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The Effect of Tailboom Strakes and Vertical Fin Modifications on the Performance and Handling Qualities of OH-58 Helicopters

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John A. Wade
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ABSTRACT

The Bell OH-58D helicopter is used in the armed reconnaissance role by the U.S. Army worldwide. Operations in support of this mission require the aircraft to be operated at a hover for extended periods of time at high altitude and in hot conditions. This places large demands on a power limited aircraft and increases pilot workload, especially in the pointing task so important to weapons delivery. The addition of aerodynamic modifications provides an inexpensive and effective method of reducing power required and pilot workload.

An investigation was conducted to determine the effects of adding tailboom strakes and a vertical fin modification (FastFin[®]) to a Bell OH-58D. The effect of the combined devices on helicopter performance, vibration and handling qualities was evaluated to determine any decrease in power required vs. power available (increased power margin). The strakes and modified fin were attached to the tailboom in such a manner as to alter the flow pattern of air passing over the tailboom. This change in flow pattern reduced the anti-torque requirements of the tail rotor. This in turn reduced the overall power requirement. The modified fin and strake combination reduced the vortices and turbulence at the tailboom and resulted in lower pilot workload and vibration in an out-of-ground-effect hover. This study also evaluated the effects on performance and handling characteristics of the helicopter. Testing included hover, low airspeed forward, rearward, sideward flight and level forward flight power measurements and handling qualities using modified Cooper-Harper and Vibration Assessment Rating (VAR) scales. Results showed an overall improvement in handling qualities and vibration levels at critical wind azimuth angles in low airspeed flight. For out-of-ground effect (OGE) hover, there was also a 2-3% reduction in power required due to the improved aerodynamic efficiency of the modified fin and strake combination.

DISCLAIMER

The views, opinions and/or findings contained in this report are those of the author and should not be construed as an official Department of Army position, or decision, unless so designated by other official documentation.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS		SYMBOLS	
ADS	Aircraft Design Standard	A	Tail Rotor Swept Area
AED	Aviation Engineering Directorate	b	Number of Blades
AFS	Army Fleet Support Incorporated	c	Mean Chord
AGL	Above Ground Level	C_T	Coefficient of Thrust
ATTC	Aviation Technical Test Center	f	Function of
AHIP	Army Helicopter Improvement Program	F	Sideforce
ASN	Army Serial Number	h.p.	Horsepower
BLR	Boundary Layer Research Incorporated	Hz	Hertz (times per second)
C.G.	Center of Gravity	Kq	Torque Ratio
CFD	Computational Fluid Dynamics	N	Rotor Shaft Angular Velocity
D.A.	Density Altitude	N_R	Rotor Speed (radians/second)
DataMARS	Data recording Analysis and Replay System	P_S	Static Pressure
ES.H.P.	Engine Shaft Horsepower	P_T	Total Pressure
ES.H.P. _{ref}	Referred Engine Shaft Horsepower	Q	Torque (foot/pounds)
FTM	Flight Test Manual	R	Rotor radius
GPS	Global Positioning System	S	Fin Surface Area
GW	Gross Weight	T_{Treq}	Tail Rotor Torque Required
HQR	Handling Qualities Rating	T_{Tgross}	Gross Tail Rotor Torque
HH	Helicopter	T	Net Thrust
IGE	In Ground Effect	V	Velocity
Kts	Knots	V_i	Vertical Induced Velocity
KTAS	Knots True Airspeed	W	Gross Weight
KIAS	Knots Indicated Airspeed	W_{ref}	Referred Gross Weight
MMS	Mast Mounted Sight	x	Separation tail rotor to fin
Mil-Std	Military Standard		
NASA	National Aeronautics and Space Administration		GREEK SYMBOLS
OGE	Out of Ground Effect	ψ	Sideslip Angle
OH	Observation Helicopter	ρ	Air Density
PC	Personal Computer	σ	Air Density Ratio
PCMCIA	Personal Computer Memory Card International Association	Ω	Blade Tip Rotational Speed (feet/second)
PEO	Program Executive Office	σ_{rs}	Rotor solidity
PA	Pressure Altitude		
RPM	Revolutions per Minute		
SCAS	Stability and Control Augmentation System		
S.H.P.	Shaft Horsepower		
USNTPS	United States Naval Test Pilot School		
VAR	Vibration Assessment Rating		
VMC	Visual Meteorological Conditions		
Wt	Weight		

1. INTRODUCTION

The Bell OH-58D helicopter is used in the armed reconnaissance role by the U.S. Army worldwide. Operations in support of this mission require the aircraft to be operated at a hover for extended periods of time at high altitude and in hot conditions. This places large demands on a power limited aircraft and increases pilot workload, especially in the pointing task so important to weapons delivery. At the maximum gross weight of the aircraft the maximum operating density altitude is sufficiently low and power available is sufficiently limited to preclude missions in several arenas of operation. The addition of aerodynamic modifications provides an inexpensive and effective method of reducing power required and pilot workload. The objectives of this research are to;

- Determine and quantify performance improvements at a hover, in low airspeed and level flight of the fin/strake modifications.
- Evaluate changes in handling qualities and vibrations.
- Evaluate fuel flow reduction.
- Examine potential use of strakes and modified fin as a low cost performance and handling qualities improvement.

1.1 Aircraft description

The OH-58D helicopter (Figure 1), manufactured by Bell Helicopter Textron, Inc is a military derivative of the company's 206A series of helicopters. The OH-58D entered service with the U.S. Army in 1985 as a result of the Army Helicopter Improvement Plan (AHIP) to improve the combat capability of the ageing OH-58A/C light observation helicopter. Improvements include a more powerful engine, an upgraded transmission and a four bladed main rotor system. There are also extensive upgrades to the avionics and weapons of the aircraft including the addition of a mast-mounted sight (MMS) and a suite of weapons such as 2.75 inch rockets and Hellfire missiles. The OH-58D is a single-engine, four-bladed, fully articulated single-main-rotor helicopter

utilizing a semi-rigid two bladed pusher tail rotor located on the left side of the helicopter for anti-torque. The aircraft is designed for a crew of two. The tail rotor is capable of producing 110 shaft horsepower (s.h.p.) at its design operating speed (100% rpm). The tailboom is a monocoque structure that supports the tail rotor drive shaft, tail rotor gearbox, vertical fin, horizontal stabilizer, and countermeasures equipment. The structure is an improvement over the OH-58A/C in that the skin and inner structural components are of heavier gauge materials. The tailboom is attached to the fuselage by four bolts. The undercarriage is of the fixed twin skid type and allows landing in unimproved areas. Weapons are carried on fixed pylons attached to either side of the fuselage structure. The aircraft is powered by a Rolls Royce turbo shaft 250-C30R/3, producing 550 s.h.p. at 100% torque. The aircraft has an irreversible flight control system with stability and control augmentation system (SCAS). The SCAS is a three-axis (pitch, roll, and yaw) digital system with a heading-hold mode. This limited-authority system is designed to improve handling qualities by providing damping for short-term external disturbances and augmenting pilot input commands. Although a great improvement in the overall capability of the aircraft was realized, the flight performance envelope was not increased significantly due to the increased weight and drag of the new modifications. A more detailed description of the OH-58D is contained in the Operator's Manual¹.



Figure 1. OH-58D Kiowa Helicopter

The addition of the strakes and fin discussed here was expected to enhance the handling qualities of the helicopter and to reduce the power required to hover and perform low speed flight (up to 30 knots indicated airspeed). Prior to beginning the flight testing, the U.S. Army Program Office for Aviation, Scout/Attack Branch at Redstone Arsenal, Alabama showed that a significant cost savings could be realized from the reduced fuel consumption associated with a reduction in engine power required (Figure 2). Figure 2 is based on the savings for pure hover at the commercial fuel price for 2007. Actual operational savings could be less depending on the cost of fuel and the time spent at a hover which is determined by the type of mission. The OH-58D is currently operated at 5500 pounds maximum gross weight but is limited to 5200 pounds to allow full autorotational capability. The data obtained were used to establish trends rather than to conduct an engineering analysis. The data showed qualitative improvements in performance and handling qualities and pointed to the need for a full quantitative evaluation. Although improvements were seen, no sensitive instruments were installed in the aircraft that could quantify the exact gains in performance.

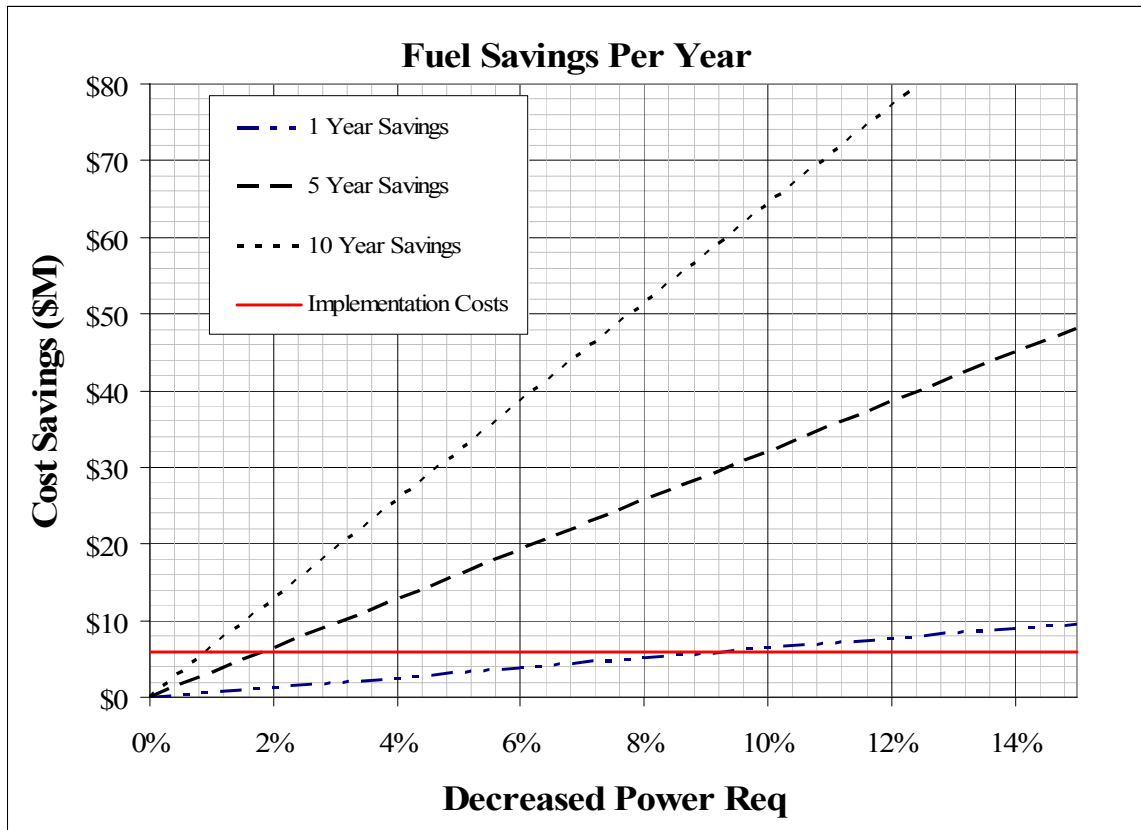


Figure 2. Potential Cost Savings of Fin/Strakes.
(Source, Dennis Boyer, Senior Engineer, PEO-Aviation, Redstone Arsenal, Alabama)
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2. BACKGROUND

2.1 Strake Theory of Operation

As the mission equipment of the OH-58D has grown to include weapons and additional mission equipment, it has become performance limited in some areas of the world where it is expected to operate. This is especially true in “hot/high” conditions (above 4000 feet Pressure Altitude and above 95 deg F) and when the helicopter is operating at or near its maximum allowable gross weight. Therefore, any performance improvement that does not entail significant modifications to the helicopter or its drive train would be an asset to the pilots in the field. One such simple modification is the addition of tailboom strakes (Figure 3). Tailboom strakes mounted on other helicopters have been shown to provide a performance increase due to reduced tail rotor power requirements. They have also been demonstrated to improve directional stability in forward flight and to reduce pilot workload by reducing necessary pedal movements in a hover². For helicopters with main rotor counterclockwise rotation (viewed from above), the strakes are located on the left side of the tailboom, under the main rotor. The upper strake serves to control the location of the stagnation point of the downwash flow over the tailboom, while the lower strake controls separation of the flow near the bottom of the tailboom.

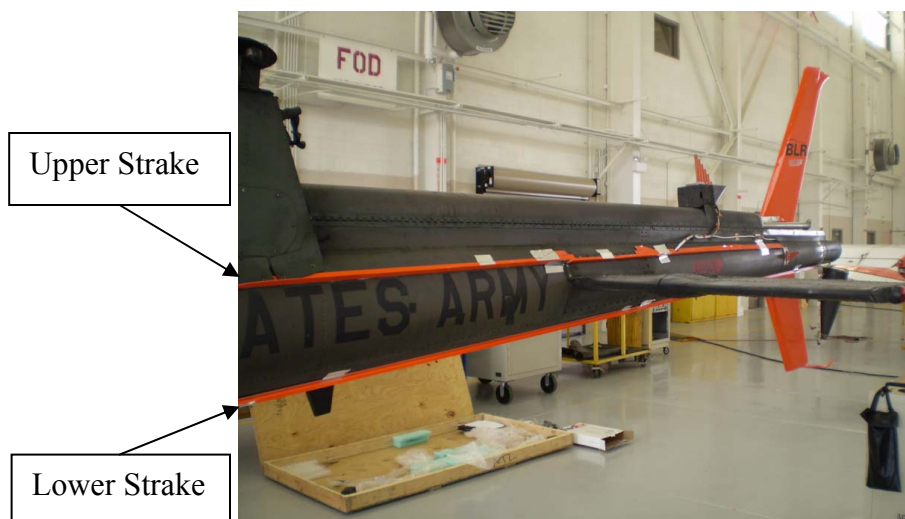


Figure 3. Strakes Mounted on OH-58D

The strakes induced a pressure gradient over the tailboom that produces a side force and yawing moments that serve to “unload” the tail rotor and reduce its power requirement. This change in pressure is illustrated in Figure 4, which depicts results from a two dimensional computational fluid dynamics analysis for separated flow using the computer program FUN2D. This program was used to calculate the flow about the two-dimensional cross-section of the tail boom. FUN2D is computer program that solves the two-dimensional Reynolds-averaged, Navier-Stokes equations on unstructured triangular grids. For the Figures showing the two dimensional airflow, it was assumed that the downwash from the main rotor in a hover descends vertically with a minimal sideward component. As a result, all analyses were run with the flow approaching the tailboom cross sections parallel to their vertical centerlines. Run conditions were a Mach number of 0.0627 and a Reynolds number of 1.48 million, based upon a basic tail boom diameter of 39.7 inches. Being a cylindrical body, there was a Von Karman vortex street calculated to form downstream of the tail boom. Approximately 2000 solution iterations were required to achieve a reasonable level of convergence. The research was conducted by Analytical Methods Incorporated for Boundary Layer Research (BLR) on the cross section of an HH-65 tailboom³. While larger in diameter than the OH-58 tailboom, the cross-sectional shapes of the HH-65 and OH-58D booms are approximately the same (i.e. circular). Since for U.S. helicopters the main rotor rotates counter-clockwise when viewed from above, the torque effect tends to make the fuselage rotate in the opposite direction (clockwise when viewed from above). The flow analysis in Figure 4 was measured at station C, which was located at approximately the mid-length of the tailboom. Since the main rotor of the HH-65 rotates in the opposite direction (i.e. clockwise when viewed from above) of a U.S. helicopter the representations in Figure 4 are reversed to show the effect of a U.S. style main rotor. For the plots of pressure coefficient, the flow was measured using a thin “slice” a model of a real HH-65 tailboom. In addition, the inflow was canted slightly left of center to replicate the real effect of swirl on the rotor wash. Figure 4a represents the analysis without strakes mounted and shows there is a low static pressure and high velocity area located on the right side of the tailboom. This is acting against the action of the tail rotor, placing a greater aerodynamic

load on the tail rotor and increasing power required to hover. The line farthest left in Figure 4a represents the coefficient of pressure (C_p) along the upwind (left side, looking forwards) side of the tailboom while the rightmost line represents the C_p along the leeward side (right side looking forward) of the tailboom. Figure 4b with two strakes mounted shows a pressure distribution that is actually aiding the tail rotor because of a lower pressure gradient on the right side of the tailboom. The green line shows the effect of one upper strake only while the red line shows the effect with both strakes installed. Where the lines are vertical with respect to the tailboom, the flow is separated and therefore has fairly uniform C_p . Comparing the lines on Figure 4 representing C_p with and without strakes it can be seen that, without the strakes, the lines of C_p on either side of the tailboom are quite close. With the addition of the strakes, there is a significant difference in C_p on each side of the tailboom. This produces lower pressure on the right than on the left (looking forwards). The net effect is reduced tail rotor thrust required by “unloading” the tail rotor with a pressure differential which reduces power required to hover. This more favorable pressure distribution serves to reduce the power requirement on the tail rotor and therefore the overall demand on the power train. The lower strake controls the point at which the airflow re-attaches to the tailboom. Without the lower strake, the re-attachment is random and is characterized by random and unpredictable oscillations in aircraft heading caused by the generation of a Von Karman vortex street. The reduction in unpredictable vortices facilitates a smoothing of pedal activity and a corresponding reduction in pilot workload.

The development of vortices around the tailboom of an OH-58 is analogous to the flow around a cylinder. The Von Karman street vortex pattern develops on the leeward side of an object, especially a cylindrical one⁴. Around the cylindrical OH-58 tailboom, the boundary layer separates from the surface and forms vortices that are highly unstable. As the flow velocity increases, vortices on both sides interact randomly and shed unpredictably. This random shedding and interaction is the main cause of directional oscillations in the helicopter at a hover. The vortex shedding occurs at a discrete frequency and is a function of the Reynolds number⁴ and Strouhal⁵ number. The frequency of this vortex shedding f , is calculated by⁵;

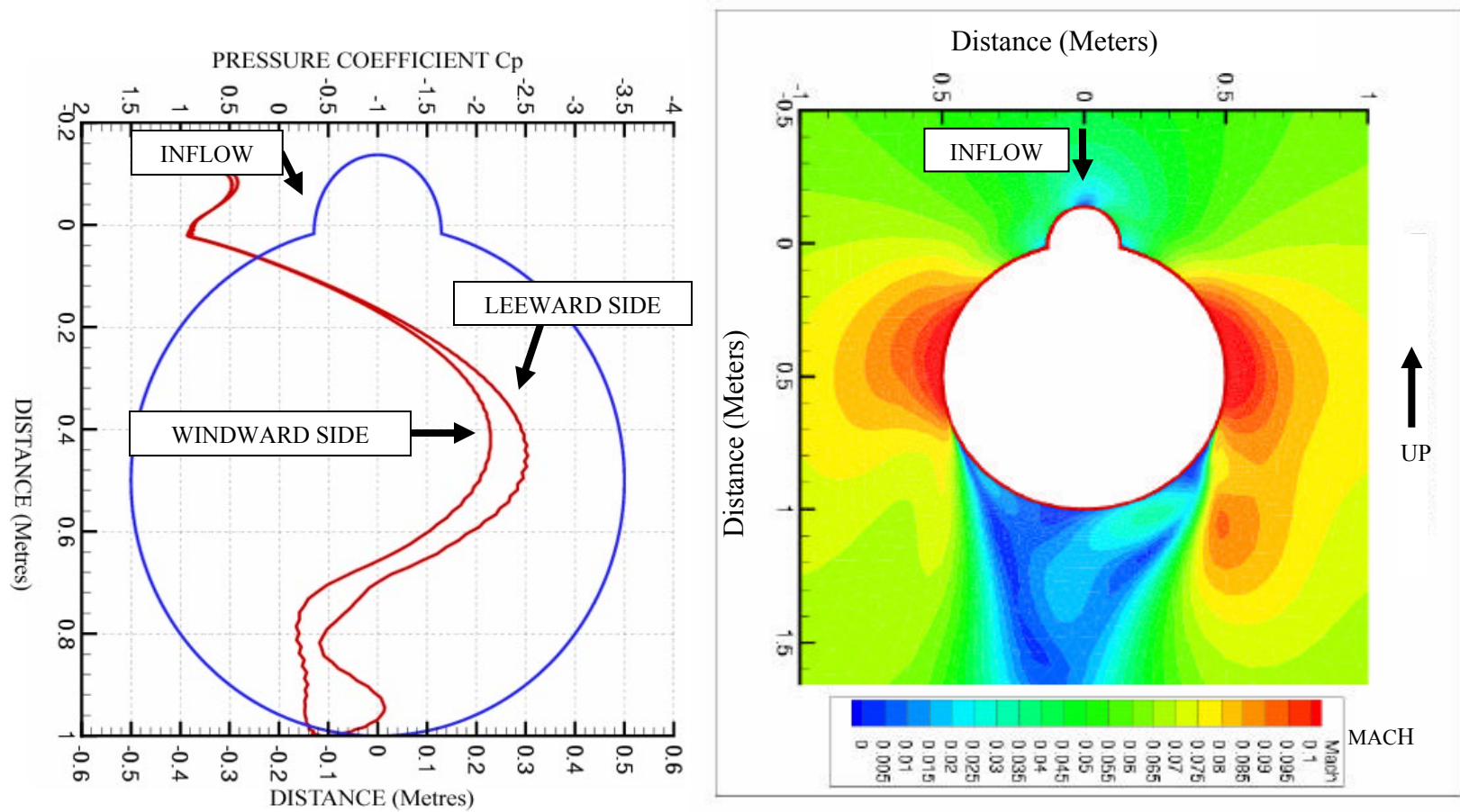


Figure 4a. Cross Section of HH-65 Tailboom Showing Airflow Pressure Gradient and Velocity. Without Strakes. Looking Forward.

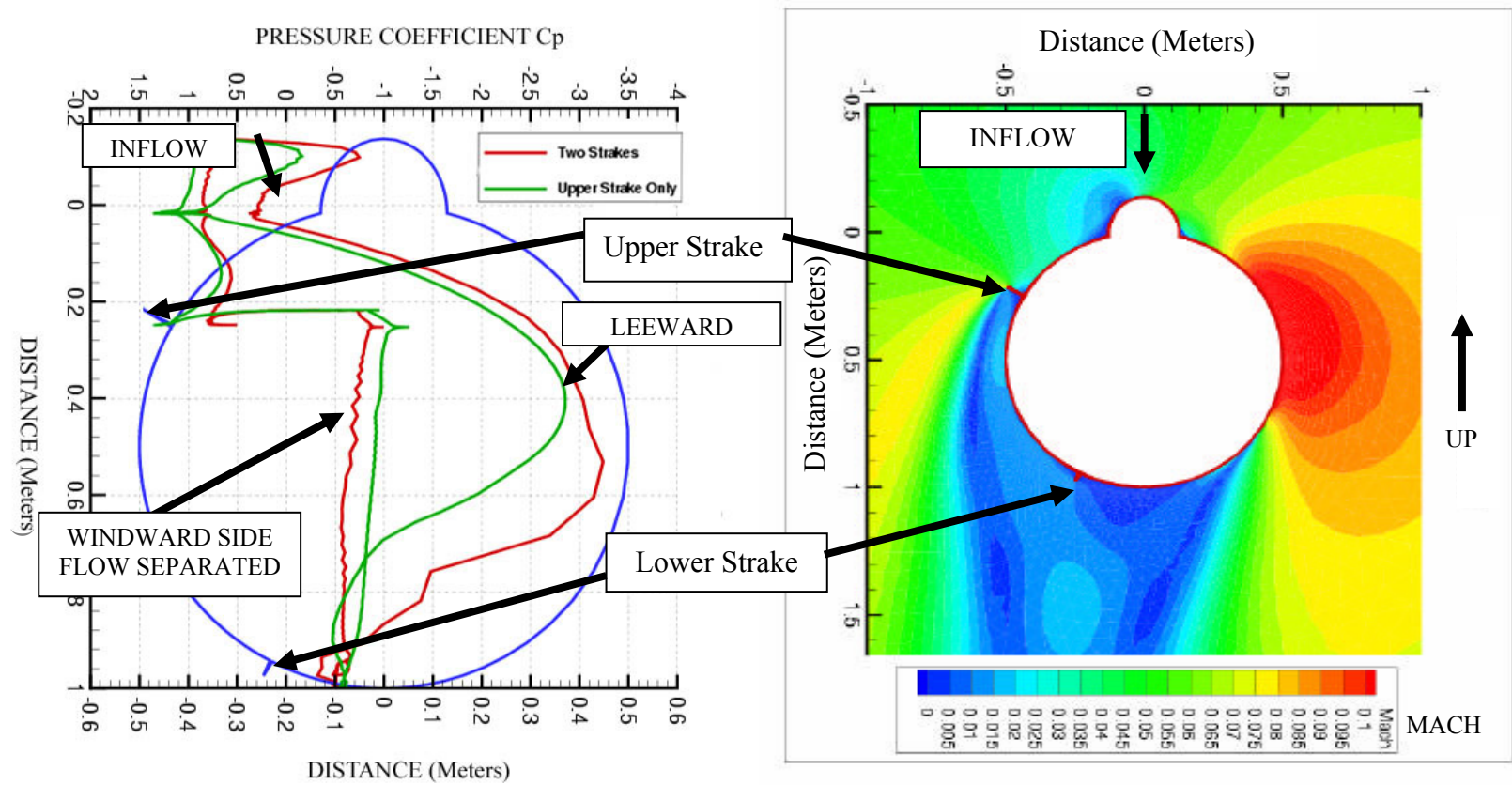


Figure 4b. Cross Section of HH-65 Tailboom Showing Airflow Pressure Gradient and Velocity. With Strakes. Looking Forward.

$$f = VS / d \quad (1)$$

where;

f = Vortex Shedding Frequency

V = Flow Velocity (feet per second)

S = Strouhal Number

d = Diameter of tailboom (cylinder, feet)

Experiments by Jones⁵, show that Strouhal numbers vary between about 0.18 and 0.24 for Reynolds numbers from 100 to 100,000,000. The average diameter of the circular OH-58D tailboom is 1 foot. The average downward vertical rotor wash velocity (V_i), as calculated by momentum theory⁶ is approximately 35 ft/sec resulting in a Reynolds number based on tailboom diameter, of about 320,000 at sea level. Experimental data show that the Strouhal number for these conditions is about 0.2⁷. The frequency of vortex shedding for the OH-58D tailboom can now be calculated as:

$$f = (35)(0.2)/(1) = 7 \text{ rad/sec} = 1.2 \text{ Hz} \quad (2)$$

Tailboom oscillations at this frequency are within a range that is generally accepted to affect the pilot's ability to maintain directional and lateral control of the helicopter. In a hover, there is also some effect of random flow unsteadiness over the tailboom, where small changes in rotor wash position and strength result in changes to the velocity and angle of attack, causing the forces on the tailboom to change rapidly⁸. There are therefore, both periodic and random disturbances around the tailboom which make maintaining a steady heading difficult, increasing pilot workload. These phenomena are at their worst in a hover when the vertical rotor wash, V_i is at its highest. On a cylindrical helicopter tailboom these disturbances result in an unpredictable yawing moment, requiring the pilot to constantly change the pedal position at varying rates to maintain a desired heading. These rapid and inconsistent pedal inputs place a strain on the drive train, increase pilot workload and increase the engine torque required to hover. The tailboom strakes control the stagnation point (upper strake) and the separation point (lower strake) of the flow with the intent of reducing these disturbances. The installation

of an upper tailboom strake was suggested in the United States as early as 1975. BLR obtained two FAA Supplemental Type Certificates^{9,10} (STC's) in 2006 covering Bell 206 helicopters modified in this way. Several limited tests were performed on the UH-60 that showed modest improvements in performance¹¹.

Further research by the U.S. Army Aeroflightmechanics Directorate and NASA at the Langley Research Center showed that the tailboom of a single-rotor helicopter causes significant yaw moments that can require up to 10% of the helicopter's available power to overcome¹². These tests were conducted using a UH-1 type helicopter. Gains were seen in pedal margin and power required with strakes installed. The greatest gains were seen with the wind 60 degrees from the nose direction at a speed of 20 knots. The mean gain in pedal margin was 6% and the mean reduction in power required was 17%, at a sideslip angle (ψ) of 60 degrees. Calculations by Crowell et. al.¹² show that 10% pedal improvement would give a UH-1 size helicopter an additional 6000 ft of operational altitude or 1700 lb more payload. The reduction in power required also decreased fuel consumption and reduced aircraft operating costs. These factors gave the strake-equipped aircraft a considerable advantage over a helicopter of standard configuration. For these tests, pilots reported a 50% improvement in their ability to maintain heading of the helicopter. It would appear that the greatest gains in performance and handling qualities were realized with the relative wind from the right side of the helicopter (for sideslip angles (ψ) between 60 and 105 degrees) at relatively low airspeed (from 10-35 knots). Research performed by NASA¹³ indicates that rotor wash passing over the tailboom of all single rotor helicopters creates a fluctuating low pressure area along the advancing blade side of the tailboom. The addition of strakes beneficially increased the side force coefficients of the tailboom, especially on one with a circular cross-section. Their research demonstrated the potential to reduce the thrust required for directional control in sideward flight. There is also some evidence that the addition of strakes to the tailboom of a Bell 206L-1 did not adversely affect tailboom vibrations and may have some small beneficial effects by reducing the amplitude of some of the vibrations¹⁴. This is relevant since the tailboom of the OH-58D has been shown to be prone to vibrations. Although acquiring tailboom vibration data was beyond the scope of the work reported

here, further investigation on the effects of strakes on tailboom vibration is warranted. Thus, based on prior analysis and testing, the Army decided to evaluate the effect of installing strakes OH-58D helicopters with the objective of reducing the power required to hover and improving heading oscillations and reducing pilot workload. An added benefit is the consequent reduction in fuel consumption and reduced operating costs.

2.2 Estimating the Effects of Strake Installation.

From a NASA study¹² using a Bell 204B with a pusher type tail rotor, further reductions in tail rotor thrust required (T_{Treq}) were realized from the installation of tailboom strakes. The largest reductions in T_{Treq} for this particular test were seen at sideslip angles (ψ) of 45 to 90 degrees. The critical sideslip angle for directional control for this helicopter was reported to be $\psi = 60^\circ$. The test compared single and dual strake installations; results for the dual installation are presented in Table 1. If it is assumed that the order of power reduction is the same for the OH-58D as for the Bell 204B, then average gains at critical angles would result in a maximum 20% reduction in T_{Treq} at certain azimuths.

Table 1. Reduction in Bell 204B Tail Rotor Thrust Required, Dual Strakes.

Sideslip angle, ψ	V (Knots indicated airspeed)	Mean Peak Reduction in T_{Treq}
45	20	21%
60	20	17%
75	15	23%
90	15	15%

2.3 Estimating the Effects of Fin Modifications.

The fin modifications, known as FastFin[®] by BLR, build on the gains of the strakes to further decrease tail rotor loads, by reducing the surface area of the fin (the planform area of the modified fin is 388 in² less than the standard fin) and modifying the trailing edge to provide more uniform flow and reduce the vortices produced by a sharp trailing edge. The fin modification reduces fin chord and adds a rounded trailing edge very much like the leading edge (Figure 5). The reduction in fin area reduces the effects of tail rotor and fin interference. The tail rotor and fin interference has two main effects. First, the rotor wash from the tail rotor striking the fin adds a force opposing the direction of thrust of the tail rotor, thereby effectively decreasing its anti torque effectiveness. The side force causes the pilot to add more left pedal in order to increase the pitch of the tail rotor blades increasing the thrust and drag of the tail rotor, increasing power required to hover. Second, the fin disturbs the airflow from the tail rotor and creates vortices on the leeward side of the fin. The vertical fin adversely affects the airflow from the tail rotor by acting as a barrier to free air flow. This effect reduces the amount of air the tail rotor can move at a given pitch setting which reduces the gross tail rotor thrust (T_{TGross}). The modified fin potentially reduces this effect. The formula below¹⁵ is used as a means of estimating the effect of this inference force. The interference force on the fin is a function of swept surface area of the fin (S), the tail rotor area (A), the separation distance between the tail rotor and the fin (x) and the rotor radius (R). This yields the interference ratio which is the side force (F) divided by the net thrust of the tail rotor (T). The gross thrust of the tail rotor is then calculated by,

$$T_{TGross} = \frac{T_{Treq}}{1 - F/T} \quad (3)$$

Where,

T_{TGross} = gross thrust of the tail rotor

T_{Treq} = tail rotor thrust required to counteract main rotor torque

F = Side Force

T = Net thrust



Figure 5. Comparison of Modified OH-58D Fin (orange) to Original Fin

Tail rotor thrust required, T_{Treq} is a constant for any given set of conditions. Therefore, reducing the interference ratio F/T is one method of reducing T_{TGross} . This may be achieved by reducing the swept surface area of the fin (S) by decreasing its chord. This is the essential theory behind the modified fin arrangement (Figure 6). Figure 6 shows the nondimensional interference force on the fin as a function of the blockage area ratio (S/A) and the separation distance between the fin and the tail rotor (x/R). To use Figure 6, enter the chart at some known value of x/R (based on mechanical measurements) on the x axis and then move up to the appropriate calculated value for area ratio (S/A). Then move towards the y axis and read interference ratio (F/T). Using Figure 8, with values of area ratio (S/A) of 0.23 and a separation ratio, x/R of 0.24 the interference ratio for this tail rotor (F/T) installation was found to be 0.13 in this example. Based on these test data at a rotor normalized net thrust (coefficient of thrust divided by the rotor solidity ratio, C_T/σ_{rs}) of 0.08, (which was selected by Prouty¹⁵ as being representative of a typical hover flight condition), C_T may be calculated by;

$$\text{Coefficient of thrust}^{16}, C_T = \frac{T}{\rho \pi R^2 (\Omega R)^2} \cong \frac{GW}{\rho A (\Omega R)^2} \quad (4)$$

and;

A = Rotor area (ft²)

T = Main Rotor thrust (lbs)

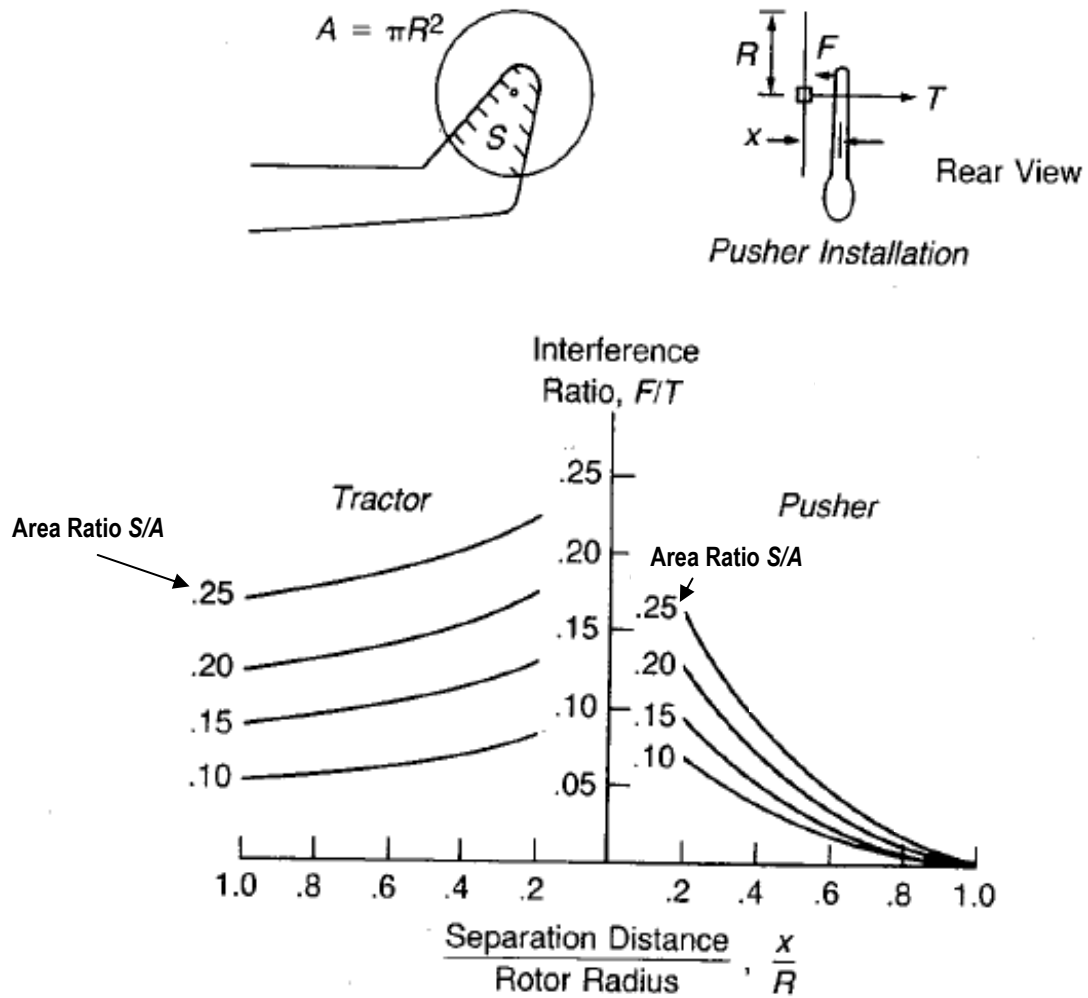
GW = gross weight (lbs)

ρ = air density (slugs/ft³)

ΩR = Blade Tip Rotational Speed (ft/sec)

From the experimental data Prouty¹⁵ found that at a blade loading of 0.08, the fin-off condition produces a 13% greater thrust coefficient than with fin-on.

To estimate the effects of fin area reduction for the OH-58D the interference ratio, F/T is calculated by entering Figure 6 on the x axis (right side of the figure for a pusher configuration) based on the parameters below;



Source; Morris, "A Wind Tunnel Investigation of Fin Force for Several Tail Rotor and Fin Configurations". NASA LWP-995, 197. Used with permission.

Figure 6. Tail Rotor - Fin Thrust Interference Ratio at a Hover

Rotor radius, $R = 32.5$ inches

Separation distance, $x = 5$ inches for 36% (tailboom area) where $x/R = 0.15$

Separation distance, $x = 25$ inches (remaining area over fin only), $x/R = 0.77$

Calculated swept area, $S = 1040 \text{ in}^2$

Calculated tail rotor area, $A = 3317 \text{ in}^2$

Using these values for the OH-58, enter figure 6 at each of the x/R values and climb vertically to intersect the extrapolated area ratio of 0.30 (for estimating purposes only), and then proceeding left to the Y axis This yields an interference ratio of 0.10 when averaged for the interference ratio of the tailboom and the fin. Using Figure 8, a reduction in area S (of the fin only) of 388 in^2 should yield a theoretical reduction in F/T (for the fin only) from 0.06 to 0.02. Thus the interference ratio for the tail rotor with the modified fin is approximately 4% less than the interference ratio for the rotor with the standard fin. As a method of estimating the effects of fin area reduction, Prouty¹⁵ uses as an example that shows a set of experimental data (Figure 7) from a test of a Lockheed “pusher” tail rotor with and without a fin installed. This chart is shown to illustrate that there is a interference caused by the fin in airflow and removal of the fin results in a significant potential reduction in tail rotor power required which in the basis for the modified fin. Comparing the interference ratios with fin on and fin off, as in Figure 9 but using a difference of 4% from the calculations above rather than 13% for C_T/σ_{rs} , the difference in power required at C_T/σ_{rs} at 0.07 (typical blade loading at typical gross weight for OH-58D) would be on the order of 4%,

Where,

C_Q = Coefficient of Torque

σ_{rs} (rotor solidity) = $bc/\pi R$

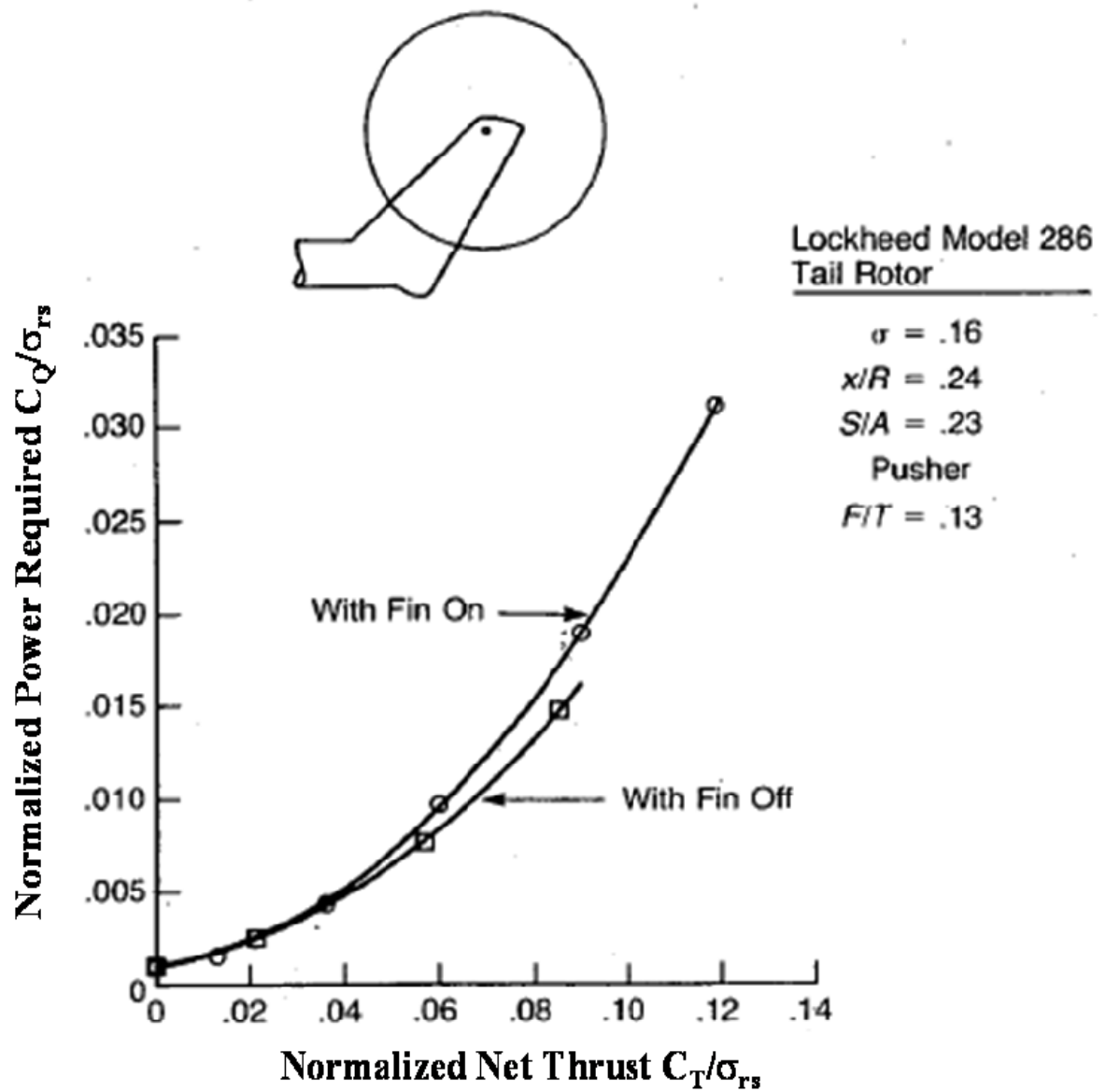
and;

b = number of blades

c = mean blade chord (in)

R = rotor radius (ft)

This effect, when coupled with the as yet unquantified, reduction in fin vortex interference (Figure 8) of the modified fin indicates a potential of up to 5% net reduction in tail rotor torque required. The figure depicts a tractor type tail rotor but the airflow patterns are the same whether the air is pulled or pushed. The areas of turbulent flow remain the same. The substitution of the sharp trailing edge of the fin with a rounded leading edge also improves aircraft directional control in rearward flight since the air is displaced across the fin chord much as it would be in forward flight. As the aircraft transitions backwards the standard fin presents a sharp trailing edge to the relative wind. This causes vortices to form in the airflow across the fin, resulting in an unpredictable disturbance that is difficult to control. The modified fin minimizes this tendency as shown in Figure 9. Given a reduction of T_{Treq} for the fin modifications of 5% and a reduction of T_{Treq} for the strakes of 20% (from section 2.2), a cumulative reduction in T_{Treq} of 25% could be expected with the installation of the modified fin and a set of double strakes. T_{Treq} is typically on the order of 18% of the overall power output of the engine at a hover, (about 100 s.h.p. in an OH-58D at a hover according to Crowell et. al¹²), therefore a net reduction in engine power required of 25 s.h.p. could be realized. Assuming an engine power output of 550 s.h.p., this represents a reduction in engine power required of 5%. A 5% reduction in engine power required significantly improves the fuel consumption rate and increases the pedal margin of the helicopter. The increase in performance, along with improved handling qualities and reduced pilot workload, is of significant benefit to the pilot when operating in hot/high altitude conditions and at or near the maximum aircraft gross weight. These are conditions where this helicopter is expected to operate and has a direct impact on mission accomplishment.



Source; Internal Lockheed document. Used with permission

Figure 7. Effect of Tail Rotor - Fin Interference on Normalized Tail Rotor Power Required versus Normalized Net Thrust

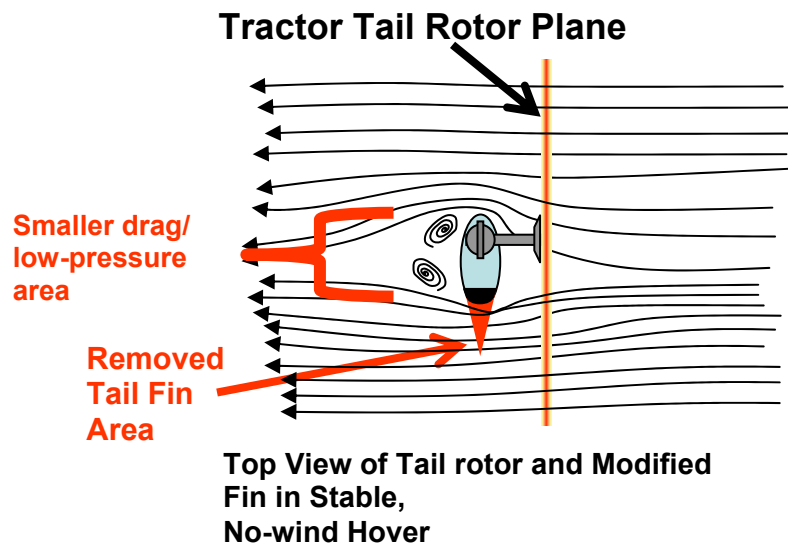
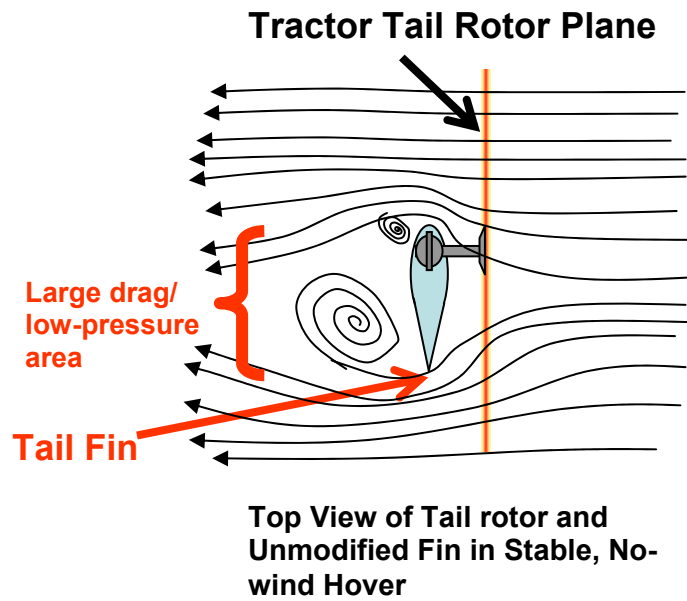


Figure 8. Airflow Over Vertical Fin Viewed from Above

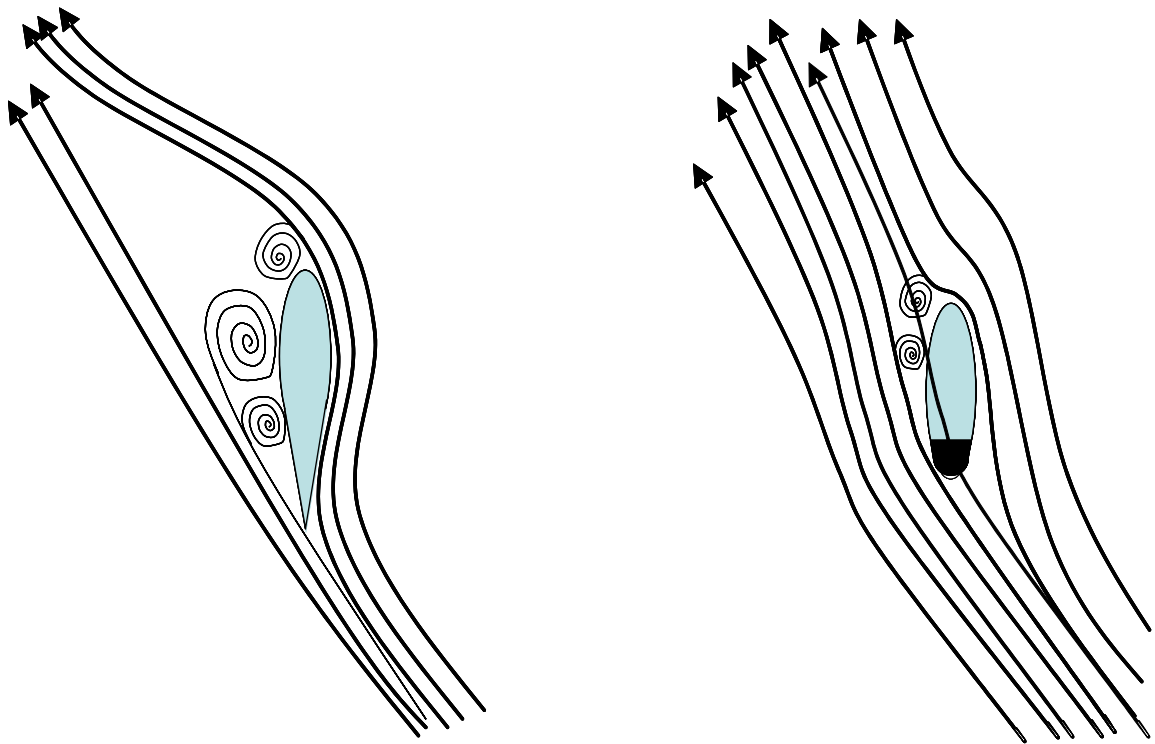


Figure 9. Airflow Over Fin in Rearward Flight. Viewed from Above

3. TEST AND TEST METHODS

The test was conducted over a 7 day period encompassing 20 flight hours spread over six flights.

3.1 Test Configuration and Methodology

3.1.1 Test Aircraft

The aircraft was Army serial number (ASN) 96-00018 configured as below and was a production representative aircraft modified for this test¹⁷. Table 2 shows the test configurations.

- Crew doors were removed.
- Mast mounted sight was installed.
- 2 Hellfire inert missiles on each pylon (except for those denoted as “light” where the missiles were removed).
- Helicopter test gross weights varied from 4720 to 5170lbs.
- Lateral center of gravity (C.G.) 1.5 to -2.1 inches (central).
- Longitudinal C.G. 109.8 to 110.5 inches (center to slightly aft).
- Stability and control system (SCAS) on (except where noted).
- Utility systems minus anti-collision light were off.
- Heading hold was off for all maneuvers.

The helicopter was also equipped with a number of appendages mounted on the tailboom. These included the mount for the radar jammer, the GPS antenna and mount, the tracker antenna and mount plus two other radio antennae. These may have disrupted some of the airflow across the strakes. It should be noted that there were several areas for improvement in this test. As can be seen from the plots, those of engine torque and fuel flow were really quite noisy. Although the trends were fairly clear, error inherent in some of these plots was nearly as great as the differences in the readings between each configuration.

Table 2. Aircraft Configurations

Test	Gross Weight (lb)	Longitudinal Center of Gravity (in)	Weapons Configuration ¹	Test Article Configuration
Checkout Flight	4,400 to 4,900	110.8-111.6	No missiles	Fin and Strakes installed
Control Positions	4,900 to 5,350	110.4-111.3	2 missiles (L) 2 missiles (R)	Baseline Fin and Strakes installed
ADS-33E Maneuvers	4,900 to 5,350	110.4-111.3	2 missiles (L) 2 missiles (R)	Baseline Fin and Strakes installed
Free Flight Hover ² (Heavy Gross Wt)	4,900 to 5,350	110.4-111.3	2 missiles (L) 2 missiles (R)	Baseline Fin and Strakes installed
Free Flight Hover (Light Gross Wt.)	4,500 to 5,350	110.4-111.3	No missiles	Baseline Fin and Strakes installed
Level Performance	4,900 to 5,350	110.4-111.3	2 missiles (L) 2 missiles (R)	Baseline Fin and Strakes installed

NOTES:

¹Weapons configuration was Hellfire launcher on each pylon.

²Heavy gross weight test points were done immediately upon arriving at test area to test at maximum gross weight possible without adding fuel or ballast. Light gross weight test points were done after the ADS-33 maneuvers. Hellfire missiles were removed to achieve the 'light' gross weight test condition.

In all cases, the technique used was free hover which had several potential inconsistencies in parameters such as drift, wind and altitude control.

There was also a potential issue with temperature, altitude and wind. The test area was a large field surrounded by tall trees. The weather reporting station was set up at ground level where the temperature and wind were recorded. It is possible that the wind at altitude was different from the surface wind due to the interference of the tree tops. Level flight tests relied upon the accuracy of an on-board outside air temperature gauge. Also, it was expected that any beneficial effects of the strakes and fin would be hard to detect at near sea level with low temperatures. This proved to be the case and so the effects were small in magnitude. This made it difficult to perform any hard analysis or draw any definitive conclusions.

It must also be remembered that due to funding and schedule issues, the sample size was very small (3) and the flight maneuvers were limited to restrict the scope. In effect what was performed was a "quick look" preliminary evaluation that was then used to determine the need for further testing and full evaluation of the modifications.

3.1.2 Aerodynamic Modifications

The modified fin was attached to the tailboom utilizing the existing four mounting bolts as the standard fin using a simple remove and replace procedure. The modified fin was 78 inches tall and was 4.9 inches narrower over its entire length than the original fin, giving it a planform area 388 square inches smaller than the original fin. The strakes were mounted to the tailboom in pieces. There were two strakes on the left side of the tailboom, one at 150 degrees and one at 60 degrees from the top center of the tailboom when viewed from the rear. The upper strake was 118.25 inches long by 1.2 inches tall tapering to 0.9 inches tall in the last 51 inches. The upper strake was mounted in three pieces. The lower strake was 139 inches long by 0.6 inches tall in the center, tapering to 0.5 inches tall at each end. The lower strake was mounted in two pieces. Some trimming was required and this was performed by Army Fleet Support (AFS) maintenance personnel at the direction of BLR. Initial mounting was achieved with 3M VHB #4936(F) two-sided tape with an aluminum tape “fairing” over the joints to prevent moisture ingress. The strakes were also attached to various existing screws and fasteners as a backup for additional strength and safety. The strength of the bond was confirmed by means of a “pull” test of up to 200lbs vertically and was deemed satisfactory since, at sea level with coefficient of drag assumed to be $C_d = 1$ since;

$$\text{Download}^{15} = q s C_d, \text{ and static pressure, } q = \frac{1}{2} \rho v^2 \text{ assuming;} \quad (5)$$

$$v = \text{velocity} = 35 \text{ ft/sec (from momentum theory}^6)$$

$$s = \text{strake area} = 1 \text{ ft}^2$$

Then $\text{Download} \cong 5 \text{ lb per strake.}$

3.1.3 Instrumentation

A military standard (MIL-STD) -1553B data monitoring, analysis and replay system (dataMARS) bus recorder was installed to record applicable parameters transmitted across the bus during the test. This device was a personal computer (PC) based recorder that recorded data from the 1553B data bus at up to 100Hz. A list of recorded parameters is shown in Table 3¹⁷.

Table 3. Parameters Recorded on dataMARS Recorder.

PARAMETER	UNITS
Airspeed	Knots True Air Speed
Altitude	Feet above Mean Sea Level
C.G. Vertical Accelerometer	Feet per second, squared
Collective Position	Percentage of full up
Embedded GPS Ground Speed	Knots Ground Speed
Engine Torque	Percentage of maximum 100%
Fuel Flow	Pounds per hour
Fuel Weight	Pounds
Lateral Stick Position	Percentage of full throw (0% = full left)
Long Stick Position	Percentage of full throw (0% = full aft)
Main Rotor Speed	Percentage of maximum 396 RPM
Mast Torque	Percentage of maximum 100%
Pedal Position	Percentage of full right
Pitch Attitude	Degrees from level on ground
Pitch Rate	Degrees per second
Pitch SCAS Command	Percentage of full throw
Radar Altimeter	Feet above ground level
Roll Attitude	Degrees from level on ground
Roll Rate	Degrees per second
Roll SCAS Command	Percentage of full throw
Total Air Temp	Degrees Celsius
Turbine Gas Temperature	Degrees Celsius
Vertical Speed	Feet per minute
Yaw Actuator Command	Percentage of full throw
Yaw Attitude	Converted to true heading in degrees
Yaw Rate	Degrees per second

Since many of the data were extracted from the 1553B digital data bus of the helicopter, no specific calibration of the instruments was possible. No measure of confidence in the data was established and the error is not well known. The data were used to show trends rather than engineering quantities. Although this method did not yield a good measure confidence, the data showed a consistent trend towards improvement.

3.2 Methodology

3.2.1 Description of Test Conditions and Maneuvers

Flight conditions were day, visual meteorological conditions (VMC). Winds were less than 5 knots for all tests. A ground station was placed at the test site within 0.5 miles of the helicopter at the surface that gave accurate surface winds using a calibrated anemometer accurate to ± 1 knot and free air temperatures using a calibrated thermometer. In order to conduct the flight test, an airworthiness release was obtained to allow takeoff gross weight to be up to 5350lbs. Density altitudes for the test varied between 1330 feet and 2210 feet. Temperatures varied from 15.5 degrees to 22 degrees Celsius, but were kept within 5 degrees Celsius for each comparable test. For the low airspeed maneuvers, a pace vehicle with a calibrated airspeed device accurate within plus or minus 0.5 knot was utilized. Tests were conducted at Cairns Army Airfield and at Fort Rucker, Alabama. An initial baseline configuration was flown without modifications. This configuration was evaluated in the same test conditions as the modified aircraft (Table 4). The flight maneuvers performed are presented in Table 4. Some tests where noted, were performed in accordance with Aeronautical Design Standard ADS-33E¹⁸. A sensitive barometer was used to record pressure altitudes. For the maneuvers shown as ADS-33E maneuvers, courses were set up with weighted cones as per the diagrams in ADS-33E. In all cases of hover test, a free hover method was used. Only data from those tests that showed significant changes from the baseline aircraft are presented here.

Table 4. Testing Flight Maneuvers

Test	Subtest	Altitude (ft AGL ¹)	Ground Speed (knots)	Configuration	Remarks ²
Low Airspeed Flight	Not Applicable	20	0 to 30 KTS	Baseline	0 to 360 degrees (deg) azimuths in 45-deg increments; airspeed increased in 5 kt increments up to 35 kt
				Fin and Strakes installed	Qualitative evaluation of pilot workload. Critical azimuth for each control with emphasis on directional control.
ADS-33E ¹⁸	Hovering Turn	15	0	Baseline	180 degree turn in each direction; winds less than 5 kts
				Fin and Strakes installed	
	Pirouette	10	10 ± 5	Baseline	Executed in both directions with stability and control augmentation system on and off
				Fin and Strakes installed	
	Acceleration and Deceleration	10 to 50	0 to 60	Baseline	Course may be run in either direction but wind direction with respect to aircraft nose should be within 45 degrees of the baseline flight and the BLR modified flight.
				Fin and Strakes installed	
	Sidestep	10 to 30	0 to 35	Baseline	Maneuver conducted to both left and right with initiation being from either direction. Lateral groundspeed will be added to wind component to give airspeed of 30 kts.
				Fin and Strakes installed	
In/Out of Ground Effect Hover Performance	Free Flight Hover	3/50	0	Baseline	In-ground-effect and out-of-ground effect hover power required tests conducted at the beginning of the flight for a 'heavy' gross weight and at the end of the flight, with M34 missiles removed, for a 'light' gross weight Skid heights of 5 to 35 ft AGL for IGE and OGE, respectively. Wind speed will be less than 5 kts.
				Fin and Strakes installed	
Level Flight Performance	W/σ	2,000 to 10,000 ft PA ⁴	30 to 100 KIAS ³	Baseline	Airspeed will be varied in 5 kt increments from 30 to 60 KIAS and 10 kt increments from 70 to 100 KIAS. C _T = 0.0050
				Fin and Strakes installed	

NOTES:

¹AGL – above ground level

²Qualitative evaluations were determined using the Cooper-Harper Ratings Scale²¹

Anemometer measured Winds within 2 kts for each configuration for each test maneuver to be considered comparable.

³KIAS – knots indicated airspeed

⁴PA – pressure altitude

⁵C_T – coefficient of thrust

3.2.2 Data Reduction and Analysis

The data extracted from the MIL-STD-1553B data bus were stored in the dataMARS internal memory and then transferred to a Personal Computer Memory Card International Association (PCMCIA) storage card. The data were then downloaded onto a PC for processing. Microsoft Excel[®] spreadsheets were used to produce the plots and charts used throughout this document. The main thrust of this investigation was to establish the overall effects of the modified fin and strake combination. The data were used mostly to establish trends that would be used to build a case for a later, more detailed analysis to confirm the observations. The following method for calculating and referring the engine shaft horsepower power (E.S.H.P.) was used¹⁹

$$\text{E.S.H.P.} = \frac{2\pi}{33,000} \cdot \text{EQ} \cdot \text{N}_R \cdot \text{GRE} \quad (6)$$

EQ = Engine Torque (ft-lbs where 100%Q = 524ft/lbs)

N_R = Main rotor RPM (where 100% N_R = 393 RPM)

GRE = engine to main rotor gear ratio = 15.307888 (specific to OH-58D)

33,000 = conversion factor (1 hp = 550 ft-lb/s; 60s = 1 min)

And, correcting for standard atmosphere;

$$\text{E.S.H.P.}_{\text{ref}} = \frac{\text{E.S.H.P.}}{\sigma} \cdot \left[\frac{\text{N}_{R\text{std}}}{\text{N}_{R\text{test}}} \right]^3 \quad (7)$$

Where;

N_{Rstd} = Main Rotor RPM on NATO Standard Day

N_{Rtest} = Main Rotor RPM under test day conditions

E.S.H.P._{ref} = Referred Shaft Horsepower

σ = Air Density Ratio = $\frac{\text{Air Density on NATO Standard Day}}{\text{Air Density under test conditions,}}$ = $\frac{\rho_{\text{test}}}{\rho_{\text{ssl}}}$

The following method for calculating referred gross weight (W_{ref}) was used²⁰

$$W_{ref} = \frac{\text{Gross Weight (test)}}{\sigma} \cdot \left[\frac{N_{Rstd}}{N_{Rtest}} \right]^2 \quad (8)$$

Where;

$$\sigma = \text{Air Density Ratio,} = \frac{\text{Air Density on NATO Standard Day}}{\text{Air Density under test conditions,}} = \frac{\rho_{test}}{\rho_{ssl}}$$

N_{Rstd} = Main Rotor RPM on NATO Standard Day

N_{Rtest} = Main Rotor RPM under test day conditions

3.2.3 Pilot Handling Qualities Ratings

The handling qualities of the helicopter during the low airspeed tests were evaluated using a modified Cooper-Harper in ADS-33E¹⁸ as shown in Figure 10. This scale provided a method for rating the subjective opinions of aircraft handling qualities. It assigns quantitative values from one to 10 in decreasing desirability, to the qualitative assessment. It is a recognized method of evaluating the handling qualities of aircraft and is in use at the Air Force, Navy and international test pilot schools. It is the standard method of handling qualities assessment at the Army's Aviation Technical Test Center.

3.2.4 Vibration Assessment Ratings

In order to accurately assess the vibrations in the helicopter, the standardized vibration assessment rating scale from Flight Test Manual (FTM) 107²¹ was used. This scale was based on one developed at the Aeroplane and Armament and Experimental Establishment in Boscombe Down, England. A copy of this figure was carried in the cockpit of the aircraft for all maneuvers completed in support of this testing. The pilots referred to the figure at the conclusion of each maneuver and qualitatively assessed the vibrations associated with the maneuver. The scale is in widespread use in flight test and is presented as Figure 11.

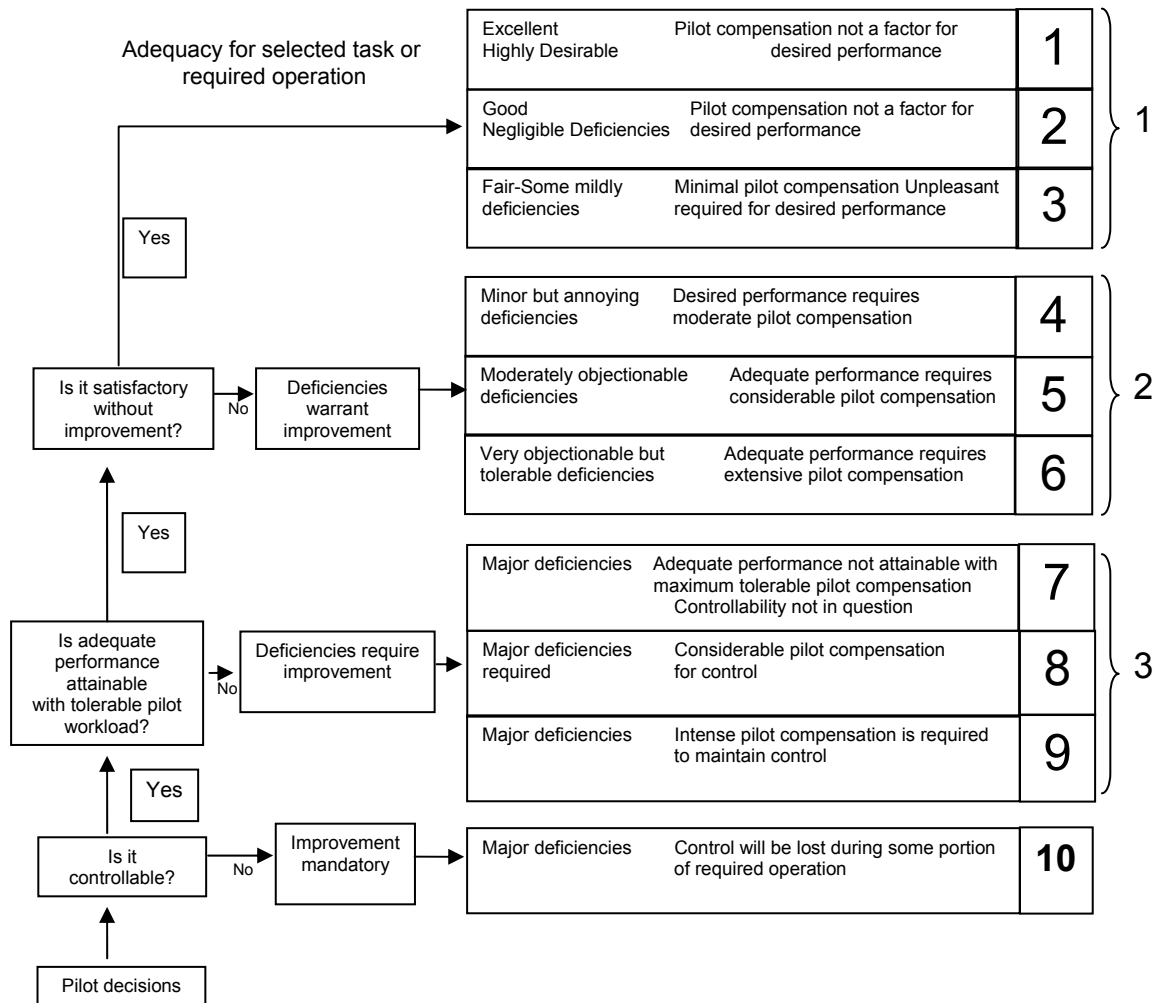


Figure 10. Modified Cooper-Harper Rating Scale

Degree of Vibration	Description	Pilot Rating
No Vibration		0
Slight	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1 2 3
Moderate	Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period.	4 5 6
Severe	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can be done only with difficulty.	7 8 9
Intolerable	Sole preoccupation of aircrew is to reduce vibration.	10

Figure 11. Vibration Assessment Rating Scale

4. DATA, RESULTS AND DISCUSSION

4.1 Hover Performance

This test (hover ladder) was conducted in accordance with the parameters in Table 4. The helicopter was hovered into a light (1-2 knot) wind at as high a gross weight as possible. Density altitude was within 250 feet between the two configurations and temperature was within 2 degrees Celsius. Gross weight was within 5 pounds. The hover height was increased in 5 foot increments. This procedure was repeated until the aircraft reached OGE height or reached an operational limitation. In this case, an operational limitation of maximum allowable engine torque was reached.

When configured with fin and strake, the helicopter required less torque to hover throughout the hover ladder. An average 3-4% less power was required to hover across the altitude range. There was a corresponding 2-4% reduction in fuel flow at each altitude (Appendix 3). This reduction in power required allowed the helicopter in the modified configuration to hover 10 feet higher than in the baseline configuration. Data were averaged across time when stable at each altitude (Figure 12).

There seemed to be little change in the frequency or amplitude of the pedal inputs, which is consistent with the low airspeed testing results for most azimuths at airspeeds of 5 knots or less. Using the formula²²:

$$C_T = \frac{T}{\rho A_D (\Omega R)^2} \cong \frac{GW}{\rho A_D (\Omega R)^2} \quad (9)$$

Where;

A_D = Rotor Disc Area = πR^2 (ft²)

C_T = Coefficient of Thrust

T = Net Thrust of the rotor (lb)

ρ = Air Density (slugs/ft³)

ΩR = Blade Tip Rotational Speed (ft/sec)

GW = Gross Weight

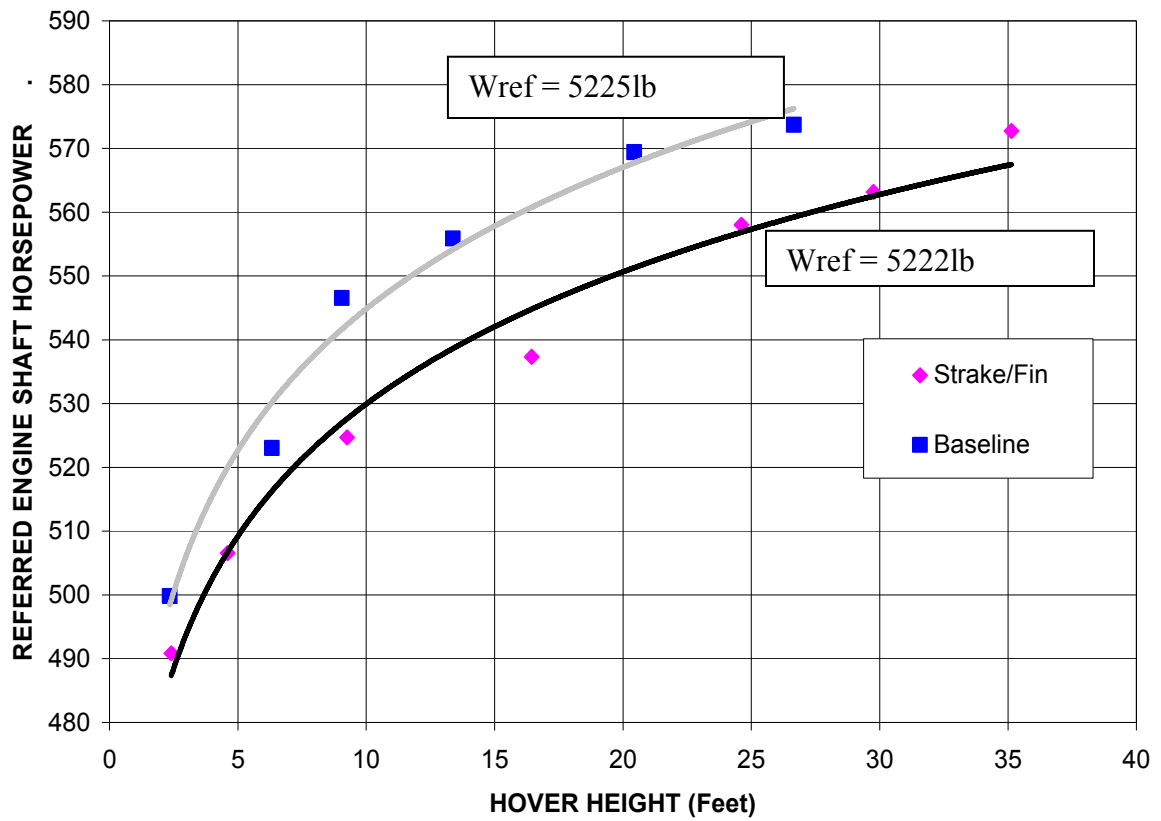


Figure 12. OH-58D Comparison of Referred Engine Shaft Horsepower Required to Hover

It can be shown that;

$$C_T = f \left[\frac{GW}{\sigma}, \text{Rotor RPM, Temperature} \right] \quad (10)$$

Where²²;

$$\sigma = \rho_{\text{test}} / \rho_{\text{ssl}}$$

and,

$$\sigma = f [\text{Temperature}]$$

In order to maximize the effect of the strakes it is desirable to increase the vertical induced flow, V_i over the Tailboom. Since an increase in thrust results in an increase in the velocity of the induced flow, this can be achieved by increasing the coefficient of thrust, C_T . Modifying any of the parameters above will affect C_T and the velocity of the induced flow. In order to raise C_T , testing should be conducted where the air density is the lowest, and the main rotor RPM is the lowest. Since lift varies as the square of velocity¹⁹ reducing rotor RPM reduces the amount of lift produced by the rotor which must be compensated for by increased angle of attack and a corresponding increase in drag and therefore the amount of torque required for a given thrust by²³,

$$\text{Net Lift} = C_L \frac{1}{2} \rho V^2 S \quad (11)$$

Where;

C_L = Coefficient of lift

ρ = Air Density (slugs/feet³)

V = Velocity of the Rotor Blade

S = Surface Area of Blade

Testing then, should be conducted in a region where the altitude is as high as possible and the temperature as high as possible. Also, it would be beneficial to slow the rotor RPM down as much as possible. The OH-58D does have a rotor RPM trim switch¹ capable of “beeping” down the rotor RPM to as low as 96%. Use of this device in small increments to reduce rotor RPM would also help drive C_T to its absolute maximum. Another way of maximizing C_T is to again apply for an air worthiness release to allow operations at very

high gross weights and to conduct the testing at the maximum gross weight possible. This would be facilitated by having the ability to refuel the helicopter at the test site to avoid reducing the gross weight by burning fuel enroute to the test site. In short, testing should be repeated using hot/high/heavy/low rotor RPM to the greatest extent possible. This procedure would also more closely replicate the conditions under which the helicopter is expected to operate in support of current and ongoing military actions such as some regions of the Middle East.

4.2 Low Airspeed Evaluation

4.2.1 Handling Qualities and Vibration Assessment Ratings

The critical azimuths and their critical control limitations for the OH-58D are shown below in Table 5. This table shows the azimuths at which various controls become the limiting factor in maintaining aircraft control. Each azimuth corresponds to the flight control which will run out of authority first. During the low speed flight tests at each azimuth, handling qualities rating (HQR) and vibration assessment ratings (VAR) were harvested from the pilots. The tests were flown at cardinal and sub cardinal headings of 0, 045, 090, 135, 180, 225, 270 and 315 degrees (45 degree increments)

Table 5. OH-58D Critical Wind Azimuth Directions

Relative Azimuth	Critical Limitation
315 Deg	Directional Pedal
225 Deg	Longitudinal Cyclic
135 Deg	Lateral Cyclic

relative to the nose of the helicopter and at true airspeeds of 5-30 knots in 5 knot increments. True airspeed was measured using a pace vehicle equipped with a device calibrated to measure true airspeed with an accuracy of ± 0.5 knots. With the strakes and modified fin installed, HQR's improved slightly in the front left and front right quadrants, but only by about one HQR point at the most, although this did improve the level of handling qualities. The HQR plots at the 315 and 045 azimuths show improvement of 1 point in both VAR and HQR. For relative azimuths of 0, 045, 135, 180, 225, 240, 270 and 315 degrees, with the fin and strake installed, the VAR did improve by one to two points especially in the 5-20 knot airspeed range. The only azimuth to show a detriment was 225-240 degrees and then only one point at airspeeds between 10 and 15 knots. When this information was correlated and compared with the pedal position plots from the same azimuths, a pattern of improved heading control began to appear at certain azimuths (Tables 6 and 7).

4.2.2 Low Airspeed Performance

Low airspeed tests were flown in accordance with Table 4. Flight parameters were recorded in real time and a complete set of flight data are presented in Appendix 1. Only those plots directly related to the test (engine torque required, pedal position, fuel flow and collective position) are presented. Flight conditions were kept within close parameters to reduce any effect of temperature, gross weight and pressure altitude. Plots were combined to compare baseline and modified configurations. Figures 13 - 15 are selected from Appendix 1 to help explain the reasons for improved pilot ratings over the baseline configuration. As illustrated in Figures 13 – 15, the pilot was able to hold the heading constant with the modifications, but with less pedal activity and workload. At these same azimuths, the VAR's were less with the strakes and fin fitted than the baseline aircraft. This indicates that the excursions from the assigned heading were less. This is supported by the theory presented in Section 2.1, which suggested that the vortices under and around the tailboom were reduced by the addition of the strakes. The reduction of

Table 6. Handling Qualities Ratings

Key;  = Baseline
 = Fin and Strakes Installed

Relative Azimuth	Airspeed (KTAS)					
	5	10	15	20	25	30
360	3	3	2	2	2	2
	3	4	3	2	2	2
045	3	3	3	3	3	3
	3	3	2	2	2	2
090	3	4	3	3	3	3
	3	4	4	3	4	4
120		3	3	3	3	3
		4	3	3	3	3
135	3	4	3	3	3	3
	3	4	3	4	4	4
150		4	3	3	3	3
		4	4	4	3	3
180	3	4	3	3	3	3
	3	4	3	4	4	4
210		3	3	3	4	3
		3	3	3	3	4
225	3	3	3	4	4	5
	3	4	4	4	5	5
240		3	3	6	5	5
		3	4	4	5	5
270	3	4	4	4	5	5
	3	4	4	5	5	5
300		3	4	4	4	4
		3	3	4	4	4
315	3	3	3	4	4	4
	3	3	3	3	4	3
330		3	4	3	2	2
		2	3	3	3	3

Table 7. Vibration Assessment Ratings

Key;  = Baseline
 = Fin and Strakes Installed

Relative Azimuth	Airspeed (KTAS)					
	5	10	15	20	25	30
360	2	2	3	3	2	2
	2	2	2	2	2	2
045	3	3	3	4	3	3
	2	2	3	3	2	3
090	3	3	3	3	3	3
	2	2	2	2	3	3
120		3	3	3	3	3
		2	3	3	3	3
135	3	3	3	3	3	3
	2	2	2	2	3	3
150		3	2	3	3	3
		3	2	2	3	3
180	3	3	4	4	4	4
	2	3	3	3	3	3
210		4	4	3	4	3
		3	3	3	2	4
225	3	3	3	4	5	5
	3	2	2	2	3	3
240		3	3	3	4	4
		3	3	5	5	4
270	3	3	3	5	5	5
	3	4	4	4	4	3
300		3	4	5	4	4
		3	3	3	4	4
315	3	3	3	4	4	4
	2	3	3	3	3	3
330		3	4	4	3	4
		3	3	3	3	3

these vortices resulted in less turbulent flow around the tailboom which reduced the heading oscillations of the aircraft. The plots of pedal position showed a smoothing of the pedal activity at relative azimuths of 045, 135, 180, 225 and 315 that was also most noticeable in the 5-20 knot airspeed range. This is the airspeed range where the greatest power and vertical induced velocity (V_i) from the main rotor were required, which is where the aerodynamic effect of the strakes should be greatest. This smoothing of pedal activity occurred at most azimuths evaluated during the low airspeed test (Appendix 1), this reduced pedal activity was indicated by a reduction in the frequency and to a lesser degree, the amplitude of the pedal input however which showed a reduction in pilot workload at each of the subject azimuths.

The plots for pedal position at the 240-270 degree relative azimuth show little if any, smoothing of the pedal activity. This may have been the result of a vortex forming around the strakes and then shedding unpredictably. The root cause of this may be the height of the strake which may have been tall enough to create a vortex when the relative wind was directly across it. There was not a reduction in the activity of the stability control and augmentation system (SCAS) accompanying the reduction in pedal activity. At the higher airspeeds, the helicopter began to transition through the transverse flow effect and the differences in pedal activity became less pronounced. The pedal activity and torque required plots (Figures 13 – 15) at the 180 relative azimuth reflect no change in VAR and HQR, but the plots at the 315 and 045 azimuths show improvement of 1 point in both VAR and HQR. At the 315 degree relative azimuth, the improved HQR actually improves the handling qualities from level 2 to level 1. Figures 13– 15 correlate closely with improvements seen in Tables 6 and 7 in that at each of the selected azimuths (except 180) the handling qualities rating improved. The VAR ratings were either unchanged or improved as at the 315 degree relative azimuth. This aircraft had a taller driveshaft cover than an OH-58A/C or Bell 206 as shown in Figure 16 and a number of appendages such as the IR jammer mount, tracker antenna mount as seen in Figure 17. The taller driveshaft cover and the appendages may have added turbulent flow, especially with the relative wind off the right front or left rear of the helicopter such as in a crosswind or translational flight.

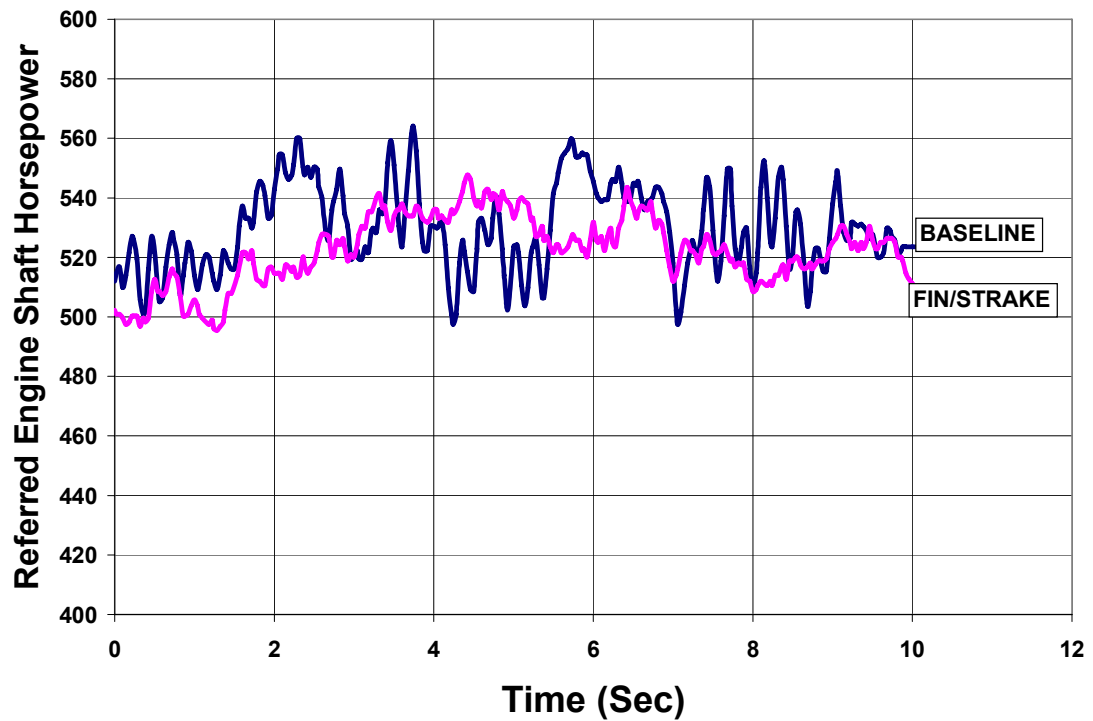
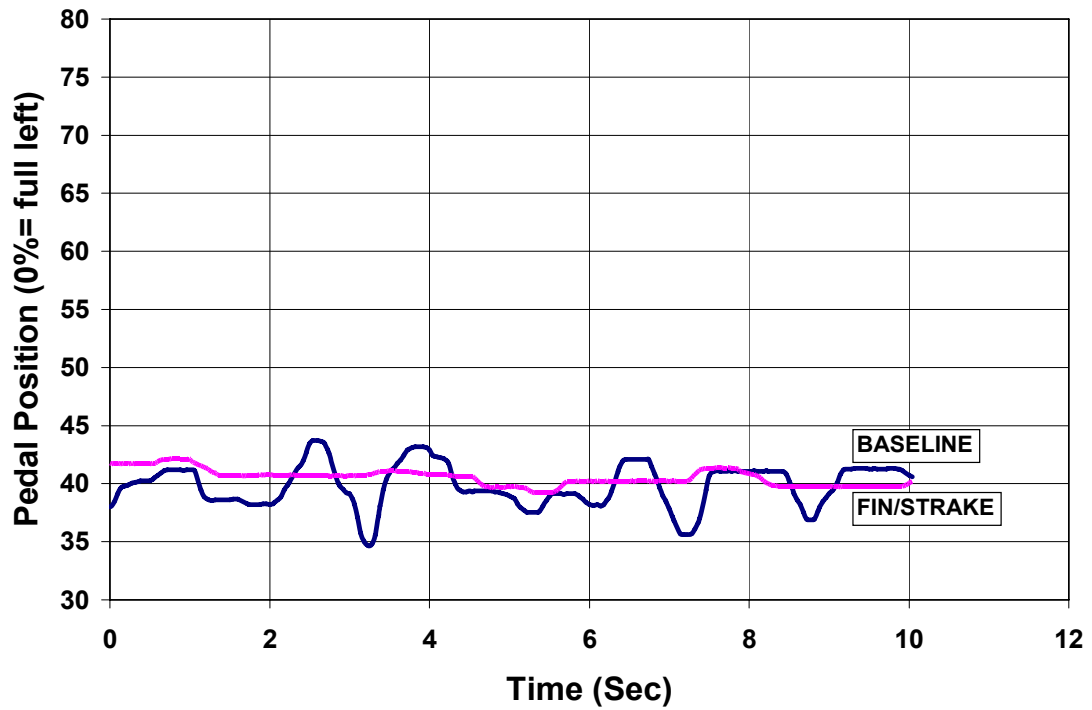


Figure 13. Pedal and Torque Activity, Hover, 10 knot wind, 180 degree Relative Azimuth

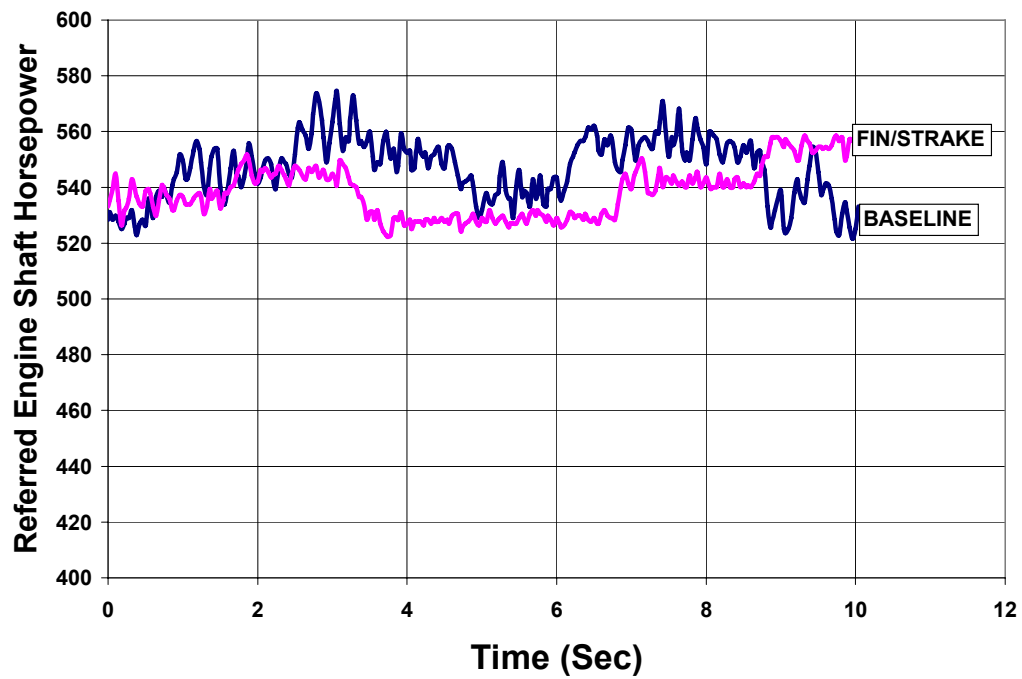
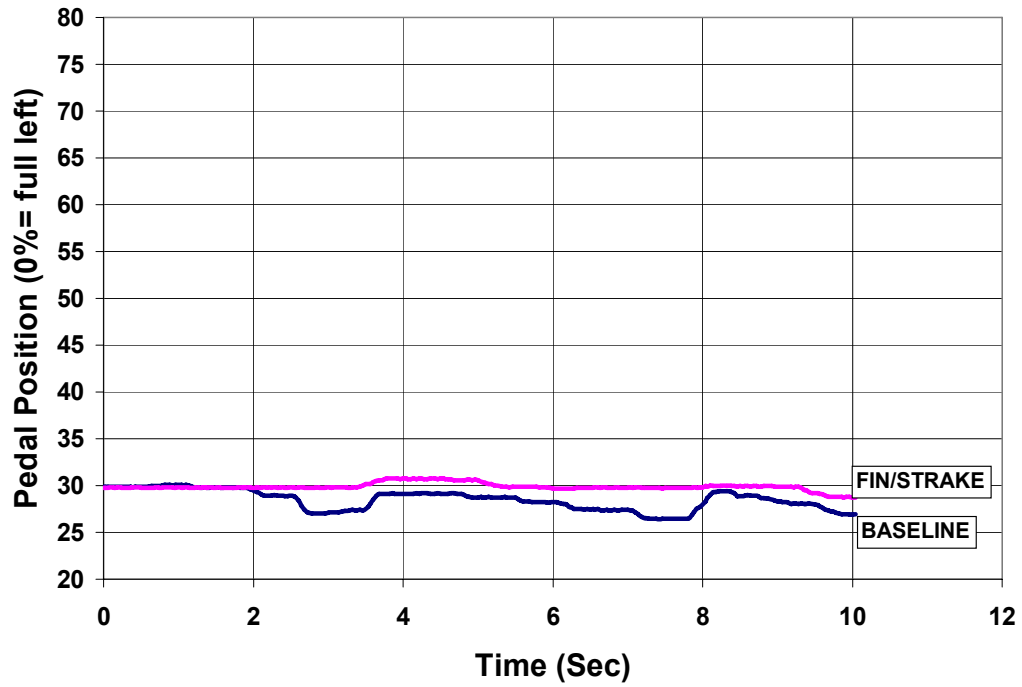


Figure 14. Pedal and Torque Activity, Hover, 15 knot wind, 045 degree Relative Azimuth

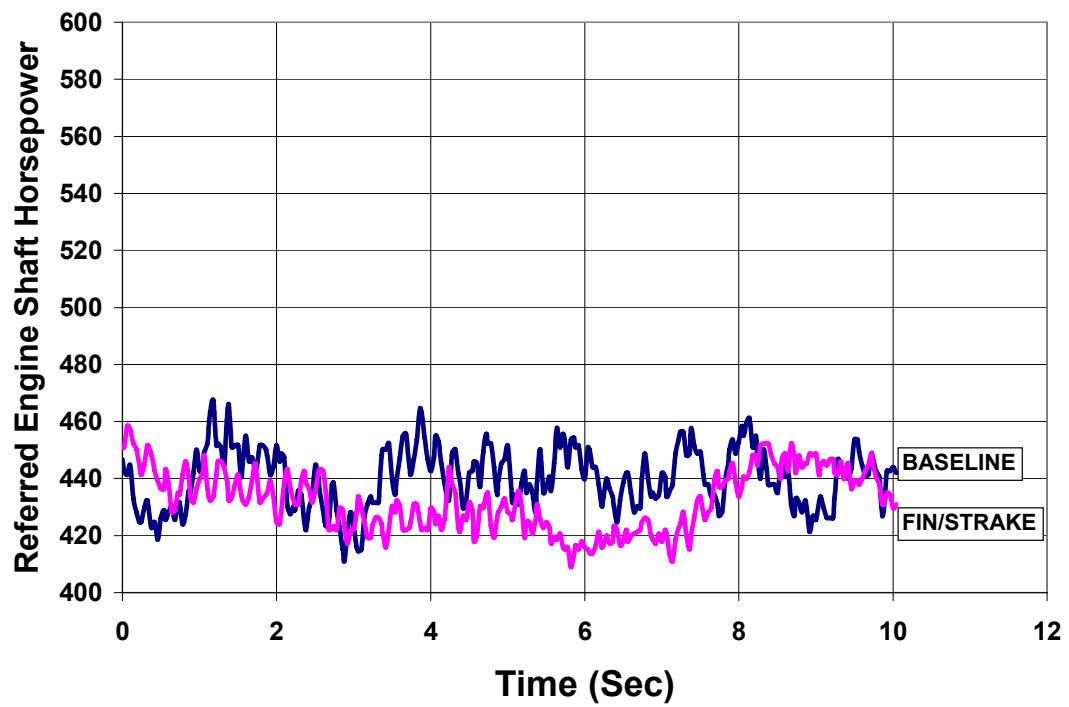
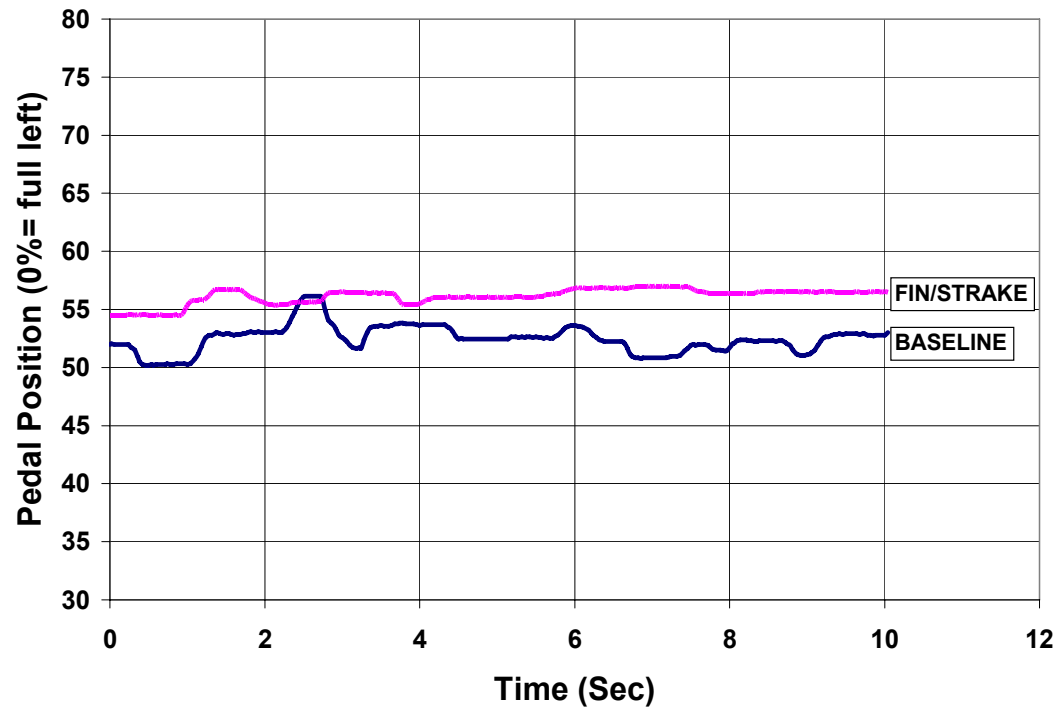


Figure 15. Pedal and Torque Activity, Hover, 20 knot wind, 315 degree Relative Azimuth

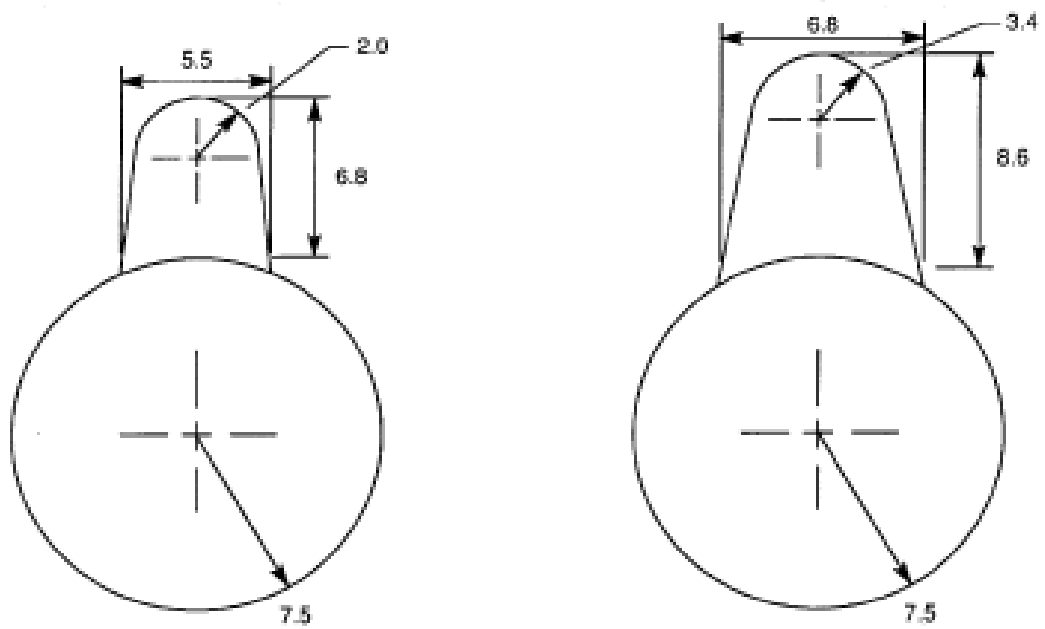


Figure 16. Comparison of Tailboom Cross Sections, Looking Forward, OH-58A Left, OH-58D Right (inches)



Figure 17. Tailboom Appendages, OH-58D

4.4 Level Flight Performance

The level flight performance test was conducted in accordance with Table 4 using the GW/σ method¹⁶ where GW refers to the gross weight of the aircraft in pounds and σ is the air pressure ratio. This method was used to maintain a constant C_T of 0.0050 throughout the test in each of the two configurations. These data were then referred and the results are shown in the plot contained in Appendix 2. The plots of referred engine shaft horsepower ($E.S.H.P_{ref}$) did not show any significant difference between the baseline and modified configurations.

5. CONCLUSIONS

5.1 Handling Qualities and Vibration Assessment Ratings

During the low airspeed tests, there was some improvement in HQR at several azimuths and there was some small detriment noted in relative azimuths around the tail of the helicopter. Very little degradation in handling qualities was noted, thus indicating that, from an HQR standpoint, there was no detriment to the handling qualities of the helicopter. The small degradation in HQR seen in azimuths around the tail could be the result of the strake being over sized for the test, resulting in vortices forming around the strakes when the wind is from the tail or left side. There was also noted a small improvement in VAR at most azimuths. Alone, the improvements in VAR and HQR were not too significant, but when viewed with respect to the entire test they support the conclusion that there is a significant overall improvement in handling qualities at certain azimuths.

5.2 Low Airspeed Performance

There was evidence that the strakes were indeed altering the airflow around the tailboom in a positive way. There was a reduction in pilot observed pedal activity in the 5-20 knot airspeed range, indicating a reduction in vortex shedding around the tailboom as predicted by the theory outlined in Section 2 of this document. This was further supported by the noted reduction in VAR at most relative azimuths except 120, 150 and 300 degrees predominantly at airspeed from 5-20 knots and improvement in HQR at 045, 090, 225, 240, 315 and 330 relative azimuths again predominantly in the 5-20 knot range. Again, this beneficial effect was most noticeable when the gross weight of the helicopter and therefore the C_T was the highest, and in low-speed flight where V_i was highest and impinging directly on the tailboom. Although this effect was small, it resulted in the pilot being able to point the helicopter more precisely with reduced pilot workload. However, this reduction in pedal activity did not result in reduced fuel flow or power required, and in some instances the fuel flow with the modifications installed actually increased a small

amount. Since the mission of this helicopter involves a number of slow speed pointing tasks, such as gunnery, the modifications will aid the pilot by allowing him/her to point the aircraft more accurately and decrease overall workload, facilitating accurate weapons delivery. The modifications seemed to smooth the airflow across the tailboom and also reduce vortex shedding below the tailboom, thus eliminating the main cause of directional oscillations. The OH-58D has a taller tail rotor drive shaft cover than the OH-58A/C or the Bell 206 civilian counterpart²⁴. Some additional airflow disruption and interference could be expected from this larger cover. Possibly a stagnation or highly turbulent area formed at the junction of the cover and the tailboom skin. This stagnation or turbulent area may have been large enough to interfere with the airflow across the upper strake, thus negating its efficacy somewhat. Should the strake be too tall, it may have added to the vortex formed around the cover/tailboom joint actually making vortex shedding worse at some azimuths. This was suspected to be the cause of the slight degradation in handling qualities at the 240-270 degree relative azimuth low airspeed testing. The OH-58D tailboom also had a number of fairings, mounts and antennae. The tailboom also had a relatively large horizontal stabilizer that may be affecting the airflow around the tailboom. It is possible that all these items are disrupting the flow of air around the tailboom to such a degree that they are reducing the effectiveness of the strakes and fin a great deal.

One possibility is to locate the upper strake on the upper left side of the tail rotor driveshaft cover. This would place the strake into the flow and avoid interference effects of the driveshaft cover. Although this is at odds with previous research by NASA²⁴, this research did not account for the large area of the appendages currently attached to the tailboom of an OH-58D. The masking effects of the appendages may force the placement and size of the upper strake to change. This research also addressed the effects of dynamic pressure on the Reynolds number. If the altitude of the test is taken as high as possible, there may be an effect on the Reynolds number that will highlight the function of the strakes. Any future testing should include the ability to measure, and if possible control, the dynamic pressure along the tailboom.

5.3 Hover Performance.

At an IGE and OGE hover there was a reduction in torque required, and a corresponding reduction in left pedal required and fuel flow. This was lower than expected or predicted by theory. This may be because of the incorrect sizing of the strakes and also, the test conditions and the number and size of the appendages on the tailboom of the helicopter. However, the difference in power required, collective position and fuel flow are significant enough to warrant further investigation in which airflow over the tailboom is at the highest. Testing then, should be conducted in a region where the altitude is as high as possible and the temperature as high as possible. Also, it would be beneficial to slow the rotor RPM down as much as possible. In the regions where C_T and V_i are high the fin and strake combination improved the performance of the helicopter. Even a relatively small decrease in power required and fuel flow makes a large difference in operating costs when spread across the fleet of OH-58D helicopters. This will translate operationally into increased range and endurance for the aircrew. The reduction in left pedal required was also significant, as this will give the pilot greater control margin, thus improving controllability in adverse wind conditions. The additional pedal margin and reduced torque required translates into operations at higher altitudes and/or increased payload such as ammunition or fuel. The reduction in power required coupled with a reduction in left pedal required shows that the modified configuration has reduced load on the tail rotor. This effect was predicted by theory and prior research as outlined in Section 2 of this document that showed that the fin and strake combination beneficially affected the side force coefficients of the tailboom by controlling the differential pressure on either side of the tailboom. Further, the reduced chord fin with the blunt trailing edge reduced tail rotor to fin interference and vortices. Although this effect was quite small within the scope of this test, a significant gain in performance at an IGE and OGE hover was realized. This benefit should increase when C_T is greater such as at higher altitudes and temperatures.

6. RECOMMENDATIONS

1) Further testing should be conducted in order to make a more definitive judgment on the effect and mission relation of these modifications. All follow-on testing should be performed using a helicopter equipped with sensitive instrumentation and recording devices and be performed at a tethered hover¹⁶. The instrumentation should be calibrated to establish a level of confidence in the data. Data thus gained should be reduced to NATO standard day conditions to facilitate accurate comparisons. This would remove some of the ambiguity of the resulting data.

2) From the data the effect of the modifications seemed more pronounced when C_t (and, therefore rotor wash velocity, V_i) was at its highest¹⁶. Therefore, further testing should be conducted in conditions that raise C_T as much as possible.

3) Since there was a change in vibrations after the addition of the fin and strake modifications, consideration should be given to performing a vibration analysis of the helicopter with the modifications installed.

4) Consideration should be given to adding a low airspeed lateral/directional evaluation (including release from steady heading side slips) to the testing to quantify and determine the effect of the modification on the lateral/directional stability of helicopter.

5) Recommend that further computational fluid dynamics (CFD) and wind tunnel testing be conducted using the actual geometry of the OH-58D tailboom to determine interference effects of the appendages and drive shaft cover on the strakes and fin. These data may be used in optimizing the design of the strakes. This would apply to the height of the strakes and their location on the tailboom in response to a full understanding of the disruptions in airflow caused by the shape and location of the tailboom appendages.

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LIST OF REFERENCES

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APPENDICES

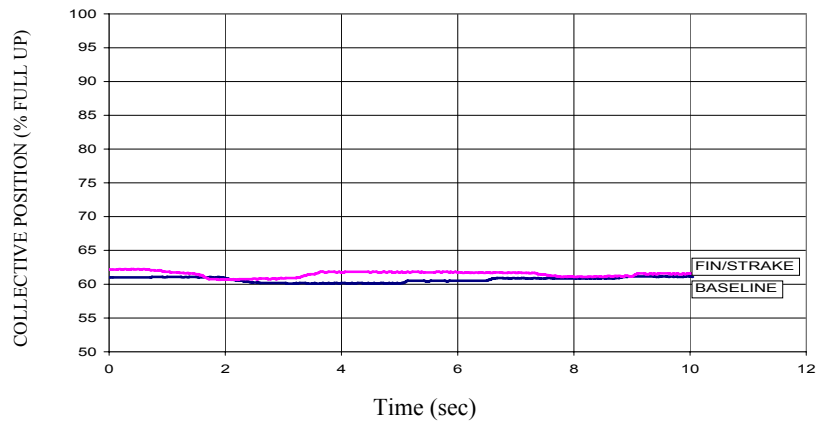
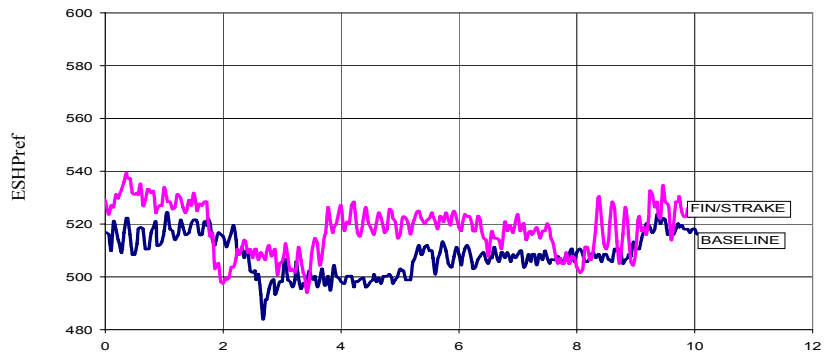
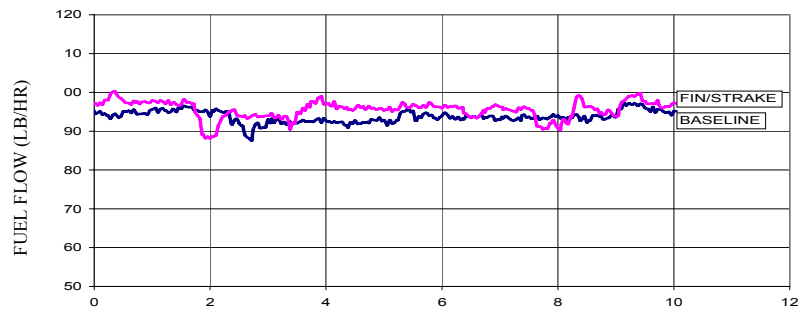
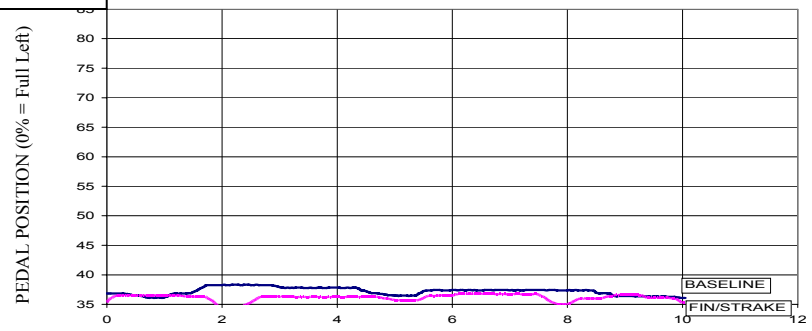
APPENDIX 1
Low Airspeed Flight Data

RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4776-4960	110.2in	1780-2030ft	17.5-20.0	396	20'	135 DEG	5

OH-58D USA S/N 96-00018
Ambient wind <5kts

— BASELINE

— FIN/STRAKE

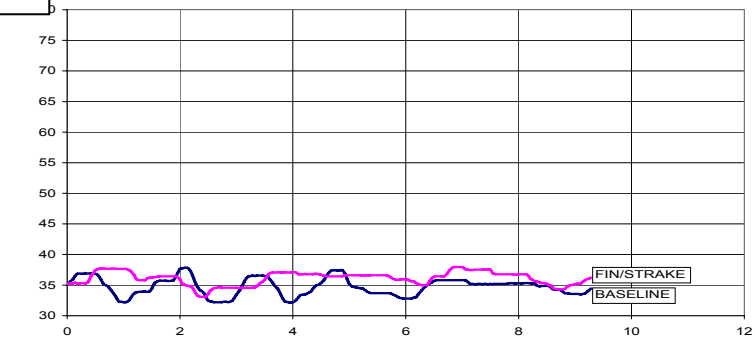


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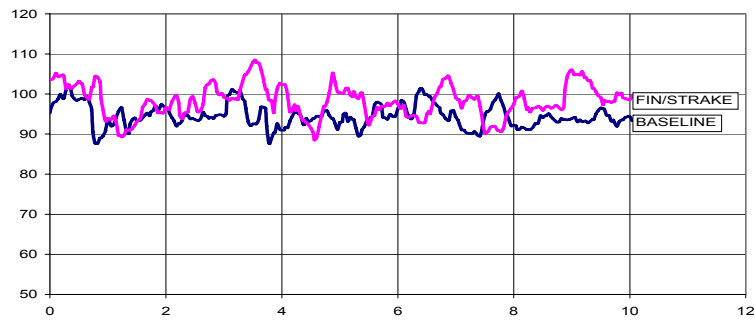
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Ambient wind <5kts

— BASELINE
— FIN/STRAKE

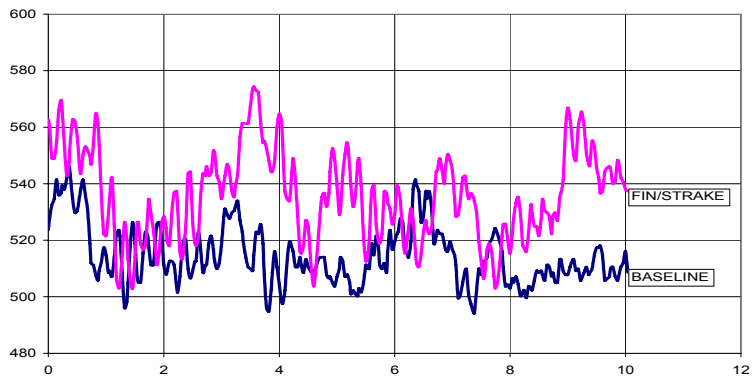
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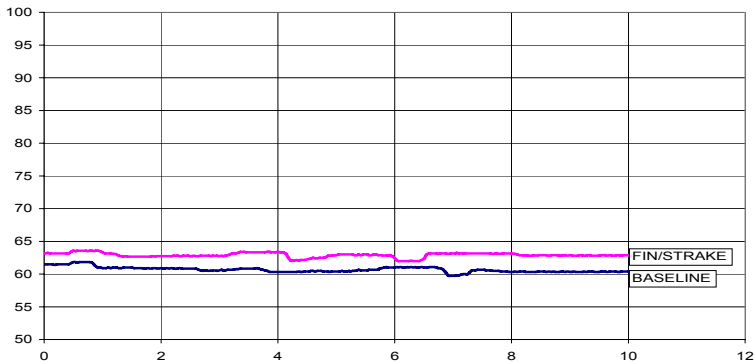
FUEL FLOW (LB/HR)



ESHPrf



COLLECTIVE POSITION (% FULL UP)

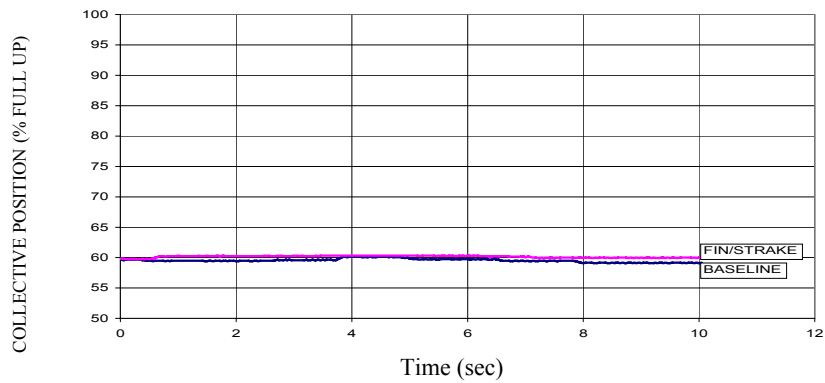
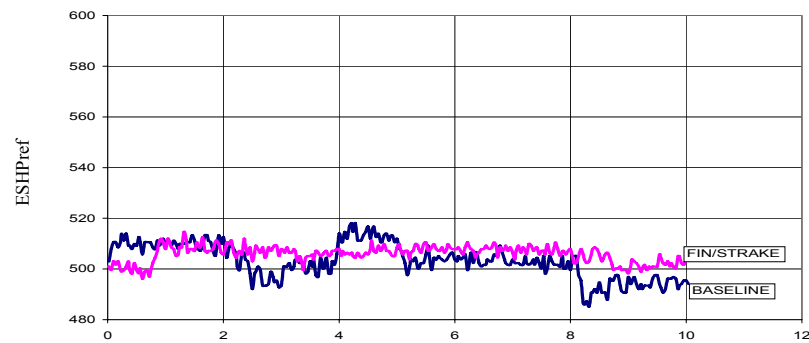
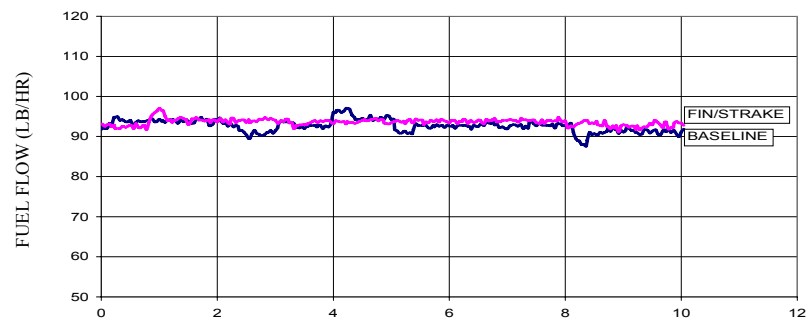
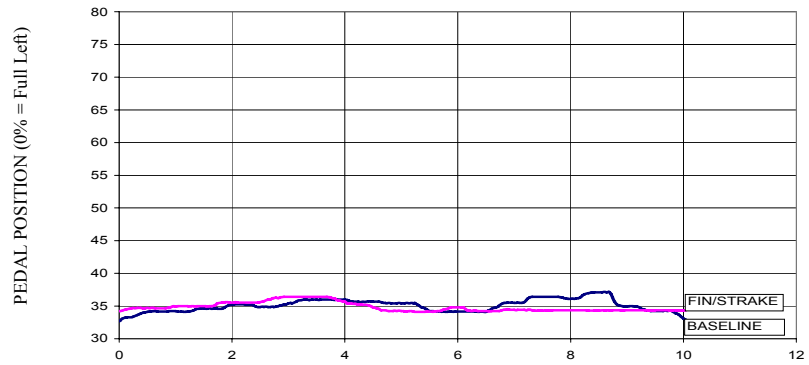


Time (sec)

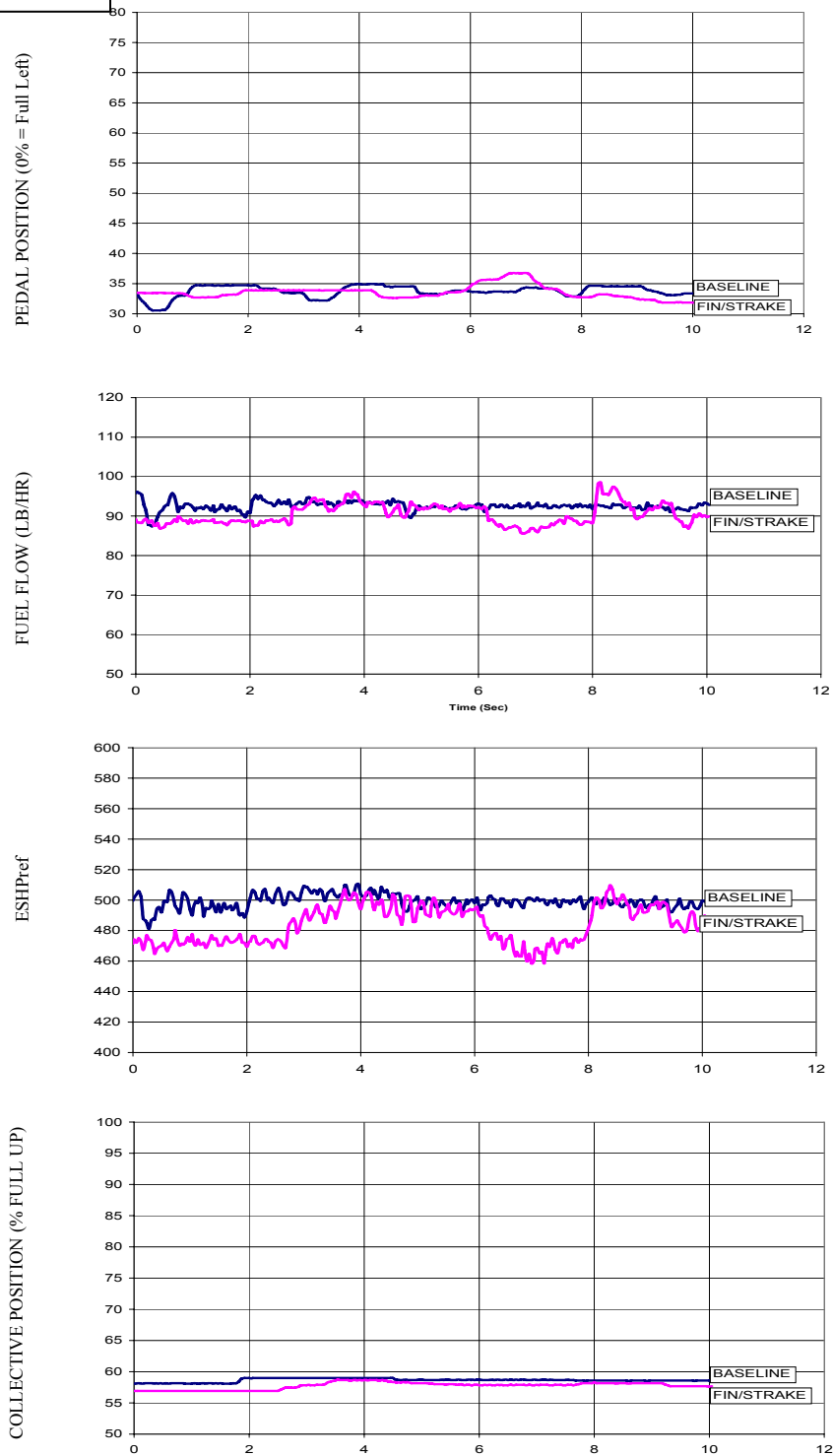
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OH-58D USA S/N 96-00018
Ambient wind <5kts

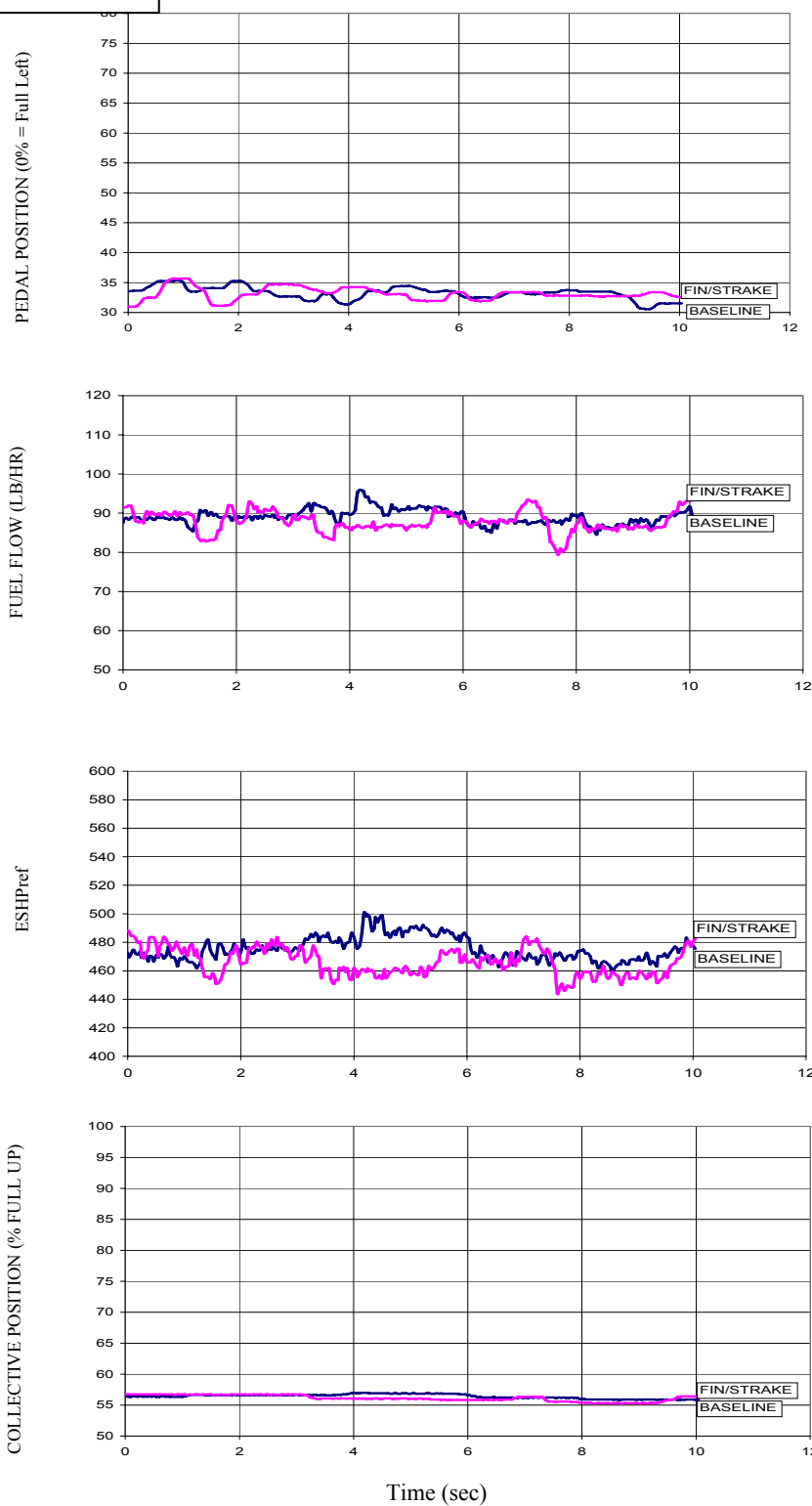
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BASELINE FIN/STRAKE							
OH-58D USA S/N 96-00018 Ambient wind <5kts							



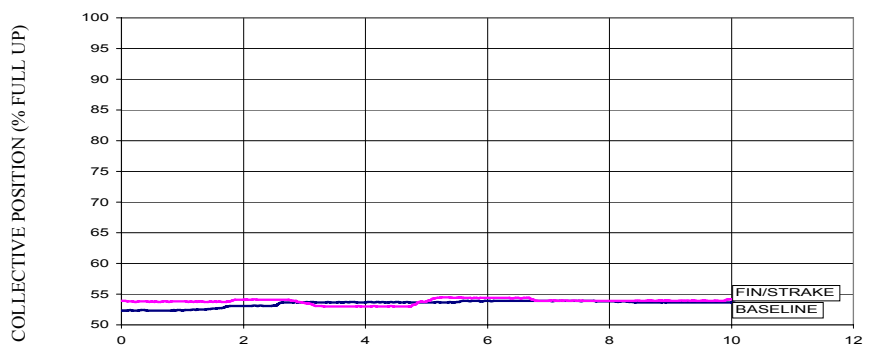
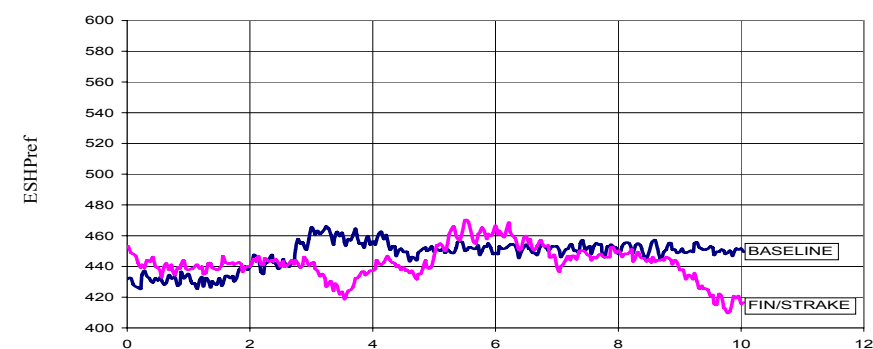
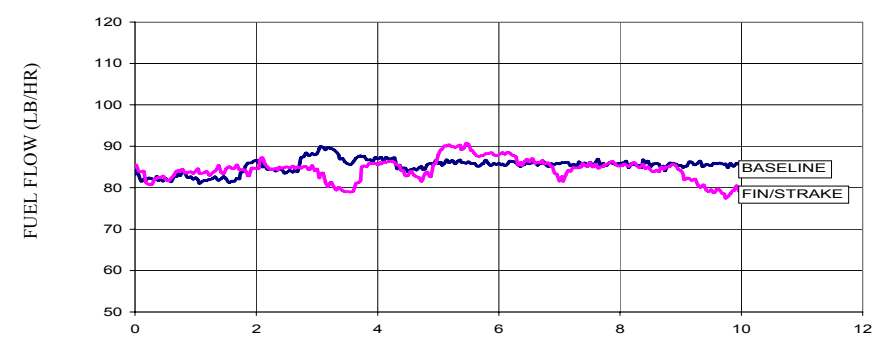
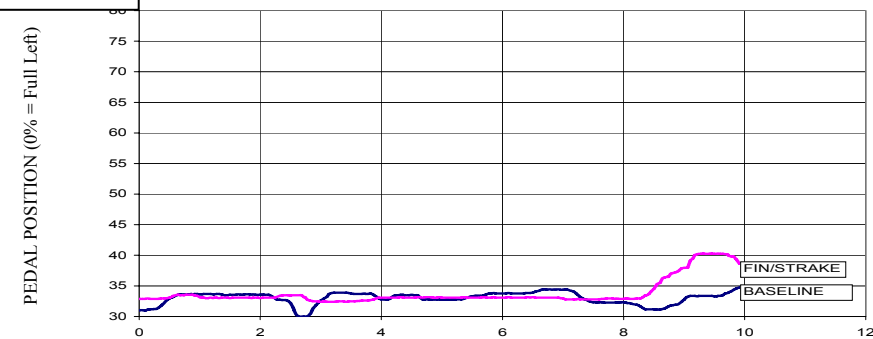
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RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ. KTAS
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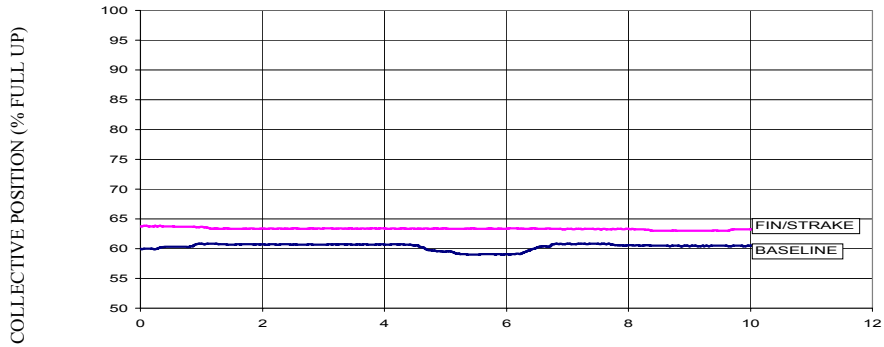
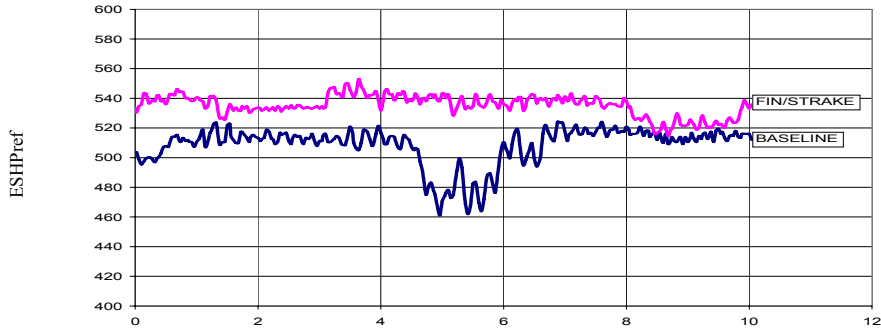
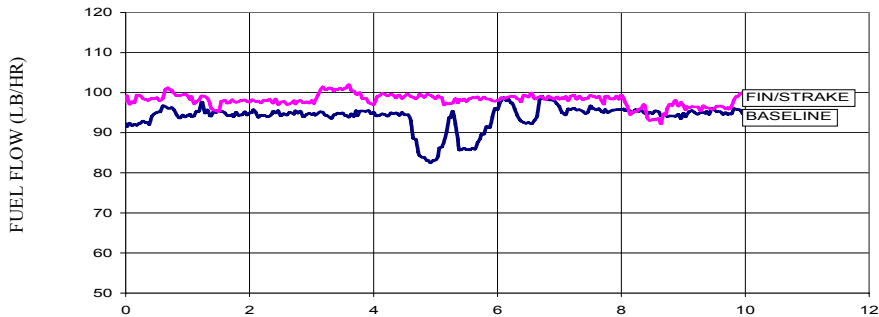
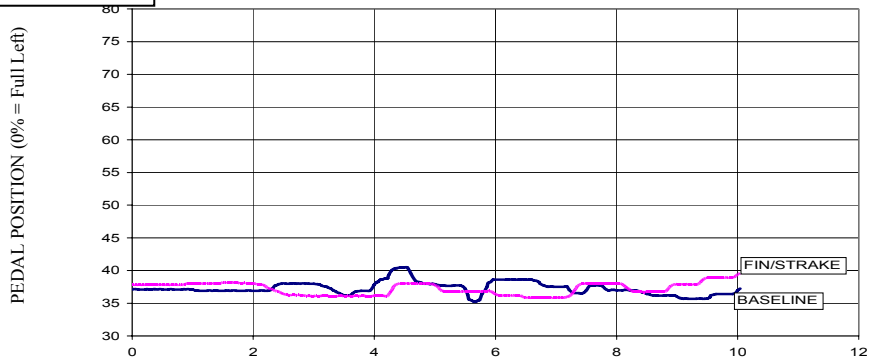
OH-58D USA S/N 96-00018
Ambient wind <5kts

— BASELINE
— FIN/STRAKE



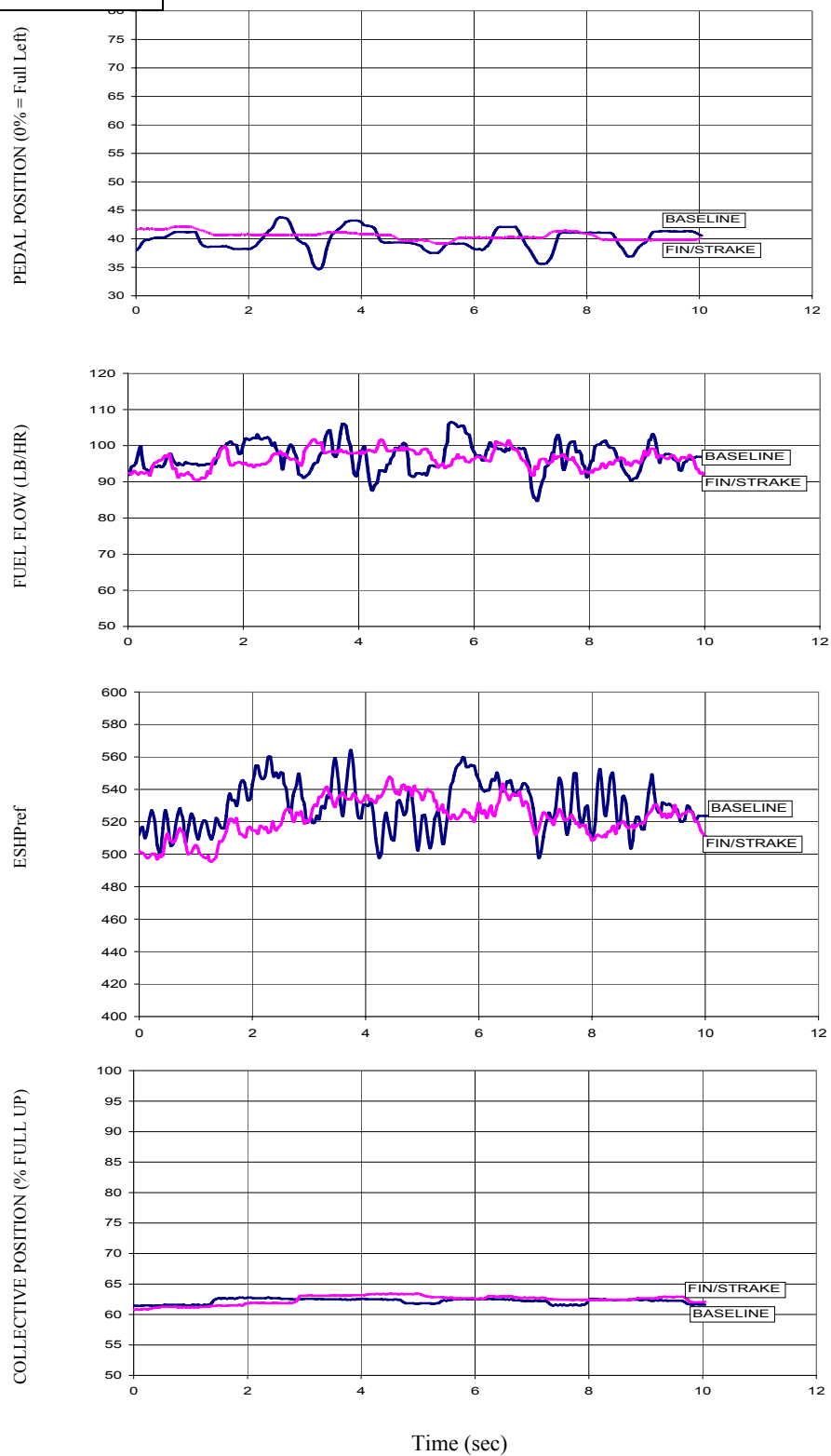
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OH-58D USA S/N 96-00018
 Ambient wind <5kts



Time (sec)

RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
5002-5062	110.3in	1980-2270ft	19.5-22.0	396	20'	180 DEG	10
■ BASELINE ■ FIN/STRAKE OH-58D USA S/N 96-00018 Ambient wind <5kts							

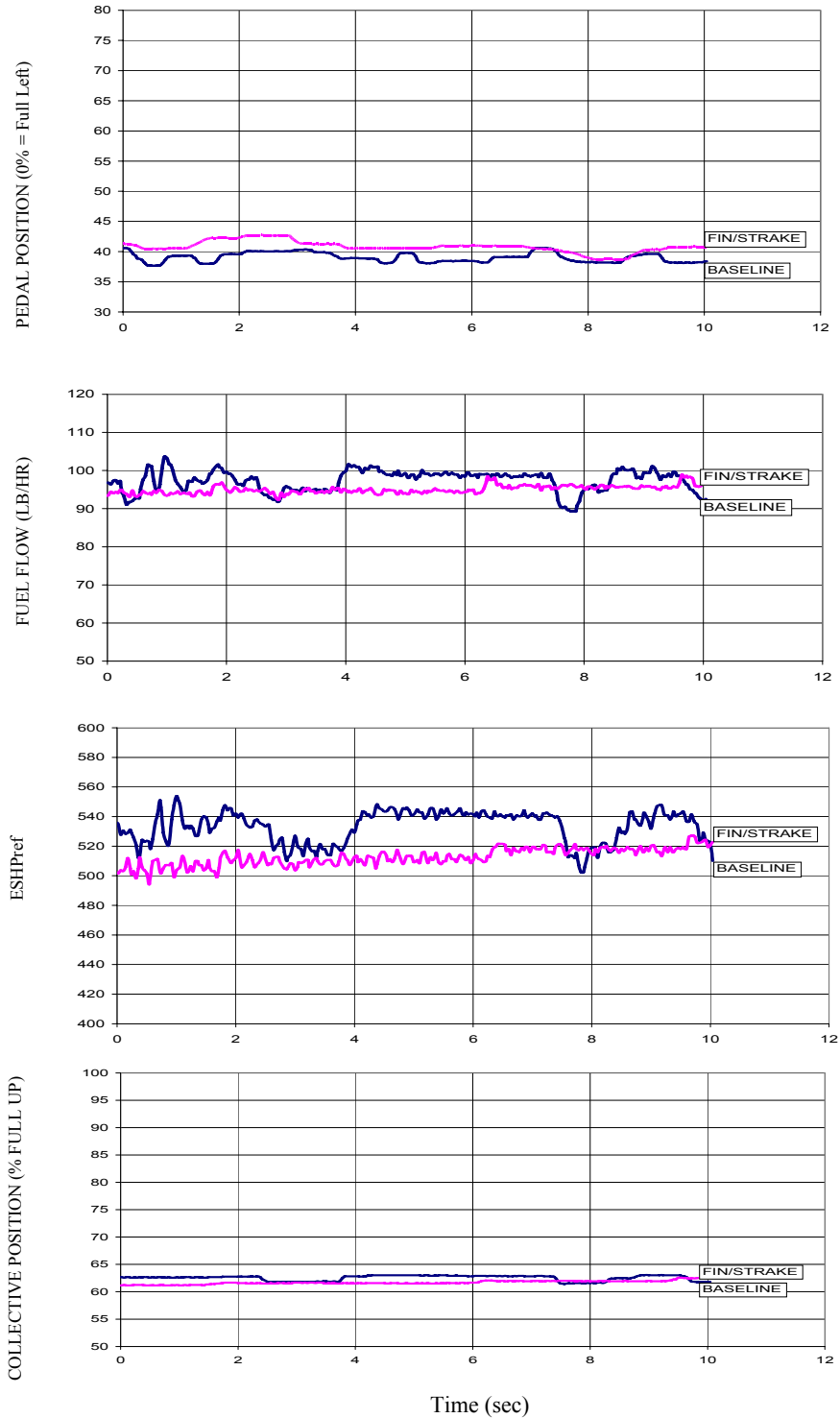


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4988-5059	110.3in	1980-2270ft	19.5-22.0	39	20'	180 DEG	15

OH-58D USA S/N 96-00018
Ambient wind <5kts

BASELINE

FIN/STRAKE

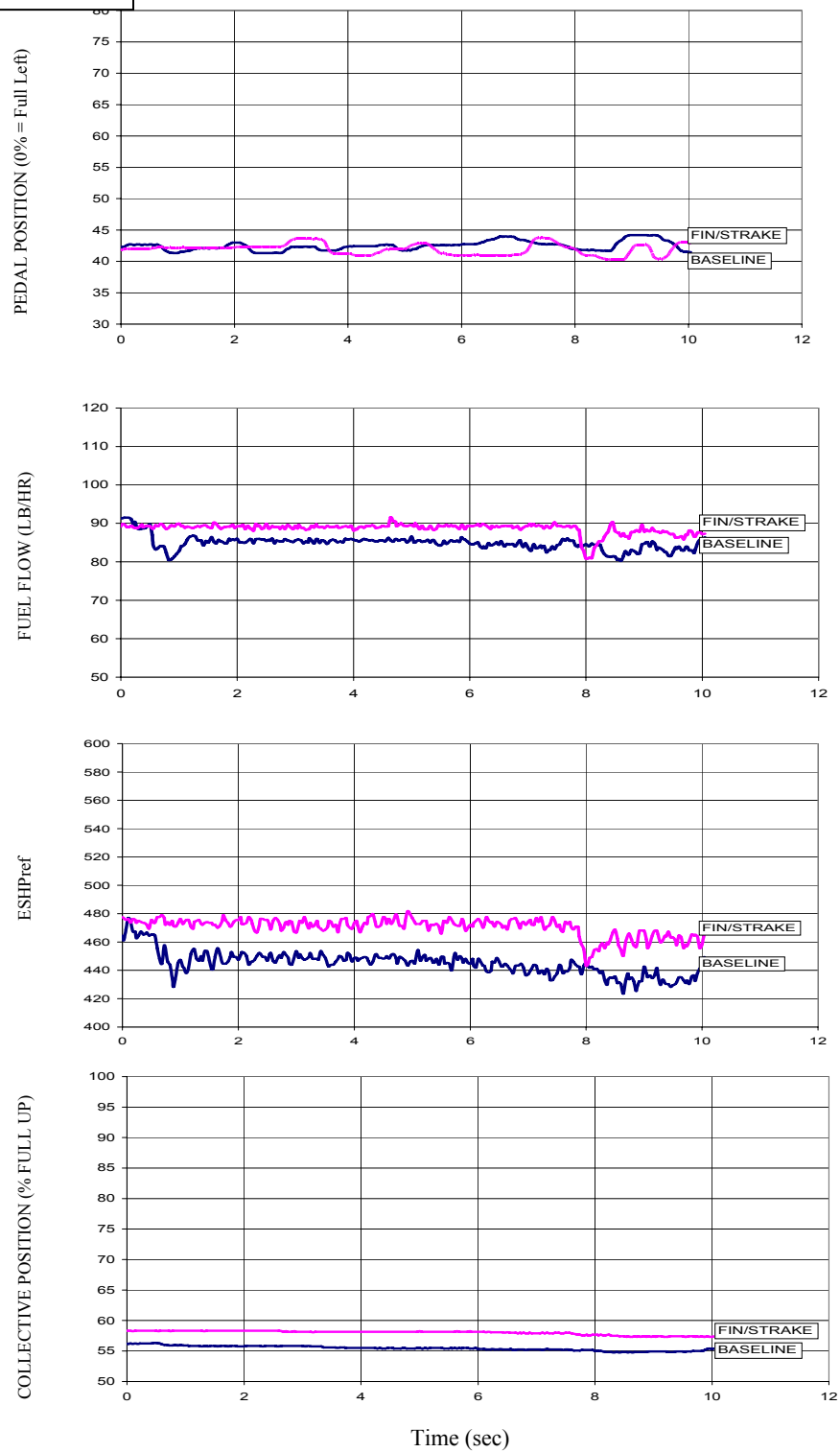


RefGROSS WT (lb)	C.G.	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4982-5057	110.3in	1980-2270ft	19.5-22.0	396	20'	180 DEG	20

OH-58D USA S/N 96-00018
Ambient wind <5kts

■ BASELINE

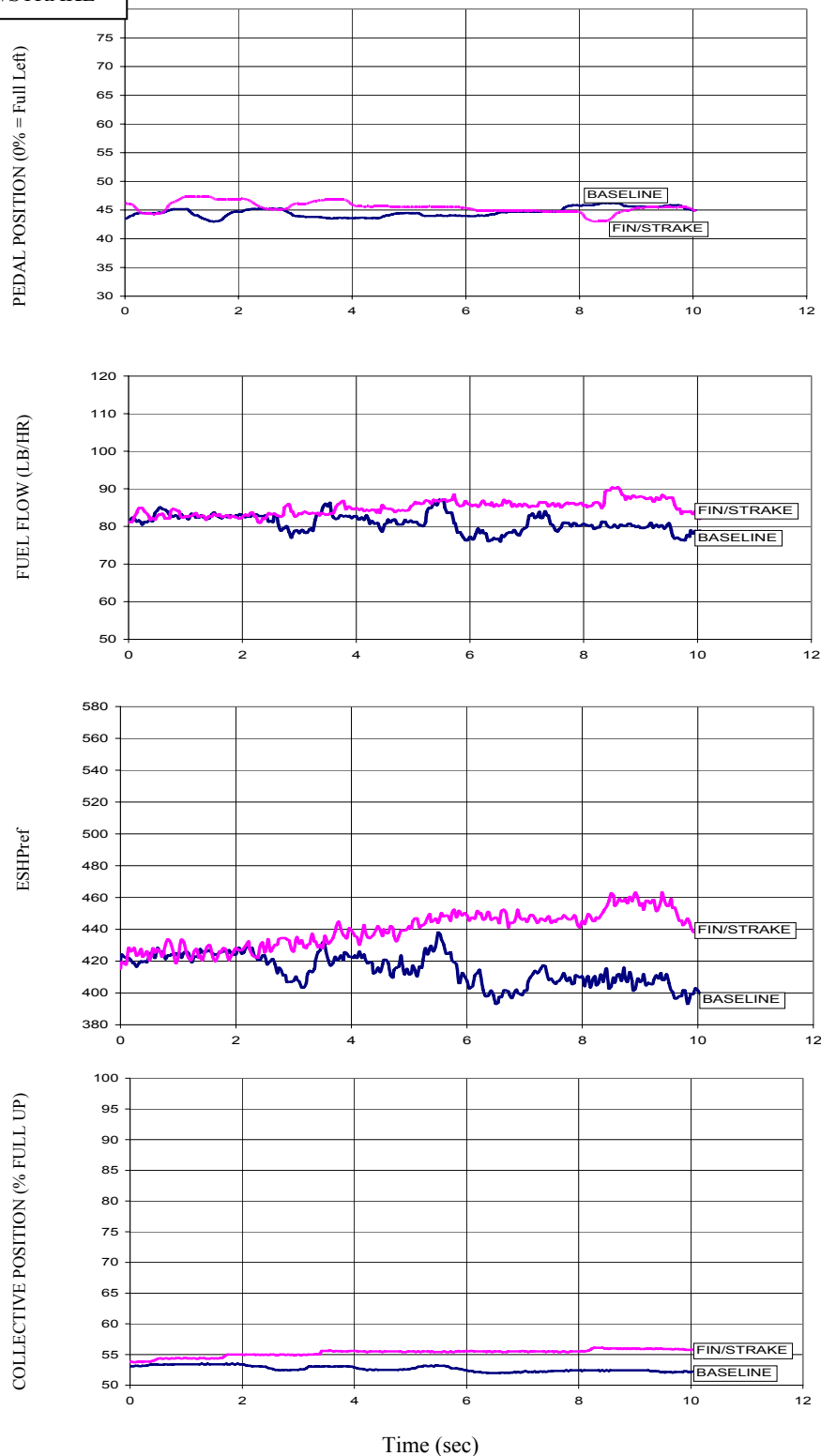
■ FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
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OH-58D USA S/N 96-00018
Ambient wind <5kts

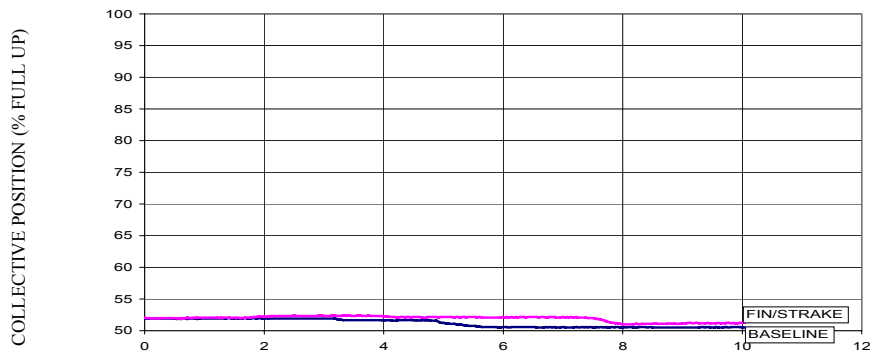
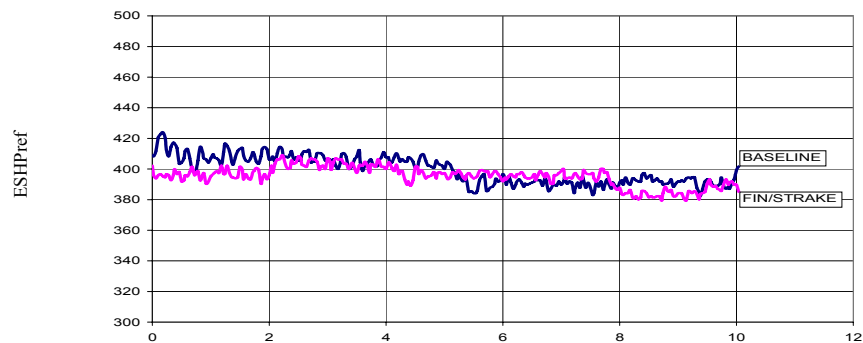
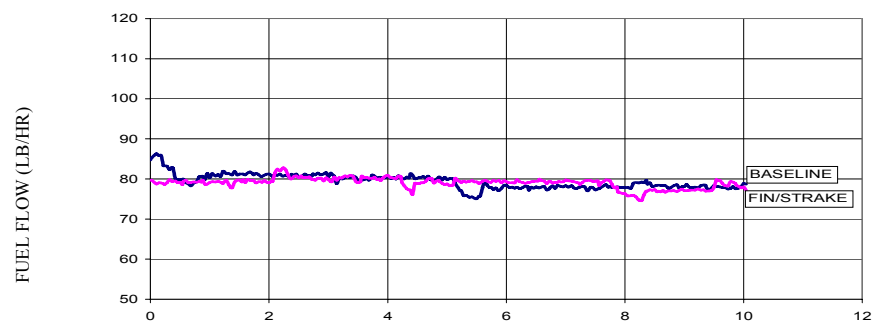
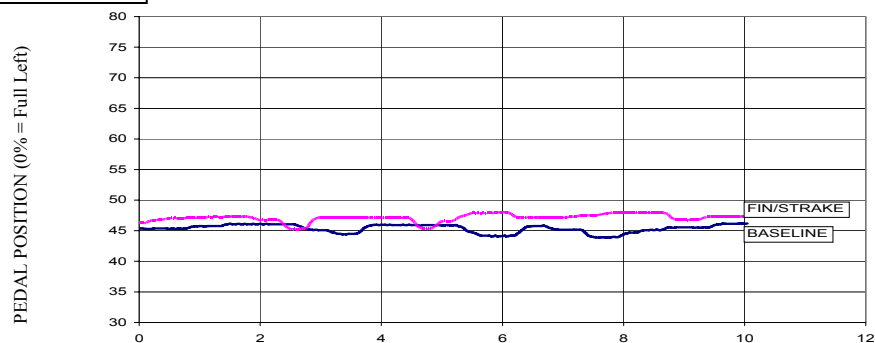
— BASELINE
— FIN/STRAKE



Ref	GROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4948-5039		110.3in	1980-2270ft	19.5-22.0	396	20'	180 DEG	30

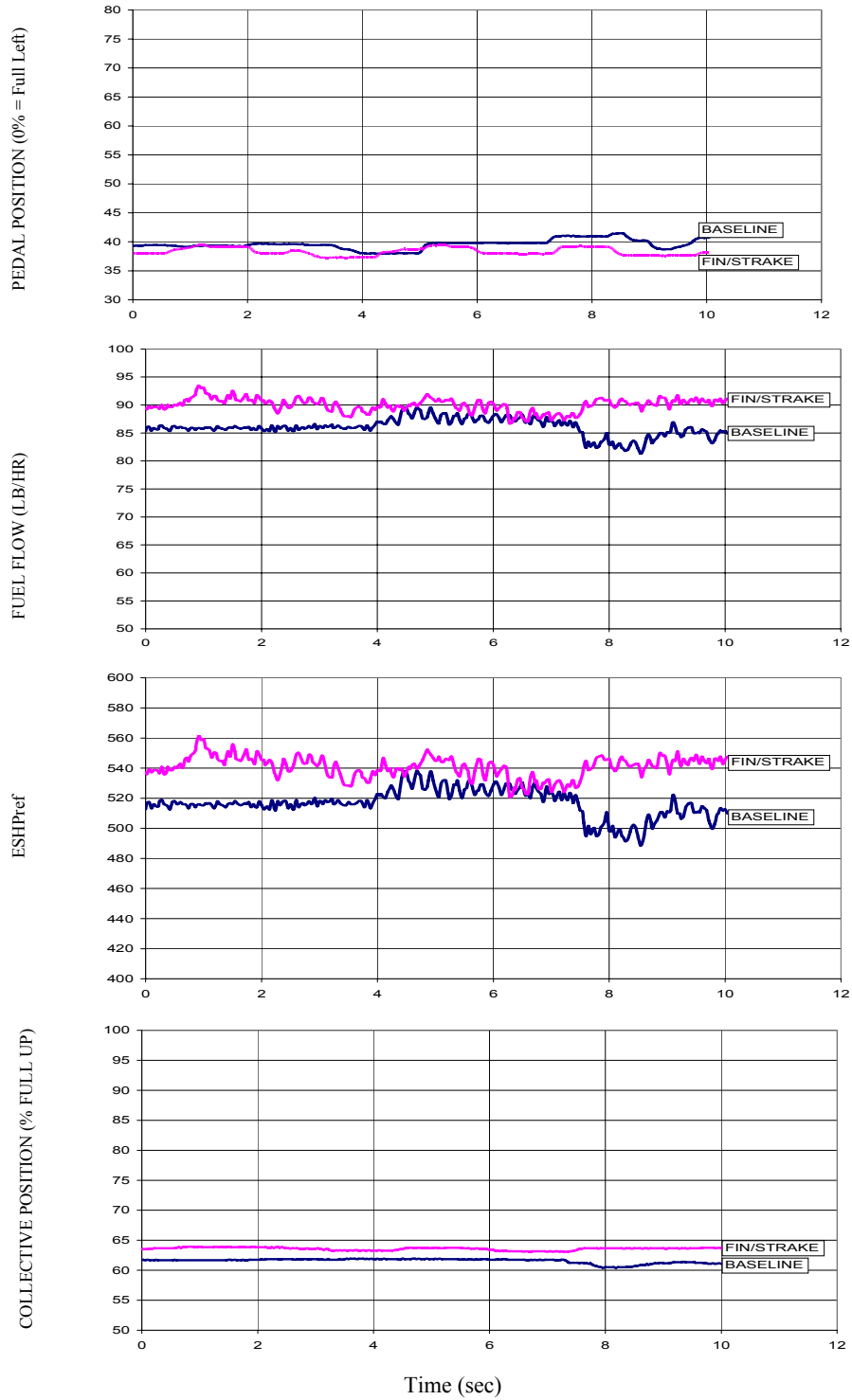
OH-58D USA S/N 96-00018

Ambient wind <5kts



Time (sec)

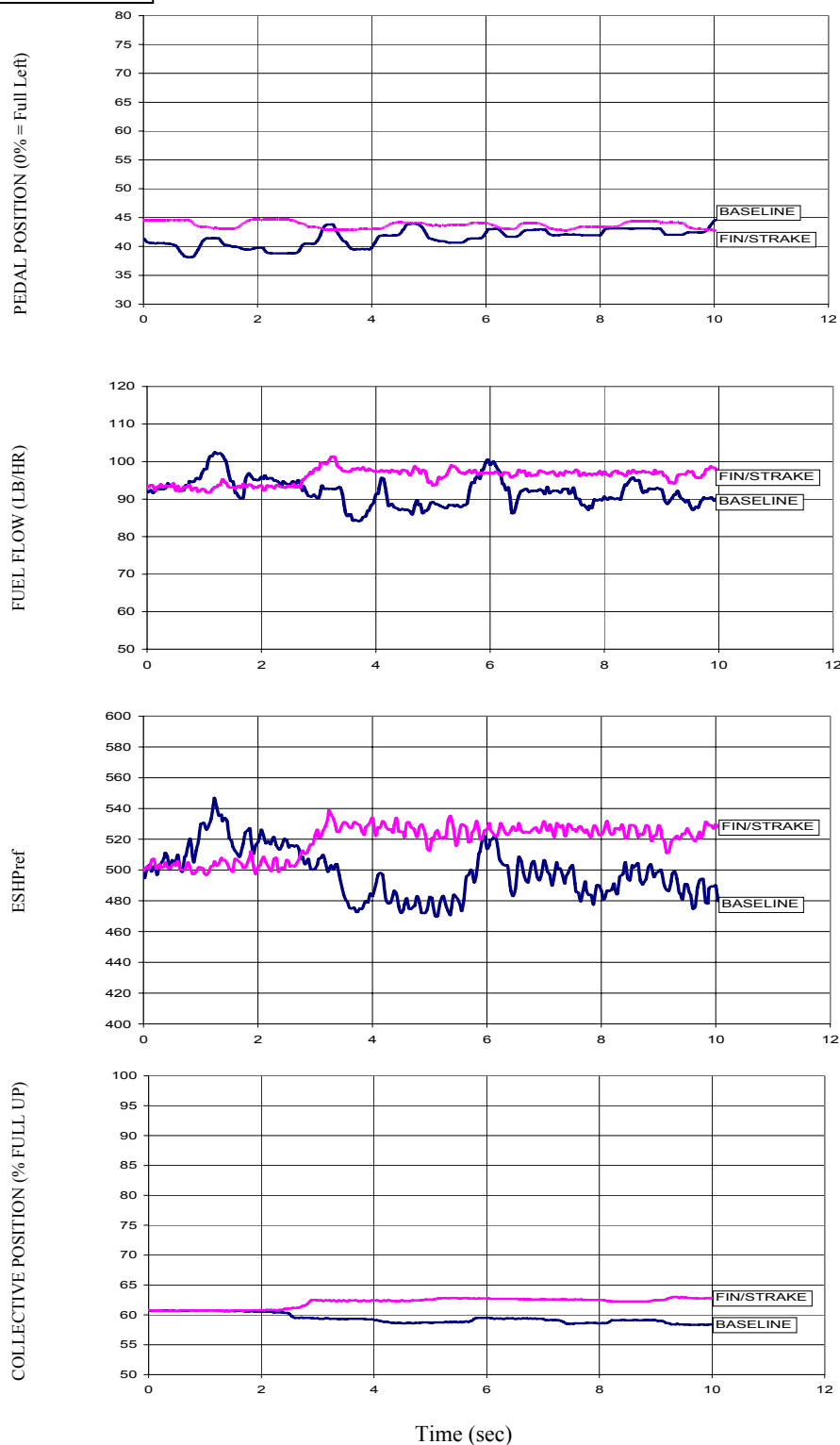
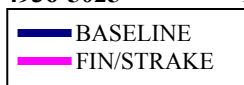
RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4755-4950	110.3in	1770-1960ft	17.5-19.5	396	20'	225 DEG	5
OH-58D USA S/N 96-00018							
Ambient wind <5kts							



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4936-5025	110.3in	1770-1960ft	17.5-19.5	396	20'	225 DEG	10

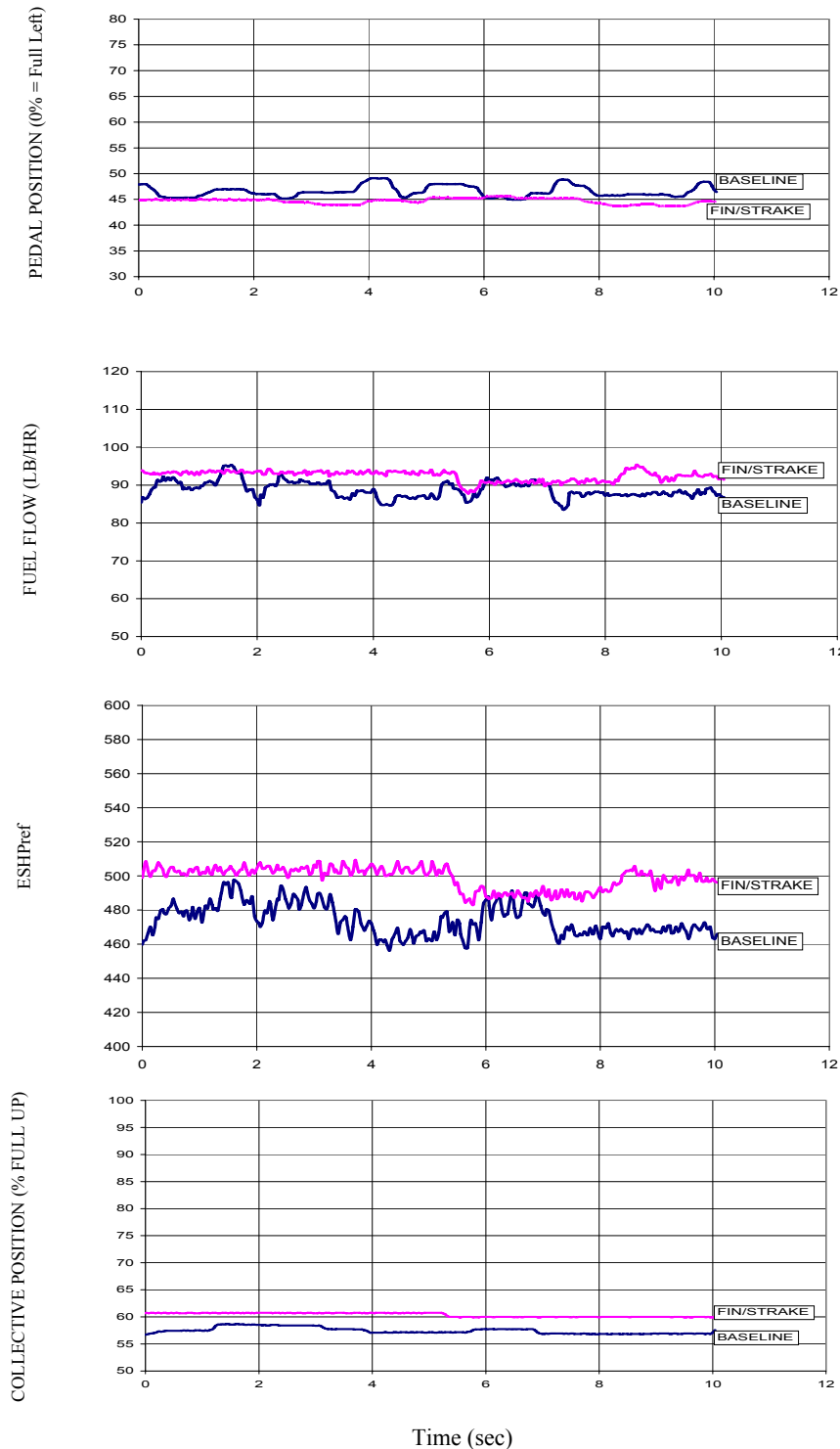
OH-58D USA S/N 96-00018

Ambient wind <5kts



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4930-5019	110.3in	1770-1960ft	17.5-19.5	396	20'	225 DEG	15

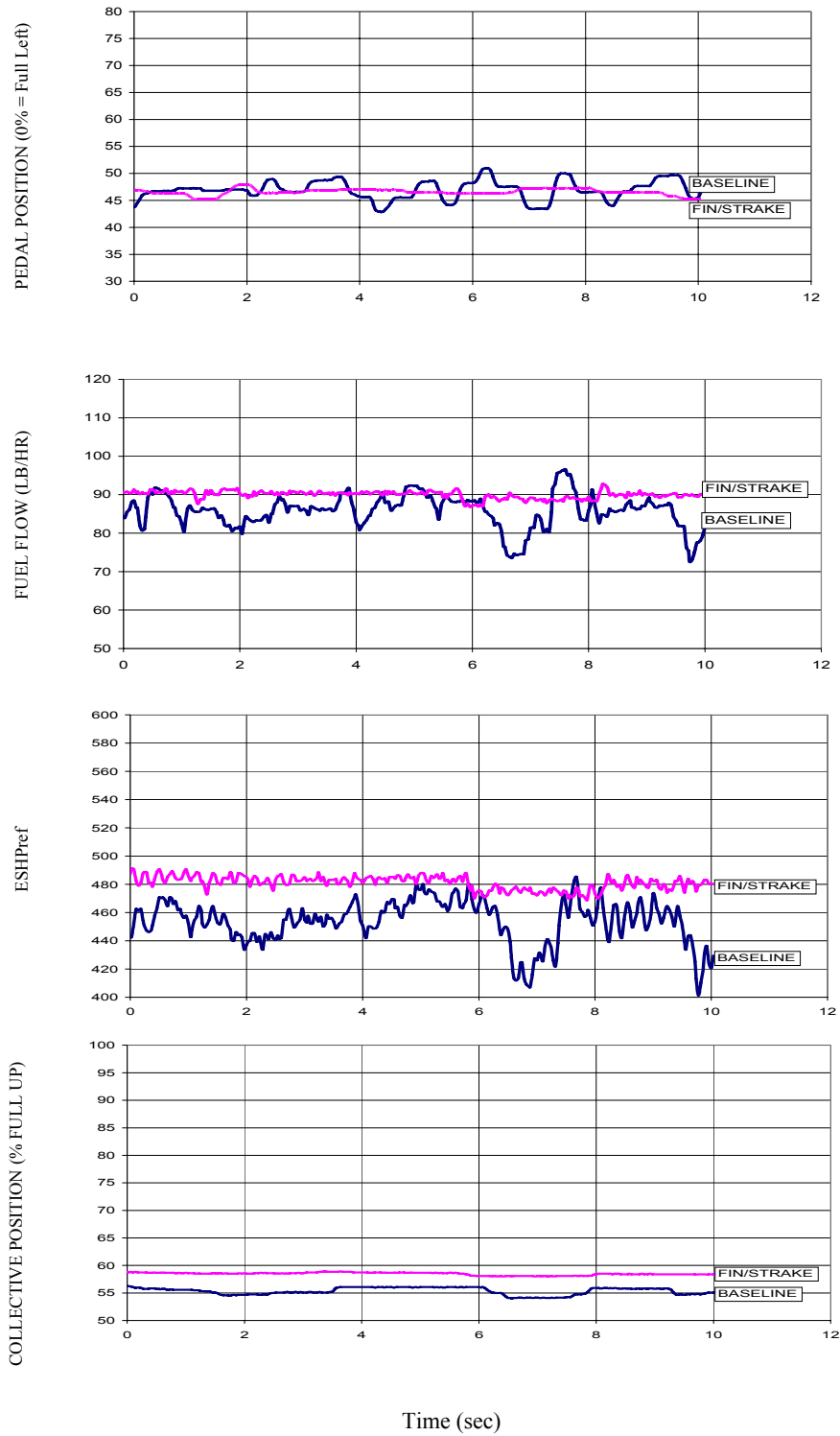
OH-58D USA S/N 96-00018
 Ambient wind <5kts



Ref	GROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4919-5010		110.3in	1770-1960ft	17.5-19.5	396	20'	225 DEG	20

OH-58D USA S/N 96-00018
Ambient wind <5kts

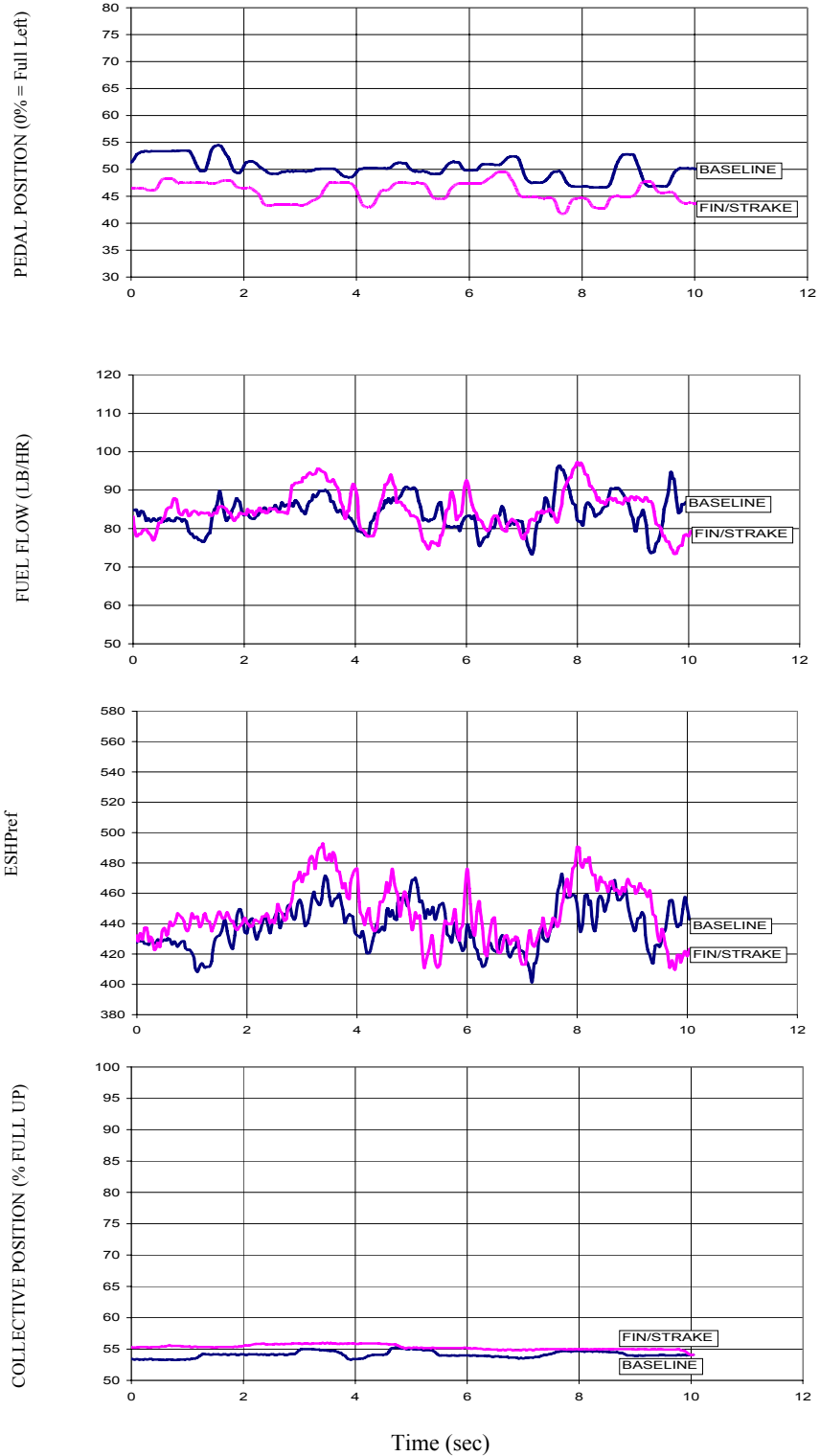
— BASELINE
— FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4911-5004	110.3in	1770-1960ft	17.5-19.5	396	20'	225 DEG	25
OH-58D USA S/N 96-00018							
Ambient wind <5kts							

BASELINE

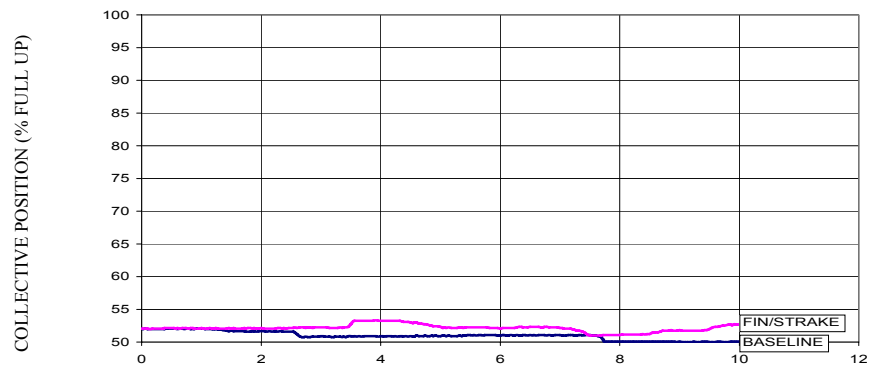
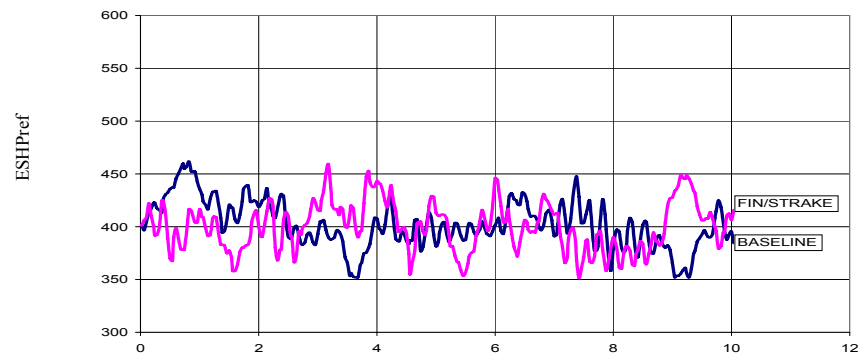
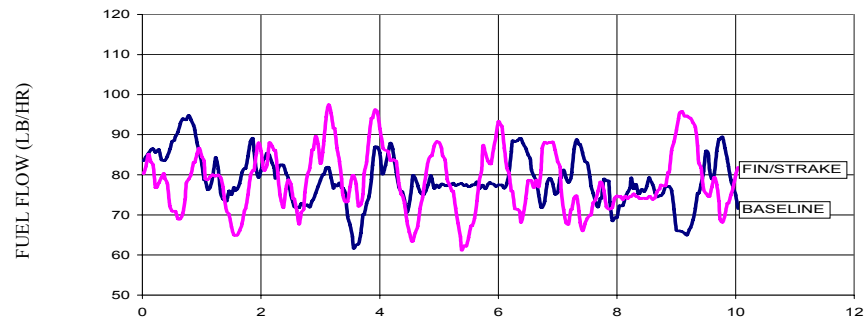
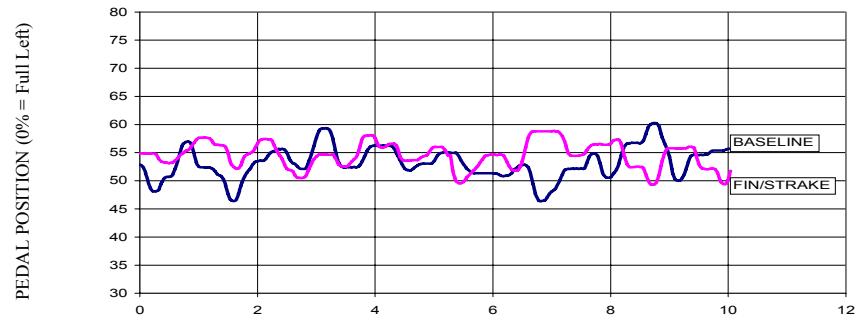
FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ. KTAS
4896-4983	110.3in	1770-1960ft	17.5-19.5	396	20'	225 DEG 30

OH-58D USA S/N 96-00018
Ambient wind <5kts

— BASELINE
— FIN/STRAKE

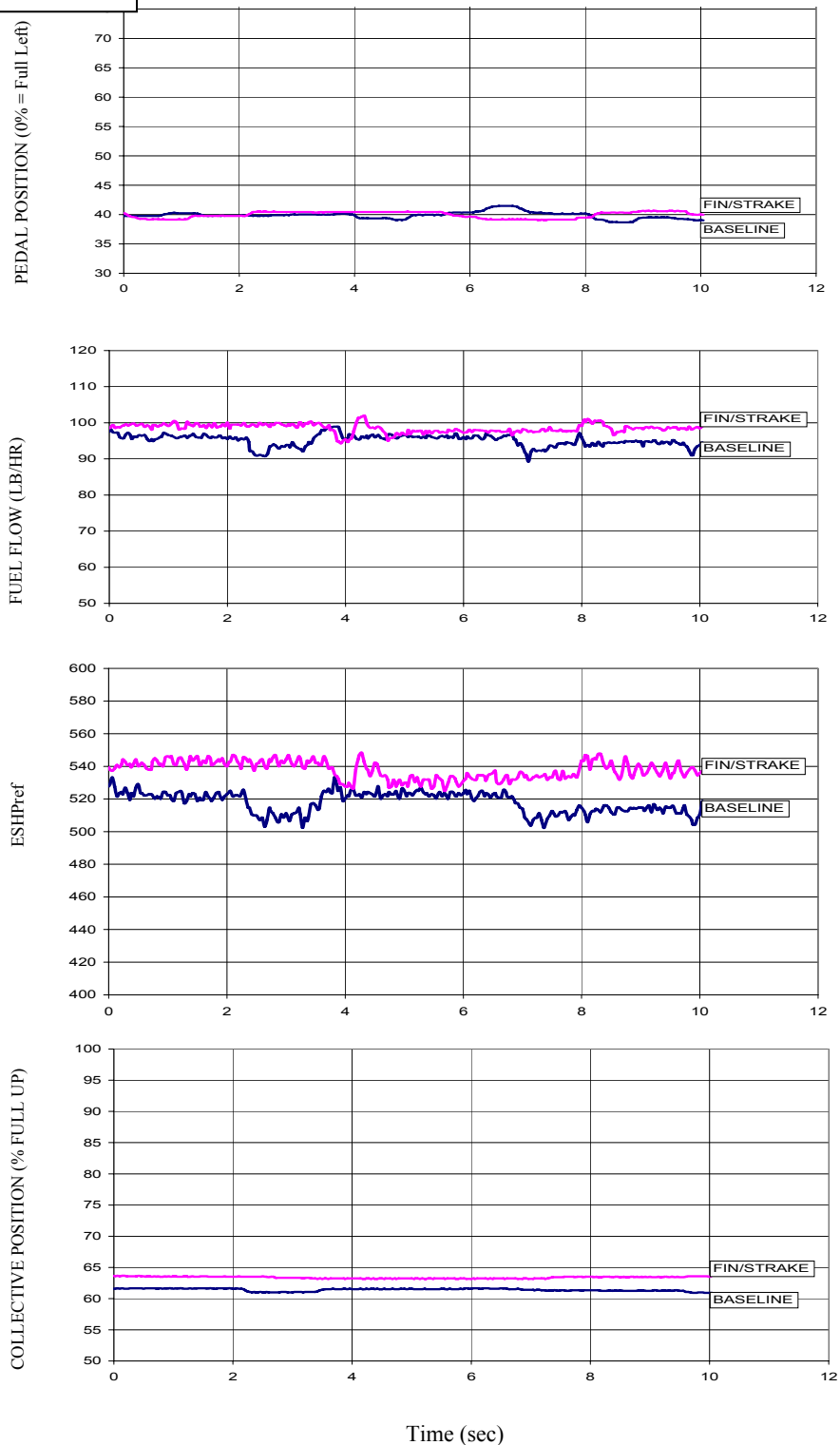


Time (sec)

RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4762-4944	110.3in	1740-1940ft	17.0-19.0	396	24'	270 DEG	5

OH-58D USA S/N 96-00018
Ambient wind <5kts

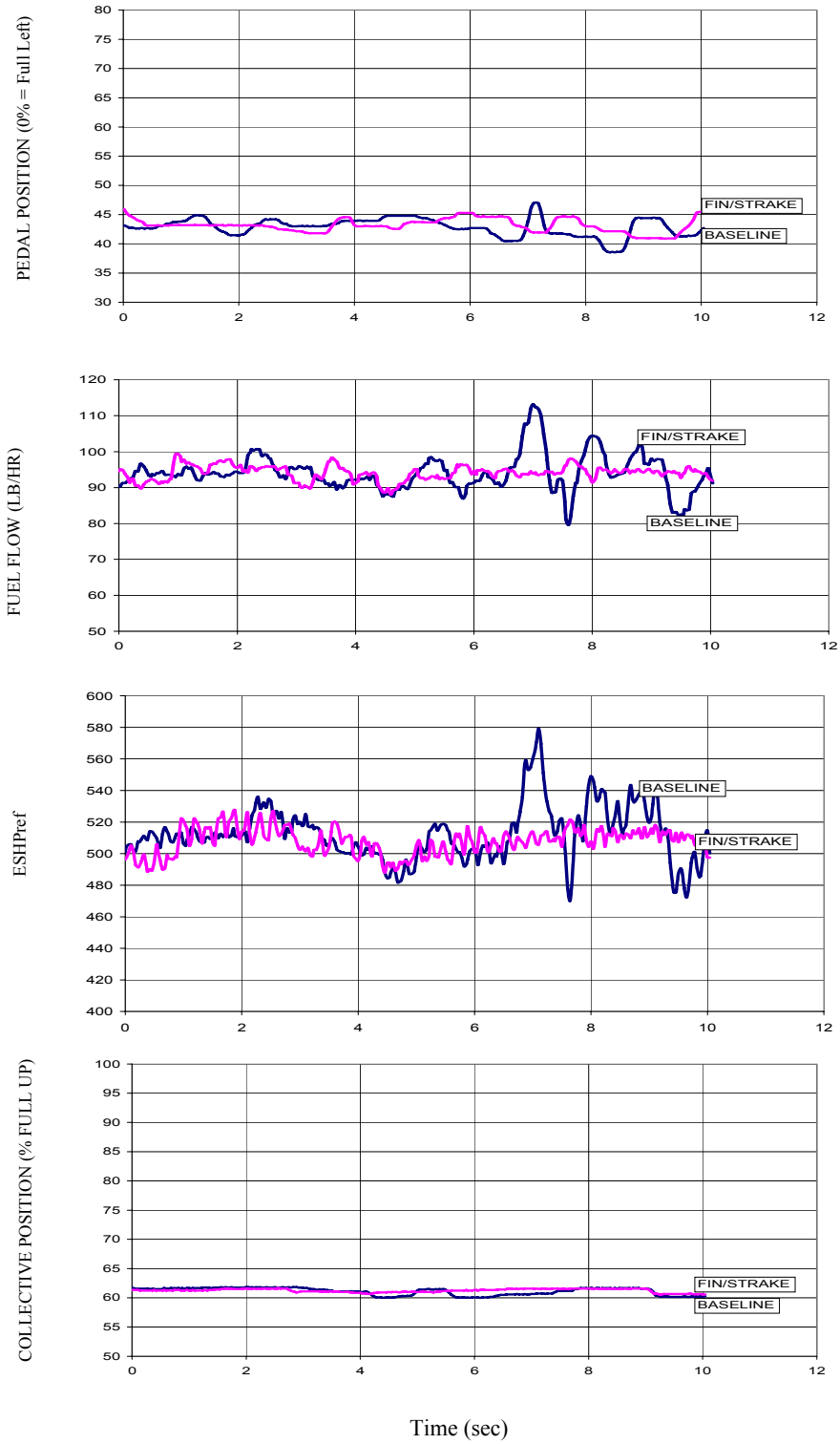
■ BASELINE
 ■ FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4880-4892	110.3in	1740-1940ft	17.0-19.0	396	24'	270 DEG	10

OH-58D USA S/N 96-00018
Ambient wind <5kts

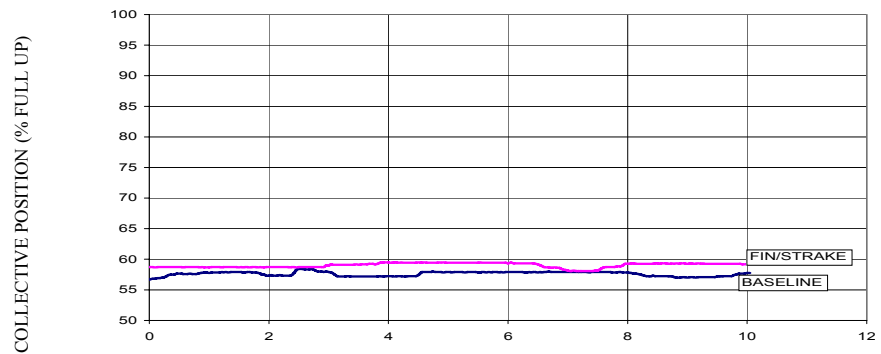
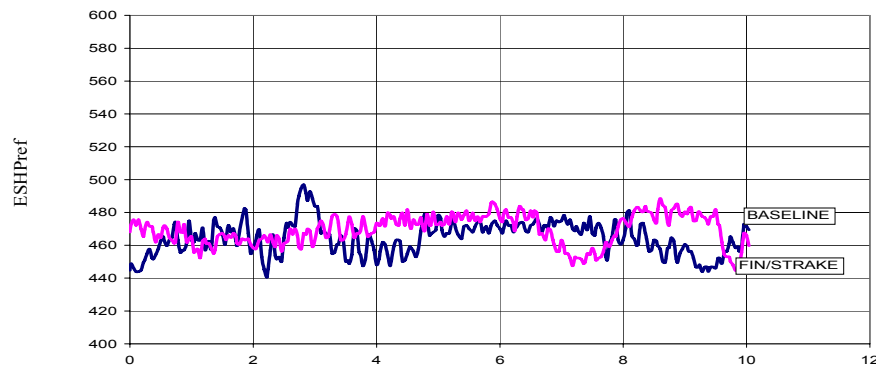
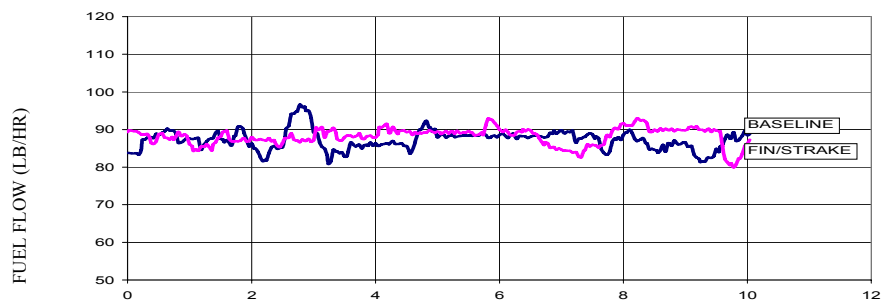
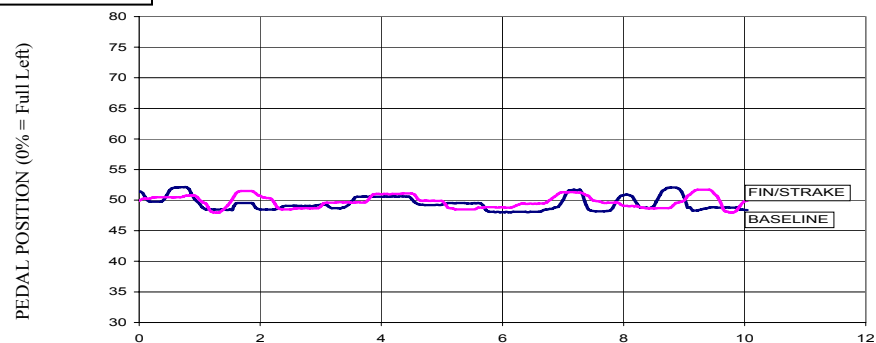
— BASELINE
— FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4885-4891	110.3in	1740-1940ft	17.0-19.0	396	24'	270 DEG	15

OH-58D USA S/N 96-00018

Ambient wind <5kts

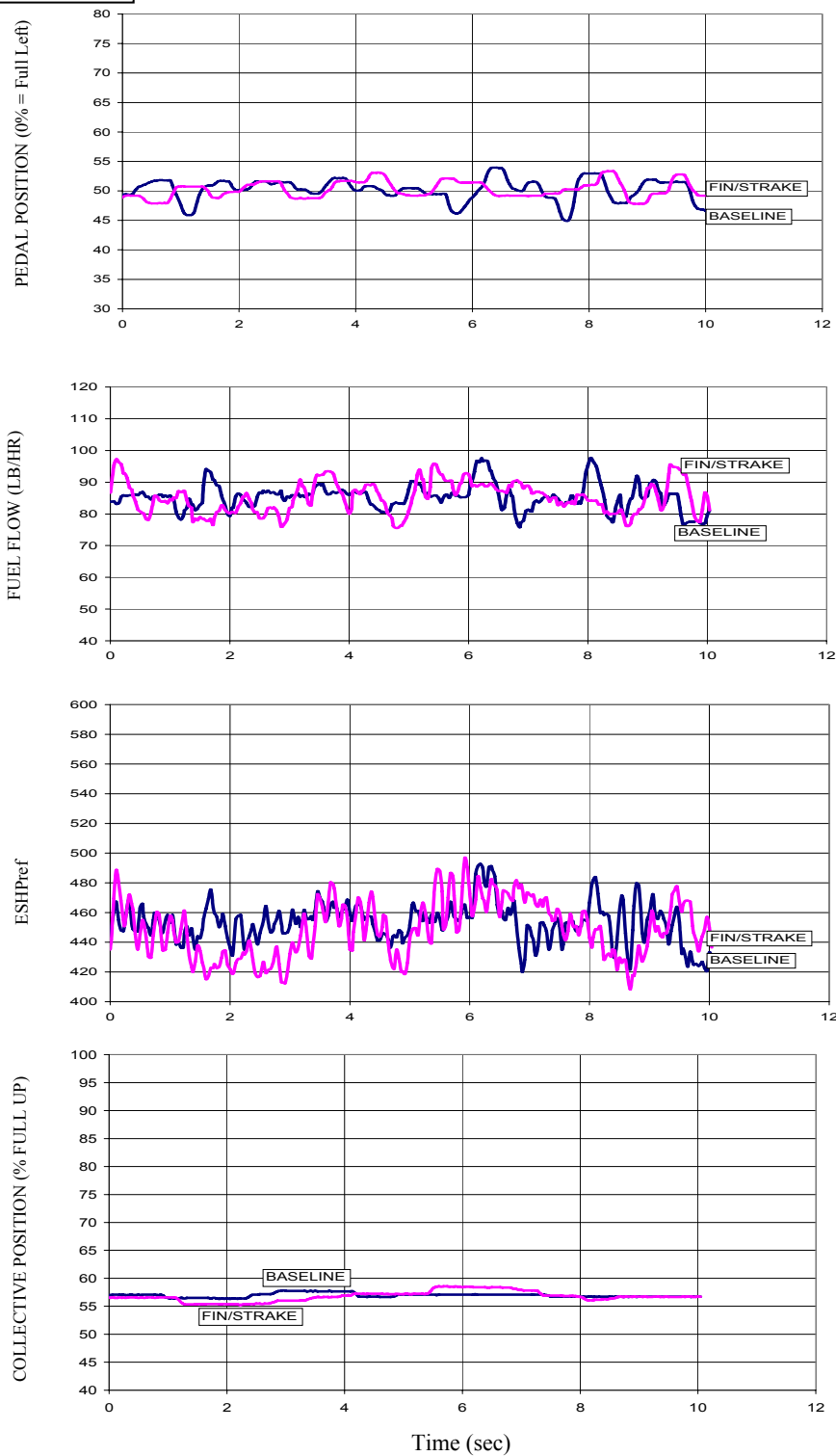


Time (sec)

RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4872-4898	110.3in	1740-1940ft	17.0-19.0	396	24'	270 DEG	20

OH-58D USA S/N 96-00018
Ambient wind <5kts

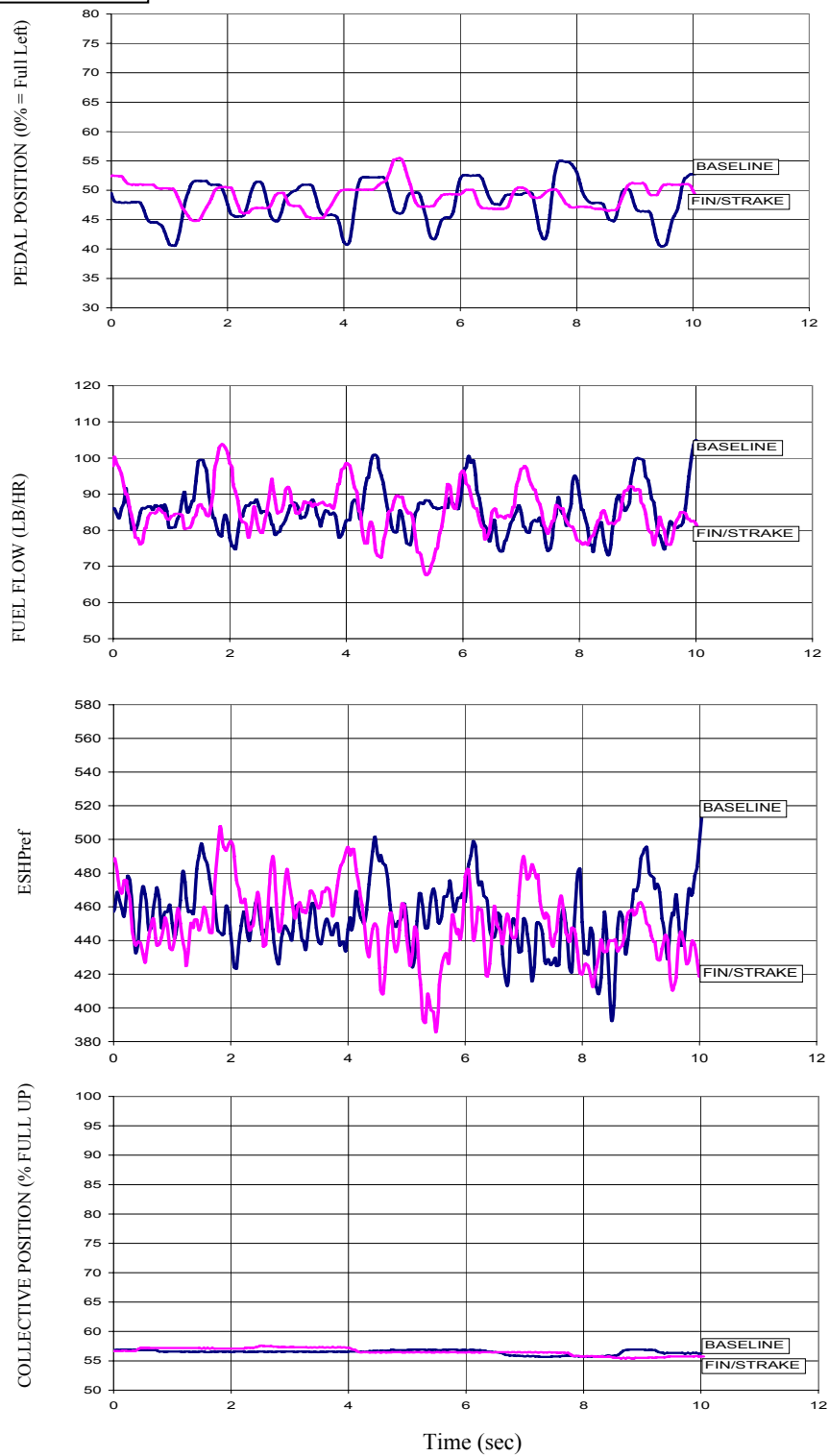
— BASELINE
— FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ. KTAS
4878-4879	110.3in	1740-1940ft	17.0-19.0	396	24'	270 DEG 25

OH-58D USA S/N 96-00018
Ambient wind <5kts

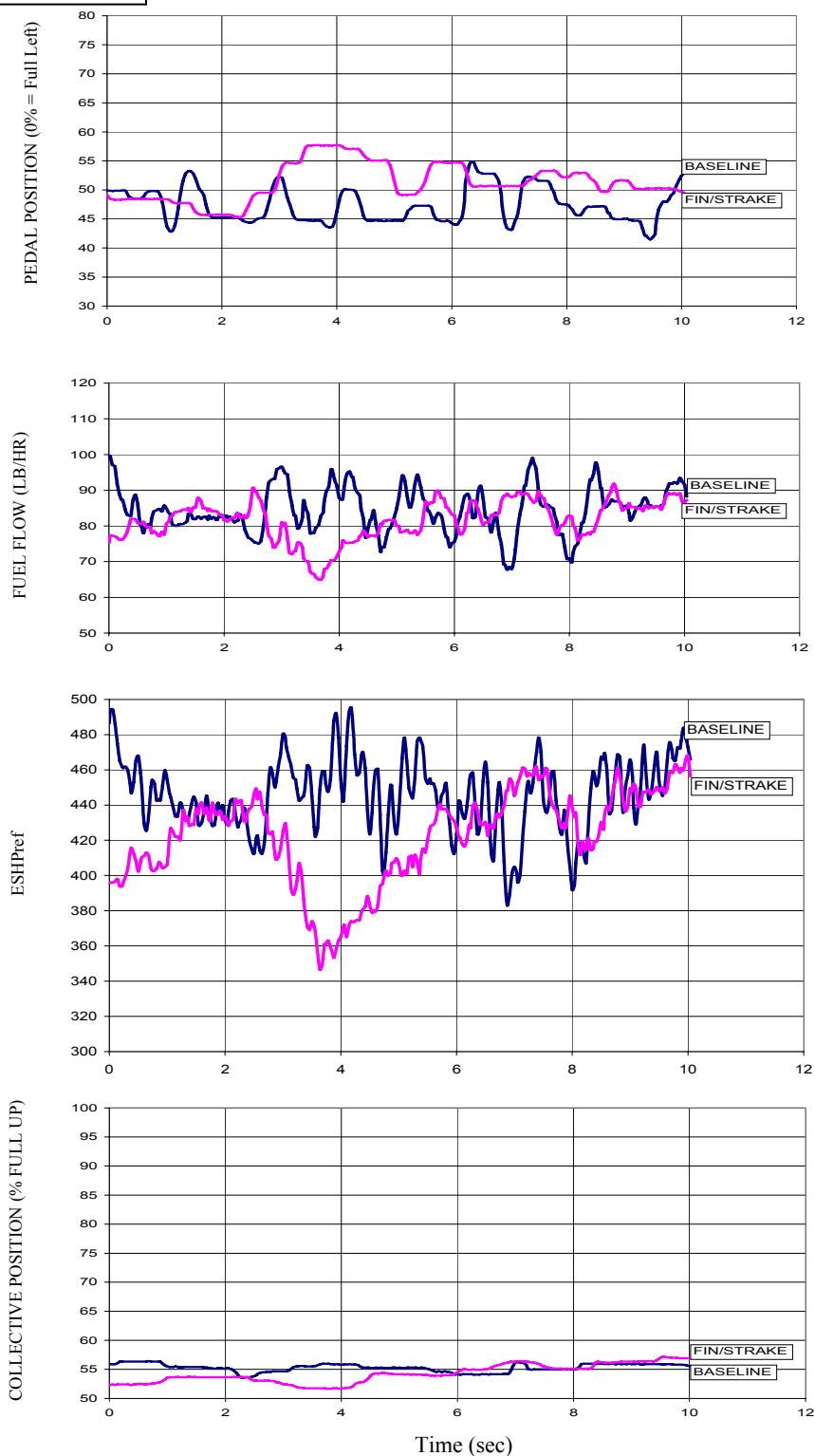
— BASELINE
— FIN/STRAKE



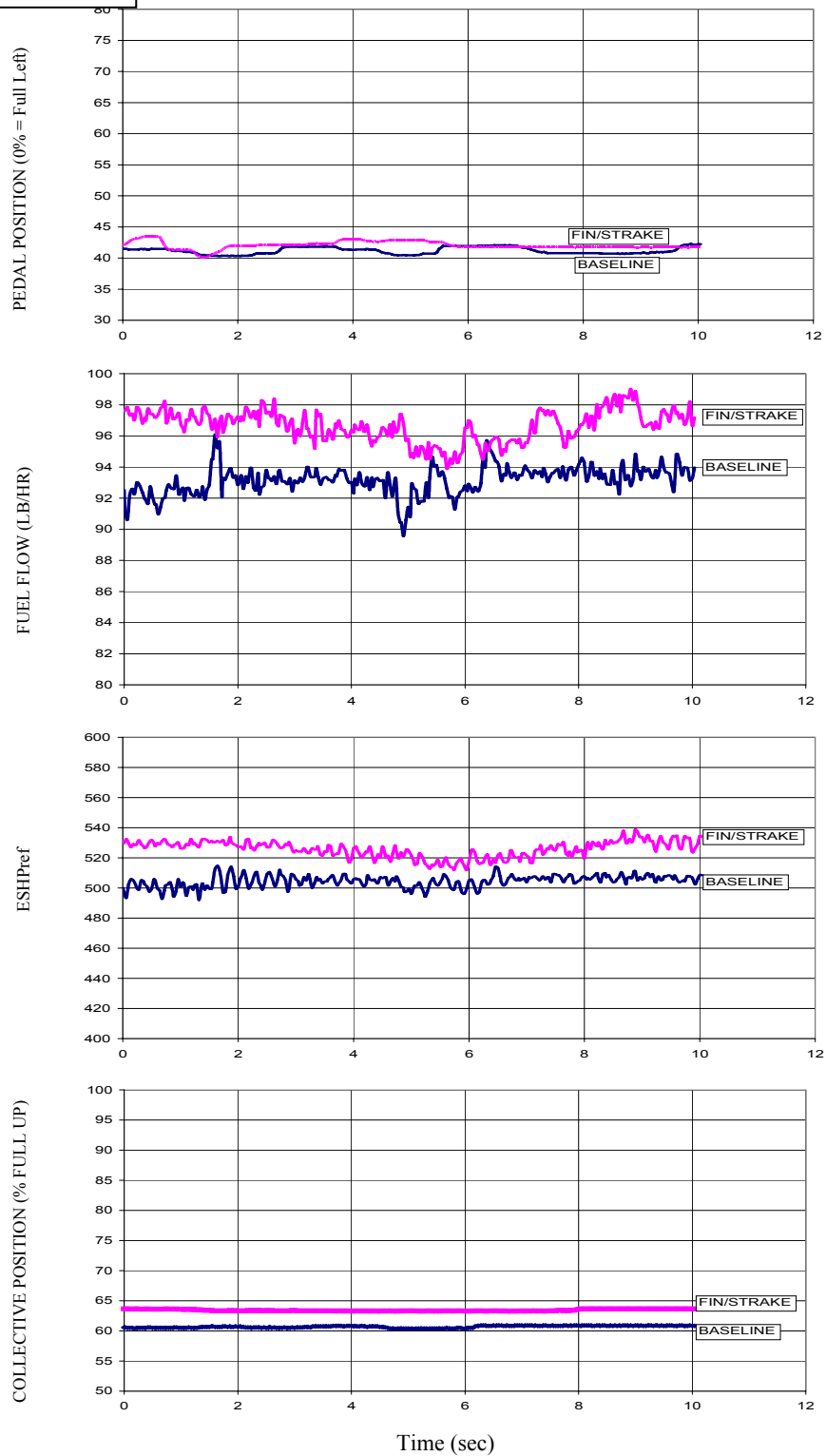
RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4853-4874	110.3in	1740-1940ft	17.0-19.0	396	24'	270 DEG	30

OH-58D USA S/N 96-00018
Ambient wind <5kts

— BASELINE
— FIN/STRAKE



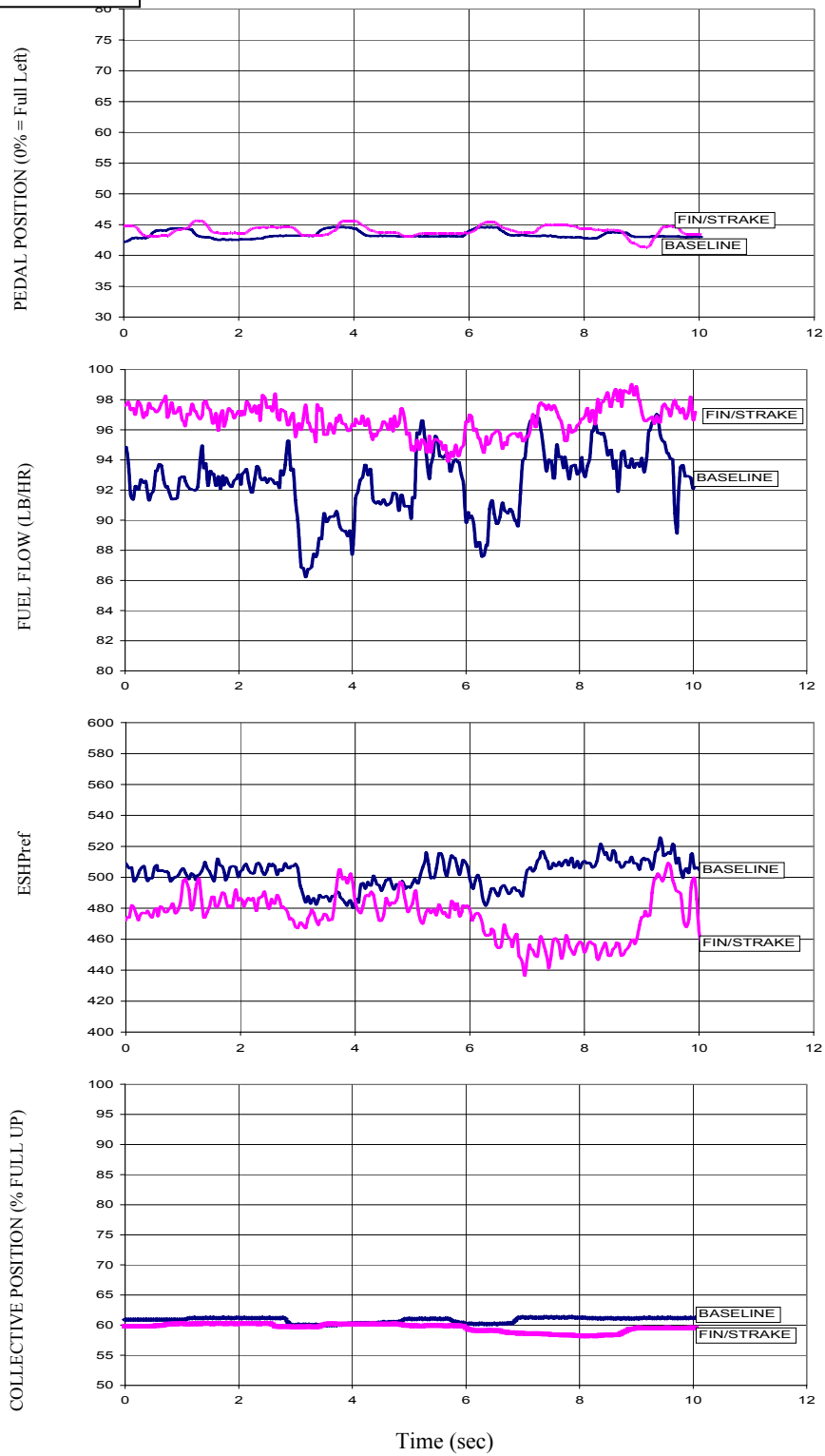
RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4762-4940	110.2in	1780-2030ft	17.5-20.0	396	22'	315 DEG	5
OH-58D USA S/N 96-00018							
Ambient wind <5kts							



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4840	110.2in	1780-2030ft	17.5-20.0	396	22'	315 DEG	10
OH-58D USA S/N 96-00018 Ambient wind <5kts							

BASELINE

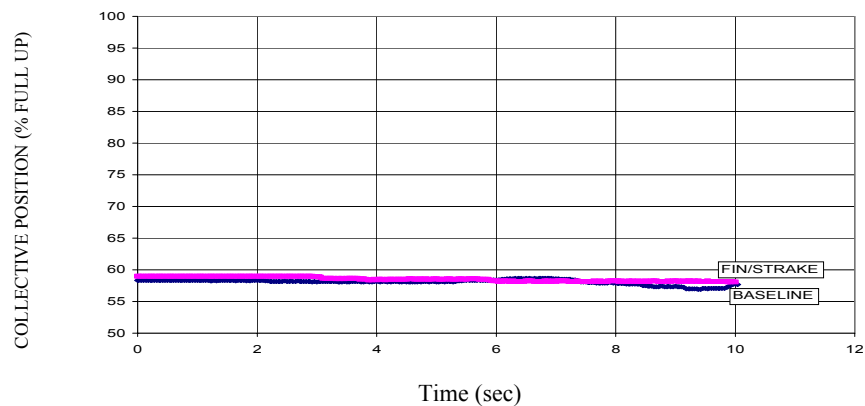
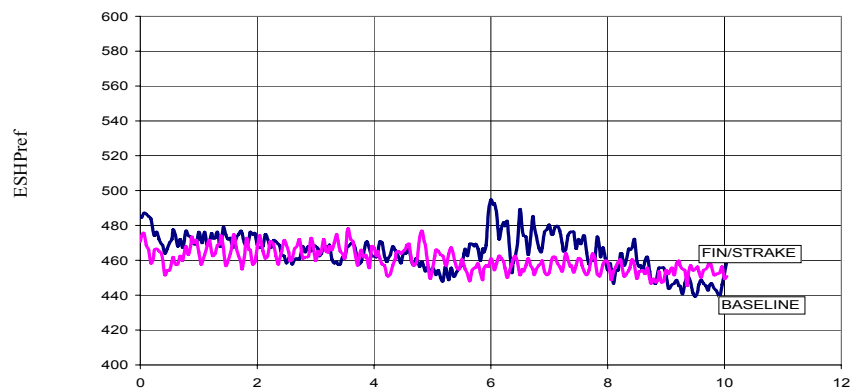
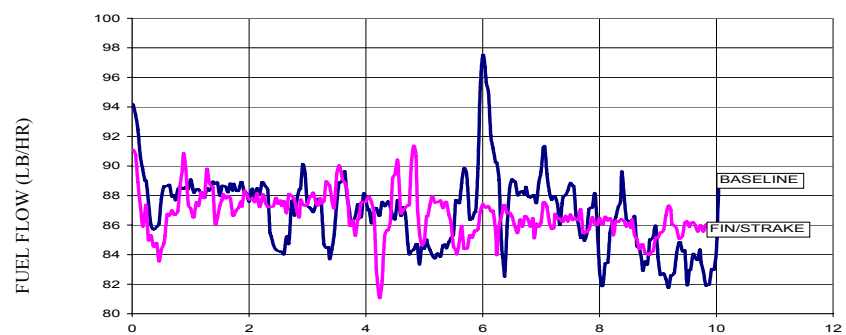
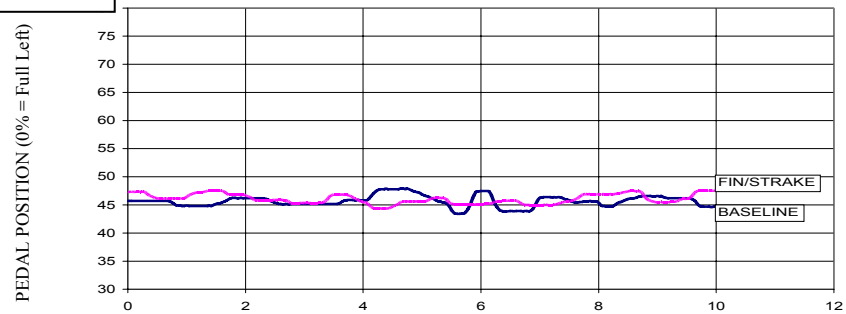
FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4834-4838	110.2in	1780-2030ft	17.5-20.0	396	22'	315 DEG	15

OH-58D USA S/N 96-00018
Ambient wind <5kts

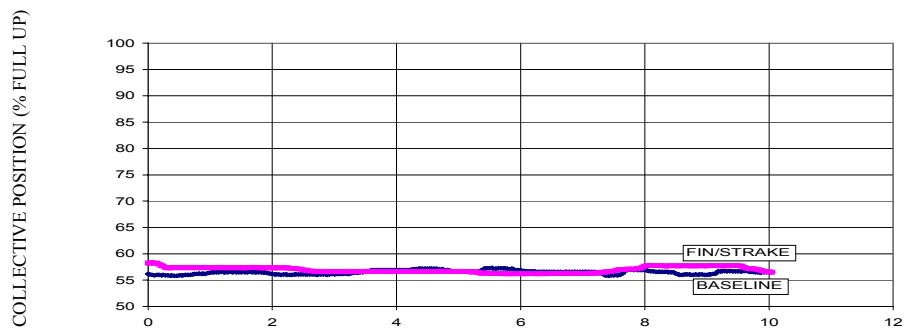
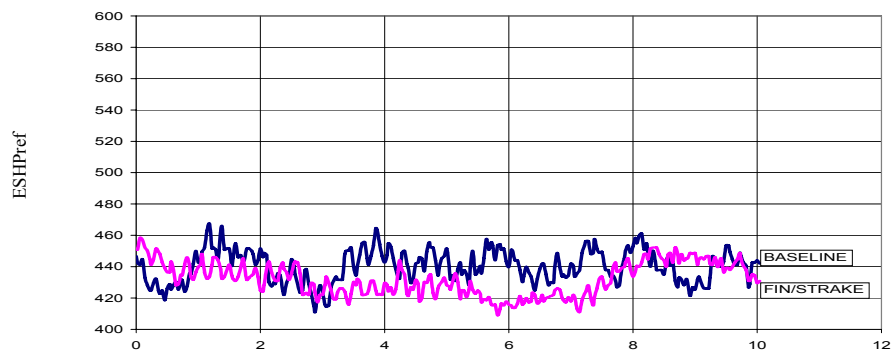
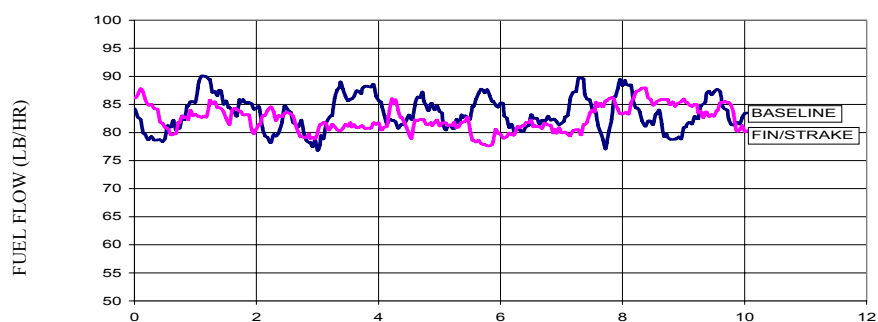
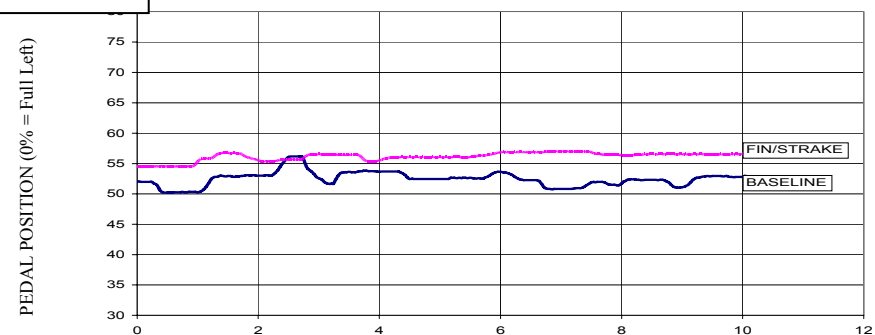
— BASELINE
— FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4839-4840	110.2in	1780-2030ft	17.5-20.0	396	22'	315 DEG	20

OH-58D USA S/N 96-00018
 Ambient wind <5kts

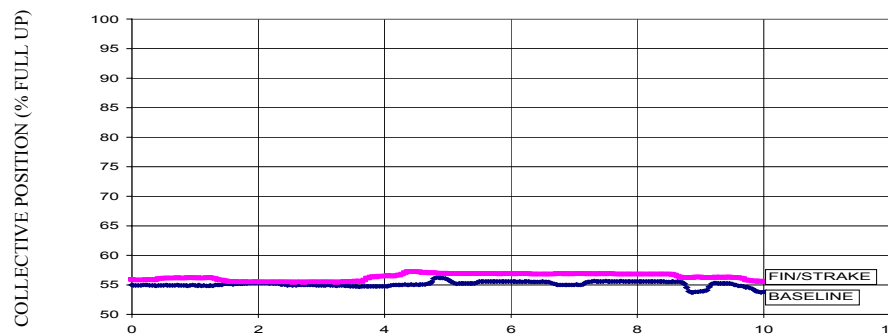
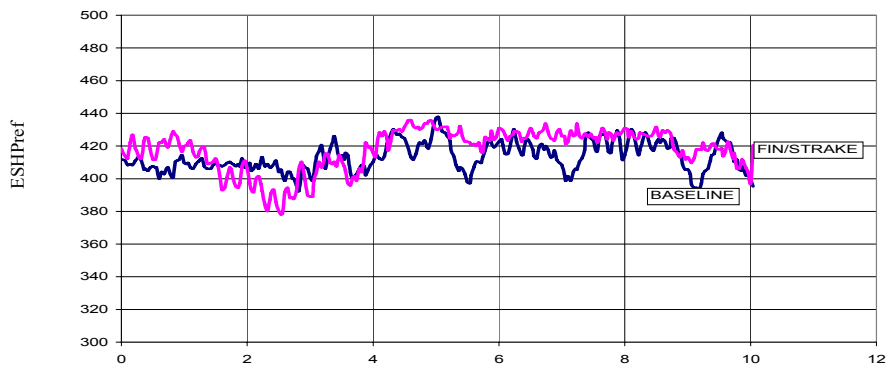
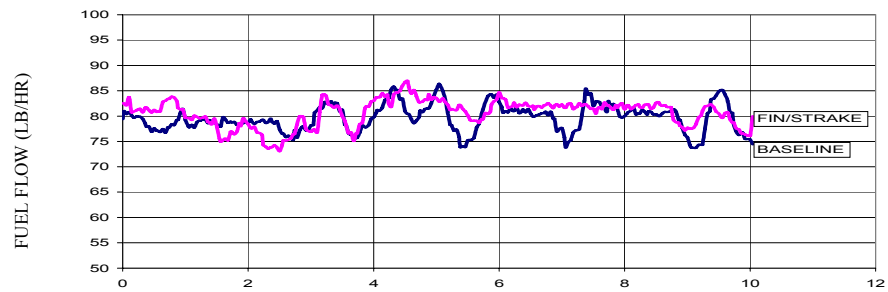
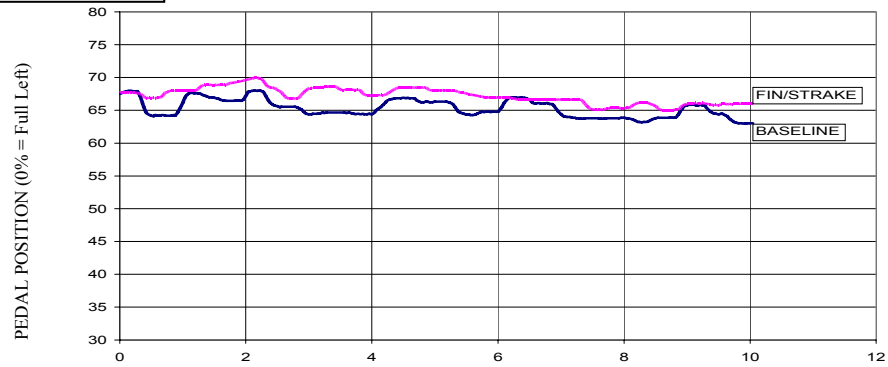
■ BASELINE
 ■ FIN/STRAKE



Time (sec)

RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4837-4840	110.2in	1780-2030ft	17.5-20.0	396	22'	315 DEG	25
OH-58D USA S/N 96-00018							
Ambient wind <5kts							

— BASELINE
— FIN/STRAKE

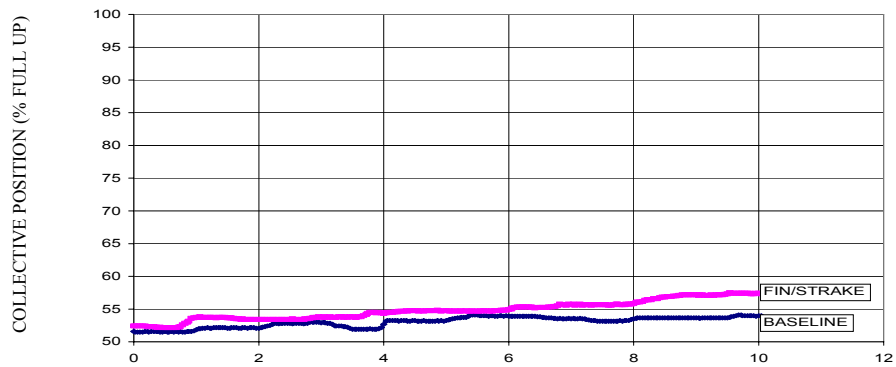
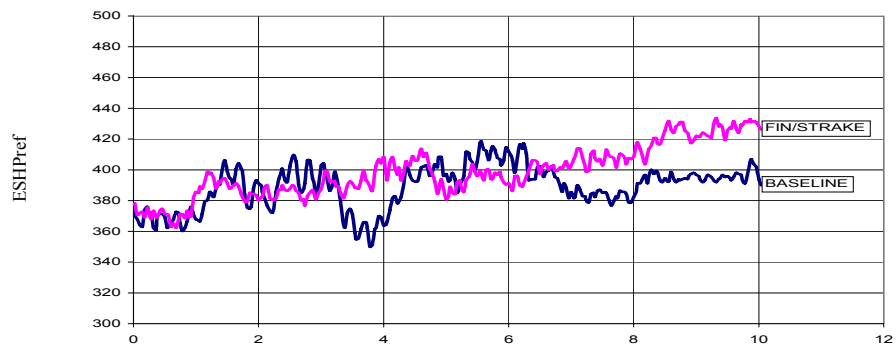
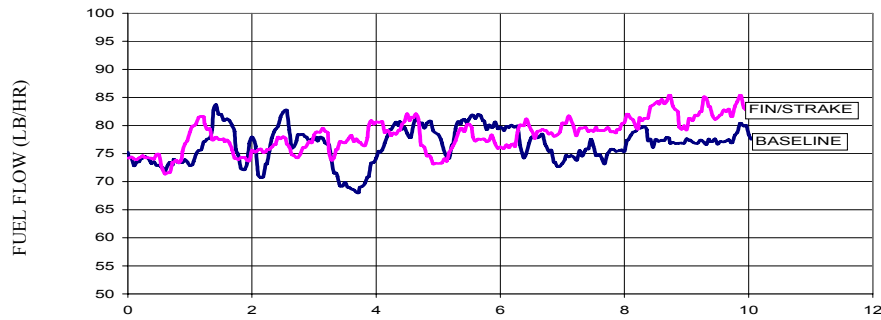
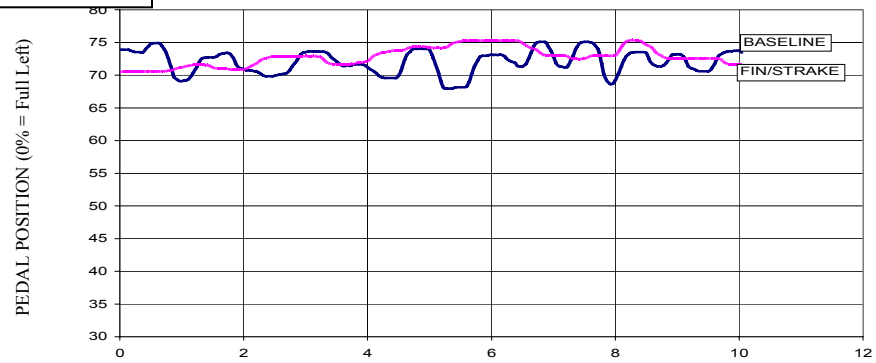


Time (sec)

RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4822	110.2in	1780-2030ft	17.5-20.0	396	22'	315 DEG	30

OH-58D USA S/N 96-00018
Ambient wind <5kts

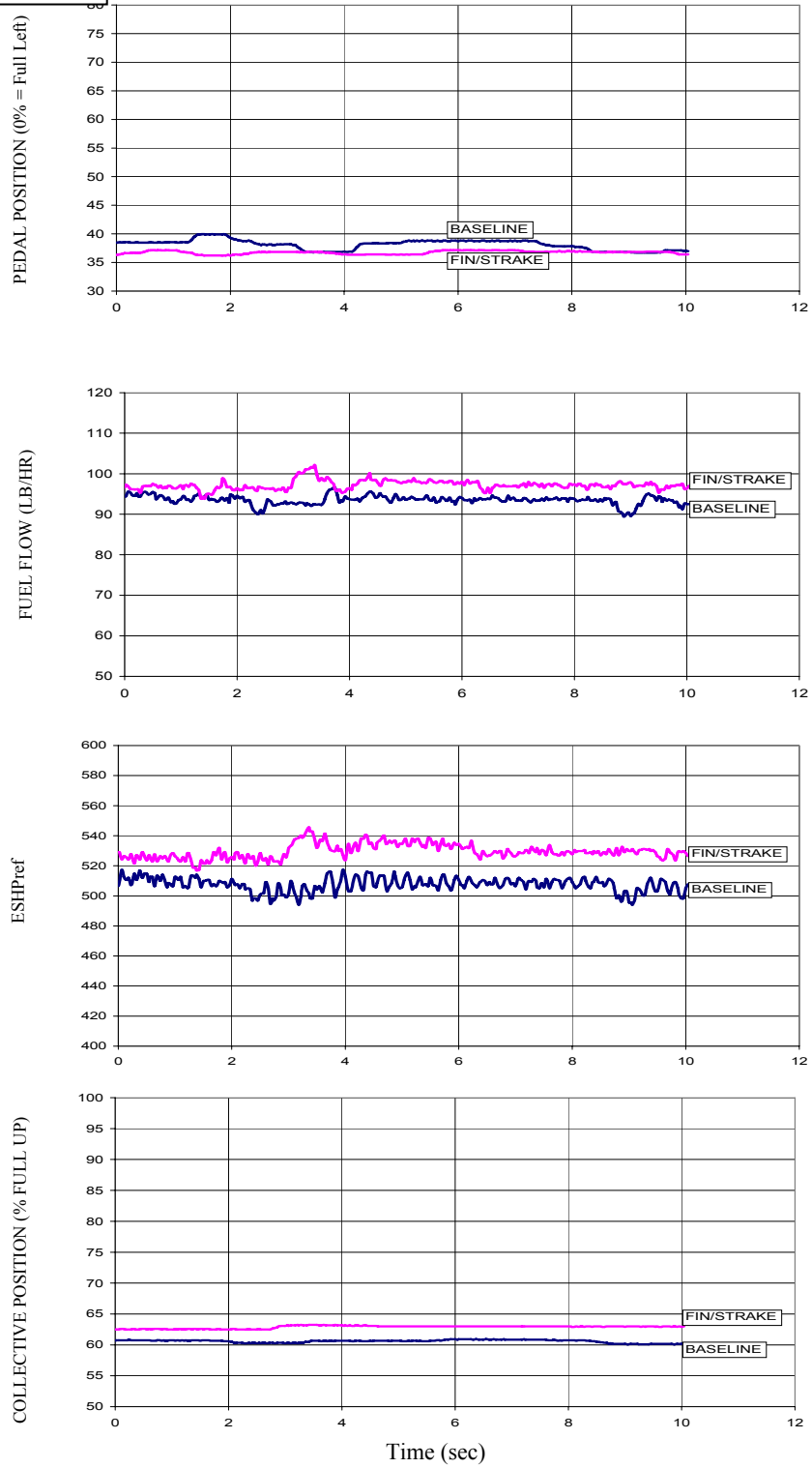
— BASELINE
— FIN/STRAKE



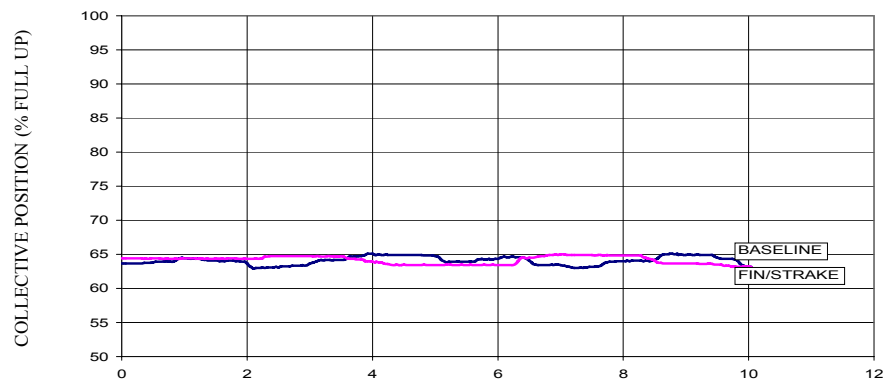
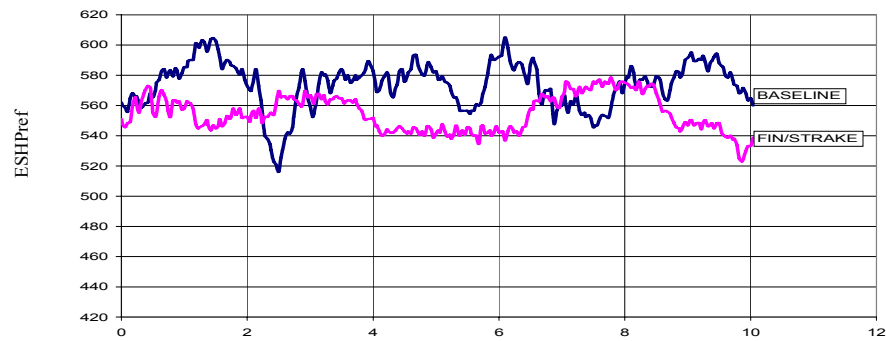
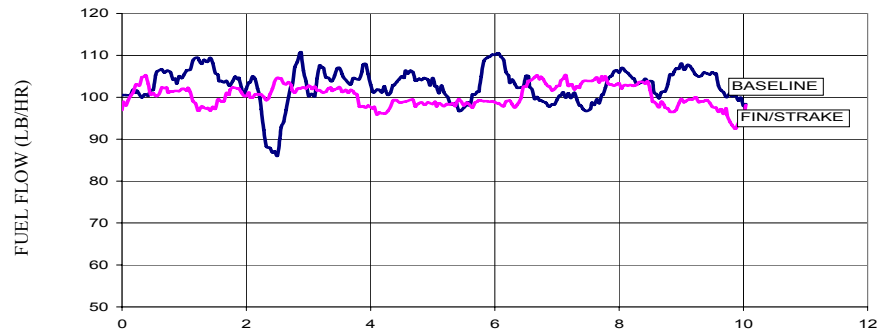
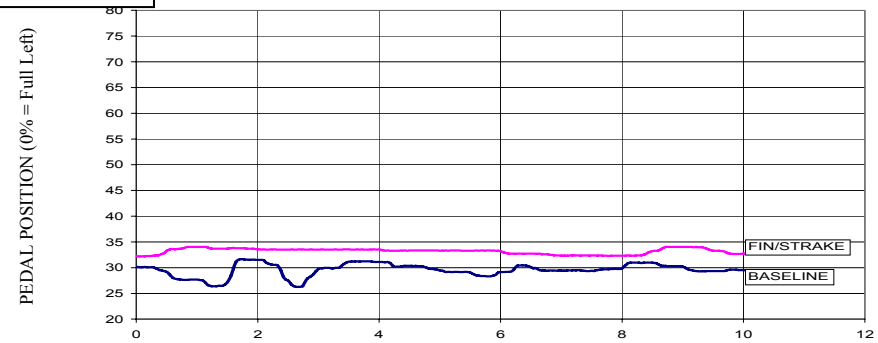
Time (sec)

RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
4762-4967	110.3in	1770-1960ft	17.5-19.5	396	23'	045 DEG	5
OH-58D USA S/N 96-00018							
Ambient wind <5kts							

— BASELINE
— FIN/STRAKE

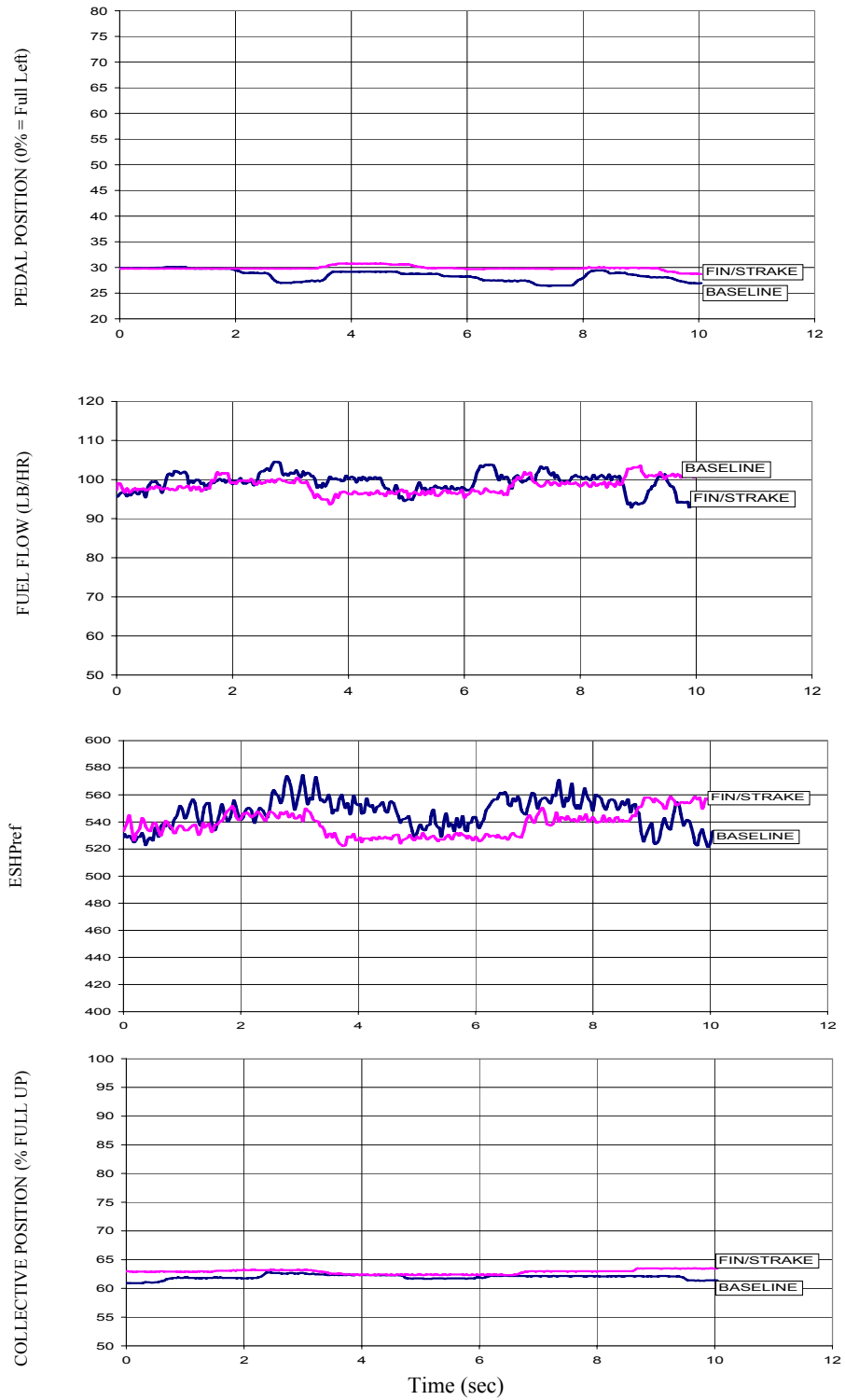


RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
5158-5159	110.3in	1770-1960ft	17.5-19.5	396	23'	045 DEG	10
BASELINE FIN/STRAKE OH-58D USA S/N 96-00018 Ambient wind <5kts							



Time (sec)

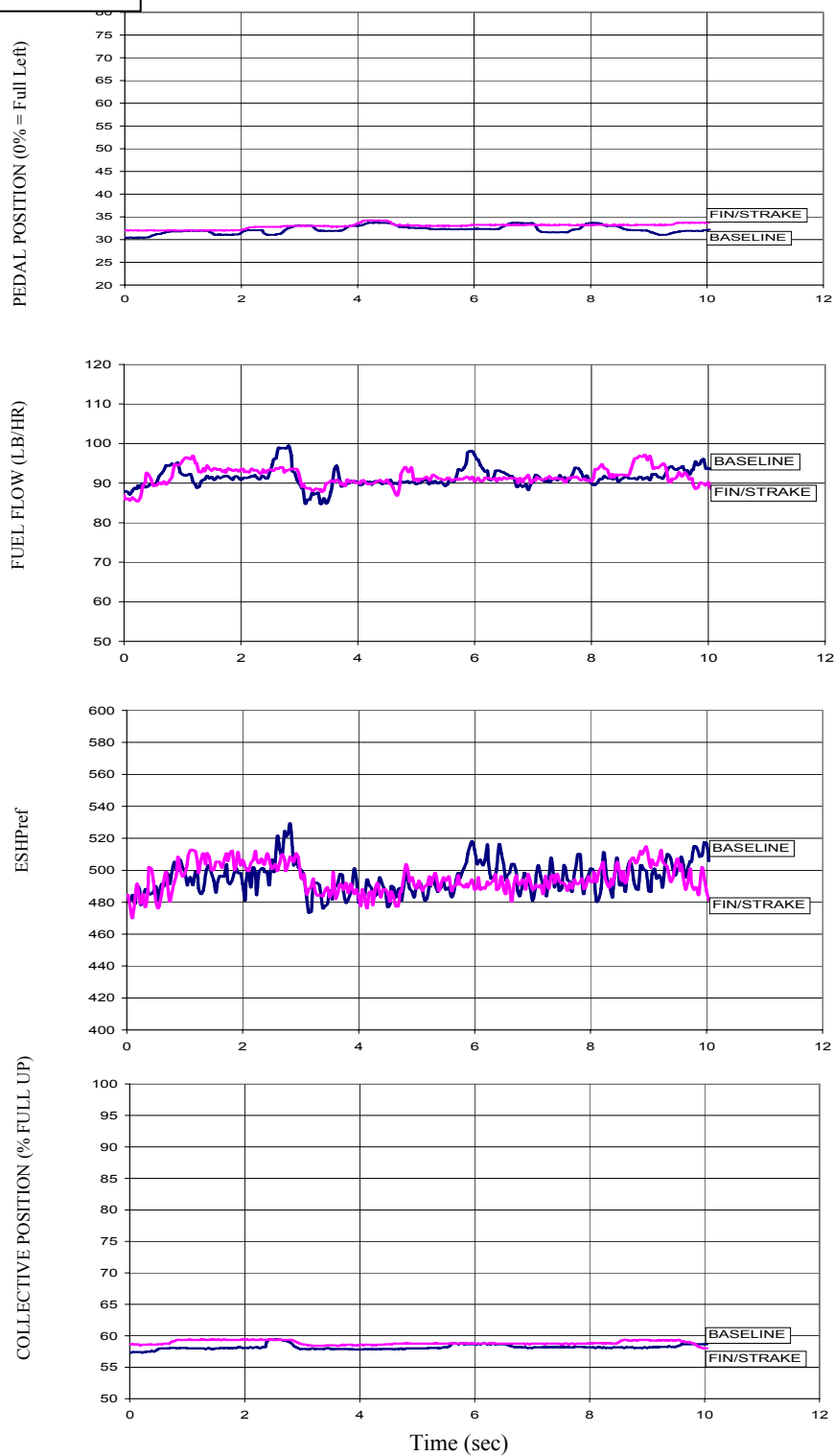
RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
5151-5153	110.3in	1770-1960ft	17.5-19.5	396	23'	045 DEG	15
BASELINE FIN/STRAKE OH-58D USA S/N 96-00018 Ambient wind <5kts							



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
5144-5148	110.3in	1770-1960ft	17.5-19.5	396	23'	045 DEG	20

OH-58D USA S/N 96-00018
 Ambient wind <5kts

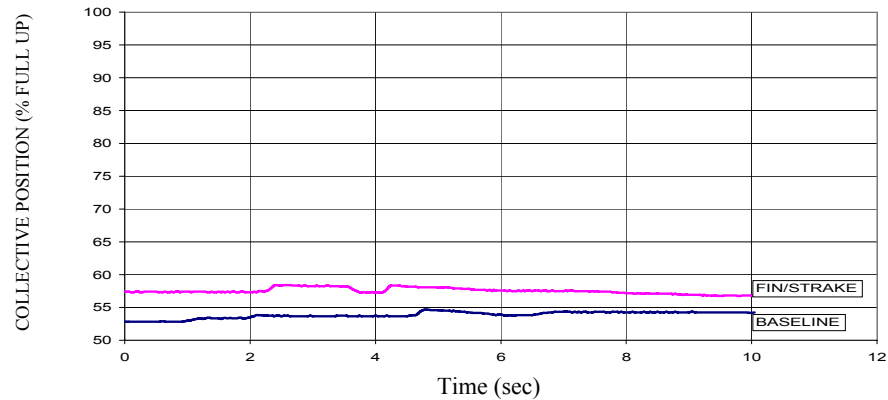
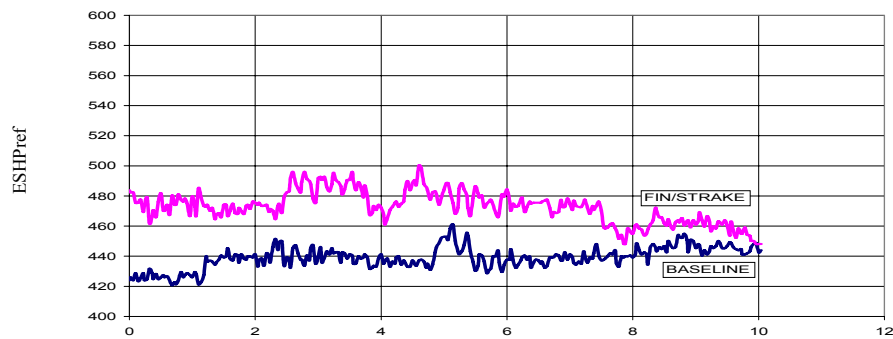
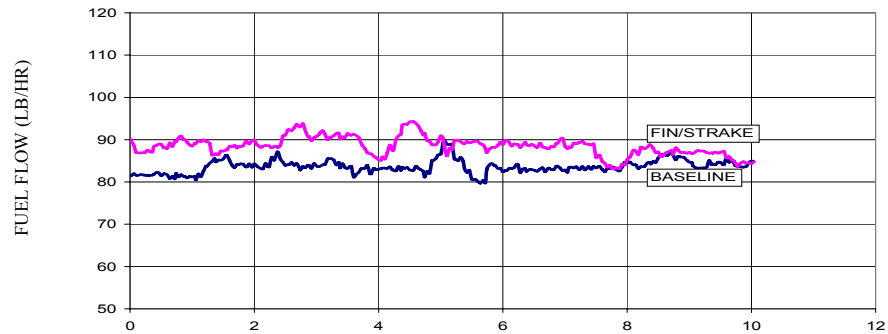
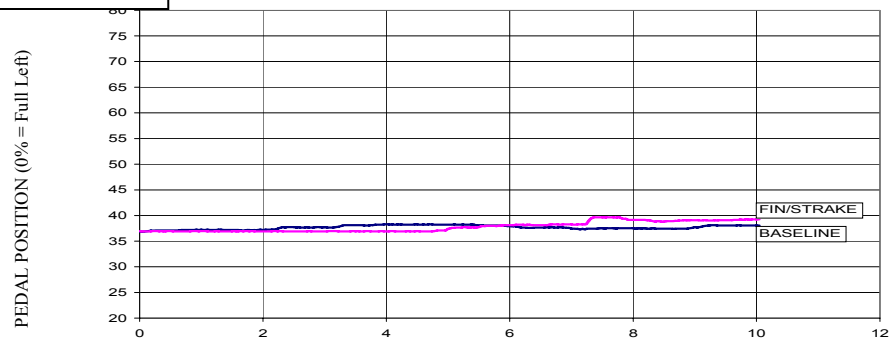
■ BASELINE
 ■ FIN/STRAKE



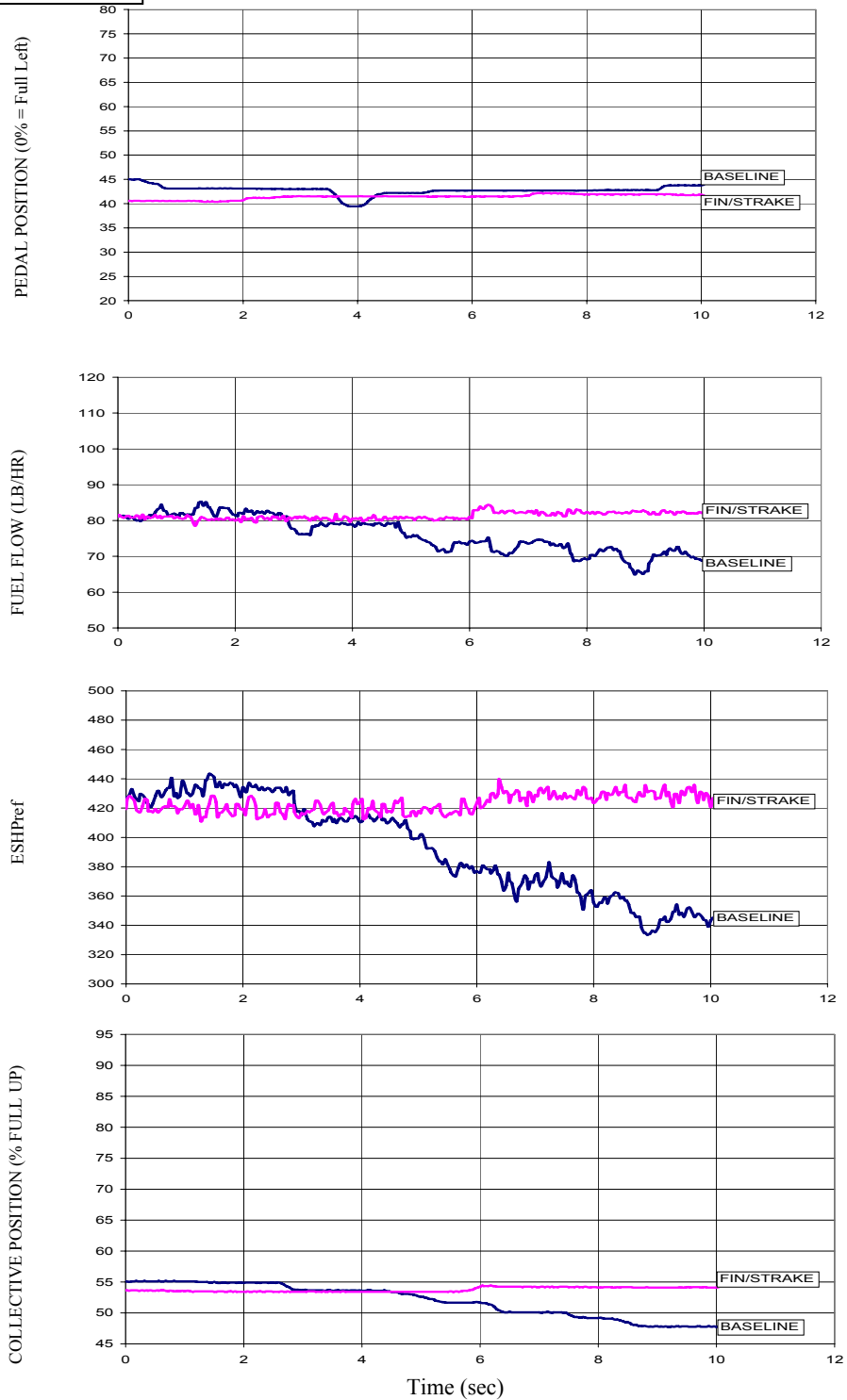
RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
5140-5143	110.3in	1770-1960ft	17.5-19.5	396	23'	045 DEG	25

OH-58D USA S/N 96-00018
 Ambient wind <5kts

■ BASELINE
 ■ FIN/STRAKE



RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	SKID HT	REL AZ.	KTAS
5129-5141	110.3in	1770-1960ft	17.5-19.5	396	23'	045 DEG	30
BASELINE FIN/STRAKE OH-58D USA S/N 96-00018 Ambient wind <5kts							



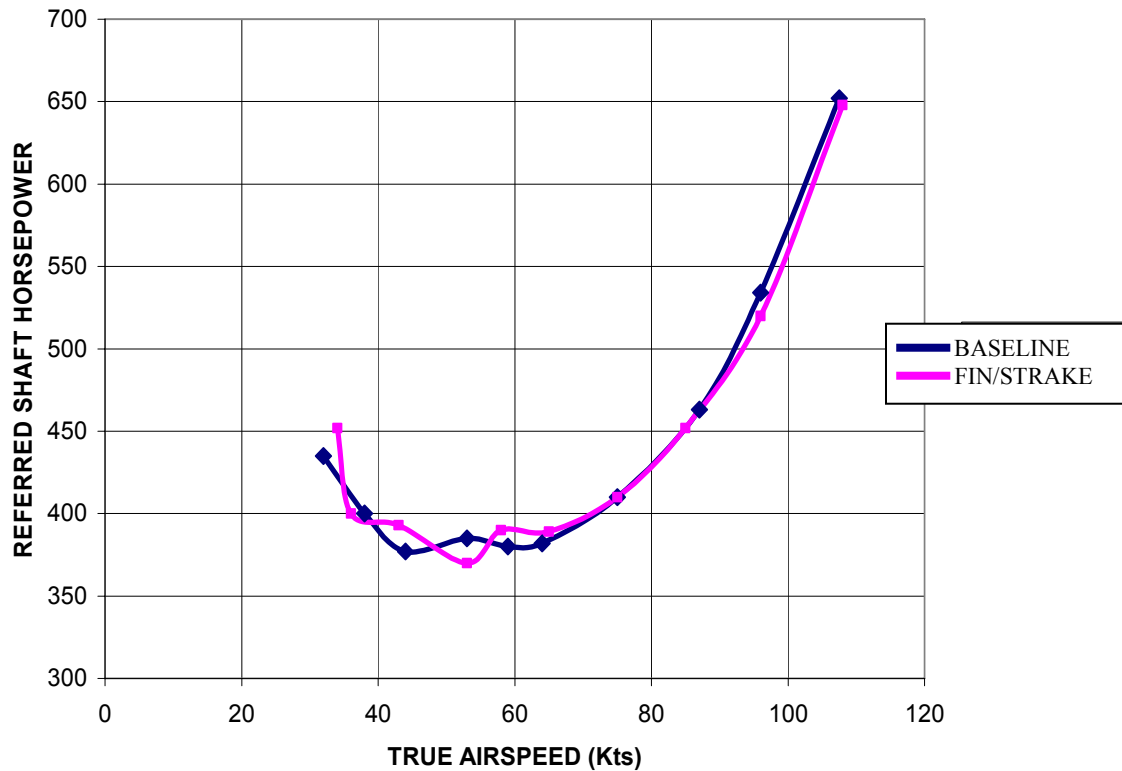
APPENDIX 2
Level Flight Performance Data

LEVEL FLIGHT

AVG:	GROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	Ct
Baseline	5180	110.2in	5160ft	16	396	0.005025
Fin/Strake	5140	109.9in	5410ft	17.5	396	0.005046

OH-58D USA S/N 96-00018

METHOD; W/ σ



APPENDIX 3

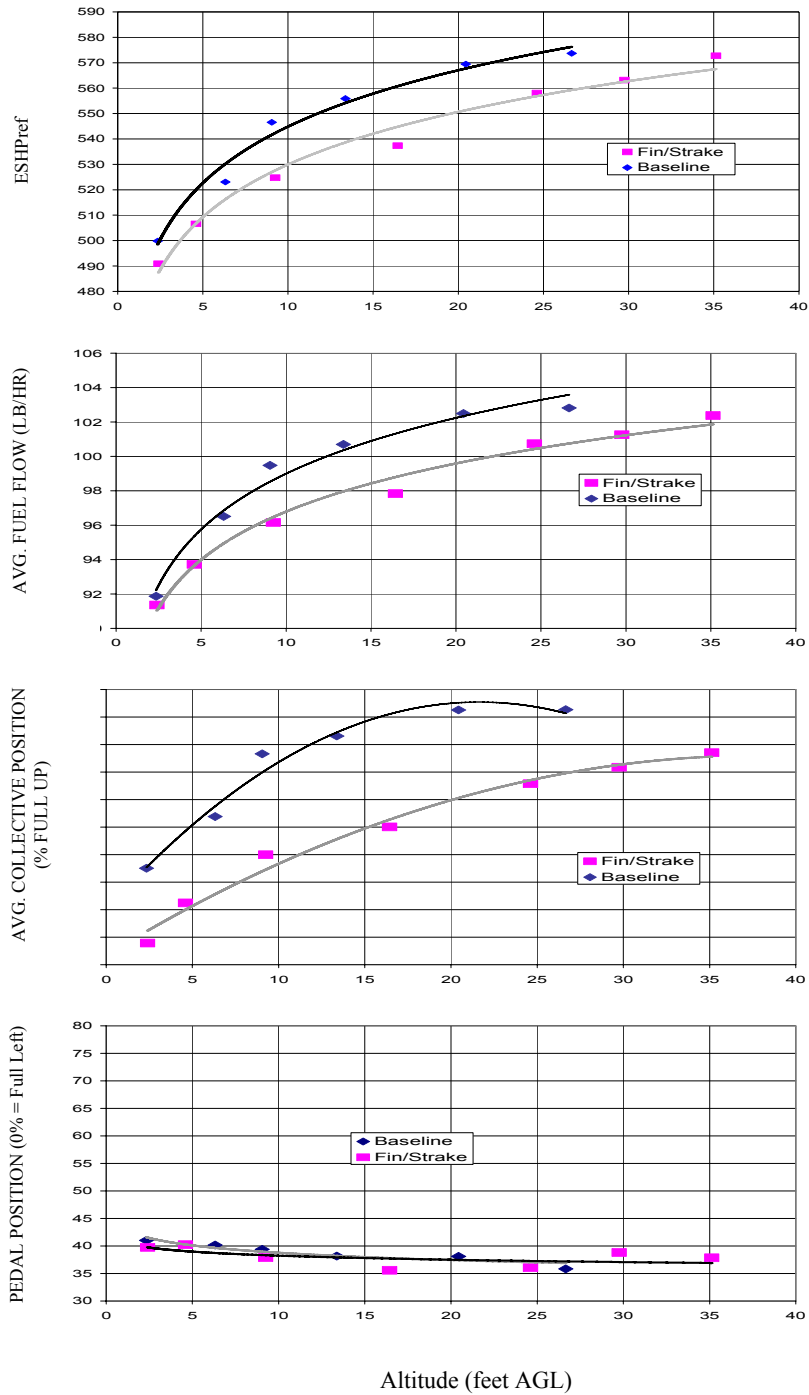
Hover Performance

HOVER PERFORMANCE

1) HOVER LADDER

AVG:	RefGROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	WIND SPEED
Baseline	5201-5225	110.4in	1785ft	19.0	396	1Kt
Fin/Strake	5201-5222	110.2in	1530ft	17.0	396	2Kt

OH-58D USA S/N 96-00018

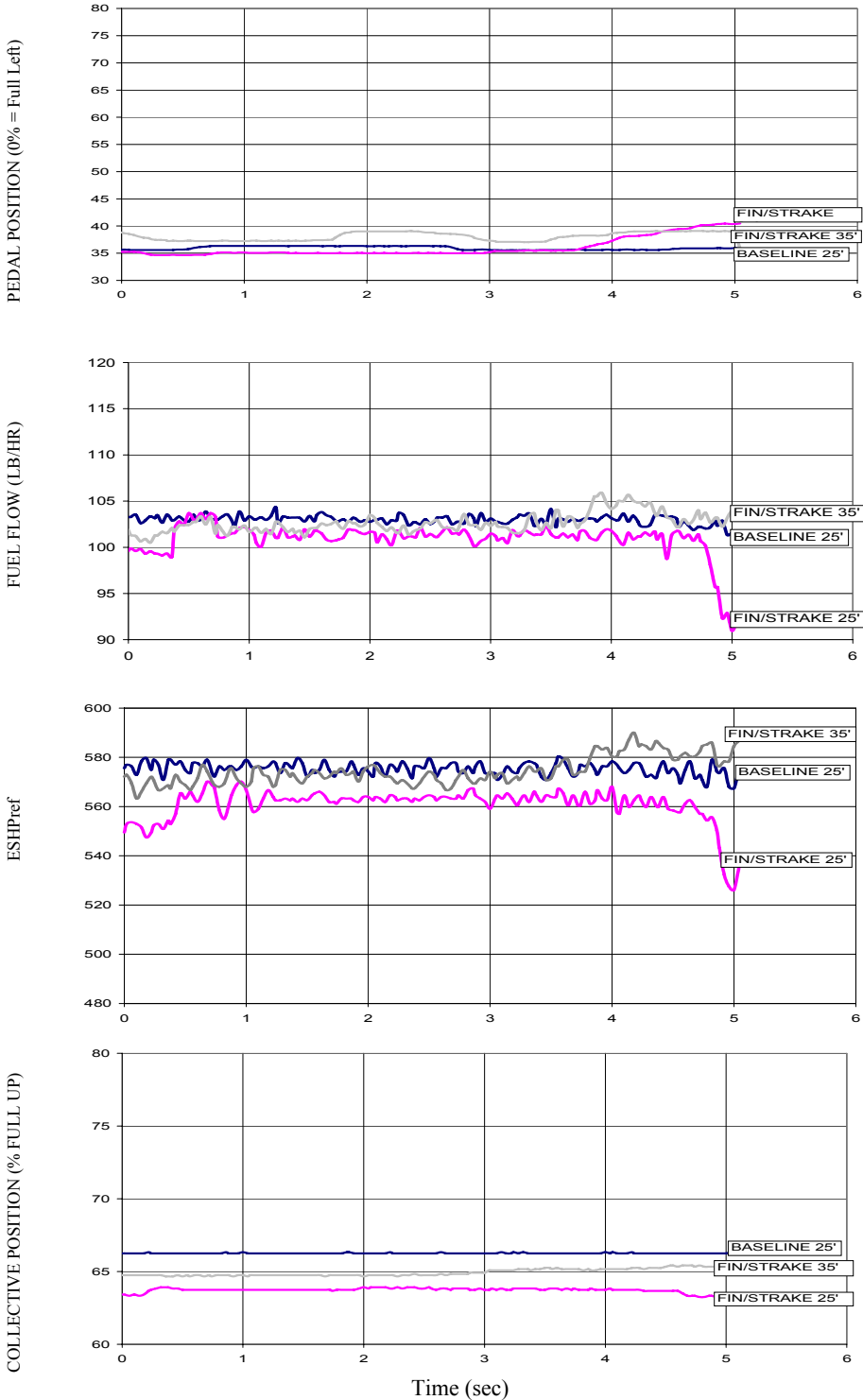


HOVER PERFORMANCE

2) OUT of GROUND EFFECT (OGE)

AVG:	Ref	GROSS WT (lb)	C.G	D.A.	OAT(°C)	ROTOR RPM	WIND SPEED
Baseline	5204	5210	110.4in	1785ft	19.0	396	1Kt
Fin/Strake	5203	5210	110.2in	1530ft	17.0	396	2Kt

OH-58D USA S/N 96-00018



VITA

John A. Wade was born in Harlow, Essex, England, and immigrated to the United States in 1978. He has been married to his wife, Carolyn for over 25 years. He has a B.S. in microbiology from Mary Washington University, Fredericksburg, Virginia, and a M.S. in Aeronautical Science from Embry-Riddle Aeronautical University, Daytona Beach, Florida. He served on active duty in the U.S. Army for 23 years and retired in 2005. Most of his active duty career was spent as a Standardization Instructor Pilot and Instrument Flight Examiner in the AH-1 Cobra and the AH-64 Apache. He was a commercial and military rated instructor pilot in both airplanes and helicopters with over 4700 flight hours. He served tours at Fort Detrick, Maryland, Mainz, Germany, Bahrain, Kuwait, Fort Campbell, Kentucky, and Fort Rucker, Alabama. John served at the U.S. Army Aviation Engineering Directorate as a Rotary-Wing Aeromechanics Analyst. He has flown 35 different types of rotary and fixed-wing aircraft. His aircraft qualifications included the TH-55, AH-1 Cobra, C-12 Huron, OH-6 Cayuse, OH-58 Kiowa, UH-1 Iroquois, UH-60 Blackhawk, and both the AH-64A Apache and AH-64D Longbow Apache. John Wade graduated with a Master of Science in Aviation Systems from the University of Tennessee, Knoxville, in May 2008.