To the Graduate Council:

I am submitting herewith a thesis written by Matthew P Mulnik entitled "Design of Alternative Flow Diverting Device Test Package for OH-58A Helicopters." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Fred Stellar, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and Dean of the Graduate School

Design of a Flow Diverting Device for OH-58A Helicopters

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Matthew P Mulnik

December 2000

DEDICATION

This thesis is dedicated to my best friend and wife,

whose love and support stretched the mıles

each day while I was ın Tennessee.

Thank you, Amber

ACKNOWLEDGEMENTS

I would lıke to thank all the members of the Aviation Systems and Flight Research Department for makıng my stay and educatıonal experıence especıally meanıngful I could not have completed this goal for my educatıon wıthout the efforts of my professors Fred Stellar, Bıll Lewis, Ralph Kimberlin, Peter Solıes, Frank Collıns, and Garry Coleman Each served a unıque part in my educatıon at UTSI. I would also like to thank Betsy Harbın, Gaıl Wells, and Mary Lo of the UTSI staff for their support in my educatıon and research work.

I would also lıke to thank my co-workers and fellow avıatıon enthusıasts for provıding a level of frıendship and sanıty My co-workers included Greg Heatherly, Mike Leigh, and Nate Callender Providing assistance on my thesis project ıncluded Kelly Mc Dougall, Alan Davıs, and Gene Hood.

ABSTRACT

The preliminary design of a flow diverter and flow visualization system was accomplished based on earlier water tunnel testing concluded in December 1997 at the University of Tennessee Space Institute. The purpose of this thesis was to demonstrate rapid prototyping of model test results The rapid prototyping included design, fabrication, and installation of an airworthy air flow diverting device for full scale helicopter flight evaluations The preliminary design was completed in effort to provide the US Army and civilian operators a low cost, effective production flow diverter for flights with the doors removed This device was tested on an OH-58A helicopter for handling qualities, level flight performance, fuselage airflow changes, and operational utility

Utilizing the systems engineering process to segment a large project into small, workable pieces, the design and fabrication of the flow diverter and flow visualization tools were completed in August 2000. The six and eight inch flow diverter of the sawtooth design and flat plate design with vortex generator tab patterns were successfully integrated and flight tested the same month of fabrication completion. The flow visualization system, consisting of a tuft screen, tuft measuring probe, and Smoke Generation System were used during flight operations to visualize the flow in and around the fuselage. Handheld video and still cameras were used to record flow data for aiding analysis

The integration and flight testing of the flow diverter and flow visualization system were successful spanning twelve days of flight testing, totaling 11 hours. None of

the installed equipment failed during the flight test program. The Smoke Generation System did not produce sufficient smoke volume to provide useful visual flow data for aiding flow analysis

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CHAPTER 1

INTRODUCTION

Background

As part of the continued efforts of the University of Tennessee Space Institute Flight Research Department the preliminary design of a flow diverter for the U S Army and civilian helicopter operators was completed based on earlier water tunnel testing conducted in 1997 by Eric Hicks [5] The flow diverter and flow visualization devices were completed concurrently with the flight test instrumentation design and installation of N88UT, a Bell OH-58A helicopter operated by the UTSI Flight Research Department To complete the preliminary design of the OH-58A flow diverter a systems engineering approach was utilized

In 1997 a study was completed by UTSI, recorded in reference [5], which assessed several flow diverting devices on the U.S Army MH-6H helicopter through water tunnel testing. The purpose of that earlier investigation was to reduce the airflow into the cabin and cockpit area when the aircraft was operated with the doors removed This configuration is necessary for Special Forces missions and desired for some civil helicopter operations Several combinations of front and rear door flow diverting devices were investigated, producing varying results The results of the water tunnel testing concluded a six-inch, saw tooth, flow diverter set at 40° altered the flow of air around the open cabin door area, to sufficiently reduce airflow into the aircraft

This full scale, flow diverter flight project utilized the University of Tennessee Space Institute's OH-58A helicopter N88UT instead of a military MH-6H (figure 1.1) to verify the earlier findings The reasons for using the UTSI OH-58A (figure 1 2) included

1. The aircraft was readily available and installed with calibrated instruments
2. The installation of prototype flow diverter on Public Category aircraft operated for aeronautical research streamlined the design approval process
3. Initial components could be fabricated utilizing readily available, spare OH-58A helicopters stored at UTSI Flight Research Hanger as templates
4 The helicopter is a good concept demonstrator

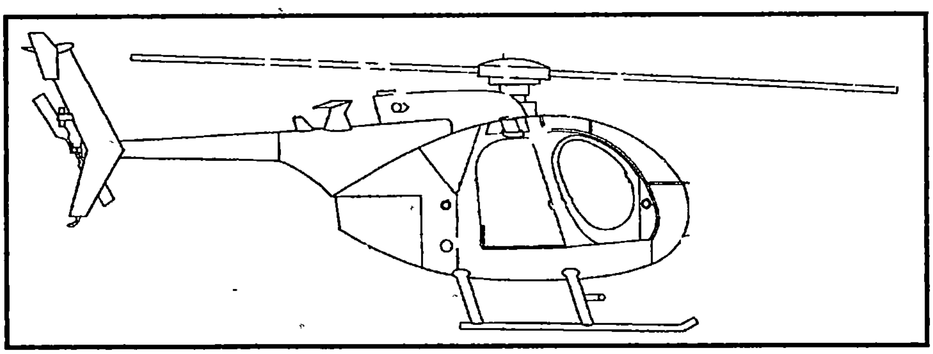

Figure 1.1: MH-6H

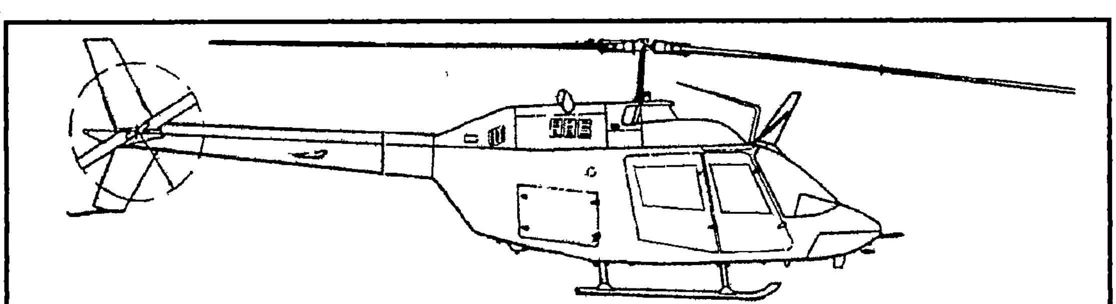

Figure 1.2: OH-58A

Theory

As a continuation of this earlier study a flow diverter for the OH-58A was conceptualized to validate the early water tunnel findings Prior testing attributed the change in airflow around the fuselage to the mixing of strong rotational flow created by the saw tooth vortex generator The diverter created a horizontal vortex at each tip, adding energy to the air surrounding the aircraft This additional energy allowed the flow to bypass the cockpit and passenger door area A conclusion was that the effectiveness of the flow diverting device was independent of the aircraft type Hicks' earlier study proved that a fluid mixing mechanism is necessary to add energy to the air. Flow diverting devices that did not utilize a means to excite the flow were unsuccessful These unsuccessful designs included flat plates and cylinders.

To validate the results of Hicks' earlier work, a base line diverting device needed to be constructed and test flown The six-inch, sawtooth diverter set at 40° was most effective in the water table tests, and therefore selected as the baseline design for flight testing

Only after the preliminary tests validated that the tail rotor authority remained unchanged and airflow was reduced through the cabin would other devices be test flown to determine a less intrusive and less hazardous device than the sawtooth edge

Purpose

Design, fabricate, and install an airworthy airflow diverting device for full scale helicopter flight evaluations.

OH-58A Test Aircraft Description

The OH-58A (figure 1.3) is a four place helicopter that is very popular in military and government agency for a variety of missions. The test helicopter was a single engine, high skid, light aircraft that was powered by an Allison 250-C20C turbine engine rated 319 shaft horsepower at sea level. The engine turns the main transmission that delivers power to the two-bladed main rotor and semi-rigid two-bladed tail rotor.

The airframe of the OH-58A used in this test was highly modified for data acquisition purposes. The only significant modifications to the exterior of N88UT were the addition of a pitot/static boom with sideslip indicator and the OAT probe. This boom was mounted into a recess located in place of the landing light retract bay on the nose of

Figure 1.3: N88UT in Baseline Configuration

the aircraft The boom extended ahead of the aircraft 5 ½ feet to record ambient air pressure independent of the pressure field surrounding the helicopter in flight

Helicopter interior modifications included flight test engineer control stations and displays for monitoring and recording 17 channels of data during flight tests Each crew position has a control and display to read parameters of flight. A forward control council, located on the center panel, and a rear station mounted between the rear seats control the system. The heart of the system is contained in the data acquisition package located in the baggage compartment of the helicopter. This data acquisition package housed all the gyros, accelerometers, daqbook, and pressure transducers and power supply. The information gathered by the data acquisition unit could be recorded and continuously displayed on a computer located in the helicopter cabin Data acquisition via the installed test equipment was not required to determine the flow diverter functionality. However, it was useful in collecting aircraft performance data.

The OH-58A, similar to the Bell 206 Jet Ranger series of aircraft, is a common aircraft design for police and news television use Operational requirements may require flying with the doors removed and a reduction in drag by utilizing flow diverters could be very beneficial for these civil applications Therefore a successful diverter device could have dual military and civilian uses.

CHAPTER 2

SYSTEMS ENGINEERING

Introduction

The systems engineering process is predominantly a problem solving activity in which a large system or concept is segmented into smaller, more manageable pieces through a means of functional decomposition This intellectual discipline is accomplished with the customer and final product or service in mind, beginning from the problem recognition and solution conceptualization to the inevitable retirement of the engineering solution [15] The customer's requirements are translated into specifications and objectives for the system, enabling a quality and affordable outcome to be produced that is effective and satisfies the customer's needs

Functional Decomposition

To break down a large system into smaller pieces a functional decomposition is used (figure 2.1) This requires the customer's requirements be analyzed to produce specifications and objectives for the design. These specifications largely determine system characteristics, and results in sub-system design characteristics To satisfy the prioritized requirements of the customer, different sub-systems are designed to support the engineering solutions, each related to the system through a series of interfaces All these sub-systems are smaller, more manageable pieces of the larger system Each level

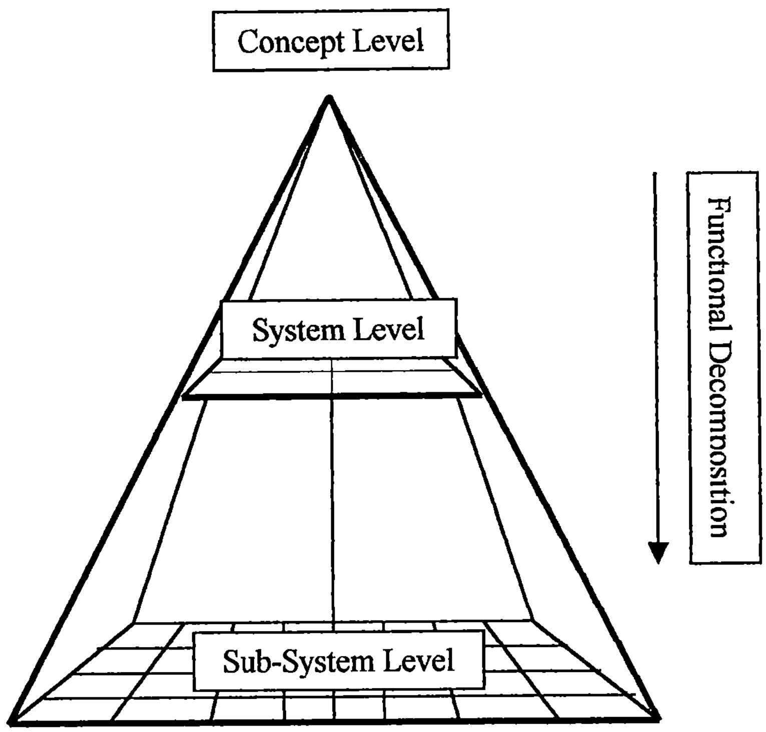

Figure 2 1 Functional Decomposition

in the design can be addressed individually Continuity of the design of the subsystems is achieved by tracking both interfaces and constraints of the system

Interfaces

Each level of the system must work together to accomplish what the system was set out to do To do this, the interfaces between each sub-system must be identified and appraised An effective way to discuss these interfaces is with the use of the SHEL model, as portrayed in figure 2 2

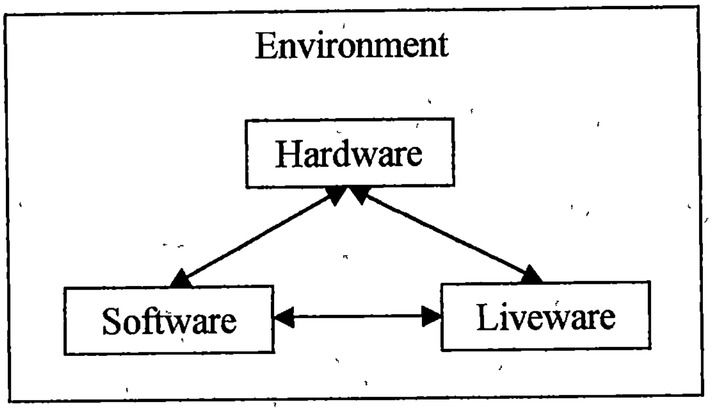

Figure 2.2. SHEL Model

The SHEL model is a concept of evaluating the interfaces between four main resources consisting of the Software (S), Hardware (H), Environment (E), and Liveware (L) in a system In the design and development of the full-scale flow diverters and flow visualization system all four of these resources and the interfaces between them were considered The system consisted of the aircraft (Hardware), Flow Diverters (Hardware), the airflow (Environment), the personnel (Liveware) on the external passenger system (EPS), and flight crew The system critical areas were identified to be the relationship between the aircraft and the Flow Diverters, representing the Hardware to Hardware (H-H) interface, between the aircrew and the Flow Diverters representing the Hardware to Live ware (L-H) interface, and the Flow Diverters and the airflow representing the Hardware to Environment (H-E) in the SHEL model [8]

Constraints

Constraints are those portions of the product development that are external to the system These include variables that originate with the customer or second parties such as the government, suppliers, and resource providers The two primary constraints of this system design were cost and scheduling Because no firm budget was established, the project costs were guided to a minimum. Every effort was made to utilize resources and materials readily available at the University of Tennessee Space Institute. Scheduling also played an important role in the development of the flow diverter Constraints in scheduling included test helicopter availability, academic schedules, and research projects competing for test helicopter resources.

Outside constraints included

- Technology
- Skills
- Costs
- Safety
- Reliability, Maintainability, and Availability
- Producability, Testability, and Supportability
- Human Engineering
- Time

Alternatives

At this point in the systems engineering process all the requirements have been gathered and an organized method of defining the system has been reached. Now, to determine the best course of action of each sub-system an organized means of decision-making was used such that the best system is designed with the customer in mind

This author chose to use the following method of solving design problems encountered during the development of the entire system.

- Define the need of the sub-system
- Identify the Objectives of the sub-system
- Generate possible Alternatives to accomplish need

- Analyze the alternatives through a systematic approach
- Select the Best Alternative
- Create the Best Alternative
- Integrate sub system into System Design

To analyze each alternative a structured, weighted table was configured as shown in table 2 1 This proved an objective means to evaluate alternative features and materials First, the evaluation traits are determined and weighted according to the most important criteria Next, alternatives are each evaluated individually by placing a (+) or (-) signifying the degree to which they possess that trait Undesirable traits are assigned negative weights. The alternative with the highest point total was selected for further development. In the case displayed in table 2 1, aluminum was chosen for the diverter material This same technique was used to select materials and features on the flow diverters and flow visualization system

Table 2 1 Weighted Table Used for Evaluating Alternatives (Diverter Material Table)

Diverter Material Selection					
Evaluation Traits	Wt	Alternatives under Evaluation			
		Aluminum	Fiberglass	Wood	Plexiglas
Availability	2	+	-	+	-
Cost	4	+	-	+	-
Strength	2	+	+	+	+
Tooling Req	4	+	-	+	-
Elasticity	3	+	-	-	+
Repairability	3	+	+	-	-
TOTAL	18	18	5	12	5

CHAPTER 3

FLOW DIVERTER

Requirements

Results of an investigation of a helicopter flow diverter through water tunnel testing were published in a UTSI Thesis entitled "Experimental Study of Alternative Flow Diverting Devices for the Modified MH-6J Helicopter " [5] The findings specified the flow diverter dimensions to achieve successful results To validate the findings, design and fabrication of the recommended flow diverter for a full-scale helicopter was required The basic diverter requirements to prove the principal of a full scale flow diverter were

- 6" Width with a 2" sawtooth
- Maintain a constant 40° angle between fuselage and diverter at 100 knots
- Provide a smooth transition to the sawtooth section not allowing air to flow between the diverter and aircraft
- Extend diverter above and below the front door jam

Desired design requirements to facilitate investigation and enhance safe operation included·

- Variable angle in 5° increments, from 30° to 55°
- Adjustable in flight (angle only)
- Smooth diverter surface to minimize parasite drag

- Variable width from 4" to 8"
- Transparent to minimize crew field of view restrictions
- Not block cockpit egress and ingress

Diverter Design

Several materials were considered for the construction of the flow diverters A matrix of desired characteristics was constructed to evaluate competing material choices (Table 2 3) Each material was evaluated against the characteristics of strength, cost, tooling required, and availability Each of these characteristics was weighted based upon priority of importance Of significant importance in this project was affordability The material evaluated included aluminum, fiberglass, plastics, and wood These materials were chosen because of the author's familiarity with working with these materials. Of these materials aluminum was selected as the best alternative Another material selection process was accomplished to address the need for preventing airflow between the diverter and the fuselage The material to transition from the windscreen to the diverter was selected to be plastic and duct tape The plastic, Plas-Tex® Poly-wall™ waterproof wall panel, was white with smooth and textured sides. Its uniform thickness was .060 inch Special removable duct tape, white in color, was selected such that minimum residue would remain on the fuselage after removing the prototype system from the aircraft This tape has a special UV light barrier that minimizes adhesive breakdown. Adhesive breakdown is the primary cause for surface contamination and destruction

The attachment interface was then evaluated Because the helicopter operations were to be conducted with the doors removed the original door hinge pin mounting holes were selected as a mounting point for the diverters This location provided a positive means of securing the diverter without making permanent changes to the airframe such as drilling and adding new fastener locations.

Design and fabrication of the diverters took place utilizing a spare OH-58 helicopter to prevent cosmetic damage on the test helicopter. Original design ideas included complex arrangements to maintain and vary the angle of the diverters, yet maintain structural integrity The lack of support structure in the front door jam area needed to be overcome by a frame or base for mounting the diverter. A 5-inch wide, 063-thickness base plate was rolled to fit the side of the slightly convex fuselage of the OH-58. The base plate was secured to the fuselage by two AN 3-17A bolts with locking hardware by utilizing a spare door hinge pin and brackets riveted to the base plate. This arrangement provided a secure point to build a variable angle diverter without compromising the structure of the helicopter for this test installation. This base plate was further reinforced against movement through five braces on the rear of the plate, which applied pressure to the door jam The entire rear of the base plate was covered with ¼" thick neoprene material to protect the rivets and fuselage paint from rubbing Also, this base plate added further protection to crew members from the protruding sawtooth edge. The pilot would contact the blunt base plate during ingress and egress, instead of the sharp sawtooth Pictures of the diverters and test components can be found in Appendix A, Figures A 1-A 4

Because two different types of diverters were to be tested, a base plate and support structure were developed such that a thinner, geometrically complex diverter could be added. The structure included the base plate, a twenty-inch piano hinge and heavy rolled plate with adjustment mechanisms The piano hinge allowed the diverter support plate to be changed in angle. A series of five slides with locking hardware held a given angle of deflection in place Precut wooden wedges were used to set the deflection angle. These wedges were cut at 30°, 35°, 40°, and 45° to aid in setting the angle of deflection on the flow diverter Adjustments to the diverter were made on the ground with 90° screwdriver and 3/8" socket ratchet The time required to adjust both diverters to a given angle was approximately seven minutes The support structure was adjustable to angles between 37° and 57°

Sawtooth Section

The exact geometry specified by the Hick's results was maintained in design of the full scale sawtooth diverter The diverter was cut from 032 2024 aluminum in a shape to best fit the contour of the fuselage. Cardboard and paper templates were used to layout the first diverter on the aluminum sheet. All diverter sections were cut by hand using tin snips because of the size of each piece was too large for available tooling. The diverter sections are shown in figure 3.1 The geometry of the sawtooth section is displayed in figure 3.2.

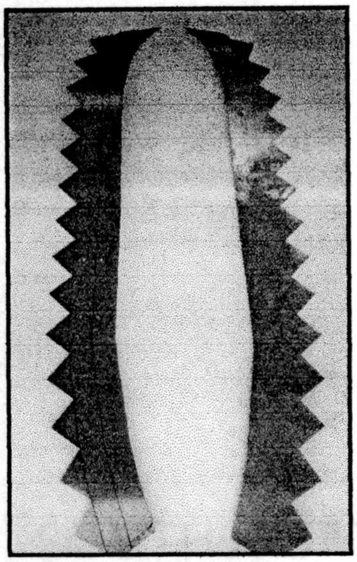

Figure 3.1: Sawtooth Section

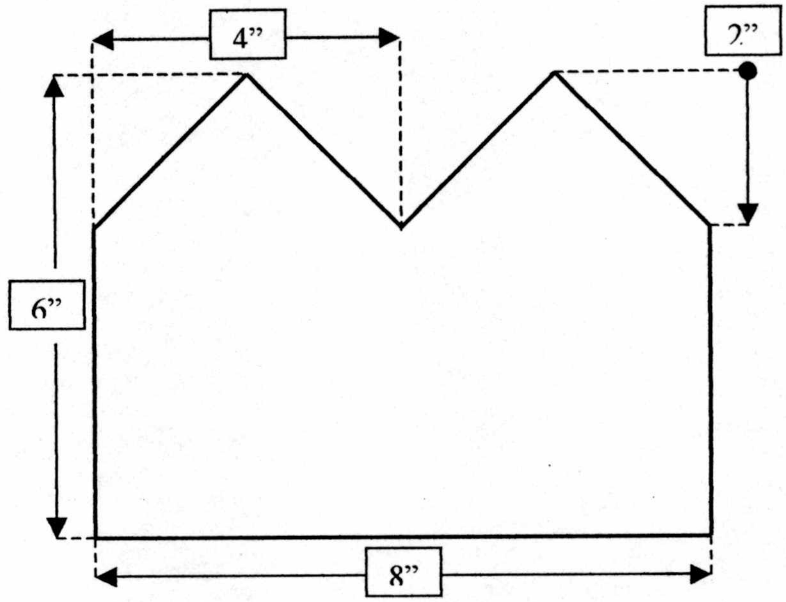

Figure 3.2: Sawtooth Geometry

Each sawtooth tip was six inches from the leading edge. The depth of each sawtooth was two-inches as shown above. Great care was taken to assure the geometry of the saw tooth and the lengths of the diverters were symmetrical. Because the fuselage contours of both sides of the aircraft were identical both sawtooth sections were fabricated from a single template that reversed for the opposite side.

This section was then temporarily attached to the support structure installed on the helicopter to assure a proper fit. Holes were marked for the fifteen 8-12 machine screws that would attach the thin aluminum diverter to the support structure. The smooth plastic was then cut to an exact fit and placed over the aluminum diverter. Figure 3.3 illustrates the overlay of materials on the diverter as viewed from above.

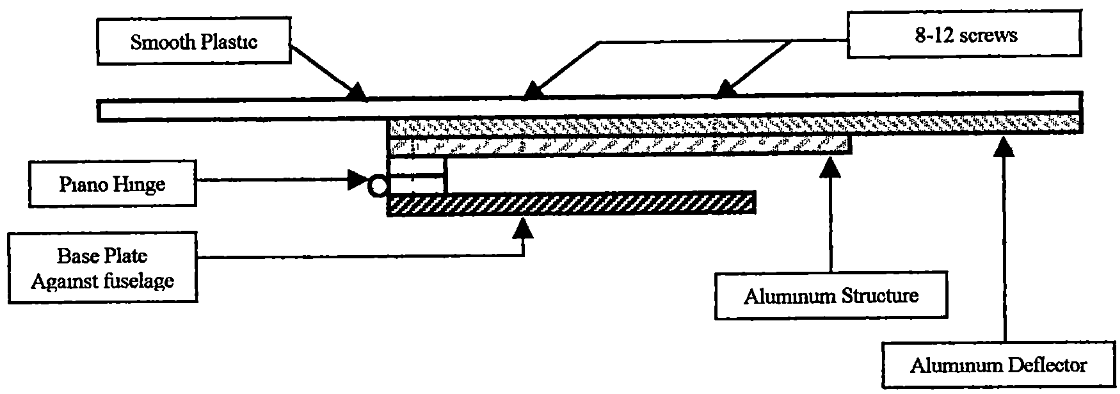

Figure 3.3: Cross-cut View of Diverter

Modified Section

A modified diverter section was designed and fabricated utilizing vortex generator tabs similar to those used on the upper surface of airplane wings The tabs were made of 016 inch aluminum with geometry consistent with those used on airplane wings Average vortex generators measure one inch in length and vary in height from ¼" to ½." For this experiment a one inch long, 3/8 inch high vortex generator was used (figure 3.4) The thinner 016 thickness aluminum was utilized for fabrication of the tabs because its superior elasticity and memory

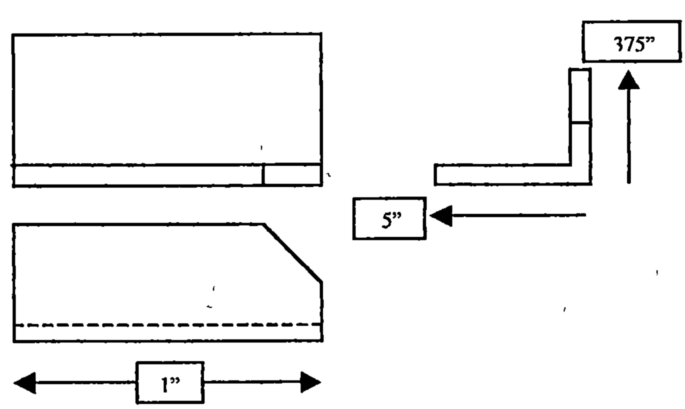

Figure 3 4· Vortex Generator Tab Geometry

The angle of attack of the vortex generator tab is important in producing a strong vortex. This was accomplished on the initial flight with the sawtooth diverter installed by recording the position of tufts on the windscreen. Based upon the observed airflow along the windscreen, the vortex generators were attached to the modified diverter at an angle of attack of 16° [13]. The vortex generators were adhered to the six inch diverter with 3M Weatherstrip Adhesive (figure 3.5). Other adhesives were tested, including super glue, silicone, and caulk, but the 3M exhibited superior qualities and bonding as established by destructively testing a sample section.

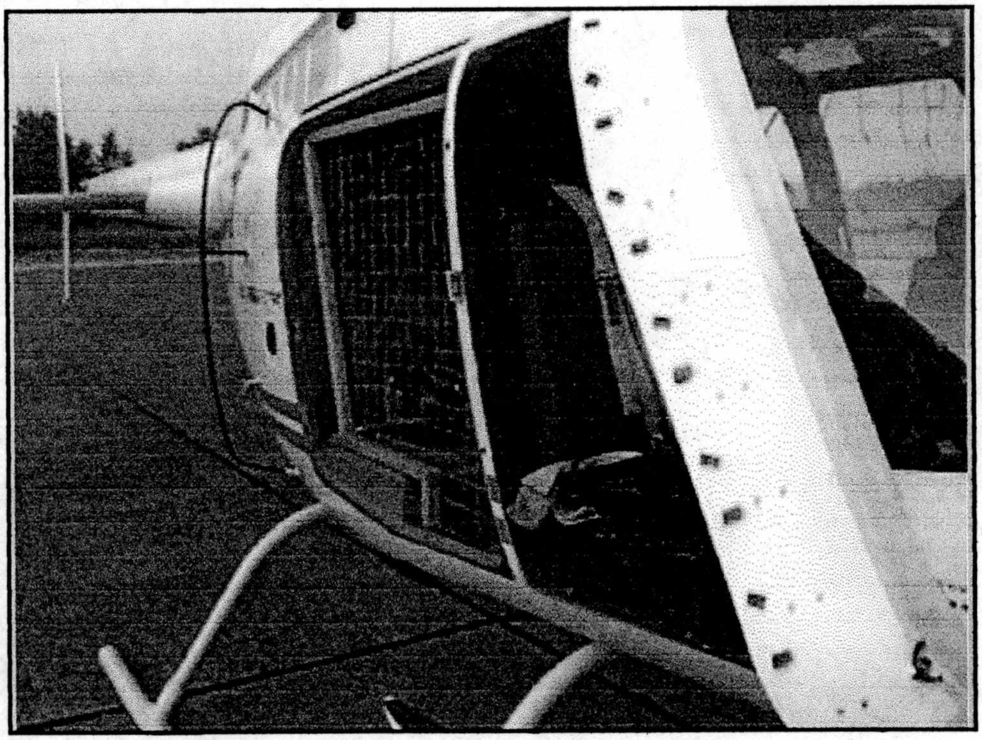

Figure 3.5: 6 Inch Flat Plate Diverter with Vortex Generator

Eight Inch Sections

To satisfy the desired requirement of variable width flow diverters an additional two inches was added to the leading edge of the sawtooth and modified section templates, giving a total width of eight inches (figure 3.6). These wider sections were cut and attached in the same manner as the smaller, six inch sections.

Safety Considerations

The sawtooth configuration posed obvious risks to operators during ingress and egress to the cockpit. To limit the risk of injury the sawtooth section was only installed

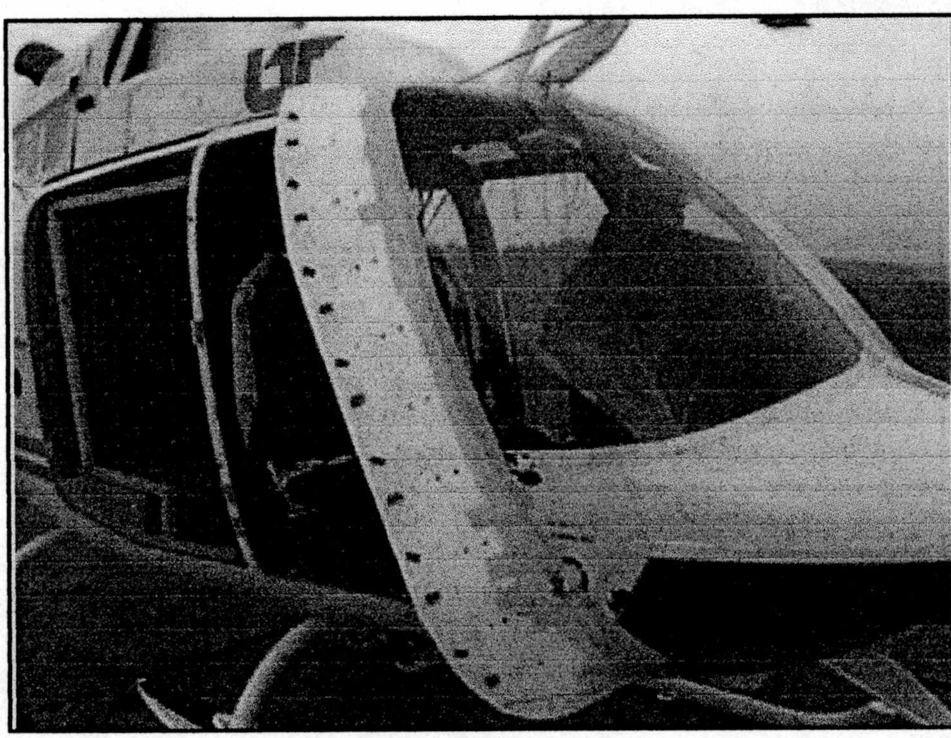

Figure 3.6: Eight Inch Flat Plate Diverter with Vortex Generators

on the aircraft during the period of flight testing. In addition, split pipe foam insulation was used to cover the sawtooth during maintenance in the UTSI Flight Research Hanger

With the diverter installed pilot ingress/egress area was decreased by 40 square inches (5%). Adequate ingress/egress was demonstrated prior to the first flight Although the original jettison hinge pins were utilized for the positive mounting of the diverters, the amount of duct tape used for a smooth flow of air to the vortex generator made it extremely difficult for the diverter to be jettisoned Additionally, to eliminate the possibility of the pilot and co-pilot accidentally pulling the jettison handle releasing the diverter hinge pins, the handle was safety wired using stainless steel 020 safety wire.

Additional pictures of the diverter attachment and installation can be found in Appendix A, figures A.5-A 10.

CHAPTER 4

FLOW VISUALIZATION

Need

To validate the change in airflow in and around the fuselage the use of flow visualization tools were required. The flow visualization system required a reliable indicator of flow into and around the cabin area in a manner that was repeatable for each test and was durable for the duration of the testing The flow visualization system required the capability of providing air flow data with the diverters installed and uninstalled.

Tuft Screen

The tuft screen was an inexpensive, yet effective way of visualizing the flow in enclosed spaces where a grid could be properly secured. Tuft screens have been successfully used in wind tunnels for many years (figure 4.1) The photo below shows the vortices created by a delta wing at various angles of attack. This same concept was implemented for helicopter in-flight flow visualization

To give a visual indication of the location where air was entering the rear cabin area a tuft screen was constructed to fit within the right rear door area, viewable to both flight test engineer positions on the left side of the aircraft (figure 4.2). The wooden tuft screen was constructed of pine 2” X 2” which was both light weight and durable The grid of nylon, tightly woven cord of 60-pound test was inside of the frame creating 2 ½ inch openings. To each intersection a tuft, 2 ¼ inches long was attached by a knot and

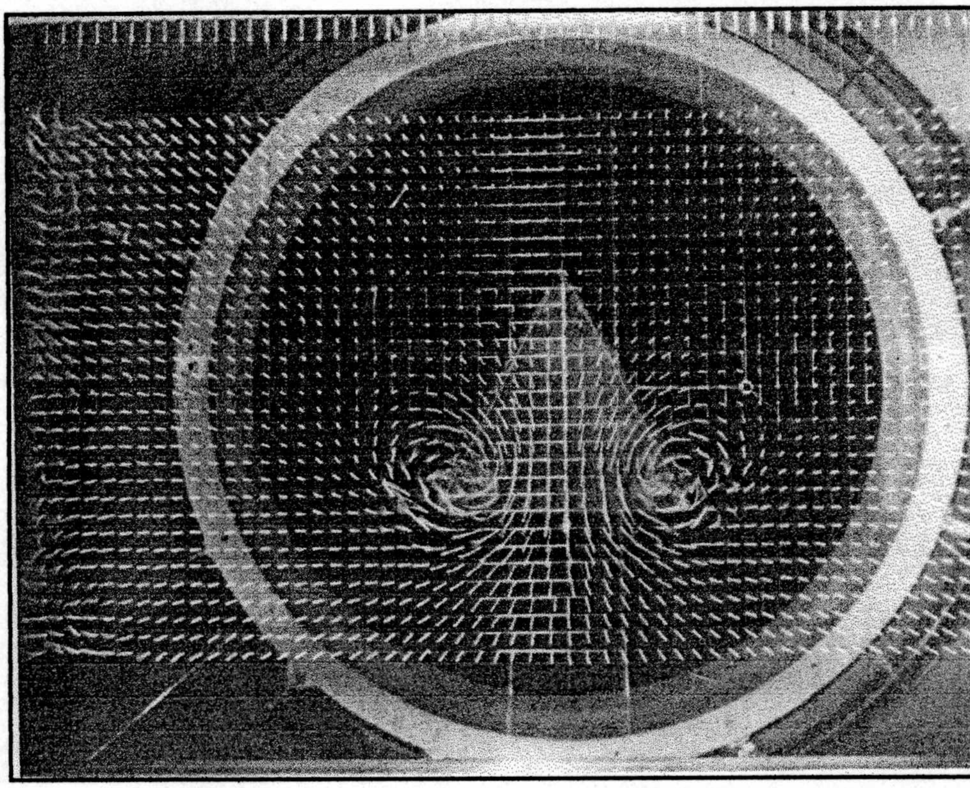

Figure 4.1: A Tuft Screen in Use at NASA [4]

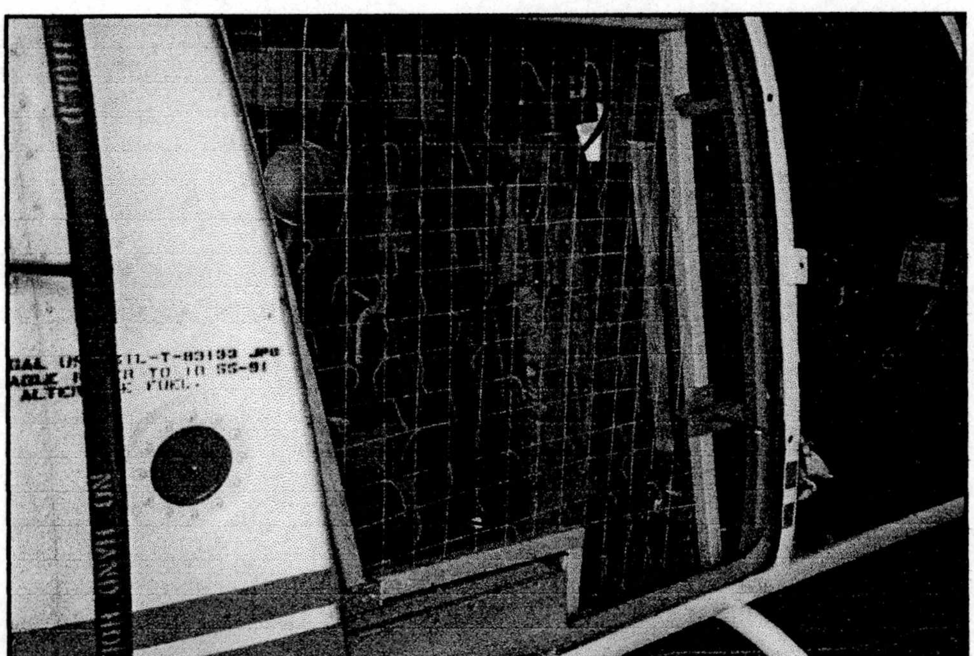

Figure 4.2: Tuft Screen Installed on N88UT

small dot of glue. The glue ensured the tuft would not untie at the grid. Orange yarn was selected for the tuft screen because it could be viewed against a variety of background colors expected in flight. Each tuft was also tied at the end with a simple overhand knot to keep the tuft from unraveling and to stabilize the tuft during flight.

The tuft screen was secured to the inside of the rear cabin opening by four brackets rigidly mounted to existing fasteners on the inside of the aircraft. Each bracket was attached to the tuft screen with an AN4 bolt. The brackets used for mounting the tuft screen are shown in Figure 4.3. Figure A.11 in Appendix A shows the unfinished tuft screen.

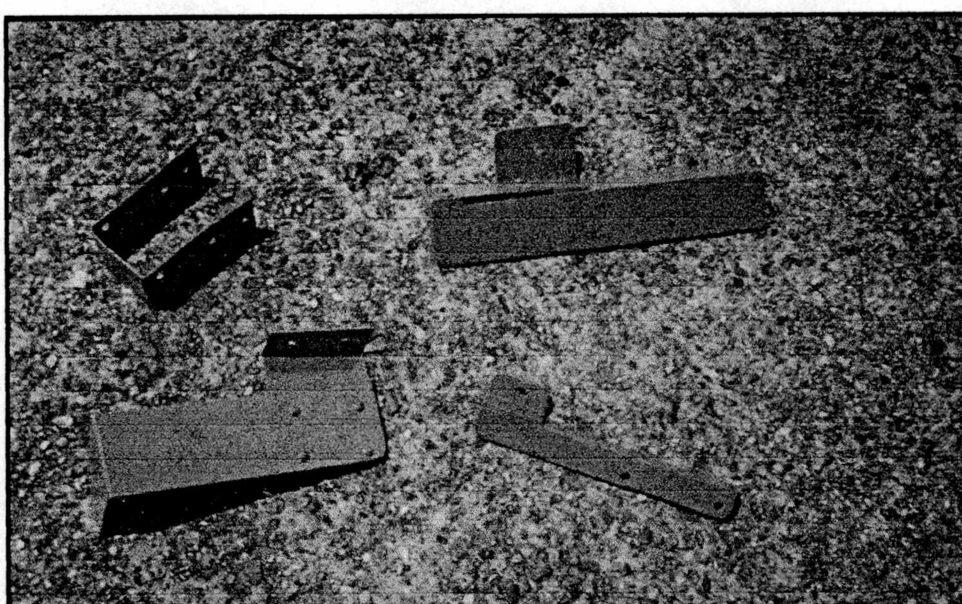

Figure 4.3: Brackets for Tuft Screen Installation

Airflow Probe

To assess the distance that the flow was diverted outward from the fuselage a fixed point of measurement was needed such that accurate, reliable, and repeatable data could be gathered. A point from which to make these measurements was located at the rear doorpost on the right side of the fuselage. This location was chosen because it best represented an operationally significant position midway on the fuselage where diverting the airflow was desired. The measurement probe consisted of two parts; a bracket and measuring probe (figure 4.4). The bracket, also used as a tuft screen brace, was attached to the right lower hinge pin cover by two No. 8 screws.

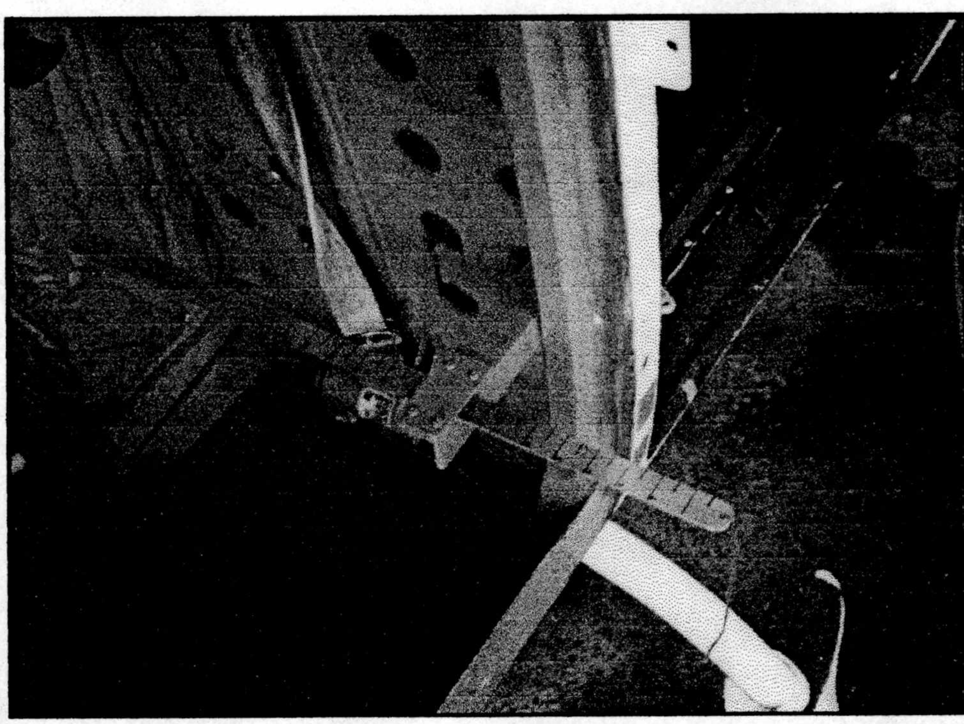

Figure 4.4: Airflow Probe

The bracket consisted of a 1 ¼ inch aluminum "L" channel on which an opening for the sliding rule could be fitted Through the one inch opening the measuring probe could be slid into the slipstream for measuring distances the airflow was diverted from the fuselage. The measuring probe was marked with ½ inch increments, zero being the hole in which the six inch tuft was tied. The measuring probe handle was bent 90 degrees to ensure it would not slide completely out of the bracket inadvertently.

Flow observations were obtained by pushing the end of the probe that extended into the cabin. By pushing the tuft into the slipstream at mid-fuselage a measurement was taken in inches from the bracket and indexed measuring probe This provided a reliable, repeatable, and accurate measurement of the boundary of the diverted flow at mid-fuselage

Smoke Generation

For complete flow visualization of the effects of the flow diverter, insertion of smoke was incorporated into the design Little documentation was available regarding previous full scale, in-flight flow visualization testing. Past work to visualize the flow around aircraft in flight had been successfully completed by NASA during the studies of the F/A-18 at high angle of attack (figure A.12). Smoke, produced by a smoke generation device fabricated by NASA, was exhausted out of tubing in a specific location to allow a chase aircraft to record the vortices formed by the fuselage (figure 4.5) Complete accounts and results of these tests can be found in references 3 and 12

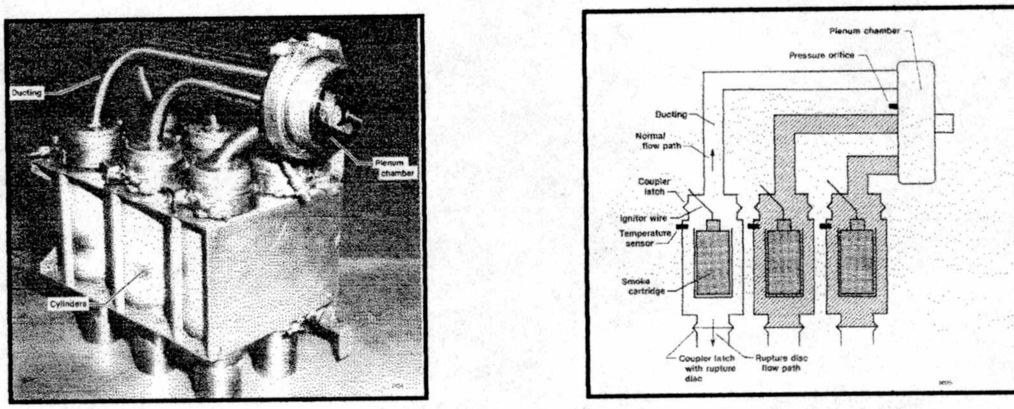

Figure 4.5: NASA Smoke Generator for F-18 Flight Testing [12]

The smoke generation device fabricated for this test used standard M-18 hand smoke grenades (figure 4.6). The smoke is commonly used for signaling or marking a target or landing zone. The smoke is available in red, green, yellow, and violet colors. The thin steel canister is filled with 11.5 ounces of colored smoke mixture with approximately one minute of burn time. The entire grenade, including fuse weighed 19 ounces. Smoke was emitted out a ½ inch hole in the bottom of the grenade. The hole was covered with tape for storage and was removed for this test. Violet colored smoke was toxic and therefore not considered in the design for safety reasons.

A preliminary Smoke Generation System (SGS) was fabricated and tested during an investigation of low-velocity airflow in and around a passenger car with the front window rolled down (figure A.13). The SGS consisted of a flat round plate with a ¾ inch hole cut in the center. To the flat plate, above the hole a flexible conduit tube of 14 inches was welded. A smoke canister was held firmly against the plate by small clasps and long bolts through the flat, round plate. The can was then fastened securely with wing nuts. The device was mounted on the front of the automobile and a rubber

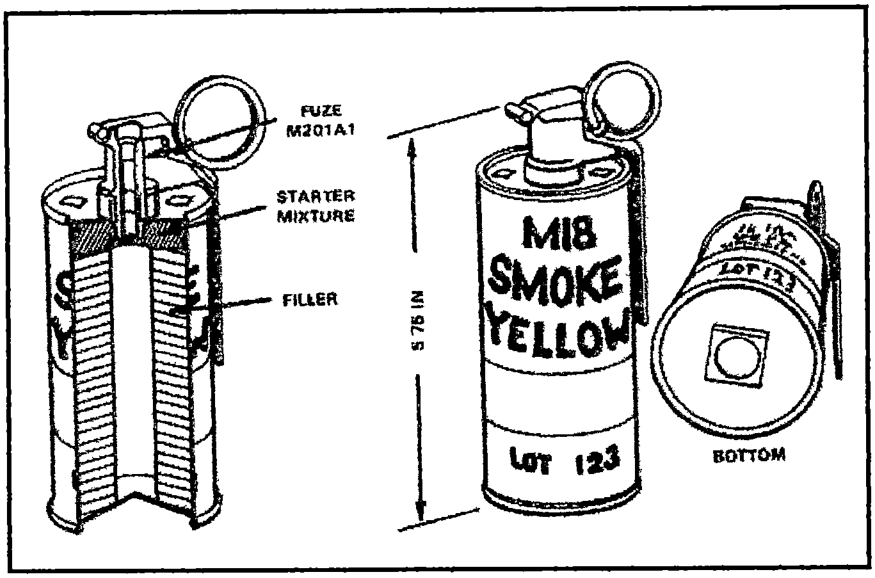

Figure 4 6 M18 Smoke Grenade [13]

tube was attached to the flexible conduit to route the smoke to the discharge location The SGS was tested during a ground run on an abandoned airstrip at 35 MPH Smoke did discharge from the end of the rubber hose, but the hose was quickly burned due to the heat generated during smoke burn Smoke inhalation by the crew occupying the car caused eye and throat irritation. Minor discoloration of the paint at the exit of the flexible conduit occurred and could not be cleaned All other residue was removed with soap and water Because the passenger compartment of the automobile quickly filled with smoke, flow visualization was ineffective and could not be recorded by the chase vehicle because of a lack of background

The SGS designed for use on the test helicopter incorporated the lessons learned from the automobile testing. Only metal and heat resistant components were used. The SGS was designed with four major parts housing and manifold, tubing, and co-pilot control The housing for two smoke grenades was machined from a single piece of aluminum. Two 3/8 inch deep recesses firmly held the smoke grenades from sliding within the device. The canisters were held firmly against the aluminum plate by a rear plate and six threaded rods utilizing nylon nut locking hardware. Two stainless steel AN819 No 6 fittings were tapped into the aluminum block such that the copper "Y" manifold assembly could be attached with flared fittings. The "Y" manifold assembly was brazed together with ½" tubing leading to a single ¾" portion. To this 4" section of larger tubing a brass coupling was used such that the length of bendable copper tubing leading to the desired location in front of the flow diverter could be removed as a separate section. A break down of the housing and manifold is shown in figure 4.7.

Mounting location alternatives considered were the lower wire striker, boom, and the landing skid. The skid was chosen because of its relative distance from the pilot and the fuselage, the simplicity of a control device, and the location did not obstruct the

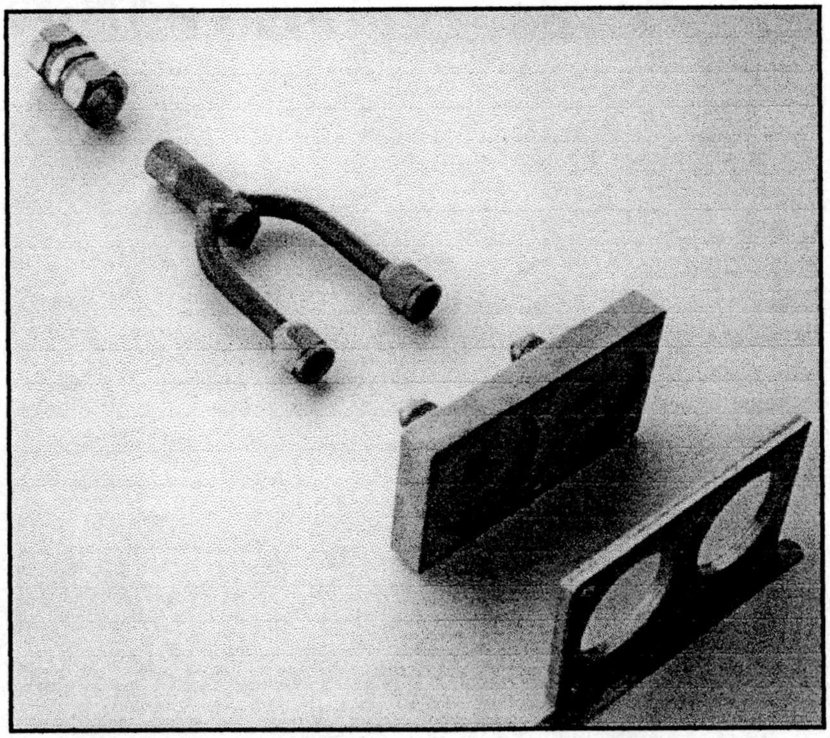

Figure 4.7: SGS Housing and Manifold

pilot's field of view (figure 4.8). Security of the long tubing required at least three attachment positions to provide adequate security and undo vibrations. The ¾" tubing was routed across the nose of the aircraft, utilizing the radar warning detection mounts. The tubing was routed across these two positions with fabricated aluminum brackets and Adel clamps with asbestos insulation to prevent heat from being transferred to the airframe. A third bracket was added between the radar detector mounting brackets. This third bracket was temporarily affixed to the boom by a hose clamp. Excess copper tubing material of approximately two inches in length was provided between the first bracket and the skid to allow for the skid to contract and spread upon take off and landing. The SGS tube routing is shown in figure 4.9.

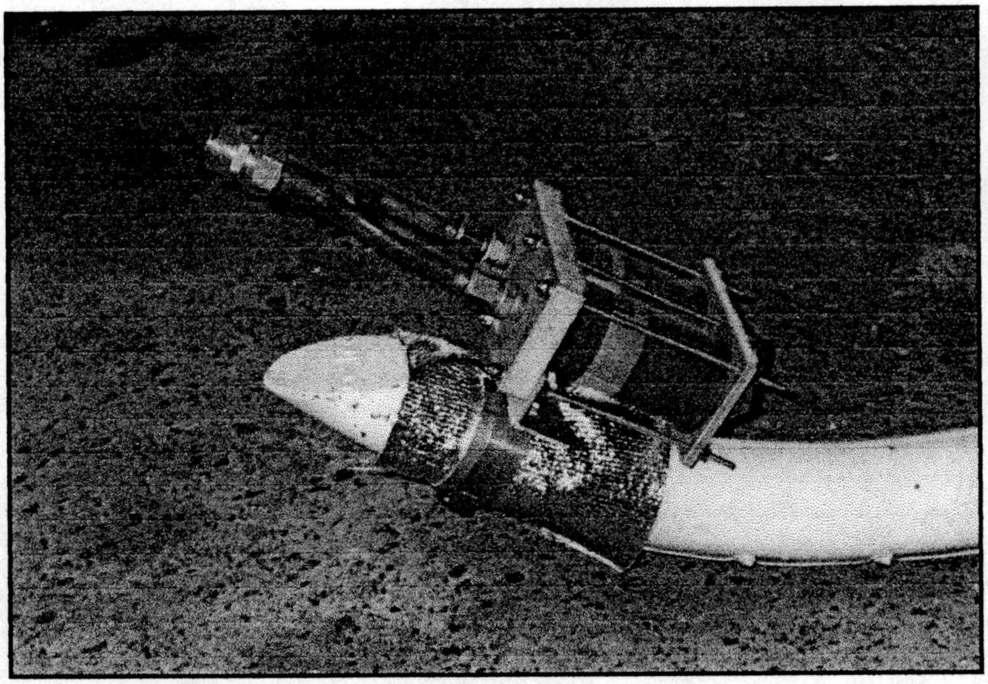

Figure 4.8: SGS Housing and Manifold Installed

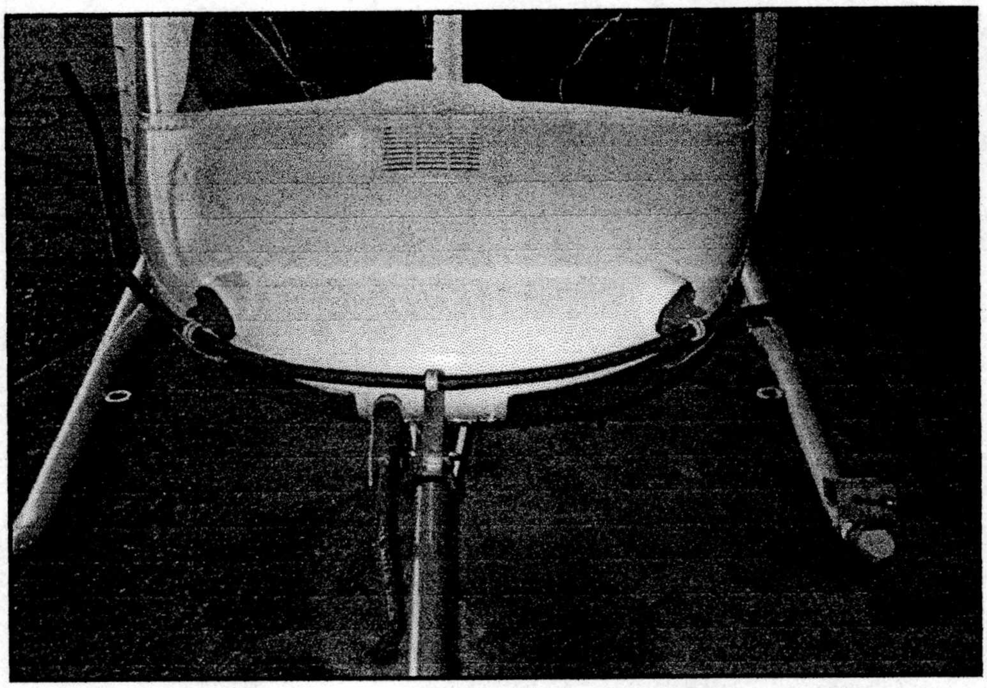

Figure 4.9: SGS Tube Routing

SGS Design Tests

On July 7, 2000, an initial test of the helicopter SGS was completed on the UTSI beach on Woods Reservoir (figure A.14). The test apparatus consisted of the smoke generator main body, mounting bracket, and twelve feet of ¾" copper tubing conformed in a smooth "U" pattern. The first firing included two yellow canisters fired simultaneously by manually pulling the pin of the fuse. The burn lasted one minute. The smoke produced from the two canisters was very dense, but flowed through the pipe exit at a slow rate of speed. With no or little breeze, the smoke was contained in an area not exceeding twenty-seven cubic yards. The main body, fittings, and entire length of tubing reached such high temperatures that it could not be touched. The device was cooled by air and water. For a second test a violet and green canister were installed. Each canister was ignited manually individually, first firing the violet, then the green Each canister burned one minute with the density of smoke exiting the length of tubing less than that of the two yellow cans fired simultaneously, but at approximately the same velocity. The smoke from each container was also confined to an area not exceeding twenty-seven cubic yards

The device was allowed to air cool and was transported to UTSI Flight Research Hanger for further examination. Upon examination the twelve foot tubing attached to the main body received sediment build up of less that 10% of the inside diameter. The sediment was rough and jagged in appearance. The long tubing was removed from the main body to reveal similar build up in the ¾ inch portion of the "Y" manifold Sediment build up was more apparent upon removing the "Y" manifold from the main aluminum block. Significant build up in the fittings and ½ inch tubing was apparent. Approximately 65% of the violet canister side (right from top) was blocked with rigid, violet-black sediment, shiny in appearance. The green canister side (left from top) was 30% blocked with the same type of material, but of a greenish color. The majority of the buildup was concentrated on the bottom of the tubing.

A second test was completed at UTSI's Flight Research Hanger on August 28, 2000. This test consisted of the SGS and its proper mounting angle as it would be on the helicopter skid (figure 4 10). Temperatures were recorded by attaching thermocouples to the "Y" copper assembly and on the ¾ " tubing 12 inches from the brass junction. Precautions were made such that the smoke did not obstruct the runway. A fire extinguisher was also on hand Grenade pins were pulled by hand

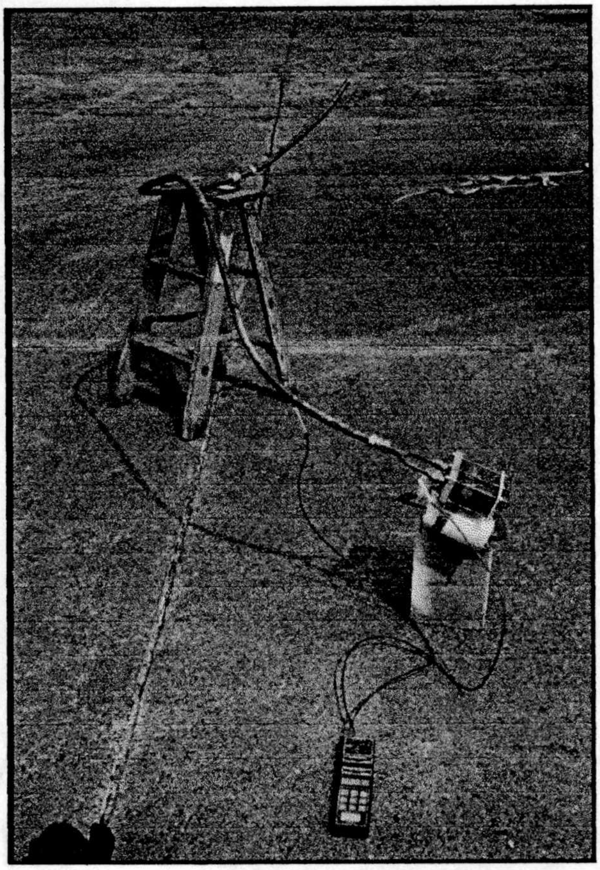

Figure 4.10: Test Operation Set-up

Test firing consisted of one yellow grenade and one green grenade. The green grenade, fired first, did not produce smoke for 30 seconds. After this time thin, green smoke escaped the end of the tubing in a slow rate. The yellow grenade was fired second (figure 4.11). Yellow smoke was immediately seen from the end of the tubing. The yellow smoke continued for 1 minute, 15 seconds. Temperatures for both test firings ranged from 320°F twelve inches from the brass coupling to 620F° at the "Y" manifold on the SGS. The temperature was not high enough to melt or damage the PVC pipe to which the SGS was attached.

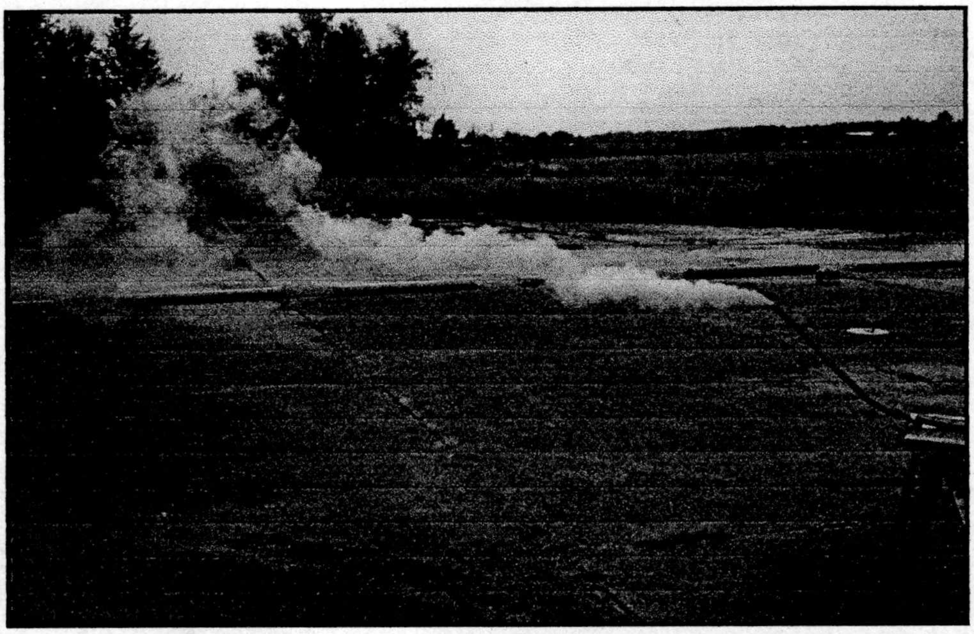

Figure 4.11: Yellow Smoke Grenade Testing

After fifteen minutes the entire device was transported to the Flight Research Hanger for disassembly and inspection. The ¾" tubing exhibited slight build-up on the interior walls through the entire length of the tubing. The side of the "Y" manifold housing the green exhibited 15% blockage throughout the length of the ½" tubing. The yellow grenade side shows yellow discoloration, but minimal build-up on the interior walls of the ½" tubing. Results of these preliminary tests concluded that the yellow smoke exhibited the most beneficial characteristics.

The SGS was designed to be operated by the flight test engineer positioned in the left front seat of the helicopter. This allowed the pilot to maintain primary attention to the flying tasks. Also, the SGS was mounted on the left skid, nearest to the left front seat. A control cable arrangement was installed to mechanically pull the firing pins of the grenades. With the co-pilot collective control removed, the bracket and cable T-handle were installed (figure 4.12). The control cable was passed through two Adel clamps for positive positioning, and then tied to the skid with standard wire ties (figure A.15).

To minimize the possibility of foreign objects entering the tail rotor two modifications were made to the M-18 smoke grenades for flight test. One, the safety lever, or spoon, was removed because it was not permanently affixed to the fuse or grenade. This safety lever is designed to jettison after being released by a soldier (figure 4.13). Also, the standard ring and cotter pin were removed and replaced with a brass one. Because the safety lever was removed a second, larger stainless steel safety pin was installed on the ground to reduce the risk of premature SGS operation (figure 4.14). The stainless steel cotter pins were labeled with "Remove Before Flight" warning flags before installation on the aircraft.

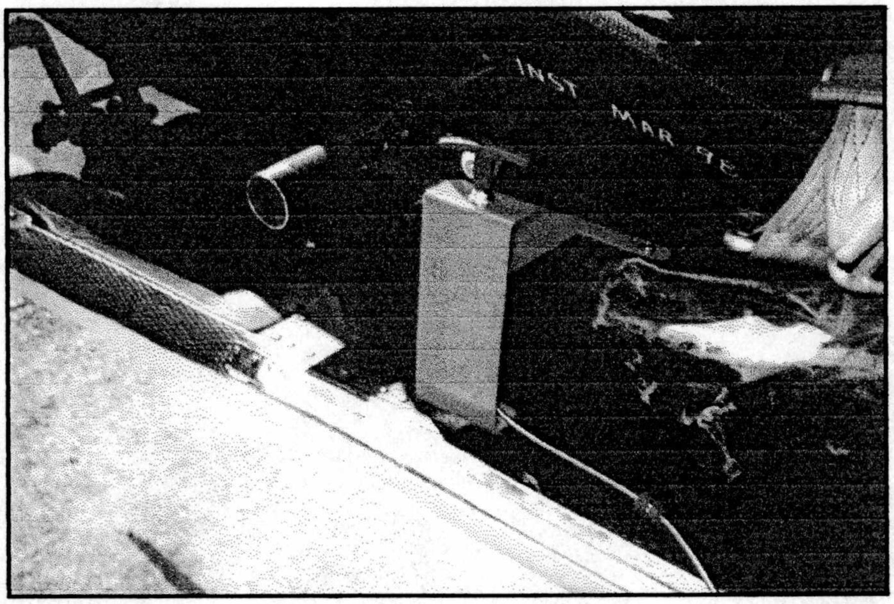

Figure 4.12: The SGS "T" Handle Control Installed

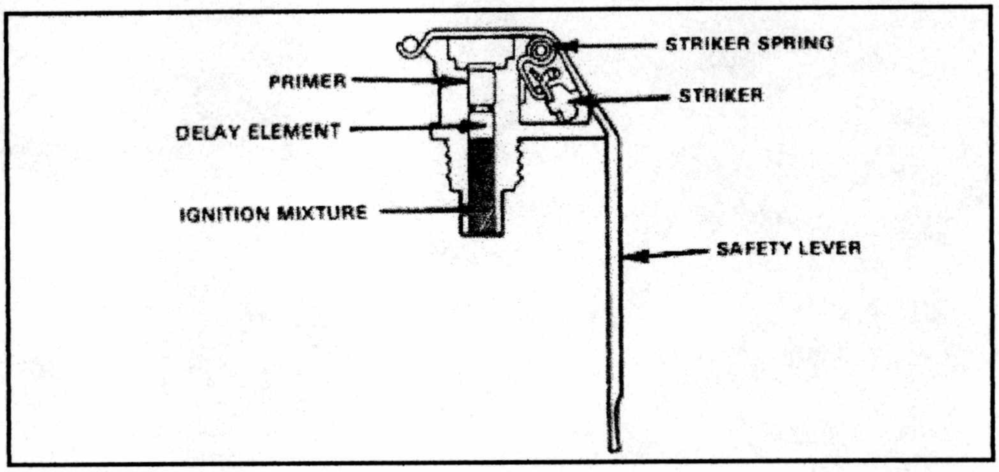

Figure 4.13: Fuse for M-18 Smoke Grenades [13]

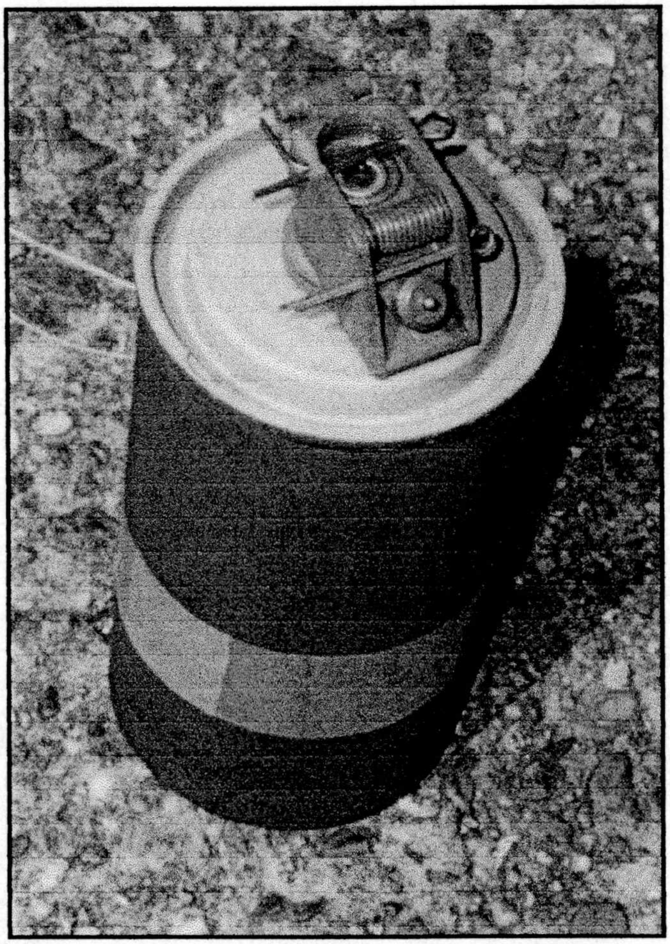

Figure 4.14: Fuse Modification

CHAPTER 5

DATA RECORDING

Objective

A large part of the development of the full scale flow diverter was the recording of the flow by visualization devices for further examination after the flight testing was completed To preserve the flow data obtained during the test flights several recording methods were considered Each of the alternatives considered were evaluated against weight, cost, operation requirements, and physical size.

Micro Video Cameras

To record motion of the tufts and smoke of the flow visualization system a video camera was required Small, lightweight lipstick cameras were considered as an effective method of recording data at many different points throughout the aircraft. Each Elmo CCD Color Video Micro Camera and power unit weighed one pound and has a wide angle of view. Each camera required its own means of recording on videotape or CD unless a special effects generator could combine all the signals to one tape In addition, the equipment required AC power. This was not a feasible solution to record flow data due to lack of helicopter AC power available.

Handheld Video Camera

A small, handheld video camera was considered for the flight test because of its availability. The Panasonic PV-L858 records data on a 8mm tape. This camera is also fully digital, allowing still photographs to be recorded internally and then downloaded to a computer in interchangeable graphics (jpeg) format The camera weighed 2 4 pounds In addition to the traditional eyepiece a fold out 3.2" LCD monitor could be used to preview camera recordings This feature was especially useful with the operator shooting at different angles from the aft flight test engineer station with secured shoulder harness on Because of the superior features of this camera it was chosen to record tuft screen and airflow data probe flow indications

Still Camera

To back-up the video camera, a traditional still camera was used to document flow visualization. The Pentex IQZoom 35 mm camera was fully automatic with flash and zoom. 400 ISO film was chosen because of the relatively fast action of the tufts in flight and bright backgrounds on sunny days The camera weighed ½ pound.

Noise Evaluation

In addition to documenting cabin airflow with video and still cameras the noise level in the cabin was evaluated for low and high pitch aerodynamic sounds To sample cabin noise a dosimeter was used instead of the common decibel meter to record an average reading as opposed to instantaneous noise levels

The meter chosen for this test is the MSA Noise Dosimeter Model 80, see figure 5.1. This dosimeter meets ANSI specifications S1.4-1971 (R1976) for type 2 Sound Level Meters and ANSI S1.25 for Personal Noise Dosimeters. The meter is "A" weighted as required by OSHA. "A" weighted dosimeters apply a weighted scale to received noise determined by the frequency's interpretation by the human ear (figure 5.2). The human ear is known to be more sensitive to certain, mid range frequencies. The dosimeter was mounted to the center control rod housing, with microphone taped to the headliner within two feet of the rear passenger's ear.

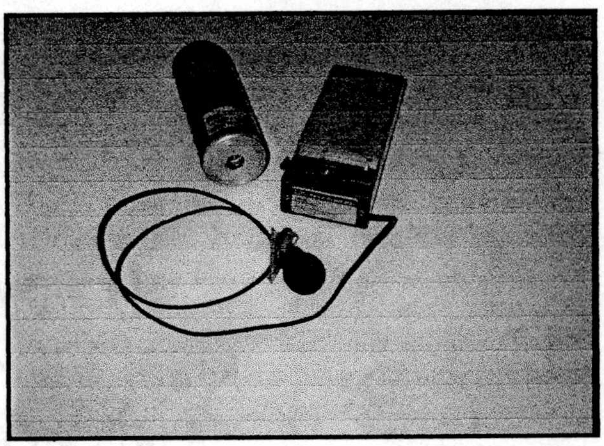

Figure 5.1: Dosimeter [10]

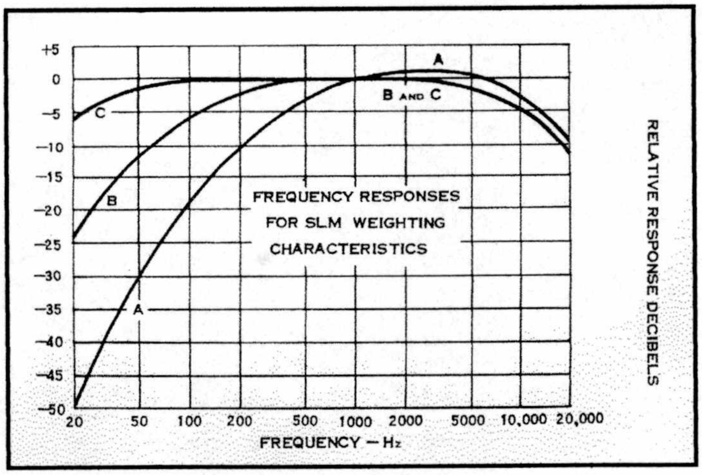

Figure 5.2: "A" Weighted Scale [10]

CHAPTER 6

TEST EQUIPMENT INSTALLATION

Installation

All four doors of N88UT were removed for the installation of the test equipment including diverters, tuft screen, airflow data probe, and dosimeter. The diverters were installed on the helicopter utilizing the original door hinge pin hardware. The leading edge of the plastic used for a smooth transition of flow from the fuselage was taped down using the special UV protected duct tape (figure 6.1). A foam cover was also temporarily attached covering the sawtooth diverter, reducing the chance of injury on the ground.

The tuft screen brackets and airflow data probe device were all installed utilizing existing attachment points within the helicopter. The tuft screen was then installed and

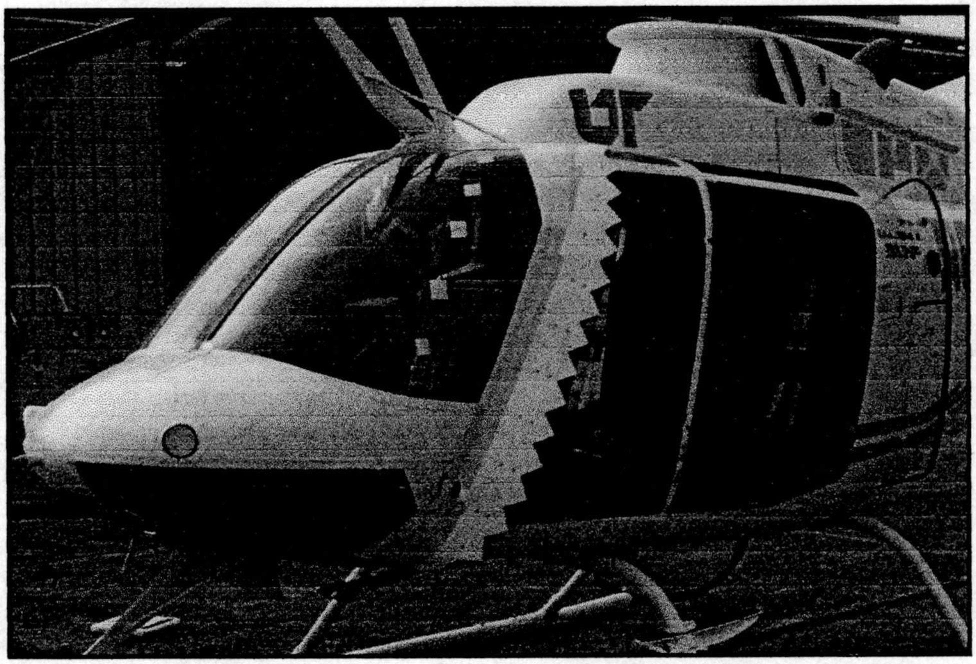

Figure 6.1: Installed Sawtooth Diverter

checked for security. The dosimeter was clipped to the fabric liner in the cabin area, but was also secured with tape for additional security during doors off operation.

In addition to the diverters and flow visualization system components a boom airspeed and altimeter instruments independent of the standard ship system were installed. This is because the static ports on the OH-58A lie directly forward of the flow diverters and the altered flow was most likely to affect the standard aircraft instruments (figure A.16). Ambient pressures gathered by the boom were recorded on the data acquisition system and displayed on indicators separate from the standard cockpit instruments. Pitot and static pressure plumbing from the boom were routed behind the instrument panel (figure 6.2) to an altimeter and airspeed indicator mounted on the glare shield of the instrument panel (figure 6.3). Both the airspeed indicator and altimeter were calibrated using bench test equipment of the Flight Research Department. The system was checked for pressure leaks after the installation was complete; no leaks were present.

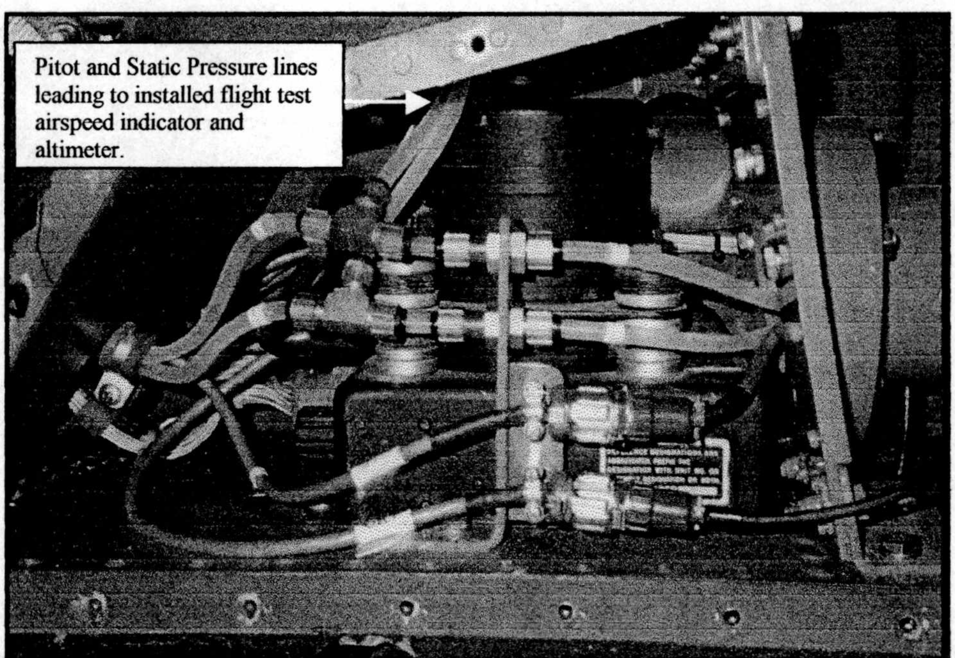

Figure 6.2: Boom Pitot and Static Plumbing to Test Instruments

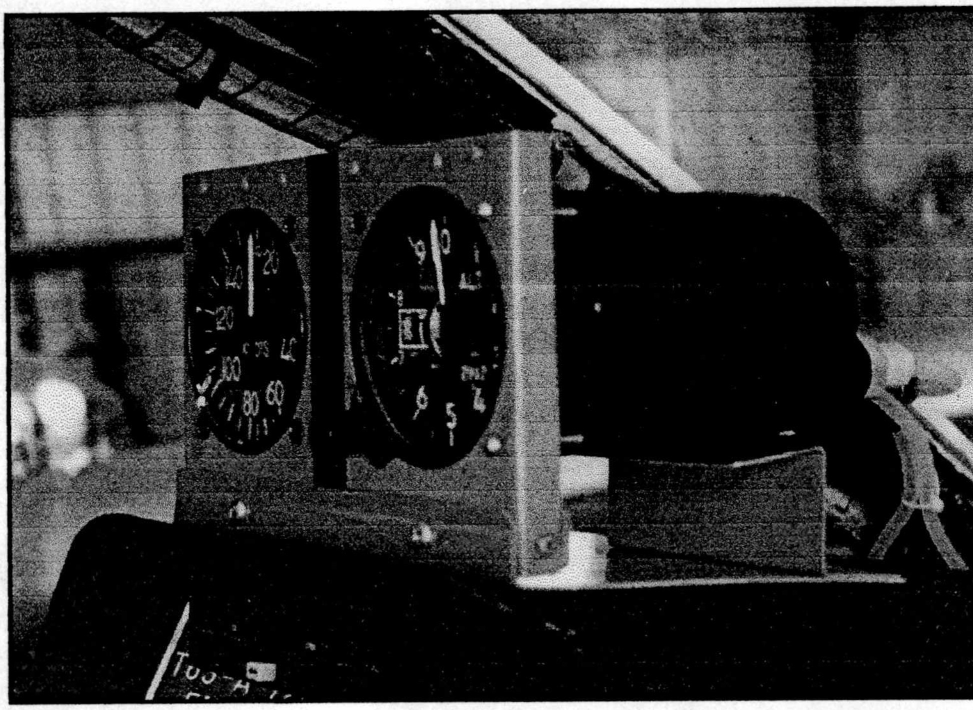

Figure 6.3: Installed Airspeed and Altimeter on Glare Shield

Safety

The corners of all the metal brackets and the flow defectors were rounded to reduce the chance of injury. All loose or unessential items were removed from the helicopter to minimize the risk of objects departing the cabin in flight. The cabin area was vacuumed to prevent eye damage from flying particles. The flight test crew was briefed on the operation of the system. Helicopter emergency procedures were reviewed with emphasis on smoke in the cockpit and loss of tail rotor situations.

Crew field of view was also evaluated and determined acceptable for flight operations. The majority of diverter hardware was located adjacent to the existing door posts. A rectilinear graph showing the change in field of view from the baseline configuration to that with the diverters installed is presented in Appendix B.

Weight and Balance

The empty weight of N88UT was determined on July 7, 2000 after completion of the instrumentation installation that included pitot-static boom, control stations, data box, and additional items noted in reference 8. All equipment removed after weighing, such as the doors, were weighed and subtracted from the empty weight of N88UT The diverters, tuft screen, airflow data probe, brackets, and audio equipment were weighed and added to the weight and balance forms for the test flights. Camera equipment, clip boards, and other flight test equipment were accounted for as part of the flight test engineer weight before each flight The weight of the removed components and flight test equipment was recorded in table 6.1.

Table 6.1: Weight and Balance Information

Item	Removed from Empty Weight	Added to Empty Weight	Location from Datum	Balance of Weight
				2001
Front Doors	18 5			1982.5
Rear Doors	16 0			1966 5
Diverters (each)		13 0	49	1979 5
Tuft Screen		5 0	88	1984.5
Tufted Slide Rule		.75	88	1985.25
SGS and Control		6.0	30	1991.25
Altimeter and A/S		3.5	32	1994.75
			Change	-6 25

System Expenses

The design, fabrication, and installation of the entire system consisting of flow diverters, flow visualization devices, data recording equipment, and other items spanned eight months Total cost of the project was minimal due to the availability of many materials and resources held by the University of Tennessee Space Institute After preliminary designs were made for the diverter and flow visualization systems, fabrication of the prototype items was completed in four months Figure 6 4 displays an schedule of the system design through test flight completion.

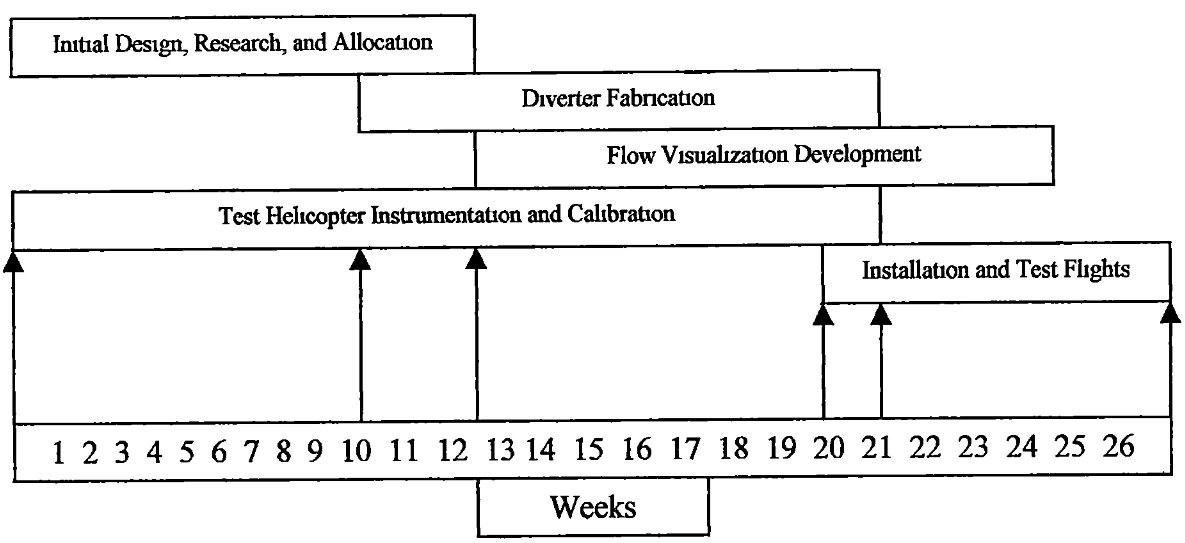

Figure 6 4 System Design and Fabrication

CHAPTER 7

FLOW VISUALIZATION TESTING

General

Initial flight tests were conducted without the flow diverter and visualization equipment installed on August 2, 2000 as part of the performance evaluation to determine baseline, doors-off performance. The flight was conducted at the Tullahoma Municipal Airport during day, VFR conditions A complete flight test plan and the results of that test can be found in reference 8.

Flow Diverters

Initial flight tests with flow diverters installed were conducted on August 4, 2000 The diverters were mounted and safety-wired, the leading edge attached to the windscreen and chin bubble using removable duct tape. This tape was selected such that the paint and Plexiglas were not damaged by standard tape adhesive It was removed with minimal paint pealing and no residue remained on the wind screen or chin bubble.

The time and tools required to change the angles was unacceptable. The helicopter was shut down for each angle change resulting in many cycles on the airframe, and low flight time. The cycle per flight hour ratio during the flight test was 0.4

Flights were conducted using the six-inch and eight-inch sawtooth and modified vortex generator diverters. It was discovered that the larger, eight inch diverters displaced more airflow from the fuselage at a given angle. In addition, as airspeed was increased the airflow was pushed further from the fuselage. No apparent bending, flexing, or vibrations of the flow diverters occurred in flight. The airflow probe measured increasing deflection of airflow away from the fuselage with increasing angles or increasing defector widths. A complete evaluation of the helicopter with installed diverters is presented in reference 8.

Flow Visualization

Assessment of the flow in and around the passenger cabin, was successful using both the tufted screen and airflow probe. The airflow probe provided an excellent depiction of the airflow around the fuselage and the location of transition from vertical to horizontal flow. Near the aircraft the tuft was nearly vertical, see figure 7.1A. As the probe was extended into the flow the tuft transitioned from its vertical orientation to a horizontal one, figure 7.1B. When the flow was horizontal, determined from orientation of the yarn, the length of probe extension outward from the helicopter was recorded. These measurements provided accurate and repeatable data to determine the

Figure 7.1: A) Airflow Probe near Fuselage B) Extended into Deflected Airflow

transition location of air flow along the fuselage The system could be easily operated, but did require the rear seat flight test engineer to loosen the shoulder harness to reach the handle to measure the flow In addition, the rod vibrated greatly when measuring distances greater than 11 inches due to the aircraft vibrations.

The tuft screen also provided valuable information on airflow in and out of the cabin area It was especially helpful in identifying where airflow was entering the cabin area. The tuft screen and data probe suffered no mechanical defect through the twelve hours of flight testing.

Results of the testing using the tufted screen demonstrated the inflow into the cabin and cockpit was not reduced sufficiently by the flow diverters. Consequently, the smoke generation was not tested in the doors off configuration for safety reasons

To monitor the airflow in the cabin and cockpit additional tufts were taped to the inside of the cabin area. These tufts provided excellent flow information There is no such thing as too many tufts

Data Recording

During the test flights visual information was recorded on videotape and still camera During the first flight no information could be gathered from the videotape. Moisture was found in the camera and on the tape upon landing The camera operated normally throughout the flight and the problem was not discovered until post-flight analysis. It was suspected that the cameras' internal components could not compensate for the quickly changing temperature and humidity conditions and condensation on the inside of the camera developed as a result The camera was moved from a cool, 73 degree air conditioned room to a very humid 73 degree OAT and then taken to an altitude of 6,000 feet with temperatures near 35 degrees The camera, upon descent to the airport and warmer temperatures began to fog up and shut down due to moisture warnings.

Still photos were taken in both flash and non-flash modes The pictures that appeared clearest with the greatest color contrast were the flash photos. A dark background for pictures provided the necessary contrast to discern tuft information from still photographs The eyepiece on the still camera was difficult to use because a helmet needed to be worn by the flight test crew A maximum of 24 exposures per day was adequate for this flight test

The dosimeter recorded little change in noise in the cabin area in all configurations with the doors off Flights with and without the diverter installed all measured 100dB to 101dB.

Performance Evaluation

Complete performance evaluation of the helicopter with the flow diverter installed is presented in reference 8. The following information summarizes some key findings The flight-testing investigated the level flight performance, and handling qualities with doors removed, with and without the flow diverters installed Consideration was also given in the design to discover ways of minimizing the airflow on the external passengers (amount of deflection), and changes in noise level. A complete table of the flight tests conducted and conditions is presented in Appendix C, Table C 1

The flow around the fuselage could be dıverted up to 16 ınches at the poınt of measurement wıth the tuft measurement probe Various dıverter configuratıons were tested, includıng the saw tooth and flat plate dıverter wıth vortex generators at dıfferent angles of deflection and lengths The measured diverted flow results are dısplayed ın figure 7 2 As depicted ın the figure 7.2, the flat plate modified with vortex generators pushed the aırflow further from the fuselage than the sawtooth at the same angle In addıtion, by lengthening the dıverter to 8 ınches the flow deflectıon was ıncreased by an estımated 3 ınches

The parasite power dıd ıncrease over the baselıne data, figure 7.3 Thıs ıs the result of the addıtıonal flat plate drag the dıverters added to the helıcopter The mean flat plate drag added to the aırcraft was 6 ft^2. It is important to note that thıs additional flat plate drag is added to the doors off configuratıon wıth no addıtıonal parasıte drag, such as external passengers or payload. No changes in handling qualıties were noted with the vortex generatıng sectıons

SGS Operation

The SGS was ınstalled on a non-ınstrumented OH-58A for flıght tests conducted on August 22, 2000. The helicopter was flown wıth the doors on as a safety precaution. The full length diverters fabricated for flıght tests could not be installed wıth the doors on. A 20 ınch length sample section was constructed of the same tested geometry and attached to the rıght front door 12 ınches aft of the exıt of the SGS tubıng. A chase

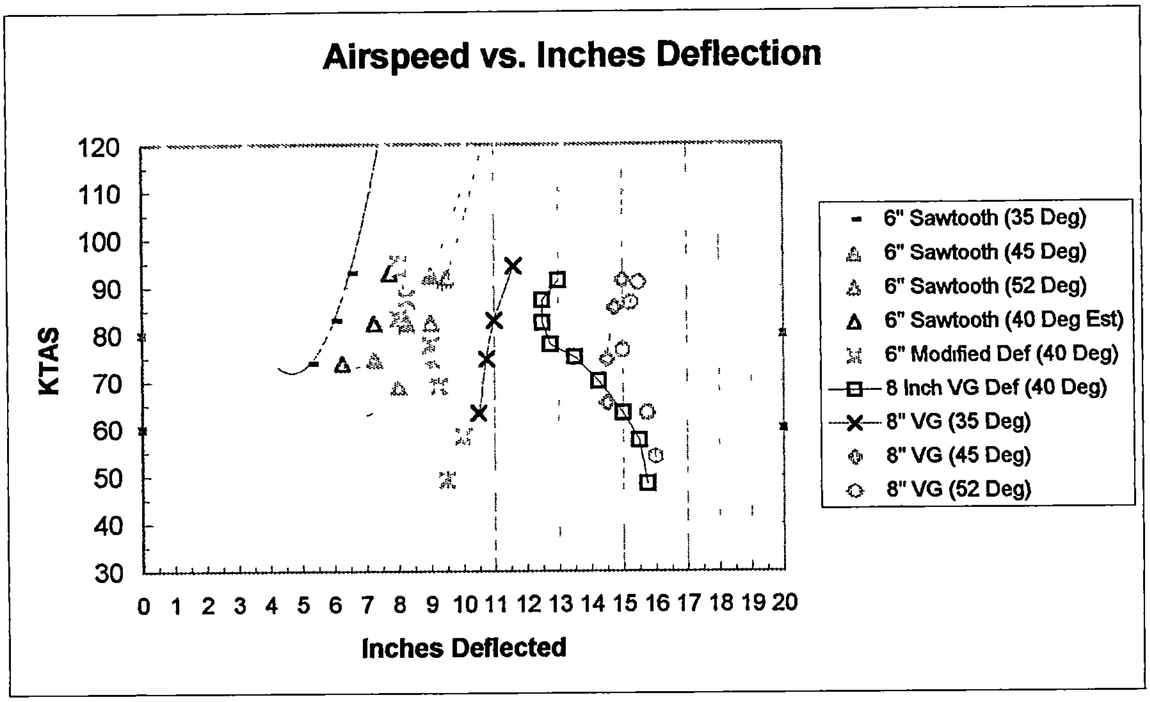

Figure 7.2: Inches Deflected vs Airspeed (Knots True) [8]

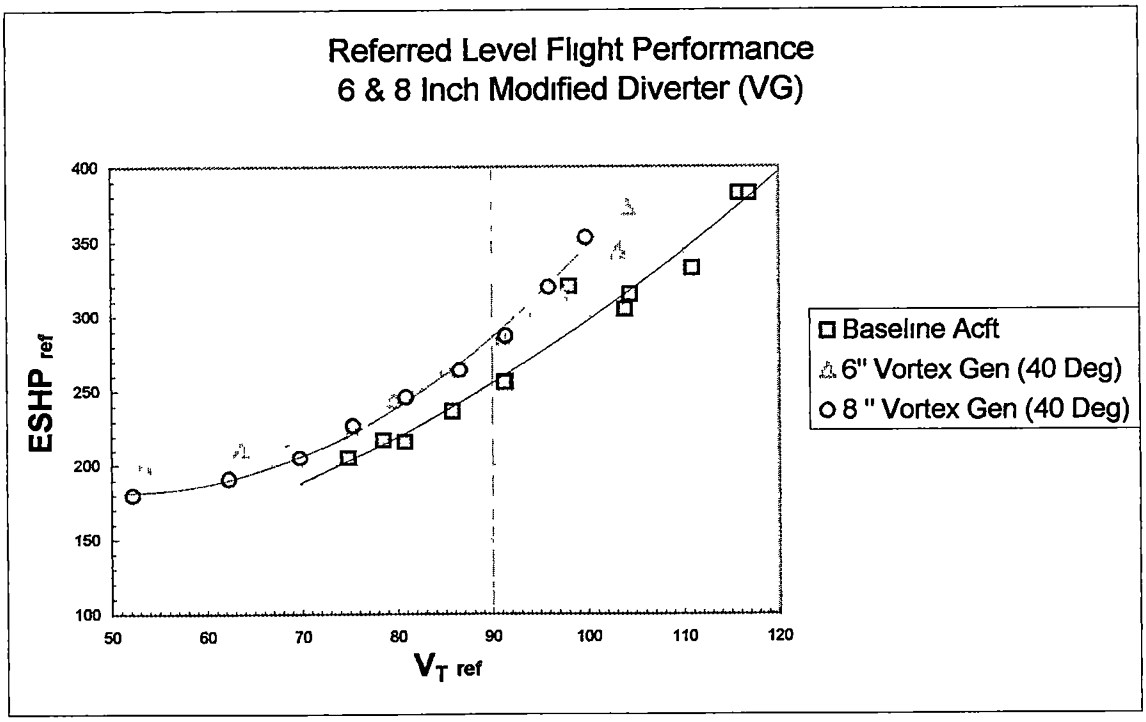

Figure 7.3· 6 Inch Flat Plate (with Vortex Generators) vs 8 Inch Flat Plate (with Vortex Generators) [8]

helicopter attempted to document the flow visualization with handheld video cameras and still cameras. See figure 7.4 for the complete installation of the SGS on the test helicopter.

The SGS control was activated by the flight test engineer without incident. The first test flight utilized the yellow smoke determined for the tests discussed in Chapter 4. Although smoke did exit the end of the tube, the volume was insufficient to visualize detailed flow characteristics by the chase helicopter against the white exterior paint of the helicopter. A second flight was conducted using red color canisters, but the

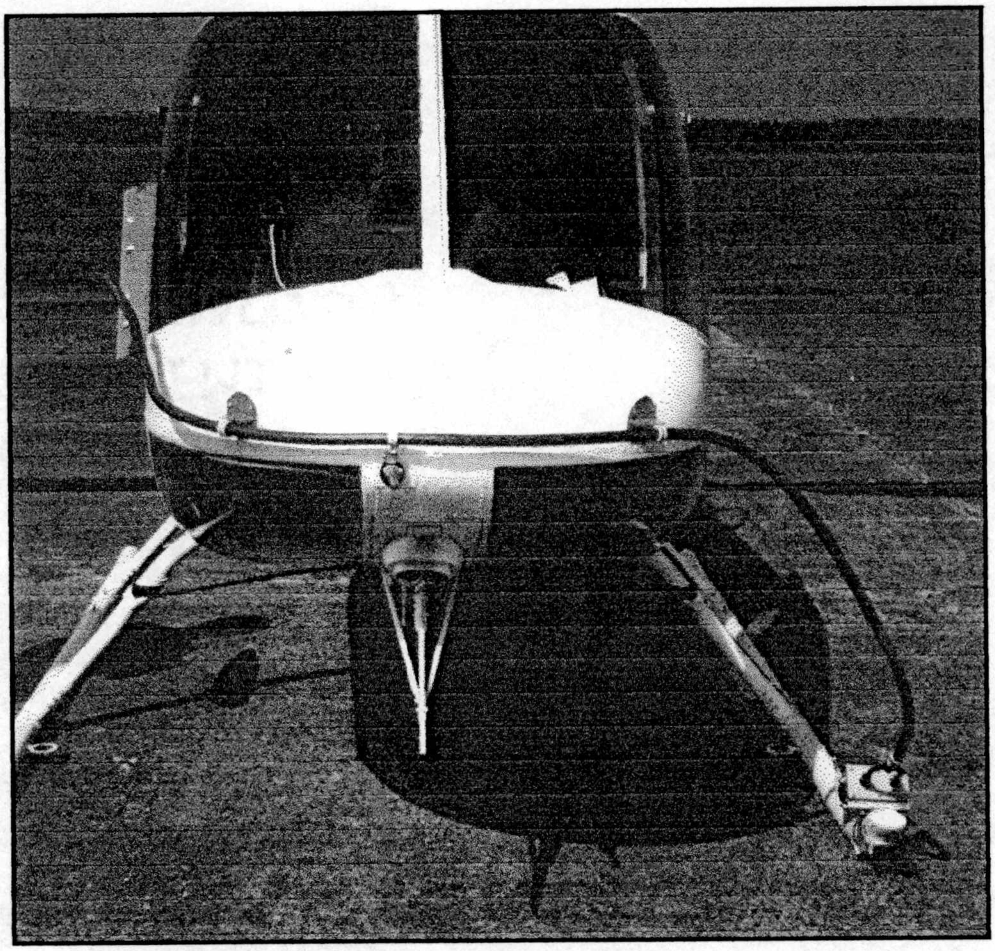

Figure 7.4: SGS Installed on Test Helicopter with 20" Sample Diverter

volume of smoke was also insufficient to discern detailed flow characteristics. In both cases burn time of the smoke grenade reached the estimated one minute. No cotterpins or SGS components came off in flight. See figure 7.5.

Upon landing the exterior of the helicopter with the SGS installed was stained in those areas that the smoke had contacted (figure 7.6). Although much of the residue was removed by hand, 30% of the staining could not be removed. Flow reached the tail rotor because evidence of smoke residue was found on the vertical fin.

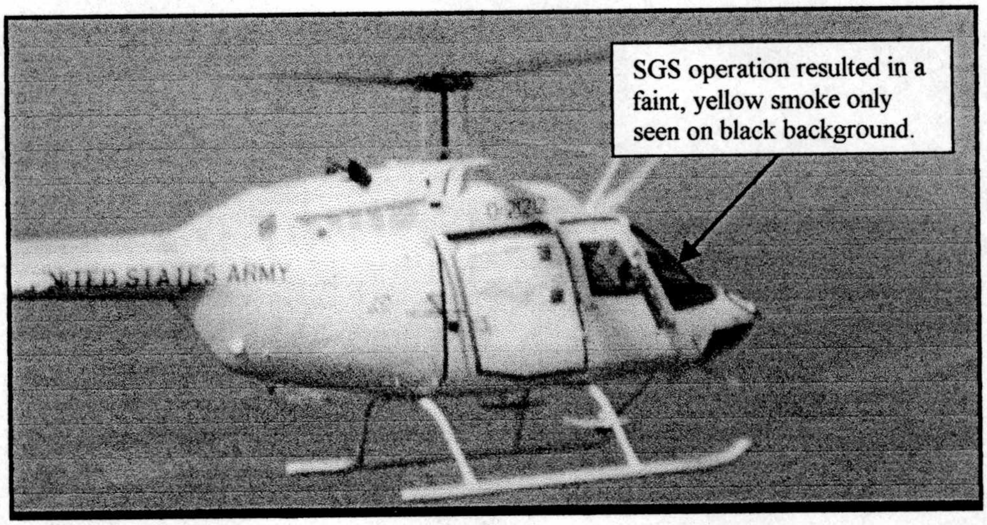

Figure 7.5: SGS Operation in Flight (Yellow Canisters)

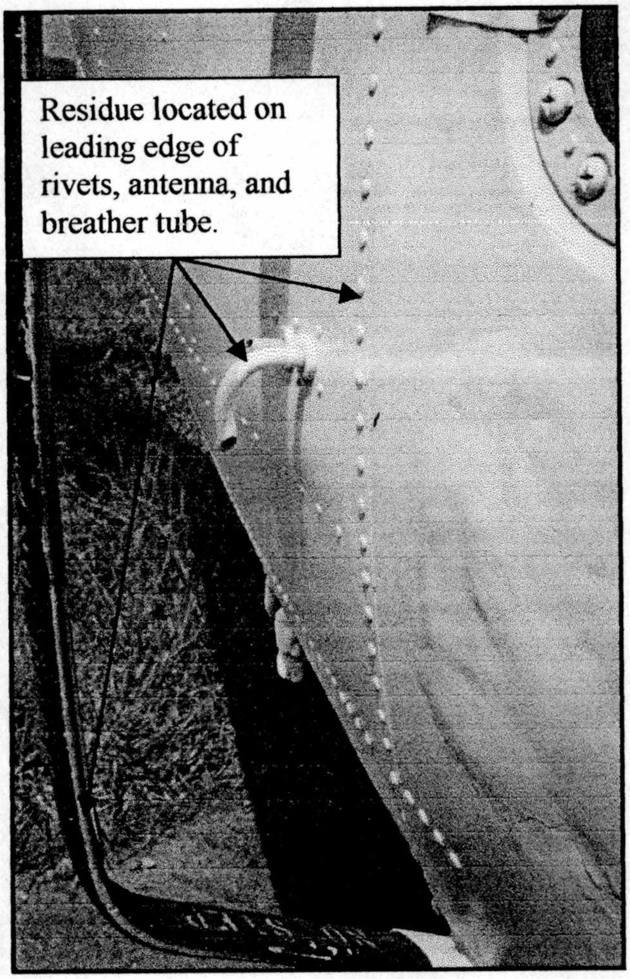

Figure 7.6: Residue from Yellow Canister Use

CHAPTER 8

FINDINGS

Flow Diverter

The flow diverter was successfully designed, fabricated, integrated, and flight-tested. The choice of material was satisfactory in terms of cost and availability. The slide mechanism for changing the diverter angle was effective, but difficult to adjust due to the tools required. The time needed to change the angle of the diverter was ten minutes, longer than the anticipated seven minutes. An equally effective means of adjusting the diverter utilizing a worm-gear or torque tube could limit the tooling required and reduce the time needed to change diverter angles Because these alternatives have a higher material cost and require complex hardware integration they were not considered for the rapid prototyping of this flow diverter

The metal flow diverters decreased the pilot field of view. Alternative materials to prevent field of view restrictions would include transparent plastic or Plexiglas Both of these materials, while slight more costly, are easily molded and very durable This product has the capability to be designed and manufactured for a variety of aircraft, including the MH-6

SGS Development

The SGS utilized M-18 smoke grenades because of their availability and low cost to the program Alternative smoke production methods were considered, but acquisition costs exceeded program funds. Fogging and smoke machines commonly used in wind tunnels or fire-training applications require AC power between 1400-1800 watts. These systems could not be installed in the test helicopter because of power limitations Additional alternatives include oil burning devices used by acrobatic aircraft, the use of water vapor in combination with high pressure air, or the use of a higher density smoke solution in canister form like that used at NASA [12]

Although the smoke volume was thought to be sufficient during ground tests, the flight environment introduced airspeed and main rotor effects disregarded . This ultimately led to a deficiency in volume of smoke available to see the detailed flow characteristics near the flow diverter.

Flow Visualization Recording

During the SGS operation flights a chase helicopter was positioned with two handheld video cameras to record the airflow over a 20 inch diverter test section. One camera, equipped with steady shot feature, recorded footage free of vibration distortion The camera with no stabilization recorded the test flight, but was distorted from the constant vibrations in the chase helicopter.

Cameras did not record detailed airflow characteristics due to very thin smoke signature and distance required for aircraft formation flight. The zoom feature of the video cameras used was sufficient, but very unsteady when focused beyond 10X A closer recording of the airflow data with cameras mounted on the aircraft equipped with the SGS would provide better footage of the detailed flow characteristics. This could be done with individual lipstick cameras, but this equipment exceeded the funds available for testing

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The design, fabrication, and installation of an airworthy airflow diverting device for full scale helicopter flight evaluations was conducted utilizing the systems engineering approach The following conclusions were identified:

1 The systems engineering approach provided a good, structured means to systematically identify and solve design problems

2. The flow diverter was safe, affordable, and satisfactory The diverter exhibited zero mechanical defects

3 The tuft screen provided good air flow data and tufts were easily recorded on both video and still cameras The orange tufts were easily seen on dark color backgrounds The screen was easy to make and install and provided repeatable flow data It is a good, cost efficient means for flow visualization

4 The airflow data probe provided repeatable measurements on the location of the slipstream airflow from the fuselage. The air flow data probe was a satisfactory device despite the difficulty in reaching the handle during some measurements

5. The SGS provided a safe, affordable method to insert smoke into the slipstream However, the SGS did not provide sufficient smoke quantity to visualize the detailed flow characteristics near the diverter test section

6. The video camera was adequate for flight testing once the effects of temperature, humidity and altitude changes were understood

7 The still camera provided valuable information and was a satisfactory compliment to video.

Recommendations

In view of these findings the following recommendations are made for further investigation

1. Further investigations of alternative, in-flight flow visualization systems need to be conducted

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REFERENCES

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APPENDICES

Appendices

Appendix A

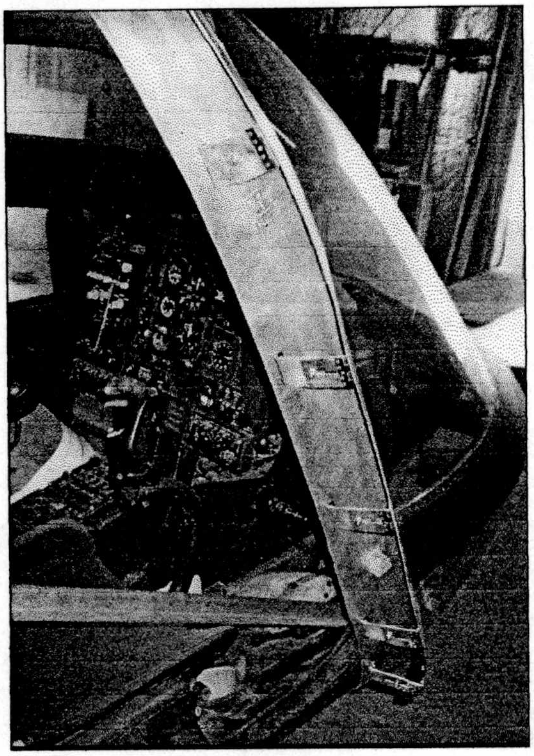

Figure A.1: Unfinished Structure

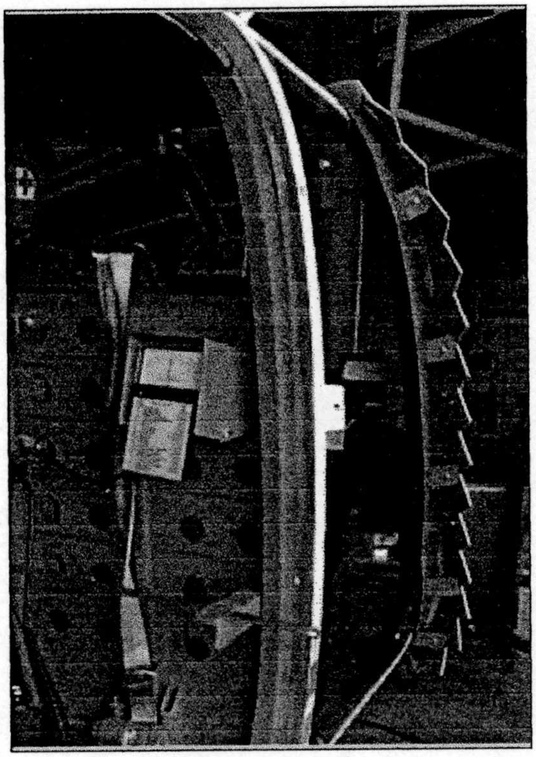

Figure A.3: Sawtooth Diverter (rear)

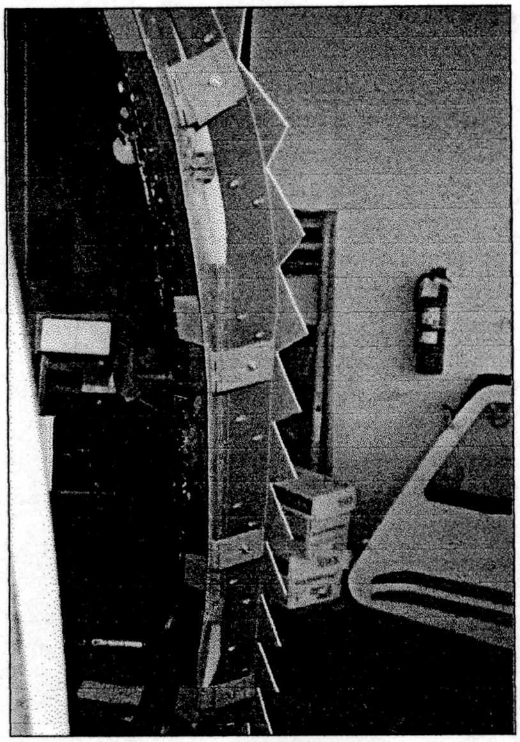

Figure A.2: Completed Diverter (rear)

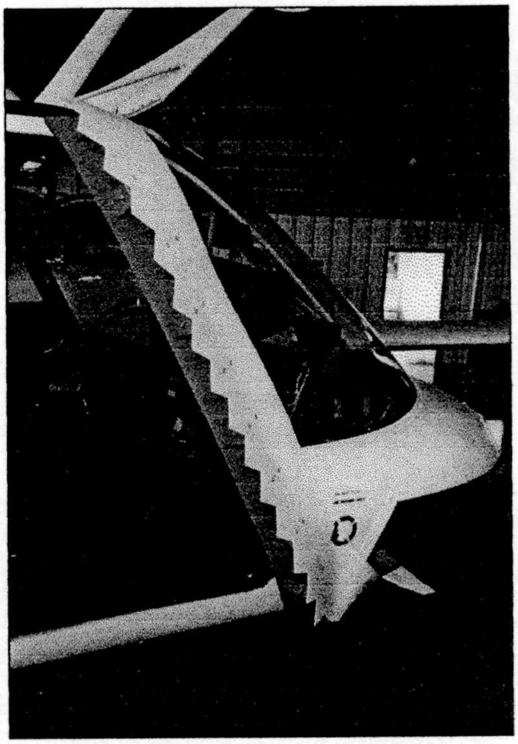

Figure A.4: Sawtooth Diverter (rear ¼)

Figure A.5: 6 Inch Sawtooth Diverter at 40 Degrees

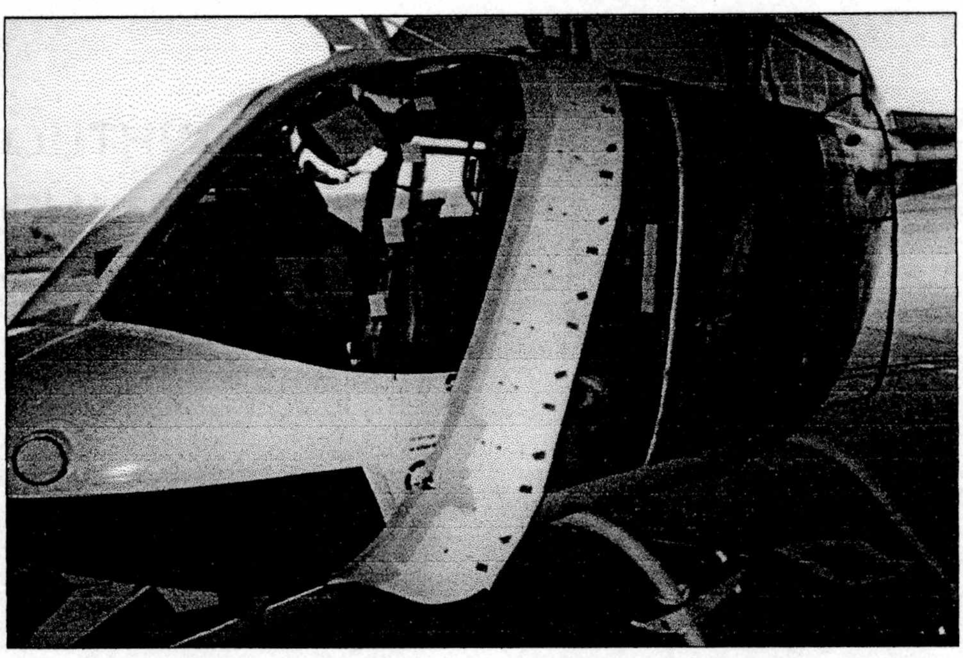

Figure A.6: 6 Inch Flat Plate Diverters with Vortex Generators

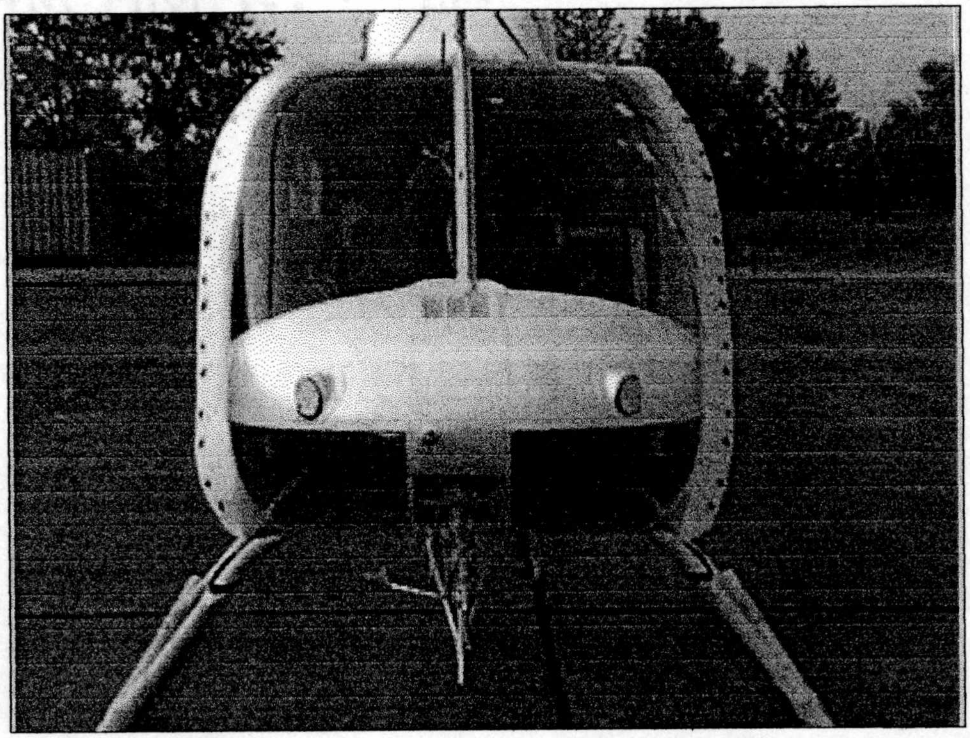

Figure A.7: 6 Inch Flat Plate Diverters with Vortex Generators at 40 Degrees

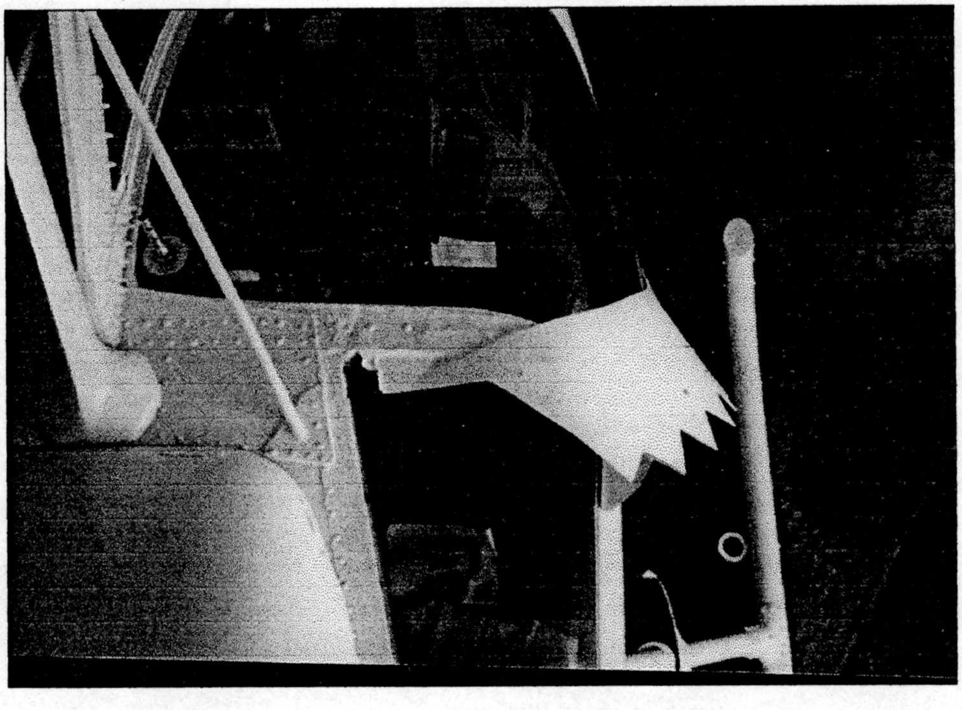

Figure A.8: 6 Inch Sawtooth Diverter at 40 Degrees (top view, right side)

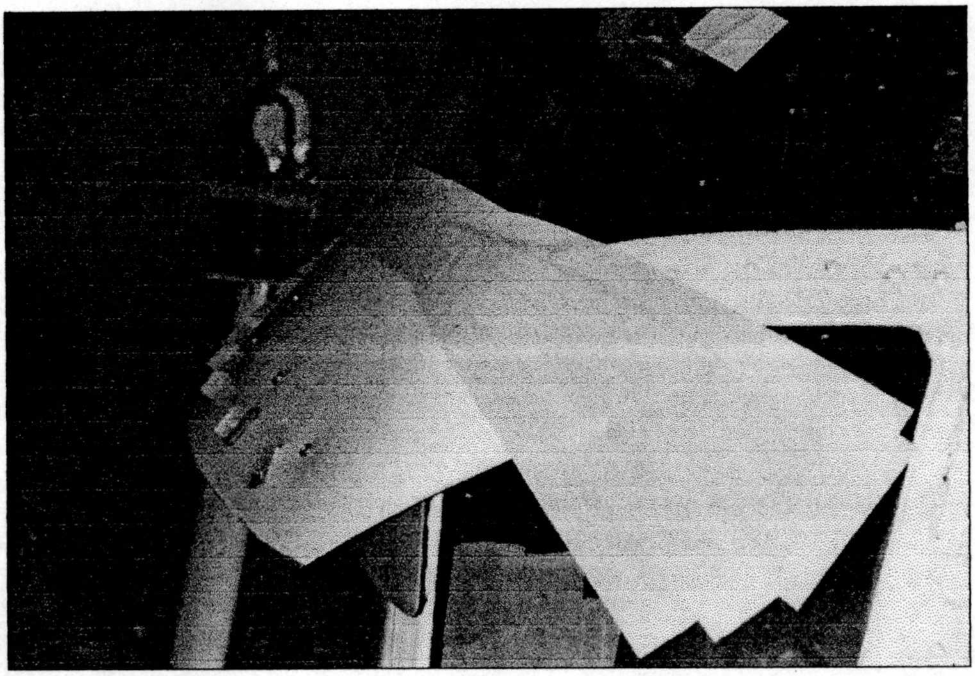

Figure A.9: 6 Inch Flat Plate with Vortex Generators (top view, left side)

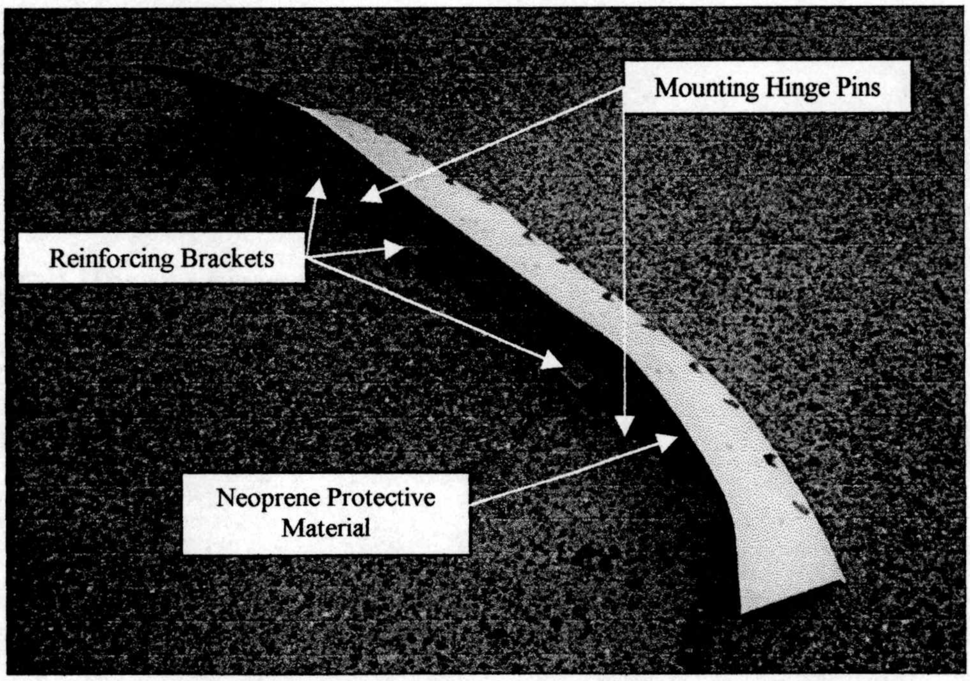

Figure A.10: Complete Flat plate Diverter Removed from Helicopter

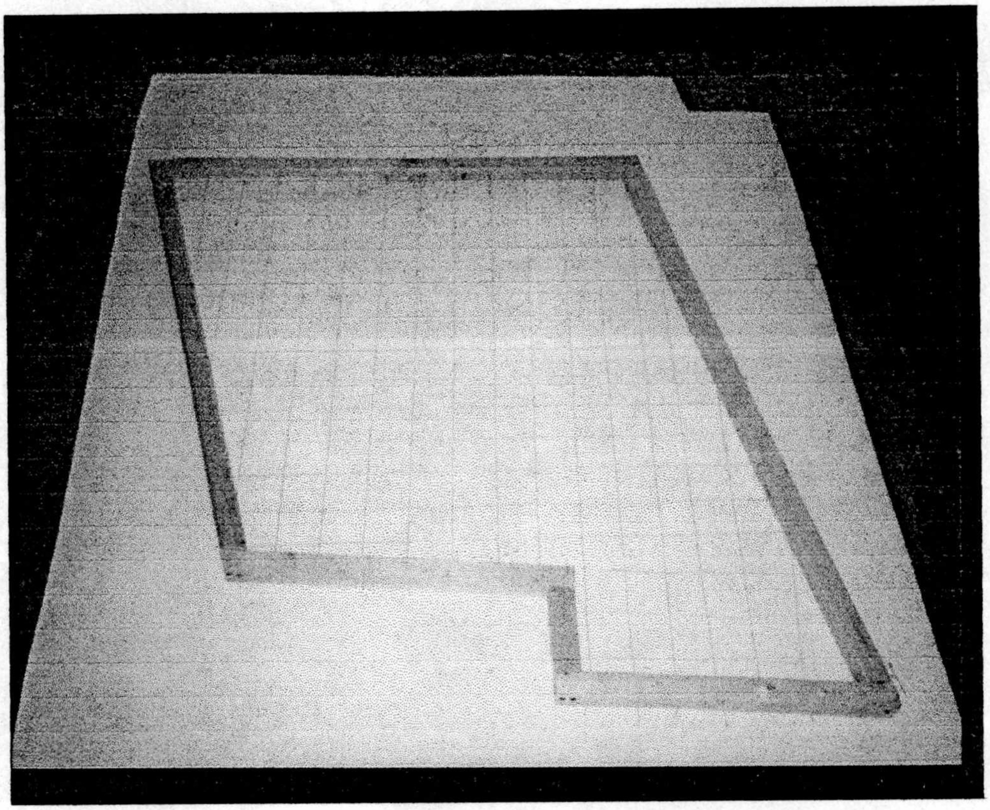

Figure A.11: Unfinished Tuft Screen

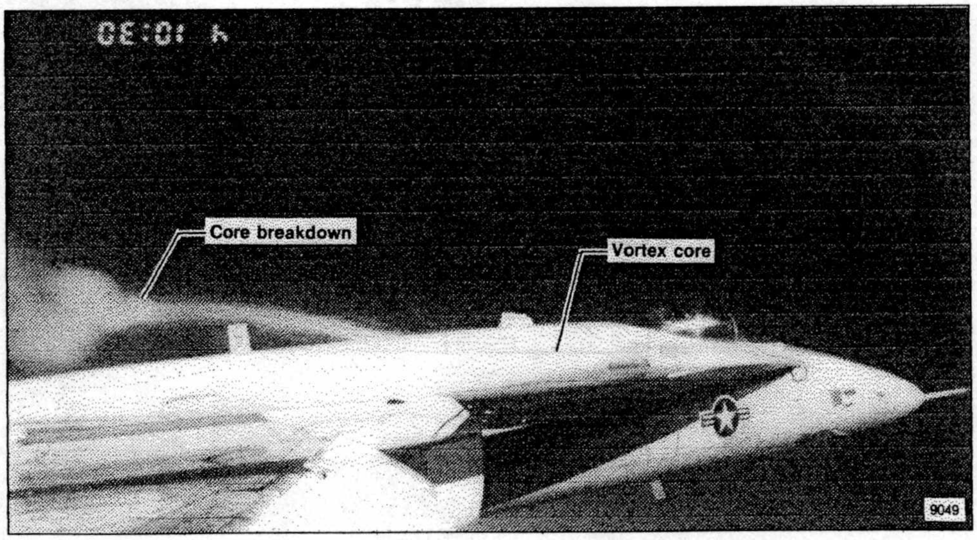

Figure A.12: NASA SGS on F-18

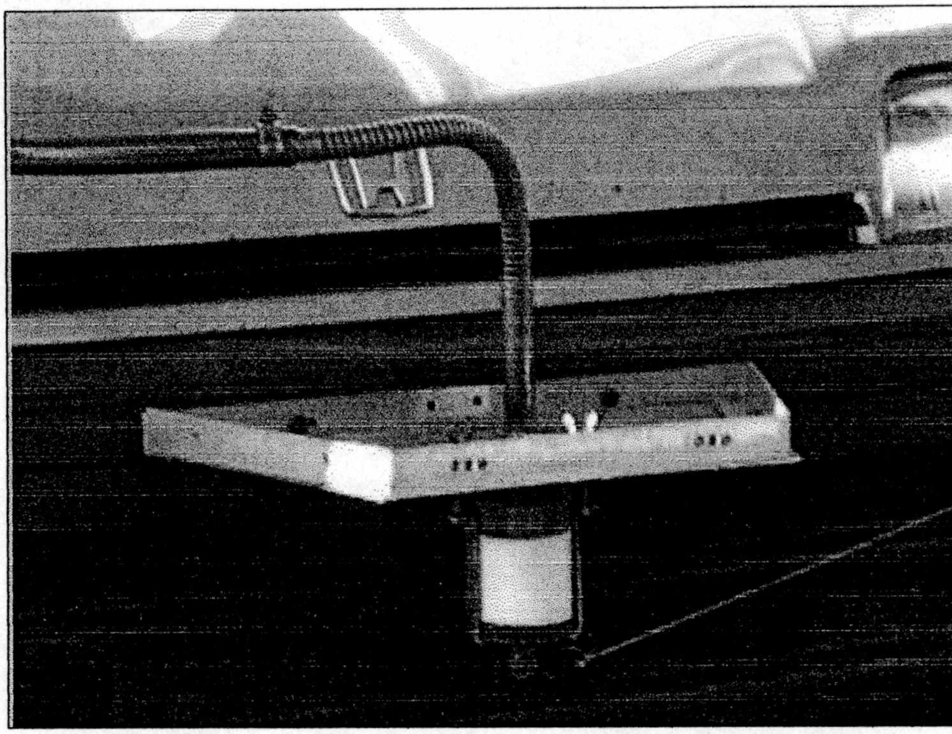

Figure A.13: Installed Sample SGS for Automobile Study

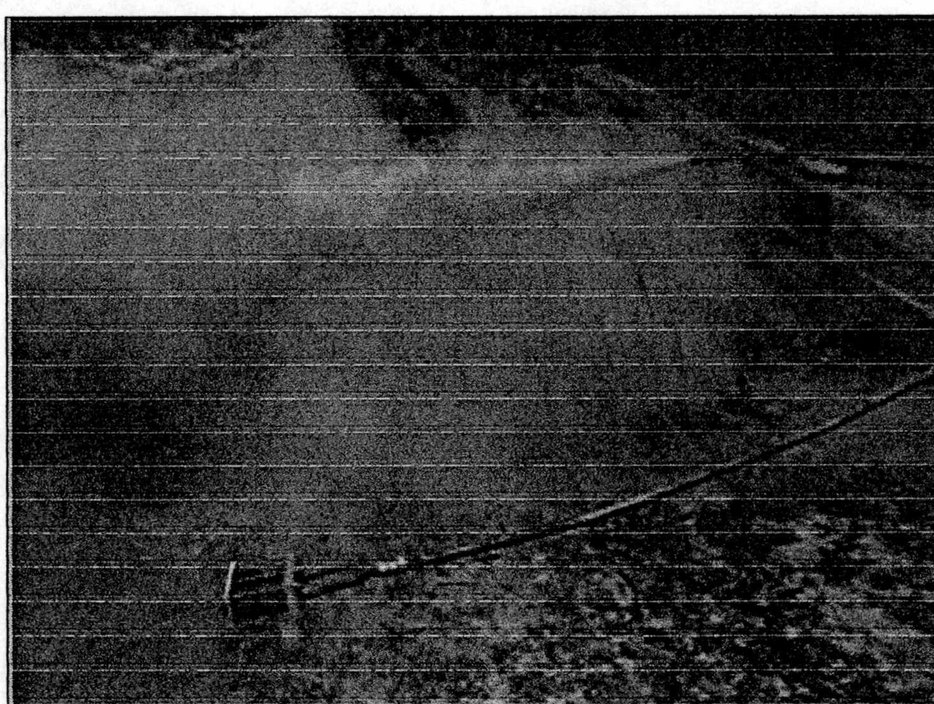

Figure A.14: Initial SGS Testing on Beach at Woods Reservoir

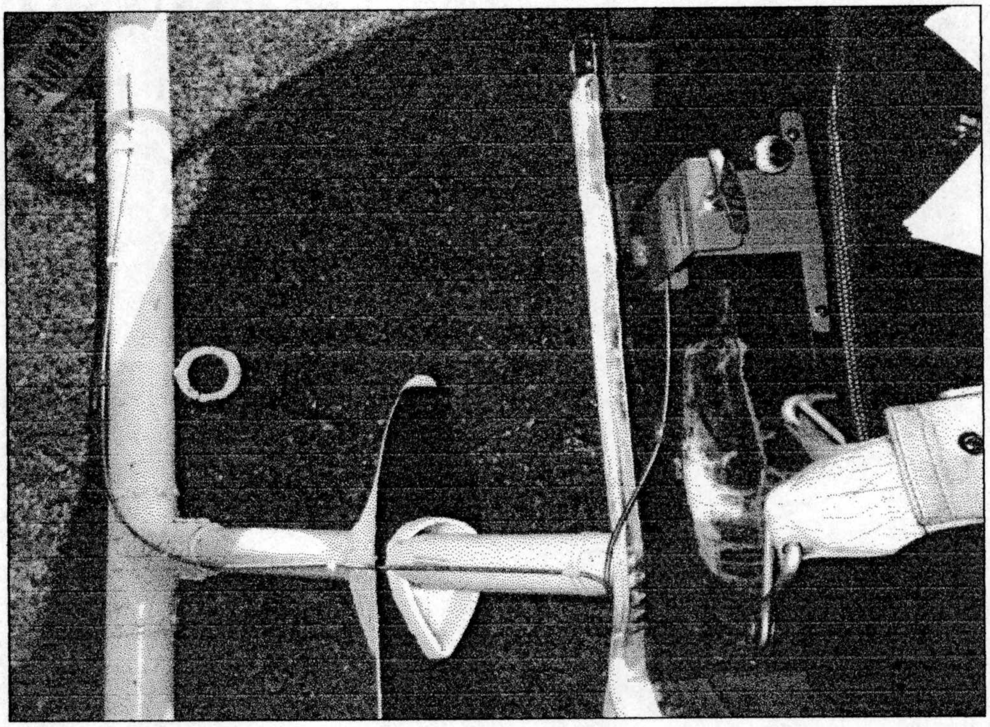

Figure A.15: SGS Control (top)

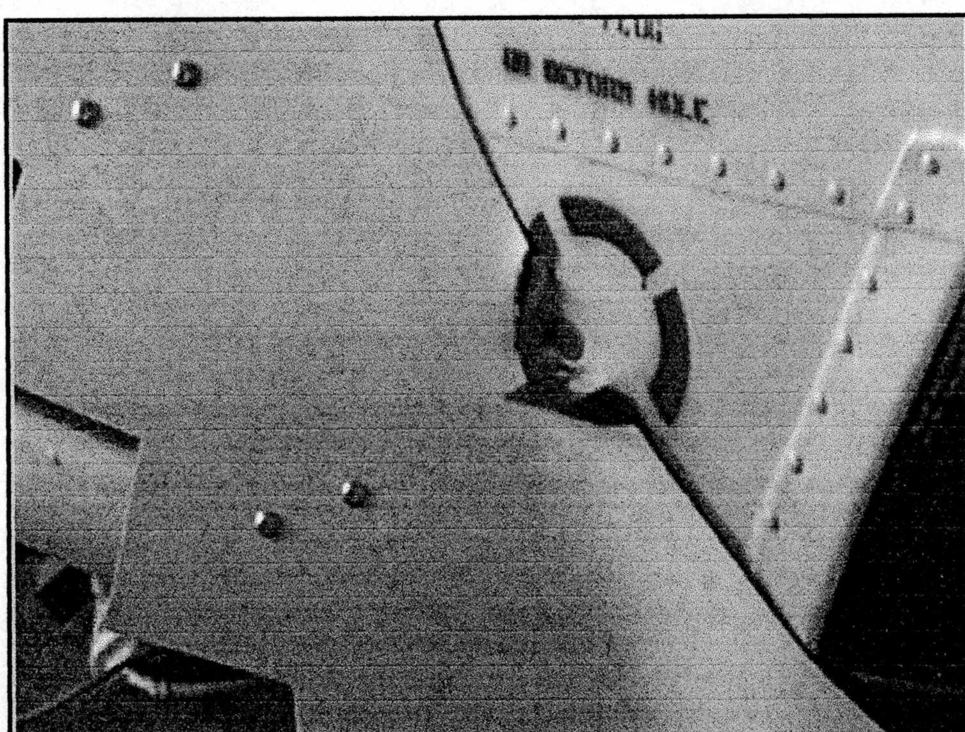

Figure A.16: Diverter Interface with Static Port

Appendix B

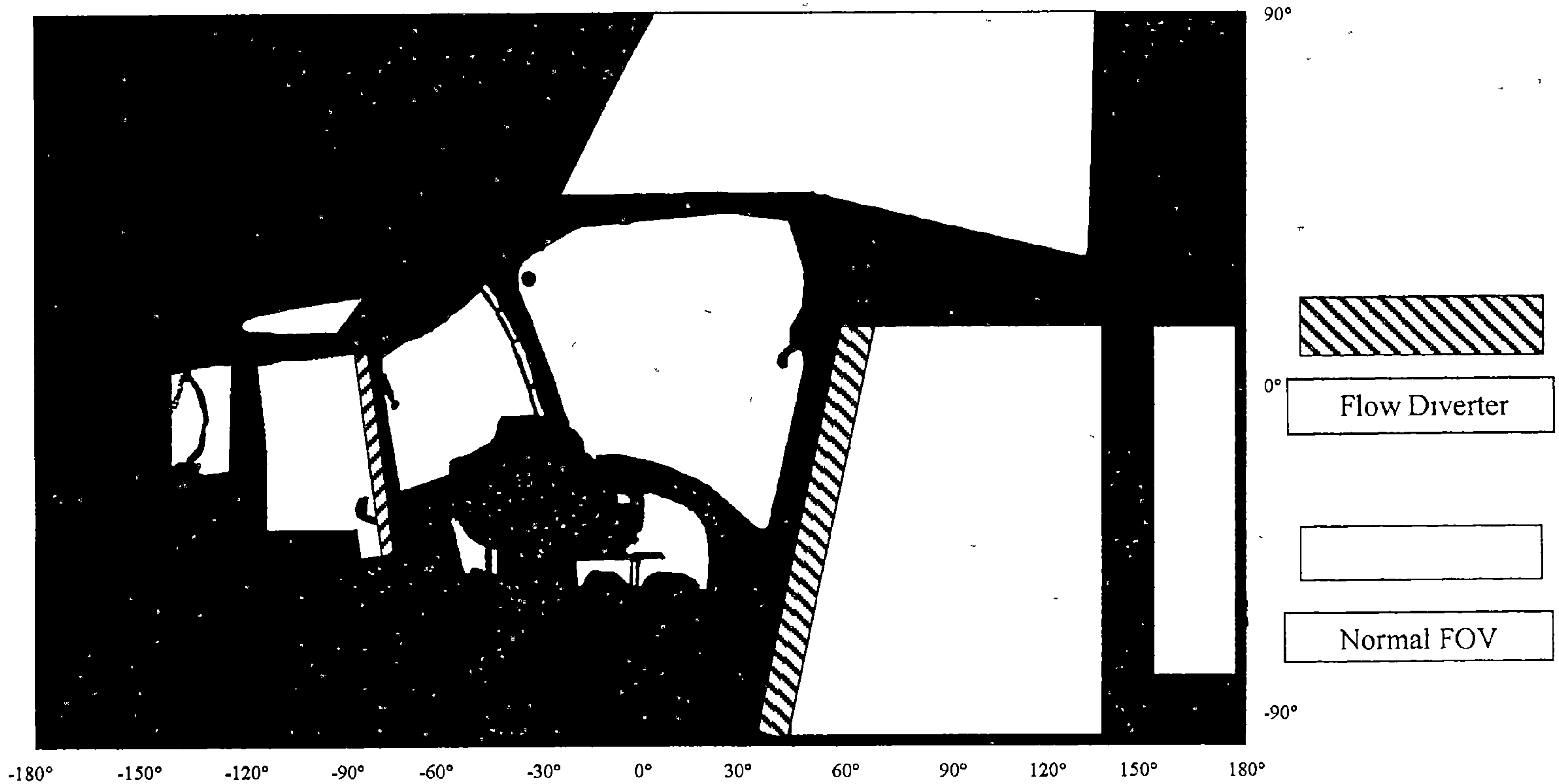

Figure B 1   OH-58A Doors Removed, 8" Flat Plate (with VG's) Flow Diverters Installed
Rectilinear Graph
(As viewed from the Design Eye Position)

Appendix C

Table C 1: Flight Test Table

Hour	Description	Crew	Target W/σ[1]	Estimated Pressure Altitude (ft)[2]	Estimated Gross Weight (lbs)[3]	Airspeed (KOAS)[4]
	Pitot Static Calibration	1 pilot, 2 FTE's	3600	1500-6500	3070	40 - 100 knots
1.5	Baseline testing & Handling Qualities (LDO)	1 pilot, 2 FTE's	3600	2900-6500 Initial target Alt ≈ 4400	≈ 3070	70 - 100 knots
1.5	Best Angle Testing	1 pilot, 2 FTE's	3600	≈ 2000	≈ 3070	90 knots
1.0	Flow Diverting Device Testing & Handling Qualities (LDO)	1 pilot, 2 FTE's	3600	2900-6500 Initial target Alt ≈ 4400	≈ 3070	60 - 100 knots
1.0	Modified Flow Diverting Device Handling Qualities (LDO)	1 pilot, 2 FTE's	3600	2900-6500 Initial target Alt ≈ 4400	≈ 3070	60 to 100 knots
0.5	Back Doors Installed Baseline	1 pilot, 2 FTE's	3600		≈ 3070	70 to 90 knots
1.0	8 inch Modified 40 Deg Level Flight	1 pilot, 2 FTE's	3600	2900-6500 Initial target Alt ≈ 4400	≈ 3070	60 to 100 knots
1.0	8 inch Modified Best angle & Level Flight	1 pilot, 2 FTE's	3600	2900-6500 Initial target Alt. ≈ 4400	≈ 3070	60 to 100 knots
0.5	Formation Training Flight	**Test Acft** 1 pilot, 1 FTE **Chase Acft** 1 pilot, 2FTE's	N/A	≈ 4400	3070	60-100 knots
1.5	Flow Visualization	**Test Acft** 1 pilot, 1 FTE **Chase Acft** 1 pilot, 2 FTE's	N/A	≈ 2500	≈3000	60- 100 knots
0.4	Flat Plate (without VGs) Noise Test	1 Pilot, 1 FTE	N/A	≈2500	≈3000	60-100 knots

VITA

Matthew Mulnik was born in St. Louis, Missouri and resided there throughout childhood. He attended public schools within the Rockwood School District where he graduated from Eureka High School June, 1995. The following September Matt enrolled at College of the Ozarks in Southwest Missouri. On May 9, 1999 he earned his Bachelor of Science in Aviation Maintenance Technology graduating Magna Cum Laude He started his graduate career at University of Tennessee Space Institute in September 1999 and completed the Aviation Systems program December 2000 graduating with his Master of Science

At College of the Ozarks and University of Tennessee Space Institute Matt utilized his technical skills maintaining school aircraft and research equipment He also enjoyed donating his time to organizations that promoted general and commercial aviation He is a member of the Professional Aviation Maintenance Administration and the American Institute of Aeronautics and Aerospace He enjoys the outdoors and flying in his spare time

After leaving the University of Tennessee Space Institute Matt pursued opportunities in the fields of aviation maintenance education and flight test engineering He currently resides in St. Louis, Missouri.