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The physical possibility of tip jet propellers for V.T.O. aircraft

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SUBJECT **THE PHYSICAL POSSIBILITY OF TIP JET PROPELLERS FOR V.T.O. AIRCRAFT.**

PREPARED BY **H.S. FOWLER**

ISSUED TO **INTERNAL**

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THE PHYSICAL POSSIBILITY OF TIP JET PROPELLERS FOR V.T.O. AIRCRAFT

INTRODUCTION

It is felt that for the 400 m.p.h. 5000 lb. load bush aircraft, propellers are the optimum means of propulsion.

Further, although it is realized that the turboprop has a better specific consumption than the tip jet propeller, the latter may well lead to a more economic aircraft design, owing to the mechanical simplicity of tilting a jet-driven propeller rather than a complete turboprop engine, or even a complete wing.

This note examines current propeller practice, and concludes that it would be possible to duct sufficient compressor delivery air through a normal propeller blade to feed a small combustion chamber on the tip, or to fill an unreheated tip nozzle. Further, it seems that an 8-bladed (4 plus 4) contraprop is a reasonable proposition as a wing-tip unit, and that one such unit on each wing tip should be reasonable for an aircraft of the size specified, with tip combustion for take-off and without for cruising. This is of course subject to fuller calculation of cycle performance.

CURRENT PROPELLER DESIGN

Considering the hollow steel bladed propeller, it appears that at present the usual form is of a roughly cylindrical core integral with the hub attachment, and covered with a fairly light steel skin, the whole being brazed together. The chord is reasonably constant at approximately .075 of the propeller diameter, and the maximum thickness, which occurs at the 50% chord line, varies from about 17% chord at near the root, to 4½% at the tip. The rear face of the blade is approximately flat, usually with a very slight convexity, while the front face is convex on an approximately circular arc. The section is in general of the NACA 16 type.

The critical Mach number for such a blade section (7% t/c) is of the order of .84 at a C_L of .3 (See Fig. 1). This results in a critical Mn curve for the whole blade, as shown in Fig. 3, in which shock stall and high loss are seen to occur at root (due to thick section of low Mn crit.) and at tip (due to high Mn).

The propulsive efficiency of a 6-blade contraprop (two discs of three blades each) is estimated at about 84% between 300/400 m.p.h. at sea level, and 82% up to 20,000 feet.

If we suggest a 16-foot-diameter prop, running at 950 r.p.m. this has a tip speed of about 800 ft/sec. At 300 m.p.h. this has a helical tip speed of 910 ft/sec, which is .84 Mn, which is reasonable by the foregoing standards.

Considering now the possibilities of such a propeller as a gas duct, the 16-foot prop will have 14-inch chord blades. A 14-inch chord, 5% t/c NACA 16 blade, for a C_L of .3, will have an area of 5.70 ins.^{2}.

A .070-inch-thick skin and .100-inch-thick hollow core will together occupy about 3.70 ins.^{2}

This leaves approximately 2.0 ins.^{2} gas duct.

For the V.T.O. aircraft specified, for take-off under adverse conditions, 300 h.p./blade of two 4-bladed contraprop pairs is required. This is estimated to require (at 140 p.s.i.a.) 90 h.p./lb./sec. at 573°K ("cold" compressor exit gas), or 150 h.p./lb./sec. at 1300°K.

a) In the first case, of "cold" running:

Air at 140 p.s.i.a. and 573°K (density = .365 lbs./ft^3) is used to give 300 h.p./blade at 90 h.p./lb./sec.

Therefore $\frac{300}{90} \times \frac{1}{.365}$ = 9.15 ft^3/sec. flow required.

Therefore speed in duct = $\frac{9.15 \times 144}{2.0}$ = 600 ft./sec. in duct.

At 573°K, Va = 1570 ft./sec.
Therefore Mn in duct = $\frac{600}{1570}$ = .38 Mn.

This assumes zero loss and zero compression due to the C.F. of the rotating blade. These factors will produce a curve of the type shown in Fig. 4.

Therefore, by a rough graphical interpolation, we would expect a .38 Mn max. duct speed at about 25% radius, about .2 Mn root speed, and about a .25 Mn tip duct speed, in our case. These numbers are quite reasonable from a loss point-of-view.

b) If we choose to burn the gas in a combustion can at the blade tip, the flow and these Mach numbers are cut by the ratio of 150 h.p./lb./sec. to 90 h.p./lb./sec. This leads to a max. duct Mn of about .23, and a tip Mn of .15.

It is obvious that the flows of either a) or b) could be doubled, if necessary.

COMBUSTION CAN SIZE

At the suggested 300 h.p./blade, and 150 h.p./lb./sec. for 1300°K burnt gas, we need 2 lbs./sec./blade of air for combustion.

By analogy with the Orenda, which has a total airflow of approximately 120 lbs./sec. through six cans, the 12-inch-diameter by 24-inch-long Orenda cans each handle 20 lbs./sec. of air.

To reduce this by $\frac{20}{2}$ (= .10)x volume, retaining say an 18-inch-long can, we have a 4 3/8-inch-diameter can. Allowing for scale, say a 5-inch-diameter by 18-inch-long can on each prop. tip.

In order to get suitable nozzle areas for "cold" and "hot" running, two separate nozzles could be fitted, and selected alternatively by a simple sleeve valve at the blade tip, spring loaded to allow flow normally through the "cold" nozzle, but changed over to the "hot" duct by fuel under centrifugal pressure when the fuel is admitted to the blades.

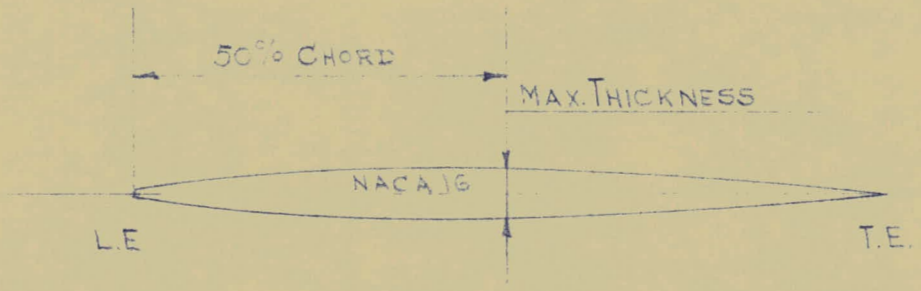


FIG. 1 THE SECTION SHOWN IS 7.5% t/c AND CAMBERED FOR A LIFT COEFFICIENT OF .2

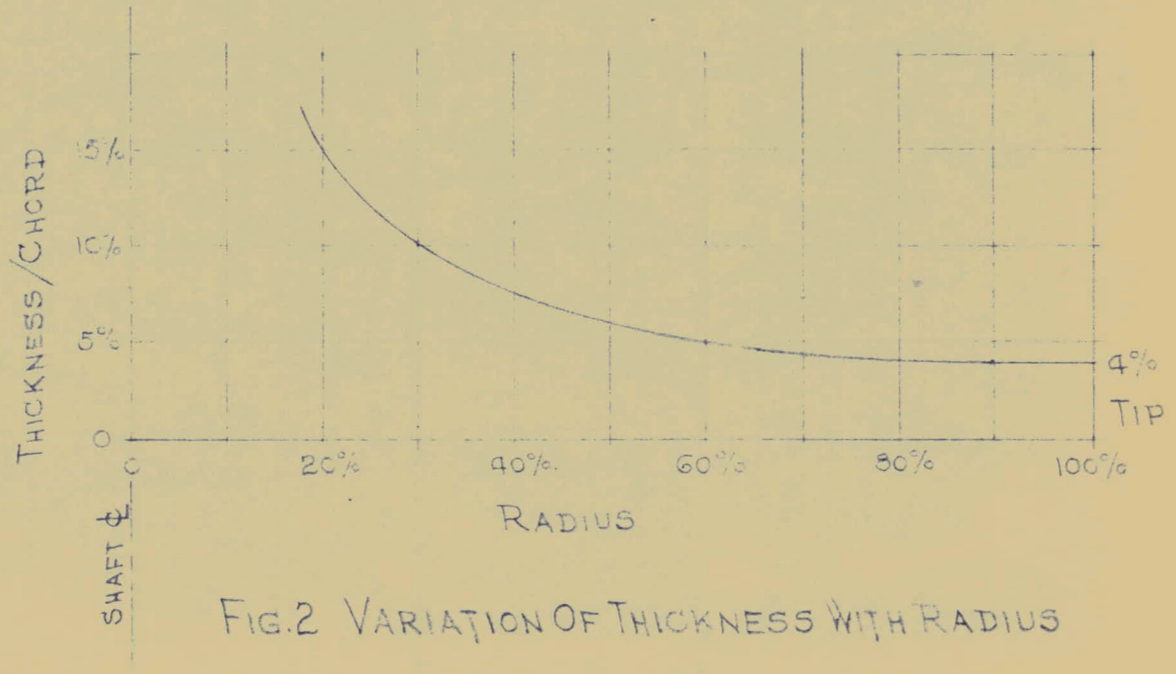


FIG. 2 VARIATION OF THICKNESS WITH RADIUS

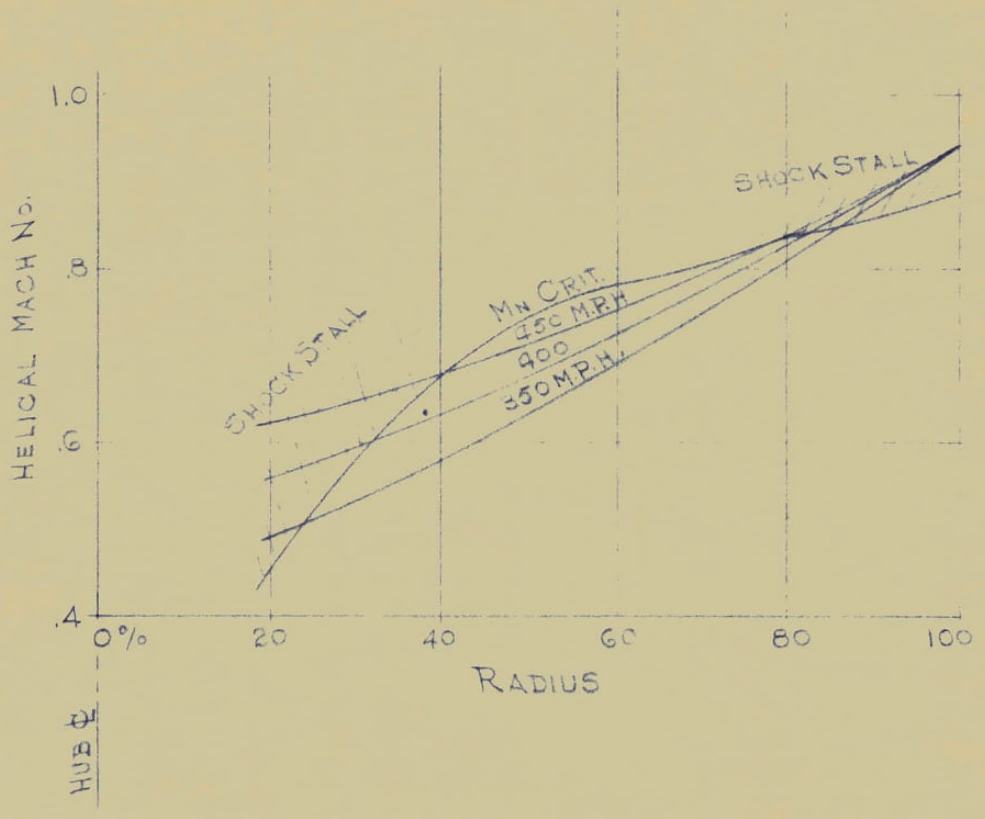
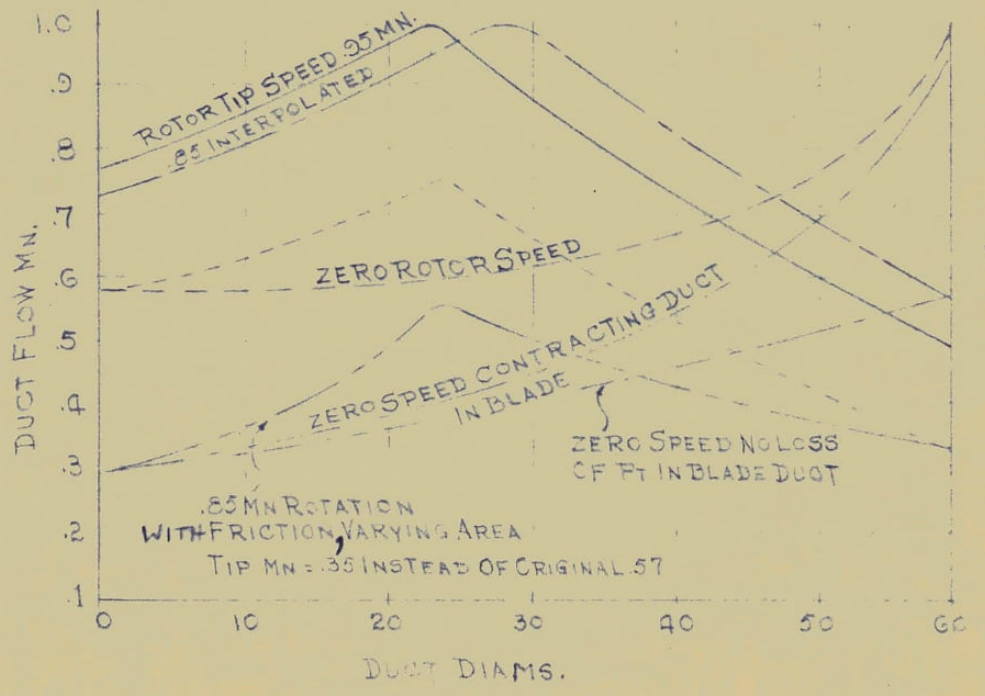

HELICAL MACH No.
1.0
.8
.6
.4
SHOCK STALL
MN CRIT.
450 M.P.H.
400
350 M.P.H.
SHOCK STALL
0%
20
40
60
80
100
RADIUS
HUB
TIP

FIG. 3


DUCT FLOW MN.
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
ROTOR TIP SPEED .95 MN.
.85 INTERPOLATED
ZERO ROTOR SPEED
ZERO SPEED CONTRACTING DUCT
IN BLADE
ZERO SPEED NO LOSS
CF FT IN BLADE DUCT
.85 MN ROTATION
WITH FRICTION, VARYING AREA
TIP MN = .35 INSTEAD OF ORIGINAL .57
0
10
20
30
40
50
60
DUCT DIAMS.

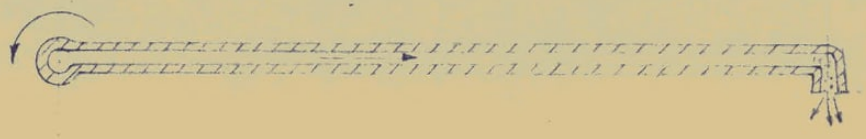



FIG. 4