



A.V. ROE & CO. LIMITED
MANCHESTER ENGLAND

AVRO VULCAN 'B' MK.I.

CARRIAGE OF BLUE STEEL

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I.P.B. 68

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ISSUED TO MASTER

A. V. ROE & CO LTD

AVRO VULCAN B. MK. 1
CARRIAGE OF BLUE STEEL

INTRODUCTION

This brochure is submitted in reply to a request made in a letter from the Resident Technical Officer (Ref. V/03/1/3247) dated 19th November 1956.

At a meeting held at Messrs. A.V. Roe & Co. Ltd.'s Chadderton factory on the 29th January 1957 (Minutes Ref. V/01/7/4196) to discuss Blue Steel installations on both Mk. 1 and Mk. 2 aircraft, "the firm demonstrated that it would be possible to carry the store on the Mk. 1 aircraft!" However, as the lower boom of the centre section front spar is not cranked on these aircraft, it is not possible to submerge the missile as much as on the Mk. 2 aircraft, and this has an adverse effect upon the aircraft's performance.

The all-up-weight of the aircraft with Blue Steel installed and bomb-bay fuel tanks is 190,163 lb. To achieve this weight together with an extension of the aft c.g. limit will require some flight development.

Wind tunnel tests show that the lower position of the Blue Steel missile on the Mk. 1 aircraft will not effect the emergency escape of the rear crew members, at speeds up to 250 kts. E.A.S.

This brochure outlines in Section 1 the proposals for the Mk. 1 installation. The performance of the aircraft is presented in Section 2 and in Section 3 an assessment of the man hours required to complete the drawings has been made.

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However, the benefits are small and it has been decided to locate the missile in a position such that it is clear of the aircraft at the front spar. This means that only the bomb doors are affected by the installation and avoids the use of a detachable fairing to cover a cut-out forward of the front spar when the missile is not being carried.

At the rear spar the missile could be lifted into the bomb-bay if Mod. 198 were incorporated. This modification is at present exclusive to Mk. 2 aircraft and is entitled "Fuselage - Centre-Section - To modify rear end of bomb-bay for carriage of new store". This would, however, locate the missile with approximately 5° of negative incidence relative to the aircraft chord line (approx. $2\frac{1}{2}^{\circ}$ in the Mk. 2 installation). No wind tunnel results upon the effect of the incidence of the missile relative to the aircraft upon the drag are available, but it is believed that this increased negative incidence would give increased drag. However, when the tail end of the missile is not lifted into the bomb-bay the lower folding fin of the missile cannot be actuated when the aircraft is on the ground.

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1.2. Missile Position

The considerations of the previous paragraph have led to a location of the missile in the position shown in Fig. 2, which is identical with the position adopted on the development installation on the Mk. 1 Vulcan now being designed by Messrs. Helliwells Ltd., under sub-contract to Messrs. A.V. Roe & Co. Ltd., (Weapons Research Division).

This design was not originally intended to be of a standard required for production aircraft, and the design of the installation will therefore require productionising.

1.3. Bomb-Bay Fairings

The present Helliwell installation retains the outboard portions of the bomb doors and replaces the inboard portions by fairings tailored to the contour of the missile. Whilst this should be satisfactory for the trials aircraft, it is considered that the drag can be reduced by a more sophisticated form of fairing. Wind-tunnel tests are being put in hand to determine the contours of such a fairing.

1.4. Equipment

The majority of the equipment installations essential to the use of the Blue Steel missile can be common

Watch that with new fairing the drag without missile is not more than before & this can be the advantage of the new fairing

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The variation of the centre of gravity with all-up-weight is depicted in Fig. 3. It will be seen that when the Blue Steel missile, R.C.M. equipment and bomb-bay fuel tanks are installed an extension of the aft c.g. limit is required. The present aft limit is 0.309c and to cover the above case it is desirable to extend the aft c.g. limit to 0.319c.

However, if the aft bomb-bay fuel tank of 392 galls is deleted then the rearward movement of the c.g. is restricted to 0.314c. This loss in fuel reduces the range by 110 n.m. but increases the target height by 150 feet (Figs. 6 and 7 respectively).

The implications of the extension of the aft c.g. limit from 0.309c to 0.319c may be fairly extensive and will involve modifications to the aircraft control system and automatic stability devices. For example the elevator artificial feel box will have to be stiffened up in order that the coefficient K can be increased in the equation:-

$$\text{Stick force } P = 8 + K \left(\frac{V_1}{100} \right)^2 \eta$$

where V_1 = indicated airspeed

η = elevator angle.

This will ensure satisfactory manoeuvring stability (i.e. stick force/"g").

With regards to static stability, there is a possibility that the stick force to

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change speed at high E.A.S. may become zero or even slightly negative. This effect is probably due to wing twist but the full implications have not yet been fully explored and this effect may not be critical.

The effect of the extended aft c.g. limit upon the auto-pilot will not be significant provided the elevator feel box is stiffened up as described above. There may be a compromise on the forward c.g. performance but this would only be important under the combined effect of high weight and forward c.g; a combination which will not arise.

Failure of the pitch damper is not serious at a c.g. position of 0.315c at a low weight and consequently at high weights the value of 0.319c is not likely to cause any concern.

Runaway of the Auto-Trimmer at an aft c.g. of 0.319c may necessitate lower setting of the cut-off accelerometer (1.7'g' at present). This would not cause embarrassment to the pilot under normal cruising manoeuvres but could possibly cause the auto-trimmer to cut out under evasive action but here again the full implications have not yet been investigated.

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The effect of increasing the all-up-weight to 190,163 lb. upon the manoeuvring performance of the aircraft will possibly restrict the attainable normal acceleration by 10%. This can either be accepted, or overcome by increasing the power of the elevator P.C.U's. At take-off the nosewheel raising speed can be maintained at the same percentage of the unstick speed as at the lower all-up-weight of 167,000 lb.

The maximum weight at which a Vulcan B. Mk. 1 has flown is 167,000 lb., and a flight development programme will be required to increase the all-up-weight to 190,000 lb. This is required for roles other than the carriage of Blue Steel, and it is recommended that an aircraft should be allocated as soon as possible for these tests.

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1.8. Load Factors

1.8.1. Flight Manoeuvres - Permissible Factors on Wing Structure.

At the overload all-up-weight of 190,163 lb. the Vulcan B. Mk. 1 can be operated successfully, but with certain provisions. It is desirable to use the bomb-bay fuel first as will be seen from the following tables. These figures are based upon the assumption that the aircraft centre of gravity is constant at 0.3098. In practice the c.g. will be aft of this limit at weights upward of 140,000 lb. as already discussed in Para. 1.7. This means that the 'g' values quoted are pessimistic and that in fact slightly higher 'g' values could be achieved.

Permissible factors. Low speed pull-out case.

	Weight	Fuel in Bomb-Bay used first	Fuel in Bomb-Bay used last
After take-off	188,563	2.46 g	2.43 g
Start of Cruise	179,063	2.69 g	2.46 g
	161,700	2.91 g	2.58 g

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main undercarriage tyres (Dunlop DC 0024T) which have a maximum permissible pressure of 260 lb./sq. inch. These tyres are the same size as those for the Mk. 1 aircraft.)

1.8.3. Emergency re-land at Take-off Weight

In the event of an emergency re-land after take-off at an A.U.W. of 190,163 lb. the maximum rate of descent that can be met without exceeding the design case for the main undercarriage units is 8.1 ft./sec. compared to the aircraft specification requirement of 8.8 ft./sec. at take-off.

With regard to the nose undercarriage unit advantage can be taken of the rearward c.g. position associated with the overload weight and under these conditions the nose undercarriage loads will not exceed those obtained during operation at the usual all-up-weight of 160,000 lb.

1.8.4. Ground manoeuvres

The increase in load on the main undercarriage units for these cases is approximately 17%. Now since the reserve factors on the undercarriage units are in the main about 1.0 and similarly for the structure the turn and swing case gives reserve factors of about 1.0, it is clear that the aircraft cannot meet the ground manoeuvre cases at 190,163 lb. without the reserve factors being less than 1.0. It is, there-

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fore, essential that when operating at the
overload weight all violent ground manoeuvres
and excessive use of the aircraft brakes
should be avoided. ✓

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The Blue Steel drag is based on high speed tunnel tests in the R.A.E. 10' x 7' high speed wind tunnel while further tests have been made in the Avro low speed wind tunnel. The wind tunnel models were, in both cases, attached directly to the fuselage without modification of the lines to provide better fairings. Further model tests and design effort will attempt to improve the attachment of Blue Steel to the Vulcan fuselage by modifications to the bomb doors combined with suitable aerodynamic fairings. Thus, although the wind tunnel drag measurements have been used to estimate the aircraft performance it is more likely that the final drag of the missile when fitted to the Vulcan Mk. 1 will be lower than assumed in the present performance calculations.

2.3. Engine Data

The performance of the aircraft is shown when using four Bristol Olympus B.01. 104 engines. The engines are assumed to operate at maximum continuous cruising power throughout the flight and the ratings applicable are shown below:-

Take-off performance - sea level

Nominal sea level static thrust-lb. 13,000
Maximum continuous power at M = 0.87
at 45,000 ft. corrected for intake
efficiency.

Thrust lb.

2,527

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Specific Fuel Consumption lb/lb/hr.	1.077
Low pressure compressor R.P.M.	6,470
Turbine Entry Temperature °K	1,140
Jet Pipe Temperature °C	590

2.4. Cruise Performance

The cruising performance of the Vulcan Mk. 1 when carrying a Blue Steel Missile has been estimated for a cruising Mach number of 0.87. Small improvements in range and altitude could be achieved by flying at a Mach number between 0.84 and 0.85, but since the general comparison would still hold, the effect of varying the cruising speed has not been considered in the present analysis.

Fig. 6 and 7 show the effect on range and altitude of increasing the fuel capacity of the aircraft. This is possible since the external mounting of Blue Steel allows additional fuel tankage to be fitted in the bomb-bay. In the present scheme three tanks are fitted capable of holding 1,120, 372 and 392 gallons respectively. It can be seen from Figs. 6 and 7 that, using the maximum fuel capacity in the bomb-bay, together with the normal aircraft fuel a substantial part of the range loss due to the additional weight and drag of Blue Steel can be recovered. There is, however, a considerable loss in half range altitude associated with the fitting of Blue Steel. This grows progressively worse as the fuel, and hence all-up

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weight, of the aircraft is increased. Using the normal fuel capacity there is a 640 n.m. loss of range and 3,080 ft. loss in half range altitude, due to fitting Blue Steel compared to the standard aircraft carrying a 10,000 lb. bomb internally. Fig. 8 shows typical flight plans for the clean aircraft and the aircraft carrying the Blue Steel missile. For the latter case two fuel capacities have been chosen, i.e. the standard fuel capacity of 9,290 galls and the maximum fuel capacity of 11,174 galls. The range and altitude performance is summarised in the following table:-

Configuration	Still air range - nautical miles	Height at half range - feet
Clean Aircraft with internally carried 10,000 lb. bomb (9,290 galls)	3,690	48,100
Aircraft with Blue Steel and normal fuel (9,290 galls)	3,050	45,020
Aircraft with Blue Steel and maximum fuel (11,174 galls)	3,565	44,130

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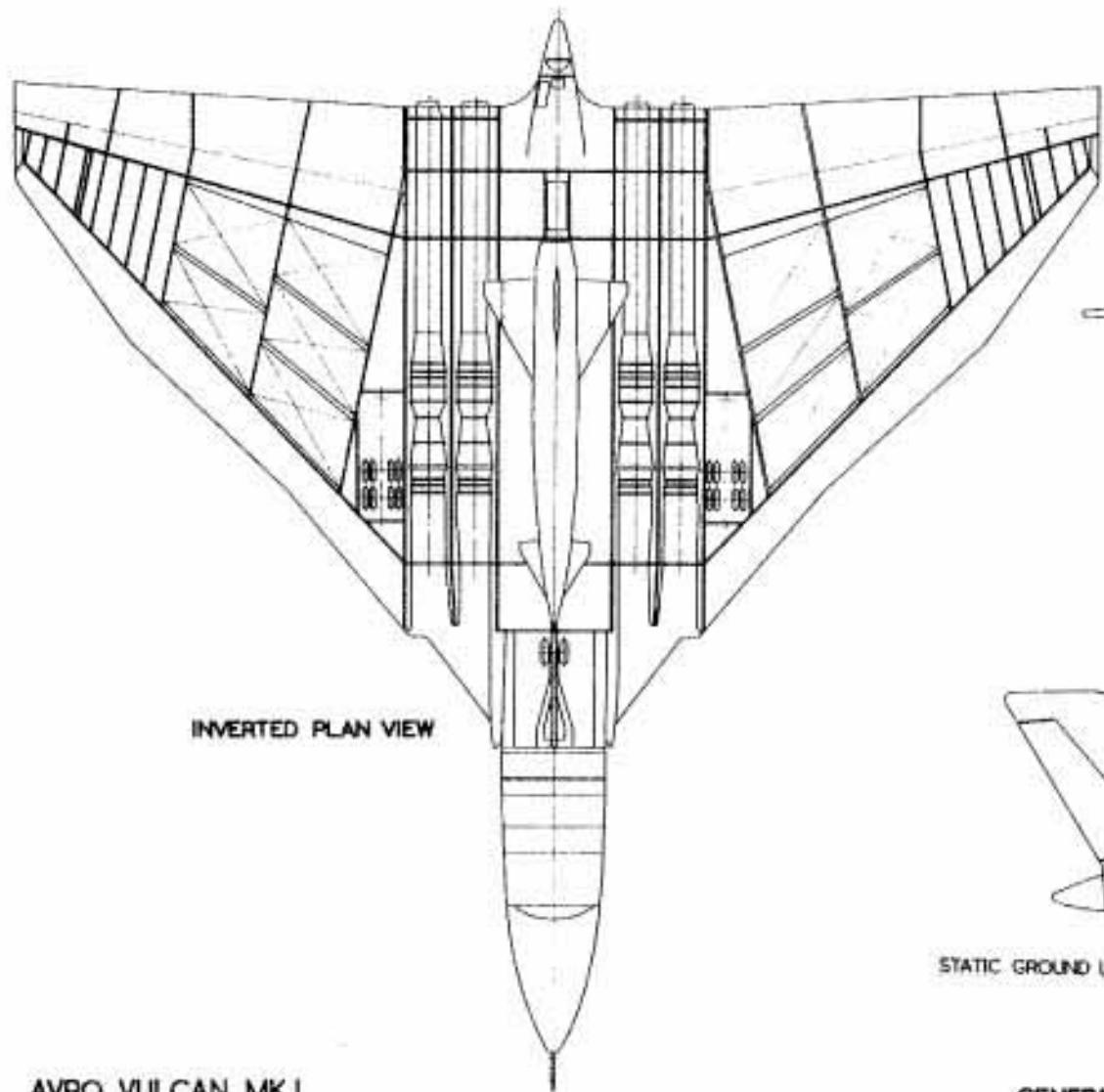
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If the Blue Steel is released at half range the total still air range may be further increased over that shown in the table above. A brief estimate shows that the range would increase by 450 n.m. in the normal fuel case.

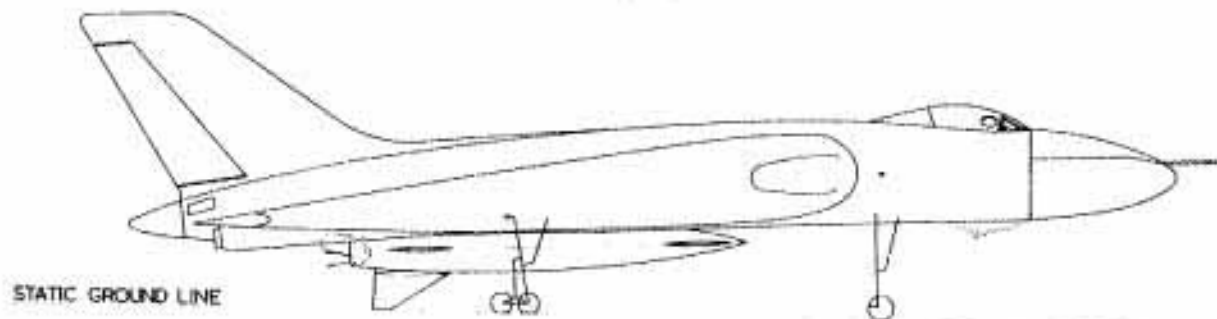
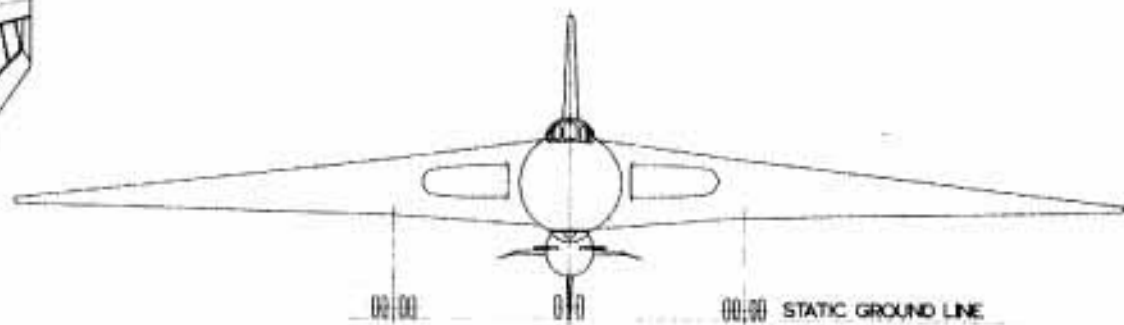
2.5. Comparison with Vulcan Mk. 2

The Mk. 2 Vulcan has a better Blue Steel installation than is possible on the Mk. 1 due to the cranked front spar. Furthermore the larger engines envisaged are more capable of absorbing the increased weight and drag of the missile. The range penalties are therefore not as great. The table overleaf compares the performance of the Vulcan Mk. 1 fitted with four Bristol Olympus 10s engines operating at maximum continuous power, with that of a Vulcan Mk. 2 fitted either with four Bristol Olympus 6 engines or with four Rolls Royce Conway 11 engines at maximum continuous power. In both cases a Blue Steel missile is carried throughout the flight and maximum fuel capacity is assumed.

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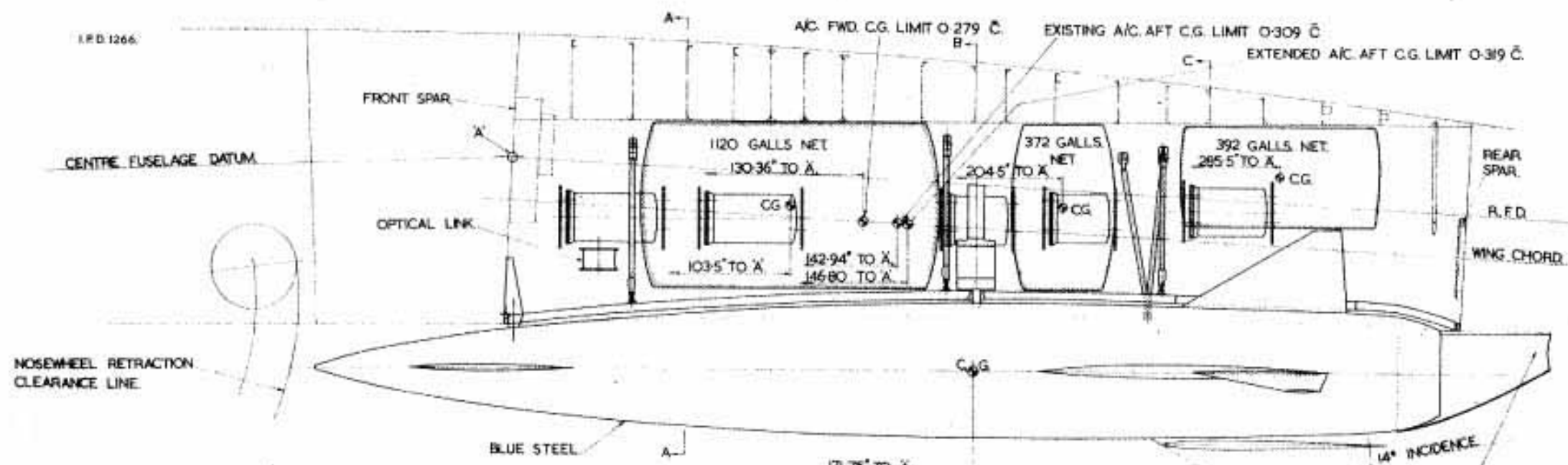


GENERAL ARRANGEMENT OF AIRCRAFT WITH BLUE STEEL MISSILE

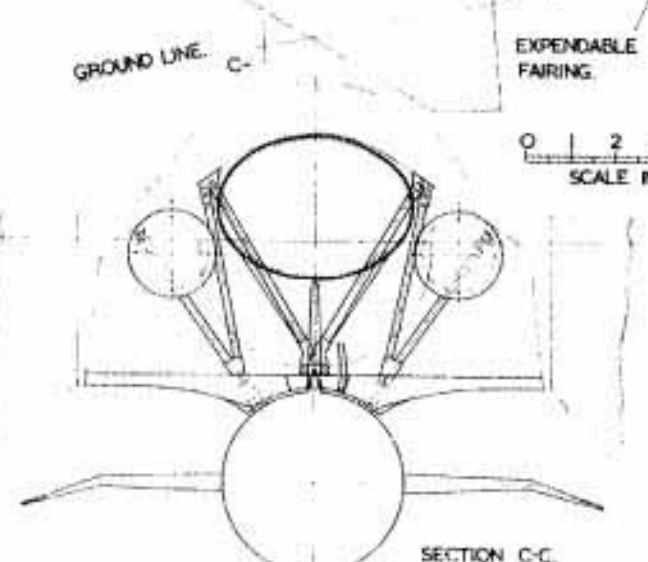
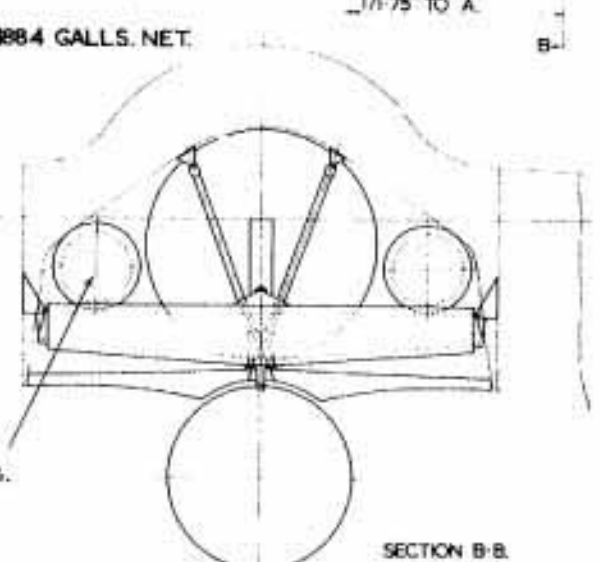
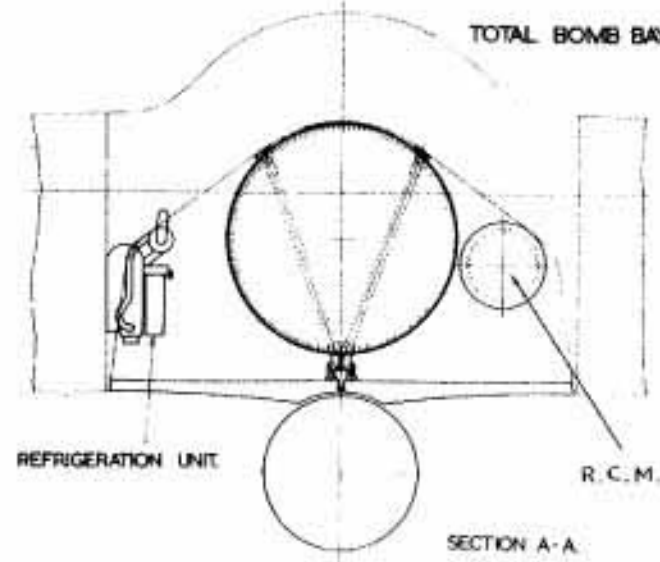
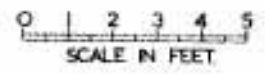
0 5 10 15
SCALE IN FEET

FIG.1

I.P.D. 1266



TOTAL BOMB BAY FUEL 1884 GALLS. NET.



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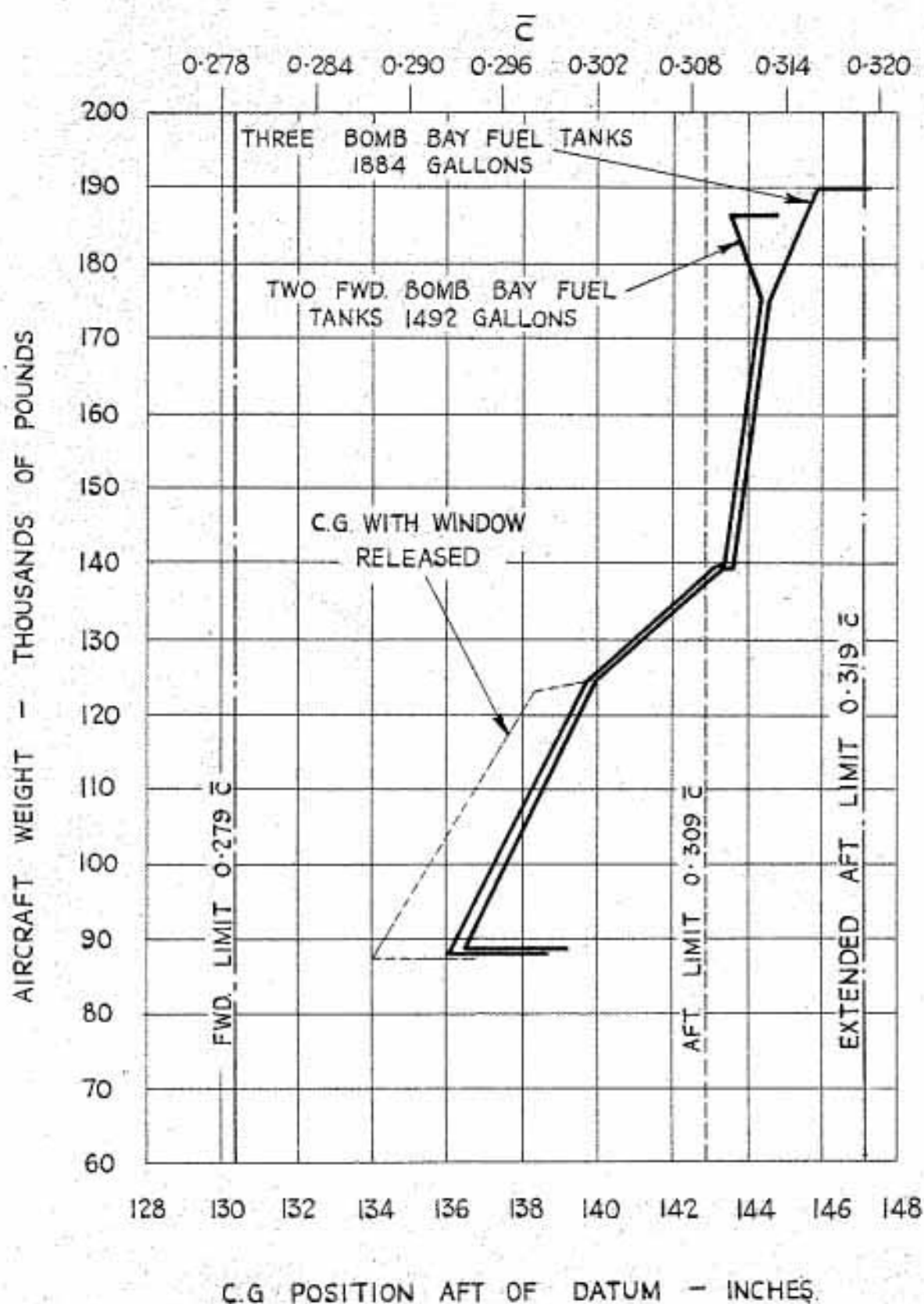
SECTION B-B

BLUE STEEL INSTALLATION

SECTION C-C

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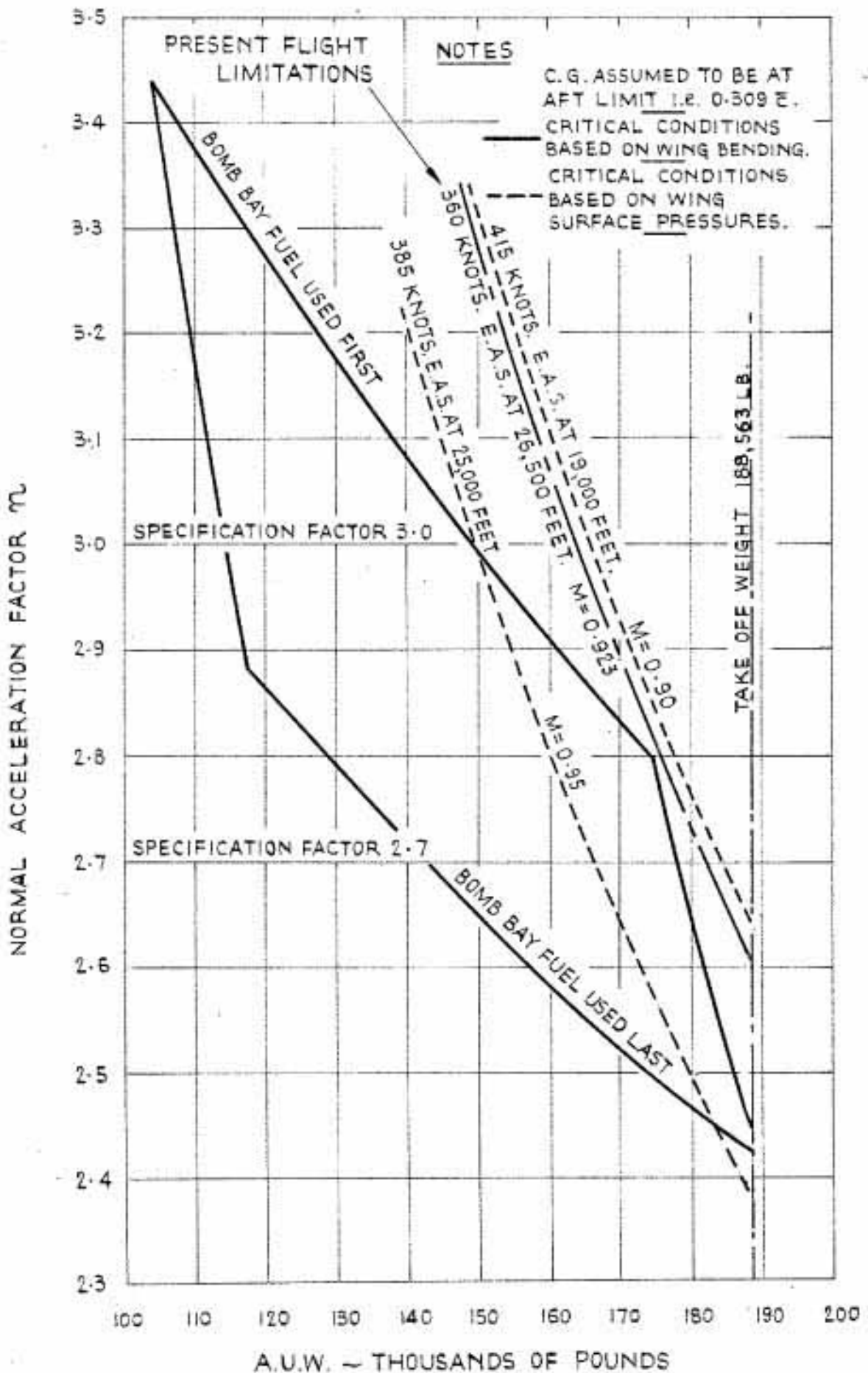
VARIATION OF C.G. WITH WEIGHT
WITH BLUE STEEL MISSILE
AND BOMB BAY FUEL



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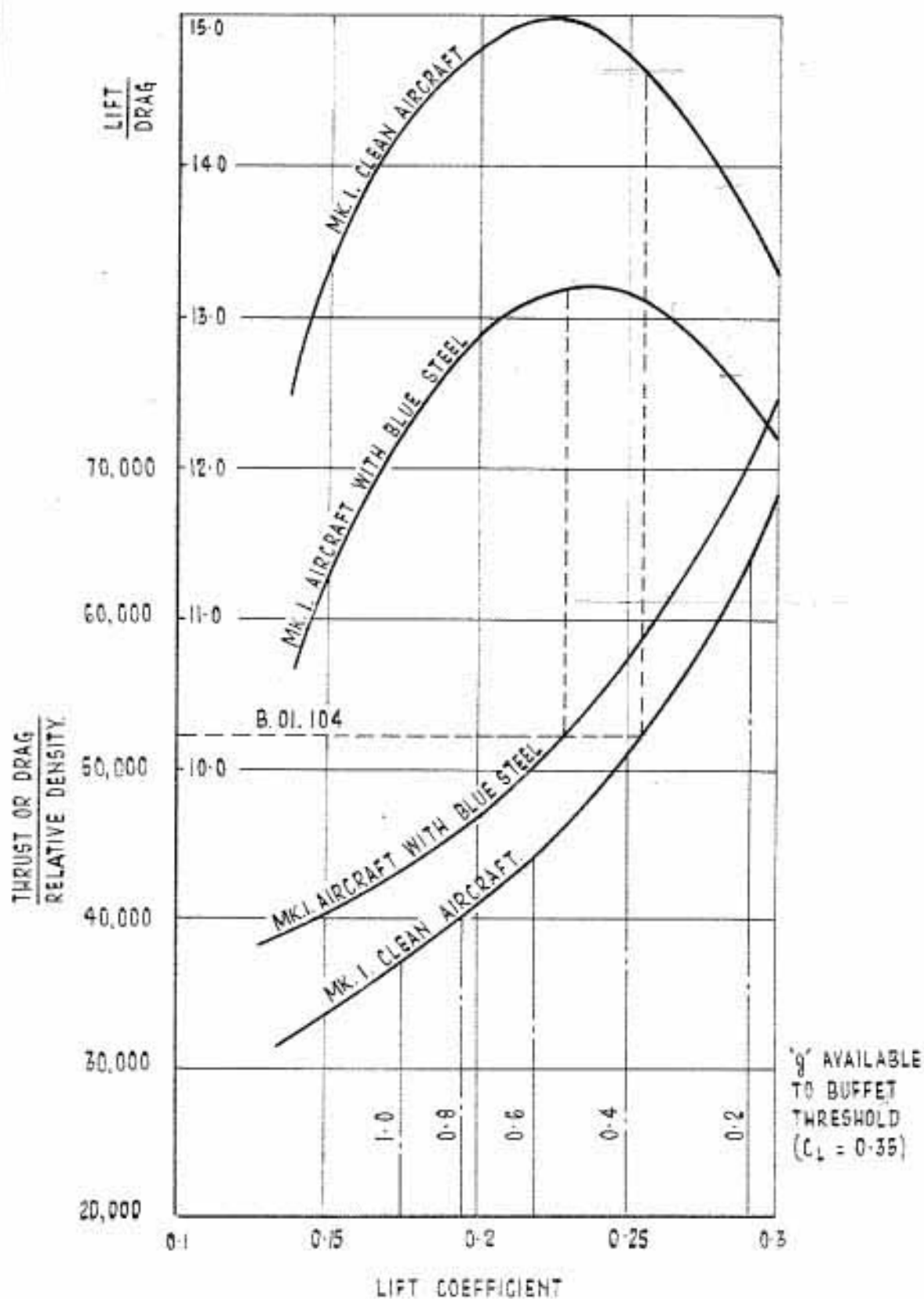
PERMISSIBLE UNFACTORED NORMAL
ACCELERATION IN SYMMETRICAL PULL-OUTS.



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VARIATION OF LIFT & DRAG IN THE
STRATOSPHERE WITH BLUE STEEL MOUNTED
COMPARED TO CLEAN AIRCRAFT.
MACH NUMBER = 0.87



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VARIATION OF STILL AIR RANGE & HEIGHT
AT HALF RANGE WITH FUEL CARRIED.

BLUE STEEL MOUNTED
CRUISE AT M=0.87
B.O.L. 104 ENGINES OPERATING AT MAX.
CONTINUOUS R.P.M.

FIG 6

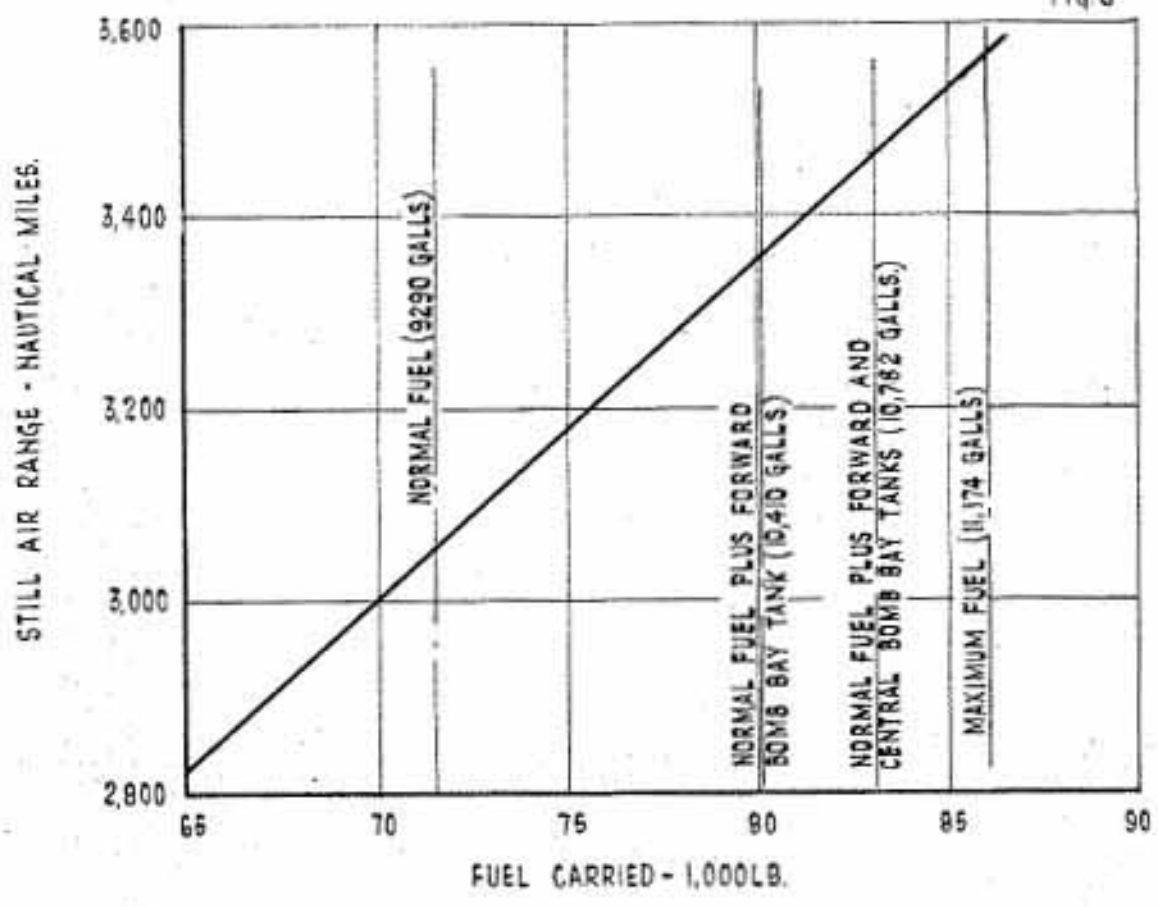
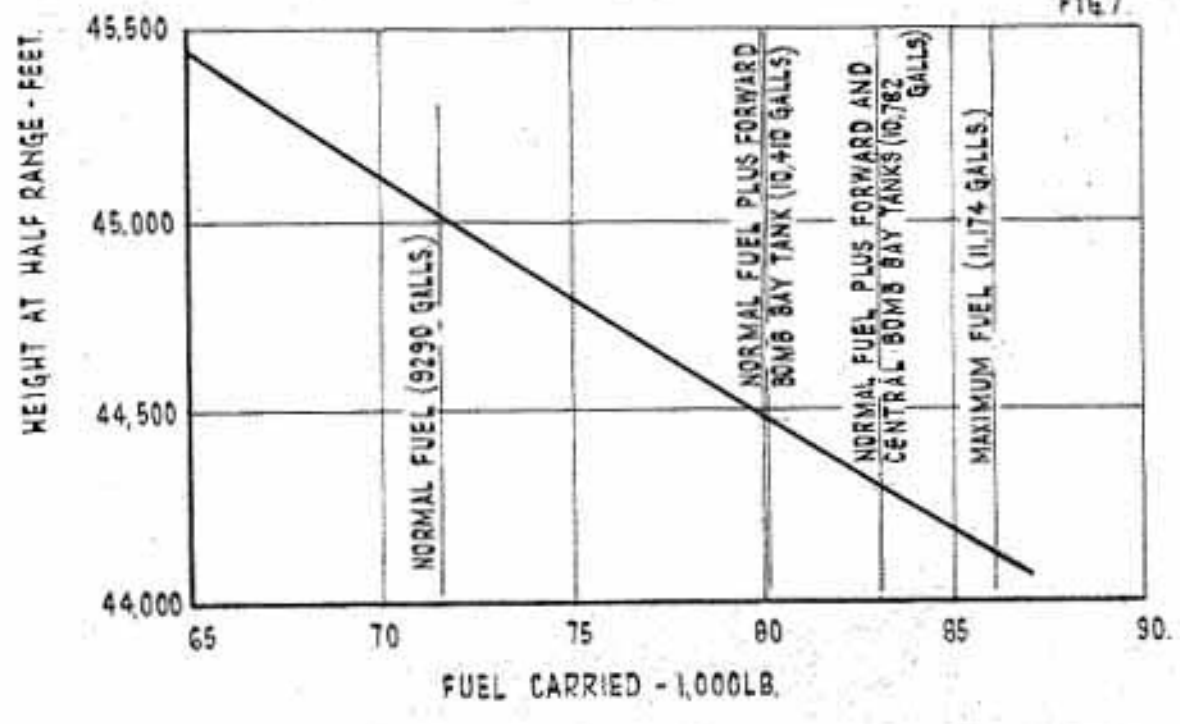


FIG 7



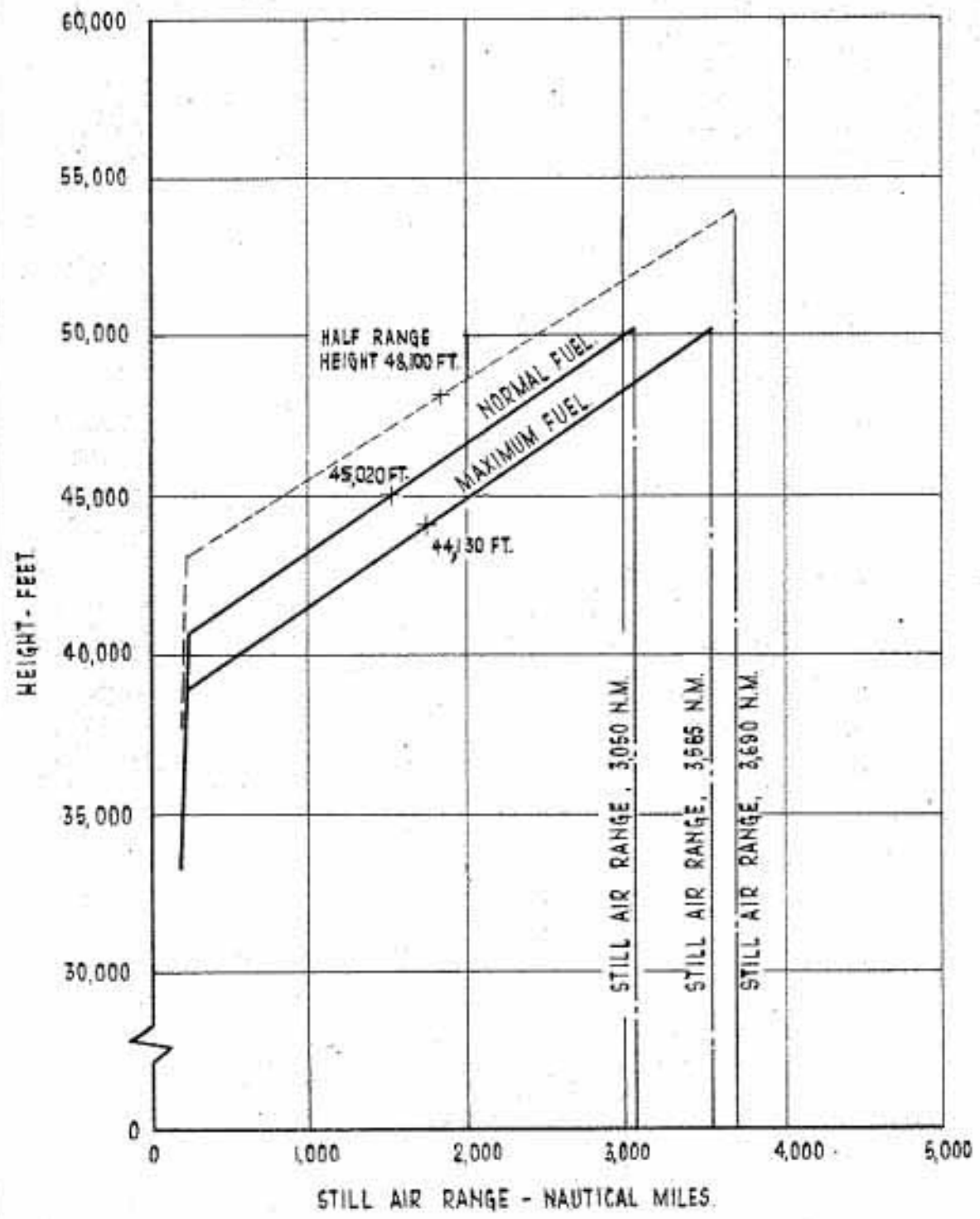
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FLIGHT PLANS
CRUISING MACH NUMBER = 0.87

----- BASIC VULCAN WITH 10,000 LB. BOMB
———— VULCAN WITH BLUE STEEL

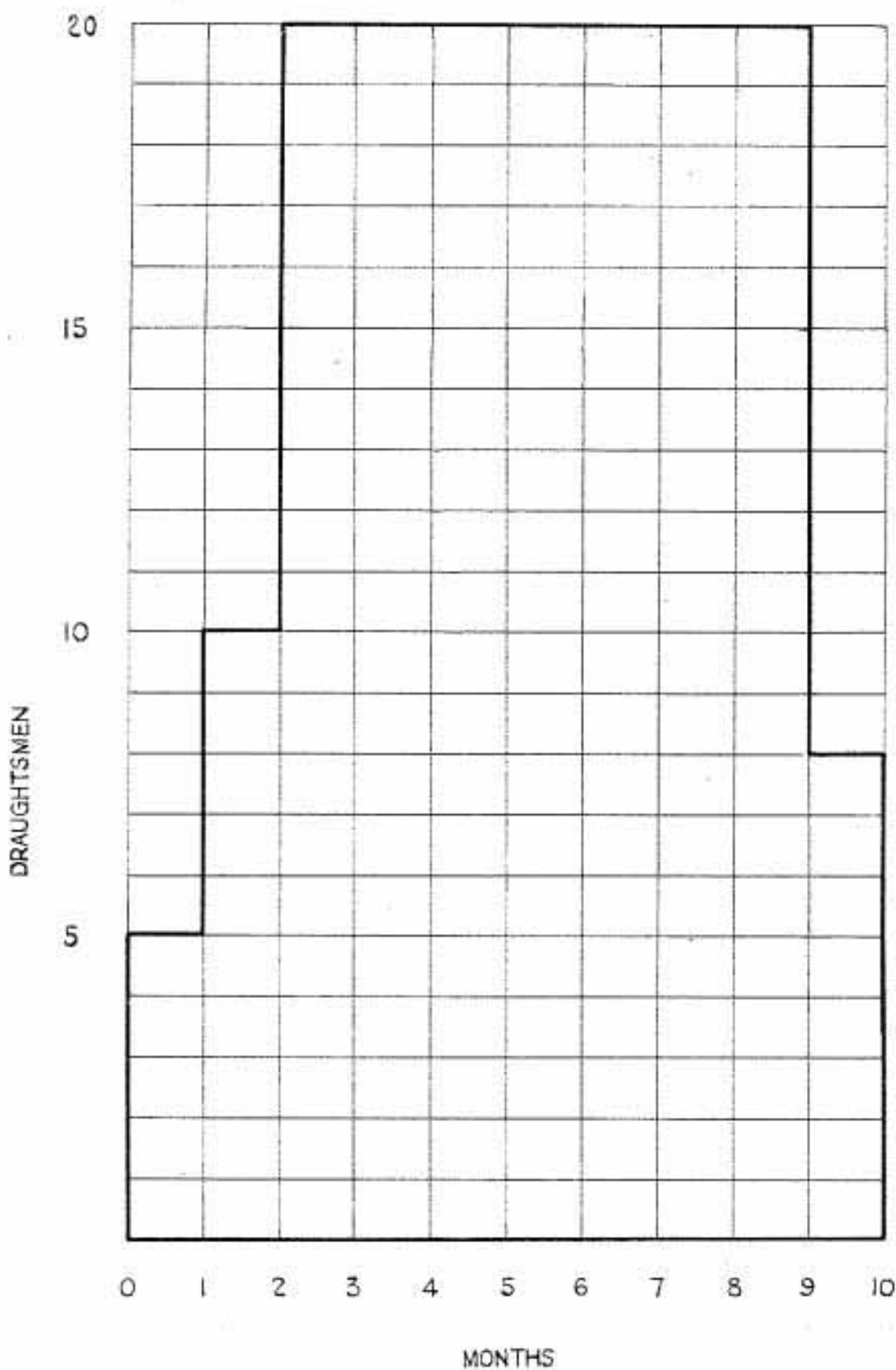
B.O.L. 104 ENGINES OPERATING AT MAX.
CONTINUOUS R. P. M.



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DESIGN PLANNING CHART
ESTIMATED MAN HOURS - 26,000



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pressure breathing
mask

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