PERFORMANCE EVALUATION OF AN OH-58A+ WITH DIMPLETAPE® INSTALLED

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

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To the Interim Provost and Dean of The Graduate School:

I am submitting herewith a thesis written by Gregg Allen Deetman entitled "Performance Evaluation of an OH-58A+ with Dimpletape® Installed". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Dr. W. Lewis, Major Professor

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Interim Vice Provost and
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DEDICATION

"So I say to you: Ask and it will be given to you; seek and you will find; knock and the door will be opened to you. For everyone who asks receives; he who seeks finds; and to him who knocks, the door will be opened." Luke 11:9-10

I praise God almighty, whose love for us is endless, for bringing his Son, our Savior Jesus Christ, into my life and changing it forever. This thesis is dedicated to my wife, children, family, and friends who have supported me with love and encouragement every step of the way.

"Trust in the Lord with all your heart and lean not on your own understanding; in all your ways acknowledge him, and he will make your paths straight."
Proverbs 3:5-6

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ABSTRACT

This flight test investigates the performance benefits of a recently developed vortex generator, called Dimpletape®, on an OH-58A+ helicopter rotor blade. This product employs the aerodynamic concepts that are used to reduce the drag on a golf ball. The manufacturer claims significant performance benefits with the product applied to airplane wings and propellers; however, no flight-testing has been conducted on commercial helicopter rotor blades.

Four different Dimpletape® lengths where flight-tested on an OH-58A+ to determine the optimum Dimpletape® length and cordwise placement on the main rotor blades for the greatest performance gain. The flight-testing consisted of a quantitative performance evaluation including hover performance (free hover method), level flight performance (W/σ, weight over density ratio test method), and autorotative performance flight tests.

The flight test results show that there is an insignificant reduction in power when Dimpletape® is applied to the outboard 10% (19.5 inches) of the rotor blade at the maximum camber point (optimum Dimpletape® length and position tested). In most of the tests Dimpletape® increased the power requirements of the rotor system.

Within the scope of these tests the author has concluded that for the given aircraft main rotor blade airfoil there is no significant performance gain with the use of Dimpletape®.

The author makes the following recommendations:

1. Do not consider Dimpletape® for operational use on rotary wing aircraft.

2. Do not perform any further testing of Dimpletape® on rotary wing aircraft.

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LIST OF ABBREVIATIONS

CG	Center-of-Gravity
ESHP	Engine Shaft Horsepower
ESGW	Engine start gross weight
$ESHP_{ref}$	Engine Shaft Horsepower, referred
$ESHP_T$	Test engine shaft horsepower
FPM	Feet Per Minute
FTE	Flight Test Engineer
FTM	Flight Test Manual
FU	Fuel used
GPS	Global Positioning System
GW	Gross Weight
HHMD	Hover Height Measurement Device
IGE	In Ground Effect
IR	Infra Red
LBS	Pounds
KCAS	Knots Calibrated Airspeed
KIAS	Knots Indicated Airspeed
KOAS	Knots Observed Airspeed
KTAS	Knots True Airspeed
$KTAS_{ref}$	Knots True Airspeed referred
MSA	Mine Safety Appliances Company
OAT	Outside Air Temperature
OGE	Out of Ground Effect
OH	Observation Helicopter
P	Power
Q	Torque

R	Rotor radius
RPM	Revolutions Per Minute
T	Thrust
TOT	Turbine Outlet Temperature
TPS	Test Pilot School
TQ	Engine Torque
USNTPS	United States Naval Test Pilot School
VNE	Velocity Never Exceed
W	Weight
W_{ref}	Referred Weight

LIST OF SYMBOLS

a	Speed of sound
A_D	Rotor disk area
b	Number of blades
c	Cord
$\bar{c}$	Average cord
$\overline{C}_{d_i}$	Average blade element induced drag coefficient
$\overline{C}_{d_o}$	Average blade element profile drag coefficient
C_{Dp}	Parasite drag coefficient
C_P	Power coefficient
C_T	Thrust coefficient
dD_o	Blade element profile drag
dF	Blade element torque force
dL	Blade element lift
dP	Blade element power required
dR	Blade element resultant aerodynamic force
f	Equivalent flat plate area
H_d	Density Altitude
H_{pc}	Calibrated Pressure Altitude
H_{po}	Observed Pressure Altitude
K_{GR}	Gear ratio constant
K_Q	Engine torque constant
M_{tip}	Blade tip Mach number
N_1	Gas producer speed
N_2	Power turbine speed
N_R	Rotor speed

LIST OF SYMBOLS (continued)

N_{RS}	Standard main rotor speed
N_{RT}	Test main rotor speed
P_{Acc}	Power accessory
P_b	Power required for b blades
P_i	Induced power
P_{loss}	Power transmission gearbox losses
P_{misc}	Miscellanious power
P_{MR}	Main rotor power
P_o	Profile power
P_p	Parasite power
P_{total}	Total power
P_{TR}	Tail rotor power
r	Radius of the blade element
T_a	Ambient Temperature
T_a (°K)	Ambient Temperature, °K
T_a (°C)	Ambient Temperature, °C
T_o	Observed Temperature
T_{ssl} (°K)	Standard Sea Level Temperature, °K
T_{TR}	Tail rotor thrust
ΔT_{ic}	Temperature Instrument Correction
V_c	Calibrated Airspeed
V_f	Forward flight velocity
v_i	Induced velocity at a hover
V_o	Observed Airspeed
V_{tip}	Blade tip velocity
V_T	True Airspeed

LIST OF SYMBOLS (continued)

V_{Tref}	Referred True Airspeed
ΔV_{ic}	Airspeed Instrument Correction
ΔV_{pos}	Airspeed Position Error
W_{ref}	Referred Weight
W_T	Test weight
W/σ	Weight over density ratio method
°C	Degree Celsius
°K	Degree Kelvin
δ	Pressure Ratio
θ	Temperature Ratio
μ	Advance ratio
ρ	Air Density
ρ_{ssl}	Air density at sea level
σ_R	Rotor solidity ratio
σ_T	Test density ratio
ψ	Blade azimuth angle
Ω	Rotor angular velocity
ΩR	Blade rotational velocity
ΩR_S	Standard blade rotational velocity
ΩR_T	Test blade rotational velocity

Chapter 1

INTRODUCTION

Purpose

The purpose of this thesis is to evaluate the performance benefits of a Dimpletape® application to the main rotor blades of an OH-58A+ helicopter.

Scope of Tests

A flight test program was executed to evaluate the potential performance benefits of Dimpletape®. The test program was conducted in 10.7 flight hours under daylight visual meteorological conditions (VMC) at Tullahoma Regional Airport, Tullahoma, Tennessee. The maximum altitude for level flight-testing for the test was 5,185 feet pressure altitude, with airspeed from 39 to 101 knots. Flight-testing to determine level flight performance was conducted at two Thrust Coefficient (C_T) values of 0.00291 and 0.00351 (corresponding referred gross weights (W_{ref}) of 2831 lbs and 3412 lbs). Autorotation flight-testing was at a C_T of 0.00351. Hover performance was tested at six C_T values 0.00271, 0.00288, 0.00306, 0.00327, 0.00347, 0.00369 (W_{ref} values 2639 lbs, 2803 lbs, 2983 lbs, 3180 lbs, 3378 lbs, and 3594 lbs respectively). The Dimpletape® was tested in four different tape lengths to determine the optimum Dimpletape® location on the rotor blade. During the test handling qualities, and acoustic level changes were noted.

Method of Tests

The testing consisted of a quantitative performance evaluation including hover performance (free hover method), level flight performance, and autorotation performance (W/σ, weight over density ratio method) flight test. The data were taken at a hover and at airspeeds from 40 knots observed airspeed (KOAS) to 100 KOAS, in 10 knot increments. Engineering tests were conducted in accordance with the U.S. Naval Test Pilot School Rotary Wing Performance Flight Test Manual, USNTPS FTM-106, and the test plan as described in the Tests and Test Conditions Table (Appendix D, Table D.1).

Background

Anthony C. Occhipinti received a patent for Dimpletape® on 30 July 1996. Dimpletape® is a pressure sensitive perforated urethane 0.015 inch tape that is placed spanwise on the maximum camber of an airplane airfoil, wings, or propellers (Figure 1.1.).

Recent applications of this airflow adherence technology have been made on two biplanes, three monoplanes and a radio controlled 50" rotor helicopter with remarkable success. A PT-13 Stearman (N66607) airspeed was increased by 8 mph by the addition of dimples to the propeller and the wing struts. A second Stearman (N813LG) with dimples on its propeller only increased its airspeed 6 mph. A 150 hp RV-3 (N107SS) airspeed was increased 10 mph by adding dimples to the propeller and airfoils. A second 180 hp RV-3 (N894FS) airspeed was increased 8 mph by dimpling the propeller only.

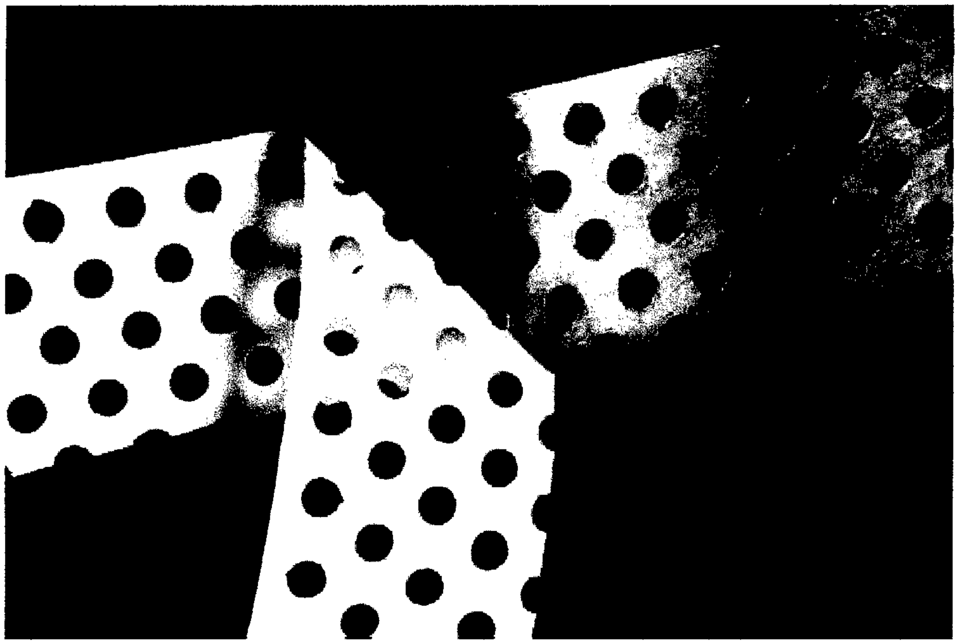

Figure 1.1. Dimpletape®.

A 125 hp Wittman Tailwind W-8 (N314T) airspeed was increased 9 mph by adding dimples to the propeller and airfoils. In addition, a 50" rotor radio controlled helicopter used less throttle and angle of attack of rotor for takeoff and made softer landings during autorotation. Each of the aircraft was noticeably quieter. The airplane's takeoff and landing were at slower airspeed, which resulted in longer tire life. [7]

All airfoils in motion through the air experience flow separation, which results in trailing edge wake. Dimpletape® energizes a thin layer of air on the surface, making it turbulent, which will make the thin air layer and the laminar airflow above it adhere to the airfoil. Dimpletape® is designed to increases aerodynamic efficiency by reducing trailing edge wake separation.[7] A reduction in trailing edge wake separation promotes a smaller wake drag behind the airfoil and increases efficiency.

Chapter 2

THEORY OF PERFORMANCE FLIGHT-TESTING

Hover Performance

The total hover power required for a single main rotor helicopter can be measured directly from the engine output. The total power required is the sum of the main rotor power (P_{MR}), tail rotor power (P_{TR}), accessory power (P_{Acc}), and transmission gearbox losses (P_{loss}). Tail rotor power is dependent on the amount of anti-toque required for any given main rotor power requirement and will vary dependent on aircraft maneuvering (left or right hovering turns). Tail rotor power is determined using the same theory as main rotor power. Accessory power consists of, but is not limited to, the power required to operate hydraulic pumps, electrical generators, and air compressors. Transmission losses are dependent on rotor speed. Typically the power required for hover is divided 85% for the main rotor, and 15% miscellaneous uses. Of the 85% about 25% provides profile power and 60% provides induced power. The 15% miscellaneous power is divided between power required for the tail rotor, accessories, and transmission gearbox losses. Only the theory for determining the main rotor power required will be discussed.

The power required to drive the main rotor is the sum of the induced power (P_i) and profile power (P_o). Induced power is the power required to develop thrust and can be estimated using momentum theory. Profile power is the power required to rotate the rotor system against a viscous action of the air and can be estimated using blade element theory. [1]

Induced Power

One method of predicting induced power is by momentum theory. Several assumptions are used in momentum theory and therefore the power prediction is not exact. Key assumptions include:

1. Inviscid, frictionless fluid.
2. Rotor acts as a disk with an infinite number of blades imparting a constant energy to the fluid.
3. Flow through the disk is uniform.
4. Constant energy flow ahead of and behind the disk.

The thrust produced by the rotor is the product of the mass flow rate through the rotor and the change in velocity of that mass. In a hover the thrust is equal to weight and the power required to accelerate the air mass through the disk can be calculated by: [1]

$$P_i = Tv_i = \sqrt{\frac{W^3}{2\rho A_D}}$$

Where:

P_i	- Induced power
v_i	- Induced velocity at a hover
T	- Thrust
ρ	- Air Density
A_D	- Rotor disk area
W	- Weight.

Profile Power (Blade Element Theory)

This analysis will analyze an element of the rotor blade at a radius, r, from the center of rotation. The blade element resultant aerodynamic force (dR) acting on the blade element is composed of two components: the blade element lift, which is normal to the local resultant velocity through the rotor (V_R); and the blade element profile drag, which is parallel to the local velocity, or: [1]

$$dR = dL + dD_o$$

Where:

dR	- Blade element resultant aerodynamic force
dL	- Blade element lift
dD_o	- Blade element profile drag.

The power required to rotate the blade element about the shaft axis is:

$$dP = dF(r)\,\Omega$$

Where:

dP	- Blade element power required
dF	- Blade element torque force
r	- Radius of the blade element
Ω	- Rotor angular velocity.

The integration over b blades produces:

$$P_b = \frac{1}{8}\sigma_R\left(\overline{C}_{d_o} + \overline{C}_{d_i}\right)\rho A_D(\Omega R)^3$$

Where:

P_b	- Power required for b blades

σ_R - Rotor solidity ratio

$\overline{C}_{d_o}$ - Average blade element profile drag coefficient

$\overline{C}_{d_i}$ - Average blade element induced drag coefficient

ρ - Air density

A_D - Rotor disk area

ΩR - Blade rotational velocity.

The blade element profile drag coefficient, C_{d_o}, varies little over the normal angle of attack and Mach number range of the rotor, and for these conditions can be assumed constant. The blade element induced drag coefficient, C_{d_i}, varies considerably with changes in angle of attack or lift coefficient. The induced power term is predicted by momentum theory. Thus the equation for profile power now becomes:

$$P_o = \frac{1}{8}\sigma_R \overline{C}_{d_o} \rho A_D (\Omega R)^3$$

Where:

P_o - Profile power

σ_R - Rotor solidity ratio

$\overline{C}_{d_o}$ - Average blade element profile drag coefficient

ρ - Air density

A_D - Rotor disk area

ΩR - Blade rotational velocity.

The power required for the main rotor can be expressed as:

$$P_{MR} = P_i + P_o = \sqrt{\frac{W^3}{2\rho A_D}} + \frac{1}{8}\sigma_R \overline{C}_{d_o} \rho A_D (\Omega R)^3$$

Where:

P_{MR}	- Main rotor power
P_i	- Induced power
P_o	- Profile power
W	- Weight
σ_R	- Rotor solidity ratio
$\overline{C}_{d_o}$	- Average blade element profile drag coefficient
ρ	- Air density
A_D	- Rotor disk area
ΩR	- Blade rotational velocity.

Nondimensional Coefficients

Induced power is a function gross weight and density altitude, and profile power is a function of the blade element average profile drag coefficient and rotor speed. The effects of these variables can be determined and expressed as nondimensional power and weight coefficients.

$$C_T = \frac{T}{\rho A_D (\Omega R)^2} \text{ and } C_P = \frac{P}{\rho A_D (\Omega R)^3}$$

Where:

C_T - Thrust coefficient

C_P - Power Coefficient

T - Thrust

P - Power

ρ - Air density

A_D - Rotor disk area

ΩR - Blade rotational velocity.

Level Flight Performance

The total power required for level flight consists of the summation of the following power requirements:

1. Induced power (P_i): Power required to produce induced flow and is based on momentum theory.
2. Profile power (P_o): Power required to drag the rotor blade through a viscous fluid, affects the main and tail rotor, and is predicted using blade element theory.
3. Parasite power (P_p): Power required to drag the fuselage through a viscous fluid, affected by equivalent flat plate area, calculated using aerodynamic theory.
4. Miscellaneous power (P_m): Power required for the tail rotor, accessory power, and transmission losses.

The individual contributions to level flight power requirements are discussed individually and reflect changes in theory due to forward flight. The basic concepts covered in hover flight will not be restated. [1]

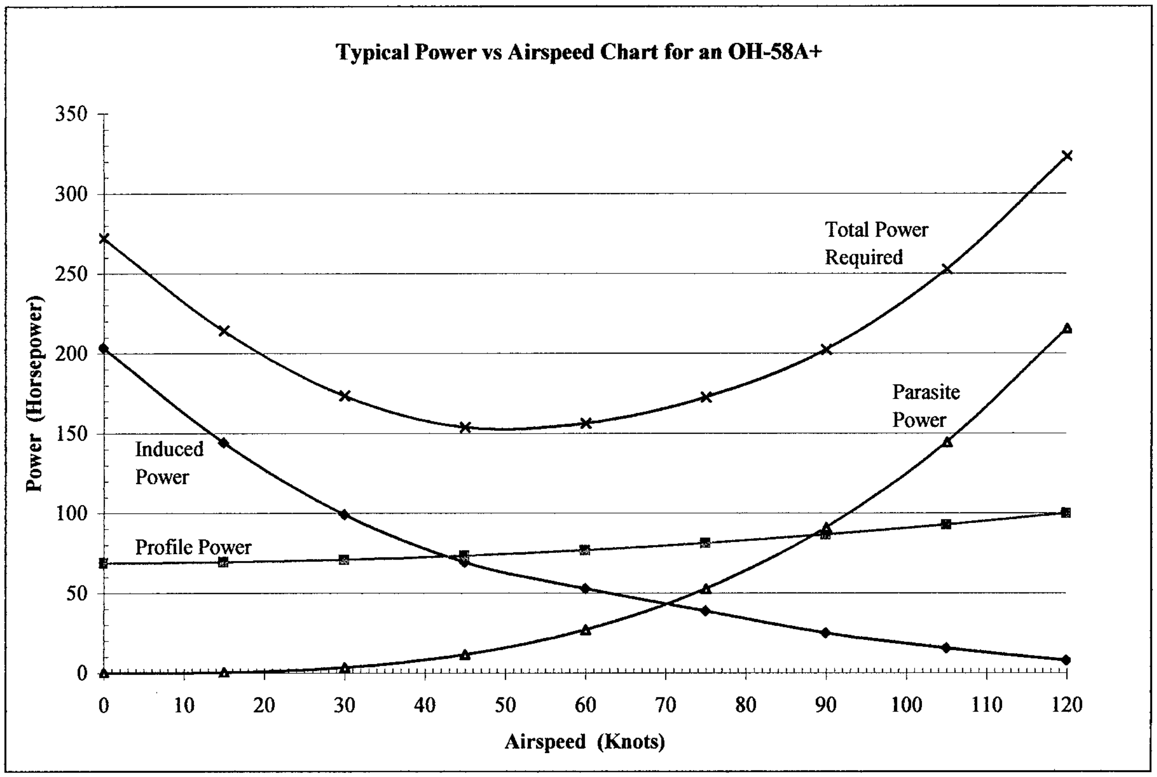

Figure 2.1. Components of Power Required in Level Flight.

<u>Induced Power</u>

Induced power in forward flight now includes the effects of forward velocity on the mass flow rate through the rotor disk area. The resultant mass flow rate is the vectorial sum of the of the component velocities (induced and forward) through the rotor. [1] As forward velocity increases, induced velocity through the rotor decreases, therefore the induced power required decreases as shown in Figure 2.1.

In deriving an equation for induced power in forward flight an assumption is made that at high forward airspeeds the resultant velocity is equal to the forward velocity. With this the equation for induced power becomes:

$$P_i = \frac{W^2}{2\rho A_D V_f}$$

Where:

P_i	- Induced power
W	- Weight
ρ	- Air density
A_D	- Rotor disk area
V_f	- Forward flight velocity.

<u>Profile Power</u>

Profile power now includes the effects of forward velocity on blade drag. The resultant velocity of the blade element is a function of azimuth angle (ψ). The average profile power for b number of blades is found by intergrating with respect to radius (dr) and azimuth (ψ).

$$P_o = \frac{b}{2\pi} \iint \frac{1}{2} C_{d_o} \rho \left(\Omega r + V_f \sin\psi\right)^3 c\,dr\,d\psi$$

Where:

P_o	- Profile power
b	- Number of blades
C_{do}	- Blade element profile drag coefficient
ρ	- Air density
Ωr	- Blade element rotation velocity
V_f	- Forward flight velocity
ψ	- Blade azimuth angle

c - Cord.

The equation for profile power is the sum of a torque factor, H1 (cordwise forces), and H2 (spanwise forces) on the blade element. Profile drag due to the torque required to pull the blade element through the air is:

$$P_{o\,Torque} = \frac{1}{8}\sigma_R \overline{C}_{d_o} \rho A_D (\Omega R)^3 (1 + \mu^2)$$

Profile power required to overcome H1 (cordwise) forces is:

$$P_{o\,H1} = \frac{1}{8}\sigma_R \overline{C}_{d_o} \rho A_D (\Omega R)^3 (1 + 2\mu^2)$$

Profile power required to overcome H2 (spanwise) forces is:

$$P_{o\,H2} = \frac{1}{8}\sigma_R \overline{C}_{d_o} \rho A_D (\Omega R)^3 (1 + 1.65\mu^2)$$

The total profile drag equation is:

$$P_o = \frac{1}{8}\sigma_R \overline{C}_{d_o} \rho A_D (\Omega R)^3 (1 + 4.65\mu^2)$$

Where:

P_o - Profile power

σ_R - Rotor solidity ratio

$\overline{C}_{d_o}$ - Average blade element profile drag coefficient

ρ - Air density

A_D - Rotor disk area

ΩR - Blade rotational velocity

μ - Advance ratio, $V_f/\Omega R$.

Figure 2.1. above shows how profile power increase with the square of forward velocity.

Parasite Power

Parasite power is composed of two elements: skin friction drag (landing gear, stores, wire strike protection equipment) and pressure drag. The fuselage components are assigned drag coefficients and summed into a total effective drag coefficient of equivalent flat plate drag (f).

$$P_p = \frac{1}{2}\rho f V_f{}^3$$

Where:

P_p - Parasite power

ρ - Air density

f - Equivalent flat plate area

V_f - Forward flight velocity.

Figure 2.1. shows how parasite power increases with the cube of forward velocity.

Miscellaneous Power

Miscellaneous power in forward flight includes the power required for the tail rotor, accessories, and transmission losses. The tail rotor power is composed of same two elements as the main rotor, induced power and profile power.

$$P_{TR} = \left(\frac{T_{TR}}{2\rho A_D V_f}\right)_{TR} + \left[\frac{1}{8}\sigma_R \overline{C}_{d_o} \rho A_D (\Omega R)^3 \left(1 + 4.65\mu^2\right)\right]_{TR}$$

Where:

P_{TR} - Tail rotor power

T_{TR} - Tail rotor thrust ($T_{TR} = \frac{Q_{MR}}{l_{TR}}$)

ρ - Air density

A_D - Rotor disk area

V_f - Forward flight velocity

σ_R - Rotor solidity ratio

$\overline{C}_{d_o}$ - Average blade element profile drag coefficient

ΩR - Blade rotational velocity

μ - Advance ratio, $V_f/\Omega R$.

Total Power

Total power in forward flight is the summation of induced power, profile power, parasite power, and miscellaneous power.

$$P_{Total} = P_i + P_o + P_p + P_{misc}$$

Where:

P_{total} - Total power

P_i - Induced Power

P_o - Profile Power

P_{misc} - Miscellanious power.

Nondimensional coefficients

The power coefficient and thrust coefficient for forward flight become:

$$C_P = \frac{C_T^{\ 2}}{2\mu} + \left[\frac{1}{8}\sigma_R \overline{C}_{d_o}\left(1 + 4.65\mu^2\right)\right] + \frac{1}{2}C_{D_p}\mu^3$$

$$C_T = \frac{W}{\rho A_D (\Omega R)^2}$$

Where:

C_P	- Power coefficient
C_T	- Thrust coefficient
μ	- Advance ratio, $V_f/\Omega R$
σ_R	- Rotor solidity ratio
$\overline{C}_{d_o}$	- Average blade element profile drag coefficient
C_{Dp}	- Parasite drag coefficient
ρ	- Air density
A_D	- Rotor disk area
V_f	- Forward flight velocity
ΩR	- Blade rotational velocity.

C_P and C_T are multiplied by standard units to produce the following flight test referred terms:

$$ESHP_{ref} = \frac{C_P \rho_{ssl} A_D (\Omega R_S)^3}{550} = \frac{ESHP_T}{\sigma_T}\left(\frac{\Omega R_S}{\Omega R_T}\right)^3$$

$$W_{ref} = C_T \rho_{ssl} A_D (\Omega R_S)^2 = \frac{W_T}{\sigma_T}\left(\frac{\Omega R_S}{\Omega R_T}\right)^2$$

Where:

$ESHP_{ref}$ - Referred engine shaft horsepower

$ESHP_T$ - Referred engine shaft horsepower

C_P - Power coefficient

C_T - Thrust coefficient

ρ_{ssl} - Air density at sea level

A_D - Rotor disk area

ΩR_S - Standard blade rotational velocity

ΩR_T - Test blade rotational velocity

σ_T - Test density ratio ($\frac{\rho}{\rho_{ssl}}$)

ρ - Test air density.

Level Flight Performance Test Technique

Level flight performance was tested by maintaining a constant value of C_T using the W/σ test technique. This constant value of C_T was maintained during the flight by increasing altitude (reducing density ratio, σ, while ΩR was maintained at 100%) as aircraft weight (W) was reduced due to fuel consumption. The test altitude was computed based on aircraft referred weight, aircraft fuel empty weight, fuel remaining, rotor speed, and air temperature at the test altitude.

Autorotative Descent

During power off descent aerodynamic forces on the blade drive the rotor system and rpm can be self-sustaining (autorotation). The local angle of attack changes across the blade due because of variations in Ωr, resulting in the sections of the blade near the hub producing "driving" forces in the plane of rotation (windmilling) and sections near the tip have "dragging" forces in the plane of rotation (absorbing the power made available by the inboard sections). [1]

During autorotation any change in the tip path plane (cyclic input) or blade pitch (collective input) cause by the pilot will change the angle of attack of each rotor blade. This change will create a new equilibrium speed for the rotor system. As an example, an increase in collective will increase the blade angle of attack. This will shift the resultant aerodynamic forces aft of the original position, increase the dragging forces, and reduce the driving forces on the blade. As a result the autorotative rpm of the rotor system will decrease.

Chapter 3

AIRCRAFT DESCRIPTION

History of the OH-58A+

The government contract for a light observation helicopter was awarded to Bell Helicopter on 8 March 1968. A total order of 2,200 aircraft was planned for the new U.S. Army helicopter designated the OH-58 Kiowa. The Kiowa soon saw action with the first aircraft delivered to the U.S. Army in May of 1969 and deployment to Vietnam in the autumn of that year. In 1976 an upgraded model was designed and tested, the OH-58C. This aircraft upgrade included an improved power plant, flat plate glass canopy, and an IR reduction package. The additional power significantly improved high altitude, hot weather performance. [5]

Description of the OH-58A+

The OH-58A+ helicopter (N88UT) is a single-engine, single main rotor, observation-type helicopter with the capability to carry four people with a maximum gross weight of 3200 pounds. The helicopter is designed for landing and takeoff from prepared and unprepared surfaces. The fuselage consists of a forward section, intermediate or transition section, and the aft or tailboom section. The forward section provides the cabin and fuel cell enclosure as well as pylon support. Entrance is gained through four doors, two on each side of the aircraft. The intermediate section supports the engine and includes equipment and electronic compartment. The tailboom supports the horizontal stabilizer, vertical stabilizer, and tail rotor.

Engine

The aircraft is equipped with an Allison T63-A-720 gas turbine engine rated at 420 shaft horsepower (uninstalled sea level, standard day conditions). The engine is installed aft of the mast and above the passenger compartment. A centrifugal type air particle separator is installed on the front of the engine to remove dirt and debris. Air is spun in the air particle separator swirl tubes removing the dirt from the air and ejecting it overboard via an eductor system. The engine fuel control governor system controls engine power output by monitoring power turbine speed and controlling gas producer speed. The pilot selects the power turbine load speed and the fuel governor automatically maintains the power required to maintain this speed. The fuel governor has a RPM control switch mounted on the pilots collective that can be used to increase or decrease power turbine speed while in flight. Cockpit engine instrumentation includes: a direct reading engine oil pressure driven torquemeter gauge (%Q), a self-generating electrically-driven Turbine Outlet Temperature (TOT) gauge (°C), a gas producer (N_1) tachometer (%RPM), and an engine (N_2) and rotor (N_R) dual-tachometer gauge (%RPM).

Transmission

The main transmission is mounted forward on the engine and is rated at 317 shaft horsepower maximum. The transmission is a single stage planetary gearbox. The main transmission transfers power to the main rotor and tail rotor assemblies. A freewheeling assembly is mounted in the accessory gearbox to transmit power from the engine to the transmission. During autorotation the freewheeling unit disengages the transmission from the engine and allows the rotor system to drive the tail rotor through the transmission. A single-stage bevel gearbox drives the tail rotor.

Rotor System

The main rotor assembly is a two-bladed, semi-rigid rotor, pre-coned, and mounted on an under-slung feathering axis hub. It is 35 feet, 4 inches in diameter and rotates at 354 RPM (100%). The two rotor blades are all metal, consisting of an extruded D-shaped aluminum alloy nose block, extruded aluminum alloy trailing edge, and aluminum honeycomb filler. Each blade is connected to the hub by means of a grip, pitch-change bearing, and tension-torsion strap assembly. The main rotor airfoil section is an 11.3% modified "droop snoot" with an average drag coefficient ($\overline{C}_{d_0}$) of 0.00123, an average chord ($\overline{c}$) of 13.0 inches, and a twist of −11.1 degrees.

Droop Snoot, forward edge camber, is a method used on the OH-58A/C for increasing the maximum lift coefficient of the rotor blade. This improvement comes from modifying the path from the stagnation point to the upper surface. Because of the less violent changes in curvature and direction experienced as the molecules travel over the nose, the local velocities are reduced. This decreases the centrifugal force on the air, delaying the formation of the laminar separation bubble and also decreasing the magnitude of the deceleration required as the air goes toward the trailing edge, thus decreasing the unfavorable pressure gradient. [8]

The two tail rotor blades have bonded aluminum skin but no honeycomb. The tail rotor airfoil section is a NACA 0012.5 with zero degrees of twist.

Flight Controls

The flight control system is a positive mechanical type with hydraulic assistance that reduces force gradients to near zero conditions. Flight controls include the cyclic control stick for longitudinal and lateral control, collective pitch lever to control blade pitch, and pedals to control heading through the tail rotor anti-torque. The cyclic stick controls the rotor tip path plane and the collective controls rotor pitch. A horizontal stabilizer of aluminum monocoque construction, with an inverted airfoil section, is mounted on the tail boom in a fixed pitch condition and aids in trimming the aircraft in level flight and increases usable C.G. range. A fixed vertical fin in sweptback upper and ventral sections is constructed of aluminum honeycomb with a light alloy skin.

Flight Instruments

The aircraft flight instrumentation consists of a pneumatic altimeter, airspeed indicator, attitude indicator, vertical speed indicator, turn and slip indicator, and free air temperature indicator. The AAU-32/A altitude encoder/pressure altimeter displays altitude on a 10,000 foot counter, 1,000 foot counter, and a 100 foot drum. A single pointer indicates hundreds of feet on a circular scale, with 50 foot center markings. At ambient pressures the altimeter should agree with field elevation ± 70 feet. The airspeed indicator has a display range of 0 to 140 knots with 10 knot center marks.[3] The airspeed is measured by sensing the difference between impact pressure from the pitot tube and static pressure. The static port and pitot tube used for recording test data are located on a test boom located on the nose of the aircraft. Locating the static and dynamic pressure source on the test boom helps minimize the effect of the pressure field created by the rotor system.

Miscellaneous

The equivalent flat plate area of the aircraft in the test configuration is 12.0 square feet. The test aircraft is equipped with high skid landing gear, which provide an additional 14 inches of ground clearance over the standard height fixed-skid landing gear. The test aircraft in Figure 3.1. is representative of production aircraft for the purpose of this test. A more complete description of the aircraft can be found in the OH-58A/C Operator's Manual. [3]

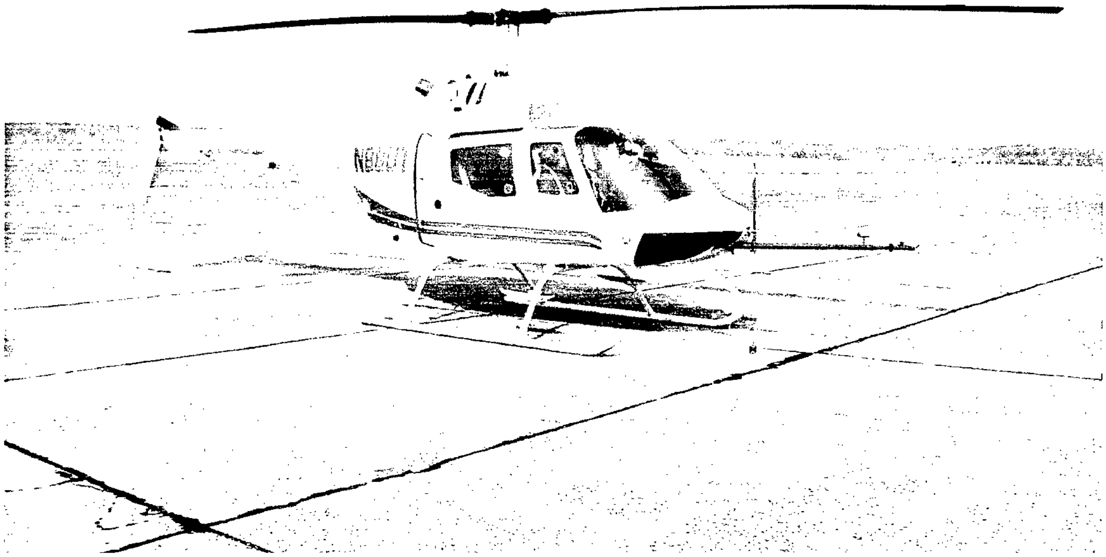

Figure 3.1. OH-58A+ (Test Aircraft - N88UT)

Chapter 4

DATA REDUCTION

Data Reduction

Data from each flight test was recorded manually on spreadsheets and with a tape recorder using cockpit instrumentation. Data was then reduced manually in accordance with the USNTPS FTM 106 and with the automated helicopter performance data reduction program developed by Mr. J. J. McCue of the U.S. Naval Experimental Test Pilot School. The following equations were used in the manual data reduction:

$$V_c = V_o + \Delta V_{ic} + \Delta V_{pos}$$

Where:

V_c	-	Calibrated airspeed
V_o	-	Observed airspeed
ΔV_{ic}	-	Airspeed instrument correction
ΔV_{pos}	-	Airspeed position error.

$$H_{p_c} = H_{p_o} + \Delta H_{p_{ic}} + \Delta H_{pos}$$

Where:

H_{pc}	-	Calibrated pressure altitude
H_{po}	-	Observed pressure altitude

ΔH_{pic}	-	Altimeter instrument correction
ΔH_{pos}	-	Altimeter position error.

$$T_a = T_o + \Delta T_{ic}$$

Where:

T_a	-	Ambient temperature
T_o	-	Observed temperature
ΔT_{ic}	-	Temperature instrument correction.

$$T_a\left(^\circ K\right) = T_a\left(^\circ C\right) + 273.15$$

Where:

T_a (°K)	-	Ambient temperature, °K
T_a (°C)	-	Ambient temperature, °C.

$$\theta = \frac{T_a}{T_{ssl}}$$

Where:

θ	-	Temperature ratio
T_a (°K)	-	Ambient temperature, °K
T_{ssl} (°K)	-	Standard sea level temperature, 288.15 °K.

$$\delta = \frac{P_a}{2116.217} = \left[1 - \left(6.875585 \times 10^{-6} \times H_{Pc}\right)\right]^{5.255863}$$

Where:

δ	-	Pressure ratio
P_a	-	Ambient pressure
H_{pc}	-	Calibrated pressure altitude.

$$\sigma_T = \frac{\delta}{\theta} = \frac{\rho_a}{\rho_{ssl}}$$

Where:

σ_T	-	Test density ratio
δ	-	Pressure ratio
θ	-	Temperature ratio
ρ_a	-	Ambient air density
ρ_{ssl}	-	Standard sea level air density.

$$ESHP_T = K_Q(Q)(N_{R_T})$$

Where:

$ESHP_T$	-	Test engine shaft horsepower
K_Q	-	Engine torque constant
Q	-	Engine torque
N_{RT}	-	Test main rotor speed.

$$ESHP_{ref} = \frac{ESHP_T}{\sigma_T}\left(\frac{N_{R_S}}{N_{R_T}}\right)^3$$

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.

$$W_T = ESGW - FU$$

Where:

W_T	-	Test weight
ESGW	-	Engine start gross weight
FU	-	Fuel used.

$$W_{ref} = \frac{W_T}{\sigma_T}\left(\frac{N_{R_S}}{N_{R_T}}\right)^2$$

Where:

W_{ref}	-	Referred weight
W_T	-	Test weight
σ_T	-	Test density ratio
N_{RS}	-	Standard main rotor speed
N_{RT}	-	Test main rotor speed.

$$\Omega R = \left(N_{R_R}\right)\left(\frac{2\pi}{60}\right)(R)$$

Where:

ΩR	-	Rotational velocity
N_{RT}	-	Test main rotor speed
R	-	Rotor radius.

$$C_P = \frac{P}{\rho_a (A_D)(\Omega R)^3}$$

Where:

C_p	-	Power coefficient
P	-	Power
ρ_a	-	Ambient air density
A_D	-	Rotor disk area
ΩR	-	Rotational velocity.

$$C_T = \frac{T}{\rho_a (A_D)(\Omega R)^2}$$

Where:

C_T	-	Thrust coefficient
T	-	Thrust
ρ_a	-	Ambient air density
A_D	-	Rotor disk area
ΩR	-	Rotational velocity.

$$V_T = \frac{V_c}{\sqrt{\sigma_T}}$$

Where:

V_T	-	True airspeed
V_c	-	Calibrated airspeed
σ_T	-	Test density ratio.

$$V_{T_{ref}} = V_T\left(\frac{N_{R_S}}{N_{R_T}}\right)$$

Where:

V_{Tref}	-	Referred true airspeed
V_T	-	True airspeed
N_{RS}	-	Standard main rotor speed
N_{RT}	-	Test main rotor speed.

$$\mu = 1.69\left(\frac{V_T}{\Omega R}\right)$$

Where:

μ	-	Advance ratio
V_T	-	True airspeed
ΩR	-	Blade rotational velocity.

$$a = 38.9678\sqrt{T_a(^{\circ}K)}$$

Where:

a	-	Speed of sound
T_a	-	Ambient temperature.

$$V_{tip} = \left(\frac{\Omega R}{1.69}\right) + V_T$$

Where:

V_{tip}	-	Blade tip velocity
ΩR	-	Blade rotational velocity
V_T	-	True airspeed.

$$M_{tip} = \frac{V_{tip}}{a}$$

Where:

M_{tip}	-	Blade tip Mach number
V_{tip}	-	Blade tip velocity
a	-	Speed of sound.

Chapter 5

FLIGHT TEST AND DATA ANALYSIS

Purpose

The purpose of this project was to evaluate the performance benefits of a Dimpletape® application to the main rotor blades of an OH-58A+ helicopter.

General

The evaluation consisted of a quantitative performance evaluation including hover performance (free hover method), level flight performance (W/σ, weight over density ratio method), and autorotation flight performance. The data were collected at a hover and at airspeeds from 40 knots observed airspeed (KOAS) to 100 KOAS, in 10 knot increments. This range of level flight airspeeds were selected to maximize observing the benefit of Dimpletape® for reduction in profile drag. Below 40 knots induced power is the major contributor to the total power requirement and above 90 knots parasite power is the major contributor. (Figure 5.1.)

Performance data of a blade with no Dimpletape® was compared to data from a blade with Dimpletape®. The Dimpletape® was installed in four different Dimpletape lengths and four different cordwise locations. The test determined Dimpletape® performance gains and the optimal Dimpletape® placement to maximize performance on an OH-58A+ helicopter.

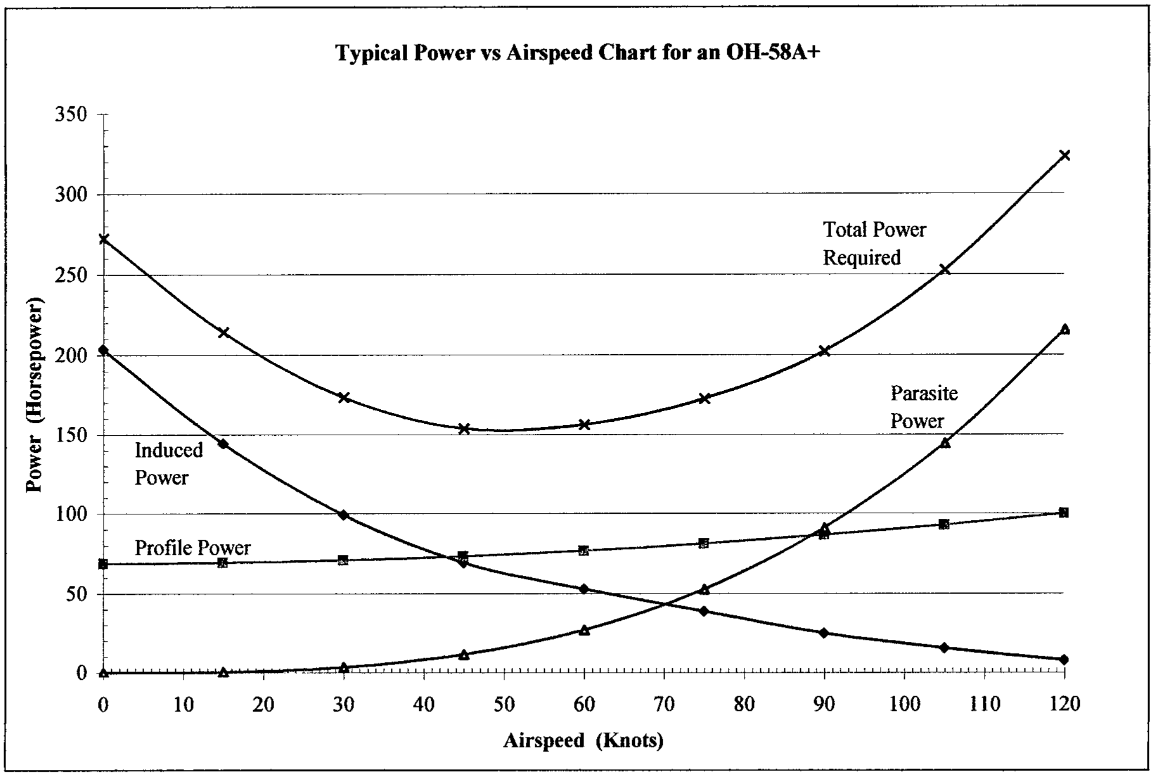

Figure 5.1. Components of Power Required in Level Flight.

An investigation was conducted to determine rotor system acoustic levels. Changes in handling qualities were also evaluated. Engineering tests were conducted per the U.S. Naval Test Pilot School Rotary Wing Performance Flight Test Manual (USNTPS FTM-106), U.S. Naval Test Pilot School Rotary Wing Stability and Control Flight Test Manual (USNTPS FTM-107), the test plan (Appendix D), and as described in the Tests and Test Conditions Table (Appendix D, Table D.1).

Dimpletape® Installation

The Dimpletape® was installed using the manufacturers recommended process. Installation procedures included: washing the main rotor blade surface area with soap and water to remove dirt and debris, and using a surface cleaner (solvent) just prior to applying the Dimpletape®. Each Dimpletape® placement was measured from the inboard side of the main rotor blade tip cap screws (approximately one inch inboard of the tip cap) and applied in six-inch lengths spanwise along the main rotor blade (Figure 5.2). The Dimpletape® was cut in six-inch lengths for safety considerations. Small sections of Dimpletape® minimize the hazards of flight control and drive system entanglement if a piece of tape debonded from the rotor blade during flight.

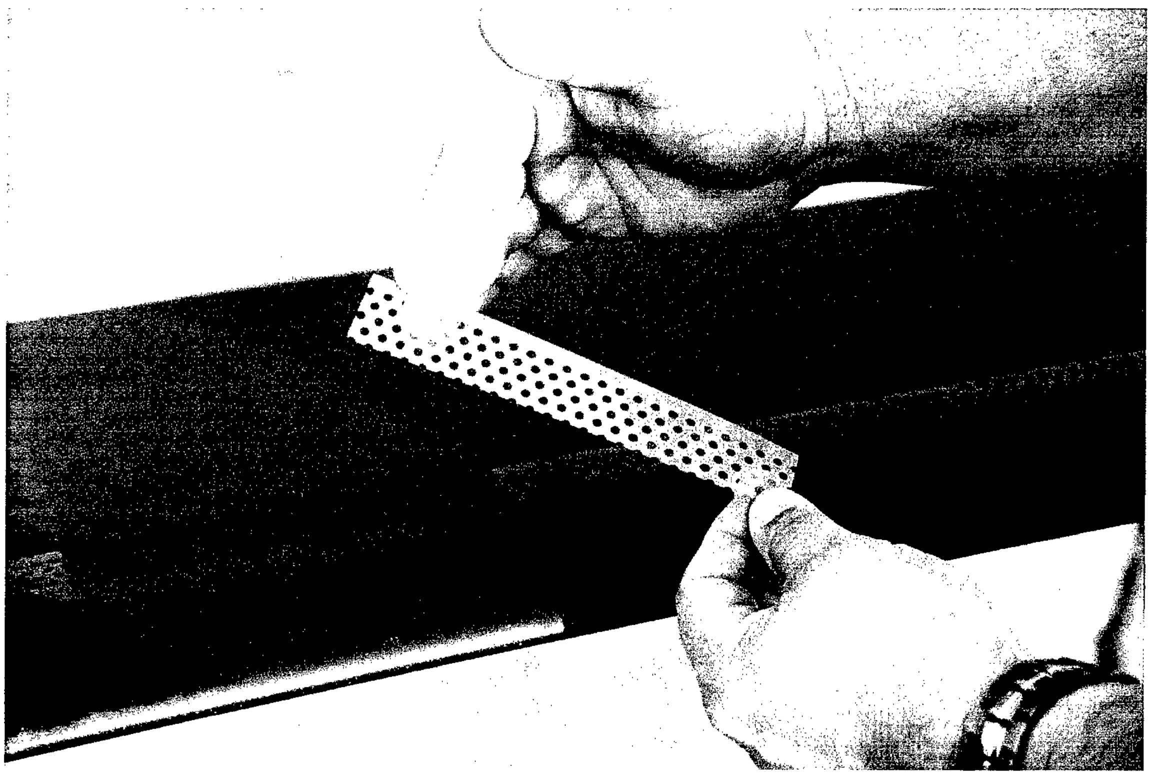

Figure 5.2. Six Inch Length of Dimpletape®.

A modified ruler (carpenters square with level attached) was used to mark a line along the blade span. The line ensured consistency in Dimpletape® positioning across the maximum camber (initial Dimpletape® positioning) of the blade. The Dimpletape® backing was removed and the tape placed on the blade. The backing material was placed on top of the Dimpletape® and pressure applied to the tape to complete the adhesion process. Table 5.1 and Figure 5.3 show the dimensions and layout of each Dimpletape® installation. The area inboard of the 75% was not installed with Dimpletape® due to the geometry of the main rotor blade doublers interrupting airflow over this area (Appendix E, Figure E.1).

Dimpletape® Adhesion

Only one debonding occurred in Dimpletape® adhesion to the main rotor blade during the 10.7 flight hours of testing. A Dimpletape® debond occurred in the outboard 10% of the main rotor blade at the 3.1 flight hour mark. The debond was approximately ½ inch long and about four inches from the inboard side of the tip cap along the leading edge of the Dimpletape®.

Table 5.1.

Dimpletape® Lengths Installed

Rotor Blade Length Percentage	Length of Dimpletape® (inches)
10%	19.5
25%	48.6
50%	97.3
75%	145.9

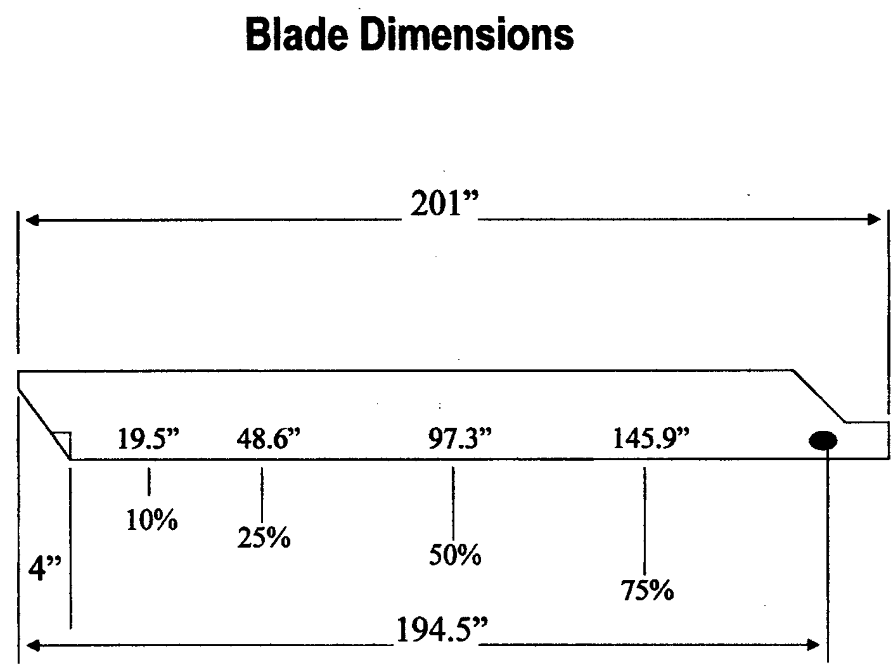

Figure 5.3. OH-58A+ Main Rotor Blade Dimensions for each Dimpletape® Length.

This section of Dimpletape® was installed at temperatures above the manufacturers required 60 degrees Fahrenheit. The debond was repaired using the manufacturers instructions by applying super glue under and along the leading edge of the debonded tape and applying pressure to the area. The Dimpletape® repair remained attached during the remainder of the flight-testing. (Figure 5.4. and Appendix E, Figure E.2.)

Acoustic Level Testing

The rotor system was evaluated to determine if Dimpletape® would reduce the acoustic level of the rotor system. An attempt was made to determine the baseline acoustic level

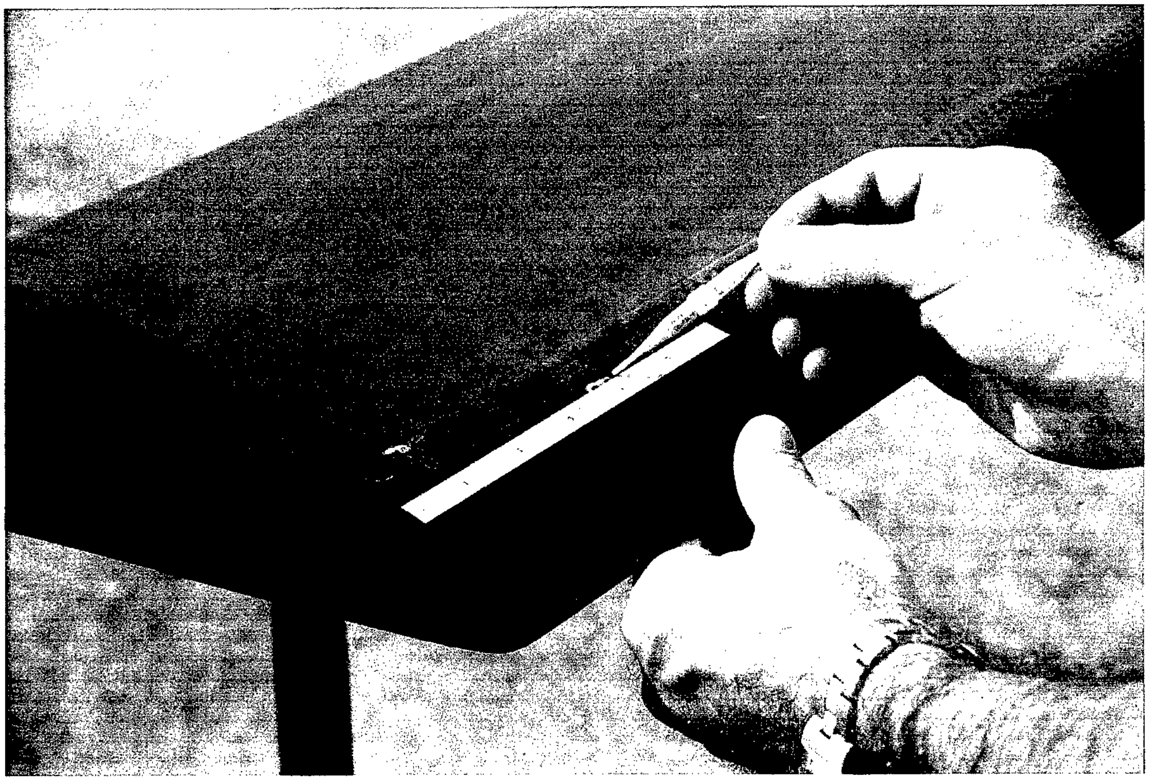

Figure 5.4. Dimpletape® Debond Position and Length.

at a distance of approximately five to ten feet outside of the rotor disk (Figure 5.5 and Appendix E, Figure E.4). The MSA Noise Dosimeter (Model 80) microphone was directed at the rotor blade tip path plane as shown in Appendix E, Figure E.3 and a measurement was attempted at various distances from the rotor system. The noise dosimeter used for the testing has a range of 80 to 130 decibels. The rotor system produced a noise level that exceeded this range and therefore the test could not be completed.

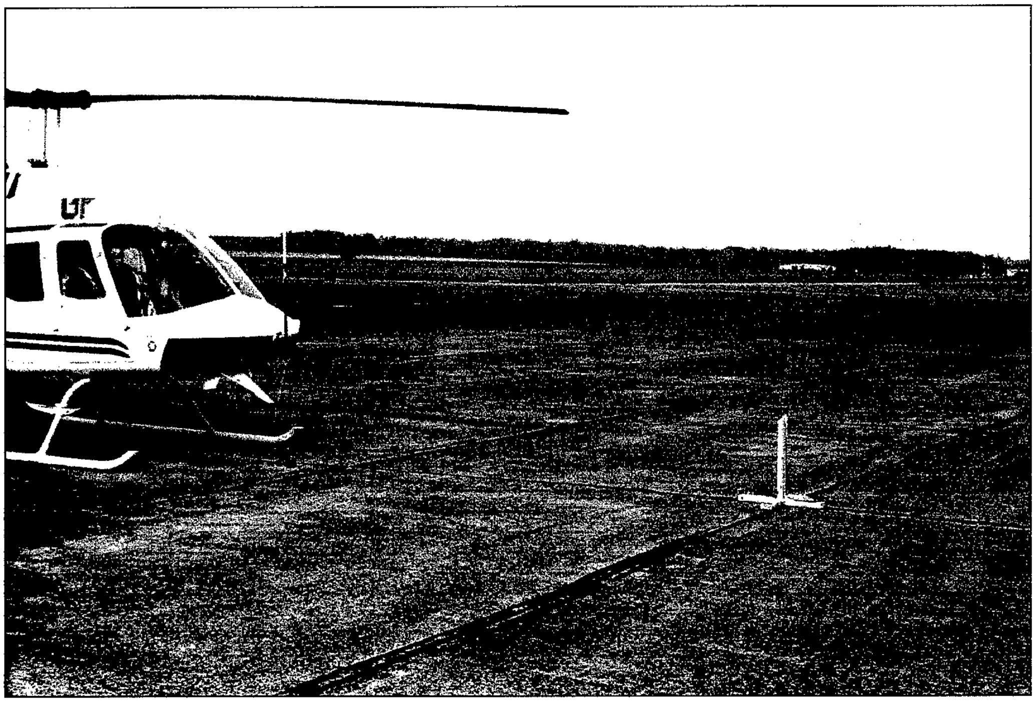

Figure 5.5. Microphone Stand Setup in Front of Aircraft.

Instrumentation and Data Acquisition

Standard cockpit instrumentation was used to acquire pertinent engine and fuel data. The aircraft test boom (Appendix E, Figure E.5.) was used to acquire altitude and airspeed data. A Hover Height Measuring Device (HHMD) was developed, fabricated, and installed on the test boom (Appendix E, Figure E.6.) during hover testing to accurately maintain hover altitude. The HHMD has a 12 inch black and white triangle pattern used to assist the pilot in maintaining altitude accurately. (Figures 5.6. and Appendix E, Figure E.4.) The HHMD black and white triangular scale is held stationary by a five-pound weight attached with a string to the position indicator. Hovering the aircraft moves the tube surrounding the scale up and down with aircraft changes in altitude.

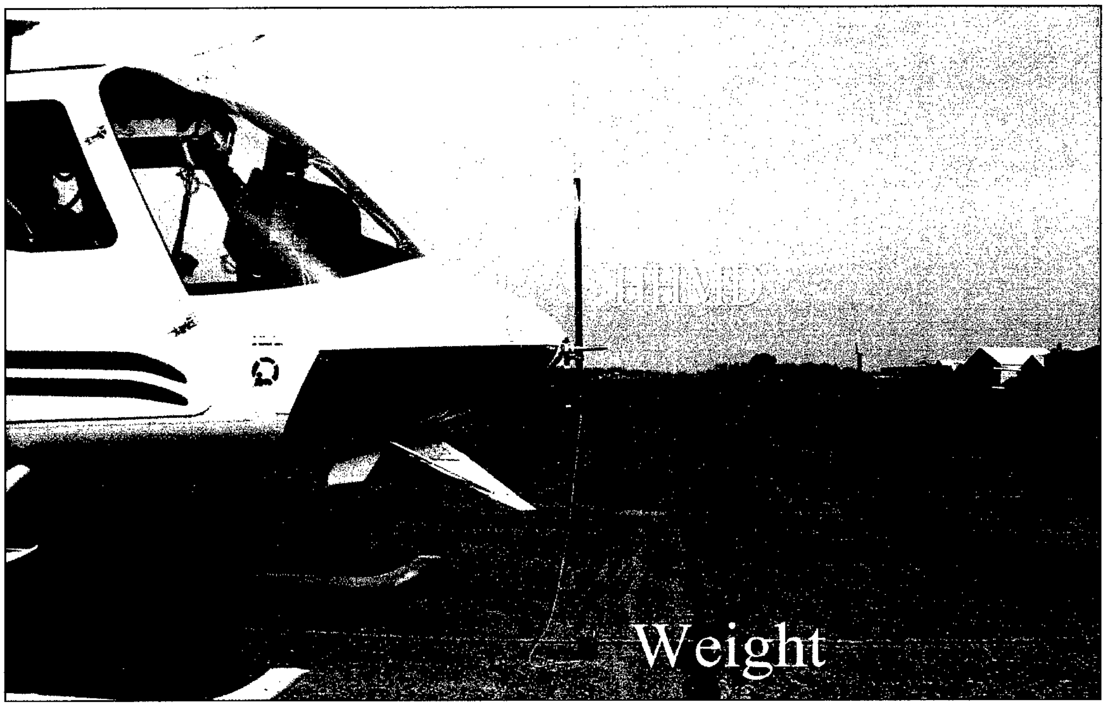

Figure 5.6. Hover Height Measuring Device (HHMD).

A spring in the bottom of the HHMD ensures consistency in scale positioning during small changes in hover altitude. Hover height for all hover flight-testing was maintained at two feet skid height. Additional equipment used consisted of a programmable calculator, stopwatch, tape recorder, and noise dosimeter.

Flight Tests and Analysis

All hover and level flight-testing was competed per U.S. Naval Test Pilot School Rotary Wing Performance Flight Test Manual, USNTPS FTM-106. Hover flight-testing was completed with winds less than three knots and was completed with predominately no wind conditions. Winds were monitored on the airfield Area Terminal Information System (ATIS) and with an anemometer in the vicinity if the test area. Temperatures varied from 1 to 26 degrees Celsius for hover testing and 14 to 24 degrees Celsius for level flight-testing. All flight-testing of Dimpletape was completed in dry conditions. Table 5.2 describes the tests and test conditions.

Pitot Static System Calibration

General

The ship and boom pitot static system were bench tested using a water manometer and mercury barometer with a vacuum pump. The test method used for the calibration of the pitot static systems were the Measured Course method outlined in FTM 106 and the Global Positioning System (GPS) method outlined in lecture notes by Dr. Ralph Kimberlin. [6]

Data Analysis

Data for the pitot system calibration are presented in Appendix A. The Boom Airspeed Indicator Calibration, Boom Altimeter Calibration, Position Error, and Instrument Corrected vs. Calibrated Airspeed charts are depicted in Appendix A, Figures A.1. through A.4. [6]

Hover Baseline *(Event 1)*

General

Free flight hover performance was evaluated by the use of a Hover Height Measuring Device (HHMD). Aircraft weight and N_R were adjusted to establish six W_{ref} values. The free flight hover test was evaluated during two flights totaling 1.0 hour. The test was conducted in a stabilized two foot IGE hover.

Table 5.2.
Test and Test Conditions

Event #	Description	Crew	Weight Referred W/σ	Pressure Altitude (ft)	C.G	Airspeed (KOAS)	Hours Flown
1	Hover Baseline Testing	1 pilot, 1 FTE, observer	2639,2803, 2983,3180, 3378,3594	820	109.6-109.9	0	1.0
2	Level flight Baseline testing	1 pilot, 1 FTE, observer	2831, 3412	1130-3110	109.5-109.8	39 to 100	1.6
3	Hover Dimpletape® Outboard ¾	1 pilot, 1 FTE, observer	2639,2803, 2983,3180, 3378,3594	895	109.6-110.2	0	0.5
4	Hover Dimpletape® Outboard ½	1 pilot, 1 FTE, observer	2639,2803, 2983,3180, 3378,3594	855	109.0-110.0	0	0.5
5	Hover Dimpletape® Outboard ¼	1 pilot, 1 FTE, observer	2639,2803, 2983,3180, 3378,3594	840	109.0-109.6	0	0.5
6	Hover Dimpletape® Outboard 1/10	1 pilot, 1 FTE, observer	2639,2803, 2983,3180, 3378,3594	850	109.3-109.9	0	0.5
7	Dimpletape® Adjusted cordwise for max reduction in profile drag	1 pilot, 1 FTE, observer	2639,2803, 2983,3180, 3378,3594	850	108.2-108.9	0	1.1
8	Level flight Dimpletape® Outboard 1/10	1 pilot, 1 FTE, observer	2831, 3412	2380-4075	109.8-110.5	40 to 101	1.1
9	Level flight Dimpletape® Outboard ¼	1 pilot, 1 FTE, observer	2831, 3412	2525-4705	109.6-110.4	40 to 100	1.2
10	Level flight Dimpletape® Outboard ½	1 pilot, 1 FTE, observer	2831, 3412	2080-5185	108.9-109.8	40 to 100	1.0
11	Level flight Dimpletape® Outboard ¾	1 pilot, 1 FTE, observer	2831, 3412	940-3640	109.7-110.0	39 to 101	1.7

At the completion of the hover test a sound signature reading was attempted. Due to limitations of the MSA Noise Dosimeter a reading was not obtained and the test terminated for the remainder of flight-testing. Helicopter loading consisted of a single pilot at the pilot station, one FTE at the co-pilot station, and observer or ballast in the passenger compartment as required. The take-off gross weight (GW) was 2683 lbs and 3101 lbs, CG ranged from 109.7 to 109.9 inches respectively.

Data Analysis

Baseline data are plotted in Appendix B along with Dimpletape® data.

Level Flight Baseline *(Event 2)*

General

Level flight performance was evaluated at two C_T values using the weight over density ratio method (W/σ). The level flight test (baseline) was evaluated during two flights totaling 1.6 hours. The pressure altitude was varied as necessary to maintain the desired W_{ref}. Helicopter loading was single pilot at the pilot station, one FTE at the co-pilot station, and observers or ballast in the passenger compartment as required. The take-off gross weight (GW) was 2649 lbs and 3065 lbs, CG was 109.6 and 109.8 inches respectively.

Data Analysis

Baseline data are presented in Appendix B along with Dimpletape® data.

Hover, Dimpletape® 75%, 50%, 25%, and 10% Lengths *(Events 3-6)*

General

Free flight hover performance was evaluated by the use of a Hover Height Measuring Device (HHMD). Aircraft weight and N_R were adjusted to establish six C_T values per Dimpletape® length. The free flight hover test of each Dimpletape® length was evaluated during four flights of approximately 0.5 hour each. The testing was conducted at a stabilized two foot IGE hover. Helicopter loading consisted of a single pilot at the pilot station, one FTE at the co-pilot station, and observer or ballast in the passenger compartment as required. The take-off gross weight (GW) averaged 2612 lbs for the light W_{ref} to 3013 lbs for the heavy W_{ref}. CG averaged 109.9 and 109.3 inches respectively.

Data Analysis

Hover data are presented in Appendix B, Figure B.1. The flight test results showed that there was a reduction in total power required (approximately one percent) when Dimpletape® was applied to the outboard 10% (19.5 inches) of the rotor blade at the maximum camber point. (Figure 5.7. and Appendix E, Figures E.7, E.8.) Power reduction at a hover in the 10% length ranged from 1.7 horsepower at a referred weight of 2400 lbs. to 4.0 horsepower at a referred weight of 3600 lbs. The average estimated error for the hover data analysis is approximately 3.8 horsepower. Data analysis results for the 10% Dimpletape® length fall within the accuracy of the tests and therefore indicate no discernable performance gain.

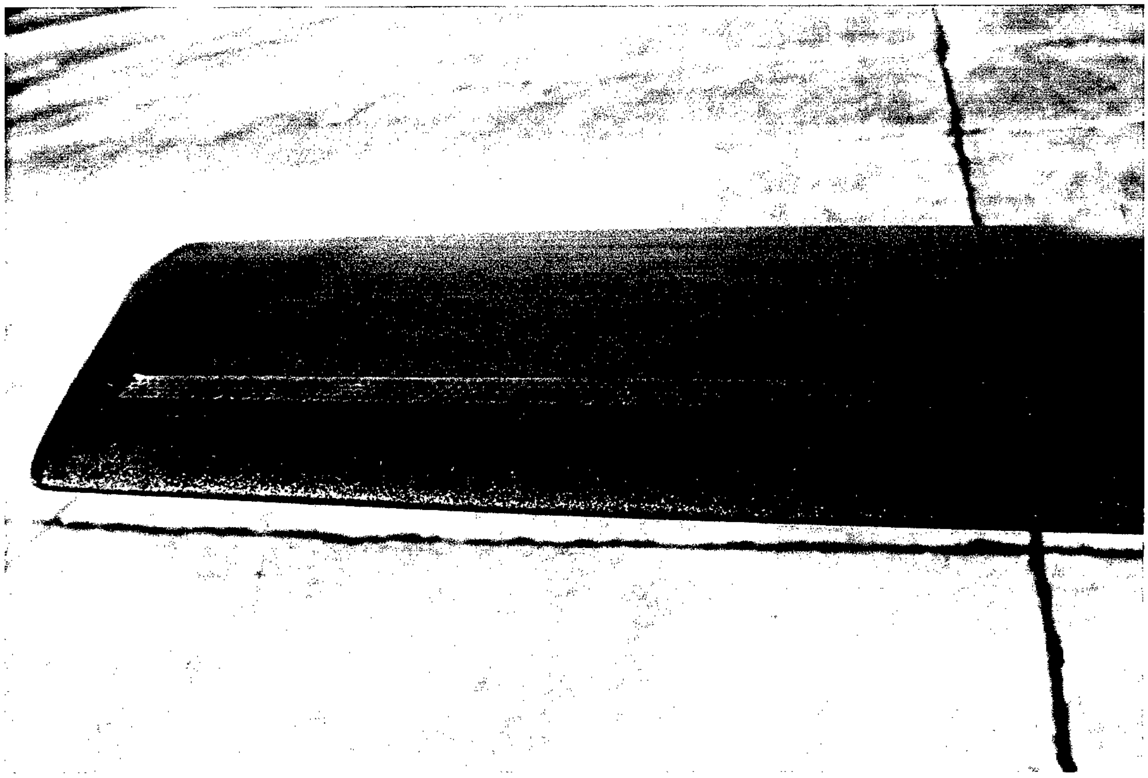

Figure 5.7. Dimpletape® at the Maximum Camber, 10% Length.

Table 5.3. indicates the change in power required to hover at two different referred weights (one light, one heavy) when compared to the baseline rotor blade with no Dimpletape® applied.

Hover, Optimum Dimpletape® Length *(Event 7)*

General

Free flight hover performance was evaluated by the use of a Hover Height Measuring Device (HHMD). Aircraft weight and N_R were adjusted to establish six C_T values per Dimpletape® cordwise placement. The free flight hover test was evaluated during two flights totaling 1.1 hour. The test was conducted at a stabilized two foot IGE hover.

Table 5.3.

Hover Power Performance

Dimpletape® Length	Δ Horsepower @ W_{ref} = 2400	Δ Horsepower @ W_{ref} = 3600	Estimated Data Analysis Error
Baseline (no Dimpletape®)	0	0	4.55
10%	**-1.7**	**-4.0**	3.48
25%	+2.2	+8.2	4.47
50%	+5.3	+6.4	2.88
75%	+8.2	+11.7	3.48

Helicopter loading consisted of a single pilot at the pilot station, one FTE at the co-pilot station, and observer or ballast in the passenger compartment as required. The take-off gross weight (GW) averaged 2841 lbs and 3160 lbs. CG averaged 108.8 inches at 2841 lbs and 108.4 inches at 3160 lbs.

Data Analysis

Hover data, optimum length, are presented in Appendix B, Figures B.2. and B.3. The 10% Dimpletape® length was chosen as the optimum length since this indicated the greatest potential for performance gain. The 10% Dimpletape® length was moved forward and aft along the rotor blade cord line in one-inch increments to determine changes in total power required to hover (Figure 5.8. and Appendix E, Figures E.9. – E.13). Moving the Dimpletape® forward increased drag and total power required to hover by approximately two percent.

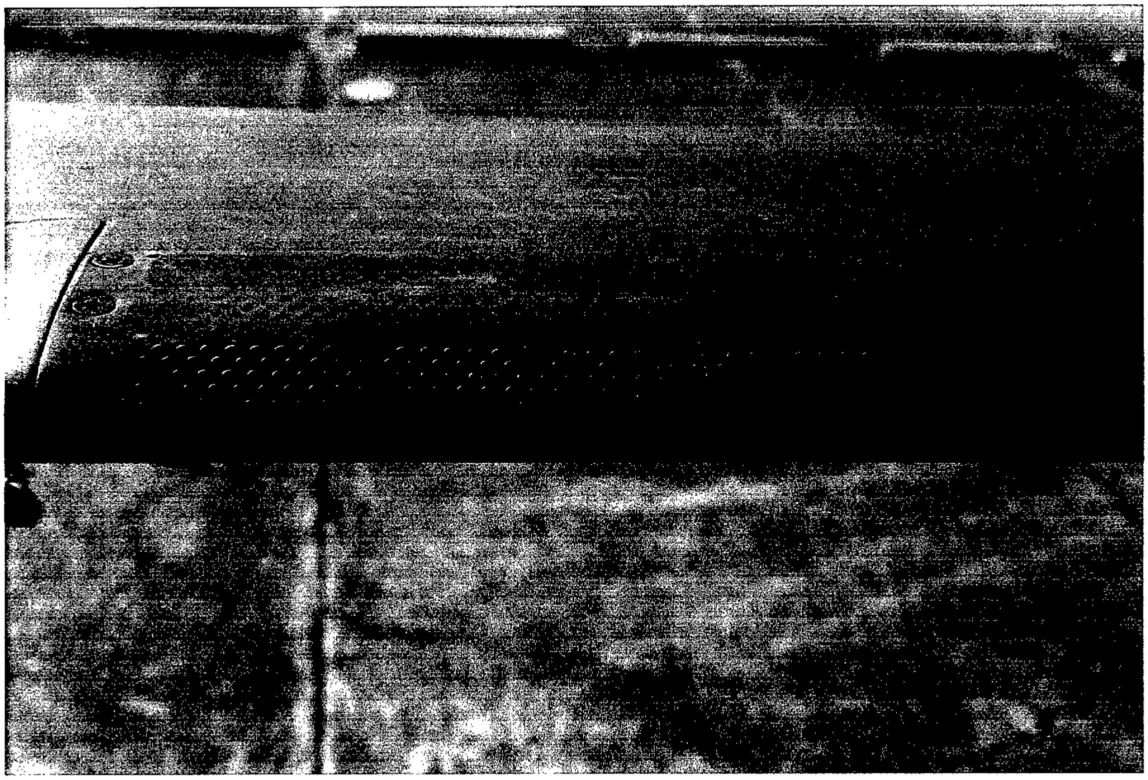

Figure 5.8. Dimpletape® Moved Forward Cordwise Two Inches from Maximum Camber Point.

Moving the Dimpletape® aft had the same effect as removing the tape from the main rotor blade and had similar power requirements as the baseline. Power reduction at a hover in the optimum length ranged from 1.7 horsepower at a referred weight of 2400 lbs. to 4.0 horsepower at a referred weight of 3600 lbs (Appendix B, Figures B.2. and B.3). The estimated error for the hover data analysis is approximately 3.48 horsepower. Data analysis results for the Optimum Dimpletape® length fall within the accuracy of the tests and therefore indicate <u>no discernable performance gain</u>. Table 5.4. indicates the change in

Table 5.4.

Hover Power Performance (Optimum Dimpletape® Length)

Cordwise Position	Δ Horsepower @ W_{ref} = 2400	Δ Horsepower @ W_{ref} = 3600	Estimated Data Analysis Error
Baseline (no Dimpletape®)	0	0	4.55
Original Position (Optimum)	**-1.7**	**-4.0**	3.48
1" Forward of Original Position	+7.2	+6.4	2.45
2" Forward of Original Position	+7.0	+10.4	3.09
1" Aft of Original Position	+0.4	-0.1	4.24

power required to hover at two different referred weights when compared to the baseline rotor blade with no Dimpletape® applied.

Level Flight, Dimpletape® 75%, 50%, 25%, 10% Length *(Events 8-11)*

General

Level flight performance was evaluated at two C_T values using the weight over density ratio method (W/σ). The Level Flight Test of Dimpletape® was evaluated during eight flights of approximately 0.6 hour each (two flights per Dimpletape® length). The pressure altitude was varied as necessary to maintain the desired W/σ. Helicopter loading consisted of a single pilot at the pilot station, one FTE at the co-pilot station, and observer or ballast in the passenger compartment as required. The take-off gross weight (GW) averaged 2615 lbs and 2939 lbs. CG averaged 110.1 inches and 109.7 inches respectively.

Data Analysis

1. **Level Flight Performance (C_T = 0.00291)** – Level Flight data for a referred aircraft weight of 2831 pounds are presented in Appendix B, Figures B.4. and B.5. At a referred gross weight of 2831 pounds the best level flight performance was obtained from the 10% Dimpletape® length (outboard 19.5" of the main rotor blade). The 10% length power requirement was greater than the baseline. The estimated error in the baseline data is 3.0 horsepower and for the 10% Dimpletape® length data is 2.2 horsepower. The results of the data analysis indicate no discernable performance gain.

   Level Flight Performance (C_T = 0.00351) - Level Flight data for a referred aircraft weight of 3412 pounds are presented in Appendix B, Figures B.6. and B.7. At a referred gross weight of 3412 pounds the best level flight performance gain was obtained from the 10% Dimpletape® length (outboard 19.5" of the main rotor blade). The reduction in power occurred at airspeeds less than 80 Knots True Airspeed (KTAS). In Table 5.5. the change in horsepower required for level flight as a result of applying the 10% Dimpletape® length is compared against the baseline. The estimated error (data scatter) in the baseline data is 4.2 horsepower and for the 10% Dimpletape® length data is 3.5 horsepower. The results of the data analysis fall within the accuracy of the tests and therefore indicate no significant performance gain.

Table 5.5.

Level Flight Performance ($C_T = 0.00351$)

KTAS	Δ Horsepower @ 10% Dimpletape® Length
40	-5.6
50	-4.5
60	-3.2
70	-1.6
80	+0.4
90	+2.5
100	+4.7

Autorotation, Dimpletape® 75%, 50%, 25%, 10% Length *(All Level Flight Tests)*

<u>General</u>

An autorotation was completed at the end of each level flight performance test. The autorotation was completed to determine any improvement in the rotor systems ability for increased acceleration due to any reduction in profile drag coefficient ($\overline{C}_{d_o}$). Autorotation rotor speed recovery rate performance was evaluated at one C_T using the W/σ method. Main rotor speed was reduced to 95% and stabilized 400 feet prior to reaching the test altitude. N_R speed recovery rate was timed from 95% to 100%. These times where compared to determine if any of Dimpletape® length reduced the time required for the main rotor speed to recover to 100%. At least two autorotations where performed for each Dimpletape® length to ensure repeatability of test results. Autorotations where performed at the conclusion of the level flight performance test for each Dimpletape® length at a referred gross weight of 3412 lbs ($C_T = 0.00351$). The pressure altitude was varied as necessary to maintain the desired W_{ref}. Helicopter loading was single pilot at the pilot station, one FTE at the co-pilot station, and observer or ballast in the passenger compartment as required.

Data Analysis

All test results for each Dimpletape® layout were within 0.3 seconds of each other. Test data varied from 3.2 seconds to 4.5 seconds with no clear trend. The results fall within the accuracy of the test in that autorotational rotor acceleration speeds are dependent on pilot technique and the accuracy of reading rotor speed at 95% and 100% from standard aircraft instrumentation. Due to these limitations this is not a valid technique for measuring autorotational rotor acceleration and therefore make this test inconclusive. Test data results are listed in Table 5.6.

Sound Level Testing *(All Hover Flight Tests)*

Due to limitations in the MSA 80 Noise Dosimeter monitoring range changes in the sound level where not recorded with the meter. Several distances and angles where tried in an attempt to measure rotor system acoustic levels. During each attempt the acoustic level exceeded the meter capability. The flight crew observed no noticeable change in acoustic level.

Table 5.6.

Autorotational Speed Recovery Rate

Dimpletape® Length	Average Elapsed Recovery Time (seconds)
Baseline	4.35
10%	4.05
25%	4.30
50%	4.30
75%	3.25

Handling Qualities *(All Flight Tests)*

Handling qualities did not vary from baseline conditions with Dimpletape® installed in any of the configurations.

Operational Considerations

The application of Dimpletape® is relatively simplistic when following the manufactures instructions. The following are several issues and observations concerning the use of Dimpletape®.

1. Dimpletape® comes from the manufacturer in boxed rolls of tape and would be easy to store until needed for installation or repairing a debonded section of tape.

2. During testing a ruler – level combination was used to ensure uniform positioning of the Dimpletape® from the rotor blade leading edge. Fleet wide installation of the Dimpletape® would require the fabrication of a jig to establish uniform positioning

of the Dimpletape® from the leading edge of the blade at the maximum camber point.

3. Prior to testing a safety requirement was established to cut and install the Dimpletape® in 6-inch sections. This requirement minimized the potential hazard of tail rotor assembly entanglement by the Dimpletape® if it were to debond from the main rotor blade. Cutting the tape to length and installing the small pieces substantially added to the installation time (approximately 0.5 to 1.5 man hour per blade depending on the installation length).

4. The manufacturer states that Dimpletape® should be applied at temperatures above 60 degrees Fahrenheit. However, during a cold weather application (seven degrees Celsius) the rotor blades had to be preheated with a hot air gun prior to the Dimpletape® application, Appendix E, Figure E.15. The tape had difficulty sticking to the rotor blade surface prior to the heat application and required more rubbing than during warm weather application to get the tape to properly bond. Cold weather operations would necessitate the preheating of the blade surface in the area of intended tape application. This would make cold weather installation and maintenance of the Dimpletape® labor intensive.

5. It is the author's view that Dimpletape® is difficult to apply during cold weather operations and will probably debond from rotor blades during harsh weather

conditions. This in itself will make the use of Dimpletape® a burden for the user to maintain.

6. After each flight the Dimpletape® was inspected for any debonded sections and repaired if necessary. The inspection of each rotor blade required approximately 0.5 man hour. The repair of the one instance of Dimpletape® debonding required approximately 0.5 man hour (glue application and drying time).

7. Dimpletape® is easy to remove by using a fingernail to get up under the edge of the tape and then peeling the tape back, Appendix E, Figure E.14. Dimpletape® leaves virtually no residue on the rotor blade when removed. Dimpletape® removal from the main rotor blades required approximately 0.5 man hour.

Chapter 6

CONCLUSIONS

The following conclusions can be drawn from the flight-testing data analysis:

1. **General** – The application of Dimpletape® will not significantly reduce the power required by the rotor system (< 1.0 %). In most of the test lengths Dimpletape® increased the power requirements of the rotor system. Dimpletape® will increase maintenance requirements.

2. **Hover Performance, Optimum Dimpletape® Length** - The 10% Dimpletape® length (maximum camber position) was evaluated as the optimum layout since this length indicated the greatest potential for performance gain. However, data analysis results for the Optimum Dimpletape® length fall within the accuracy of the tests and therefore indicate <u>no measurable performance improvement</u>.

3. **Level Flight Performance** - At referred gross weights of 2831 pounds and 3412 pounds there is <u>no measurable performance improvement</u> with the use of Dimpletape®.

4. **Autorotaional Speed Recovery Rate** - Test data results varied from 3.2 seconds to 4.5 seconds with no clear trend. This indicates no enhanced or degraded recovery rate.

5. **Acoustic Level** – The flight crew did not observe any changes in the noise level from the baseline rotor system when Dimpletape® was applied.

6. **Handling Qualities** - Handling qualities did not vary from baseline conditions with Dimpletape® installed in any of the configurations.

7. **Dimpletape® Adhesion** – A Dimpletape® debond (approximately ½ inch along the leading edge) occurred in the outboard 10% of the rotor blade. The debond was repaired using the manufacturers instructions. This repair withstood the remainder of the testing without further incident.

8. **Operational Considerations** – The application of Dimpletape® is simplistic when following the manufacturer's instructions. However, it is the author's view that Dimpletape® will probably debond from rotor blades during adverse weather conditions and require repetitive maintenance procedures for repairing the tape. Dimpletape® is also a tail rotor hazard when applied in long lengths to the rotor blades. A complete debond of a full length section of Dimpletape® would have the potential for wrapping

around tail rotor components and jeopardizing aircrew safety. This will make the use of Dimpletape® a significant burden for the user to maintain.

Chapter 7

RECOMMENDATIONS

Test results indicate that Dimpletape® did not significantly reduce power requirements for the aircraft tested and with this in mind the author makes the following recommendations:

1. Do not consider Dimpletape® for operational use on rotary wing aircraft.

2. Do not perform any further testing of Dimpletape® on rotary wing aircraft.

Works Consulted

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1. Flight Test Manual, "*Rotary Wing Performance*" Naval Air Test Center, USNTPS-FTM-No. 106, 31 December 1996.

2. Flight Test Manual, "*Rotary Wing Stability and Control.*" Naval Air Test Center, USNTPS-FTM-No. 107, 31 December 1995.

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APPENDICIES

Appendix A: **Test Aircraft Pitot Statics.**

Appendix B: **Flight Test Data.**

Appendix C: **Aircraft Weight and Balance.**

Appendix D: **Dimpletape® Test Plan.**

Appendix E: **Dimpletape® and Instrumentation Installation.**

A P P E N D I X   A

TEST AIRCRAFT PITOT STATICS

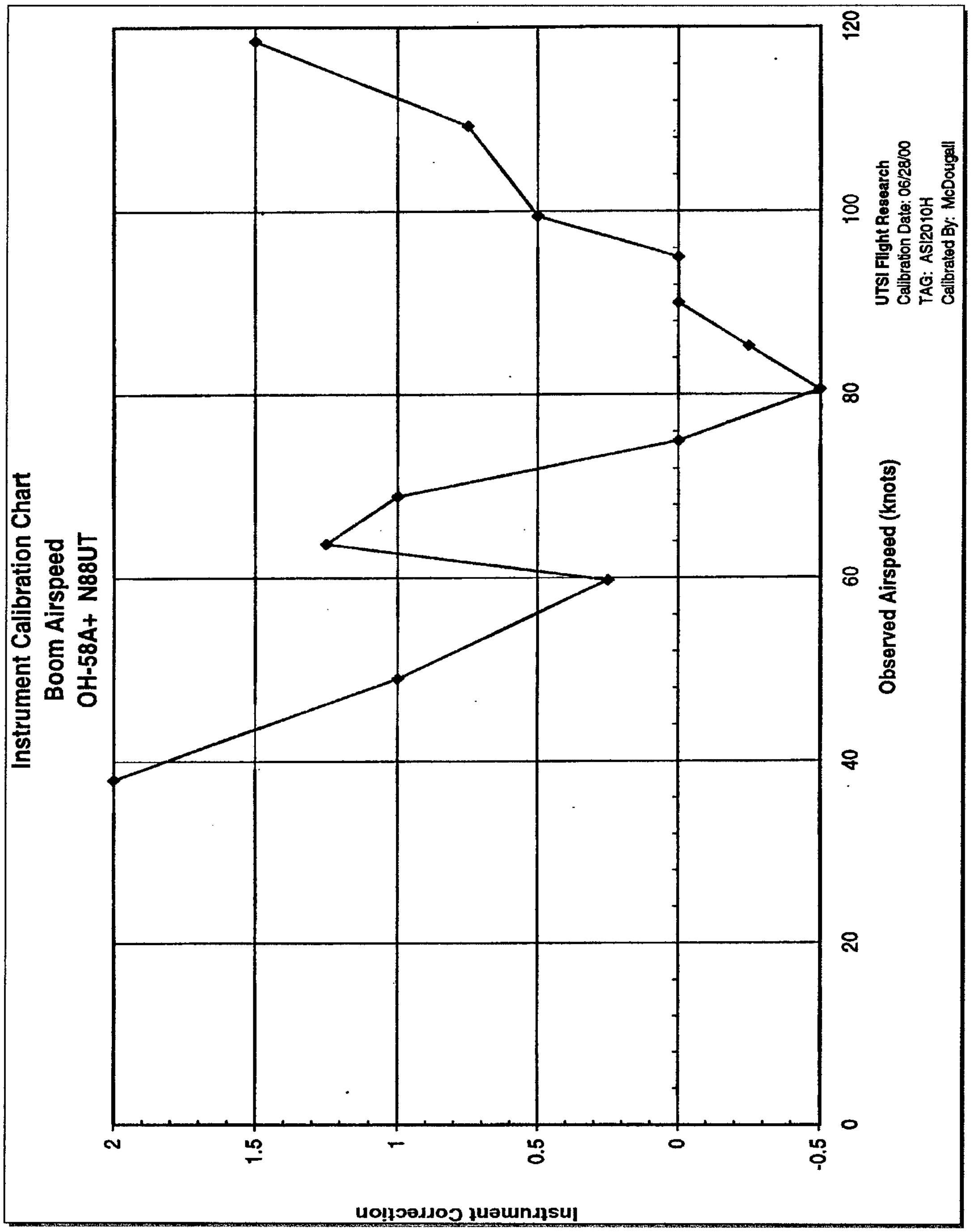


Figure A.1. N88UT Boom Airspeed Indicator Calibration Chart. [6]

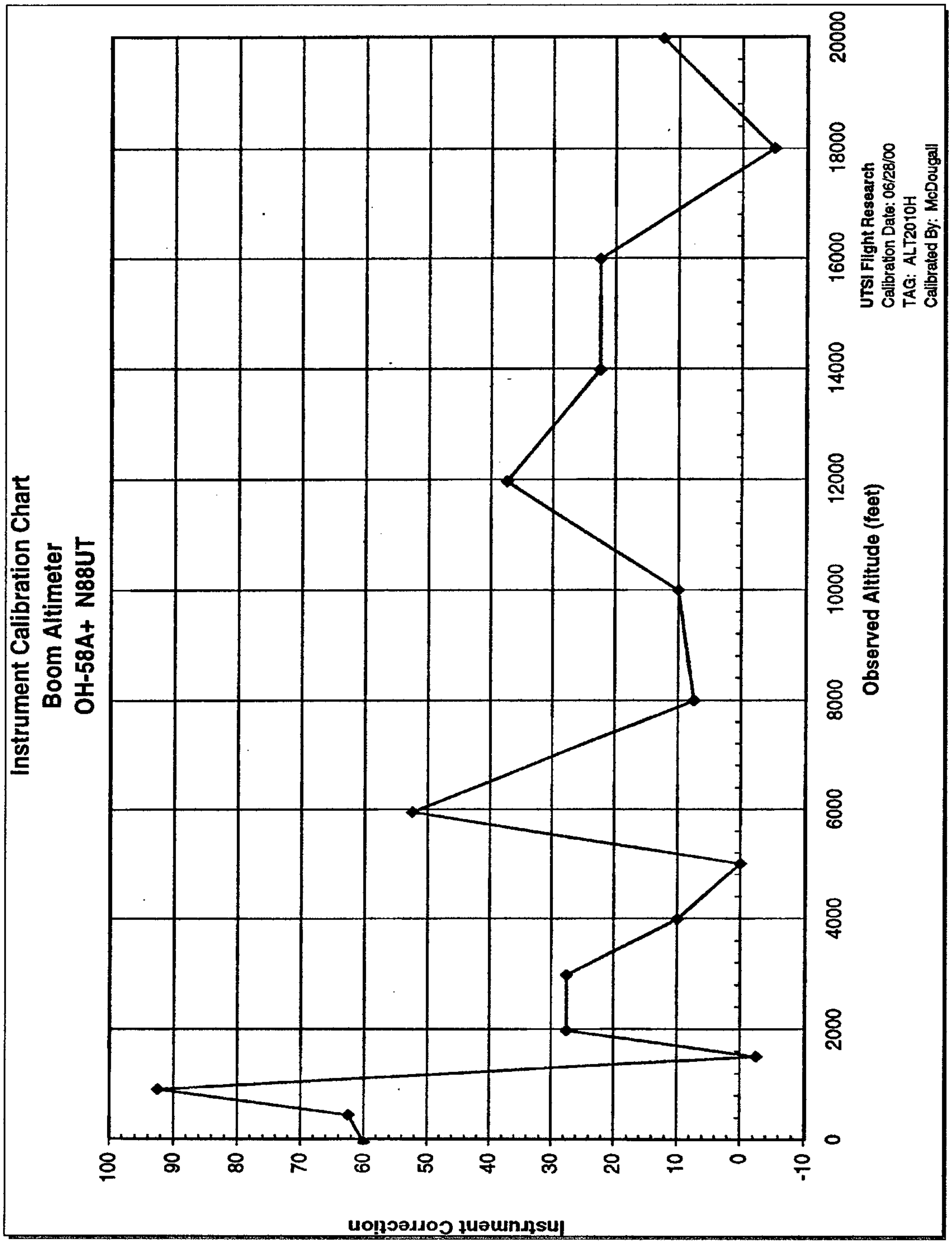


Figure A.2. N88UT Boom Altimeter Calibration Chart. [6]

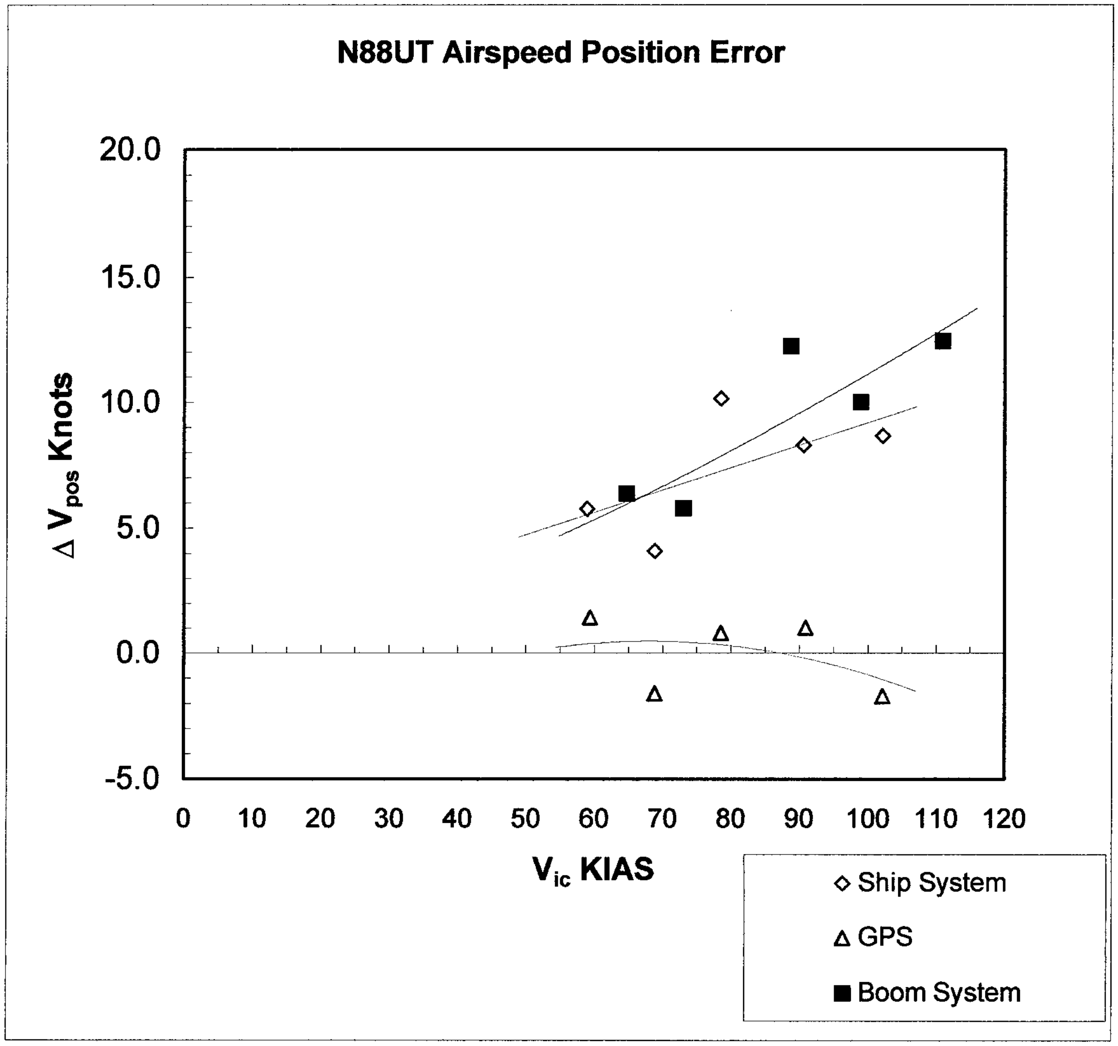


Figure A.3. N88UT Position Error Chart. [6]

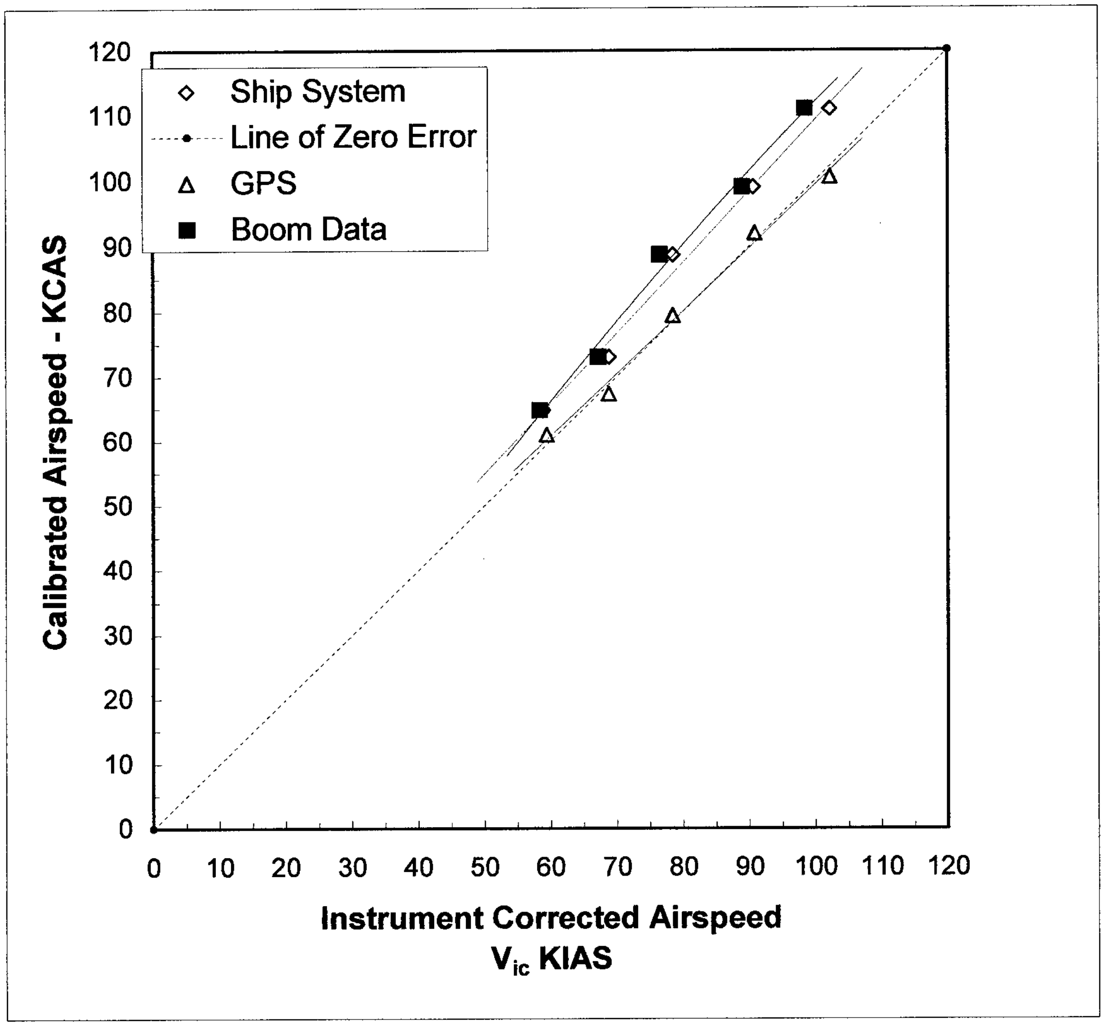


Figure A.4. N88UT Instrument Corrected vs. Calibrated Airspeed Chart. [6]

APPENDIX B

FLIGHT TEST DATA

Aircraft:	OH-58A+	**Date:**	30-31 October 2000
Pilot:	Lewis	**FTE's:**	Deetman, Callendar, Mulnik, Davis
Test:	Referred Hover Performance	**C_T:**	.00271, .00288, .00306, .00327, .00347, .00369

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 2639 lbs., 2803 lbs., 2983 lbs., 3180 lbs., 3378 lbs.,3594 lbs., Average CG 109.7.

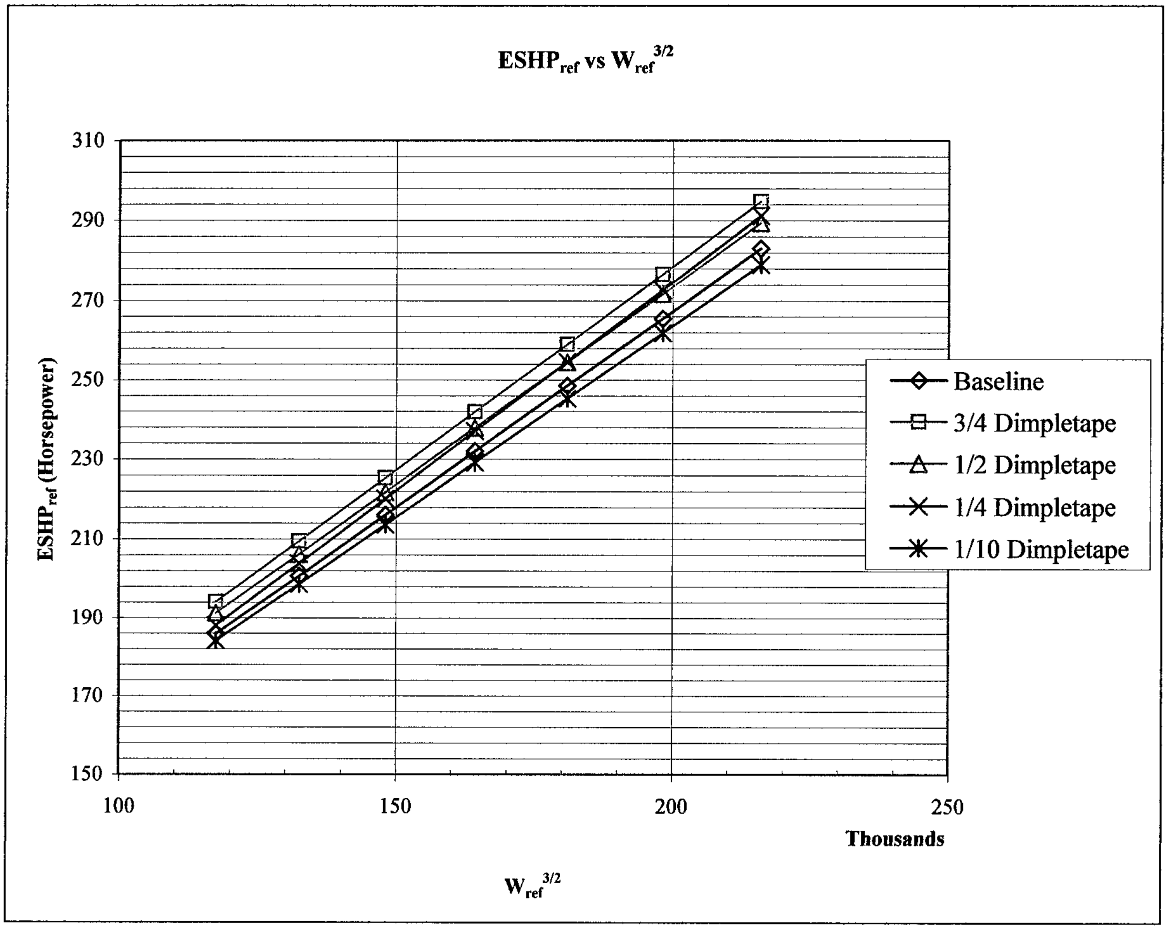


Figure B.1. Referred Hover Performance Comparison of Dimpletape® Lengths.

Aircraft:	OH-58A+	**Date:**	15 November 2000
Pilot:	Lewis	**FTE's:**	Deetman, Callendar
Test:	Referred Hover Performance	**C_T:**	.00271, .00288, .00306, .00327, .00347, .00369

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 2639 lbs., 2803 lbs., 2983 lbs., 3180 lbs., 3378 lbs.,3594 lbs., Average CG 109.0.

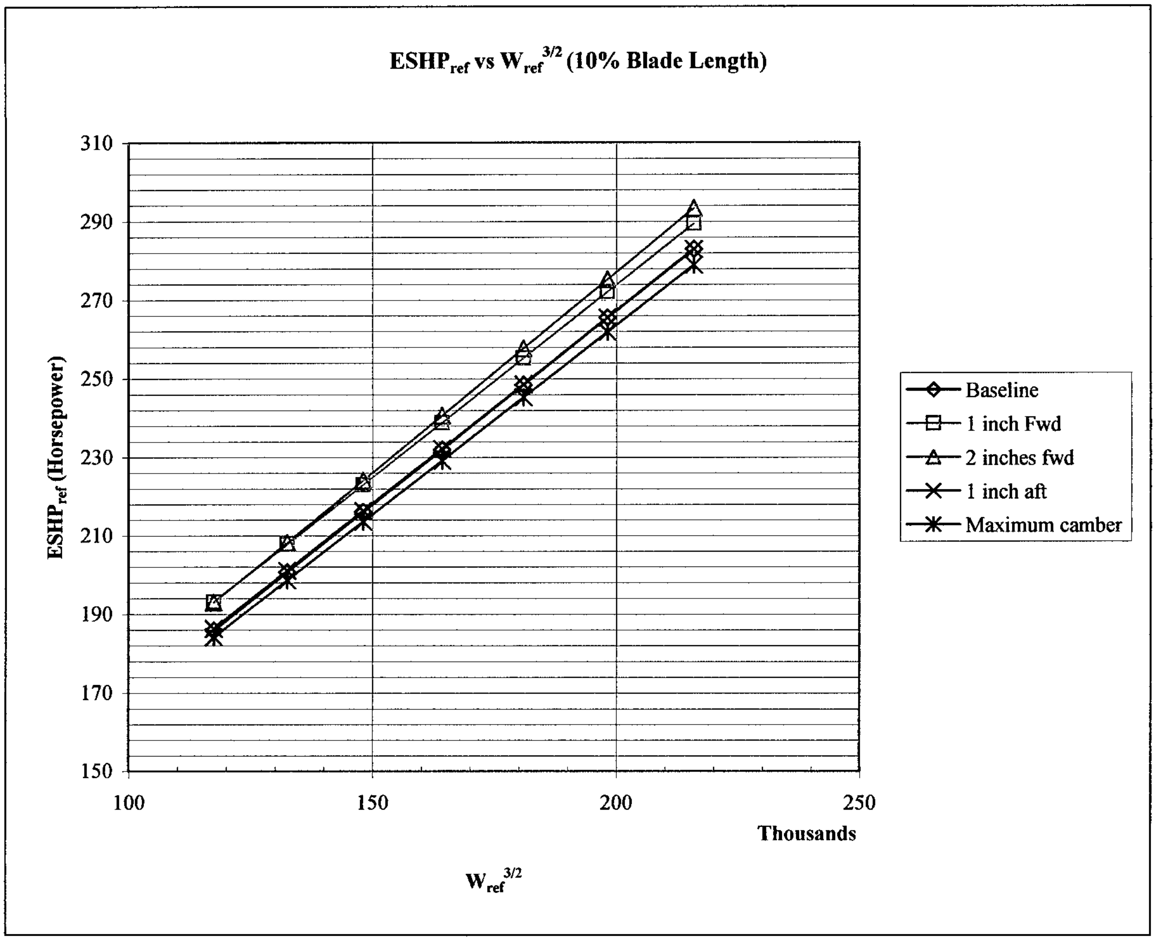


Figure B.2. Referred Hover Performance Comparison of Dimpletape® Lengths at 10% Blade Length, Optimum Layout.

Aircraft:	OH-58A+	**Date:**	15 November 2000
Pilot:	Lewis	**FTE's:**	Deetman, Callendar
Test:	Referred Hover Performance	**C_T:**	.00271, .00288, .00306, .00327, .00347, .00369

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 2639 lbs., 2803 lbs., 2983 lbs., 3180 lbs., 3378 lbs., 3594 lbs., Average CG 109.0.

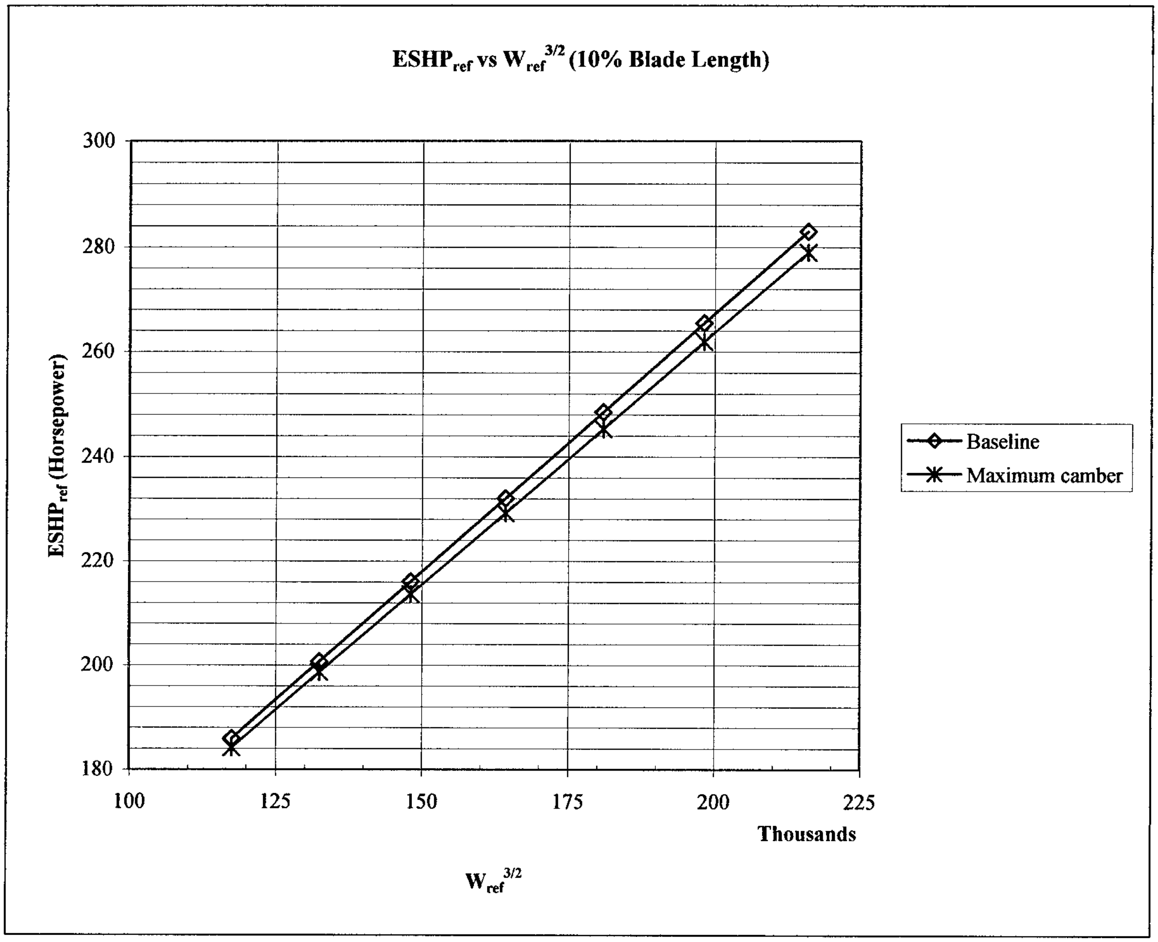


Figure B.3. Expanded View, Referred Hover Performance Comparison of Dimpletape® Length at 10% Blade Length, Optimum Layout, Baseline versus Maximum Camber.

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Referred Level Flight	**C_T:**	.00291

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W/σ 2831 lbs., Average CG 109.8.

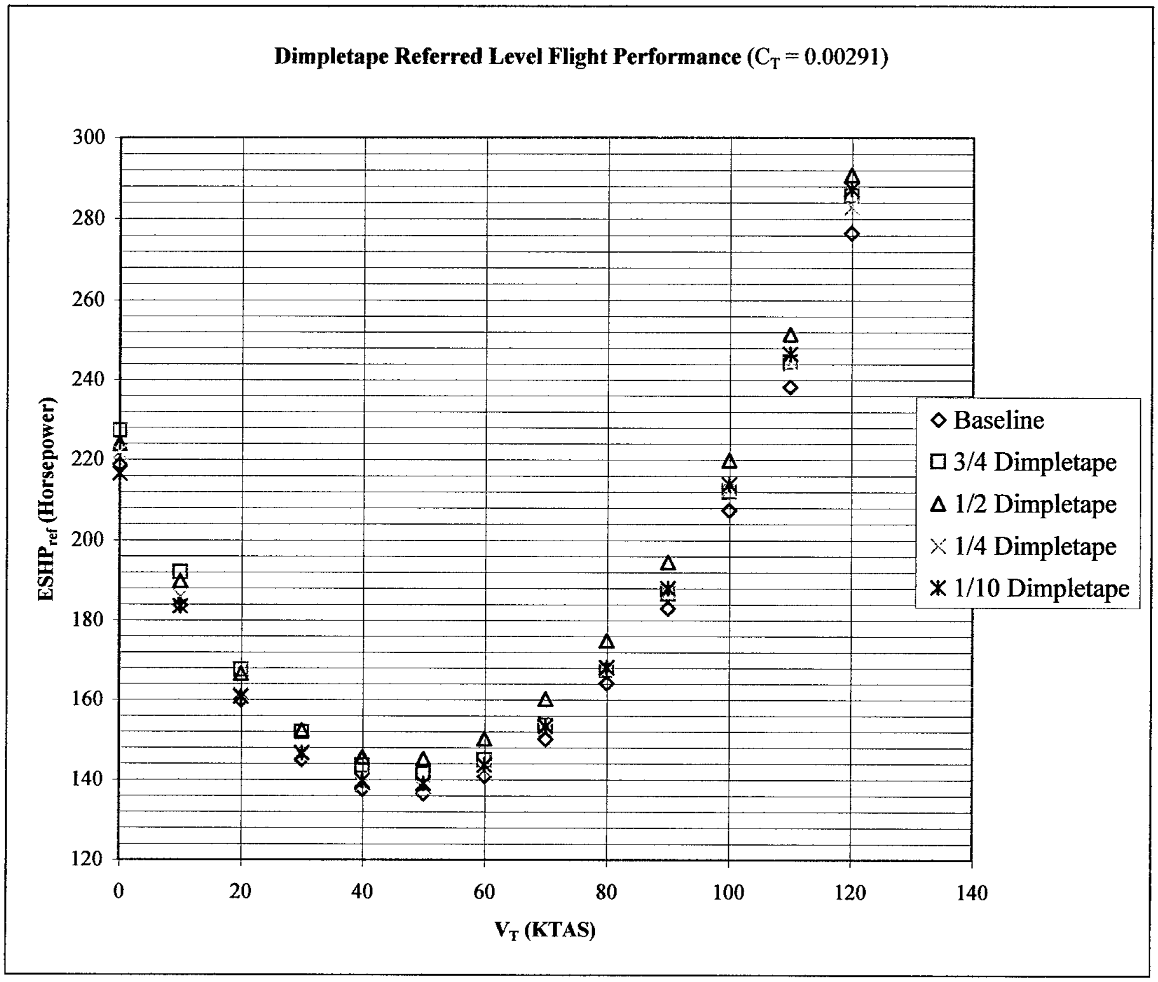


Figure B.4. Referred Level Flight Comparison of Dimpletape® Lengths,

C_T = 0.00291.

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Referred Level Flight	**C_T:**	.00291

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W/σ 2831 lbs., Average CG 109.8.

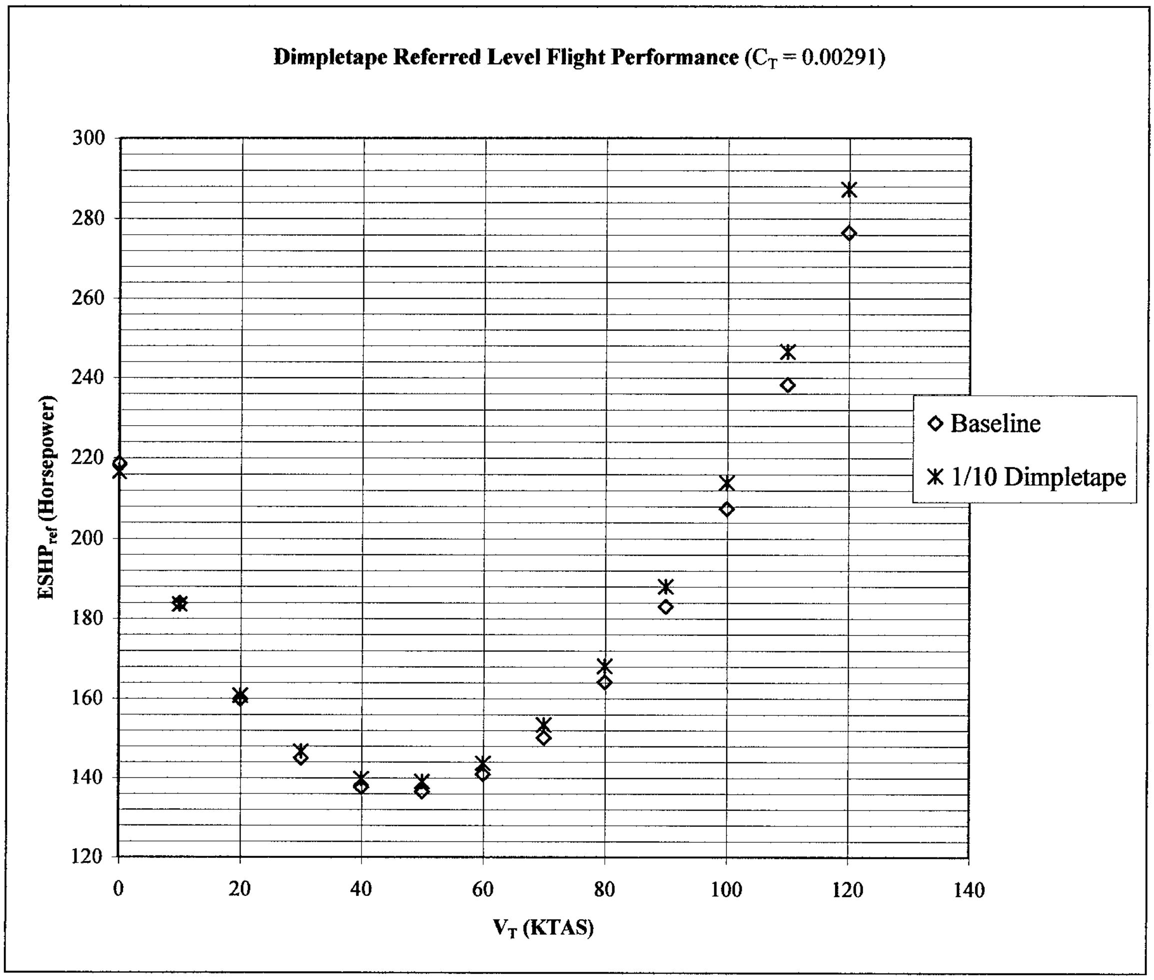


Figure B.5. Expanded View, Referred Level Flight Comparison of Dimpletape® Lengths, Baseline versus 10% Dimpletape® Length, C_T = 0.00291.

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Referred Level Flight	**C_T:**	.00351

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 3412 lbs., Average CG 109.8.

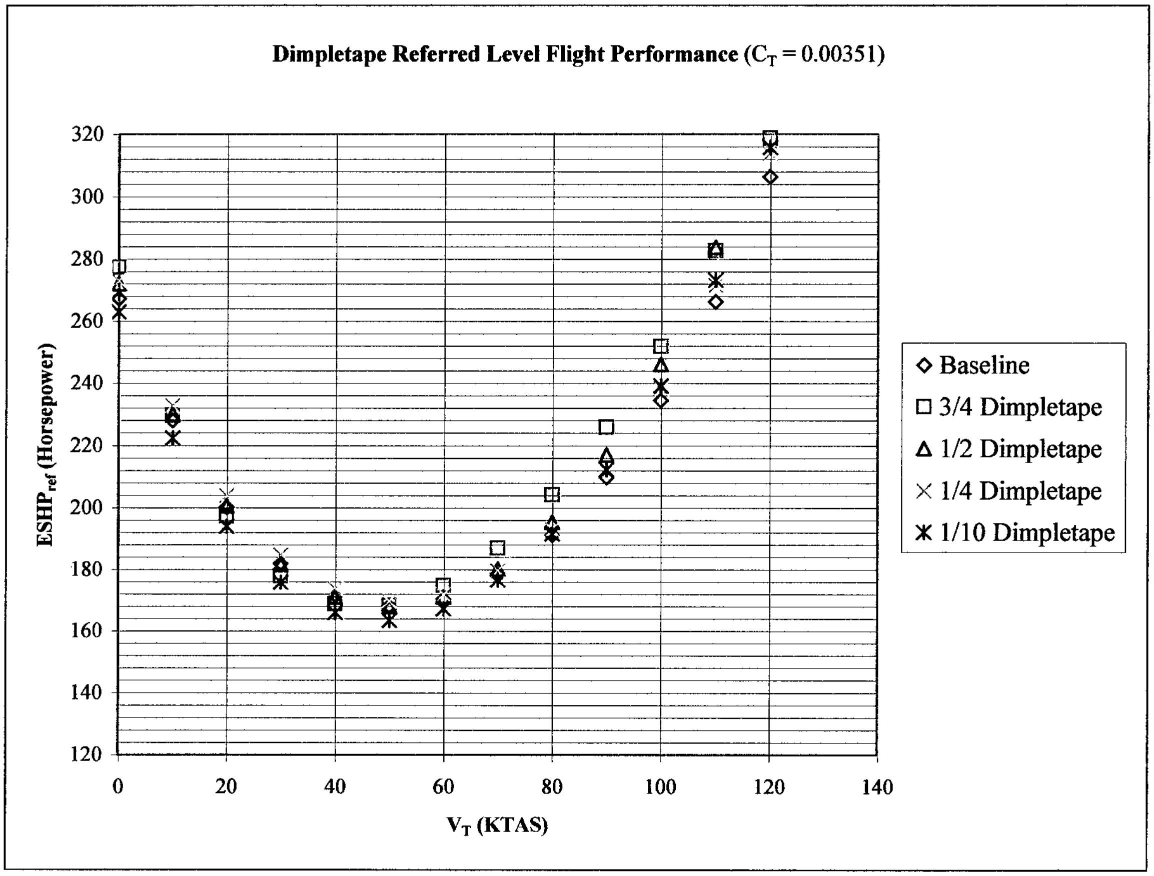


Figure B.6. Referred Level Flight Comparison of Dimpletape® Lengths,

C_T = 0.00351.

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Referred Level Flight	**C_T:**	.00351

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 3412 lbs., Average CG 109.8.

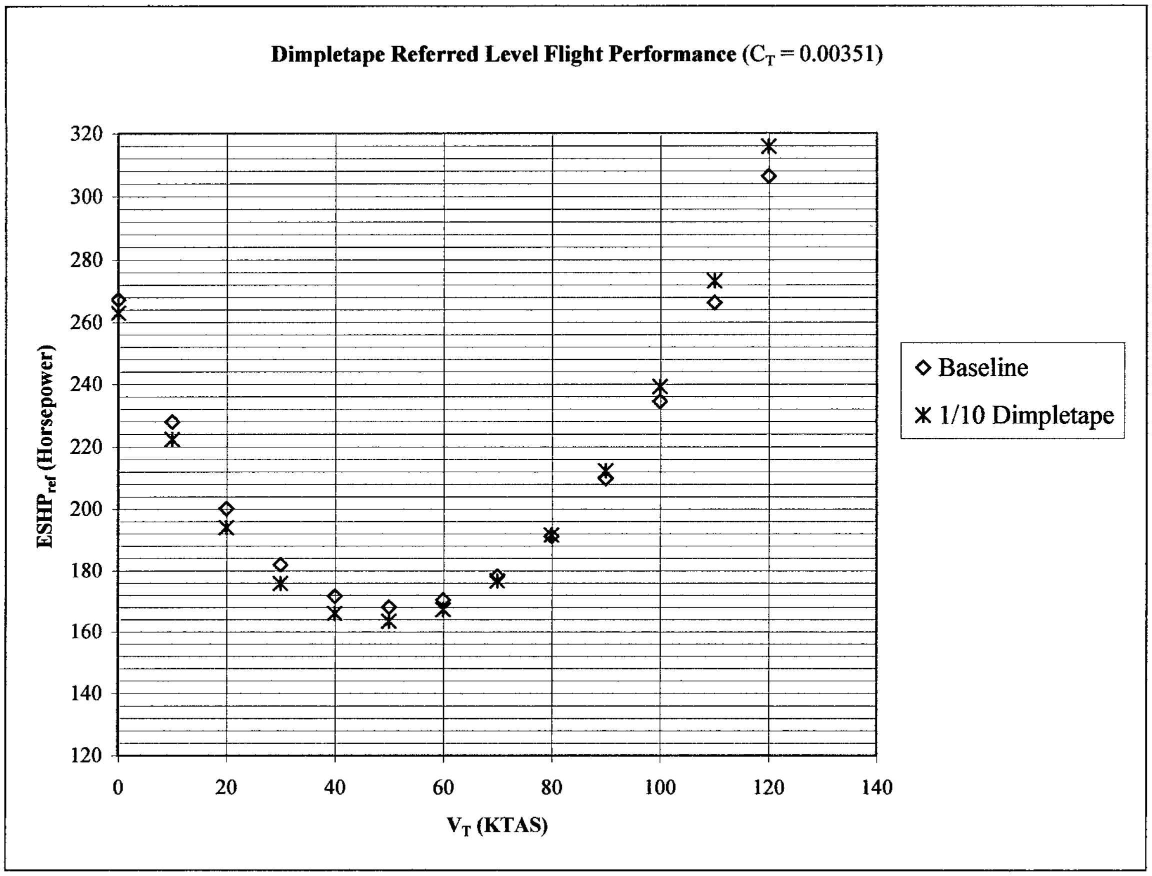
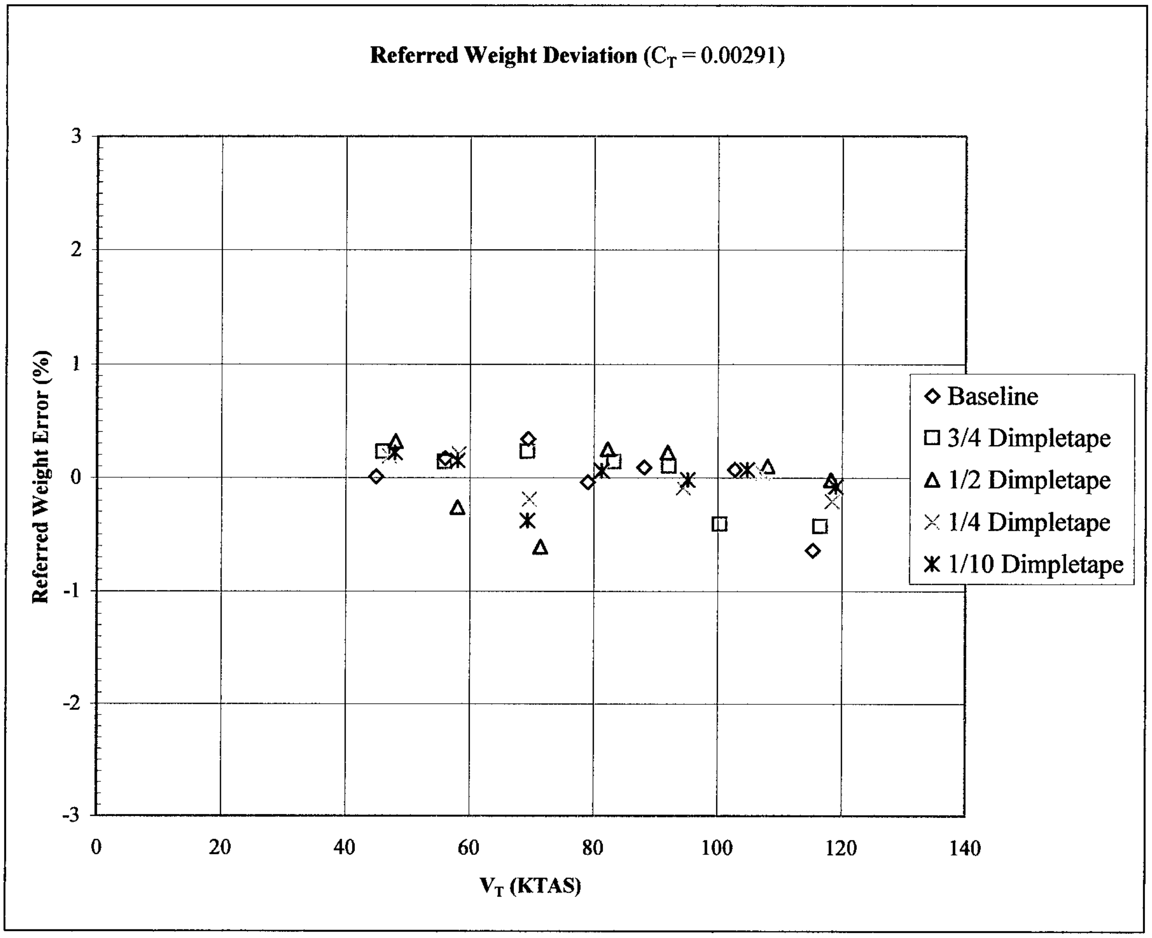


Figure B.7. Expanded View, Referred Level Flight Comparison of Dimpletape® Lengths, Baseline versus 10% Dimpletape® Length, C_T = 0.00351.

Aircraft:	OH-58A+	**Date:**	2 – 4 August 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Referred Weight Deviation	**C_T:**	.00291

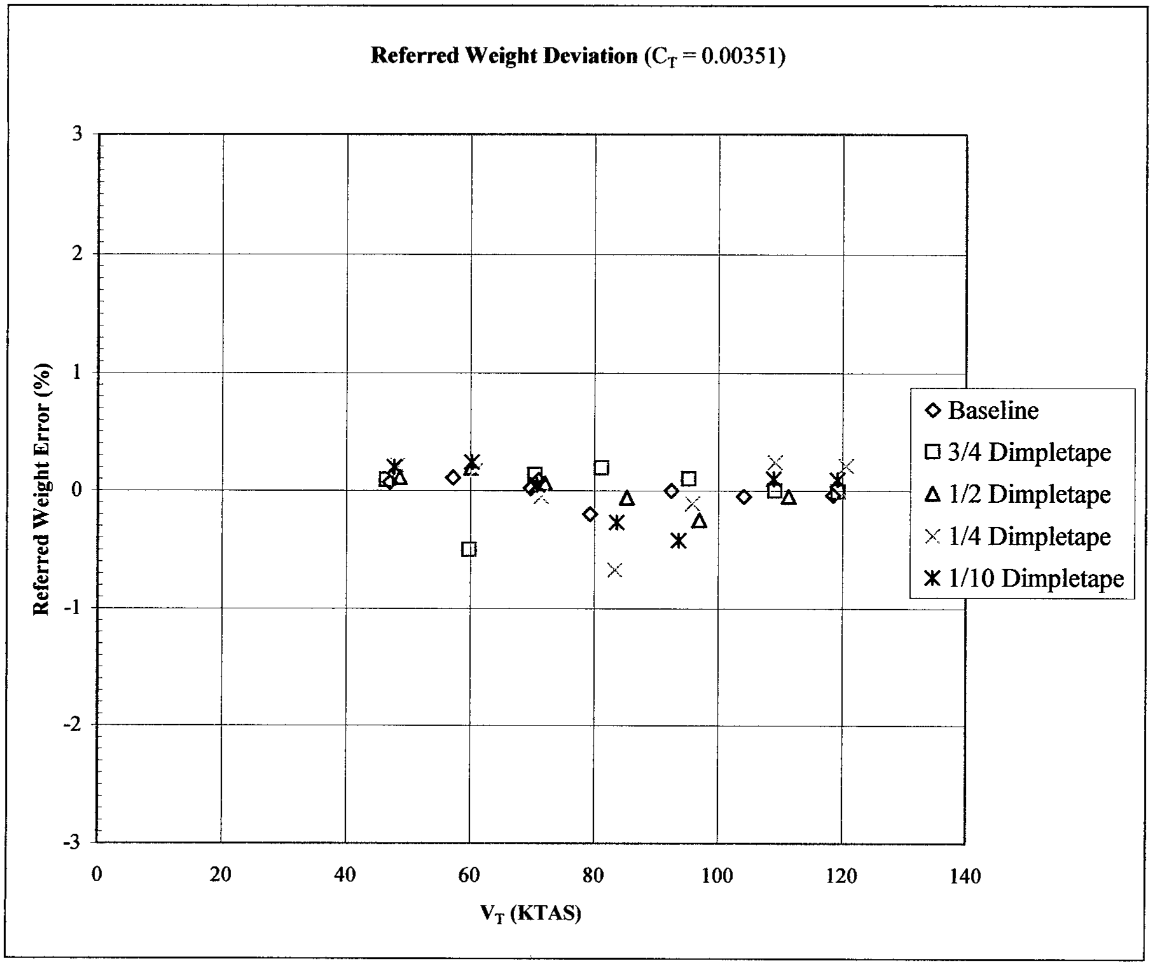
Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W/σ 2831 lbs., Average CG 109.8.



B.8. Referred Weight Deviation (C_T = 0.00291)

Aircraft:	OH-58A+	**Date:**	2 – 4 August 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Referred Weight Deviation	**C_T:**	.00351

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W/σ 3412 lbs., Average CG 109.8.



B.9. Referred Weight Deviation (C_T = 0.00351)

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Level Flight Performance	**C_T:**	.00291

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 2831 lbs., Average CG 109.8.

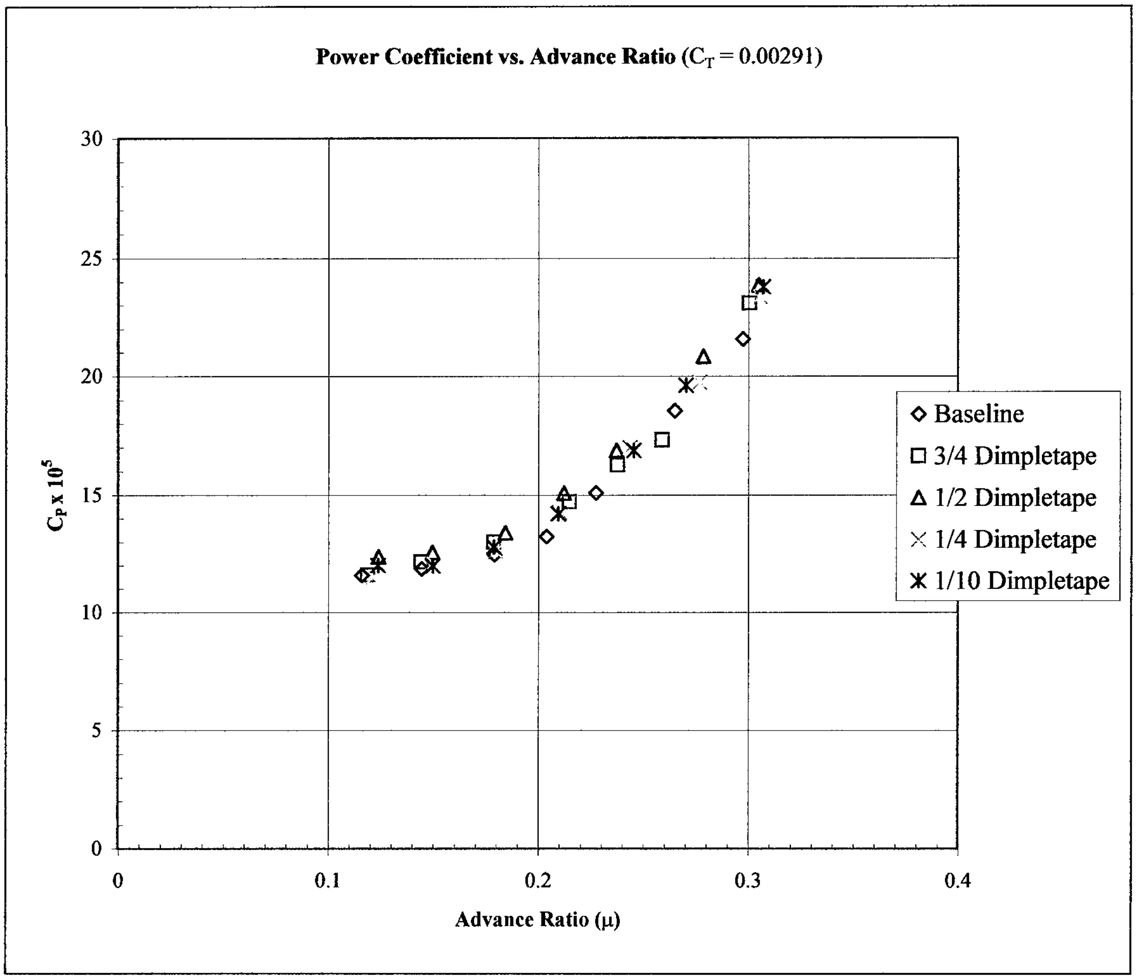


Figure B.10. Power Coefficient versus Main Rotor Blade Advance Ratio,

C_T = 0.00291.

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Level Flight Performance	**C_T:**	.00351

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 3412 lbs., Average CG 109.8.

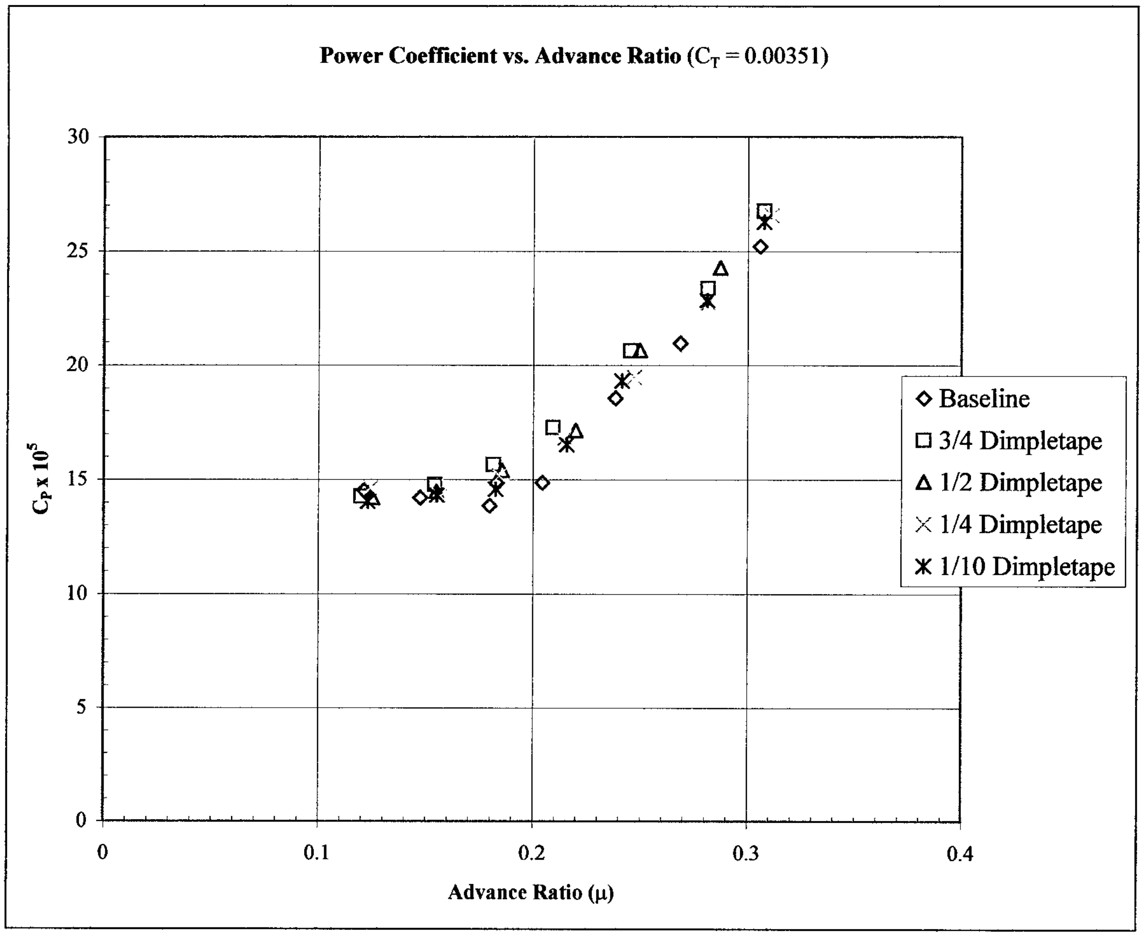


Figure B.11. Power Coefficient versus Main Rotor Blade Advance Ratio,

C_T = 0.00351.

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Level Flight Performance	**C_T:**	.00291

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 2831 lbs., Average CG 109.8.

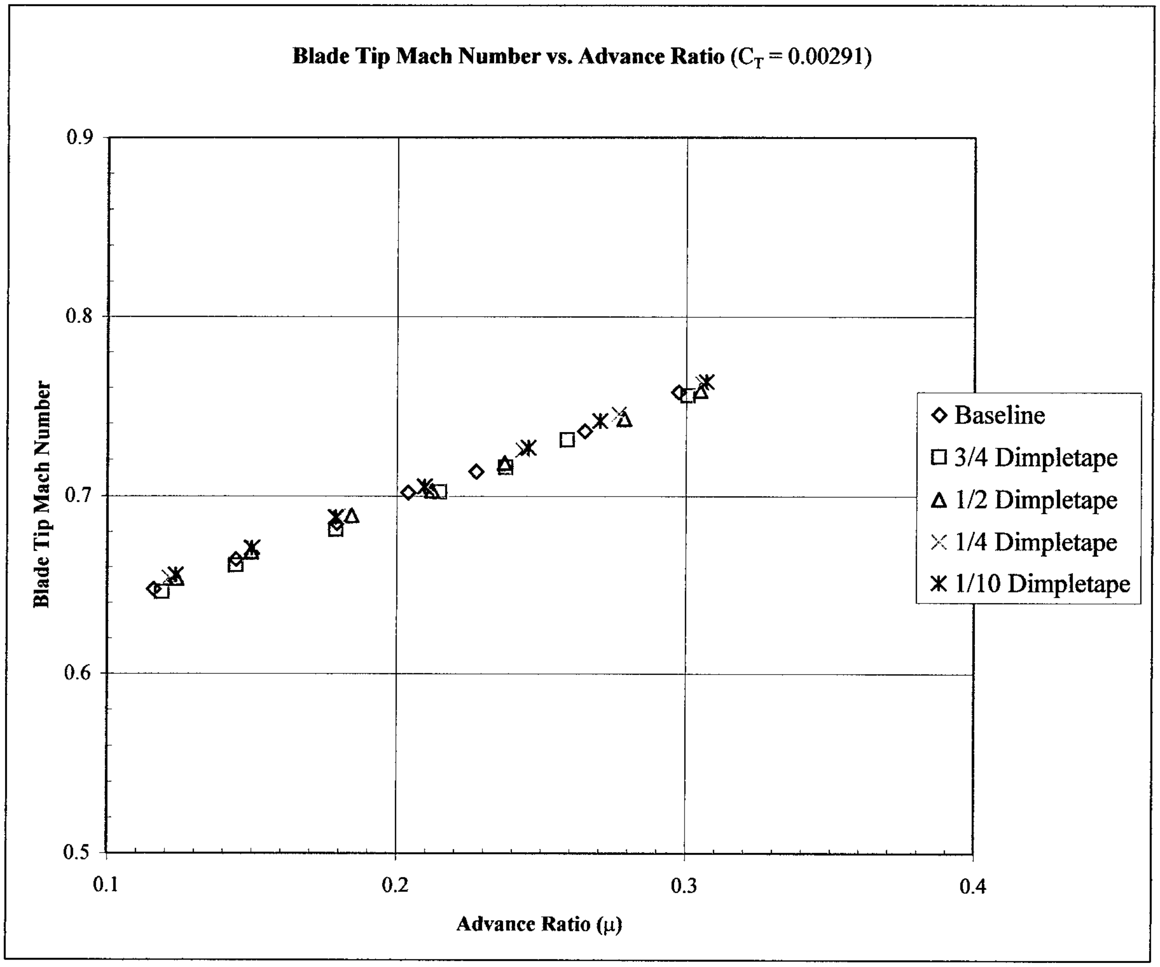


Figure B.12. Blade Tip Mach Number versus Main Rotor Blade Advance Ratio,

C_T = 0.00291.

Aircraft:	OH-58A+	**Date:**	30 October – 3 November 2000
Pilot:	Lewis, Stellar	**FTE's:**	Deetman, Callendar, Agramunt
Test:	Level Flight Performance	**C_T:**	.00351

Configuration: High skid gear installed, Pitot static probe installed, All doors removed, W_{ref} 3412 lbs., Average CG 109.8.

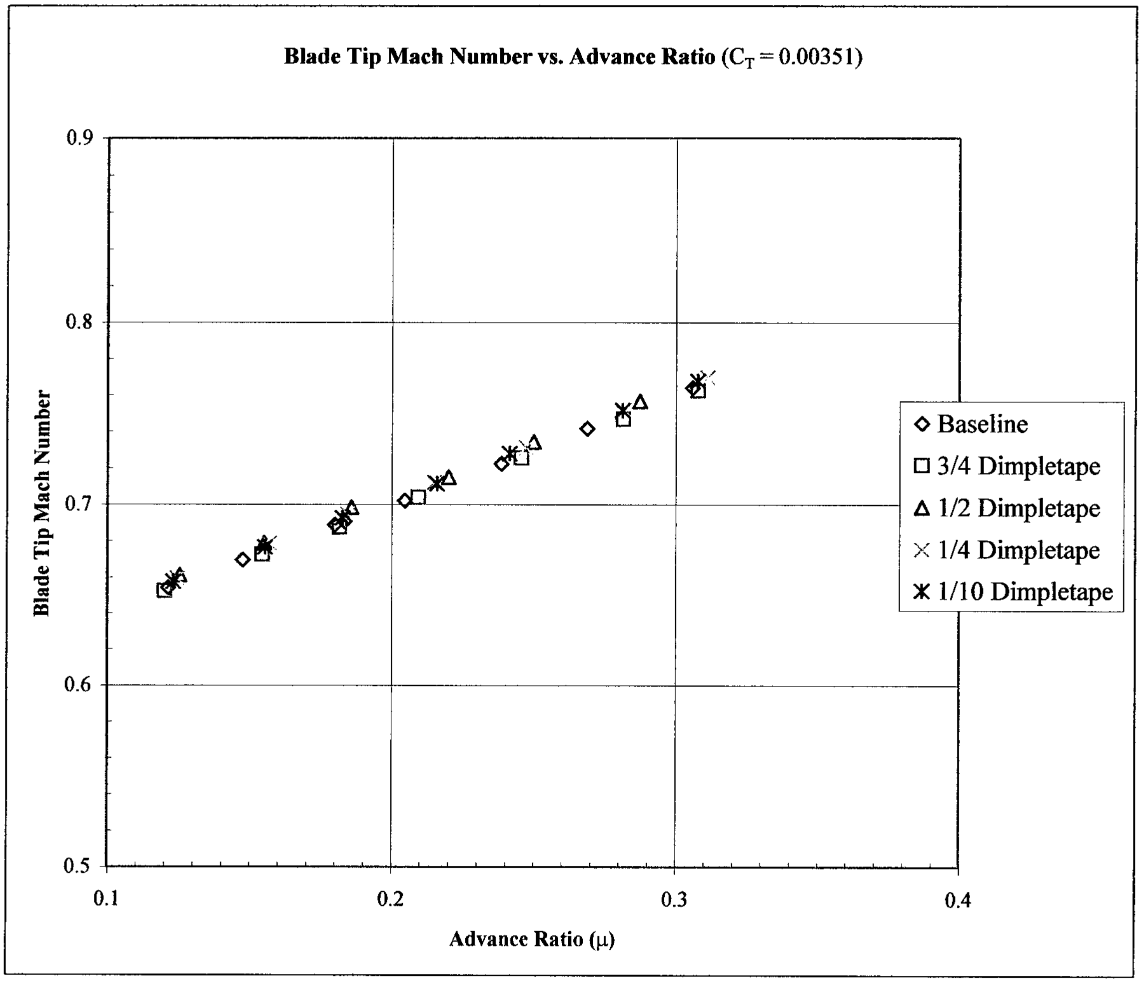


Figure B.13. Blade Tip Mach Number versus Main Rotor Blade Advance Ratio,

C_T = 0.00351.

APPENDIX C

AIRCRAFT WEIGHT AND BALANCE

OH-58A+ Weight & Balance
30-Oct-00

Crew: Lewis Deetman Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	100	104	104.0
Left Rear Seat	198	104	205.9
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2701		2939.2
Fuel	400		463.2
Takeoff Condition	3101		3402.4
Corrections	0	85	0.0
Takeoff (Corrected)	3101	109.72	3402.4
Expendables	0		
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 290 lbs. Remain	-110		-123.6
Landing Condition	2991		3278.9
Corrections	0		0.0
Landing (Corrected)	2991	109.62	3278.9

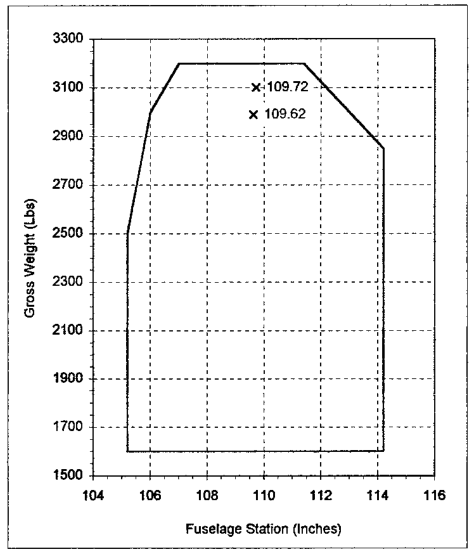


Figure C.1.
Weight and Balance
Hover Baseline Performance Testing - Heavy

OH-58A+ Weight & Balance
30 Oct 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2403		2629.3
Fuel	280		320.2
Takeoff Condition	2683		2949.5
Corrections	0	85	0.0
Takeoff (Corrected)	2683	109.93	2949.5
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 180 lbs. Remain	-100		-112.2
Landing Condition	2583		2837.3
Corrections	0		0.0
Landing (Corrected)	2583	109.85	2837.3

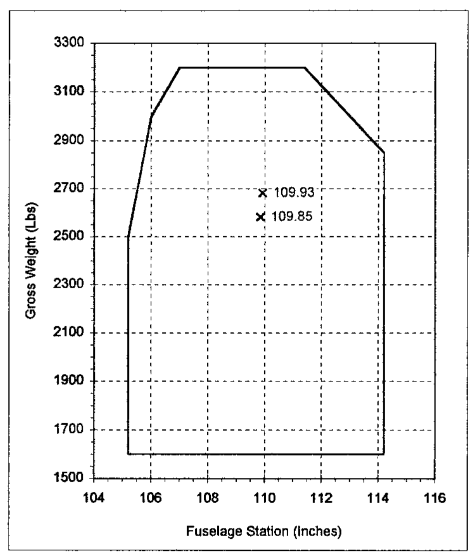


Figure C.2.
Weight and Balance
Hover Baseline Performance Testing - Light

OH-58A+ Weight & Balance
31-Oct-00

Crew: Lewis Deetman Mulnik

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	150	104	156.0
Left Rear Seat	204	104	212.2
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2757		2997.5
Fuel	425		493.4
Takeoff Condition	3182		3490.9
Corrections	0	85	0.0
Takeoff (Corrected)	3182	109.71	3490.9
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 325 lbs. Remain	-100		-112.2
Landing Condition	3082		3378.7
Corrections	0		0.0
Landing (Corrected)	3082	109.63	3378.7

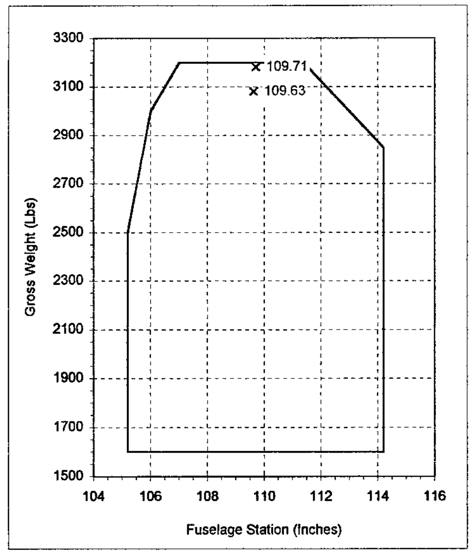


Figure C.3.
Weight and Balance
Hover 75% Dimpletape Length - Heavy

OH-58A+ Weight & Balance
31 Oct 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2403		2629.3
Fuel	250		285.0
Takeoff Condition	2653		2914.3
Corrections	0	85	0.0
Takeoff (Corrected)	2653	109.85	2914.3
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 175 lbs. Remain	-75		-83.9
Landing Condition	2578		2830.4
Corrections	0		0.0
Landing (Corrected)	2578	109.79	2830.4

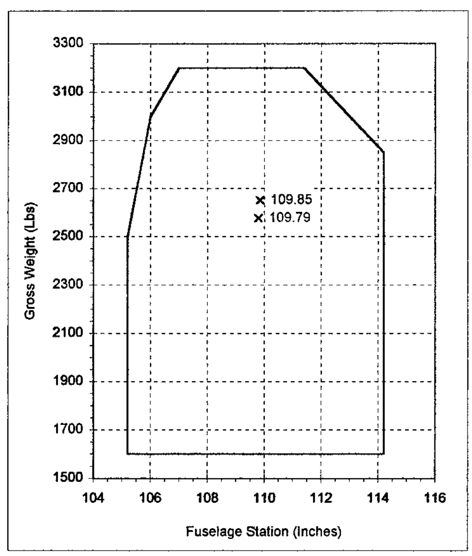


Figure C.4.
Weight and Balance
Hover 75% Dimpletape Length - Light

OH-58A+ Weight & Balance
31-Oct-00

Crew: Lewis Deetman
Davis

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	125	104	130.0
Left Rear Seat	161	104	167.4
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2689		2926.7
Fuel	175		197.9
Takeoff Condition	2864		3124.7
Corrections	0	85	0.0
Takeoff (Corrected)	2864	109.10	3124.7
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 105 lbs. Remain	-70		-78.3
Landing Condition	2794		3046.4
Corrections	0		0.0
Landing (Corrected)	2794	109.03	3046.4

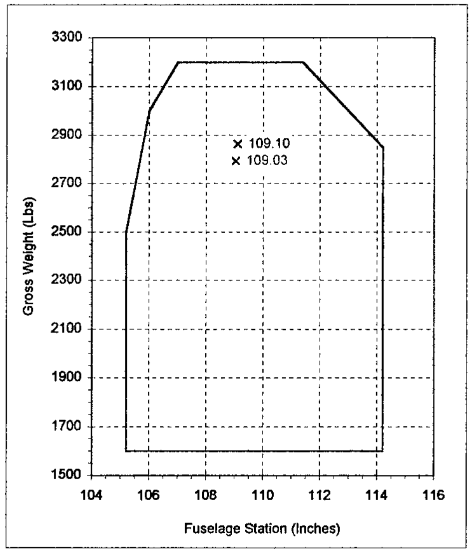


Figure C.5.
Weight and Balance
Hover 50% Dimpletape Length - Heavy

OH-58A+ Weight & Balance
31 Oct 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2403		2629.3
Fuel	170		192.2
Takeoff Condition	2573		2821.5
Corrections	0	85	0.0
Takeoff (Corrected)	2573	109.66	2821.5
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 80 lbs. Remain	-90		-100.9
Landing Condition	2483		2720.6
Corrections	0		0.0
Landing (Corrected)	2483	109.57	2720.6

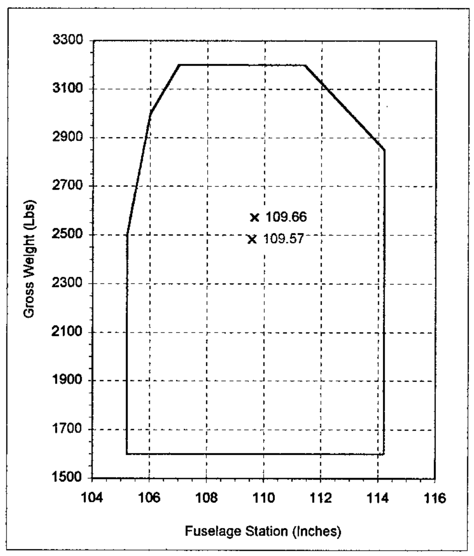


Figure C.6.
Weight and Balance
Hover 50% Dimpletape Length - Light

OH-58A+ Weight & Balance

31-Oct-00

Crew: Lewis Deetman Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	200	104	208.0
Left Rear Seat	198	104	205.9
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2801		3043.2
Fuel	220		250.0
Takeoff Condition	3021		3293.2
Corrections	0	85	0.0
Takeoff (Corrected)	3021	109.01	3293.2
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 155 lbs. Remain	-65		-72.7
Landing Condition	2956		3220.6
Corrections	0		0.0
Landing (Corrected)	2956	108.95	3220.6

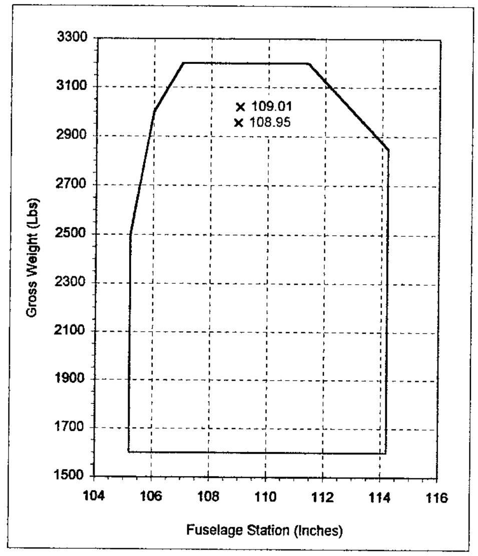


Figure C.7.
Weight and Balance
Hover 25% Dimpletape Length - Heavy

OH-58A+ Weight & Balance

31 Oct 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2403		2629.3
Fuel	155		174.9
Takeoff Condition	2558		2804.2
Corrections	0	85	0.0
Takeoff (Corrected)	2558	109.63	2804.2
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 100 lbs. Remain	-55		-61.4
Landing Condition	2503		2742.8
Corrections	0		0.0
Landing (Corrected)	2503	109.58	2742.8

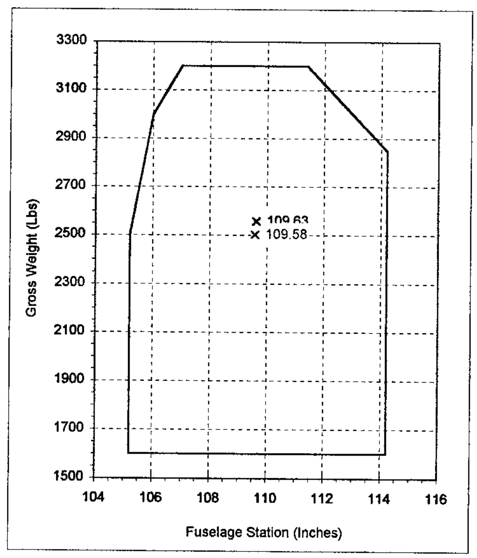


Figure C.8.
Weight and Balance
Hover 25% Dimpletape Length - Light

OH-58A+ Weight & Balance
31-Oct-00

Crew: Lewis Deetman
Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	100	104	104.0
Left Rear Seat	198	104	205.9
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2701		2939.2
Fuel	285		326.1
Takeoff Condition	2986		3265.3
Corrections	0	85	0.0
Takeoff (Corrected)	2986	109.35	3265.3
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 205 lbs. Remain	-80		-89.6
Landing Condition	2906		3175.7
Corrections	0		0.0
Landing (Corrected)	2906	109.28	3175.7

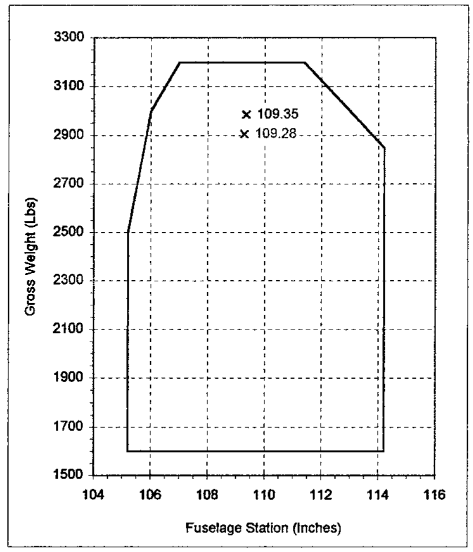


Figure C.9.
Weight and Balance
Hover 10% Dimpletape Length - Heavy

OH-58A+ Weight & Balance
31 Oct 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	166	65	107.9
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2403		2629.3
Fuel	260		296.7
Takeoff Condition	2663		2926.0
Corrections	0	85	0.0
Takeoff (Corrected)	2663	109.88	2926.0
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 175 lbs. Remain	-85		-95.2
Landing Condition	2578		2830.8
Corrections	0		0.0
Landing (Corrected)	2578	109.81	2830.8

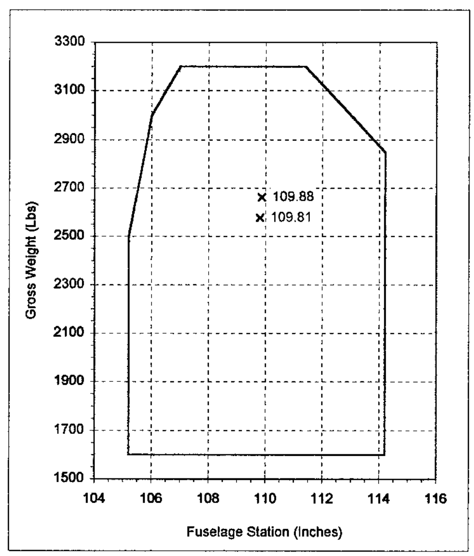


Figure C.10.
Weight and Balance
Hover 10% Dimpletape Length - Light

OH-58A+ Weight & Balance

15-Nov-00

Crew: Lewis Deetman Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	300	104	312.0
Left Rear Seat	298	104	309.9
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	3002		3251.9
Fuel	150		169.2
Takeoff Condition	3152		3421.1
Corrections	0	85	0.0
Takeoff (Corrected)	3152	108.54	3421.1
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 130 lbs. Remain	-20		-22.2
Landing Condition	3132		3398.8
Corrections	0		0.0
Landing (Corrected)	3132	108.52	3398.8

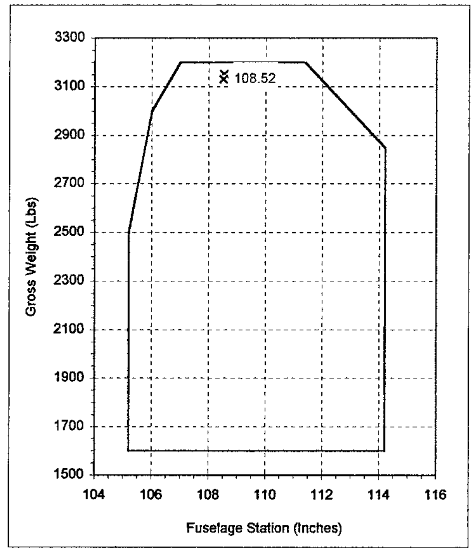


Figure C.11.
Weight and Balance
Hover 10% Optimum Dimpletape Length - Moved 1" Fwd - Heavy

OH-58A+ Weight & Balance

15 Nov 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	200	104	208.0
Left Rear Seat	100	104	104.0
	0	100	0.0
Operating Wt.	2704		2942.0
Fuel	130		146.3
Takeoff Condition	2834		3088.3
Corrections	0	85	0.0
Takeoff (Corrected)	2834	108.97	3088.3
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 100 lbs. Remain	-30		-33.4
Landing Condition	2804		3054.9
Corrections	0		0.0
Landing (Corrected)	2804	108.95	3054.9

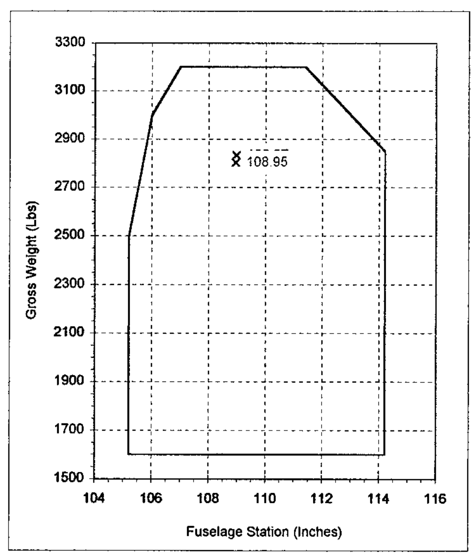


Figure C.12.
Weight and Balance
Hover 10% Optimum Dimpletape Length - Moved 1" Fwd - Light

OH-58A+ Weight & Balance

15-Nov-00

Crew: Lewis Deetman Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	300	104	312.0
Left Rear Seat	323	104	335.9
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	3027		3277.9
Fuel	105		117.9
Takeoff Condition	3132		3395.7
Corrections	0	85	0.0
Takeoff (Corrected)	3132	108.42	3395.7
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 45 lbs. Remain	-60		-67.0
Landing Condition	3072		3328.7
Corrections	0		0.0
Landing (Corrected)	3072	108.36	3328.7

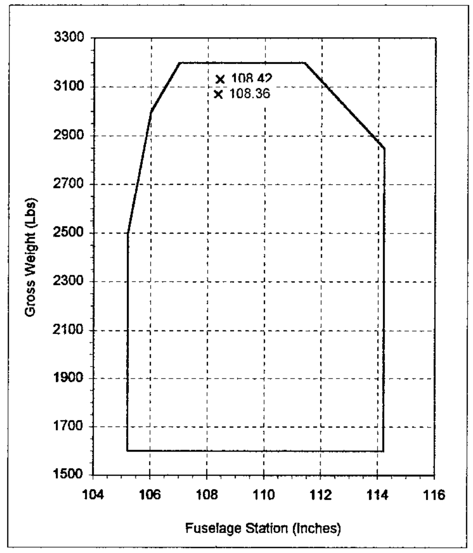


Figure C.13.
Weight and Balance
Hover 10% Optimum Dimpletape Length - Moved 2" Fwd - Heavy

OH-58A+ Weight & Balance

15 Nov 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	200	104	208.0
Left Rear Seat	125	104	130.0
	0	100	- 0.0
Operating Wt.	2729		2968.0
Fuel	100		112.2
Takeoff Condition	2829		3080.2
Corrections	0	85	0.0
Takeoff (Corrected)	2829	108.88	3080.2
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 65 lbs. Remain	-35		-39.0
Landing Condition	2794		3041.2
Corrections	0		0.0
Landing (Corrected)	2794	108.85	3041.2

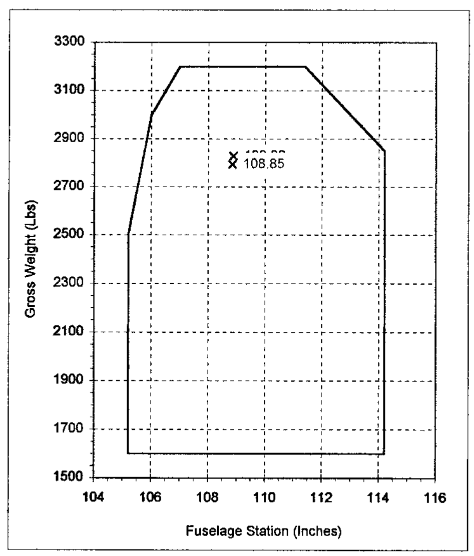


Figure C.14.
Weight and Balance
Hover 10% Optimum Dimpletape Length - Moved 2" Fwd - Light

OH-58A+ Weight & Balance
15-Nov-00

Crew: Lewis Deetman Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	198	65	128.7
Right Rear Seat	325	104	338.0
Left Rear Seat	260	104	270.4
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	3020		3258.5
Fuel	175		197.9
Takeoff Condition	3195		3456.4
Corrections	0	85	0.0
Takeoff (Corrected)	3195	108.18	3456.4
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 155 lbs. Remain	-20		-22.2
Landing Condition	3175		3434.2
Corrections	0		0.0
Landing (Corrected)	3175	108.16	3434.2

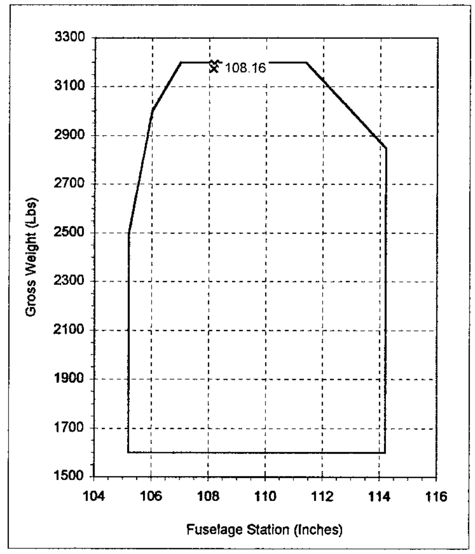


Figure C.15.
Weight and Balance
Hover 10% Optimum Dimpletape Length - Moved 1" Aft - Heavy

OH-58A+ Weight & Balance
15 Nov 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	198	65	128.7
Right Rear Seat	175	104	182.0
Left Rear Seat	100	104	104.0
	0	100	0.0
Operating Wt.	2710		2936.1
Fuel	150		169.2
Takeoff Condition	2860		3105.3
Corrections	0	85	0.0
Takeoff (Corrected)	2860	108.58	3105.3
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 120 lbs. Remain	-30		-33.4
Landing Condition	2830		3071.9
Corrections	0		0.0
Landing (Corrected)	2830	108.55	3071.9

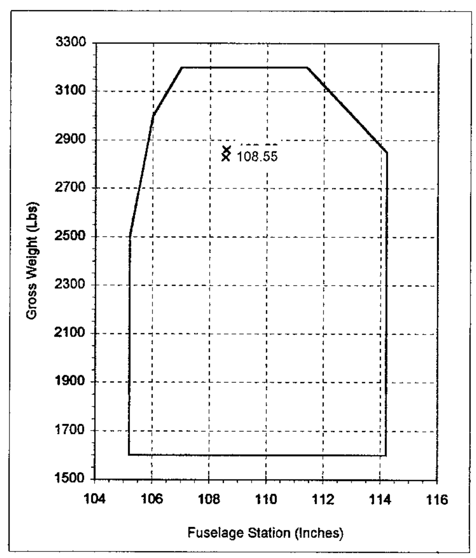


Figure C.16.
Weight and Balance
Hover 10% Optimum Dimpletape Length - Moved 1" Aft - Light

OH-58A+ Weight & Balance
30-Oct-00

Crew: Lewis Deetman
Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	100	104	104.0
Left Rear Seat	196	104	203.8
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2700		2937.8
Fuel	365		421.1
Takeoff Condition	3065		3358.9
Corrections	0	85	0.0
Takeoff (Corrected)	3065	109.59	3358.9
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 250 lbs. Remain	-115		-129.2
Landing Condition	2950		3229.7
Corrections	0		0.0
Landing (Corrected)	2950	109.48	3229.7

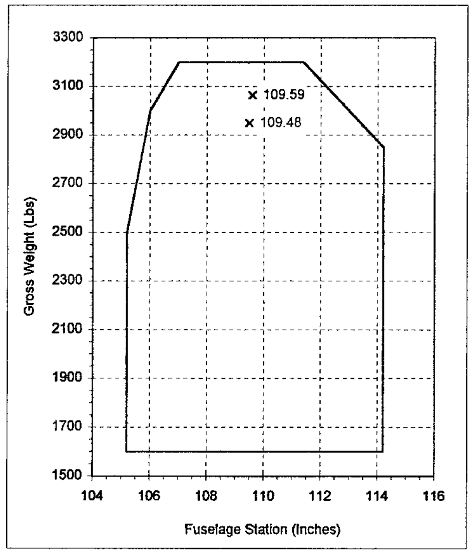


Figure C.17.
Weight and Balance
Baseline Level Flight - Heavy

OH-58A+ Weight & Balance
30 Oct 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2404		2630.0
Fuel	245		279.2
Takeoff Condition	2649		2909.1
Corrections	0	85	0.0
Takeoff (Corrected)	2649	109.82	2909.1
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 120 lbs. Remain	-125		-140.6
Landing Condition	2524		2768.5
Corrections	0		0.0
Landing (Corrected)	2524	109.69	2768.5

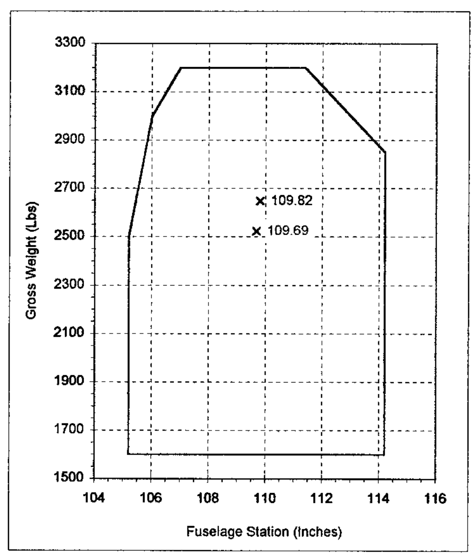


Figure C.18.
Weight and Balance
Baseline Level Flight - Light

OH-58A+ Weight & Balance
1-Nov-00

Crew: Lewis Deetman
Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	0	104	0.0
Left Rear Seat	196	104	203.8
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2600		2833.8
Fuel	415		481.3
Takeoff Condition	3015		3315.1
Corrections	0	85	0.0
Takeoff (Corrected)	3015	109.95	3315.1
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 250 lbs. Remain	-165		-186.4
Landing Condition	2850		3128.7
Corrections	0		0.0
Landing (Corrected)	2850	109.78	3128.7

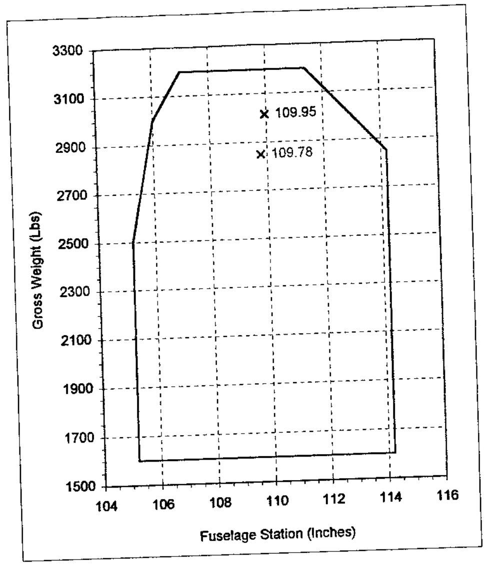


Figure C.19.
Weight and Balance
Level Flight 75% Dimpletape Length - Heavy

OH-58A+ Weight & Balance
2 Nov 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2404		2630.0
Fuel	245		279.2
Takeoff Condition	2649		2909.1
Corrections	0	85	0.0
Takeoff (Corrected)	2649	109.82	2909.1
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 120 lbs. Remain	-125		-140.6
Landing Condition	2524		2768.5
Corrections	0		0.0
Landing (Corrected)	2524	109.69	2768.5

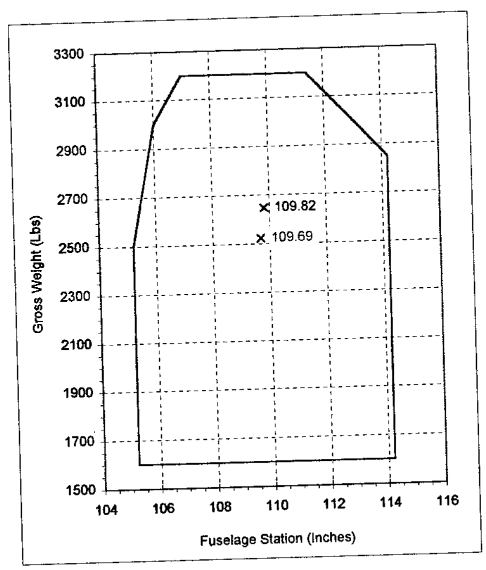


Figure C.20.
Weight and Balance
Level Flight 75% Dimpletape Length - Light

OH-58A+ Weight & Balance
2-Nov-00

Crew: Lewis Deetman Callendar

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	100	104	104.0
Left Rear Seat	196	104	203.8
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2700		2937.8
Fuel	165		186.4
Takeoff Condition	2865		3124.2
Corrections	0	85	0.0
Takeoff (Corrected)	2865	109.05	3124.2
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 50 lbs. Remain	-115		-129.2
Landing Condition	2750		2995.0
Corrections	0		0.0
Landing (Corrected)	2750	108.91	2995.0

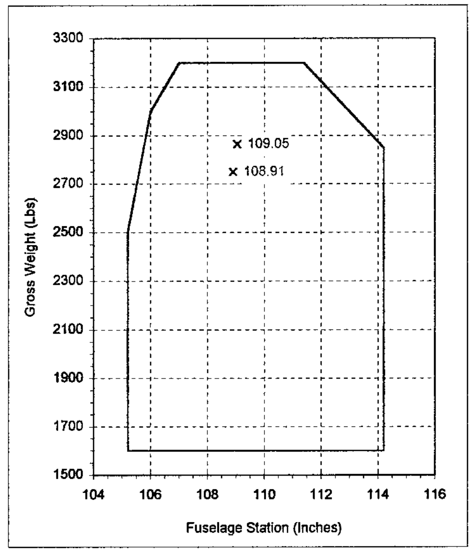


Figure C.21.
Weight and Balance
Level Flight 50% Dimpletape Length - Heavy

OH-58A+ Weight & Balance
2 Nov 00

Crew: Lewis Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	236	65	153.4
Copilot	167	65	108.6
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2404		2630.0
Fuel	245		279.2
Takeoff Condition	2649		2909.1
Corrections	0	85	0.0
Takeoff (Corrected)	2649	109.82	2909.1
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 140 lbs. Remain	-105		-117.9
Landing Condition	2544		2791.2
Corrections	0		0.0
Landing (Corrected)	2544	109.72	2791.2

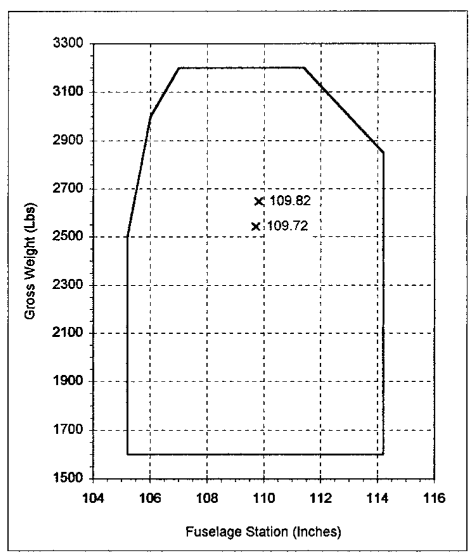


Figure C.22.
Weight and Balance
Level Flight 50% Dimpletape Length - Light

OH-58A+ Weight & Balance
3-Nov-00

Crew: Stellar Deetman
Agramunt

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	192	65	124.8
Copilot	167	65	108.6
Right Rear Seat	175	104	182.0
Left Rear Seat	161	104	167.4
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2696		2950.8
Fuel	210		238.4
Takeoff Condition	2906		3189.2
Corrections	0	85	0.0
Takeoff (Corrected)	2906	109.74	3189.2
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 130 lbs. Remain	-120		-134.9
Landing Condition	2786		3054.3
Corrections	0		0.0
Landing (Corrected)	2786	109.63	3054.3

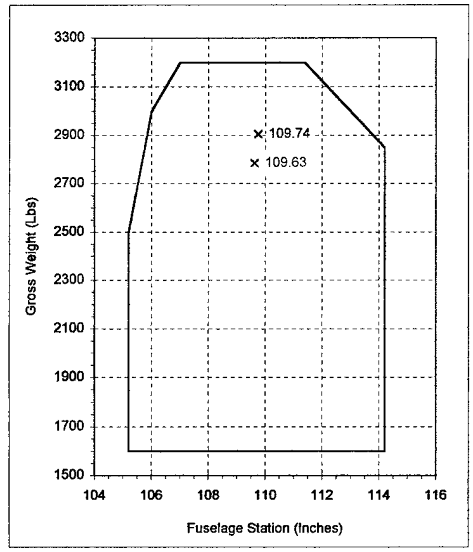


Figure C.23.
Weight and Balance
Level Flight 25% Dimpletape Length - Heavy

OH-58A+ Weight & Balance
3 Nov 00

Crew: Stellar Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	192	65	124.8
Copilot	167	65	108.6
Right Rear Seat	50	104	52.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2410		2653.4
Fuel	200		226.8
Takeoff Condition	2610		2880.2
Corrections	0	85	0.0
Takeoff (Corrected)	2610	110.35	2880.2
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 90 lbs. Remain	-110		-123.6
Landing Condition	2500		2756.6
Corrections	0		0.0
Landing (Corrected)	2500	110.26	2756.6

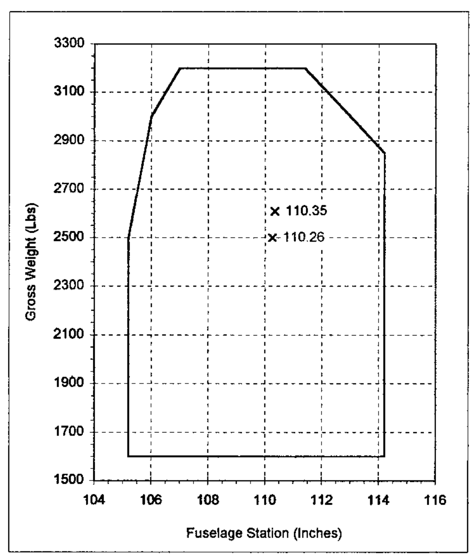


Figure C.24.
Weight and Balance
Level Flight 25% Dimpletape Length - Light

OH-58A+ Weight & Balance
3-Nov-00

Crew: Stellar Deetman Agramunt

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	192	65	124.8
Copilot	167	65	108.6
Right Rear Seat	175	104	182.0
Left Rear Seat	160	104	166.4
Baggage Compartment	0	170	0.0
Misc Equip	0	105	0.0
Operating Wt.	2695		2949.8
Fuel	265		302.6
Takeoff Condition	2960		3252.3
Corrections	0	85	0.0
Takeoff (Corrected)	2960	109.88	3252.3
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 200 lbs. Remain	-65		-72.7
Landing Condition	2895		3179.7
Corrections	0		0.0
Landing (Corrected)	2895	109.83	3179.7

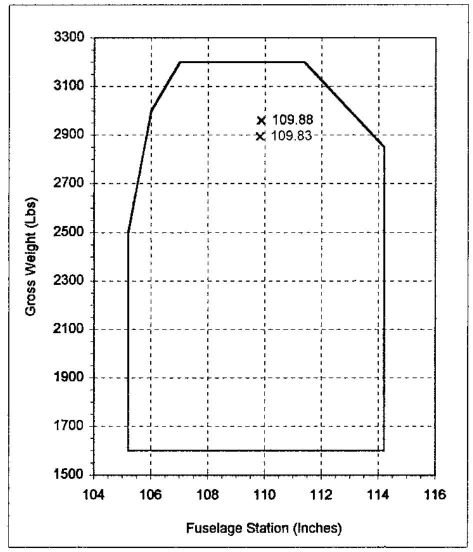


Figure C.25.
Weight and Balance
Level Flight 10% Dimpletape Length - Heavy

OH-58A+ Weight & Balance
3 Nov 00

Crew: Stellar Deetman

	Weight	Arm/C.G.	Moment
Aircraft Basic Wt.	2001		2368.0
Pilot	192	65	124.8
Copilot	167	65	108.6
Right Rear Seat	0	104	0.0
Left Rear Seat	0	104	0.0
	0	100	0.0
Operating Wt.	2360		2601.4
Fuel	190		215.2
Takeoff Condition	2550		2816.6
Corrections	0	85	0.0
Takeoff (Corrected)	2550	110.45	2816.6
Expendables			
Copilot	0	65	
Right Rear Pax	0	104	
Left Rear Pax	0	104	
Fuel 100 lbs. Remain	-95		-106.5
Landing Condition	2455		2710.0
Corrections	0		0.0
Landing (Corrected)	2455	110.39	2710.0

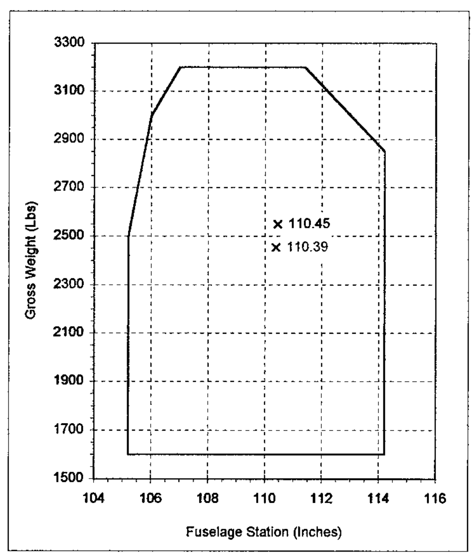


Figure C.26.
Weight and Balance
Level Flight 10% Dimpletape Length - Light

APPENDIX D

DIMPLETAPE® TEST PLAN

TEST PLAN

Purpose

The purpose of this test is to evaluate the performance benefits of a Dimpletape® application to the main rotor blades of an OH-58A+ helicopter. The test will determine optimal tape application length to maximize performance gains. A baseline will be established with the OH-58A+ helicopter and compared to data from four different lengths of Dimpletape®.

The rotor system will be evaluated for a reduced acoustic level. A baseline sound level will be measured and compared with the acoustic level generated with each Dimpletape® length. Changes in handling qualities will be noted.

Scope of Tests

Test and Test Conditions

The tests will be conducted in a maximum of 20.0 flight hours. All flights will be conducted under daylight visual meteorological conditions (VMC) at Tullahoma Regional Airport, Tullahoma, Tennessee. The tests and test conditions matrix is presented as Table D.1.

Test Envelope

The test will be conducted within the limits of the OH-58A/C Operator's Manual. The maximum altitude for level flight-testing for the purpose of this test is 10,000 feet pressure altitude. Airspeed will be from 0 to V_{NE}. The V_{NE} limits from, paragraph 5-19, with doors installed will be used. [3]

Test Loadings

Flight-testing to determine level flight performance will be conducted at two referred gross weights (W_{ref}) 2831 lbs and 3412 lbs. Autorotation flight-testing will be at a W_{ref} of 3412 lbs. Hover performance will be tested at several W_{ref} values 2639 lbs, 2803 lbs, 2983 lbs, 3180 lbs, 3378 lbs, and 3594 lbs. Test loading will be varied by the number of personnel aboard or ballast in the aircraft and the amount of fuel used during the tests. The actual aircraft test gross weight will vary from 2614 to 3150 pounds for hover and level flight testing, while the center of gravity (CG) varies from 109.7 to 109.6 inches respectively. Gross weight for autorotation will be 3150 pounds, with a CG of 109.6 inches. Test loading is included in Table D.1.

Test Lengths

The test will be conducted on an OH-58A+ helicopter in four different tape lengths as shown below. The predominate data will be taken at a hover and at airspeeds from 40 knots observed airspeed (KOAS) to 100 KOAS, in 10 knot increments, to evaluate changes in power. During the test handling qualities, and sound signature reduction will be investigated.

- Length 1 — Dimpletape® applied to the outboard 3/4 length of main rotor blades.
- Length 2 — Dimpletape® applied to outboard 1/2 of each main rotor blade.
- Length 3 — Dimpletape® applied to outboard 1/4 of each main rotor blade.

- Length 4 — Dimpletape® applied to outboard 1/10 of each main rotor blade.
- Optimum Test — An iterative spanwise and cordwise tape arrangement. The spanwise length will be determined based on the results of the first four tests. The cordwise position will be adjusted to evaluate the change in profile power by placing Dimpletape® at different cord distances from the leading edge.

The aircraft configuration for all tests will be: Flight test pitot static system (Boom) installed, main rotor blades will be washed prior to Dimpletape® application, doors installed and all engine bleed air systems off.

Method of Tests

Test Methods and Procedures

The testing will consist of a quantitative performance evaluation including hover performance (free hover method), level flight performance, and autorotation performance (W/σ, weight over density ratio method) flight test. The data will be taken at a hover and at airspeeds from 40 knots observed airspeed (KOAS) to 100 KOAS, in 10 knot increments, to amplify any results due to reduced coefficient of drag ($\overline{C}_{d_0}$). An investigation will also be conducted to determine any reduction in rotor system sound signature. Any changes in handling qualities will also be noted in test results. Engineering tests will be conducted in accordance with the U.S. Naval Test Pilot School Rotary Wing Performance Flight Test Manual, USNTPS FTM-106, U.S. Naval Test Pilot School Rotary Wing Stability and Control Flight Test Manual, USNTPS FTM-107, and this test plan as described in the Tests and Test Conditions Table (Table D.1).

Free Flight Hover Test (Baseline)

Free flight hover performance will be evaluated by the use of a Hover Height Measuring Device (HHMD). Aircraft weight and N_R will be adjusted to establish four W_{ref} values per Dimpletape® length. The free flight hover test will be evaluated during two flights totaling 0.5 hour. The test will be conducted in a stabilized IGE hover. At the completion of the hover test a sound signature reading will be taken while at a stabilized IGE hover. Helicopter loading will be single pilot at the pilot station, one FTE at the co-pilot station, and observers or ballast in the passenger compartment as required. The take-off gross weight (GW) will vary from 2614 to 3150 pounds and CG from 109.7 to 109.6 inches respectively.

Free Flight Hover Test (Dimpletape® installed)

Free flight hover performance will be evaluated by the use of a Hover Height Measuring Device (HHMD). Aircraft weight and N_R will be adjusted to establish four W_{ref} values per Dimpletape® length. The free flight hover test of each Dimpletape® length will be evaluated during ten flights of approximately 0.5 hour each (two flights per Dimpletape® length). The tests will be conducted in a stabilized IGE hover. At the completion of each hover test a sound signature reading will be taken while at a stabilized IGE hover. Helicopter loading will be single pilot at the pilot station, one FTE at the co-pilot station, and observers or ballast in the passenger compartment as required. The take-off gross weight (GW) will vary from 2614 to 3150 pounds and CG from 109.7 to 109.6 inches respectively.

Level Flight Performance Test (Baseline)

Level flight performance will be evaluated at two referred gross weights (W_{ref}) using the weight over density ratio method, (W/ σ, The level flight test (baseline) will be evaluated during two flights of approximately 1.0 hour each. The initial pressure altitude will be 2700 feet. The pressure altitude will be varied as necessary to maintain the desired W_{ref}. Helicopter loading will be single pilot at the pilot station, one FTE at the co-pilot station, and observers or ballast in the passenger compartment as required. The take-off gross weight (GW) will vary from 2614 to 3150 pounds and CG from 109.7 to 109.6 inches respectively.

Level Flight Test (Dimpletape® Installed)

Level flight performance will be evaluated at two referred gross weights (W_{ref}) using the weight over density ratio method, (W/ σ, The Level Flight Test of Dimpletape® will be evaluated during ten flights of approximately 1.0 hour each (two flights per Dimpletape® length). The initial pressure altitude will be 2700 feet. The pressure altitude will be varied as necessary to maintain the desired W/σ. Helicopter loading will be single pilot at the pilot station, one FTE at the co-pilot station, and observers or ballast in the passenger compartment as required. The take-off gross weight (GW) will vary from 2614 to 3150 pounds and CG from 109.7 to 109.6 inches respectively.

Autorotation Rotor Speed Recovery Rate (Baseline)

Autorotation Rotor Speed Recovery Rate performance will be evaluated at one W_{ref} using the W/σ method. Autorotation N_R speed will be reduced to 95% and stabilized 400 feet prior to passing through the test altitude. Autorotation N_R steady state speed will be determined prior to reaching test altitude. N_R speed recovery rate will be measured from

95% to 100%. The test will be completed twice to ensure repeatability. Autorotation Rotor Speed Recovery Rate test (Baseline) will be evaluated during a single flight of approximately 0.5 hour. The initial pressure altitude will be 2700 feet. The pressure altitude will be varied as necessary to maintain the desired W_{ref}. Helicopter loading will be single pilot at the pilot station, one FTE at the co-pilot station, and observers or ballast in the passenger compartment as required. The center of gravity (CG) will be 109.6 inches at the take-off gross weight (GW) of 3150 pounds.

Autorotation Rotor Speed Recovery Rate (Dimpletape® installed)

Autorotation Rotor Speed Recovery Rate performance will be evaluated at one W_{ref} using the W/σ method. Autorotation N_R speed will be reduced to 95% and stabilized 400 feet prior to passing through the test altitude. Autorotation N_R steady state speed will be determined prior to reaching test altitude. N_R speed recovery rate will be measured from 95% to 100%. The test will be completed twice to ensure repeatability. Autorotation Rotor Speed Recovery Rate test will be evaluated during five flights of approximately 0.5 hour. The initial pressure altitude will be 2700 feet. The pressure altitude will be varied as necessary to maintain the desired W_{ref}. Helicopter loading will be single pilot at the pilot station, one FTE at the co-pilot station, and observers or ballast in the passenger compartment as required. The center of gravity (CG) will be 109.6 inches at the take-off gross weight (GW) of 3150 pounds.

INSTRUMENTATION AND DATA EXTRACTION/PROCESSING

Sensitive instrumentation and data recording equipment is installed onboard the test aircraft. Cockpit instrumentation will be used to acquire engine and flying parameters. The external equipment required to collect the desired test data are: A programmable calculator, stopwatch, portable voice recorder, decibel meter, and HHMD. Data will be recorded on kneeboard cards by the FTE and on a portable voice recorder. The data will be analyzed manually, using TPS computer programs or manual data reduction using an Excel spreadsheet and presented in the final report.

Where:

$$W_{ref} = \frac{W_T}{\sigma_T}\left(\frac{\Omega R_S}{\Omega R_T}\right)^3$$

$$M_{TIP} = \frac{\frac{(\Omega R_T)}{1.69} + \frac{V_c}{\sqrt{\sigma}}}{a}$$

$$C_T = \frac{\frac{W_T}{\sigma_T}}{\rho_{ssl} A_D (\Omega R)^2}$$

W_{ref}	-	Referred weight
W_T	-	Test weight
σ_T	-	Density ratio
ΩR_S	-	Standard RPM blade rotational velocity
ΩR_T	-	Test RPM blade rotational velocity
H_d	-	Density altitude
M_{TIP}	-	Blade tip Mach number
V_c	-	Calibrated airspeed
a	-	Speed of sound at test conditions
C_T	-	Coefficient of Thrust
ρ_{ssl}	-	Standard sea level density
A_D	-	Area of the rotor disk.

The data will be recorded on hand-held data cards and micro cassette recorders. The following will be taken at each data point:

Vo	-	Ship observed airspeed

Q - Ship torque

N_R - Rotor RPM

Fuel - Fuel remaining

H_{Po} - Observed pressure altitude

OAT - Observed outside air temperature.

Test Criteria: (Hover)

Wind less that 3 knots (ground referenced).

Engine bleed air systems off.

Stabilized engine power demand.

Minimum vertical and horizontal translations.

Minimum cyclic control inputs.

No directional control inputs, orient into existing wind.

Data Requirements: (Hover)

Stabilize 15 seconds minimum before recording data.

H_{Po} - $\pm$ 0.5 feet.

N_R - $\pm$ 0.5%.

Maximum drift $\pm$ 3 ft (ground referenced).

Maximum hover height $\pm$ 3 ft OGE (ground referenced).

Test Criteria: (free flight)

Balanced (ball centered), wings level, unaccelerated flight.

Engine bleed air systems off.

Stabilized engine power demand.

Data Requirements: (free flight)

Stabilize on data for 60 seconds prior to recording data.

V_o - $\pm$ 1 knot.

H_{Po} - $\pm$ 20 feet.

N_R - $\pm$ 0.5%.

Test Criteria: (autorotation)

Constant airspeed.

Stabilized rate of descent.

Calm air.

Ball centered, unaccelerated flight.

Constant heading.

Data requirements: (autorotation)

Stabilized 400 feet prior to altitude band.

V_o - ± 2 knots.

Heading ± 2 degrees.

The data will be reduced manually using the process outlined in reference 1 and with the automated helicopter performance data reduction program developed by Mr. J.J. McCue.

Special Precautions

Safety Considerations

The hover flight, level flight, and autorotation test involve the mounting of non-standard equipment on the test aircraft. The test crew must have a thorough knowledge of aircraft limitations. All flight testing shall be conducted within the established flight envelope and normal operating limitations contained in the Aircraft Operator's Manual.[3] The crew must be aware of any unusual handling characteristics or vibrations and must not proceed if these occur. The Dimpletape® will be perforated in six-inch sections to allow any piece than might come loose to tear easily. Smaller pieces of tape will minimize the potential hazard of tape entering the tail rotor system. During all tests the crew must remain vigilant to air traffic and obstacle avoidance.

Risk Management

The flight shall be conducted in VFR conditions during daylight. Emergency actions will be developed and briefed by the aircrew prior to the installation of experimental (non-standard) equipment. The overall risk associated with the conduct of this test is assessed to be low.

Management

Schedule/Milestones

Coordination meeting is scheduled on 26 September 2000 at the UTSI hangar facility for the crew involved in the flight test. The flights are scheduled to start 27 September 2000 pending approval of the test plan by the thesis committee.

Test plan approval	8 September 2000
Main rotor blade preparation	11-15 September 2000
Baseline hover, level flight, and autorotation	27 September 2000
Installation of Dimpletape®	29 September 2000
Hover, level flight, and autorotation with	3-6 October 2000
Dimpletape®	24 October 2000
	till completion

Personnel Assignment

Dr. Lewis is assigned as the aircraft pilot-in-command and project advisor. CW3 Deetman is assigned as the test director and FTE for each of the tests.

Reports

An individual Report of Test Results will be completed as soon as practicable after the successful completion of the flight tests. The report will summarize the differences in hover, level flight, and autorotation recovery rate performance of the OH-58A+ without Dimpletape® and with Dimpletape® installed in the five configurations. The report will include any changes in handling qualities and acoustic levels of the rotor system.

Table D.1.

Test and Test Conditions

Event #	Description	Crew	Target W/σ [1,6]	Estimated Pressure Altitude (ft) [1]	Estimated Gross Weight (lbs) [2]	CG	Airspeed (KOAS)[3]	Remark [4]
1	Hover Baseline Testing	1 pilot, 1 FTE, observers	2639,2803, 2983,3180, 3378,3594	1000	≈ 2614, 3150	109.6, 109.7	0	
2	Level flight Baseline testing	1 pilot, 1 FTE, observers	2831, 3412	≈ 2700	≈ 3150, 2614	109.6, 109.7	40 to 100	.00291 .00351
3	Hover Dimpletape® Outboard 3/4	1 pilot, 1 FTE, observers	2639,2803, 2983,3180, 3378,3594	≈ 1000	≈ 2611, 3150	109.6, 109.7	0	
4	Hover Dimpletape® Outboard 1/2	1 pilot, 1 FTE, observers	2639,2803, 2983,3180, 3378,3594	≈ 1000	≈ 2614, 3150	109.6, 109.7	0	
5	Hover Dimpletape® Outboard 1/4	1 pilot, 1 FTE, observers	2639,2803, 2983,3180, 3378,3594	≈ 1000	≈ 2614, 3150	109.6, 109.7	0	
6	Hover Dimpletape® Outboard 1/10	1 pilot, 1 FTE, observers	2639,2803, 2983,3180, 3378,3594	≈ 1000	≈ 2614, 3150	109.6, 109.7	0	
7	Dimpletape® Adjusted for max reduction in profile drag (note 5)	1 pilot, 1 FTE, observers	2639,2803, 2983,3180, 3378,3594	≈ 1000	≈ 2614, 3150	109.6, 109.7	0	
8	Level flight Dimpletape® Outboard 1/10	1 pilot, 1 FTE, observers	2831, 3412	≈ 2700	≈ 2614, 3150	109.7, 109.6	40 to 100	
9	Level flight Dimpletape® Outboard ¼	1 pilot, 1 FTE, observers	2831, 3412	≈ 2700	≈ 2614, 3150	109.7, 109.6	40 to 100	
10	Level flight Dimpletape® Outboard ½	1 pilot, 1 FTE, observers	2831, 3412	≈ 2700	≈ 2614, 3150	109.7, 109.6	40 to 100	
11	Level flight Dimpletape® Outboard ¾	1 pilot, 1 FTE, observers	2831, 3412	≈ 2700	≈ 2614, 3150	109.7, 109.6	40 to 100	
12	Level Flight Dimpletape® Adjusted for max reduction in drag (note 5)	1 pilot, 1 FTE, observers	2831, 3412	≈ 2700	≈ 2614, 3150	109.7, 109.6	40 to 100	

Notes:
1. Pressure altitude, σ, VNE are calculated for a standard day and lapse rate.
2. Gross weight of 3150 is computed allowing 50 pounds fuel burn to initial data point.
3. Maximum airspeed tested shall be limited by VNE.

4. Acoustic level measurement will be taken at a stabilized IGE hover.
5. An iterative spanwise and cordwise tape arrangement. The spanwise length will be determined based on the results of the first four test lengths. The cordwise length will be adjusted to evaluate the change in profile power by placing Dimpletape® at different cord distances from the leading edge.
6. W_{ref} (W/σ). was calculated using standard day. Rotor RPM is varied between 95% (336 RPM), 98% (347RPM), and 101% (358 RPM) to test several aircraft loadings.

APPENDIX E

DIMPLETAPE® AND INSTRUMENTATION INSTALLATION

Figure E.1 Overhead View (75% Dimpletape® Length).

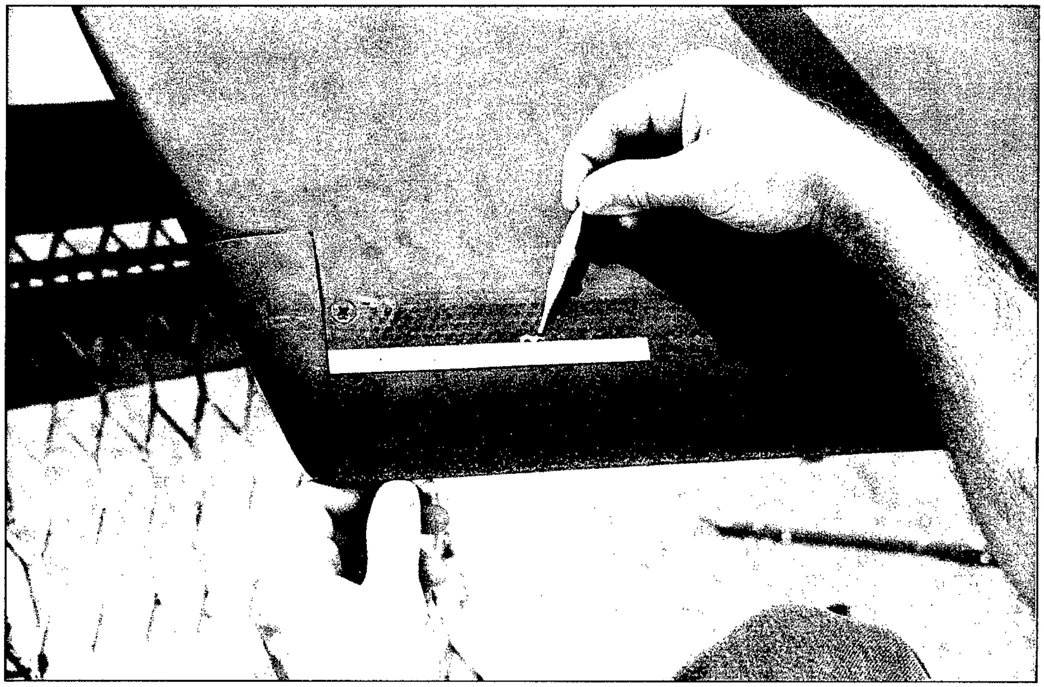


Figure E.2. Dimpletape® Debond Repair.

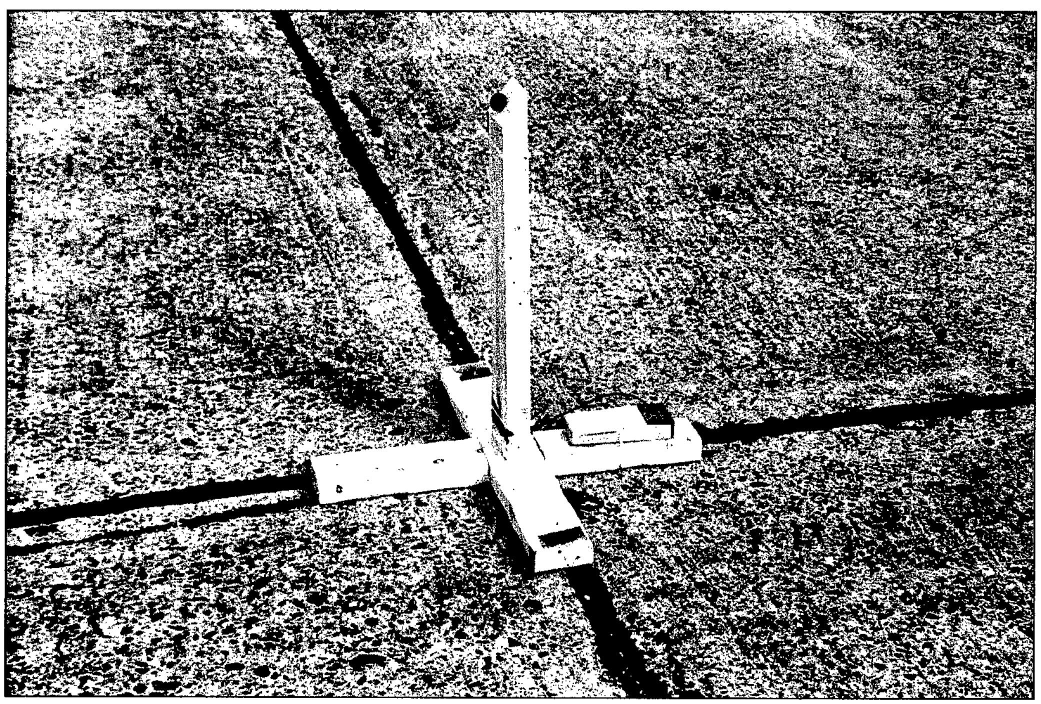
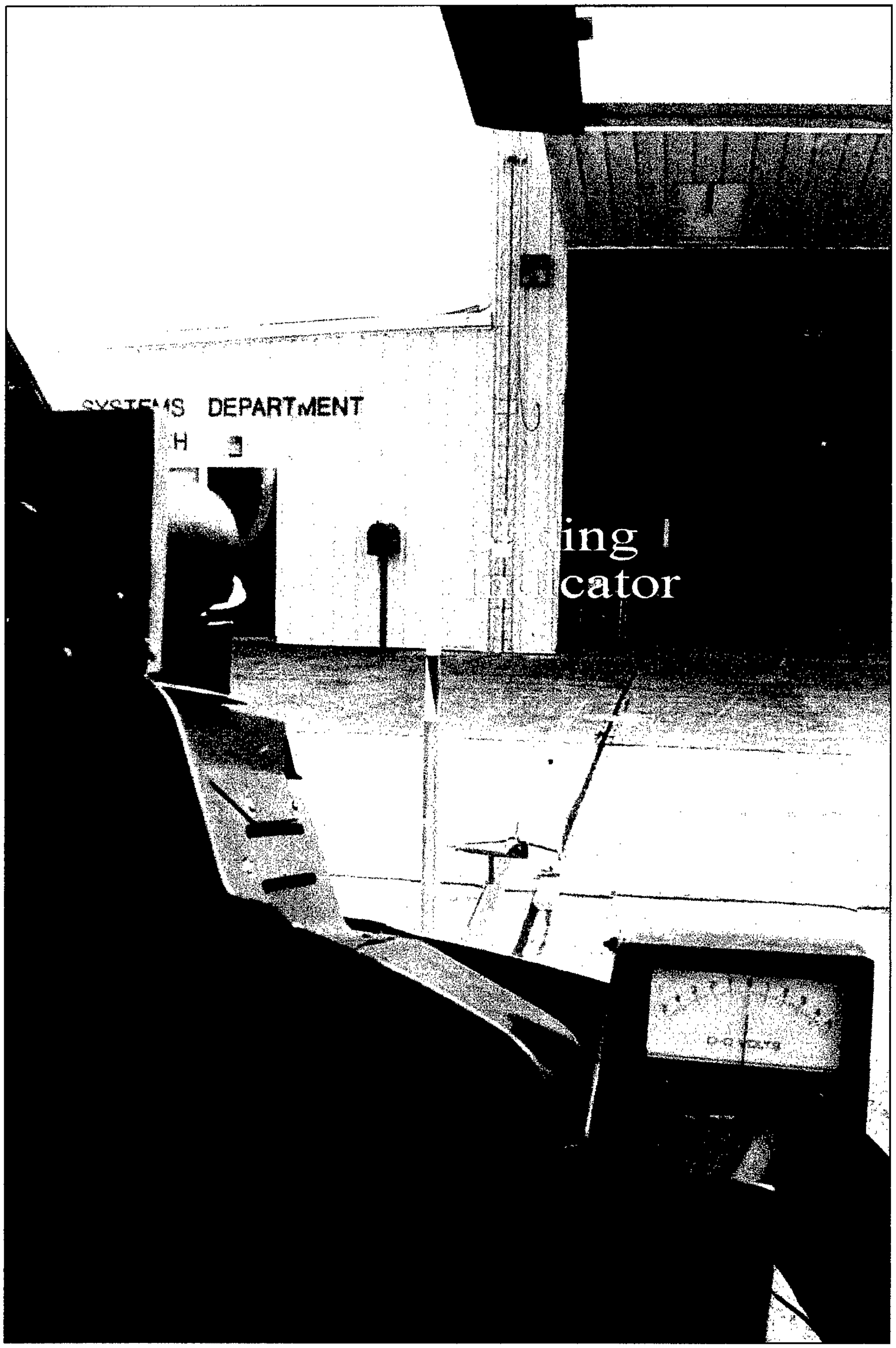


Figure E.3. Microphone Stand.



E.4. Pilot View of HHMD Indicator.

Figure E.5. Aircraft with Pitot Static Test Boom.

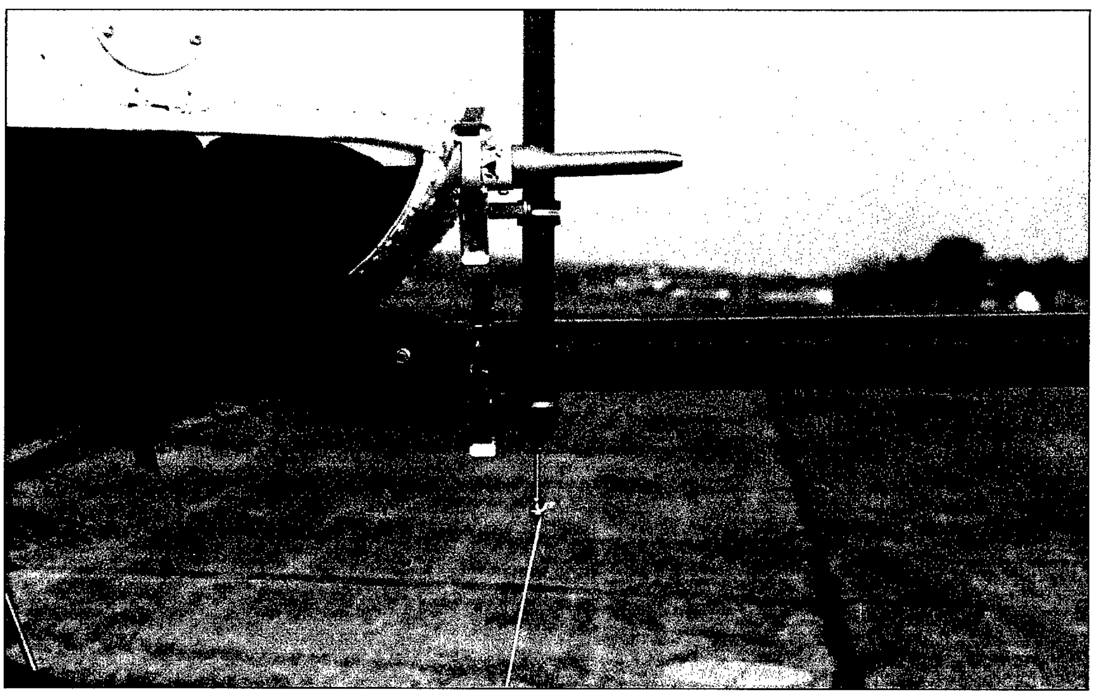


Figure E.6. HHMD Attachment Points.

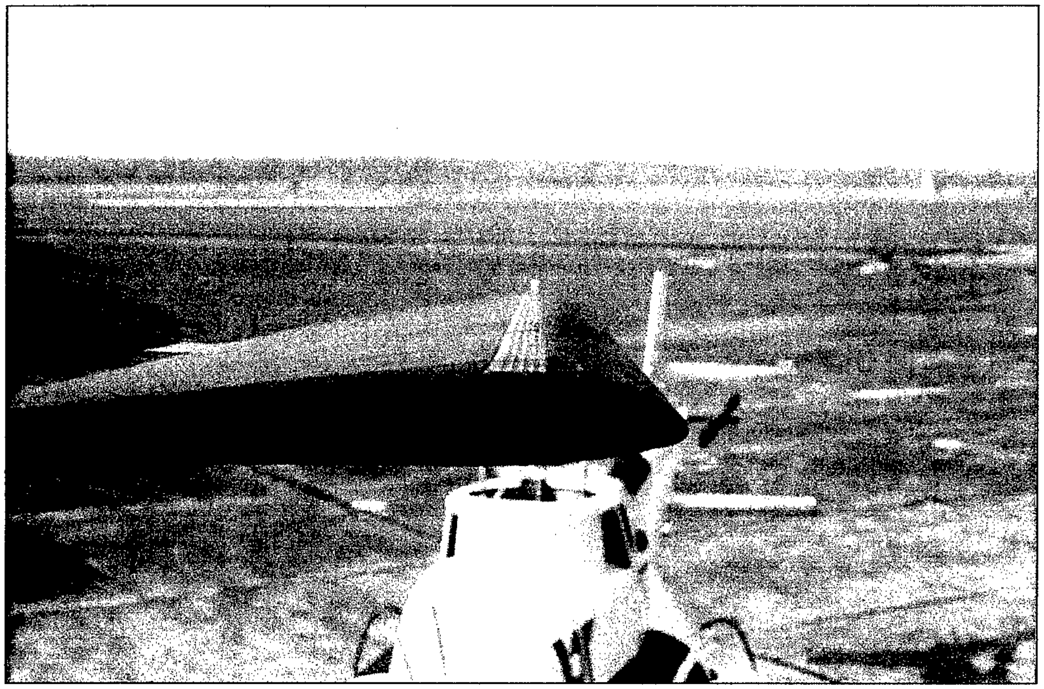


Figure E.7. Initial Maximum Camber Dimpletape® Positioning.

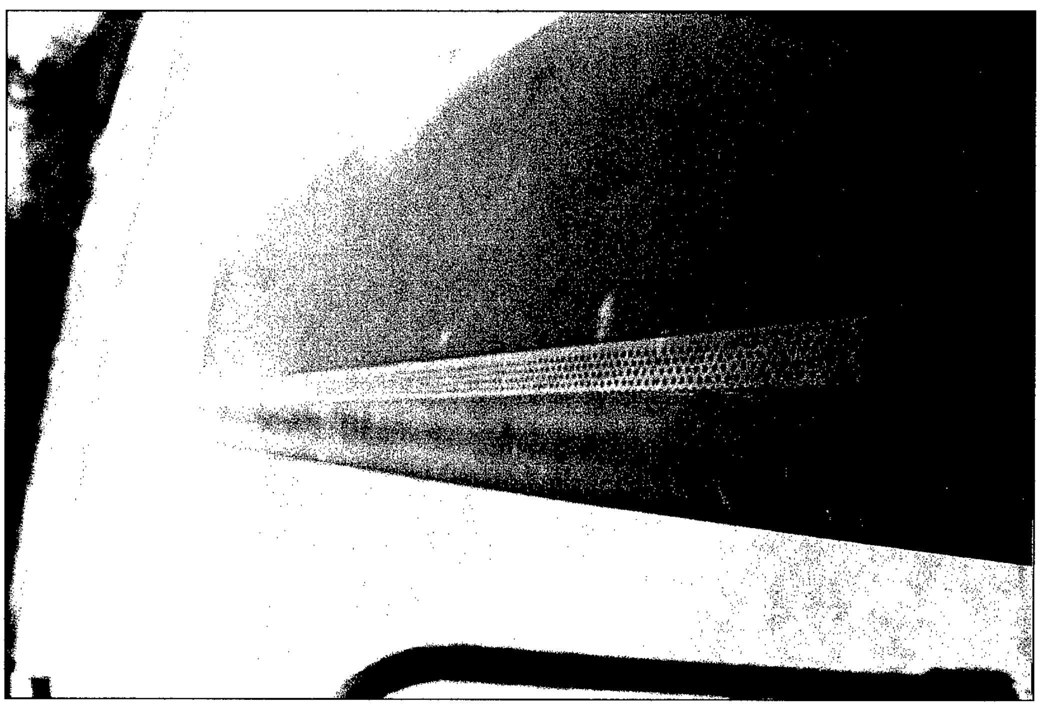


Figure E.8. Overhead Dimpletape® View (50% Rotor Blade Length).

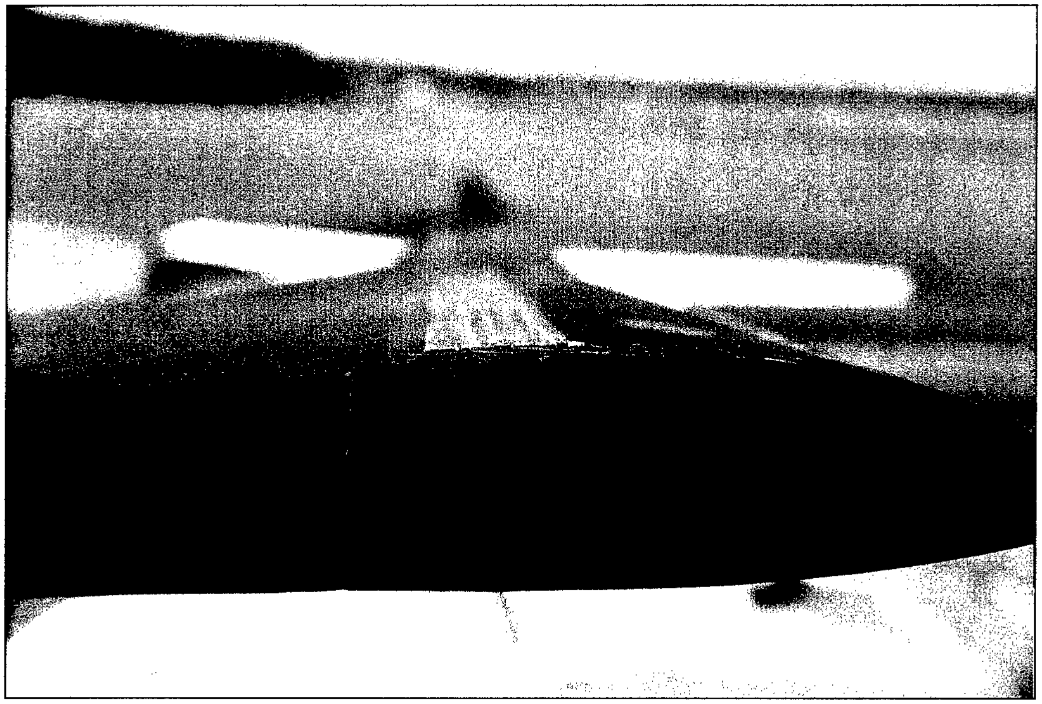


Figure E.9. Dimpletape® Positioned Cordwise, Aft 1" (10% Length).

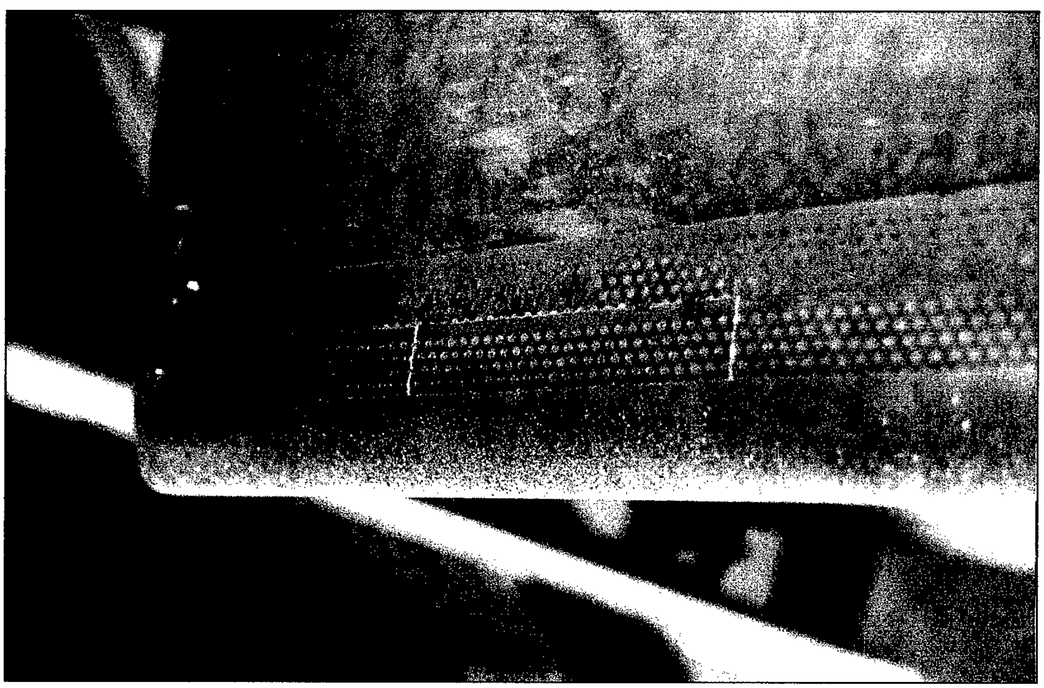


Figure E.10. Dimpletape® Positioned Cordwise, Forward 1" (10% Length).

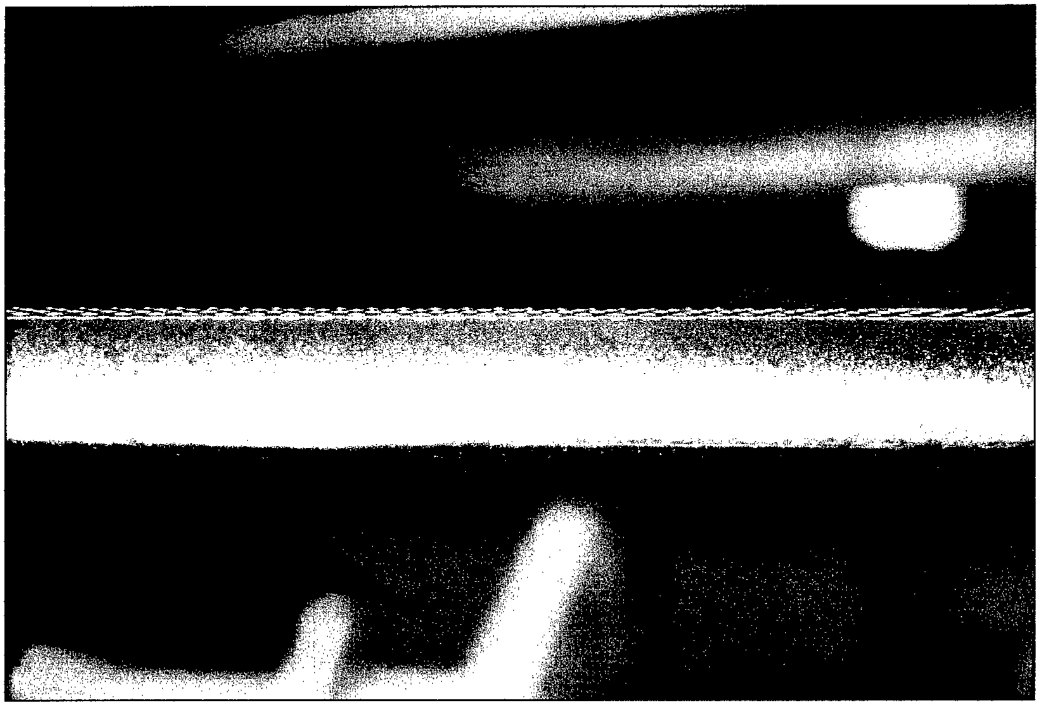


Figure E.11. Dimpletape® Positioned Cordwise, Forward 1" (10% Length).

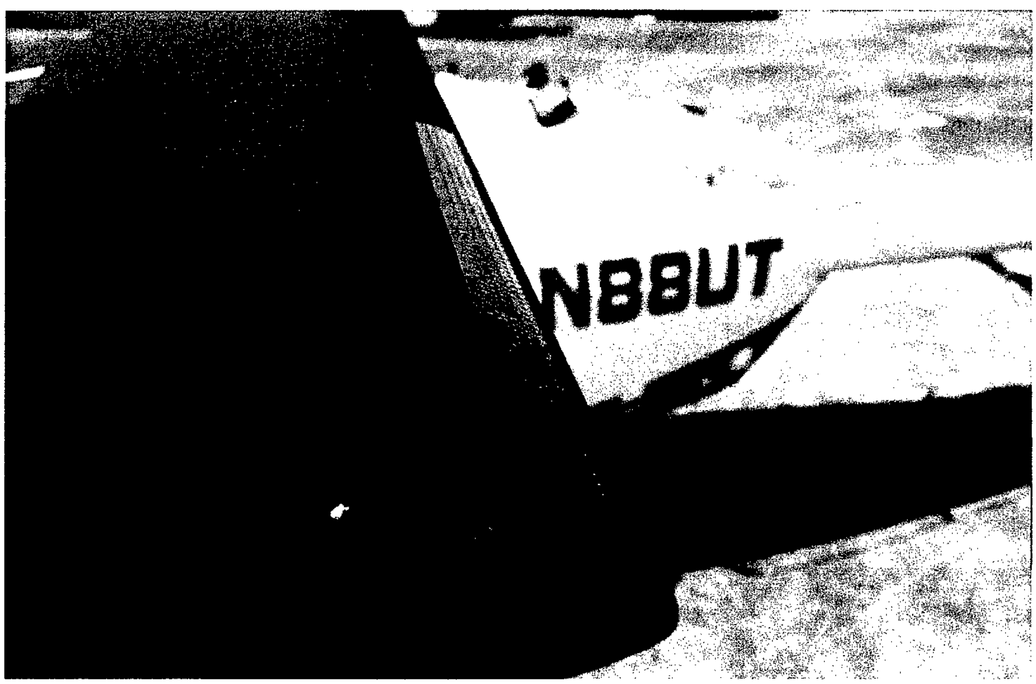


Figure E.12. Dimpletape® Positioned Cordwise, Forward 2" (10% Length).

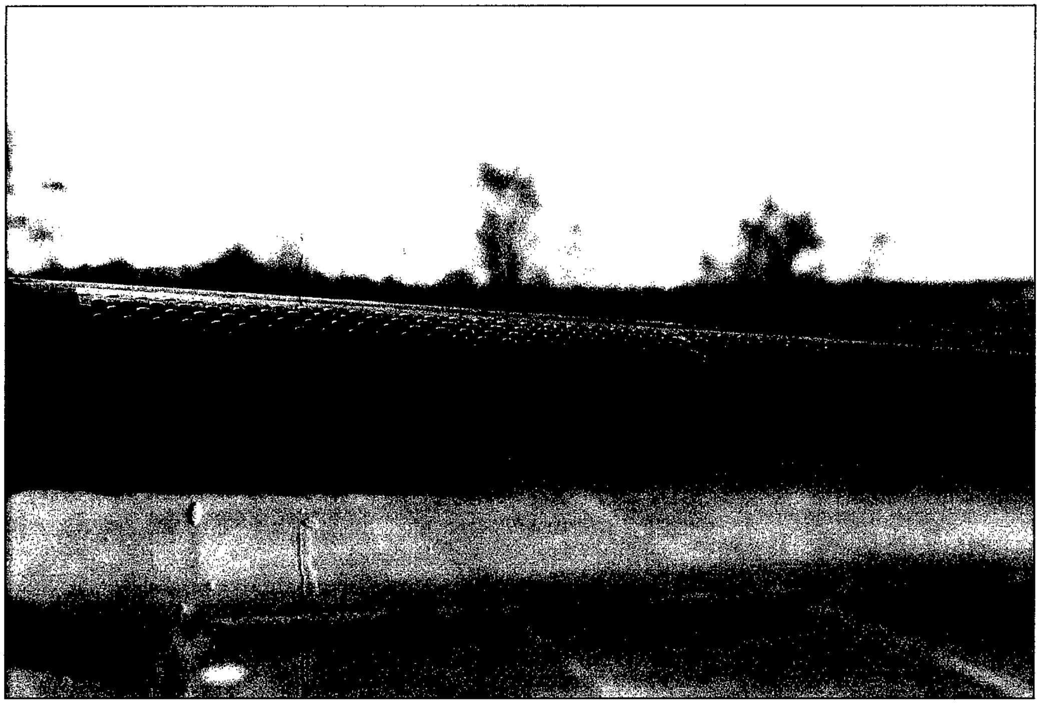


Figure E.13. Dimpletape® Positioned Cordwise, Forward 2” (10% Length).

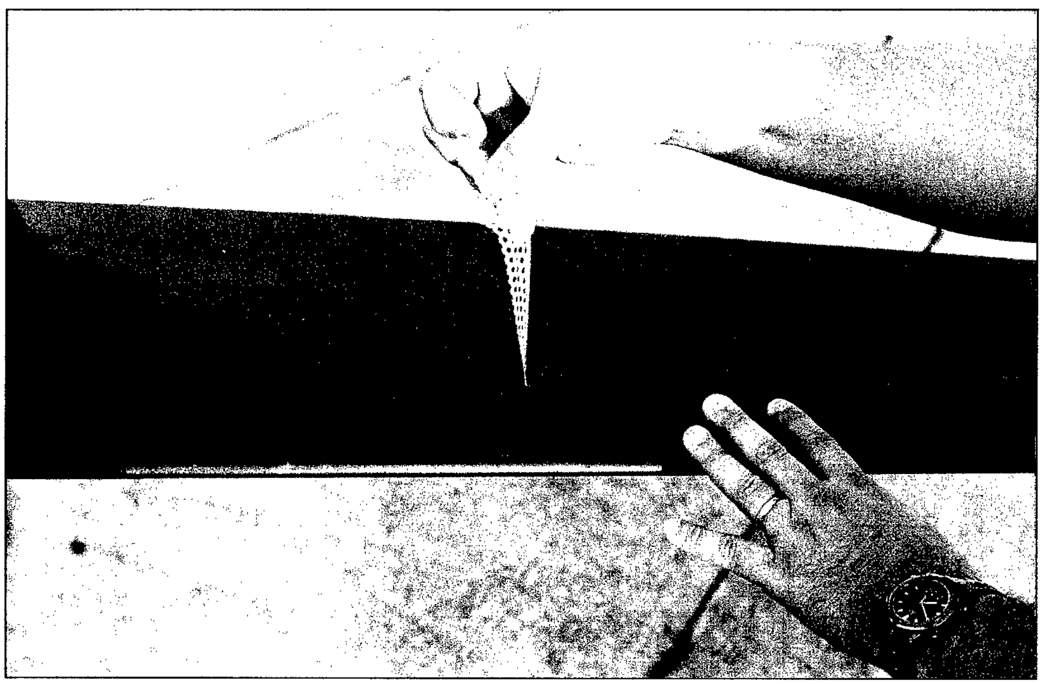


Figure E.14. Dimpletape® Removal.

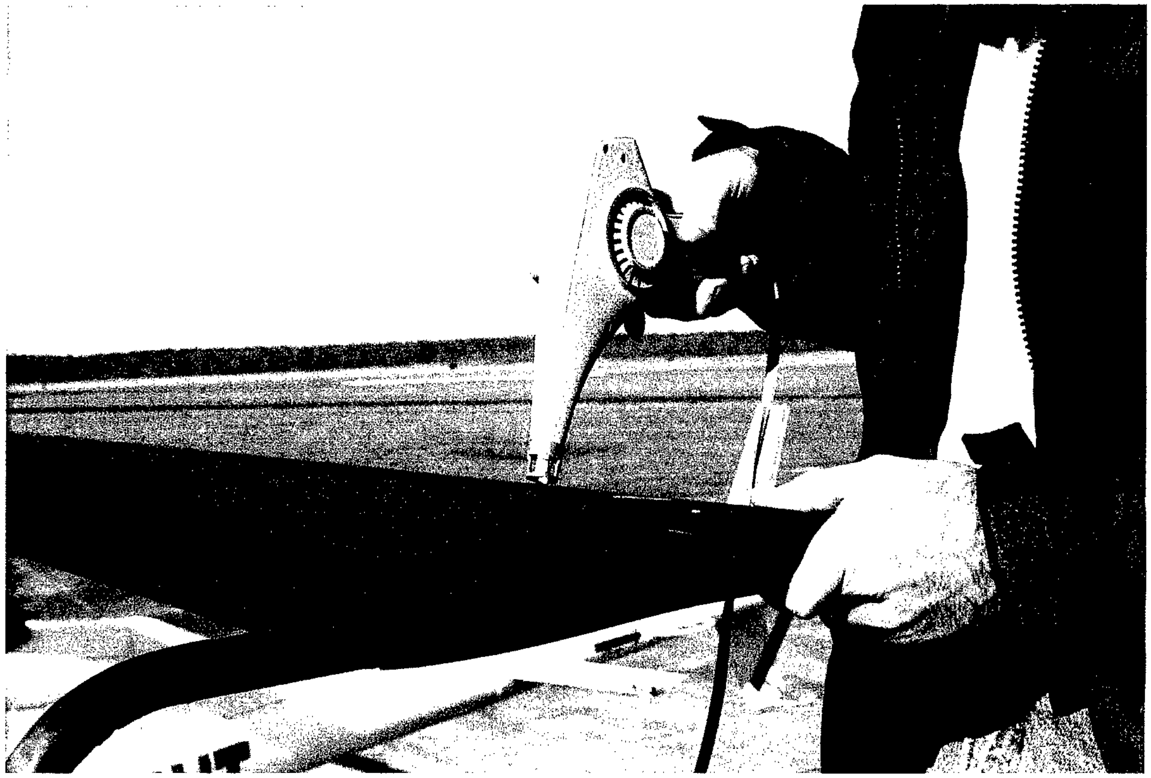


Figure E.15. Heating Rotor Blade with Hot Air Gun Prior to Dimpletape® Application.

VITA

Gregg Allen Deetman was born to Gerry and Bonnie Deetman in the town of Hamilton Ontario, Canada on 21 September 1961. He graduated from Hazelwood West High School, St. Louis, Missouri in 1980. He enlisted in the U.S. Navy to attend the Nuclear Power School in 1980. During his tour of duty he was stationed as an Engineering Laboratory Technician on the USS Nathaniel Greene SSBN 636 home based out of Holy Lock, Scotland. In 1986 he completed his Naval tour and attended St. Louis Community College. He joined the U.S. Army in 1988 to attend Initial Entry Rotary Wing Course and graduated as a distinguished honor graduate in January of 1989. He served as a Maintenance Officer flying the AH-64A Apache helicopter. His service included a tour to Germany (1993–1998) and two tours to Bosnia-Herzegovina (1997, 1999). He earned his Bachelor of Science degree in Professional Aeronautics with Embry Riddle Aeronautical University in August of 1996. In March of 2000 he was selected for the U.S. Army experimental test pilot program. Gregg graduated from the University of Tennessee Space Institute in August of 2001 with a Master of Science degree in Aviation Systems with a follow on assignment to attend the U.S. Naval Engineering Test Pilot School at Patuxent River Naval Air Station, Maryland.