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## **Helicopter Visual Aid System**

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The results of an evaluation of police helicopter effectiveness revealed a need for improved visual capability. A JPL program developed a method that would enhance visual observation capability for both day and night usage and demonstrated the feasibility of the adopted approach. This approach made use of remote pointable optics, a display screen, a slaved covert searchlight, and a coupled camera. The approach was proved feasible through field testing and by judgement against evaluation criteria.

### **Introduction**

Recently, many law enforcement agencies have integrated helicopters into their patrol activities, and the trend toward their use is continuing to increase on a national scale. Experience with these aerial patrols led to recognition of the limitations of the basic observation system. The initial system was comprised of the helicopter, the observer, and sometimes minimal visual aids such as binoculars or a camera. This minimal amount of support equipment for the full range of police missions, conducted both at night and during the day, limits the potential value of the helicopter system. Many attempts have been made to adapt equipment designed for other purposes to use on police helicopter patrols. Little effort has been made, however, to design equipment specifically for the police helicopter in its performance of the patrol function.

In response to this need, the Jet Propulsion Laboratory has developed a visual aid system for helicopters that is based on a set of requirements derived from law enforcement agencies (Ref. 1).

### **Problem Definition and Task Objectives**

The initial definition of the problem was based upon a previous civil systems task. In this task, the Los Angeles Police Department's helicopter patrol program was evaluated, with one element of this effort being the

assessment of various means by which patrol effectiveness could be increased. A major item identified was improved visual capability.

To confirm some of these observations, and to provide a broader base of understanding of the range of missions and their requirements, a nationwide survey was conducted involving 10 law enforcement organizations. This survey:

- (1) Confirmed the pressing need for improved visual capability.
- (2) Pointed out that the "general patrol" mission was the most appropriate one upon which to focus attention.

From this, the fundamental functional requirements for a visual aid system were established to be:

- (1) It should provide an increased field of view, coupled with the capability to see at night without visible illumination. Minimum resolution should be equivalent to that of the unaided eye under conditions of daylight illumination.
- (2) It should provide an improved capability to see during normal conditions of daylight illumination through an increased field of view as above and with increased resolution.
- (3) It must provide evidence-gathering capability through airborne photography.

The objective of the Phase-I task was the demonstration of feasibility of the adopted approach. Key to the accomplishment of this objective were the following:

- (1) Establish system requirements.
- (2) Perform testing of items of critical technology.
- (3) Design and fabricate a breadboard model of the system.
- (4) Perform a field test of the system utilizing the support of a law enforcement agency.

## **System Constraints and Requirements**

Physical constraints were generally bounded by the characteristics of the Bell-47 G-5 helicopter, which was chosen to be the test vehicle.

The technical requirements established for a visual aid system are outlined below.

- (1) Mode of operation: daytime operation under ambient light conditions and nighttime operation using either visible illumination or nonvisible infrared illumination.
- (2) Fields of view: the field of view centerline shall be pointable from the horizon to approximately 45° below the horizon and from a forward

position to 90° right azimuth. In addition, it shall be capable of variable magnification.

- (3) Visual resolution: daylight resolution capable of resolving line pairs on a 1951 Air Force resolution chart, which are separated by 50  $\mu$ rad, and which have typical brightness values equal to or greater than 1000 ft-L. At night, have the capability to distinguish line pairs separated by 250  $\mu$ rad and have typical brightness due to ambient illumination of 0.001 ft-L.
- (4) Display characteristics: the image shall be erect and nonreverted and shall have a minimum brightness of 1 ft-L. It shall also incorporate an indicator that shows the orientation of the line of sight relative to the vehicle. A similar indicator shall be provided for the pilot.
- (5) Searchlight: the searchlight shall be slaved in azimuth and elevation to the turret subassembly and shall be capable of remote control by the observer. The capability shall exist to remotely control the filter elements required for both visible and covert illumination of a target.

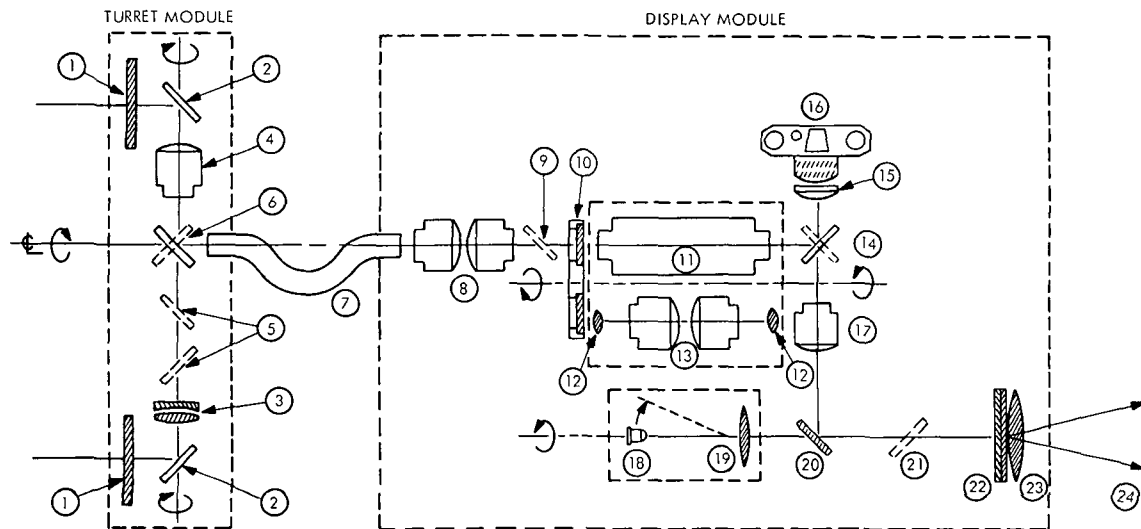
## System Description

The breadboard Visual Aid System model consisted of five modular elements: the optical turret, the optical display, the searchlight, the control console and the auxiliary generator. Where appropriate, components were chosen from commercially available stock, although the majority were, of necessity, designed and fabricated specifically for this task.

The Visual Aid System optics and electro-optics were packaged into two separate modules: a turret module, located underneath and forward on the "chin" of the vehicle, that contained the front objective lenses and turning mirrors, and a display module, located in the helicopter cabin in front of the observer, that contained the balance of the optics. A flexible, image-carrying fiber-optics bundle connected the two modules. This connection allowed considerable freedom in location and orientation of the modules and decoupled the vibration modes between them. A description of this system, keyed to Fig. 1, is presented below.

One of the two objective lenses (3 and 4) alternatively provided a focused image upon the end of the fiber optics bundle (7), the selection depending upon the orientation of the switching mirror (6). Each of the objective lenses "looked out" through a flat glass window (1). Turning mirrors (2) were coupled to the windows in an optical scanning head. Rotation as shown about the common axis of the objective lenses represents an elevation scan. Rotation of the entire turret about the center line shown at the left of Fig. 1 represents an azimuth scan.

Objective lens (3) was a 530-mm-focal-length, 127-mm-diam, air-spaced doublet designed for this task by the JPL Fortran Optical Lens Design Program. The design was optimized for full aperture in the near infrared to correspond to nighttime use with infrared illumination.



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|---------------------------------|--------------------------------|-------------------------------|--------------------------------------|
| ① TURRET WINDOWS                | ⑦ FIBER OPTICS ROPE            | ⑬ RELAY LENS PAIR No. 2       | ⑲ POSITION INDICATOR PROJECTION LENS |
| ② TURRET TURNING MIRRORS        | ⑧ RELAY LENS PAIR No. 1        | ⑭ DISPLAY SWITCHING MIRROR    | ⑳ COMBINING MIRROR                   |
| ③ 21-in. FOCAL LENGTH OBJECTIVE | ⑨ DISPLAY TURNING MIRROR No. 1 | ⑮ CLOSE FOCUS ATTACHMENT LENS | ㉑ DISPLAY FOLDING MIRROR             |
| ④ 3-in. FOCAL LENGTH OBJECTIVE  | ⑩ FILTER WHEEL                 | ⑯ 35-mm STILL CAMERA          | ㉒ PUPIL SPLITTER                     |
| ⑤ TURRET FOLDING MIRRORS        | ⑪ IMAGE INTENSIFIER            | ⑰ PROJECTION LENS             | ㉓ VIEWING FIELD LENS                 |
| ⑥ TURRET SWITCHING MIRROR       | ⑫ FIELD LENSES                 | ⑱ LIGHT EMITTING DIODE        | ㉔ EXIT PUPIL PLANE                   |

**Fig. 1. Optical schematic**

Objective lens (4) was an 85-mm, f/1.8 Takumar lens normally supplied on an amateur 35-mm camera. The lens was found to have excellent imaging in both the near-infrared and visible regions, although a slight change in focal distance existed between the two.

The turret turning mirrors (2) and the larger one of the two folding mirrors (5) were large Pyrex blanks that were weight relieved by hot pressing a waffle configuration into the back of the blank. Weight-relief factors of 35% (65% remaining) were achieved with the larger mirrors.

The fiber optics bundle (7) was an adaptation of an imaging bundle developed for the U. S. military helicopter-borne INFANT<sup>1</sup> Visual Aid System. The bundle is solid at each end and flexible in between. It consisted of approximately 800,000 optical conduits, each 10  $\mu\text{m}$  in diameter, grouped into larger fibers consisting of a 6 by 6 matrix of the individual clad fibers fused together. The bundle was 4 ft in length and sheathed in plastic links and foam rubber.

The fiber optics bundle served a number of purposes. In addition to transmitting an intact image - visible or infrared - from the turret to the display without transmitting mechanical motions from one to the other, the bundle had adequate flexibility to allow its solid end at the turret to be twisted nearly a full turn each way. By twisting the bundle, image rotations, which would otherwise be introduced by the turret azimuth and elevation scan rotations, were removed from the image that was presented to the display unit.

The first relay lens pair, item 8 in the display module, was two f/1.5 military Starlight Scope objective lenses mounted face to face. The function of this relay lens pair was to collect the visible or infrared light from the fiber optics bundle and reform the image either at the photocathode of the image intensifier (11), or at the field lens (12) for further relay through the display module. The Starlight Scope objectives were the only candidate shelf optics and were deemed good enough to prove feasibility in a breadboard demonstration. However, some aberrations were undesirably large in the pair, and a very significant light loss occurred due to an effective f/3.4 solid angle as seen from the image.

The filter wheel (10) contained, in one position, a multilayer filter to pass near-infrared and exclude visible light and, in a second position, a clear piece of glass of an appropriate thickness to correct the visible light focal length of the first relay lens pair (8).

The image intensifier (11) was a cascaded three-stage, electrostatically imaged intensifier with an S-20 extended-red photocathode, and a P-20 phosphor screen. The photocathode and the phosphor screen were each 40 mm in diameter. The tube was developed under contract to the Army Night Vision Laboratories for use in military applications. The tube is nominally

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<sup>1</sup> INFANT: Iroquois Night Fighter and Night Tracker

rated as having a total light-output-to-light-input gain of 35,000; however, production units typically have gains of 100,000.

Relay lens pair (13) was mounted in a turret with the image intensifier and could be rotated into position to relay a visible image from the first relay pair (8). Schneider-Xenotar, 100-mm-focal-length,  $f/2.8$  photographic lenses were chosen for this application. Two were used, mounted face to face. Field lenses (12) were located at the input and exit image locations to minimize vignetting, which is the principle drawback to this configuration, approximately 30% at the field edge.

Display switching mirror (14) had two operating positions: one directed light from the image intensifier or second relay lens to a 35-mm recording camera (16), and the other to a projection lens (17), which forms the final image at the viewer end of the display.

The projection lens (17) was selected to be an  $f/2.9$ , 152-mm-focal-length Dallmeyer Pentac. The lens was designed for infinity correction, but was used here at a magnification of 4.4 to provide a display image 6.7 in. in diameter at the viewing field lens (23).

The viewing field lens (23) and pupil splitter (22) provided a pair of exit pupils imaged approximately 16 in. beyond the viewing field lens. The exit pupils were approximately 1 in. in diameter and spaced on center by an average human adult interpupillary separation of a little less than 3 in. It was at this location that an observer positioned his eyes to look into the display.

Items 18 and 19 are a light emitting diode (LED) and a projection lens, respectively, which are incorporated into a position indicator. The LED was mounted onto a torquer-driven assembly that was gimballed to allow reproducing the azimuth and elevation angles of the turret assembly.

The combining mirror (20) incorporated a multilayer coating that reflected virtually all of the visible light and presented a bright scene image to the display, yet transmitted about half of the LED illumination. Projection lens (19) then formed an image of the LED emitter area at the pupil splitter and viewing field lens. The red position dot was seen with both eyes superimposed upon the presented scene.

### **Optical Turret**

The major functions of the optical turret illustrated in Fig. 2 were to provide azimuth and elevation scanning for the objective lenses; focusing of the optics; selection of magnification; a mechanization to maintain the horizon level at the display; image motion stabilization; support structure to maintain alignment of the elements; and a housing to provide a protective enclosure against environmental conditions.

Servo-driven, the turret rotated in azimuth through  $180^\circ$ , from straight forward clockwise to straight backward. In elevation, the pointing limits of  $0^\circ$  (horizontal) to  $75^\circ$  below the horizon were achieved. The skew rate of the turret was measured to be  $22.5^\circ/\text{s}$  in azimuth and  $26.0^\circ/\text{s}$  in elevation.

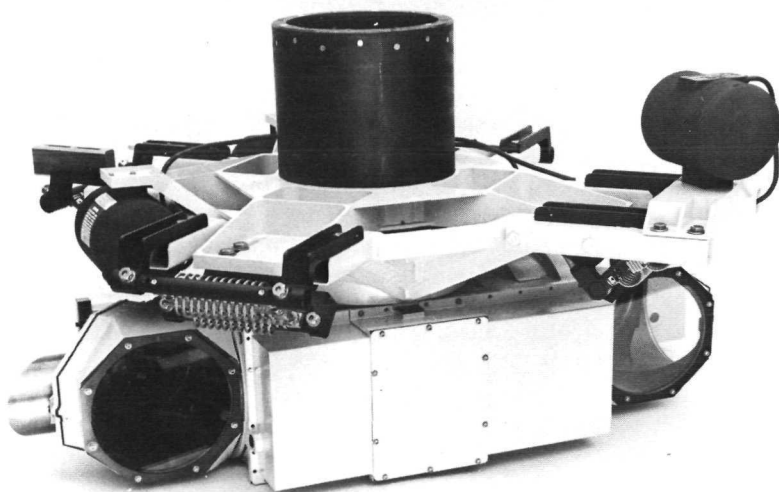


Fig. 2. Turret module, full assembly

The details of image motion stabilization combined three techniques. First, vibration isolators were used between the helicopter and the suspended portion of the turret. Second, large stabilizing gyros were added to the isolated member to increase the rotational inertia. Third, rate gyros were mounted on the turret to sense angular motion, and through the control system, the elevation and azimuth servos were driven to directly compensate for that motion.

Magnification changes were accomplished by rotating a diagonal mirror to direct the optical axis from a one-power ( $1\times$ ) objective lens to the seven power ( $7\times$ ) objective lens. Accurate indexing was achieved through a motor-driven Geneva mechanism.

One feature that is familiar to us is the level horizon at the top of a scene whatever direction we may turn our head. To help maintain orientation, it was decided to present a display with the horizon at the top, which would be fixed with respect to the observer even though the helicopter should roll and pitch. The concept used in the turret utilized rotating mirrors for scanning and as a result caused unwanted image and horizon rotation that required compensation. This was achieved through rotation of the fiber optics rope in response to each of these turret functions.

The mechanization was accomplished by utilizing a geared differential and motor-driven follow-up mechanism, which summed inputs from

elevation and azimuth axes and the switching mirror position (1× or 7×) and provided the proper rotational position for the fiber optics rope end.

### Optical Display

Several functions were provided in the display module. These were, principally, display of the image (day or night), conversion of infrared to visible light (night), intensification of the visible or infrared image (night), and display of the turret-pointing position indicator (day or night). Certain ancillary functions were mechanized: a filter wheel for selection of either infrared only or full visible; a camera for recording the scene in the display unit; reticle illumination (night) and display tilt to accommodate the sitting height of the various observers.

Figure 3 shows the display module mounted on a supporting stand prior to installation on the helicopter. The upright drum housed the day-night turret. The knob visible above the camera allowed rotation of the turret after pulling the detent plunger knob located on the side of the drum below the camera. The similar knob on the bottom of the drum housing provided

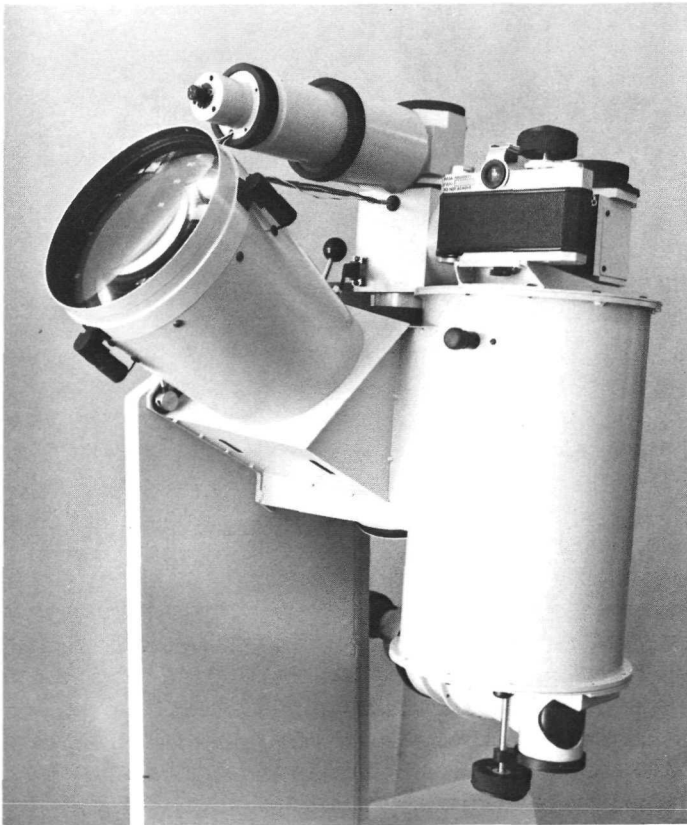


Fig. 3. Display module



for rotation of the filter wheel. The fiber optics rope entered the display module from bottom far side as seen in this photograph.

### Searchlight

The searchlight used for the breadboard Visual Aid System was the commercially available SX-16 "Nightsun" manufactured by Spectrolab of Sylmar, California. The light is in wide use by law enforcement agencies for nighttime airborne search and tactical operations. It has a 1600-W xenon short arc lamp that supplies about 20,000 lm in a beam that may be controllably varied in flight from 4° to 10° in diameter. It is servo-driven and slaved to the look vector of the optical turret.

In addition to providing a very powerful visible beam, the xenon searchlight had an equally powerful infrared beam. Approximately 70 W of radiation were emitted in the wavelength interval of 800 to 900 nm – approximately the same as was emitted in the visible interval of 450 to 650 nm.

As procured from Spectrolab, the searchlight had either of two windows mounted in a light-baffled, air-ducted shell (Fig. 4). One was a clear window

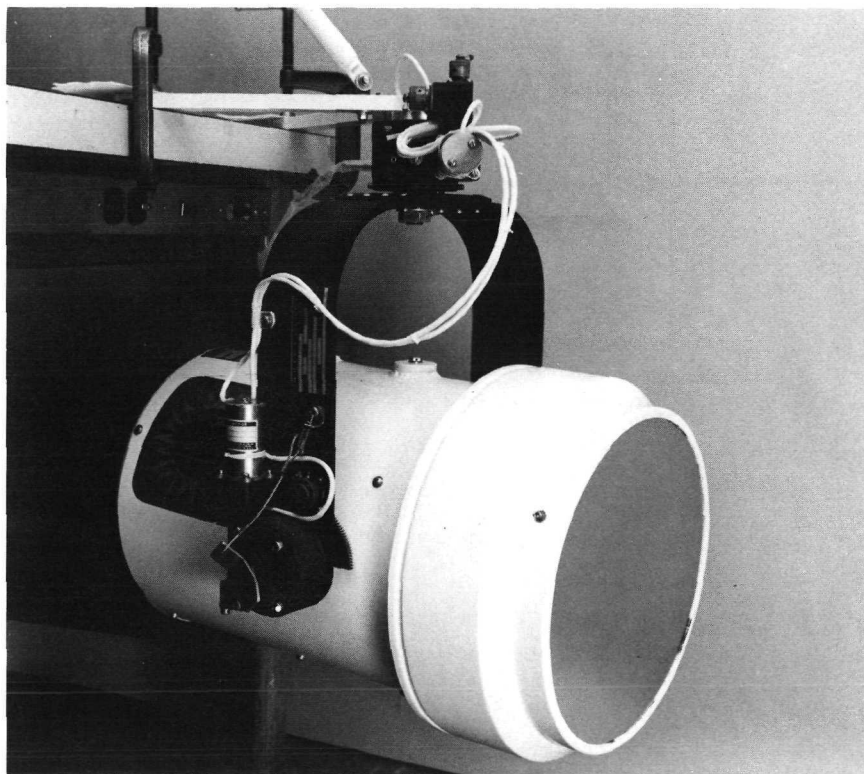


Fig. 4. Searchlight

that passed essentially all visible and near-infrared radiation. The other had a multilayer interference filter that passed the near-infrared, but reflected essentially all visible radiation back to the bulb. The 10% and 90% points on the transmission curve were 775 and 840 nm, respectively. This transmission characteristic reduced the visibility of the direct searchlight beam to an appearance similar to that of the helicopter running lights when viewed from a distance. However, at distances of 1000 ft or so, the large angle subtended by the searchlight reflector distinguished it from running lights.

### Control Console

Figure 5 is a photograph of the control console in its breadboard configuration. It was located between the pilot and observer, in a position where the controls were conveniently operated by the observer's left hand.

It provided control over the system as indicated by the functions on the control panel. Pointing of the turret look vector was accomplished by a control stick mounted to a floor pedestal in front of the observer. A rate

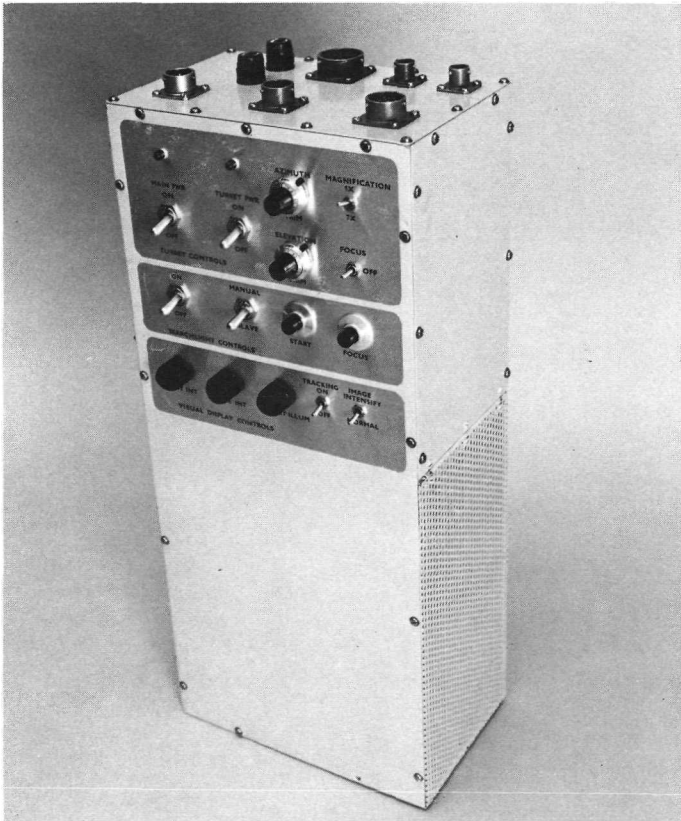


Fig. 5. Control box

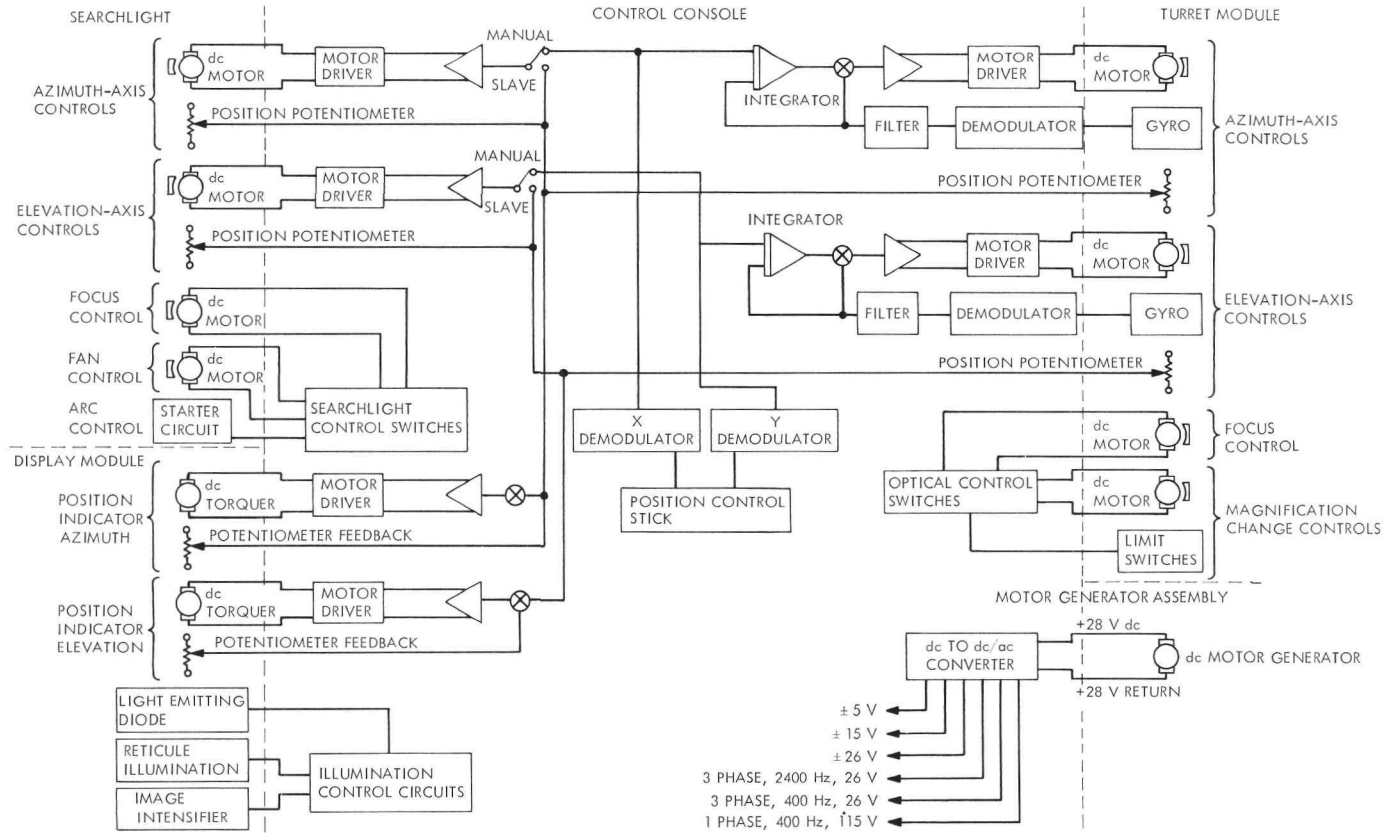


Fig. 6. Electronic control and power conversion

control stick mechanization was selected for the human interface with the turret drives, largely because of the results of a previous study that had shown superior pointing accuracy of an airborne payload by an operator using this type of control. The rate stick provided a plus and minus voltage output proportional to the force vector applied for each of two orthogonal directions. The stick had an appearance similar to an aircraft control stick, except that it did not significantly deflect in response to manual control pressure.

Figure 6 is a functional block diagram illustrating the approach taken for electronic control and power conversion. The control console is shown inside dotted lines in the center of the diagram and the functional interconnections with the other modules of the helicopter Visual Aid System are shown. Interconnections with the turret module, the searchlight module, the display module, and the generator assembly are shown in sufficient detail to make clear the type of control used for positioning and controlling the various parts of the Visual Aid System.

### Helicopter Installation

Installation of the Visual Aid into the police helicopter (Bell 47G-5) is illustrated in Fig. 7.



Fig. 7. Completed helicopter installation

## Test Program

The purpose of the test program was to determine the feasibility of the system and to evaluate its technical behavior. Criteria were established to guide the determination of system feasibility. The criteria by which feasibility was measured consisted of two basic requirements: the satisfaction of image quality and certain human factors specifications. It was required that these criteria either be met or that a high probability of success in meeting them in subsequent phase be demonstrated. These criteria along with corresponding results are listed in Tables 1 and 2.

Of the 23 criteria listed, 21 were successfully met with a rating of "fair" to "excellent". In two areas the results were judged "poor" by the criteria. These were: linear image motion (1) and camera implementation (13).

The selected approach to image stabilization was a compromise resulting from hardware availability and program constraints. It was anticipated that a stability problem would arise resulting from this decision to use servo-driven gear trains rather than direct-coupled torquers, but that feasibility could be proven with this alternative approach. The test program confirmed the existence of the stability problem and isolated the cause and the effects.

Table 1. Test results -- image quality

Criteria No.	Item	Requirement	Performance
Stability			
1	Linear image motion	Linear vibration, $10 \mu\text{rad p-p} \geq 2 \text{ Hz}$	$\sim 1000 \mu\text{rad p-p}$ at $\sim 5 \text{ Hz}$ (poor)
2	Rotational image motion	Rotational vibration, $1^\circ \text{ p-p} \geq 2 \text{ Hz}$	None detectable (excellent)
Day/night resolution (static)			
3	Day	Visible, $50 \mu\text{rad}$ ( $7\times$ )	$110 \mu\text{rad}$ ( $7\times$ ) (fair)
4	Night	Infrared, $250 \mu\text{rad}$ ( $7\times$ )	$170 \mu\text{rad}$ ( $7\times$ ) (good)
Brightness/glare			
5	Daylight system transmission	5%	4% (good)
6	Night image intensification	$330\times$	$27\times$ (fair)
7	Night display brightness	1 to 10 ft-L	1.1 ft-L (good)
8	Glare, day	Subjective	Fair to good
9	Glare, night	Subjective	Excellent

Table 2. Test results — human factors

Criteria No.	Item	Requirement	Performance
Stability			
10	Control console	Subjective	Fair, needs human factor engineering
11	Rate stick	Subjective	Fair to good
12	Position indicator	Subjective	Excellent
13	Camera control	Subjective	Poor, needs automation
Optical display interface			
14	Exit pupil spread	60 to 76 mm	59 to 76 mm (excellent)
15	Exit pupil, night	18 mm	37 mm (excellent)
16	Exit pupil, day	18 mm	1×, 36 mm; 7×, 28 mm; (excellent)
17	Magnification	1×, 7×	1.1×, 6.9× (good)
18	Field of view	1× 19° 7× 2.7°	1×, 17°; 7×, 2.7°; (excellent)
19	View sector	Azimuth 0° to 90° Elevation 0° to -45°	Azimuth 0° to 180°; elevation 0° to -75°; (good)
20	Position indicator	Subjective	Excellent
Comfort/fatigue factors			
21	Sitting position	Subjective	Fair, should be 4 to 6 in. closer
22	Left arm position	Subjective	Good
23	Eyestrain	Subjective	Good

It is felt that the general approach to the mechanization was proper and that with the use of torquers, the control system deadband would be significantly reduced and the stability problem would be alleviated. The problem and its solution are not new and unique, but have been encountered several times in other applications with success.

Except for exposure control, the camera for the breadboard model was intended to be manual. Remote film advance drive and automatic reflex/shutter operation from a control button were judged to be unnecessary for a breadboard demonstration. The camera was adequate for ground test data recording; however, the camera was located just out of reach for an observer restrained by a seat belt and a shoulder harness. In addition, the time required in flight to manually operate the camera resulted in loss of target in the field of view. Consequently, the camera was useless in flight testing.

A prototype model Visual Aid System would see a fully automatic implementation, with camera control located on the rate stick. This would eliminate the usage problems that were encountered.

## Conclusions

This task has demonstrated that the visual aid concept can provide improved daytime visual capability, greatly improved nighttime capability, surveillance from greater distances and/or altitudes, covert operation at night through the use of the IR Searchlight, and a photographic recording of the scene being viewed.

The anticipated problem area, that of image stability, was present but not to such an extent as to detract from feasibility demonstration. It resulted from a decision to limit the full implementation of the control system and it affected performance in the manner predicted, but not to the extent anticipated.

## Reference

1. Baisley, R. L., *Helicopter Visual Aid System, Vols. I and II*. Document 650-155, Jet Propulsion Laboratory, Pasadena, Calif., in press. (Internal Document.)