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DRBS 0300-3
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TL.104-58/04

DEFENCE RESEARCH BOARD

MEMORANDUM

Ottawa, Ontario,
11 April 1958.

SA/CGS

Avro VTOL Aircraft

I forward herewith a copy of a report prepared by this Directorate giving an assessment of the Avrocar for the "Aerial Jeep" mission. Although the method of analysis employed was of necessity approximate, it will be observed that the results are in substantial numerical agreement with such company performance claims as have been published. However, there are a number of significant omissions from the Avrocar brochure, and it is on these points where the deficiencies of the design become apparent.

In our view, the Avrocar does not represent the most efficient solution to the "Aerial Jeep" role. Accordingly, insofar as Canadian interests are concerned, we would like to see these directed towards other more promising means for achieving a VTOL capability.

Further analysis is in progress with a view to assessing the usefulness of the Avrocar principle in the supersonic regime.

Original Signed by
A. W. R. GILCHRIST

J. L. Orr,
D Eng R.

Same to SA/CNS

RL 503

# The Suitability of the Avrocar for the Aerial Jeep Mission

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## Summary

It is shown that the Avrocar is inferior, as a hovering vehicle, to all other types of VTOL devices except for direct jet lift types such as the Rolls Royce Flying Bedstead. It is also demonstrated that in forward flight over the aerial jeep speed range this inferiority persists. These conclusions rest on fundamental laws of physics; the characteristics are inherent in the design and cannot be overcome by refinements.

The consequence of greatest significance to the operator is that the fuel consumption is remarkably high. At full take-off weight the distance covered in a typical mission with full tanks is only of the order of 12 miles, even if no allowance for fuel reserves is made.

It is pointed out that other possible configurations for the aerial jeep mission are considerably superior in this respect.

Certain other reservations concerning the Avrocar are also indicated.

## Introduction

From discussions with Canadian Army officers it has been established that an aerial jeep operating "in the nap of the earth" will be confined to a speed range of 0-50 mph, with 25 mph as a typical figure. This is confirmed by the requirements of the US Aerial Jeep specification, and by one's natural expectation that flying in and out of ground cover at minimum clearance heights cannot be carried out at high speeds.

Calculations based on momentum theory have been made to indicate the Avrocar performance over this speed range. These calculations do not replace detailed performance analysis, but constitute a first approximation thereto. However it is emphasized that the results check quite well with the few performance figures given by Avro in the Avrocar brochure. In this connection it should be noted that the brochure range figures do not refer to aerial jeep operation, but to operation at the most favourable speeds, which are much above those possible for flying in ground cover; in some cases they refer to flight at 20,000 ft. which is scarcely an Army mission.

## Hovering

Basic considerations of momentum and energy have been used to calculate the lift obtainable per horsepower for a thrust-supported vehicle. This quantity, usually called the power loading, is a function of the thrust (or weight, since thrust=weight in the hover) per sq.ft. of disc area. The disc area is the area of the circle swept by the helicopter rotor or propeller; in the case of the AVROCAR the intake port area is used.

The results are shown in fig.1. Typical operating ranges for helicopters and propellers are shown, as well as the point representing the Avrocar. The latter does not fall on the curve because of favourable duct effects which have been allowed for.

Note that for the expenditure of 1 horsepower the typical helicopter produces more than 10 pounds of lift; a propeller-powered VTOL aircraft produces 4-5 pounds of lift; while the Avrocar produces less than 2 pounds of lift. For vehicles of given weight the relative fuel flow with equally efficient engines is directly proportional to these numbers. At its maximum gross weight the Avrocar in free air hovering will use fuel at the rate of nearly 500 gallons per hour; close to the ground this fuel flow will fall about 20% according to NACA data. Allowing for the reduction in weight as fuel is burnt off, the full tankage of 148 gallons will permit approximately 30 minutes hovering time. The brochure value of 50 minutes refers to a light weight case.

Hovering (cont'd)

It should be noted that aerial jeep designs having disc loadings between propeller and helicopter values would use about one quarter of the fuel required by the Avrocar in hovering.

Forward Flight

While Avro figures confirm the very high fuel flows found for the hovering case, the Company claims that the Avrocar makes use of "efficient wing lift" in forward flight, thus giving it a considerable advantage over certain other designs. Calculations have shown that over the aerial jeep speed range, engine lift is actually much more efficient than 100% wing lift for the Avrocar. However it was also found that by dividing the weight between engine and wing lift in the optimum way (a "black box" would presumably be required to select this mode of flight in practice) an improvement was theoretically possible over either pure wing lift or pure engine lift. Further investigation showed that very little of this gain could be realized in practice, because the angle of attack became impossibly large.

The power required for flight at various forward speeds was then calculated subject to the condition that the angle of attack is the lesser of the optimum value or an arbitrary value considered to be a reasonable limit. This is presented in fig.2. The significant feature of the result is that the power required remains at high levels throughout the speed range of interest. Fig.2 relates to free air operation; some favourable effect due to ground proximity may be expected to remain in forward flight. In the hovering case Avro claim a 33% decrease in power required due to this effect. NACA data show a decrease of this amount over the degraded level prevailing in free air, and half of this amount if degradation due to base suction does not occur. Thus a 20% decrease in power required may be assigned as an upper bound in the forward flight case.

At a mean speed of 25 mph close to the ground the fuel flow rate is approximately 6 gallons per minute at maximum gross weight. The maximum tankage of 148 gallons would give an endurance of about 25 minutes with no allowance for reserves. This corresponds to a distance covered of 10½ miles. Making allowance for fuel burn-off increases the distance covered to just over 12 miles.

The mileage per gallon is 0.084: this is better expressed as 12 gallons per mile!

High Speed Flight

Although speeds beyond 50 mph are out of the aerial jeep range, calculations were extended to check maximum speed and cruise performance at the most favourable speeds.

A maximum speed of the order of 300 mph was estimated; the brochure value is 360 mph. This figure depends critically on the zero lift drag coefficient, and the method of trimming. No claim is made for accuracy since detailed analysis is necessary. Either figure is far in excess of aerial jeep requirements.

The minimum power speed is approximately 130 mph and the corresponding power required is 1500 HP. No ground proximity allowance is made in this case since it would be necessary to maintain adequate ground clearance at this speed.

The speed for best range is approximately 200 mph. At this speed the power required is about 1870 HP. Using appropriate specific fuel consumption values indicates a fuel consumption of about 0.65 mpg (1.55 gallons per mile). This is markedly better than the low speed fuel consumption; however it is emphasized that this high speed cruise mission is distinct from that of the aerial jeep, and that VTOL aircraft of other configurations designed for a high speed cruise mission could achieve much better fuel economy.

High Speed Flight (cont'd)

These figures indicate a maximum range in high speed sea level cruise of just under 100 miles. Allowance for fuel burn-off would increase the value to somewhat over 100 miles. The Avro brochure value is 120 miles, which is in substantial agreement.

Payload and Weight

The Avro brochure gives the empty weight as 1920 lb., and the fuel weight (full tanks) 1060 lb. The maximum gross weight is given as 5650 lb. Crew weight is 2 x 180 = 360 lb.

The gross weight figure is limited by the VTOL requirement, and is closely confirmed by the present calculations. The indicated payload is thus 5650 - 1920 - 1060 - 360 = 2310 lb. This figure is considered dubious for two reasons.

Firstly, the outstandingly high fuel consumption limits the range in the aerial jeep role to such an extent that greatly increased tankage would be necessary to perform even a modest mission. A 25-mile radius mission would necessitate quadrupling the fuel load, which would make the payload negative.

Secondly, the empty weight figure is so much below those currently achieved in aeronautical practice as to require detailed justification. Deducting the known bare weight of the engines leaves a total of 1,000 lb., or 17½% of the gross weight, to cover structure, rotor, ducting, pneumatic and electrical systems, equipment, tankage, controls, trapped liquids, etc.

For comparison, the HUP-4 helicopter which is of comparable gross weight, has bare fuselage weight of almost this amount. This figure excludes rotor, engine, engine accessories, transmission, fuel system, undercarriage, furnishings, instruments, radio, electrical system, etc.: it is the weight of the empty structural shell.

Careful weight studies are necessary before any conclusions can be drawn, but on prima facie evidence the brochure payload figures must be heavily discounted.

Stability

It is admitted by the Company that the Avrocar is longitudinally and directionally unstable. Their solution is to install automatic stabilizing equipment. It is not suggested that this is not a feasible solution, although more than the simple rate sensors being considered by the Company is likely to be necessary; the problem is a difficult one. It remains to be seen if adequate control can be maintained with the stabilised system. Weight, cost, and complexity are further aspects requiring consideration.

Cargo Space

Most of the space within the vehicle envelope is occupied by propulsive machinery, fuel tanks, and ducts; space for cargo is restricted and of awkward shape. The cargo space is also remote from the centre of gravity, making careful balance of load essential; this is a drawback under field conditions.

Airportability

The present vehicle design does not appear to lend itself to simple break-down and assembly for transport by air. It may be possible to overcome this objection by redesign.

Cost

The high installed power which it is necessary to provide in the Avrocar is likely to make the cost per unit high. The operating costs are high because of the fuel consumption characteristics already discussed.

Exhaust Velocity

As a further consequence of the basic difficulty of the Avrocar design - its high disc loading - the velocity of the effluent gases is very high. This may lead to operational difficulties: concealment in ground cover is not much use if the vehicle is heralded by a dust storm. The possibility of small pebbles being carried into the mechanism must also be investigated.

Conclusion

The Avrocar suffers from a number of very serious disadvantages for the aerial jeep role. Most of these stem from a single cause - the excessively high disc loading of the design. The vehicle's designer has stated that he has investigated this matter and that the Avrocar in its present configuration has the optimum disc loading possible with this design.

It is concluded that other configurations lending themselves to more favourable values of this critical parameter should be investigated for the aerial jeep mission.

Prepared bY:

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18/MAR/1958

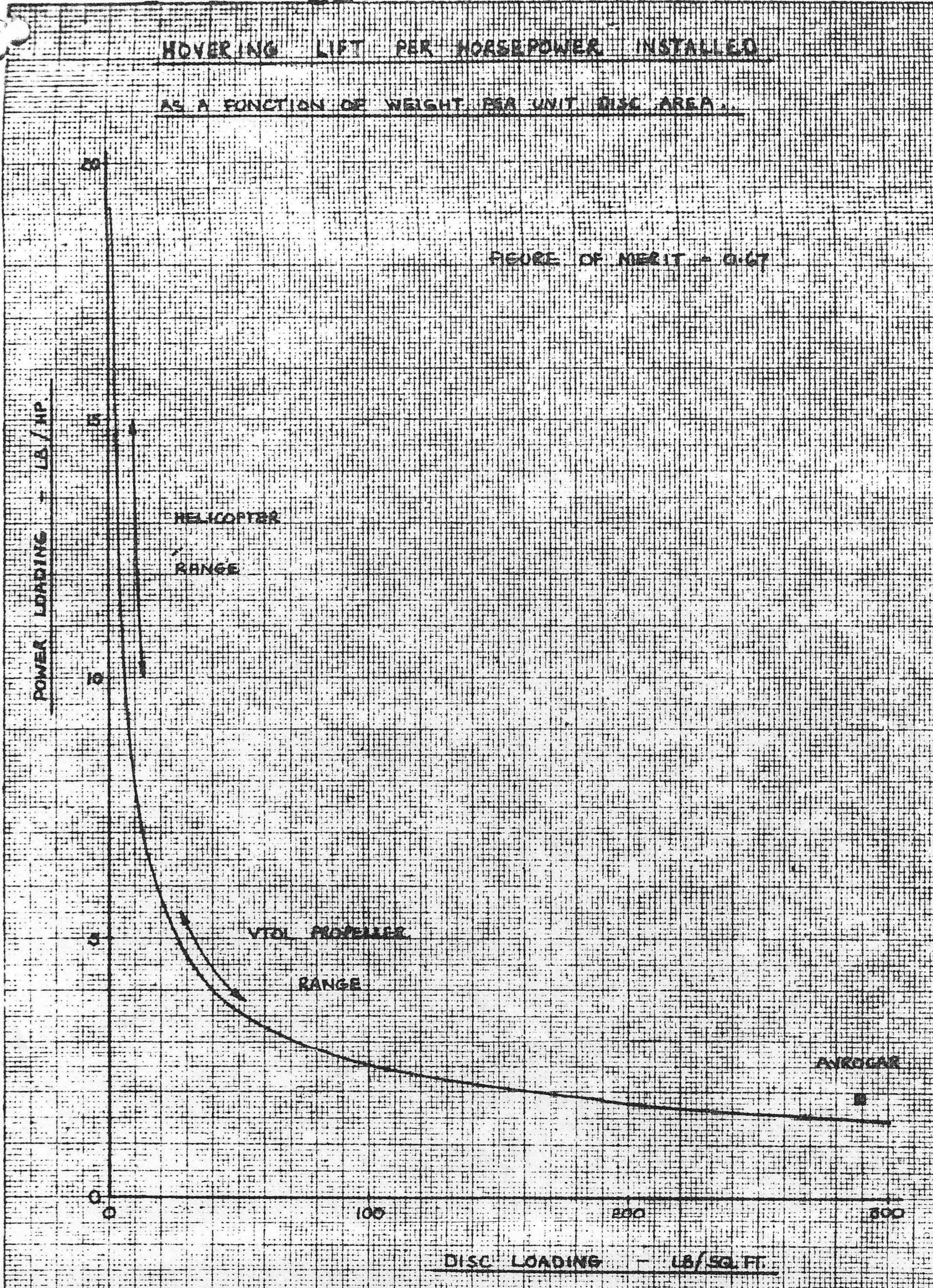
HOVERING LIFT PER HORSEPOWER INSTALLED
AS A FUNCTION OF WEIGHT PER UNIT DISC AREA.
FIGURE OF MERIT = 0.67
POWER LOADING - LB/HP.
20
15
10
5
0
HELICOPTER RANGE
VTOL PROPELLER RANGE
AVROCAR
0
100
200
300
DISC LOADING - LB/SQ.FT.

FIGURE 1.

AVROCAR — POWER REQUIRED CURVE

A.U.W. = 6650 lb SEALEVEL O.G.E

α LIMITED TO 10 DEGREES

AERIAL JEEP SPEED RANGE

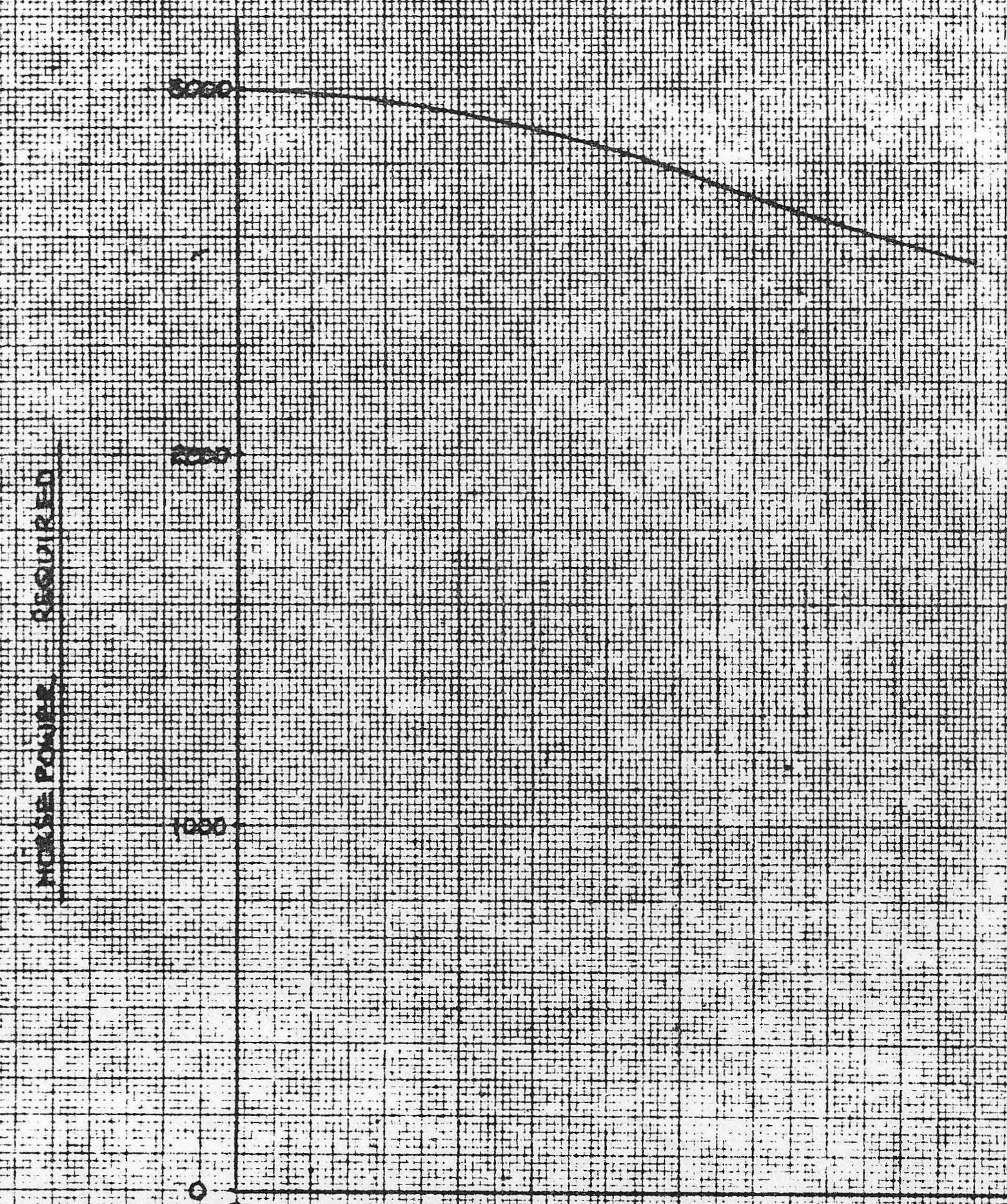


FIGURE 2

SECRET

FOR CANADIAN EYES ONLY



# AVROCAR PERFORMANCE ESTIMATE

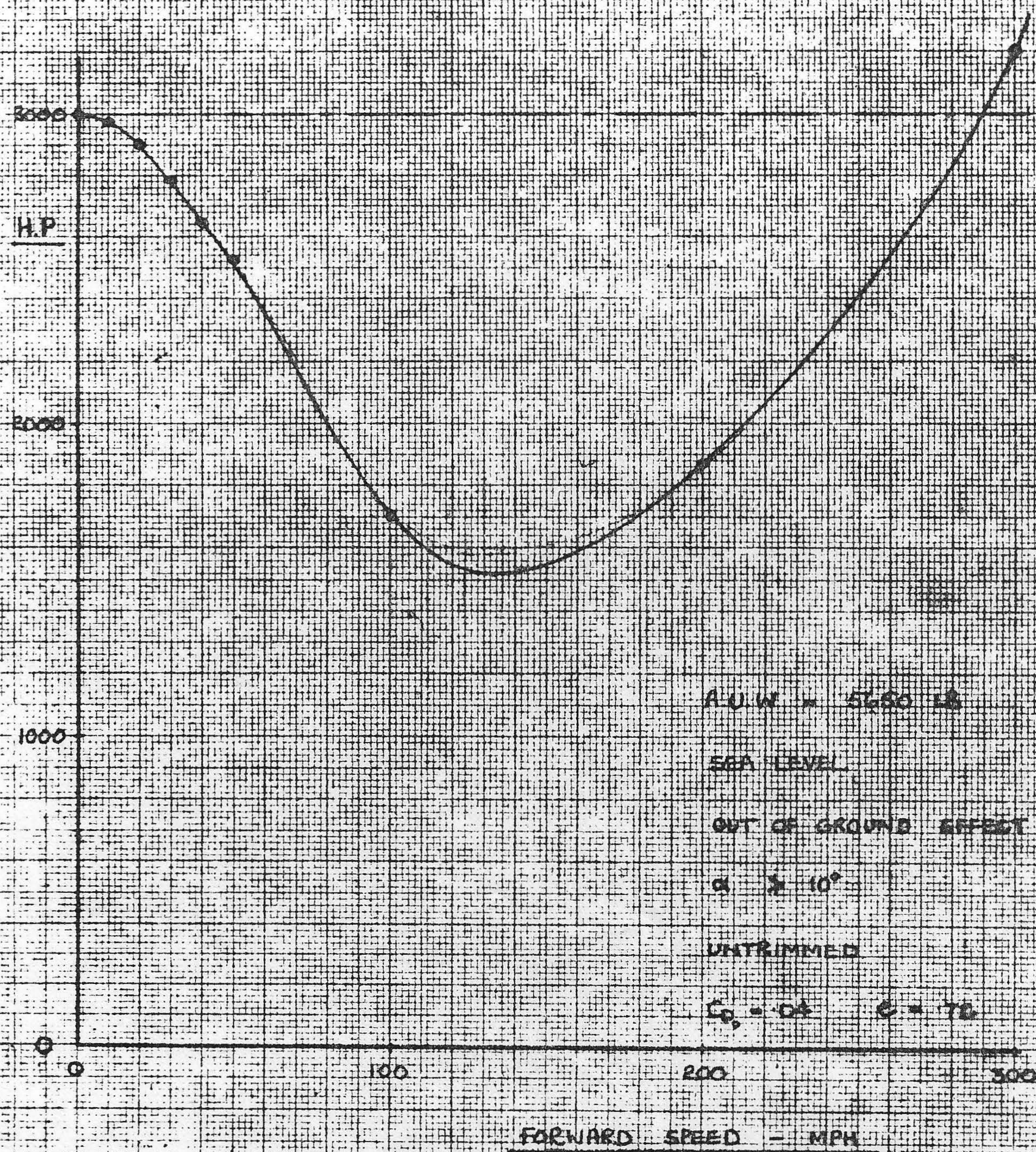


FIGURE 3