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**EFFECTS ON LEVEL FLIGHT PERFORMANCE OF THE
OPTIMIZED WIND DEFLECTOR MODIFICATION FOR THE
MD-500 HELICOPTER**

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Adam Joseph Cowan

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DEDICATION

This thesis is dedicated to my wife, Tammy and my children, Darby and Shelby. They have courageously stood by me through countless moves and deployments. Their love, patience, and unselfish support have allowed me to realize my dreams. Also to my father and mother, Richard and Linda Cowan, who instilled in me a strong work ethic and gave me the required tools to succeed.

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ABSTRACT

This thesis investigates the effects of personnel wind deflector devices on the level flight performance of an MD-500D helicopter configured with external passenger provisions. Numerous helicopter organizations operate with external passenger configurations. These configurations result in personnel exposure to high winds and an increase in parasite drag. Level flight performance is degraded by the increase in parasite drag caused by the external passengers. Wind deflectors were mounted on the forward portion of the fuselage to protect external passengers from the effects of wind exposure (high wind loads and wind chill factor) by deflecting the wind away from the fuselage. The purpose of this investigation is to determine the effects of the wind deflector modification on level flight performance; specifically the change in: engine shaft horsepower required, equivalent flat plate area, maximum attainable endurance, and maximum attainable range. Four helicopter external configurations were test flown, and the data compared to determine the affects on performance caused by the wind deflector modification. The constant W/σ flight test technique was used in measuring the power required for level flight in each of the four configurations. With four manikins mounted outside the aircraft and wind deflectors installed, the maximum level flight speed and maximum range increased by 4.8% and 7.1% respectively. These percentages are relative to the aircraft with four manikins mounted outside the aircraft and no wind deflectors installed. Without manikins

mounted outside the aircraft and wind deflectors installed, the maximum level flight speed and maximum range decreased by 7.6% and 11% respectively. These percentages are relative to the aircraft without manikins or deflectors mounted outside the aircraft. Maximum endurance was not affected by the wind deflector modification.

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ABBREVIATIONS AND SYMBOLS

A_D	Rotor Disc Area
C_D	Drag Coefficient
C_P	Power Coefficient
C_T	Thrust Coefficient
D_P	Parasite Drag
E	Endurance
EP	External Passenger/Passengers
EPS	External Passenger System
ESGW	Engine Start Gross Weight
$ESH P_{av}$	Engine Shaft Horsepower Available
$ESH P_{req}$	Engine Shaft Horsepower Required
$ESH P_T$	Engine Shaft Horsepower, Test
f	Equivalent Flat Plate Area
FTM	Flight Test Manual
FU	Fuel Used
GPS	Global Positioning System
KCAS	Knots Calibrated Airspeed
KIAS	Knots Indicated Airspeed
K_Q	Engine Torque Constant
nm	Nautical Mile
N_R	Main Rotor Speed
OAT	Outside Air Temperature
P_i	Induced Power
P_m	Miscellaneous Power
P_o	Profile Power
P_p	Parasite Power
q	Dynamic Pressure

Q	Torque
R	Range
RSHP	Rotor Shaft Horsepower
S	Surface Area
SR	Specific Range
T	Thrust
TOT	Turbine Outlet Temperature
TRK	Aircraft Ground Track
USNTPS	U.S. Navy Test Pilot School
V	Velocity
V_{Emax}	Maximum Endurance Airspeed
V_f	Forward Velocity
V_H	Maximum Forward Airspeed
V_i	Induced Velocity
VMC	Visual Meteorological Conditions
V_R	Resultant Velocity
V_{Rmax}	Maximum Range Airspeed
V_T	True Airspeed
V_{Tref}	Referred True Airspeed
W	Weight
W_{ref}	Referred Weight
W_T	Test Weight
ρ	Air Density
σ	Air Density Ratio

CHAPTER 1

INTRODUCTION

Background

Many rotary wing operators throughout the world, for operational considerations, require flight with cabin/crew doors removed, and in some cases require personnel operating entirely outside the relative safety of the aircraft while in flight. Rotary-wing operators that require doors off and EP configurations (Figure 1) include law enforcement, fire fighting, search and rescue, military, and electrical utilities. These operational necessities result in three related problems: physical fatigue of external passengers, buffeting and turbulence in the cockpit, and a reduction in level flight performance.

External passenger (EP) configurations present a human factors issue in the form of physical fatigue. Physical fatigue, caused by high relative wind loads exerted on the EP and wind chill factors, can lead to a decrease in task efficiency. In extreme cases (cold temperatures, precipitation) cold weather injuries can result.

Another human factors issue is buffeting and turbulence in the cockpit caused by air-flow being deflected around the EP. This air-flow into the cockpit increases crew work load when referring to flight publications and makes internal communications difficult which can lead to crew coordination errors.

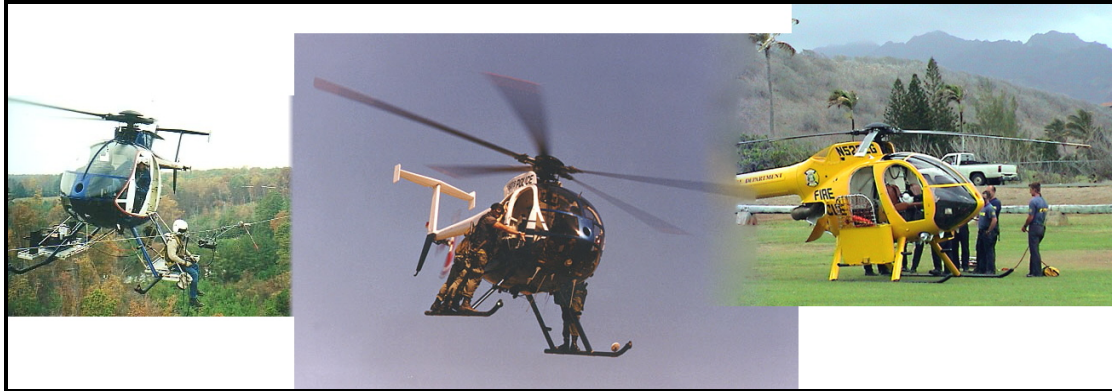


Figure 1. Helicopter Operations Requiring Doors Off and External Passenger (EP) Configurations.

EP configurations greatly increase the parasite drag of the helicopter caused by the additional frontal area. This increase in drag results in a degradation in aircraft performance. A wind deflector was designed and optimized to reduce the effects of the above mentioned issues and will be discussed in Chapter II.

Literature Search

Considerable research has been conducted on the deflection of wind around open doors and EP configured helicopters.

In 1997 Hicks [1] investigated the flow fields generated around the fuselage of the U.S. Army MH-6J Little Bird helicopter (military equivalent to the MD-500D). Hicks' research was conducted in the University of Tennessee Space Institute (UTSI) Water Tunnel Test Facility, where he used flow

visualization techniques to investigate the effects of flow diverting devices placed on an aircraft model of the MH-6J. The purpose of Hicks' investigation was to identify a flow diverter that could alter the flow field around the rear passenger compartment, thereby reducing the high inflow of air into the compartment.

In 2000 McDougall [2] investigated the effects of flow diverting devices mounted on an OH-58A helicopter for applications to an MH-6 helicopter. Results from flight tests indicated that such flow diverting devices were effective in reducing the equivalent flat plate area of the helicopter in the EP configuration.

In 2005 Lewis [3] conducted wind tunnel tests investigating the effects of wind deflectors mounted on an MD-500 helicopter model in the clean and EP configurations. This aircraft specific research indicated the effectiveness of wind deflectors mounted on the MD-500 helicopter and led to the recommendation of several wind deflector designs and actual flight tests of a wind deflector modified MD-500.

In 2006 Wright [4] incorporated recommendations made by Lewis into his own research and designed several wind deflectors. Actual flight tests were conducted on an MD-500D helicopter to determine the optimized wind deflector based primarily upon the reduction of wind loads on EP. The optimized wind deflector, as determined by Wright, is the deflector used in this level flight performance investigation.

Test Aircraft Description

The test aircraft MD-500D (Model 369D, registration number N500VS) helicopter is a five place, turbine powered, rotary-wing aircraft constructed primarily of aluminum alloy (Figure 2). The main rotor is a fully articulated five-bladed system, with anti-torque provided by a 2-bladed semi-rigid type tail rotor.

Power from the Allison 250-C20B turboshaft engine is transmitted through the main drive shaft to the main rotor transmission and from the main transmission through a drive shaft to the tail rotor. An overrunning clutch, placed between the engine and main rotor transmission permits free-wheeling of the rotor system during autorotation. The MD-500 series of helicopters are used primarily in law enforcement, light utility duties, and military special operations; Table 1 lists the dimensions, weights, and performance data of the helicopter.

The test helicopter was modified with an external passenger system (EPS) consisting of two aluminum external benches joined in the middle by two aluminum support beams that ran through the cabin. The cabin doors were removed to allow the support beams to extend outside the aircraft to support the external benches (Figure 3). Rescue Randy Combat Challenge manikins manufactured by Simulaids Incorporated were selected for EP simulators. These manikins featured articulating joints and weight distributions similar to that of the human body. Four manikins, two on each side of the aircraft (Figure 4), were mounted on the EPS during the ingress flight testing.



Figure 2. Test Aircraft, MD-500D

Table 1. MD-500D Characteristics

Characteristic/Parameter	Data
Length ¹	30.7 ft
Height	8.9 ft
Main Rotor Diameter	26.4 ft
Operating Weight (1 Pilot)	1651 lbs
Usable Fuel	422 lbs
Payload	927 lbs
Maximum Take-Off Weight	3000 lbs
Maximum Cruise Speed ²	135 kts
Maximum Range ²	239 nm
Maximum Endurance ²	2.7 hours
Service Ceiling ³	13,900 ft
Hover IGE ^{3,4}	8500 ft
Hover OGE ^{3,5}	6000 ft
Take-Off Power Rating ⁶	375 hp
Continuous Power Rating	350 hp

1) Length measured from forward tip of main rotor arc to aft tip of tail rotor arc.

2) Standard Sea Level conditions.

3) International Standard Atmosphere (ISA).

4) IGE- In Ground Effect.

5) OGE- Out of Ground Effect

6) Take-off power rating limited to 5 minutes.

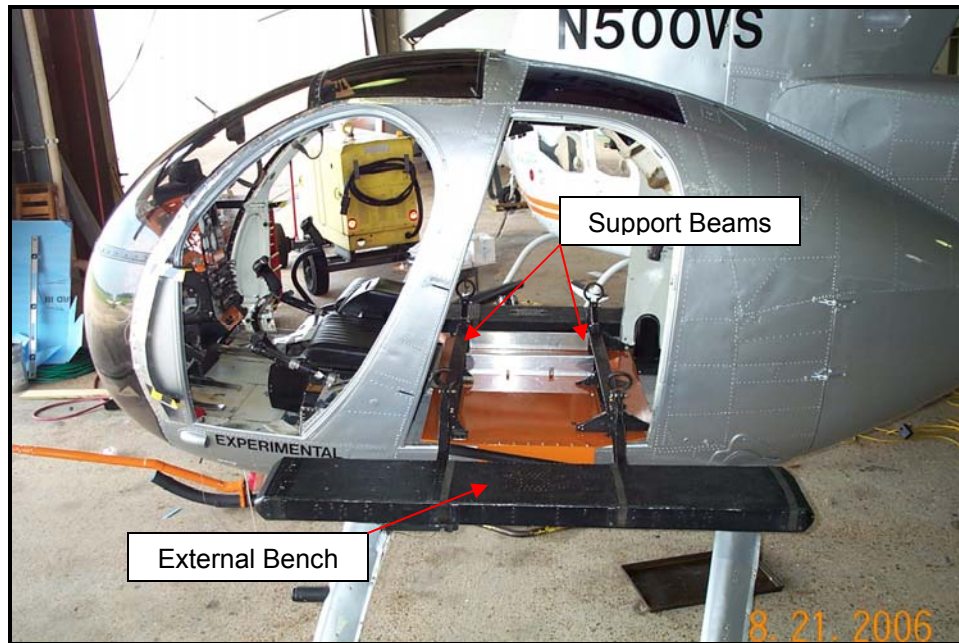


Figure 3. External Bench and Support Beams of the EPS



Figure 4. Manikins Seated on EPS

Objective

This investigation is based upon the flight tests of four different MD-500D helicopter external configurations (Figure 5); the first configuration represents the external passenger (EP) configuration:

- 1) Ingress – External Passenger System (EPS) and manikins
- 2) Ingress-Modified – EPS, manikins, and optimized wind deflector installed.
- 3) Egress – EPS only, no manikins, no deflector.
- 4) Egress-Modified – EPS, no manikins, and optimized wind deflector installed.

The overall objective of this investigation is to determine the level flight performance effects caused by the optimized wind deflector modifications (improved performance, degradation in performance, or no effects).

The specific objectives are to determine the change in the following performance parameters due to the wind deflector modification:

- 1) Engine Shaft Horse Power Required ($ESHP_{req}$).
- 2) Equivalent flat plate area over the egress configuration (Δf).
- 3) Maximum endurance.
- 4) Maximum range.

By comparing these specific performance changes, the effects of the optimized wind deflector modification on performance can be determined.

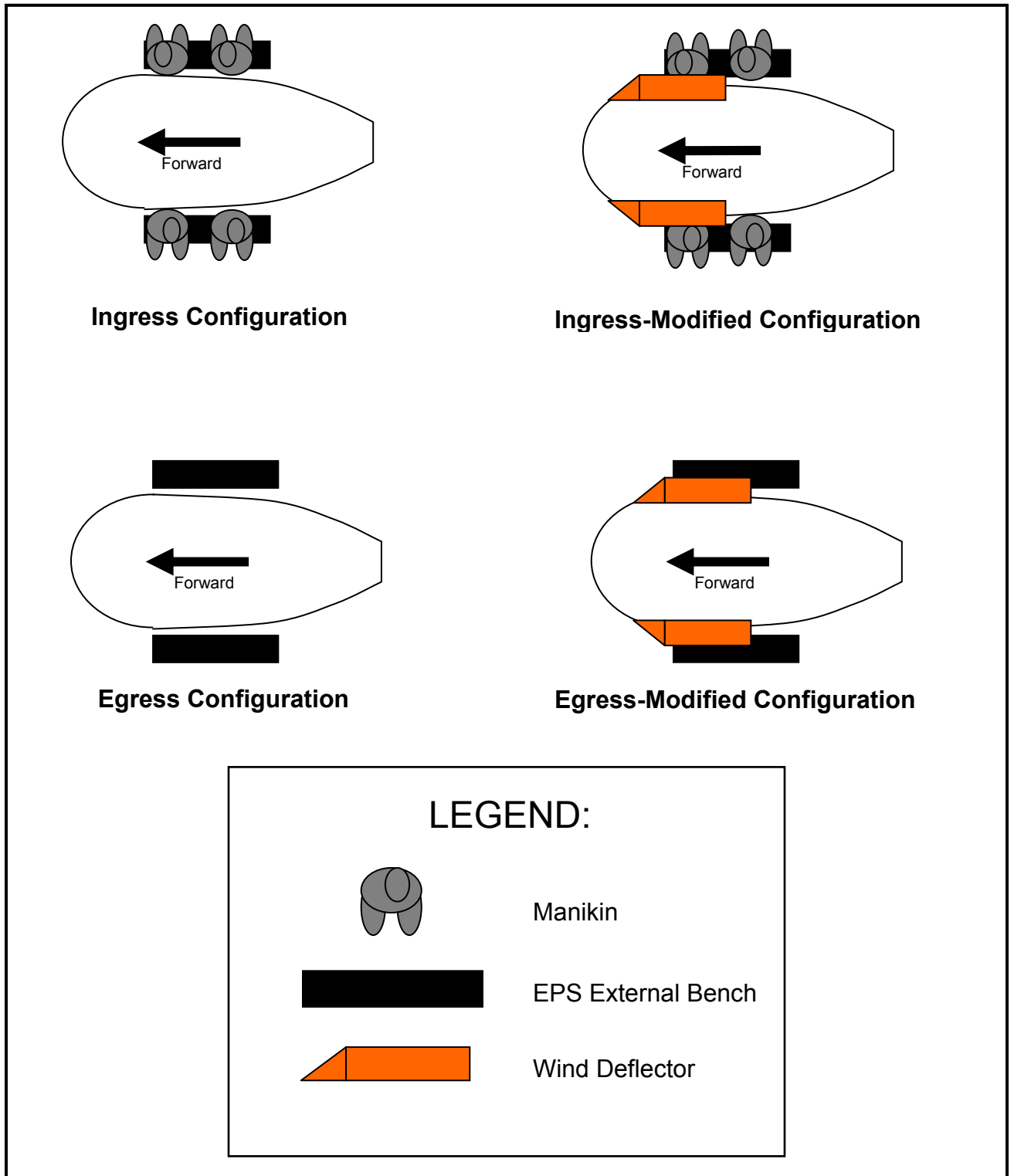


Figure 5. Description of Helicopter External Configurations

CHAPTER II

OPTIMIZED WIND DEFLECTOR

Purpose

The EP configuration results in an increase in equivalent flat plate area over the clean configuration. An aerodynamic fairing forward of the cockpit could reduce this equivalent flat plate area by deflecting the slipstream around the EP resulting in less parasite drag due to flow separation. The following discussion illustrates the effects of EP on total helicopter equivalent flat plate area and parasite power required in cruise flight.

External Passenger Effects on Equivalent Flat Plate Area

The equivalent flat plate area is the frontal area of a flat plate with a drag coefficient of 1.0, which has the same drag as the object whose drag is being determined.

To fully appreciate the effects EP have on helicopter level flight performance, an understanding of the equivalent flat plate area of the MD-500 helicopter is required. Prouty [5] determines the equivalent flat plate area of an OH-6A, including the rotor hub, landing gear, and empennage to be approximately 6.0 ft². The OH-6A is the militarized version of the MD-500 and has a similar shape and dimensions.

Wright estimates the lateral surface area of an average male is 5.5 ft². This estimate includes required clothing, retention harness, and equipment required for EP helicopter operations; this value represents the surface area presented to the slipstream outside the helicopter on one side. Zatsiorsky [6] calculates the lateral parasitic drag coefficient of the human body to be 1.1; this is used to calculate the equivalent flat plate area of an EP.

$$f = C_D S \quad (\text{Equation 1})$$

Where

f = Equivalent flat plate area of an EP

C_D = Lateral parasitic drag coefficient of human body

S = Surface area

This calculation gives an equivalent flat plate area of 6.1 ft² for an external passenger on only one side of the aircraft and must be doubled and added to the original flat plate area (6.0 ft²) to yield a total equivalent flat plate area of 18 ft² for the EP configuration. The EP configuration results in three times the equivalent flat plate area over the clean configuration.

Flat Plate Area Effects on Parasite Power Required

The total power required in forward flight is made up of four elements: induced power, profile power, parasite power, and miscellaneous power (all discussed in Chapter III). Only parasite power is affected by an increase in equivalent flat plate area.

$$P_p = \frac{1}{2} \rho f V_f^3 \quad (\text{Equation 2})$$

Where

P_p = Parasite power

ρ = Ambient air density

f = Equivalent flat plate area of EP configured helicopter

V_f = Forward flight velocity

The above equation shows a direct relationship between equivalent flat plate area and parasite power; parasite power required in the EP configuration should be three times that of the clean configuration.

The EP configuration will always result in an increase in equivalent flat plate area over the clean configuration; however the equivalent flat plate area may be reduced by an optimized wind deflector installed forward of the EP.

Optimized Wind Deflector Design

Wright began the design and fabrication of the optimized wind deflector based on recommendations by McDougall and Lewis. The deflector configuration was specified by three parameters: deflector angle (referenced to aircraft centerline), deflector width (leading to trailing edge), and deflector length (from lower forward to upper aft edges) (Figure 6). The forward manikins on the EPS were instrumented with a load cell to give the force exerted by the

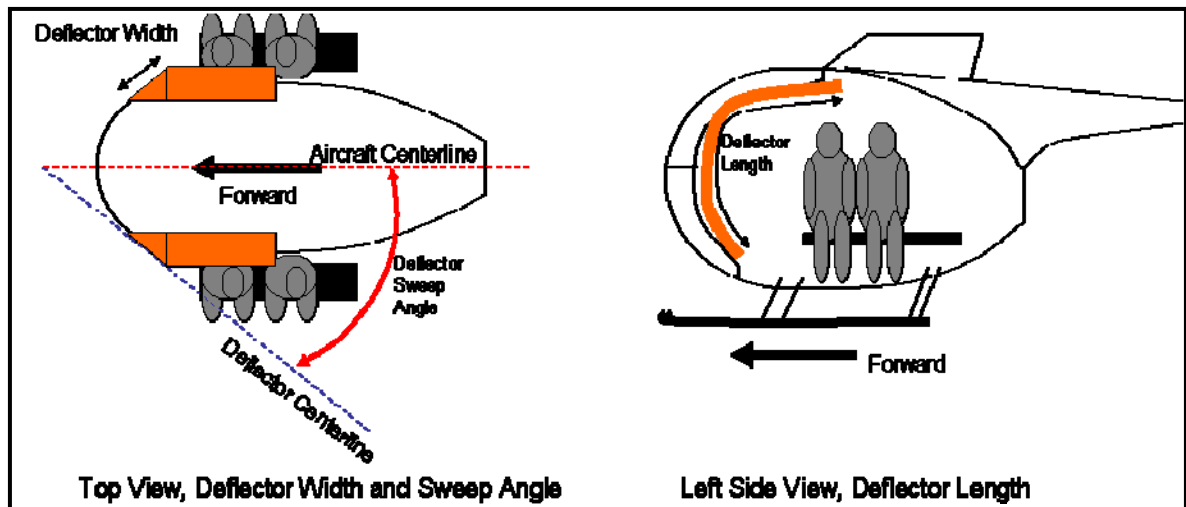


Figure 6. Wind Deflector Dimensions and Location.

slipstream on the manikins along the longitudinal axis. Wright selected the optimum wind deflector based primarily on the reduction in EP longitudinal force at 80 KIAS. Additional consideration was given to performance, crew egress, field-of-view, and cockpit turbulence.

Deflector Width and Sweep Angle

Wright chose to fabricate deflectors with widths of 8, 10, and 12 inches. Sweep angles of 40° and 50° were selected based on prior investigations conducted by McDougal and Lewis. This resulted in seven different wind deflector configurations. Based upon force reduction on the manikins, the flight test data indicated that the 50° sweep, 12 inch deflector was optimum. This configuration was considered insufficient because the 50° sweep, 12 inch deflector was an unacceptable obstruction to field-of-view and crew egress. After considering field-of-view and crew egress criteria, Wright selected the 50° sweep, 8 inch

deflector, modified with a .55 inch Gurney flap as optimal (Figure 7). Wright estimated that the Gurney flap on the trailing edge allowed the 50° sweep, 8 inch deflector to achieve an EP air load reduction equivalent to a 50° sweep, 11.2 inch deflector, but without the restriction to field-of-view and crew egress concerns.

Deflector Length

Wright established the forward lower attachment point of the deflector by existing mounting points near the forward lower corner of the cockpit door frames. Wright established the length based upon drag data obtained from Lewis. It was determined that longer characteristic lengths resulted in less parasite drag. With this in mind, Wright designed the deflectors to be as long as practicable without interfering with rappelling hard points located above the

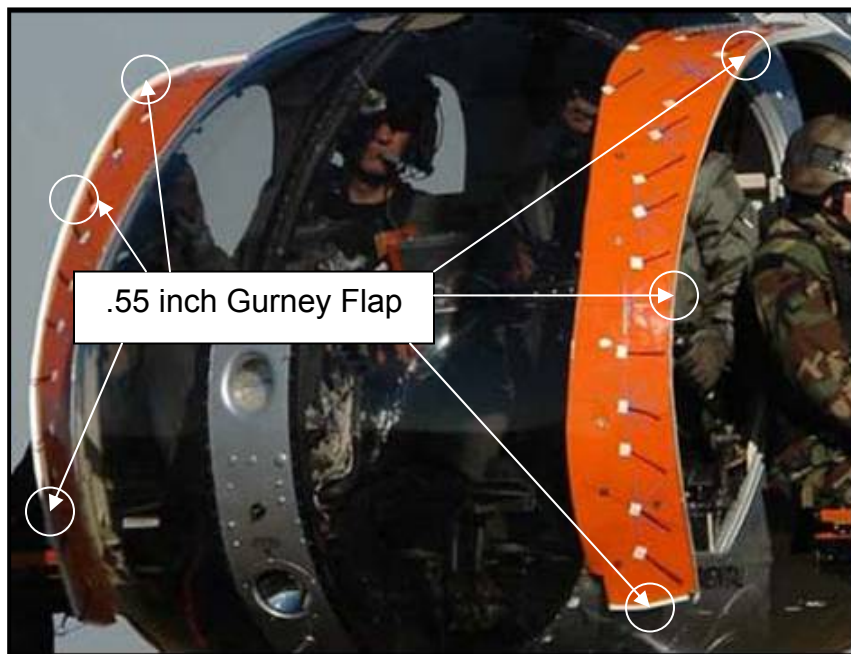


Figure 7. Optimized Wind Deflector: 50° Sweep, 8 inch with Gurney Flap.

passenger doors. The trailing edge terminated approximately three inches forward of this hard point. This resulted in an optimized wind deflector length of approximately 6.5 ft.

Airframe Integration

The trailing edge of the windscreen and chin bubbles are secured to the fuselage with 36 aircraft grade steel machine screws with elastic lock nuts (Figure 8). The windscreen and chin bubble frames were deemed capable of sustaining the loads placed on the deflectors in forward flight. The wind deflectors were mounted to the frame via a deflector adapter and these 36 screws and lock nuts. This was considered an advantageous mounting location due to the reinforced nature of the frame and its far forward location on the fuselage.

Deflector Material Selection

Wright chose to fabricate the deflectors from composite materials due to the compound curves required to fit the deflector to the rounded fuselage. Wright determined a foam core-fiberglass sandwich composition would provide the required stiffness and strength to withstand the anticipated loads. This material was also chosen due to its relative ease of fabrication and low cost. The Gurney flap was fabricated from a one-inch plastic corner molding strip and secured to the deflector with double sided tape.

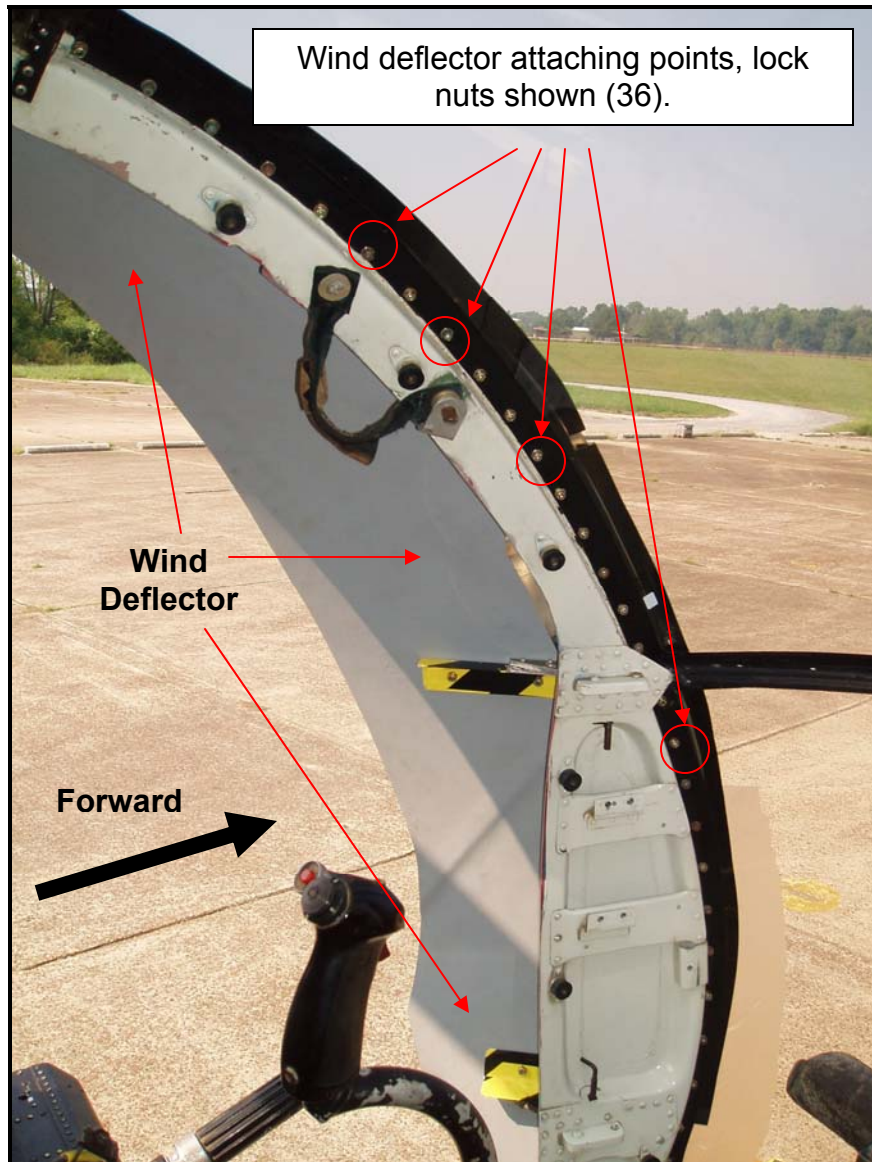


Figure 8. Wind Deflector Attaching Points (Left Pilot Seat Looking Out)

CHAPTER III

HELICOPTER LEVEL FLIGHT PERFORMANCE THEORY

General

The reference for this chapter is the Rotary Wing Performance Flight Test Manual (USNTPS-FTM-No. 106) [8]. The elements that make up the total power required in level flight are better understood when examined individually. The total power required in level flight (Figure 9) is defined as the summation of the following elements:

- 1) Induced power (P_i): Power required to produce induced flow, affects main and tail rotor, discussed in terms of the momentum theory.
- 2) Profile power (P_0): Power required to drag the rotor blade through a viscous fluid, affects main and tail rotor, discussed in terms of the blade element theory.
- 3) Parasite power (P_p): Power required to drag fuselage through a viscous fluid, affected by equivalent flat plate area, discussed in terms of aerodynamic theory.
- 4) Miscellaneous power (P_m): Power required overcoming cooling losses, transmission losses, accessory power (hydraulic and electrical) and tail rotor power required, discussed in terms of mechanical efficiency as a function of forward speed. This power is not delivered to the main rotor shaft.

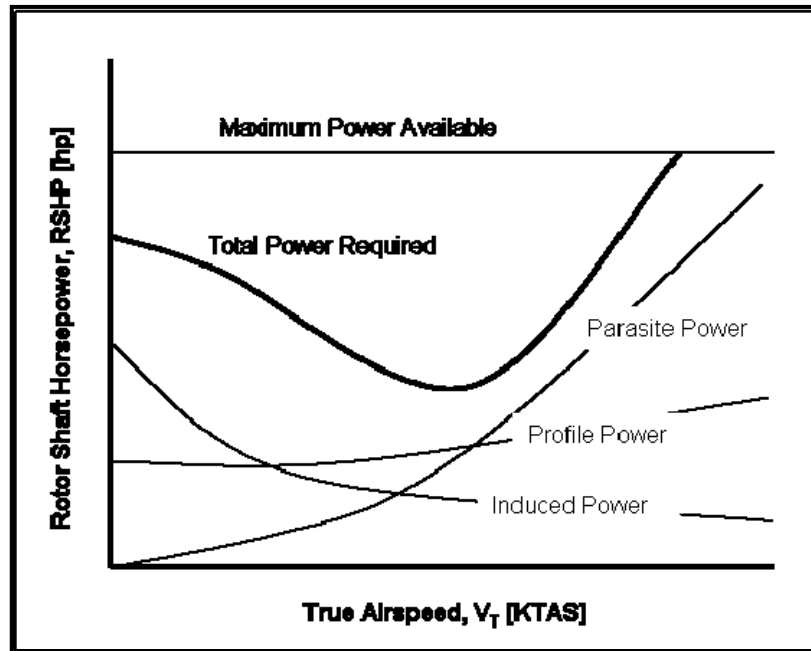


Figure 9. Analysis of Power Required in Level Flight

Induced Power

The mass flow rate through the rotor system is a function of the vectorial sum of the velocity components at the rotor. The component velocities include the forward airspeed of the helicopter (V_f) and the velocity induced by the rotor disc (V_i). At relatively high forward airspeeds, the resultant velocity (V_R) is assumed equal to the forward airspeed of the helicopter; the velocity induced by the rotor disc becomes small. The thrust vector (T) is assumed perpendicular to the rotor tip path plane and, for small angles of tilt, can be considered equal to the helicopter weight.

The momentum theory is useful in analyzing induced power in forward flight. Thrust in forward flight is the product of the mass flow rate and the change in velocity.

$$T = \rho A_D V_R (2v_i) \quad (\text{Equation 3})$$

The induced velocity in forward flight can now be determined.

$$v_i = \frac{T}{\rho 2 V_R A_D} \quad (\text{Equation 4})$$

Where

T = Thrust in forward flight

ρ = Density

A_D = Rotor disc area

V_R = Resultant velocity

v_i = Induced velocity in forward flight

For small tip path tilt angles and relatively high forward airspeeds:

$$T = W$$

$$V_R = V_f$$

Where

W = Weight

V_f = Forward flight velocity

Induced power in forward flight (P_i) as a function of weight and forward airspeed can now be determined.

$$P_i = T v_i = \frac{T^2}{\rho 2 V_R A_D} = \frac{W^2}{\rho 2 V_f A_D} \quad (\text{Equation 5})$$

Profile Power

The blade element theory is used to analyze the rotor blade profile power in forward flight. The resultant velocity at the rotor blade is a function of azimuth angle (ψ) and is cyclic in magnitude. The average profile power for the number of rotor blades (b) is obtained by integrating the following equation with respect to radius (dr) and azimuth ($d\psi$).

$$P_0 = \frac{b}{2\pi} \iint \frac{1}{2} C_{d0} \rho (\Omega r + V_f \sin \psi)^3 c dr d\psi \quad (\text{Equation 6})$$

Where

- P_0 = Profile power
- b = Number of blades
- C_{d0} = Blade element profile drag coefficient
- ρ = Density
- Ωr = Blade element rotational velocity
- V_f = Forward flight velocity
- ψ = Blade azimuth angle
- c = Blade chord

After integration and giving consideration to span-wise flow along the rotor blades, the profile power can be determined.

$$P_0 = \frac{1}{8} \sigma_R C_{d0} \rho A_D (\Omega R)^3 (1 + 4.65 \mu^2) \quad (\text{Equation 7})$$

Where

- σ_R = Rotor solidity ratio, $bc/\pi R$

ΩR = Blade tip rotational velocity

μ = Advance ratio, $V_f / \Omega R$

Parasite Power

Parasite drag of a fuselage is composed of two elements: skin friction and pressure drag due to flow separation. Because the fuselage is not a pure symmetrical shape, the components of the fuselage (landing gear, rotor mast, vertical fin, external hard points, wind defectors, etc.) are assigned an equivalent flat plate area (f).

The component equivalent flat plate area (f) can be expressed by dividing the parasite drag (D_p) by the dynamic pressure (q).

$$f = \frac{D_p}{q} \quad (\text{Equation 8})$$

This represents the frontal area of a flat plate with a drag coefficient of one, which has the same drag as the object whose drag is being estimated. The parasite drag of various components is based upon theory, previous wind tunnel tests, or flight tests of similar components.

These component equivalent flat plate areas are added together to form a total fuselage equivalent flat plate area. This summation is used in determining the parasitic drag of the helicopter.

$$D_p = \frac{1}{2} \rho \Sigma f V^2 \quad (\text{Equation 9})$$

Where

D_p = Parasite drag

ρ = Density

Σf = Summation of component equivalent flat plate areas

V = Velocity

The parasite power in forward flight is the product of parasite drag and velocity.

$$P_p = \frac{1}{2} \rho \Sigma f V_f^3 \quad (\text{Equation 10})$$

Where

P_p = Parasite power

V_f = Forward flight velocity

The change in equivalent flat plate area (Δf) for different helicopter configurations flown at the same velocity, weight, and density can be calculated from the change in engine shaft horsepower required ($\Delta \text{ESHP}_{\text{req}}$).

$$\Delta \text{ESHP}_{\text{req}} = \frac{\Delta f \rho V_T^3}{1100} \quad (\text{Equation 11})$$

Where

$\Delta \text{ESHP}_{\text{req}}$ = Change in engine shaft horsepower required

Δf = Change in helicopter equivalent flat plate area

V_T = True airspeed

Change in equivalent flat plate area can now be determined.

$$\Delta f = \frac{\Delta \text{ESHP}_{\text{req}} (1100)}{\rho V_T^3} \quad (\text{Equation 12})$$

Miscellaneous Power

Miscellaneous power in forward flight is made up of transmission losses, accessory power, and tail rotor power. Transmission losses are dependent upon rotor speed. Accessory power is dependant upon the number and load requirement of the accessories (hydraulic pumps, generators, and oil coolers). Accessory power is usually small in comparison to total power required. Tail rotor power is the sum of the induced and profile power required to maintain trimmed flight (in the yaw axis).

Thrust required by the tail rotor to maintain trimmed flight can be determined from the main rotor torque and tail rotor moment arm.

$$T_{TR} = \frac{Q_{MR}}{l_{TR}} \quad (\text{Equation 13})$$

Where

T_{TR} = Tail rotor thrust

Q_{MR} = Main rotor torque

l_{TR} = Tail rotor moment arm

Tail rotor power required can now be calculated; the first term represents the induced power, the second term represents the profile power.

$$P_{TR} = \left(\frac{T_{TR}^2}{2A_D V_f \rho} \right)_{TR} + \left[\frac{1}{8} \sigma_R C_{d0} A_D (\Omega R)^3 \rho (1 + 4.65 \mu^2) \right]_{TR} \quad (\text{Equation 14})$$

Where

P_{TR} = Tail rotor power required

T_{TR} = Tail rotor thrust

ρ = Density

A_D = Rotor disc area

V_f = Forward flight velocity

σ_R = Rotor solidity ratio

C_{d0} = Average blade element profile drag coefficient

ΩR = Blade rotational velocity

μ = Advance ratio

Miscellaneous power is usually expressed in terms of mechanical efficiency. The mechanical efficiency includes the three elements of the miscellaneous power and varies as a function of forward airspeed.

$$\eta_m = \frac{RSHP}{ESHP} \quad (\text{Equation 15})$$

Where

η_m = Mechanical efficiency

RSHP = Rotor shaft horsepower

ESHP = Engine shaft horsepower

A mechanical efficiency value of 0.85 is typical. Typically, ESHP is composed of 85% RSHP and 15% miscellaneous power. This 15% miscellaneous power is split between the transmission losses, accessory power, and tail rotor power.

Total Power Required

The total power required in forward flight is the summation of induced, profile, parasite, and miscellaneous power.

$$P_{TOTAL} = P_i + P_0 + P_p + P_m \quad (\text{Equation 16})$$

Where

P_{TOTAL} = Total power

P_i = Induced power

P_0 = Profile power

P_p = Parasite power

P_m = Miscellaneous power

The main rotor power required is the sum of the induced, profile, and parasite power.

$$P_{MR} = \left(\frac{W^2}{2A_D V_f \rho} \right)_{MR} + \left[\frac{1}{8} \sigma_R C_{d0} A_D (\Omega R)^3 \rho (1 + 4.65 \mu^2) \right]_{MR} + \left(\frac{1}{2} \rho V_f^3 f \right) \quad (\text{Equation 17})$$

Where

P_{MR} = Main rotor power

W = Weight

ρ = Density

A_D = Rotor disc area

V_f = Forward flight velocity

σ_R = Rotor solidity ratio

C_{d0} = Average blade element profile drag coefficient

ΩR = Blade tip rotational velocity

μ = Advance ratio

f = Equivalent flat plate area

Nondimensional Coefficients

The main rotor power required to maintain forward flight is dependent upon weight, density, velocity, and rotor speed. Generalized flight data can be established by using nondimensional relationships for variables in the main rotor power required equation.

$$C_P = \frac{C_T^2}{2\mu} + \left[\frac{1}{8} \sigma_R C_{d0} (1 + 4.65\mu^2) \right] + \left(\frac{1}{2} C_{Dp} \mu^3 \right) \quad (\text{Equation 18})$$

Where

C_P = Power coefficient

C_T = Thrust coefficient

μ = Advance ratio

σ_R = Rotor solidity ratio

C_{d0} = Average blade element profile drag coefficient

C_{Dp} = Parasite drag coefficient

The power coefficient (main rotor power) is a function of the thrust coefficient (weight) and the advance ratio (velocity). In determining the power coefficient, the advance ratio is varied as the thrust coefficient is held constant.

$$C_T = \frac{\left(\frac{W}{\sigma_T} \right)}{\rho_{ssl} A_D (\Omega R)^2} \quad (\text{Equation 19})$$

Where

C_T = Thrust coefficient

W = Weight

σ_T = Test density ratio

ρ_{ssl} = Standard sea level air density

A_D = Rotor disc area

ΩR = Blade tip rotational velocity

In flight test, the thrust coefficient (C_T) is held constant by one of the following methods:

- 1) Maintain ΩR constant and vary W and σ_T to keep W/σ_T constant.
- 2) Maintain σ_T constant and vary W and ΩR to keep $W/(\Omega R)^2$ constant.

Referred Level Flight Performance

Nondimensional parameters (C_P , C_T , and μ) are generally not intuitive to the test pilot. For this reason, forward flight performance data are usually presented in terms of the referred system.

When the nondimensional parameters are multiplied by standard values, the following referred terms are obtained.

$$RSHP_{ref} = \frac{C_P \rho_{ssl} A_D (\Omega R_S)^3}{550} = \left(\frac{RSHP_T}{\sigma_T} \right) \left(\frac{N_{RS}}{N_{RT}} \right)^3 \quad (\text{Equation 20})$$

$$W_{ref} = C_T \rho_{ssl} A_D (\Omega R_S)^2 = \frac{W_T}{\sigma_T} \left(\frac{N_{RS}}{N_{RT}} \right)^2 \quad (\text{Equation 21})$$

$$V_{Tref} = \mu(\Omega R_T) = V_T \left(\frac{N_{RS}}{N_{RT}} \right) \quad (\text{Equation 22})$$

Where

$RSHP_{ref}$ = Referred rotor shaft horsepower

$RSHP_T$	= Test rotor shaft horsepower
C_P	= Power coefficient
ρ_{ssl}	= Standard sea level air density
A_D	= Rotor disc area
Ω_{RS}	= Standard blade rotational velocity
Ω_{RT}	= Test blade rotational velocity
σ_T	= Test density ratio
W_{ref}	= Referred weight
W_T	= Test weight
C_T	= Thrust coefficient
N_{RS}	= Standard main rotor speed
N_{RT}	= Test main rotor speed
V_{Tref}	= Referred true airspeed
V_T	= True airspeed
μ	= Advance ratio

Referred horse power can be expressed as either rotor shaft horse power (RSHP) or engine shaft horsepower (ESHP). Level flight performance is based upon ESHP; RSHP is determined using the mechanical efficiency factor (η_m). The expression for the referred engine shaft horsepower is:

$$ESHP_{ref} = \frac{ESHP_T}{\sigma_T} \left(\frac{N_{RS}}{N_{RT}} \right)^3 \quad (\text{Equation 23})$$

Where

$ESHP_{ref}$ = Referred engine shaft horsepower

$ESHP_T$ = Test engine shaft horsepower

σ_T = Test density ratio

N_{RS} = Standard main rotor speed

N_{RT} = Test main rotor speed

The referred system results in sea level, standard day performance values and eliminates the need to determine nondimensional parameters (C_P , C_T , and μ).

CHAPTER IV

FLIGHT TEST

Purpose

The purpose of this test program was to determine the level flight performance changes caused by the optimized wind deflector modification. Four specific performance parameters were selected to provide an objective comparison between the four aircraft configurations:

- 1) Engine Shaft Horse Power Required ($ESHP_{req}$).
- 2) Equivalent flat plate area relative to the egress configuration (Δf).
- 3) Maximum endurance.
- 4) Maximum range.

The effects of the optimized wind deflector modification on level flight performance can be determined by analyzing and comparing these objective performance changes.

The level flight performance flight test techniques in the Rotary Wing Performance Flight Test Manual (USNTPS-FTM-No. 106) [8] were used in this investigation for data acquisition.

General

The flight test was conducted in three phases: air data calibration, engine performance assessment, and level flight performance assessment of the four aircraft configurations (Figure 5):

- 1) Ingress – External Passenger System (EPS) and manikins
- 2) Ingress-Modified – EPS, manikins, and optimized wind deflector installed.
- 3) Egress – EPS only, no manikins, no deflector.
- 4) Egress-Modified – EPS, no manikins, and optimized wind deflector installed.

The egress configuration is the baseline for comparing the change in equivalent flat plate area. All four configurations were flown with crew and cabin doors removed. All test flights were conducted during daylight hours in visual meteorological conditions (VMC); each flight and associated conditions of the three phase flight test program are depicted in Table 2.

Instrumentation and Data Acquisition

Data for this flight test program came from the ship instrumentation, supplemented by a fuel flow meter and a hand held Global Positioning System (GPS). Data was recorded after aircraft stabilization by hand on flight test data cards included in Appendix A.

Table 2. Test Phases and Conditions

Phase	Configuration	Gross Weight [lb]	Center of Gravity¹ [in]	Pressure Altitude [ft]	Ambient Temperature [°C]	Airspeed [KCAS]	Remarks
Air Data Calibration	Ingress-Modified	2975 to 2912	Not Recorded	950 to 965	15	41 to 79	-GPS Reciprocal Method.
Engine Performance Assessment	Ingress-Modified	2890 to 2813	Not Recorded	830 to 940	9	0 to 79	
	Ingress-Modified	2884 to 2804	Not Recorded	850 to 970	9	0 to 90	
	Ingress-Modified	3017 to 2922	Not Recorded	700 to 2650	-1 to 4	0 to 87	
Level Flight Performance Assessment	Ingress	2849 to 2768	98.5 to 98.6	830 to 2100	12 to 17	0 to 85	-Constant W/ σ method (3000 lbs). -N _R constant at 103% -Level flight from 40 to V _H ² by 10 kt increment.
	Ingress-Modified	2975 to 2912	98.4 to 98.5	850 to 1320	9 to 11	0 to 90	
	Egress	2809 to 2746	100.7	900 to 2400	14 to 20	0 to 105	
	Egress-Modified	2903 to 2785	100.8 to 100.9	750 to 1830	10 to 15	0 to 97	

1) Fuselage station, aft of datum.

2) V_H is the maximum level flight speed.

For the air data calibration portion of the flight test program, the following parameters were recorded:

- 1) Observed airspeed (V_o).
- 2) GPS ground speed (V_{GPS}).
- 3) Pressure altitude (H_P).
- 4) Ambient Temperature (T_a).
- 5) Aircraft heading (HDG).
- 6) Aircraft track (TRK).

These parameters came from the ship instrumentation with the exception of V_{GPS} and TRK; these parameters came from the hand held GPS.

For the engine and level flight performance assessments, the following parameters were recorded:

- 1) Observed airspeed (V_o).
- 2) Pressure altitude (H_P).
- 3) Outside Air Temperature (T_a).
- 4) Engine torque (Q) in percent of maximum.
- 5) Gas generator speed (N_1) in percent of maximum.
- 6) Rotor speed (N_R) in percent of maximum.
- 7) Turbine Outlet Temperature (TOT).
- 8) Fuel flow (ω_f).
- 9) Fuel remaining (f_C).

These parameters came from the ship instrumentation with the exception of ω_f and f_C ; these parameters came from the fuel flow meter instrumentation.

Test Methods and Techniques

Air Data Calibration

The air data calibration was conducted using the GPS Reciprocal Method [7]. Determination of the airspeed and altimeter correction data was required for the level performance data processing. The air data calibration results are included in Appendix C.

Engine Performance Assessment

The engine performance assessment was conducted after the air data calibration. Engine performance was required to define the engine shaft horsepower available as a function of true airspeed. The engine performance assessment results are included in Appendix B.

Level Flight Performance Assessment

There are two flight test methods that can be used in obtaining level flight performance. Both methods maintain a constant thrust coefficient (C_T).

- 1) Maintain ΩR constant and vary W and σ_T to keep W/σ_T constant.
- 2) Maintain σ_T constant and vary W and ΩR to keep $W/(\Omega R)^2$ constant.

The first method (W/σ method) is the easiest and most efficient. The rotor speed is held constant (by a governor) at the normal setting and the density altitude is increased (aircraft climbs between data points) as fuel is consumed to keep referred weight (W/σ) constant. This procedure is easier to conduct because C_T is held constant without requiring the pilot to manually reduce the rotor speed as fuel is consumed.

Because no direct method exists for determining the density ratio, considerable preflight planning is required to determine the required pressure altitude to fly for a constant referred weight.

A W/σ chart (Appendix D) is constructed to show the variation of density ratio and fuel consumed required to produce the desired constant referred weight. The W/σ chart is constructed using fuel remaining numbers and allows the pilot to be at the exact gross weight desired when the data point is recorded. The required pressure altitude for each data point is established by checking the OAT once the airspeed has stabilized. Pressure altitude is adjusted until the correct OAT is attained to produce the required σ . When the correct σ is attained, the aircraft is flown in stabilized flight as fuel is consumed to arrive at the required gross weight. Data are recorded in wings level, unaccelerated flight at the required gross weight; record the most important data first: airspeed and torque.

By repeating the test for different W/σ values, a complete level flight performance envelope can be constructed. The entire speed range from

approximately 30 knots to V_H should be explored while placing emphasis on the area surrounding the predicted airspeed for minimum power required (bucket airspeed).

Data Reduction

The object of the level flight performance data reduction is to produce a comparison of ESHP required to true airspeed at a specific referred weight. The manual data reduction process used for this study follows the Rotary Wing Performance Flight Test Manual (USNTPS-FTM-No. 106) [8].

Calibrated pressure altitude and ambient temperature are determined to allow calculation of the property ratios.

$$H_{Pc} = H_{Po} + \Delta H_{Pic} + \Delta H_{pos} \quad (\text{Equation 24})$$

Where

H_{Pc} = Calibrated pressure altitude

H_{Po} = Observed pressure altitude

ΔH_{Pic} = Altimeter instrument correction

ΔH_{pos} = Altimeter position error

$$T_a = T_o + \Delta T_{ic} \quad (\text{Equation 25})$$

Where

T_a = Ambient temperature

T_o = Observed temperature

ΔT_{ic} = Temperature instrument correction

Property ratios can now be calculated; the test density ratio is needed to determine the referred Engine Shaft Horsepower ($ESHP_{ref}$), referred weight (W_{ref}), and true airspeed (V_T).

$$\delta = \frac{P_a}{P_{ssl}} = \left(1 - 6.876 \times 10^{-6} H_{Pc}\right)^{5.256} \quad (\text{Equation 26})$$

Where

δ = Pressure ratio

P_a = Ambient Pressure

P_{ssl} = Standard sea level pressure

H_{Pc} = Calibrated pressure altitude

$$\theta = \frac{T_a}{T_{ssl}} = \frac{(T_a + 273.2)}{288.2} \quad (\text{Equation 27})$$

Where

θ = Temperature ratio

T_a = Ambient temperature, °C

T_{ssl} = Standard sea level temperature

$$\sigma_T = \frac{\rho_a}{\rho_{ssl}} = \frac{\delta}{\theta} \quad (\text{Equation 28})$$

Where

σ_T = Test density ratio

ρ_a = Ambient air density

ρ_{ssl} = Standard sea level density

δ = Pressure ratio

θ = Temperature ratio

When calculating the ESHP, an engine torque constant (K_Q) is required to equate the engine torque and rotor speed with ESHP. The Allison 250-C20B has a takeoff rating of 375 ESHP and a continuous rating of 350 ESHP. For this flight test, continuous level flight performance was evaluated. The maximum continuous torque indication limit is 81.3 pounds per square inch (psi) and the normal rotor speed is 103%.

$$350 \text{ ESHP} = K_Q \times 81.3 \text{ psi} \times 103\% \quad (\text{Equation 29})$$

$$K_Q = .0418 \frac{\text{ESHP}}{\% \text{psi}} \quad (\text{Equation 30})$$

The test ESHP can now be calculated.

$$\text{ESHP}_T = K_Q (Q) (N_{RT}) \quad (\text{Equation 31})$$

Where

ESHP_T = Test engine shaft horsepower

K_Q = Engine torque constant (unique for each aircraft)

Q = Engine torque

N_{RT} = Test main rotor speed

The referred ESHP can now be calculated and represents the power required at standard sea level conditions.

$$\text{ESHP}_{\text{ref}} = \frac{\text{ESHP}_T}{\sigma_T} \left(\frac{N_{RS}}{N_{RT}} \right)^3 \quad (\text{Equation 32})$$

Where

$ESHP_{ref}$ = Referred engine shaft horsepower

$ESHP_T$ = Test engine shaft horsepower

σ_T = Test density ratio

N_{RS} = Standard main rotor speed

N_{RT} = Test main rotor speed

The aircraft test weight decreases as fuel is consumed and must be known to determine the referred weight.

$$W_T = ESGW - FU \quad (\text{Equation 33})$$

Where

W_T = Test weight

$ESGW$ = Engine start gross weight

FU = Fuel used

The referred weight can now be calculated; from a performance standpoint, this weight represents the weight of the aircraft at standard sea level conditions.

$$W_{ref} = \frac{W_T}{\sigma_T} \left(\frac{N_{RS}}{N_{RT}} \right)^3 \quad (\text{Equation 34})$$

The referred true airspeed can now be determined.

$$V_c = V_o + \Delta V_{ic} + \Delta V_{pos} \quad (\text{Equation 35})$$

Where

V_c = Calibrated airspeed

V_o = Observed airspeed

ΔV_{ic} = Airspeed instrument correction

ΔV_{pos} = Airspeed position error correction

$$V_T = \frac{V_c}{\sqrt{\sigma}} \quad (\text{Equation 36})$$

Where

V_T = True airspeed

$$V_{Tref} = V_T \left(\frac{N_{RS}}{N_{RT}} \right) \quad (\text{Equation 37})$$

Where

V_{Tref} = Referred true airspeed

The specific range must be determined to calculate the maximum range.

$$SR = \frac{V_T}{1.05\omega_f} \quad (\text{Equation 38})$$

Where

SR = Specific range, nmi/lb

$1.05\omega_f$ = Fuel flow plus 5%

Endurance is calculated from fuel available and fuel flow.

$$E = \frac{F_{av}}{1.05\omega_f} \quad (\text{Equation 39})$$

Where

E = Endurance

F_{av} = Maximum fuel available

The change in equivalent flat plate area (Δf) for different helicopter configurations (optimized wind deflector installed vs. not installed) flown at the same referred true airspeed and referred weight can be calculated from the change in referred engine shaft horsepower.

$$\Delta ESHP_{ref} = \frac{\Delta f \rho_{ssl} V_{Tref}^3}{1100} \quad (\text{Equation 40})$$

Where

$\Delta ESHP_{ref}$ = Change in referred engine shaft horsepower

Δf = Change in helicopter equivalent flat plate area

ρ_{ssl} = Standard sea level density

V_{Tref} = Referred true airspeed

Change in equivalent flat plate area can now be determined.

$$\Delta f = \frac{\Delta ESHP_{ref} (1100)}{\rho_{ssl} V_{Tref}^3} \quad (\text{Equation 41})$$

Level Performance Test Flights

Four performance test flights were conducted, one in each aircraft/deflector configuration. All test flights were conducted at a referred weight of 3000 lbs while maintaining a constant rotor speed of 103% (the W/ σ method was used). The referred weight was held constant for all four configurations to ensure that the ESHP was affected only by the optimized

deflector modification and not a change in aircraft gross weight. A crew of two, consisting of a UTSI rotary wing test pilot and an Aviation Systems Student (thesis author) conducted the four test flights. Table 3 lists the four aircraft/deflector configurations that were test flown along with flight conditions.

Ingress Configuration Test Flight

The ingress configuration (EPS and manikins installed, no deflectors) (Figure 10) test flight was conducted on December 16, 2006 with a flight time of 0.5 hours. With the four manikins installed, no ballast was needed to maintain the referred weight at 3000 lbs. The average gross weight and average center of

Table 3. Level Performance Flight Tests and Conditions

Configuration	Gross Weight [lb]	Center of Gravity¹ [in]	Pressure Altitude [ft]	Ambient Temperature [°C]	Airspeed [KCAS]	Remarks
Ingress	2849 to 2768	98.5 to 98.6	830 to 2100	12 to 17	0 to 85	-Constant W/ σ method (3000 lbs). -N _R constant at 103% -Level flight from 40 to V _H ² by 10 kt increment.
Ingress-Modified	2975 to 2912	98.4 to 98.5	850 to 1320	9 to 11	0 to 90	
Egress	2809 to 2746	100.7	900 to 2400	14 to 20	0 to 105	
Egress-Modified	2903 to 2785	100.8 to 100.9	750 to 1830	10 to 15	0 to 97	

1) Fuselage station, aft of datum.

2) V_H is the maximum level flight speed.



Figure 10. Ingress Configuration

gravity were 2923 lbs and 98.6 inches respectively. The pressure altitude test band was 1300 to 2100 ft. Pressure altitude was increased as fuel was consumed to maintain a constant referred weight of 3000 lbs. At airspeeds greater than approximately 40 KIAS the relative wind was directed into the cockpit and cabin by the manikins outside the pilot stations. This turbulence in the cockpit made the hand recording of flight data difficult and normal internal communications impossible.

Ingress-Modified Configuration Test Flight

The ingress-modified configuration (EPS, deflectors, and manikins installed) (Figure 11) test flight was conducted on December 16, 2006 with a



Figure 11. Ingress-Modified Configuration

flight time of 0.4 hours. With the four manikins installed, no ballast was needed to maintain the referred weight at 3000 lbs. The average gross weight and average center of gravity were 2913 lbs and 98.5 inches respectively. The pressure altitude test band was 1100 to 1320 ft. Pressure altitude was increased as fuel was consumed to maintain a constant referred weight of 3000 lbs. Turbulence in the cockpit was totally eliminated by the optimized wind deflector modification.

Egress Configuration Test Flight

The egress configuration (EPS installed, no manikins, and no deflectors) (Figure 12) test flight was conducted on December 16, 2006 with a flight time of



Figure 12. Egress Configuration (Baseline)

0.4 hours. Because the four manikins were removed, 299 lbs of ballast were installed in the cabin to enable the referred weight to be maintained at 3000 lbs. The average gross weight and average center of gravity were 2772 lbs and 100.7 inches respectively. The pressure altitude test band was 1950 to 2400 ft. Pressure altitude was increased as fuel was consumed to maintain a constant referred weight of 3000 lbs. Turbulence in the cockpit was present, but to a lesser degree than with manikins mounted (ingress configuration). Above approximately 60 KIAS, data recording and normal internal communications were difficult. This configuration was considered the baseline for calculating the change in equivalent flat plate area caused by the deflector modification and manikins.

Egress-Modified Configuration Test Flight

The egress-modified configuration (EPS and deflectors installed, no manikins) (Figure 13) test flight was conducted on December 12, 2006 with a flight time of 0.6 hours. The optimized wind deflectors were installed and the four manikins were removed. Because the four manikins were removed, 471 lbs of ballast were installed in the cabin to enable the referred weight to be maintained at 3000 lbs. The average gross weight and average center of gravity were 2914 lbs and 100.9 inches respectively. The pressure altitude test band was 1200 to 1830 ft. Pressure altitude was increased as fuel was consumed to maintain a constant referred weight of 3000 lbs. Turbulence in the cockpit was totally eliminated by the optimized wind deflector modification.



Figure 13. Egress-Modified Configuration

CHAPTER V

RESULTS AND DISCUSSION

General

The results of the level flight performance evaluation are presented in the following order:

- 1) Unprocessed torque and fuel flow data.
- 2) Engine Shaft Horse Power required (ESHP_{req}).
- 3) Equivalent flat plate area relative to the egress configuration (Δf).
- 4) Maximum endurance.
- 5) Maximum range.

The egress configuration had the smallest equivalent flat plate area; for this reason, this configuration was selected as the baseline when comparing equivalent flat plate area. A typical cruise speed of 80 KTAS was selected for comparing the equivalent flat plate area between the configurations.

Results and Discussion

Unprocessed Torque and Fuel Flow Data, All Configurations

Plots of the unprocessed torque and fuel flow data (cockpit indications) with respect to calibrated airspeed show considerable variation in torque and fuel

flow required between the four evaluated aircraft configurations at the same airspeeds (Figures 14 and 15). Data for these plots came directly from the test flight data cards in Appendix A and have not been referred to sea level standard conditions. The following results have been referred to sea level standard.

ESHP Required, Ingress and Ingress-Modified Configurations

Engine Shaft Horsepower required ($ESHP_{req}$) is an airframe characteristic which represents the power required to overcome the total drag. Engine Shaft Horsepower available ($ESHP_{av}$) is an installed engine characteristic which represents the maximum power available to overcome total drag. In order to determine aircraft level flight performance, these two characteristics ($ESHP_{req}$ and $ESHP_{av}$) are combined (Figure 16).

A comparison of level flight performance in the ingress and ingress-modified configurations indicate that the optimized wind deflector modification resulted in a slight decrease in $ESHP_{req}$ at airspeeds greater than 50 KTAS. At airspeeds less than approximately 50 KTAS, the $ESHP_{req}$ of the two configurations converged. This indicates that only parasite power was reduced with the optimized wind deflector modification (induced, profile, and miscellaneous power were not affected by the modification).

At 80 KTAS the $ESHP_{req}$ for the ingress and ingress-modified configurations were 328 hp and 310 hp respectively. This 18 hp reduction in parasite power was a direct result of the deflection of the relative wind around the EP by the optimized wind deflectors.

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 12 & 16 December 2006

Engine: Allison Model 250-C20B

Weight: 2975-2762 lbs

Center of Gravity: 100.7-100.9 in

Pressure Altitude: 1100-2400 ft

Outside Air Temperature: 9-16°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Ingress ~ EPS, Manikins, No Deflectors

Ingress-Modified ~ EPS, Manikins, Deflectors

Egress ~ EPS, No Manikins, No Deflectors

Egress-Modified ~ EPS, No Manikins, Deflectors

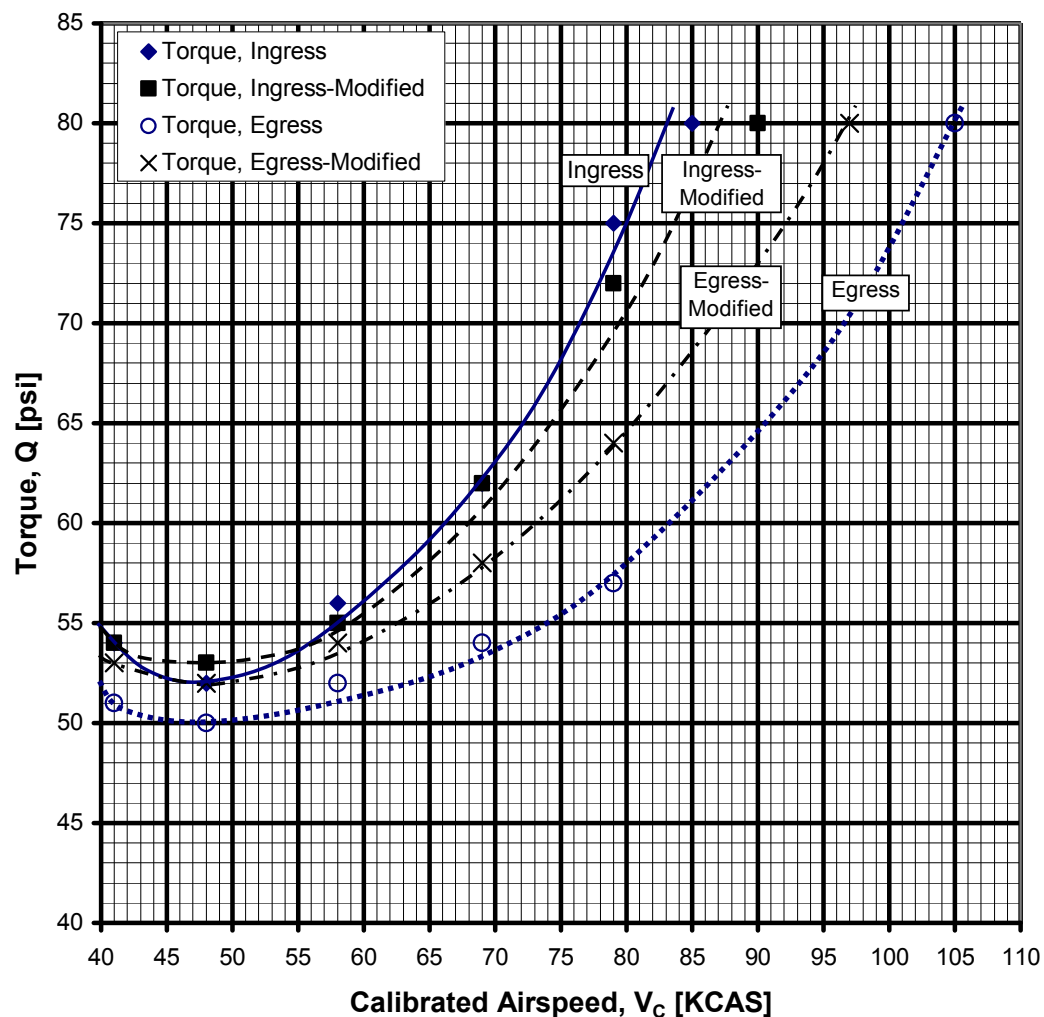


Figure 14. Torque Required vs. Calibrated Airspeed, All Configurations

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 12 & 16 December 2006

Engine: Allison Model 250-C20B

Weight: 2975-2762 lbs

Center of Gravity: 100.7-100.9 in

Pressure Altitude: 1100-2400 ft

Outside Air Temperature: 9-16°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Ingress ~ EPS, Manikins, No Deflectors

Ingress-Modified ~ EPS, Manikins, Deflectors

Egress ~ EPS, No Manikins, No Deflectors

Egress-Modified ~ EPS, No Manikins, Deflectors

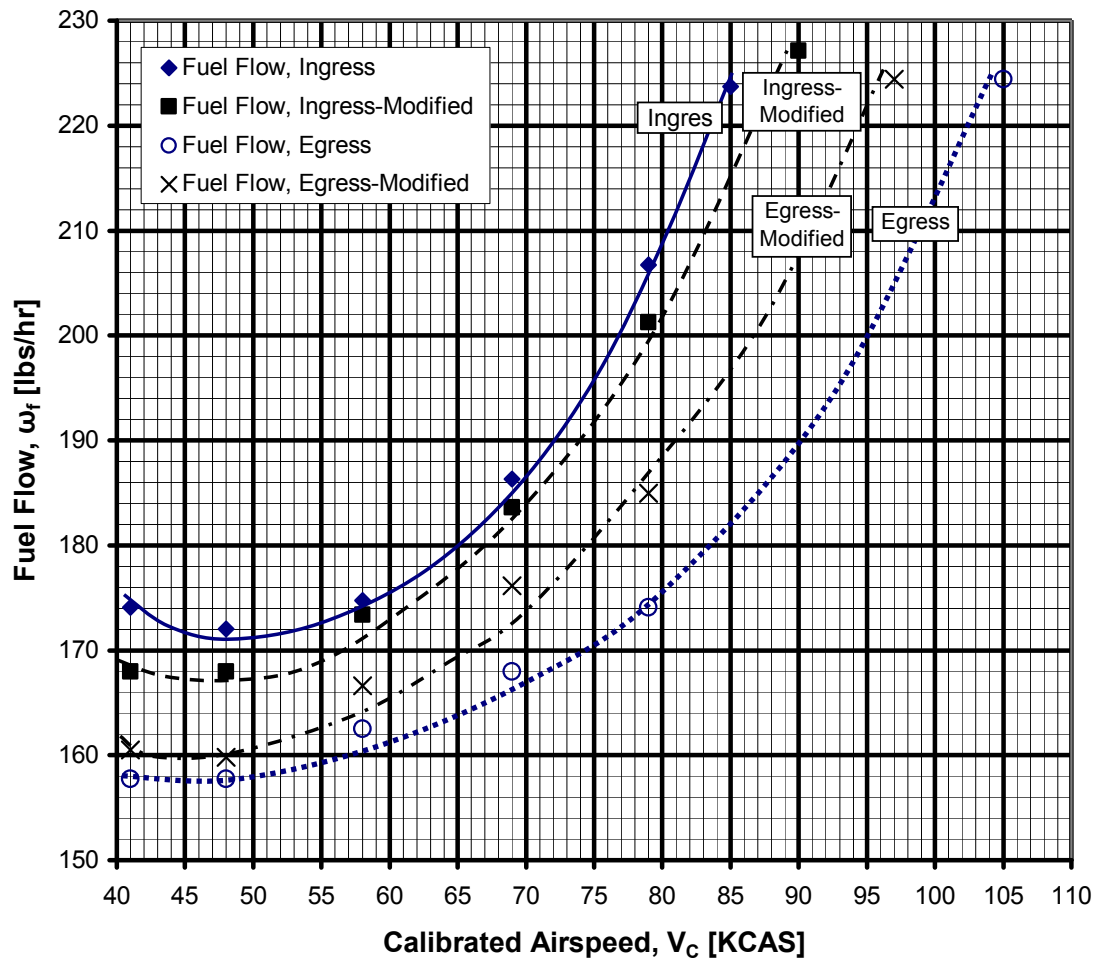


Figure 15. Fuel Flow vs. Calibrated Airspeed, All Configurations

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 16 December 2006

Engine: Allison Model 250-C20B

Referred Weight: 3000 lbs (W/σ)

Center of Gravity: 98.4-98.6 in

Pressure Altitude: Sea Level

Outside Air Temperature: 15°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Ingress ~ EPS, Manikins, No Deflectors

Ingress-Modified ~ EPS, Manikins, Deflectors

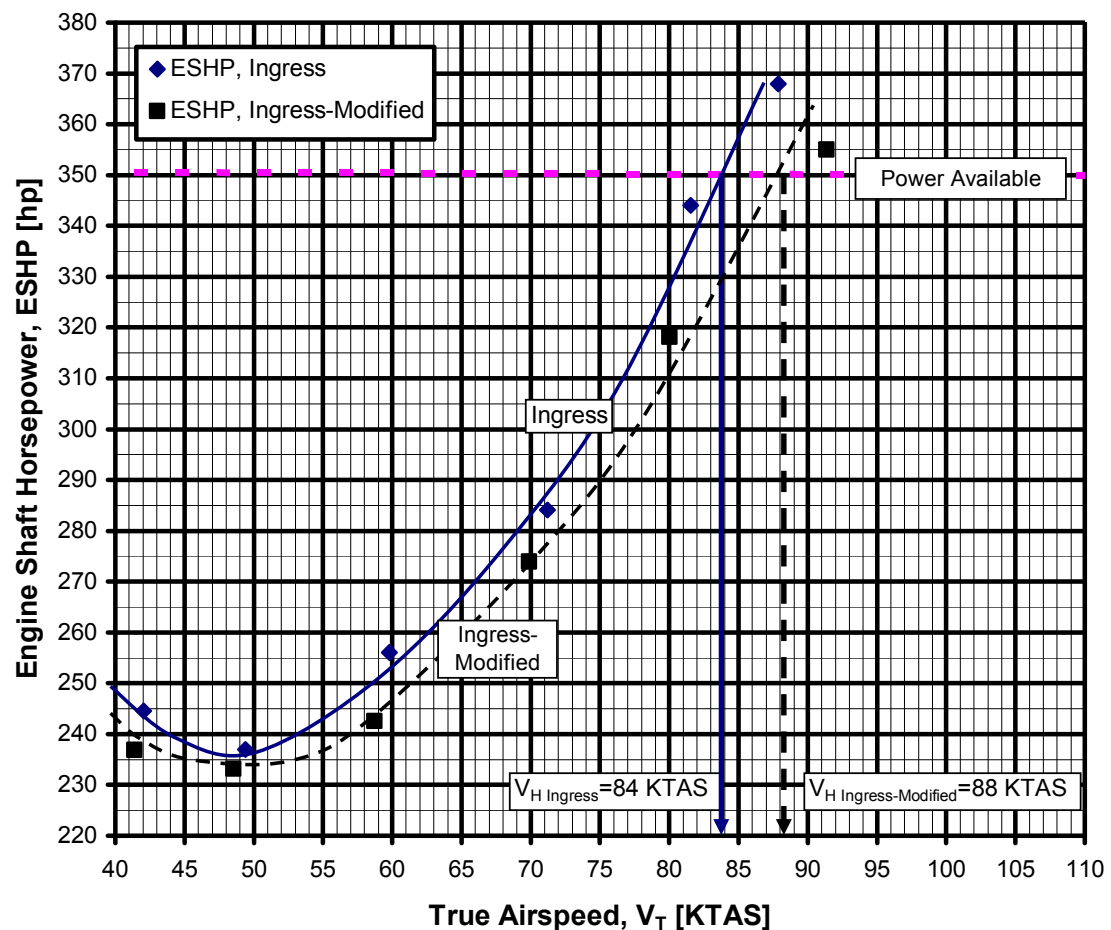


Figure 16. Engine Shaft Horsepower vs. True Airspeed, Ingress and Ingress-Modified Configurations

The maximum level flight speed (V_H) for the ingress and ingress-modified configurations were 84 KTAS and 88 KTAS respectively. The reduction in parasite drag due to the optimized wind deflector modification resulted in a 4 knot increase in V_H over the ingress configuration.

ESHP Required, Egress and Egress-Modified Configurations

A comparison of aircraft level flight performance in the egress and egress-modified configuration (Figure 17) indicates that the optimized wind deflector modification resulted in an increase in $ESHP_{req}$ at airspeeds greater than 60 KTAS. At airspeeds less than approximately 50 KTAS, the $ESHP_{req}$ of the two configurations converged. At 80 KTAS the $ESHP_{req}$ for the egress and egress-modified configurations were 264 hp and 287 hp respectively. This 23 hp increase in $ESHP_{req}$ was a direct result of the increase in parasite drag caused by the optimized wind deflector modification.

The maximum level flight speed for the egress and egress-modified configurations were 105 KTAS and 97 KTAS respectively. The increase in parasite drag due to the optimized wind deflector modification resulted in an 8 knot decrease in V_H relative to the egress configuration.

ESHP Required, All Configurations

A comparison of the level flight performance for all four configurations illustrates the effects of the optimized wind deflector modification on the performance envelope of the aircraft (Figure 18). The ingress configuration had

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 12 & 16 December 2006

Engine: Allison Model 250-C20B

Referred Weight: 3000 lbs (W/ σ)

Center of Gravity: 100.7-100.9 in

Pressure Altitude: Sea Level

Outside Air Temperature: 15°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Egress ~ EPS, No Manikins, No Deflectors

Egress-Modified ~ EPS, No Manikins, Deflectors

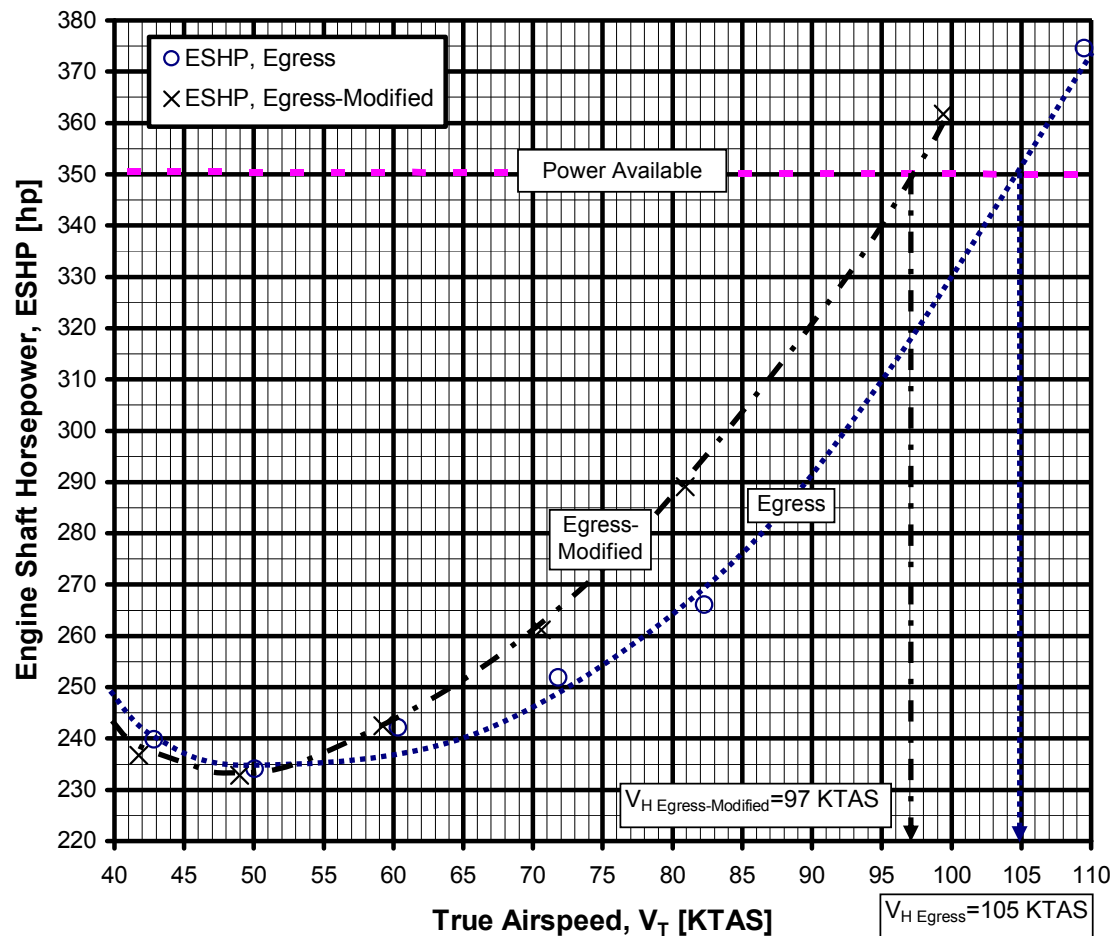


Figure 17. Engine Shaft Horsepower vs. True Airspeed, Egress and Egress-Modified Configurations

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 12 & 16 December 2006

Engine: Allison Model 250-C20B

Referred Weight: 3000 lbs (W/ σ)

Center of Gravity: 100.7-100.9 in

Pressure Altitude: Sea Level

Outside Air Temperature: 15°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Ingress ~ EPS, Manikins, No Deflectors

Ingress-Modified ~ EPS, Manikins, Deflectors

Egress ~ EPS, No Manikins, No Deflectors

Egress-Modified ~ EPS, No Manikins, Deflectors

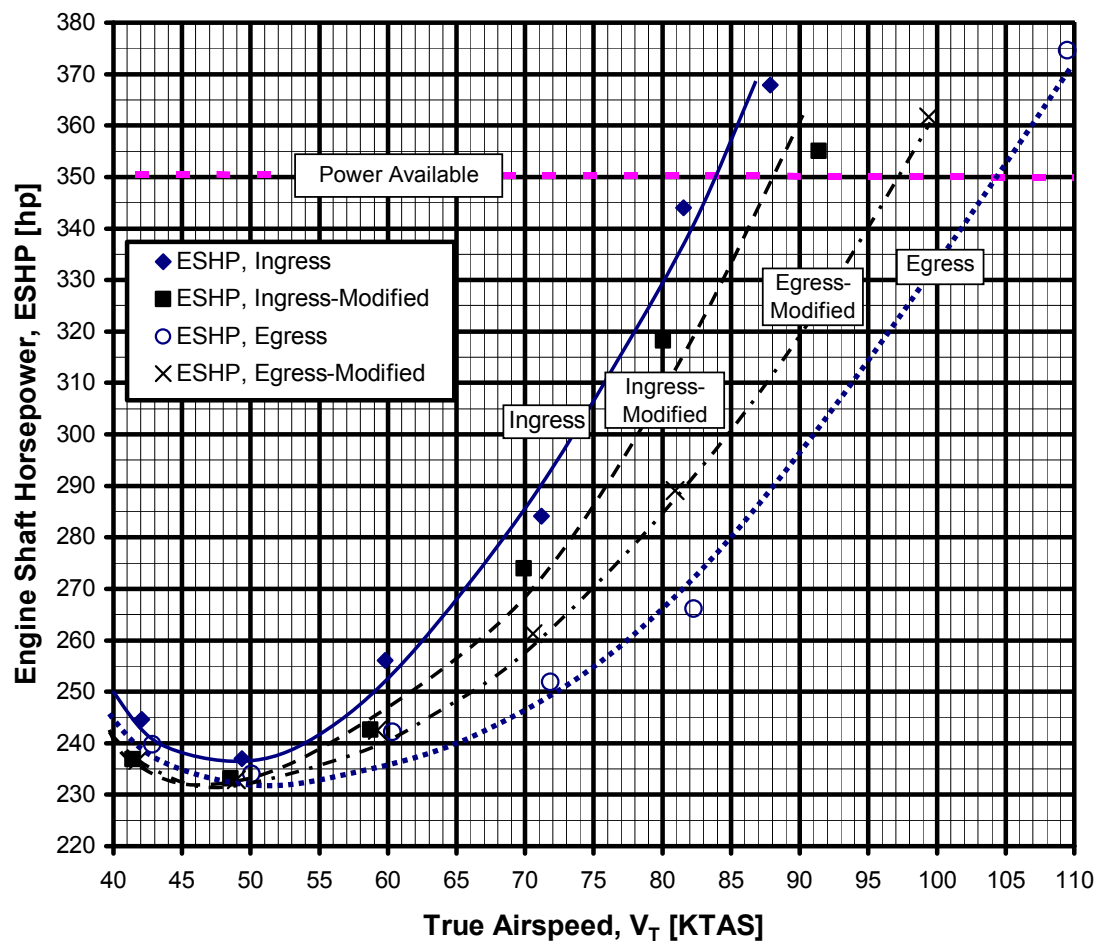


Figure 18. Engine Shaft Horsepower vs. True Airspeed, All Configurations

the smallest performance envelope (area between the $ESHP_{av}$ and $ESHP_{req}$ curves). Application of the optimized wind deflector modification slightly increased the performance envelope (ingress-modified configuration).

The egress configuration had the largest performance envelope; application of the optimized wind deflector modification decreased the performance envelope (egress-modified configuration).

Performance benefits with the optimized wind deflector installed were only realized when the EPS was occupied by the four manikins. Performance was diminished by the optimized wind deflector when the EPS was not occupied by the manikins.

The power requirement at airspeeds less than approximately 50 KTAS is similar for all configurations. This airspeed is called the bucket airspeed and represents the airspeed where minimum power is required to maintain level flight. At airspeeds less than the bucket airspeed, induced power required is the greater part of total power required. Aircraft weight is the most influential factor affecting induced power required. Because the referred weight of the aircraft remained at 3000 lbs for all configurations, the power required curves converge at airspeeds less than the bucket airspeed. At airspeeds greater than the bucket airspeed, parasite power required is the greater part of total power required. The wind deflector modification changed the pressure drag characteristics of the helicopter due to flow separation variations between configurations; this resulted in a

divergence of the four power required curves at airspeeds greater than the bucket airspeed.

Equivalent Flat Plate Area Comparison

The equivalent flat plate area of the four configurations was determined relative to the egress configuration. This relative equivalent flat plate area (Δf) was calculated from the change in $ESHP_{req}$ ($\Delta ESHP_{req}$) at 80 KTAS and then added to the equivalent flat plate area (f) of the clean OH-6A (6.0 ft²). Table 4 lists the $ESHP_{req}$, $\Delta ESHP_{req}$, Δf , and total f of the four configurations.

At 80 KTAS the equivalent flat plate area for the ingress configuration was calculated to be 18 ft². The effects of the EP can be determined by comparing this value to the egress configuration value of 6.0 ft². With the manikins exposed to the relative wind (ingress configuration), f increased by 12 ft².

At 80 KTAS the equivalent flat plate area for the ingress and ingress-modified configurations was calculated to be 18 ft² and 15 ft² respectively. By directing the relative wind around the EP, the optimized wind deflector modification resulted in a decrease in f by 3.0 ft².

At 80 KTAS the equivalent flat plate area for the egress and egress-modified configurations was calculated to be 6.0 ft² and 10 ft² respectively. The optimized wind deflector modification resulted in an increase in f by 4.0 ft².

Benefits of the wind deflector modification in reducing the equivalent flat plate area was only realized when the EPS was occupied by the four manikins (ingress-modified configuration). The modification resulted in an increase in

Table 4. Equivalent Flat Plate Area Comparison

Configuration	ESHP _{req} ¹ at 80 KTAS [hp]	Δ ESHP _{req} ² [hp]	Δf^2 [ft ²]	f^3 [ft ²]
Ingress	328	+64	+12	18
Ingress-Modified	310	+46	+8.6	15
Egress (Baseline)	264	0	0	6.0
Egress-Modified	287	+23	+4.3	10

1) ESHP_{req} values from Figures 10 and 11.

2) Values are relative to egress configuration.

3) Values based upon Prouty [5] OH-6A equivalent flat plate area estimation of 6.0 ft².

equivalent flat plate area when the EPS was not occupied (egress-modified configuration).

Maximum Endurance, All Configurations

Maximum endurance in this investigation refers to the endurance attained from the maximum usable fuel (422 lbs of Jet-A) at the maximum endurance airspeed; no fuel reserve was considered in the reporting of the results.

Fuel flow (ω_f) as a function of true airspeed was determined to allow the calculation of the maximum endurance ($E_{\max}$) and corresponding airspeed (Figure 19 and 20). A five percent tolerance was applied to the fuel flow ($1.05 \cdot \omega_f$) as recommended per the Rotary Wing Performance Flight Test Manual.

The maximum endurance airspeed ($V_{E_{\max}}$) is found at the minimum fuel flow point. The $V_{E_{\max}}$ for all configurations was determined to be approximately 50 KTAS. The corresponding fuel flows produced an $E_{\max}$ of 2.37 hours for all

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 16 December 2006

Engine: Allison Model 250-C20B

Referred Weight: 3000 lbs (W/ σ)

Center of Gravity: 98.4-98.6 in

Pressure Altitude: Sea Level

Outside Air Temperature: 15°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Ingress ~ EPS, Manikins, No Deflectors

Ingress-Modified ~ EPS, Manikins, Deflectors

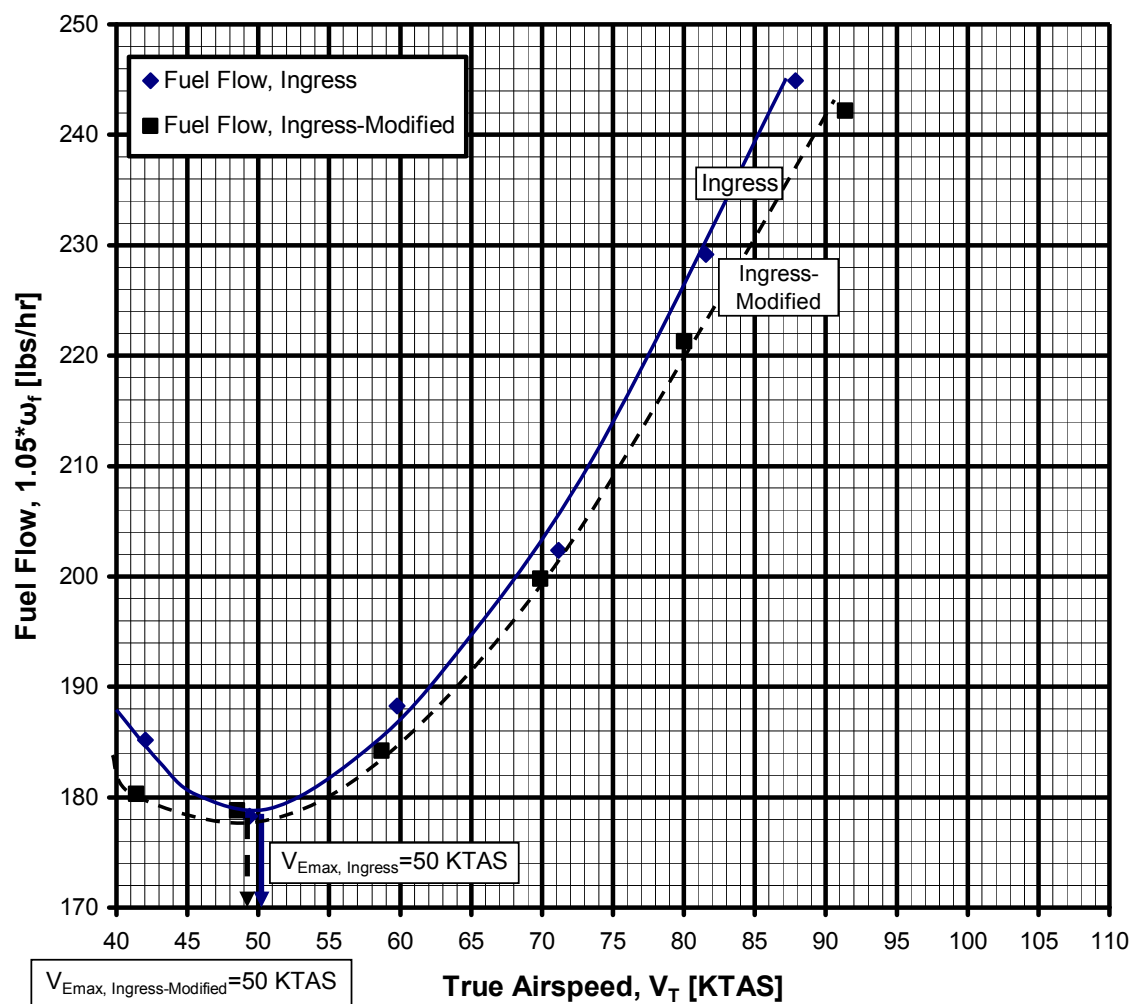


Figure 19. Fuel Flow vs. True Airspeed, Ingress and Ingress-Modified Configurations

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 12 & 16 December 2006

Engine: Allison Model 250-C20B

Referred Weight: 3000 lbs (W/ σ)

Center of Gravity: 100.7-100.9 in

Pressure Altitude: Sea Level

Outside Air Temperature: 15°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Egress ~ EPS, No Manikins, No Deflectors

Egress-Modified ~ EPS, No Manikins, Deflectors

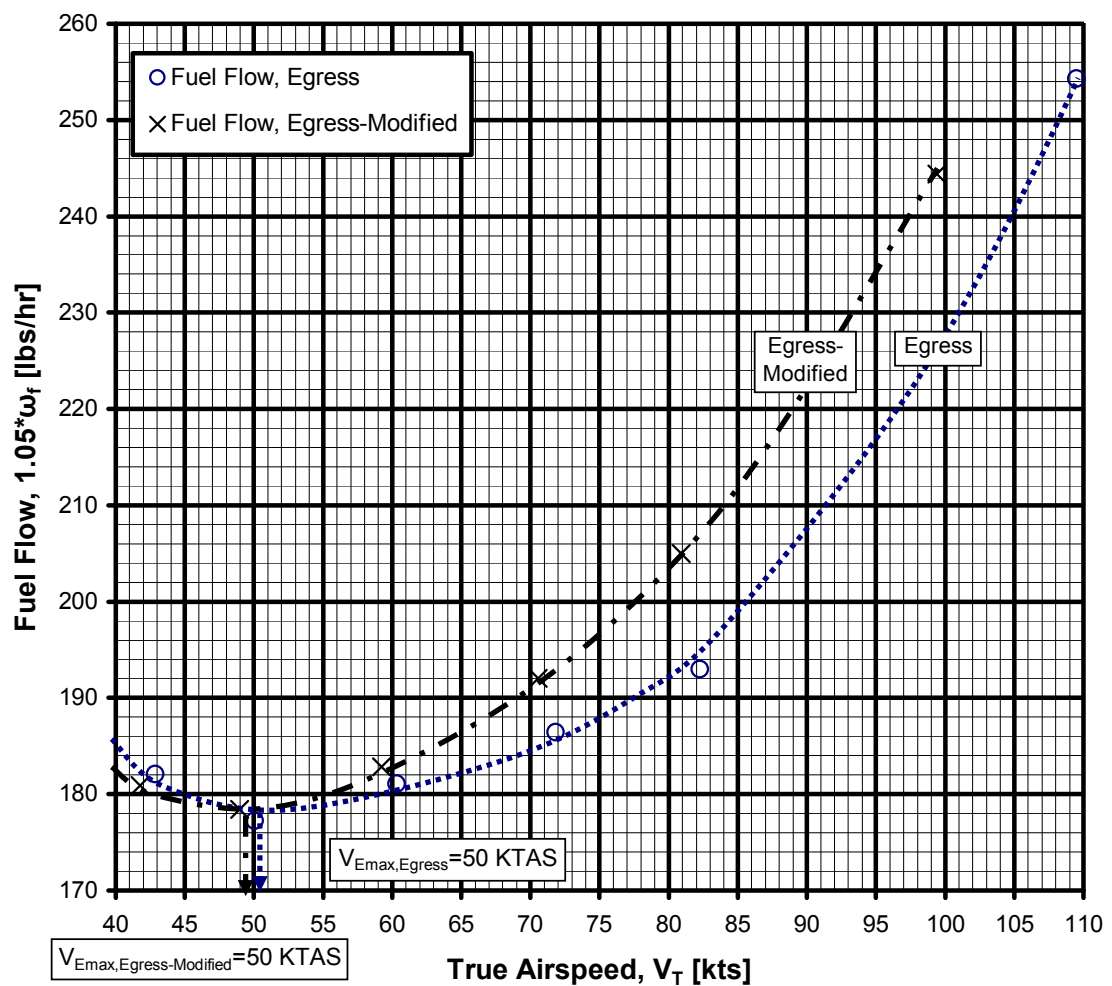


Figure 20. Fuel Flow vs. True Airspeed, Egress and Egress-Modified Configurations

configurations. The optimized wind deflector modification had no significant effect on the maximum endurance.

Maximum Range, Ingress and Ingress-Modified Configurations

Maximum range in this investigation refers to the range attained from the maximum usable fuel (422 lbs of Jet-A) at the maximum range airspeed; no fuel reserve was considered in the reporting of the results.

Specific Range (SR) as a function of true airspeed was determined to allow the calculation of the maximum range ($R_{\max}$) and corresponding airspeed (Figure 21). A five percent tolerance was applied to the fuel flow ($1.05 \cdot \omega_f$) as recommended per the Rotary Wing Performance Flight Test Manual.

The maximum range airspeed ($V_{R_{\max}}$) is found at the maximum SR point. However, this point could not be determined because the SR continued to increase with airspeed until the maximum level airspeed (V_H) was attained. For this reason, the maximum range was calculated using the SR at V_H for the ingress and ingress-modified configurations. The ingress and ingress-modified configuration $V_{R_{\max}}$ (V_H) were determined to be 84 KTAS and 88 KTAS respectively. The corresponding SR produced an $R_{\max}$ of 140 nm in the ingress configuration and 150 nm in the ingress-modified configuration. The optimized wind deflector modification resulted in an $R_{\max}$ increase of 10 nm with the EPS occupied by the four manikins.

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 16 December 2006

Engine: Allison Model 250-C20B

Referred Weight: 3000 lbs (W/ σ)

Center of Gravity: 98.4-98.6 in

Pressure Altitude: Sea Level

Outside Air Temperature: 15°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Ingress ~ EPS, Manikins, No Deflectors

Ingress-Modified ~ EPS, Manikins, Deflectors

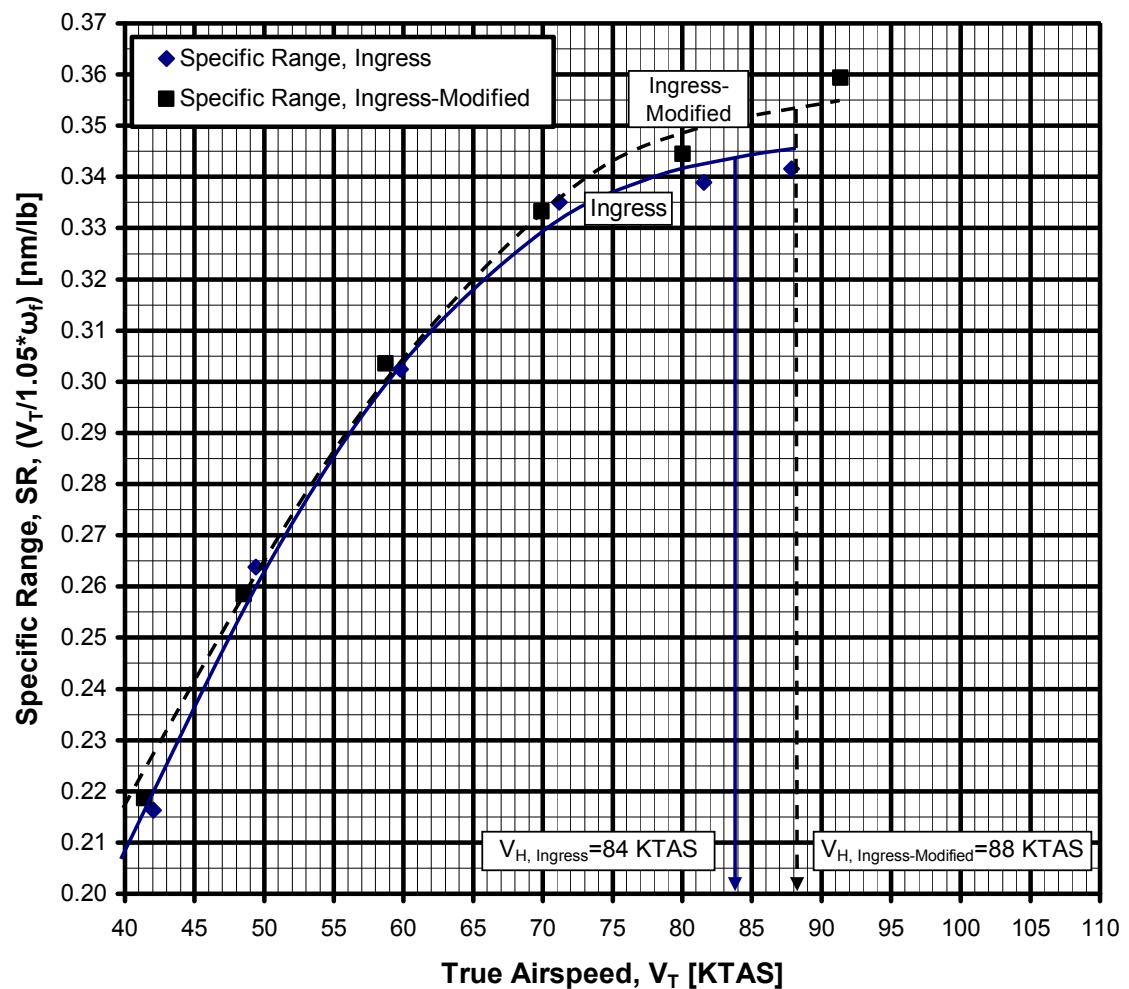


Figure 21. Specific Range vs. True Airspeed, Ingress and Ingress-Modified Configurations

Maximum Range, Egress and Egress-Modified Configurations

As in the ingress configurations, the maximum SR for the egress configurations could not be identified prior to reaching V_H (Figure 22). For this reason, the maximum range was calculated using the SR at V_H for the egress and egress-modified configurations. The egress and egress-modified configuration $V_{R_{max}}$ (V_H) were determined to be 105 KTAS and 97 KTAS respectively. The corresponding SR produced an R_{max} of 180 nm in the ingress configuration and 160 nm in the ingress-modified configuration. The optimized wind deflector modification resulted in an R_{max} decrease of 20 nm without the EPS occupied by the four manikins.

Uncertainty Analysis

The primary objective of the wind deflector project was to reduce the wind forces exerted on the EP. For this reason, a majority of the allotted flight test time was spent determining the optimized wind deflector design. An additional (secondary) objective was to determine the changes in level flight performance caused by the optimized wind deflector modification. Only four flights were available for this phase of the project, as the mandatory termination date was approaching (three of the four flights were conducted on the same day). Because only four performance flights were conducted (one flight in each configuration), only one data point was produced for each configuration at

Aircraft Model: MD-500D (N500VS)

Test Flight Date: 12 & 16 December 2006

Engine: Allison Model 250-C20B

Referred Weight: 3000 lbs (W/ σ)

Center of Gravity: 100.7-100.9 in

Pressure Altitude: Sea Level

Outside Air Temperature: 15°C

Crew: Allison/Cowan

Configuration Descriptions: Cockpit and Cabin Doors Removed

Egress ~ EPS, No Manikins, No Deflectors

Egress-Modified ~ EPS, No Manikins, Deflectors

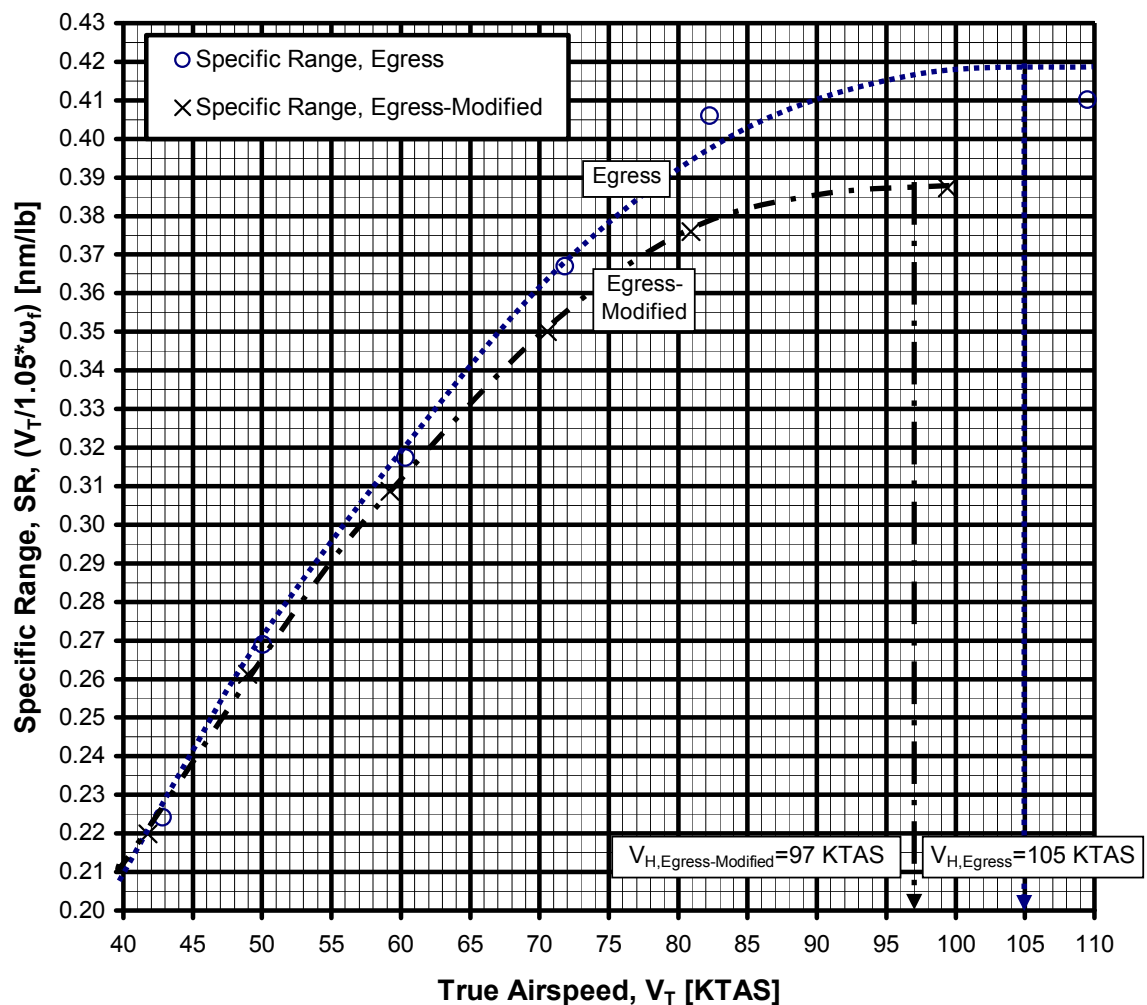


Figure 22. Specific Range vs. True Airspeed, Egress and Egress-Modified Configurations

the target airspeeds. This resulted in a sample population of one and prevented application of statistical methods such as a distribution mean or standard deviation of the sample population.

Measurement of engine torque (Q) was the primary determination of the engine shaft horsepower required ($ESHP_{req}$). Due to oversight, the torque meter was not calibrated prior to the flight test program. Calibration of this instrument would have enabled the determination of the systematic error (bias) contained within the torque meter. A larger sample population of torque readings at each configuration/airspeed combination would have minimized the effects of the random errors (lack of pilot precision in reading the gauge).

The results of this investigation stand to reason and support the expected outcomes. However, due to the sample population size of only one and the lack of torque meter calibration, the certainty of the calculated $ESHP_{req}$ values could not be determined.

CHAPTER VI

CONCLUSTIONS AND RECOMMENDATIONS

Conclusions

The overall objective of this investigation was to determine the effects of the optimized wind deflector modification on level flight performance (improved performance, degradation in performance, or no effects). The specific objectives were to compare the $ESHP_{req}$, equivalent flat plate area, maximum endurance, and maximum range of the four configurations to determine the effects of the optimized wind deflectors on level flight performance. Table 5 lists the derived performance parameters that correspond to the specific objectives.

Engine Shaft Horsepower Required

The optimized wind deflector modification reduced the $ESHP_{req}$ when the EPS was occupied by manikins (ingress-modified configuration vs. ingress configuration) at airspeeds above approximately 50 KTAS. This was caused by a reduction in pressure drag (less flow separation) due to the deflectors directing the slipstream around the manikins. This reduction in pressure drag resulted in a 4.8% increase in V_H .

The optimized wind deflector modification increased the $ESHP_{req}$ when the EPS was not occupied by manikins (egress-modified configuration vs. egress

Table 5. Derived Performance Parameters, All Configurations

Configuration	V_H [KTAS]	f at 80 KTAS [ft ²]	$V_{E_{max}}$ [KTAS]	E_{max} [hr]	$V_{R_{max}}$ [KTAS]	R_{max} [nm]
Ingress	84	18	50	2.37	84	140
Ingress-Modified	88	15	50	2.37	88	150
Egress	105	6.0	50	2.37	105	180
Egress-Modified	97	10	50	2.37	97	160

configuration) at airspeeds above approximately 50 KTAS. This was caused by an increase in pressure drag (more flow separation) due to the deflectors interrupting flow along the side of the fuselage. This increase in pressure drag resulted in a 7.6% reduction in V_H .

Equivalent Flat Plate Area

The egress configuration was the cleanest configuration with an equivalent flat plate area of 6.0 ft². The ingress configuration resulted in an increase in equivalent flat plate area of 200%. The ingress-modified configuration resulted in an increase in equivalent flat plate area of 150%. The optimized wind deflector modification reduced the equivalent flat plate area by 17% when the EPS was occupied by manikins (ingress-modified configuration

vs. ingress configuration). The egress-modified configuration resulted in an increase in equivalent flat plate area of 67%.

Maximum Endurance

The optimized wind deflector modification had no significant effect on the maximum endurance.

Maximum Range

The optimized wind deflector modification resulted in a 7.1% increase in maximum range when the EPS was occupied by manikins (ingress-modified configuration vs. ingress configuration). The optimized wind deflector modification resulted in an 11% reduction in maximum range when the EPS was not occupied by manikins (egress-modified configuration vs. egress configuration).

End State

With external passengers, the optimized wind deflector modification resulted in a modest increase in level flight performance (+4.8% V_H , +7.1% maximum range). However, without external passengers, the optimized wind deflector modification resulted in a slight reduction in level flight performance (-7.6% V_H , -11% maximum range).

The primary benefits of the optimized wind deflector modification (50° 8 inch deflector with Gurney flap) (Figure 23) were the reduction of wind forces on the external passengers and the elimination of wind turbulence in the cockpit.



**Figure 23. MD-500D Modified with Optimized Wind Deflector
(50°- 8 inch Deflector with Gurney Flap)**

Within the scope of this investigation, the optimized wind deflector should not be considered a significant performance enhancing or degrading modification.

Recommendations

Based upon the results and conclusions of this level flight performance evaluation, the following recommendations are made:

- 1) Validate the results of this investigation by conducting a more comprehensive level flight performance evaluation. Several flight tests should be conducted in each configuration to provide a larger sample

population of data points for each target airspeed. This could also be accomplished by using a digital data acquisition system.

- 2) An uncertainty analysis should be performed prior to flight testing. This will allow the determination of the statistical significance of the optimized wind deflector modification on performance.
- 3) Explore the feasibility of a quick disconnect optimized wind deflector. This would allow the deflector to be removed and stowed inside the cabin, eliminating the performance degradation when the EPS is not occupied by external passengers.

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APPENDICES

APPENDIX A

Data Tables

Table 6. Flight Test Data Card 1, Engine Assessment

Test Aircraft		ACFT ID		DATE		PURPOSE		
MD-500D		N500VS		06 Dec 06		Engine Assessment, Solies Force Balance Evaluation		
CREW: Allison/Cowan								
Time				Fuel [gal]				
T/O 1310		LDG 1328		T/O 21.4		LDG 10.2		
AWOS/REMARKS: 200/07 >10 sm BKN060 BKN070 9/-4 30.17								
V ₀ [kts]	H _{P0} [ft]	T _a [°C]	Q [%]	N1 [%]	N _R [%]	TGT [°C]	W _f [gal/hr]	fc [gal]
FPOD	865	9	27	82.5	103	540	17.5	21.5
HVR	830	9	72	95.5	103	680	30.7	20.6
40	865	9	49	90.5	103	600	23.6	19.6
50	860	9	50	90.0	103	600	24.2	19.0
60	920	9	57	91.0	103	610	25.4	18.2
70	940	9	64	94.0	103	640	28.0	17.6
80	930	9	72	96.0	103	680	30.7	17.1
HVR	840	9	71	95.5	103	660	29.8	16.3
Card Number: 1 Configuration: Ingress-Modified Zero Fuel Weight: 2743.7 lbs. Acft. Engine Start Weight:								

Table 7. Flight Test Data Card 2, Engine Assessment

Test Aircraft	ACFT ID	DATE	PURPOSE					
MD-500D	N500VS	06 Dec 06	Engine Assessment, Solies Force Balance Evaluation					
CREW: Allison/Cowan								
Time		Fuel [gal]						
T/O 1415	LDG 1432	T/O 20.6	LDG 8.8					
AWOS/REMARKS: 200/07 >10 sm OVC060 9/-5 30.16								
V ₀ [kts]	H _{P0} [ft]	T _a [°C]	Q [%]	N1 [%]	N _R [%]	TGT [°C]	W _f [gal/hr]	fc [gal]
FPOD	890	9	26	82.0	103	535	17.3	14.6
HVR	850	9	70	95.0	103	680	30.7	14.0
40	900	9	55	91.5	103	600	24.2	13.4
50	920	9	53	90.5	103	605	24.3	13.4
60	920	9	52	90.5	103	620	25.8	12.5
70	940	9	62	93.5	103	640	27.4	12.0
80	950	9	73	96.0	103	680	30.7	11.5
90 V _H	970	9	81	89.0	103	710	33.6	10.8
Card Number: 2 Configuration: Ingress-Modified Zero Fuel Weight: 2743.7 lbs. Acft. Engine Start Weight:								

Table 8. Flight Test Data Card 3, Engine Assessment

Test Aircraft		ACFT ID		DATE		PURPOSE		
MD-500D		N500VS		07-Dec-06		Engine Assessment		
CREW: Allison/Cowan								
Time				Fuel [gal]				
T/O 0902		LDG 0940		T/O 40.1		LDG 26.2		
AWOS/REMARKS: 290/10 >10 sm SKC 4/-3 30.33								
V _o [kts]	H _{Po} [ft]	T _a [°C]	Q [%]	N ₁ [%]	N _R [%]	TGT [°C]	W _f [gal/hr]	fc [gal]
FPOD	730	4	27	81.5	103	520	17.6	39.7
HVR	700	4	71	95.0	103	660	30.4	38.8
40	2100	0	54	90.5	103	580	24.8	36.0
50	2220	0	53	90.0	103	570	23.7	34.5
62	2320	0	56	91.5	103	600	25.3	34.0
70	2450	-1	63	93.0	103	620	27.2	33.0
80	2575	-1	71	95.5	103	655	29.6	32.0
87 V _H	2650	-2	80	97.5	103	700	32.5	30.5
Card Number: 3 Configuration: Ingress-Modified Zero Fuel Weight: 2743.7 lbs. Acft. Engine Start Weight:								

Table 9. Flight Test Data Card 4, Ingress Configuration

Test Aircraft		ACFT ID		DATE		PURPOSE		
MD-500D		N500VS		16-Dec-06		Level Flight Performance W/ σ = 3000 lbs.		
CREW: Allison/Cowan								
Time				Fuel [gal]				
T/O 1110		LDG 1140		T/O 17.1		LDG 5.2		
AWOS/REMARKS: 210/07 >10 sm SKC 17/11 30.14								
V _o [kts]	H _{Po} [ft]	T _a [°C]	Q [%]	N1 [%]	N _R [%]	TGT [°C]	W _f [gal/hr]	fc [gal]
FPOD	870	17	26	82.5	103	560	18.1	17.9
HVR	830	17	72	96.5	103	705	31.4	17.9
40	1300	16	54	92.5	103	630	25.6	16.7
50	1850	12	52	93.0	103	640	25.3	15.0
60	1950	12	56	94.0	103	640	25.7	14.2
70	2000	12	62	94.5	103	655	27.4	13.1
80	2030	12	75	98.0	103	710	30.4	12.3
85 V _H	2100	12	80	99.0	103	720	32.9	11.3
Card Number: 4 Configuration: Ingress-Baseline Zero Fuel Weight: 2732.7 lbs. Acft. Engine Start Weight: 2963.9 lbs.								

Table 10. Flight Test Data Card 5, Ingress-Modified Configuration

Test Aircraft		ACFT ID		DATE		PURPOSE		
MD-500D		N500VS		16-Dec-06		Level Flight Performance W/ σ = 3000 lbs.		
CREW: Allison/Cowan								
Time				Fuel [gal]				
T/O 0840		LDG 0900		T/O 34.1		LDG 24.7		
AWOS/REMARKS: 170/03 7 SKC 9/8 30.14								
V _o [kts]	H _{Po} [ft]	T _a [°C]	Q [%]	N1 [%]	N _R [%]	TGT [°C]	W _f [gal/hr]	fc [gal]
FPOD	900	11	26	82.0	103	540	17.9	33.2
HVR	850	11	74	96.5	103	690	31.7	32.3
40	1100	9	54	90.5	103	600	24.7	30.4
50	1175	9	53	91.5	103	605	24.7	29.5
60	1150	10	55	92.3	103	620	25.5	28.5
70	1100	11	62	94.0	103	640	27.0	27.4
80	1300	9	72	96.5	103	690	29.6	26.4
90 V _H	1320	10	80	98.5	103	720	33.4	25.7
Card Number: 5 Configuration: Ingress-Modified Zero Fuel Weight: 2743.7 lbs. Acft. Engine Start Weight: 2974.9 lbs.								

Table 11. Flight Test Data Card 6, Egress Configuration

Test Aircraft		ACFT ID		DATE		PURPOSE		
MD-500D		N500VS		16-Dec-06		Level Flight Performance W/ σ = 3000 lbs.		
CREW: Allison/Cowan								
Time				Fuel [gal]				
T/O 1335		LDG 1357		T/O 9.5		LDG .3		
AWOS/REMARKS: 180/05 >10 sm SKC 19/8 30.09								
V _o [kts]	H _{Po} [ft]	T _a [°C]	Q [%]	N1 [%]	N _R [%]	TGT [°C]	W _f [gal/hr]	fc [gal]
FPOD	920	20	26	82.5	103	570	17.8	9.5
HVR	900	20	70	96.0	103	710	30.9	9.0
40	1950	16	51	91.5	103	620	23.2	7.7
50	2200	14	50	92.0	103	620	23.2	6.4
60	2250	14	52	92.2	103	630	23.9	5.7
70	2300	14	54	93.0	103	640	24.7	5.3
80	2320	14	57	93.5	103	650	25.6	4.5
105 V _H	2400	14	80	99.0	103	740	33.0	3.4
Card Number: 6 Configuration: Egress-Baseline Zero Fuel Weight: 2387.2 lbs. Acft. Engine Start Weight: 2803.2 lbs.								

Table 12. Flight Test Data Card 7, Egress-Modified Configuration

Test Aircraft		ACFT ID		DATE		PURPOSE		
MD-500D		N500VS		12-Dec-06		Level Flight Performance W/ σ = 3000 lbs.		
CREW: Allison/Cowan								
Time				Fuel [gal]				
T/O 0910		LDG 0947		T/O 50.6		LDG 33.2		
AWOS/REMARKS: 170/13 >10 sm SKC 15/9 30.26								
V _o [kts]	H _{Po} [ft]	T _a [°C]	Q [%]	N ₁ [%]	N _R [%]	TGT [°C]	W _f [gal/hr]	fc [gal]
FPOD	790	15	26	82.5	103	555	18.0	50.8
HVR	750	14	71	96.5	103	700	31.1	50.0
40	1200	13	53	92.2	103	620	23.6	48.8
50	1375	12	52	90.0	103	595	23.5	47.1
60	1550	11	54	90.5	103	605	24.5	46.2
70	1725	10	58	93.0	103	640	25.9	45.3
80	1800	10	64	94.5	103	660	27.2	44.2
97 V _H	1830	10	80	98.5	103	710	33.0	43.1
Card Number: 7 Configuration: Egress-Modified Zero Fuel Weight: 2559.2 lbs. Acft. Engine Start Weight: 2975.2 lbs.								

APPENDIX B
Engine Assessment Figures

Engine Assesment, $ESHP_{corr}$ vs. $N1_{corr}$

Aircraft Model: MD-500D
Aircraft ID: N500VS
Configuration: All Doors Removed
Crew: Allison/Cowan
Average Gross Weight: 2975 lbs
Center of Gravity: 98.5 - 100.7 in

Test Flight Date: 6&7 December 2006
Pressure Altitude: Sea Level
OAT: 15°C

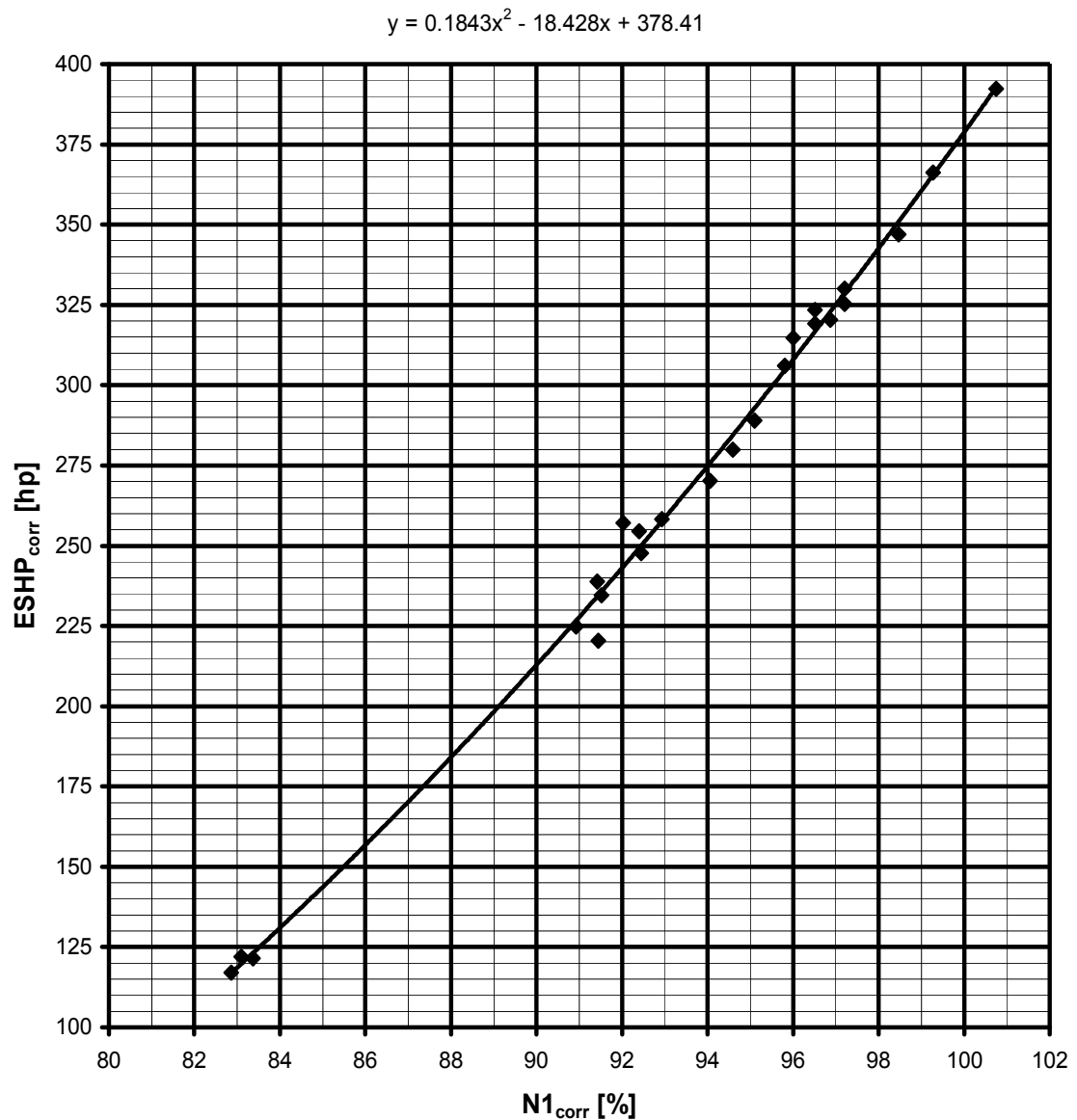


Figure 24. Engine Assessment 1

Engine Assessment, $\omega_{\text{Fuel corr}}$ vs. $N1_{\text{corr}}$

Aircraft Model: MD-500D
Aircraft ID: N500VS
Configuration: All Doors Removed
Crew: Allison/Cowan
Average Gross Weight: 2975 lbs
Center of Gravity: 98.5 - 100.7 in

Test Flight Date: 6&7 December 2006
Pressure Altitude: Sea Level
OAT: 15°C

$$y = 0.1416x^2 - 18.752x + 704.54$$

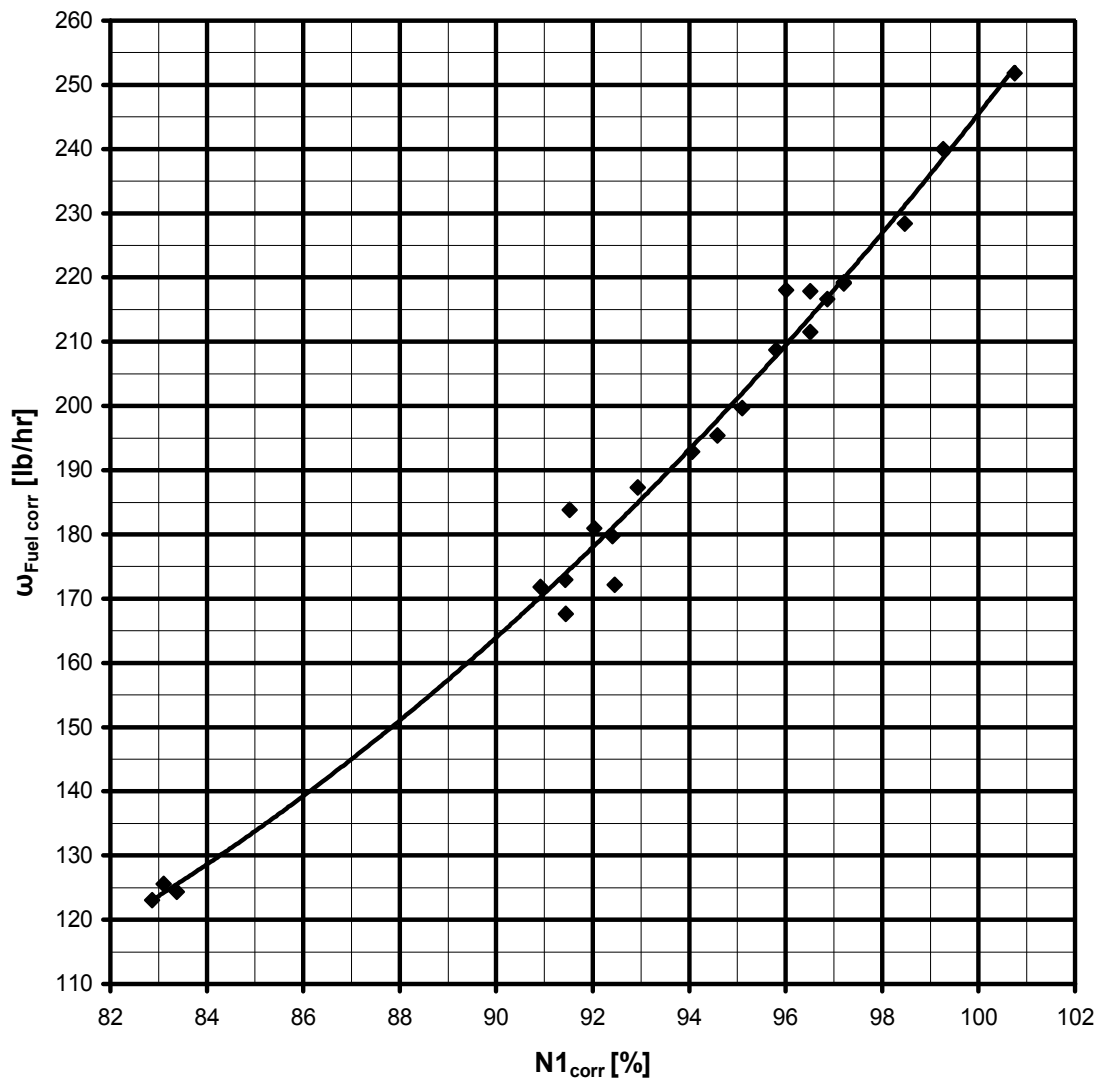


Figure 25. Engine Assessment 2

Engine Assesment, TGT_{corr} vs. $N1_{corr}$

Aircraft Model: MD-500D
Aircraft ID: N500VS
Configuration: All Doors Removed
Crew: Allison/Cowan
Average Gross Weight: 2975 lbs
Center of Gravity: 98.5 - 100.7 in

Test Flight Date: 6&7 December 2006
Pressure Altitude: Sea Level
OAT: 15°C

$$y = 0.4436x^2 - 69.577x + 3272$$

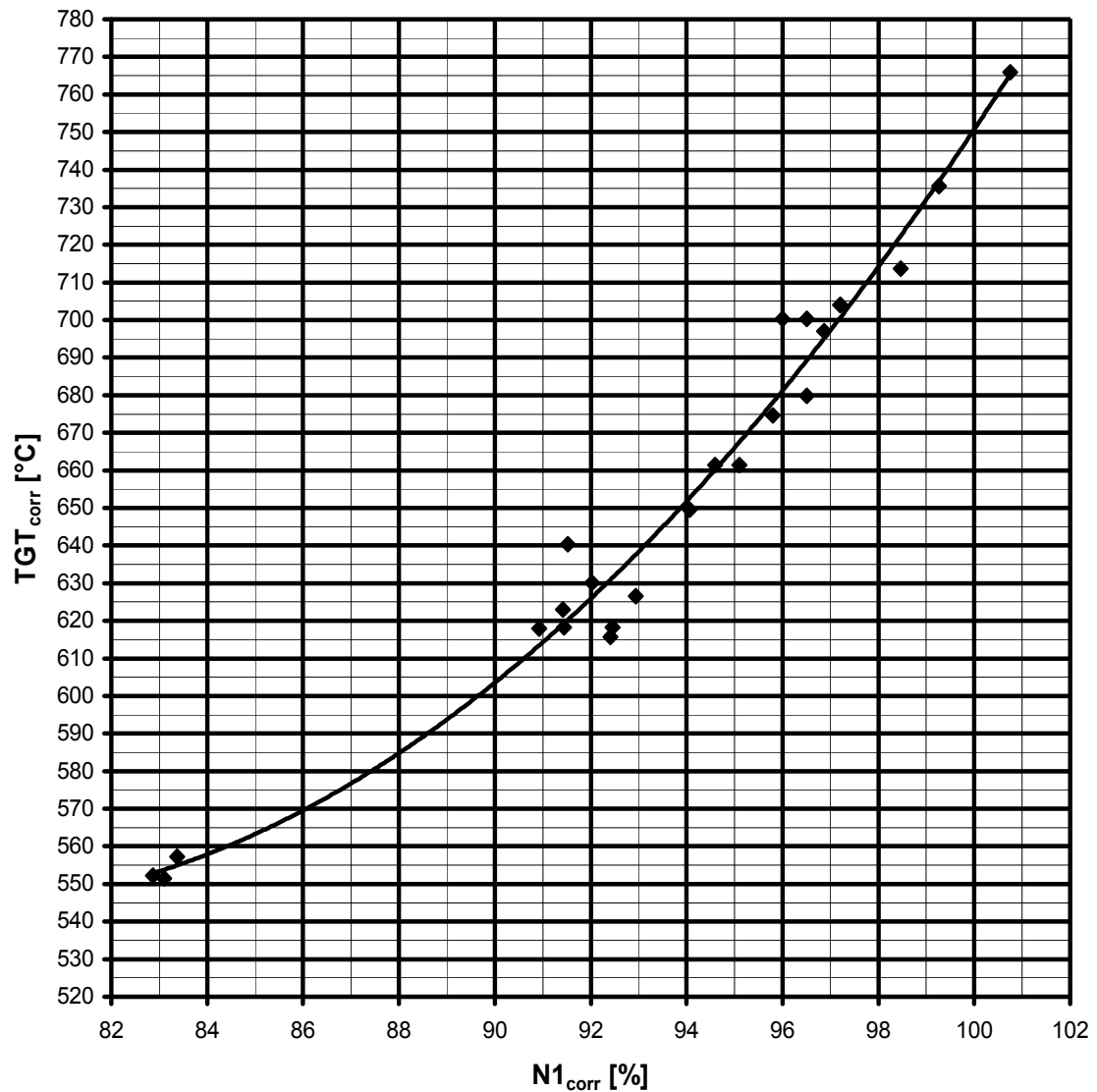


Figure 26. Engine Assessment 3

Engine Assesment, SFC vs. N1_{corr}

Aircraft Model: MD-500D
Aircraft ID: N500VS
Configuration: All Doors Removed
Crew: Allison/Cowan
Average Gross Weight: 2975 lbs
Center of Gravity: 98.5 - 100.7 in

Test Flight Date: 6&7 December 2006
Pressure Altitude: Sea Level
OAT: 15°C

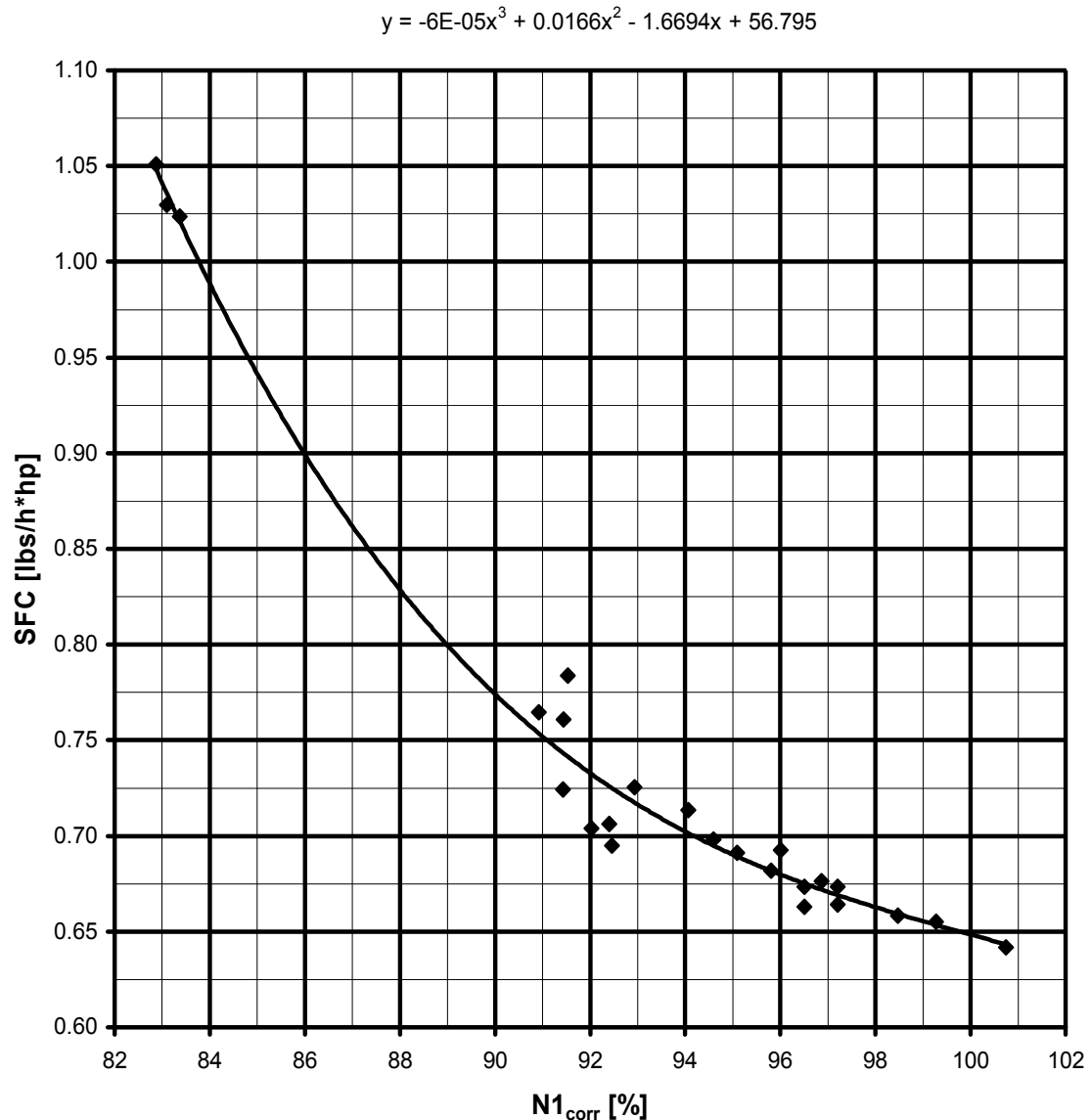


Figure 27. Engine Assessment 4

Engine Assesment, $\omega_{\text{Fuel corr}}$ vs. $\text{ESHP}_{\text{corr}}$

Aircraft Model: MD-500D
Aircraft ID: N500VS
Configuration: All Doors Removed
Crew: Allison/Cowan
Average Gross Weight: 2975 lbs
Center of Gravity: 98.5 - 100.7 in

Test Flight Date: 6&7 December 2006
Pressure Altitude: Sea Level
OAT: 15°C

$$y = 0.0002x^2 + 0.3515x + 78.708$$

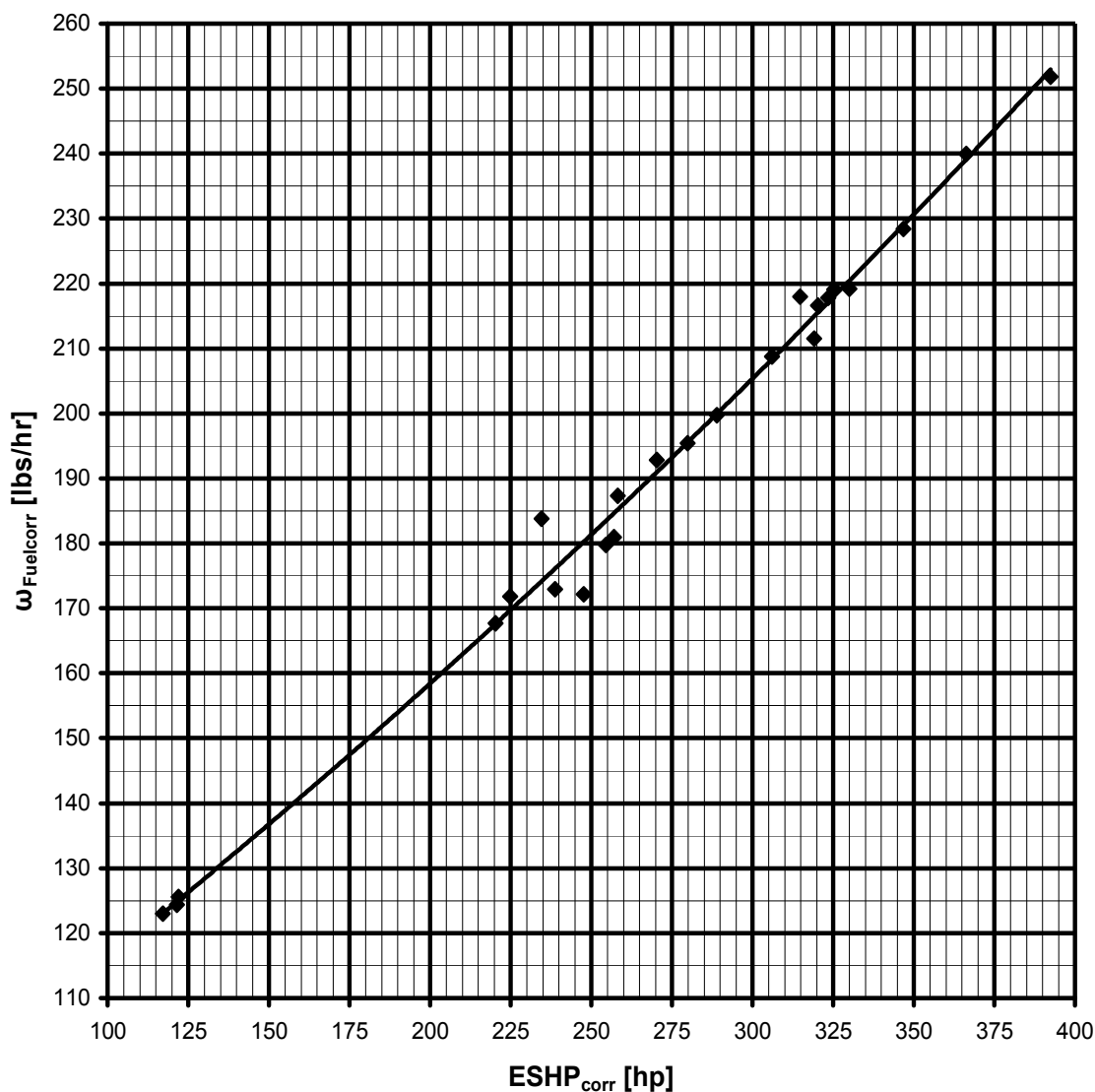


Figure 28. Engine Assessment 5

ESHP_{Available} vs. TAS

Aircraft Model: MD-500D
Aircraft ID: N500VS
Configuration: All Doors Removed
Crew: Allison/Cowan
Average Gross Weight: 2975 lbs
Center of Gravity: 98.5 - 100.7 in

Test Flight Date: 6&7 December 2006
Pressure Altitude: Sea Level
OAT: 15°C

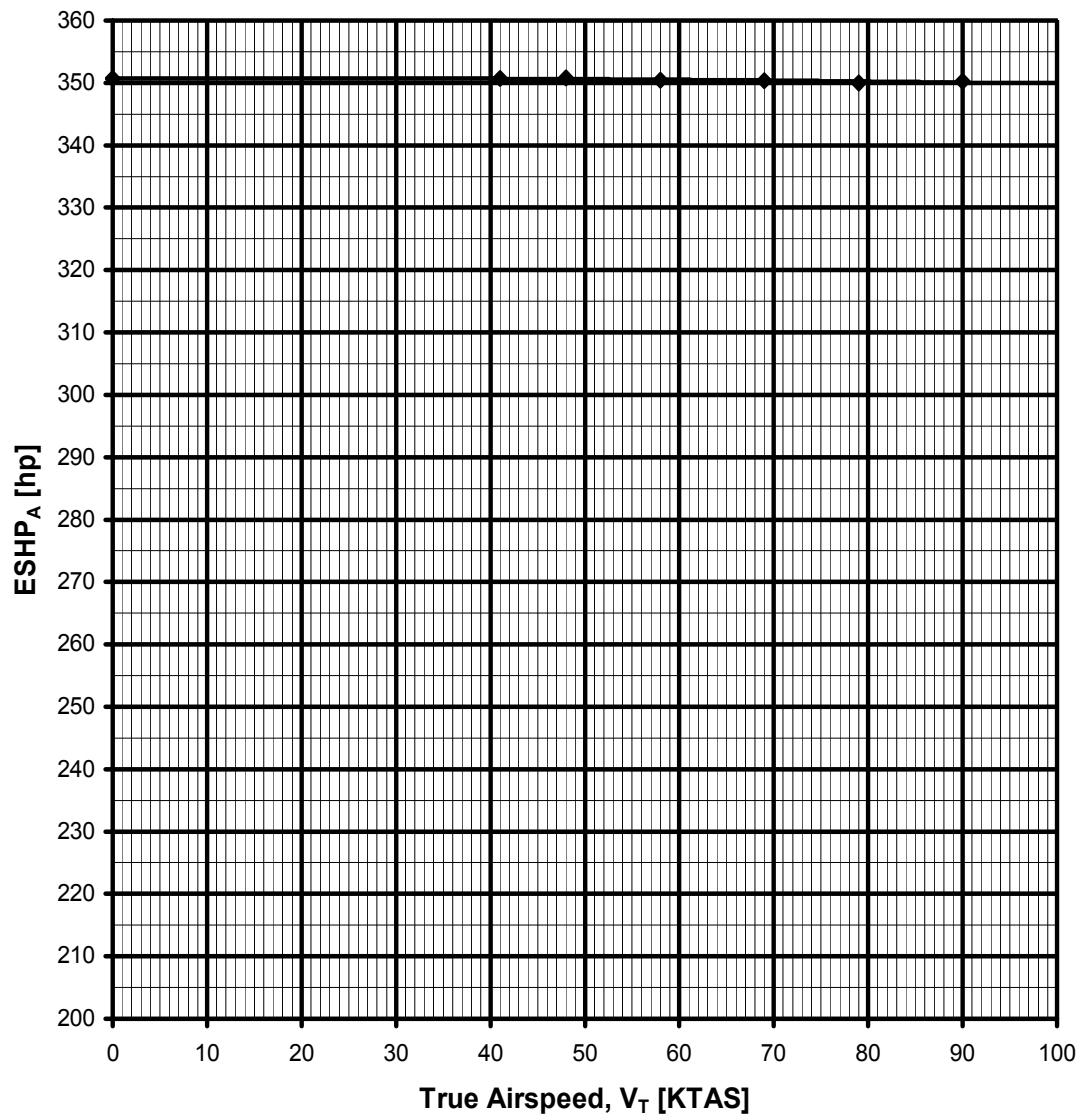


Figure 29. Engine Assessment 6

APPENDIX C
Air Data Calibration Figures

Airspeed Instrument Error Correction vs. Observed Airspeed

Aircraft ID: N500VS

18 December 2006

Aircraft Model: MD-500D

Calibrated By: Leigh, Cowan

Method: Manometer at UTSI Flight Research Facility

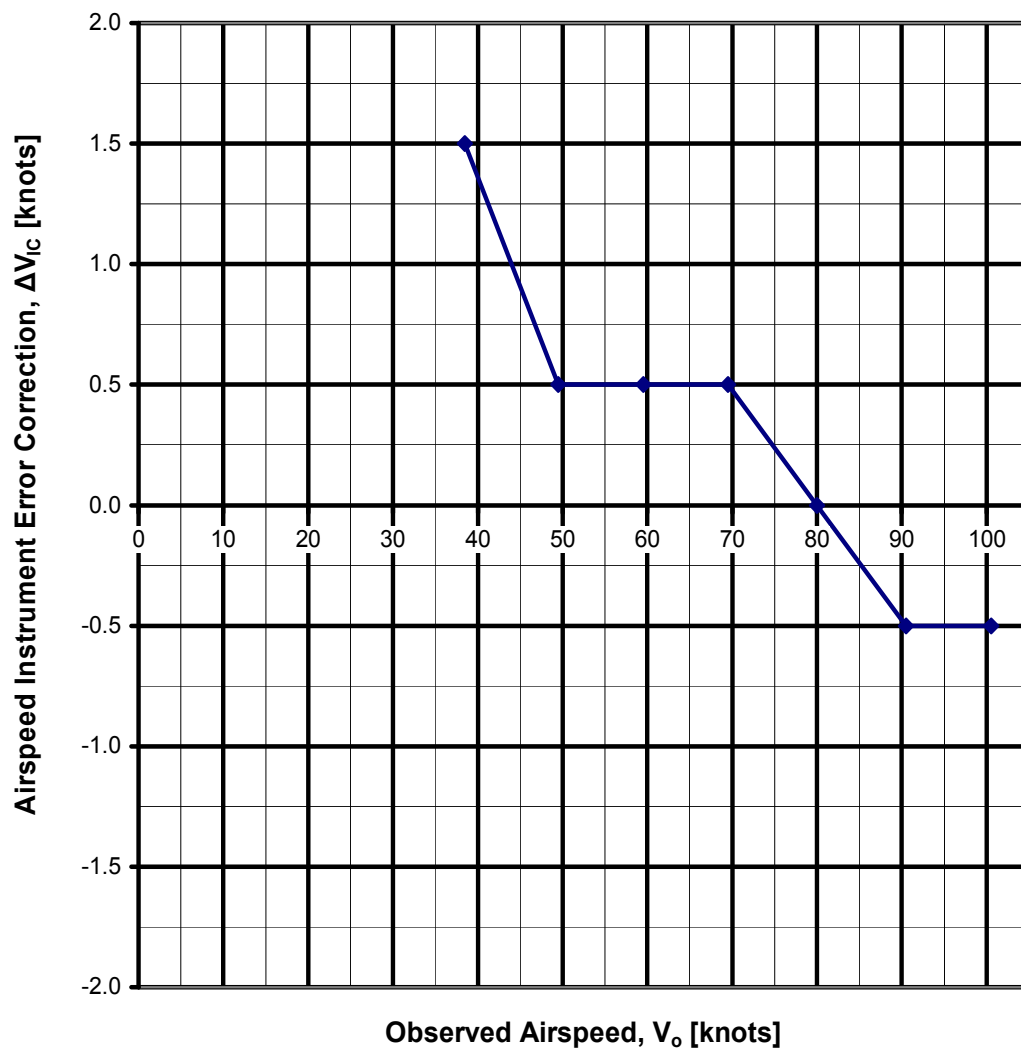


Figure 30. Airspeed Instrument Error Correction

Airspeed Position Error Correction vs. Instrument Corrected Airspeed

Aircraft ID: N500VS
Aircraft Model: MD-500D
Configuration: Ingress-Modified
Crew: Allison/Cowan
Gross Weight: 2975 lbs
Center of Gravity: 98.5 in
Pressure Alt: 950 ft
OAT: 15°C
Method: GPS Reciprocal Heading

8 October 2006

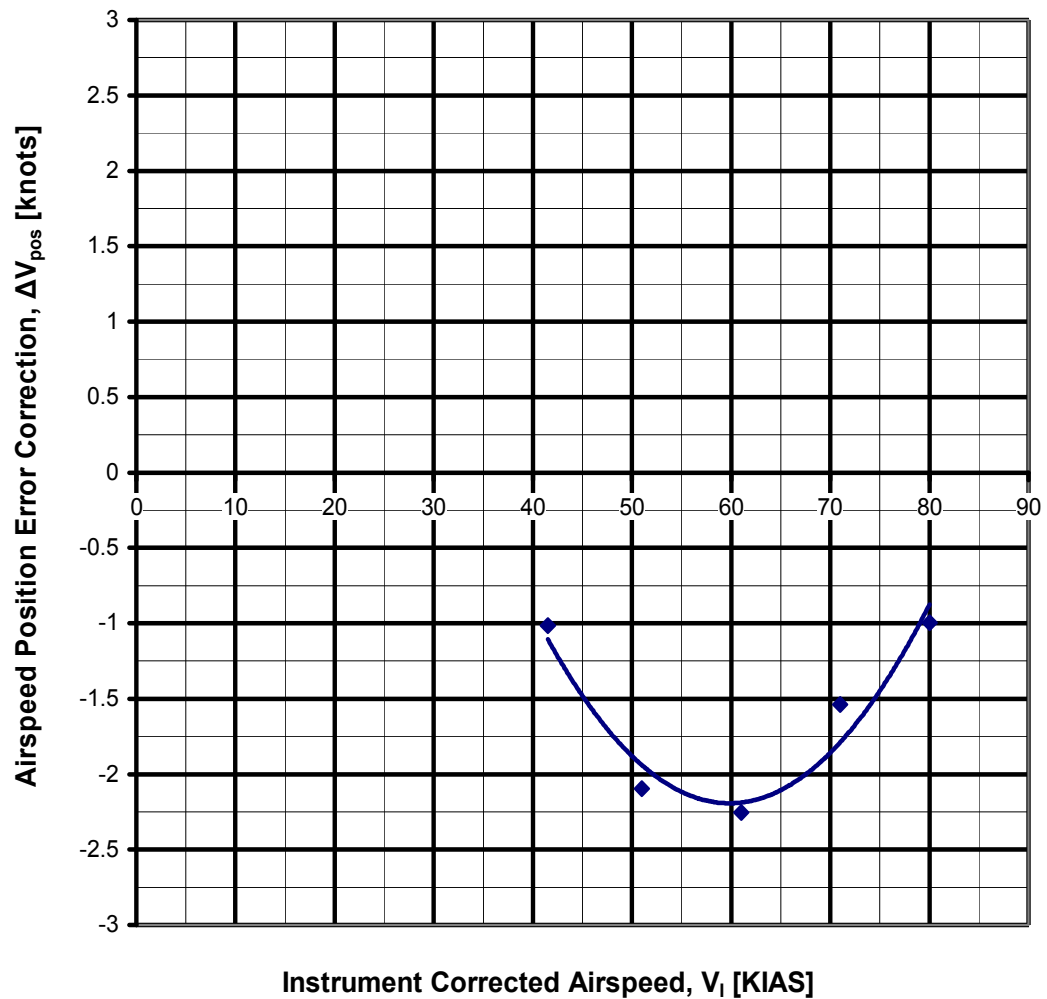


Figure 31. Airspeed Position Error Correction

Altitude Position Error Correction vs. Instrument Corrected Airspeed

Aircraft ID: N500VS
Aircraft Model: MD-500D
Configuration: Ingress-Modified
Crew: Allison/Cowan
Gross Weight: 2975 lbs
Center of Gravity: 98.5 in
Pressure Alt: 950 ft
OAT: 15°C
Method: GPS Reciprocal Heading

8 October 2006

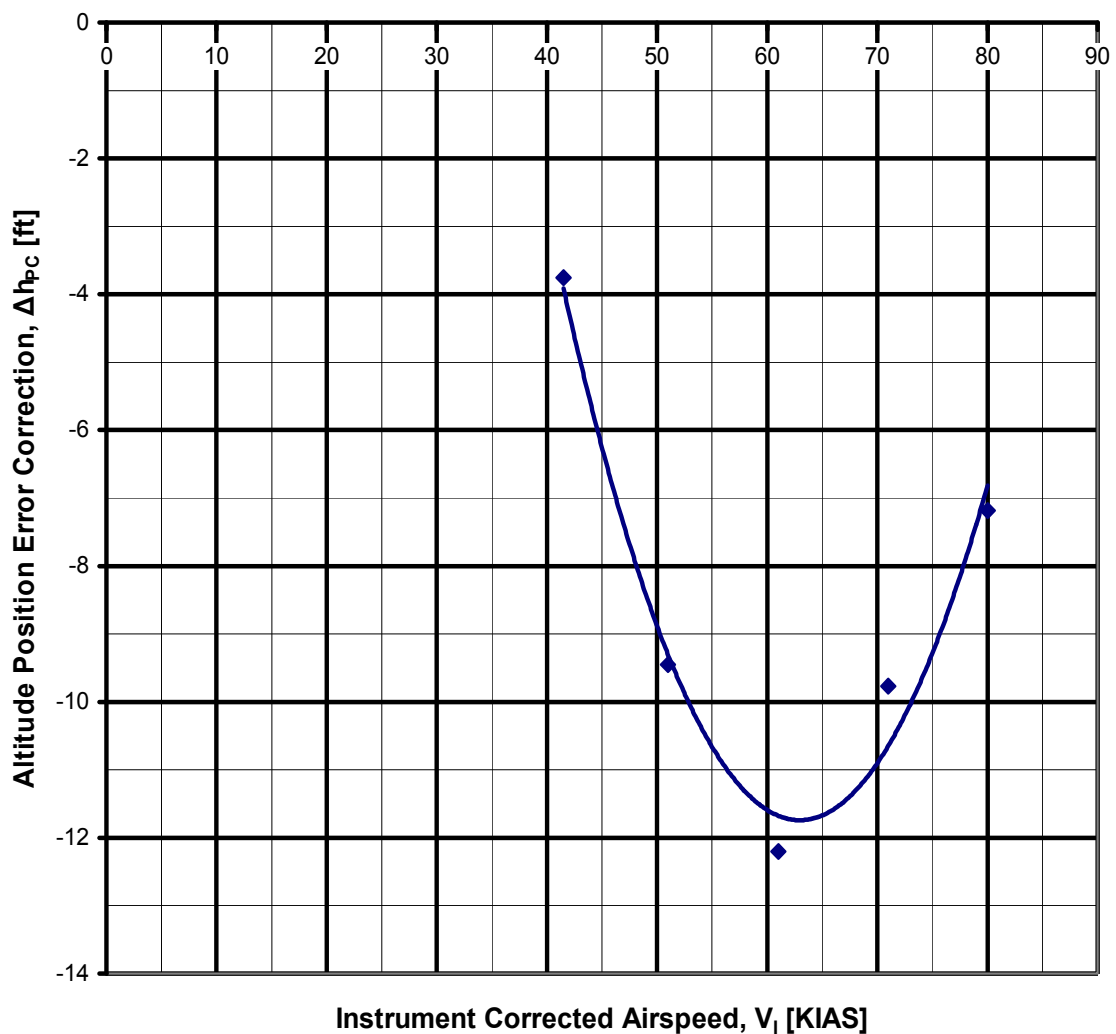


Figure 32. Altitude Position Error Correction

APPENDIX D
W/ σ Method Working Figures

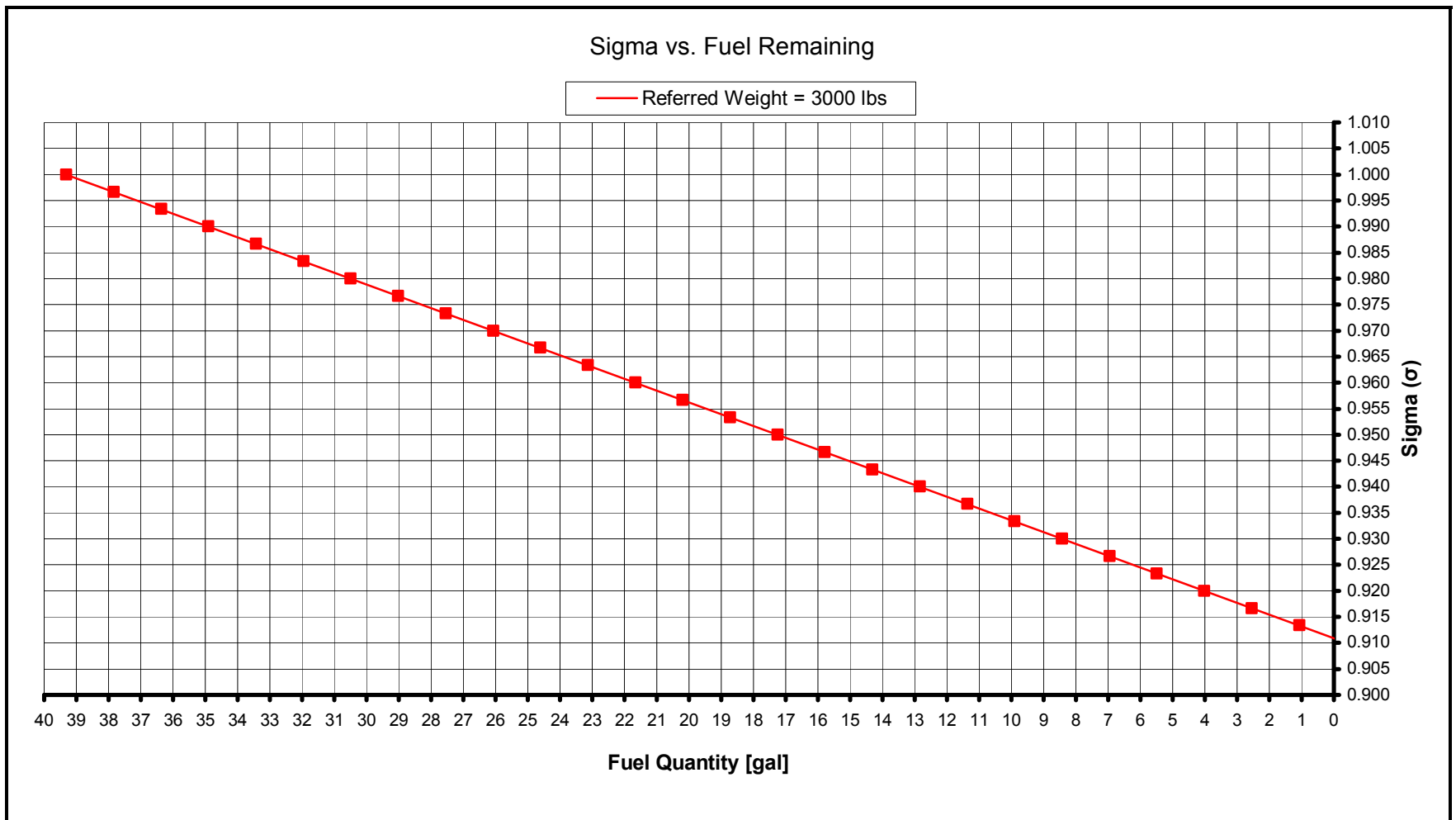


Figure 33. Sigma vs. Fuel Remaining

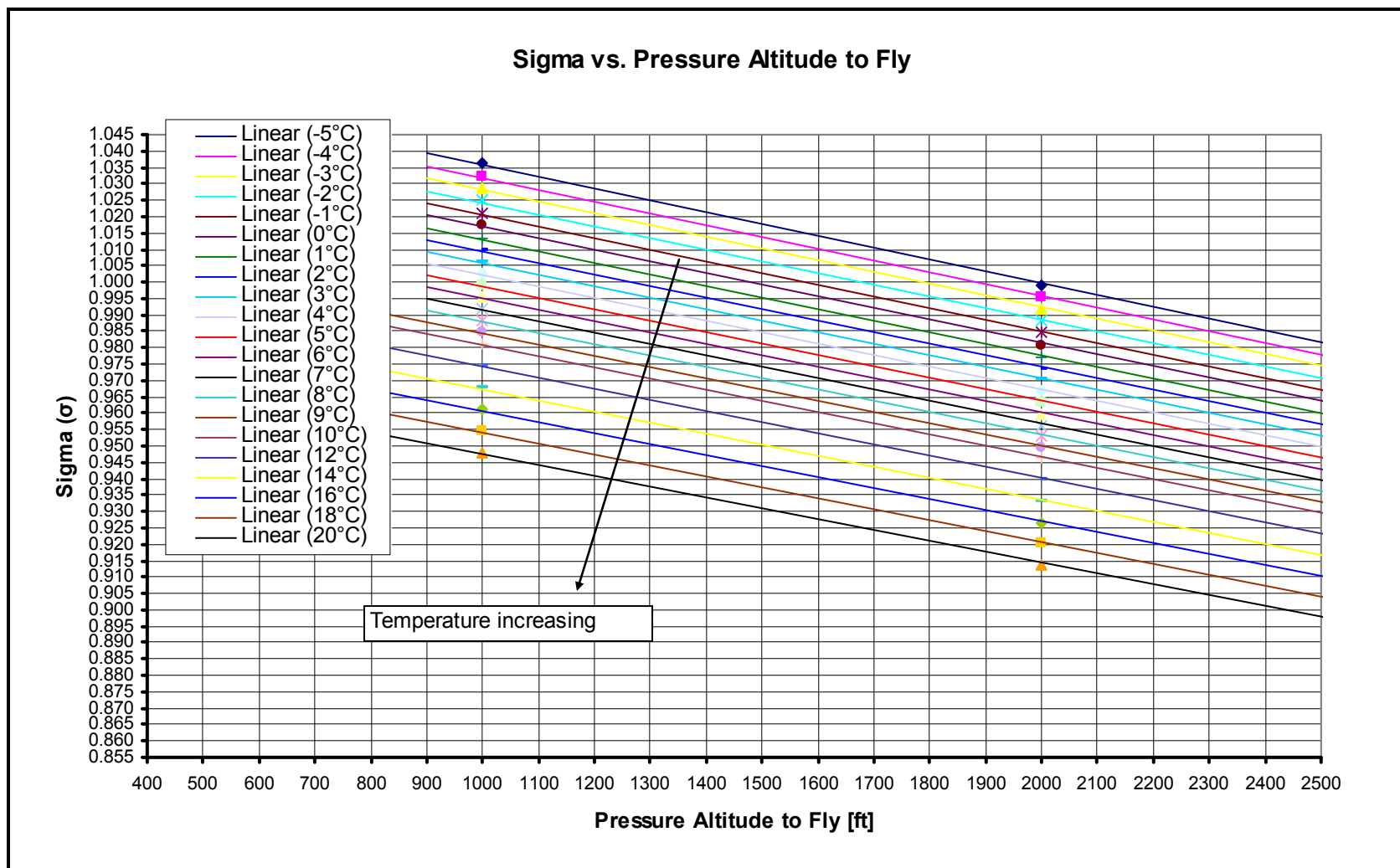


Figure 34. Sigma vs. Pressure Altitude to Fly

VITA

Adam Joseph Cowan was born at the Grand Forks Air Force Base, ND on May 30, 1971. He was raised in Edgerton, KS and graduated from the Gardner-Edgerton High School in 1989. After attending the Johnson County Community College and the University of Kansas, he enlisted in the U.S. Army as a helicopter repairman in 1993. In 1994 he attended Warrant Officer Candidate School and Army Flight School at Ft. Rucker, AL. Upon graduation from flight school, he was assigned as a UH-60 Blackhawk helicopter pilot in the First Cavalry Division at Ft. Hood, TX. While serving with the "Cav" he was deployed to Bosnia for seven months to conduct peace keeping duties. In 1999 he was assigned to the Second Infantry Division as a Blackhawk instructor pilot in South Korea. In 2000, he was assigned to the 82nd Aeromedical Evacuation Company at Ft. Riley, KS as a Blackhawk instructor pilot and instrument examiner. While serving with the 82nd MED, he deployed to Kuwait for four months to support of Operation Southern Watch. In 2003 he attended the Fixed Wing/Special Electronic Mission Aircraft course and was assigned to the 15th Military Intelligence Battalion at Ft. Hood, TX. He deployed to Iraq in 2004 as an RC-12 P/Q Gaurdrail pilot where he flew intelligence, surveillance, and reconnaissance (ISR) missions in support of Operation Iraqi Freedom. In 2006 he was selected to attend advanced civil schooling and the Navy Test Pilot School. In 2007 he

graduated from the University of Tennessee Space Institute with a Master's Degree in Aviation Systems and will start Navy Test Pilot School in 2008.