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I am submitting herewith a thesis written by Rodney C. Allison entitled "A Non-Developmental Item (NDI) Solution for Taskload Reduction of A/MH-6 Mission Pilots." 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.

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Accepted by the Council:

Associate Vice Chancellor and
Dean of The Graduate School

A PROPOSED NON-DEVELOPMENTAL ITEM (NDI) SOLUTION TO TASK LOAD REDUCTION FOR THE 160TH SOAR A/MH-6 MISSION PILOTS

A Thesis
Presented for the
Master of Science
Degree
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Rodney C. Allison

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DEDICATION

This thesis is dedicated to those members of my family, both here and gone, near and far, who have offered me nothing less than unselfish support, encouragement, and love throughout my life. May I be so honored to follow their example. To my wife and children who, because of their love, support, and patience, have made this manuscript possible. My most grateful thanks goes to our Lord Jesus Christ, through whom all things are possible.

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ABSTRACT

A thesis presented on a proposed non-developmental item (NDI) solution to task load reduction for the 160th Special Operations Aviation Regiment A/MH-6 mission pilots. This manuscript focuses on the study of taskload assessment methods, aircraft specification compliance, handling qualities flight test, operational mission requirements, and future design considerations in an effort to discover ways of reducing cockpit workload. As a result of the studies, it was determined that the easiest and least expensive method to reduce pilot workload would be the incorporation of an automatic flight control system into the A/MH-6 aircraft. Hence, this manuscript concludes that installation of an Astronautics Corporation 3-axis autopilot is the foremost solution for taskload reduction.

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AC	Advisory Circular
ACAH	Attitude Command and Attitude Hold
ADI	Attitude Direction Indicator
ADS	Aeronautical Design Standard
AFCS	Automatic Flight Control System
AH	Attack Helicopter
ARTI	Advanced Technology Program
ASE	Automatic Stabilization Equipment
CDI	Course Deviation Indicator
CFR	Code of Federal Regulations
CH	Cargo Helicopter
CG	Center-of-Gravity
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FARP	Forward Area Refuel Point
FLOT	Forward Line of Troops
GPS	Global Positioning System
HSI	Horizontal Situation Indicator
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
KCAS	Knots Calibrated Airspeed
KIAS	Knots Indicated Airspeed
MD	McDonnell Douglas
MH	Mission Helicopter
MDHC	McDonnell Douglas Helicopter Company
MIL SPEC	Military Specification
MIL STD	Military Standard
NDI	Non-Developmental Item
NOE	Nap of the Earth
NVG	Night Vision Goggle
OH	Observation Helicopter
PH	Position Hold
RCDH	Rate-Command with (Direction) Heading Hold
RCHH	Rate Command and (Height) Altitude Hold
SAS	Stability Augmentation System
SCAS	Stability and Control Augmentation System
SHSS	Steady Heading Side Slip

LIST OF ABBREVIATIONS (continued)

SOAR	Special Operations Aviation Regiment
SOP	Standard Operating Procedure
STC	Supplemental Type Certificate
TRC	Translational-Rate-Command
UCE	Usable Cue Environment
UH	Utility Helicopter
VCR	Vibration Cue Rating
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

Chapter 1

INTRODUCTION

Background

After the failure of Operation RICE BOWL, the attempted U.S. hostage rescue in Iran in April 1980, the United States Army was tasked by the National Command Authority (NCA) to develop an organic rotary-wing aviation capability which could operate effectively during the hours of complete darkness. The NCA determined the interoperability between the services was too vast to overcome and a more cohesive organization with internal assets would be the optimum solution. In other words, the Army would provide internal helicopter support for its' own assaulting forces. The mission would be to return to Iran and make a second attempt to rescue the hostages.(Snyder, 1997)

The U.S. Army began testing and evaluation to develop the required special operations aviation capabilities. Volunteers were chosen to form Task Force 158 and develop tactics, techniques, and procedures for aviation in special operations mission profiles. The 101st Airborne Division (Air Assault) at Fort Campbell, Kentucky provided the UH-60s and CH-47s while the Army National Guard initially provided the OH-6 light observation helicopters. The 101st was selected because it had recently fielded the UH-60

Black Hawk helicopter which was already proven to be extremely reliable and safe while conducting demanding missions. Additionally, the 101st possessed a large number of CH-47 medium-lift helicopters that could complement the smaller Black Hawks and agile OH-6. Beginning in June 1980, intensive training was conducted focusing on long-range, low-level, night flying with primitive full-faced AN/PVS-5 night vision goggles (NVGs). (Nightstalker, 1997)

The mission requirements were to provide precision landing capabilities, provide covering or preemptive gunfire and provide observation of the enemy in the immediate objective area. The landings required placing troops on building rooftops, flat or pitched, or onto moving vehicles. The OH-6 aircraft, modified to carry 2.75-inch rockets and 7.62-millimeter gattling guns, were to provide precision gunfire. Pilots of the gun-ships additionally provided the observation and reporting. The mission additionally required using no lights, while flying single-pilot, using only primitive NVGs. (Snyder, 1997)

The testing and evaluation resulted in the development of the OH-6 light-helicopter company, the extended range and lift UH-60, and the extended range FARP capable CH-47. Upon resolution of the hostage crisis in early 1981, the Army recognized that it took a great deal of time, training, and resources to develop the unique capabilities to accomplish a special operations mission. The Army also realized there might not be sufficient time to prepare and respond to future crisis. The decision was therefore made to form a standing Army Special Operations Aviation Task Force known as Task Force

160 consisting of volunteers from Task Force 158th. The 160th quickly established a reputation in the Special Operations community as a unit that could deliver: always at the right place at the right time with the right assets. On 1 April 1982, Task Force 160 was designated as the 160th Aviation Battalion and subsequently became the 160th Special Operations Regiment. Noteworthy however, the 160th has continued to be referred to as Task Force 160 to this day.(Nightstalker, 1997)

Accomplished Missions

In 1987, Operation PRIME CHANCE (1987-1989) was initiated to protect ships passing through the Persian Gulf. The 160th participated through sustained nighttime operations while supporting a joint military task force under very difficult and hazardous conditions. Aircrews of the 160th habitually operated from small deck ships 30 feet above the water at night with very limited visibility using night vision goggles. Instrument flight capability and proficiency were a necessity. Operation PRIME CHANCE resulted in the first successful night combat engagement that neutralized an enemy threat while using aviator night vision goggles and forward looking infrared devices. The 160th presence deterred numerous attacks on international shipping and slowed the mine-laying process. Once again the 160th proved to be a decisive weapon with international implications.(Nightstalker, 1997)

160th Special Operations Mission Requirements

The 160th must be proficient and capable of deploying worldwide at a moments notice. Additionally, the 160th pilots must be proficient and capable at a variety of special mission tasks. The primary missions of the A/MH-6J helicopters (Figure 1.1.) are to support specified missions of the U.S. Joint Special Operations Command. In the execution of these missions, the aircraft and crew must be capable of both unopposed and opposed low altitude insertion and extraction of special warfare personnel. The missions require operation in both the over-land and over-water environment, and are performed primarily at night using night-vision goggles and at extremely high gross weights. Crews are subsequently trained to be proficient in pinpoint-accuracy, low-level terrain navigation, close formation flight, confined area landings, suppressive fire techniques, small-deck shipboard landings, and precision night hovering also both over-water and over-land. The terrain may range from remote desert, vast ocean, ragged mountains, or congested urban area of large cities. At all time the pilots are required to maintain flight at the minimum altitude conceivable, both to minimize radar tracking and to aid in terrain contrast. All of these flight regimes require significant out-the-window visual tasks. Proficiency in the use of NVGs is considered essential to safe accomplishment of the mission.

A typical mission, if there is one, could last 6-8 hours with only refueling stops lasting only 1-2 minutes each. The pilot must fly the aircraft, monitor the engine instruments,

Figure 1.1. AH-6 Special Operations Helicopter.

monitor the flight instruments, maintain ground clearance and execute pinpoint-navigation using a hand-held-map. These missions are accomplished as the single-pilot maintains continuous hands-on-the-controls flight, during the hours of darkness, possible combat environment, at maximum gross weight, all while using night vision goggles.

Night Vision Goggles

Night vision goggles (NVGs) were developed in the early 1970s for ground vehicle operators and were later adapted for aviation. The NVGs used a rectangular-box type faceplate for supporting the image intensifying tubes. This faceplate blocked ALL peripheral vision, critical for flying a helicopter. The tubes provided minimal light intensification in low illumination. NVGs provide a monochromatic image of the scene by intensifying available light to provide an image that is visible to the human eye. Their effectiveness is related to ambient illumination. Areas with low visual contrast are difficult to discriminate and, if ambient light goes below the goggle's threshold, the pilot sees "sparkles." Conversely, very bright light sources automatically reduce their gain, limiting overall scene definition. This automatic adjustment is necessary to reduce the risk of "blooming" or "whiteouts" caused by extremely bright lights. However, such automatic adjustments can reduce display gain to the point that pilots lose all external visual-flying references.[Hart, 1984] When weapons are fired or any sudden source of light energy occurs (explosions, searchlights, etc.), the NVG's automatic gain immediately causes a "shutdown" of the tubes thus removing all visual reference from the pilots for two to-three seconds. This shutdown occurs every time the gun-ship's weapons systems are fired.(Snyder, 1997)

At best, visual acuity with NVGs is half as good as with the unaided eye and their field of view is only 40 degrees. Because their resolution is relatively poor, tasks that require the precise use of visual cues are preformed more poorly, maneuvering capabilities are limited and pilot workload is increased exponentially. Furthermore, distant objects appear to be smaller and further away (although NVGs provide 1:1 magnification), causing pilots to overshoot approaches and terminate approaches in a high hover. This problem is moderated however through experience. (Hart, 1984)

The original full-faced AN/PVS-5 NVGs are focused to optical infinity and must be refocused or removed to view cockpit instruments, therefore increasing transition times. Today however, the aviator night vision imaging system (ANVIS), which is designed for pilots (Figure 1.2.), is positioned several millimeters away from pilots' eyes (so they can look at instruments beneath the goggles), and the material around the goggles is cut away to allow unaided peripheral vision.(Nagel, 1988) The new ANVIS goggles relieved the peripheral vision problem thereby relieving the cockpit work load as to allow instruments and maps to be viewed directly.

The Army today incorporates workload factors into risk analysis and crew rest guidelines, reflecting the inherent dangers of the NVG environment. The factor for

NVG flight is currently 2.3 for every hour flown. Expressed in flight hours, the Army considers NVG flight 2.3 times as stressful as unaided day flight.

Figure 1.2. Aviator Night Vision Goggles (ANVIS).

Chapter 2

TASK LOAD REDUCTION

Introduction

In order to look at workload reduction, it is necessary to determine tasks required for mission accomplishment in the mission environment. This environment includes the aircraft and the pilot interface. A complete understanding of the aircraft including the pilot interfaces (i.e. cockpit and controls) must be included. The control description should include any AFCS system incorporated into or proposed for the aircraft. When a proposed system is used, it becomes necessary to specify compliance issues through flight test. This sequence if followed throughout this manuscript.

Army aviators, especially special operations helicopter pilots, operate in one of the most complex environments in today's world. Although special operation's helicopters are equipped with a variety of electronic navigation equipment (e.g., Omega, Doppler, INS, TACAN, and GPS), the primary tool used for navigation and geographical orientation is the hand-held map. During visual navigation, which is essential for low-level flights, pilots must correlate information from navigational instruments and maps with visual features in the terrain to maintain geographical orientation. This is a highly complex, demanding, cognitive task, requiring integration of map and navigational information with the dynamically changing, and often restricting out-the-window view. It requires the pilot to focus his visual attention on the immediate environment, to maintain flight path control and avoid obstacles, and relate information in the visual scene (a 3D, egocentric view) to remembered landmarks or those depicted on maps (a 2D, world view). [(Battiste, 1993)]

Non-linearity, combined arms and coalition operations and reliance on electronic information and digital inter-connectivity characterize the battlefield. Special operation's helicopter crewstation complexity has increased greatly. The number and complexity of avionics and mission equipment subsystems installed on the aircraft has grown dramatically. This proliferation has lead to an interface crisis because the aviator must use and respond to a large number of diverse subsystems.[(Vienneau 1987)] To avoid crew information and tactile overload, a comprehensive approach to rotorcraft subsystem and information management is needed.

Workload Analysis

During the last twenty years or so, the need to assess pilot workload during flight has become an important factor in the development of new aircraft, systems, and operating procedures. For many years, the most used technique for assessing workload in flight has been some form of subjective reporting by experienced pilots. However, this technique is somewhat vulnerable to perceived ideas and to bias and so the use of an additional, more objective, measure would seem to be necessary if the acquisition of misleading data from inappropriate reporting is to be avoided. To date there are no widely recognized methods to objectively assess a pilot's in-flight workload outside a laboratory. There is however, a large variety of subjective techniques used in assessing the pilot's workload. These techniques range from the Cooper-Harper scale, NASA's TLX (Task Load Index), NASA's Bipolar Rating Scale, and Advanced Technology (ARTI) program just to name a few.

The workload assessment methods described in this section were initially developed for, and used on, the Advanced Technology (ARTI) program. Although ARTI was only applied during daytime operations, the ARTI method more closely matched the special operations mission than any other test method available. ARTI focused on determining the feasibility of successful single pilot operation of Scout/Attack aircraft for Army missions of the 1990s. Task analysis, test pilot interviews and critiques by human factors experts were an integral part of the entire workload assessment in determining a task analysis measurement.

As alluded to previously, workload is one of those soft human-factors concepts, like motivation, that is inferred to exist by observing the relative behavioral reactions to certain conditions. It is a qualitative concept that is not reflected in any universally accepted units of measure. A working definition of workload is therefore presented and utilized throughout the estimation and measurement processes.

> Workload - the number of tasks done per unit time modified by the level of difficulty, stress and fatigue.[Vienneau,1987]

Although human beings have an intuitive understanding of workload and can recognize when their workload is too high, mental workload is difficult to define. Additionally, it must be noted that there is no simple relationship between emotional state and the characteristics of a mission. The same mission can be a threat or a challenge. Positive expectations of being able to handle a situation are helpful and negative expectations may reduce tolerance of frustration. Stress of any kind can make a threat out of a challenge.(Svensson (1994)

Workload Measurement

Although the abstract nature of workload defies an exact definition, let alone measurement, it is essential, when conducting controlled experiments, to be capable of quantitatively assessing workload. The ARTI workload definition was used to define a set of measurables that could be assessed. The concept of a "unit task" was introduced, which would be considered the fundamental unit of workload for the purpose of experimentation. The experiments were divided into part-task and full-mission experiments. The part-task experiments were used to exploit the impact of specific automation features on pilot workload and system performance. In these part-task experiments, the pilot's objectives for the mission were to reach the destination by way of a predetermined flight route in a minimum amount of time while conducting routine communication tasks. The entire route took place in a simulated high threat area mandating nap-of-the-earth (NOE) flight. Checkpoint-dependent altitude restrictions were also incorporated to ensure high workload. The experiment was conducted using both manual navigation and automated navigation. Full mission experiments were also conducted to assess the overall pilot workload and system performance throughout the mission. The mission was an all-encompassing mission. The mission began with the pilot departing the Forward Area Arming and Refueling point (FARP) with four-wingman enroute to the Forward Line of Troops (FLOT). The pilot navigates to the battle position where he engages several threats and is then called to provide support and coordinate the pickup of personnel at a nearby location by a utility helicopter. After the pickup, the pilot escorts the utility helicopter as they return to the FARP. (Vienneau, 1987)

The measurables were tallied in real-time throughout the mission, yielding a taskload profile curve. After processing the real data, the taskload profile was differentiated to obtain the workload profile. Finally, these profiles were collected and analyzed so that results could be obtained. (Vienneau, 1987)

ARTI Results

The part-task investigations provided insight into the impact of automating the aircraft controls, navigation and communication task on pilot workload and system performance. The automated system was instrumental in reducing both the average workload and the maximum workload by 23% and 17%, respectively, as well as decreasing time enroute by 70%. Flight path deviation also improved significantly. The average and maximum deviation improved 69% and 65%, respectively. (Svensson, 1994)

The ARTI experiments were conducted during daylight conditions. The added difficulties of NVGs would greatly increase the workload and by using the Army crew endurance method, by at least a factor of 2.3. The workload for the 160th mission pilot is the highest conceivable workload environment. Automation during NVG flight operations should consequently reduce the workload by an even greater amount than as did in the ARTI experiments.

The effect workload has on mission performance varies from aviator to aviator. Task performance greatly depends on the number of tasks, task combination, flight experience and resource demands. Adding automation increases the number of tasks performed by the system, which potentially reduces the task loading on the human. (Svensson, 1994) Automation such as an Automatic Flight Control System (AFCS) will aid to free the crew to more effectively prosecute the battle by managing the myriad of significant and insignificant data deluging the cockpit. AFCS integration will relieve the pilot of one or more piloting task so that a higher order of operational tasking can be assumed.

Aeronautical Design Standard (ADS-33)

The flying and ground handling qualities requirements for military rotorcraft are specified in the Aeronautical Design Standard (ADS-33). Compliance with the requirements is demonstrated using analysis, simulation, and flight test at the appropriate milestones during the rotorcraft design and development. ADS-33 requirements are predicated on a given usable cue environment, what can the pilot see visually either outside or inside the cockpit. Based on a determined UCE, a specified level of aircraft stability is required to accomplish each task at the designated level of performance.

From an ADS-33 standpoint, the acceptability of flying qualities of rotorcraft are quantified in terms of "Levels" that are defined for each specific mission task. Each value, or combination of values, represents a minimum condition necessary to meet one of the three "Levels" of acceptability (Figure 2.1.). The allowable limits in the operational flight envelope are "Level 1" for all flight conditions.

ADS-33 specifies flight control response-types for specific mission tasks. Response-type is defined as characterization of the rotorcraft response to a control input in terms of well-

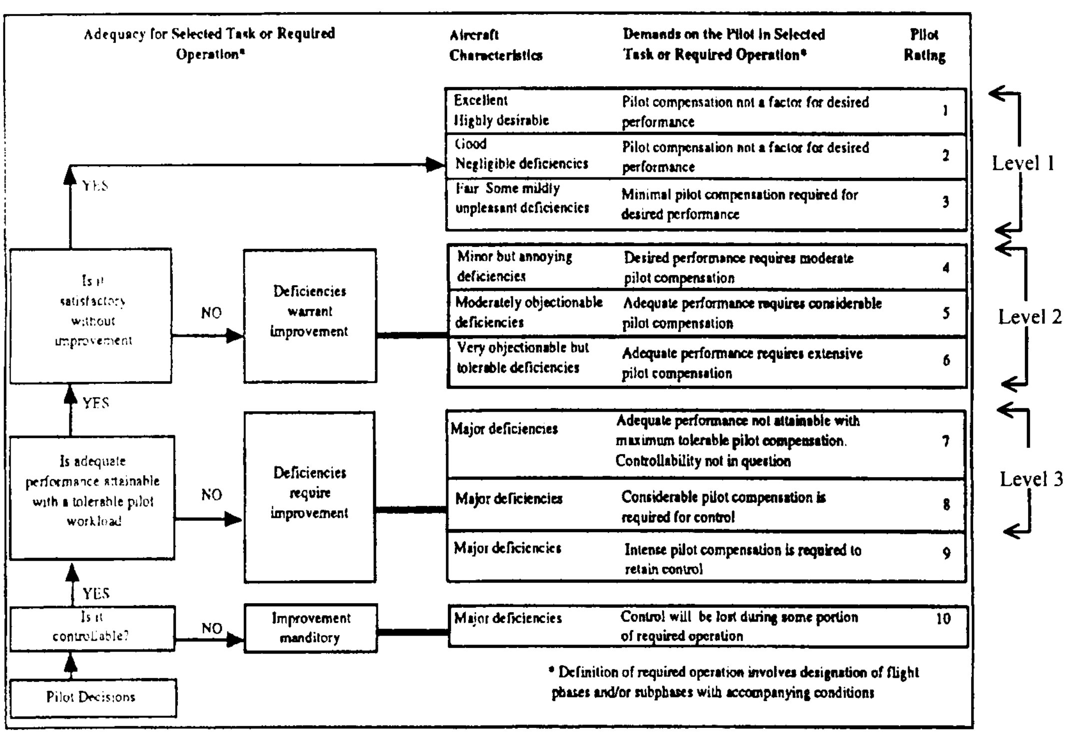


Figure 2.1. Definition of Flying Qualities Levels.

recognized stability augmentation systems (i.e. Rate, Rate Command/Attitude Hold, etc.). The required response-types are dependent on the Usable Cue Environments (UCE) resulting from mission visual environments, including vision aids and displays. The specified response-types are intended to be minimums allowable.

The response-types required for each mission task and UCE are specified for each axis of control for hover, low speed (Figure 2.2.) and forward flight (Figure 2.3.). It is recognized that maneuvering will, in general, be less aggressive in a degraded visual environment.

	UCE = 1		UCE = 2		UCE = 3	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Vertical takeoff and transition to forward flight - clear of earth.	Rate	Rate	Rate	Rate	Rate	Rate
Precision Hover. Slung load pickup and delivery. Slung load carrying. Shipboard landing including RAST recovery. Vertical takeoff and transition to near-earth flight. Hover-taxi/NOE-traveling. Rapid Slalom (note a).			ACAH+RCDH +RCHH	Rate+RCDH	TRC+RCDH +RCHH+PH	ACAH+RCDH +RCHH
Slope landing. Precision vertical landing. Pull-up/Push-over (note a).			ACAH+RCDH			ACAH+RCDH
Rapid Bob-up & Bob-down (note a). Rapid Hovering turn.			ACAH+RCDH +RCHH+PH			Rate+RCDH +RCHH+PH
Tasks involving divided attention operation (see Para. 2.5.2). Sonar dunking (note b). Mine sweeping (note b).	Rate+RCDH +RCHH+PH					
Rapid transition to precision hover (note a). Rapid sidestep (note a). Rapid accel and decel (note a). Target acquisition and tracking (note a and c).	Rate					

Figure 2.2. Required Response-Type for Hover and Low Speed Flight.

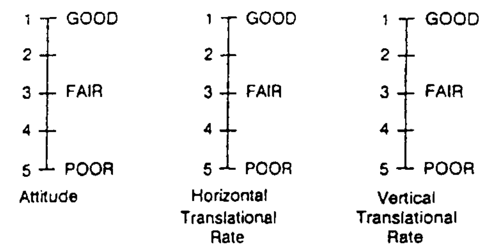
Pitch and Roll Attitude	
RATE	PITCH - RATE OR ATTITUDE, ATTITUDE HOLD REQUIRED (RCAH OR ACAH) ROLL - RATE WITH ATTITUDE HOLD (RCAH).
Ground attack Slalom Pull-up/Push-over Assault landing Sonobuoy deploy VMC cruise/climb/ descent Air combat	IMC cruise/climb/descent IMC departure IMC autorotation IMC approach (constant speed) IMC decelerating approach (3-cue flight director required) Air-to-air refuel Mid-air retrieval Weapons delivery requiring a stable platform

Figure 2.3. Required Response-Type for Forward Flight.

In determining the UCE, the displays and vision aids provided to the pilot shall be assessed to determine their effectiveness for stabilization and control. The UCE is defined using the visual cue ratings (VCRs) scale (Figure 2.4.) obtained from the UCE scale (Figure 2.5.) during the flight assessment. The VCRs are to be made by at least three pilots and the UCE shall be obtained by using the mean VCRs in the UCE scale. The test aircraft must meet the requirements for the rate response-type and have a Level 1 mean pilot rating.

Using the method specified above for the A/MH-6 in the following conditions, a UCE=2 was determined:

- Precision hover or target acquisition and tracking,
- Single-pilot using NVGs with 17% moon illumination and,
- Light turbulence and calm winds.



DEFINITIONS OF CUES

X = Pitch or roll attitude and lateral, longitudinal, or vertical translational rate.

Good X Cues: Can make aggressive and precise X corrections with confidence and precision is good.

Fair X Cues: Can make limited X corrections with confidence and precision is only fair.

Poor X Cues: Only small and gentle corrections in X are possible, and consistent precision is not attainable.

Figure 2.4. Visual Cue Rating (VCR). Used When Making UCE Determinations.

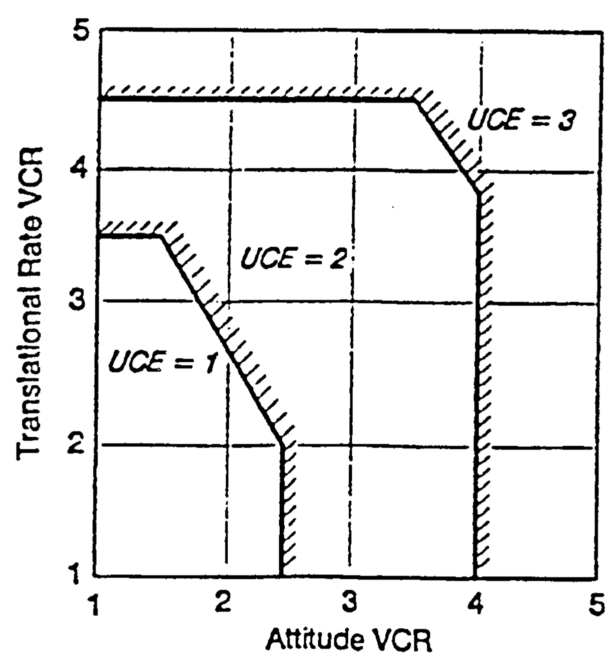


Figure 2.5. Definition of Usable Cue Environment.

In a degraded visual environment (Usable Cue Environment 2), for precision tasks of pitch pointing task (aerial gunnery) or precision hover operations (Rappelling), ADS 33 requires Attitude Command Attitude Hold, Rate Command with Heading Hold, and Vertical Rate Command with Altitude Hold for level 1 handling qualities. For level 2 handling qualities and a UCE=2, ADS-33 mandates at least a Rate Command system with Heading Hold.

The A/MH-6J has no response-type stability augmentation and therefore does not comply with the requirements of ADS-33. In order for the aircraft to meet the minimum requirements of ADS-33 for its designated mission, a Rate-Command, Heading Hold system should be employed.

Chapter 3

AIRCRAFT DESCRIPTION

Development History

The McDonnell Douglas MD 500 and A/MH-6 series helicopter have a history that dates back to the early 1960's. Originally designed and built by the Aircraft Division of Hughes Tool Company, the "Hughes 500" appeared as the result of a 1961 United States Army design competition for a light observation helicopter. Hughes' entry into this competition was a single-engine, turbine-powered helicopter called the OH-6A Cayuse. (Figure 3.1.) Specific design features of the Cayuse included a fully-articulated four-blade rotor system, two-blade tail rotor, 317 shaft horsepower Allison 250-C18A turbine engine and an empennage that utilized a vertical fin, short ventral fin, and upwardly canted horizontal stabilizer opposite the port-mounted tail rotor. The outstanding performance of the helicopter coupled with its ability to carry up to six crew members eventually led Hughes to a victory in the competition and in 1965 the U.S. Army placed an initial order for 714 OH-6A's. [Taylor, 1970]

During the spring of 1966, military and civilian pilots publicly demonstrated the performance capabilities of the Cayuse by setting 23 international records over a two-month period, including a non-stop straight-line flying distance of 2,213 miles and a

Figure 3.1. US Army OH-6A Cayuse.

maximum closed-course speed of 171.81-mph (149.3 knots). Not surprisingly, the military placed additional orders for the high performance helicopter, pushing the total up to 1,434 units with deliveries to be completed by August 1970. Such strong demand for the OH-6A by the U.S. military inevitable drew interest from foreign governments and the private sector, and in 1968 production began on the Hughes 500 and 500M helicopters for civil and foreign military customers, respectively.[Taylor, 1970]

Between 1968 and 1982, further improvements and modifications to the Hughes 500 helicopter led to the 500C and 500D versions. The first new version, the Hughes 500C, was produced through 1978 and came with an upgraded engine (the 400-shp Allison 250-C20) and improved hot-and-high performance. Its appearance, though, was virtually unchanged from the original Hughes 500. Remodeling the helicopter did occur, however, in 1975 with the introduction of the Hughes 500D. Obvious changes included a T-tail empennage with endplate fins for improved forward flight stability and a five-blade main rotor. The 500D package also included a more powerful 420-shp Allison-C20B engine and numerous performance improvements. Accompanied by the aviation boom of the late 1970's, Hughes sold over 1,000 500D helicopters between 1976 and 1981. Shortly thereafter, in early 1982, the next version of the helicopter, the Hughes 500E, was introduced. (Taylor, 1982)

In late 1982, the Hughes 500D was replaced by the 500E as the basic U.S. production version (Figure 3.2.). Boasting a more streamlined nose, new endplate fins for the horizontal stabilizer, new "T" grouping of flight instruments, and a number of interior refinements including increased passenger leg and head room, the Hughes 500E represented a significant improvement over its predecessors. Production of the model continued for more than decade with little change in design. In fact, the most notable change witnessed by this model occurred on paper when, in 1984, Hughes Helicopters Inc. became a subsidiary of the McDonnell Douglas Corporation. In 1985, Hughes Helicopters was renamed to McDonnell Douglas HelicopterCompany (MDHC) and the Hughes 500E adopted its current "MD-500E" designation. (Taylor, 1989)

The MD-530FF Lifter, first sold in 1984, is a specialized derivative of the MD-500E designed to operate at high altitudes and temperatures with the capability to carry external loads of up to 2000 pounds. On the military side, derivatives of both the MD-500E and 530FF existed as the 500MG Defender and 530MG Defender, respectively.

The U.S. Army has used nearly all versions of the MD-500 by the 160th Special Operation Aviation Regiment. The versions include converted OH-6As to AH-6C and MH-6B followed later by more converted OH-6A to AH-6C MH-6C. Eventually the U.S. Army purchased new-built MH-6E and AH-6F and AH-6G that were converted MD-500Ds. Other models include the MH-6H and the AH-6J. The models in operation today are the MH-6J and the AH-6J. The AH-6J is normally configured with 7.62mm mini-guns and 2.75-inch rockets while the MH-6J is configured for passenger transport.

Figure 3.2. MD-500E Helicopter.

Model Tested

The test helicopter is a highly modified Hughes 500D aircraft. The A/MH-6J utilizes the Hughes 500D airframe but is upgraded to the powertrain of the commercial MDHC 530FF. Modifications include longer main and tail rotor blades, extended tail boom, and an Allison Model 250-C30 engine.

The A/MH-6J (Figure 3.3.) is a multipurpose, turbine-powered light helicopter with a maximum cruise speed of 121 knots and service ceiling of 16,000 feet MSL. Capable of seating up to seven persons, the A/MH-6J is more commonly configured for a crew of two with two front seats and a rear cargo compartment. In the US military versions of the A/MH-6J, the right front seat is the pilot's seat. The rear seats can be removed and the back of the cabin used as a cargo area. Four doors (two on each side of the fuselage) allow for entry and egress of crew and cargo and are removed if desired. Transparent acrylic panels make up the cockpit windscreen and windows for the doors, allowing for a generous field-of-view. Forward of the seats and on the centerline of the aircraft is a T-shaped instrument panel. The horizontal portion of the panel houses various flight instruments, engine instruments, and warning indicators while the vertical portion of the panel is available for radios and circuit breakers. Additional avionics are located in the compartment space located beneath the floorboard of the pilot and front passenger positions.

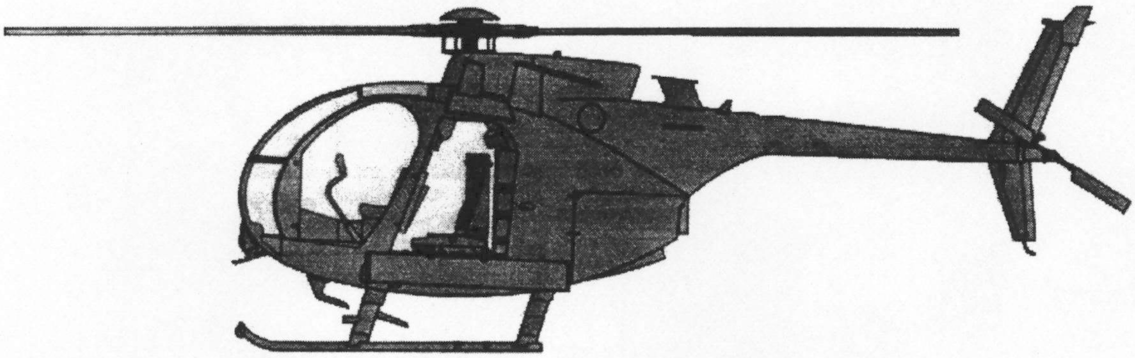


Figure 3.3. U.S Army AH-6J Helicopter.

The A/MH-6J fuselage is a semi-monocoque structure constructed primarily of aluminum alloy. It has a central framework consisting of a center beam, two bulkheads (one between the front seats, the cargo compartment, and one between the cargo compartment and the engine), and a mast support structure. The mast supports the rotor hub and absorbs the associated lifting loads. Similar to the fuselage, the tailboom is a monocoque structure of aluminum alloy frames and skin. It supports the stabilizers, tail rotor assembly, and tail rotor transmission. As a whole, the fuselage plus tailboom airframe rests on a non-retractable skid-type landing gear that is attached to the fuselage at twelve points (three attachments at each of four strut locations). Nitrogen charged dampers between the struts and the structure provide for cushioned landings and increased ground stability.

Housed at the juncture of the fuselage and tailboom is a 650 shaft horsepower Allison 250-C30 turbine engine. Clamshell doors forming the lower aft end of the fuselage allow access to the engine and its compartment. Fuel for the power system is drawn from two interconnected bladder fuel cells, one on either side of the aircraft centerline beneath the rear-seat floorboards, with a total capacity of 64 U.S. gallons. The engine transmits power to the rotors through an overrunning clutch (to allow for autorotation), drive shafts and two transmissions. The main transmission, located above the cargo compartment, distributes engine power to the main and tail rotors. The main rotor receives power directly from the main transmission by way of the main rotor driveshaft. The tail rotor, however, receives power from the main transmission through a tail rotor drive shaft and separate tail rotor transmission. Located at the aft end of the tailboom, the tail rotor transmission directly feeds the tail rotor assembly.

The two primary lifting and control mechanisms of the A/MH-6 helicopter are the main rotor and tail rotor assemblies. The main rotor group consists of five main rotor blades attached to a fully articulated rotor hub with offset flapping hinges. A scissors assembly, swashplate and associated mixer control mechanisms completes the arrangement. Rotation of the main rotor is counterclockwise as seen above per standard "American" rotation. The pilot's cyclic and collective controls yield authority over main rotor tilt and pitch, respectively, allowing for pitch, roll, horizontal and vertical velocity control over the aircraft. Somewhat more straightforward is the tail rotor group which consists of two variable-pitch blades attached semi-rigidly to a short output shaft belonging to the tail rotor transmission. Rotation of the tail rotor is counterclockwise as seen from the left side. The pilot's tail rotor control pedals, or anti-torque pedals, provide authority over tail rotor pitch which allows for directional control over the aircraft. Together, the main rotor and tail rotor assemblies provide the helicopter with six-degree-of-freedom motion capabilities and allow the pilot full control over the aircraft in all axes.

As briefly noted above, the pilot's controls consist of a conventional arrangement including cyclic control stick, anti-torque pedals, and collective control stick. The cyclic stick and anti-torque pedals are located directly in front of the pilot's seat, while the collective control is located to the left of the pilot's seat. The entire control system, from pilot to both rotors, is a solid mechanically linked type that uses tubular push-pull rods throughout. Hence, the control system is reversible (i.e. rotor moments are fed back to the pilot via controls). Hydraulic boost is not incorporated by any of the systems. However, the cyclic control stick, which provides lateral and longitudinal control over the main rotor, does employ a hydraulic one-way lock device on its longitudinal component. The lock device resists un-commanded aft movement of the cyclic stick (i.e. feedback from the main rotor) for positions aft of trim. The anti-torque and collective systems receive partial control assistance through the use of bungee springs. In the anti-torque system, a bungee spring resists right pedal movement to assist in anti-torque control and is set to provide zero pedal force in balanced cruise flight. In the collective system, the bungee spring is set to assist in movement of the collective away from the center or mid-pitch position.

As an aid to the pilot in forward flight, electric force trim has been incorporated into the cyclic control system. Two trim actuators are utilized for this purpose: one for the lateral cyclic control linkage and one for the longitudinal cyclic control linkage. The actuators employ pre-loaded springs to provide direct force feedback to the stick. Therefore, the cyclic stick moves in response to trim input. Control of either trim actuator is accomplished through a five-position thumb switch located atop the cyclic control grip (Figure 3.4.). Spring loaded to the off position (center), the switch allows movement fore and aft for pitch trim, and left and right for roll trim. With this system, lateral and longitudinal control forces can be trimmed to zero (absolute centering) throughout the speed range of the aircraft.

An important part of the A/MH-6 design is the horizontal and vertical stabilizing surfaces of the T-tail empennage section. Although immovable and hence uncontrollable by the pilot, the surfaces provide increased stability in forward flight. Directional stability is enhanced by the flat-sided, constant-thickness airfoil of the vertical stabilizer section that extends above and below the tailboom. The lower half of the vertical stabilizer serves to lower the center of pressure of the section for lateral-directional concerns and serves as a mount for the tail skid. Both the upper and lower portions of the stabilizer form an oblique angle with the tailboom that provides for increased effectiveness in climbing and descending flight. Attached to the top of the vertical stabilizer is the horizontal stabilizer section. Comprised of an inverted NACA 6518 airfoil, the horizontal stabilizer is designed to enhance the longitudinal stability

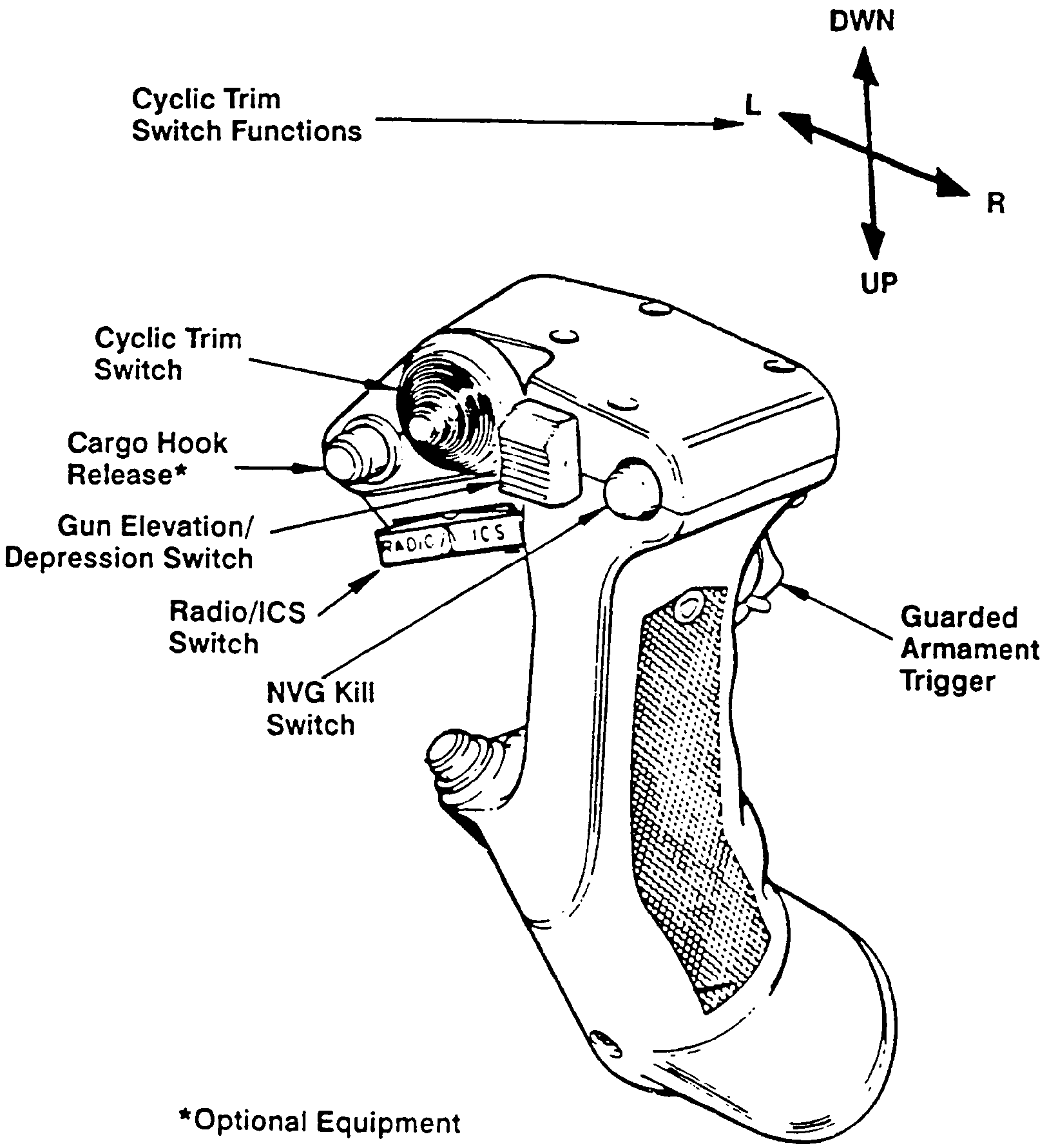


Figure 3.4. Pilot's Cyclic Control Grip.

characteristics of the helicopter. End plates on the horizontal stabilizer serve to increase the effective aspect ratio of the surface by a factor of approximately 1.4. Additionally, the center of the horizontal stabilizer is offset to the right of the aircraft centerline due to the mounting of the vertical stabilizer on the starboard side of the tailboom. This, too, serves an advantage since it places more of the horizontal stabilizer in the higher dynamic pressure flow field of the advancing rotor.[Prouty, 1990]

Baseline Aircraft

In 1993, the University of Tennessee Space Institute in Tullahoma, Tennessee performed an evaluation to demonstrate the single-pilot instrument flight capability of a modified civil MD-500E helicopter (Figure 3.5.). Aircraft modifications include the following:

- Installation of a 3-axis autopilot system with yaw stability augmentation system;
- Modified center console to place all avionics within reach of the pilot while sitting upright;
- Installation of an emergency electrical bus, a second battery, and a second inverter;
- Installation of a dual pitot-static system, one for instruments and one for the autopilot;
- Installation of a 5-inch attitude indicator with flight director; (Figure 3.6.)
- Installation of a stand-by attitude indicator and
- Installation of a radio-select switch on the cyclic.

Figure 3.5. Single-Pilot IFR Certified MD-500E.

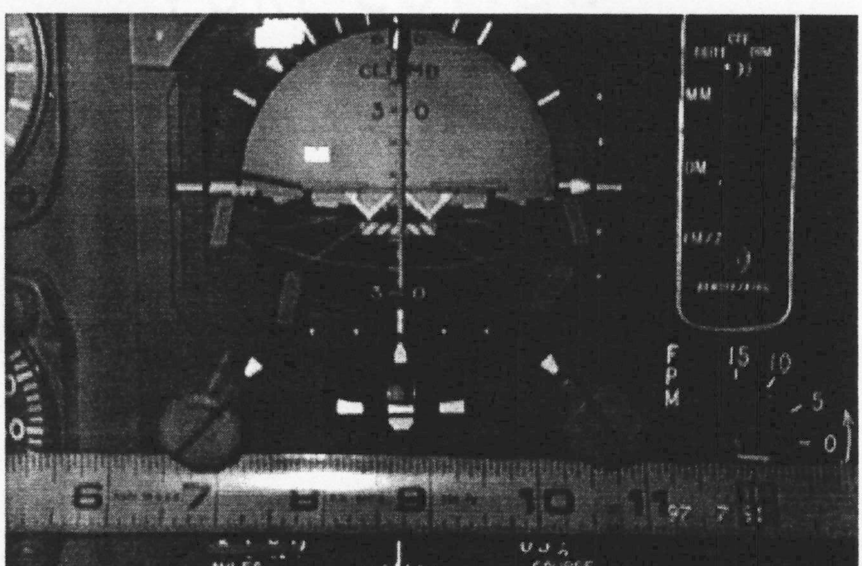


Figure 3.6. "5-inch" Attitude Indicator with Flight Director.

Without the use of the autopilot, the helicopter demonstrated stability and performance characteristics that met or exceeded the objective requirements of the Federal Aviation Regulations (FAR). Stability and control of the MD-500E was evaluated throughout the IFR envelope. Qualitative test included simulated instrument flight including precision approaches in both normal and degraded modes of instrument and flight operations.(Acree and Kimberlin, 1994) The evaluation concluded the MD-500E, as tested, met or exceeded all FAR requirements for single-pilot instrument flight. In late 1995, a Supplemental Type Certificate (STC) certifying single-pilot IFR flight operations was issued for the MD-500E. Noteworthy, the autopilot, except for the yaw damper, is not required for IFR flight and is considered a pilot "workload reliever."

AUTOMATIC FLIGHT CONTROL SYSTEM DESCRIPTION

Helicopter Automatic Flight Control System

The term AFCS (Automatic Flight Control System) has come to be applied to most forms of stability and control augmentation equipment. Acronyms have been assigned, coined in some cases, by various airframe and equipment manufacturers; ASE (Automation Stabilization Equipment) by Sikorsky, SAS (Stabilization Augmentation System) by Boeing Helicopters, and SCAS (Stability/Control Augmentation System) by Bell Helicopter. This equipment is installed to improve the basic flying qualities and handling qualities of the aircraft. Couplers and flight directors are at the top of the hierarchy of equipment that fall under the heading of AFCS. They provide for automatic flight path control with varying degrees of benefit, ranging from simple workload reduction to enhanced mission capability. (Green, 1996)

There are two basic reasons for incorporating AFCS; basic augmentation and coupled or automatic functions. Basic augmentation is incorporated to enhance inherent vehicle characteristics. These characteristics include; decouple collective to yaw, suppress divergent gust response, and/or provide static directional stability. Basic augmentation will also reduce the pilot workload during execution of short-term precision task such as sling loads, confined area hover, small ship landing or aerial gunnery. (Green, 1996)

Coupled or automatic functions enhance precision and/or reduce long term workload. These functions will permit the man-machine to accomplish a task which otherwise is not possible. Additionally, automatic functions will relieve the pilot of one or more piloting tasks so that a higher order of operational tasking can be assumed. (Green, 1996)

There are various definitions and concepts normally associated with AFCS.

Short-term verses Long-term – Short-term response generally refers to the initial motions that are the results of gust inputs, pilot control or AFCS input. The period between zero and five seconds is clearly in the short-term domain. Long term response generally refers to the motions of the aircraft that follow initial responses. The period subsequent to eight seconds is clearly the long-term domain.

Stability verses Control Augmentation – Considering basic AFCS functions, control augmentation involves sensing of control displacements with resultant feed forward or lagged signals. Stability augmentation refers to all devices which enhance stability but which do not involve cockpit position sensing.

Open Loop verses Closed Loop – When referring to pilot involvement, one can picture the pilot participating (closed loop) or observing only (open loop).

Inner Loop verses Outer Loop – An inner loop input typically accomplished via series actuators that do not move the controls while outer loop inputs are accomplished via parallel actuators which move one or more of the pilot's cockpit controls.

Split Axis – When an AFCS is designed to operate in two or more axis, and one of these fails or is secured, continued operation with the remaining axis on line is referred to as split axis operations. (Green, 1996)

FAA Requirements

The FAA requires that if an AFCS stabilizes the helicopter by allowing the pilot to "fly through" and perceive a stable, well-behaved vehicle, it qualifies as a stability augmentation system and, if reliable, receives credit for use in complying with all handling qualities requirements. If the AFCS does not provide a "fly through" capability or allow the pilot to perceive a stable, well-behaved vehicle through controls, then it tends to remove him from active involvement in flying and is eligible as a workload reliever. (AC 27-1, 1985)

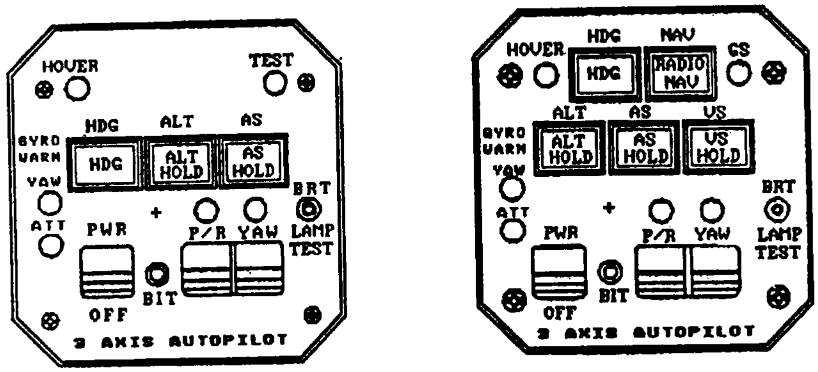
Astronautics Autopilot System Description

The 3-Axis Autopilot System provides attitude retention with automatic trim in pitch, roll and yaw in cruise mode and pilot-managed trim for the three axis in hover mode. The principle function of the 3-Axis Autopilot System is to stabilize the aircraft to reduce pilot fatigue and workload during all phases of flight. The control of the collective remains a closed-loop task.

The basic system, part number 155450-1, includes Heading Hold (HDG), Altitude Hold (ALT HOLD) and Airspeed Hold (AS HOLD) submodes to provide steering to a selected heading with either altitude or airspeed retention.

The advanced system, part number 147640-1, additionally provides for coupling to radio navigation equipment (VOR, ILS, or GPS) as well as providing flight director and deviation indicator drivers. It also adds a Vertical Speed Hold (VS HOLD) submode to provide vertical speed retention. Except where these submodes are concerned, the operation of the coupled and uncoupled versions is identical. The Control Panel/Coupler (Figure 4.1.) augments the basic system with the addition of the RADIO NAV pushbutton and VS HOLD pushbutton. This panel also provides a glideslope indicator which indicates glideslope capture and contains electronics to provide flight director coupled and uncoupled modes.

The autopilot system (Figure 4.2.) consist of a remote autopilot computer, three parallel actuators (pitch, roll and yaw), yaw series actuator, sensors for airspeed/altitude and lateral acceleration, yaw-rate gyro and a control panel. The autopilot receives pitch attitude, roll attitude, vertical speed datum, heading datum, course datum, lateral deviation, vertical deviation and related data from other systems in the aircraft. Autopilot Disengage (A/P DIS) and Heading Set (HDG SET) pushbuttons are located on both pilot cyclic sticks. The pilot's A/P DIS pushbutton is an alternate action switch and the co-pilot's A/P DIS pushbutton is a momentary action switch. The Instantaneous Vertical Speed Indicator speed selection knob, Horizontal Situation Indicator course and heading selection knobs and radio receiver controls are also used to control the autopilot. The autopilot outer-loop is limited in authority in roll to 30 percent of full travel and in pitch to 52 percent of full travel around the cyclic control stick position when the



Control Panel, part number 155450-1 Control Panel/Coupler, part number 147640-1

Figure 4.1. Autopilot Control Panels.

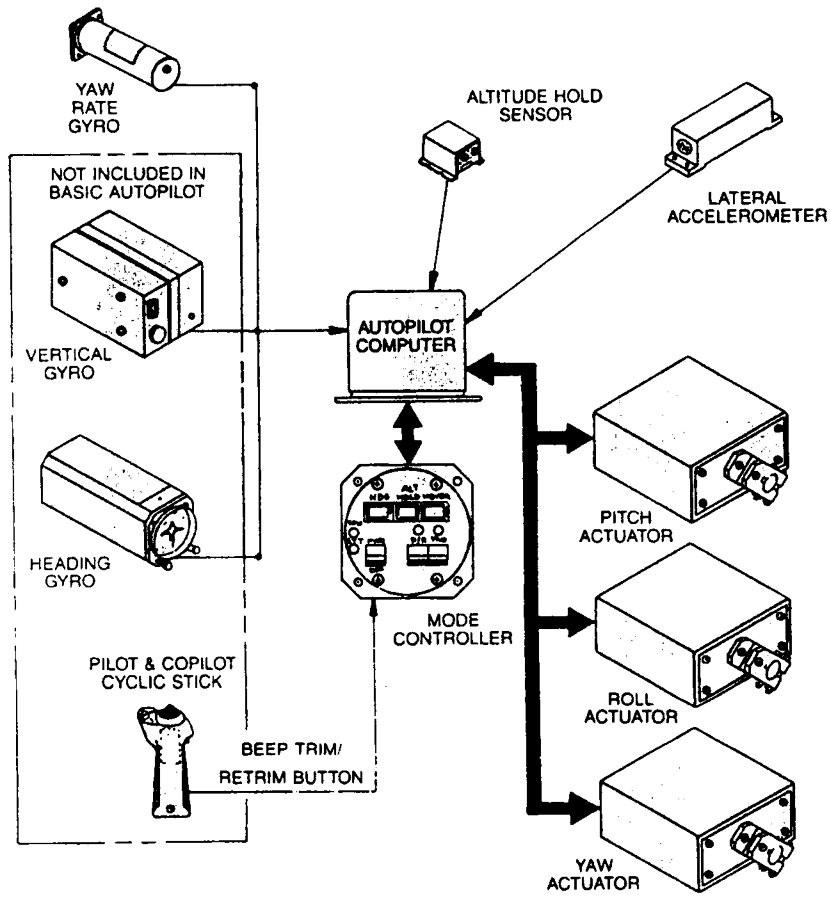


Figure 4.2. Astronautics Autopilot Components.

autopilot Pitch/Roll mode is engaged. Optimum autopilot engagement position is the cyclic control neutral position although the autopilot may engage at any cyclic position. An applied force to the cyclic of 5 increasing to 10 pounds backs up the actuator motors causing a current over 1 ampere which will activate the aircraft trim system. Force gradient indicates system operation. To override the pitch and roll actuator clutches, the cyclic may be forced beyond the autopilot stops with approximately 22 pounds force on the stick. The pitch and roll actuator clutches are opened and the actuators centered anytime the P/R mode is disengaged. The P/R mode is disengaged anytime the pilot's A/P DIS pushbutton on the cyclic grip is pressed and released, or the co-pilot's A/P DIS pushbutton on the cyclic grip is pressed and held. The Pitch/Roll (P/R) mode will re-engage at the cyclic stick position when the pilot's A/P DIS pushbutton is re-activated (pressed and released a second time) or when the co-pilot's A/P DIS pushbutton is released. The P/R mode is also disengaged anytime the P/R switch on the control panel is set to off. The P/R green light on the control panel will extinguish anytime the P/R mode has been disengaged and the aircraft will be trimmed for existing flight conditions.

The autopilot has full authority in the yaw axis through the yaw parallel actuator. The yaw series (inner-loop) actuator has 10 percent of total authority in the yaw axis and is used to dampen high frequency component of yaw rate. The yaw series actuator reacts to input from the yaw rate gyro in hover and through the autopilot computer in cruise. The autopilot computer washes out yaw rate gyro inputs in cruise to allow smoother turns. The yaw series actuator also reacts to input from the lateral accelerometer in cruise through the autopilot computer to provide for coordinated turns. Upon autopilot initiation, the yaw rate gyro is powered to operating speed and the yaw parallel actuator motor is inhibited. When the YAW switch on the control panel is set on, the yaw parallel actuator retains pedal position. When an applied pedal force exceeds the breakout force threshold, seven pound positively increasing to eleven pounds, the pedal position adjust to a new trim position proportional to the applied force and hold the new trimmed position. The yaw series-actuator position feedback changes pedal position to restore average yaw series actuator operation about its center position. Approximately 40 pounds of applied pedal force will override the yaw force feel actuator clutch. When the YAW switch is set to off, a spring in the aircraft linkage deflects pedals left with force of 15 pounds.

Flight director and deviation outputs are continuously available for the applicable modes on the panel/coupler. With the Flight Director Coupler (FDC) coupled/uncoupled switch on the aircraft instrument panel, selecting uncoupled operation allows flight director and deviation cues to be flown manually through the cyclic beep switch system while the autopilot continues to provide attitude retention and stabilization. Selecting coupled operation couples the autopilot actuators to the selected mode.

Updates to the System

The Astronautics Corporation AFCS major components include a control panel, computer, computer mount, roll actuator, pitch actuator, series yaw actuator, parallel yaw actuator, rate gyro, altitude sensor, and an accelerometer. The weight penalty due to the AFCS installation in the MD-500E, as currently installed, is 42 pounds. Since the installation into the MD-500E, there have been updates to the AFCS system in an effort to reduce the overall weight. Updates include the integration of the computer into the control panel. This computer integration saves five to six pounds over the original configuration. Thus, the computer integration no longer requires the mounting space for the computer or the computer mount. Additional updates to the system include reduced weight actuators. The weight reduction is accomplished by using the actuator-motor frame as a structure while additionally drilling holes in distinct places throughout the actuator mounts. The updated actuators reduce the actuator weight approximately two to three pounds each. The total weigh reduction as a result of the updates to the system is approaching twelve pounds. As a result of the weight reduction, the total system weighs approximately twenty-three pounds. In the event of a yaw SAS only installation, the total system weight would be less than six pounds. A table of the autopilot components and weights are provided in Appendix B as Table B.1 and B.2.

Chapter 5

FLIGHT TEST RESULTS AND DISCUSSION

Purpose

The purpose of the flight test was to determine compliance with 14 CFR Part 27 Appendix B airworthiness criteria for normal helicopter category instrument flight and to verify similarity with the previously tested single-pilot IFR certified MD-500E. During this flight test, the handling qualities of the AH-6J helicopter were evaluated at various weight and center-of-gravity configurations in an effort to parallel the MD-500E initial IFR flight test.

General

Although the yaw SAS is required for IFR flight, the handling qualities of the MD-500E met the Part 27 Appendix B criteria with the AFCS disengaged. Testing with the AFCS disengaged precluded requiring the full AFCS for IFR operation. Additionally, this allowed for similarity testing of the AH-6J that has no AFCS installed.

No deficiencies were identified in accordance with 14 CFR Part 27 Appendix B criteria. The overall handling qualities were degraded at maximum gross weight due to pitch sensitivity at high load factors, control feedback forces, and rotor speed variations.

Dynamic stability testing identified an easily excited neutral to lightly damped long-term pitch oscillation during descent.

Trimability

During the handling qualities evaluation, the trimability characteristics of the flight control system were evaluated. During each maneuver, pilot trim system control inputs were accomplished through the "beep" switch located on the pilot and copilot cyclic stick. Upon activation of the "beep" switch, a noticeable ½ second delay occurred before relief of undesirable control forces. The forces could be trimmed to zero at all airspeeds in compliance with 14 CFR Appendix B to Part 27 (III).

Mechanical Characteristics

Cyclic control-system mechanical characteristics were evaluated during ground runs and in stabilized in-flight conditions in all configurations. The lateral and longitudinal cyclic control force gradient was positive in that increasing control force was required for increasing control deflection. Friction was minimal and break out, including friction, was approximately one pound. Total system free play was ¼ inch and centering was strongly positive.

Static Longitudinal Stability

Static longitudinal stability characteristics were evaluated in high altitude level flight, level flight, 1000-feet-per-minute (fpm) descents, and 3-degree approach configurations at the conditions presented in Appendix CD, Table C.3. Data are presented in Appendix D

Figure D.1. Positive static longitudinal stability near trim was exhibited, for all flight configurations, as indicated by the requirement for increasing forward longitudinal control displacement with an increase in airspeed. The gradient of longitudinal control position with airspeed was low in all configurations. Pitch attitude, control forces, and control displacement cues to an off trim condition in a speed range of ± 20 knots from trim were small yet clearly perceptible to the pilot. The test data parallels the flight data for both the MD500E and the AH-6G previously tested. The static longitudinal stability complies with 14 CFR Appendix B to Part 27 (IV) in that stick force increases with increasing or decreasing speed and the control displacement cues to an off trim condition are clearly perceptible to the pilot.

Static Lateral-Directional Stability

Static lateral-directional stability characteristics were evaluated in level flight, 1000-fpm descents and 3-degree approach configurations at the conditions presented in Appendix CD, Table C.4. Data are presented in Appendix D, Figures D.2 and D.3. The aircraft exhibited positive static directional stability at all conditions tested, as indicated by increased left directional control with increased right sideslip, and right directional control with left sideslip. Strong positive dihedral effect was indicated by increased right lateral control with increased right sideslip, and increased left lateral control with left sideslip. Sideforce cues were weak about trim as evidenced by small change in roll attitude with sideslip. Sideforce cues became more evident as the sideslip increased away from trim. Longitudinal cyclic movement with sideslip was not excessive throughout the speed ranges. The static lateral-directional stability complies with 14 CFR Appendix B to Part 27 (V) in that static directional stability was positive and no adverse lateral stability was exhibited. The data also parallel the flight data for both the MD500E and the AH-6G previously tested.

Dynamic Longitudinal Stability (Short Period)

The short-term dynamic stability was evaluated during level flight, 1000-fpm descents, and 3-degree approaches and the conditions presented in Appendix C, Table C.5 The short-term dynamic stability characteristics were evaluated following single axis, 1-hertz, 1-inch cyclic doublets. Following the input, all controls were held fixed until the motion subsided or until recovery became necessary. There was no apparent coupling to the lateral-direction axes from the longitudinal doublets or the short-term response. Oscillations damped to ½ amplitude in one cycle or less. The short period stability complies with 14 CFR Appendix B to Part 27 (VI)(1) in that dynamic longitudinal stability short period was well damped with all configurations damping to ½ amplitude in one cycle or less. The data are comparative to the flight data for both the MD500E and the AH-6G previously tested.

Dynamic Longitudinal Stability (Long Period)

The long-term dynamic stability was evaluated during level flight, 1000-fpm descents, and 3-degree approaches and the conditions presented in Appendix C, Table C.5. The data are presented in Figure D.4. The long-term longitudinal characteristics were evaluated by decreasing airspeed 10 knots from trim then returning and fixing the controls at the trim position while observing the aircraft response. The phugoid periods ranged from 12 to 30 seconds depending on the configuration. In the 1000-fpm descent configuration the long-term longitudinal stability indicated an easily excited neutral to lightly damped long-term pitch oscillation having a period of 12 seconds independent of center-of-gravity or gross weight. This oscillation does not create a problem for the pilot. The long period stability complies with 14 CFR Appendix B to Part 27 (VI)(b)(1-3) in that all phugoids examined during this test were lightly damped or oscillations having a period of 10 seconds or more did not achieve double amplitude in less than 10 seconds. These data are similar to the flight data for the AH-6G previously tested.

Dynamic Lateral-Directional Stability (Dutch Roll)

The dynamic lateral-directional stability was evaluated during level flight, 1000-fpm descents, and 3-degree approaches and the conditions presented in Appendix C, Table C.5. The dynamic lateral-directional stability characteristics were evaluated by displacing the aircraft from trim with a one-inch, ½ Hz pedal doublet and observing aircraft response. The aircraft was not instrumented to record ϕ to β ratio so the values for ϕ to β ratio were taken from cockpit indications. This evaluation indicated all dynamic lateral-directional stability configurations were well damped. The dutch-roll motion was predominately in yaw, with a very small degree of coupling to the lateral axis. In every configuration tested, in compliance with 14 CFR Appendix B to Part 27 (VI)(1), oscillations damped to ½ amplitude in one cycle or less. These test data correspond to the flight data for both the MD500E and the AH-6G previously tested.

Spiral Stability (Aperiodic Response)

The spiral stability was evaluated during level flight, 1000-fpm descents, and 3-degree approaches and the conditions presented in Appendix C Table C.5. The data are presented in Appendix D, Figure D.5. The spiral stability characteristics were evaluated by displacing the helicopter from trim, using the cyclic control, rolling into a 10 degree bank, stabilizing momentarily, returning the controls to the trim position and observing the aircraft response. The apparent spiral mode for the aircraft is neutral. The spiral stability complies with 14 CFR Appendix B to Part 27 (VI)(5) in that any aperiodic response may not achieve double amplitude in less than six seconds. These data are similar to the flight data for both the MD500E and the AH-6G previously tested.

Conclusions

The static longitudinal control force stability was positive in all configurations tested as was the static directional stability. The aircraft exhibited positive lateral stability throughout the control motion or force. The short-term was well damped and predominately deadbeat. All long-term motion was lightly damped. The dynamic lateral-directional characteristics resulted in two to three oscillation peaks, mostly in yaw, that damped to ½ amplitude in one cycle or less. The apparent spiral mode was neutral in every configuration tested.

The handling qualities of the AH-6J helicopter were evaluated for various weight and center-of-gravity configurations and through flight-testing it was determined that it complies with the FAA's airworthiness criteria for normal helicopter category instrument flight. Additionally, the flight test verified similarity to previously tested flight data of the MD-500E currently single-pilot IFR certified.

Chapter 6

FUTURE DESIGN CONSIDERATIONS

Introduction

The future design considerations for the A/MH-6 aircraft include the possibility of incorporating a tail rotor canted fifteen degrees down to the left. The objective of the tail rotor canting consideration would be to resolve problems that currently exist with the limited aft center-of-gravity range. Additionally at high power settings, their exist within the current tail rotor design, a deficiency where small tail rotor movements often cause the tail rotor to flap beyond the allowable limit.[Webre, 1989] Tail shaft inclination from horizontal provides a vertical upward component of tail rotor thrust which improves performance and may expand aft center-of-gravity limits while also reducing the excessive tail rotor flapping.

Proponents of this concept cite the advantages as the more efficient use of hover power. The canted tail rotor thrust vector has an upward component providing the ability to trim with a center-of-gravity position behind the main rotor. Additionally, the canted tail rotor may alleviate un-commanded aircraft motion in sideward flight due to vortex ring state of the tail rotor. A canted tail rotor may also reduce the probability of tail rotor flap stop contact. The primary disadvantage is the development of off-axis response with control and rate inputs. Off-axis coupling can be mechanically compensated for in one flight condition. Deviations from this design configuration will result in unwanted coupling to the un-augmented aircraft. "Although the UH-60A control and AFCS design solved the coupling problems associated with the canted tail rotor, the feeling is that unless forced into an aft center-of-gravity problem by other constraints, the canted tail rotor should not be considered." (Gerdes, 1983) To maintain the existing MD-500 airframe, the 160th may be forced into the canted tail rotor design in an effort to extend the aft center-of-gravity limit and reduce the chance of tail rotor flap stop contact.

Coupling Moment Derivatives

Because the helicopter's asymmetric configuration, inter-axis response or coupling is a significant factor in assessing flying qualities. Main rotor torque changes and tail rotor vertical positions are substantial contributors. As an example, main rotor torque changes resulting from collective and inflow change produce yawing moments. High tail rotor thrust lines produce roll moments, as a minimum, with directional control inputs.

A method to assess coupling effects is to consider the flight condition and control effects on the moment equations. Coupling moment derivatives encompass roll moment (L), pitch moment (M), and the yaw moment (N).

In the discussion of the equations of motion for a helicopter, a basic sign convention specifying the parameters in the equations of motion is defined in Figure 6.1.

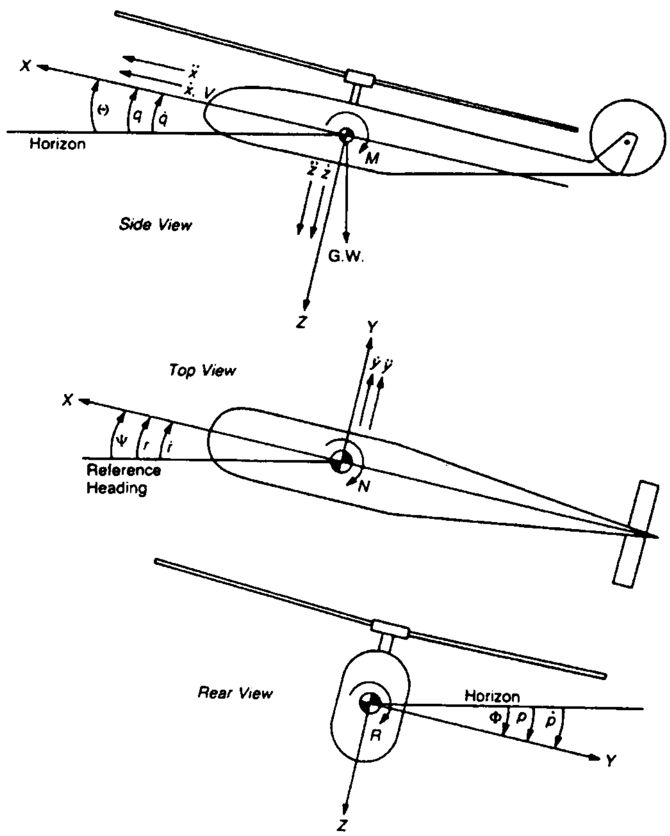


Figure 6.1. Parameters in the Equations of Motion.

Coupling due to roll moment is more predominant when the tail rotor thrust line is above or below the center-of-gravity. Yaw moment is not a prominent contributor since most yaw rates are normally very low. The prevailing contributor due to tail rotor cant is the pitch moment(M).

Coupling moment derivatives encompass pitching moment due to tail-rotor pitch angle ($M_{\theta TR}$) where a positive change in tail rotor pitch results in a upward (+) pitching of the nose of the aircraft. Additionally, pitching moment due to positive lateral velocity or sideslip results in a pitch up. For an aircraft with the tail rotor above the center-of-gravity, pitching moment due to positive yaw of the aircraft results in a reduced thrust that in turn causes a pitch up. The results of these coupled longitudinal derivatives are due to the inclination of tail rotor thrust vector out of the vertical plane (Figure 6.2.).

$$M_{\theta TR} = \frac{1}{I_{yy}} l_t \frac{\partial T_{TR}}{\partial \theta_{TR}} \sin \; i_{TR}$$

$$M_V = \frac{1}{I_{yy}} \times \frac{\partial a_{1s}}{\partial v}$$

$$M_r = \frac{1}{I_{yy}} \times \frac{\partial a_{1s}}{\partial r}$$

Where:

$M_{\theta TR}$	Pitching moment due to tail-rotor pitch angle.
M_V	Pitching moment due to lateral velocity or sideslip.
M_r	Pitching moment due to yaw.
I_{yy}	Moment of inertia about the y axis, pitch moment of inertia.
l_t	Distance from the tail to the center-of-gravity.
T_{TR}	Tail rotor thrust.
θ_{TR}	Tail rotor pitch angle.
a_{1s}	Longitudinal flapping angle.
v	Lateral velocity.
r	Yaw rate.
i_{TR}	Tail rotor inclination out of vertical plane.

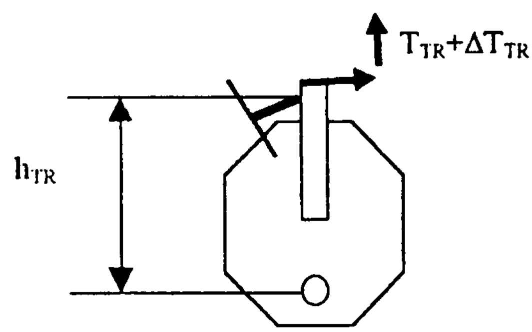


Figure 6.2. Roll and Pitching Moments due to Tail Rotor Thrust. Canted Configuration.

Discussion

Various helicopter configurations incorporate combinations of longitudinal shaft tilt, lateral shaft tilt, and tail inclination. Tail inclination from vertical provides a vertical upward component of tail rotor thrust to improve performance and may expand aft center-of-gravity limits. The canted tail rotor produces pitching moments when tail rotor thrust is changed. Tail rotor thrust changes also cause rolling moments if the tail rotor axis is not vertically aligned through the center-of-gravity. The moments generated and the aircraft angular acceleration depend on the time development of the flight parameters and control inputs. A method to eliminate the inter-axis coupling manifested by these designs, mixing of the cockpit control inputs is performed prior to their application at the flight control servos. Another is to minimize the effects of aircraft coupled motion through stabilization. Coupling generated by helicopter flight conditions variables for configurations with main rotor shaft tilt and /or canted tail rotors generally are not compensated by the mechanical mixing unless properly scaled flight conditions signals are provided to appropriate AFCS. (USNTPS, 1995)

The A/MH-6 currently does not incorporate an AFCS and no AFCS is intended for the future design A/MH-6 encompassing the canted tail rotor. As briefly summarized above, the effects of coupling will demand a solution to compensate for the off-axis coupling.

Specification Requirements

Existing specifications for helicopters are very general regarding coupling.

MIL-H-8501A states:

"For all operating conditions, longitudinal, lateral, directional, or vertical control motions shall not produce adverse response of helicopter due to mechanical coupling in the control system".

MIL-F-83300: states:

"Control inputs or aircraft motions about a given aircraft axis shall not induce objectionable control forces or aircraft motions about any other axis."

"The application of any cockpit control input necessary to meet any pitch, roll or yaw performance requirement of this specification shall not result in any objectionable aircraft attitudes or angular rates about the axes not under consideration."

ADS-33 states:

"Control inputs to achieve a response in one axis shall not result in objectionable responses in one or more of the other axes."

Limits on what is "adverse" or "objectionable" are not quantified. Any evaluation of coupling effects on mission suitability/acceptability is therefore subjective. (USNTPS, 1995) The mission determines the maneuvers flown thus the mission suitability is the ultimate reason for conducting any handling qualities evaluation.

Based upon the mission requirements of the 160th A/MH-6 aircraft, canting the tail rotor out of the vertical plane will require special consideration and flight-testing. The AH-6 gun-ship will need special consideration for tracking tasks and maneuverability while the MH-6 lift aircraft will require close attention to maneuvering or out-of-ground effect hovering tasks.

An example of a typical AH-6 mini-gun or rocket engagement is presented below:

The aircraft approaches the target at low level and high speed. As the aircraft nears the objective, the pilot aggressively pulls aft on the cyclic to increase altitude and decelerate maintaining power constant (collective fixed). The pilot then aggressively pushes the cyclic forward to engage the target from overhead thereby increasing the accuracy of the engagement. He then aligns the aircraft with the target and begins firing. When the firing of the weapons commences, the aircraft yaws and pitches from the motion produced from the weapons. The pilot then attempts to realign the aircraft with the target and completes the engagement run. Once the engagement dive is complete, the pilot violently rolls and pitches the aircraft to laterally displace himself from the exploding objective.

As you can visualize from the just described engagement, to analyze the encounter one uses all available coupling derivatives. From analyzing of the coupling derivatives of the maneuvers of this engagement, it is evident that the effects of off-axis coupling created from a canted tail rotor will demand a solution for compensation. Incorporation of an AFCS would be the only practical solution.

Chapter 7

CONCLUSIONS

160th Mission Requirements

The 160th A/MH-6 mission dictates that the basic aircraft weights remain as light weight as possible to therefore increase payload all while operating at the maximum allowable gross weight. Each additional pound of equipment installed on the aircraft will therefore require a tradeoff in either fuel or payload.

The handling qualities requirements for military rotorcraft are specified in the Aeronautical Design Standard (ADS-33). ADS-33 mandates, for a UCE=2, Attitude Command Attitude Hold, Rate Command with Heading Hold, and Vertical Rate Command with Altitude Hold for level 1 handling qualities. For level 2 handling qualities, ADS-33 mandates at least a Rate Command system with Heading Hold.

The A/MH-6J has no response-type stability augmentation and therefore does not comply with the requirements of ADS-33.

Workload Analysis

"Reduction of crew workload" is used increasingly as a rationale for the development of sophisticated and expensive cockpit systems. Such a rationale is futile, unless the precise need for this reduction can be defined, and the desired improvement can be shown to have been achieved as a result of the new development. It follows that quantifying workload is pointless unless the data can be readily applied to the improvement of cockpit design. Whatever the results and conclusions of a workload reduction application conclude, its result should aid in effective mission task execution.

Divided-attention task is defined as "The pilot flying the rotorcraft is required to perform non-control-related sidetasks for a moderate period of time"[(ADS 33, 1994)]. Because the mission of the A/MH-6 mission is invariably a divided-attention task; it requires considerable cockpit organization. The mission dictates a high stress and high workload environment. Efficient interaction between the aircrew and cockpit systems reduces the likelihood of errors, and thus leads to enhanced safety. [(Davies, 1994)]

The workload of the A/MH-6 aviator is extremely high and needs to be reduced. Every item on the aircraft has been updated through the years as technology progressed (GPS, Argus 7000, increased horsepower, etc.) yet the handling qualities of the A/MH-6 have never been addressed. The handling qualities must be addressed in an effort to reduce the crew workload and thus enhance safety and increase mission effectiveness.

Flight Test

The results of the flight test of the AH-6J aircraft confirm that the handling qualities are comparable to that of the IFR certified MD-500E. The handling qualities, for all configurations tested, were commensurate and in compliance with the requirements of 14 CFR 27, App. B.III through VI criteria. Noteworthy however, although the flight test data from the MD-500E complied with the FAA Part 27 Appendix B criteria for IFR certification, one of the two FAA test pilots stated that the "pitch attitude, control forces, and control displacement cues to an off trim condition were not clearly perceptible to the pilot" as required by FAA Part 27 Appendix B (IV). As a result of this development, IFR certification was initially denied. To aid in stability and attempt to convince the one FAA test pilot, the yaw SAS made a IFR required item and an "equivalent level of safety" was requested and subsequently granted. The "equivalent level of safety" was granted based on the inherent stability of the aircraft and ease of control during simulated IFR as a result of the cues from the large "5-inch" attitude indicator.

NDI Solution

Automatic functions enhance precision and/or reduce long term workload. These functions permit the man-machine to accomplish a task which otherwise is not possible. Additionally, automated functions relieve the pilot of one or more piloting tasks so that a higher order of operational tasking can be assumed.

Research indicates only one company exists with a 3-axis automatic flight control system (AFCS) certified for IFR operations in a MD-500 series aircraft. The Astronautics Corporation 3-Axis system provides attitude retention with automatic trim in pitch, roll and yaw in cruise mode and pilot-managed trim for the 3-axis in hover mode.

Because the A/MH-6J has no stability augmentation system, installation of an Astronautics Corporation automatic flight control system into the A/MH-6 aircraft is the proposed non-developmental item (NDI) solution for task load reduction for the 160th Special Operations Aviation Regiment A/MH-6 mission pilots.

AFCS greatly alleviates workload and allows the pilot to thoroughly assess mission progress and system operation, thus enhancing flight safety. Incorporation of an AFCS will allow compliance with ADS-33 while enhancing crew performance and mission execution.

Hardware Trade-off Analysis

The existing system, as on the MD-500E, incorporates two yaw actuators; a series in the tailboom and a parallel under the right pilot footwell. The parallel actuator is a force-feel actuator with fly-through capability weighing approximately 11 pounds. This actuator provides heading hold while in hover and trimmed and coordinated flight in cruise. Without the parallel actuator, the series actuator will provide in-flight trim. The series actuator receives input from a rate gyro (Electronic Quartz Crystal, no moving parts) and a side accelerometer. Additionally, the yaw series actuator provides yaw damping as necessary to aid in reduction of off-axis coupling, gust damping, and yaw as a result of asymmetric gunnery operations. The series actuator weighs only 2.9 pounds. Based on the A/MH-6 mission weigh restrictions verses high weight of the parallel actuator, the parallel actuator should not be utilized in the A/MH-6 installation. Sacrificing the parallel actuator will only eradicate heading hold operations, which is not a mode extremely beneficial for the A/MH-6 aircraft. The total weight reduction as a result of the system updates, and the exclusion of the parallel actuator, is nearly 23 pounds.

Required Integration

The Astronautics Corporation currently has a design and installation proposal to install their updated and certified MD500E/530F AFCS into the US Army A/MH-6 aircraft. The installation process is merely a "bolt on" installation. With the incorporation of the computer into the control panel, mounting space for the remaining components are currently available in both the AH and the MH-6 aircraft. In addition, with the incorporation of the computer into the control panel, comes a redesigned control panel that is placed into a rectangular-shaped case and mounted either horizontally (Figure 7.1.) or vertically (Figure 7.2.). Mounting locations include the center console or the side of the instrument panel.

Modifications include a series yaw damper in the tail boom which attaches in-line to the tail rotor control tube.. The pitch and roll actuators attach directly to the existing cockpit control. The remaining components are installed as per the installation drawings. A drawing of the component locations along with photographs of major component items are provided in Appendix E as Figures E1 thru E.15.

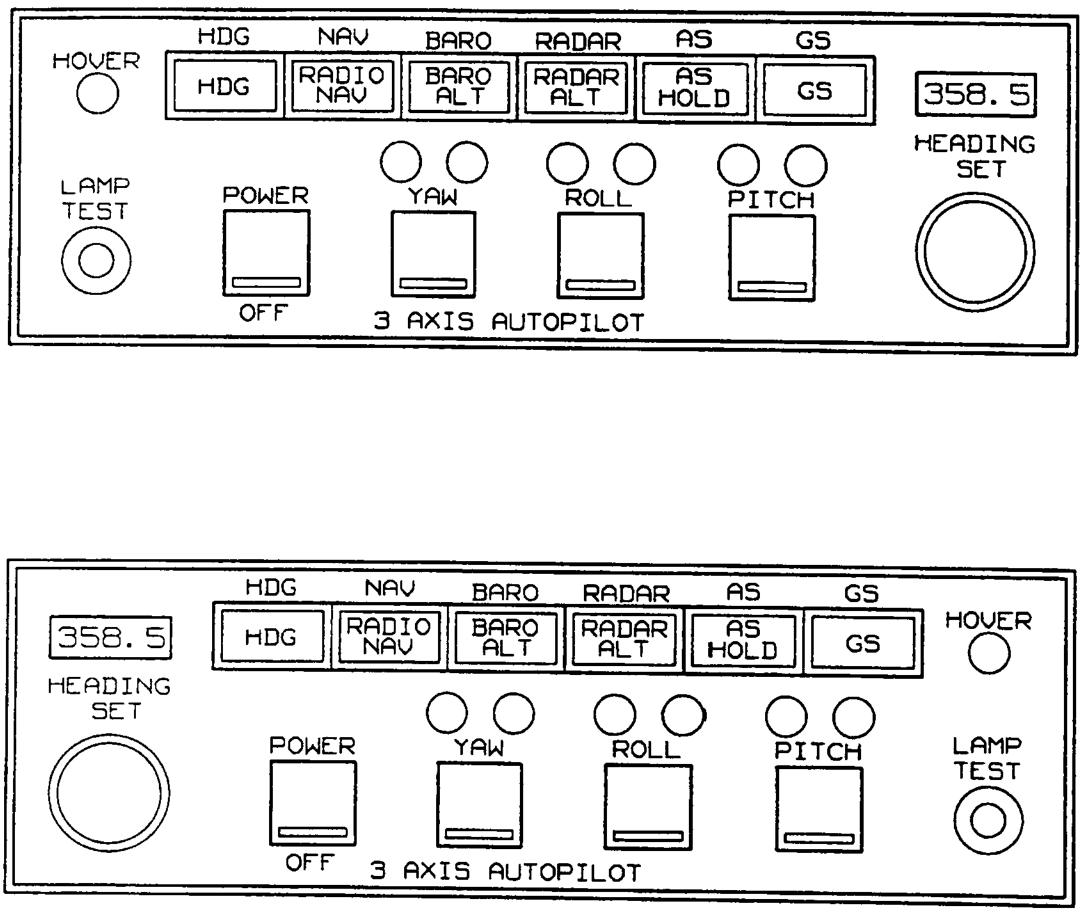


Figure 7.1. **Horizontal Options for the Integrated 3-Axis Autopilot Control Panel.**

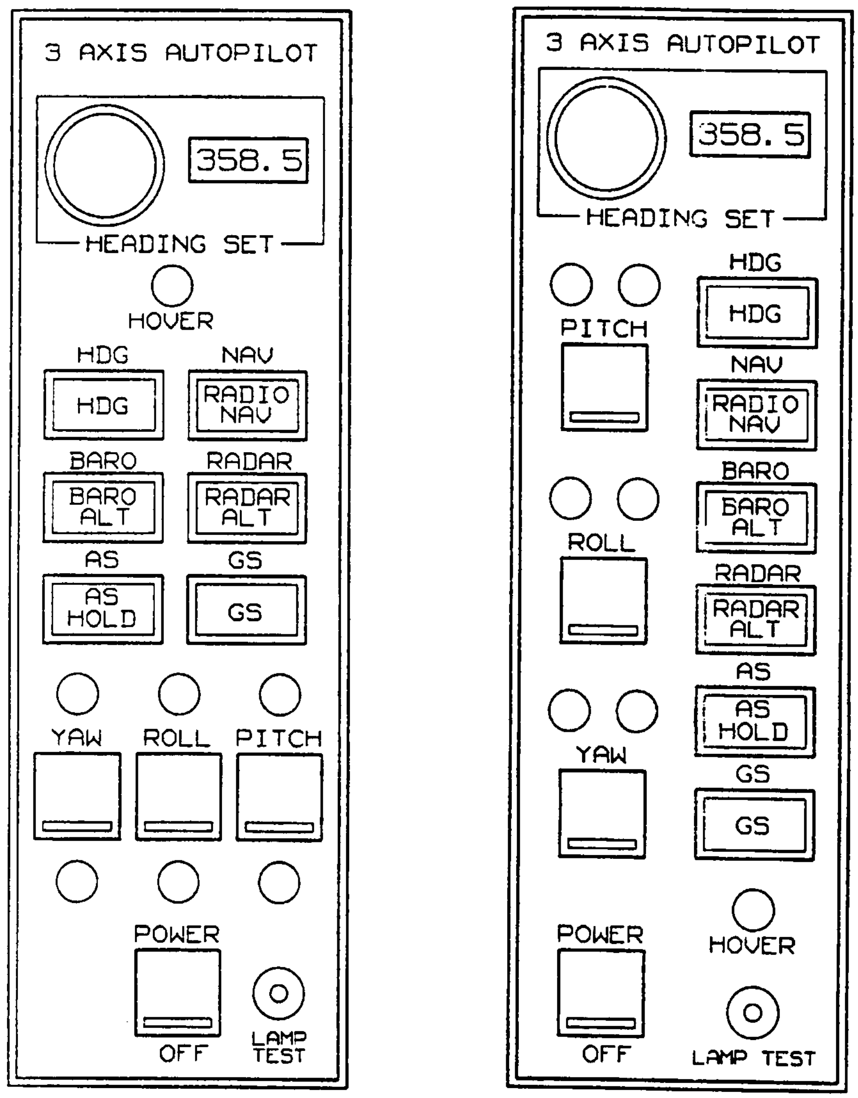


Figure 7.2. Vertical Options for the Integrated 3-Axis Autopilot Control Panel.

FAA requirements

As part of DOD 5000, acquisition streamlining is highly encouraged. As a part of this initiative, DOD is mandated to eliminate MIL STD and MIL SPEC and encouraged to utilize industrial specifications, ISO 9000. As an additional cost reduction technique, the services should buy Commercial off-the-shelf (COTS) items to preclude paying non-recurring developmental charges. This approach was taken when procuring the A/MH-6 aircraft. The FAA certified the original Hughes 500D and DOD accepted this certification in lieu of MIL SPEC compliance.

The Astronautics AFCS is FAA certified and can therefore be accepted by DOD based on aircraft similarity. Additionally, as with the MD-500E, for the A/MH-6 to meet the IFR certification requirements, the following modifications should be completed:

- Install a standby attitude indicator, [FAR 27 VIII a (2), 1992]

- Require a means in the generating system to automatically de-energize and disconnect from the main bus any power source developing hazardous overvoltage,[FAR 27 VIII b (2), 1992]

- "Should" provide for a capability to continue to the destination in the event of a single failure in the electrical system (i.e. second battery),[AC 27-1 (13)(i.), 1987]

- Install a separate pitot and static source for the autopilot and,[AC 27-1, 1987]

- Require an alternate static source for single-pilot IFR.[FAR 27 VIII b (5)(v), 1992]

Chapter 8

RECOMENDATIONS

As a result of the study on the taskload reduction, the ADS 33 handling qualities requirements, and the special operations mission requirements of the A/MH-6 helicopter, the following recommendations are made:

- Recommend installation of the updated/integrated Astronautics AFCS into at least one AH or MH-6 for a system-performance evaluation.

- If the complete 3-axis AFCS system is not selected for installation, at a minimum, a yaw SAS should be incorporated. While the weight penalty would be low, installation of a yaw SAS would greatly aid in elimination of yaw excursions and couplings, thereby reducing the overall pilot workload.

- Upon installation and initial system-performance evaluation, recommend an assessment by operational unit personnel take place to validate this study.

- During the current cockpit modernization effort, incorporate, as a minimum size, a 5-inch attitude indicator (ADI) to replace the 4-inch ADI presently installed. During restricted visibility or IMC flight, an oversized ADI is a significant aid to the pilot's trim effort task.

- Integrate the AFCS components, including a large attitude indicator, into future cockpit modernization efforts.

- If additional certification testing is required to FAA certify the integrated AFCS components, recommend the certification occur in the IFR MD-500E aircraft in an attempt to maintain the single-pilot IFR certification without extensive modification to the existing A/MH-6 aircraft.

- If the decision is made to introduce a canted tail rotor, an AFCS must be installed. Without an AFCS, off-axis coupling would make desired performance during aerial gunnery or precision hover during rappelling operations unattainable.

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APPENDICES

APPENDIX A

MD-500E and A/MH-6J Physical Data

Rotor Characteristics

	Main	Tail
Number of Blades	5	2
Rotor Diameter (ft)	27.35	4.75
Rotor Disc Area (ft^2)	587.5	17.72
Blade Chord (constant) (inches)	6.75	5.33
Blade Twist (deg)	9.5 washout	9.5 washout
Total Blade Area (ft^2)	38.46	2.10
Solidity (thrust weighted)	0.0653	0.1150
Airfoil Section, NACA	0015	63-415
Delta 3 (ft^2)	0	30
Droop Stop Flapping (deg)	-6	10 soft, 15 hard
Droop Stop Coning (deg)	0 static,	-2 rotating
Built-in Collective Pitch at 3/4 radius (straps untwisted, deg)	7.75	4.03
Flap Hinge Offset (inches)	6	-

Rotor Speed Limits

	MAIN ROTOR		TAIL ROTOR	
	(rpm)	(ft/sec)	(rpm)	(ft/sec)
Maximum Pwr Off				
Design	533	763	3182	791
Redline	508	727	3033	754
Minimum Pwr Off				
Design	390	559	2328	579
Redline	410	587	2448	609
Maximum Pwr On	477	684	2848	708
Minimum Pwr On	473	677	2824	702

Stabilizer Data

Horizontal Stabilizer P/N SKD-421-087-511

Span (ft)	5.33
Tip Chord (ft)	1.22
Root Chord (ft)	1.90
Area (ft^2)	8.18
Airfoil Root	NACA 6518 Inverted
Airfoil Tip	NACA 6515 Inverted

Figure A.1. A/MH-6J Dimensional Data.

Weights (lb)		Engines	
Empty	1,455	Type	Allison 250-C20B
Maximum takeoff	3,000	Number	1
Fuel capacity	416	Max. T.O. rating	420 shp
		Max. usable power	375 shp

Rotor Parameters		Main Rotor	Tail Rotor
Radius (ft)	R	13.2	2.3
Chord (ft)	c	.56	0.44
Solidity	σ	.068	.119
No. of blades	b	5	2
Tip speed (ft/sec)	ΩR	680	704
Twist (deg)	θ_1	-9	-8.6
Hinge offset ratio	e/R	.032	- - -
Airfoil		NACA 0015	NACA 63-415
Collective range (deg)		0 to 14.3	-13 to 27
Longitudinal cyclic range (deg)		-7 to 17	- - -
Lateral cyclic range (deg)		-8.5 to 5.5	- - -
Polar Moment of Inertia (slug ft^2)	J	263	.23

Stabilizer Parameters	Horizontal	Upper Vertical	Lower Vertical
Span (ft)	5.33	3.54	2.29
Tip Chord (ft)	1.22	0.94	0.59
Root Chord (ft)	1.90	1.27	1.27
Area (ft^2)	8.18	3.91	2.14
Airfoil Root	NACA 6518 Inverted	13.4% thick*	13.4% thick*
Airfoil Tip	NACA 6515 Inverted	18.3% thick*	28.0% thick*
Incidence	9° relative to hub plane	- - -	- - -
End Plates	(2) four-sided polygons	- - -	- - -
End Plate Total Area (ft^2)	2.38	- - -	- - -

*Vertical stabilizer is flat sided, constant thickness (2.06 inch) section.

Figure A.1. A/MH-6J Dimensional Data (continued).

Incidence (deg) (relative to hub plane)	8.92-9.42
Total Area of End Plates, (ft^2)	1.42 each

Upper Vertical Stabilizer - Portion above Centerline of Boom

Span (ft)	3.45
Tip Chord (ft)	0.94
Root Chord (ft)	1.27
Area (ft^2)	3.91
Airfoil Root	13.4 % thick- modified section*
Airfoil Tip	18.3 % thick- modified section*

Lower Vertical Stabilizer - Portion Below Centerline of Boom

Span (ft)	2.29
Tip Chord (ft)	0.59
Root Chord (ft)	1.27
Area (ft^2)	2.14
Airfoil Root	13.4 % thick- modified section*
Airfoil Tip	28.0 % thick- modified section*

* Vertical Stabilizer is flat sided, constant thickness (2.06 inches) section

CONTROL RIGGING, DESIGN

Main Rotor

Collective Pitch, Full Travel, min	14.25 deg (up to down)
Collective Pitch at Down Stop	0 to 3 deg. (ground adjustable) 0 to 3 deg (gnd adjustable)
Range of Cyclic Pitch Blade Angles from Neutral Rigging Position, minimum	Forward 17 deg Aft 7 deg Left 7 deg Right 5.5 deg

Tail Rotor

Range of Blade Pitch Angles at 3/4 radius (deg)	13 (right thrust) 27 (left thrust)

Figure A.2. MD-500E Dimensional Data.

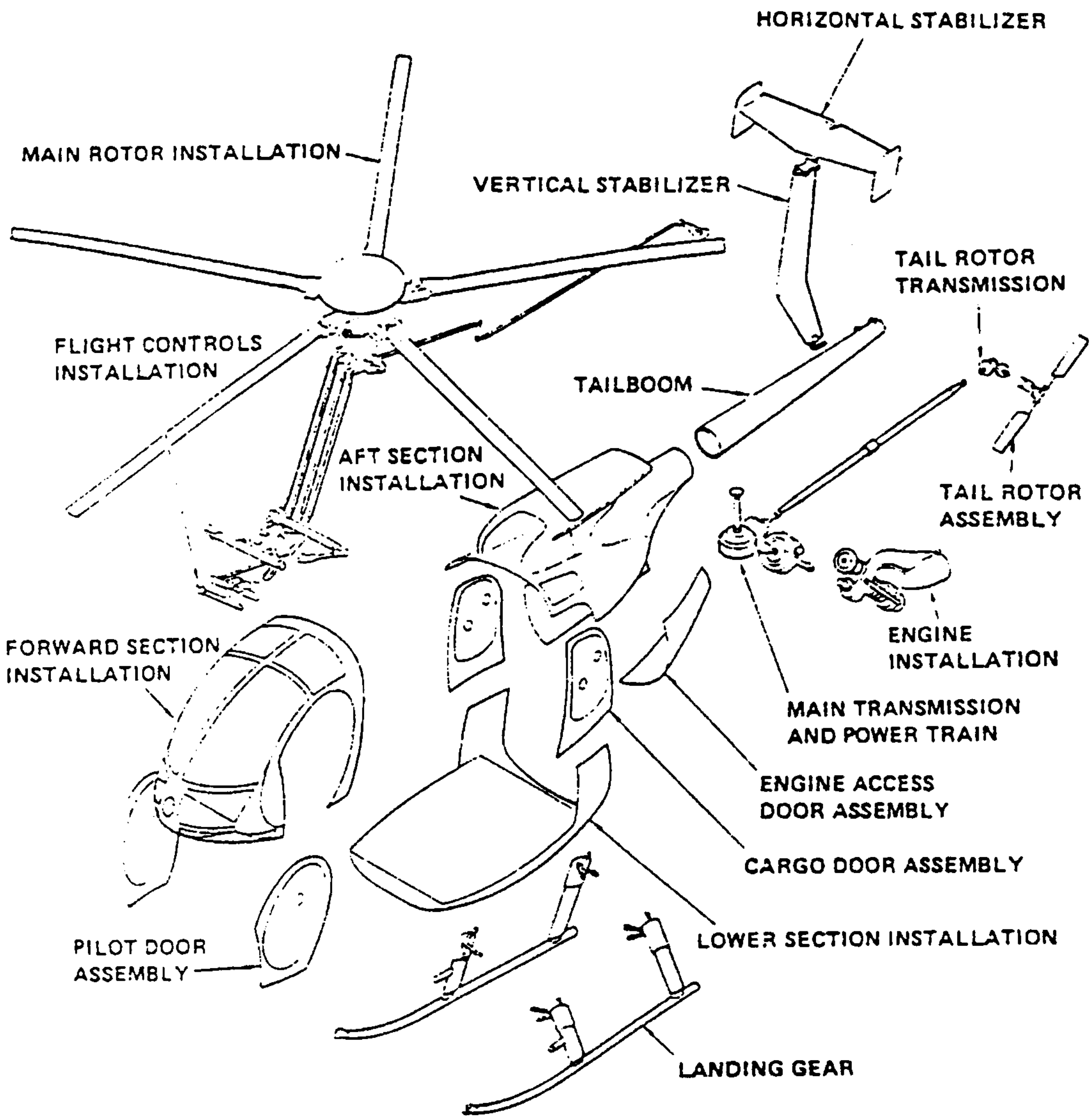

Figure A.3. MD-500 and A/MH-6 Major Components.

APPENDIX B

Weight and Balance

QUANITY	DESCRIPTION	WEIGHT
1	COMPUTER	5.0
1	ACCELEROMETER	0.2
1	ALTITUDE SENSOR	1.2
1	COMPUTER MOUNTING	0.7
1	CONTROL PANEL	2.6
1	ROLL ACTUATOR	6.3
1	PITCH ACTUATOR	6.8
1	YAW SERIES ACTUATOR	2.9
1	YAW ACTUATOR	11.0
1	HARNESS	4.1
1	RATE GYRO	1.0
	TOTAL	41.8

Table A.1. 131500-21 Autopilot MD-500E Installation.

QUANITY	DESCRIPTION	WEIGHT (full updated system)	WEIGHT (yaw SAS only)
1	COMPUTER/CONTROL	5.0	2.0
1	ACCELEROMETER	0.1	
1	ALTITUDE SENSOR	0.9	
1	ROLL ACTUATOR	4.3	
1	PITCH ACTUATOR	4.8	
1	YAW SERIES ACTUATOR	2.9	2.9
1	HARNESS	4.1	2.0
1	RATE GYRO	1.0	1.0
	TOTAL	23.1 lbs.	5.9 lbs.

Table A.2. Updated Autopilot MH-6 Installation with Yaw SAS Option.

APPENDIX C

TEST PLAN

TEST PLAN

PURPOSE:

The purpose of this test is to collect data for comparison to the MD-500E as tested to verify similarity with the A/MH-6J aircraft.

DESCRIPTION OF THE AIRCRAFT:

The aircraft to be tested is the U.S. Army AH-6J helicopter. The AH-6 helicopter is a derivative of the civilian equivalent MD-530FF. This versions intended use is for high altitude, high temperature, or heavy gross-weight operation. This turbine-powered helicopter has a five-bladed fully articulated main rotor and a two-bladed tail rotor. The control system, from cyclic to rotors, is a mechanically linked type that uses tubular push-pull rods throughout. Hydraulic boost is not incorporated by any of the systems. Hence, the control system is reversible in that the rotor hinge moments are fed back to the controls. The control stick does use a hydraulic one-way lock device on its longitudinal component. The lock resists un-commanded aft movement of the cyclic stick for positions aft of trim. For additional details see the AH-6J Operators Manual.

SCOPE OF THE TEST:

Test and test conditions are presented in Table C.1 thru C.3. The test will be conducted in mission configuration in accordance with the unit standard operating procedures. This configuration includes rocket and mini-guns mounted. Data collecting will be accomplished conducted during day, VMC conditions near the Tullahoma airport. The test will consist of 4 flights for a total of 4 flight hours. The test will be to verify compliance in accordance with FAR Part 27, Appendix B.

METHOD OF TEST:

The test will be conducted in accordance with the U.S. Naval Test Pilot Manual. The test matrix Table C.1 thru C.3 details the test to be conducted on each flight.

INSTRUMENTATION:

The following onboard instruments will be utilized:

Airspeed indicator
Altimeter
Altitude Indicator
Engine instruments (torquemeter, TGT, rotor & engine RPMs)
GPS display (groundspeed and Beta determination)

The following instrumentation will be installed for flight test:

Beta String & reference (marked to ± 10°)
Cyclic position (longitudinal and lateral tape measures)
Pedal position (floor marking)

Additionally, a hand-held force gauge, video camera and a stopwatch will be utilized. Illustrations of the installation is shown in Appendix F.

LIMITATIONS:

Limited to a low altitude test sight. Gross weight and CG matching to the nearest possible. The test is limited to test day conditions.

SAFETY:

All persons in and around the aircraft will remain clear of the tail rotor at all times when the rotors are turning. Persons will approach and retreat from the aircraft at a forty-five degree angle from the nose.

Qualified and current pilot required performing the test flight. Observe normal operating limitations. Maintain proper lookout doctrine. Maintain situational awareness. Prior to dynamic maneuvers, the test pilot will conduct controllability checks. All operations will be conducted in accordance with unit SOP, aircraft operator's manual, and any applicable airworthiness release. In the event of an in-flight malfunction the test pilot will execute the appropriate procedure in accordance with the aircraft operators manual.

Observe the response during the maneuver; however, analyze the response and make comments both oral and written after the recovery is complete.

Test	Objectives	Methods	FAR Requirement
Trimability	Ability to zero control forces		27B: II
Mechanical Character	Near-trim breakout & freeplay	Force & displacement	AC27-1: b.(2)
Static Long Stability	Discrete points & free returns	Force vs. airspeed	27B: IV
Static Lat.-Dir. Stability	Steady Heading Sideslips (SHSS)	Forces, sideslip, bank & coupling	27B: V
Short Period	Pitch doublets	Damping & frequency (w/video)	27B: VI (1)
Phugoid	"Gust" pitch attitude excitations	Damping & frequency	27B: VI (4)
Spiral Mode	± 10° bank control release	Bank vs. time	27B: VI (2)
Dutch Roll	Rudder doublets	Damping & frequency (w/video)	27B VII (2)

Table C.1. Test Matrix.

Parameter	Minimum	Maximum
Weight (lbs.)	2150	3950
C.G. (inches aft of datum)	99.0	103.5
Airspeed (KCAS)	54	121
Altitude (feet MSL)	1500	10000
(feet AGL)	500	10000
Bank Angle (degrees)	0	+/- 45
Pitch Angle (degrees)	0	+/- 20
Yaw Angle (degrees)	0	+/- 15

Table C.2. Flight Test Envelope.

Static Longitudinal Stability

Test Configuration	CG & Weight	Trim Power (torque)	Trim Speed (KCAS)	Speed Range (KCAS)	Altitude (feet MSL)	Remarks
Climb (V_Y)	Fwd/Aft Heavy	Max Cont[1]	V_Y	+ and –20kts from trim	<3000	
Cruise	Fwd/Aft Mid	Level Flight	.9 V_H or .9 V_{NE} [2]	.7 to 1.1 V_H or V_{NE} [3]	<3000	
Cruise	Fwd/Aft Low	Level Flight	.9 V_H or .9 V_{NE} [2]	.7 to 1.1 V_H or V_{NE} [3]	10,000	
Slow Cruise (V_{MINI})	Fwd/Aft Heavy/Light	Level Flight	1.1 V_{MINI}	.9 V_{MINI} to 1.3 V_{MINI} [4]	<3000	
Descent	Fwd/Aft Mid	1000 fpm	.8 V_H or .8 V_{NE} [5]	+ and –20kts from trim	<3000	
Approach	Fwd/Aft Heavy/Light	3° glide slope	80	55-100 [6]	<3000	

[1]Not to exceed 1000fpm
[2]Whichever is lower
[3]Not to exceed 20 knots from trim
[4]Or 20 knots above trim, whichever is greater.
[5]Whichever is lower
[6]From .7 recommended approach speed to 20 knots above.

Table C.3. Test Configurations.
(Static Longitudinal Stability).

Static Lateral-Directional Stability

Test Configuration	CG & Weight	Trim Power (torque)	Trim Speed (KCAS)	Altitude (feet MSL)	Remarks
Climb (V_Y)	Fwd/Aft Heavy	Max Cont.	V_Y	<3000	
Cruise	Fwd/Aft Mid	Level Flight	.9 V_H or .9 V_{NE}	<3000	
Slow Cruise (V_{MINI})	Fwd/Aft Heavy/Light	Level Flight	1.1 V_{MINI}	<3000	
Descent	Fwd/Aft Mid	1000 fpm	.8 V_H or .8 V_{NE}	<3000	
Approach	Fwd/Aft Heavy/Light	3° glide slope	80	<3000	

Up to 10 degree either side of trim
Test for all ranges of airspeed, power, and vertical speed.

Table C.4. Test Configurations.
(Static Lateral-Directional Stability).

DYNAMIC STABILITY
Longitudinal Short Period
Long Period (Phugoid)
Lateral-Directional
Dutch Roll – Aircraft is not instrumented therefore observe "any oscillation having a period of < 5 seconds must damp to ½ amplitude in not more than 1 cycle."
Spiral (Aperiodic Response)

Test Configuration	CG & Weight	Trim Power (torque)	Trim Speed (KCAS)	Altitude (feet MSL)	Remarks *
Climb (V_Y)	Fwd/Aft Heavy	Max Cont.	V_Y	<3000	
Cruise	Fwd/Aft Mid	Level Flight	.9 V_H or .9 V_{NE}	<3000	
Slow Cruise (V_{MINI})	Fwd/Aft Heavy/Ligh t	Level Flight	1.1 V_{MINI}	<3000	
Descent	Fwd/Aft Mid	1000 fpm	.8 V_H or .8 V_{NE}	<3000	
Approach	Fwd/Aft Heavy/Ligh t	3° glide slope	80	<3000	

*Conduct a simulated autorotation in each trim mode in forward/heavy configuration to verify controllability. Check for objectionable cyclic to collective or roll-yaw-pitch cross coupling.

Table C.5. Test Configurations.
(Dynamic Stability).

APPENDIX D

Flight Test Data

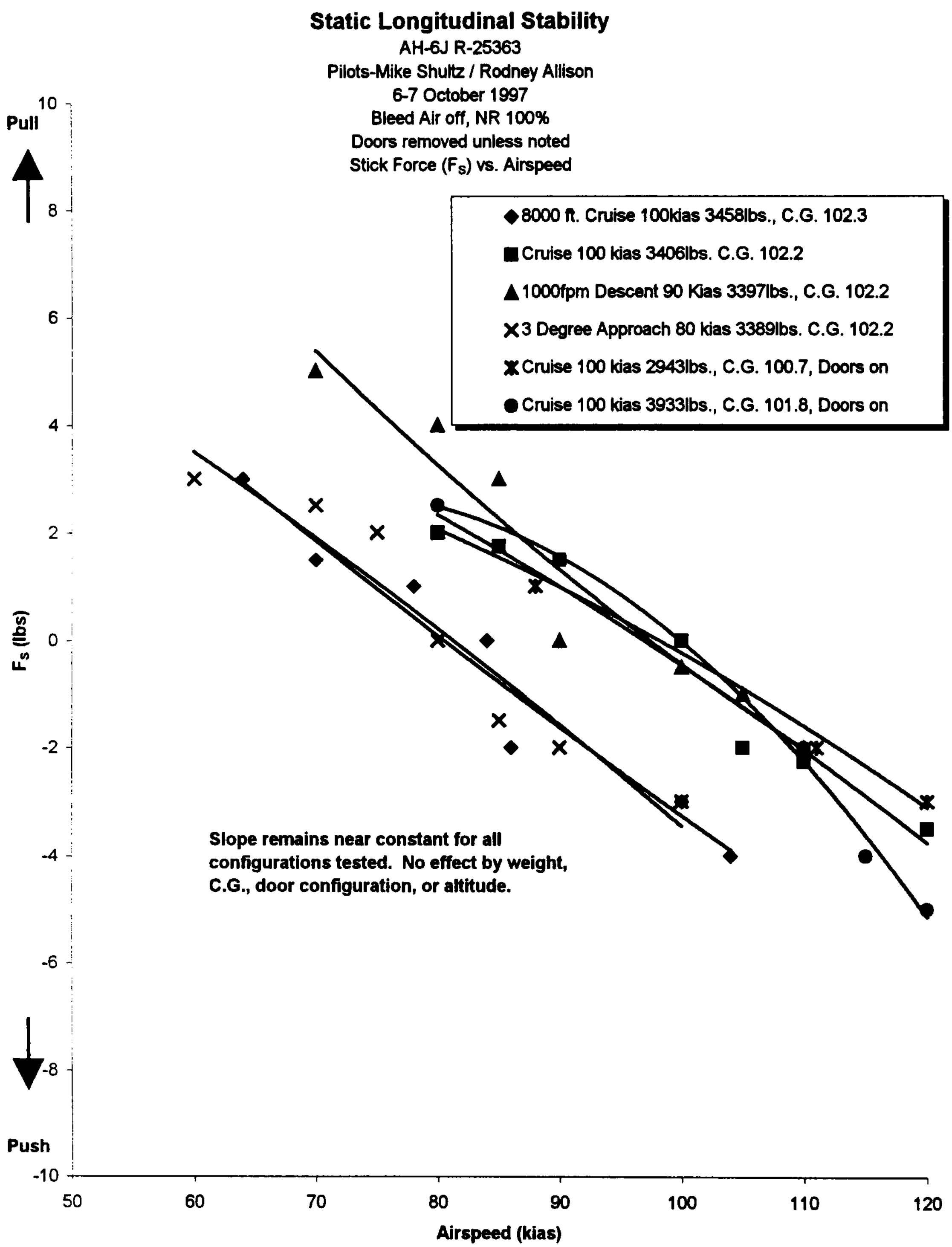

Figure D.1. Static Longitudianal Stability.

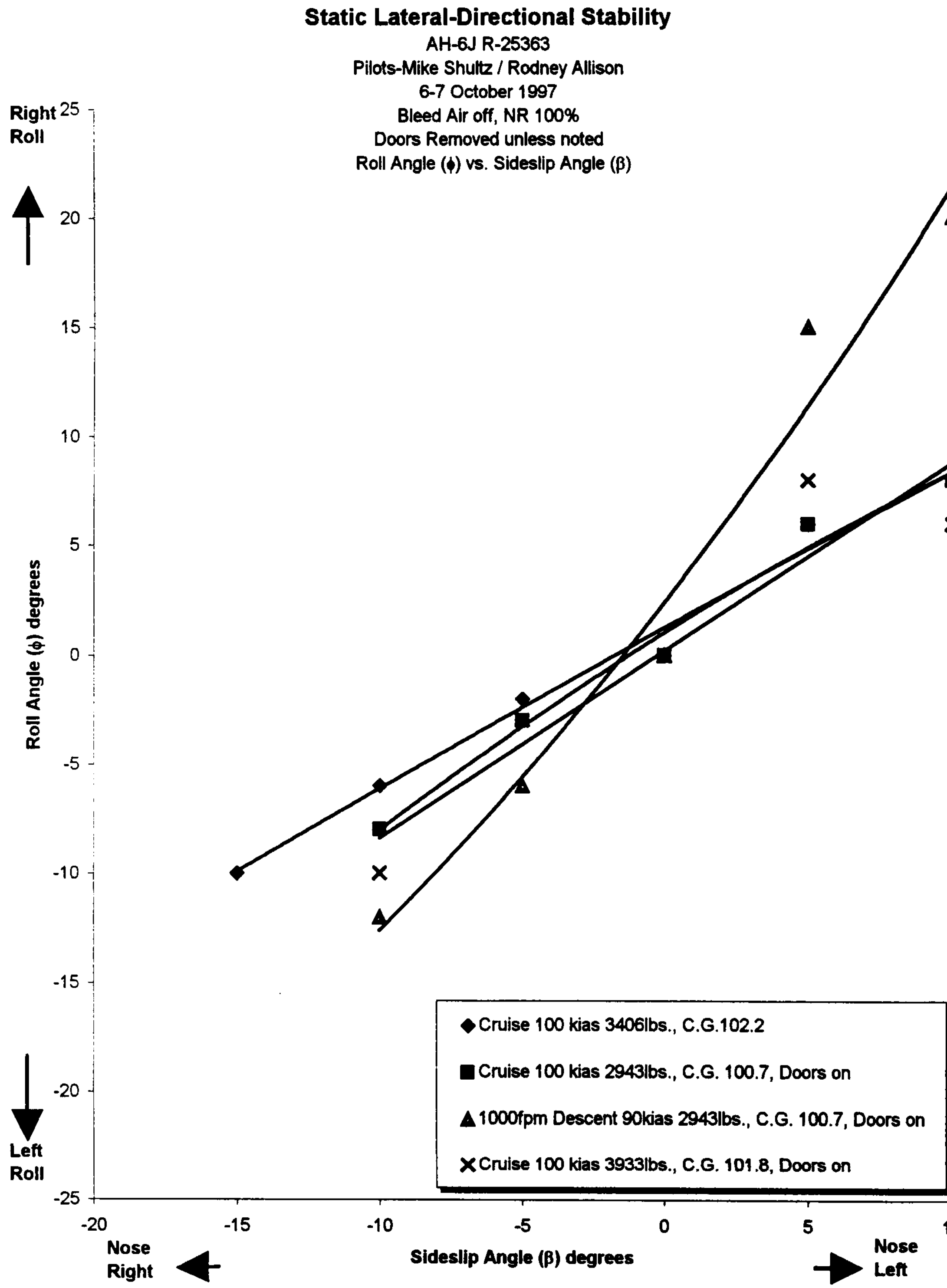

Figure D.2. Static Lateral-Directional Stability (ϕ/β).

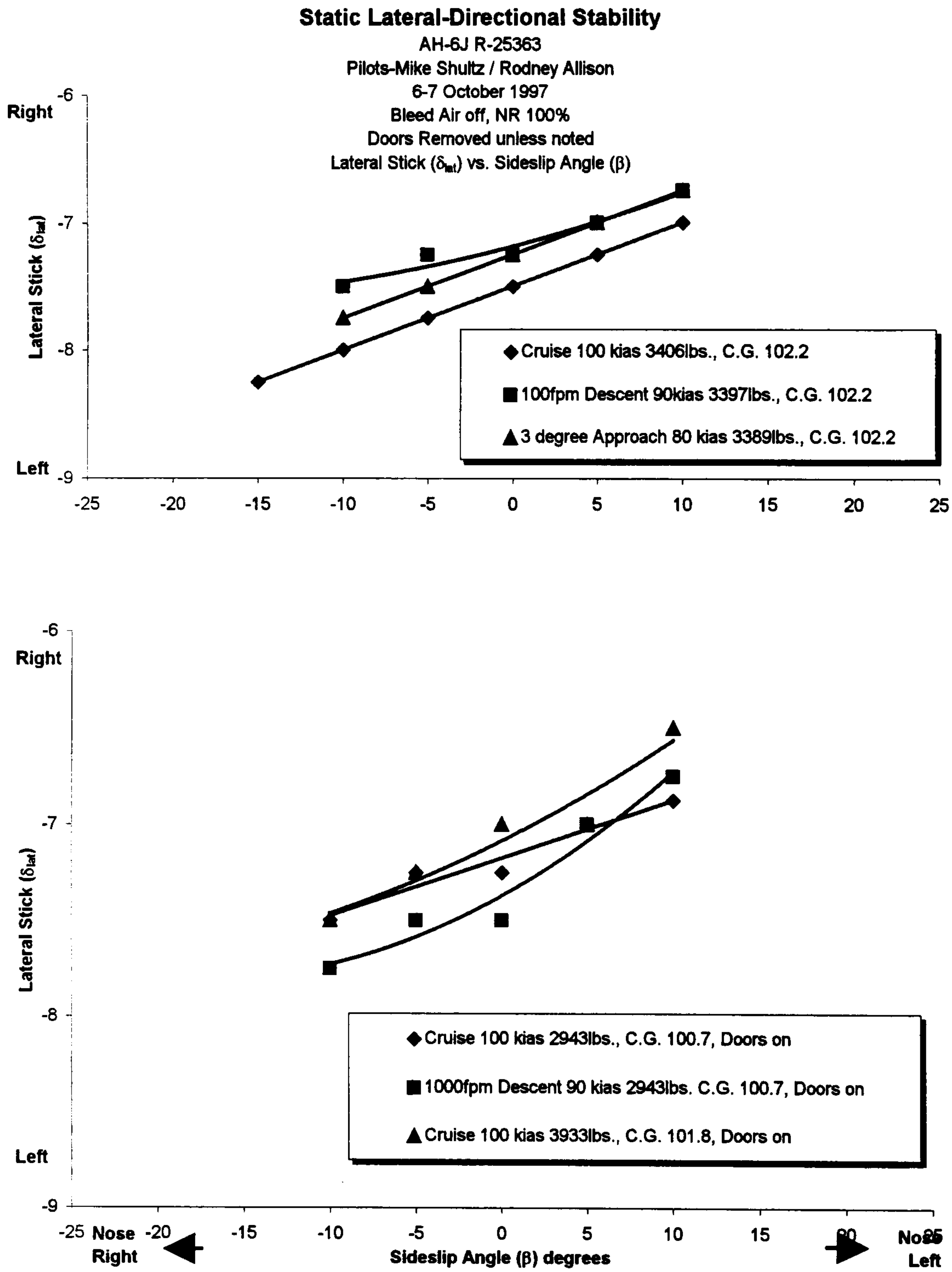

Figure D.3. Static Lateral-Directional Stability (δ_{lat}/β).

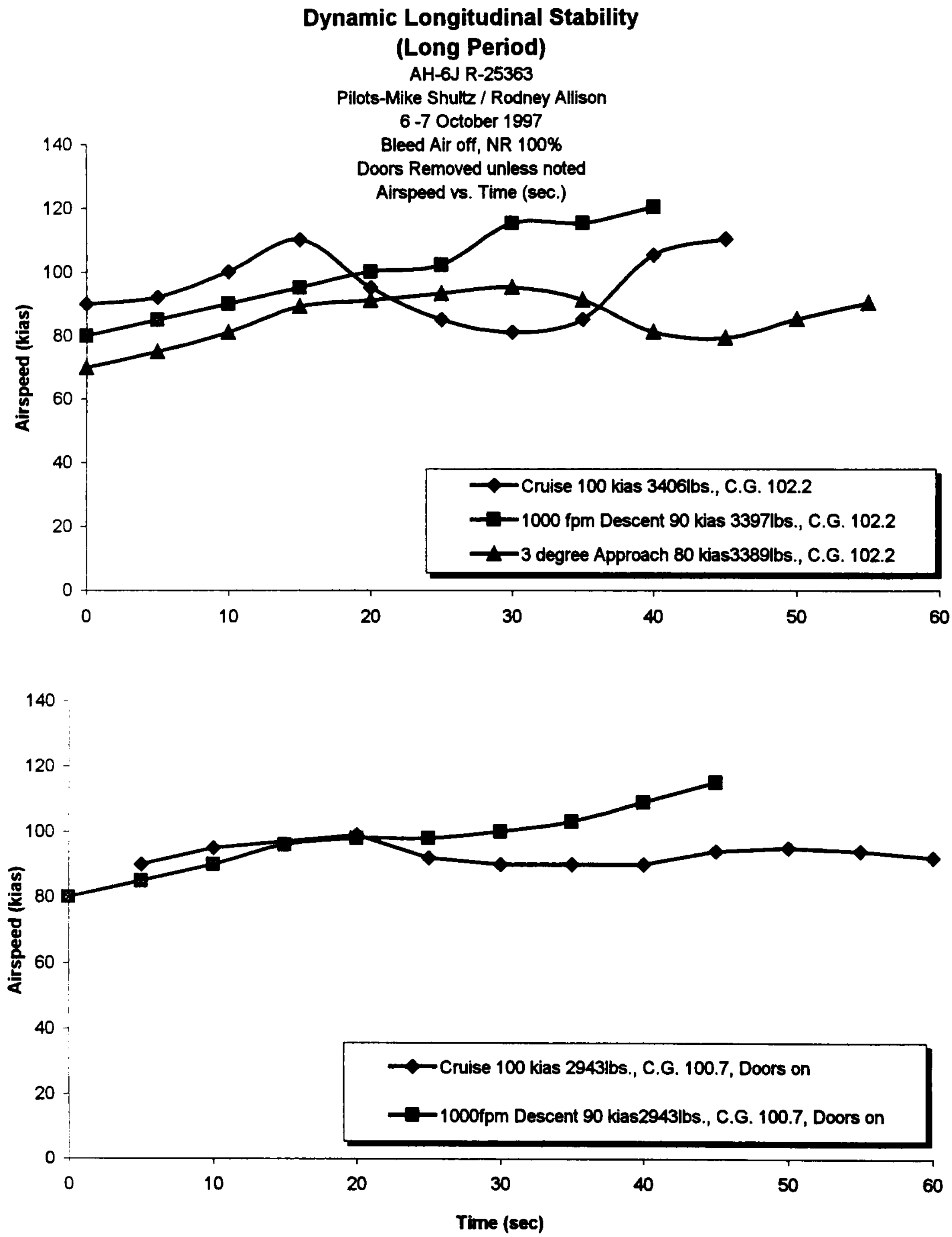

Figure D.4. Dynamic Longitudinal Stability (Long Period).

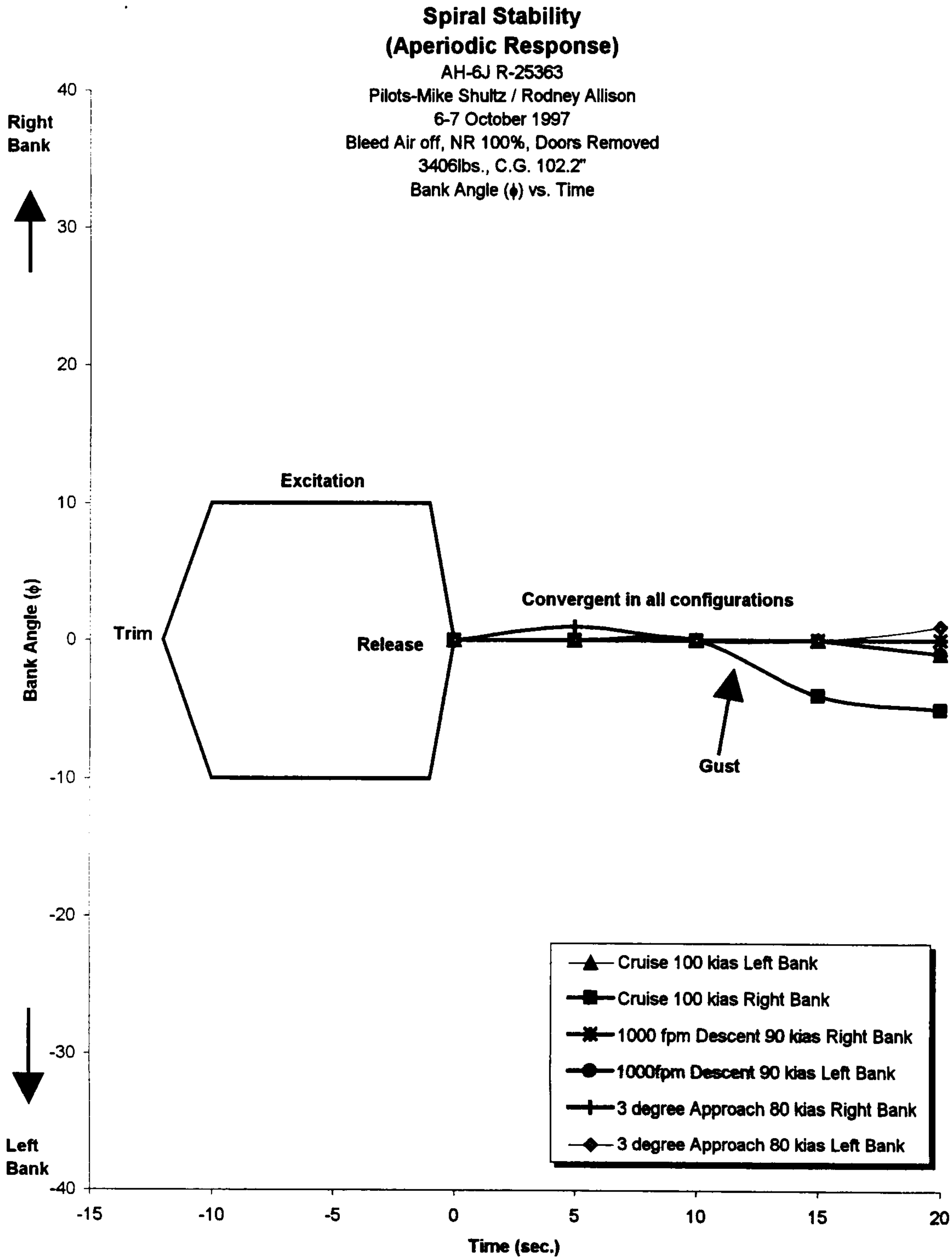

Figure D.5. Spiral Stability (Aperiodic Response).

APPENDIX E

AFCS Installation Illustrations

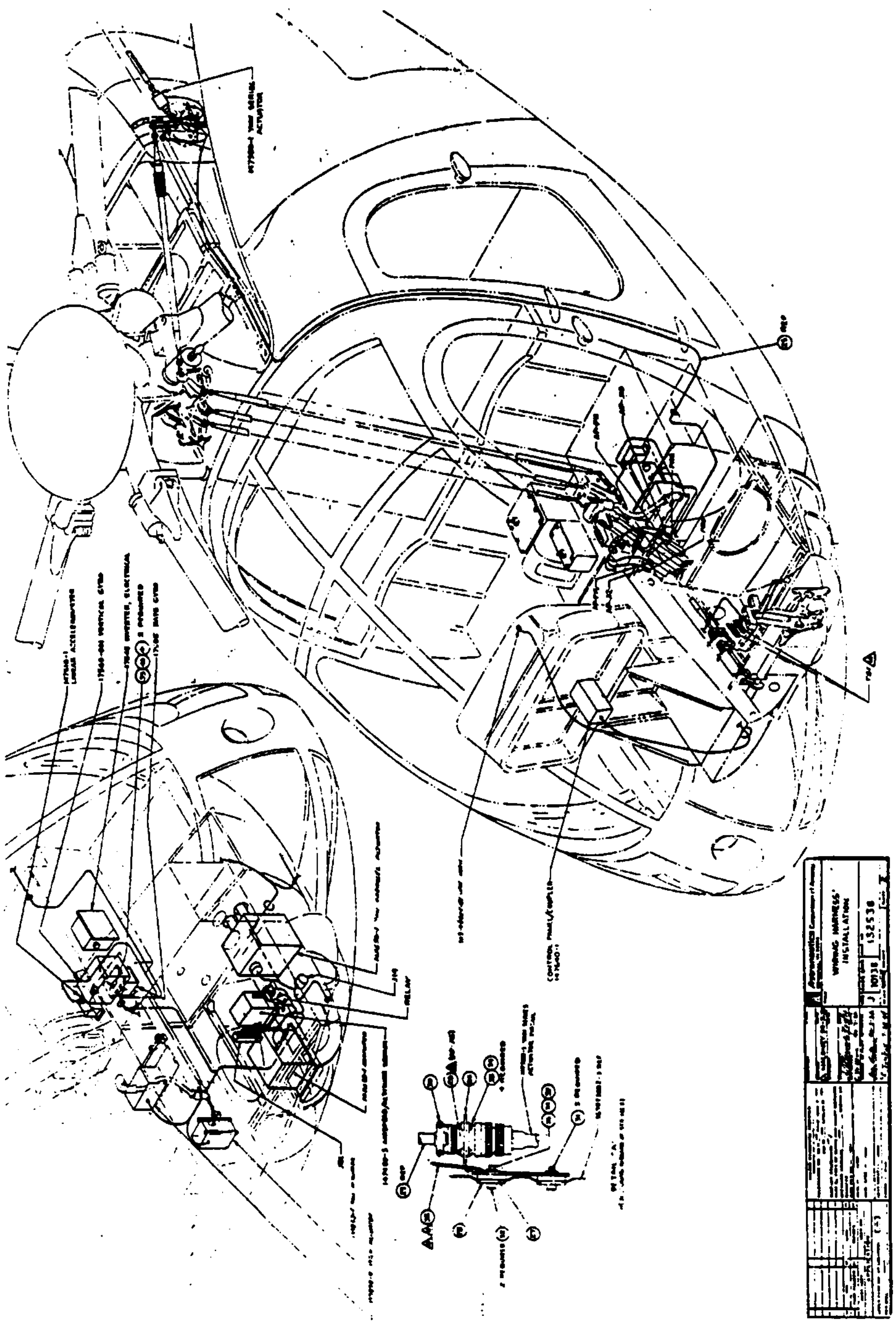

Figure E.1. Component Installation Diagram.

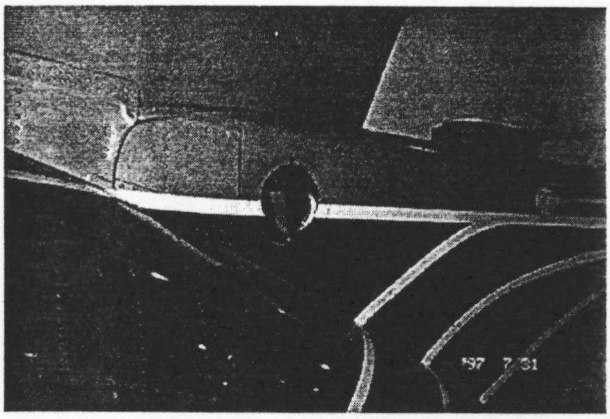

Figure E.2.. Tailboom Access Panel.

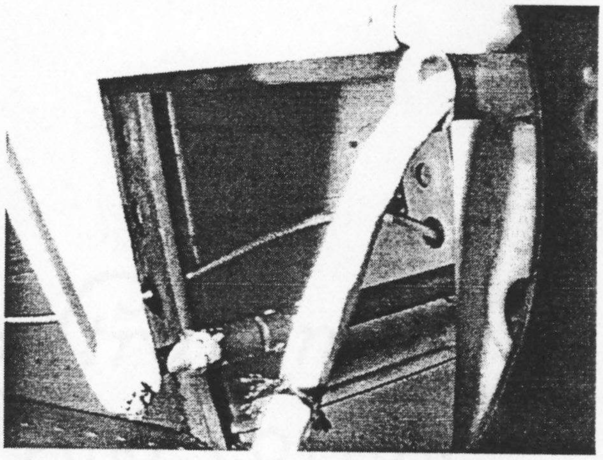

Figure E.3. Yaw Series Actuator Location (before installation).

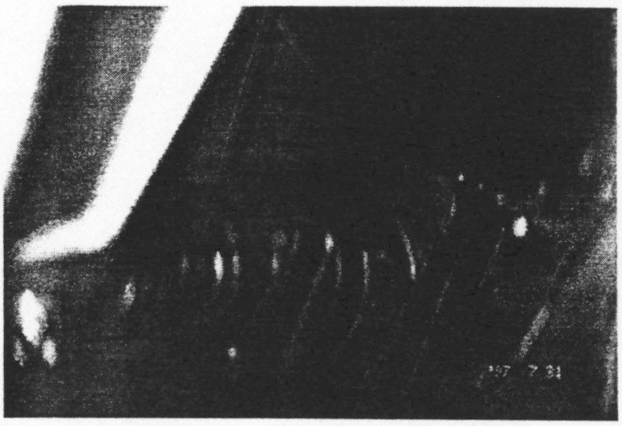

Figure E.4. Yaw Series Actuator Installed in Tailboom.

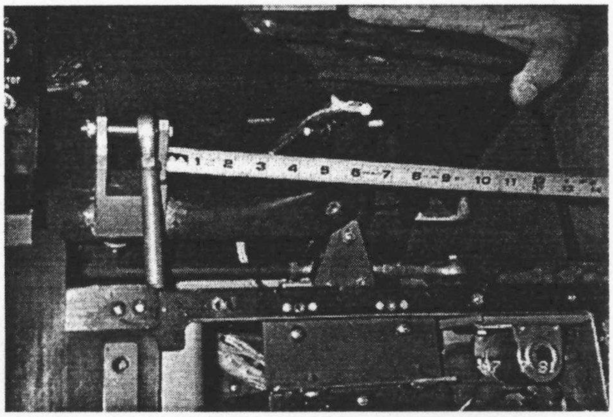

Figure E.5. Pitch Actuator Mounting (as seen from above).

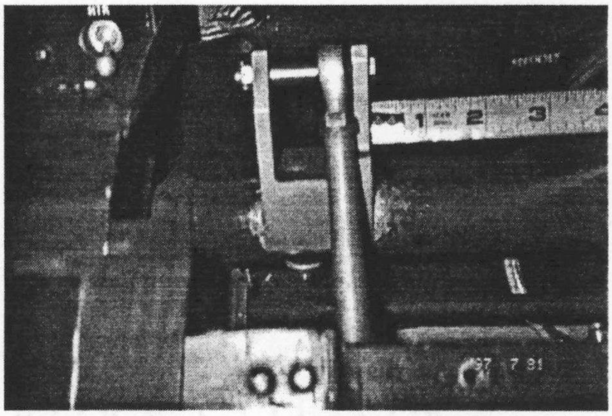

Figure E.6. Pitch Actuator Mounting (close-up).

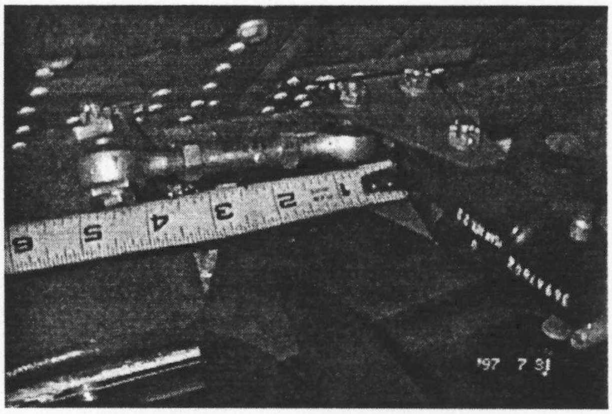

Figure E.7. Roll Actuator Mounting (as seen from above).

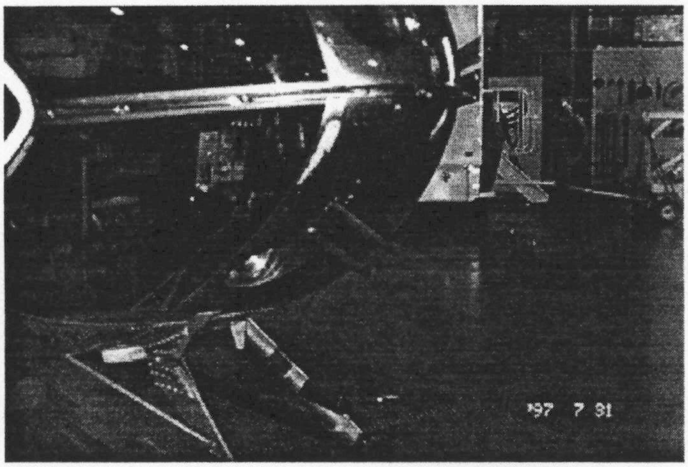

Figure E.8. Dual Pitot Tube Mounting Location.

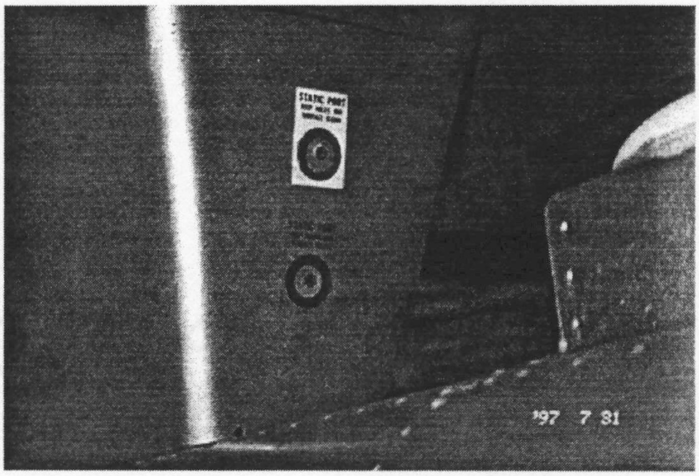

Figure E.9. Dual Static Port Mounting Location.

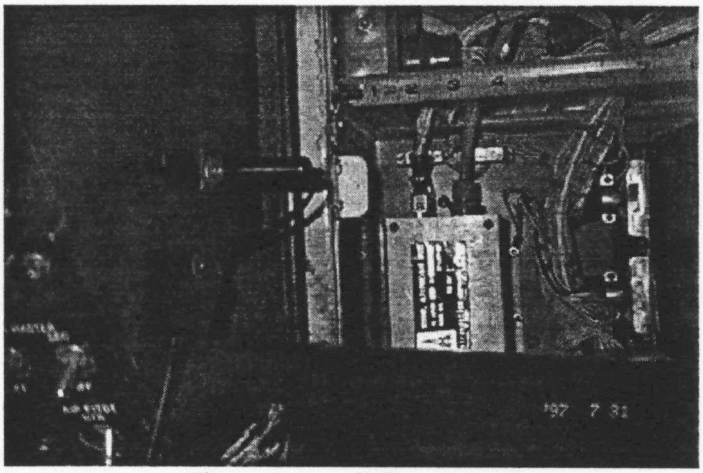

Figure E.10. Air Data Sensor

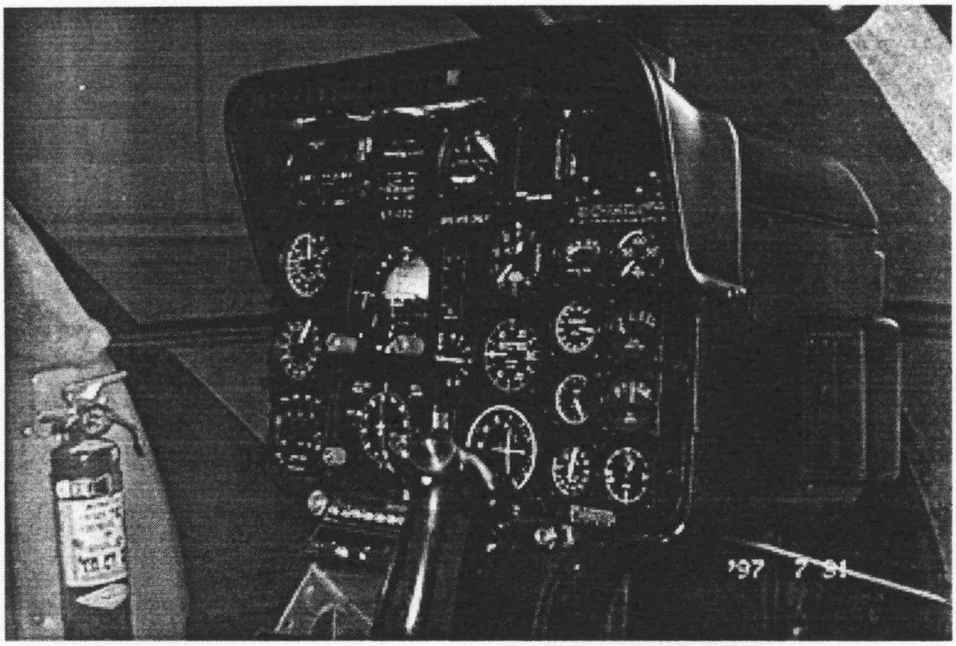

Figure E.11. MD-500E Cockpit Configuration
(as seen from outside right side).

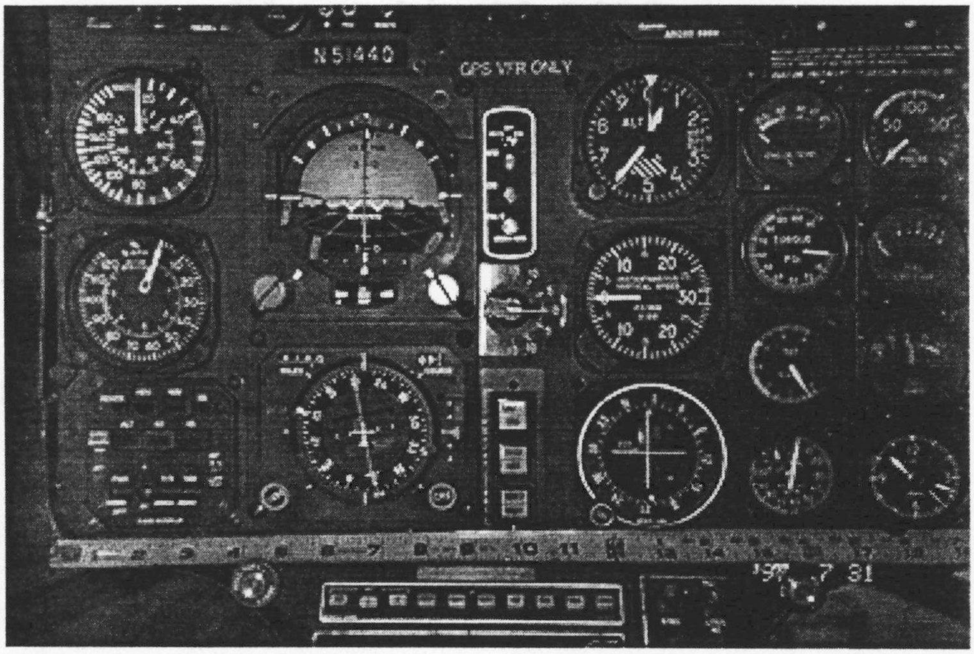

Figure E.12. MD-500E Cockpit Configuration.

APPENDIX F

Instrumentation Illustrations

Figure F.1. A/MH-6J Front View.

Figure F.2. A/MH-6J Left-Side View.

Figure F.3. A/MH-6J Right-Side View.

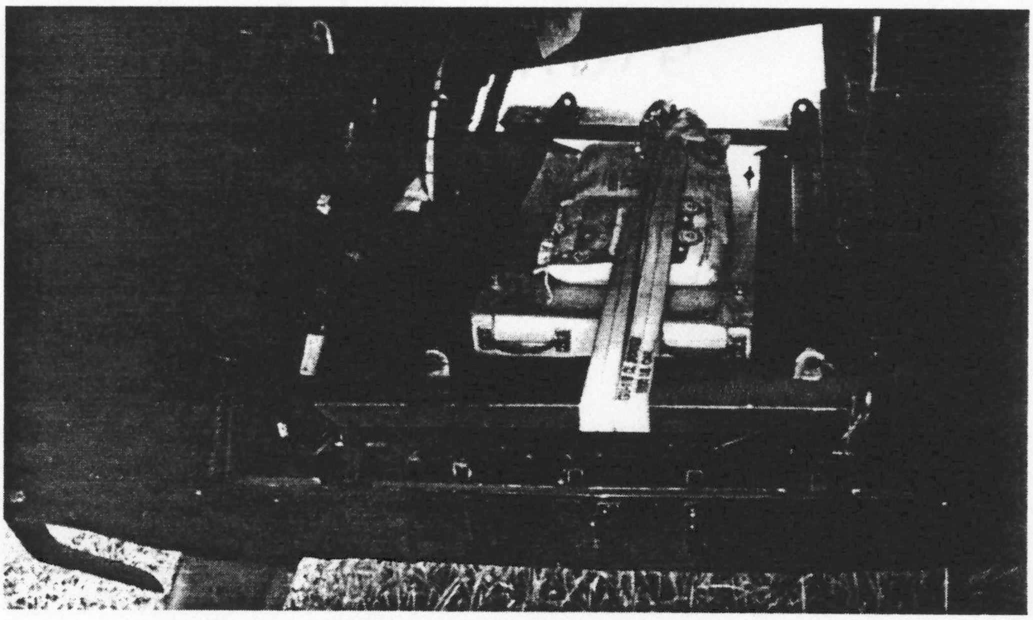

Figure F.4. Ballast Used.

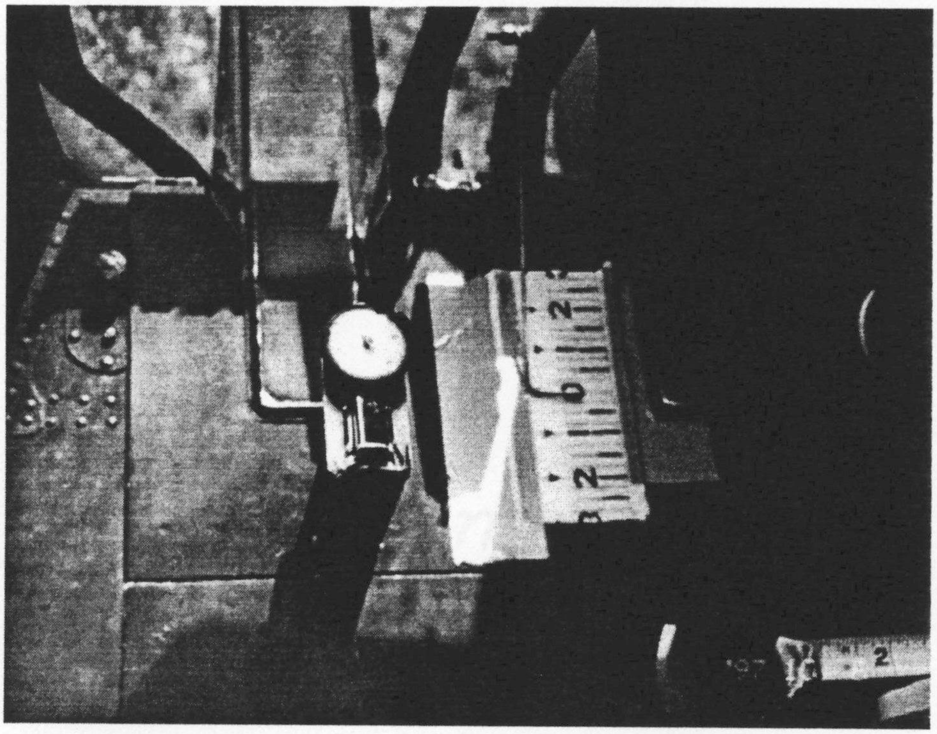

Figure F.5. Hand-held Force Gauge and Tail Rotor Pedal Position Indicator.

VITA

Rodney Allison was born to Loreta and Tommy Allison in February 1961 in the town of Paragould, Arkansas. Raised in the Light, Arkansas, he graduated from Stanford High School in 1979. Soon after graduation from high school, he enlisted in the United States Army as an Airplane Repairman. During his first assignment at Randolph Air Force Base, Texas he earned his private pilots certificate which lead to an application and acceptance to the United States Army's Initial Entry Rotary Wing Course. He graduated from flight school in January 1983 an honor graduate, and flew a variety of aircraft, both rotary and fixed wing, throughout the next fourteen years. During this time, he earned an Associate Degree in Business Administration and a Bachelor of Science Degree in Professional Aeronautics, both with honors, from Embry-Riddle Aeronautical University. Additionally, during this time, he earned his Commercial and Instrument Pilot certificate for both single- and multi-engine airplanes and an Airline Transport Pilot and Instructor Pilot Certificate rating for helicopters. He is a veteran of the Iran-Iraq war in the Persian Gulf, Operations Desert Shield and Storm, and the conflict in Somalia. In April 1990, he married Cynthia Hammond of Paragould, Arkansas. They now have two children, Troy and Sarah. Rodney graduated from the University of Tennessee Space Institute in December 1997 with a Master of Science degree in Aviation Systems with a follow on assignment to attend the U.S. Naval Engineering Test Pilot School at Patuxent River, Maryland.