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Powerplants for VTOL aircraft: the effects of fan disc loading on the weight and cost of systems using wing-immersed fans for vertical thrust

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SECURITY CLASSIFICATION O P E N

SUBJECT

POWERPLANTS FOR VTOL AIRCRAFT: THE EFFECTS OF FAN DISC LOADING ON THE WEIGHT AND COST OF SYSTEMS USING WING-IMMERSED FANS FOR VERTICAL THRUST

PREPARED BY E. Philip Cockshutt and N. Galitzine

ISSUED TO

THIS MEMORANDUM IS ISSUED TO FURNISH INFORMATION IN ADVANCE OF A REPORT. IT IS PRELIMINARY IN CHARACTER, HAS NOT RECEIVED THE CAREFUL EDITING OF A REPORT, AND IS SUBJECT TO REVIEW.

SUMMARY

The weight and cost of the hovering powerplant system (gas generators plus fans plus hovering fuel) are examined as a function of the fan disc loading for the range 200 to 1000 lb/ft^2. The optimum loading, for the mission and conditions specified, is demonstrated to lie between 500 and 750 lb/ft^2.

POWERPLANTS FOR VTOL AIRCRAFT: THE EFFECTS OF FAN DISC LOADING ON THE WEIGHT AND COST OF SYSTEMS USING WING-IMMERSED FANS FOR VERTICAL THRUST

1.0 INTRODUCTION

In a recent study (Ref. 1), calculated performance and weight data were presented for a category of VTOL powerplants in which highly loaded fans (500 lb/ft^2) were used to augment the hovering thrust of conventional turbojet engines. In the present note the fan disc loading has been allowed to vary from 200 lb/ft^2 up to 1000 lb/ft^2, and the weight of powerplant and hovering fuel to fulfil a specified mission has been examined as a function of the disc loading. Assumptions have further been made concerning the purchase cost of gas generators and fans, and the powerplant cost is then examined as a function of the disc loading.

2.0 METHOD

The methods and assumptions are in general identical with those of the reference study (Ref. 1), and the chief features are listed below.

2.1 Gas Generator Parameters

Turbine Inlet Temperature	1300°K
Compressor Temperature Rise	300°C
Available Specific Power	137 hp/lb/sec
Residual Specific Thrust	15.5 lb/lb/sec
Specific Fuel Consumption	0.533 lb/hr-hp

2.2 Fan Parameters

Momentum Theory Efficiency	80%
Disc Loading	200 $\longrightarrow$ 1000 lb/ft^2
Hub/Tip Ratio	.15 $\longrightarrow$ .35
Tip Speed	800 ft/sec

Two counter-rotating fan stages.

Two-stage tip-turbine drive.

2.3 Mission Parameters

Aircraft gross weight	40,000 lb.
Installed fan thrust	53,333 lb.
Gas generators	8
Fans	16
Hovering time	10 mins.

2.4 Weight Parameters

Gas Generator Weight vs. Mass Flow relation as per Fig. 10 (Ref. 1).

Fan Weight vs. Diameter relation $W \propto D^{2.7}$

2.5 Cost Parameters

Gas Generator Cost	$50/lb weight
Fan Cost	$25/lb weight
Fuel Cost	$.025 lb
Powerplant Life (for complete write-off)	2000 hr. total (333 hr. hovering)

3.0 DISCUSSION OF RESULTS

3.1 System Weights

In Fig. 1, the contributions of gas generators, fans, and hovering fuel to the hovering system weight are set out as a function of fan disc loading; in Fig. 2, scale drawings of three of the fans are set out.

It is immediately seen that at low disc loadings the fan becomes very large, and hence its weight preponderates over

the modest advantages it produces in gas generator and fuel weights. Admittedly some of the fan design assumptions are perhaps most favourable to the original 500 lb/ft^2 disc loading, but the magnitude of the weight penalty in the 200 lb/ft^2 case appears extremely formidable to overcome.

If one considers only the weight of machinery installed, the optimum disc loading lies between 800 and 1000 lb/ft^2; including the weight of hovering fuel, the optimum lies near 700 lb/ft^2, but the curve is extremely flat between 500 and 1000 lb/ft^2.

3.2 System Costs

Cost data as a function of disc loading are presented in Fig. 3. It should be pointed out that the proposed cost data are rather arbitrarily assigned, and that only the relative costs are considered significant.

Considering only the installed machinery, the optimum disc loading appears again to be of the order of 700 lb/ft^2, but the curve is very flat between 500 and 1000 lb/ft^2. If one includes fuel costs, the optimum drops to the order of 500 lb/ft^2.

4.0 CONCLUSIONS

1. From the point of view of both weight and cost, the optimum disc loadings would appear to lie in the range between 500 and 750 lb/ft^2.

2. The use of disc loadings as low as 200 lb/ft^2 would produce a very severe penalty in system weight and cost.

5.0 REFERENCE

Cockshutt, E.P.
Galitzine, N. Powerplants for VTOL Aircraft: A Proposed Dual-Operation System using Wing-Immersed Fans for Vertical Thrust.

N.R.C. Laboratory Report (to be published)

Fig 1.

HOVERING SYSTEM WEIGHT

40,000 LB GROSS WEIGHT AIRCRAFT

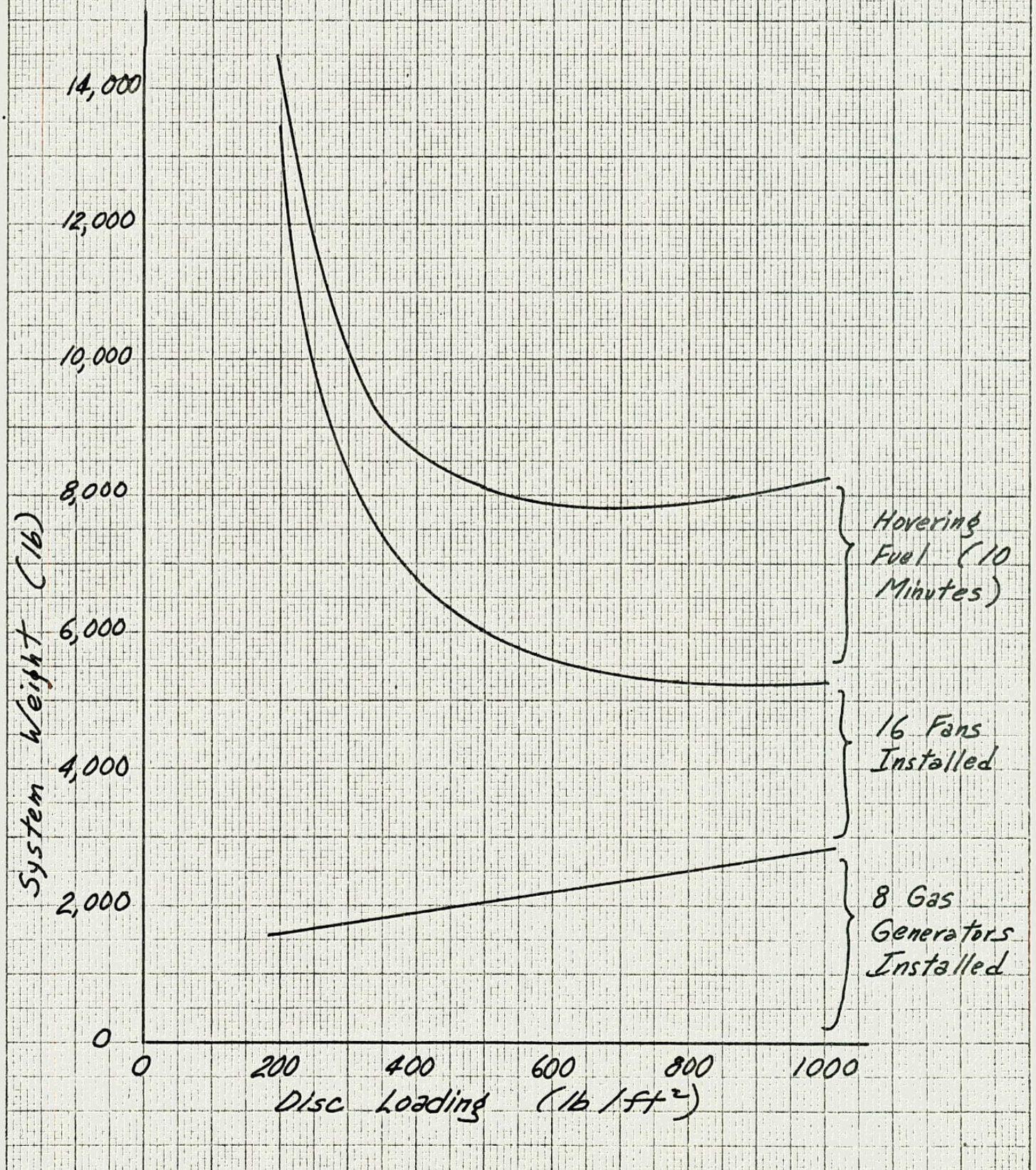
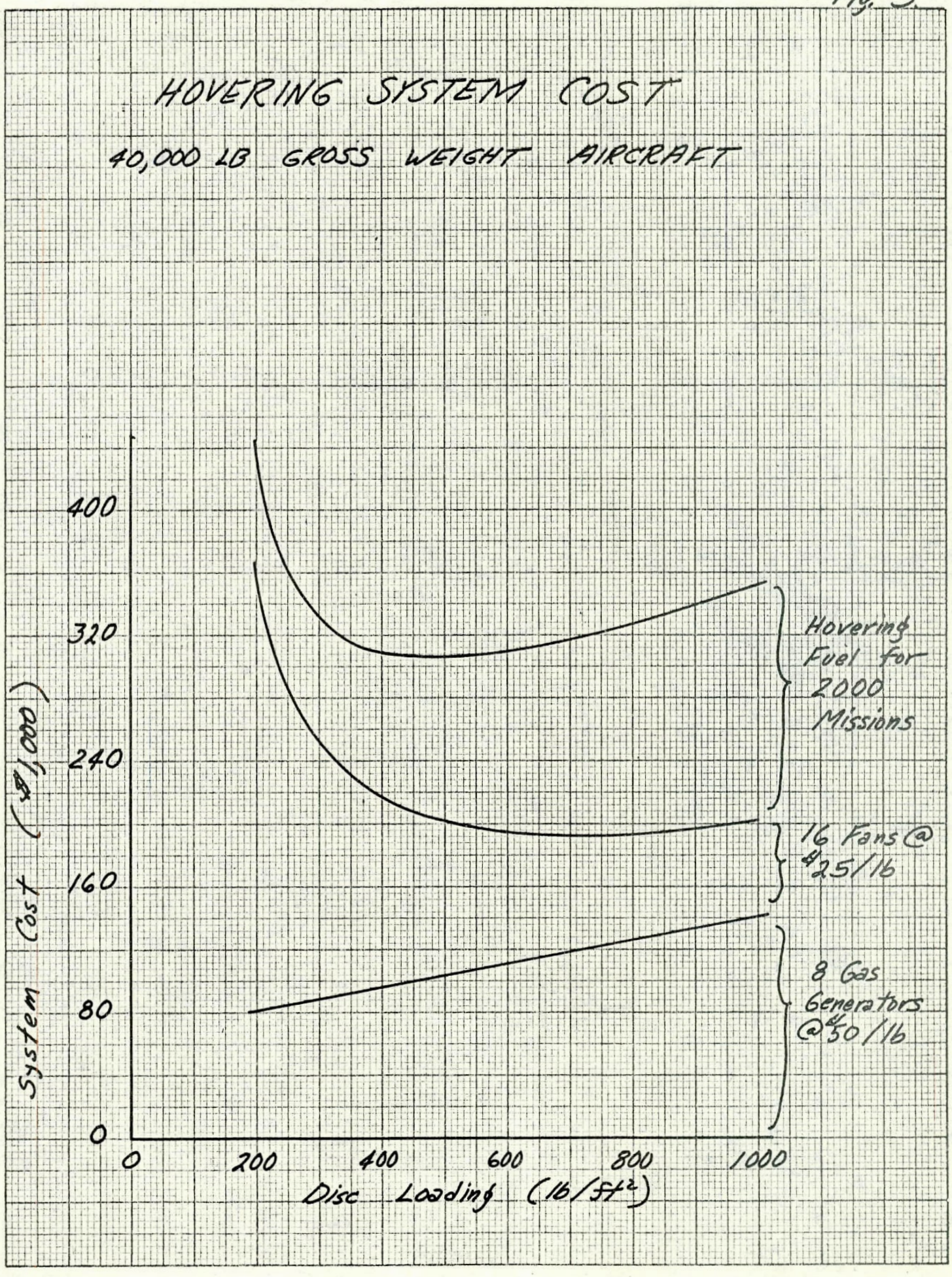


Fig. 3


HOVERING SYSTEM COST
40,000 LB GROSS WEIGHT AIRCRAFT
400
320
240
160
80
0
System Cost ($1,000)
0
200
400
600
800
1000
Disc Loading (lb/ft²)
Hovering Fuel for 2000 Missions
16 Fans @ $25/lb
8 Gas Generators @ $50/lb