U.S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

PRELIMINARY FLIGHT TEST DATA

XH-51A RIGID ROTOR HIGH SPEED FLIGHT PROGRAM

INTERIM REPORT NO. 9

DECEMBER 1964
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TSL-121-2/65

DATE PROCESSED: 10/18/65

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This report summarizes the flight test results of the Phase IV, XH-51A compound helicopter testing. For this program, an XH-51A helicopter was modified to incorporate a wing and a J-60 auxiliary jet engine. The purpose of this phase was to obtain flight test data on performance, stability, maneuverability, critical stresses and vibration at speeds up to an objective of 200 knots. The data included in this report presents the results in these areas at speeds up to a level flight true airspeed of 210 knots.

The completion of this phase represents the end of the flight testing required by the original contract. Preparation of a final report is in progress.

Results and Discussion

Performance

Level flight performance of the compound helicopter in terms of shaft horsepower required is shown on Figure 1. This data has been corrected to sea level standard day and shows performance as a pure helicopter, with the J-60 engine at idle and in full compound flight. Figure 2 shows the jet thrust required for the same flight condition. Figure 3 shows the tail rotor power required. Equivalent total propulsive power requirement can be seen by summing the curves shown in Figures 1, 2, and 3. Figure 4 shows the variation of rotor lift which was measured during the performance testing. Note that at the high speeds the rotor was very nearly unloaded.

Flying Qualities

Cyclic control stick positions in trimmed level flight are shown on Figure 5. During the course of the program, the incidence of the control gyro arms was reduced from 30 degrees to 5 degrees to reduce structural loads in the gyro drive system. This resulted in a change in the aerodynamic forces which produce a gyro processing moment and an apparent shift in the static stick-fixed longitudinal stability. Actual longitudinal stability, evidenced by the pitching moment of the wing-body against the rotor system was not altered by the gyro arm incidence change.

As forward flight speed was increased, measurement of the one per revolution flapwise bending in the main rotor, resolved to show the pitching and rolling components, indicated increasingly negative longitudinal stability. To restore positive longitudinal stability, the size of the horizontal tailplane was increased. Figures 6 and 7 show the effect of the change in area of the horizontal tailplane on the pitching component of the main rotor one per revolution flapwise bending.

Tail rotor pedal position is shown in Figure 8 and indicates that ample directional control margins existed at high speed.
Maneuvering stability was comfortably positive throughout the test program. This is shown on Figure 9.

Structures:

Structural measurements including loads in the main rotor hub and blades, control gyro arms, main rotor pitch link, tail rotor, horizontal stabilizer, wing bending, and main rotor lift were obtained. A review of the loads measured indicates that the major structural item most likely to govern the fatigue life of the vehicle is the main rotor hub at station 7.0. Hub flapwise and chordwise bending moments were measured at hub station 6. These station 5 bending moments can be converted to stress at station 7 by the following factors:

Station 6 flapwise bending moment, inch pounds $\times 1.42 = \text{station 7 stress, psi}$

Station 6 chordwise bending moment, inch pounds $\times 0.152 = \text{station 7 stress, psi}$

Assuming a stress concentration factor of 3, the hub at station 7 has an estimated endurance limit cyclic stress of 26,000 psi.

The compound helicopter was initially flown without the auxiliary J-60 jet engine operating. These tests were conducted from hover to a forward speed of 96 knots CAS. The structural loads with the J-60 off are shown in Figures 10 and 11. The structural loads on these plots are essentially the same as the conventional XH-51A helicopter loads extrapolated to the weight and C.G. of the compound helicopter.

The next series of tests were conducted with the J-60 at idle (approximately 200 pounds of thrust). The structural loads with the J-60 at idle are shown in Figures 10 and 12. These plots show that the main rotor hub loads decrease with the added thrust from the J-60 at idle. With increased J-60 thrust for level flight, tests were conducted to determine the optimum collective blade angle setting for the higher speeds. The structural loads are plotted versus collective blade angle for the various speeds and collective blade settings up to 158 knots CAS, Figures 13, 14, and 15. From these tests, the optimum collective blade angle setting from a blade loads standpoint was determined to be approximately 4.5 degrees. The main rotor hub loads for this collective blade angle setting are also plotted versus calibrated airspeed on Figure 10.

With the large horizontal stabilizer at zero degree incidence, tests were conducted at 120 knots and 140 knots with variations in collective to determine the effect of collective blade angle setting. The data from these tests are plotted in Figures 16, 17, and 18. Extrapolation of these data to the higher speed conditions indicated that a collective setting around 3.8 degrees would be a satisfactory compromise angle for proceeding to high speeds with a constant collective blade angle.
The speed was built up to 201.5 knots CAS in approximately 10 knot increments with the collective blade angle held at approximately 3.8 degrees. The data from these tests are plotted versus airspeed in Figures 19 through 23.

The main rotor blade flapwise cyclic bending at station 6 shown in Figure 19 increased almost linearly with speed to a maximum value of 15,300 inch pounds at 201.5 knots. As can be seen in Figure 23, the majority of this moment was caused by the one per revolution pitch and roll components of the blade bending.

The cyclic flapwise bending at station 6 of 15,300 inch pounds converts to a cyclic stress of 21,700 psi at station 7. The cyclic chordwise moment at station 6 of 18,200 inch pounds converts to a stress of 2,800 psi at station 7. The sum of the two results in a maximum possible cyclic stress of 24,500 psi as compared to an estimated endurance limit of 26,000 psi.

Main rotor pitch link axial loads are shown in Figure 21. The maximum cyclic loads are only 137 pounds as compared to an estimated endurance limit of 1,400 pounds. Note that there has been no tendency for the loads to increase rapidly with speed increase. The blade feathering and torsion loads have increased only very gradually with increase in airspeed.

Gyro arm flap and chord bending loads also are shown in Figure 21. At speeds above 170 knots, the gyro arm incidence angle setting was reduced from 30 degrees to 5 degrees. This had negligible effect on the cyclic chordwise loads, but did reduce the cyclic flapwise loads. The incidence angle was changed to reduce the steady torsion load on the gyro drive shaft. The cyclic loads measured are well below the estimated endurance limit of the gyro arms.

Measurements of tail rotor flapwise bending at station 19.5 were obtained at speeds above 170 knots. These are shown in Figure 22. Analysis of data obtained during previous tests with the three-blade main rotor had shown that station 19.5 was the most critical bending station on the tail rotor. The cyclic loads fall somewhat below what might be expected by extrapolating the measurements as a regular helicopter; however, they are approaching the estimated endurance limit of 790 inch pounds. Linear extrapolation of the data indicates that the endurance limit would be reached at a speed somewhere between 230 and 240 knots CAS.

Measured horizontal stabilizer bending loads are shown in Figure 20. There is a difference between the average load L and R indicating an apparent swirl in the air flow in that area. The static loads are well under the limit static strength. The cyclic loads obtained are reasonably high and the frequency of motion is at tail rotor rotational frequency. The symmetrical first bending mode of the stabilizer, as determined by ground shake tests, is 30.5 cps. The tail rotor rotational frequency is 35 cps and apparently the two frequencies are close enough together to provide a reasonable amount of excitation to the stabilizer. To help alleviate this, cable guy wires were strung from the stabilizer tips to the fuselage top and bottom at the stabilizer. These helped keep the oscillatory amplitude from building up too rapidly. The estimated endurance
limit for the stabilizer is 3,200 inch pounds. This was exceeded by 22 per cent for a few minutes of flight time in the runs at speeds above 180 knots.

Autorotation Entries

Structural loads during the transition from powered flight to autorotation and during the autorotation are usually less than experienced in powered level flight and therefore are not shown.

Maneuvering Conditions

The load factors obtained at various airspeeds with the J-60 jet engine off are shown in Figure 24. The maximum speed obtained with jet off was 134 knots CAS and the maximum load factor was 1.51 g's with the minimum load factor of 0.4 g's. With the jet engine operating, the speed-load factor values obtained are plotted in Figure 25. The maximum load factor obtained was 1.8 g's and the minimum 0.64 g's. All load factors are corrected to a weight of 4,300 pounds.

Main rotor flapwise and chordwise bending moments at station 6 and flapwise bending moment at station 157 are plotted versus load factor in Figures 26, 27, and 28. With the jet engine on and the collective blade angle lowered, the flapwise average bending moments at station 6 are more negative due to the reduced rotor lift. The cyclic loads scatter considerably and do not appear to have any significant trend with either load factor or rotor lift. With reduced rotor lift, the chordwise loads, both average and cyclic, are reduced considerably at all load factors. At station 157, the flapwise cyclic bending loads appear to be somewhat smaller with a reduced collective blade angle (jet engine on), whereas the average loads appear to be relatively unaffected by the collective blade angle.

The flapwise and chordwise cyclic loads are the maximum loads that occurred during the maneuver and do not necessarily occur at the time of the maximum load factor.

Vibration

Cabin vibration levels are shown on Figure 10 for the pure helicopter mode and Figure 11 with the J-60 at idle. Due to the high gross weight and the power levels required, these vibration levels are excessive.

In compound flight, the vibration levels are greatly reduced and are shown on Figure 29 for frequencies of 4 per revolution and higher.
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LOCKHEED HELICOPTER
MODEL XH-51A
SHIP - BuNo 151263

CYCLIC CONTROL POSITIONS IN LEVEL FLIGHT

COMPUND HELICOPTER

FIGURE 5

SYN 0 0 1 1 1 1 1 1 1
TEST 196 197 199 201 206 208 210 211

CYCLIC STICK ROLL POSITION - IN.

- RIGHT
- LEFT

CYCLIC STICK YAW POSITION - IN.

- AFT

AFT LIMIT = 4.80 IN.

- 0
- 1
- 2

FWD LIMIT = 5 IN.

- 0
- 1
- 2
- 3
- 4
- 5

CALIBRATED AIRSPEED - KNOTS

(1002.5)
ROLL & PITCH COMPONENT VS. COLLECTIVE BLADE ANGLE

\[ \text{YBLADE-PILOT} \]

\[ \text{24.2 ft. Horiz. Stab. @ 0.0 deg.} \]

\[ \text{Z-62} \text{ ON} \]

\[ \text{1/2000 Scale} \]

\[ \text{1 in. 1000} \]

\[ \text{FIGURE 7} \]
TAIL ROTOR PEDAL POSITION IN LEVEL FLIGHT
COMPOUND HELICOPTER

FIGURE 8

SYMBOLS:
- O
- □
- △
- ○
- ●
- ▽
- ○
- △
- □
- ○
- ●

TESTS: 196 197 199 201 206 208 210 211

CONSTANT COLLECTIVE (θ = 3.8°)
J-60 POWER AS REQ'D.

VARYING COLLECTIVE
J-60 @ IDLE

CALIBRATED AIRSPEED
~ KNOTS.
**LOCKHEED HELICOPTER**
**Model XH-51A**

**MANEUVERING STABILITY: COMPOUND HELICOPTER**

**J-60 ENGINE OPERATING**

*SN# BUMO 11263*

**FIGURE 2**

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<td>4400</td>
<td>2550</td>
<td>-3.49</td>
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</tbody>
</table>

**Configuration Notes:**

1. **Cyclic Stick Pitch Sensitivity = 100%**
2. **Gyro Arm Angle = 30°**
3. **Horiz. Tail Inc. = 1" (25mm)**
4. **31.5 lb. Bag Weight**
   **Installed (7.2 lb.)**
5. **Landing Gear Up**
6. **Speed Sensor Off**
7. **Using Swivel-Head Airspeed System**

*Cyclic Stick Pitch Force in lb.
Cyclic Stick Pitch in deg.*

*130Kts/485lb
Horiz/980lb
Load Factor = 1.0*
MAIN ROTOR BLADE LOADS is COLLECTIVE 1, 4, 7 BLADE ROTOR
J-60 ON
7.51 STP 30" HORIZ. STAB.
2-1.0 DEG.

FIGURE 13

..
Figure 14

4 BLADE FOTOR

7.57 SQ.FT HORIZ. STAB A - 10 DEG.

LOADS VS. COLLECTIVE BLADE ANGLE

IN LBS. X 100

COLLECTIVE BLADE ANGLE - DEG.

100K CAS
120K CAS
130K CAS
140K CAS
150K CAS
160K CAS
<table>
<thead>
<tr>
<th>FLAPWISE BENDING MOMENT STA.G</th>
<th>CHORDWISE BENDING MOMENT STA.G</th>
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<tbody>
<tr>
<td>IN. LBS x 1000</td>
<td>IN. LBS x 1000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
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<td>10</td>
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</tr>
<tr>
<td>60</td>
<td>60</td>
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</table>

*Main rotor blade loads* for collective blade angle...
LOAD vs COLLECTIVE BLADE ANGLE

4 BLADE ROTOR

J-50 ON

NOS: 12

STAB. AREA 24.25 SQ. FT. ± 0.0 DEC

DARKER SYMBOLS - CYCLE
OPEN SYMBOLS - AVERAGE

FORM 9794A

FIGURE 18
MAIN ROTOR BLADE LOADS VS. CALIBRATED AIRSPEED

**BLADE ROTOR**

**J-60 ON.**


Δ denotes lower collective.

Darkened symbols - cyclic.

Open symbols - avg.

**Figure 20.**
TAIL ROTOR FLAP BEND STA 17.5 vs CALIBRATED AIRSPEED
4 BLADE ROTOR

HORIZONTAL AREA 24.2 sq. ft. @ 0.0 DEC.
GR. WT = 4500 lb. C.G. 4.25 IN. AGT
DARKER SYMBOLS - CYCLIC
OPEN SYMBOLS - AVERAGE
O. ORBITT, SOUTHERN CALIFORNIA

PUSH FL RT
1000
800
600
400
200
0
0 20 40 60 80 100 120 140 160 180 200 220 240

M.R. 3 BLADE
DATA AVE.

CYCLIC
ROLL & PITCH COMPONENT: 4. CALIBRATED AIRSPEED

H-1 blade rotor

24 sf. ft. horiz. stab. @ 0.0 deg.
Gr. wt. = 7540 lbs. C.G. = 4.25 in. left

\( \Delta \) denotes lower collective

FIGURE 23
XH-51A BUNO151263 S/N 1002 COMPOUND
V-N DIAGRAM
GROSS WT. - 4300 LBS.  C.G. - .08/ABWD. - 44 IN. LT.
J-60 OFF

FIGURE 34

LOAD FACTOR - % of 4300 LBS.

CALIBRATED AIRSPEED - KNOTS
Figure 29

CABIN VIBRATIONS vs. CALIBRATED AIRSPEED

4 Blade Rotor

VERTICAL pilots seat - 1 PER REV vs. CALIBRATED AIRSPEED - KNOTS