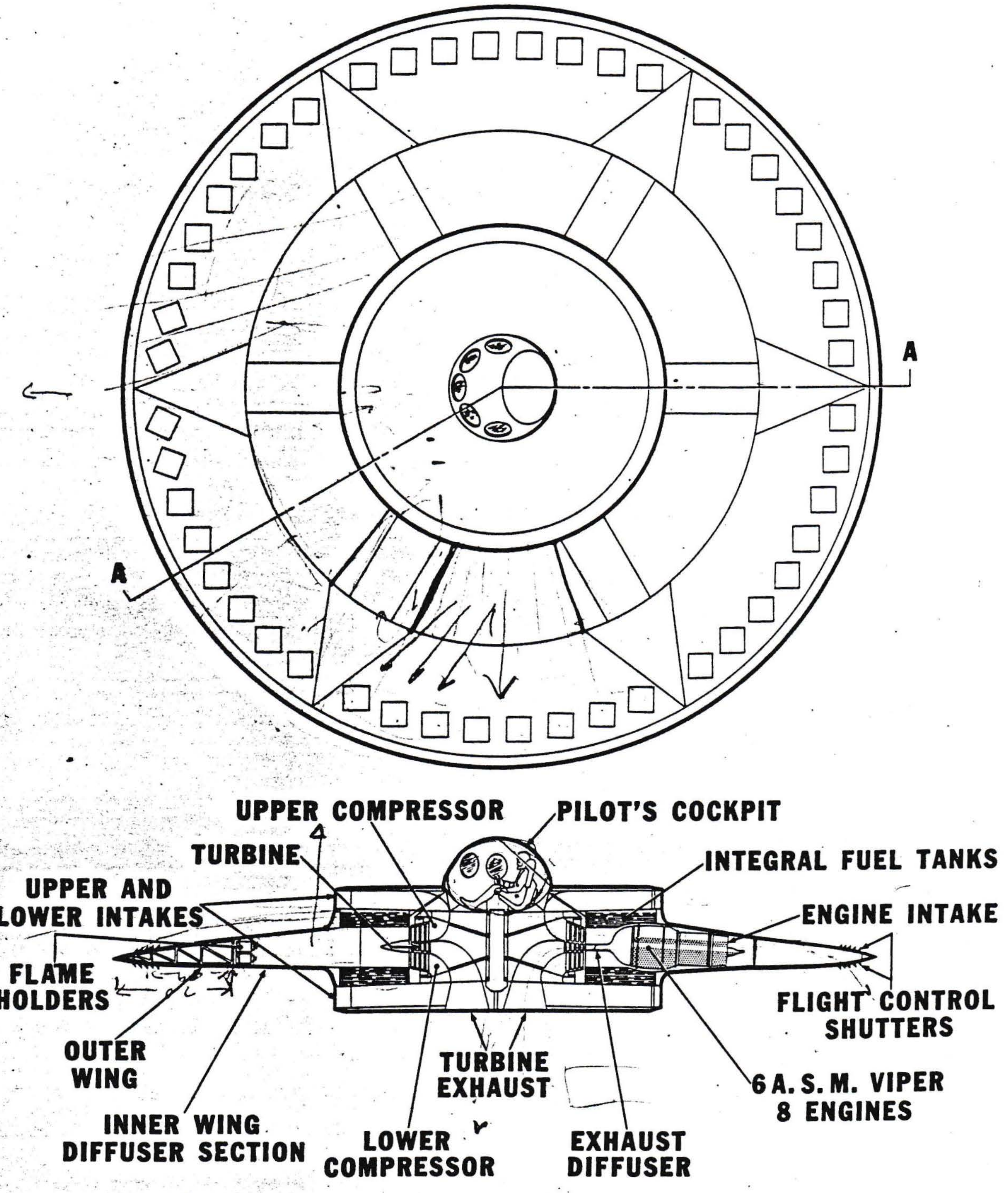
4.7 Pressure Pulsation

The maximum pressure pulsation in the combustor must not exceed

± 5.0 lb./sq. in.

4.8 Combustor Life

An initial life of 100 hours on the removable components of the combustor will be acceptable for the prototype aircraft.



SECTION A-A

FIG. 1 PLAIN VIEW AND SECTION THROUGH AIRCRAFT

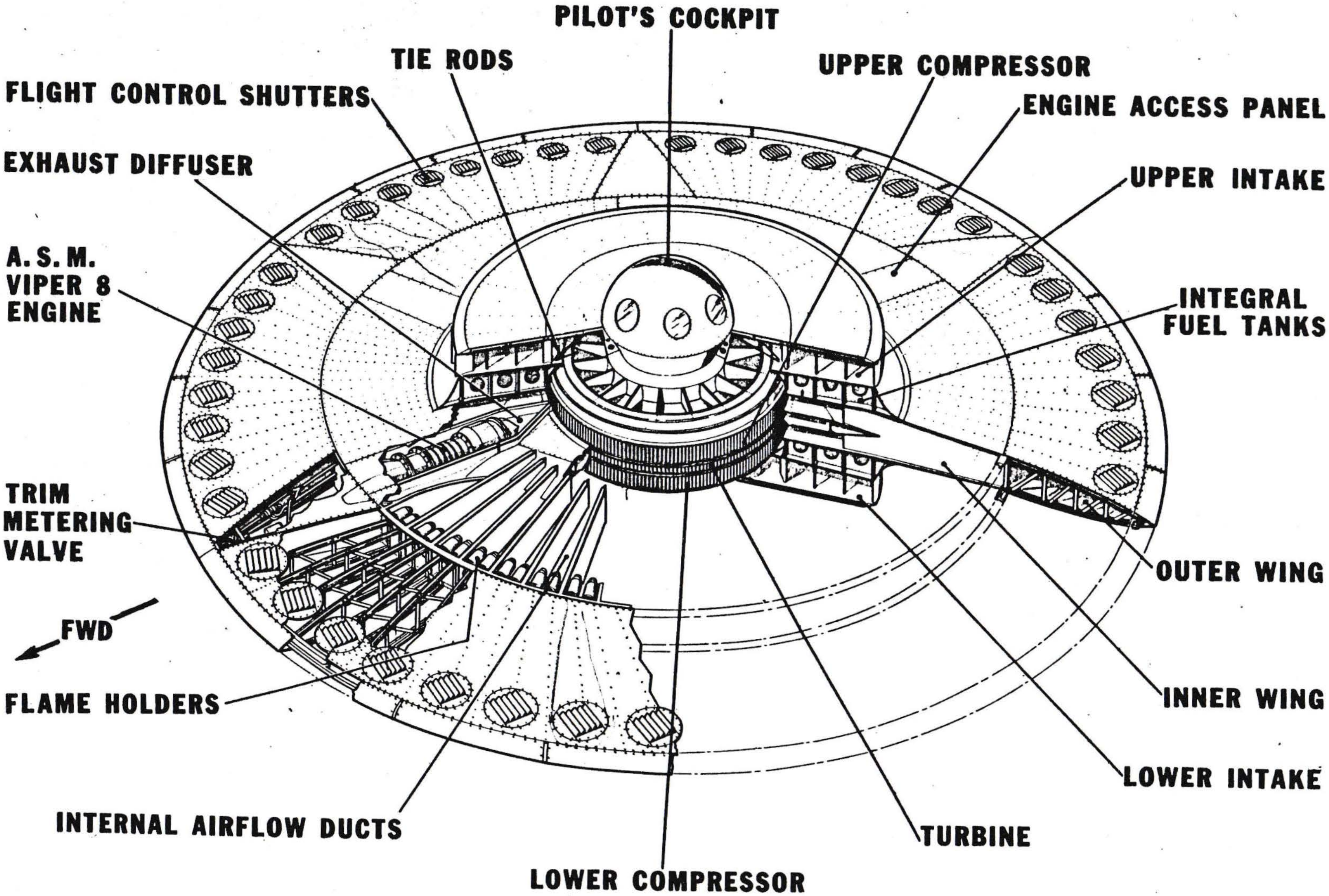


FIG. 2 CUTAWAY OF AIRCRAFT STRUCTURE

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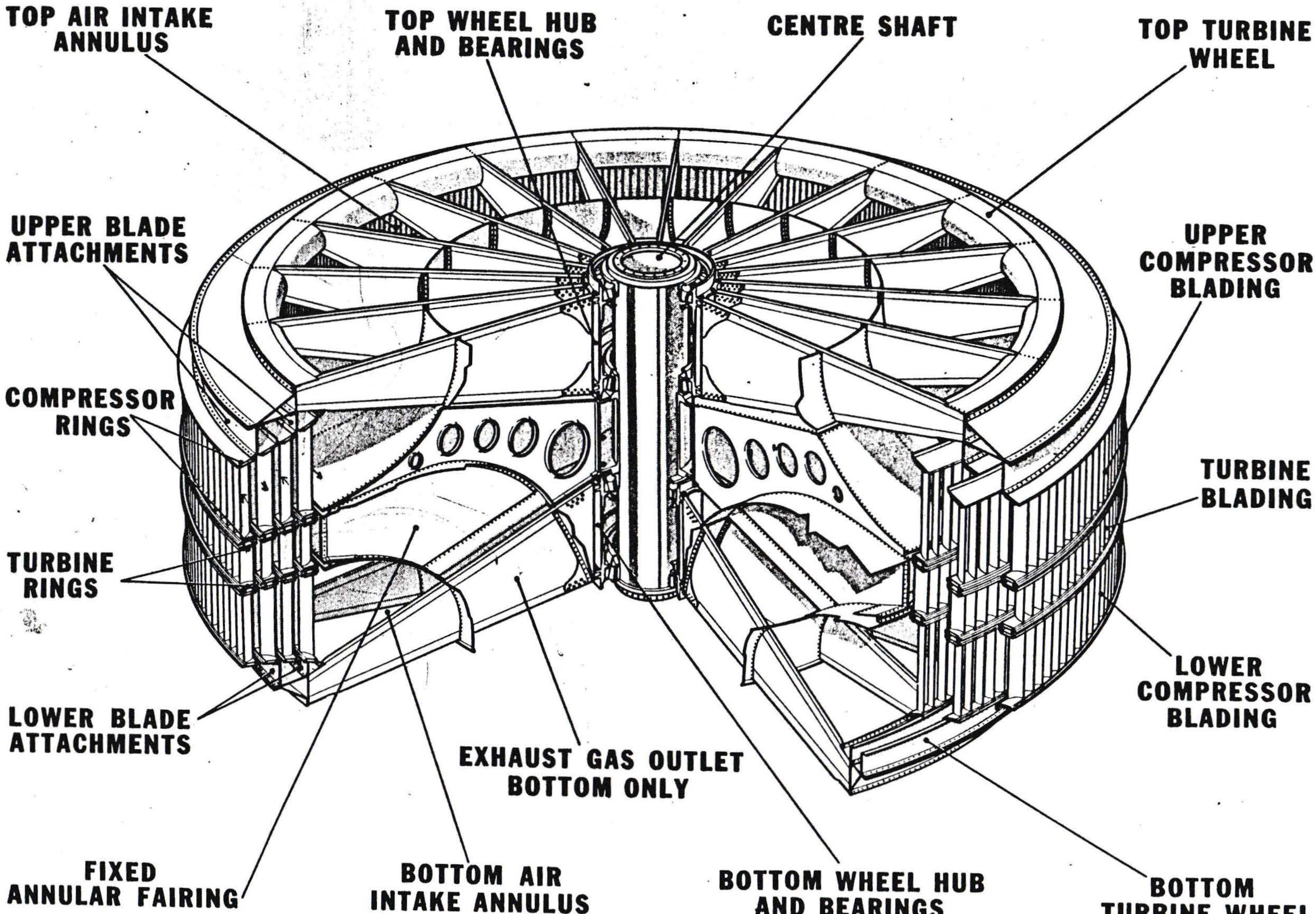

FIG. 3 TURBINE-COMPRESSOR ASSEMBLY

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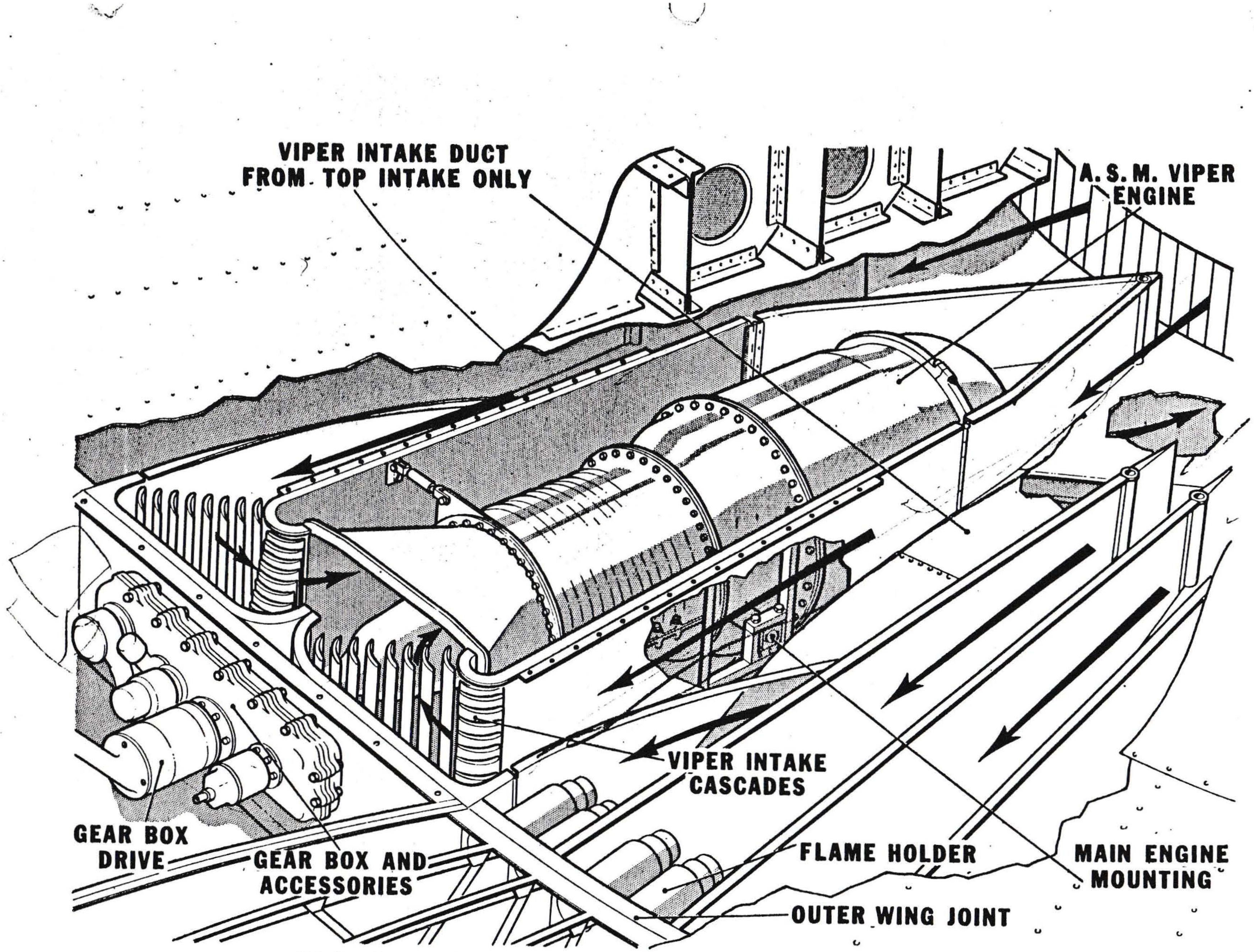

FIG. 4 A.S. VIPER ENGINE INSTALLATION

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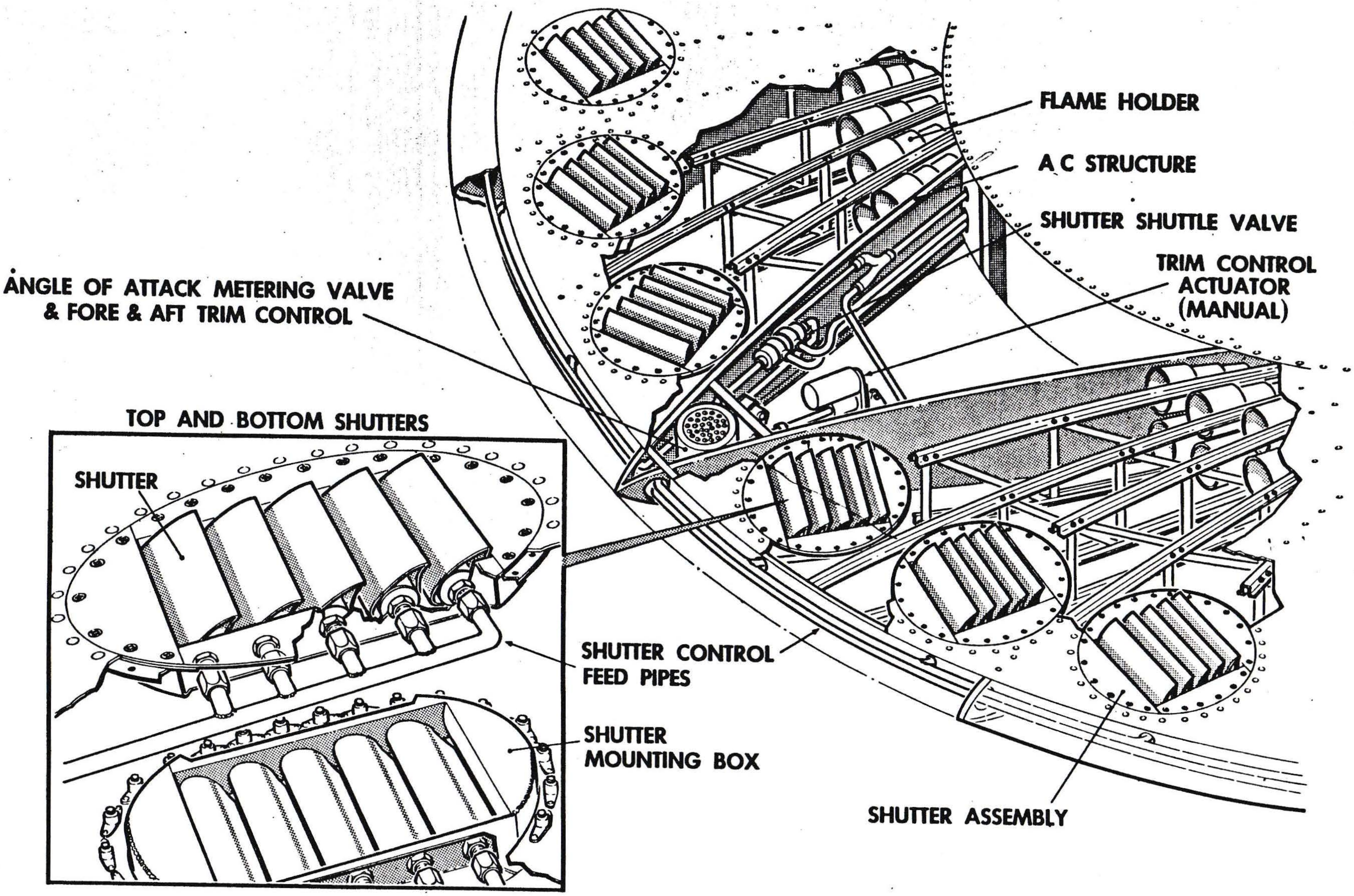

CUTAWAY OF CONTROL SHUTTERS

FIG. 5

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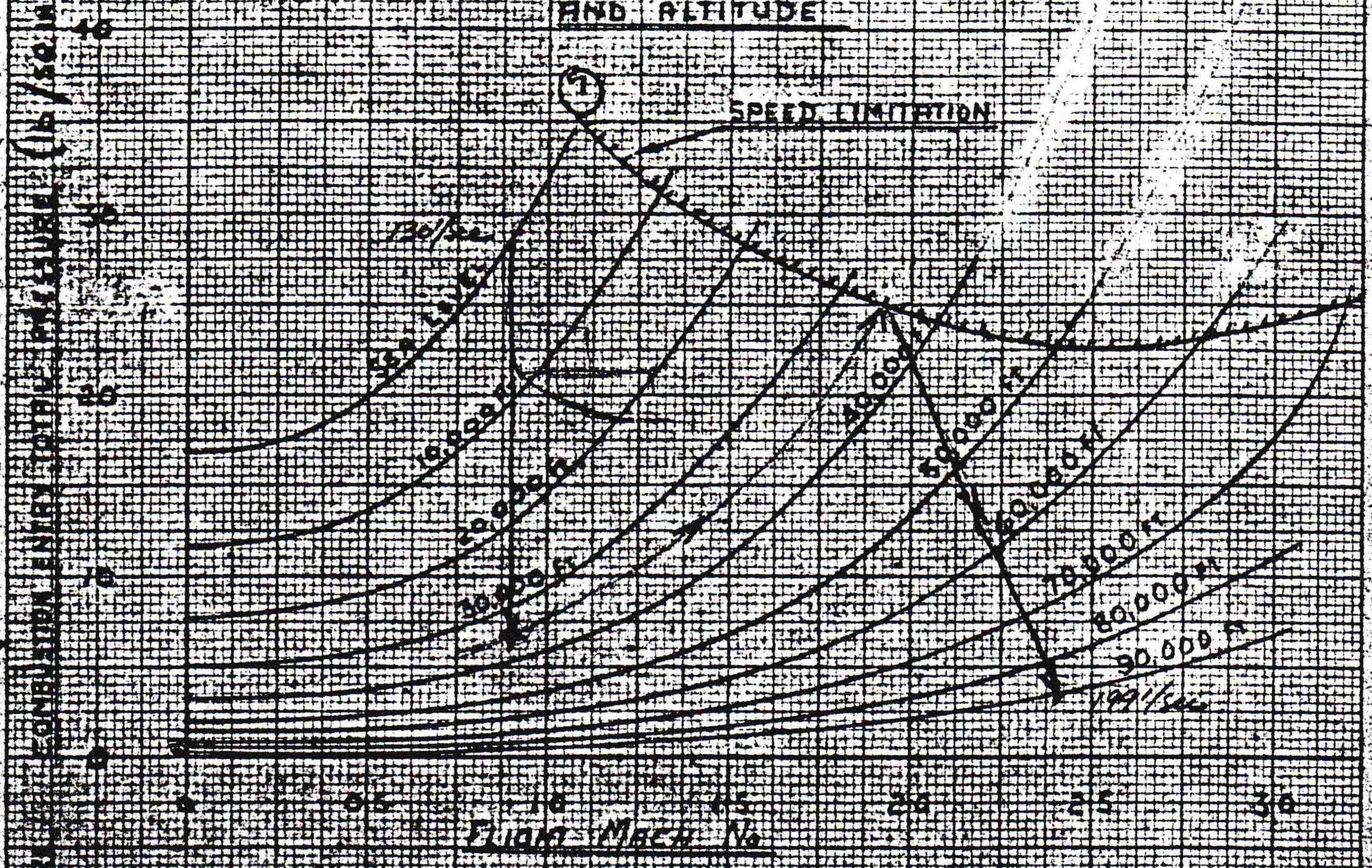
PROJECT P.V. 704

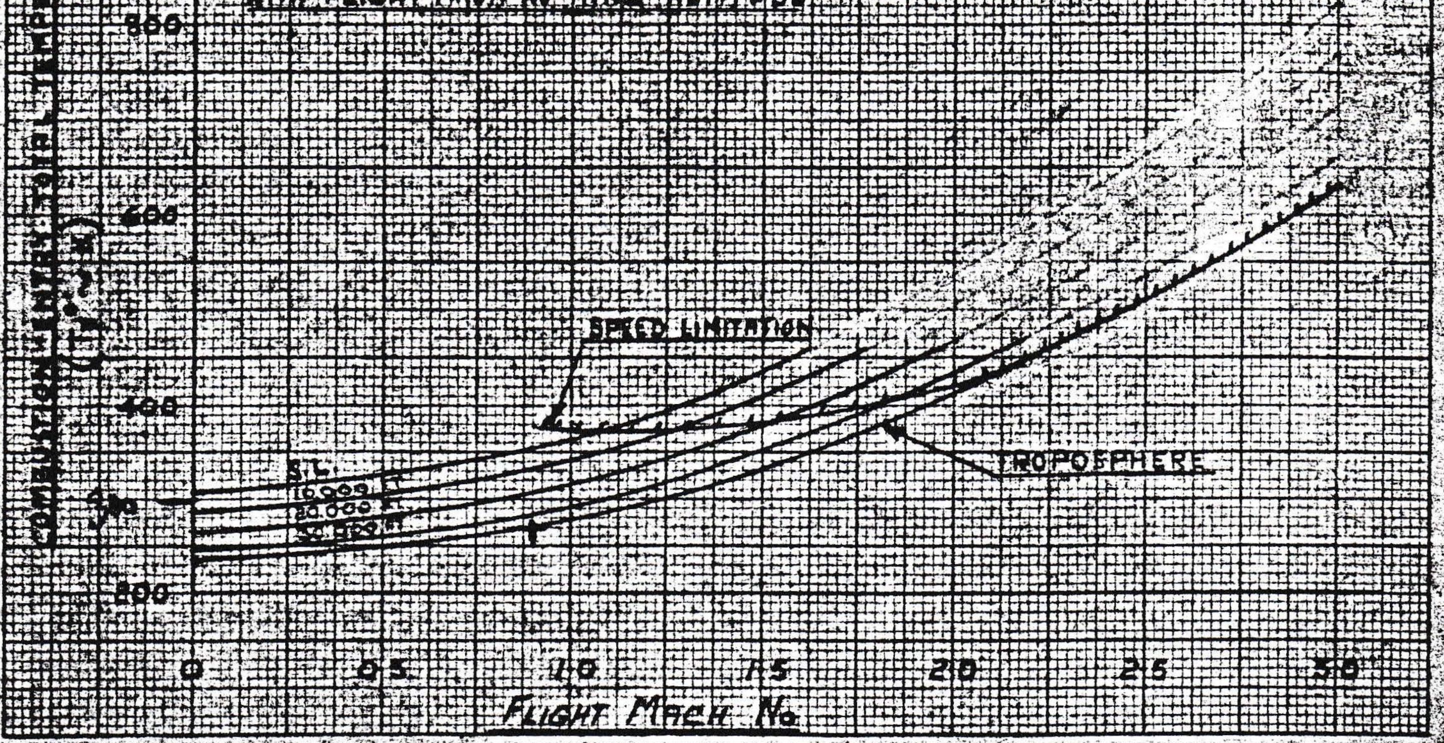
FIG 6.

VARIATION COMBUSTION ENTRY TOTAL PRESSURE WITH FLIGHT MACH No AND ALTITUDE



VARIATION COMBUSTION ENTRY TOTAL TEMPERATURE WITH FLIGHT MACH No AND ALTITUDE

FIG 7



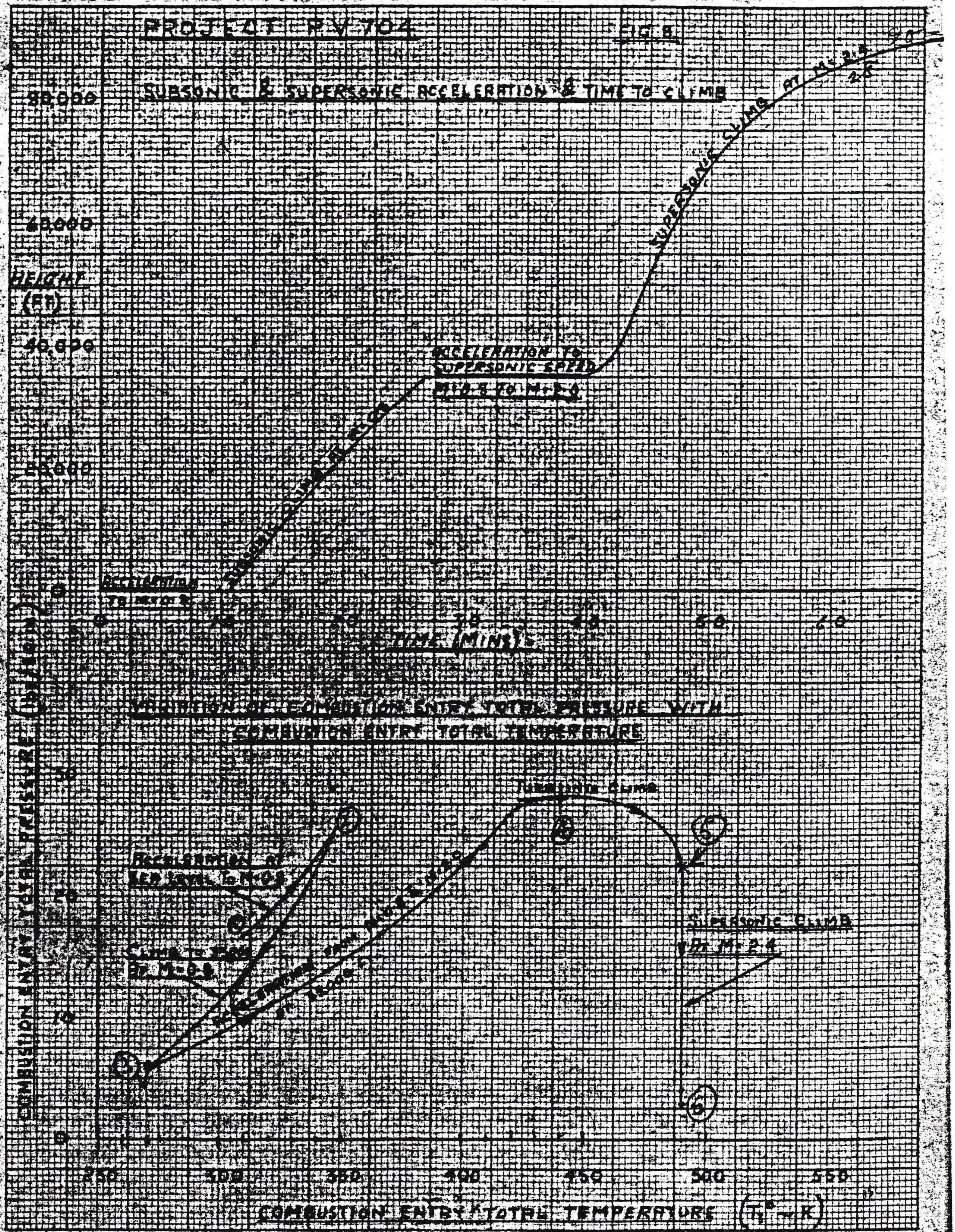
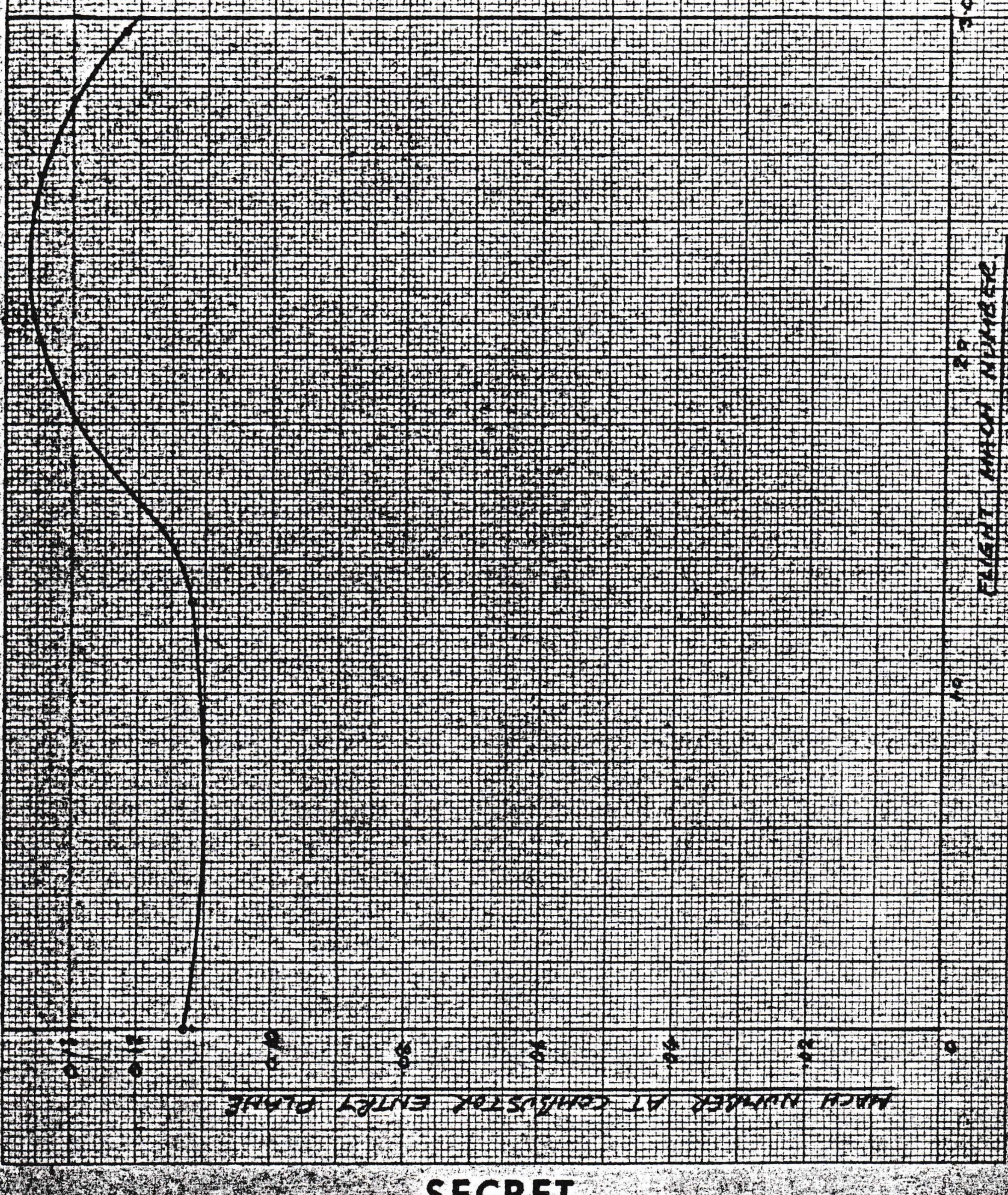
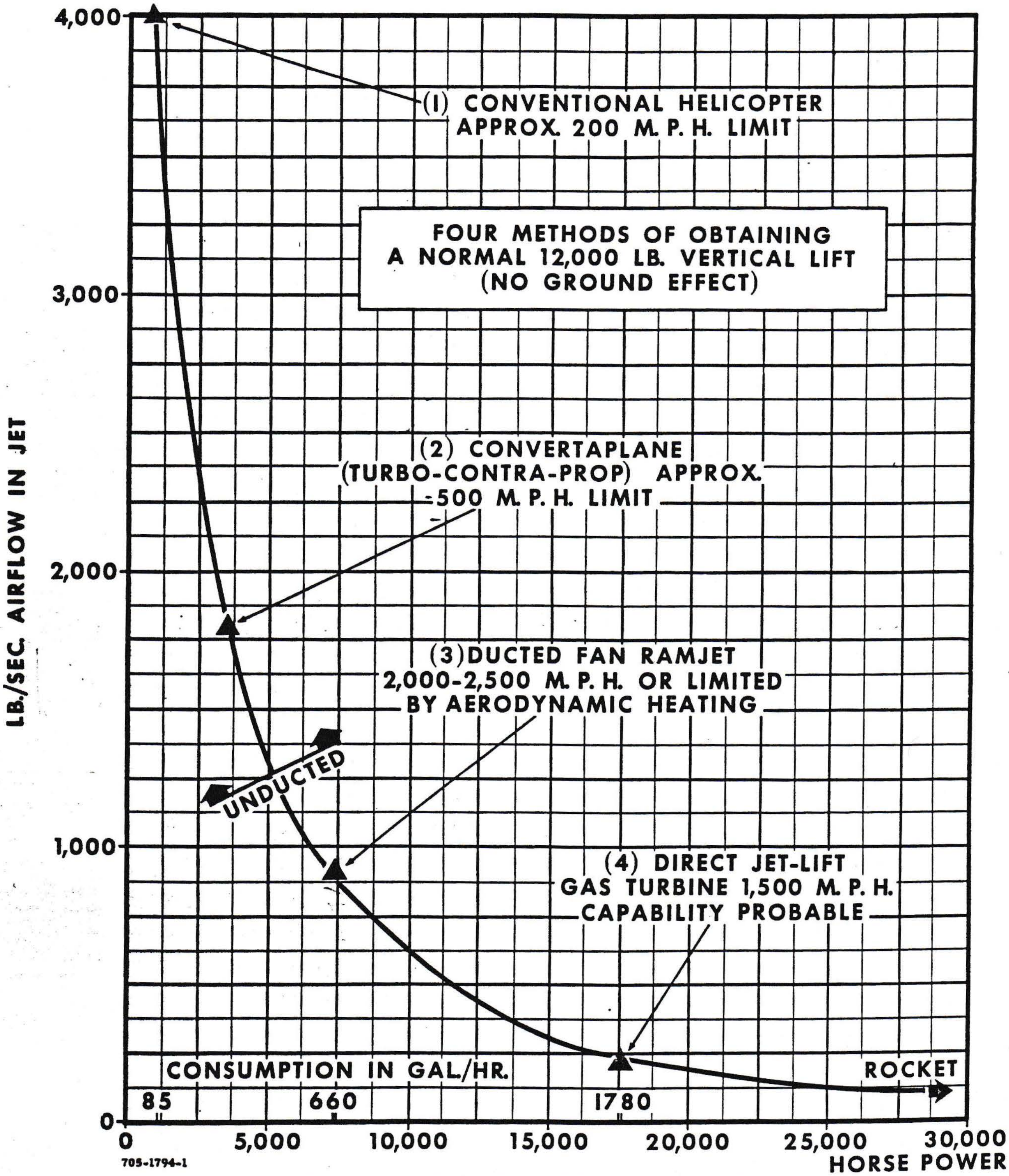

PROJECT P.V. 704
FIG. 8.
SUBSONIC & SUPERSONIC ACCELERATION & TIME TO CLIMB
HEIGHT (FT)
40,000
SUPERSONIC CLIMB AT M=2.4
ACCELERATION TO SUPERSONIC SPEED
TIME (MINS)
0
10
20
30
40
50
60
VARIATION OF COMBUSTION ENTRY TOTAL PRESSURE WITH COMBUSTION ENTRY TOTAL TEMPERATURE
COMBUSTION ENTRY TOTAL PRESSURE
SUBSONIC CLIMB
ACCELERATION AT SEA LEVEL TO M=0.8
SUPERSONIC CLIMB AT M=2.4
0
10
20
30
250
300
350
400
450
500
550
COMBUSTION ENTRY TOTAL TEMPERATURE

FIG. 8 VARIATION OF INLET MACH NUMBER TO COMBUSTION CHAMBER WITH FLIGHT MACH NUMBER IN STRATOSPHERE

AT S.L HOVERING $M_3 = 0.112$





V.T.O. EFFICIENCY CHART

FIG. ~~56~~ 10

BLACK PLATE