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FORMULAS FOR TAKEOFF PERFORMANCE P3-A,B AND C AIRPLANES.(U)
JUL 78 J G CARRILLO, W M PURDY

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SUMMARY

↙ The increase in program steps to more than 200 and larger memory storage of handheld computers appears to make practicable their use in preflight planning of military missions by flight crews. Such application would provide greater accuracy and enhance efficient utilization of airplane capability. Contract No. N00014-77-C-0461 authorized development of formulas to calculate takeoff field length requirements and pertinent airspeeds and powerplant performance to test the feasibility of this application.

This report contains formulas for the performance items authorized by the contract. It is recommended that they be programmed for use with a handheld computer and that computer solutions be evaluated for flight planning for service missions of P-3 airplanes. ↗

INTRODUCTION

Contract No. N00014-77-C-0461 authorized development of formulas to calculate aerodynamic and power plant performance for P-3A, B and C airplanes. The authorized scope for the initial phase includes weight and balance, fuel distribution during loading, power forecast at 80 KIAS, field lengths and takeoff and refusal airspeeds. The formulas are to be applicable to handheld computers. Methods used to calculate the values for the performance charts in the P-3 NATOPS Flight Manuals required large capacity such as available in the IBM 360 series computers and so would not be suitable for even the most recently developed handheld computers.

The formulas in this report are intended for the use of a mathematician who is to program the calculation routines. It is expected that flight crews will be able to calculate each item of performance using the same parameters now used to read NATOPS Flight Manual performance charts. Calculation routines recorded on magnetic cards to insert into the computer will replace performance charts.

METHOD

Flight test performance data for the airplane and power plant used to develop the performance charts in the P-3A, B and C NATOPS Flight Manuals are the basis for the formulas and coefficients in this report. Solutions with these formulas will provide the same answers as the flight manual charts except where use of a digital computer provides greater accuracy. In some cases as indicated in discussion of individual performance items, use of a digital computer makes feasible more efficient use of airplane capability.

Derivation of formulas for acceleration and stopping distances and definition of rotation, liftoff and climb out speeds are given in Reference 1. Powerplant performance is given in References 2 and 3. Low order formulas to match the powerplant performance curves have been derived. This system of simple formulas provides the required accuracy because of the limited range of airspeed and altitude needed for takeoff performance prediction.

- Ref. 1. Lockheed Report 15839, "Flight Test Performance Analysis Procedures for the Model P3V-1," 9 April 1962 by D. R. Wyrick and D. M. Braught.
2. Allison Model Specification No. 479C, Navy Model T56-A-10W Turboprop Engine, 1 August 1962.
3. Allison Model Specification No. 670A, Navy Model T56-A-14 Turboprop Engine, 30 April 1965.

GLOSSARY OF TERMS

ϵ		braking effectiveness due to runway surface condition, i.e.: dry runway = 1.00 icy runway 0.25
H	feet	field pressure altitude
$\frac{p}{p_0}$		ratio of field atmospheric to sea level pressure
σ		atmospheric density ratio
S	feet	runway distance traveled
SHP		shaft horsepower on cockpit instruments
SHP (predicted)		engine specification SHP corrected for P-3 installation effects without anti-ice inlet heating
SHP (A-I)		SHP (predicted) with anti-ice inlet heating
SHP (actual average)		average engine performance of individual airplane
SHP (expected)		predicted SHP corrected to average engine performance of individual airplane
SHP (limit)		maximum SHP permitted by NATOPS
Δ SHP		SHP (expected) - SHP (limit) > 0
t	$^{\circ}\text{C}$	air temperature at runway
Thrust (expected)	lb.	combined propeller and jet thrust for SHP (expected)
T_e	lb.	combined thrust from propeller and jet per engine
T_{e_3}	lb.	T_e when three engines are operating
T_{e_4}	lb.	T_e when four engines are operating

GLOSSARY OF TERMS (Continued)

T_J	lb.	jet thrust
T_P	lb.	propeller thrust
TIT	$^{\circ}C$	Turbine inlet temperature
V	KIAS	true airspeed
V_{EF}	KIAS	engine failure airspeed
V_i	KIAS	airspeed indicator reading
V_{MC}	KIAS	minimum control airspeed on the runway with one engine failed
V_{RO}	KIAS	speed to begin rotation to takeoff attitude
V_{LOF}	KIAS	speed at liftoff
V_{50}	KIAS	speed when 50 feet above point at liftoff
W	lb.	airplane weight
V_S	KIAS	stall speed with zero thrust

PERFORMANCE FORMULAS

Weight and Balance

Procedure

Airplane gross weight and moment are determined using DD365E and entering the data on DD365 Form F. Basic airplane weight and moment are from the actual weighing record. Items are determined individually and entered on Form F for oil, crew, personal equipment, baggage, cargo, internal stores cabin and bomb bay, armament and fuel. Moments for items not shown in the tables of DD365E can be computed using the following equation:

$$\text{INDEX or MOM/} = \frac{\text{WEIGHT x ARM}}{1000}$$

where:

WEIGHT = weight of the item in pounds (kilograms).

ARM = distance of the item from the reference datum and is in inches (centimeters). This distance is determined from the airplane diagram in DD365E.

The total weight and index on line 10 of DD365F are then used to compute C.G. position in percent, gear down.

All warnings, cautions, and explanatory notes on charts of DD365E must be observed.

Formulas

Using inches and pounds:

$$\text{C.G.} = \left(\frac{\left[\frac{\text{INDEX or MOM/} \times 1000}{\text{WEIGHT}} \right] - 545.9}{168.7} \right) \times 100$$

Using centimeters and kilograms:

$$\text{C.G.} = \left(\frac{\left[\frac{\text{INDEX or MOM/} \times 1000}{\text{WEIGHT}} \right] - 1386.6}{428.5} \right) \times 100$$

Fuel Loading

Procedure

Normal procedure requires fueling tanks 1, 2, 3 and 4 equally. Fuel is carried in tank 5 only when the four wing tanks are full. In addition the fuel load in tanks 1 and 4 must be at least a certain amount that varies with total airplane weight to permit full load factor maneuvering. Formulas are provided to calculate this minimum fuel load that must be carried in tanks 1 and 4.

Formulas

Standard P-3A Airplane:

$$\text{MFT} = 0.25 (\text{ZFW} + \text{F} - \text{PSW} - 72429)$$

where:

MFT = Minimum fuel per tank required in tanks 1 and 4 until full at 10439 pounds.

ZFW = Airplane weight without fuel.

F = Total fuel weight.

PSW = Weight of all pylons and pylon mounted stores except not more than 616 pounds may be included per station for stations 12, 13, 14 and 15.

Increased Weight Capability Airplanes and all P-3C Airplanes:

$$MFT = 0.25 (ZFW + F - PSW - 78045)$$

where:

PSW = Includes actual weights at stations 12, 13, 14 and 15.

Airspeeds for Takeoff Planning

Background

Several factors affect airspeed for rotation to takeoff attitude, airspeed for liftoff and for climbout over obstacles. For instance adequate directional control in case of engine failure must be assured when rotating to takeoff attitude. The amount of directional control needed depends upon engine output that varies with ambient temperature, atmospheric pressure and selection of power rating. A chart depicting all these variables would be complex and tedious to use; therefore, a simplified schedule has been provided in the Natops Flight Manual for normal use. This chart only shows the effect of airplane weight. Obviously it cannot provide the same margin of safety at both high and low powers. To provide more optimum performance at lower powers, Natops presents a more complex chart of alternate speed schedules.

Calculation of the optimum airspeed for rotation, the resulting speed at liftoff and the proper speed for climbing over obstacles can be readily accomplished with a handheld computer with a knowledge of engine thrust. Solutions to the formulas in this section will provide the same level of safety under all operating conditions and hence will deviate somewhat from the simpler approach of Natops. In other words, the goals sought by the Natops charts now can be achieved with the formulas in this section.

Procedure

The airspeed to begin rotation to takeoff attitude is calculated from ambient conditions using airplane weight and thrust predicted by the Shaft Horsepower and thrust calculation procedures. Correction of predicted SHP is made by knowledge of how much average engine performance deviated from predicted SHP during previous takeoffs of the same airplane. Formulas are provided also to calculate speeds for liftoff and climb out on four engines and with power from three engines if takeoff is continued after an engine failure. The selection of speeds has been indexed to the thrust to weight ratio at 100 KTAS. SHP and thrust calculation procedures have been formulated based on entry of KIAS into the computer; therefore this procedure includes calculation of KIAS from KTAS. The procedure is summarized in Table I; and storage of results, some for use in later calculations, is indicated. Table II provides a format for use of the pilot in preflight planning.

Formulas

$$\frac{p}{p_0} = \left(1 - 68758 \times 10^{-10} H\right)^{5.2557}$$

$$\sigma = \frac{p}{p_0} \times \frac{288.15}{t + 273.15}$$

$$v_i = 100 \sigma^{0.5}$$

$$v_s = 0.3303 W^{0.5}$$

$$v_{MC} = 1.14 T_e^{0.5}$$

$$\text{if } \frac{T_e}{W} \geq 0.063:$$

$$\text{if } \frac{T_e}{W} < 0.063:$$

$$v_{RO} = v_s \left(0.61 + 7.11 \frac{T_e}{W}\right)$$

$$v_{RO} = v_s \left(1.15 - 1.48 \frac{T_e}{W}\right)$$

$$v_{LOF} = v_s \left(0.59 + 8.41 \frac{T_e}{W}\right) \text{ FOUR ENGINE}$$

$$v_{LOF} = v_s \left(1.14 - 0.33 \frac{T_e}{W}\right)$$

$$v_{50} = v_s \left(0.58 + 9.60 \frac{T_e}{W}\right) \text{ FOUR ENGINE}$$

$$v_{50} = v_s \left(1.12 + 1.03 \frac{T_e}{W}\right)$$

$$v_{LOF} = v_s \left(0.61 + 7.97 \frac{T_e}{W}\right) \text{ THREE ENGINE}$$

$$v_{LOF} = v_s \left(1.15 - 0.61 \frac{T_e}{W}\right)$$

$$v_{50} = v_s \left(0.61 + 8.57 \frac{T_e}{W}\right) \text{ THREE ENGINE}$$

$$v_{50} = 1.15 v_s$$

TABLE I. PROCEDURE FOR DETERMINING AIRSPEEDS

STEP	ENTER	RECALL	CALCULATE	STORAGE LOCATION
A	H			1
			$\frac{p}{p_0}$	2
B	t		t + 273.15	3
			σ	4
		$\frac{p}{p_0}$	V_i	5
			T_e	6
C	(SHP and thrust procedure)			
D	W		$\frac{T_e}{W}$	7
			V_s	8
			V_{MC}	9
			V_{RO}	10
			V_{LOF} (four engine)	11
			V_{50} (four engine)	12
			V_{LOF} (three engine)	13
			V_{50} (three engine)	14
				15

TABLE II. AIRSPEEDS FOR TAKEOFF PLANNING

Pressure altitude _____ ft.	ambient temperature _____ °C
Previous average engine performance this a/c _____	$\frac{\text{SHP (actual)}}{\text{SHP (predicted)}}$
Gross weight	lb.
TIT rating	°C
True airspeed	KTAS 100
Indicated airspeed	KIAS
Power (predicted)	SHP
Power (expected)	SHP
Thrust (expected)	lb.
V_{MC}	KIAS
V_{RO}	KIAS
V_{LOF} with 4 engines	KIAS
V_{50} with 4 engines	KIAS
V_{LOF} with 3 engines	KIAS
V_{50} with 3 engines	KIAS

Power and Thrust

Procedure

The formulas that have been derived for power and thrust prediction include a number of common terms and so are presented together. The pilot will use the values of predicted power to see that engine performance has not deteriorated. Thrust is required for determination of the distance to accelerate and the speeds to rotate, takeoff and climbout. The calculations are lengthy; and so a diagram of the entire calculation procedure has been provided to assist computer programming, Table III.

TABLE III. UNAUGMENTED SHP AND THRUST PROCEDURE

STEP	ENTER	RECALL	CALCULATE	STORAGE LOCATION
A	V_i	σ	V	6
		t	5 terms with V and t	7
				8-12
B	TIT		2 terms with TIT	13
				14-15
		$\frac{P}{P_o}$, (8) - (15)*	SHP (predicted)	16
C	(A-I)	$\frac{P}{P_o}$, V, TIT, t	SHP (A-I)	17
D	$\frac{\text{SHP (actual)}}{\text{SHP (predicted)}}$		SHP (expected)	18
E	SHP (limit)		Δ SHP	19
			select SHP	20
F	No. of engines		select F, C	21,22
		SHP		
		other terms	T_e	23

* () numbers in storage

Unaugmented SHP for any value of Turbine Inlet Temperature from the normal power rating of the T56-A-10W engine to the maximum power rating of the T56-A-14 engine can be calculated using one set of formulas by entering the appropriate value of TIT into the routine. A correction formula is shown to calculate the reduction in power that occurs with engine anti-icing. An additional set of formulas is provided for calculation of power for the T56-A-10W engine with water-alcohol injection.

A correction formula is included to be applied when experience shows that SHP can be expected to be different from engine specification performance, SHP (predicted).

On cold days throttling to lower than TIT rating may be required to avoid exceeding limit SHP. In such event limit SHP is to be used to calculate thrust.

Formulas

For T56-A-14 and T56-A-IOW engines without water-alcohol augmentation:

$$\begin{aligned} \text{SHP}(\text{predicted}) = & \left[\frac{P}{P_0} \left(1 + \frac{0.00013 V^2}{t+273.15} \right)^{3.5} \left(0.9808 + 24 \times 10^{-6} \text{TIT} \right) \right] \\ & \times \left[9.6837 \text{TIT} - 4644.8 - (0.02892 \text{TIT} - 10.88) (1.8t + 23 \times 10^{-5} V^2 + 32) \right. \\ & \left. + (1.8t + 23 \times 10^{-5} V^2 + 491.6)^{0.5} (0.0469V + 0.379) (0.94 - 0.007t) \right] \end{aligned}$$

Correction to SHP for engine anti-icing:

$$\begin{aligned} \text{SHP}(\text{A-I}) = & \text{SHP}(\text{predicted}) - \left[\frac{P}{P_0} \left(1 + \frac{0.00013 V^2}{t+273.15} \right)^{3.5} \left(0.9808 + 24 \times 10^{-6} \text{TIT} \right) \right] \\ & \times (145 + 0.203 \text{TIT} - 0.73 t) \end{aligned}$$

For T56-A-10W engines with water-alcohol augmentation:

$$\begin{aligned} \text{SHP}(\text{predicted}) = & \left[\frac{P}{P_0} \left(1 + \frac{0.00013V^2}{t+273.15} \right)^{3.5} \left(0.9808 + 24 \times 10^{-6} \text{TIT} \right) \right] \\ & \times \left[4935 - 4.25 \left(1.8t + 23 \times 10^{-5} V^2 + 32 \right) - 0.0375 \left(1.8t + 23 \times 10^{-5} V^2 + 32 \right)^2 - 380 \frac{P}{P_0} \right. \\ & \left. + \left(1.8t + 23 \times 10^{-5} V^2 + 491.6 \right)^{0.5} \left(0.0469V + 0.379 \right) \left(0.94 - 0.007t \right) \right] \end{aligned}$$

Effectiveness of water-alcohol decreases rapidly at low inlet temperatures and at altitude; therefore, use 10°C for t for altitudes above 2000 feet when air temperature is less than 10°C .

Correction of SHP(predicted) for average engine performance on same airplane:

$$\text{SHP}(\text{expected}) = \frac{\text{SHP}(\text{actual average})}{\text{SHP}(\text{predicted})} \times \text{SHP}(\text{predicted})$$

$$T_e = T_p + T_j$$

$$T_p = F \left[103.6 + 1.605V - \frac{0.02304}{\sigma} (0.995 \text{ SHP}-C) \right] \frac{0.995 \text{ SHP}-C}{V}$$

$\text{SHP} = \text{SHP}(\text{expected})$ or $\text{SHP}(\text{limit})$ whichever is less

For four engines: $F = 0.893$, $C = 106$

For three engines: $F = 0.881$, $C = 131$

$$T_j = 0.8 \left[\frac{p}{p_o} \left(1 + \frac{0.00013 v^2}{t+273.15} \right)^{3.5} \left(0.9808 + 24 \times 10^{-6} \text{TIT} \right) \right]$$

$$\times \left\{ \left[246.7 + 0.681 \text{TIT} - (0.8212 + 0.002039 \text{TIT}) (1.8t + 23 \times 10^{-5} v^2 + 32) \right] \right.$$

$$\left. \times (0.000248v + 1.0015) - (1.79 - 0.0065t) v \right\} - 0.07 \Delta \text{SHP}$$

$$\Delta \text{SHP} = \text{SHP}(\text{expected}) - \text{SHP}(\text{limit})$$

Applied only when $\Delta \text{SHP} > 0$

For T56-A-10W engines $\text{SHP}(\text{limit}) = 4300$

For T56-A-14 engines $\text{SHP}(\text{limit}) = 4600$

In all formulas

$$v = \frac{v_i}{\sigma 0.5}$$

Four Engine Acceleration Distance

Procedure

Distance to accelerate to any value of KIAS on a dry runway with four operating engines can be calculated using the formula below. Calculating distance required to attain 80 KIAS, refusal speed, rotation speed and liftoff speed may be accomplished readily to provide checks of engine performance as takeoff progresses. The format of Table IV provides a systematic way to record results. Table IV also acts as a reminder that the thrust in the distance formulas must be that at the root-mean-square speed of the acceleration segment. It is to be recalled that predicted SHP is corrected to that expected for the individual airplane based upon previous average engine performance; thus all distance calculations are tailored to individual airplane capability.

TABLE IV. REFUSAL AND DECISION SPEEDS

Pressure altitude _____ ft.		ambient temperature _____ °C
Previous average engine performance this a/c _____		$\frac{\text{SHP (actual)}}{\text{SHP (predicted)}}$
RUNWAY _____ length _____ ft.		slope up/down _____ % brake eff. _____
WIND _____ KTAS from _____ °		head/tail _____ KTAS XWIND _____ KTAS
Correction: (1 - 0.0125 x headwind) or (1 + 0.02 x tail wind) W = (1 + 0.08 x % upslope) or (1 - 0.06 x % downslope) S =		
Gross Weight		lb.
TIT rating		°C
Limit power		SHP
80 KIAS predicted power		SHP
80 KIAS expected power		SHP
Four-Engine Acceleration	V_i	KIAS
	0.707 V_i	KIAS
	Thrust	lb.
	Distance	ft.
	Distance xWxS	ft.
Takeoff Abort	V_{EF} (Refusal)	KIAS
	0.707 V_{EF}	KIAS
	Thrust at 0.707 V_{EF}	lb.
	Thrust at V_{EF} (3-eng)	lb.
	Accel-stop distance	ft.
	A-s distance xWxS	ft.
Takeoff with engine failure	V_{LOF} (3-eng)	KIAS
	V_{EF} (Decision)	KIAS
	0.707 V_{EF}	KIAS
	Thrust (4-eng)	lb.
	$0.707(V_{EF}^2 + V_{LOF}^2)^{0.5}$	KIAS
	Thrust (3-eng)	lb.
	Takeoff distance	ft.
T.O. distance xWxS	ft.	

Formula

$$S = \frac{(0.0422 - 3 \times 10^{-8} W) W \frac{V_i^2}{\sigma}}{4 T_{e_4} - 0.025W - \left(0.171 - 0.000164 \frac{V_i}{\sigma^{0.5}}\right) V_i^2}$$

Distance for Refused Takeoff

Determination of Refusal Speed

Procedure

The distance traveled during a refused takeoff due to an engine failure consists of the following five segments:

1. A four-engine acceleration.
2. A three-engine acceleration prior to power reduction following engine failure.
3. A short coasting period.
4. A deceleration with three engines at ground idle to maximum speed for brake application.
5. Further deceleration to stop with wheel braking.

It is assumed that only the fifth segment calculation needs to be varied due to a wet or icy runway, i.e., a runway condition reading (RCR) within the range of 23 to 5.

The procedure is to assume a KIAS for engine failure and calculate the total distance to accelerate and stop. The process is repeated until the maximum speed that can be accommodated by the available runway length is determined that is not greater than liftoff speed. This is refusal speed.

Calculations will be aided by appropriate entries to Table IV. Power and thrust for the four-engine acceleration segment is based upon the root-mean-square speed as usual. For the small speed change while accelerating on three engines, thrust at engine failure speed is used to calculate the distance traveled.

Formulas

$$S = \frac{(0.422 - 3 \times 10^{-8} W) W \frac{V_{EF}^2}{\sigma}}{4 T_{e_4} - 0.025 W - \left(0.171 - 0.000164 \frac{V_{EF}}{\sigma 0.5}\right) V_{EF}^2} + \frac{0.02865 W \left(5 \frac{V_{EF}}{\sigma 0.5} + 6.25\right)}{3 T_{e_3} - 0.025 W - \left(0.242 - 0.00067 \frac{V_{EF}}{\sigma 0.5}\right) \sigma \left(2 \frac{V_{EF}^2}{\sigma} + \frac{5 V_{EF}}{\sigma 0.5} + 6.25\right)} + 3.2 \left(\frac{V_{EF}}{\sigma 0.5} + 2.5\right) + A$$

$$\text{if } \frac{V_{EF}}{\sigma 0.5} > 120 \left(\frac{127,500}{W}\right)^{0.5} - 2.5:$$

$$A = \frac{0.134 W}{\sigma} \ln \left[\frac{\frac{3\sigma}{W} \left[156 + 1.97 \left[\left(\frac{V_{EF}}{\sigma 0.5} + 2.5 \right)^2 + 120^2 \times \frac{127,500}{W} \right]^{0.5} + 0.2695 \left[\left(\frac{V_{EF}}{\sigma 0.5} + 2.5 \right)^2 + 120^2 \times \frac{127,500}{W} \right] + 0.1093 \left(\frac{V_{EF}}{\sigma 0.5} + 2.5 \right)^2 + 0.025}{\frac{3\sigma}{W} \left[156 + 1.97 \left[\left(\frac{V_{EF}}{\sigma 0.5} + 2.5 \right)^2 + 120^2 \times \frac{127,500}{W} \right]^{0.5} + 0.2695 \left[\left(\frac{V_{EF}}{\sigma 0.5} + 2.5 \right)^2 + 120^2 \times \frac{127,500}{W} \right] + 1574.4 \times \frac{127,500}{W} + 0.025} \right]}{\sigma \left[0.5 \left(0.422 - 17 \times 10^{-7} W \right) - 0.087 \right]} \ln \left[\frac{B}{B - \frac{4.41\sigma}{W} \times 120^2 \times \frac{127,500}{W} \left[0.5 \left(0.422 - 17 \times 10^{-7} W \right) - 0.087 \right]} \right]$$

$$B = \frac{3\sigma}{W} \left[156 + 236.4 \left(\frac{127,500}{W} \right)^{0.5} + 3881 \times \frac{127,500}{W} \right] + \left(0.422 - 17 \times 10^{-7} W \right)$$

$$\text{if } \frac{V_{EF}}{\sigma 0.5} \leq 120 \left(\frac{127,500}{W}\right)^{0.5} - 2.5:$$

$$A = \frac{0.01 W}{\sigma \left[0.5 \left(0.422 - 17 \times 10^{-7} W \right) - 0.087 \right]} \ln \left[\frac{B}{B - \frac{4.41\sigma}{W} \left(\frac{V_{EF}}{\sigma 0.5} + 2.5 \right)^2 \left[0.5 \left(0.422 - 17 \times 10^{-7} W \right) - 0.087 \right]} \right]$$

Takeoff Distance with Engine Failure

Determination of Decision Speed

Procedure

The formula for calculating distance to liftoff from a dry runway consists of adding a formula for calculating distance to accelerate with three engines to the formula for distance to accelerate with four engines. An engine failure speed is assumed, then the distance to liftoff is calculated. Calculations are repeated until the minimum value is obtained for the available length of runway. This is decision speed. Decision speed must not be less than the minimum control speed in Table II.

Airplane weight must be reduced if decision speed exceeds refusal speed.

The entries necessary to perform the calculations have been included in Table IV.

Formula

$$S = \frac{(0.0422 - 3 \times 10^{-8} W) W \frac{V_{EF}^2}{\sigma}}{4 T_{e_4} - 0.025 W - \left(0.171 - 0.000164 \frac{V_{EF}}{\sigma^{0.5}}\right) V_{EF}^2} + \frac{\left[0.0281 + 0.00023 \left(\frac{V_{LO} - V_{EF}}{\sigma^{0.5}}\right)\right] \frac{W}{\sigma} (V_{LO}^2 - V_{EF}^2)}{3 T_{e_3} - 0.025 W - \left[0.242 - 0.00047 \left(\frac{V_{LO}^2}{\sigma^{0.5}}\right)\right] (V_{LO}^2 + V_{EF}^2)}$$

Three-Engine Ferry Takeoff Distance

Procedure

Formulas are provided for calculating takeoff performance when only three engines are operative and the propeller on the fourth engine is either feathered throughout the takeoff or has been removed. A reasonable schedule of power application on the asymmetrical engine to assure directional control throughout is approximated by calculating distances for four segments. Each segment requires separate calculation of SHP and thrust.

Formula

$$\begin{aligned}
 S = & \frac{101.7 W}{\sigma (2 T_{e_3} + 1929 + 249 \sigma - 0.025 W)} \\
 & + \frac{305 W}{\sigma (2 T'_{e_3} + 958 + 332 \sigma - 0.025 W)} \\
 & + \frac{131.2 W}{\sigma (2 T''_{e_3} - 26 + 2244 \sigma - 0.025 W)} \\
 & + \frac{\left(\frac{24.98}{\sigma^{0.5}} + 148 \right) W}{\sigma \left(3 T'''_{e_3} - 7676 + \frac{2655}{\sigma^{0.5}} - 0.025 W \right)}
 \end{aligned}$$

where:

T_{e_3} = thrust at 25 KIAS

T'_{e_3} = thrust at 75 KIAS

$T_{e_3}'' = \text{thrust at 107.5 KIAS}$

$T_{e_3}''' = \text{thrust at 126 KIAS}$

Conversion to SI Units

The formulas in this report are compatible with the units used for the instruments in the P-3 series airplanes for direct application to flight planning by P-3 flight crews. Although the methods of solution may have wider application, the formulas in this report contain constants peculiar to P-3 performance prediction and so cannot be directly applied to calculation of performance of other airplanes. Because of the above, the formulas are basically in English units; and because of their complexity, units of the International System have not been included in parentheses. Terms to convert to the International System by direct substitution in the formulas are given below:

In Place Of:

feet
horsepower
knots
pounds force

Insert:

3.281 meters
0.001341 joules/second
1.943 meters/second
0.2248 newtons

EXAMPLE

Calculation of takeoff performance and appropriate speed schedules varies somewhat from Natops Flight Manual procedure. A numerical example of the use of Tables II and IV is given on following pages. Table II should be completed before starting Table IV. Using Table II speeds, all the speeds of Table IV can be entered. The next step is to calculate all the SHP and thrust values. The final step is to calculate all distances.

Known conditions are entered first in Table II including the TIT rating to be observed. A value of 100 KTAS has been printed on the chart because the six speeds to be calculated have been based upon the thrust-to-weight ratio at 100 KTAS. The procedure yields the value of KIAS prior to calculating SHP and thrust, providing an extra check on power output during takeoff. After thrust has been calculated using the routine that limits SHP to 4600, the six speeds are calculated based on this thrust at 100 KTAS.

The first column in Table IV shows the SHP to be expected at 80 KIAS and the runway distance to get there. The second column shows total runway lengths for a four-engine takeoff, an aborted takeoff and a takeoff continued after engine failure. The first speed in the second column is of course, V_{LOF} with four engines from Table II. For an aborted takeoff the value of V_{RO} will usually be satisfactory for V_{EF} (Refusal). For a takeoff after engine failure the minimum value for V_{EF} (Decision) should be V_{MC} . A higher value will be chosen if experience indicates available runway length may be exceeded. The next step is to calculate the ".707 speeds" upon which the values of thrust are based. Then all thrusts should be calculated before calculating any distances. Finally the calculated distances are compared with runway length available. If either distance for engine failure exceeds available runway length, an additional calculation with another value of V_{EF} will be required.

TABLE II. AIRSPEEDS FOR TAKEOFF PLANNING

Pressure altitude	<u>0</u> ft.	ambient temperature	<u>25</u> °C
Previous average engine performance this a/c	<u>1.00</u>	$\frac{\text{SHP (actual)}}{\text{SHP (predicted)}}$	
Gross weight	lb.	120,000	
TIT rating	°C	932	
True airspeed	KIAS	100	
Indicated airspeed	KIAS	98.31	
Power (predicted)	SHP	3,255	
Power (expected)	SHP	3,255	
Thrust (expected)	lb.	5,863	
V _{MC}	KIAS	87.29	
V _{RO}	KIAS	123.30	
V _{LOF} with 4 engines	KIAS	128.59	
V ₅₀ with 4 engines	KIAS	133.91	
V _{LOF} with 3 engines	KIAS	128.17	
V ₅₀ with 3 engines	KIAS	131.58	

TABLE IV. REFUSAL AND DECISION SPEEDS

Pressure altitude <u>0</u> ft.		ambient temperature <u>25</u> °C		
Previous average engine performance this a/c <u>1.00</u>		$\frac{\text{SHP (actual)}}{\text{SHP (predicted)}}$		
RUNWAY <u>15</u>	length <u>10K</u> ft.	slope up/down <u>0.5%</u>	brake eff. <u>1.0</u>	
WIND <u>10</u> KTAS	from <u>180</u> °	head/tail <u>9</u> KTAS	XWIND <u>5</u> KTAS	
Correction: $(1 - 0.0125 \times \text{headwind})$ or $(1 + 0.02 \times \text{tail wind})$ $W = 0.89$ $(1 + 0.08 \times \% \text{ upslope})$ or $(1 - 0.06 \times \% \text{ downslope})$ $S = 1.04$				
Gross Weight	lb.	120,000	120,000	
TIT rating	°C	932	932	
Limit power	SHP	4,600		
80 KIAS predicted power	SHP	3,235		
80 KIAS expected power	SHP	3,235		
Four-Engine Acceleration	V_i	KIAS	80	128.59
	$0.707 V_i$	KIAS	56.56	90.91
	Thrust	lb.	6,577	5,941
	Distance	ft.	1,376	4,333
	Distance xWxS	ft.	1,274	4,111
Takeoff Abort	V_{EF} (Refusal)	KIAS		123.30
	$0.707 V_{EF}$	KIAS		87.17
	Thrust at $0.707 V_{EF}$	lb.		5,985
	Thrust at V_{EF} (3-eng)	lb.		5,574
	Accel-stop distance	ft.		6,908
A-s distance xWxS	ft.		6,394	
Takeoff with Engine Failure	V_{LOF} (3-eng)	KIAS		128.17
	V_{EF} (Decision)	KIAS		87.29
	$0.707 V_{EF}$	KIAS		61.71
	Thrust (4-eng)	lb.		6,436
	$0.707 (V_{EF}^2 + V_{LOF}^2)^{0.5}$	KIAS		109.64
	Thrust (3-eng)	lb.		5,666
	Takeoff distance	ft.		5,829
T.O. distance xWxS	ft.		5,395	

CONCLUSIONS

1. Formulas in this report are suitable for programming a high capacity handheld computer.
2. Use of the computer by flight crews in preflight planning will provide rapid and more accurate performance prediction.
3. Use of the computer will enhance more efficient operation of the P-3 airplanes through use of optimum techniques such as regular use of the more efficient alternate schedules for rotation and climbout speeds.

RECOMMENDATIONS

1. It is recommended that the performance formulas in this report be programmed efficiently by a mathematician experienced in computer programming.
2. Experience should be gained with computer performance calculations by flight crews conducting regular service missions to compare with method using NATOPS performance charts.

APPENDIX A. COMPARISON WITH NATOPS FLIGHT MANUAL

The airspeeds for takeoff planning in this report are different from the simplified schedule in the Natops Flight Manual. The speeds in this report provide a consistent level of control for all conditions rather than compromising for simplicity. The differences usually will be small except for high power, light weight and cold days when report speed for rotation may be 5 or 6 KIAS greater than Natops with corresponding increases in takeoff and climb speeds. The ground minimum control speed based on thrust generally will be lower than Natops based on SHP because using SHP had to allow for maximum possible thrust on the coldest possible day.

Use of either set of speeds will of course, provide corresponding SHP and runway length values. Formulas for the simplified speed schedule in the Natops Flight Manual are given below.

If $W \leq 108,000$

$$V_{RO} = 115$$

$$V_{LOF} = 121$$

$$V_{50} = 142.5 - 0.128 \frac{W}{1000} \quad \text{FOUR ENGINE}$$

$$V_{50} = 124.5$$

If $W > 108,000$:

$$V_{RO} = 52.6 + 0.582 \frac{W}{1000}$$

$$V_{LOF} = 62.8 + 0.542 \frac{W}{1000}$$

$$V_{50} = 76.2 + 0.487 \frac{W}{1000}$$

$$\text{THREE ENGINE } V_{50} = 66.8 + 0.539 \frac{W}{1000}$$

Calculated values of SHP without water-alcohol augmentation and without anti-ice bleed agree closely with Natops charts from 932 to 1077°C TIT. Maximum disagreement is on hot days at high TIT values, calculated values may be 1% greater at altitude.

Excellent agreement for SHP with water-alcohol augmentation exists from sea level to 4000 feet. At 8000 feet and 45°C air temperature the calculated value is 3% less than the Natops chart.

With anti-ice on, calculated and Natops SHP values agree well for 1077°C TIT. The calculation procedure is based on the 2.9% bleed established in previous flight tests and so should be completely accurate. As TIT rating is reduced the Natops temperature correction chart becomes less accurate, particularly near 0°C and sea level. At 971 and 932°C TIT the Natops value of SHP is 5% too great.

A number of required runway lengths have been calculated and compared with Natops covering the range of airplane weight, ambient temperature, altitude and TIT ratings. The values for four-engine takeoff distance, rejected takeoff distance and takeoff distance with a failed engine agree generally within the readability of the Natops charts. The Natops charts become somewhat inaccurate around the edges.