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STABILIZED TERRAIN OPTICAL POSITION SENSOR (STOPS) FLIGHT TEST REPORT

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This report presents the flight test results and evaluation of a brassboard model self-contained hover position sensor and obstacle clearing device. The brassboard model of the self-contained, absolute, position sensor referred as Stabilized Terrain Optical Position Sensor (STOPS) was successfully installed and flown on the Avionics Research and Development Activity's Experimental Vehicle for Avionics Research (EVAR) project helicopter.

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The results derived from the test indicate that position radial accuracies of better than 5 feet can be expected at constant (60 feet AGL) altitude. For mission maneuvers such as the bob-up and remask, designed for the AAH, position radial errors are in the order of 10 to 20 feet.

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1. INTRODUCTION

This report presents the flight test effort for the Stabilized Terrain Optical Position Sensor (STOPS) project. The STOPS brassboard gimbal was integrated into a hover system and was successfully flown on the Experimental Vehicle for Avionics Research (EVAR) project helicopter of the US Army Avionics Research and Development Activity, Fort Monmouth, New Jersey.

a. Background. The STOPS was envisioned as a self-contained position sensor and obstacle clearing device for helicopters equipped with a night vision system such as a Forward Looking Infrared (FLIR) or a Low Light Level TV (LLLTV). The tactical deployment of Army helicopters such as the Advanced Attack Helicopter (AAH), Advanced Scout Helicopter (ASH), MEDEVAC, etc., during night operations will require some visual means for obstacle clearance and possibly a self-contained hover aid device.

A concept was formulated which provided this capability. Assuming a night vision sensor with a field-of-view (FOV) of 45° by 60° is rigidly mounted near the nose of a helicopter, the presentation of the image on a panel mounted display (PMD) appears as shown in Figures 1 and 2. Given this condition, by inserting a mirror in the upper portion of the FOV (Figure 3) and with the appropriate image reinversion (electronically performed), the STOPS concept is achieved and the presentation is as shown in Figure 4. This presentation allows the pilot to see in front as well as beneath the helicopter. A simulation ensued which demonstrated the potential of the conceptual system.[1] This was later followed by a flight test simulation of STOPS[2] on the Research Aircraft Visual Environment (RAVE) project helicopter.

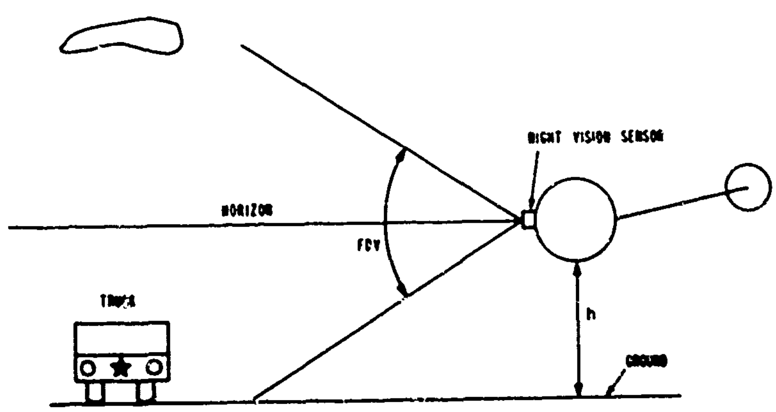

Figure 1. Present system

[1] A report on the FY-74 Avionics In-House Laboratory Independent Research (ILIR), "*Stabilized Terrain Optical Position Sensor (STOPS),* ECOM-4283 Technical Report, December 1974.
[2] *Manual Precision Hover with Superimposed Symbology on FLIR Image,*" Milelli, R. J.; Johnson, D. C.; Tsoubanos, C. M.; AHS 31st Annual National Forum, Washington, DC, May 1975.

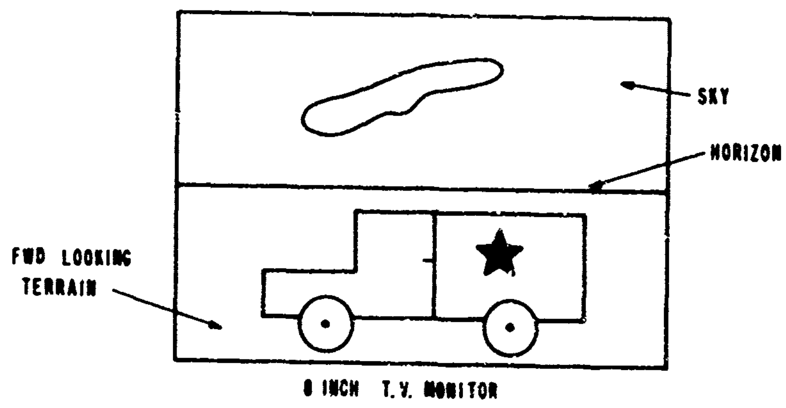

Figure 2. Present pilot presentation on TV monitor

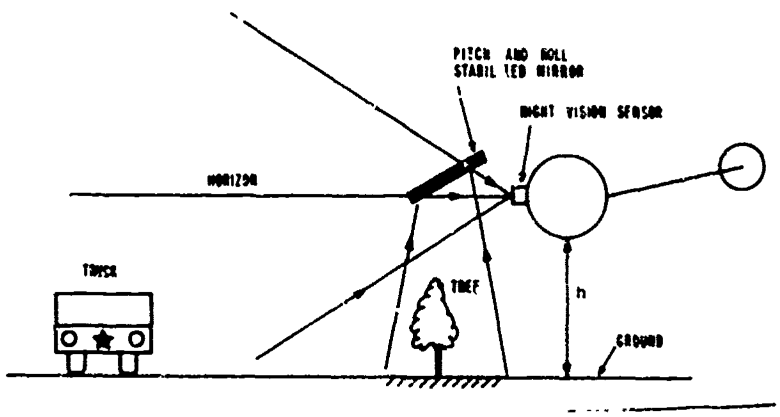

Figure 3. Proposed system

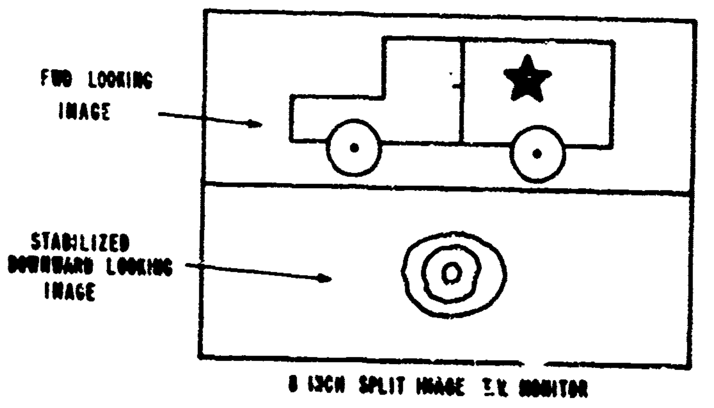

Figure 4. Proposed pilot presentation on TV monitor

The successful ground simulation with verification of the concept during the flight test effort and acceptance by the test subjects encouraged the continuation of the concept into the procurement of a brassboard model for flight testing.

b. Objective. The objective of this flight test effort was to demonstrate the capability and potential of the STOPS brassboard model as a self-contained hover aid and obstacle clearing device.

2. SYSTEM DESCRIPTION

a. Gimballed Mirror Assembly. The STOPS brassboard model was designed and fabricated by Actron Industries under Contract Number N62269-75-C-0312. Figure 5 shows the two-axis gimbal system. It is of conventional design and consists of outer roll and inner pitch gimbals to which a mirror is attached. The operating limits of the gimbal system are ±15° in roll and +15° up to -25° down in pitch. The servo system error is less than ±1/2° in roll and ±1/4° in pitch. A 7- by 12-inch mirror designed to operate in the 8-14 micron Infrared (IR) region is attached to the pitch axis of the gimbal. Overall weight of the brassboard model is 47.5 lbs. The physical size of the gimbal and mirror was dictated by the existing location of the FLIR and daylight TV camera within the nose of the test helicopter. The brassboard model was designed with the added flexibility for switching mirror position to view either the FLIR or daylight TV installed at the time on the helicopter. More will be presented on this in the aircraft installation description.

The design of the STOPS system did not include provisions for stowing the mirror during normal NOE flying. This mode was discussed, but due to the increase in cost, the existing design was accepted. The selected standby or stow mode resulted in the mirror being parallel to the ground and positioned 6° up from the optical centerline of the TV camera. This caused some obscuration of the image which was unacceptable to the pilots for Nap-of-the-Earth (NOE) flying, but since NOE flights were not to be performed it did not become a major issue. In any future design, the capability of stowing the mirror completely away from the sensor field-of-view would be implemented.

The integration of the gimbal with the required electronics for the hover system configuration is shown in Figure 6.

b. Symbol Generator. The symbol generator used in this flight test program was a modified version of an existing analog unit flown in two previous studies.[3,4] This modified unit (Figure 7) the so-called STOPS Tactical Avionics System Simulator Integrated Trajectory Error Display (TITED) included the image inverter and also incorporated the variable time constants for the complemented velocity and acceleration signal drive requirements. It also provided three symbology modes, enroute, approach/transition, and hover. Of primary interest during the flight test was the hover symbology with some emphasis on the approach/transition symbology mode. These symbology modes are described below.

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[3] *"Development and Flight Test Evaluation of a Self-Contained Infrared Hover System,"* Tsoubanos, C. M., US Army Avionics R&D Activity, Fort Monmouth, NJ, Technical Report ECOM-4520, August 1977.
[4] *"Doppler Hover System,"* Tsoubanos, C. M., US Army Avionics R&D Activity, Fort Monmouth, NJ, Technical Report AVRADA-78-10, April 1978.

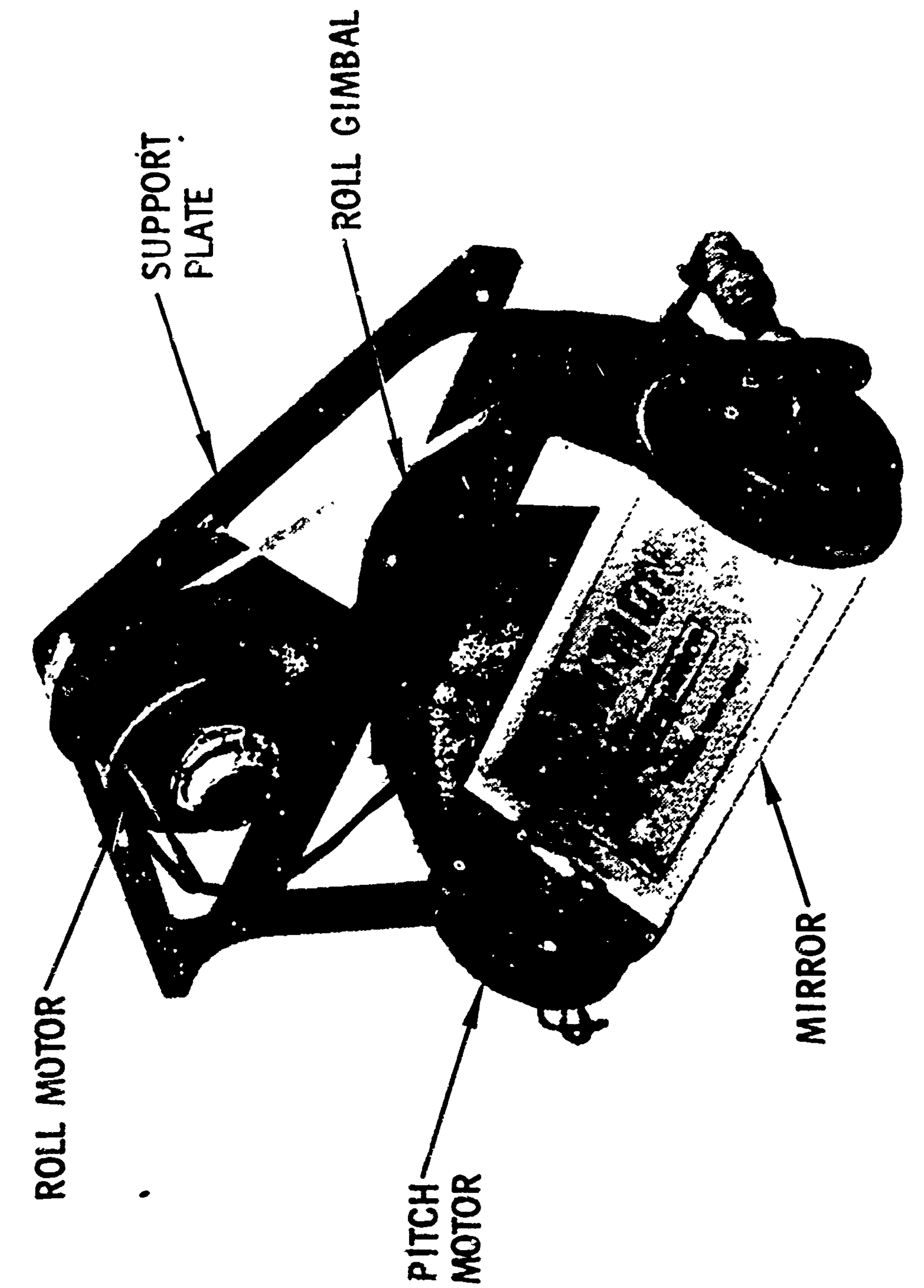


Figure 5. Gimbal-mirror assembly (with shroud removed)

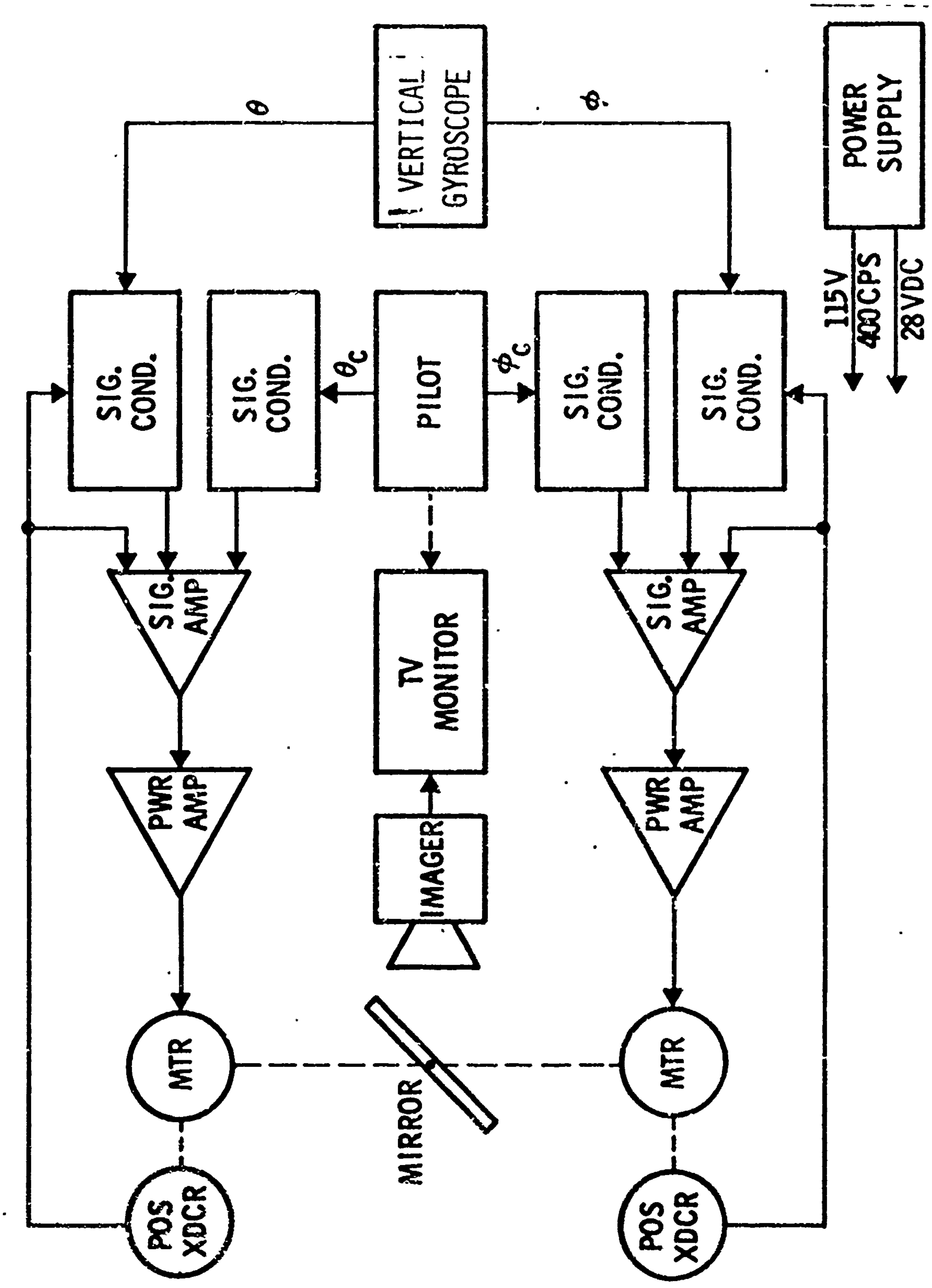


Figure 6. Gimbal-mirror signal drive diagram

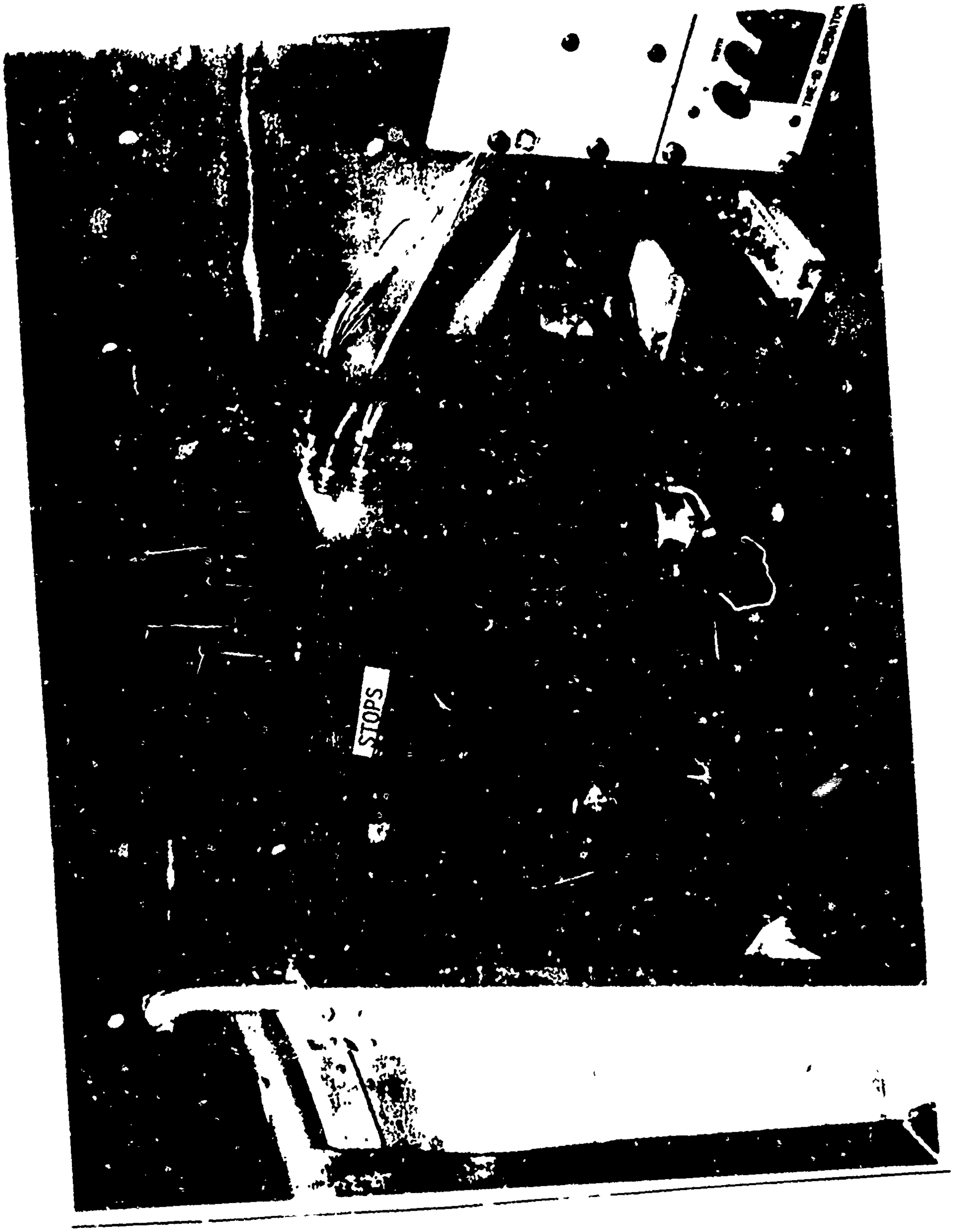


Figure 7. STOPS TITED symbol generator

(1) Hover Display Symbology Mode. The hover symbols used in the STOPS evaluation are shown in Figure 8.

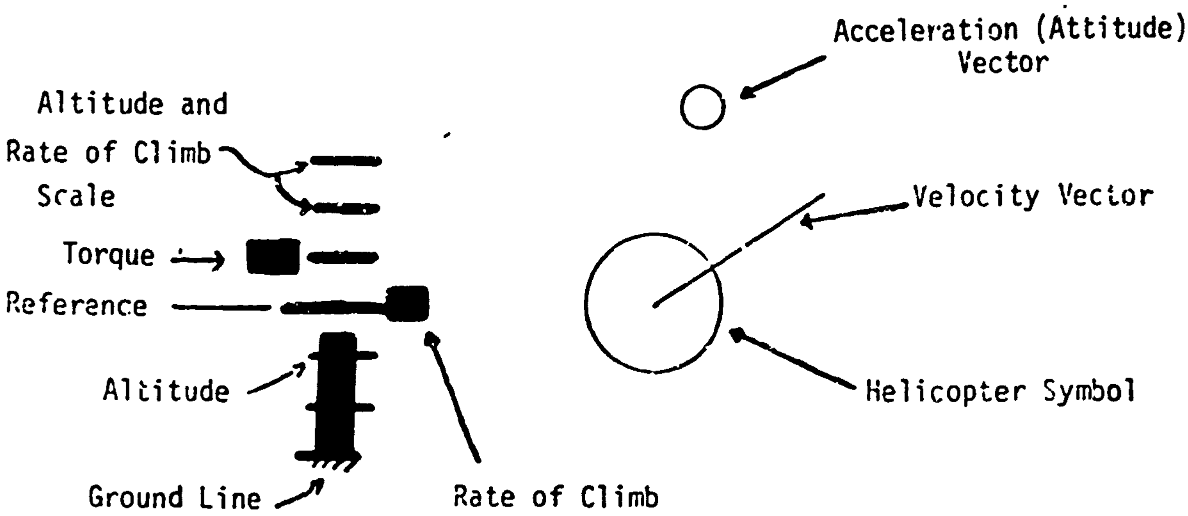


Figure 8. STOPS transition and/or hover displayed symbology

This symbology represents quantitative flight information essential for executing a precise hover mission. In the center of the display a large circle symbolically represents the helicopter rotor and/or display reference. Helicopter ground velocity is measured about this reference while helicopter acceleration is measured about the aircraft's velocity vector tip. To the left of the helicopter reference are displayed torque, rate of climb, and radar altitude. One scale is used to reference the three parameters. The ground line symbol is the reference for zero altitude and zero torque. A larger horizontal line to the left of the rate of climb symbol is the reference for zero rate of climb. This symbology is superimposed electronically over a ground video scene. The pilot then uses the symbology to control helicopter altitude and to maintain position over some selected ground reference. The technique for maintaining an accurate hover using the symbology would be as follows: The pilot selects on his video a ground (position information) reference, for example, a shrub. He places the acceleration symbol on the selected reference by manipulating the cyclic. By maintaining the acceleration symbol over the reference, the helicopter translates towards the reference. When the helicopter symbol becomes centered over the ground reference, the pilot is at the desired hover point and the acceleration and velocity vector values become zero (in an ideal case). An analytical explanation of the above technique may be found in reference 5.

While the horizontal symbolic information acceleration, velocity vector and video position provide the pilot the means to maintain a stable hover, the torque, rate of climb and radar altitude assist him in accurately holding his position in space. Pilot manipulations of the collective allow him to see instantaneous torque changes, followed by vertical rates and ultimately, by altitude changes. By selecting the desired altitude, the pilot can use the torque symbol along with the rate of climb/descent and radar altitude symbol to maintain an accurate altitude.

The symbology gains selected for this flight test are similar to those determined in the simulator and a previous hover flight test[2] to be optimum at a 50-foot altitude. They are expressed as inches of symbol movement on the display per measured aircraft quantity and are as follows:

Position gain K_p = 0.08 in/ft (12.5 ft/in)

Velocity gain K_v = 0.4 in/fps (12.5 fps/in)

Acceleration (attitude) gain K_a = 0.25 in/deg (4.0 deg/in), (2.25 fps^2/in)

Altitude (gain) K_h = 0.1 in/ft (100 ft/in)

Rate of Climb gain K_h = 0.001 in/fpm (1000 fpm/in)

Torque gain (K_q = 0.02 in/% (50%/in)

The selected gains for position, velocity, and acceleration form a second order critically damped symbol movement for optimum hover performance. The gains and/or ratios between these displayed parameters are also applicable for helicopter altitude changes, provided the position sensor output is constant as a function of altitude. If this is not the case, and it would not be for an angular position sensor such as STOPS, the gains optimized for one altitude would probably degrade hover performance at other altitudes. Techniques such as a zoom lense and/or velocity and acceleration gain changes can be implemented as a function of altitude to maintain the desired gain values. These techniques were not incorporated. A decision was made to retain the optimized gain for a 50-foot hover altitude throughout the helicopter altitude excursions and accept the anticipated degraded hover performance at the other altitudes.

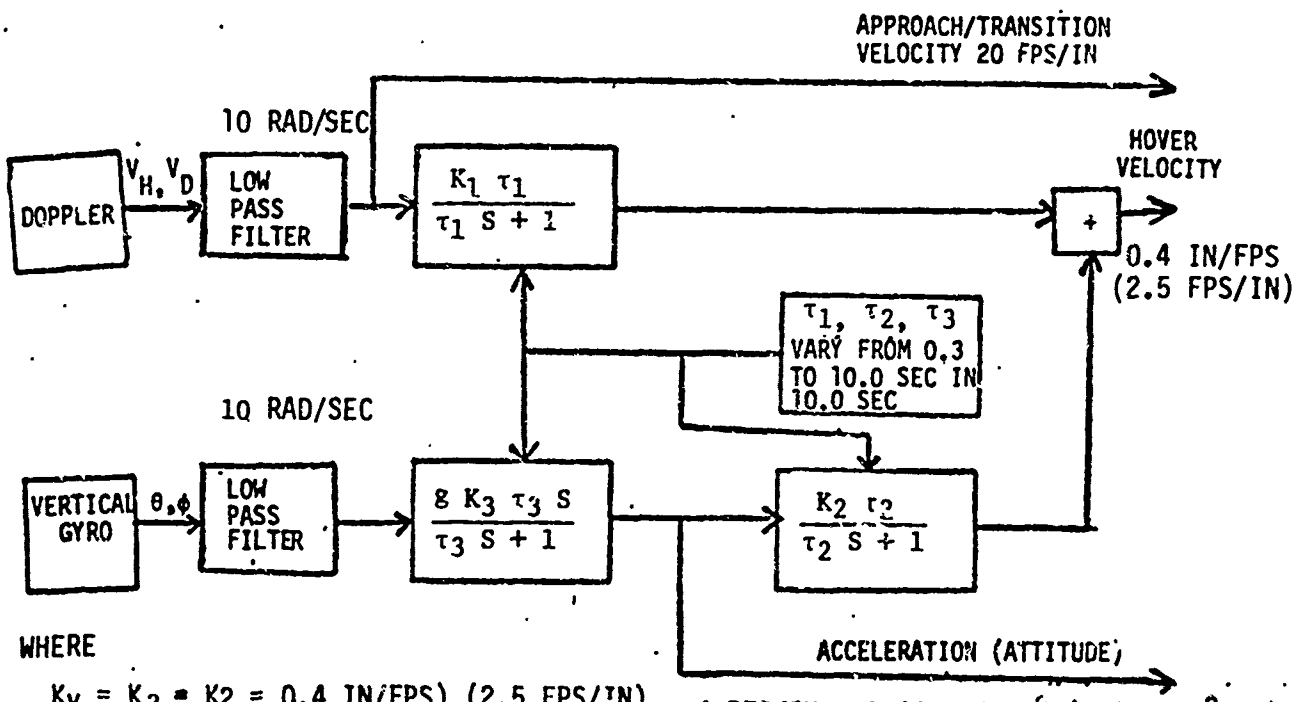
(2) Approach/transition mode. The approach/transition symbology format is identical to the hover with only one exception. The velocity vector is now scaled at 20 fps/in and is driven from the raw doppler V_H and V_D velocity signals. All other displayed symbols have the same gains used for the hover mode.

(3) Symbol drive requirements. The necessary sensors to drive the symbology are the vertical gyro, radar altimeter, IVSI (rate-of-climb), heading gyro and Lightweight Doppler Navigation System (LDNS). The outputs of these sensors are processed and shaped to reduce signal noise and provide appropriate gain for symbol movement.

An assumption is made that for a single rotor helicopter, translational acceleration may be approximated by attitude for small angles (less than 10 degrees). Steady state trim attitude offsets are removed through the use of a washout filter circuit with appropriate time constants. This approach was successfully demonstrated in some previous studies[2,5] and as a result was incorporated in this test.

Of particular interest is the signal processing used to implement the velocity vector drive for the hover mode. The velocity vector drive is a complemented signal derived from the LDNS and vertical gyro[5] by use of the filtering technique shown in Figure 9.

A variable time constant was incorporated into the processing as recommended in a previous study.[5] This resulted in the velocity vector becoming a useful parameter in less than 10 seconds after switching to the hover mode rather than the 30 seconds previously required.[4] To provide this, a technique was implemented within the symbol generator which switched appropriate valued capacitors into the circuit of concern in order to vary the time constants. The following diagram (Figure 9) shows the complementary velocity source and the variable time constants.



WHERE

$K_V = K_2 = K2 = 0.4$ IN/FPS) (2.5 FPS/IN)

$K_a = K_3 = 0.25$ IN/DEG (4.0 DEG/IN)

Figure 9. Block diagram of complemented velocity generation with time varying time constants

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[5] *Tactical Hover Under NOE Conditions*," SHUPE, N. K.; Clark, R. F.; AAA Symposium, Fort Monmouth, NJ, April 1976.

The above selection allows the doppler to provide velocity at frequencies below 0.1 rad/sec and the pseudo integration of the attitude provides velocity above 0.1 rad/sec.

(4) Mirror image inverter. One of the design problems with the STOPS concept which had to be solved was the inversion of the fore-aft downlooking image due to the mirror. The diagram of Figure 10 shows the two fields-of-view of interest labeled "A" and "B." Field-of-view "A" is the one which requires reinversion. This particular problem could have been resolved by using a prism or other means, but would have resulted in a large and complex system. Therefore, the mirror image re-inversion was performed electronically.

The reinversion of the image, to a normal view as would be seen through the chin bubble of a helicopter, was performed on the vertical sync signal of the TV monitor. This modification splits the vertical ramp signal in half. Half the ramp is used for a normal presentation. The other half of the ramp is inverted. This inverted ramp is used to correct for mirror image inversion. Figure 11 illustrates the reinversion.

Figure 11a shows the normal TV image as it would be seen with the mirror mounted in front of the camera. (See Figure 10 for portion of imager field-of-view labeled "A" and "B".) The typical vertical ramp is shown on the right.

On Figure 11b, the two images, forward and downlooking are relocated to make them normal to an out of the cockpit view, but the downlooking image has yet to be corrected. The modified ramp for this relocation is shown on the right.

Figure 11c shows the image that would be seen through the chin bubble, as well as the cockpit window. The vertical ramp inversion is also shown.

c. Pilot's Mirror Control Unit. While the pilot navigated to the hover point, the mirror was in the stowed position. At the specific hover area, he used the Pilot's Mirror Control Unit to activate STOPS. This automatically positioned the mirror at an angle in front of the imaging sensor to look directly beneath the nose of the helicopter. It also activated the image inverter circuitry and turned the symbology on which resulted in the presentation of the split image with superimposed symbology on the TV monitor. In addition to these functions, the unit also had a mirror pitch and roll bias control. This bias option allowed the pilot to change the attitude of the mirror to check for ground obstacles beneath the aircraft before actual movement of the helicopter was made. A picture of the Pilot's Mirror Control Unit (PMCU) installed on the EVAR third station left side console is shown in Figure 12.

3. FLIGHT TEST EFFORT

The flight test vehicle for this program was the Experimental Vehicle for Avionics Research (EVAR) project helicopter. A cutaway view of the helicopter and the location of the various sensors are shown in Figure 13. A description of the helicopter, a Marine CH-53A Model, and its avionics subsystems may be found in Reference 1. For this flight test program, the STOPS brassboard model and ancilliary hardware had to be installed on the helicopter. A description of the ancilliary hardware and system installation follows.

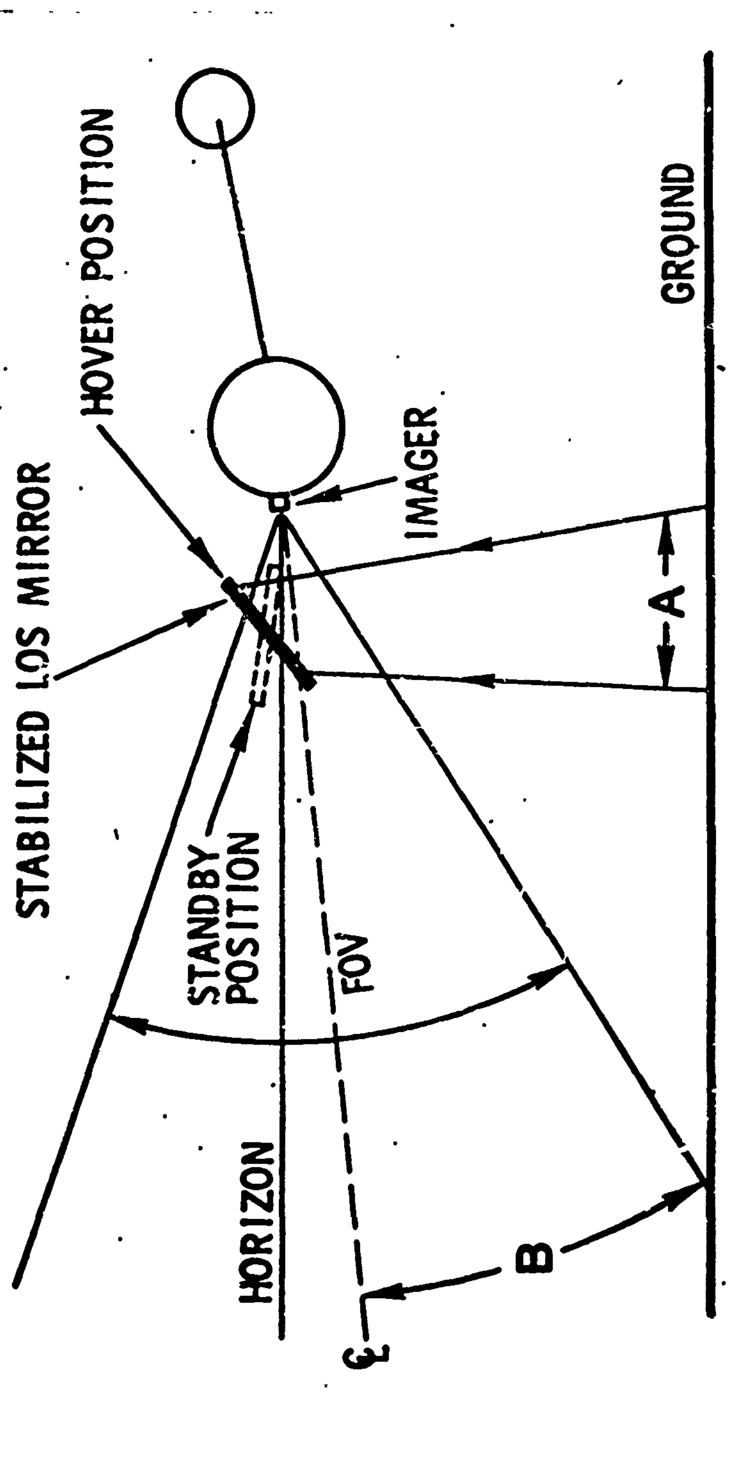


Figure 10. STOPS FOV diagram

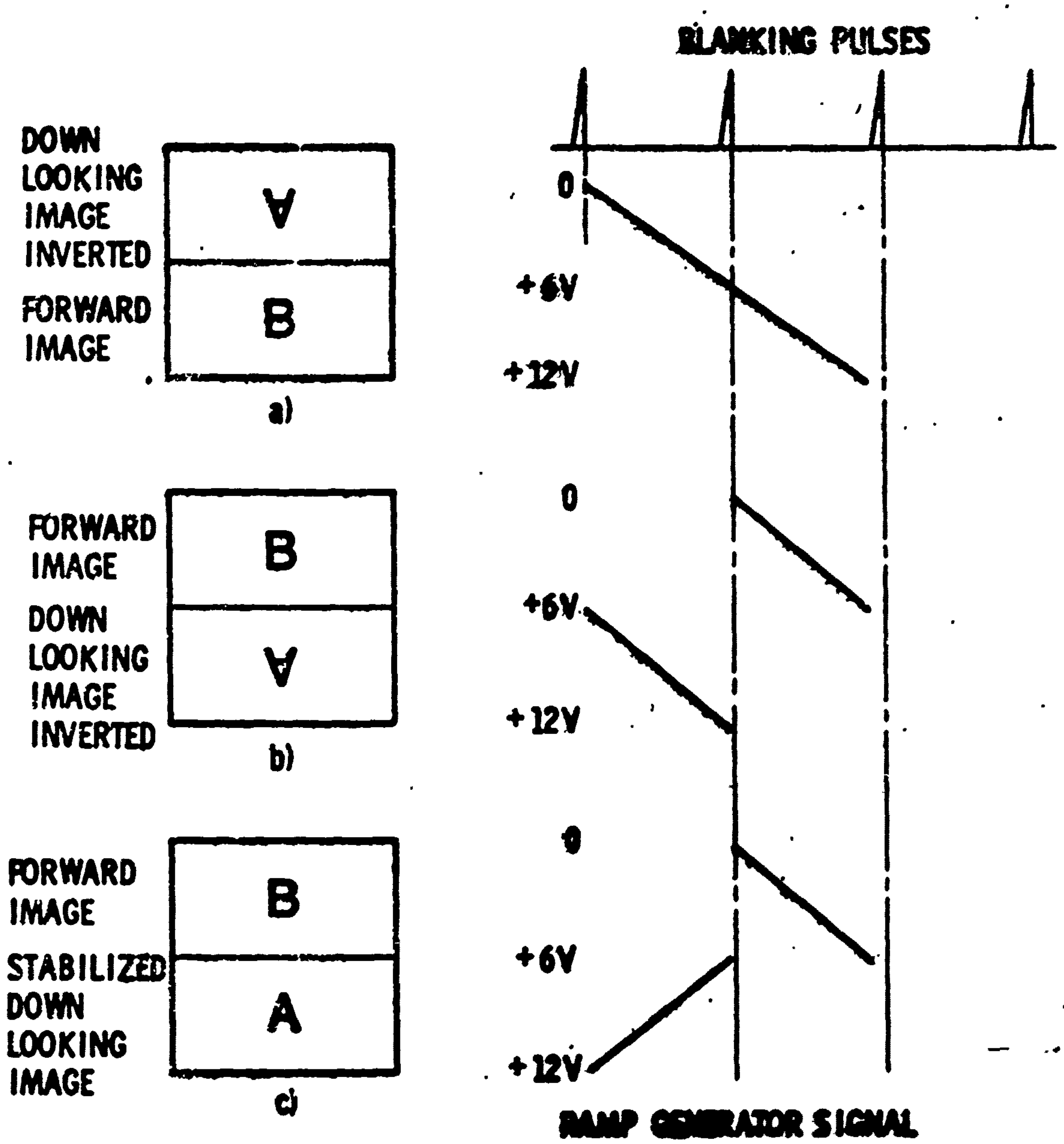


Figure 11. Electronic image inversion

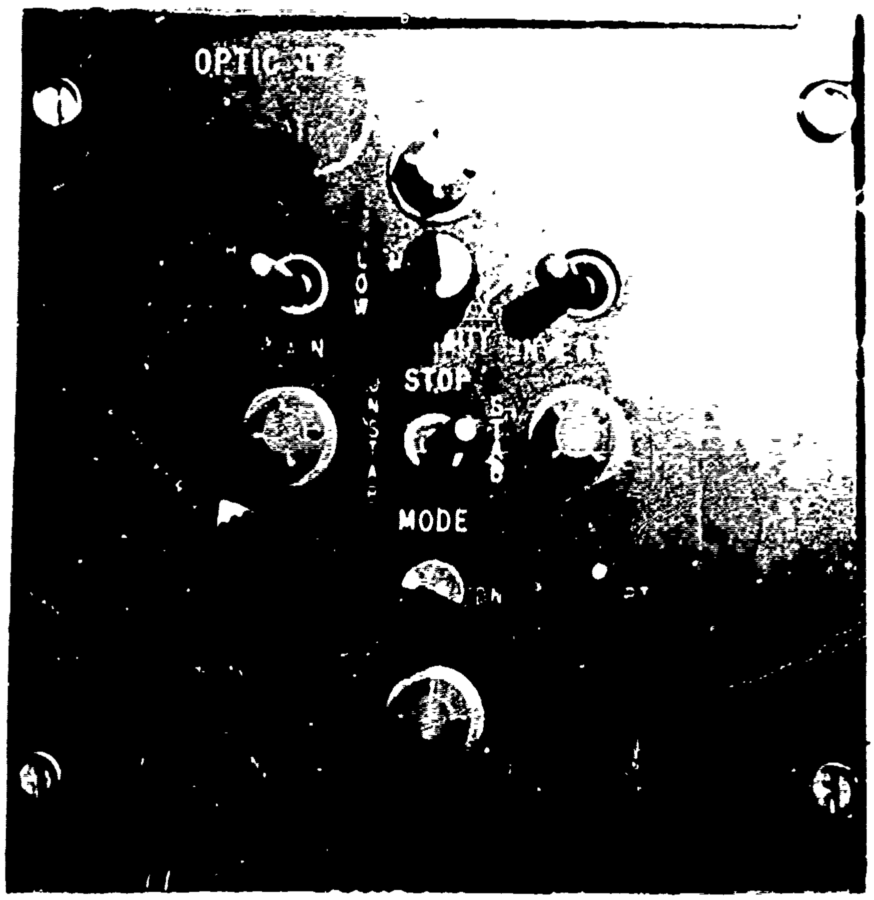


Figure 12. Pilot mirror control unit

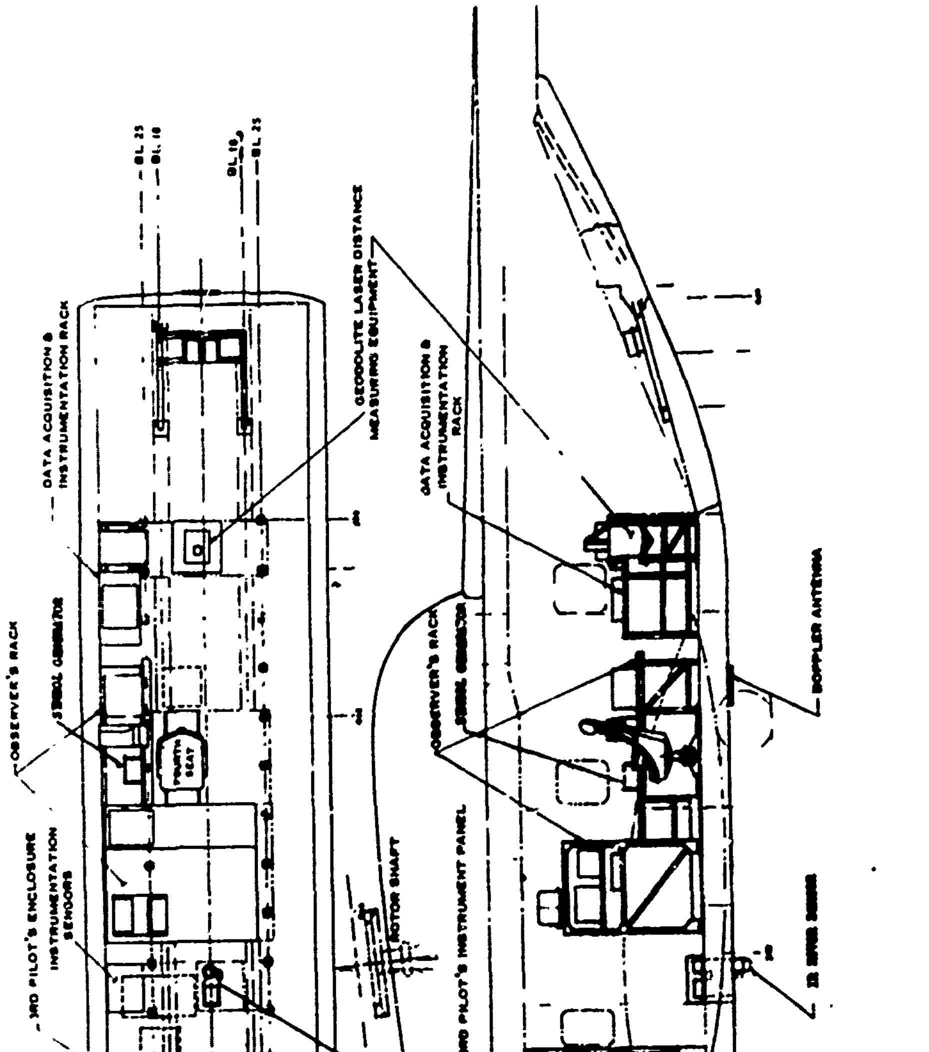


Figure 13. EVAR showing sensor location

a. Hardware Installation. The STOPS Gimbal was designed as stated earlier to be used with either a FLIR or daylight TV system. In the absence of a FLIR, the daylight TV camera was used to provide the imagery. A picture of the installation is shown in Figure 14.

The installation was accomplished by Naval Air Development Center (NADC) project support personnel. No mechanical installation problems were encountered. A major area of concern was the helicopter vibration environment and the possible wind loading on the gimbal due to the rotor downwash. The cover and the mounting plate, designed by NADC, were adequate to eliminate any downwash effects and to reduce any apparent gimbal system vibrations. After the installation, checkout and calibration was accomplished in a short time. During this checkout, it was discovered that as the helicopter altitude increased to greater than 150 feet, some jitter was visible on the STOPS image. By increasing the servo gain on the STOPS gimbal, the jitter was eliminated.

(1) Lightweight Doppler Navigation System (LDNS). The Singer Kearfott LDNS (Figure 15), was used in this flight test program to provide the low frequency velocity component required for the velocity vector. No installation difficulties were encountered since it has been previously installed on the EVAR project helicopter.[4] However, some grounding problems were encountered between the LDNS and the symbol generator, but were easily remedied.

(2) Actron daylight velocity sensors. The Actron Model HG-453, Random Scene Motion Sensors (RSMS)[2], convolution-type electro-optical sensors, were rigidly mounted on a plate in the "cargo hook well" (Figure 16) of the project helicopter. It was the intention to use these sensors, after the helicopter angular rates were subtracted out, to provide backup velocity information for the velocity vector in the absence of the Lightweight Doppler Navigation System (LDNS). In the initial checkout, it was discovered that the RSMS signal was of poor quality and contained an offset, which could not be readily corrected. Due to the flight schedule constraints, little time was allocated in troubleshooting to correct the RSMS sensor problems and the effort was deleted from the flight test.

(3) V/R IR sensor. A single axis velocity/range (V/R) infrared sensor procured by NADC from Actron Industries[3] for a Navy application was installed in the cargo "hook well" (Figure 17). Its output signals V/R, track and fail states were made available for recording for future analysis. The sensor was flown by NADC project personnel over ships at various helicopter altitudes and speeds. The objective was to collect IR sensor data to evaluate the device for the specific Navy application.

b. Instrumentation/Data Collection. All signals required for the hover symbology and others such as the helicopter angular rates and flight controls cyclic, collective and pedal positions were made available for recording purposes.

(1) Data Acquisition Unit (DAU): The EVAR onboard DAU[2] was used to record the following helicopter parameters: pitch, roll, heading, pitch rate, roll rate, yaw rate, cyclic, collective, pedal position, torque, radar altitude, and rate-of-climb. In addition to these, the doppler analog velocity outputs from the Steering Hover Indicator Unit (SHIU), V_H, V_D, and V_V, the STOPS mirror, pitch and roll feedback signals and the RSMS signals were also recorded for the data reduction phase of the program.

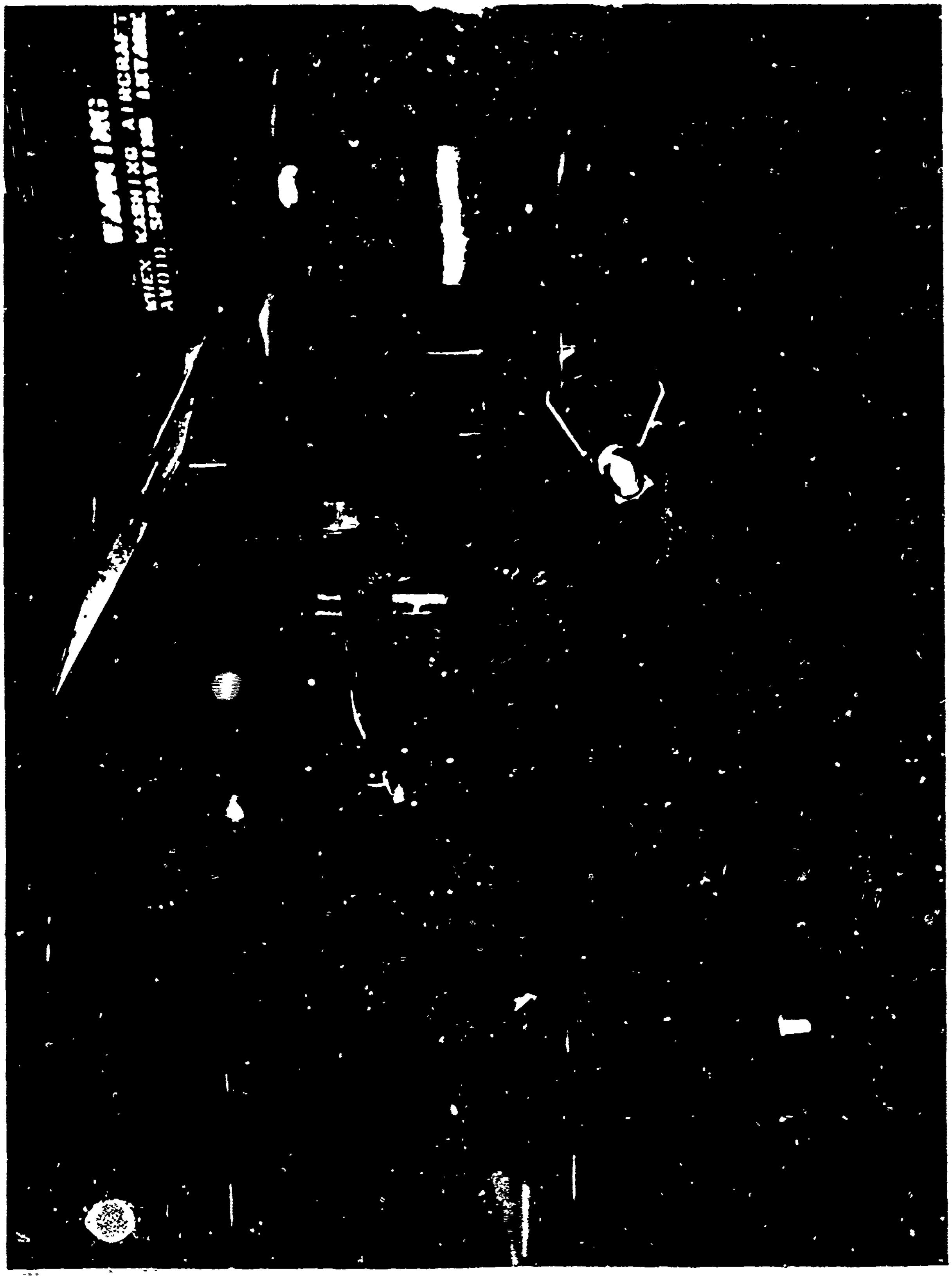
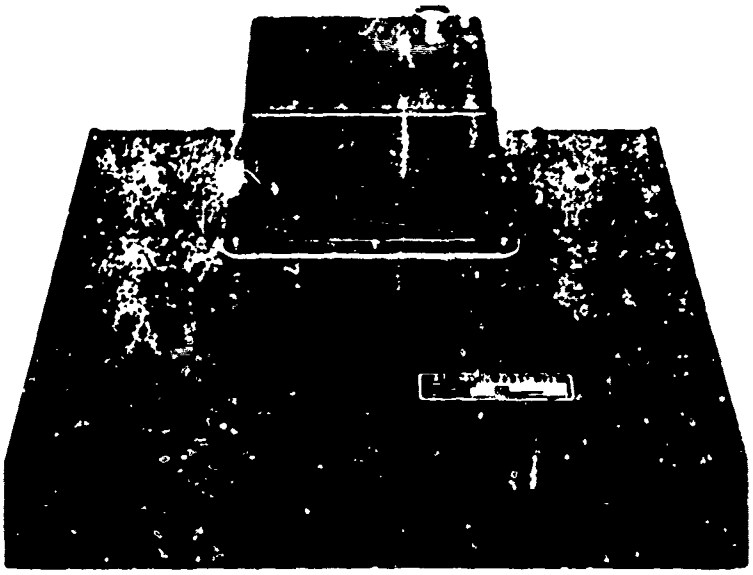


Figure 14. STOPS brassboard model



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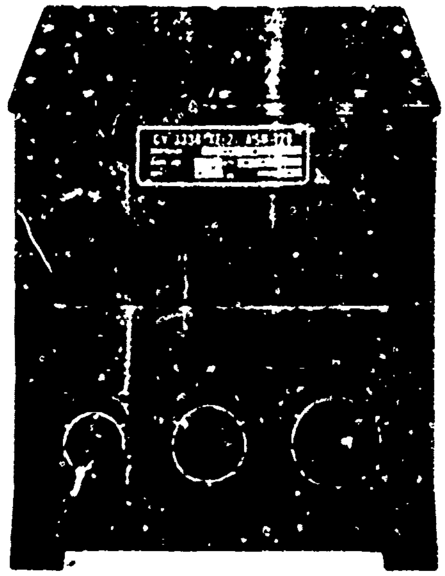
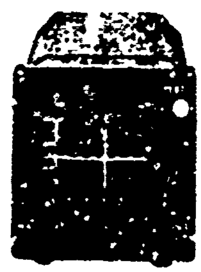


CONVERTER, SIGNAL DATA, RADAR
CV-3338( )/ASN-128

COMPUTER-DISPLAY UNIT
CP-1252( )/ASN-128



STEERING HOVER INDICATOR UNIT

Figure 15. Lightweight doppler navigation system

Figure 16. Daylight Random Scene Motion Sensors

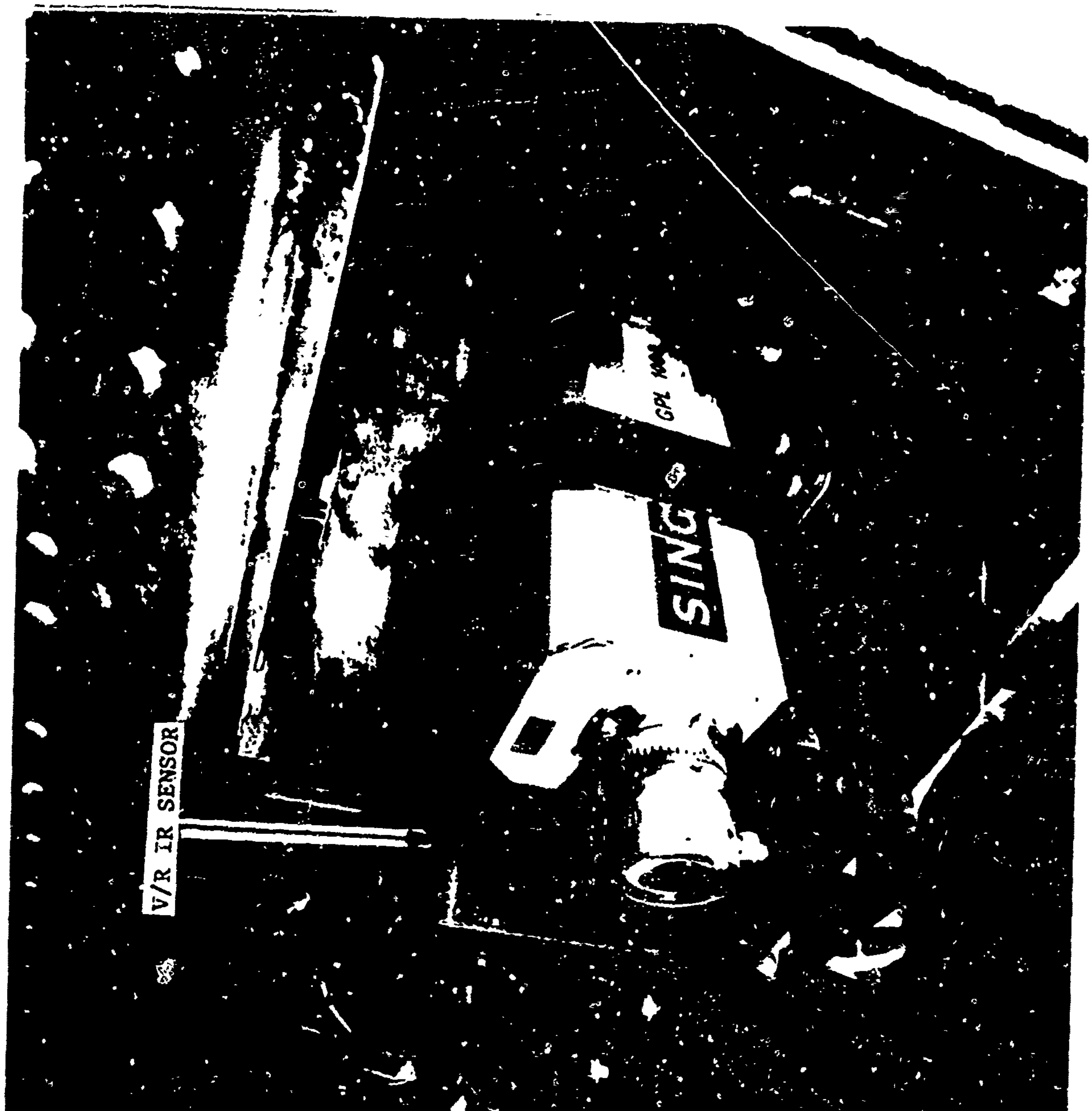


Figure 17. V/R IR sensor

(2) Video Position Recording System (VPRS). To record the pilot hover performance, the downlooking TV camera system as described in Reference 4 was utilized. A 1-second code pulse of a 5-KH_Z tone was recorded on the audio track of the video tape for synchronizing the DAU and this tape during the data reduction phase.

c. Flight Test Design Plan. The Flight Test Design Plan for evaluating the STOPS model with the hover symbology and various maneuvers was based on the experience and results of the TASS simulation[1] and the RAVE flight test effort.[4] The design plan further included the implementation of an approach to a specified hover point and completion of the prescribed hover maneuver. The plan included some tactical hover missions which were conducted at Indiantown Gap, PA.

(1) Missions. Two mission maneuvers were flight tested: a "bob-up"/remask, and an approach/transition to a hover. The "bob-up"/remask maneuvers are typical AAH or ASH maneuvers. The "bob-up" maneuver allows the helicopter, from a position masked by natural or man-made features, to increase its altitude to a sufficient height to engage a target. The remask maneuver allows the helicopter to rapidly descend to masked altitude to avoid enemy detection. The approach/transition to a hover maneuver was included in the test to determine pilot ability to fly the helicopter using the symbology and STOPS imagery to a selected area and initiate a hover. This maneuver had not been successfully flown in the earlier hover flight test programs[2,4].

(2) Cell selection. Using the above two mission maneuvers, the following cells were selected and flown by the subject pilots.

Cell 1 - Stabilized mirror with hover symbology. This cell contained the split screen TV image and hover symbology. The STOPS image was stabilized in pitch and roll.

Cell 2 - Unstabilized mirror with hover symbology. This cell is similar to Cell 1 with the exception that the STOPS gimbal does not compensate for aircraft pitch and roll attitude changes. Thus, the STOPS image is unstabilized.

Cell 3 - Front seat hovers. This is a baseline cell of the subject pilot performance while flying the helicopter from the front seat or normal visual flight rules (VFR).

Cell 4 - Stabilized mirror - no hover symbology. This cell is similar to Cell 1 with the exclusion of the symbology.

Cell 5 - Approach/transition to a hover. This cell utilized both the split screen and full screen forward-looking imagery (STOPS in standby mode) with the approach/transition symbology. Once the subject pilot made the approach/transition to the hover point, then this cell became identical to Cell 1.

The flight test matrix used for evaluation is shown in Table 1.

TABLE 1. FLIGHT TEST MATRIX

	Pilots	Runs
Cell 1	2	12
Cell 2	2	9
Cell 3	2	4
Cell 4	2	4
Cell 5	2	12

(3) Subject pilots and training. Two subject pilots flew the STOPS system. Both subjects, CPT L. Carpen and CW3 C. Tidey were knowledgable with the EVAR project helicopter and had considerable time flying panel mounted displays and the hover symbology. In addition, they were also familiar with the stabilized STOPS concept since they had flown it in the TASS simulator. Therefore, very little time was required for training for this mode. Considerable time was required, however, to train the pilots to fly the unstabilized split screen image with symbology Cell 2 and also the stabilized split screen imagery without symbology Cell 4.

The approach/transition Cell 5 maneuver to a hover necessitated a lengthy training phase, also. This maneuver had been attempted in a previous flight test' but was not readily accomplished. The image, presented on a 9-inch diagonal TV monitor, was viewed from approximately 28-inch distance with an apparent minification of 6:1. This configuration presents the pilot with velocity cues which are higher than he would observe visually out of the cockpit window. Thus, the pilot has a tendency to slow down the helicopter to an apparent speed which is comparable to that achieved or required in a normal out-of-the-window approach maneuver. To alter this thinking, the pilots had to be continuously reminded to rely on the velocity vector for ground rate and to only use the imagery for background information and for selecting the ground reference for terminating the approach/transition maneuver.

To fly this maneuver, the pilots experimented using the STOPS display mode or STOPS in Stand-By mode. They finally concluded that the forward-look presentation (STOPS in Stand-By) was best for most of the maneuver with the STOPS mode selected near the hover point in order to locate the hover point reference. They also determined that the optimum speed to enter the approach/transition maneuver was in the 30-40 fps range. Any higher speeds made the velocity vector unusable since the pilot could not see its tip. By keeping the ground speed in the above range, the velocity vector was always present and provided the appropriate ground speed cues.

The training consisted of the following scenario. The front seat command pilot would fly the helicopter around the prescribed NADC pattern and would line up with the runway. Once the subject pilot saw the runway, he informed the command pilot of this and requested him to reduce the helicopter speed to 30-40 fps. The command pilot complied, and at the appropriate time, the subject pilot at the consent of the command pilot took control of the helicopter and flew the approach to a hover point. He would terminate the maneuver with a bob-up and remask mission. At the completion of the "bob-up" and remask, the subject pilot would accelerate the helicopter to 30-40 fps and once again enter into a second approach/transition maneuver to a new hover area. At the completion of this hover, the command pilot would fly the helicopter around the pattern and position the helicopter for the subject pilot for the next training run.

d. Flight Test Procedures. All testing was conducted at the NADC airfield under visual meteorological conditions during daylight hours. After obtaining required clearance from the NADC tower to operate in a specific area within the airfield, the command safety pilot flew the helicopter to the hover site. While at the hover site, the subject pilot entered the third pilot test station, and coordinated with the command pilot to engage the 3rd station flight controls. With these engaged, the command pilot allowed the subject pilot to fly the helicopter over some prominent ground reference, for example, the center of the airfield compass rose.

Using this as a reference, the pilot flew the appropriate cells. The onboard observer informed the test subject when to initiate the hover and timed the run. He also informed the test subject when to enter into the Initial Hover (IH) 50 feet, Bob-up (BU) 150-200 feet, High Altitude Hover (HH) 200 feet, Remask (RM) to 50 feet, and Low Hover (LH) 50 feet submaneuvers.

e. Data Reduction. Data recorded on the two tapes, one tape from the DAU and one from the video recorder, was used to determine quantitative hover performance for the cells flown.

In order to reduce the data, the video tape had to be digitized. This digitized data was synchronized with the DAU data and used to calculate hover performance. The procedure for digitizing required a Tektronix 4551 light pen unit. The particular system generates X and Y voltages proportional to the position of a light pen tracking the video image. Specifically, an operator initiated the digitizing of the video information by holding the light pen on the surface of the monitor over a selected reference point. He then allowed the video recorder to replay the record imagery of the particular data run. As the ground image information changed, the observer had to manually move the light pen to follow the initial selected reference. The light pen position was sampled and digitized at 0.1 second intervals. The 1 second, modulated 5-KHz pulse recorded on the audio track was used to synchronize the computer clock to the data tape. If the original selected point went off the face of the monitor, the operator would select a new reference and the movement of the pen (X, Y voltages) to the new reference point would be incorporated in the data reduction.

Using the above technique, all video data tapes were reduced to digital format. This new digitized tape with data samples every 0.1 second was synchronized with the DAU flight data for the actual ground position error computation. The reduction program written for the Doppler Hover System[4] Study was used to account for helicopter attitude, heading and altitude and to perform the statistical computations.

The expected error of this technique was shown in Reference 4 to be less than 5 feet. This error is considered acceptable. The program computed mean, standard deviation, variance, maximum, minimum, range, initial and final values. It also computes histograms of doppler velocities, radar altitude, hover radius and hover radious about the mean position. A sample copy of the computer printout is shown in Figure 18.

CELL 1

STABILIZED MIRROR STOPS

SUMMARY DATA FOR RUNS 570 610 620 660 690 770 820 830 852 860 890 900 VARIABLE	MEAN	STANDARD DEVIATION	RMS	MAXIMUM VALUE	MINIMUN VALUE	VARIANCE	RANGE	INITIAL VALUE	FINAL VALUE
1 34 LATERAL VELOCITY(F/S)	1.449	1.375	1.998	8.692	-5.248	0.18917E 01	13.940	0.000	0.000
2 44 LONG VELOCITY(F/S)	1.561	1.585	2.224	9.840	-7.708	0.25178E 01	17.548	0.000	0.000
3 46 VG-341 ROLL(DG)	-2.914	0.894	3.048	-0.179	-6.072	0.79933E 00	5.894	0.000	0.000
4 47 PEDALS(PCT)	40.553	1.758	40.591	44.039	36.645	0.30905E 01	7.395	0.000	0.000
5 55 VG-341 PITCH(DG)	7.424	0.809	7.448	10.437	5.145	0.65470E 00	5.292	0.000	0.000
6 60 PITCH(CP) (DEG)	236.049	11.288	236.339	240.540	204.025	0.12742E 03	36.515	0.000	0.000
7 64 RADAR ALT(FT)	46.363	7.082	46.901	65.426	11.858	0.52152E 02	53.570	0.000	0.000
8 69 LASER ALT( )	-0.148	2.601	2.605	4.318	-4.639	0.67661E 01	8.957	0.000	0.000
9 71 ROLL (CP) (DEG)	-116.487	7.388	116.641	-115.225	-177.829	0.54581E 02	62.624	0.000	0.000
10 72 HEADING MA-1(DG)	309.192	110.982	328.507	539.912	180.000	0.12317E 05	359.912	0.000	0.000
11 81 HEADING CG(DG)	0.378	0.016	0.378	0.355	0.273	0.24132E-03	0.082	0.000	0.000
12 93 YAW RATE(CG)(DG/S)	-0.234	0.660	0.701	2.429	-2.298	0.43617E 00	4.727	0.000	0.000
13 4 ROLL RATE(CG)(DG/S)	0.749	0.094	0.755	1.163	0.482	0.88655E-02	0.681	0.000	0.000
14104 PITCH RATE(CG)(DG/S)	0.744	0.074	0.746	1.177	0.349	0.55402E-02	0.828	0.000	0.000
15105 TORQUE LEFT(PCT)	-7.865	1.076	7.938	-4.100	-10.750	0.11576E 01	6.650	0.000	0.000
16116 LAT STICK POS(PCT)	62.850	2.891	62.916	70.313	54.125	0.83579E 01	16.188	0.000	0.000
17117 LONG STICK POS(PCT)	60.622	1.738	60.647	66.379	55.228	0.37209E 01	11.151	0.000	0.000
18118 COLLECTIVE(PCT)	69.679	2.567	69.726	74.162	62.910	0.65874E 01	11.252	0.000	0.000
19 VIDEO POSITION NORTH	1.016	4.5[illegible]6	4.629	16.023	-12.000	0.20391E 02	28.030	0.000	0.000
20 VIDEO POSITION EAST	1.029	4.798	4.907	13.271	-12.300	0.23019E 02	25.571	0.000	0.000
21 VIDEO POSITION LONG	-0.595	3.994	4.039	12.271	-10.304	0.15955E 02	22.575	0.000	0.000
22 VIDEO POSITION LAT	-0.296	5.399	5.403	12.717	-15.973	0.29149E 02	28.690	0.000	0.000
23 HOVER RADIUS	5.750	3.513	6.746	16.220	0.000	0.12343E 02	16.222	0.000	0.000
VIDEO POS LONG-MEAN	-0.000	2.815	2.815	12.729	-9.992	0.79247E 01	22.721	0.000	0.000
VIDEO POS LAT-MEAN	-0.000	2.953	2.953	11.647	-10.485	0.87183E 01	22.132	0.000	0.000
HOVER RADIUS-MEAN	3.525	2.054	4.003	12.741	0.005	0.42208E 01	12.656	0.000	0.000

Figure 18. Sample of computer printout

STOPS

SUMMARY DATA FOR RUNS 570 610 620 660 692 770 820 832 850 862 892 920

CELL LIMITS	REL FREQ	CUM FREQ
< -8	0.00	0.00
-8- -6	[illegible]	[illegible]
-6- -4	0.19	0.19
-4- -2	0.72	0.89
-2- 0	8.38	9.27
0- 2	61.16	70.42
2- 4	26.11	96.54
4- 6	3.07	99.60
6- 8	0.27	99.87
8- 10	0.13	100.00
> 10	0.00	100.00

LAT VEL(DOP)

CELL LIMITS	REL FREQ	CUM FREQ
< -8	0.70	[illegible]
-8- -6	[illegible]	[illegible]
-6- -4	0.76	[illegible]
-4- -2	1.20	[illegible]
-2- 0	9.57	[illegible]
0- 2	53.04	64.90
2- 4	29.86	[illegible]
4- 6	[illegible]	[illegible]
6- 8	0.81	99.77
8- 10	0.23	100.00
> 10	0.00	100.00

LONG VEL(DOP)

CELL LIMITS	REL FREQ	CUM FREQ
< 0	0.00	0.00
0- 25	0.06	0.06
25- 50	64.56	64.61
50- 75	35.39	100.00
75-100	0.00	100.00
100-125	0.00	100.00
125-150	0.00	100.00
150-175	0.00	100.00
175-200	0.00	100.00
200-225	0.00	100.00
>225	0.00	100.00

RADAR ALTITUDE

CELL LIMITS	REL FREQ	CUM FREQ
<-40	0.02	[illegible]
-40--30	0.00	[illegible]
-30--20	0.02	[illegible]
-20--10	0.31	[illegible]
-10- 0	53.72	54.21
0- 10	45.43	99.44
10- 20	0.56	100.00
20- 30	0.00	100.00
30- 40	0.00	100.00
40- 50	0.00	100.00
> 50	0.00	100.00

VIDEO POS LONG

Figure 18. Sample of computer printout - Continued

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STOPS

SUMMARY DATA FOR RUNS 570 610 620 660 690 770 820 830 850 860 890 920

CELL LIMITS	REL FREQ	CUM FREQ
<-40	0,00	0,00
-40--30	0,00	0,00
-30--20	0,00	0,00
-20--10	7,59	7,59
-10- 0	41,97	49,56
0- 10	48,30	97,86
10- 20	2,14	100,00
20- 30	0,00	100,00
30- 40	0,00	100,00
40- 50	0,00	100,00
> 50	0,00	100,00

VIDEO POS LAT

CELL LIMITS	REL FREQ	CUM FREQ
< 0	0,00	0,00
0- 10	83,53	83,53
10- 20	16,[illegible]7	[illegible]
20- 30	[illegible]	[illegible]
30- 40	[illegible]	[illegible]
40- 50	[illegible]	[illegible]
50- 60	[illegible]	[illegible]
60- 70	[illegible]	[illegible]
70- 80	[illegible]	[illegible]
80- 90	[illegible]	[illegible]
> 90	[illegible]	[illegible]

HOVER RO

CELL LIMITS	REL FREQ	CUM FREQ
< 0	0,00	0,00
0- 5	80,24	80,24
5- 10	19,38	99,62
10- 15	0,38	100,00
15- 20	0,00	100,00
20- 25	0,00	100,00
25- 30	0,00	100,00
30- 35	0,00	100,00
35- 40	0,00	100,00
40- 45	0,00	100,00
> 45	0,00	100,00

HOVER RO-MEAN

Figure 18. Sample of computer printout - Continued

4. FLIGHT TEST RESULTS

The results of the STOPS flight test effort are shown in Figures 19 through 30. To best explain these results, each cell will be analyzed separately and a comparison of the cells will be presented.

a. Cell 1. Stabilized STOPS. Figure 19 shows the cumulative frequency of the hover performance of the hover radius about the mean position. As can be seen, the IH and LH at the 50-percent point are less than 5 feet. This error is comparable to the TASS STOPS simulation[1] and slightly larger than the flight test of the stimulated STOPS.[2] The errors accumulated for the BU, HH are twice those for the IH and errors for the RM are three times those for the IH. These increased errors can be expected since the position symbology gain which is now represented by the actual ground image was optimized for the 50-foot altitude and not for 200 feet and pilot has the additional task of monitoring altitude variations. Also, as altitude increases, the initial selected hover point is much more difficult to resolve. As stated earlier in the symbology description section by optimizing the symbology gains for one particular altitude degraded hover performance was expected for different altitudes. The data appears to substantiate the assumption.

The translational position error contribution (Figure 20a) is predominant in the fore-aft axis, especially during the BU, HH, and RM. The fore-aft to lateral standard deviation ratio is approximately 2 to 1. These position errors correlate well with the results of the DHS flight test study.[4]

A comparison of the standard deviation results of the IH position errors (Figure 20b) with the results obtained under the Low Level Night Operations (LLNO)[6] effort for a similar maneuver shows no significant difference. The mean of the standard deviations of the position errors for this study is 2.5 feet and for the LLNO less than 2 feet. This agreement between the LLNO simulated STOPS and the actual STOPS brassboard model testing verify the results of the current flight test and confirm the STOPS potential.

Some further explanation is necessary to clarify the cause of the higher than normal position errors encountered during the remask maneuver. As can be seen on Figures 20a and 20b, the remask maneuver position errors are greater. The most likely explanation for this is probably due to,

(1) inability of the pilot to select a well defined ground reference,

(2) concentration of the pilot on the altitude and rate of descent, and

(3) The measurement technique for determining hover performance error.

All these factors contribute varying degrees of error to the pilot's performance. These factors also contribute errors during the bob-up and higher hover but to a lesser degree. To further explain this, for the bob-up maneuver, the pilot iniates the hover from a well defined ground hover reference. As the bob-up maneuver is executed, this reference becomes much smaller and the position cues

[6]"*Low Level Night Operations Study*," Systems Engineering Team, Advanced Avionics Systems Technical Area, Avionics Laboratory, Technical Report ECOM-4417, Fort Monmouth, NJ, June 1976.

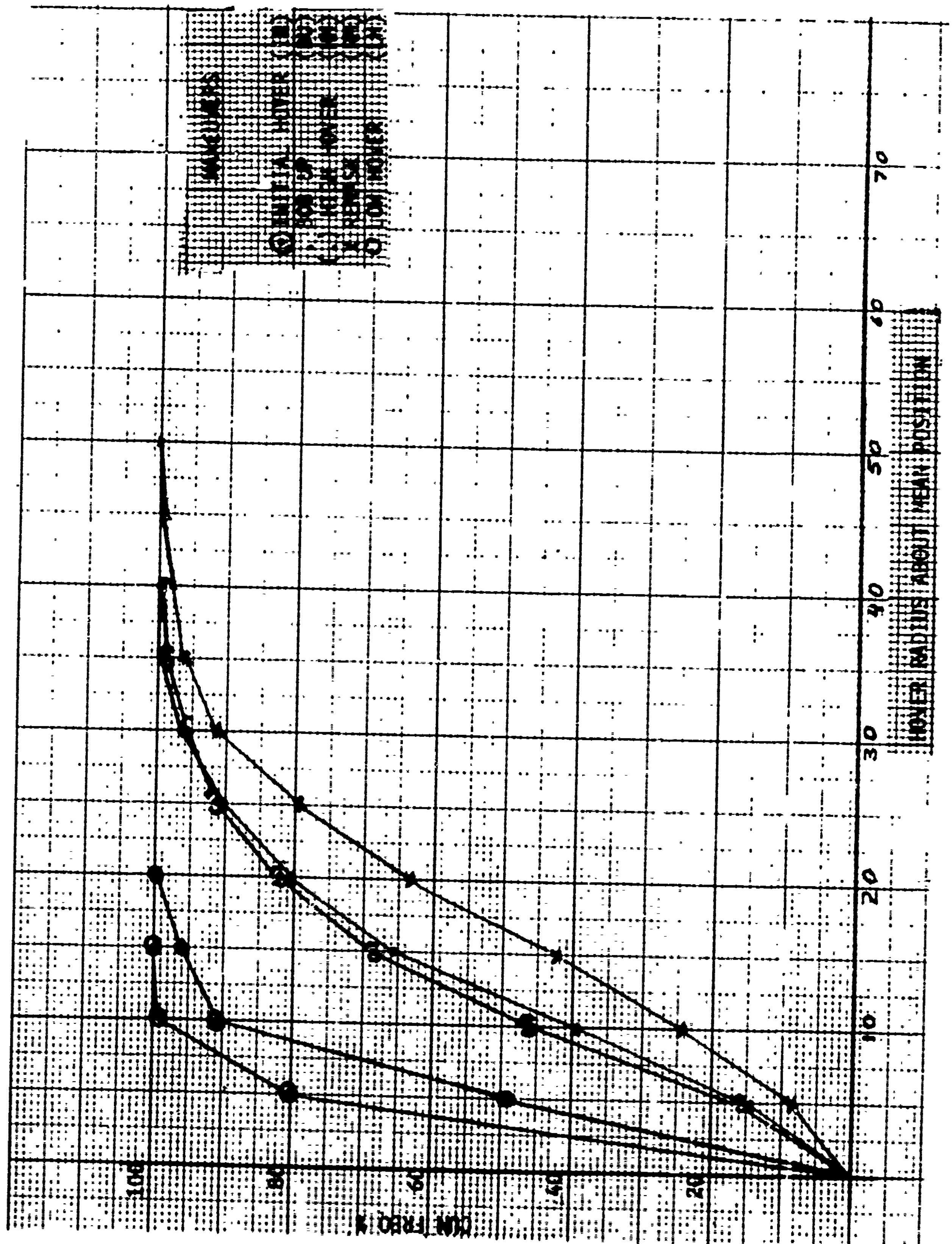
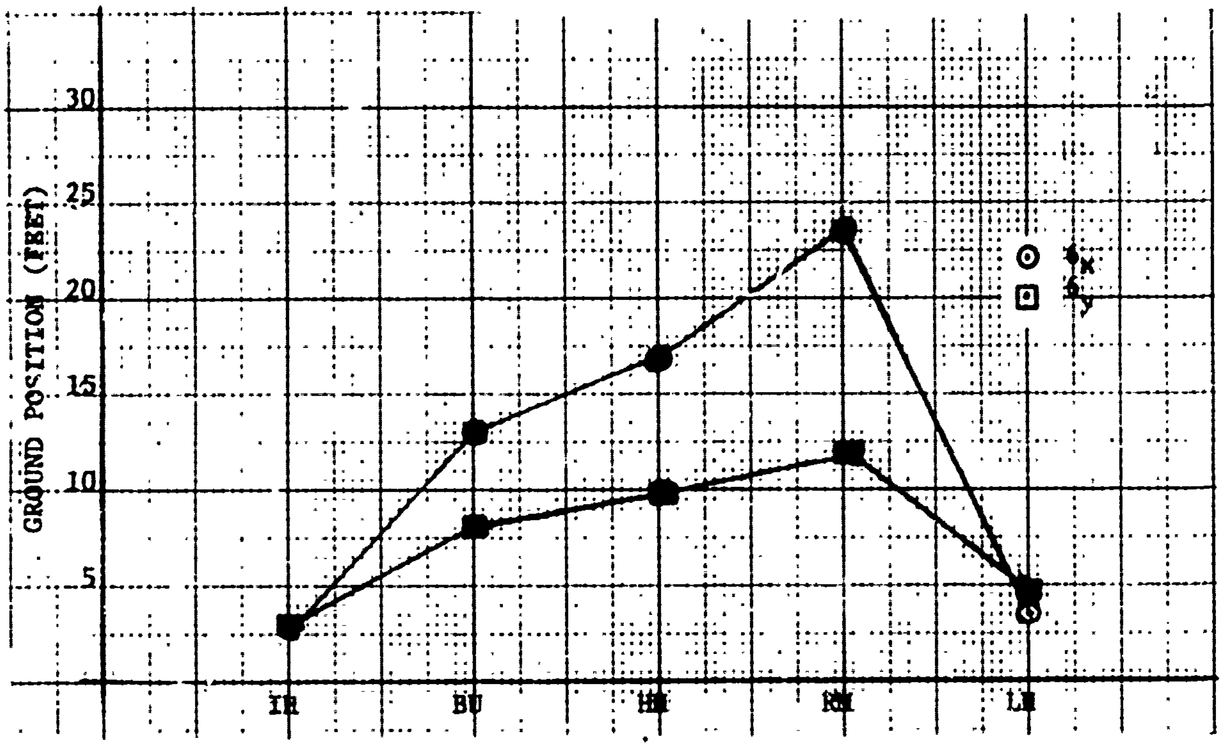
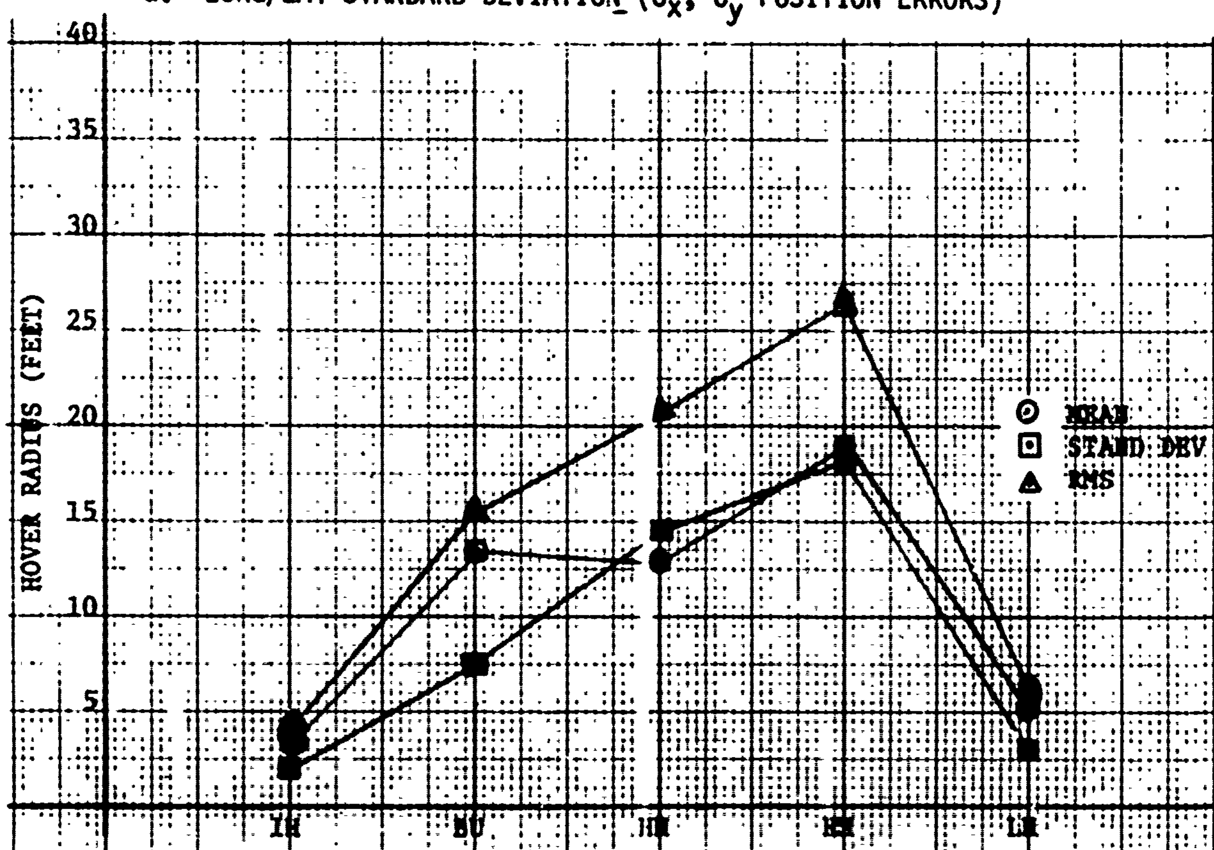


Figure 19. Cell 1 - stabilized mirror with symbology (hover radius cumulative histogram)



a. LONG/LAT STANDARD DEVIATION (6$_x$, 6$_y$ POSITION ERRORS)



b. HOVER RADIUS ABOUT MEAN POSITION

Figure 20. Cell 1 - stabilized mirror with symbology (hover radius statistics)

presented to the pilot are not as pronounced. This, along with the cross controlling of cyclic and collective, tend to increase the position error. It should be mentioned that the data collected is referenced about the ground hover point selected just prior to changing altitude. As the helicopter ascends and the ground reference becomes less discernible to the pilot due to loss of resolution, in his attempt to optimize the hover, he may have been forced to select a different and more pronounced ground target. However, performance is still measured about the original selected hover point. Thus, the pilot is penalized although he may be holding a precise hover over the new reference.

For the high altitude hover (HH), the radial position errors (Figure 20b) are slightly greater than those of the bob-up (BU) maneuver. This tends to substantiate the explanation of the inability of the pilot to resolve the original reference point at the higher altitude. The penalty is again higher position errors caused by the continuous wandering in search of a pronounced or the original reference point about which the data is measured.

Returning to the remask maneuver, the pilot selects a ground target at the high hover. He uses this reference and initiates his descent. This position accuracy tends to decrease since he must pay close attention to the rate of descent and altitude. As he descends and the ground detail becomes more discernible, he may recognize some prominent feature or even the initial hover point and may try to hover over this point. By doing so, he again is penalized in his hover performance. This is depicted by the larger errors during RM shown in Figure 20b as compared to the other four submaneuvers of the same cell.

The altitude standard deviations about the mean for the IH, HH, and LH are shown in Figure 21. It appears that the subject has difficulty maintaining precise altitude at the high hover. An explanation might be that the pilot may tend to relax his altitude control since the aircraft is clear of obstacles. Also, since he is near the lower gain of displayed altitude, the altitude excursions appear smaller and he devotes less time in optimizing or stabilizing altitude. In retrospect, it would have been ideal to hover the helicopter near a tree line and only have the pilot just break mask. This would have forced him to pay closer attention to altitude.

b. Cell 2. Unstabilized STOPS. The results of Cell 2 are shown in Figures 22, 23, and 24. Figure 22 shows the cumulative frequency of the hover performance. As can be seen, the IH and LH position errors are less than 10 feet at the 50-percent point. For the HH and BU, the errors increase by 10 feet and for the RM by 15 feet. The major position error standard deviation is in the lateral axis as shown in Figure 23a. The hover radius standard deviation about the mean position for the IH and LH are approximately 5 feet as shown in Figure 23b, with higher errors accumulated in the BU, HH, and RM maneuvers.

The ability of the subjects to maintain altitude during the IH, HH, and LH is shown in Figure 24. The standard error for the IH and LH is in the order of 10 feet. The subjects seem to have greater difficulty in maintaining accurate altitude at the HH. The standard altitude errors of Cell 2 are comparable to those of Cell 1.

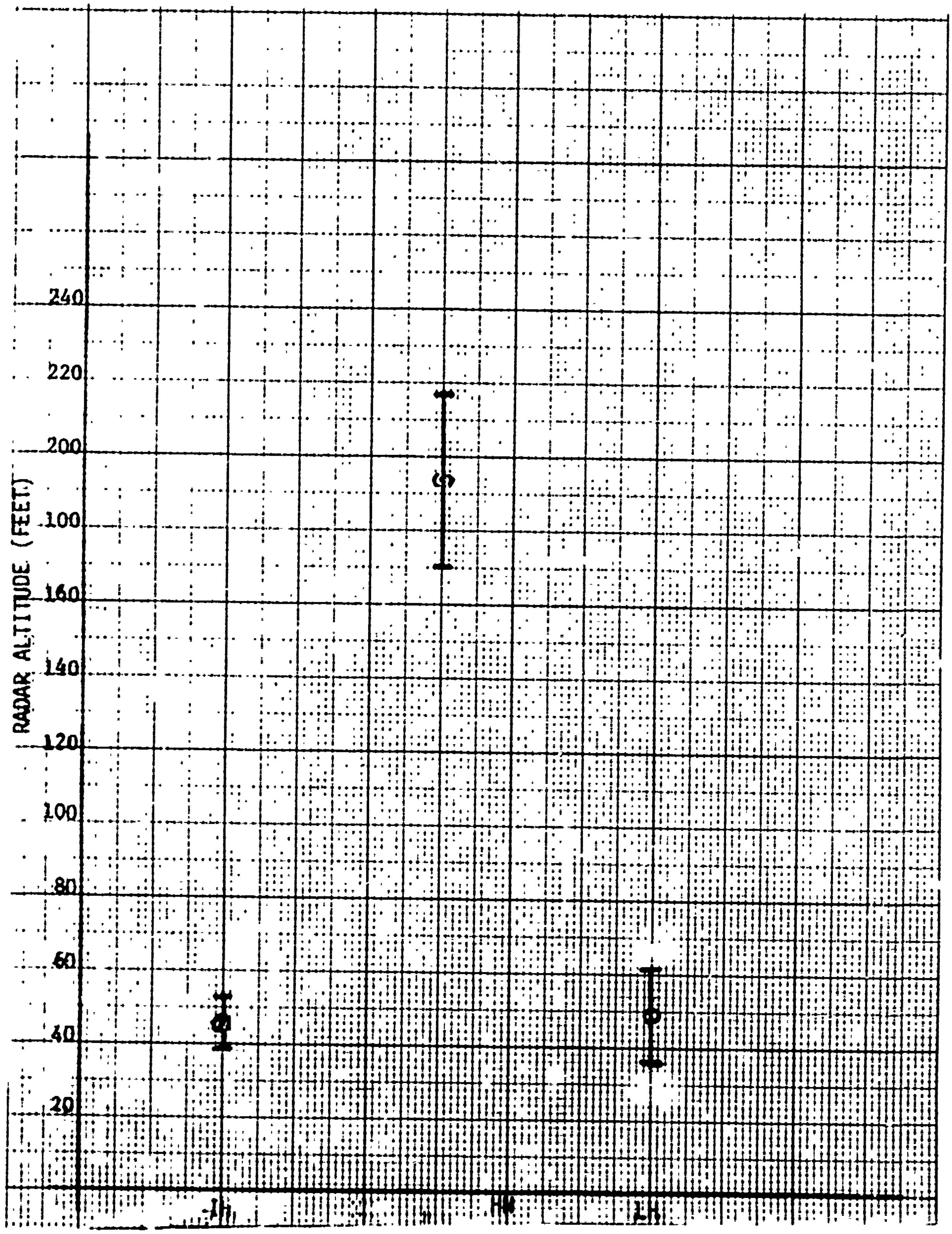


Figure 21. Cell 1 - stabilized mirror with symbology (altitude mean and standard deviation)

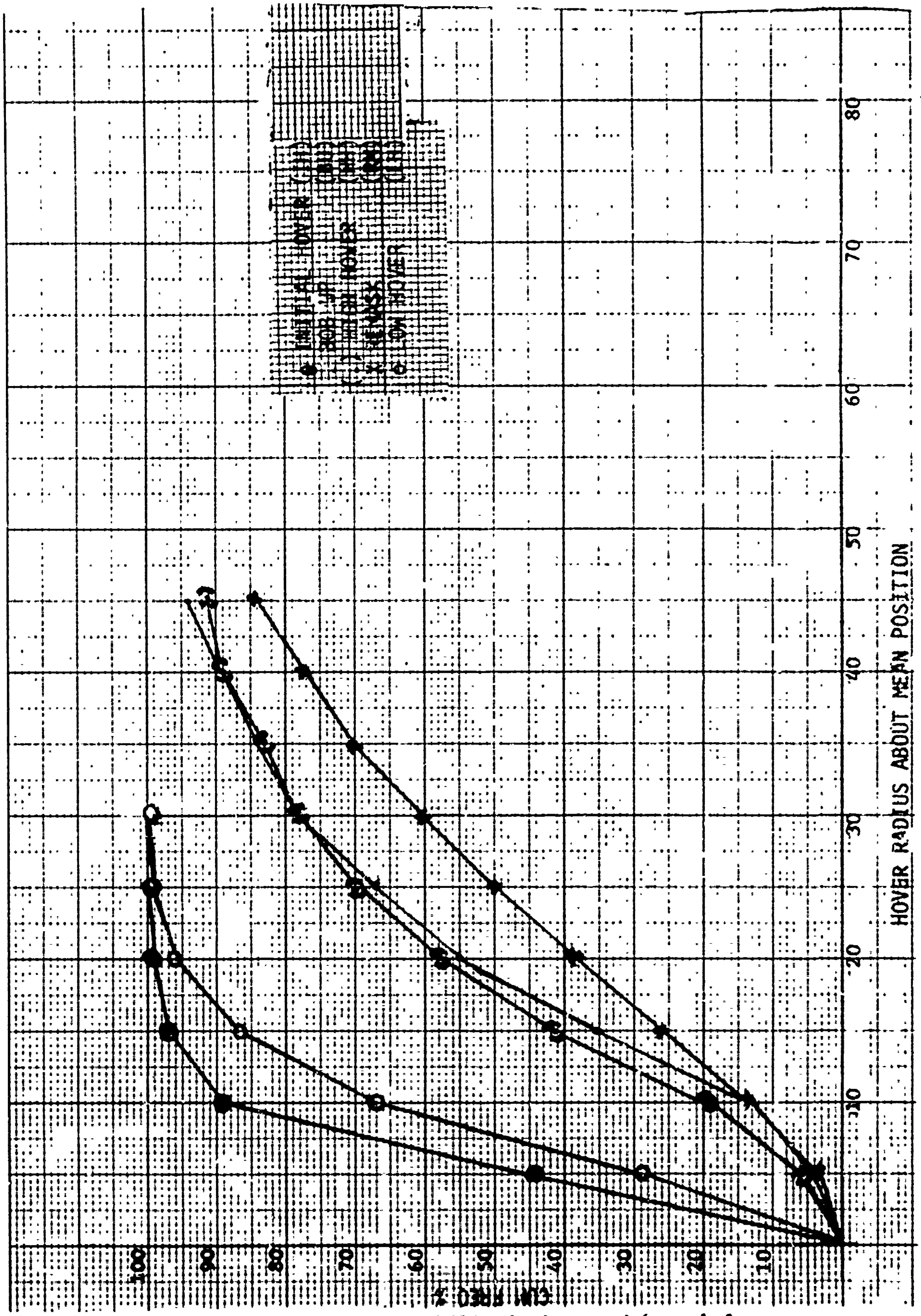
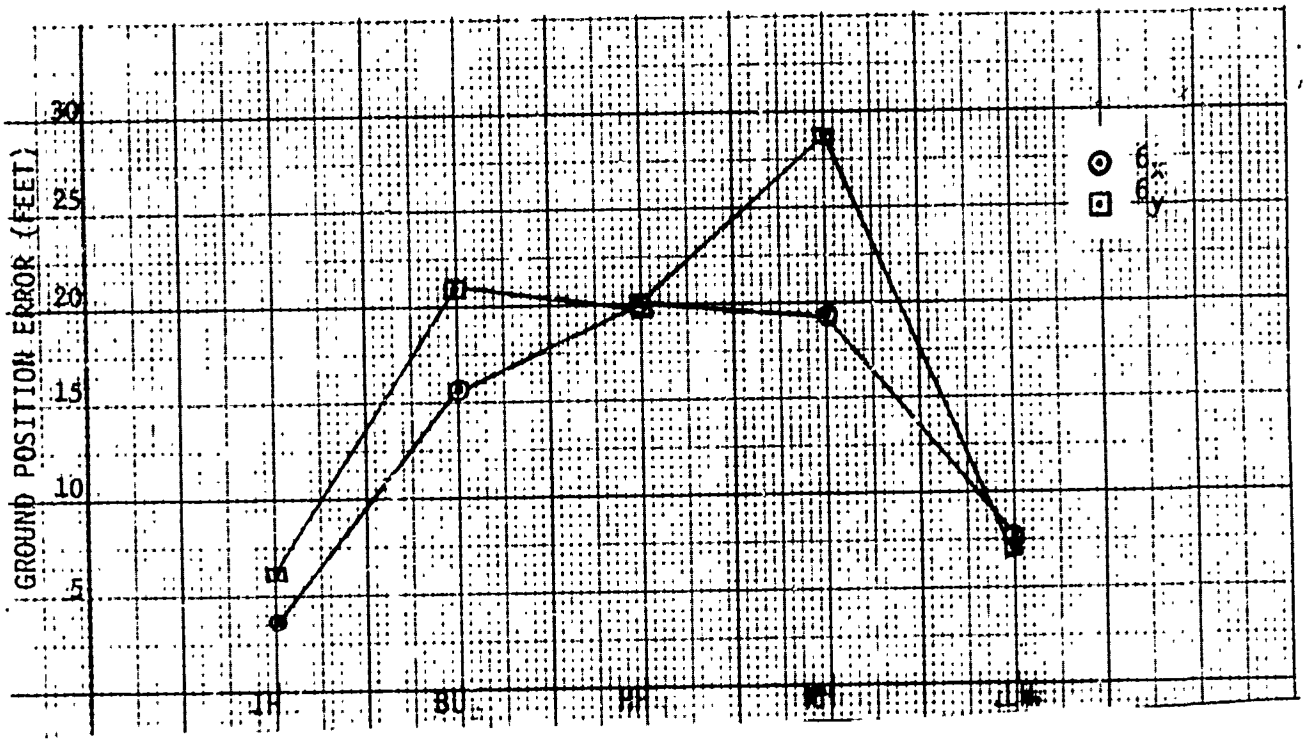
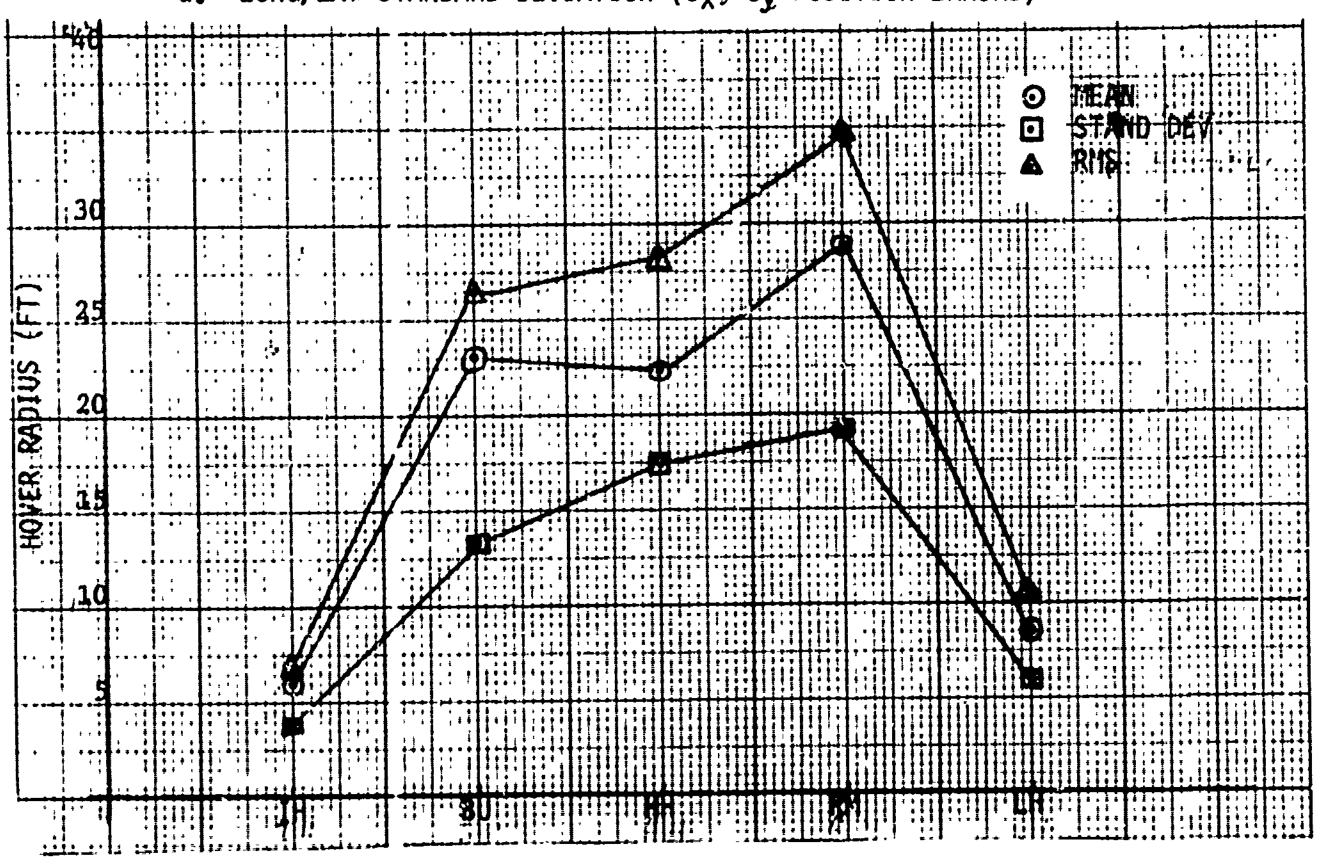


Figure 22. Cell 2 - unstabilized mirror with symbology
(hover radius cumulative histogram)



a. LONG/LAT STANDARD DEVIATION (6_x, 6_y POSITION ERRORS)



b. HOVER RADIUS ABOUT MEAN POSITION

Figure 23. Cell 2 - unstabilized mirror with symbology (hover radius statistics)

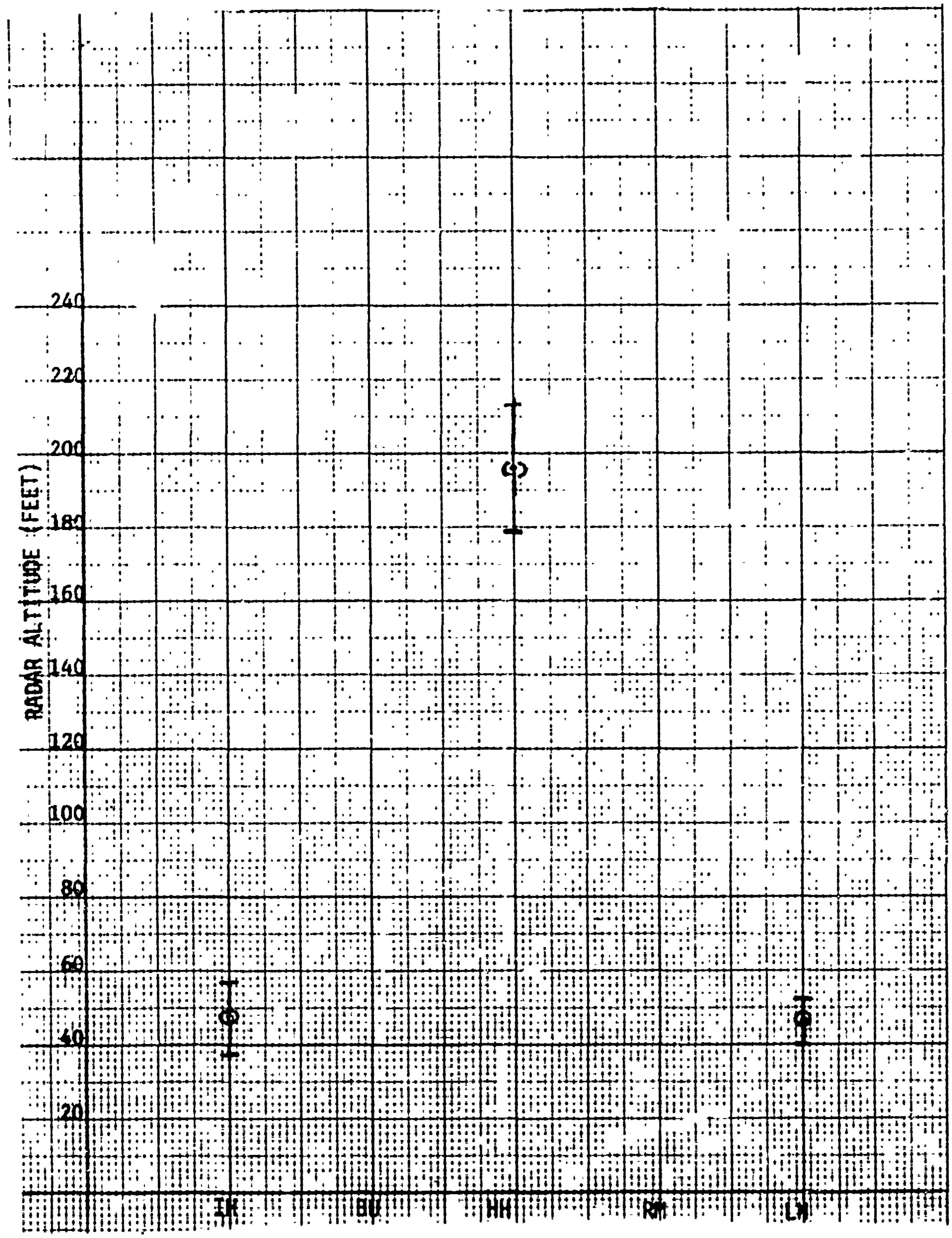


Figure 24. Cell 2 - unstabilized mirror and symbology (altitude mean and standard deviations)

c. Cell 3. Front Seat - The results of Cell 3 are shown on Figures 25, 26, and 27. As can be seen in Figure 25, the front seat subject is able to hover within a 10-foot radius 50 percent of the time during the IH, HH, and LH. There is an increase of approximately 8 feet for the BU and RM maneuvers. These results confirm the findings of a previous study[4] as to what hover accuracy can be expected from a pilot with all available visual cues.

Figure 26a show the standard deviations for each axis. The hover radius mean, standard deviation and RMS are shown in Figure 26b. These figures also reflect the previous findings.[4] In questioning the pilots about their performance from the front seat, they tend to believe that the hovers are "perfect." The quantitative measurement shows otherwise. This may imply that pilot opinion in judging performance might not be realistic.

Their ability to maintain altitude (Figure 27) seem to be much better than in the previous two cells. It is quite probable, that since the deviations are less than 10 feet, the altitude hold might have been engaged.

d. Cell 4. Stabilized Mirror, No Symbols, Constant Altitude. Figure 28 shows the cumulative probability of the hover performance without symbology. This cell was designed with the bob-up and remask maneuvers, but due to the inability of the pilot to stabilize the helicopter, the bob-up and remask were eliminated. The results of the Cell 4 at constant altitude, approximately 60-feet hover, indicate that the pilot can achieve a rather "good" hover. A comparison with Cell 1 shows that for this cell, at the 50-percent point, the hover radius has more than doubled. At the 80-percent point, the Cell 4 radius is almost 15 feet while that of Cell 1 is only 5 feet. The errors associated with this cell at a constant altitude can be classified acceptable. However, since the subjects could not accomplish the bob-up and remask maneuvers using this cell, one may conclude that such a configuration without symbols has a limited application.

Attempts to fly other cells, such as Cell 2 without symbology, were quickly terminated. It was rather difficult to maintain a stable hover, and the safety pilots usually would override the test subject and assume control of the helicopter.

e. Cell 5. Hover Maneuvers after Completion of Approach/Transition to a Hover. This particular cell provides a good insight to the potential of imagery and superimposed symbology for accomplishing the terminal area maneuvers. The ability of the test subject to use this information to decelerate the helicopter to a complete stop, perform the required hover submaneuvers and then accelerate and make an approach to a new hover area, was demonstrated successfully. The data shown on Table 2 reflect that the deceleration was initiated at an average altitude of 81 feet and 20 fps average forward speed. The average ground speed increased to 27 fps with the average altitude increasing to 114 feet before finally settling to an average of 40 feet or 10 feet less than the desired value of approximately 50 feet. The test subject then completed the required hover submaneuvers. From this location the test subject accelerated/decelerated the helicopter to a new hover area.

For this acceleration/deceleration maneuver, the subject pilot attained an average maximum speed of 36 fps and 112-feet altitude before settling to an average of 30 feet or 20 feet less than th desired value of 50 feet.

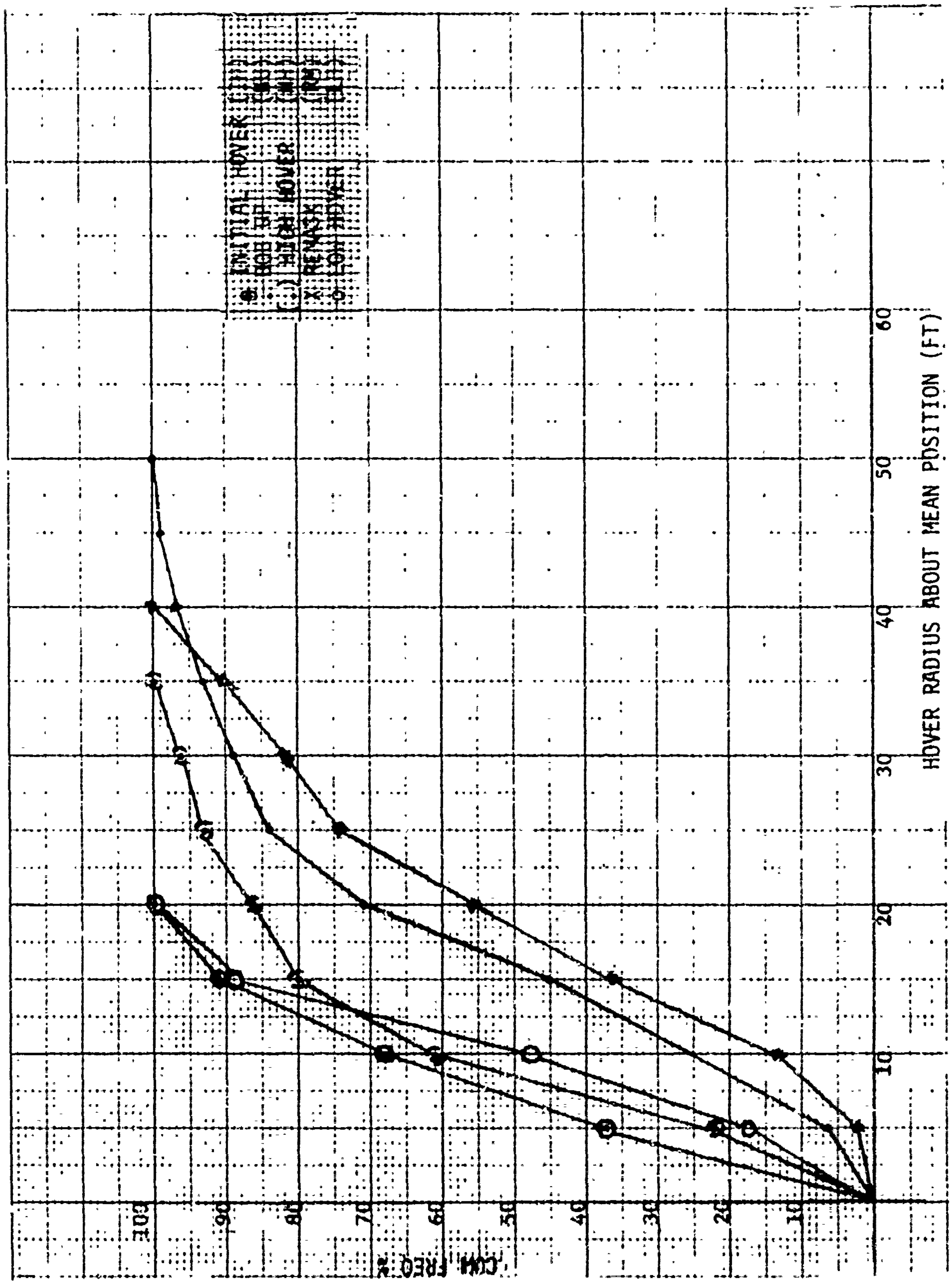
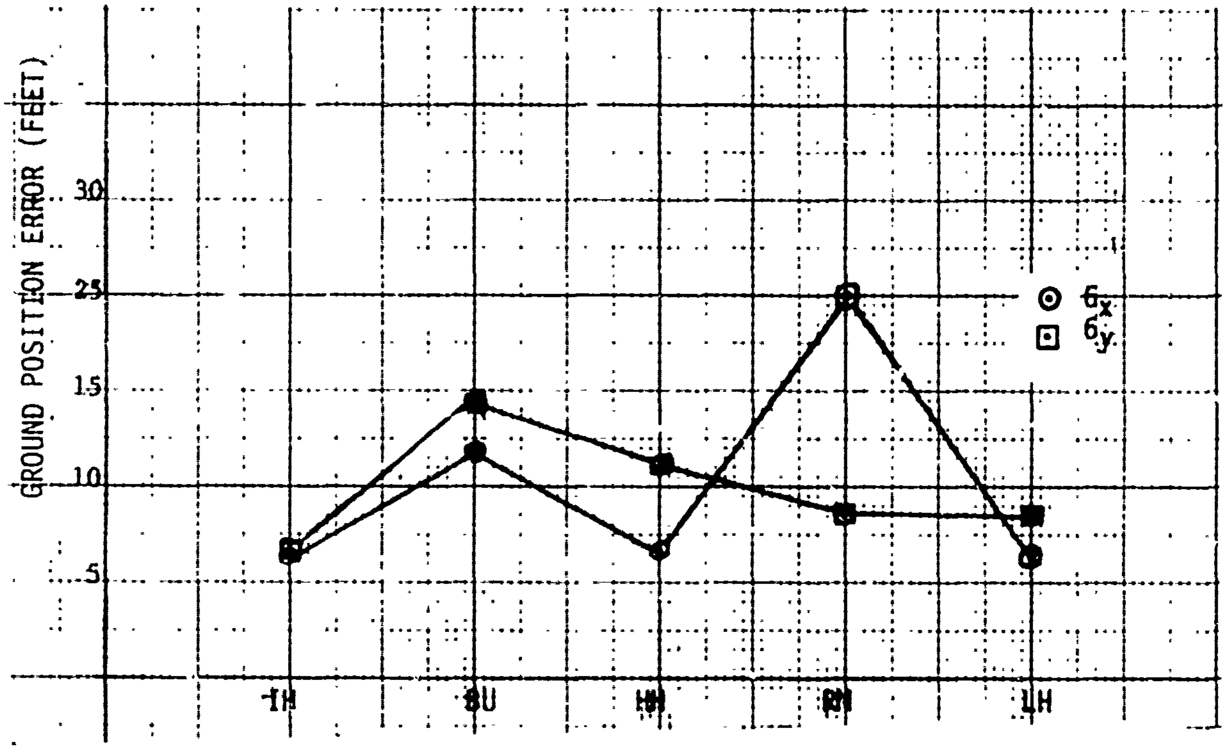
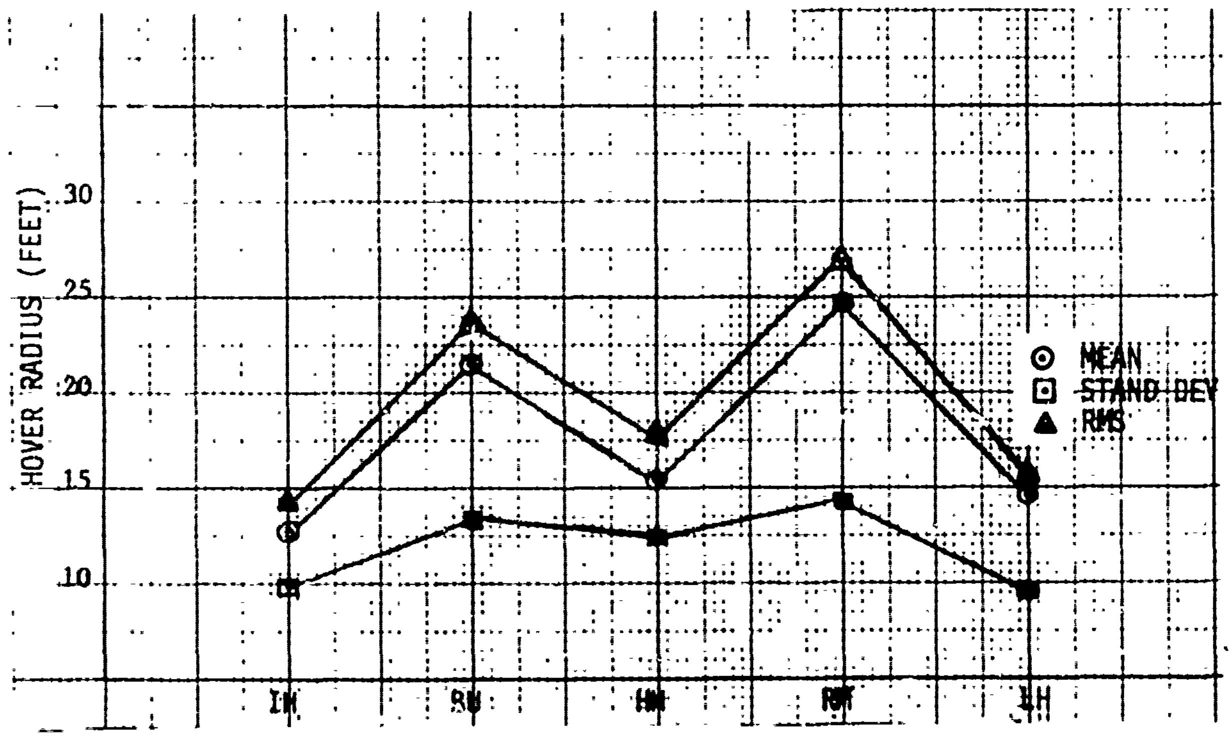


Figure 25. Cell 3 - front seat (VFR) performance
(hover radius cumulative histogram)



a. LONG/LAT STANDARD DEVIATION (6x, 6y POSITION ERRORS)



b. HOVER RADIUS ABOUT MEAN POSITION

Figure 26. Cell 3 - front seat (VFR) performance
(hover radius statistics)

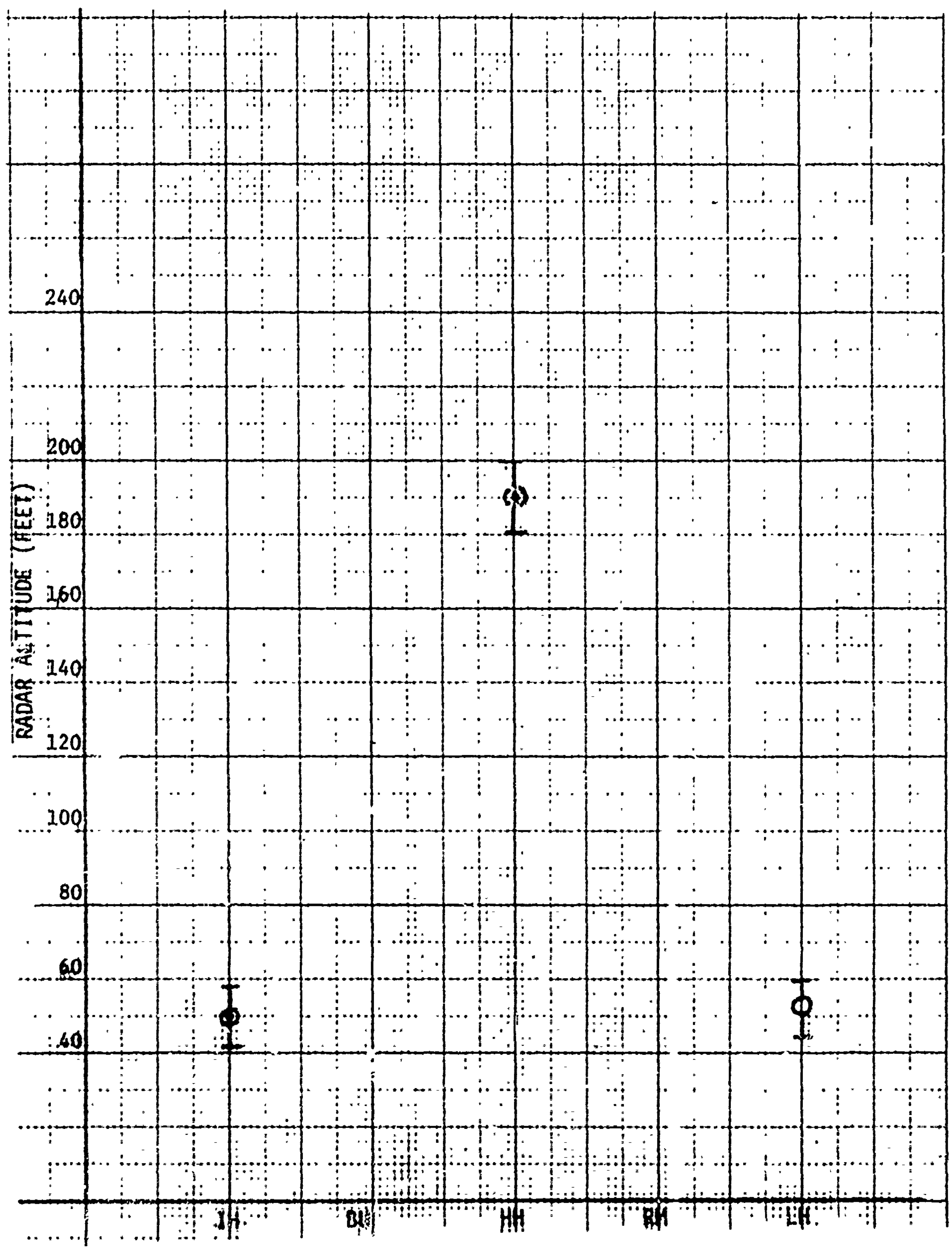


Figure 27. Cell 3 - front seat (VFR) performance (altitude mean and standard deviation)

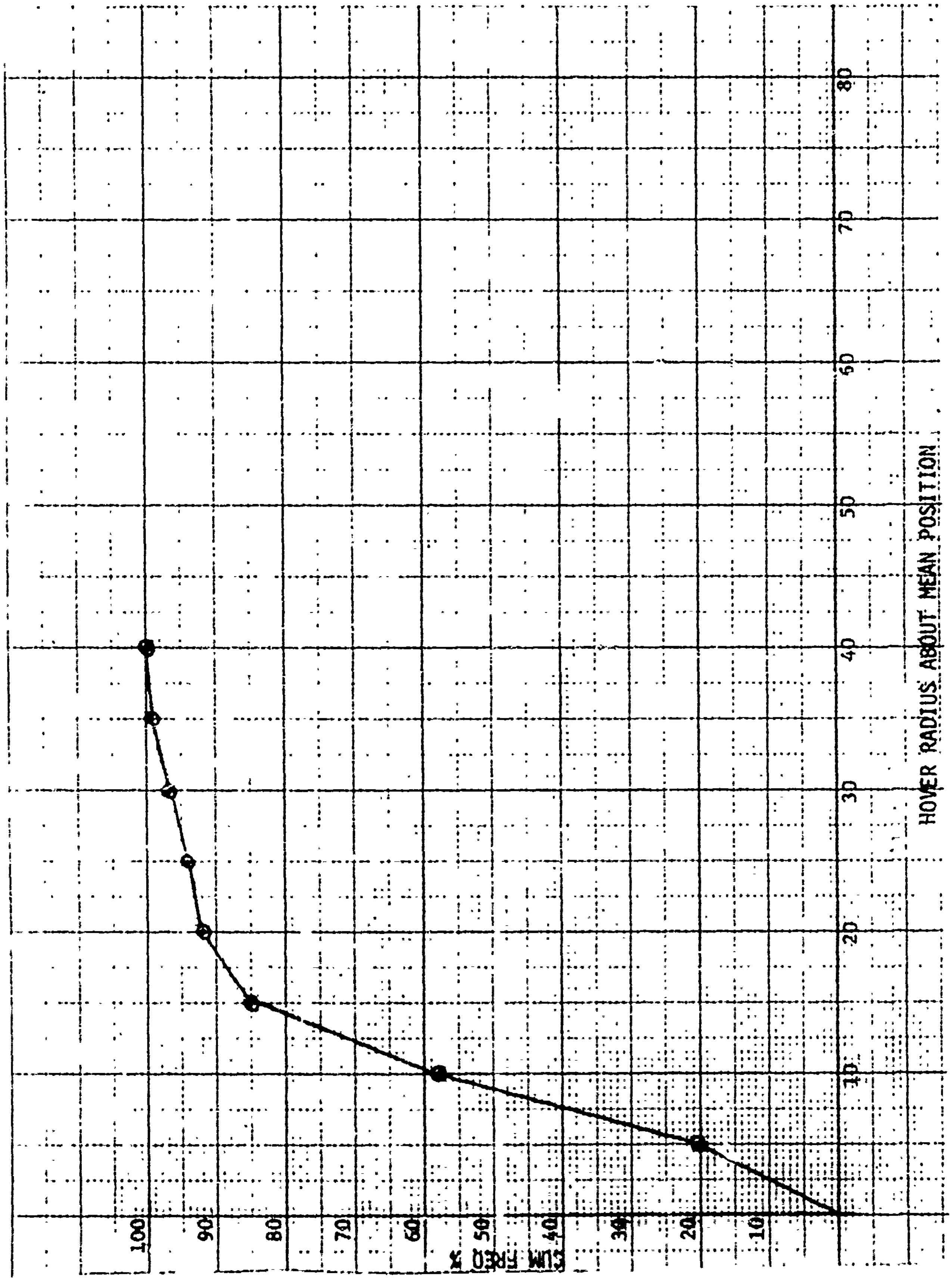


Figure 28. Cell 4 - stabilized mirror, no symbols, constant altitude (hover radius cumulative histogram)

It is rather difficult to explain the low altitude achieved from the desired value. The explanation offered is that the pilot is so preoccupied in monitoring the information in the center of the display, primarily velocity and acceleration, that altitude control becomes a secondary task and not very tightly controlled.

TABLE 2. APPROACH TO A HOVER AREA

Maneuver to a Hover Point	Gnd Velocity (fps) Long.		Lateral		Radar Altitude (Ft)		
	Initial	Max	Max Left	Max Right	Initial	Max	Min
Deceleration	20.0	27.0	6.1	7.6	81.0	114.0	40.0
Acceleration/ Deceleration	4.3	36.0	8.0	7.1	52.0	112.0	30.0

The results of Cell 5 are shown in Figures 29, 30, and 31. As stated earlier, this cell is identical to Cell 1 with the exception being that for this cell the subject pilot had to fly or transition the helicopter from approach to some specified hover point, then proceed with the hover maneuvers. Hover performance was measured only after the subject pilot determined that he had the aircraft stabilized over a point and felt comfortable with his hover performance. The results of this cell are more realistic than those of Cell 1. Whereas for Cell 1, the subject assumed control of the helicopter while in a stable precise hover; for Cell 5, they had to achieve a stable hover primarily using the imagery before data collection was initiated.

As can be seen in Figure 29, the results are slightly degraded from those of Cell 1. At the 50-percent point, the hover radius of Cell 5 is in the range of 5.5 to 22.5 feet for all the maneuvers whereas for Cell 1, the range is from 3 to 17 feet. The longitudinal axis (Figure 30a) contributes greater position error than the lateral axis, especially during the high altitude and remask maneuvers. There is no appreciable difference in standard deviation between the longitudinal and lateral axes during the IH, BU, and LH maneuvers.

The hover radius mean, standard deviation and RMS are shown on Figure 30b. The values and trends are similar to those obtained with Cell 1 with the exception of an increase of approximately 5 feet for Cell 5.

The cause for this increase is rather difficult to explain, since both Cells 1 and 5 are in essence similar. The only difference between the two is that Cell 5 is initiated after the completion of the approach to a hover area, while Cell 1 was initiated from a stable hover over a well defined ground reference. The general hover reference point was the compass rose of the airfield or the threshold of the runway strip. However, within these general reference points, the runs for Cell 1 used the center of the compass rose (a 3-foot diameter black disk or a painted yellow disk at the threshold of the runway. For Cell 5, the subject pilot after viewing the video tapes does not appear to have used the same reference points. Rather, as he approached the compass rose or the runway threshold and saw some ground detail, he tried to assume a stable hover as soon as possible and request data collection initiation. The lack of the well defined hover reference may have contributed to the increase of the higher position error for Cell 5 as compared to Cell 1.

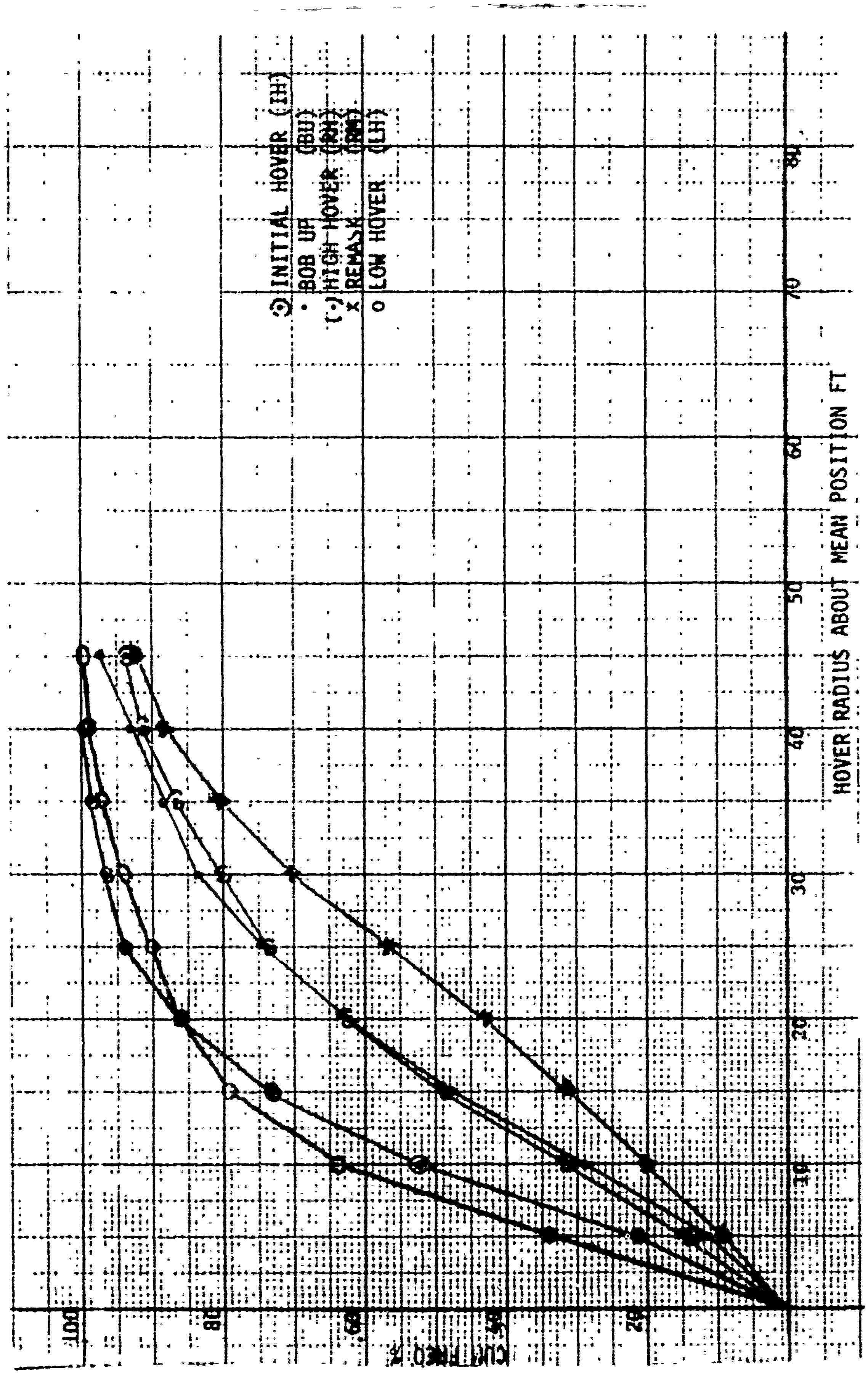


Figure 29. Cell 5 - approach/transition to a hover (hover radius cumulative histogram)

The altitude standard deviations (Figure 29) about the mean altitude for the IH and HH appear to be greater than the errors of Cell 1. It is very possible that the subject pilot was more preoccupied during the approach/transition to a hover area with helicopter stability and position control rather than altitude accuracy. This inability to control altitude more precisely is also reflected for the high hover. The only explanation which is offered is that since the helicopter is sufficiently high, the pilot may concentrate more in controlling helicopter position rather than altitude. This is especially true since the downlook image resolution and gain are reduced at high altitudes. Therefore, the pilot has to pay closer attention to the hover symbology, velocity, and acceleration to maintain position and less time may be devoted to altitude control.

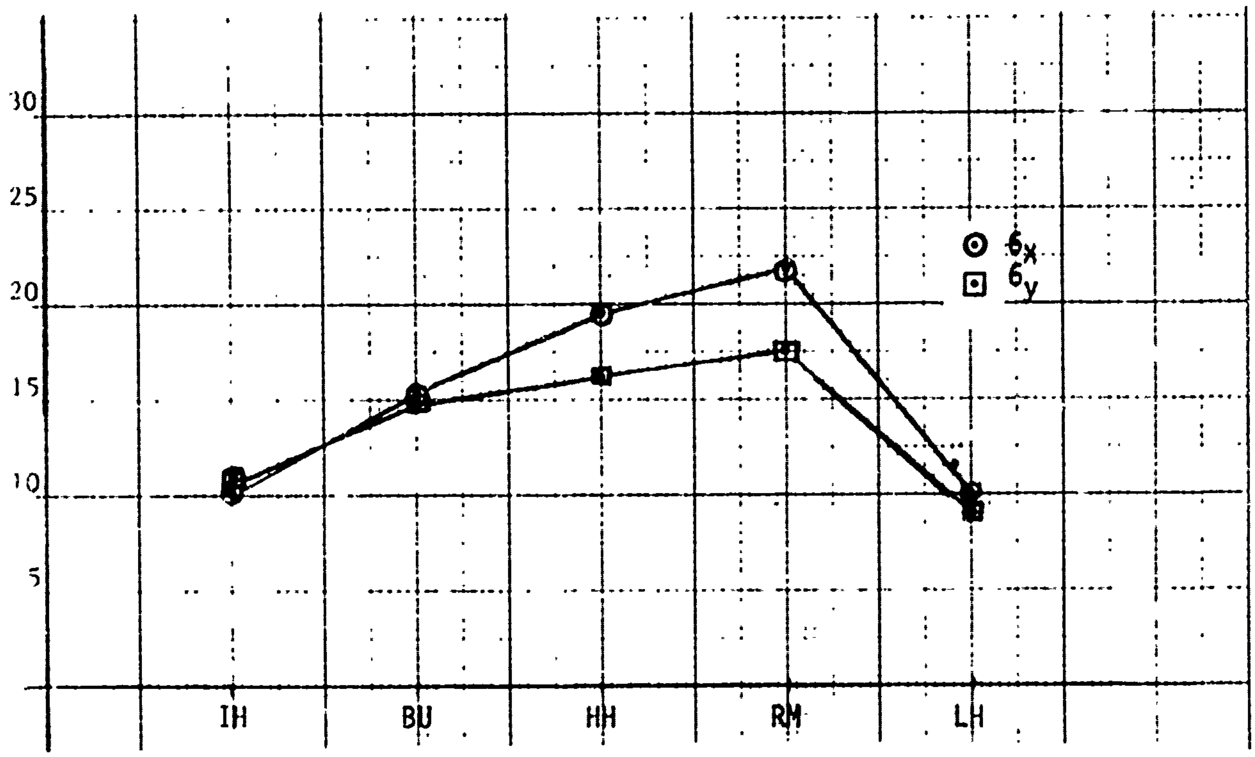
f. Special Runs. Just prior to the completion of the flight test program, the Navy safety pilots were asked to participate as subject pilots and fly the STOPS system. They willingly agreed; however, due to other commitments, they did not have time available for training, but wished to fly the system anyway. They were briefed on the system and the symbology prior to liftoff. At the hover site, two Navy pilots observed an Army subject pilot flying the system. The Navy pilots, one at a time, sat at the 3rd station and, after some familiarization with the 3rd seat flight controls, flew the STOPS System, Cell 1. Each had approximately 10 minutes of training and then flew two runs for data. They flew a constant altitude hover with altitude and heading maintained by the front seat safety pilot. The results of these flights are shown in Figure 32.

Although not enough data was collected for any statistical significance, it is interesting to note that their ability to comprehend the STOPS display presentation and manipulate the symbology to achieve a stable hover after very limited training effects favorably on the system. It should also be noted that neither pilot had flown using a 2-dimensional display or symbology previous to this encounter.

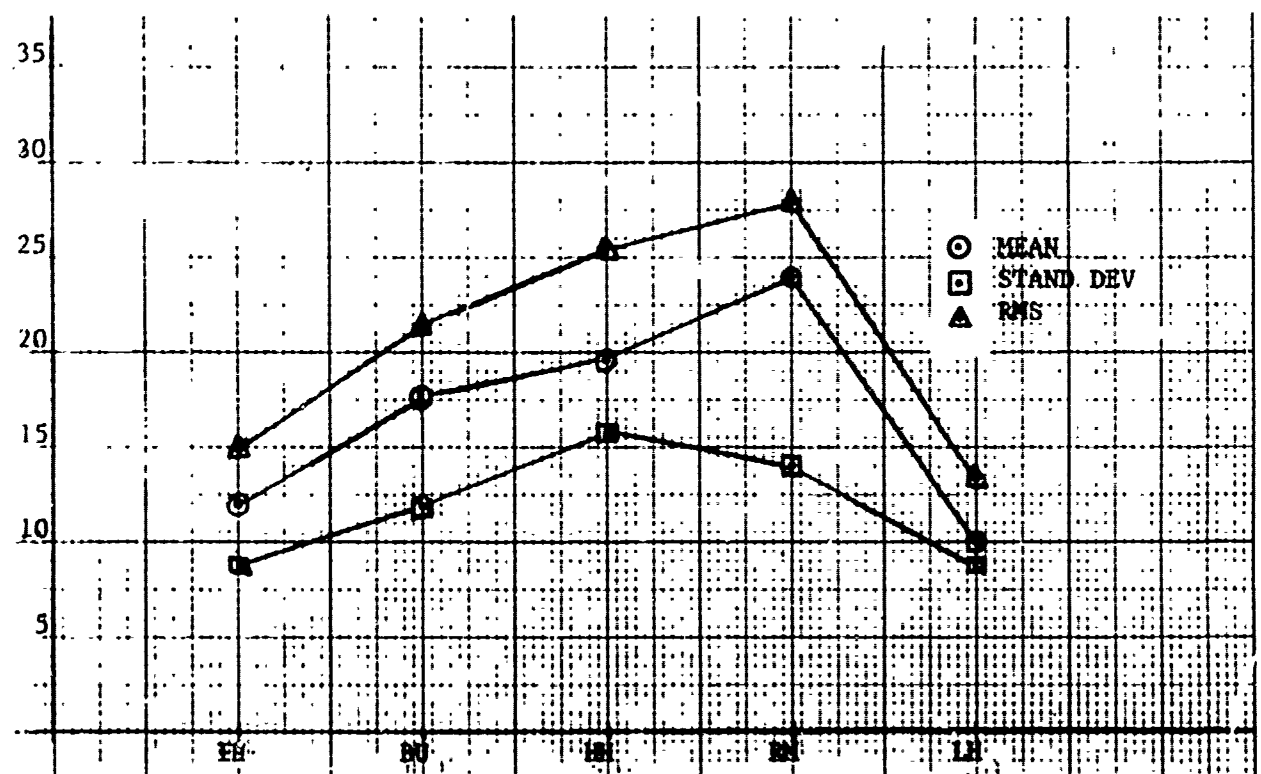
g. Aircraft Control and Attitude Excursions. Figure 33 shows the standard deviation of percent of full travel of the flight controls for Cells 1, 2, 3, and 5. Cell 4 is not included since it was a constant altitude hover. The general trend of these curves seem to reflect higher control displacement during the bob-up, high hover, and remask maneuvers. In comparison to the baseline Cell 3, Cell 1 deviations are higher overall while those of Cell 2 are only higher for the lateral cyclic. The control motions of Cell 5 are higher than those of Cell 3. This may be indicative of increased workload imposed on the pilot in his attempt to transition from approach to a hover maneuver.

Figure 34 shows the standard deviations of the pitch and roll helicopter attitudes of Cells 1, 2, 3, and 5. In general, there is a greater deviation in attitude for the dynamic maneuvers such as the bob-up and remask and also for the high hover. In comparison to the baseline Cell 3, Cell 1, Cell 2, and especially Cell 5 show an overall increase in the attitude standard deviation. This increase in attitude deviation may be attributed to the pilot forcing the helicopter to attain a more precise hover.

h. Subject Pilot Comments. The subject pilot comments favored the potential offered by the STOPS concept (Cell 1) as a visual means for obstacle clearing below the helicopter and its ability to allow them to easily and safely



a. Lat/long standard deviation (6_x, 6_y position errors)



b. Hover radius performance about mean position (ft)

Figure 30. Cell 5 - approach/transition to a hover
(hover radius statistics)

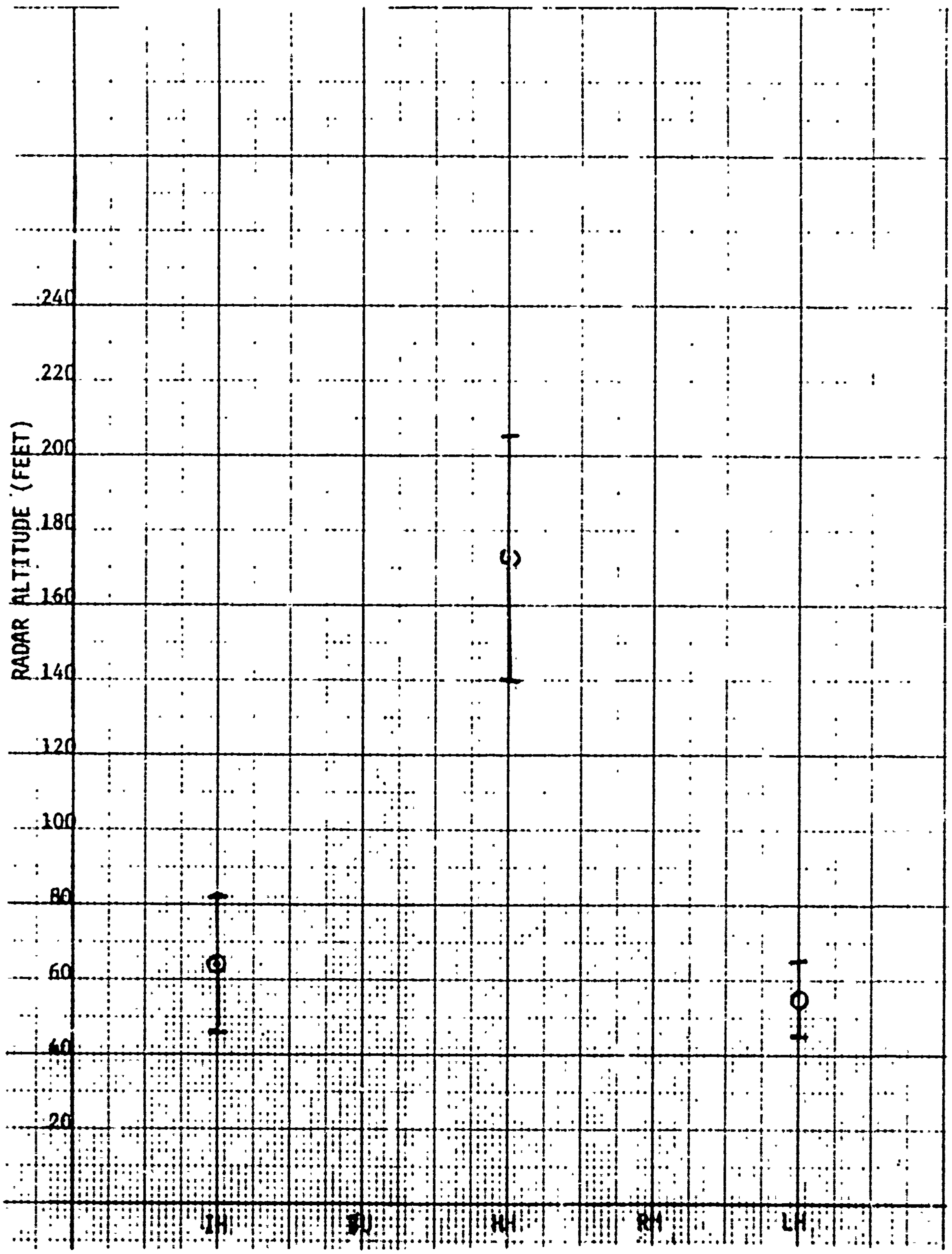


Figure 31. Cell 5 - approach/transition to a hover (altitude mean and standard deviation)

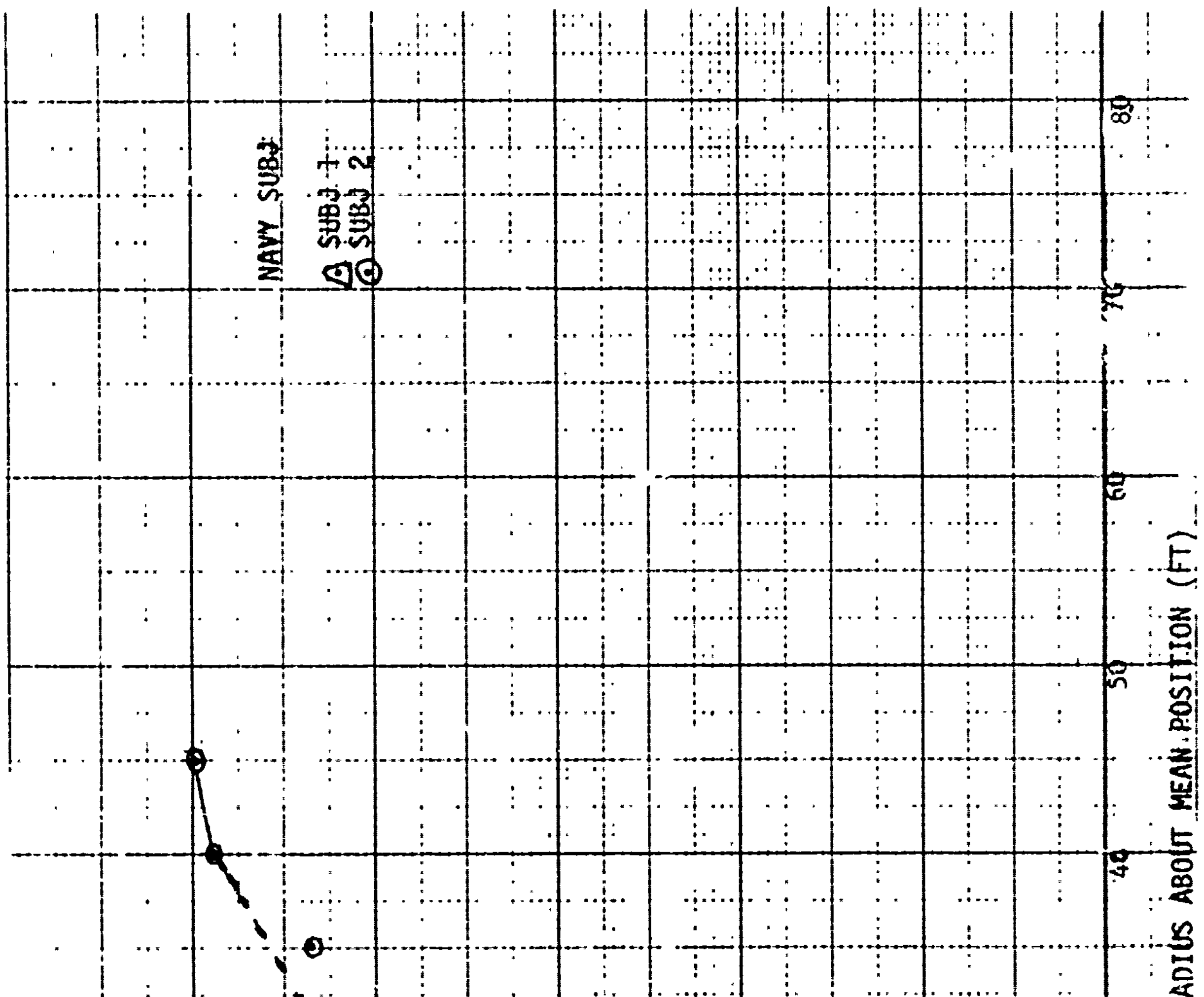


Figure 32. Special runs constant altitude
(hover radius cumulative histogram)

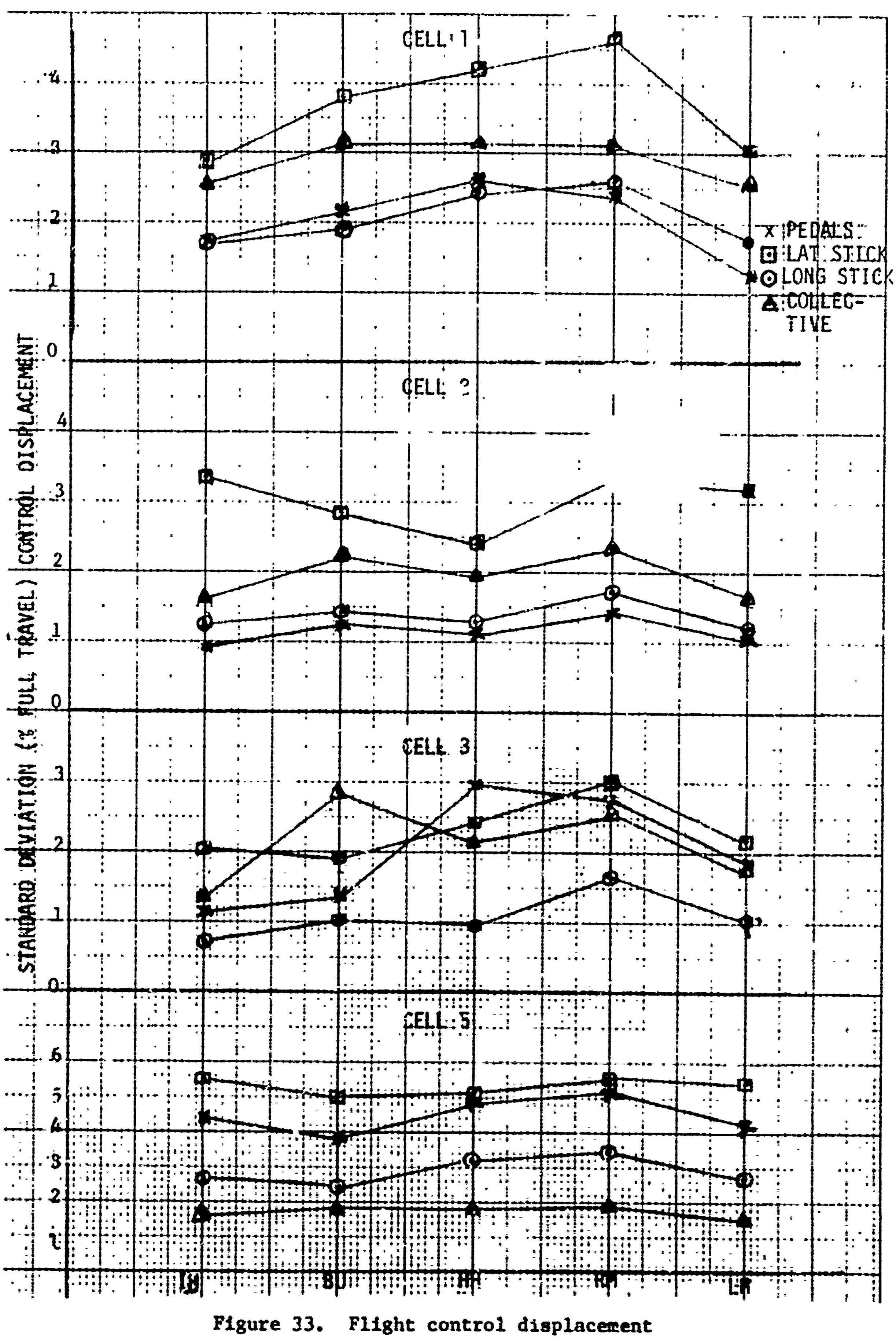


Figure 33. Flight control displacement

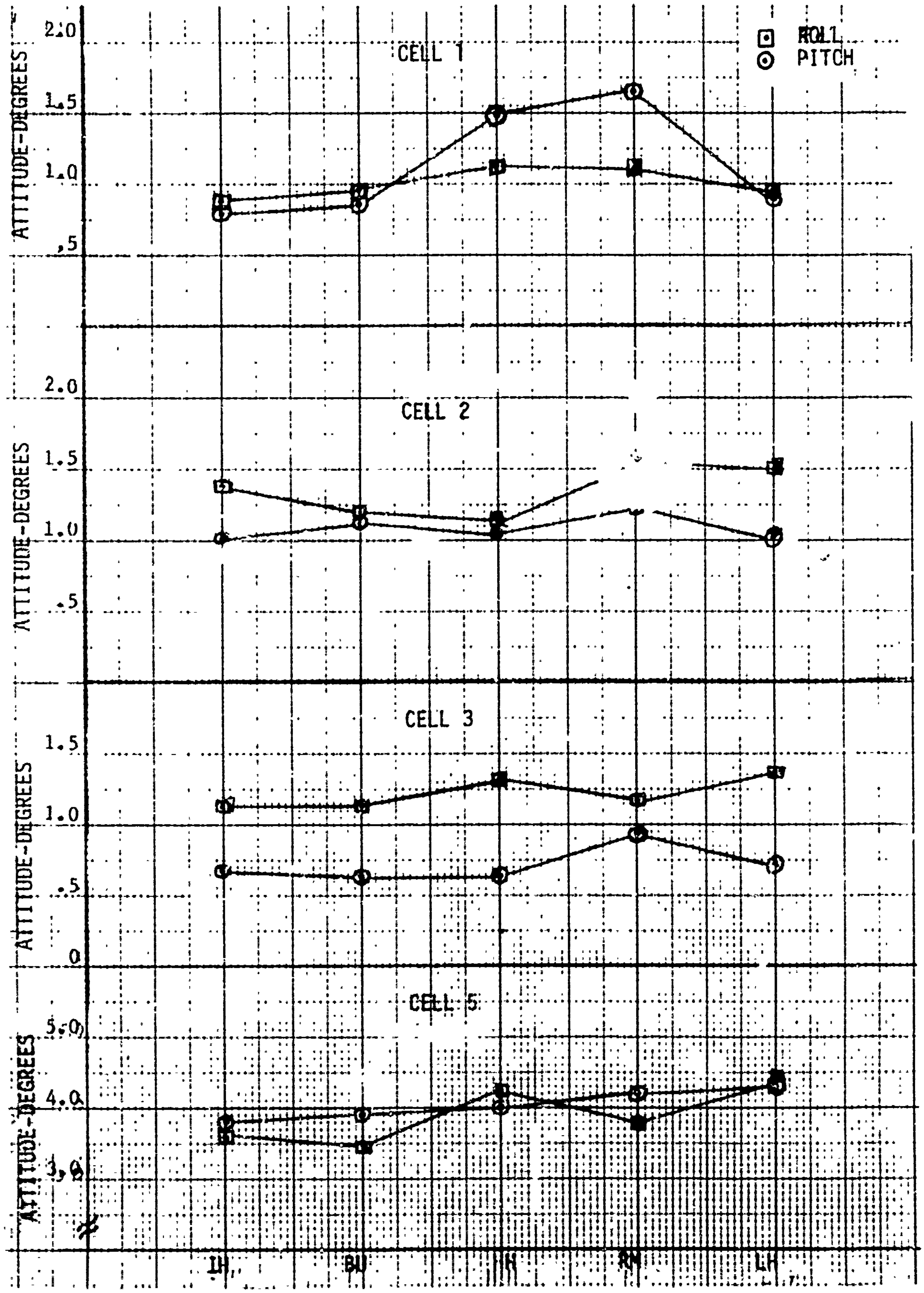


Figure 34. Standard deviation of helicopter attitude

perform the hover, bob-up, and remask maneuvers. They objected to the obscuration of the image caused by the stow position of the mirror and the location of the mirror and symbology mode control switches (Figure 12). They felt that the mirror mode control as well as the symbology mode formating switch should be incorporated on the cyclic or collective stick controls. The hover symbology was readily accepted with the exception of heading. The heading deviation symbology did not provide them adequate information and they preferred to engage the helicopter heading hold system.

The pilots also commented on the need for some means of indicating an upper and lower limit setting on the radar altitude symbology.

5. CONCLUSIONS/OBSERVATIONS

The STOPS brassboard flight test evaluation substantiates the earlier ground base and flight test simulation results of the system's potential to provide a self-contained hover aid. The split image presentation along with the hover symbology provide the test subject the means to perform the "bob-up" and remask maneuvers with ease and confidence. Specific conclusions based on the flight test results are as follows:

a. STOPS Gimbal.

(1) The STOPS gimbal was successfully integrated and flown on the EVAR project helicopter.

(2) The STOPS gimbal angle freedom was sufficient for the EVAR attitudes encountered.

(3) Image smear or jitter from the mirror was unnoticeable.

(4) The split screen presentation did not adversely affect the test subject.

(5) The obstruction of 4° to 6° in the center of the FOV with the mirror in STANDBY mode was unacceptable.

b. STOPS Hover System.

(1) The STOPS with the hover symbology concept was successfully demonstrated as a self-contained hover system.

(2) Subject pilots preferred to fly Cell 1 stabilized mirror symbology over other cells.

(3) Very little training was required to fly Cell 1, as demonstrated by the Navy subjects.

(4) The hover radius position errors for Cell 1 ranged from approximately 2.5 feet for the IH and LH to 7.5 feet for BU, 15 feet for HH, and 18 feet for the RM.

(5) The findings for Cell 1 are similar to those derived in the STOPS ground simulation as well as the earlier flight test simulation program.

(6) The position errors of Cell 2 (unstabilized mirror with symbology) are higher than those of Cell 1, and attempts to perform the hover maneuvers with an unstabilized mirror image without symbology were not successful.

(7) Hover radius errors under VFR conditions, Cell 3, are in the range of 5 to 10 feet.

(8) The incorporation of the transition-to-a-hover mode symbology was successfully demonstrated by having the subjects initiate the transition from approach to a hover at 20-25 knots airspeed.

(9) Cell 5, the approach/transition maneuver, indicates that pilot performance degrades slightly, and that pilot workload (stick movement) increases over those cells that were initiated from a stable hover.

6. RECOMMENDATIONS

The successful flight test demonstration of the brassboard model STOPS in the various configurations tested, leads one to believe that it truly has a potential application in military and possibly civil helicopter[7] operations in such areas as logging and perhaps offshore transportation of personnel on the oil rig platforms. The following recommendations are offered to improve the overall STOPS hover system concept.

a. The brassboard design should be miniaturized and integrated with the appropriate night vision sensor to reduce the present weight and size.

b. That the present design be altered to eliminate the obscuration of the image when the mirror is in the stow position.

c. That the capability to maintain the same display position gain for any altitude be incorporated.

d. That the mirror activation and symbology mode controls be provided on the collective or cyclic for easy access.

[7]Stabilized terrain optical position sensor - US Patent #3,944,729, March 16, 1976.