CANADIAN GOVERNMENT PROGRAM FOR THE AVROCAR PHASE 1

COMPARISON OF THE DIRECT OPERATING COSTS OF LIGHT AIRCRAFT WITH DEVELOPED VERSIONS OF THE AVROCAR

500/PERF/430

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AVRO AIRCRAFT LIMITED

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1.0 INTRODUCTION

The purpose of this report is to compare the operating economics of developed versions of the Avrocar with those of existing commercial light aircraft.

The approach is similar to that of 500/PERF/425 (Ref. 1) in which a simplified form of the direct operating cost equations, based solely on the aircraft weights, cruising speed, and fuel consumption during cruise, is obtained. In the present report, however, the annual aircraft utilization is assumed to be 1000 hours.

Published data for existing light aircraft and estimated weights and performance figures for two lifting fan vehicles are inserted in the simplified formulae to produce comparative cost data.

2.0 METHOD OF ANALYSIS

2.1 Derivation of Method

The method of analysis is based on the SBAC system (Ref. 2) but with labour costs approaching those given by the ATA system (Ref. 3) to make the total direct operating costs representative of North American conditions. The derivation is similar to that in Section 2 of Ref. 1, the only modification being that the annual utilization rate for light aircraft is assumed to be 1000 hours.

The derivation of the method is not repeated in this report: the original report should be referred to if further information is desired. For convenience a list of the basic assumptions made, the direct operating cost equations used, and definitions of all necessary terms, is given in Section 2.2.

2.2 Simplified Method for Determining Direct Operating Costs of Light Aircraft

Basic assumptions:-

Cost of empty aircraft less engines and fans	$30 per pound
Cost of reciprocating engines	$25 per pound
Cost of turbine engines	$60 per pound
Cost of fans	$60 per pound
Crew cost, pilot	$24 per hour
Cost of fuel - gasolene	$.263 per imp. gallon
- turbine fuel	$.145 per imp. gallon

Cost of Oil - 4% of fuel cost for reciprocating engines

- 1% of fuel cost for turbine engines

Weight of fuel - gasolene	7.0 lb. per imp. gallon
- turbine fuel	7.8 lb. per imp. gallon

Aircraft insurance - 4% per annum for fixed wing aircraft

- 6% per annum for rotary wing aircraft

Landing cost - $.55 per 1000 lb. of all up weight for fixed wing aircraft

- $.165 per 1000 lb. of all up weight for rotary wing aircraft

2.2 Simplified Method of Determining Direct Operating Costs of Light Aircraft (Continued)

Annual Utilization	1000 hours
Aircraft less engines and fans:	
Spares holdings	10%
Obsolescence period	10 years
Residual value	20%
Engines:	
Spares holdings	50%
Obsolescence period	10 years
Residual value	20%
Overhaul period - fixed wing aircraft	1200 hours
- rotary wing aircraft	600 hours
Fans:	
Spares holding	10%
Obsolescence period	10 years
Residual value	20%

Cost relationships:

Based on the above assumptions, the direct operating costs are:

$$DOC/hr = .00521\,W_a + .00888\,W_e + .01042\,W_f + .00055(AUW)/t_B + .0391\,\frac{V_c}{NAMP} + 24$$

dollars per hour for a fixed wing piston engined aircraft

$$= .00521\,W_a + .02132\,W_e + .01042\,W_f + .00055(AUW)/t_B + .0187\,\frac{V_c}{NAMP} + 24$$

dollars per hour for a fixed wing turbine engined aircraft

$$= .00581\,W_a + .01402\,W_e + .01162\,W_f + .000165(AUW)/t_B + .0391\,\frac{V_c}{NAMP} + 24$$

dollars per hour for a rotary wing piston engined aircraft

2.2 Simplified Method of Determining Direct Operating Costs of Light Aircraft (Continued)

$$= .00581\ W_a + .03364\ W_e + .01162\ W_f + .000165\ (AUW)/t_B + .0187\ \frac{V_c}{NAMP} + 24$$ dollars per hour for a rotary wing turbine engined aircraft

$$DOC/n.m. = \left[DOC/hr\right]\left[\frac{1}{V_c} + \frac{1}{3S}\right]$$ dollars per nautical mile for fixed wing aircraft

$$= \left[DOC/hr\right]\left[\frac{1}{V_c} + \frac{1}{6S}\right]$$ dollars per nautical mile for rotary wing aircraft

where

AUW = aircraft all up weight at take-off, lb.

DOC = direct operating cost, dollars

hr. = hour

NAMP = cruise nautical air miles per pound of fuel consumed

n.m. = nautical mile

S = stage length, nautical miles

t_B = Block time, hours

$= \frac{S}{V_c} + \frac{1}{3}$ hours for fixed wing aircraft

$= \frac{S}{V_c} + \frac{1}{6}$ hours for rotary wing aircraft

V_c = mean cruise speed, knots

W_a = weight of empty aircraft less crew, less bare engines, less fans

W_e = weight of bare engines

W_f = weight of fans, including rotors, cases, stators, hubs and bearings.

NOTE: An aircraft such as a GETOL machine which, although airborne, requires a long acceleration run close to the ground before it can climb to a height of 50 ft. is assumed to obey the fixed wing aircraft relationships. An aircraft which on take-off climbs vertically to at least 50 ft. and then accelerates, is assumed to obey the rotary wing aircraft relationships.

3.0 DIRECT OPERATING COSTS OF EXISTING AIRCRAFT

The direct operating costs of existing light aircraft is obtained by inserting the data of Table 1 in the relationships of Section 2.2. The tabulated data is derived from trade publications (Ref. 4 to 14) and due to descrepancies between the various sources must be assumed to be approximate only.

Table 1 presents the available data for fixed wing and rotary wing light aircraft. Payload vs Range curves, based on the allowances of the simplified method, are given in Fig. 1.

The derived direct operating costs are presented in Fig. 2 and Fig. 3, fixed wing and rotary wing results being given on the same figure. Fig. 2 is a plot of the Direct Operating Cost per Nautical Mile vs Range, and Fig. 3, a plot of the Direct Operating Cost per Ton Nautical Mile vs Range.

TABLE 1

EXISTING LIGHT AIRCRAFT CONSIDERED IN THE COST ANALYSIS

Aircraft	Engines No.	Engines Type	AUW lb.	Op.Weight Empty, lb.	Max.Pay-load, lb.	Max. fuel lb.	Cruise speed,kts.	Cruise Alt.ft.	Ref.
FIXED WING									
D.H. ÷									
Beaver L 20	1	P & W R 985	5,100	3,027	2,073	569	124	5,000	13,14
Beachcraft ÷									
Debonair 33	1	Con.10-470J	2,900	1,930	970	294	124	10,000	12
Cessna ÷									
Bird Dog L 19A	1	Con. 0-470-11	2,400	1,698	702	245	87	8,000	4,14
172	1	Con. 0-300-A	2,200	1,460	740	252	84	7,500	6,14
210	1	Con. 0-470 E	2,900	1,960	940	390	119	10,000	9
310	2	Con. 0-470-M	4,600	3,152	1,448	600	145	15,000	14
Mooney ÷									
Mk. 20A	1	Lyc.0360-A1A	2,450	1,640	810	210	143	10,000	8,14
Piper ÷									
Comanche	1	Lyc.0360-A1A	2,550	1,645	905	300	139	8,000	7
ROTARY WING									
Bell ÷		Franklin							
Trooper 47 G-3		6VS -335	2,550	1,739	811	241	78	0	11
Cessna ÷									
CH-1		Con.FSO-470A	3,000	2,175	825	465	87	0	5,14
Hiller ÷									
12E		Lyc.10-540-B1A	2,700	1,900	800	276	73	0	10

Note:- Above figures assume that each aircraft has a crew of 1.

4.0 DIRECT OPERATING COSTS OF LIFTING FAN AIRCRAFT

Direct operating costs are presented for two lifting fan configurations. The first configuration, referred to as VTOL in the text, is an Avrocar development powered by two General Electric J85 engines, with VTOL capabilities. The second configuration, designated GETOL in the text, is more conventional; it is powered by Turbomeca Astazou 2 engines, and has GETOL capabilities.

The weight breakdowns used for costing purposes, extracted from Ref. 15, are:

TABLE 2

Item		Configurations	
		VTOL	GETOL
W_a	lb.	2,163	4,532
W_e	lb.	650	580
W_f	lb.	621	130
Crew of 1		200	200
Operational Weight Empty	lb.	3,634	5,442
Max. fuel lb.		3,360	960
Max. useful load, lb.*		4,560	1,360
Max. allowable weight, lb.		8,194	6,822

* - Useful load = weight of fuel plus weight of payload.

Performance figures are extracted directly from Ref. 16.

The method of analysis in each case is to estimate direct operating costs as a function of the cruising speed for a fixed block distance, then select the speed giving the minimum cost as being the pertinent value for the range. Payload vs Range curves are superimposed on Fig. 1. Cruising Speed vs Range curves are presented in Fig. 4. The derived direct operating cost curves are superimposed on Fig. 2 and Fig. 3.

5.0 COMMENTS

5.1 Presentation of Results

The operational role of light aircraft is more frequently to transport individuals than to transport cargo. As passenger accommodation is dependent on the shape and size of the cargo space available, as well as the allowable payload, the cost per passenger mile can not be directly related to the cost per ton mile.

Direct Operating Cost per Nautical Mile vs Range curves (Fig. 2) are presented to allow the cost of operating the aircraft as personnel carriers to be determined.

5.2 Direct Operating Costs per Nautical Mile

The results in Fig. 2 indicate that the GETOL vehicle has operating costs per flight mile which are comparable to those of the Cessna 310. The VTOL vehicle has operating costs which are of the same magnitude as the helicopters considered.

The cost breakdown indicates that the crew costs are the major part (50% to 65%) of the operating costs of the existing aircraft but a minor part (15% to 33%) of the operating costs of the lifting fan aircraft, and that the considerably larger operating costs per hour of the lifting fan vehicles is compensated for by their higher predicted cruising speeds (see Table 1 and Fig. 4). A reduction in crew cost and/or a reduction in cruising speed of the lifting fan vehicles, will make the comparison less favourable to the lifting fan vehicles.

The cost per nautical mile is not sensitive to small variations in the weight breakdown, therefore any change in the predicted weights will not effect Fig. 2 appreciably.

5.3 Direct Operating Costs per Ton Nautical Mile

The results in Fig. 3 indicate that at ranges up to 200 nautical miles the GETOL vehicle has operating costs approximately 100% higher than those of the Beaver, the best existing fixed wing aircraft considered, but about 30% lower than those of the helicopters. For the same ranges, the VTOL vehicle has operating costs slightly below those of the Beaver. Due to the relatively high fuel consumptions associated with their high cruising speeds severely reducing the payloads, both vehicles have sharply rising costs at ranges greater than 200 nautical miles.

As the costs per ton nautical mile are obtained by dividing Fig. 2 results by the payloads in tons, comments on cost variations in Section 5.2 also apply to Fig. 3. In addition, however, the curves are sensitive to any variation in payload, a reduced payload increasing the costs. An increase in empty aircraft weight, or an increase in the estimated fuel consumption, would therefore adversely effect the costs per ton-mile of the lifting fan vehicles.

6.0 CONCLUSIONS

A comparison of the direct operating costs of existing light aircraft and helicopters with those of two configurations of lifting fan vehicles indicates that the lifting fan vehicles have comparable costs to the existing aircraft.

On a cost per mile basis the GETOL configuration of 6,822 lb. AUW has operating costs of the same order as those of the Cessna 310 with 4,600 lb. AUW. The VTOL configuration of 8,194 lb. AUW has costs of the same order as the Bell 47-G3 helicopter with 2,550 lb. AUW. With both lifting fan vehicles the higher operating costs per hour are compensated for by the higher predicted cruising speeds.

The cost per ton mile curves indicate that at ranges of up to 200 n.m. the GETOL configuration costs are approximately 100% greater than the Beaver, which is the best of the light aircraft considered, but 30% lower than the Bell 47 G-3, the best helicopter considered. For similar ranges the VTOL configuration has slightly lower costs than the Beaver. The operating costs of the lifting fan vehicles increase rapidly as the range is extended beyond 200 n.m.

A reduction in the assumed crew costs would be more favourable to the light aircraft and helicopter costs than it would to the lifting fan vehicle costs. Failure to attain the high predicted cruising speeds, or the estimated empty weights, of the lifting fan vehicles would raise their operating costs appreciably.

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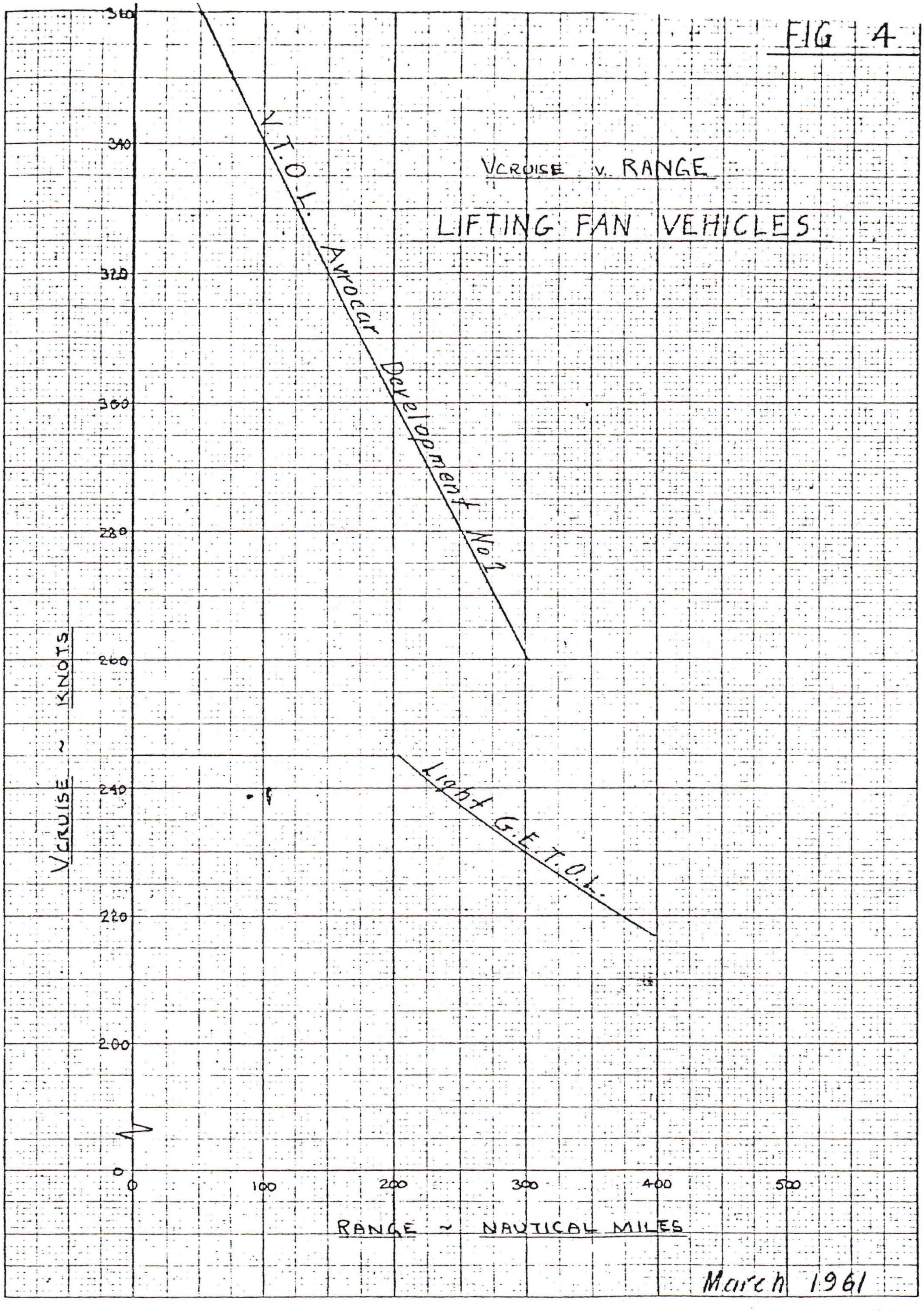
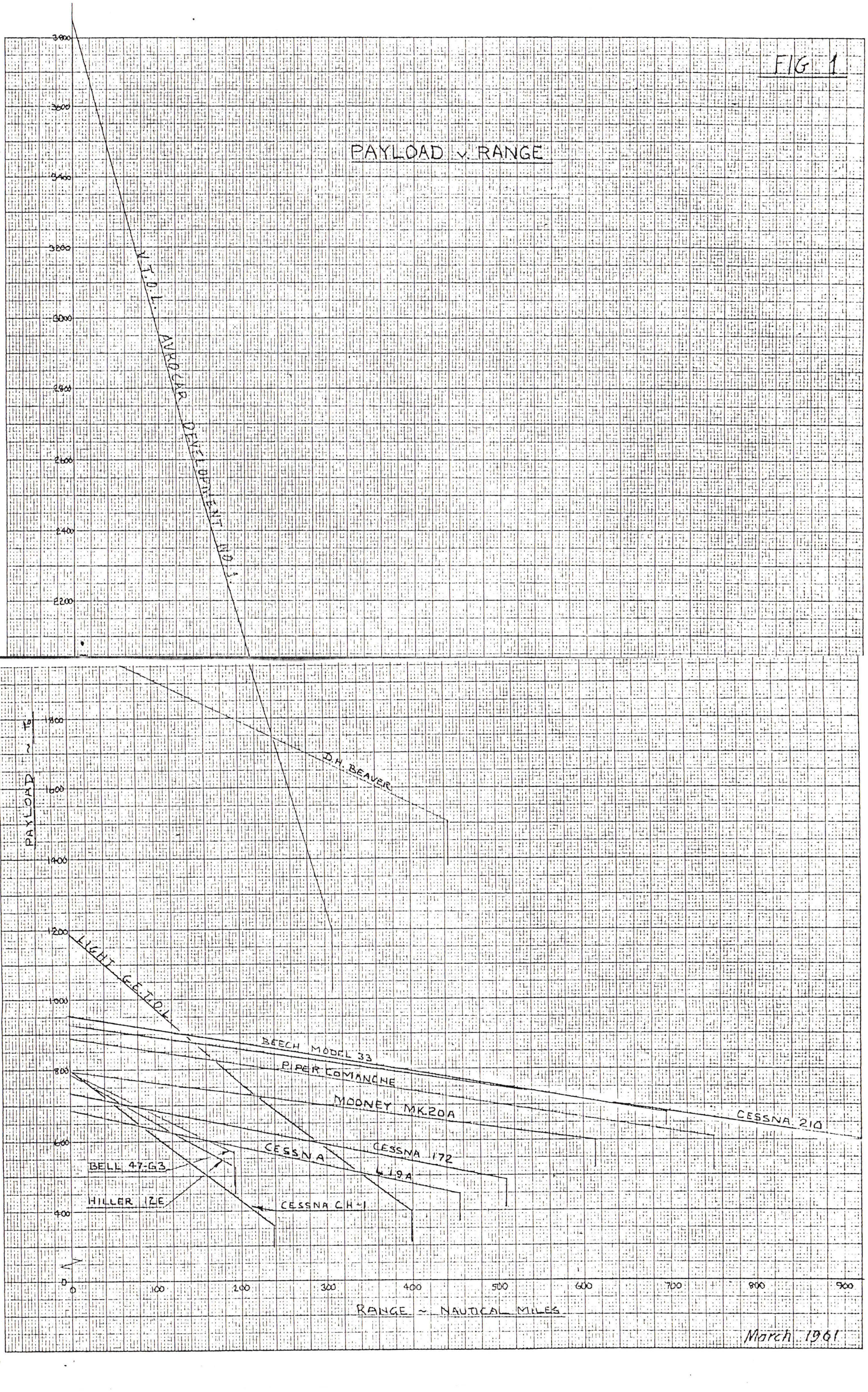


FIG 4
VCRUISE v. RANGE
LIFTING FAN VEHICLES
V.T.O.L. Avrocar Development No 2
Light G.E.T.O.L.
VCRUISE ~ KNOTS
RANGE ~ NAUTICAL MILES
360
340
320
300
280
260
240
220
200
0
0
100
200
300
400
500
March 1961



10 X 10 TO THE CM. KEUFFEL & ESSER CO. 359-14L
FIG 1
PAYLOAD v. RANGE
V.T.O.L. AVROCAR DEVELOPMENT NO.1.
D.H. BEAVER
LIGHT G.E.T.O.L.
BEECH MODEL 33
PIPER COMANCHE
MOONEY MK20A
CESSNA 210
CESSNA 172
CESSNA
L19A
BELL 47-G3
HILLER 12E
CESSNA CH-1
PAYLOAD ~ lb
RANGE ~ NAUTICAL MILES
March 1961

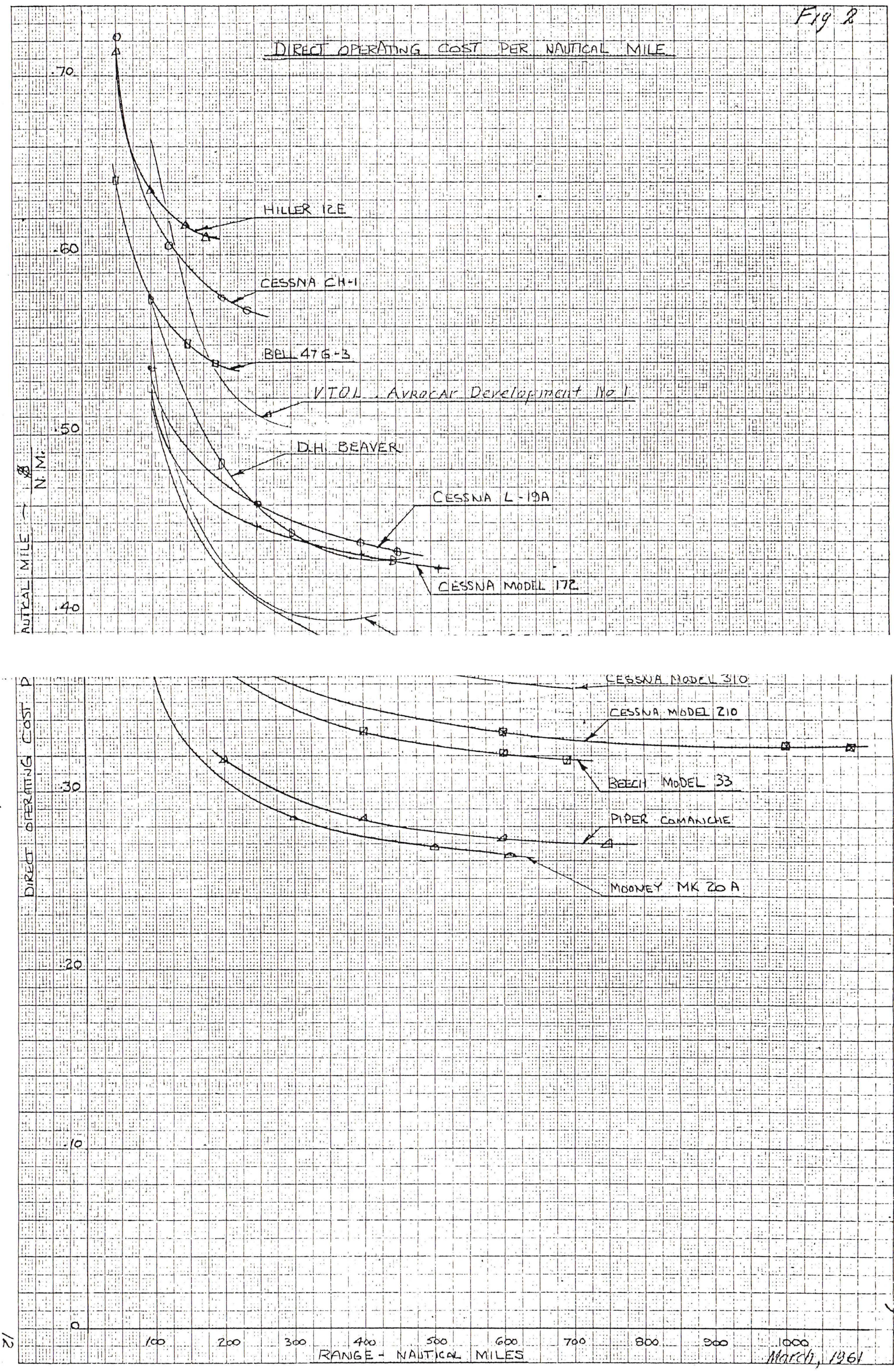


Fig 2
DIRECT OPERATING COST PER NAUTICAL MILE
HILLER 12E
CESSNA CH-1
BELL 47G-3
VTOL Avrocar Development No 1
D.H. BEAVER
CESSNA L-19A
CESSNA MODEL 172
CESSNA MODEL 310
CESSNA MODEL 210
BEECH MODEL 33
PIPER COMANCHE
MOONEY MK 20 A
DIRECT OPERATING COST - NAUTICAL MILE - $ N.M.
.70
.60
.50
.40
.30
.20
.10
0
100
200
300
400
500
600
700
800
900
1000
RANGE - NAUTICAL MILES
March, 1961
Fig 2

FIG 3

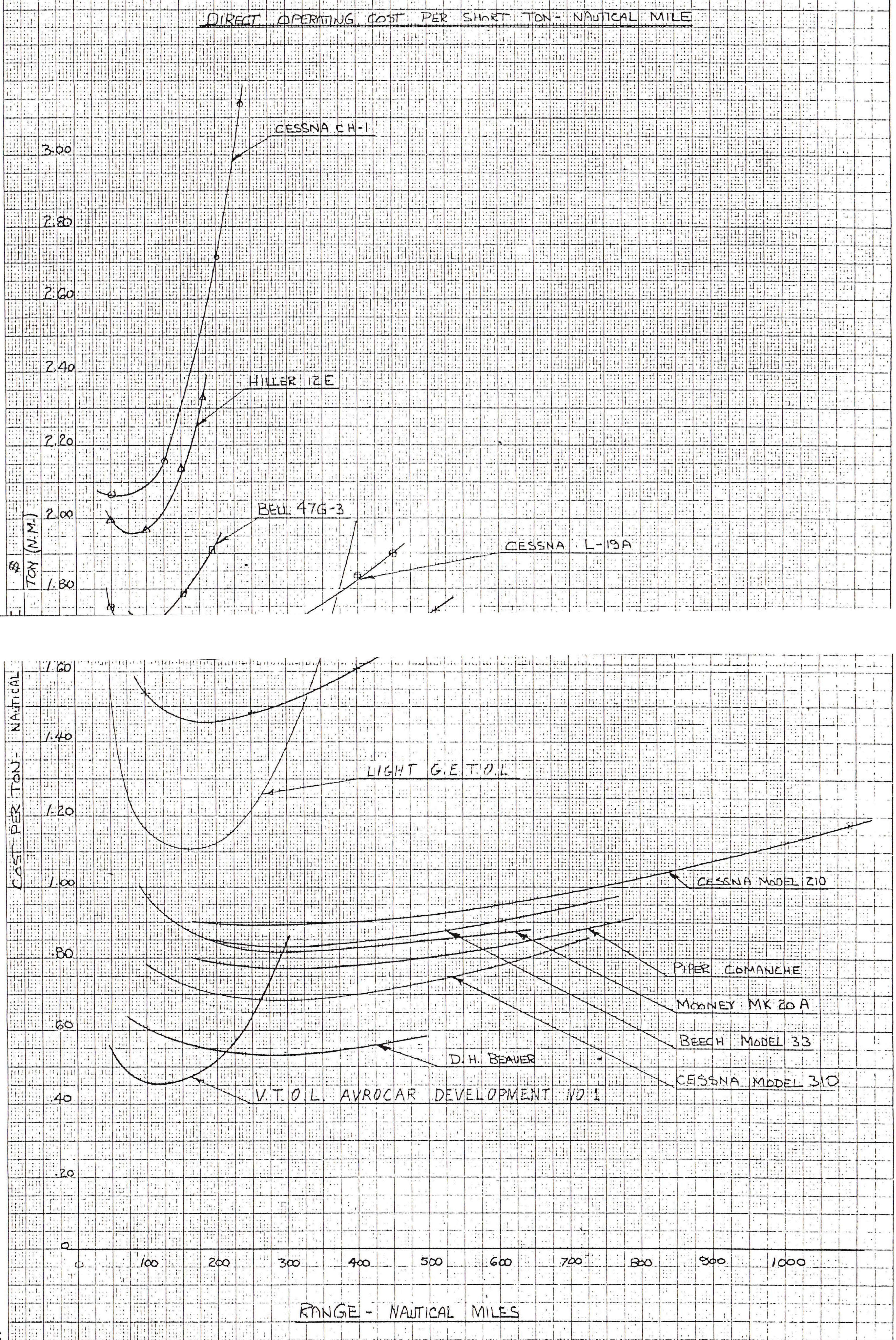


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FIG 3