NASA Technical Memorandum 84913

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SUMMARY

This paper presents an overview of the remotely piloted research vehicle (RPRV) activities at the NASA Dryden Flight Research Facility from their beginning to the present. The development of RPRVs as flight test tools is discussed, and system configuration is presented. Solutions derived from human factors experience related to flight activities and pilot responses have contributed to overall system capability. The development and use of visual displays, which are a critical feature of successful RPRV flights, are discussed briefly. Directions for future RPRV efforts are presented.

INTRODUCTION

The Dryden Flight Research Facility of the National Aeronautics and Space Administration's Ames Research Center has been working with unmanned vehicles for 14 years. These remotely piloted research vehicles, or RPRVs, are valuable research tools for testing aircraft performance in situations too hazardous to risk pilots. This paper presents an overview of the RPRV activities at Dryden.

First, it is important to make a distinction between the types of vehicles with which we are working at Dryden and other types of unmanned vehicles. The primary characteristic of the RPRVs discussed in this paper is that a pilot is in full control of the vehicle for the duration of the test.

As early as 1966, the need for a method to test aircraft in high-risk flight situations was apparent. In addition, escalating costs were threatening to reduce the extent of flight test programs, adding risks for operational pilots if aircraft were to go into production without thorough testing. Dryden had already gained experience in testing small-scale aircraft using model airplane techniques. The value of the pilot in the loop was unquestioned for flight testing. By 1969, a primitive RPRV was operational.

Since that time, RPRVs as flight test tools have evolved continuously. The systems now in regular use are quite sophisticated and extremely adaptable. They are capable of emulating a variety of aircraft in a broad range of flight regimes using a number of control and display systems. The critical role of the pilot in flight test has been demonstrated repeatedly, and many system anomalies have been uncovered with no risk to human life. RPRVs are powerful research tools that will continue to serve a significant function in flight testing.

DRYDEN BACKGROUND

The mission of the Dryden Flight Research Facility (DFRF, fig. 1) is to test aircraft. In general, we are concerned with new, relatively untried, high-performance aircraft, or existing vehicles that have developed anomalies. We often work with military vehicles, usually of the fighter or reconnaissance type. All of our personnel and facilities are oriented towards high-performance vehicles. In short, we use unmanned vehicles as tools in our primary activity of flight test and not as end products.

The NACA High-Speed Test Station, predecessor of DFRF, was established in 1946 with a dozen people from Langley Research Center. Its first mission was to test the rocket-powered X-1 aircraft in flight. That assignment climaxed in October 1947 with

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the world's first supersonic flight. Since then, Dryden has been the leader in flight test techniques, and has been involved in the development and testing of vehicles ranging from the very slow (such as the Lunar Lander Research Vehicle) to the very fast (including the triple-sonic YF-12 aircraft). Among the latter have been some vehicles that may stretch the term "aircraft" to its credibility limits.

The rocket-powered X-15 aircraft is foremost among those borderline vehicles. This was an aircraft in the sense that it began and ended its flight where aerodynamic forces were dominant. However, it also operated outside the perceptible atmosphere and was the vehicle in which the first pilots received their astronaut wings. In this same category were the lifting bodies — the wingless, bathtub-shaped vehicles that were the forerunners of the space shuttle.

All these vehicles were tested in the most demanding laboratory possible — the actual flight environment. Along the way, we learned by planning, execution, analysis, a few mistakes, and a little luck how to test a new idea in aircraft, getting the maximum information for the minimum risk and cost. We have and use sophisticated data gathering and analysis techniques; shops and technicians that can build, maintain, and operate a bewildering variety of aircraft and operating systems; engineers who can design innovative and complex controls, propulsion systems, and structures; and highly trained and experienced research test pilots. Flight tests are controlled by direct means from control rooms similar to those that manage the spaceflights.

REMOTELY PILOTED RESEARCH VEHICLES

With all the sophisticated equipment and techniques available to Dryden, why use RPRVs? As you undoubtedly know, the cost of building a new aircraft is rising constantly. As the need for speed, agility, stores capacity, range, and survivability increases, so does the cost. The cost of testing an aircraft is also increasing, but if flight testing is curtailed, there is a possibility of an aircraft's reaching production with some of its idiosyncracies undiscovered. There may be a need for an aircraft to operate in an environment or flight profile that cannot be tested in the wind tunnel or in computer simulation with sufficient confidence to risk a pilot's life. Even with a good design, adequate funding, sufficient development time, and careful construction, there are unknowns that can only be resolved by flight testing. RPRVs can be an answer.

RPRVs at DFRF were developed as tools to solve a myriad of problems. All these problems had one or both of the following factors: The flight environment posed high risks, or the cost to test a system fully qualified to carry a human pilot was prohibitive. A precursor to RPRV techniques was the use of a combination of radio-controlled-model equipment and leftover telemetering equipment to test an early design of a reentry vehicle called the Hyper III (fig. 2). This was a good example of the application of unmanned techniques: The vehicle concept was the result of a paper study and was never intended to be built. Consequently, nothing was known about its characteristics. It was not important enough to justify building a fully rated vehicle.

This first RPRV at Dryden was simply constructed of Dacron over a tubular frame. A rudimentary, low-speed wing was added and the vehicle was ready to fly. Dropped from a helicopter, it was flown under the control of a pilot on the lakebed below, in a cockpit copied from the Dryden simulator (fig. 3). The only displays were airspeed altitude, angle of attack, control surface positions, and an eight ball showing roll, pitch, heading, and sideslip. The pilot was an experienced test pilot and easily

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flew the vehicle to within 200 m of the ground, directly in front of the control station. At this point, an experienced radio-controlled-model flyer took over and visually landed the vehicle. This was December 1969.

Even at this early stage, some of the differences and similarities in human factors for RPRVs, radio-controlled (RC) models, and conventional aircraft were evident. With only the minimal instrumentation mentioned, the RPRV pilot was able to detect and damp out oscillations in the vehicle as it was towed aloft by the helicopter. On the other hand, when the RC flyer took over, he was forced to command large excursions to see the results of his control movements.

The loading effects of remote flying were indicated in the pilot's postflight comments. A veteran of many thousands of hours in simulation flying and first flights in exotic experimental vehicles such as the first lifting bodies, he nevertheless was stimulated emotionally and physically as much as in live first flights. There was no chance to hit the reset button, discuss the problem, and try again. There was only one chance, and its success was entirely his responsibility. Further corroboration that responsibility was a greater driver of physiological response than fear for personal safety was obtained in many later RPRV flights.

After this initial proof-of-concept flight, the systems gradually gained in sophistication as we gained experience. The iterations were numerous, sometimes misdirected, and always informative. The RPRV technique was applied successfully to vehicles that could not have been tested as thoroughly in any other way.

In the early 1970s, a serious problem facing fighter aircraft designers was stalls and spins. The Air Force was committed to a concentrated research program to study and correct the problem. The unknowns involved in full-scale aircraft testing of departures, behavior in spin, and recovery techniques were great enough to pose a definite threat to the pilot and aircraft. In an attempt to solve the stall and spin problem, a model was built of a typical high-performance fighter aircraft, scaled large enough to validate any research techniques and small enough to be carried aloft under the wing of a modified B-52 airplane (fig. 4). A 3/8-scale model of the F-15 aircraft was chosen because of the full-scale aircraft's inherent stability, resistance to spins, and ease of recovery if forced to spin. The flights of the F-15 RPRV, later referred to as the spin recovery vehicle (SRV, fig. 5), were very successful, and rapidly returned large amounts of data at low cost with no risk to human life. The value and validity of the RPRV flight test technique was demonstrated to even the most hardened skeptic.

From these first cautious steps evolved a powerful flight test technique. The most important feature of this approach has been the inclusion of the pilot in the control loop. Unlike military drones, an RPRV is intended to explore unknown engineering territory, the nature of which precludes the use of autopilots or preprogrammed control systems. In fact, the uniqueness of each flight may require that control systems be changed during a flight to compensate for unexpected responses. Some vehicles have maneuver autopilots to perform very specific tasks, but it is still the pilot's job to establish the appropriate flight conditions for the maneuver and to recover from it. The pilot has complete responsibility for determining emergency options, evaluating the vehicle performance and handling qualities, and performing required data maneuvers. Just as in manned flight testing, flight profiles and attempted data points may be changed to respond to dynamic conditions. Only an experienced test pilot can provide such response.

RPRV SYSTEMS

The current configuration of our RPRV systems was developed with active input from the pilots. The cockpits used for RPRV flights are based on a common framework (fig. 6). 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 RPRV cockpit is treated as an extension of simulation techniques and is designed to be easily modified. The instrument panels are plug-in devices and can be interchanged in a few minutes. The panel formats are never representative of a specific aircraft but are rather tailored to the immediate task.

All our unmanned RPRVs have had one thing in common: an aircraft that served as the test bed for all of the operational and piloting techniques and much of the equipment that were later applied to the more glamorous programs. The Piper Comanche, or PA-30 (fig. 7), is a 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 remain untouched (fig. 8). It was a logical and practical step to convert this aircraft to a RPRV. The aircraft has been especially valuable in developing video systems for RPRV forward visual display and for training pilots in the unique atmosphere of remote flight. 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.

The nucleus of our RPRV facility is the RPRV/RAV laboratory (fig. 9). (The remotely augmented vehicle (RAV) capability is discussed later.) Preflight, checkout, and flight support for the RPRV and RAV systems are provided by two Varian 73 computers, two Varian 77 computers, and one Varian 620f computer. The telemetry consists of two pulse-code modulation (PCM) and four hangar PCM downlink systems; two uplink systems and four hangar uplink trunking systems; and a 12-MHz-bandwidth video system. Communications equipment includes ultrahigh frequency (UHF) and very frequency (VHF) flight communications nets, and ground intercom nets, signal conditioning, and patchable switching systems. The cockpit stations have, in addition to the cockpits themselves, a graphics display system, an X-Y position plotting system, and various input/output (I/O) devices.

One of the features of the system that makes it valuable as a research tool is the ability to manipulate the command signals sent to the vehicle (fig. 10). This is accomplished by two modes of uplink transmission: the Babcock direct and the computer. The Babcock is an encoder-decoder system that converts the cockpit analog control signals to digital, merges them with cockpit discrete signals, and transmits them directly to the vehicle. Except for timing information, these signals are not processed.

In the computer mode, the cockpit analog signals are sent to one of the computers. These signals, along with downlink feedback signals, are processed according to selected control laws which have been preprogrammed into the computer. Signals so generated are then sent to the Babcock for encoding and transmission. Appropriate control laws are normally selected before flight but can be changed during flight if desired. The control mode can also be switched between direct and computer during flight. Because of the duality of the system, control signals can originate in an appropriately equipped aircraft with a pilot on board, be transmitted to the ground computer for processing, and be retransmitted to the aircraft where they are sent to the vehicle control system to actuate surfaces. This latter mode is called the remotely augmented vehicle (RAV).

FLIGHT TEST RESULTS

In addition to the Hyper III and PA-30 aircraft, vehicles tested with the Dryden RPRV system have included the 3/8-scale F-15 spin recovery vehicle (SRV), the drones for aerodynamic and structural testing (DAST), the oblique-wing aircraft, and the highly maneuverable aircraft technology (HiMAT) vehicle (fig. 11). Each of these demonstrated the special nature of RPRV systems and their value in flight testing. The SRV was intentionally subjected to and safely recovered from spins up to 270 deg/sec. One of the DAST vehicles lost a wing while testing beyond flutter-limit boundaries. The vehicle was reclaimed after the resultant crash and rebuilt. The oblique-wing aircraft tested a concept that some claimed would not fly: a wing set at an oblique angle to reduce high-speed drag while maintaining low-speed lift. It flew, and the confidence gained from that test led to the construction and testing (with a live pilot on board) of an aircraft whose wing could be skewed during flight.

The HiMAT vehicle tested the design and performance of a complete series of totally new flight concepts and high-risk technologies (fig. 12). The most advanced technology on the HiMAT was the use of composite materials for 30 percent of its construction, including the wing (ref. 1). Besides being lighter than conventional materials, the composites allow for aeroelastic tailoring. The material fibers are so oriented during construction that the wing will twist in a favorable direction under aerodynamic loading, increasing maneuvering capability under g stresses by 10 percent. Onboard computers receive and modify the telemetered commands from the ground station before sending them to the control surfaces, and also control the vehicle's propulsion system.

HUMAN FACTORS

Early in the development period, the effects of RPRV flight on the pilot were noted. During the peak of flight activity, human factors personnel studied the use of different visual presentations for the RPRV pilot and the stresses and workloads the pilot experienced.

Previously, I mentioned the stimulation the first RPRV pilot felt during his first RPRV flight. He had also been concerned about the absence of motion cues, a common apprehension about unmanned vehicles in general. As the systems increased in complexity, we attempted to address this concern by attaching straps to the pilot's waist, chest, or head. These straps were pulled by small motors driven by lateral acceleration telemetered from the aircraft. This provided the pilots with a substitute for the proprioceptive cues they might feel in sideslip. Although the pilots reported that it now felt more natural to use the rudder pedals to center the ball for sidelsip, it did not appear to reduce subjective workload or increase performance. That idea was subsequently relegated to the "nice try" bin.

One of the recurring problems was the pilot's difficulty in perceiving position relative to the ground during the last hundred meters to touchdown. Operationally, it was handled by having the flight test engineer, who is always at the RPRV 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 unnecessarily high and could be reduced with better video. The problem of height perception was felt to be critical and related to the degradation of depth cues.

An attempt was made to resolve this depth perception problem by using a stereoscopic video system based loosely on a design proposed for use with the remote manipulator arm on the space shuttle (fig. 13). The concept worked but offered no advantage because of the limitations of the existing video transmission and reception system. There is only so much information that can be packed into the available bandwidth, and passing two separate images through a system designed for one required multiplexing. The demultiplexing was not as successful as the multiplexing, and the resultant separated images were never free from cross-talk ghosts (ref. 2).

PHYSIOLOGICAL MEASUREMENTS

As the system approached its present level of sophistication and more programs were being considered, we began monitoring the heart rates of the pilots. This was part of a long-range effort by the human factors group to obtain heart rate data under actual flight conditions for a variety of aircraft and test conditions. Many human factors people hoped to find some physiological parameter that would be easy to obtain in strenuous situations and would be unambiguously indicative of mental workload. Statistical manipulations of heart rate were the prime candidates.

Analysis of heart rate never gave us the universal answer to pilot loading but did enable us to observe the parallels between a pilot's physiological response to RPRV control and to conventional flight. As an example, consider the first flight of the F-15 RPRV. The program called for a complex sequence of 36 data maneuvers, performed as quickly as possible since the vehicle had no engine. The vehicle was air-launched at an altitude of 15,000 m and was flown as a glider down to 5000 m in 9 min at which point a series of parachutes deployed and the vehicle was recovered by helicopter in a midair snatch. The pilot did not have to worry about approach and landing. The pilot who controlled this flight is normally quite calm, and his heart rate usually remains below 80 beats/min, even during hazardous manned flights. However, shortly after the RPRV was dropped, his heart rate jumped to 150 beats/min and plateaued at 130 beats/min for most of the flight.

Some of his comments (which were echoed by later RPRV pilots) were on the aptness of the term "remote pilot": ". . . the feeling is of remoteness from the essential verifying, comforting sensations of flight. . . . The difference between simulation and flight is enormous in this respect. Only the most superficial evidence that the flight is proceeding properly is quite enough in simulation, but in flight much more concrete and diverse evidence is demanded. In remote piloting this evidence is harder to come by — at least it was on this first experience" (ref. 3).

All test flights at DFRF, including the RPRV flights, are preceded by many hours of simulation (fig. 14). However, neither the overall intensity of the remote experience nor the subjective time compression was anticipated. To compensate, simulation rates were increased until the pilot felt that events were occurring at the same pace as they were in flight. The selected rate was 1.5 times real time. After more flights, this was adjusted slightly, and the rate we use today for simulation preparatory to an RPRV flight is 1.4 times real time.

HORIZONTAL LANDING

Failures encountered in the midair recovery system suggested that the RPRVs should have horizontal landing capability. In a real sense, this capability already existed: During one of the F-15 SRV flights, the vehicle broke away from the recovery helicopter after it had been tethered and ground control relinquished. The ground pilot reestablished control and attempted to fly the vehicle back to the dry lakebed. Because the vehicle was low and did not have enough energy left to reach a flat area, the pilot was forced to land it in rough terrain. He brought it in smoothly, flared, and set it down on its belly. As the vehicle slid to a stop, he was still able to command a last minute maneuver to avoid a rapidly approaching Joshua tree. As spectacular as this recovery was, it was accomplished with a visual system that could be best described as marginal. Up to this time, most RPRV flights had been done almost entirely by instrumentation with the video used only for the most general orientation.

There were several advantages to adding landing gear and capability to the RPRV system. With the removal of the elaborate parachute system, the vehicle had more available weight for experimental purposes, and weight distribution could be studied more easily. The elimination of the close coordination necessary for successful midair recovery made for much simpler operations, and flights did not have to be cancelled for lack of recovery helicopters. There was a price, however. The workload demands on the pilots were higher, especially during the approach and landing. The marginal video system became intolerable, and it was necessary to develop adequate video systems to permit regular operations.

The workhorse PA-30 aircraft was pressed into service, and several variations of magnification, contrast, camera location, lens focal length, and aim angle were examined by the RPRV pilots while flying the PA-30 aircraft as an RPRV. The safety pilots in this study were also RPRV qualified and served as onboard observers and performance evaluators. A compromise video system was adopted which served the critical needs as well as possible within the constraints of the existing equipment. In the course of this study, the value of the PA-30 aircraft as an RPRV trainer and simulator was realized.

TRAINING

As the RPRV flight test technique evolved, more pilots were added to the team. A training protocol was established whereby each new RPRV pilot began in the PA-30 aircraft. During the video study, a monitor had been mounted in the left panel and connected directly to a nose-mounted camera. New RPRV pilots began training by executing a standard series of flight maneuvers in visual-flight-rule (VFR) conditions, including many touch-and-go landings. The next step was to repeat all of those maneuvers using only the monitor for their forward field of view. For the second series of maneuvers, they were "under the hood" — that is, a surrounding black drape completely blocked their view outside the aircraft. This step was repeated until they were confident of their ability to land the vehicle using only the monitor. Finally, they were placed in the ground cockpit to fly the PA-30 as an RPRV. The progression was natural, and all the pilots made the transition without difficulty.

CURRENT AND FUTURE ACTIVITIES

Facility Improvements

Currently, the entire RPRV ground facility is being updated and expanded (fig. 15). The new area will include the DFRF simulation facility as well as the RPRV/RAV facility. New equipment and subsystems will include four SEL 2750 32-bit computers for RPRV use and one SEL 8780 for simulation. The telemetry downlink will also pass through the computer so that the data can be manipulated before being displayed in the cockpit. In addition to three simulation cockpits, the RPRV area will also have three cockpits, one of which will be used with a 180° projection system called the variable acuity remote viewing system (VARVS).

In conventional aircraft displays, as well as in head-up displays, there are as many variations of what is needed to do a good piloting job as there are aircraft designers, human factors engineers, and pilots. No matter how excellent a particular display scheme may be, it cannot summarily be dropped into an operational vehicle without posing some risk to the operator. Simulation does not give the whole answer because the infamous reset button always allows escape. The loading effect of the RPRV method of flight test offers realistic conditions with that very important responsibility factor right where it belongs — with the pilot.

That loading effect is in part due to the restrictive nature of the forward visual field. The normal-aspect-ratio, broadcast-quality, monochromatic video system used for RPRV work at Dryden does not provide the normal visual cues present in live flight. RPRV pilots have been more dissatisfied with this aspect of the method than with any other. As mentioned, the early studies were designed to produce a workable system in the least time. In that regard, they were successful. However, as the flight tests gained in complexity and the RPRV vehicles gained capabilities, the need for augmented video systems became great.

The failure of the stereo idea left us with the perception problem. The human vision system (eye-brain) uses many more cues than just binocular disparity to establish position in space. Among these are relative sizes and perspective in both static and dynamic conditions, and 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 gives a pronounced fisheye effect — that is, very small images across the field of view, and poor resolution.

To maintain resolution within the available system, a nonlinear lens system was devised which emulates the human eye (fig. 16). It is nonlinear in the sense that its focal length varies as a function of the radial distance from the central axis (ref. 4). The effect is an oddly distorted image with a 20° cone about the central axis having normal size and resolution, with the image size and resolution decreasing rapidly as the edge is approached. Since resolution is sacrificed in the peripheral vision area which has poor resolution anyway, no acuity function is lost. The distorted image is normalized upon presentation by projecting it through an identical lens onto a hemispherical dome (fig. 17). This concept is called the variable acuity remote viewing system (VARVS) and will form an important part of RPRV systems at Dryden.

The Transport Crash Test Program

One of the most interesting programs planned for the near future is the transport crash test (TCT). Examining crashworthiness and recently proposed fuel-fire suppression systems is difficult under single-item laboratory conditions. Under dynamic conditions it becomes very expensive. If it were possible to incorporate these concepts in a single vehicle and fly the vehicle into a representative crash situation, all systems could be tested under real conditions. Enter the RPRV and the TCT. A complete instrumentation package and an RPRV system are being installed on an obsolete medium-sized transport aircraft to prepare it for one last flight. The aircraft will be flown to a precise impact point at an exact glide angle and descent velocity with all flight conditions being monitored. The flight will not take place until 1984; however, because of the precision required by the task, the RPRV pilot has already begun training in the PA-30 aircraft.

CONCLUDING REMARKS

Successful, effective, manned aircraft than can be flown with confidence and safety are our final product. The RPRV is a useful tool in the evaluation process, providing precision test capability, repeatable test maneuvers, and the flexibility to alter test plans quickly and cheaply. In addition, we get that all-important human feedback — the observations, insights, and trained evaluations that only a pilot in the loop can give.

Dryden's RPRV expertise and facilities are an important tool in NASA's repertoire of flight test techniques. The technique will continue to serve a significant function in flight testing whenever personnel risks and costs preclude more conventional test procedures.

Ames Research Center
Dryden Flight Research Facility
National Aeronautics and Space Administracion
Edwards, California, June 2, 1983

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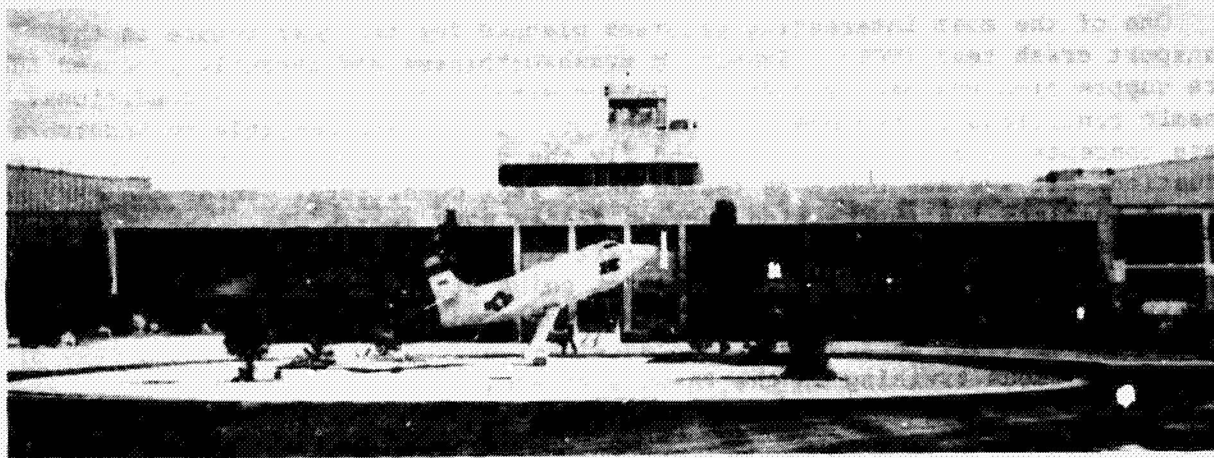

ECN 12506

Figure 1. The Dryden Flight Research Facility.

E 20464

Figure 2. Hyper III reentry vehicle.

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Figure 3. Hyper III ground-based cockpit.

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Figure 4. F-15 RPRV on its way to an airborne launch from a B-52 mothership.

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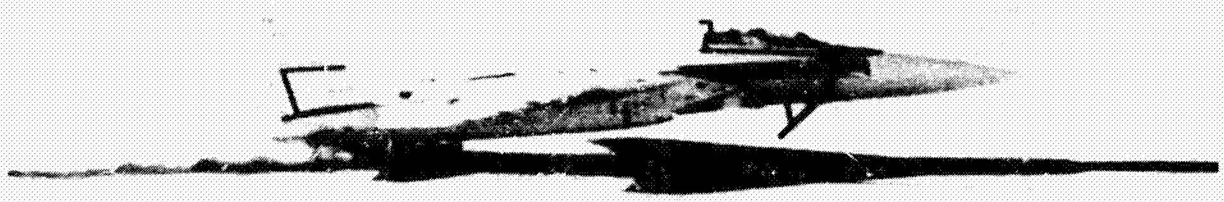

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Figure 5. The spin recovery vehicle (SRV) RPRV in a pilot-controlled landing on the Edwards AFB dry lakebed.

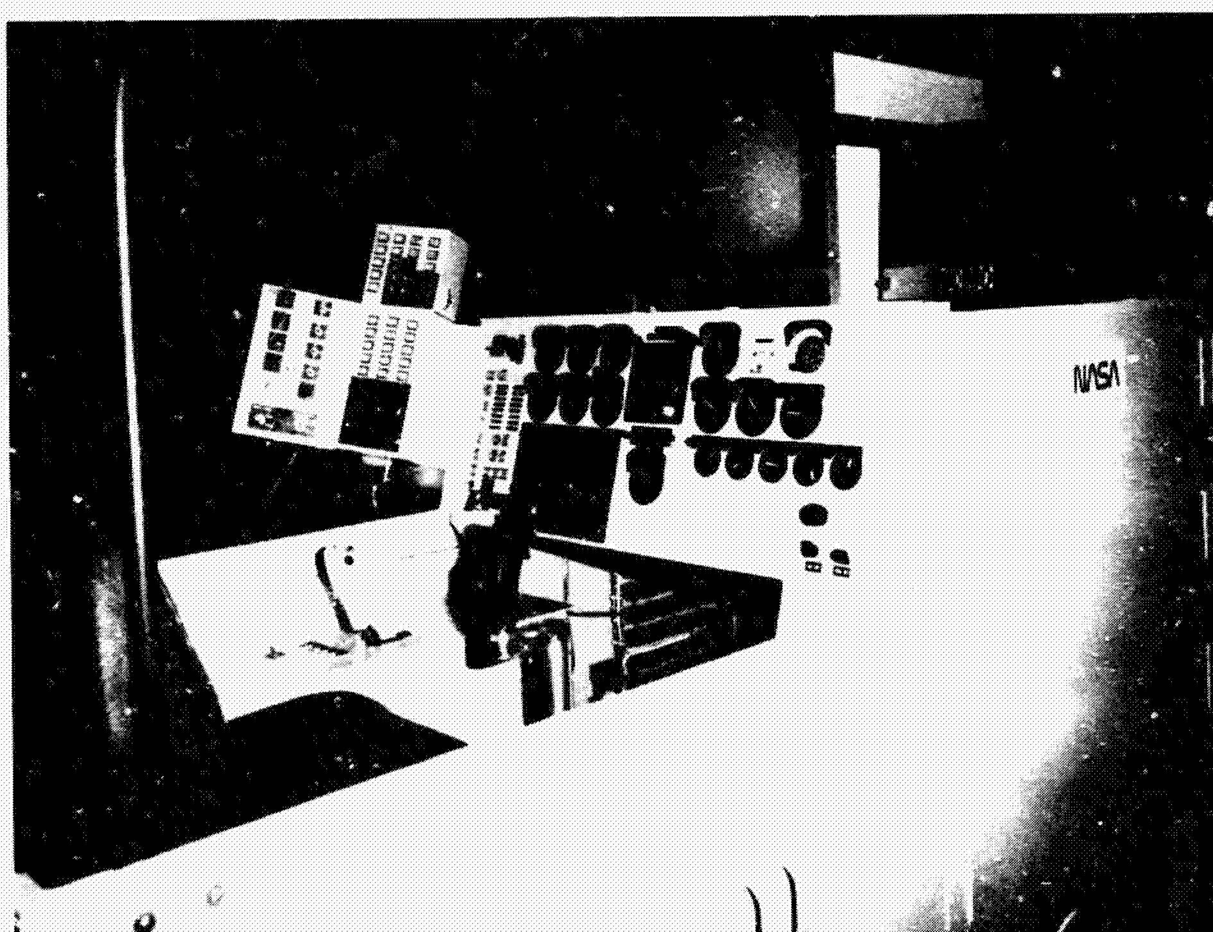

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Figure 6. A typical RPRV cockpit at Dryden.

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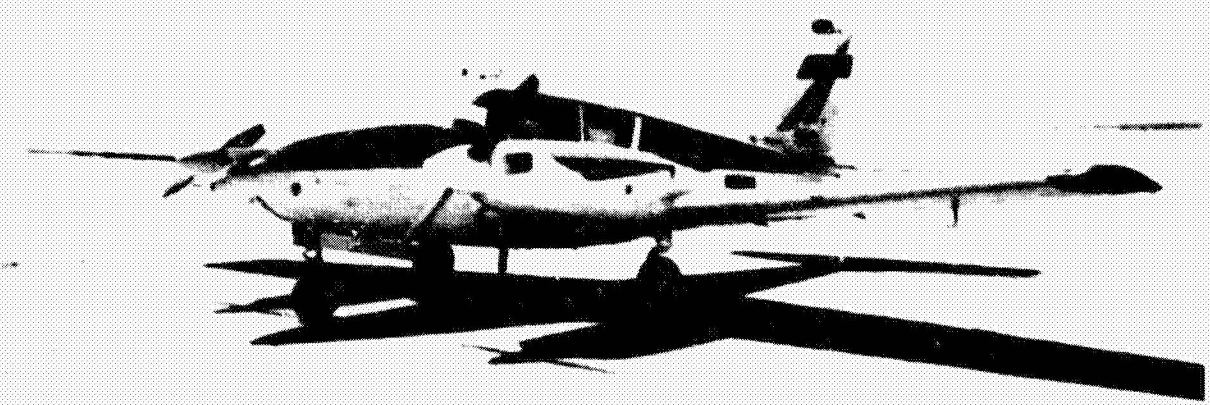

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Figure 7. PA-30 aircraft. Primary video camera locations are in the nose and atop the cabin.

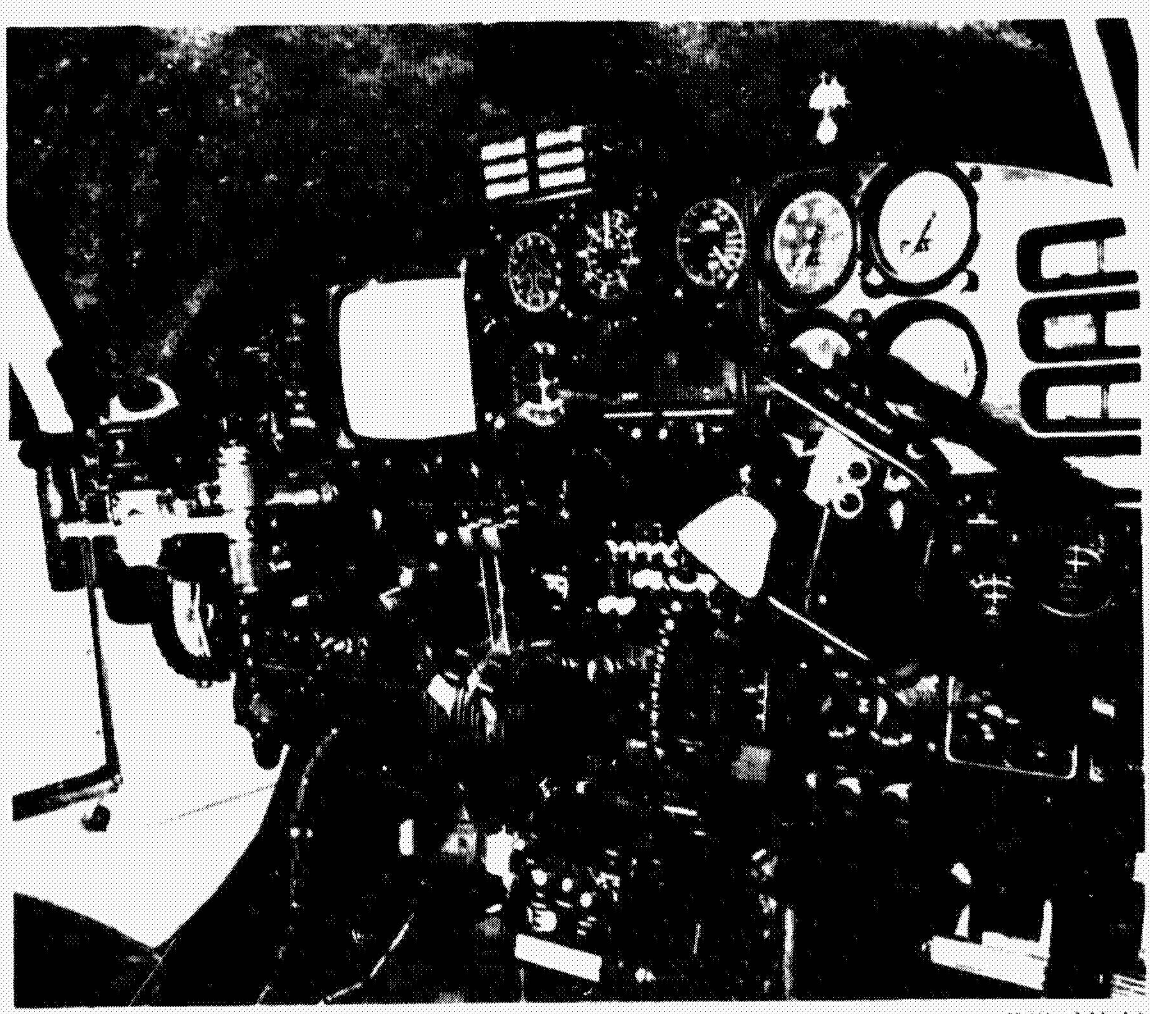

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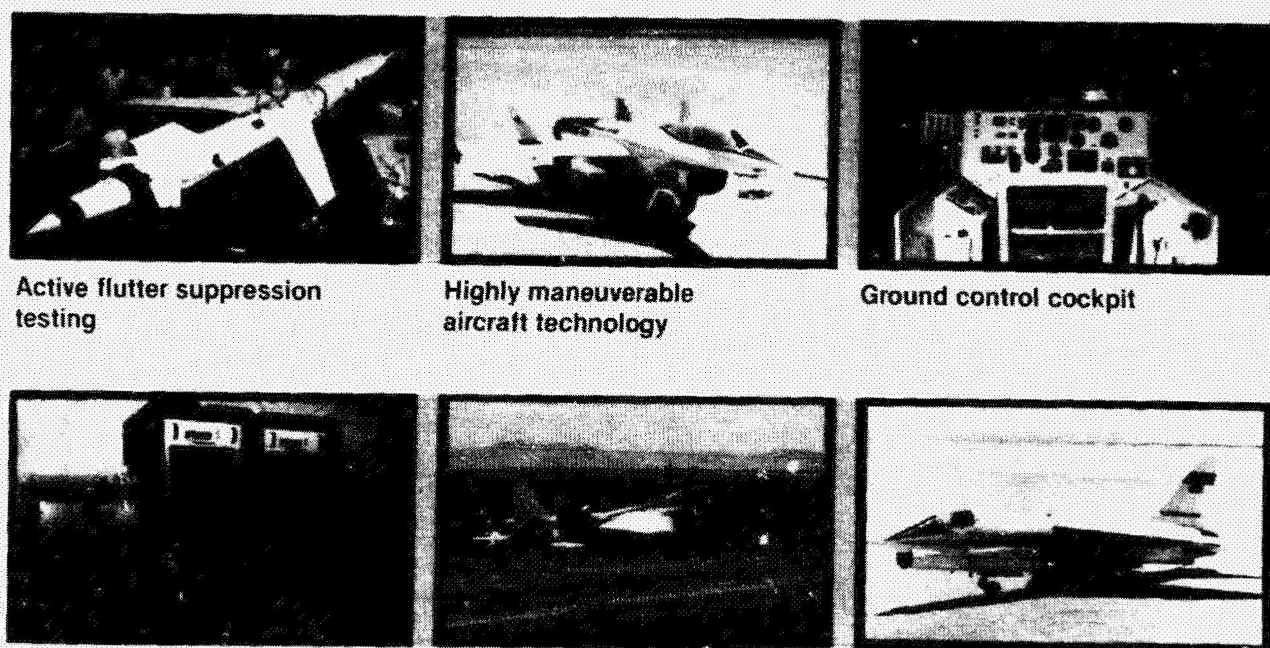
Figure 8. PA-30 instrument panel showing closed-circuit monitor on left side.



Active flutter suppression testing

Highly maneuverable aircraft technology

Ground control cockpit

Control computer

Spin research testing

Advanced control law verification (RAV)

Figure 9. Dryden's RPRV/RAV facility.

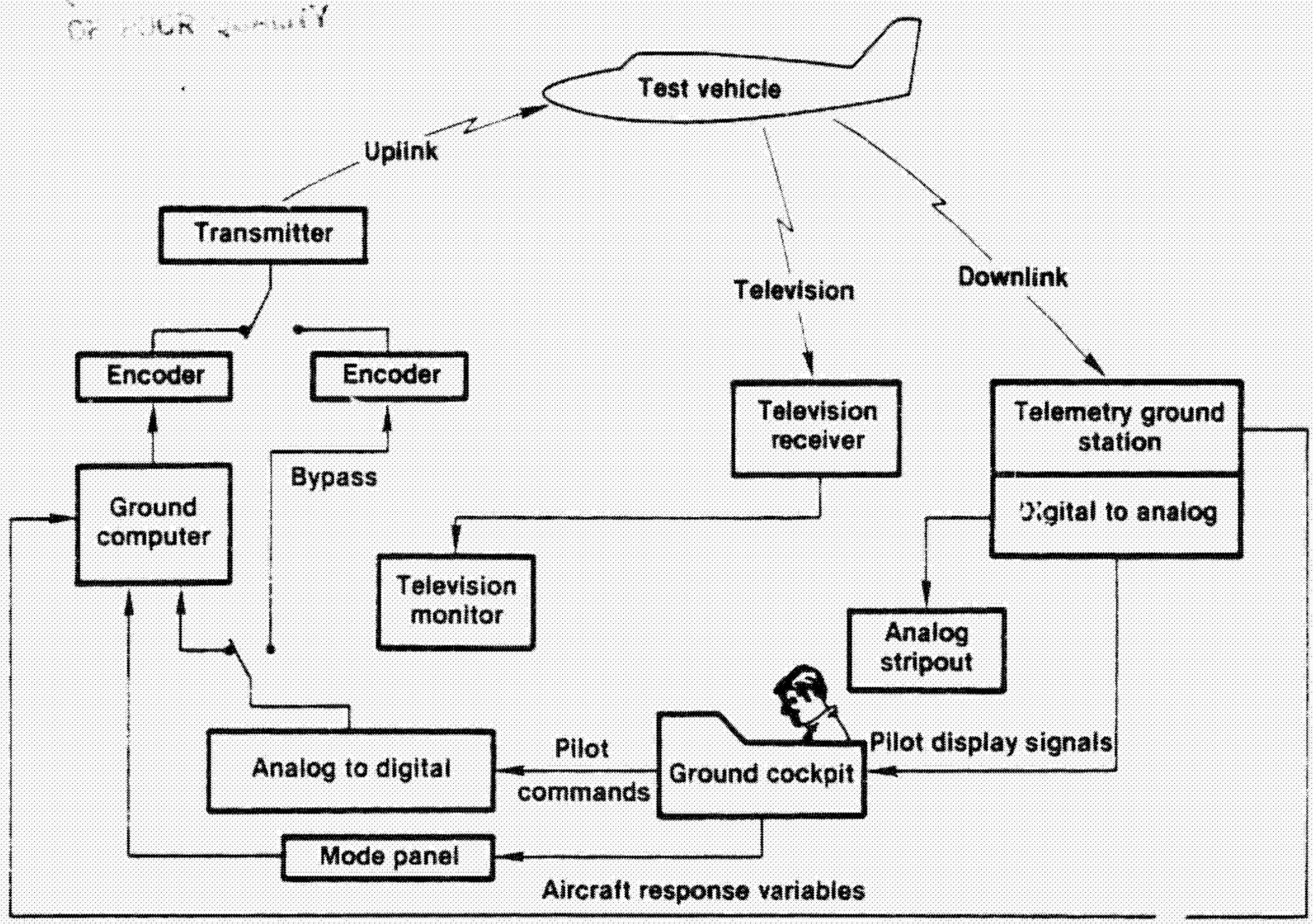


Figure 10. The generalized RPRV system.

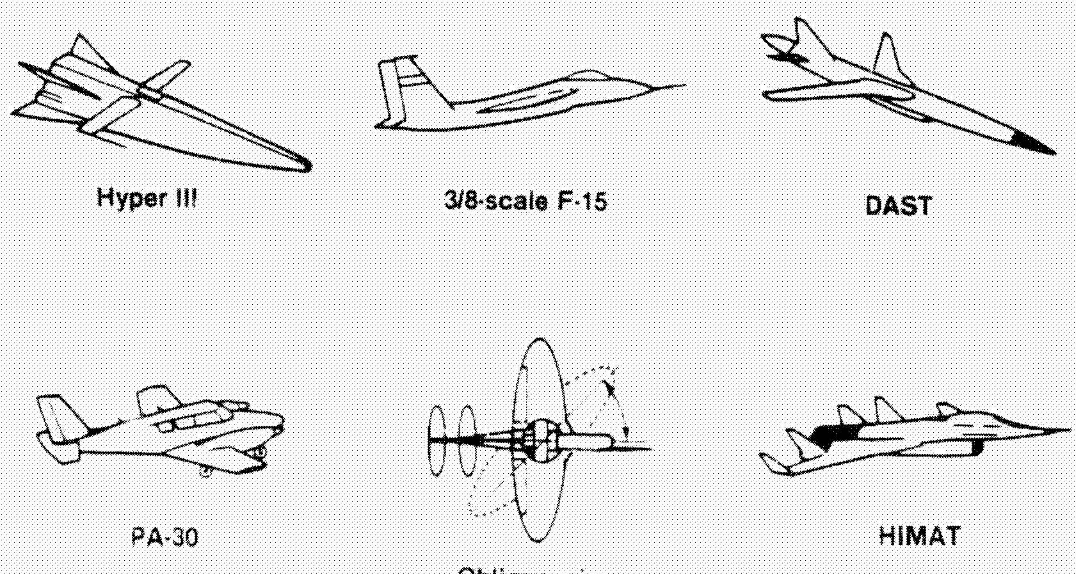


Figure 11. Some RPRVs flown at DFRF.

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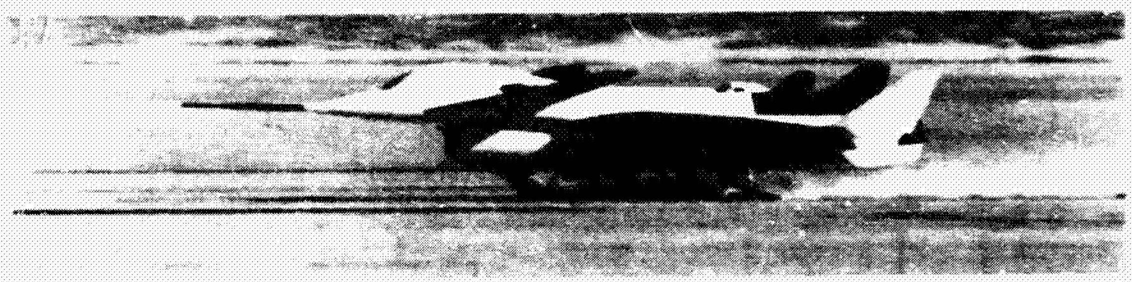

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Figure 12. The HiMAT RPRV.

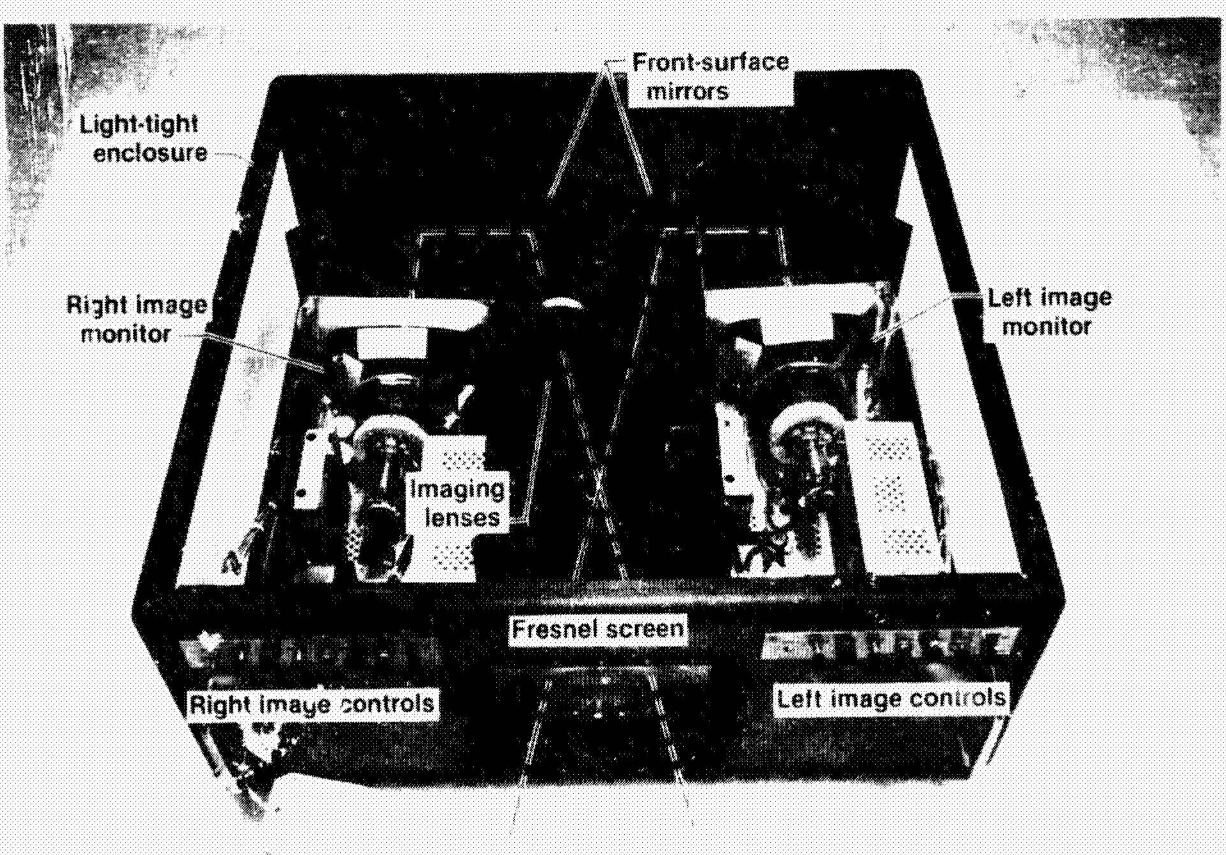

Figure 13. Stereo video-operator's display.

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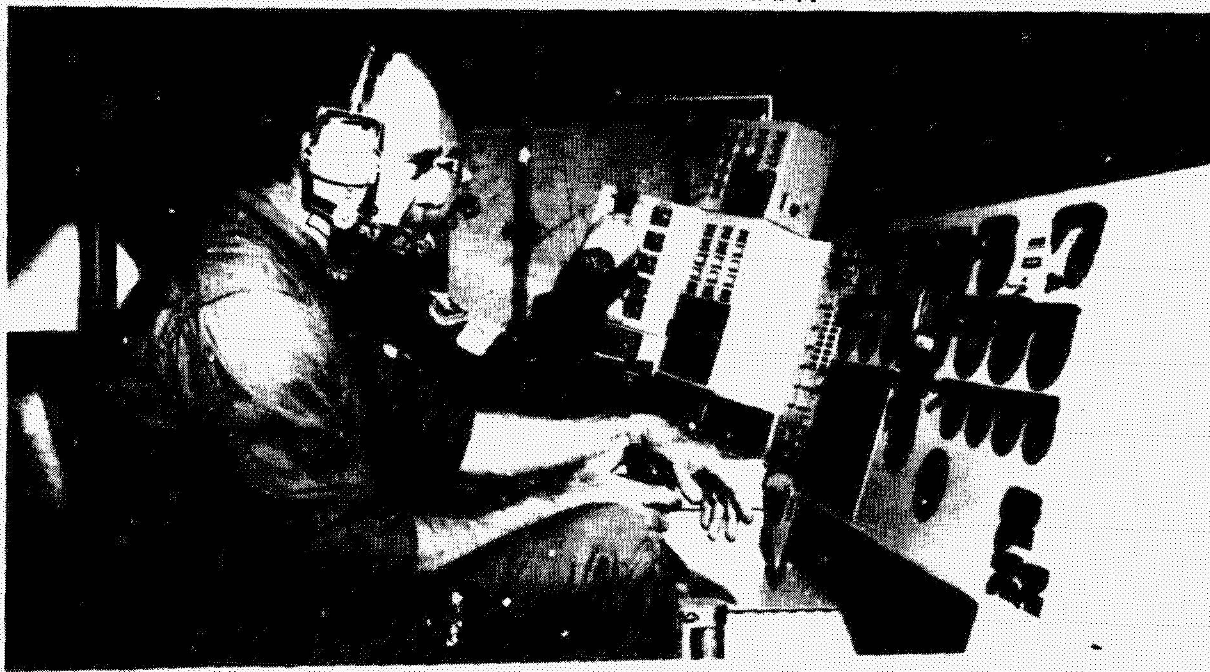

ECN 10925

Figure 14. Pilot in RPRV simulation cockpit.

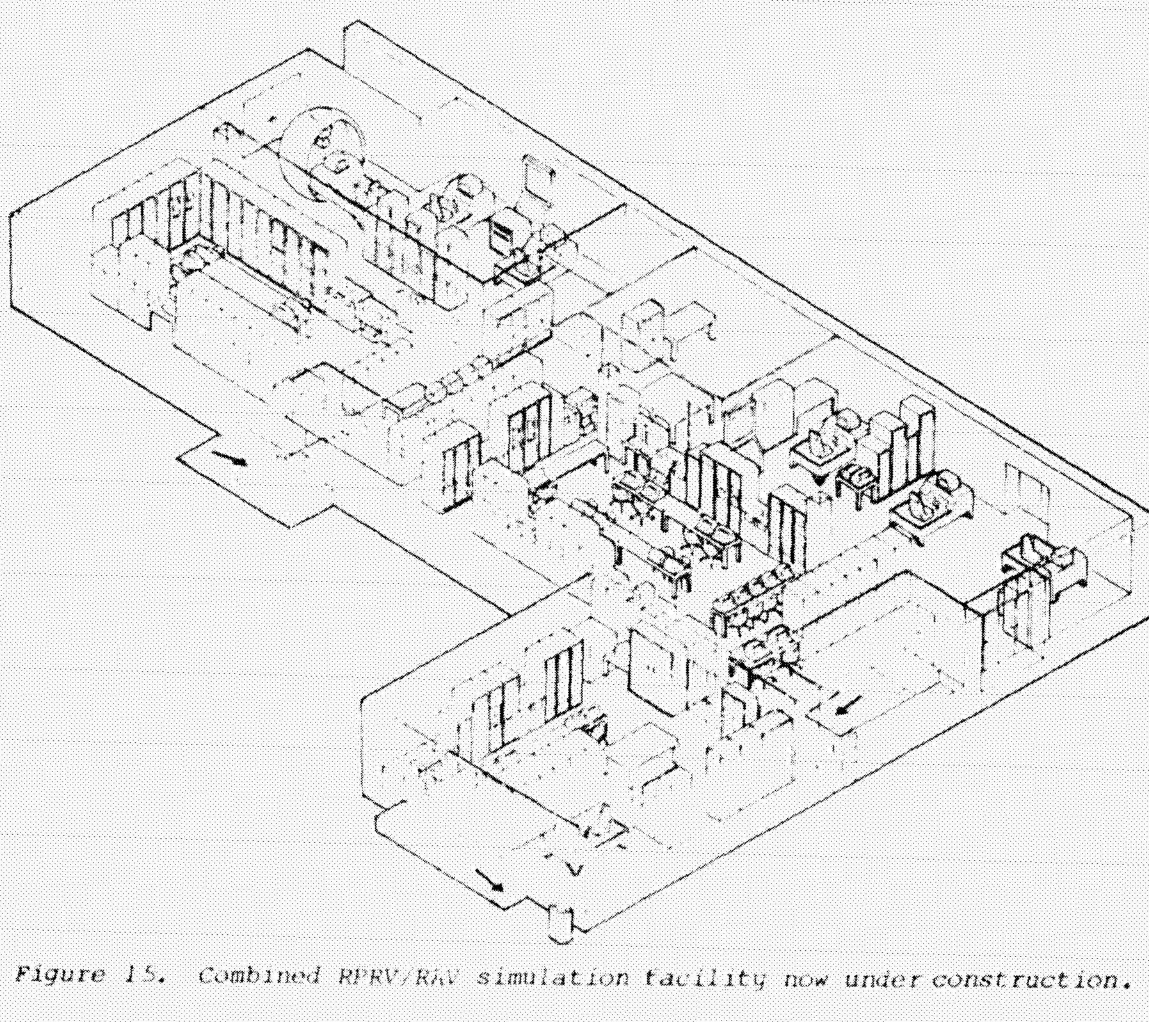

Figure 15. Combined RPRV/RAV simulation facility now under construction.

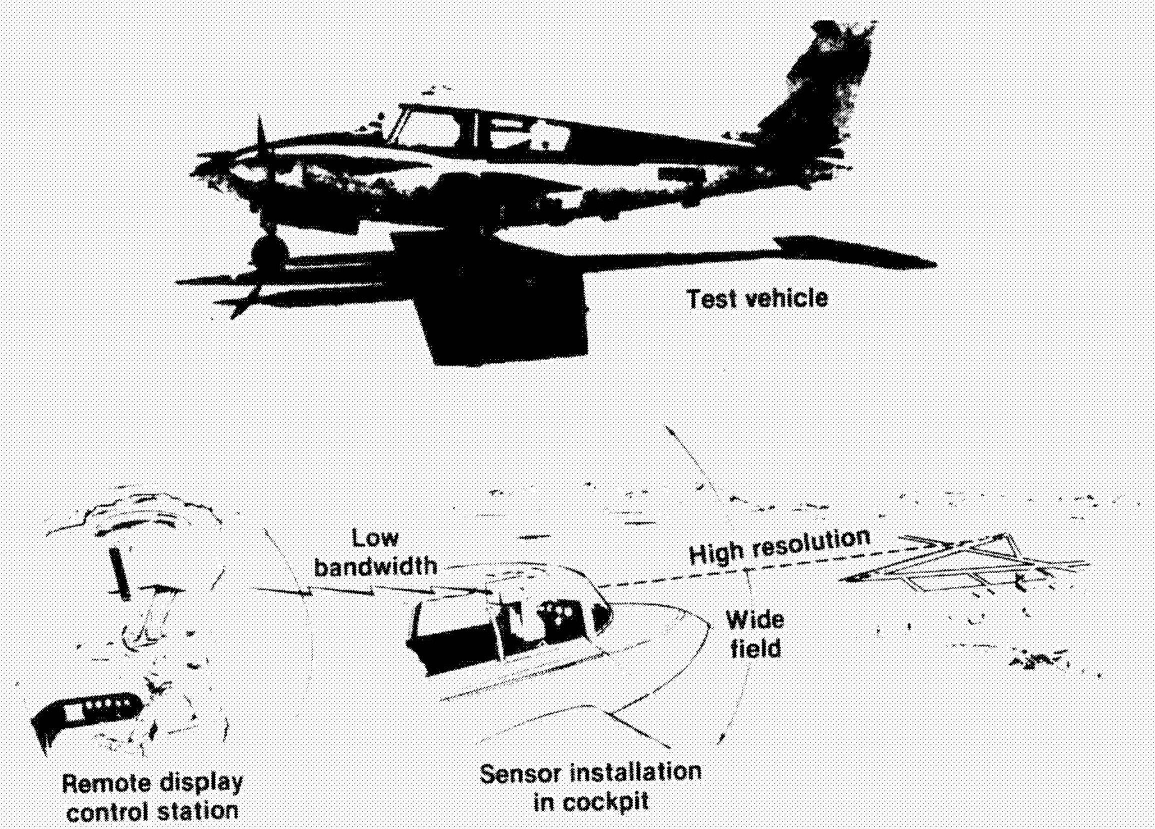

Figure 16. VARVS.

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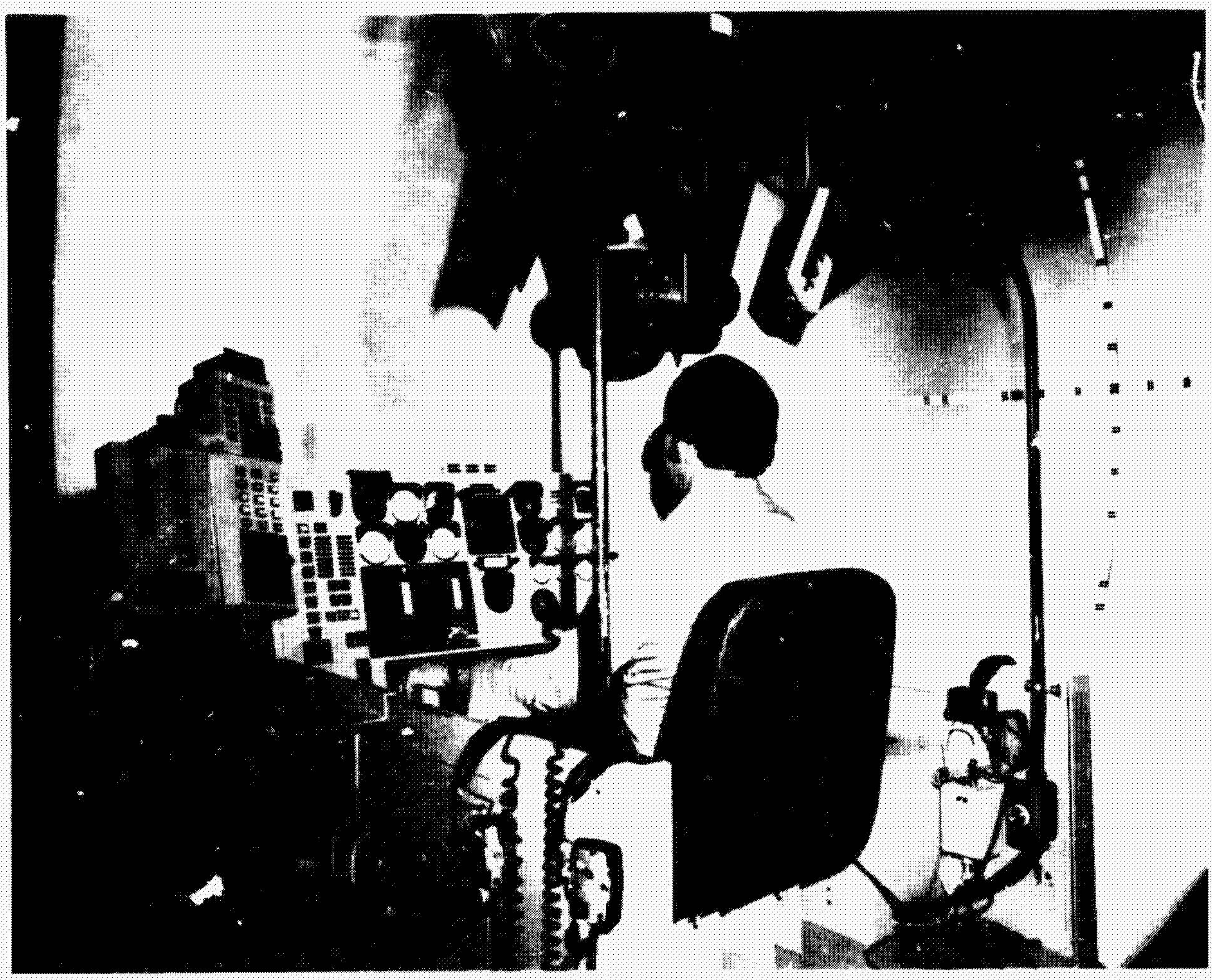

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Figure 17. VARVS projection dome with RPRV cockpit.