AD-A147 188

USAAEFA PROJECT NO. 82-15-1

# UH-60A EXTERNAL STORES SUPPORT SYSTEM FIXED PROVISION FAIRINGS DRAG DETERMINATIONS

ROBERT A. WILLIAMS
CW4, AV
PROJECT OFFICER / PROJECT PILOT

ROBERT M. BUCKANIN
PROJECT ENGINEER

ROBERT MACMULLIN
CPT (P), AV
PROJECT PILOT

WILLIAM ABBOTT
PROJECT ENGINEER

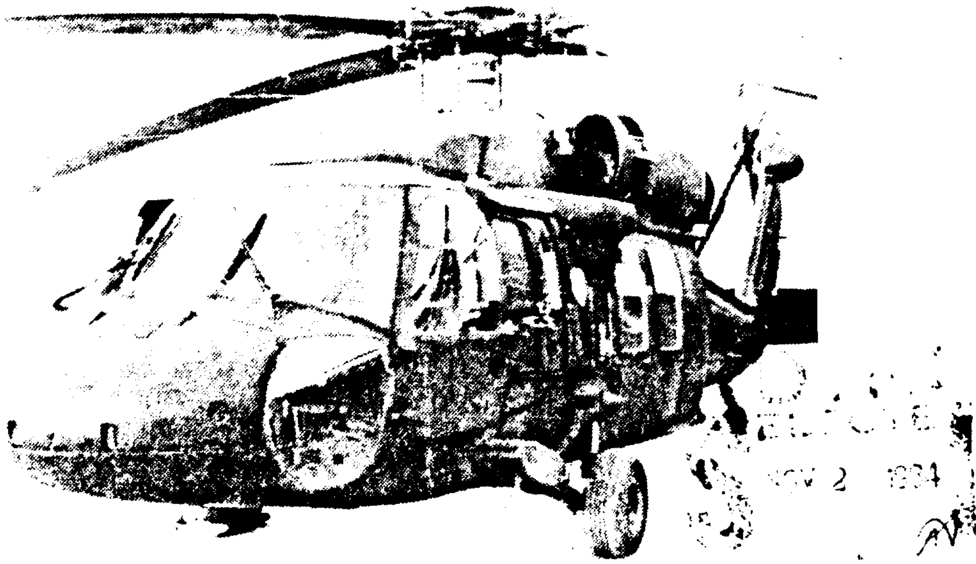
JOSEPH O. MIESS
CW4, AV
PROJECT PILOT

GARY L. SKINNER
PROJECT ENGINEER

USAAEFA

FINAL REPORT

MAY 1984





UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

## DISCLAIMER NOTICE

The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

## DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed. Do not return it to the originator.

## TRADE NAMES

The use of trade names in this report does not constitute an official endorsement or approval of the use of the commercial hardware and software.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>USAAEFA PROJECT NO. 82-15-1 | 2. GOVT ACCESSION NO.<br>AD A147188 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>UH-60A EXTERNAL STORES SUPPORT SYSTEM FIXED PROVISION FAIRINGS DRAG DETERMINATION | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final Report<br>30 Aug - 22 Sep 1983<br>6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>ROBERT A. WILLIAMS ROBERT MACMULLIN<br>JOSEPH O. MIESS ROBERT BUCKANIN<br>WILLIAM Y. ABBOTT GARY L. SKINNER | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>US ARMY AVN ENGINEERING FLIGHT ACTIVITY<br>EDWARDS AIR FORCE BASE, CA 93523-5000 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>68-3-BH019-01-68-EC |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>US ARMY AVIATION SYSTEMS COMMAND<br>4300 GOODFELLOW BOULEVARD<br>ST. LOUIS, MO 63120-1798 | | 12. REPORT DATE<br>MAY 1984<br>13. NUMBER OF PAGES<br>48 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED<br>15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Equivalent Flat Plate Area
External Stores Support System
Fixed Provision Fairings
Hover Capability
UH-60A
Performance Evaluation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A comparative performance evaluation of the UH-60A helicopter in the normal utility configuration and with the External Stores Support System (ESSS) fixed provision fairings configuration (ESSS wings removed) was conducted at Edwards AFB, California. A total of eight flights were flown between 30 August and 22 September 1983 for a total of 10.0 productive hours. The increase in equivalent flat plate area due to installation of the ESSS fixed provision fairings was 2.5 feet2. With the ESSS fixed provision fairings installed at the out-of-ground

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

effect hover guarantee conditions of 95 percent intermediate rated power at 4700 feet pressure altitude on a 35°C day, the hover capability was reduced 466 pounds. Incorporating the weight of the airframe fixed provisions will reduce the payload by 596.6 pounds or the equivalent of eliminating two combat equipped troops and 117 pounds of fuel or equipment.

**DEPARTMENT OF THE ARMY**
HEADQUARTERS, US ARMY AVIATION SYSTEMS COMMAND
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120 -1798

REPLY TO
ATTENTION OF

AMSAV-E

SUBJECT: Directorate for Engineering Position on the Final Report of USAAEFA Project 82-15-1, UH-60A External Stores Support System Fixed Provision Fairings Drag Determination

SEE DISTRIBUTION

1. The purpose of this letter is to establish the Directorate for Engineering position on the subject report. The subject evaluation was conducted to determine the increased drag due to the External Store Support System (ESSS) fixed provision fairings and hover performance with the ESSS fixed provision fairings installed. In August 1977, USAAEFA conducted an Airworthiness and Flight Characteristics (A&FC) evaluation of the normal utility configured UH-60A using aircraft, S/N 77-22716. Following development of the ESSS, AEFA conducted an A&FC evaluation of the ESSS configured UH-60A using aircraft S/N 77-22714, which included a comparison of the full ESSS and ESSS fixed provision hover performance. When the results of the hover performance tests of the UH-60A A&FC and ESSS A&FC were compared, a download penalty due to the ESSS fixed provisions of 5 percent of gross weight out of ground effect (HOGE) and 7.4 percent of gross weight in ground effect (HIGE) was shown. This appeared to be excessive and it was decided to conduct back to back tests using the UH-60A A&FC aircraft (S/N 77-22716). This back to back test (ESSS fixed provisions on vs ESSS fixed provisions off) is reported here.

2. The back-to-back test results reported herein show penalties of 0.5 percent of design gross weight HIGE, 2.7 percent of design gross weight HOGE and 2.5 $ft^2$ equivalent flat plate drag area in forward flight. The accuracy of these results is supported by AEFA's ability to exactly reproduce, in these tests, the UH-60A A&FC HOGE tests conducted on the same helicopter six years earlier. A review of the back-to-back tests reported here shows the test conditions were comparable (density altitude, temperature and rotor tip speed) for both configurations, ESSS fixed provisions on and off. There is very little scatter in the data, but there is a distinct difference between the data of the two configurations. However, these data differ significantly with the penalties predicted by the contractor's analysis of 0 percent design gross weight HIGE and HOGE and 1 $ft^2$ equivalent flat plate drag area in forward flight.

AMSAV-E
SUBJECT: Directorate for Engineering Position on the Final Report of USAAEFA Project 82-15-1, UH-60A External Stores Support System Fixed Provision Fairings Drag Determination

3. This Directorate agrees with the report conclusions and recommendations, except that the UH-60A operator's manual should not be updated until completion of the A&FC evaluation of the sixth year production UH-60A (AEFA Project No. 83-25). The A&FC of the sixth year UH-60A will strengthen the data base of performance measurements with ESSS fixed provisions on and off and clear up some anomalies in flight performance data (non-dimensional hover performance variation with density altitude and inflection points on advancing tip Mach number trends).

FOR THE COMMANDER:

Ronald E. Gormont

RONALD E. GORMONT
Acting Director of Engineering

# TABLE OF CONTENTS

# INTRODUCTION

## BACKGROUND

1. The US Army has stated a requirement for self deployment capability for the UH-60A helicopter. To satisfy this requirement, Sikorsky Aircraft (SA), Division of United Technologies, has designed the External Stores Support System (ESSS), which consists of airframe fixed provisions and an external stores subsystem. The external stores subsystem can be removed and the UH-60A can be flown in this configuration with the fixed provision fairings installed.

2. In August 1983 the US Army Aviation Engineering Flight Activity (USAAEFA) was tasked by the US Army Aviation Systems Command (ref 1, app A) to evaluate aircraft performance with the fixed provision fairings.

## TEST OBJECTIVES

3. The objectives of this test were to determine the increased drag due to the fixed provision fairings and to obtain hover performance data with fixed provision fairings installed.

## DESCRIPTION

4. The test helicopter was a UH-60A, US Army S/N 77-22716, the third production UH-60A. Primary mission gross weight (ref 2, app A) is 16,260 pounds and the present maximum alternate gross weight is 20,250 pounds. The UH-60A is powered by two General Electric T700-GE-700 turboshaft engines, each rated at 1553 shaft horsepower (shp) installed at sea level, standard-day static conditions. Installed dual-engine power is transmission limited to 2828 shp. In the ESSS configuration, the UH-60A is equipped with integral airframe fixed provisions and a removable external stores subsystem. With the external stores subsystem (wings) removed, a set of aerodynamic fairings (fixed provision fairings) are installed. The fixed provision fairings used during this evaluation were handmade and had significantly smoother surface texture and slight shape differences when compared to the 6th year production UH-60A fairings (photos 4 and 5, app B). A more detailed description of the UH-60A and the fixed provision fairings is included in appendix B.

## TEST SCOPE

5. The flight testing was performed at Edwards Air Force Base, California (2302 feet). A total of eight flights were conducted between 30 August and 22 September 1983 for a total of 15.6 flight test hours of which 10.0 were productive flight hours. USAAEFA calibrated and maintained the test instrumentation and performed all required maintenance on the helicopter. Personnel from SA installed the tested fixed provision fairings. Flight restrictions and operating limitations observed during the test are contained in the operator's manual (ref 3, app A). Testing was conducted in accordance with the test plan (ref 4, app A) at the conditions shown in table 1.

Table 1. Test Conditions[1]

| Type | Gross Weight (lb) | Longitudinal Center of Gravity (FS) | Density Altitude (ft) | Referred Rotor Speed (RPM) | Trim Airspeed (KTAS) |
|---|---|---|---|---|---|
| Hover | 14,900 to 23,200[2] | 353 (MID) | 3280 to 3780 | 242 to 261 | 0 |
| Level Flight | 14,500 to 16,200 | 347 (FWD) | 7510 to 13,860 | 258 | 45 to 168 |

NOTES:

[1]Tests were conducted at a mid lateral center of gravity (0.1 inch left) in two configurations: normal utility and ESSS fixed provision fairings.
[2]Aircraft gross weight plus cable tension

## TEST METHODOLOGY

6. A detailed listing of the test instrumentation is contained in appendix C. Established flight test techniques and data reduction procedures were used (ref 5, app A), and are described in appendix D. The flight test data were obtained from test

instrumentation displayed on the instrument panel and recorded on magnetic tape installed in the aircraft. Real time telemetry monitoring of selected data parameters was used during these tests.

# RESULTS AND DISCUSSION

GENERAL

7. Limited performance flight testing was conducted on the UH-60A helicopter to determine the comparative performance differences between the normal utility configuration, as described in USAAEFA Report No. 77-17 (ref 6, app A), and the ESSS fixed provision fairings configuration. The increase in equivalent flat plate area ($F_e$) due to installation of the ESSS fixed provision fairings was 2.5 feet$^2$. At the out-of-ground effect (OGE) hover guarantee conditions of 95 percent intermediate rated power (IRP) at 4700 feet pressure altitude (Hp) on a 35°C day, the hover capability was reduced 466 pounds.

HOVER PERFORMANCE

8. Hover performance tests were conducted at Edwards AFB, CA at the conditions and configurations listed in table 1. A left main wheel height of 5.3 feet was used for in-ground effect (IGE) and 100 feet for OGE. The tethered hover method was used to obtain the majority of the data with a limited amount gathered using the free flight hovering method. A cable tensiometer was used to measure total thrust less gross weight. Variations in the coefficient of thrust ($C_T$) were attained by varying cable tension or rotor speed. Hover test results are presented in figures 1 and 2, appendix E. Test data with the fairings installed, compared to the normal utility configuration, indicate an increase in power required of approximately 1 percent to hover at 5.3 feet and 4 percent to hover OGE. When the same comparison was made during a previous test (ref 7, app A), an increase in power required of 11 percent (IGE) and 7 percent (OGE) was noted. This difference between test results for the same configuration confirms the observation reported in the previous test, that the increase in power required was too great. Since test results presented in this report agree with the Airworthiness and Flight Characteristics Evaluation OGE test results in the normal utility configuration (ref 6), and a baseline was flown for each wheel height, the previous data should be disregarded. The increase in power required, to hover with the ESSS fixed provision fairings installed as reported herein, is representative and should be incorporated in the operator's manual.

9. The standard day OGE hover ceiling at the primary mission gross weight of 16,260 pounds using IRP was 11,200 feet in the normal utility configuration as published in USAAEFA Report

No. 77-17 (ref 6, app A). With the fairings installed there was a decrease of 850 feet in the hover ceiling. At 4000 feet $H_p$ on a 35°C day, the maximum gross weight of 17,721 pounds for OGE hover in the normal utility configuration decreased 522 pounds to 17,199 pounds with the ESSS fixed provision fairings installed. At the hover performance guarantee condition of 95 percent IRP at 4700 feet $H_p$ on a 35°C day, the hover capability was reduced 466 pounds from 16,570 to 16,104 pounds. Incorporating the weight of the airframe fixed provisions (130.6 pounds, table 1, app B) will reduce the payload by 596.6 pounds (466 + 130.6 pounds) or the equivalent of eliminating two combat equipped troops and 117 pounds of fuel or equipment.

## LEVEL FLIGHT PERFORMANCE

10. Level flight performance tests were conducted at the conditions listed in table 1 to determine power required and fuel flow at various airspeeds. The method used maintained the ratio of gross weight to pressure altitude ratio ($W/\delta$) and referred rotor speed (ratio of rotor speed to ambient temperature ratio) ($N_R/\sqrt{\theta}$) constant resulted in a constant $C_T$. This was accomplished by increasing altitude as fuel was consumed and adjusting rotor speed for changes in ambient temperature. Each test was flown in ball-centered flight by reference to a calibrated lateral accelerometer. Level flight test results in the normal utility configuration are presented in figures 3 through 5, appendix E, and with th ESSS fixed provision fairings installed in figures 6 through 8. The baseline power required and inherent sideslip curves shown in these figures were derived from USAAEFA Final Report No. 81-16 (ref 8, app A). With the ESSS fixed provision fairings installed on the UH-60A helicopter, $F_e$ increased 2.5 feet$^2$ which reduces the level flight airspeed by 2 knots at maximum continuous power.

# CONCLUSIONS

11. Based on this limited evaluation, installation of the ESSS fixed provision fairings on the UH-60A helicopter resulted in the following conclusions:

a. Power required to hover was increased compared to test results of the normal utility configured UH-60A (para 8).

b. Power required to hover was decreased compared to previous test results of an ESSS fixed provision fairings configured UH-60A (para 8).

c. Drag in level flight increased by 2.5 feet$^2$ of equivalent flat plate area (para 10).

# RECOMMENDATIONS

12. The following recommendations are made:

a. The hover performance data obtained during USAAEFA Project No. 82-15, dated December 1983, should be disregarded (para 8).

b. The increase in power required with the ESSS fixed provision should be incorporated in the operator's manual (para 8).

# APPENDIX A. REFERENCES

1. Letter, AVRADCOM, DRDAV-DI, 31 August 1983, subject: Airworthiness and Flight Characteristics Test of the UH-60A Configured with the External Stores Support Syscem (ESSS), USAAEFA Project No. 82-15.

2. Prime Item Development Specification, Sikorsky Aircraft Division, "DARCOM-CP-2222-S1000D Part I", 15 October 1979.

3. Technical Manual, TM55-1520-237-10, *Operator's Manual, UH-60A Helicopter*, Headquarters Department of the Army, 21 May 1979, with change 21 dated 12 August 1983.

4. Disposition Form, USAAEFA, DAVTE-TB, 12 August 1983, subject: Test Plan for USAAEFA Project No. 82-15-1, UH-60 ESSS (Fixed Provision Fairings), Drag Determination.

5. Engineering Design Handbook, Army Material Command, AMC Pamphlet 706-204, *Helicopter Performance Testing*, 2 August 1974.

6. Final Report, USAAEFA Project No. 77-17, *Airworthiness and Flight Characteristics Evaluation UH-60A (Black Hawk) Helicopter*, September 1981.

7. Final Report, USAAEFA Project No. 82-15, *Airworthiness and Flight Characteristics Test of the UH-60A Configured with the Prototype External Stores Support System (ESSS)*, December 1983 (to be published).

8. Final Report, USAAEFA Project No. 81-16, *UH-60A Expanded Gross Weight and Center of Gravity Evaluation*, Unpublished.

9. Technical Manual, TM55-1520-237-23-2, *Aircraft General Information Manual, UH-60A Helicopter*, Headquarters Deparment of the Army, 29 December 1978.

10. Final Report, USAAEFA Project No. 82-09, *Preliminary Airworthiness Evaluation of UH-60A with a Improved Airspeed System*, Unpublished.

# APPENDIX B. AIRCRAFT DESCRIPTION

## GENERAL

1. The Sikorsky UH-60A (Black Hawk) is a twin turbine engine, single-main-rotor helicopter capable of transporting 11 combat troops plus a crew of three. It is equipped with 3 nonretractable conventional wheel-type landing gear. A movable horizontal stabilator is located on the lower portion of the tail rotor pylon. The main and tail rotors are both four-bladed with a capability of manual main rotor blade and tail pylon folding. The cross-beam tail rotor with composite blades is attached to the right side of the pylon and is canted 20 degrees upward from the horizontal. A complete description of the aircraft is contained in the operator's manual (ref 3, app A) and the aircraft general information manual (ref 9).

## EXTERNAL STORES SUPPORT SYSTEM (ESSS) FIXED PROVISION FAIRINGS

2. In the ESSS configuration, the UH-60A is equipped with integral airframe fixed provisions and a removable external stores subsystem. With the external stores subsystem removed, a set of aerodynamic fairings (fixed provision fairings) (photos 1 through 4) are installed. The fixed provision fairings used during this evaluation were handmade (fiberglass) and when compared to the 6th year production UH-60A fairings, significant surface texture and slight shape differences were noted. Photo 4 is a top view side-by-side comparison of both fixed provision fairings. Photo 5, a top view of a 6th year production UH-60A fairing, shows the rough surface texture. Table 1 is a detailed weight description of the airframe fixed provisions provided by the Aviation Systems Command.

## AIRSPEED/STABILATOR MODIFICATIONS

3. The airspeed/stabilator system on the test aircraft included five modifications from the original production aircraft in an attempt to eliminate pitch oscillations during takeoff, improve climb handling qualities, and reduce large position error during various airspeed regimes. Three changes were incorporated in the pitot-static pressure systems and two changes were electrical circuit modifications to the stabilator amplifiers in the stabilator system. Major features of this system are summarized in table 2 and are described in detail in the Preliminary Airworthiness Evaluation of UH-60A with an Improved Airspeed System (ref 1[illegible], app A).


Photo 1. Fixed Provision Fairings
Looking Aft (Test Aircraft)

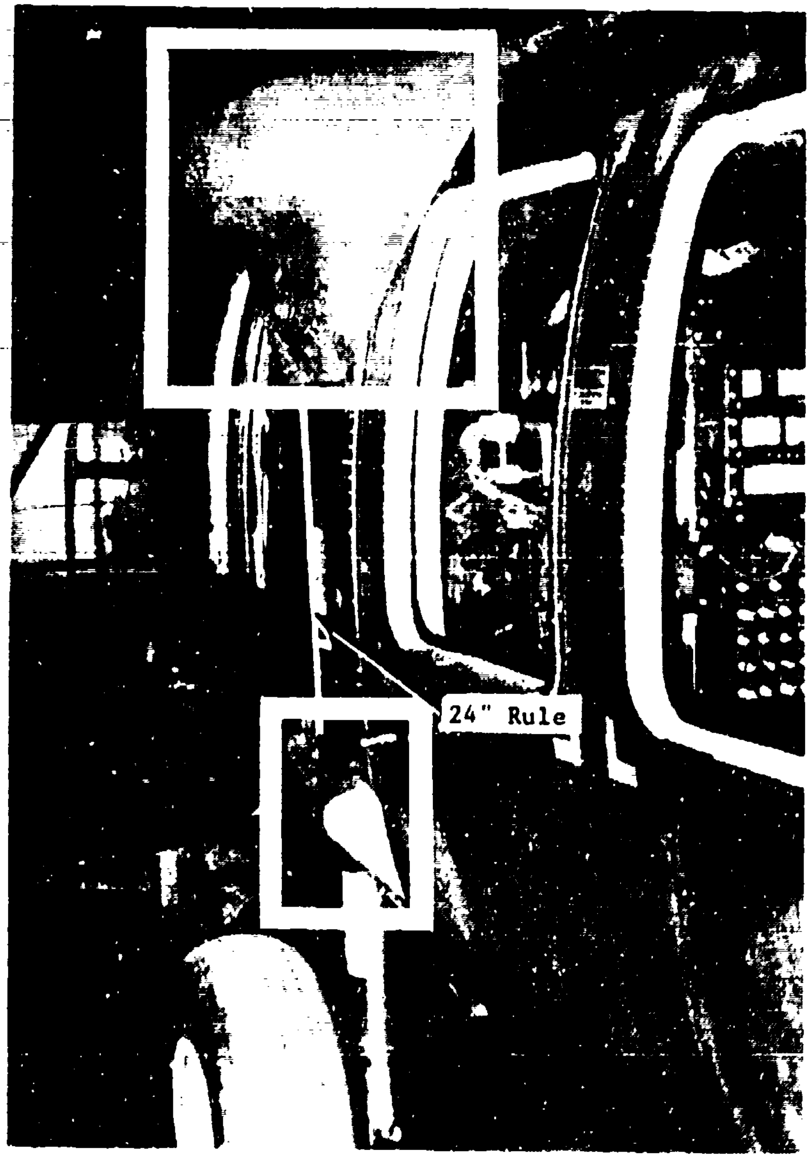



Photo 2. Fixed Provision Fairings
Looking Forward (Test Aircraft)

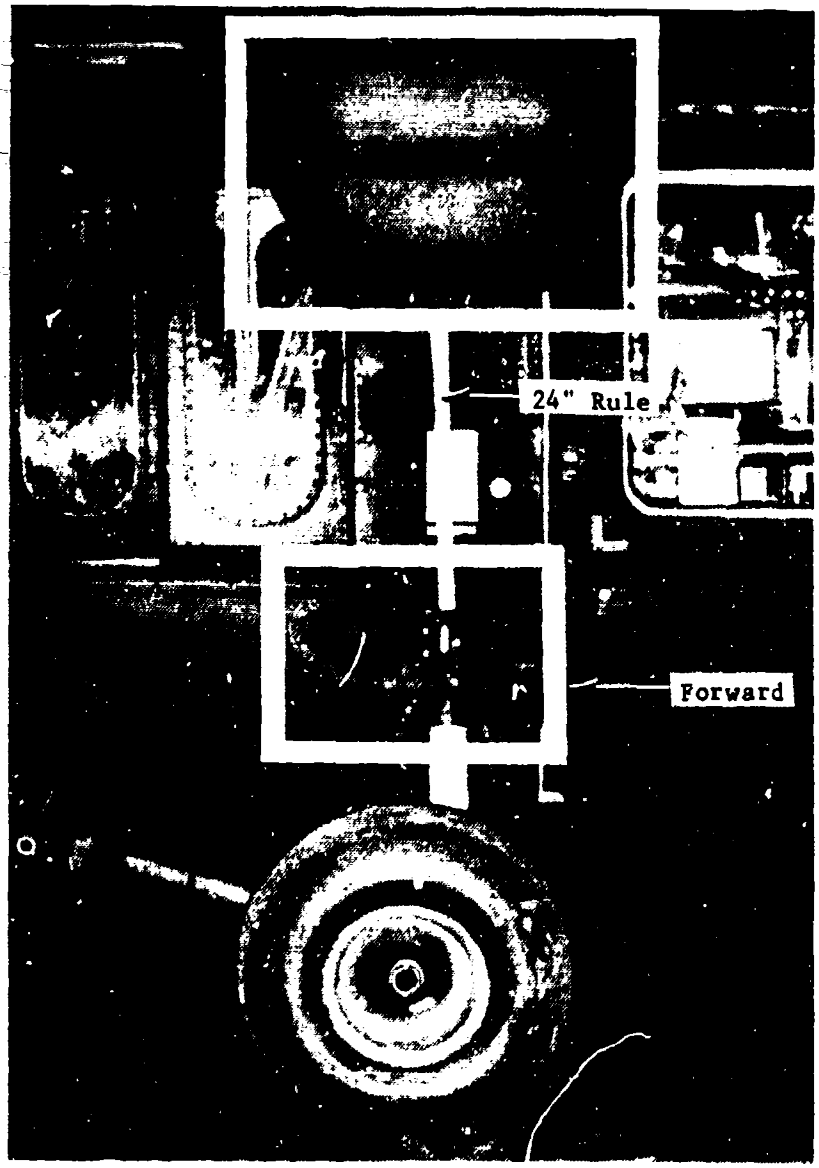



Photo 3. Fixed Provision Fairings
Left Side

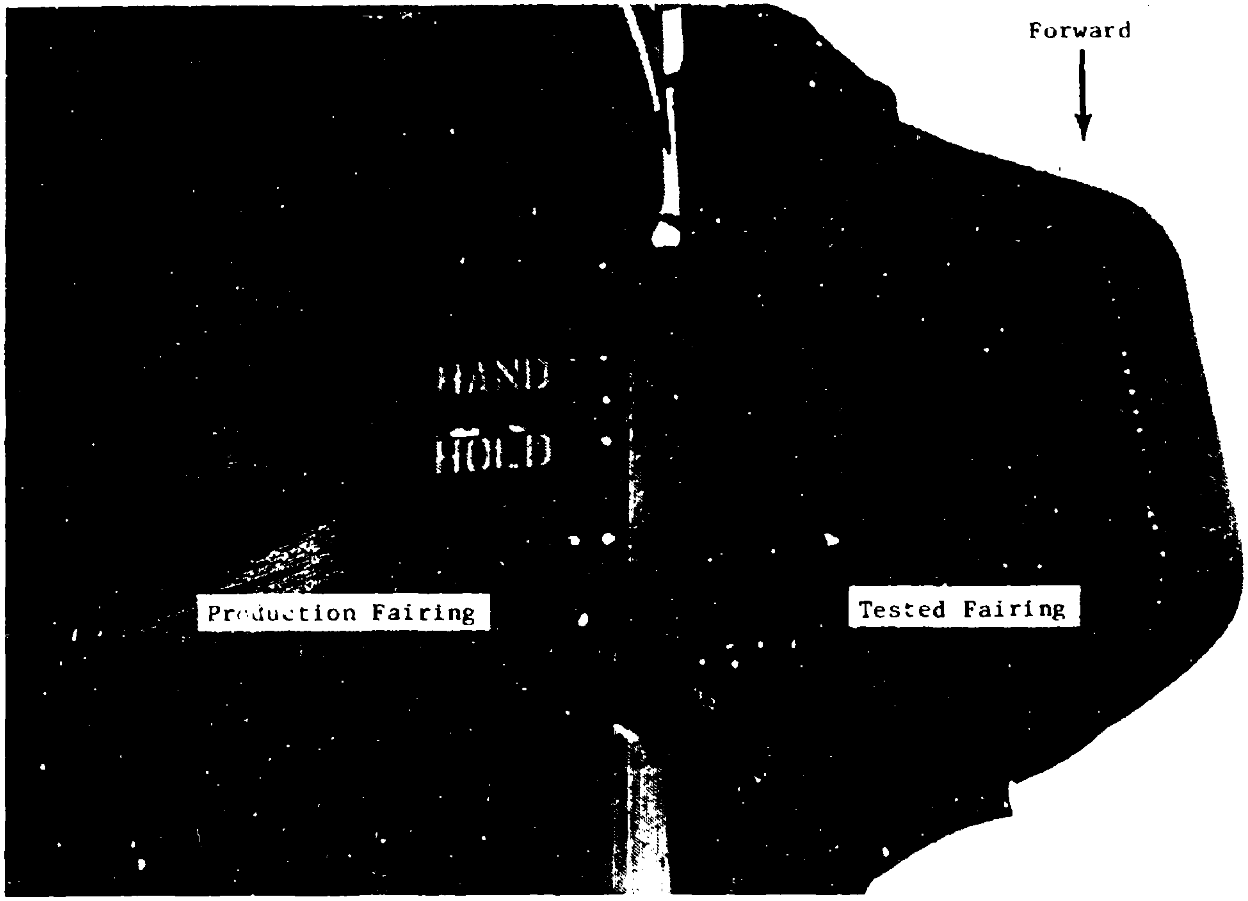



Photo 4. Comparision of Fixed Provision
Fairings Looking Down

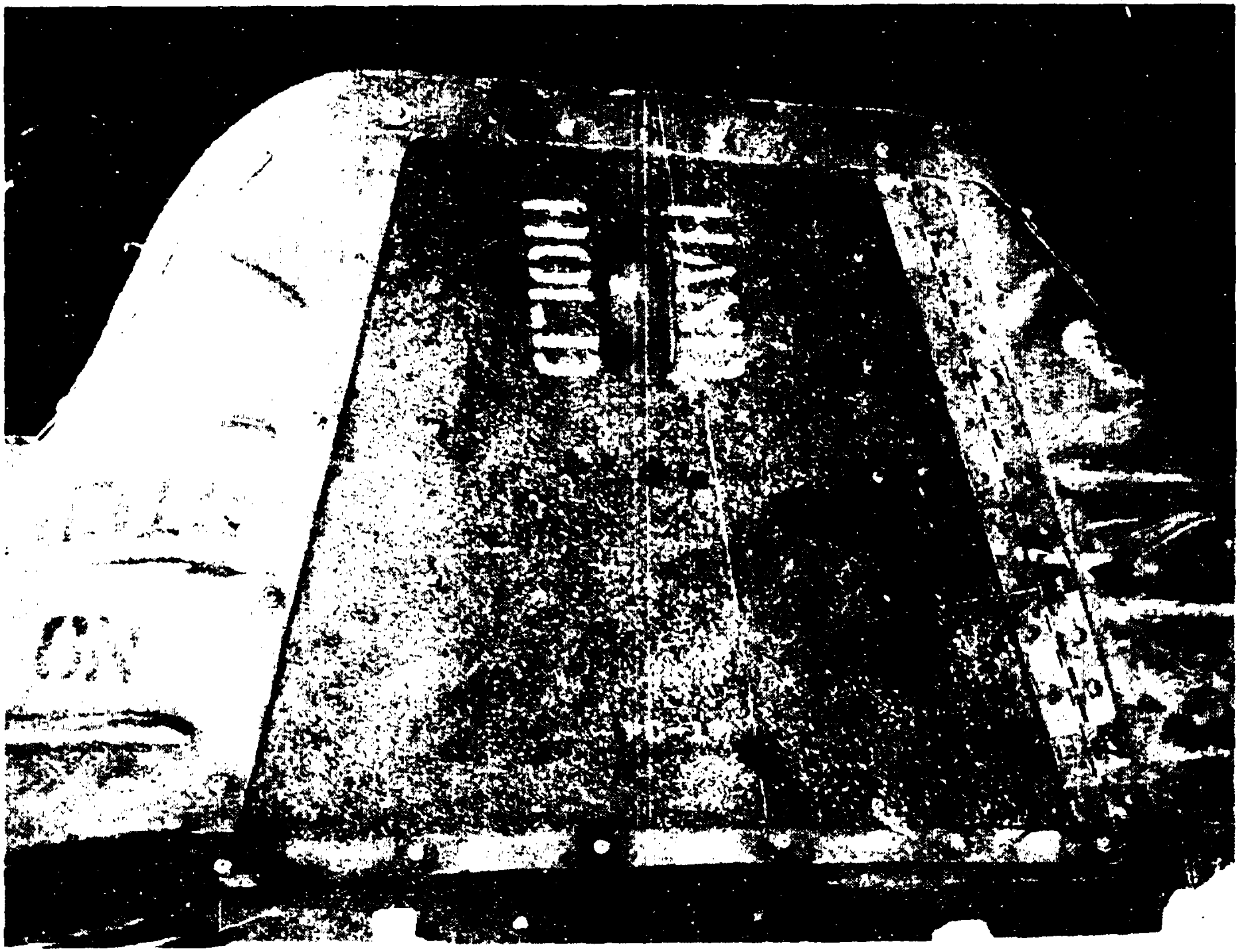



Photo 5. Sixth Year Production Fairing

Table 1. Airframe Fixed Provisions - Detail Weights

| | Weight (lb) | Horizontal Arm | Lateral Arm | Vertical Arm |
|---|---|---|---|---|
| Upper Fitting Sta. 295 (2) | 17.1 | 295.0 | 0 | 260.0 |
| Lower Fitting Sta. 295 (2) | 6.6 | 295.0 | 0 | 217.1 |
| Upper Fitting Sta. 308 (2) | 18.8 | 308.0 | 0 | 260.0 |
| Lower Fitting Sta. 308 (2) | 7.9 | 308.0 | 0 | 217.1 |
| Longitudinal Structure (2) | 5.1 | 301.5 | 0 | 263.3 |
| Jettison System | 7.2 | 235.0 | 0 | 218.0 |
| Auxiliary Fuel System - Provisions in Main Tank | 2.2 | 428.5 | -6.8 | 225.5 |
| Auxiliary Fuel System - Provisions in Fuselage | 10.9 | 348.0 | 0 | 263.0 |
| Auxiliary Fuel System - Wiring in Fuselage | 1.1 | 369.0 | 0 | 265.0 |
| Bleed Air System | 2.6 | 315.5 | -0.8 | 266.7 |
| Mine Dispenser | 2.0 | 255.0 | 0 | 250.0 |
| Work Platform | 16.3 | 301.5 | 0 | 266.1 |
| Frames 295 and 308 Beef-up | 17.6 | 301.5 | 0 | 251.2 |
| Fuselage Steps | 7.2 | 295.0 | 0 | 241.0 |
| TOTAL AIRFRAME FIXED PROVISIONS | (122.6) | (303.9) | (-0.1) | (250.7) |
| Removable Fairings | 8.0 | 301.3 | 0 | 251.4 |
| Total Change to UH-60A Baseline | (130.6) | (303.7) | (-0.1) | (250.7) |

Table 2. Airspeed/Stabilator System Configuration

| Item | Original Production | Current Production |
|---|---|---|
| Stabilator Airspeed Damping | 0.4 sec | 3.0 sec (electrical) |
| Pitot-Tube Orientation | Straight | Rolled 20 deg outboard 3 deg down |
| Stabilator Program | -- | Collective gain reduced |
| Airspeed Indicator Damping | 0.0 sec | 0.4 sec |
| Vertical Speed Indicator Static Source Location | Pitot Tubes | Cabin |

ENGINES

4. The primary power plants for the UH-60A helicopter are General Electric T700-GE-700 front drive turboshaft engines, rated at 1553 shaft horsepower (shp) at a power turbine speed 20,900 rpm (sea level, standard day installed). The engines are mounted in nacelles on either side of the main transmission. Each engine has four modules: cold section, hot section, power turbine section, and accessory section. Design features include an axial-centrifugal flow compressor, a through-flow combustor, a two-stage air-cooled high pressure gas generator turbine, a two-stage uncooled power turbine, and self contained lubrication and electrical systems. Pertinent engine data are shown below.

| | |
|---|---|
| Model | T700-GE-700 |
| Type | Turboshaft |
| Rated power | 1553 shp installed at sea level, standard-day static conditions at 20,900 rpm |
| Compressor | Five axial stages, 1 centrifugal stage |
| Combustion chamber | Single annular chamber with axial flow |
| Gas generator stages | 2 |
| Power turbine stages | 2 |
| Direction of engine rotation (aft looking fwd) | Clockwise |
| Weight (dry) | 415 pounds max |
| Length | 47 in. |
| Maximum diameter | 25 in. |
| Fuel | MIL-T-5624 grade JP-4 or JP-5 |

BASIC AIRCRAFT INFORMATION

5. General data of the UH-60A helicopter are as follows:

Gross Weight

| | |
|---|---|
| Maximum alternate gross weight | 20,250 pounds |
| Empty weight | Approximately 10,620 pounds |
| Primary Mission gross weight | 16,260 pounds |
| Fuel capacity | 364 gallons |

| | |
|---|---|
| **Main Rotor** | |
| Number of blades | 4 |
| Diameter | 53 ft, 8 in. |
| Blade chord | 1.73/1.75 ft |
| Blade twist | -18 deg (equivalent) |
| Blade tip sweep | 20 deg aft |
| Blade area (one blade) | 46.7 sq ft |
| Airfoil section (root to tip) designation<br>thickness (percent chord) | SC1095/SC1095R8<br>9.5 percent |
| Main rotor mast tilt (forward) | 3 deg |
| <u>Tail Rotor</u> | |
| Number of blades | 4 |
| Diameter | 11 ft |
| Blade chord | 0.81 ft |
| Blade twist (equivalent linear) | -18 deg |
| Blade area (one blade) | 4.46 sq ft |
| Airfoil section (root to tip designation)<br>thickness (percent chord) | SC1095/SC1095R8<br>9.5 percent |
| Cant angle | 20 deg |

Gear Ratios

| Main Transmission | Input RPM | Output RPM | Ratio | (Teeth) |
|---|---|---|---|---|
| Input bevel | 20,900.0 | 5747.5 | 3.6364 | (80/22) |
| Main bevel | 5747.5 | 1206.3 | 4.7647 | (81/17) |
| Planetary | 1206.3 | 257.9 | 4.6774 | $\frac{(228 + 62)}{62}$ |
| Tail takeoff | 1206.3 | 4115.5 | 0.2931 | (34/116) |
| Accessory bevel (generator) | 5747.5 | 11,805.7 | 0.4868 | (37/76) |
| Accessory spur (hydraulics) | 11,805.7 | 7186.1 | 1.6429 | (92/56) |
| Intermediate Gearbox | 4115.5 | 3318.9 | 1.2400 | (31/25) |
| Tail Gearbox | 3318.9 | 1189.8 | 2.7895 | (53/19) |
| Overall | | | | |
| Engine to main rotor | 20,900.0 | 257.9 | 81.0419 | |
| Engine to tail rotor | 20,900.0 | 1189.8 | 17.5658 | |
| Tail rotor to main rotor | 1189.8 | 257.9 | 4.6136 | |

# APPENDIX C. INSTRUMENTATION

1. The test instrumentation was installed, calibrated and maintained by the US Army Aviation Engineering Flight Activity personnel. A test boom with a swiveling pitot-static tube and angle of attack and sideslip vanes, was installed at the nose of the aircraft. The data acquisition system utilized pulse code modulation encoding on magnetic tape onboard the aircraft, and to the ground for real time monitoring through telemetry transmission. Data was displayed or recorded as indicated below.

Pilot Station

Airspeed (boom)
Altitude (boom)
Altitude (radar-dual range)*
Rate of climb*
Rotor speed (sensitive)
Engine torque* **
Turbine gas temperature ($T_{4.5}$)**
Engine gas generator speed**
Control positions
    Longitudinal
    Lateral
    Pedal
    Collective
Stabilator position*
Angle of sideslip
Sensitive bank angle (center of gravity lateral acceleration)

Copilot/Engineer Station

Airspeed (ship's system)
Altitude (ship's system)
Rotor speed*
Engine torque* **
Total air temperature
Engine fuel used (totalizer)
APU fuel used (totalizer)
Ballast cart position
Time code display
Run number
Event switch

Digital (PCM) Data Parameters

Airspeed (ship)
Airspeed (boom)
Altitude (boom)

*Ship's system/not calibrated
**Both engines

Altitude (ship)
Altitude (radar)
Total air temperature
Rotor speed
Engine torque**
Turbine gas temperataure ($T_{4.5}$)**
Engine gas generator speed**
Engine power turbine speed**
Engine fuel flow**
Engine fuel used**
Main rotor shaft torque
Main rotor shaft bending
Tail rotor shaft torque
Tail rotor impress pitch
Stabilator position
Ballast cart position
Control positions
    Longitudinal
    Lateral
    Pedal
    Collective
Stability augmentation system actuator output positions
    Longitudinal
    Lateral
    Directional
Angle of attack
Angle of sideslip
Aircraft attitude
    Pitch
    Roll
    Yaw
Aircraft angular rate
    Pitch
    Roll
    Yaw
Linear acceleration
    Center of gravity normal
    Center of gravity lateral
    Center of gravity longitudinal
Time of day
Run number
[illegible]

**Both engines

# APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

## AIRCRAFT WEIGHT AND BALANCE

1. The aircraft was weighed in the test configuration with full oil and all fuel drained prior to the start of the program. The initial weight of the aircraft was 14,750 pounds with the longitudinal center of gravity (cg) located at fuselage station (FS) 359.5 with the cg of the empty ballast cart located at FS 301. The fuel cells and external sight gages were calibrated on a previous evaluation. The measured fuel capacity using the gravity fueling method was 364 gallons. The fuel weight for each test flight was determined prior to engine start and after engine shutdown by using the external sight gage to determine the fuel volume and measuring it's specific gravity. Aircraft cg was controlled by a moveable ballast system which was manually positioned to maintain a constant cg while fuel was burned. The moveable ballast system was a cart (2000 pound capacity) attached to the cabin floor by rails and driven by an electric screw jack with a total longitudinal travel of 72.3 inches.

## PERFORMANCE

### General

2. Helicopter performance was generalized through the use of nondimensional coefficients as follows using the 1968 US Standard Atmosphere:

a. Coefficient of Power ($C_P$):

$$C_P = \frac{SHP\ (550)}{\rho A (\Omega R)^3} \qquad (1)$$

b. Coefficient of Thrust ($C_T$):

$$C_T = \frac{GW + CABLE\ TENSION}{\rho A (\Omega R)^2} \qquad (2)$$

c. Advance Ratio ($\mu$):

$$\mu = \frac{V_T\ (1.6878)}{\Omega R} \qquad (3)$$

Where:

SHP = Engine output shaft horsepower (total for both engines)

$\rho$ = Ambient air density ($lb\text{-}sec^2/ft^4$)

A = Main rotor disc area = 2262 $ft^2$

$\Omega$ = Main rotor angular velocity (radians/sec)

R = Main rotor radius = 26.833 ft

GW = Gross weight (lb)

Cable Tension = Tension of tether hover cable (lb)

$$V_T = \text{True airspeed (kt)} = \frac{V_E}{1.6878\sqrt{\rho/\rho_o}}$$

1.6878 = Conversion factor (ft/sec-kt)

$\rho_o$ = 0.0023769 ($lb\text{-}sec^2/ft^4$)

$V_E$ = Equivalent airspeed (ft/sec) =

$$\left\{\frac{7(70.7262\,P_a)}{\rho_o}\left(\left[\left(\frac{Q_c}{P_a}\right)+1\right]^{2/7}-1\right)\right\}^{1/2}$$

70.7262 = Conversion factor ($lb/ft^2$-in.-Hg)

$Q_c$ = Dynamic pressure (in.-Hg)

$P_a$ = Ambient air pressure (in.-Hg)

At the normal operating rotor speed of 257.9 (100%), the following constants may be used to calculate $C_P$ and $C_T$:

$\Omega R$ = 724.685

$(\Omega R)^2$ = 525,168.15

$(\Omega R)^3$ = 380,581,411.2

3. The engine output shaft torque was determined by use of the engine torque sensor. The power turbine shaft contains a torque

sensor tube that measures the total twist of the shaft. A concentric reference shaft is secured by a pin at the front end of the power turbine drive shaft and is free to rotate relative to the power turbine drive shaft at the rear end. The relative rotation is due to transmitted torque, and the resulting phase angle between the reference teeth on the two shafts is picked up by the torque sensor. This torque sensor was calibrated in a test cell by the engine manufacturer. The output from the engine torque sensor was recorded on the on-board data recording system. The output SHP was determined from the engine's output shaft torque and rotational speed by the following equation.

$$SHP = \frac{Q(N_P)}{5252.113} \tag{4}$$

Where:

$Q$ = Engine output shaft torque (ft-lb)

$N_P$ = Engine output shaft rotational speed (rpm)

5252.113 = Conversion factor (ft-lb-rev/min-SHP)

The output SHP required was assumed to include 13 horsepower for daylight operations of the aircraft electrical system, but was corrected for the effects of test instrumentation installation. A power loss of 1.82 horsepower was determined for electrical operation of the instrumentation.

Shaft Horsepower Available

4. Shaft horsepower available for the T700-GE-700 engine installed in the UH-60A was obtained from data received from Aviation Systems Command and presented in USAAEFA Report No. 77-17 (ref 5, app A). This data was calculated using the General Electric engine deck number 80024, dated 26 February 1981 with a power turbine shaft speed of 20,900 rpm. The installation losses used were based on 0.25 degree C engine inlet temperature rise in a hover, exhaust losses as obtained from the Sikorsky aircraft Document Number SER-70410, Revision 2, dated 8 March 1979, inlet ram pressure recovery as obtained from the Sikorsky Prime Item Development Specification, and an inlet temperature rise in forward flight assuming an adiabatic rise referenced to a zero degree rise in a hover.

## Hover Performance

5. Hover performance was obtained by the tethered hover technique. Additional free flight hover data were accumulated to verify the tethered hover data. All hover tests were conducted in winds of less than 3 knots. Tethered hover consists of restraining the helicopter to the ground by a cable in series with a load cell. An increase in cable tension, measured by the load cell, is equivalent to increasing gross weight. Free-flight hover tests consisted of stabilizing the helicopter at a desired height using the radar altimeter as a height reference. All hovering data were reduced to nondimensional parameters of $C_P$ and $C_T$ using equations 1 and 2, respectively. Adjustments in $C_P$ for changes in density altitude as presented in reference 5, app A, were required for dimensional comparisons.

## LEVEL FLIGHT PERFORMANCE

6. Each speed power was flown in ball centered flight by reference to a calibrated lateral accelerometer at a predetermined $C_T$ and referred rotor speed $(N_R/\sqrt{\theta})$. To maintain the ratio of gross weight to pressure ratio $(W/\delta)$ constant, altitude was increased as fuel was consumed. To maintain $N_R/\sqrt{\theta}$ constant, rotor speed was decreased as temperature decreased.

Where:

$\theta$ = Temperature ratio = $\dfrac{OAT + 273.15}{288.15}$

OAT = Ambient air temperature (°C)

$N_R$ = Main rotor speed (rev/min)

$\delta$ = Pressure ratio = $\dfrac{P_a}{P_{ao}}$

$P_{ao}$ = 29.92126 in.-Hg

Changes in equivalent flat plate area were determined from the following equation.

$$\Delta F_e = \frac{\Delta C_P\ 2A}{3} \qquad (5)$$

The effects of external instrumentation drag were determined by the following equation, where the $\Delta F_e$ was estimated to be 0.833 ft$^2$.

$$\Delta SHP_{instr\ drag} = \frac{\Delta F_e\ (\rho/\rho_0)(V_T{}^3)}{96254} \tag{6}$$

Where:

96254 = Conversion factor (ft$^2$-kt$^3$/SHP)

Power required for level flight at the test day conditions was determined using the following equation.

$$SHP_t = SHP - \Delta SHP_{instr\ drag} - 1.82 \tag{7}$$

7. Test-day (measured) level flight data was corrected to average test day conditions by the following equations.

$$SHP_s = SHP_t \frac{(\delta_s\sqrt{\theta_s}) \left[\dfrac{N_R}{\sqrt{\theta}}\right]_s^3}{(\delta_t\sqrt{\theta_t}) \left[\dfrac{N_R}{\sqrt{\theta}}\right]_t^3} \tag{8}$$

$$V_{T_s} = V_{T_t} \frac{\left[\dfrac{N_R}{\sqrt{\theta}}\right]_s}{\left[\dfrac{N_R}{\sqrt{\theta}}\right]_t} \tag{9}$$

Where:

Subscript t = Test day

Subscript s = Average test day

8. The specific range (SR) data were derived from the test level flight power required and fuel flow ($W_{F_t}$). Selected level flight performance SHP and fuel flow data for each engine were referred as follows.

$$SHP_{REF} = \frac{SHP_t}{\delta\theta^{0.5}} \tag{10}$$

$$W_{F_{REF}} = \frac{W_{F_t}}{\delta\theta^{0.55}} \tag{11}$$

A curve fit was subsequently applied to this referred data and was used as the basis to correct $W_{F_t}$ to standard day fuel flow using the following equation.

$$W_{F_s} = W_{F_t} + \Delta W_F \tag{12}$$

Where:

$\Delta W_F$ = Changes in fuel flow between $SHP_t$ and $SHP_s$

The following equation was used for determination of specific range.

$$SR = \frac{V_{T_s}}{W_{F_s}} \tag{13}$$

# APPENDIX E. TEST DATA

INDEX

**FIGURE 2**

**NONDIMENSIONAL HOVER PERFORMANCE**

**UH-60A USA S/N 77-22716**

**WHEEL HEIGHT = 100 FT**

| SYMBOL | METHOD | CONFIGURATION | DENSITY ALTITUDE (FT) | REFERRED ROTOR SPEED (RPM) | OAT (DEG C) |
|---|---|---|---|---|---|
| ⊡ | TETHERED | ESSS F P FAIRINGS | 3700 | 259 | 21.5 |
| ⊙ | TETHERED | ESSS F P FAIRINGS | 3600 | 246 | 21.0 |
| ■ | FREE | ESSS F P FAIRINGS | 3740 | 256 | 22.0 |
| ● | FREE | ESSS F P FAIRINGS | 3700 | 242 | 22.0 |
| ◆ | TETHERED | NORM UTILITY | 3340 | 258 | 19.5 |
| △ | TETHERED | NORM UTILITY | 3300 | 261 | 20.0 |
| ★ | TETHERED | NORM UTILITY | 3300 | 251 | 19.5 |
| ▽ | TETHERED | NORM UTILITY | 3300 | 244 | 19.5 |

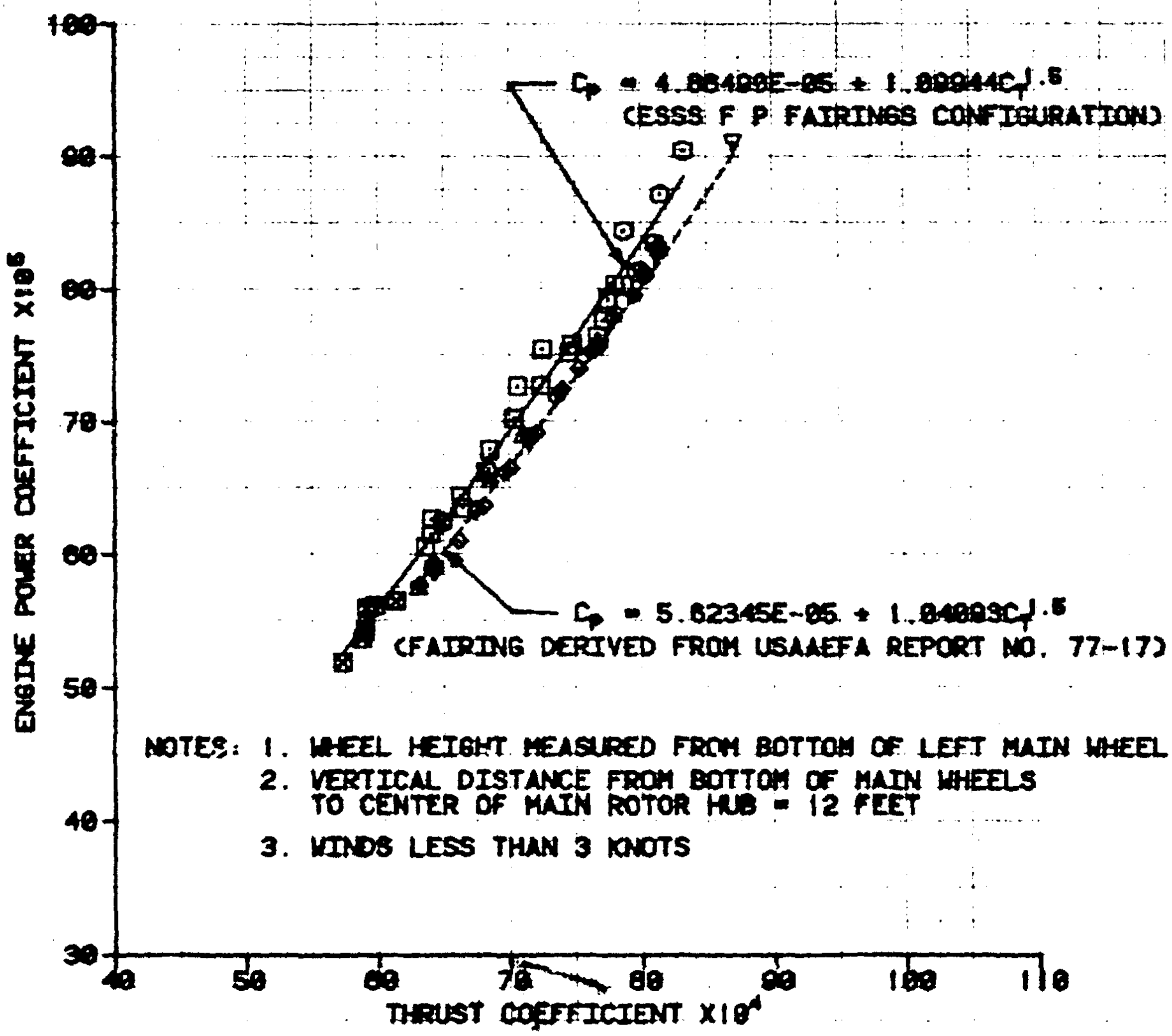


FIGURE 3
LEVEL FLIGHT PERFORMANCE
UH-60A USA S/N 77-22716

AIRCRAFT CONFIGURATION: NORMAL UTILITY

| AVG GROSS WEIGHT (LB) | AVG CG LOCATION LONG (FS) | AVG CG LOCATION LAT (BL) | AVG DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | AVG REFERRED ROTOR SPEED (RPM) | AVG THRUST COEFFICIENT |
|---|---|---|---|---|---|---|
| 14,400 | 347.1 (FWD) | 0.1 LT | 10,280 | 14.5 | 258.1 | 0.007011 |

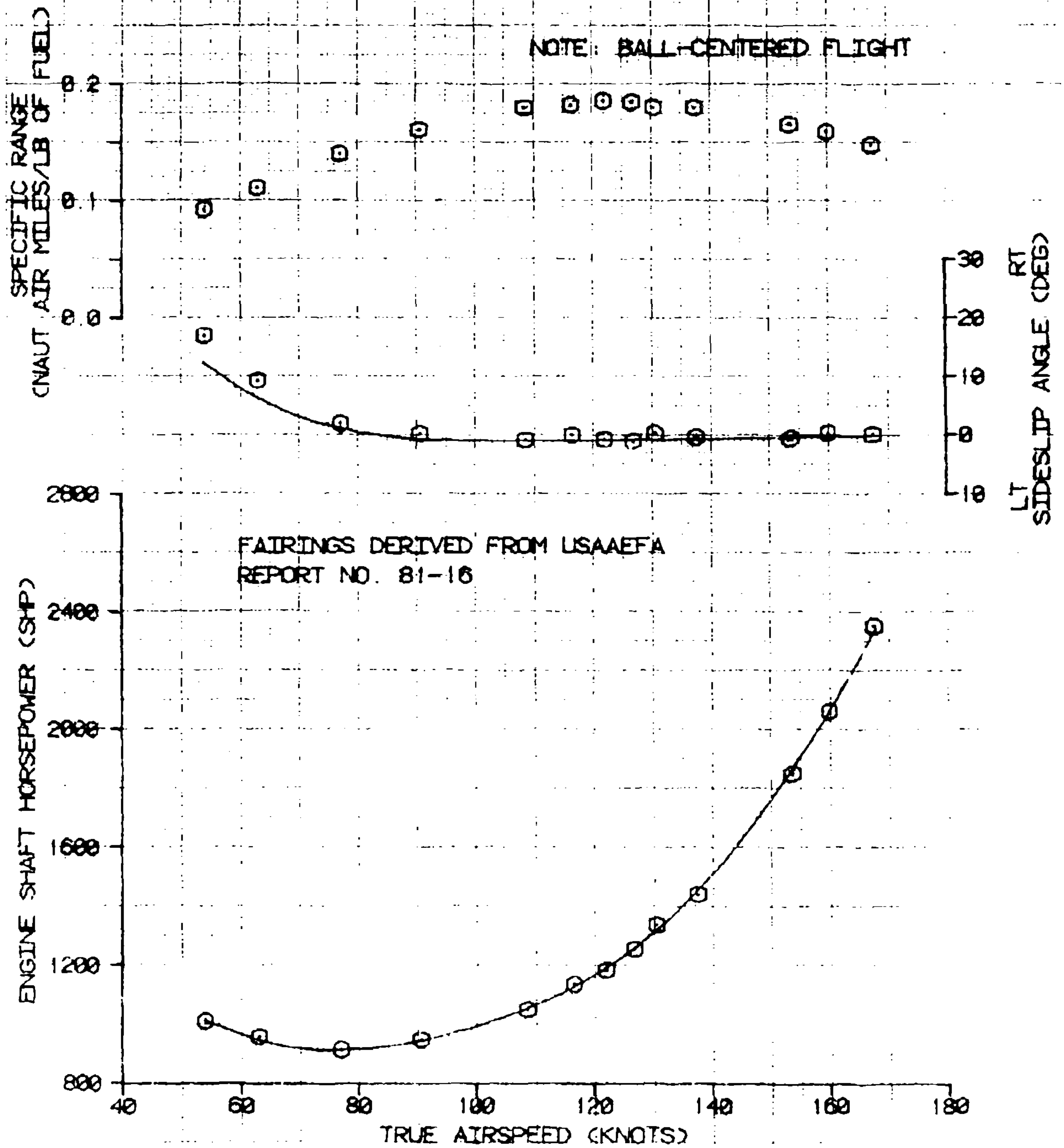


FIGURE 4
LEVEL FLIGHT PERFORMANCE
UH-60A USA S/N 77-22716

AIRCRAFT CONFIGURATION: NORMAL UTILITY

| AVG GROSS WEIGHT (LB) | AVG CG LOCATION LONG (FS) | AVG CG LOCATION LAT (BL) | AVG DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | AVG REFFERRED ROTOR SPEED (RPM) | AVG THRUST COEFFICIENT |
|---|---|---|---|---|---|---|
| 15,920 | 347.1(FWD) | 0.1 LT | 11,510 | 14.5 | 258.2 | 0.008002 |

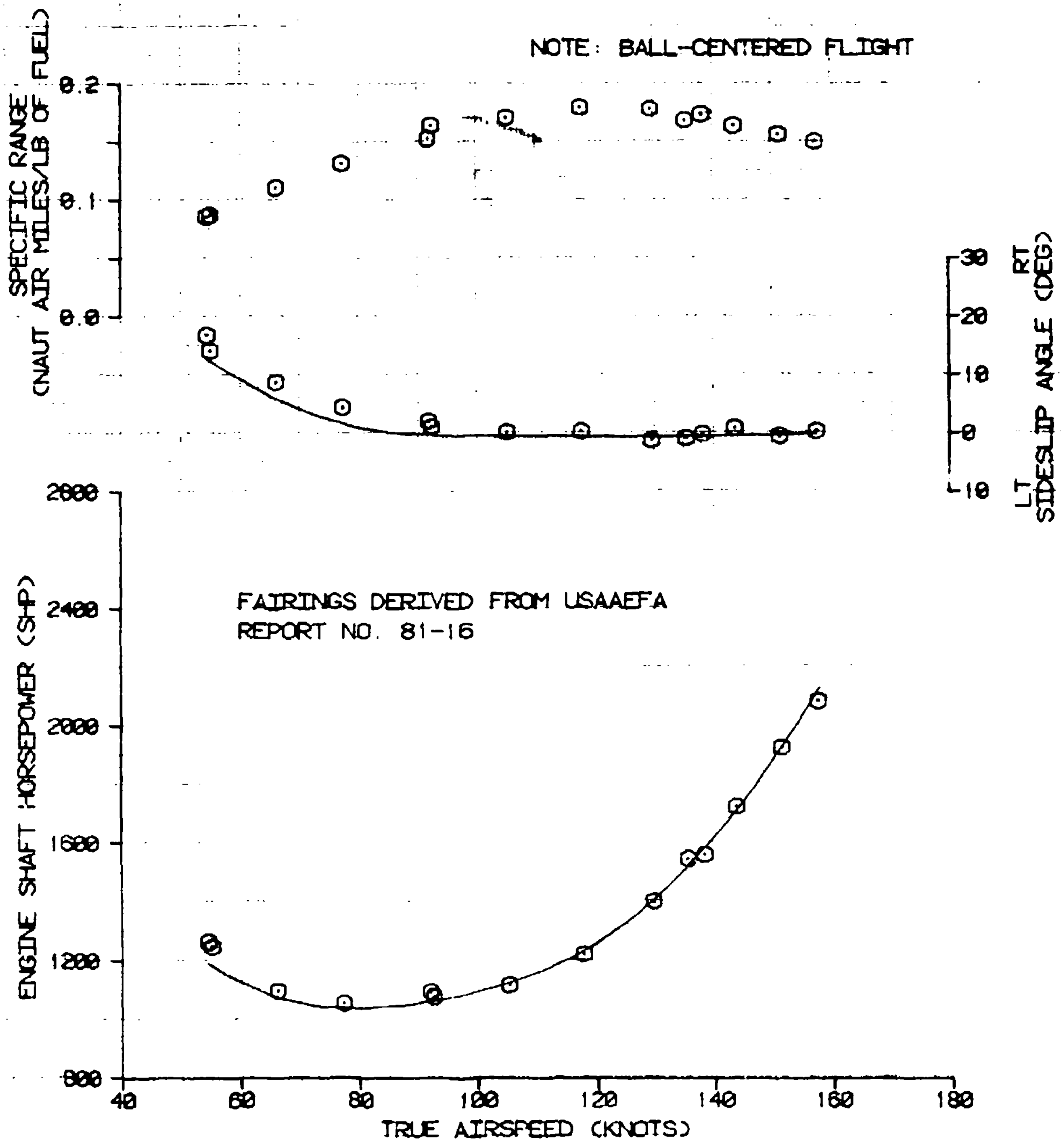


FIGURE 5
LEVEL FLIGHT PERFORMANCE
UH-60A USA S/N 77-22716

AIRCRAFT CONFIGURATION: NORMAL UTILITY

| AVG GROSS WEIGHT (LB) | AVG CG LOCATION LONG (FS) | AVG CG LOCATION LAT (BL) | AVG DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | AVG REFFERRED ROTOR SPEED (RPM) | AVG THRUST COEFFICIENT |
|---|---|---|---|---|---|---|
| 16,190 | 347.1(FWD) | 0.1 LT | 13,860 | 7.0 | 258.0 | 0.009018 |

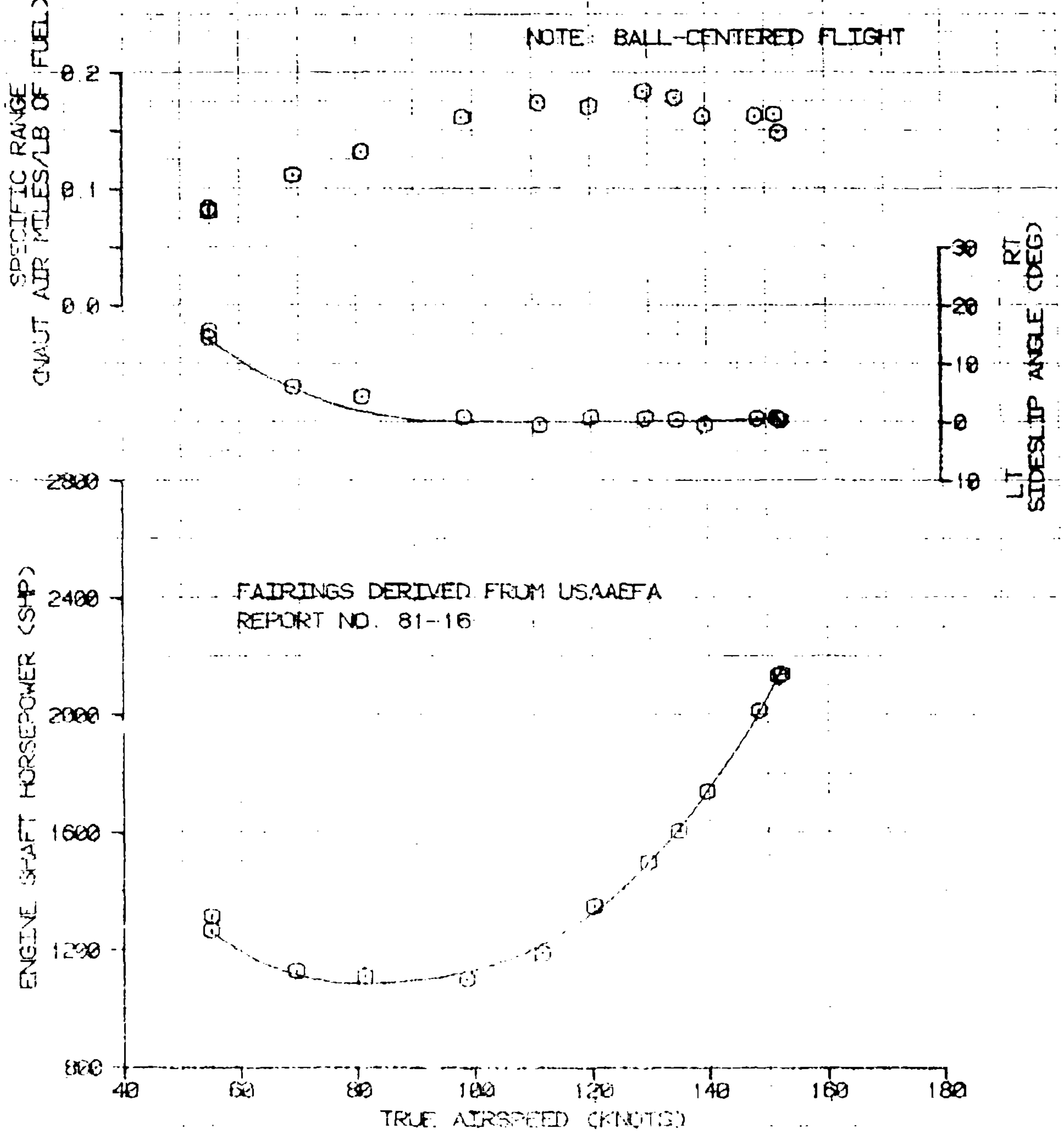
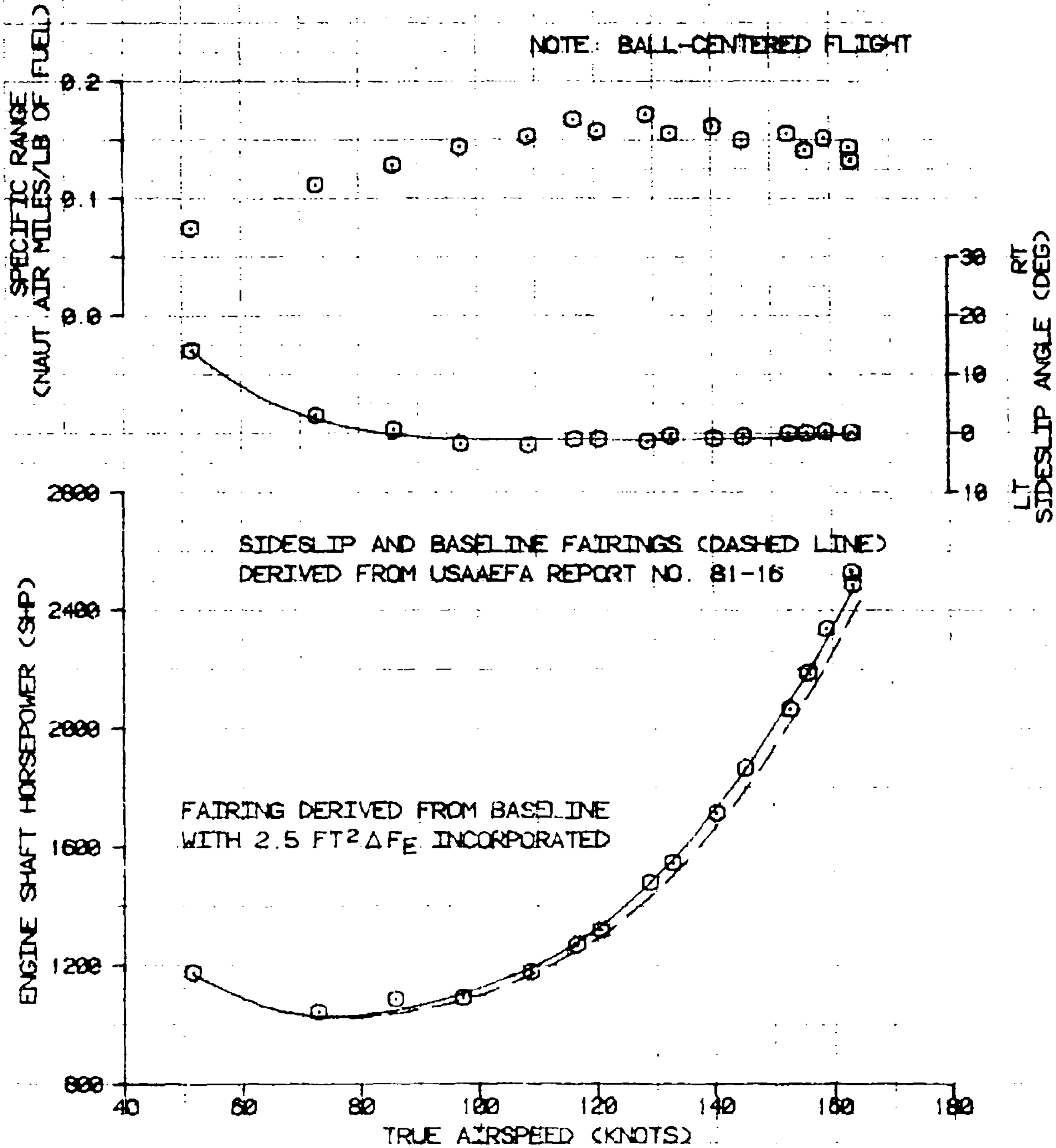


FIGURE 6
LEVEL FLIGHT PERFORMANCE
UH-60A USA S/N 77-22716

AIRCRAFT CONFIGURATION: ESSS F. P. FAIRINGS

| AVG GROSS WEIGHT (LB) | AVG CG LOCATION LONG (FS) | AVG CG LOCATION LAT (BL) | AVG DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | AVG REFERRED ROTOR SPEED (RPM) | AVG THRUST COEFFICIENT |
|---|---|---|---|---|---|---|
| 16,100 | 347.0(FWD) | 0.1 LT | 7510 | 20.0 | 258.2 | 0.007006 |




46 1513

FIGURE 7
LEVEL FLIGHT PERFORMANCE
UH-60A USA S/N 77-22716

AIRCRAFT CONFIGURATION: ESSS F. P. FAIRINGS

| AVG GROSS WEIGHT (LB) | AVG CG LOCATION LONG (FS) | AVG CG LOCATION LAT (BL) | AVG DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | AVG REFERRED ROTOR SPEED (RPM) | AVG THRUST COEFFICIENT |
|---|---|---|---|---|---|---|
| 16,120 | 347.2(FWD) | 0.1 LT | 10,950 | 13.5 | 258.4 | 0.007075 |

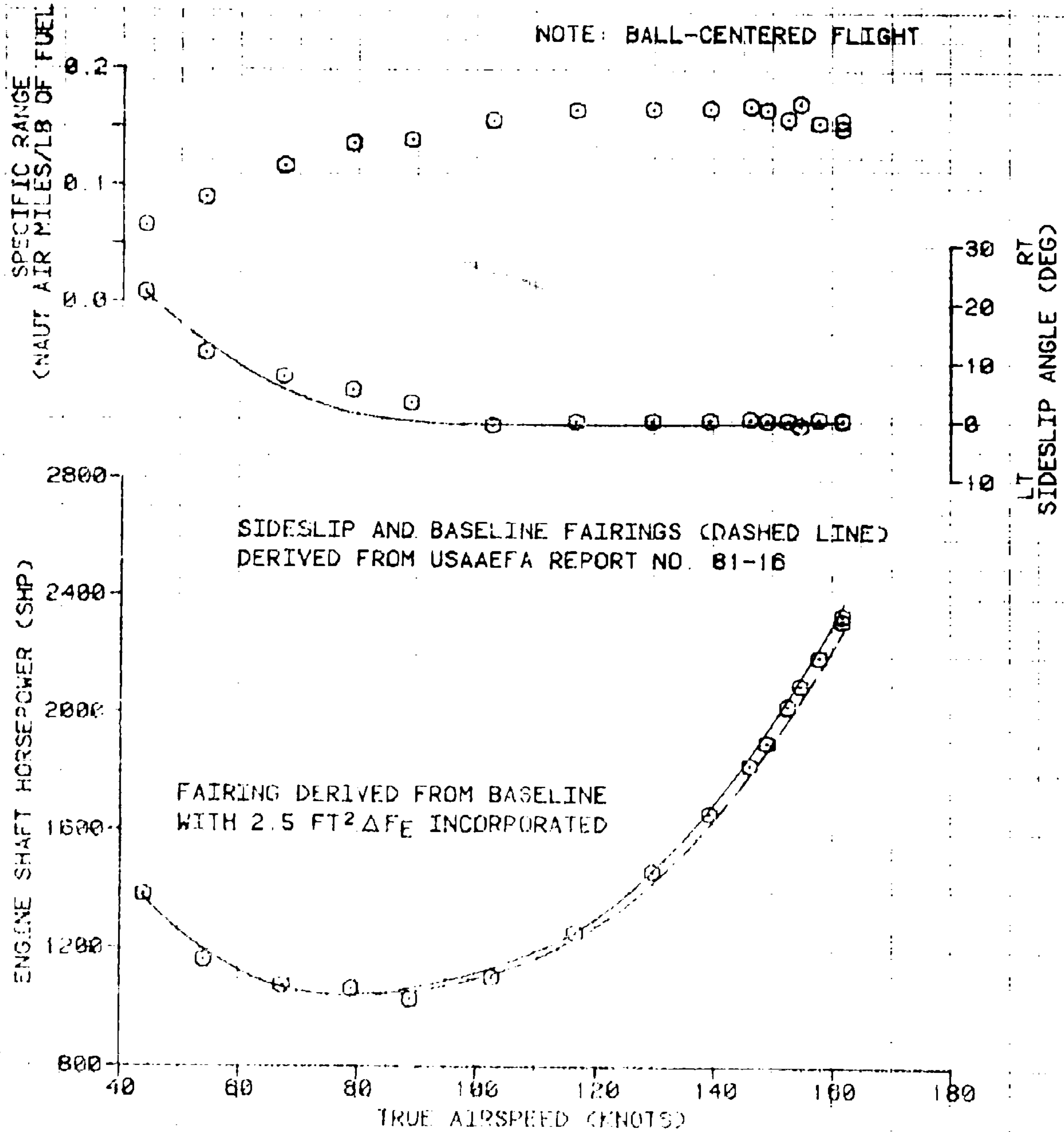
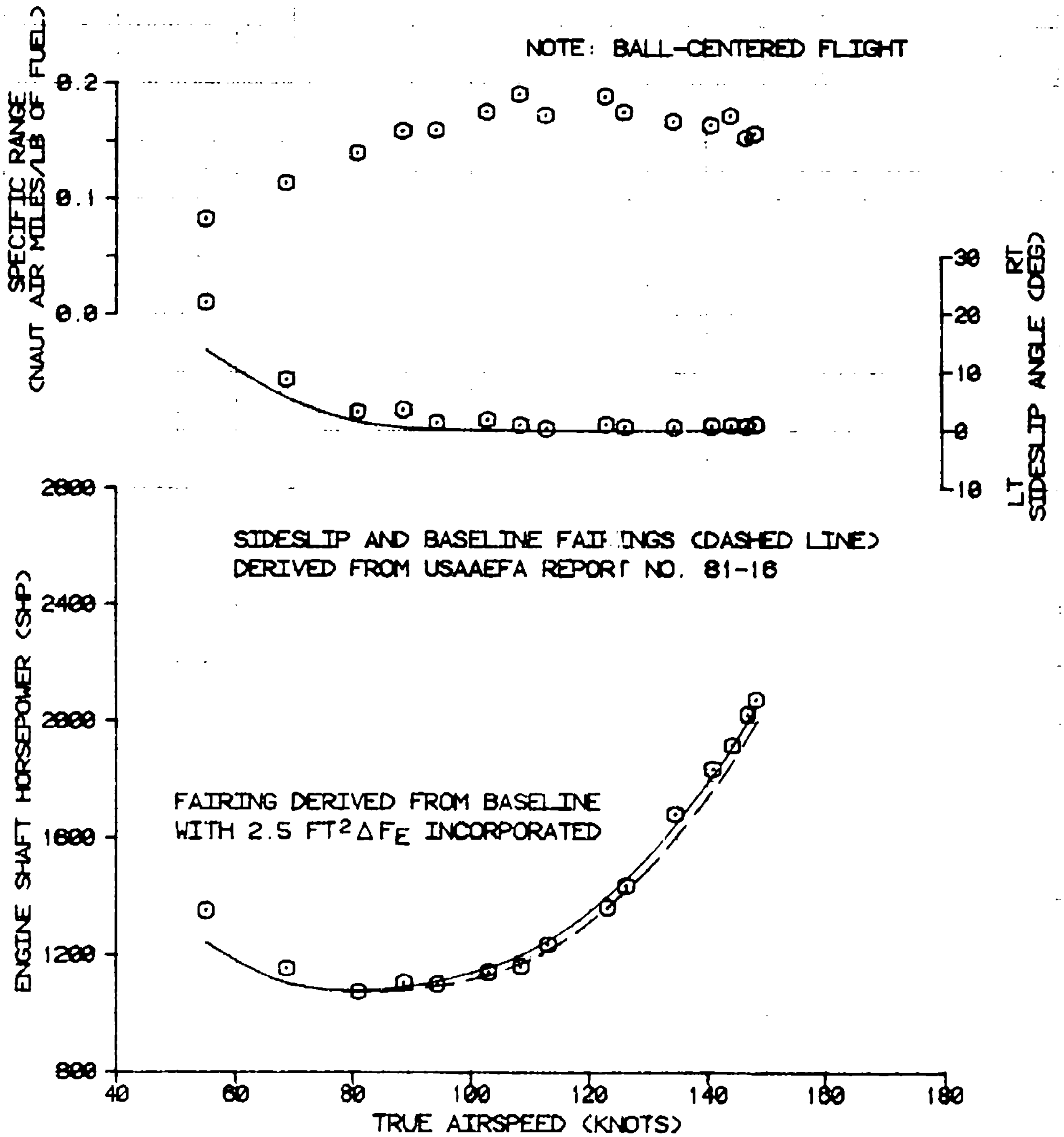


FIGURE 8
LEVEL FLIGHT PERFORMANCE
UH-60A USA S/N 77-22716

AIRCRAFT CONFIGURATION: ESSS F. P. FAIRINGS

| AVG GROSS WEIGHT (LB) | AVG CG LOCATION LONG (FS) | AVG CG LOCATION LAT (BL) | AVG DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | AVG REFFERRED ROTOR SPEED (RPM) | AVG THRUST COEFFICIENT |
|---|---|---|---|---|---|---|
| 16,120 | 347.2(FWD) | 0.1 LT | 13,850 | 6.0 | 258.1 | 0.009006 |



# DISTRIBUTION

| | |
|---|---|
| HQDA (DALO-SMM, DALO-AV, DALO-RQ, DAMO-HRS, DAMA-PPM-T, DAMA-RA, DAMA-WSA, DACA-EA) | 8 |
| US Army Materiel Command (AMCDE-SA, AMCQA-E, AMCDE-I, AMCDE-P, AMCQA-SA, AMCSM-WA AMCQA-ST) | 7 |
| US Army Training and Doctrine Command (ATTG-U, ATCD-T, ATCD-ET, ATCD-B) | 4 |
| US Army Aviation Systems Command (AMSAV-ED, AMSAV-EI, AMSAV-EL, AMSAV-EA, AMSAV-EP, AMSAV-ES, AMSAV-Q, AMSAV-MC, AMSAV-ME) | 11 |
| US Army Test and Evaluation Command (DRSTE-CT-A, DRSTE-TO-O) | 2 |
| US Army Logistics Evaluation Agency (DALO-LEI) | 1 |
| US Army Materiel Systems Analysis Agency (DRXSY-R, DRXSY-MP) | 2 |
| US Army Operational Test and Evaluation Agency (CSTE-ASD-E) | 1 |
| US Army Armor Center (ATZK-CD-TE) | 1 |
| US Army Aviation Center (ATZQ-D-T, ATZQ-TSM-A, ATZQ-TSM-S, ATZQ-TSM-U) | 4 |
| US Army Combined Arms Center (ATZLCA-CM) | 1 |
| US Army Safety Center (IGAR-TA, IGAR-Library) | 2 |
| US Army Research and Technology Laboratories (AVSCOM) (SAVDL-AS, SAVDL-POM (Library)) | 2 |
| US Army Research and Technology Laboratories/Applied Technology Laboratory (SAVDL-ATL-D, SAVDL-Library) | 2 |
| US Army Research and Technology Laboratories/Aeromechanics Laboratory (AVSCOM) (SAVDL-AL-D) | 1 |

| | |
|---|---|
| US Army Research and Technology Laboratories/Proplusion Laboratory (AVSCOM) (SAVDL-PL-D) | 1 |
| Defense Technical Information Center (DDR) | 12 |
| US Military Academy, Department of Mechanics (Aero Group Director) | 1 |
| MTMC-TEA (MTT-TRC) | 1 |
| ASD/AFXT, ASD/ENF | 2 |
| US Naval Post Graduate School, Department Aero Engineering (Professor Donald Layton) | 1 |
| Assistant Technical Director for Projects, Code: CT-24 (Mr. Joseph Dunn) | 2 |
| 6520 Test Group (ENML/Stop 238) | 1 |
| Commander, Naval Air Systems Command (AIR 5115B, AIR 5301) | 3 |
| US Army Aviation Systems Command (AMCPM-BH-Q) | 5 |
| Sikorsky Aircraft Division, United Technologies Corporation (Mr. Richard Connor) | 5 |
| General Electric (Mr. Koon) | 2 |