AD NUMBER	
ADA800709	
CLASSIFICATION CHANGES	
TO:	unclassified
FROM:	restricted
LIMITATION CHANGES	
TO: Approved for public release; distribution is unlimited.	
FROM: Distribution authorized to DoD only; Foreign Government Information; NOV 1946. Other requests shall be referred to British Embassy, 3100 Massachusetts Avenue, NW, Washington, DC 20008.	
AUTHORITY	
DSTL, AVIA 6/9994, 19 Oct 2009; DSTL, AVIA 6/9994, 19 Oct 2009	

Reproduced by

AIR DOCUMENTS DIVISION

TECHNICAL INTELLIGENCE

T-2

AMC

HEADQUARTERS AIR MATERIEL COMMAND

WRIGHT FIELD, DAYTON, OHIO

The U.S. GOVERNMENT

IS ABSOLVED

FROM ANY LITIGATION WHICH MAY ENSUE FROM THE CONTRACTORS IN-FRINGING ON THE FOREIGN PATENT RIGHTS WHICH MAY BE INVOLVED.

AIR MATERIEL COMMAND
WRIGHT FIELD, DAYTON, OHIO

REEL — C

341

A. I. I.

9504

RESTRICTED

SUITABLE FOR CONTROLLED DISTRIBUTION

RESTRICTED
REPORT No: AERO. 2172

Incl 116

R0-74230

352567

BRITISH RESTRICTED Equals
UNITED STATES RESTRICTED

ROYAL AIRCRAFT ESTABLISHMENT

Farnborough. Hants.

ATI No. 9504

24 ft. TUNNEL TESTS ON A "PADDLE BLADE" PROPELLER

by

A. B. HAINES, B.Sc.

[redacted]

NPR

Inclosure 1 to Rpt. R-1321-47
Military Attache, London.

RESTRICTED

Class No. 553.662.001.5

Report No. Aero 2172
November, 1946

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

24 ft. Tunnel Tests on a "Paddle Blade" Propeller

by

A.B. Haines, B.Sc.

R.A.E. Ref: Aero.1522/4/29

SUMMARY

The report contains the results of tests made in the R.A.E. 24 ft. tunnel on a de Havilland propeller having conventional Clarke Y sections and the paddle blade type of plan form.

The report describes analyses of the results made both by single radius and full strip theory methods. The data provided will enable estimates to be made of the performance of paddle blade propellers under various flight conditions and in particular will give a quantitative idea of the improvements to be expected for high power loadings i.e. beyond the stall.

The principal general conclusions are:-

1. Use of the same lift drag data in 8 radius strip theory calculations for both paddle blade and normal propellers is justified.

2. The gains found in flight tests for paddle blade propellers must be principally ascribed to the effects of NACA 16 series sections.

3. R.A.E. charts based on single radius data may be pessimistic in predicting the peak efficiencies of paddle propellers at high tip speed (by 1.5 to 2% for $M_T = 0.85$).

4. The mean stalling performance is better than would be expected even on an activity factor basis. This enables other design modifications, e.g. thin roots, 16 series sections etc. to be made to improve the top speed performance without causing serious losses at take off or climb.

5. Therefore the general conclusion is that use of the paddle type of plan form is fully justifiable even though it does not appear to offer any direct shock stalling relief.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Figures contd.

1 Introduction

Comparative flight tests have been made on various aircraft fitted with alternative propellers of conventional and "paddle blade" plan forms. These have included de Havilland tests on several Mosquito aircraft.[1,2,3] Tests on a Mosquito fitted with Merlin 77 engines have shown improvements of up to 7 m.p.h. in top speed and little change in the climb resulting from use of a wide 3 bladed instead of a narrow 4 bladed propeller[3]. Appreciable gains in cruising efficiency have also been obtained in A. & A.E.E. tests on Lancasters and in B.O.A.C. trials with York aircraft through fitting paddle blade propellers. In all these and similar cases, the relative performance of the paddle blade propellers was better than would be calculated using existing data derived from tests on Clark Y sectioned propellers of normal plan form. As, however, the paddle blade propellers in these examples had N.A.C.A. 16 series sections while the conventional propellers had Clark Y sections, it was still uncertain how much of the advantages of the paddle blade were due to plan form and how much to section shape. It has been shown by Haines in ref.3 that better agreement with the de Havilland test results could be achieved by using lift-drag data for N.A.C.A. 16 series sections derived from flight performance trials on a Spitfire 21 aircraft fitted with propeller of conventional plan form.

In order to settle how much really was due to plan form and to obtain quantitative data, it was decided to test in the R.A.E. 24 ft. tunnel a paddle blade propeller having Clark Y sections. This ensured that comparative data on propellers of conventional plan form were available. The present report contains the test results on this propeller together with an analysis of these results into both "single radius" and section data. These data have been used to provide estimates of the performance of the paddle blade under various flight conditions for comparison with estimates [4,5,6] based on the previously existent data.

2 Details of propeller and tests

The propeller tested in the R.A.E. 24 ft. wind tunnel was a 2 bladed version of the 12 ft. diameter 4 bladed de Havilland propeller, Drg. No.P4542536, used on the Hornet aircraft. This propeller is a cropped version of a basic design of 13 ft. diameter and the blades are of the "paddle" variety with wide tips. Details of the plan form and thickness and pitch distributions are given in fig.1, which also shows for comparison purposes, the conventional plan form of the Rotol metal design (RA.4014)[7] for the Spitfire IX. This propeller was chosen for comparison because it had the same thickness ratio at 0.7 radius as had the paddle blade, and also had a similar pitch and thickness distribution except at the roots. The blade plan forms are compared in fig.1 and the pitch and thickness distributions in fig.2.

The principal design characteristics of the paddle blade propeller are :

Solidity at 0.7 radius = 0.076 for 2 blades.

Activity Factor = 110.5 (compared with 70.6 for the Spitfire propeller mentioned above)

$(\text{Thickness/chord})_{0.7\ \text{radius}} = 7.0\%$

Thickness/chord = 30% for $r/R = 0.19$

Section shape : Clark Y.

The propeller was tested at five pitch settings: 10.1°, 15°, 19.9°, 25° and 35.1°.* At the four lower pitch settings, the tests were made over the full range of tunnel speed and for various rotational speeds reaching a tip Mach number of 1 for 10°, 15°; of 0.9 for 20° and of 0.8 for 25°. Owing to the limitations of power, it was only possible to run at 800 r.p.m. or less at the 35° setting - it has however previously been shown[8] that the performance of stalled propellers is not appreciably dependent on Mach number. The range of mean operating incidence covered by the above programme was from -1° to 20° at low Mach number and from -1° to 6° at the highest Mach number.

3 Results of tests

As usual, the measured thrust values have been reduced to propulsive thrust coefficients K_T

where

$$K_T = \frac{\text{Propulsive thrust}}{\rho n^2 D^4}$$

and propulsive thrust $= (T - R) + R_o$.

where

T = "free air" thrust,

R = drag of nacelle and pylon with propeller operating,

R_o = drag of nacelle and pylon without propeller,

$T - R$ = tunnel balance reading.

For a propeller of 12 ft. diameter, it may be expected that the propulsive thrusts will be about 2.25% below the free air values on the basis of the estimated drag in slipstream.

The results for the five different pitch settings are contained in tables 1-5 which give the values of thrust and torque coefficients and efficiency for differing advance ratio and tip Mach number. The significance of the results can however best be seen from the analysis and calculations recorded in the following sections.

4 Analysis into mean "single radius" data

An analysis of the test results for all pitch settings was made by Lock's single radius method[9]. The results analysed were for tip Mach numbers of 0.785**, 0.895, 1.005 and also the lowest tip Mach number covered at each pitch setting. The actual value of the solidity at the 0.7 radius was used initially, so that no account was taken of the plan form. The resulting $C_D - C_L$ curves are shown in fig.3, while the C_L vs α curve at low Mach number is given in fig.4 (curve A).

Since some methods of calculating propeller performance, e.g. the de Havilland[10] use the blade activity factor as the criterion of plan form where

---

* A few readings were also taken for a setting of 5° but these have not been computed.

** only $C_D - C_L$ curve shown.

$$\text{Activity Factor} = \frac{10^5}{D^5} \int_{0.2R}^{R} c \; r^3 \, dr ,$$

the curves of mean C_D vs C_L and C_L vs α were also calculated using a corrected solidity such that the ratio $\frac{\text{paddle blade activity factor}}{\text{corrected solidity}}$ equalled the ratio $\frac{\text{activity factor}}{\text{solidity}}$ for the Rotol Spitfire propeller with which comparison was being made. This corrected solidity = 1.16 × true solidity.

4.1 Comparison of C_L vs α curves (low Mach number)

In fig.4, a comparison is made of the C_L vs α curve (B) for the Rotol Spitfire blade with the C_L vs α curves derived for the paddle blade both on the basis of its true solidity at the 0.7 radius (A) and secondly on the basis of the corrected solidity as above defined (C). A and B therefore provide a comparison based on solidity and B and C, are based on activity factor. In making the comparison, it should be remembered that the blades are of approximately the same thickness ratio at 0.7 radius; while at the tips, the paddle blade is 1% thicker and at the roots, it is much thinner, being 30% thick outboard of r/R = 0.19 instead of at r/R = 0.25 as for the Spitfire blade (see also fig.2). The paddle blade also has a slightly larger twist.

The following conclusions result from the comparison:

(i) the no-lift angle for the paddle blade is 0.6° less - this probably results from its thinner sections inboard of 0.7 radius.

(ii) $\left(\frac{dC_L}{d\alpha}\right)$ below the stall for the Rotol blade lies intermediate between the values for the paddle blade on the two conventions. $\left(\frac{dC_L}{d\alpha}\right)$ should not depend appreciably on the blade thickness distribution and so this result suggests that for unstalled blades, the activity factor formula lays too much stress on the blade tips. This can be explained by the facts shown in para.6 and fig.15 that both $\frac{d\phi_o}{dJ}$ and $\frac{dC_L}{d\phi_o}$ wash out towards the blade tips. To achieve agreement in the values of $\frac{dC_L}{d\alpha}$ for the two blades, the paddle blade solidity should be multiplied by 1.06 (rather than 1.16 as on the activity factor convention).

Curve D in fig.4 shows the performance beyond the stall of the paddle blade when its solidity and mean no lift angle have been corrected to give the same C_L vs α curve (B) as for the Spitfire propeller below the stall.

(iii) beyond the stall, $\frac{dC_L}{d\alpha}$ for the paddle blade retains roughly half its value before the stall and so at high incidence, the paddle blade achieves a much higher C_L than the conventional blade. The onset of the stall occurs for roughly the same C_L - this is discussed in the next section (para. 4.2).

4.2 Comparison of low speed C_D vs C_L curves

These curves are compared on two bases: in fig.5 on activity factor and in fig.6 on the true solidity corrected by the 1.06 factor deduced above. It is seen from fig.6 that on the latter basis, there is exact agreement for $C_L < 0.5$ and thus in minimum C_D; from $C_L = 0.5$ to about 0.85, the paddle blade has a slightly higher C_D but that for higher C_L values, i.e. beyond the stall, the paddle blade has a steadily increasing advantage.

It is important to remember that because of the thinner root sections of the paddle blades, the two propellers would not be expected to stall at the same C_L even if they had the same plan form. On the basis of previous experience[11], the thinner roots of the paddle blade would have been expected to lower the stalling C_L (defined for precision as C_L for $C_D = 0.1$) by 0.11. Therefore apart from the effects of the plan form, a stalling C_L of 0.88 would have been expected rather than 0.99 as for the Rotol blade. Actually, even on an activity factor basis (fig.5), C_L is 0.91 and with the effective solidity required to give agreement at lower C_L, the stalling C_L is almost 1.0. It seems therefore that the good agreement between curves (fig.6) derived for the two propellers on the latter basis is a coincidence and that the effect of the plan form is more equivalent to what would be expected from the blade activity factor.* The bad effects on the stalling C_L of the thin root sections has been more than counteracted by the effectiveness of the tip sections and both figs.5 and 6 show how this effect becomes more marked with further increase of C_L.

4.3 Comparison of Mach number effects

Both figs. 5 and 6 also show the effect of increasing the tip Mach number from about 0.5 to 1.0 on the mean drags of the two propellers. Since it is the minimum drag values that are considered in particular, it is probably fairer to accept the comparison of fig.6. It will be seen that for approximately the same increase in tip Mach number, $C_{D_{min}}$ for the paddle blade has increased by only 0.008 compared with 0.015 for the conventional propeller. (Only the performance of the outer sections should determine this increase. These sections are slightly thicker on the paddle blade (fig.2).)

This result does not necessarily imply that the performance of the tip sections is better than would be calculated by full strip theory (see para.6) - but it does show the weakness of any mean section or activity factor method in coping with propellers of widely differing plan forms or twists. The following section (para.5) shows how much estimates of propeller performance under climbing and cruising conditions are affected by these discrepancies in mean data.

5 Comparison of paddle blade performance with estimates from R.A.E. charts

Forward speeds equal to 0.2 and 0.4 of the speed of sound were considered. For each forward speed, a curve of efficiency against power coefficient was found for a 4 bladed paddle propeller for a relatively low and for a moderate tip Mach number, both lying within the range of typical operation. The estimates were made, using -

(i) the C_D - C_L data derived (fig.3) from the paddle blade tests,

(ii) the charts of ref.5 considering the propeller as of conventional

---

*This might have been expected since the objection noted earlier (para.4.1(ii)) to the activity factor would only seriously apply to the C_L vs α curves.

plan form taking its true solidity value at the 0.7 radius, and

(iii) the same charts but increasing the solidity in the ratio of the value of $\frac{\text{activity factors}}{\text{solidity}}$ for the paddle blade and the standard propeller of the charts.

It should be noted that this standard propeller was 7.5% thick at the 0.7 radius and has very much thicker roots being 30% thick at r/R = 0.29 instead of at r/R = 0.19. It would be expected to have a much better stalling performance than a conventional propeller having the same thickness distribution as the paddle blade.

The results of the calculations are given in figs.7 and 8. It is seen that -

(i) the peak efficiencies for the paddle blade roughly agree with the chart values (based on true solidity) for the lower tip Mach numbers (0.6 and 0.66) but for M_T = 0.85 and 0.87 at the two forward speeds, the chart estimates are between 1.5% and 2% low,

(ii) at high power coefficients, the paddle blade is consistently above the chart values based on true $(\text{solidity})_{0.7}$ but are usually below the chart values based on the activity factor.

It is clear that the figures quoted for the differences in peak efficiency remain roughly true for the range of C_P giving $\eta > 60\%$ at $V/_a = 0.2$ and that giving $\eta > 70\%$ at $V/_a = 0.4$, which, it can be seen from the power scales given in figs. 7,8, cover all cases likely to be met in practice.

Figs.7 and 8 are useful principally in showing the order of error likely to be incurred by using the standard charts for a paddle blade of the type tested: accurate estimates should be based on the derived C_D - C_L data (fig.3).

6 Comparison of section drag data

The previous paragraphs have shown the possible order of error in using charts based on normal mean data in estimating the performance of paddle blades but to find out whether the plan form does really delay the shock stalling of the blade, it is necessary to carry out an analysis by the full 3 radius strip theory method.

6.1 Method of drag analysis

The method has been fully described in refs. 12, 13. The procedure consists in considering a series of combinations of advance ratio and pitch setting and in deriving directly from the measured values of thrust and efficiency, the variation with tip Mach number of the power lost (K_{PS})* in overcoming the compressibility drag increment. This power loss coefficient K_{PS} is also calculated from the estimated C_D - C_L data (obtained from previous work[6,12]) and by comparing the calculated and experimental K_{PS} vs M curves, the estimated C_D - C_L data can be corrected until agreement is achieved.

---

* $K_{PS} = \int q\, s\, C_{DS}\, d\,(r_c^2)$ in notation of ref.12 where C_{DS} = compressibility drag increment.

The comparison between experiment and calculation is given in figs.9 - 11 for which K_{PS} has been converted into $\Delta\eta$ where

$$\Delta\eta = \frac{\eta_o}{K_Q} \times K_{PS} .$$

In this formula,

K_Q is the measured value for the appropriate tip Mach number, and

η_o is the measured datum low speed efficiency for the appropriate J and pitch setting.

The conversion ratio $\frac{\eta_o}{K_Q}$ depends therefore on J, M_T and $\theta_{0.7\,R}$ but is the same for both calculated and experimental K_{PS}. Hence the comparison is still really between the K_{PS} values but is now expressed in a more satisfactory unit where discrepancies appear as errors in estimating efficiency loss. It should be noted that by the above definition, $(\Delta\eta)_{exptl.}$ does not equal the value that would be directly read off the experimental efficiency curves (or deduced from tables 1 - 3).

6.2 Results of drag analysis

The K_{PS} and hence $\Delta\eta$ values (figs.9 - 11) were first calculated using the M_D * data[6] now in general use for Clark Y sections. It will be seen from figs. 9 - 11 that the order of agreement with the measured values was not good, e.g. at low incidences, (fig.9), the calculated efficiency loss for M_T = 1.0 was as much as 0.04 in excess of the measured, while at higher incidences (figs. 10, 11) the reverse tended to occur. This suggests that the correction to be made to the M_D data to produce agreement should be applied to the incidence rather than the actual M_D values.

Now the basis for the existing data for sections thinner than 10% thick rests on an analysis[13] which did not make any allowance for the twist under load of the propellers** being tested. The data are therefore strictly applicable without correction to propellers which twist the same amount when running. This fact was checked in an unpublished analysis of the results of 24 ft. tunnel tests on the 2 blade versions of the same propellers. Twist measurements had been made on these propellers and hence allowance could be made for it in the analysis. The M_D vs α_o curves approximately corrected for this are shown in fig.12 for sections 6 - 7% thick. Provided, therefore, the twist of a propeller is allowed for in calculating the incidence distributions along the blade, the curves of fig.12 should be used.

Accordingly, the twist of the present paddle blade was calculated for one typical condition ($\theta_{0.7\,R}$ = 15°, J = 0.3, M_T = 0.9) by the methods and data discussed in ref 14. The resulting twist along the blade and also the proportion of it due merely to centrifugal action is shown in fig.13. The twist due to centrifugal action has greatly increased owing to the plan form - for a propeller with conventional plan form such as that of P 55409 B and a similar thickness distribution to that of the paddle blade, the twist at the tips due to

---

* critical Mach number for drag.

** The 3 blade versions of the de Havilland propeller P 55409 B and variants.

centrifugal action would be only about 0.6° instead of the 1.45° shown on fig.13. It follows that ignoring the blade twist when calculating the incidence distributions will lead to serious errors.

For blades whose thickness ratio at the tips is at least 6%, ref.14 suggests that the calculated values of blade twist are accurate. The estimates for the paddle blade can therefore (fig.1) be relied upon, particularly as the centrifugal twist is such a high proportion of the total* (fig. 13). Rough estimates were made of how the aerodynamic twist varies with J and pitch setting** and the incidence distributions along the blade were then recalculated, allowing for the twist. Typical distributions are shown in fig.15. Now values of the compressibility drag power loss K_{PC} and hence of $\Delta\eta$ were obtained, using these incidence distributions and the M_D curves of fig.12.

It is seen in figs. 9 - 11 that the order of agreement has been greatly improved. At the important 15° setting when the incidence near the tips is about the optimum, the agreement is now within ± 0.5%. At 10°, there is excellent agreement for J = 0.3 while for J = 0.2 to modify the data to achieve agreement would upset the 15° comparison. At 20°, also, the agreement has been considerably improved and over the range 0.3 < J < 0.5 it is within 1%.

There are two reasons** why the comparison for the 20° setting must be less reliable. First, as shown in fig.14 for J = 0.6, 0.5, η is falling with increasing M_T at constant J over the complete range of M_T. Only the fall for high M_T can be ascribed to the increase in C_D at Mach numbers beyond the critical and hence the datum efficiency has been taken to be where the η vs M_T curve has an inflexion (see fig.14). This reduces the certainty in the experimental K_{PS} values.

Secondly, owing to the large washout on the blades (fig.15), for this setting the blade tends to become shock stalled first over the centre sections owing to their high incidence. There is no reliable evidence from blades of conventional plan form on the critical speeds of sections, say 7.5% thick at 8° incidence or more and so, it would be surprising if perfect agreement between calculation and experiment were found for these conditions.

6.3 Conclusions from section analysis

Particularly in view of the reservations of para. 6.2 above on the 20° setting comparison, the results definitely indicate that provided allowance is made for the differing blade twists, use of the section drag data derived from propellers of conventional plan form leads to satisfactory estimates of the performance of the paddle blade at high Mach number. There is certainly no consistent correction that need be made over the range where existing data is considered reliable. Owing to the large washout on the blades, use of the results to extend the data to higher incidences cannot however be recommended.

The final conclusion is that use of the same "8 radius" compressibility lift-drag data for propellers of both conventional and paddle plan form should lead to an accurate comparison of their performance.

---

* The uncertain element in calculating the blade twist is the centre of pressure position at high Mach number which merely affects the aerodynamic twist.

** This of course becomes difficult when the high incidences of the 20° setting (fig.15) are reached.

centrifugal action would be only about 0.6° instead of the 1.45° shown on fig.13. It follows that ignoring the blade twist when calculating the incidence distributions will lead to serious errors.

For blades whose thickness ratio at the tips is at least 6%, ref.14 suggests that the calculated values of blade twist are accurate. The estimates for the paddle blade can therefore (fig.1) be relied upon, particularly as the centrifugal twist is such a high proportion of the total* (fig. 13). Rough estimates were made of how the aerodynamic twist varies with J and pitch setting** and the incidence distributions along the blade were then recalculated, allowing for the twist. Typical distributions are shown in fig.15. New values of the compressibility drag power loss K_{PS} and hence of $\Delta\eta$ were obtained, using those incidence distributions and the M_D curves of fig.12.

It is seen in figs. 9 - 11 that the order of agreement has been greatly improved. At the important 15° setting when the incidence near the tips is about the optimum, the agreement is now within ± 0.5%. At 10°, there is excellent agreement for J = 0.3 while for J = 0.2 to modify the data to achieve agreement would upset the 15° comparison. At 20°, also, the agreement has been considerably improved and over the range $0.3 < J < 0.5$ it is within 1%.

There are two reasons** why the comparison for the 20° setting must be less reliable. First, as shown in fig.14 for J = 0.6, 0.5, η is falling with increasing M_T at constant J over the complete range of M_T. Only the fall for high M_T can be ascribed to the increase in C_D at Mach numbers beyond the critical and hence the datum efficiency has been taken to be where the η vs M_T curve has an inflexion (see fig.14). This reduces the certainty in the experimental K_{PS} values.

Secondly, owing to the large washout on the blades (fig.15), for this setting the blade tends to become shock stalled first over the centre sections owing to their high incidence. There is no reliable evidence from blades of conventional plan form on the critical speeds of sections, say 7.5% thick at 8° incidence or more and so, it would be surprising if perfect agreement between calculation and experiment were found for these conditions.

6.3 Conclusions from section analysis

Particularly in view of the reservations of para. 6.2 above on the 20° setting comparison, the results definitely indicate that provided allowance is made for the differing blade twists, use of the section drag data derived from propellers of conventional plan form leads to satisfactory estimates of the performance of the paddle blade at high Mach number. There is certainly no consistent correction that need be made over the range where existing data is considered reliable. Owing to the large washout on the blades, use of the results to extend the data to higher incidences cannot however be recommended.

The final conclusion is that use of the same "8 radius" compressibility lift-drag data for propellers of both conventional and paddle plan form should lead to an accurate comparison of their performance

---

* The uncertain element in calculating the blade twist is the centre of pressure position at high Mach number which merely affects the aerodynamic twist.

** This of course becomes difficult when the high incidences of the 20° setting (fig.15) are reached.

at high Mach number particularly if the blades are operating near peak efficiency. This supports the conclusion of ref.3 that most of the gain in performance found in actual flight tests should be ascribed to the effects of the NACA 16 series shape rather than to the plan form.

7 General summary of conclusions

1. Comparisons of the performance at high Mach number of propellers of conventional and of paddle plan form by 8 radius strip theory using the same lift drag data for both propeller types should be accurate, particularly near peak efficiency.

2. The gains in top speed and cruising performance found for NACA 16 sectioned paddle blade propellers in flight tests must therefore be ascribed principally to the effects of the section shape.

3. In analysing the performance of blades of differing plan form running at high rotational speeds, allowance for the blade twist is essential.

4. Peak efficiencies for paddle blades derived from charts based on single radius data from conventional propellers are reliable for tip Mach numbers of about 0.6 but become pessimistic for higher tip speeds (1.5 to 2% low for $M_T = 0.85$).

5. The mean stalling performance of the paddle blade is better than would be expected even on an activity factor basis (when due allowance has been made for other variables such as root thickness).

6. Treating C_L for $C_D = 0.1$ as the stalling criterion, adoption of the paddle plan form more than outweighs the thinning of the blade section at $r/R = 0.25$ from 29.5% to 17%.

7. It is clear that although the paddle plan form apparently offers no direct shock stalling relief, use of it together with thin, 'high speed' sections will enable improvements in top speed performance to be made with no resulting loss and even possibly a gain in take-off performance. Its use is therefore fully justifiable.

List of symbols

a	speed of sound
c	blade chord
C_L	lift coefficient
C_D	drag coefficient
D	diameter (ft.)
$J = \frac{V}{nD}$	advance ratio
$K_T = \frac{T}{\rho n^2 D^4}$	thrust coefficient
$K_Q = \frac{P}{2\pi\rho n^3 D^5}$	torque coefficient
K_{PS}	compressibility drag power loss coefficient
M_T	tip Mach number = $\frac{\text{tip speed}}{\text{speed of sound}}$

M_D	Mach number beyond which C_D begins to rise sharply
n	rotational speed (revs/sec)
P	power input
r	section radius
R	tip radius
s	solidity
t/c	thickness chord ratio
V	forward speed (ft/sec.)
α	incidence
θ	pitch setting

$$A.F. = \frac{10^5}{D^5} \int_{0.2R}^{R} c\, r^3\, dr \quad \text{Activity factor.}$$

$$\Delta\eta = \frac{\eta_0}{K_Q} K_{PS} \text{ : loss in efficiency due to } K_{PS}$$

References

No.	Author	Title, etc.
1	Mullin	Mosquito propeller blades. de Havilland Report R 139. Various supplements 1943 - 44.
2	Haines	Summary of de Havilland report No.R 139 with some additional calculations. R.A.E. Tech. Note No. Aero 1419. April 1944.
3	Haines	An estimation of the characteristics of NACA 16 propeller sections based on flight performance trials. R.A.E. Tech. Note No.Aero 1626. A.R.C. Report No.8650. A.P. 502. April 1945.
4	Haines Chater	Revised charts for the determination of the static and take off thrust of a propeller. R.A.E. Report No.Aero 2135, A.R.C. 9747, AP.566. May 1946.
5	MacDougall	Charts for the determination of propeller efficiencies in the climbing and cruising ranges. R.A.E. Report No.Aero 2022. A.R.C. Report No.8595, A.P.499. February 1945.
6	Haines	Revised values of C_L and C_D for Clark Y sections for use in propeller strip theory calculations. R.A.E. Report No.1973 A.R.C. Report No.8177 AP. 472 September 1944 (see also R.& M.2036).

No.	Author	Title, etc.
7	Haines and Chater	24 ft. tunnel tests on a Rotol metal Spitfire propeller. Test results and data for single radius calculations. R.A.E. Tech. Note No. Aero 1728. A.R.C. Report No. 9378, AP. 546. November 1945.
8	Monoghan	Mean lift and drag data for stalled propellers. R.A.E. Tech. Note No. Aero. 1629. A.R.C. Report No. 8678, AP. 504. April 1945.
9	Lock	A graphical method of calculating the performance of an airscrew. R. & M. 1849. August 1938.
10	Cleaver, Gillmore, Mullin	de Havilland Report R.83.
11	Haines and Chater	24 ft. tunnel tests on a Rotol wooden Spitfire propeller. Test results and data for single radius calculations. R.A.E. Tech. Note No. Aero. 1780. A.R.C. 9713, AP. 563. April 1946.
12	Pankhurst and Haines	An account of the derivation of high speed lift and drag data for propeller blade sections. R. & M. No. 2020. August 1945.
13	Haines	Compressibility drag data for propeller calculations. An analysis of some recent tests in 24 ft. tunnel. R.A.E. Report No. Aero 1795. A.R.C. 6631, A.P. 378. January 1943.
14	Haines	A comparison between the calculated and measured twist of a propeller under load. R.A.E. Tech. Note No. Aero. 1806. A.R.C. Report No. 9957, A.P. 578.

Attached: Drgs. 19695S - 19708S.

Circulation:

C.S.(A)	R.T.P.(T.I.B.)	200
D.G.S.R.(A)	A.D.R.D.T.2	
D.S.R.(A)	A.D.R.D.E.4	
A.D.A.R.D.(Res.) - Action	D.E.R.D.	
A.D.S.R. (Records)	A. & A.E.E.	
D.A.R.D.	M.A.E.E.	
P.D.T.D.	A.R.C. for Prop.Sub.Com.	30
	N.P.L. (Mr. Lock)	

Table 1

de Havilland Hornet "Paddle-blade" propeller
Drg. No. P 4542536

Diameter = 12 ft. No. of blades = 2

$\theta_{0.7R} = 10.1^{\circ}$

N	J	M_T	K_Q	K_T	η
1200	0.162	0.670	0.00323	0.0528	0.422
	0.252	0.671	0.00284	0.0387	0.547
	0.336	0.672	0.00223	0.0236	0.567
	0.419	0.674	0.00141	0.0069	0.325
	0.504	0.677	0.00040	-0.0114	-
1400	0.160	0.781	0.00336	0.0546	0.412
	0.216	0.782	0.00310	0.0456	0.507
	0.288	0.783	0.00269	0.0332	0.566
	0.360	0.784	0.00209	0.0196	0.538
	0.432	0.787	0.00124	0.0032	0.177_5
	0.504	0.790	0.00041	-0.0120	-
	0.613	0.792	-0.00095	-0.0376	-
1600	0.160	0.891	0.00359	0.0573	0.406_5
	0.252	0.891	0.00308	0.0410	0.536
	0.313	0.897	0.00261	0.0295	0.563
	0.378	0.896	0.00198	0.0151	0.459
	0.442	0.894	0.00127	-0.0006	-
	0.506	0.895	0.00049	-0.0148_5	-
1700	0.159	0.948	0.00379	0.0593	0.397
	0.237	0.947	0.00334	0.0453	0.513
	0.295	0.953	0.00291	0.0335	0.542
	0.355	0.954	0.00235	0.0204	0.492_5
	0.417	0.953	0.00167	0.0056	0.223
	0.476	0.951	0.00098	-0.0091	-
	0.508	0.953	0.00064	-0.0163	-
1800	0.162	1.002	0.00415	0.0613	0.380_5
	0.224	1.000	0.00374	0.0497	0.475
	0.278	1.007	0.00327_5	0.0375	0.509
	0.336	1.007	0.00279	0.0249	0.479
	0.393	1.005	0.00213	0.0101	0.296
	0.448	1.007	0.00150	-0.0038_5	-
	0.480	1.007	0.00112_5	-0.0112	-

Table 2

de Havilland Hornet "Paddle-blade" propeller
Drg. No. P 4542536

Diameter = 12 ft.   No. of blades = 2

$\theta \doteq 15^\circ$

N	J	M_T	K_Q	K_T	η
1000	0.208	0.565	0.00592	0.0816	0.453
	0.302	0.566	0.00552	0.0674	0.587
	0.401	0.567	0.00477	0.0514	0.687
	0.501	0.569	0.00359	0.0334	0.738
	0.603	0.572	0.00198	0.0131	0.635
	0.703	0.575	0.00005	-0.0075	-
1200	0.194	0.667	0.00604	0.0830	0.429
	0.252	0.676	0.00592	0.0764	0.517
	0.336	0.677	0.00540	0.0631	0.624
	0.418	0.679	0.00467	0.0491	0.704
	0.504	0.680	0.00361	0.0329	0.733
	0.587	0.684	0.00227	0.0153	0.633
	0.670	0.686	0.00074	-0.0011	-
	0.714	0.688	-0.00019	-0.0111	-
1400	0.196	0.779	0.00640	0.0864	0.421
	0.290	0.781	0.00588	0.0719	0.565
	0.362	0.782	0.00529	0.0595	0.650
	0.437	0.785	0.00453	0.0463	0.711
	0.509	0.788	0.00351	0.0312	0.719
	0.579	0.791	0.00230	0.0172	0.689
	0.614	0.795	0.00181	0.0100	0.540
1600	0.199	0.890	0.00708	0.0916	0.410
	0.254	0.890	0.00676	0.0831	0.498
	0.317	0.892	0.00611	0.0718	0.595
	0.382	0.893	0.00552	0.0595	0.657
	0.445	0.895	0.00481	0.0477	0.701
	0.506	0.898	0.00379	0.0337	0.719
	0.539	0.904	0.00332	0.0271	0.703
1700	0.239	0.946	0.00748	0.0898	0.458
	0.299	0.947	0.00689	0.0790	0.548
	0.360	0.950	0.00617	0.0669	0.623
	0.418	0.951	0.00542	0.0548	0.673
	0.477	0.954	0.00451	0.0419	0.707
	0.508	0.960	0.00401	0.0349	0.702
1800	0.340	1.003	0.00707	0.0737	0.573
	0.395	1.005	0.00615	0.0614	0.630
	0.450	1.009	0.00535	0.0496	0.665
	0.480	1.010	0.00484	0.0423	0.669

Table 3

de Havilland Hornet "Paddle-blade" propeller
Drg. No. P 4542536

Diameter = 12 ft. **No. of blades = 2**

$\theta = 19.9^{\circ}$

N	J	MT	K_Q	K_T	η
800	0.233	0.447	0.00964	0.1023	0.3945
	0.384	0.449	0.00859	0.0869	0.621
	0.510	0.452	0.00758	0.0692	0.735
	0.634	0.455	0.00583	0.0466	0.809
	0.764	0.458	0.00337	0.0223	0.804
	0.892	0.462	0.00023	-0.0026	-
1000	0.306	0.559	0.00929	0.0976	0.512
	0.408	0.560	0.00854	0.0846	0.644
	0.509	0.561	0.00766	0.0689	0.729
	0.614	0.564	0.00624	0.0504	0.787
	0.716	0.567	0.00441	0.0315	0.817
	0.814	0.572	0.00222	0.0120	0.702
	0.871	0.574	0.00082	0.0008	0.143
1200	0.223	0.676	0.01041	0.1081	0.369
	0.339	0.675	0.00962	0.0976	0.546
	0.421	0.678	0.00989	0.0861	0.643
	0.510	0.678	0.00808	0.0718	0.723
	0.593	0.681	0.00692	0.0563	0.769
	0.678	0.681	0.00533	0.0394	0.796
	0.721	0.686	0.00454	0.0314	0.795
1400	0.224	0.784	0.01140	0.1121	0.350
	0.290	0.786	0.01070	0.1060	0.458
	0.362	0.786	0.01004	0.0981	0.564
	0.436	0.788	0.00937	0.0874	0.650
	0.510	0.786	0.00835	0.0735	0.715
	0.581	0.787	0.00738	0.0605	0.759
	0.620	0.795	0.00680	0.0534	0.775
1600	0.318	0.894	0.01186	0.1098	0.468
	0.383	0.891	0.01068	0.1013	0.568
	0.448	0.892	0.01015	0.0908	0.639
	0.510	0.895	0.00941	0.0795	0.688
	0.543	0.897	0.00881	0.0729	0.716

Table 4

de Havilland Hornet "Paddle-blade" propeller
Drg.No. P 4542536

Diameter = 12 ft. No. of blades = 2

$\theta = 25^{\circ}$

N	J	M_T	K_Q	K_T	η
800	0.252	0.450	0.01671	0.1193	0.2865
	0.382	0.449	0.01434	0.1112	0.471
	0.511	0.452	0.01300	0.1030	0.645
	0.636	0.454	0.01175	0.0874	0.752
	0.763	0.458	0.00963	0.0639	0.808
	0.891	0.462	0.00698	0.0417	0.849
	1.015	0.466	0.00374	0.0189	0.820
	1.080	0.471	0.00196	0.0076	0.665
1000	0.243	0.561	0.01701	0.1198	0.272
	0.306	0.561	0.01575	0.1180	0.365
	0.407	0.563	0.01430	0.1114	0.505
	0.508	0.564	0.01329	0.1040	0.634
	0.610	0.567	0.01232	0.0922	0.729
	0.711	0.571	0.01099	0.0758	0.780
	0.809	0.575	0.00908	0.0577	0.816
	0.868	0.576	0.00792	0.0472	0.825
1200	0.242	0.674	0.01723	0.1221	0.274
	0.339	0.675	0.01592	0.1178	0.400
	0.423	0.677	0.01491	0.1136	0.512
	0.508	0.679	0.01393	0.1070	0.622
	0.592	0.682	0.01309	0.0977	0.705
	0.680	0.680	0.01177	0.0833	0.766
	0.724	0.683	0.01125	0.0762	0.780
1400	0.366	0.776	0.01650	0.1193	0.422
	0.440	0.780	0.01566	0.1165	0.522
	0.514	0.784	0.01490	0.1112	0.612
	0.582	0.786	0.01406	0.1037	0.685
	0.621	0.789	0.01366	0.0976	0.709

Table 5

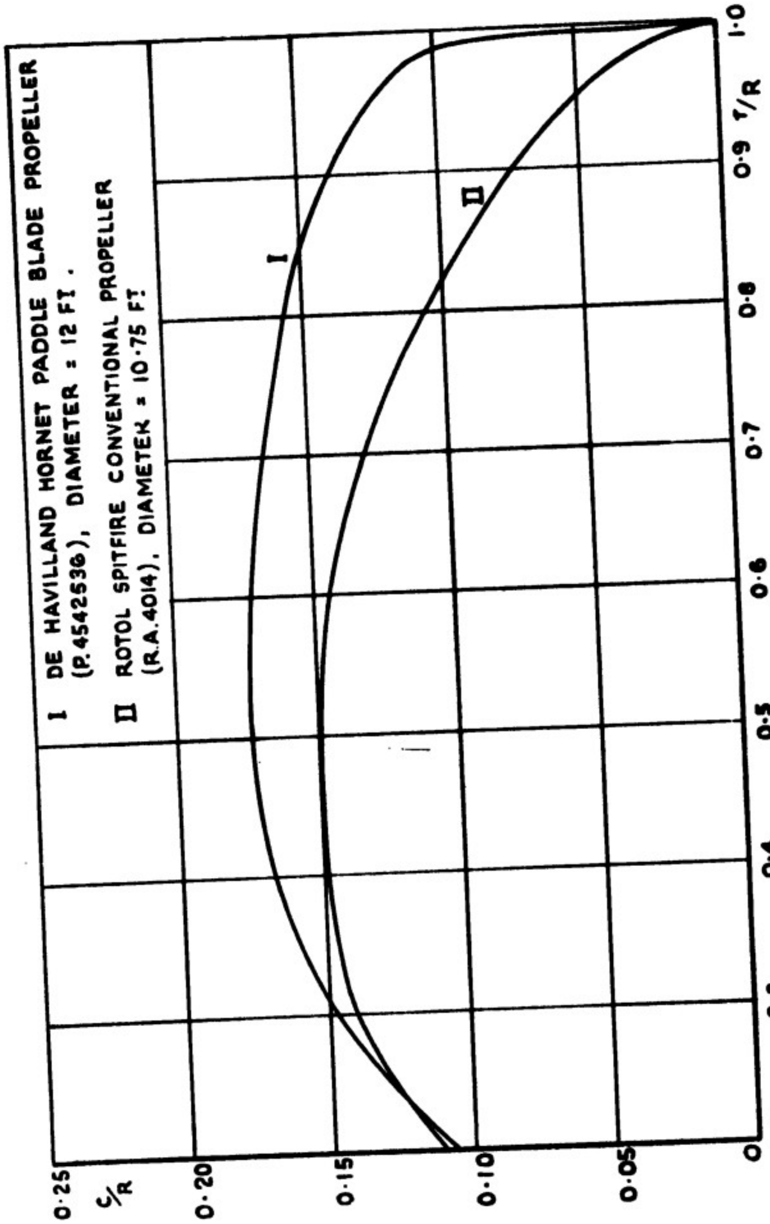
de Havilland Hornet "Paddle-blade" propeller
Drg. No. P 4542536

Diameter = 12 ft. No. of blades = 2

$\theta = 35.1^{\circ}$

N	J	M_T	K_Q	K_T	η
550	1.565	0.341	0.00573	0.0198	0.862
600	1.435	0.366	0.01032	0.0404	0.892
650	1.324	0.392	0.01389	0.0579	0.880
700	1.150	0.415	0.01880	0.0852	0.832
700	1.225	0.418	0.01695	0.0732	0.845
800	0.289	0.451	0.03351	0.1460	0.201
800	0.630	0.456	0.02844	0.1287	0.4545
800	0.755	0.458	0.02632	0.1232	0.564
800	0.882	0.464	0.02423	0.1177	0.684
800	1.004	0.469	0.02216	0.1070	0.775

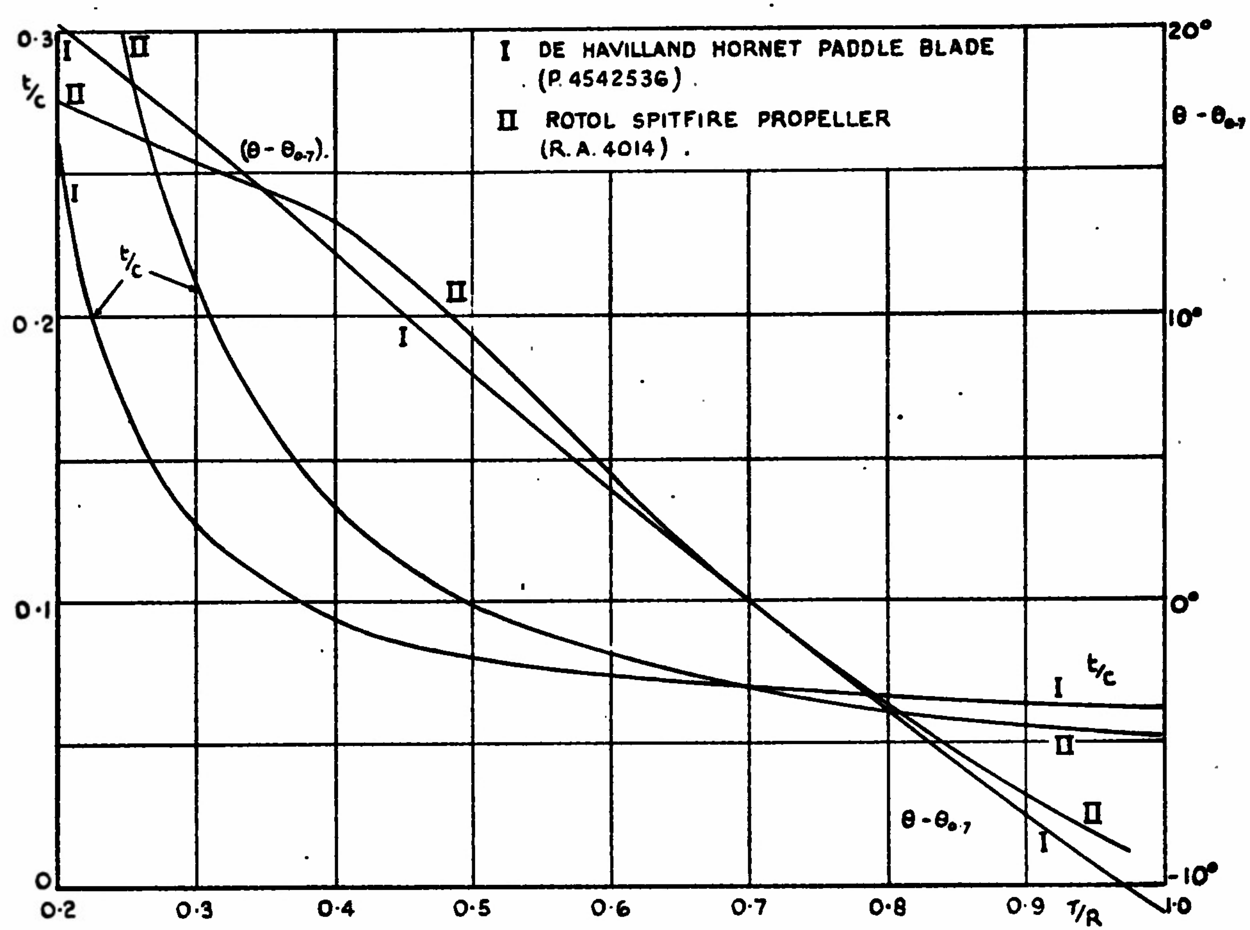
FIG. 1.



COMPARISON OF PLAN FORMS OF PADDLE BLADE AND CONVENTIONAL PROPELLERS.

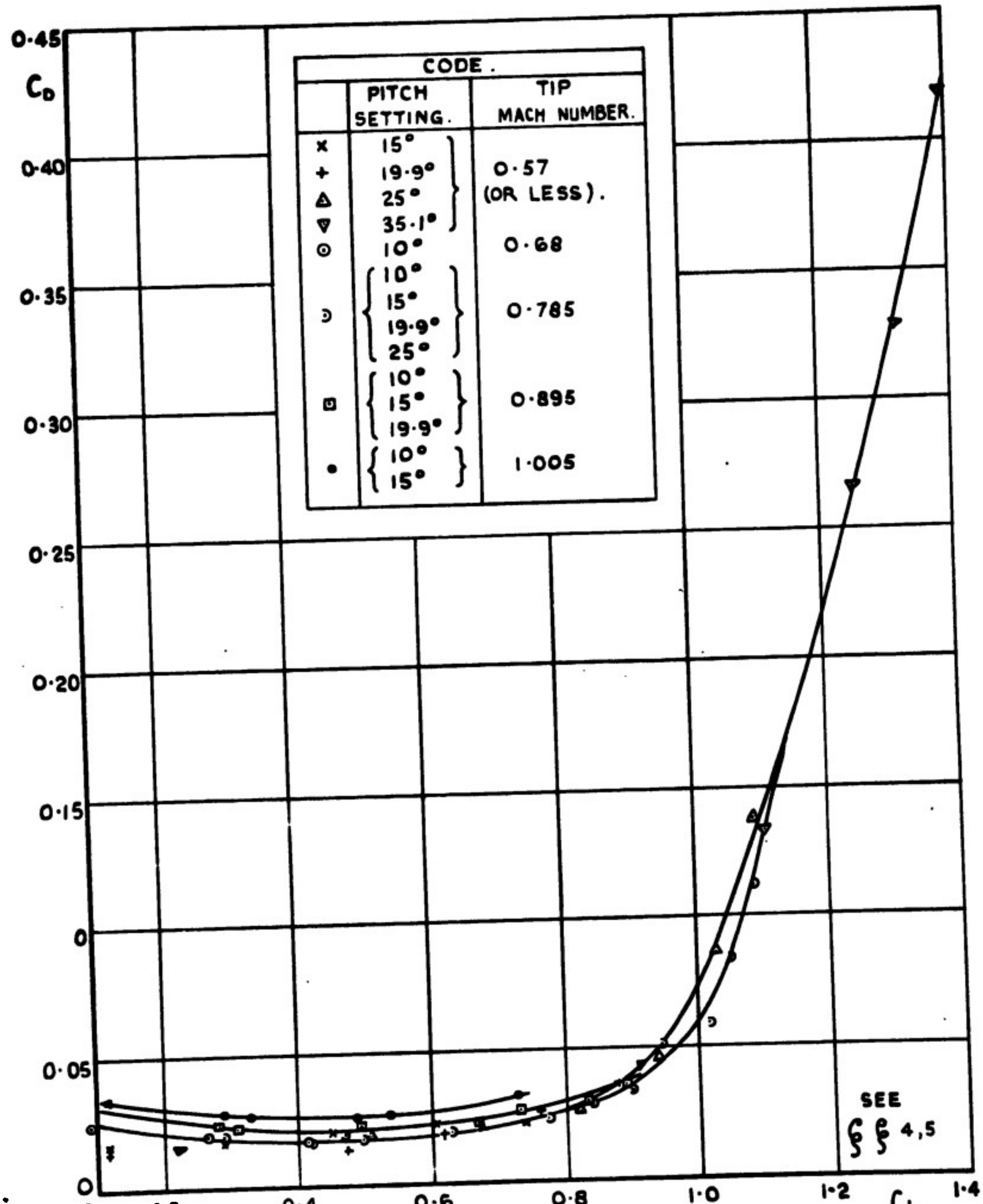
196965.

FIG. 2.



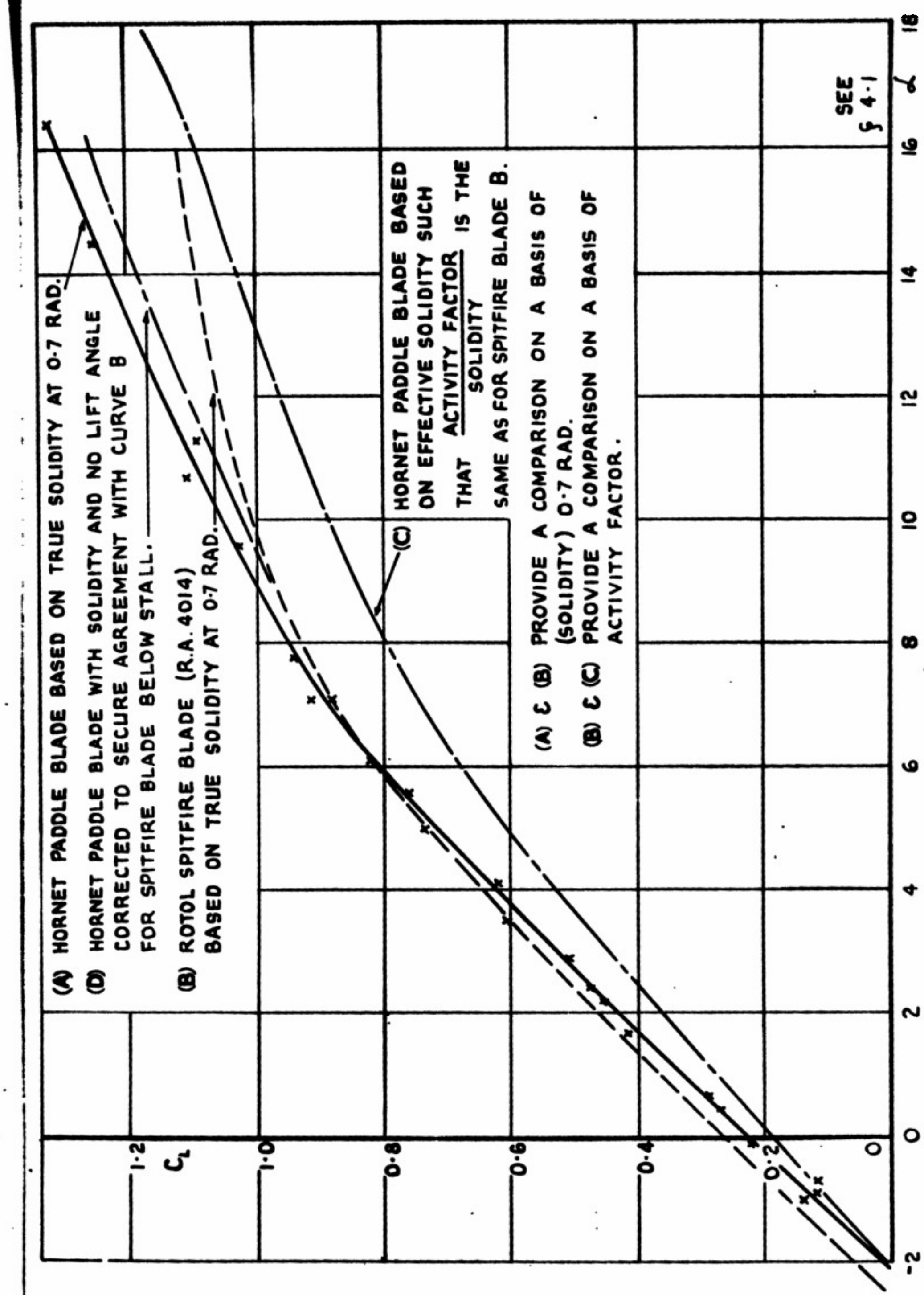
COMPARISON OF PITCH AND THICKNESS DISTRIBUTIONS OF PADDLE BLADE AND CONVENTIONAL PROPELLERS.

FIG. 3.



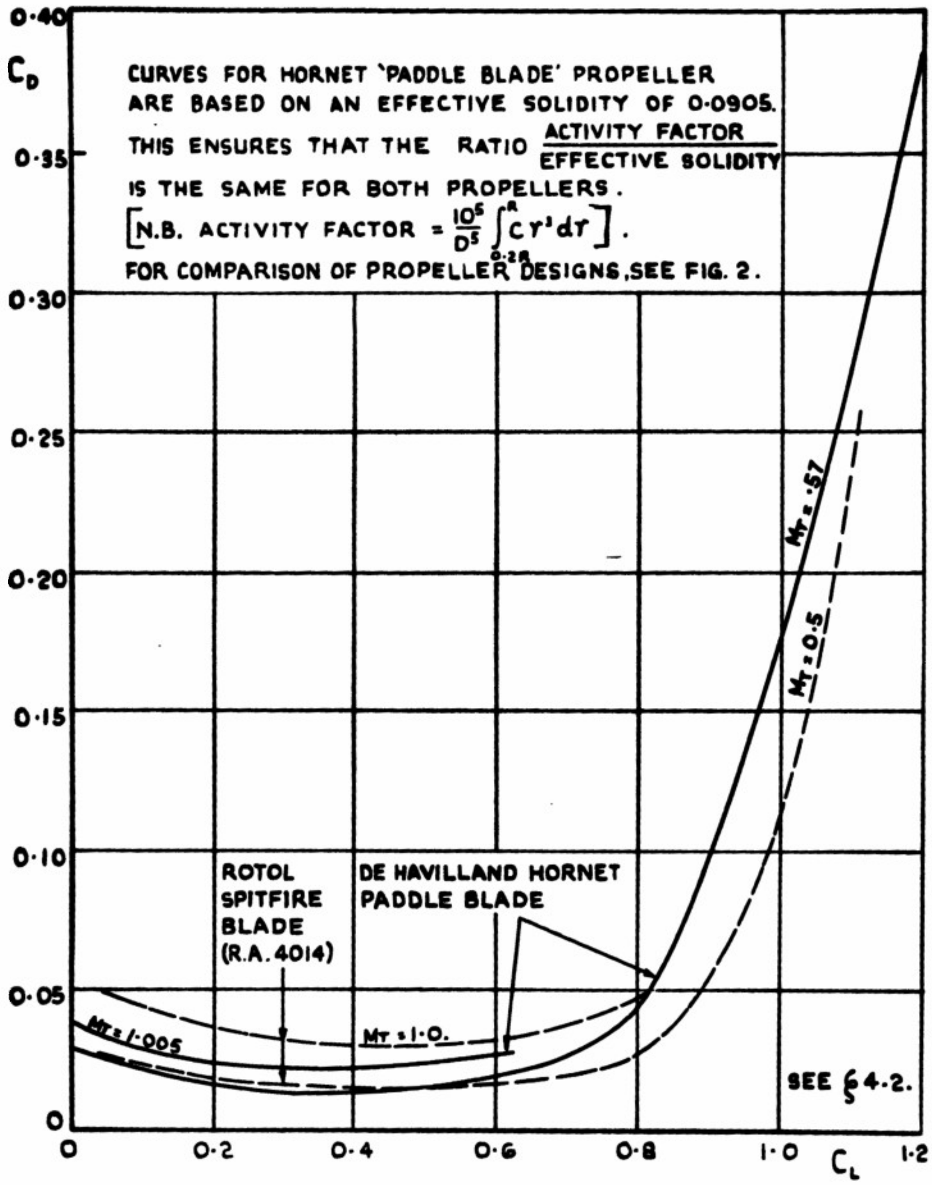
MEAN C_D-C_L CURVES BASED ON TRUE SOLIDITY AT 0·7 RADIUS.

FIG. 4



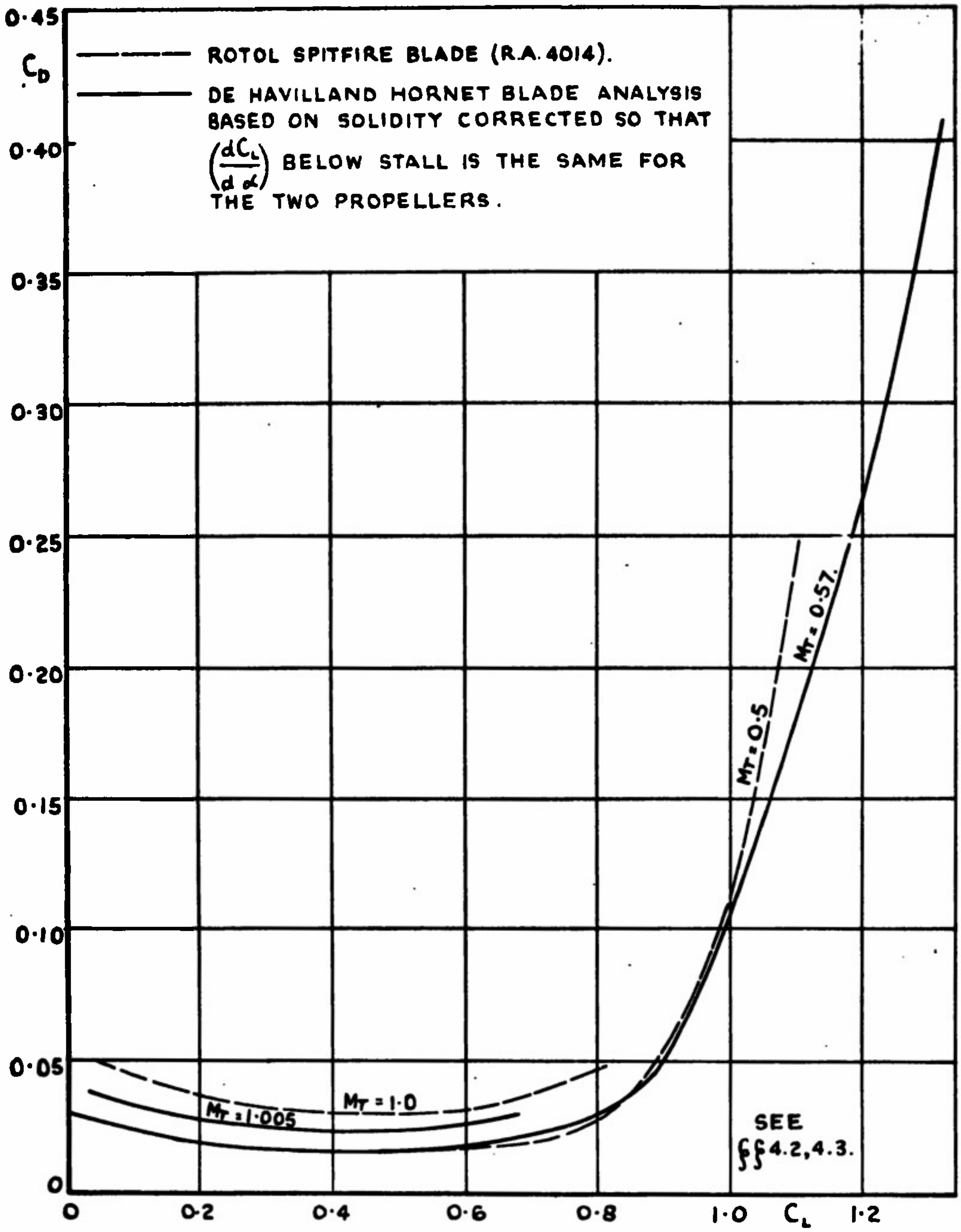
COMPARISON OF C_L vs α CURVES FOR M_T = 0·57.

FIG. 5.



COMPARISON OF C_D-C_L POLARS OF PROPELLERS BASED ON ACTIVITY FACTORS.

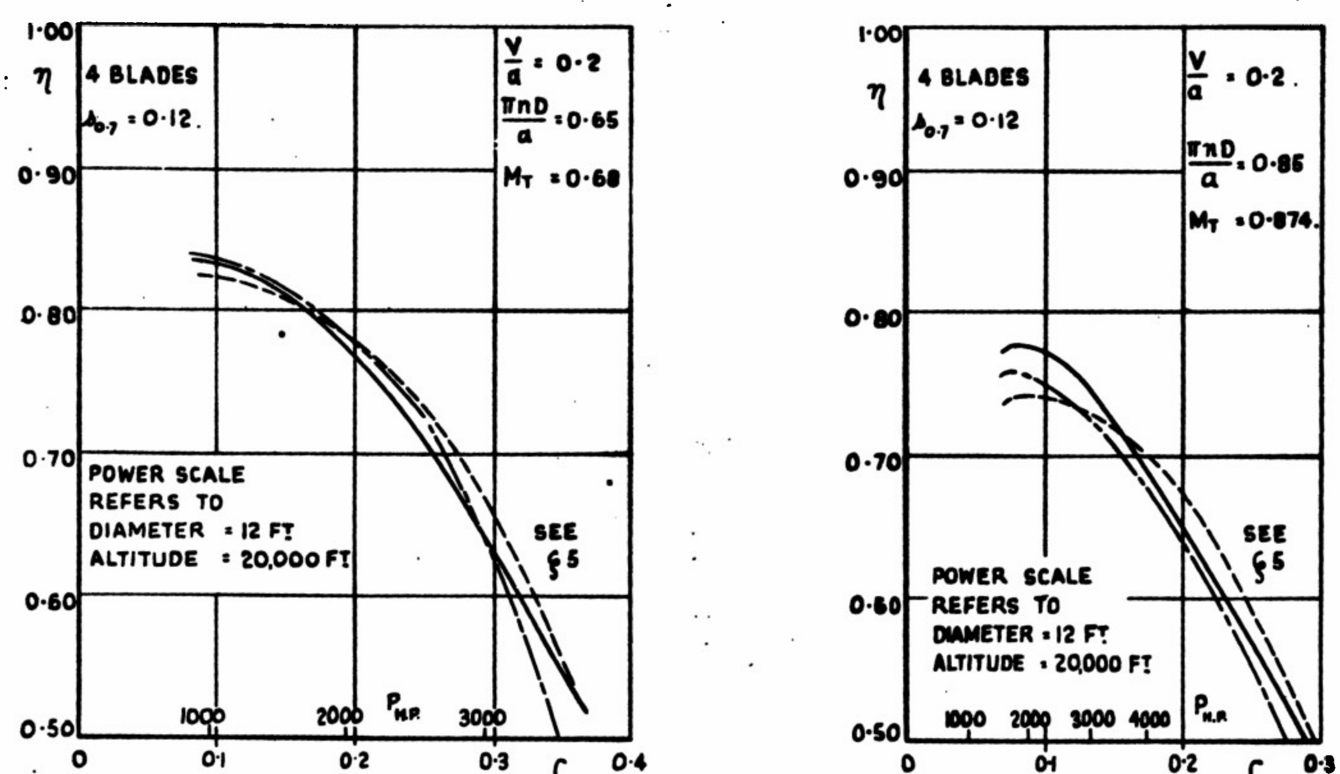
FIG. 6



COMPARISON OF C_D-C_L POLARS OF PROPELLERS BASED ON CORRECTED SOLIDITIES.

23

FIG. 7.



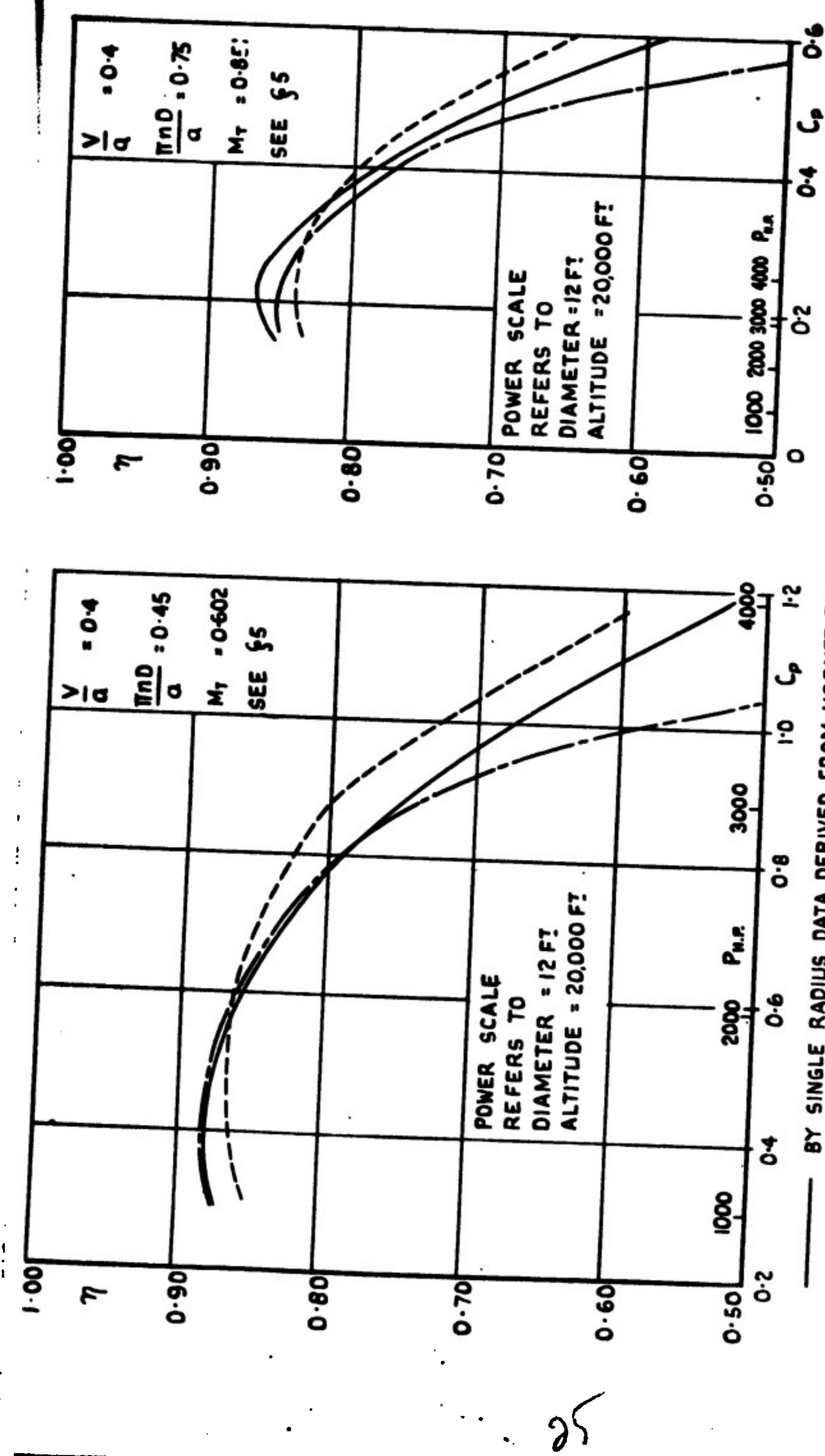
——— BY SINGLE RADIUS DATA DERIVED FROM HORNET PADDLE BLADE TEST RESULTS.
—·—·— BY CHARTS OF AERO 2022 FOR STANDARD CLARK Y 7½% THICK PROPELLER.
– – – – BY ABOVE CHARTS BUT INCREASING $\delta_{0.7}$ IN RATIO OF ACTIVITY FACTORS OF THE TWO PROPELLERS.

COMPARISON OF CRUISING EFFICIENCIES USING DATA FOR PADDLE BLADE AND STANDARD PROP'S.

(i) V/a = 0·2.

0 19702 S.

FIG. 8.



—— BY SINGLE RADIUS DATA DERIVED FROM HORNET PADDLE BLADE TEST RESULTS.

— — BY CHARTS OF AERO 2022 FOR STANDARD CLARK Y 7½% THICK PROPELLERS.

— · — BY ABOVE CHARTS BUT INCREASING $A_{0.7}$ IN RATIO OF ACTIVITY FACTORS OF PADDLE BLADE AND STANDARD PROPELLERS.

COMPARISON OF CRUISING EFFICIENCIES.

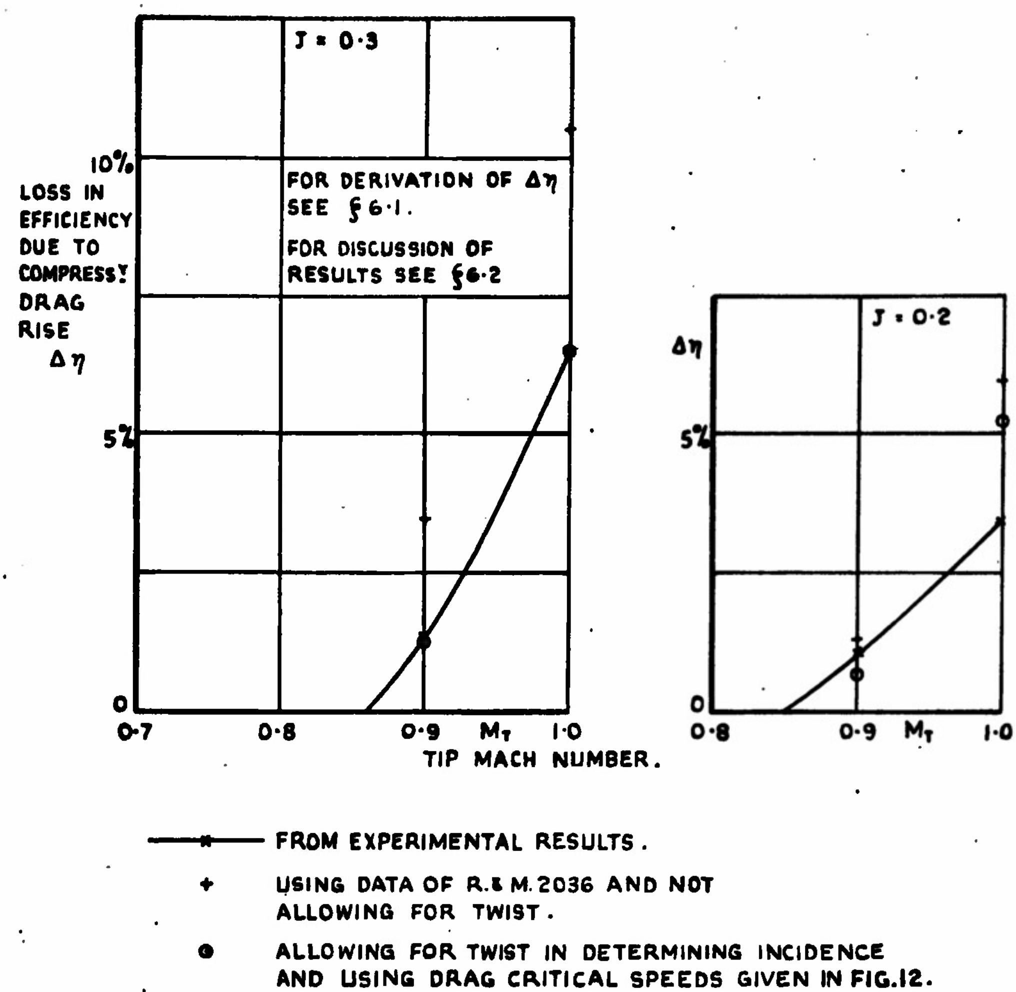
(i) V/a = 0·4.

25

NO. 19703 S.

REPORT AERO 2172.

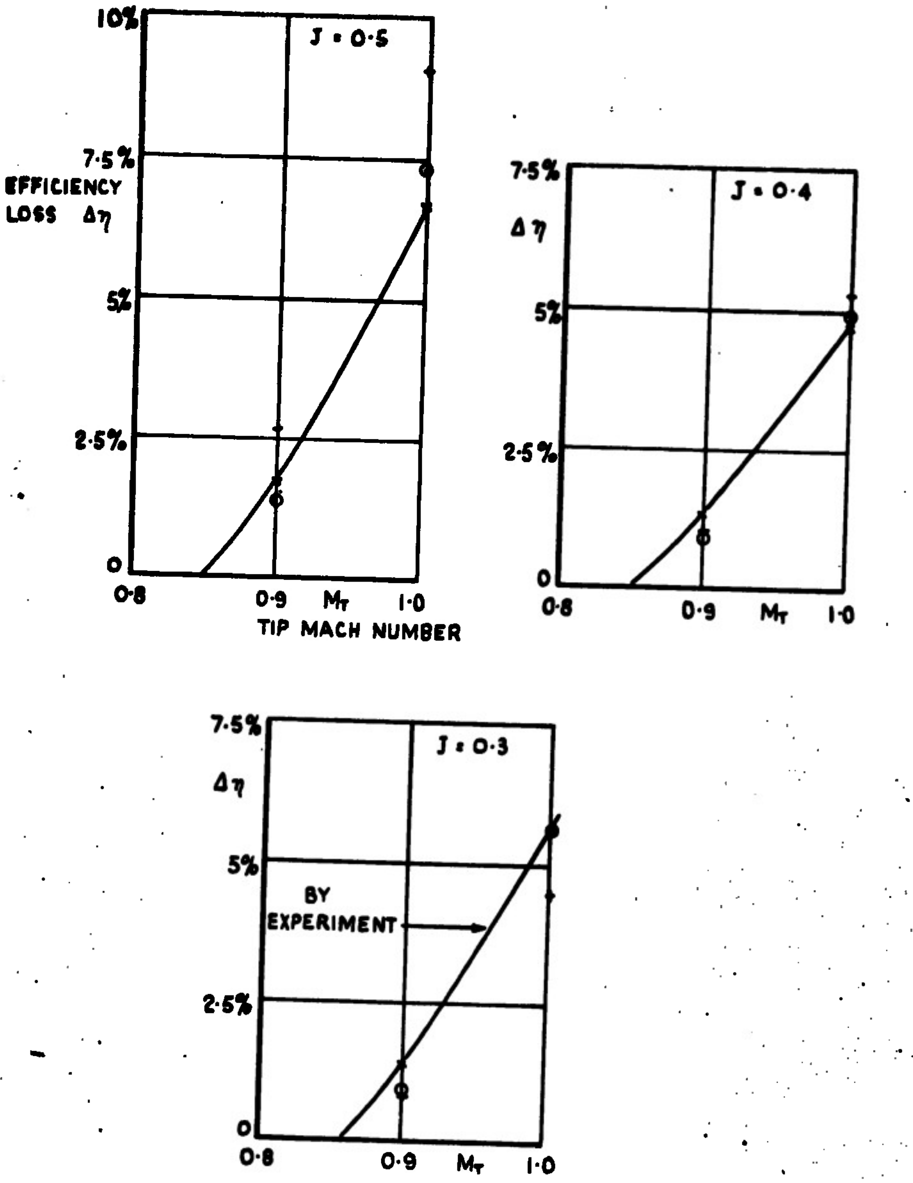
FIG. 9.



COMPARISON OF VALUES OF EFFICIENCY LOSS DUE TO COMPRESSIBILITY FOUND BY EXPERIMENT AND CALCULATION.

(i) $\theta_{0.7R} = 10{\cdot}1^\circ$

FIG. 10.

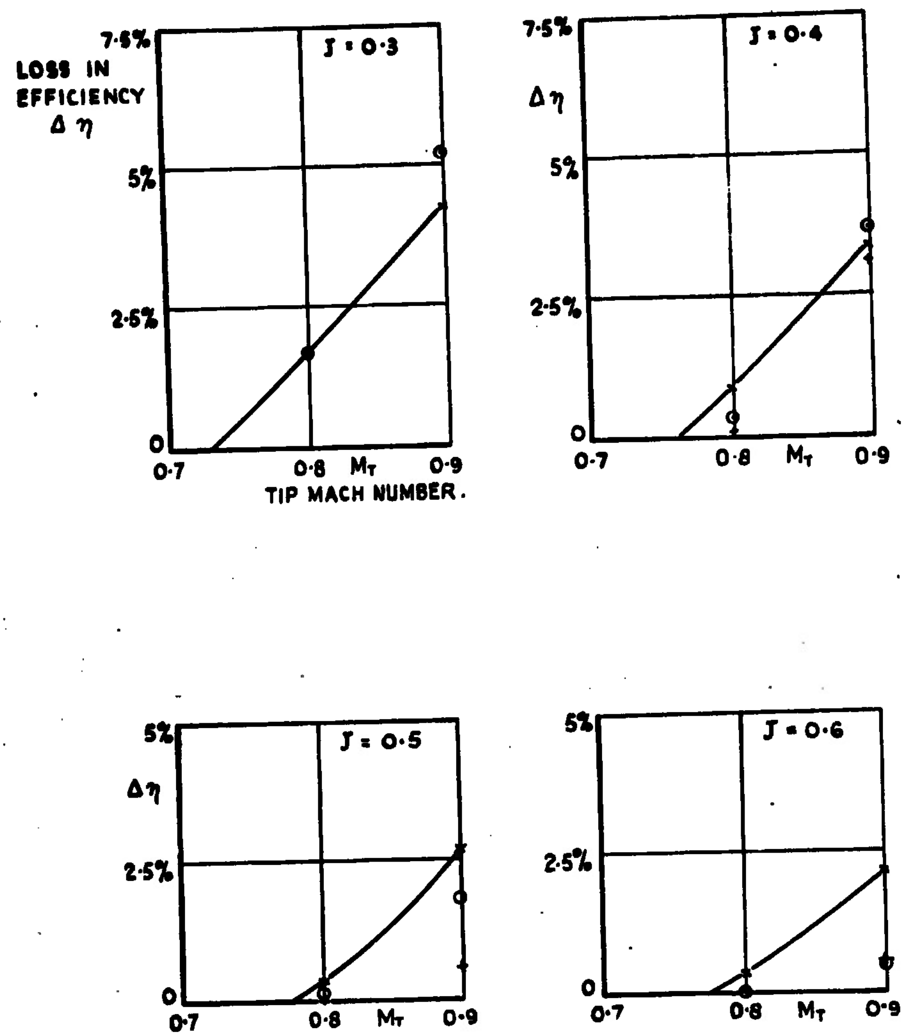


FOR DERIVATION OF Δη SEE §6.1;
FOR DISCUSSION OF RESULTS SEE §6.2.

COMPARISON OF VALUES OF EFFICIENCY LOSS DUE TO COMPRESSIBILITY FOUND BY EXPERIMENT AND CALCULATION.

(ii) θ = 15°

FIG. 11.



FOR DERIVATION OF Δη SEE § 6.1;
FOR DISCUSSION OF RESULTS SEE § 6.2.

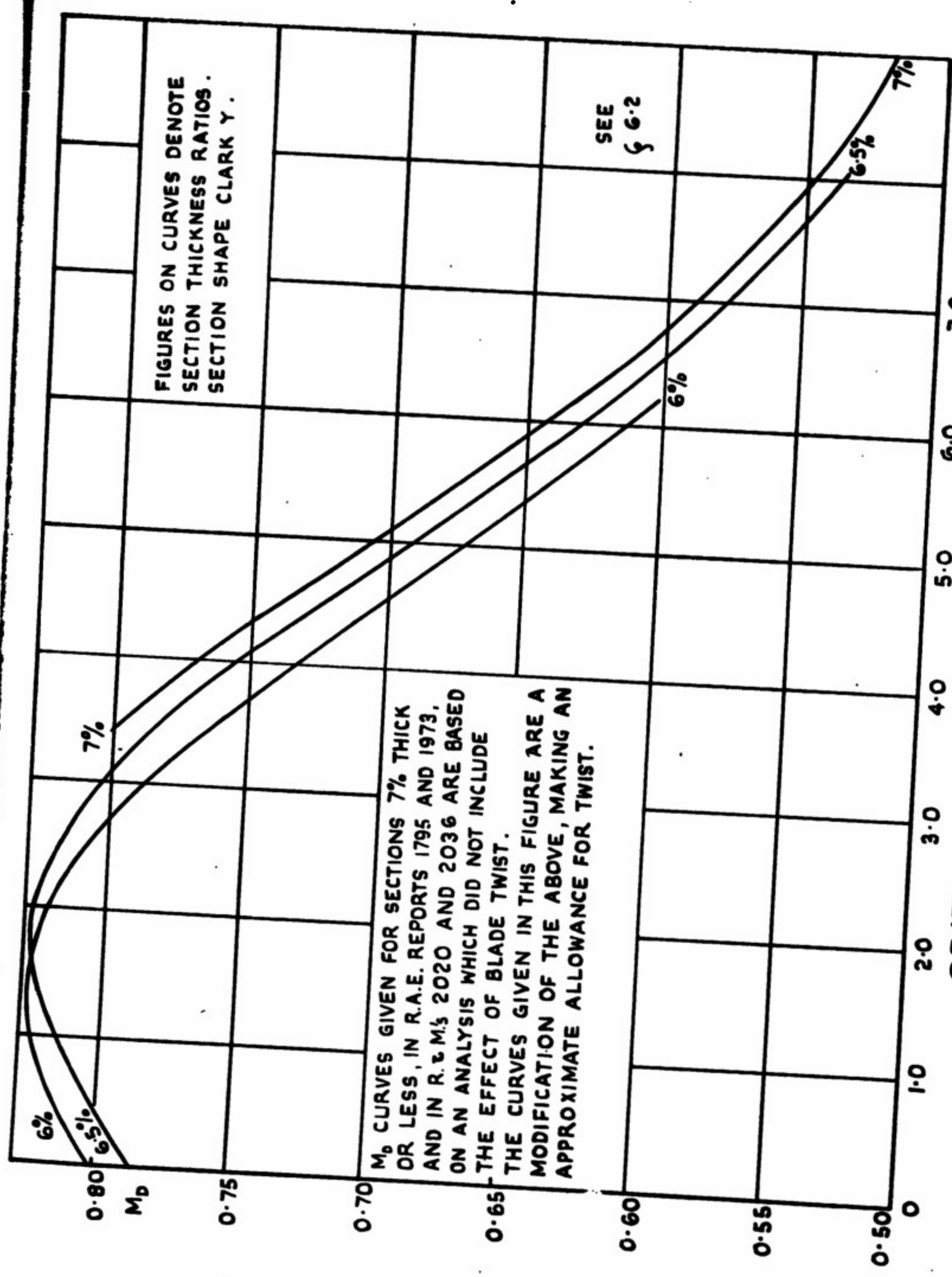
COMPARISON OF VALUES OF EFFICIENCY LOSS. DUE TO COMPRESSIBILITY FOUND BY EXPERIMENT AND CALCULATION.

(iii) θ = 19·9°

No. 19706 S

REPORT AERO 2172

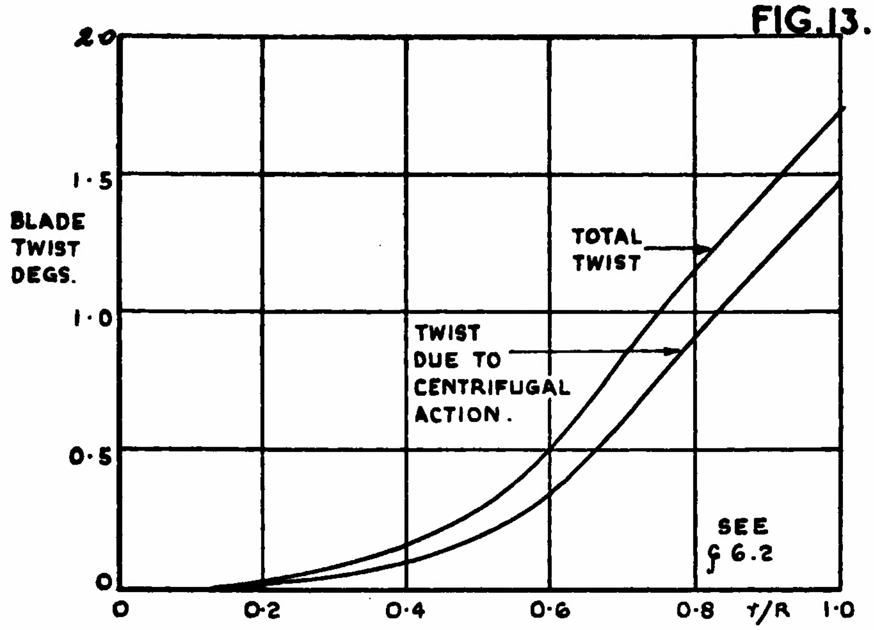
FIG. 12.



CRITICAL MACH NUMBERS FOR DRAG.

24

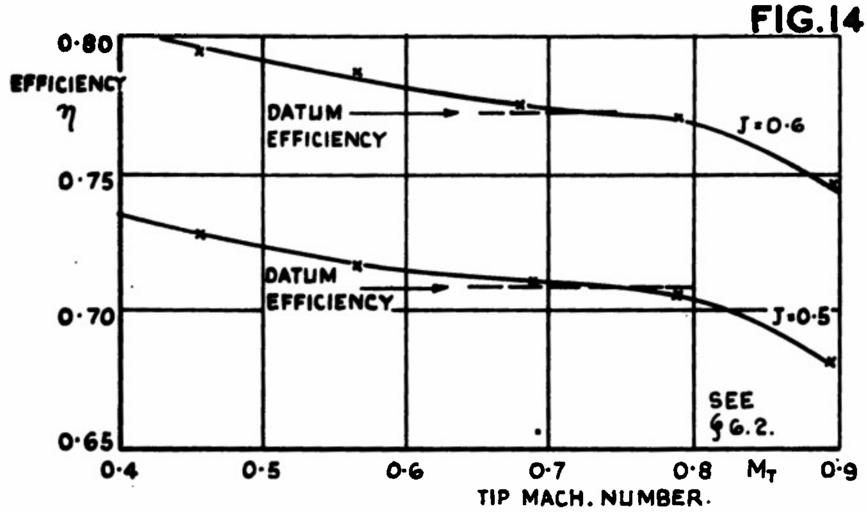
FIG.13.



CALCULATED TWIST ALONG PADDLE BLADE.

$M_T = 0{\cdot}9$, $J = 0{\cdot}3$, $\theta_{0{\cdot}7R} = 15°$.

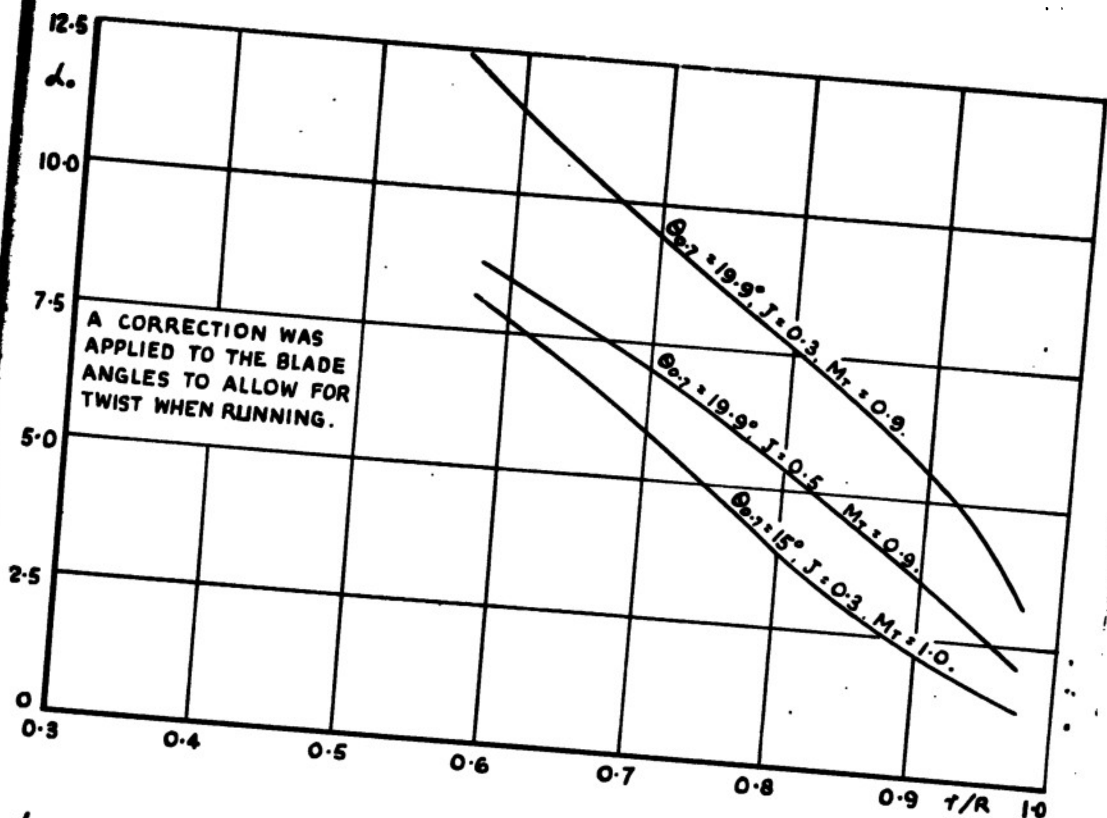
FIG.14.



VARIATION OF EFFICIENCY WITH TIP MACH No.

$\theta_{0{\cdot}7R} = 19{\cdot}9°$.

FIG. 15.



α_o = INCIDENCE MEASURED FROM LOW SPEED ZERO LIFT DATUM.

SPECIMEN INCIDENCE DISTRIBUTIONS ALONG BLADE.

REEL - C

341

A. I. I.

9504

RESTRICTED

TITLE: 24 ft Tunnel Tests on a Paddle Blade Propeller	ATI- 9504
	REVISION (None)
AUTHOR(S) : Haines, A. B.	ORIG. AGENCY NO. AERO-2172
ORIG. AGENCY : Royal Aircraft Establishment, Farnborough, Hants	
PUBLISHED BY : (Same)	PUBLISHING AGENCY NO. (Same)

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Nov' 46	Restr.	Gt. Brit.	English	31	tables, graphs

ABSTRACT:

Tests were conducted on a de Havilland propeller with conventional Clarke Y sections. Results are analyzed by single radius and full strip theory methods. Data enable performance estimates to be made under various flight conditions and give quantitative idea of improvements to be expected for high-power loadings. Use of paddle type plan form is fully justifiable even through it does not appear to offer any direct shock stalling relief.

DISTRIBUTION: Copies of this report obtainable from CADO.

DIVISION: Propellers (11) SECTION: Aerodynamics (1)	SUBJECT HEADINGS: Propellers - Aerodynamics (75478); Propellers - Testing (75480)
ATI SHEET NO.: R-11-1-19	

Central Air Documents Office Wright-Patterson Air Force Base, Dayton, Ohio	AIR TECHNICAL INDEX	

RESTRICTED

ATI-	9504
REVISION	(None)
ORIG. AGENCY NO.	AERO-2172
PUBLISHING AGENCY NO.	(Same)

TITLE: 24 ft Tunnel Tests on a Paddle Blade Propeller

AUTHOR(S) : Haines, A. B.
ORIG. AGENCY : Royal Aircraft Establishment, Farnborough, Hants

PUBLISHED BY : (Same)

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Nov'46	Restr.	Gt. Brit.	English	31	tables, graphs

ABSTRACT:

Tests were conducted on a de Havilland propeller with conventional Clarke Y sections. Results are analyzed by single radius and full strip theory methods. Data enable performance estimates to be made under various flight conditions and give quantitative idea of improvements to be expected for high-power loadings. Use of paddle type plan form is fully justifiable even through it does not appear to offer any direct shock stalling relief.

DISTRIBUTION: Copies of this report obtainable from CADO.

DIVISION: Propellers (11)
SECTION: Aerodynamics (1)

SUBJECT HEADINGS: Propellers - Aerodynamics (75478); Propellers - Testing (75480)

ATI SHEET NO.: R-11-1-19

Central Air Documents Office
Wright-Patterson Air Force Base, Dayton, Ohio

AIR TECHNICAL INDEX

C

EO 10501 dd 5 NOV 1953

[dstl]

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#: ADA800709

Date of Search: 19 Oct 2009

Record Summary: AVIA 6/9994
Title: Paddle blade propeller: 24ft tunnel tests
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department): 2172
Held by The National Archives, Kew

This document is now available at the National Archives, Kew, Surrey, United Kingdom.

DTIC has checked the National Archives Catalogue website (http://www.nationalarchives.gov.uk) and found the document is available and releasable to the public.

Access to UK public records is governed by statute, namely the Public Records Act, 1958, and the Public Records Act, 1967.
The document has been released under the 30 year rule.
(The vast majority of records selected for permanent preservation are made available to the public when they are 30 years old. This is commonly referred to as the 30 year rule and was established by the Public Records Act of 1967).

This document may be treated as UNLIMITED.