VISUAL SYSTEMS FOR REMOTELY CONTROLLED VEHICLES

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The Dryden Flight Research Facility of the National Aeronautics and Space Administration's Ames Research Center has been working with unmanned vehicles for 15 years. These Remotely Controlled Vehicles (RCVs) provide valuable research tools for testing aircraft performance in situations too hazardous to risk human operators. Even though the costs for thorough testing of high-performance aircraft continue to rise, this testing could not be reduced without jeopardizing operational pilots who might fly such aircraft after they went into production. RCVs provide an excellent way to test the high risk periods of an aircraft's lifespan than by removing the pilots from physical danger while leaving them in complete control of the vehicle.

Visual systems were simple and direct in the first RCVs. Since the early techniques derived from radio-controlled model work, the beginning visual information system was direct observation. When it was time to test full-scale vehicles, they were dropped from helicopters and flown under the control of a pilot on the lakebed below (Fig. 1). An experienced test pilot sat in an open cockpit copied from those used for simulators and flew the vehicle to within 200 meters of the ground, at which point an experienced RC model pilot took over and landed the vehicle.

Even in these early experiments, the effects of differences in visual information inputs were apparent. Both pilots had direct view of the vehicle, but the test pilot in the cockpit had supplemental information (Fig. 2). The cockpit had airspeed, altitude, angle of attack, control surface positions, and an attitude indicator showing roll, pitch, heading, and sideslip; all telemetered from the flight vehicle. With this information, the test pilot was able to detect and damp out oscillations as the vehicle was being towed by the helicopter. When the RC pilot took over, he was forced to command large excursions in the vehicle so that he could see the results of his command inputs.

Through the years of development which followed, a powerful flight test technique evolved (Fig. 3). The most important feature of this methodology has been the inclusion of the pilot in the control loop. Unlike military drones, an RCV is intended to explore unknown engineering territory, the nature of which precludes the use of autopilots or preprogrammed control systems, unless they are what is being tested. The uniqueness of each flight may require that control systems be changed during a flight to compensate for unexpected responses. Just as in flight testing with human operators, flight profiles and attempted data points may be changed to respond to dynamic conditions.

RCV SYSTEMS

The current configuration of our RCV systems was developed with active input from the test pilots. The cockpits used for RCV flights are based on a common framework (Fig. 4). The layout for instrumentation is largely a matter of pilot preference unless the particular study involves scan patterns, displays, or the effects of innovative instrumentation. In this respect, the

RCV cockpit is treated as an extension of simulation techniques and is designed to be easily modified. The instrument panels are plug-ins and can be interchanged in a few minutes. The panel formats are not representative of a specific aircraft but are tailored to the immediate task. These cockpit stations also have a graphics display system, an X-Y plotting system, and various input/output (IO) devices.

Despite the variety of potential information systems in these cockpits, the pilots consistently reported difficulty in perceiving position relative to the ground during the last 100 meters to touchdown. Operationally, this is handled by having the flight test engineer, who is always at the RCV pilot's side during a test, call out the closing altitude from a radar altimeter. This was necessary because the pilot's entire attention was focused on the forward field of view, and the only deviation he allowed himself was the briefest of glances at the airspeed. The pilots felt that the workload was unecessarily high and could be reduced with better video. The problem of height perception was critical and felt to be related to the degradation of depth cues.

The visual systems used for the RCVs were developed using a single vehicle (Fig. 5). The Piper Comanche, or PA-30, is our flying workbench, laboratory, simulator, and trainer. Originally used for experimental control systems work, the left seat controls can be operated electrically while the right seat controls are not modified. In addition to its usefulness in developing video systems for RCV forward field of view, the PA-30 was especially valuable for training pilots in the unique environment of remote flight (Fig. 6). The dual controls in the vehicle allow the rapid installation and testing of untried concepts since the vehicle can be instantly returned to normal operation and is always flown with an onboard safety pilot.

When the transition from outside to inside visual systems began, the press of time and the limitations of available equipment dictated a configuration which was functional, if limited. In the PA-30, this took the simple form of a nose mounted camera with a single fixed focal length lens and a single 22 cm (9 inch) diagonal monochromatic monitor. In the training setup, the monitor was mounted in the left side cockpit panel and hardwired to the nose camera. The pilot learned to fly the PA-30 while "under the hood" using only the monitor for forward visual information. In the RCV arrangement, the monitor was atop the cockpit panel inside the RCV facility and the video signal was telemetered down from the vehicle along with aircraft instrumentation information.

A great variety of vehicles were flown with this configuration (Fig. 7). In addition to the PA-30, which is still in use, there was the 3/8 scale F-15 which later became the Spin Recovery Vehicle. High-performance and exotic aircraft were well represented by the HIMAT and DAST vehicles. A vehicle with an oblique wing was tested in a cooperative program with Ames-North. Presently the world's largest RCV, a Boeing 720, is being prepared for the Controlled Impact Demonstration program (Fig. 8).

VISUAL SYSTEMS

There are definite perceptual limitations inherent in a narrow field of view system. Depending on the orientation of the the Line of Sight (LOS) of the video system relative to the vehicle's longitudinal axis, a steep approach may cause the horizon to be lost from view. If the vehicle is pitched up, the runway may not be seen. When close to touchdown with a very narrow field of view, this situation may result in both the horizon and the runway disappearing. Use of a motorized zoom lens is not acceptable because it would give the pilot another variable and another control at a critical point in the flight. Even a programmed zoom would introduce a variable at a time when the pilot needs a consistent visual field for reference.

All RCV pilots commented on the difficulty of perceiving height during the approach and landing. A possible solution was a three-dimensional video system (Fig. 9). This was tested using an adaptation of a system originally suggested for use with the Space Shuttle Remote Manipulator Arm. Two separate video systems were paralleled and the views presented to the pilot with a fresnel imaging system which did not require the use of special glasses (Fig. 10).

This concept has numerous advantages over other possible stereo displays. Since the fresnel lens collects light over a large field and concentrates it at the exit pupils, image illumination is optimized. The lack of operator worn optical aids is important for RCV work. Cockpit instrumentation and peripheral displays may be scanned without re-accommodating. This mechanization has one major disadvantage; a restriction of available head movement. Visual information is perceived in a realistic manner as long as the eyes are within a 3.3 cm horizontal by 7.6 cm vertical by 15.2 cm longitudinal volume.

This system was evaluated in flight using the PA-30 and met with limited success. In general, the system worked and provided the pilot with binocular vision far beyond the normal 6 meter limit of unaided human vision. However, spacing the viewing lenses at interocular distances necessary to achieve such spatial resolution, produced another perceptual problem. The eye-brain system apparently rescaled the perceived images to match normal interocular distances and caused size discrimination difficulties. In addition, the unavailability of an independent dual video transmission system neccessitated the multiplexing of the incoming signals. Equipment design flaws prevented adequate separation of the received signals and the resultant images were always contaminated with ghosted images. The system was judged to be impractical without extensive development.

PRESENT APPROACH

Flying current RCVs produces a loading effect on the pilots which is due in large part to the restrictive nature of the forward field of view. The normal aspect ratio, broadcast quality, monochromatic video system does not provide the normal visual cues present in live flight. Pilots have been more dissatisfied with this aspect of the system than with any other. Of course, the early work was intended to produce a workable method in the shortest possible time. In that regard, it was successful. However, as the flight tests gained in complexity and the RCV vehicles gained capabilities, the need for augmented video systems became great.

As mentioned, the stereo system was not viable given the current state of development. The spatial perception problem remained. The human (eye-brain) vision system uses many more cues than just binocular disparity to establsh spatial position. Among these are relative sizes and perspective in both static and dynamic conditions, and also closure rates and streaming in dynamic conditions. Considering the motion sensitivity of the peripheral vision and the effect of the large human visual field in establishing orientation, a very wide angle video system would seem to answer many of the forward view questions. However, cramming a wide field of view into a limited bandwidth system results in very small images across the entire field and poor resolution. This combination of factors led to the use of a non-linear lens system.

VARVS

The Variable Acuity Remote Viewing System (VARVS) was conceived as a technique for resolving the FOV/resolution/ bandwidth tradeoffs that exist in remote viewing systems (Fig. 11). This system is based on the fact that integration of the human eye acuity function shows only about 130,000 pixels are required to fully support the human vision. This quantity is well within the capabilities of conventional video systems.

The technique utilizes a non-linear optical system in both the sensing and display equipment. The non-linearity is achieved by a special lens which translates a uniform pixel array on its image plane into the object field as a variable angular array. This can be contrasted with the "Fish Eye" wide angle lens which projects into the object field with equal angular increments. In another sense, this lens will record the same angular detail the eye would see when viewing the same scene and compress this detail into a uniform matrix of equal sized picture elements on its image plane. This image can be scanned with a broadcast quality tv having a 525 line raster scan. Conventional transmission equipment can then also be used to send the image information to a remote location. When received, the image is projected by a light valve projector onto a hemispherical screen by an identical non-linear lens (Fig. 12).

This projected image is viewed in apparent high acuity and correct geometric perspective when the observer's eye is aligned with the projector's optical axis. In the original design, an eye position sensor was postulated as a means to eliminate image to eye misalignment by repositioning the sensor through a narrow band control link. This motion subsystem has not been used in RCV work since the vehicles are generally too small to accomodate a slewing camera mount. The camera-lens system alone achieves an effective 140 degree FOV, which is more than usually seen from a normal cockpit. High resolution occurs in a 20 degree cone centered on the head position axis. The head tracking capability will be used in simulator studies.

The key to this idea is the non-linear lens (Fig. 11). This lens was originally designed by McDonnell Aircraft and fabricated from glass using numerically controlled grinding machines, a difficult and expensive process. Modern optical fabrication techniques including laser polishing, plastic casting, and graded density optical materials can be expected to reduce the cost, size and weight.

The difference between the non-linear lens and a fish-eye lens is best seen in comparison. Apparent positive magnification exists near the center of the image, decreasing towards the perimeter. A 525 line raster can extract the same angular detail from this image that would take a 10,000 line raster for the fish-eye image. The very unique properties of this optical system form the basis for a series of psychophysiological studies on the interaction of human operators and Remotely Controlled Vehicles.

LANDING CUE ASSESSMENT STUDY (LCAS)

In LCAS, the peripheral motion thresholds of pilot observers will be quantified in roll, pitch, vertical rate and forward velocity. The Peripheral Visual Cue Assessment Laboratory at Ames North is presently determining these parameters using very sparse computer generated imagery. To successfully apply the results of this study to the real world of flight, it is necessary to verify and amplify those results in a more realistic visual environment.

The motions created by the computer in the laboratory phase of LCAS will be duplicated as closely as possible by video taping live scenes from a precisely controlled camera platform atop a moving truck. These scenes will simulate the subtle maneuvers made during the last moments before touchdown in a normal landing. The responses by observers will be compared to the results of the Ames North Laboratory experiments.

This experiment will be repeated using the PA-30 as an RPV to assess the effect of this visual system on the landing qualities of RCVs.

DOD INTERESTS

The USAF Human Resources Laboratory is using the VARVS as a development tool in the design and evaluation of a full field of view simulator for combat aircraft training. Ultimately, this would envision the use of highly realistic computer generated imagery. Since current equipment of sufficient power to do this in real time is huge, rare, and extremely expensive; interim designs will use the video method to present realistic, interactive scenes to simulator operators.

The United States Naval Ocean Systems Command has expressed an interest in using this methodology to provide better visual input from a free-roaming ground vehicle operating in a forward observer mode.

Both of these applications fit well within the capabilities of the VARVS. Additional development is required for special purposes, such as light weight, probably plastic lenses, for the USAF and ruggedized equipment for the USN.

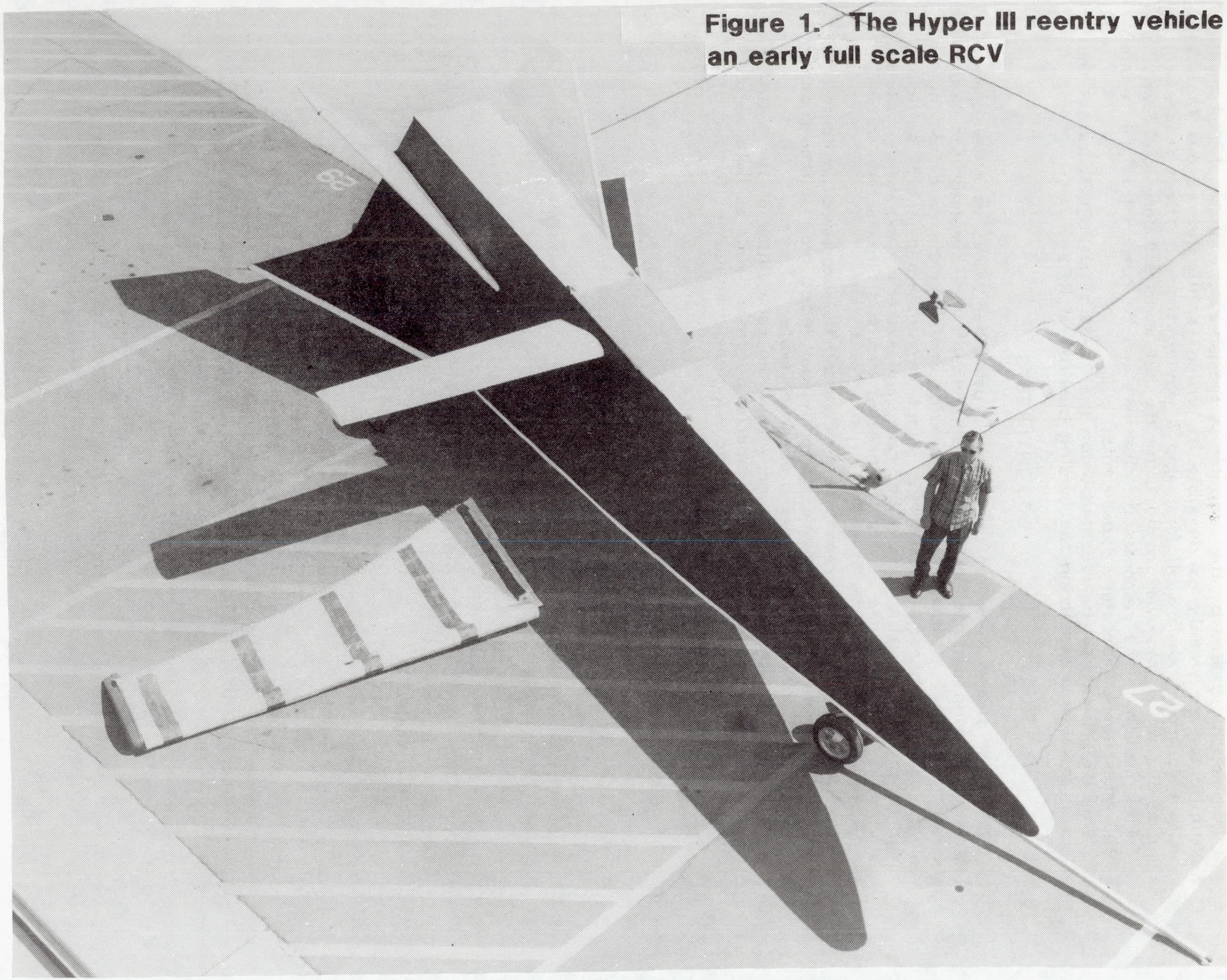


Figure 1. The Hyper III reentry vehicle an early full scale RCV

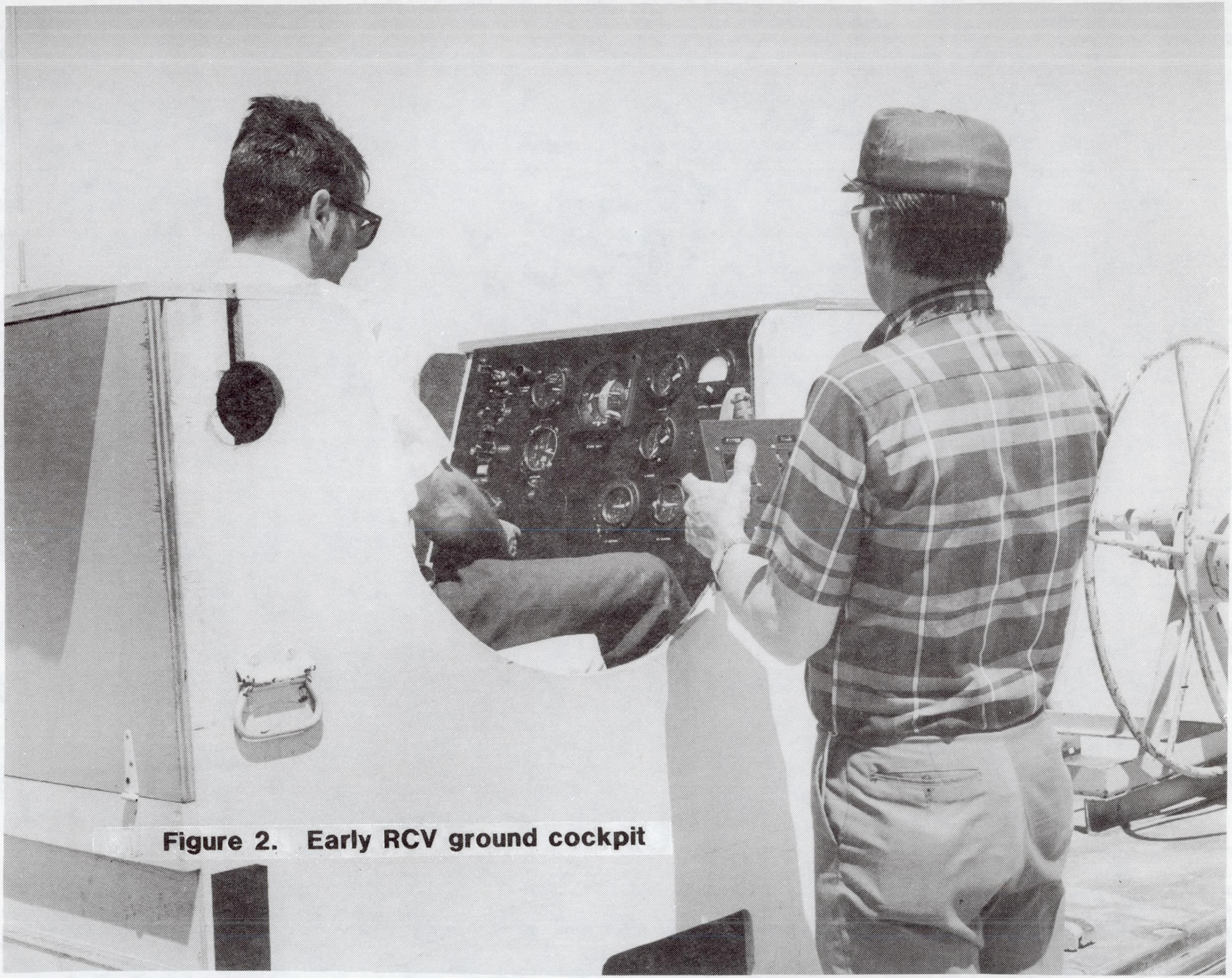
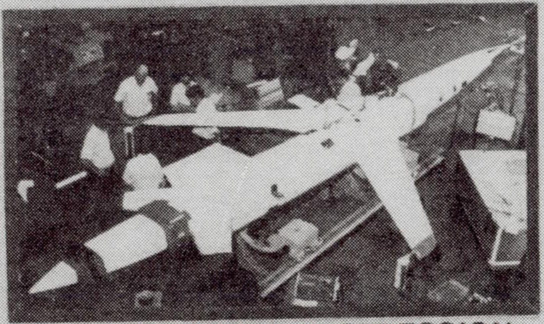


Figure 2. Early RCV ground cockpit

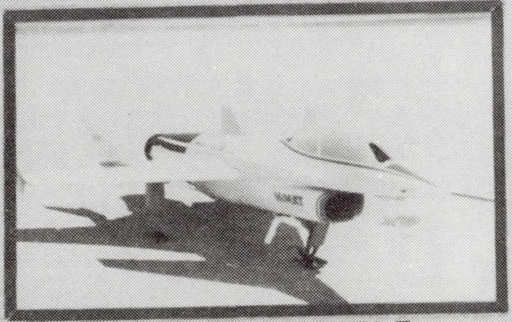
NASA
DFRC 79-190

REMOTELY PILOTED VEHICLE (RPV)/REMOTELY AUGMENTED VEHICLE (RAV) FACILITY

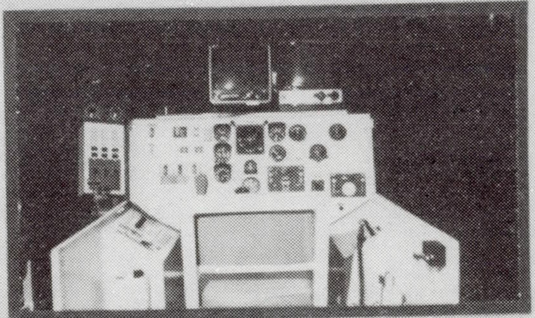
PURPOSE: Low Cost Flight Test of Advanced High Risk Concepts on Control Systems Development



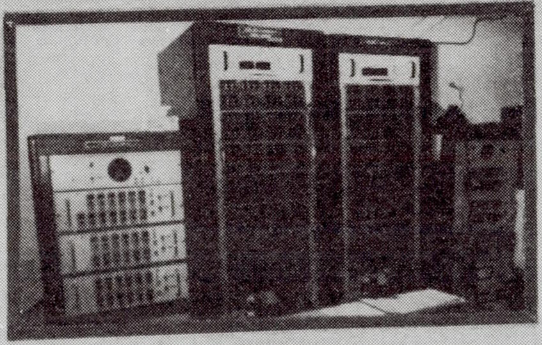
ACTIVE FLUTTER SUPPRESSION TESTING



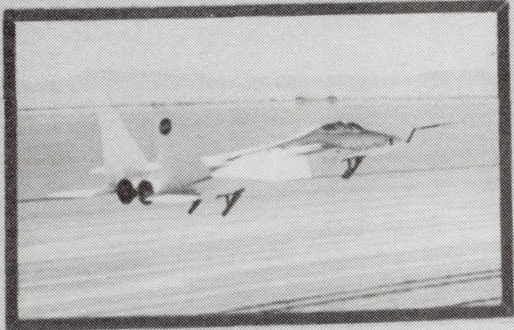
HIGHLY MANEUVERABLE AIRCRAFT TECHNOLOGY



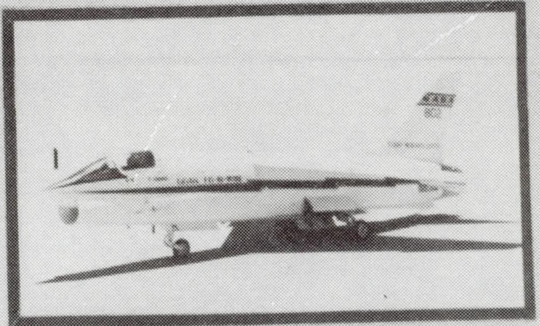
GROUND CONTROL COCKPIT



CONTROL COMPUTER



SPIN RESEARCH TESTING



ADVANCED CONTROL LAW VERIFICATION (RAV)

Figure 3. Some aspects of Remotely Controlled/Remotely Augmented Vehicle operations at Dryden

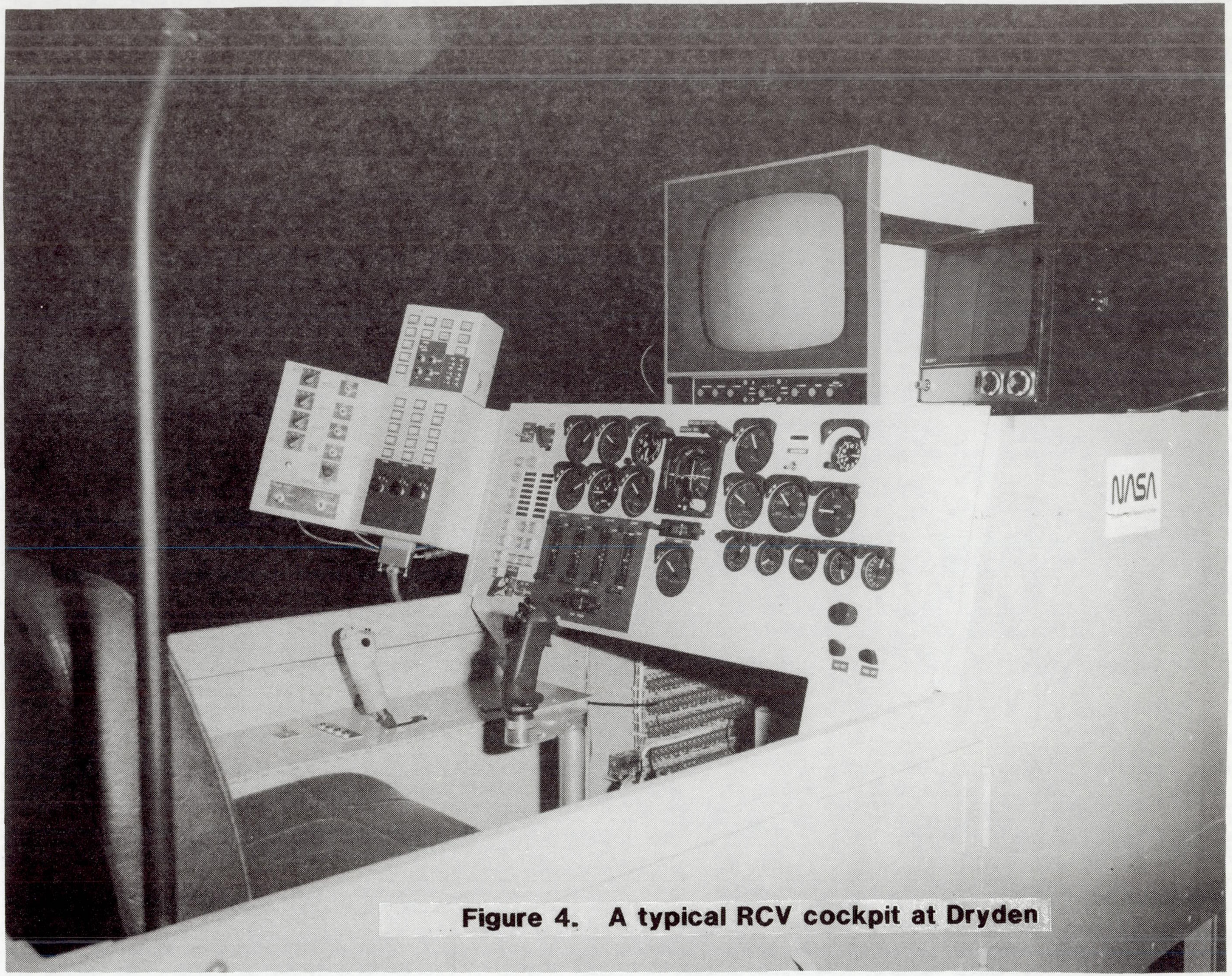


Figure 4. A typical RCV cockpit at Dryden

Figure 5. PA-30 aircraft. Primary camera locations are in the nose and atop the cabin

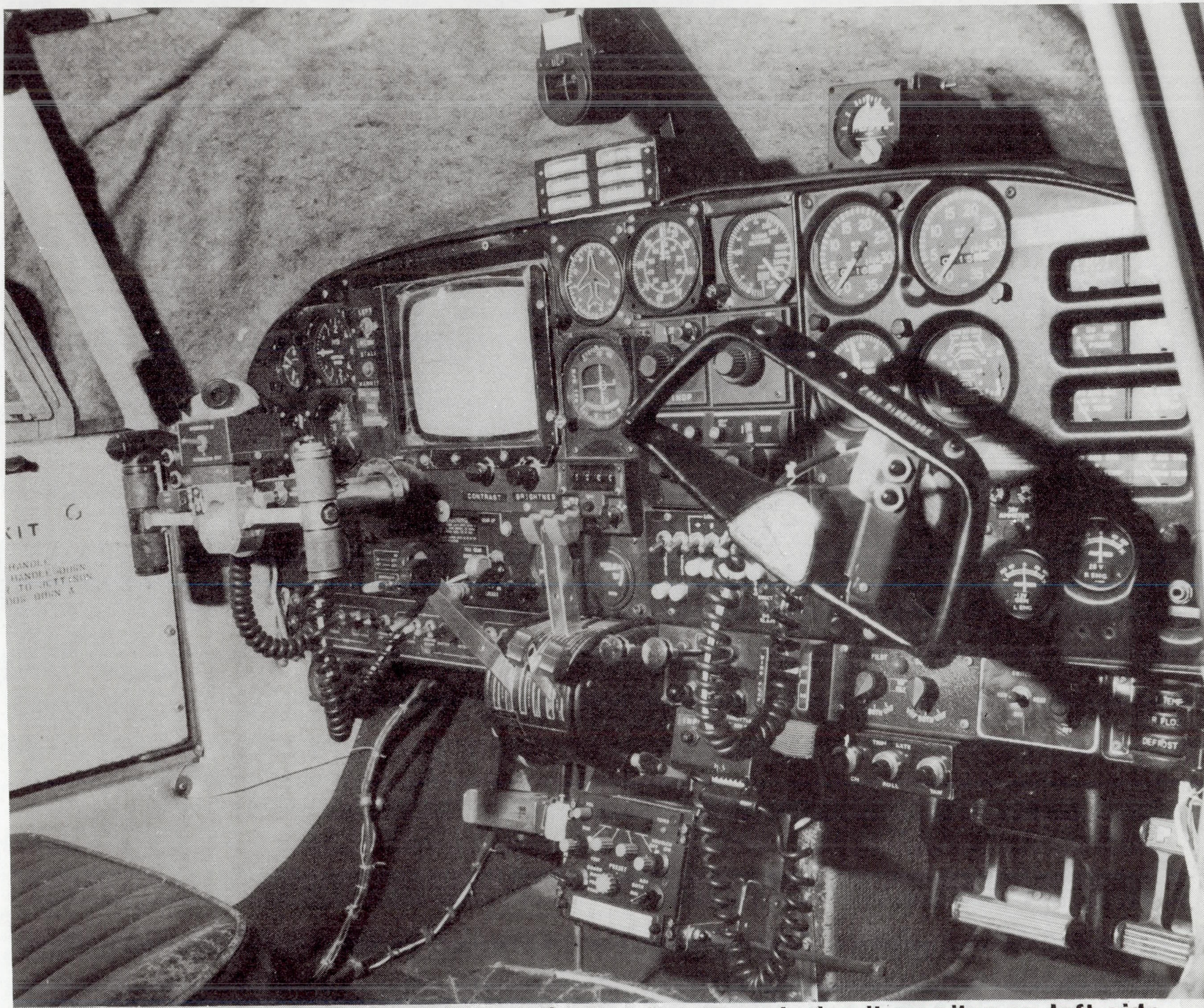


Figure 6. PA-30 instrument panel showing closed-circuit monitor on left side

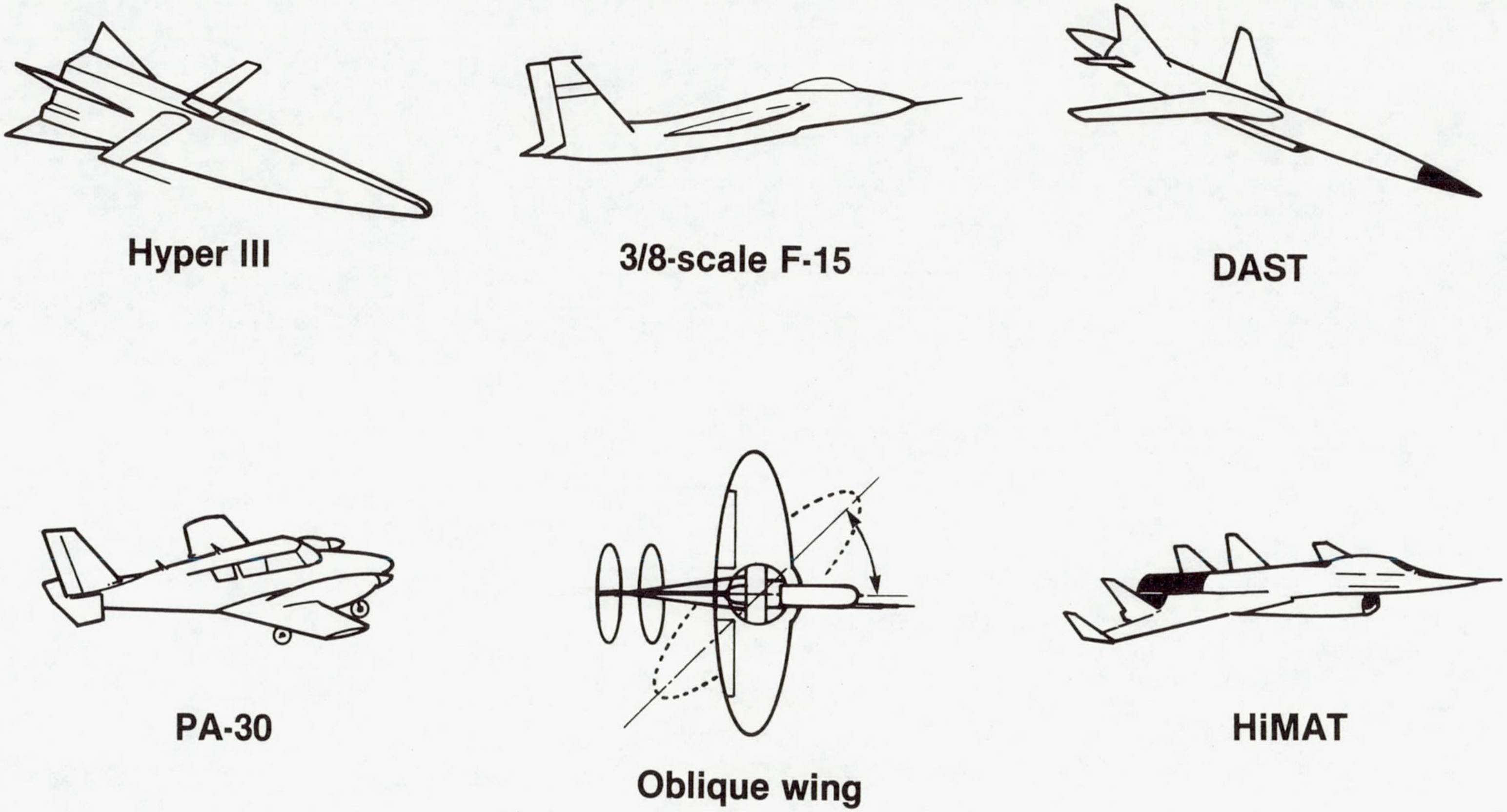


Figure 7. Some RCVs flown at Dryden

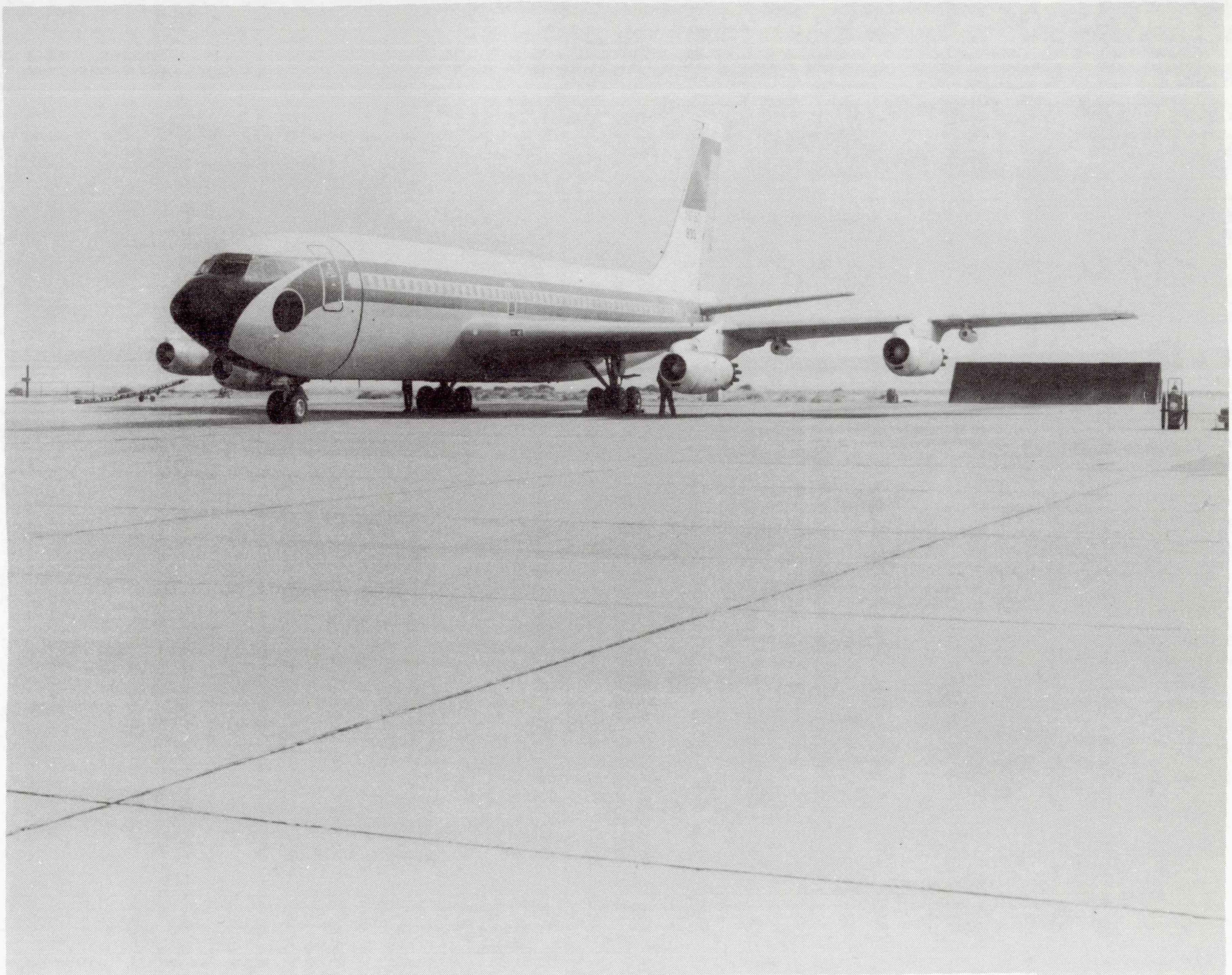


Figure 8. Controlled Impact Demonstration--test vehicle

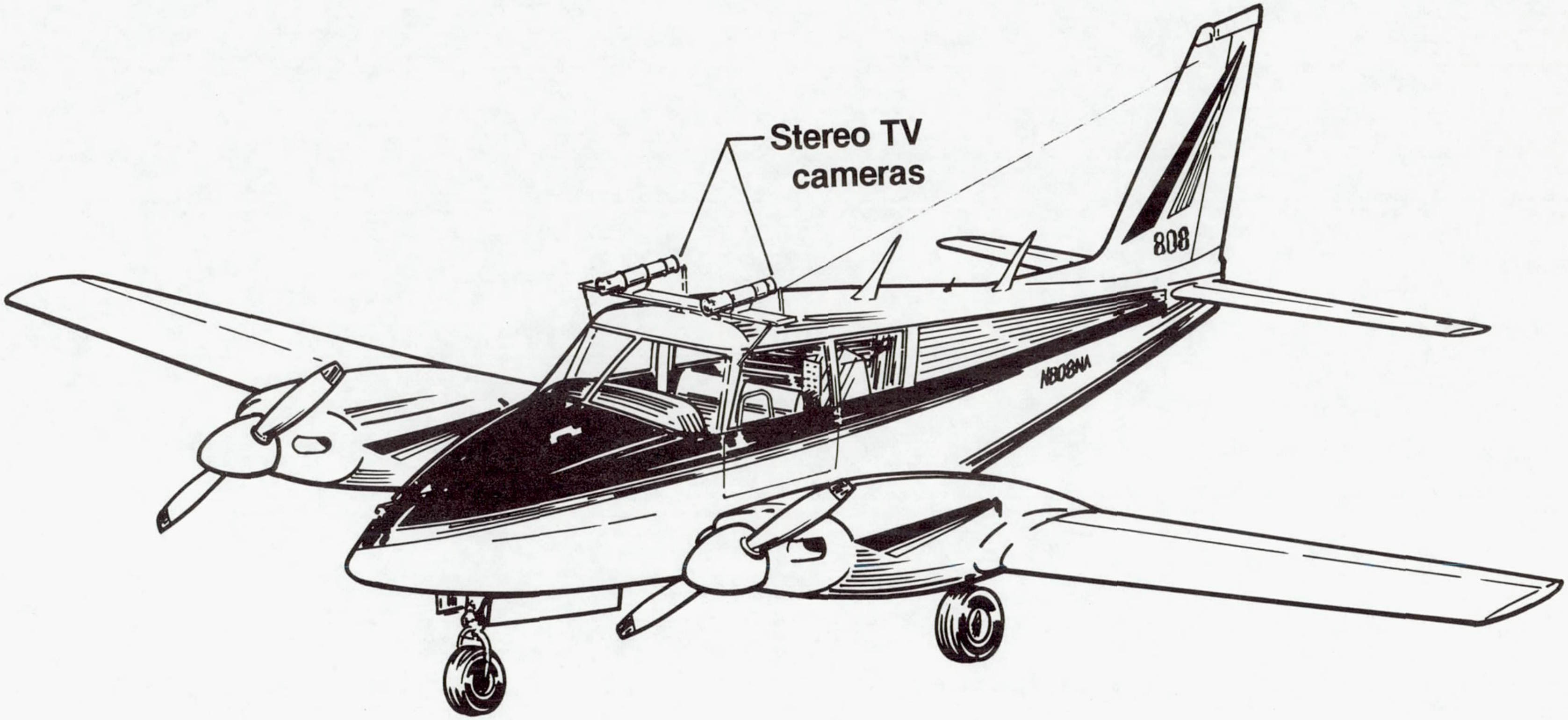


Figure 9. PA-30, showing the location of the Stereo-TV cameras

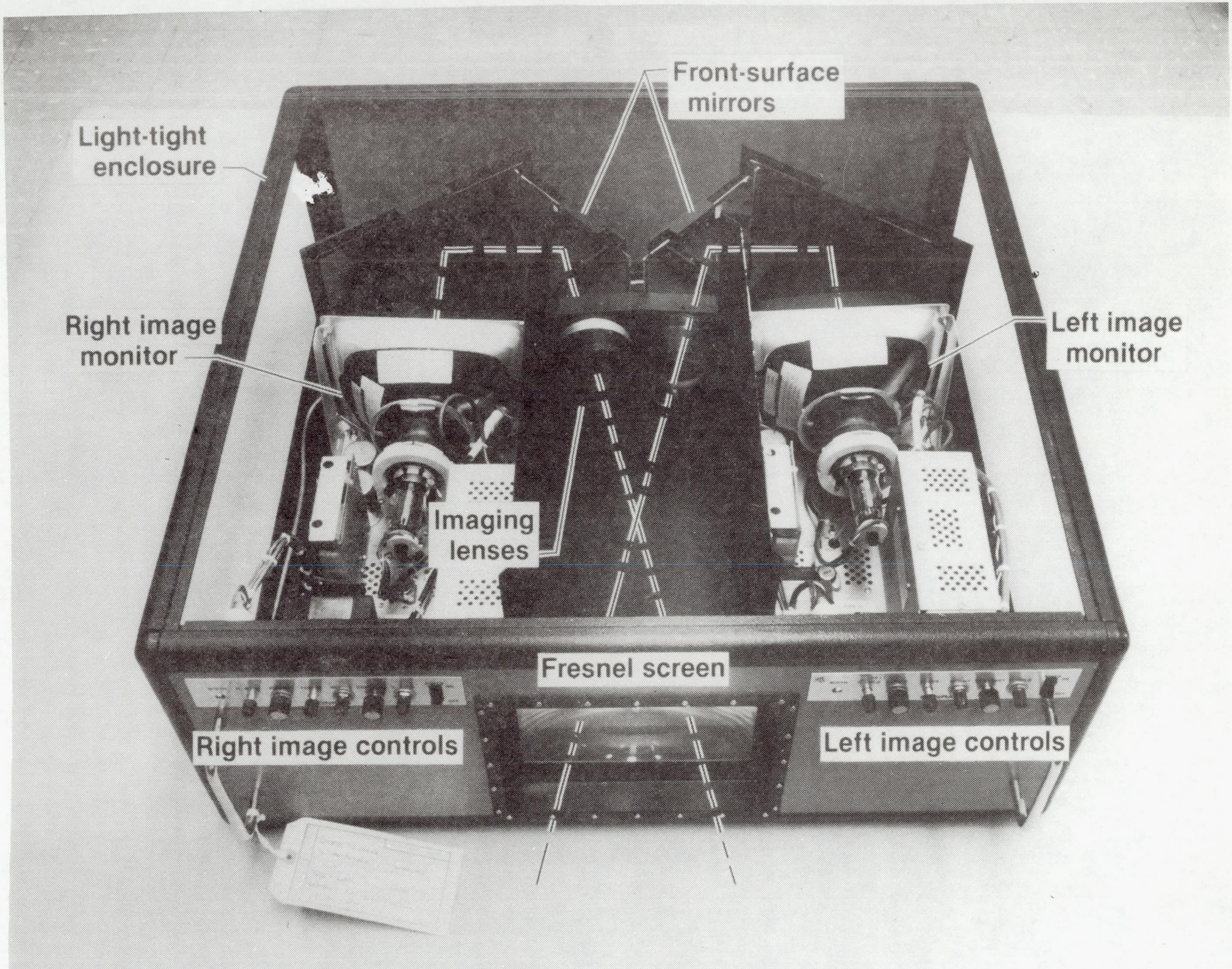
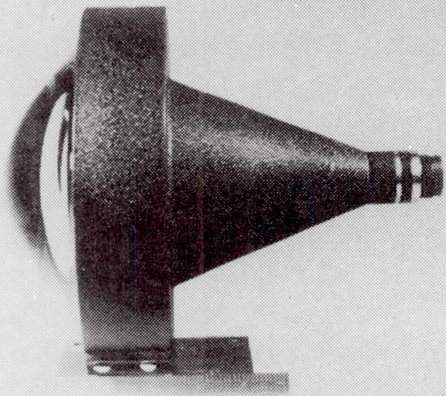
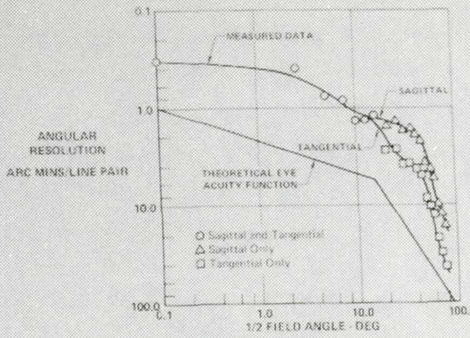


Figure 10. Stereo-TV Display

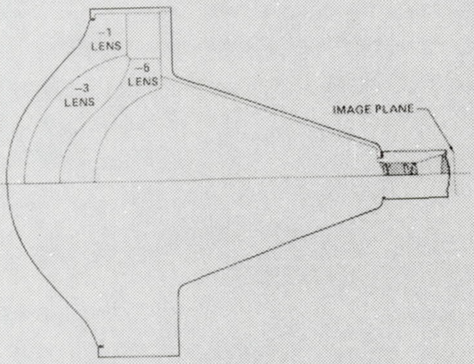
NON-LINEAR LENS



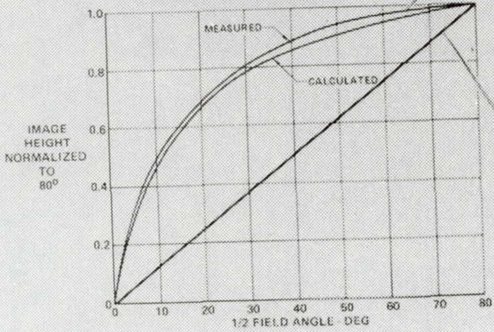
LENS RESOLUTION CHARACTERISTICS



LENS DRAWING



LENS IMAGE/OBJECT TRANSFER CHARACTERISTICS



NON-LINEAR LENS USED WITH CONVENTIONAL TV RASTER GIVES

- 160° FOV
- EYE ACUITY RESOLUTION

SIGNIFICANT REDUCTION OF DATA TRANSMISSION BANDWIDTH EVEN IN NARROW FOV APPLICATION

NON-LINEAR LENS IMAGE

CONVENTIONAL FISH EYE LENS IMAGE

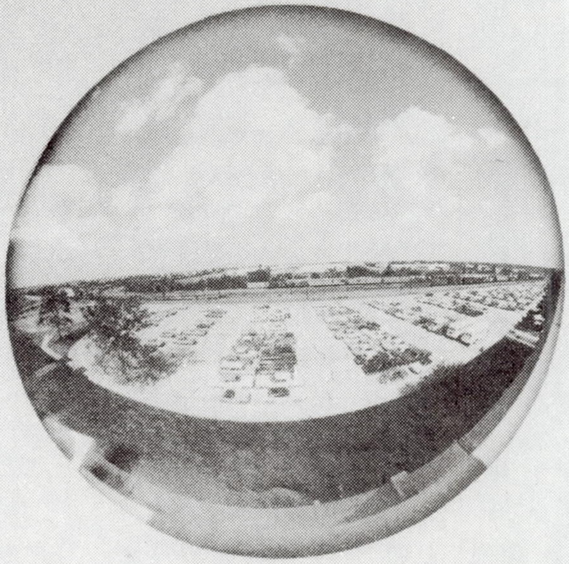


Figure 11. Variable Acuity Remote Viewing System (VARVS)

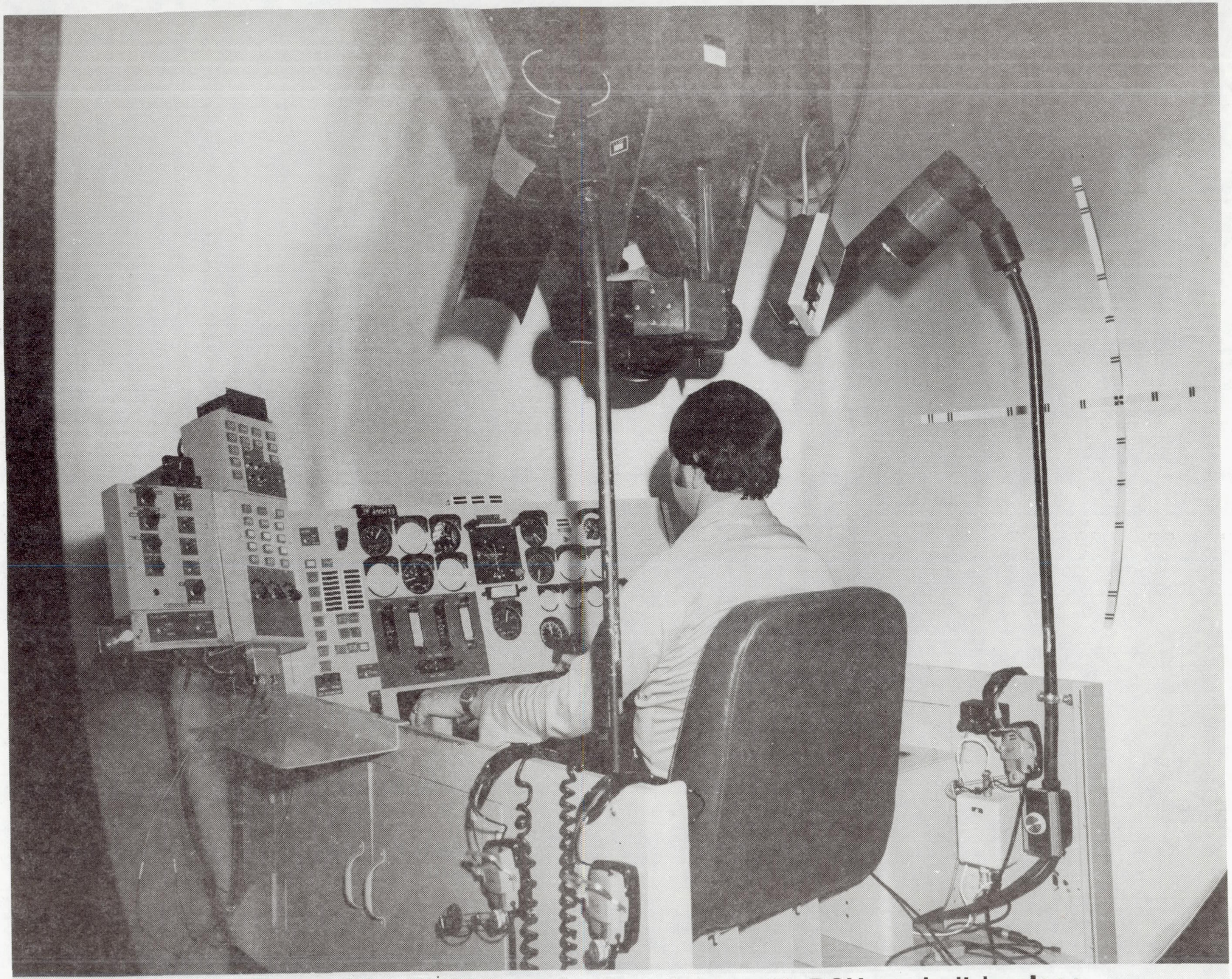


Figure 12. VARVS projection dome with RCV cockpit in place