

AD-765 159

FAA ALL WEATHER LANDING SIMULATION STUDIES  
DEVELOPMENT OF PILOT ORIENTATION FILM FOR LOW  
VISIBILITY LANDINGS

CALIFORNIA UNIVERSITY

PREPARED FOR  
FEDERAL AVIATION ADMINISTRATION

MAY 1973

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AD 765159

# FAA ALL WEATHER LANDING SIMULATION STUDIES DEVELOPMENT OF PILOT ORIENTATION FILM FOR LOW VISIBILITY LANDINGS

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Springfield VA 22151  
May 1973



## FINAL REPORT

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Prepared for

DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION  
Systems Research & Development Service  
Washington, D.C. 20591

This report has been prepared by the Institute of Transportation and Traffic Engineering, University of California, for the Systems Research & Development Service, Federal Aviation Administration, under Contract DOT-FA7-2WA2698. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification or regulation.



1. Report No. FAA-RD-73-61	2. Government Accession No. ----	3. Recipient's Catalog No. ---	
4. Title and Subtitle FAA ALL WEATHER LANDING SIMULATION STUDIES DEVELOPMENT OF PILOT ORIENTATION FILM FOR LOW VISIBILITY LANDINGS.		5. Report Date May 1973	6. Performing Organization Code ---
		8. Performing Organization Report No. -----	
7. Author(s) Don O. Horning and Alvah J. Miller		10. Work Unit No. (TRAIS) 013-323-013	
9. Performing Organization Name and Address University of California Institute of Transportation and Traffic Engineering Richmond Field Station Berkeley, California 94804		11. Contract or Grant No. DOT-FA 72 WA-2698	
		13. Type of Report and Period Covered FINAL REPORT	
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research & Development Service Washington, D C 20591		14. Sponsoring Agency Code ---	
15. Supplementary Notes  H 760			
16. Abstract  This report summarizes the activity of the project in achieving the task objective of developing a film suitable for pilot orientation for low visibility landings. To complete the task, the degree of realism that could be obtained in the Fog Chamber was greatly heightened by modifications to the runway surface (i.e., in-setting runway lights, improving surface texture and markings, and increasing contrast at edge of runway), providing 6 degrees of motion to the 35 mm camera on a programmable basis in order that aircraft flight trajectories could be matched from simulator to Fog Chamber, and improvement in the fog control system for uniform high and low density fogs. Techniques were developed to use existing aircraft training simulators to provide filmed instrumented approaches, these then to be used as the basis for 1) the aircraft flight trajectory information, and 2) showing by visual means the actual aircraft performance under approach conditions as indicated by the instruments. Also described is the Film Library for the FAA of 72 Fog Chamber approaches matching the simulator approaches. These have been filmed in day, night, and under various visibility conditions, and the Film Library of 18 simulated approaches using a Boeing 707 Simulator. The report indicates the techniques by which these films can be used as visual aids in Pilot Orientation.			
17. Key Words Low-visibility Landings Fog Chamber  Flight Simulation Study		18. Distribution Statement  Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151	
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages # 66	22. Price \$ 3.50

## ACKNOWLEDGEMENTS

The project DOT-FA7-2WA2698 was under the direction of Professor Robert Horonjeff. The following individuals were very helpful in the development of the basic program and were considered to be the Advisory Committee for the technical phases of work involving the needs of the aviation community with regard to all-weather landing conditions.

Mr. David D. Thomas	Flight Safety Foundation
Captain James Fleming (Retired)	Pan American World Airways, Inc.
Mr. Ralph Noltemeir	FAA

Other individuals also were extremely helpful in making suggestions and comments as the project work continued.

Mr. Ken Burroughs	Air Line Pilots Association
Captain Larry DeCelles	ALPA All Weather Committee
Captain E. J. Burke	ALPA All Weather Committee
Captain William Ballinger	Pan American World Airways, Inc.
Captain Victor McHenry	Pan American World Airways, Inc.

Special thanks must go to Captain William Ballinger, of Pan American World Airways, Inc., who was the pilot for all of the approaches filmed in the Pan American World Airways, Inc., Boeing 707 Training Simulator.

Captain James Fleming (Retired) was most helpful in preparing the flight scenarios, the graphic reduction of the simulator trajectories for use in the Fog Chamber, in the identification of specific film sequences to be used in the final film, and the continual support he gave to the completion of the project activity.

Others closely associated with various phases of the work and to whom thanks must be given for their individual contributions are:

Professor D. M. Finch  
Mr. Karl Mellander  
Mr. Jerry Jeffress  
Mr. Melvin McNabb  
Mrs. Mildred Mohr

Special thanks must also go to Mr. Don Weed and Mr. Don Hendricks, of Film Effects of Hollywood, for their efforts to process excellent films from the negative materials submitted to them.

Finally, we want to thank all of the many representatives of FAA who have been most helpful with their suggestions and patient with us in the execution of the contract work.

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## FINAL REPORT

### FAA ALL-WEATHER LANDING SIMULATION STUDIES DEVELOPMENT OF PILOT ORIENTATION FILM FOR LOW VISIBILITY LANDINGS

#### Purpose of Program

The purpose of the current FAA All-Weather Landing Simulation Study utilizing the UC-FAA Fog Chamber was to produce 1) a film library of simulated approaches and 2) a film which would be useful for pilot orientation for low visibility landings.

#### Scope of Program

The scope of the current project involved modification of the Fog Chamber to accommodate the following:

1. The development of techniques and mechanisms for transporting a 35 mm camera in the normal six degrees of freedom of the conventional aircraft in such a manner that the approach flight trajectory of typical aircraft could be simulated accurately;
2. The development of more accurate methods of control of the simulated fog in the Chamber;
3. The preparation of the 10th scale runway to increase the degree of realism which would enhance the usefulness of the filmed material.

Other objectives were to:

1. Create a film library of various flight trajectories in the Fog Chamber under varying conditions of low visibility as well as night, dusk, and daylight background brightness.
2. Prepare a film library of the flight instruments in an aircraft training simulator being operated to duplicate various approach flight attitudes, these approaches to be flown by an experienced pilot.
3. Assemble a complete film of approaches and other useful flight information for pilot orientation of simulated landing conditions in low visibility.

## Fog Chamber Background and Status

The UC-FAA Fog Chamber was developed for the specific purpose of providing a test area in which low visibility conditions encountered by pilots in making airport approaches and landings could be produced and controlled. The facility consists of a 1000 ft long building 20 ft wide. On the floor of the building is constructed a 10th scale replica of the approach lighting system and runway of a typical airport runway, complete with markings and lights. A pilot's canopy, or cockpit, suspended on a tramway within the building provides the means of making approaches to the runway on a fixed 2-1/2° glide slope. The speed of the tramway can be adjusted to represent to the proper scale normal aircraft approach and landing speeds.

The status of the Fog Chamber as of July 1, 1971 was:

1. The runway and its lighting system were in poor repair after 10 years of usage.
2. The lighting system was mounted above the surface of the runway and the appearance even in films had little realism. This was particularly noticeable during daylight operations.
3. Fog control for very thin and very heavy fog conditions was marginal, particularly from the standpoint of uniformity throughout the length of the Fog Chamber. The extremes of very dense or very light fogs were difficult to obtain with any reasonable degree of repeatability.
4. The flying cockpit had severe limitations as to size; also, speed and position control were entirely manual and subject to considerable variations. The movement of the cockpit was limited to three degrees of motion, namely: yaw, transverse, and along the axis of the Fog Chamber. These constraints had been limitations to the usefulness of the Chamber for some of the tasks proposed by FAA.

The above Fog Chamber limitations were discussed at length by an advisory committee of flight experts in determining the possible value of films which might be used for pilot orientation. The group concluded that it would be useful to the national aviation community to provide more realistic and controlled standard reference conditions for approach and landing operations in low visibility conditions. Based on this, a program was proposed which would eliminate some of the Fog Chamber deficiencies and permit greater realism to be effected in films for pilot orientation.

## Genesis of Pilot Orientation Film Study

Previous work at the Fog Chamber had produced several films of standard approaches under various conditions of low visibility. The reasoning behind these films was the incidence of fog at airports is infrequent; pilots seldom are called upon to land in low visibility conditions. Therefore, the appearance of runway approach lights, the threshold and the touchdown zone in conditions of low visibility are unfamiliar to many pilots. However, there is a need for all pilots to be shown what the visual cues are that will make an

approach and landing possible under these conditions. As mentioned, previous work at the Fog Chamber had produced films which had a reasonable degree of realism for the approach and runway. These external views, combined with films of the operational flight instruments in a training simulator, had resulted in useful films. The development of the filming technique used has been described in detail in Report No. FAA-RD-71-64, "Development of Film Techniques for Runway Lighting Outage Studies." With this background experience and the unique advantages of the UC-FAA Fog Chamber, it was proposed that a wide spectrum of approach and landing conditions be filmed. These films would constitute a library from which almost any approach flight path which could be flown by normal aircraft could be demonstrated for pilot orientation. It was also proposed that the previously mentioned deficiencies in the Fog Chamber be corrected to the extent that time and funds would permit. The contract task was divided into four major phases.

Phase I was the refinement of the Fog Chamber and the motion picture techniques used to simulate various aircraft approach trajectories.

Phase II was the preparation of a series of background scenes taken in a suitable training simulator covering the aircraft approach configurations finally established as being useful, these to include go-around operations and premature ground impacts in the approach zone.

Phase III was the computer oriented analysis of these scenes and the generation of programmable flight path data as needed for Fog Chamber cockpit motions duplicating the simulated approach.

Phase IV was the preparation of composite scenes showing simulated landings as viewed by a pilot in adverse weather conditions.

To accomplish this, a comprehensive work program was developed.

### Work Program Details

#### A. Runway Resurfacing and Marking

The original runway had been laid in asphaltic concrete with a nominal 2 inch thickness over an engineered fill compacted to a prescribed maximum density. The plane of the runway surface had been specified to be flat within 0.1 inch per 100 ft. This close tolerance was met at the time of installation, but over the period of 10 years, differential settlement had occurred which left hollow spots in which water collected. These pools, during daylight filming, reflected the building structure and further degraded the realism.

To effect a more realistic runway, the 15 ft wide by 600 ft long section of the runway was resurfaced. Provision was made in the resurfacing to 1) provide for inseting the runway lights, 2) provide a crown to the runway similar to a normal airport, and 3) establish a single plane to close tolerance for the entire runway length. Screed boards were laid down and fastened firmly to the existing pavement. These screed boards were leveled to less than 0.1 inch in the entire 600 ft of runway surface. The variation in asphalt depth laid was from 3/4 inch to over 5 inches, indicating to some degree the extent of the soil

movement. Plywood of the proper thickness and size was laid down at each point where the touchdown zone lights were to be imbedded. When these were removed after the paving was completed, the touchdown zone lights were re-installed. Fig. 1 shows the surface of the runway with inset light units. A similar treatment provided the means of imbedding the runway centerline lights.

After the asphalt had been laid, the side screed boards were removed and Portland cement concrete with a fine aggregate mixture was poured from the edge of the runway to the edge of the old floor. The resultant tapered concrete section was surface dyed green to provide a modified contrast between the runway and the area which included the edge lights.

To provide the runway markings, 3M self-adhesive tape was used. This tape had a metallic foil base and was coated with a Traffic White paint. A stippling provided a suitable reflective surface for easy viewing. Extremely sharp edges of the runway marks could be obtained by using this tape. No difficulties were experienced with the markings which were installed to represent the U. S. Standard. Fig. 2 shows the runway marking as seen by a pilot as he approaches the runway.

## B. Fog Chamber Cockpit Simulator Modifications

### 1. Design and Motion Limits of Vertical Motion Boom.

To achieve complete aircraft flight trajectory simulation, it was necessary to add a system to the cockpit to permit vertical motion to the camera. Two basic designs were considered: a carriage assembly which would ride in a pair of vertical tracks or a pivoting boom system. It was decided that the boom system was preferable, since it would be less complex and would allow a larger vertical travel.

Numerous restrictions were necessarily imposed on the design, due to the requirement that the boom structure be lightweight, rigid and compatible with the cockpit and tramway system. These restrictions and the procedure used to determine the final design of the boom were:

The position of the tramway tracks relative to the roof support trusses in the Fog Chamber restricted the upper limit of travel of the camera to 46 inches above the normal 2-1/2° in line glide slope position.

To provide the most realistic filming, the camera should be on the normal 2-1/2° glide slope at the pilot's eye position when the boom was positioned parallel to the steel tramway rails. To effectively achieve this, the pivot point of the boom was placed 19.2 inches above the plane of the runway when the cockpit was at the touchdown point. 45 degrees above and 45 degrees below this normal position were chosen as the maximum practical vertical angular motions of the boom. Larger angular motion with a boom of substantial length would conflict with the rafters above the track and would also complicate the design of the safety breakway feature incorporated to insure that there be no damage to the boom, should it be driven into the floor of the Fog Chamber.

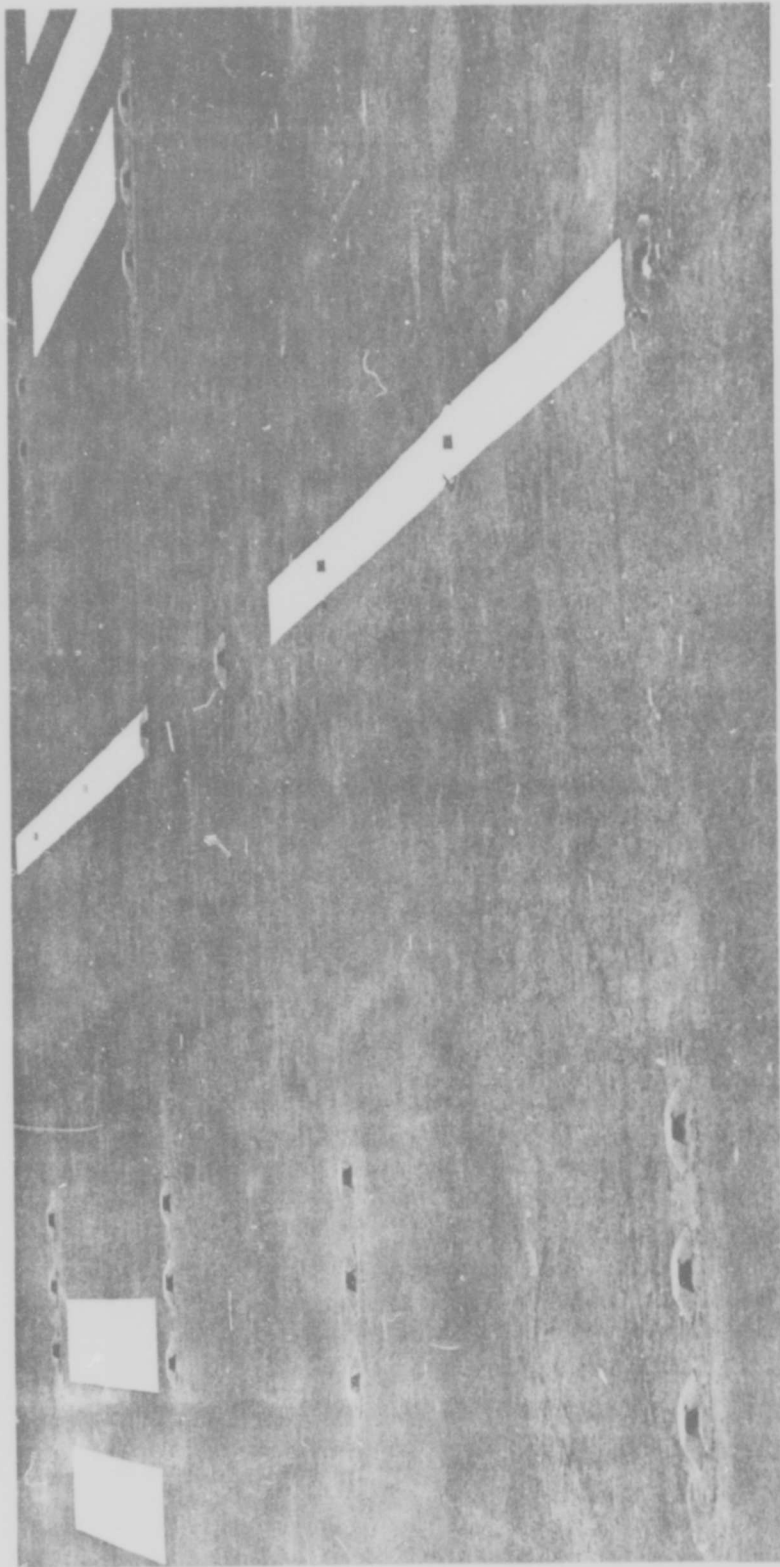


Fig. 1. Resurfaced runway showing inset light unit.

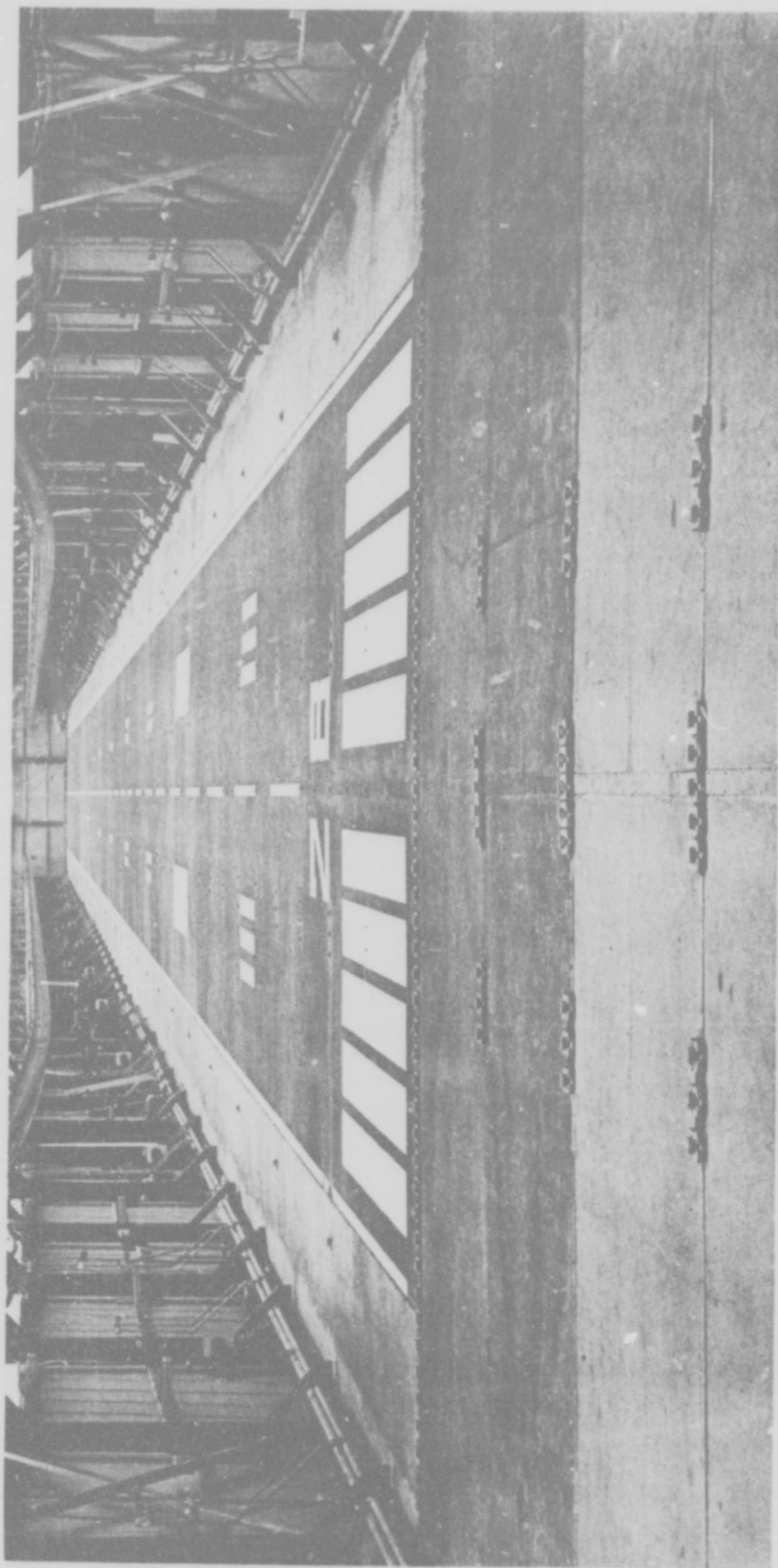


Fig. 2. Resurfaced runway as seen approaching threshold.

To minimize the power required of the boom drive system and to minimize vibration of the camera, it was necessary to counterbalance the boom so that the boom's center of mass with the camera in position would be at the pivot point. With this counterbalancing, the drive system needs minimal power, just enough power to start, accelerate, and decelerate the boom at the design rate. At constant speed, the power source needs only to overcome the frictional forces of the system. The boom also should not require any power to maintain a fixed position.

The position of the counterbalance was placed as far from the pivot point as possible to minimize the weight needed; however, the counterbalance had to be shaped by design so that it would clear the floor of the Fog Chamber with the boom at the upper limit of travel (the counterbalance at the lower limit of travel). This requirement, along with the design criteria of pivot point height and maximum angular motion, limited the counterbalance position to a maximum of 26 inches from the pivot point. Taking into account this limitation on placement of the pivot point and the center of mass of the counterweight and using an estimated weight of 60 lbs for the camera, modified camera mount and blade assembly, the total weight of the assembled boom was 500 lbs. This was considered to be the maximum additional weight which could be added to the tramway structure without exceeding its safe structural limits.

The lower limit of travel for the boom was established to provide a 1-1/2° glide slope, as compared to the normal 2-1/2° glide slope. Assuming a boom length of slightly over 7.0 ft with the camera in the lowest possible position (approximately 60 inches below the pivot point), the camera could be made to follow a 1-1/2° glide slope. To allow a small margin of useful motion, the boom length was set at 7-1/2 ft. A longer boom could have been constructed; however, the possibility of unwanted camera movement due to vibration as well as the greatly increased weight required for counterbalancing precluded a longer boom.

The most secure portion of the tramway assembly from which to hang the boom was found to be the structural members supporting the wheels for the transverse motion. Attachment to these structural steel members gave solid support for the boom to minimize vibration. These structural members also had bolted-on steel plates which could be utilized as mounts for the boom support assembly which allowed the boom to be easily removed. The spacing of these plates fixed the boom width at 30 inches.

Using these constraints on dimensions and weights, the basic structure of the boom was designed. The structure is basically a box frame with diagonal members in the sides, top and bottom. The aluminum tubing diameter was picked so the longest members would still fall within the short column length-to-diameter ratio for proper stiffness. The tubing (2.00 inch diameter with a .058 inch wall) was used throughout to simplify the work of joining the members.

The carriage assembly on which the camera system mounts is attached to the end of the vertical motion boom with a parallelogram arrangement. The top of the carriage attaches to the boom by a ball bearing mounted shaft which permits the carriage to pivot freely. The bottom of the carriage is attached back to the boom support structure by two aluminum tubes, both ends of which are on a sleeve bearing. This mounting arrangement forces the carriage to remain level with the runway as the boom is raised or lowered.

A hydraulic system was picked to drive the boom because of its inherently positive control. This hydraulic drive system also has the advantage of adding little weight to the boom assembly, since the hydraulic power unit could be placed inside the cockpit, and the 18 inch throw, 2 inch diameter hydraulic cylinders could be mounted on the boom support structure. A 1/2 horsepower hydraulic pump unit producing 300 psi was used to provide the motive force. The completed boom with camera and blade assembly mounted in place is shown in Fig. 3. Figs. 4 and 5 show the upper and lower limits of vertical travel of the boom. Fig. 6 shows the boom in a position parallel to the 2-1/2° glide slope of the steel support tracks of the tramway.

## 2. Construction of Cockpit Shell.

The Cessna cockpit shell previously used on the tramway could not be used, due to the space requirements of the new electronic controls and the mounting requirements of the boom support structure. Therefore, it was decided to build a new cockpit shell to replace the Cessna. Several advantages were realized with the new cockpit. Primarily it has the advantage of being larger in all dimensions. It has adequate head room and width to accommodate fully adjustable seats in the forward area. It also has square corners and a larger flat floor, making it much easier to install test equipment. A rear doorway makes entry from the 3rd floor platform much more convenient and the new cockpit provides a structurally sound and stable platform.

The revised cockpit was built to the maximum size allowed by the tramway structure. The cockpit frame was built from structural steel angle and "T" bar with 1/8 inch thick steel gussets in the corners for added rigidity. All joints were welded. The covering is all plywood except for the left and right sides, which are galvanized steel sheet. The front section was built to be totally removable so that various configurations of nose section could be added if desired. Thus, a nose piece could be built to provide more realism, including a simulated cockpit instrument panel and windscreen, if such were to be needed for future testing. Fig. 7 shows a portion of the interior of the cockpit with the hydraulic pump manual boom control and cockpit control console. Fig. 8 is a closeup view of the control console and the paper tape unit for automatic positioning of the cockpit, boom and camera mount.

## 3. Revisions to Camera Mount.

The original camera mount developed for the filming of the study on "Random Outages" provided three degrees of movement in pitch, roll, and yaw. Modifications to this mount were made to suit the needs of the current program.

The original camera mount moved rapidly, as all forward motion of the tramway while filming was based on 10th scale speeds. To obtain high translational speeds, large stepping motors with large step sizes were used. The development of a revised electronic control system (see Section D) permitted reduced tramway speeds, slower camera framing rates and slower camera movements. Therefore, small stepping motors with small step intervals could be mounted. These smaller motors reduced the overall weight of the camera mount and increased the step resolution from 20 minutes of arc to 2 minutes of arc.

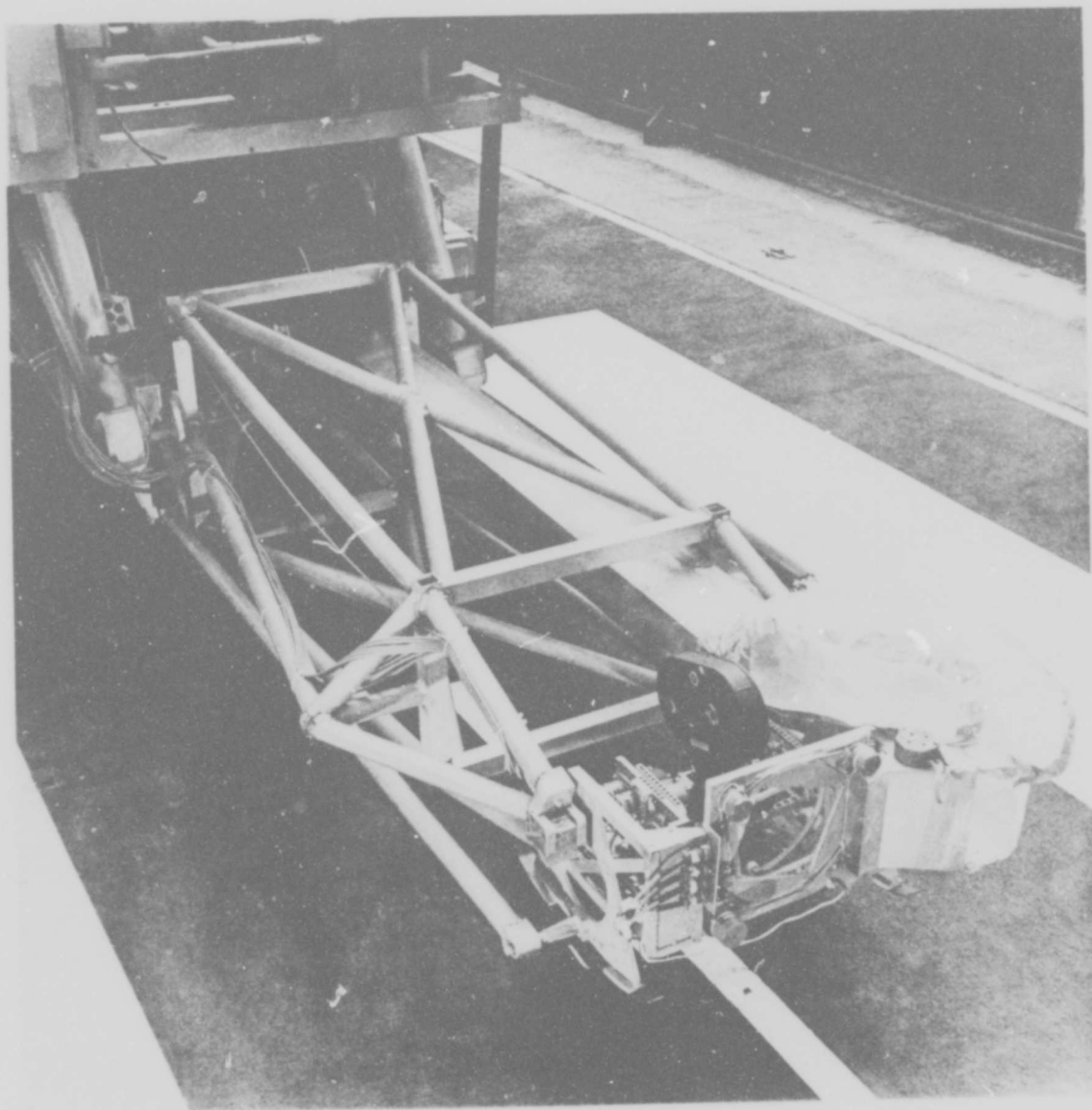


Fig. 3. Vertical travel camera boom with camera and blade assembly mounted.

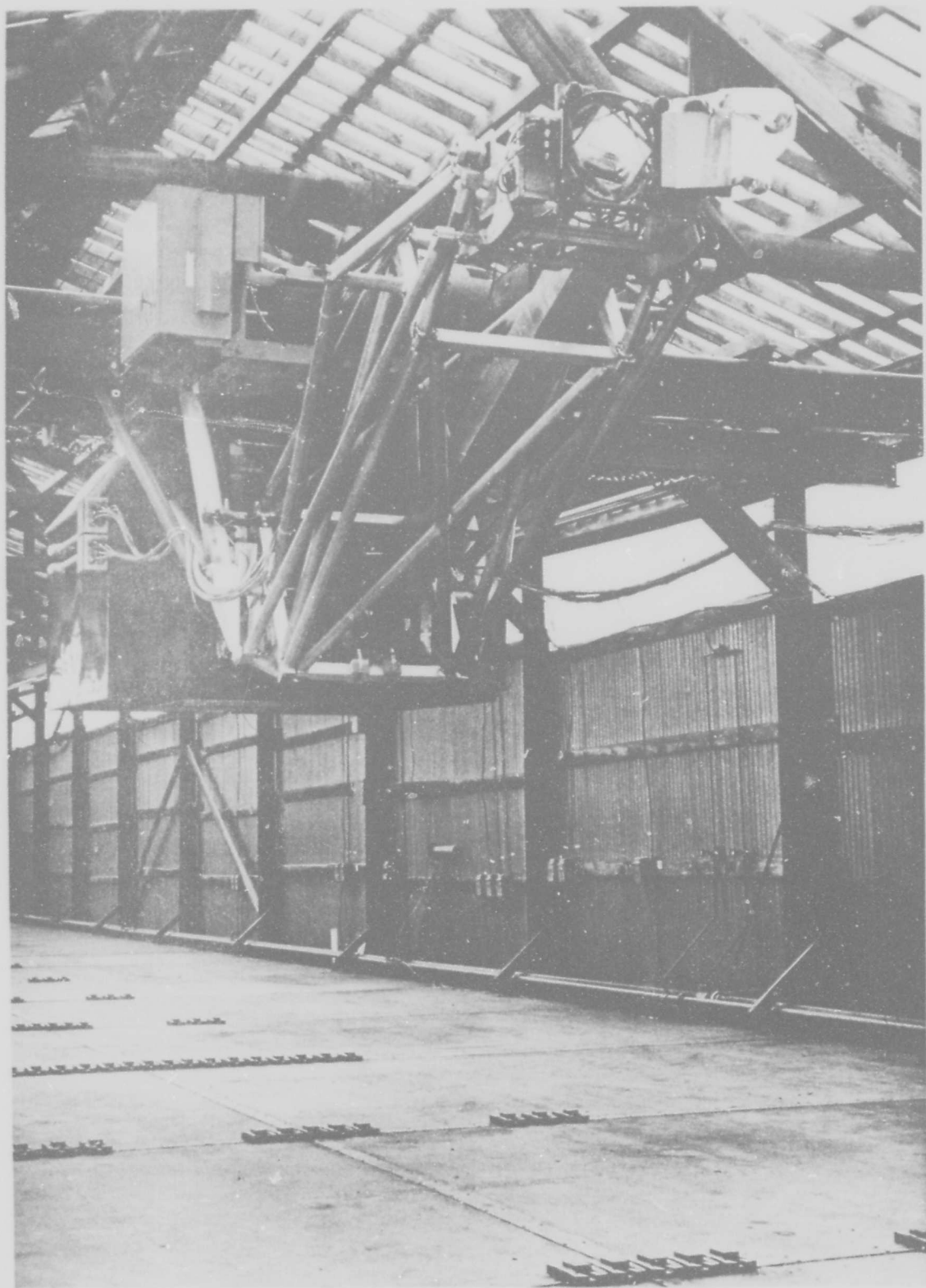


Fig. 4. Upper limit of vertical travel of camera boom.

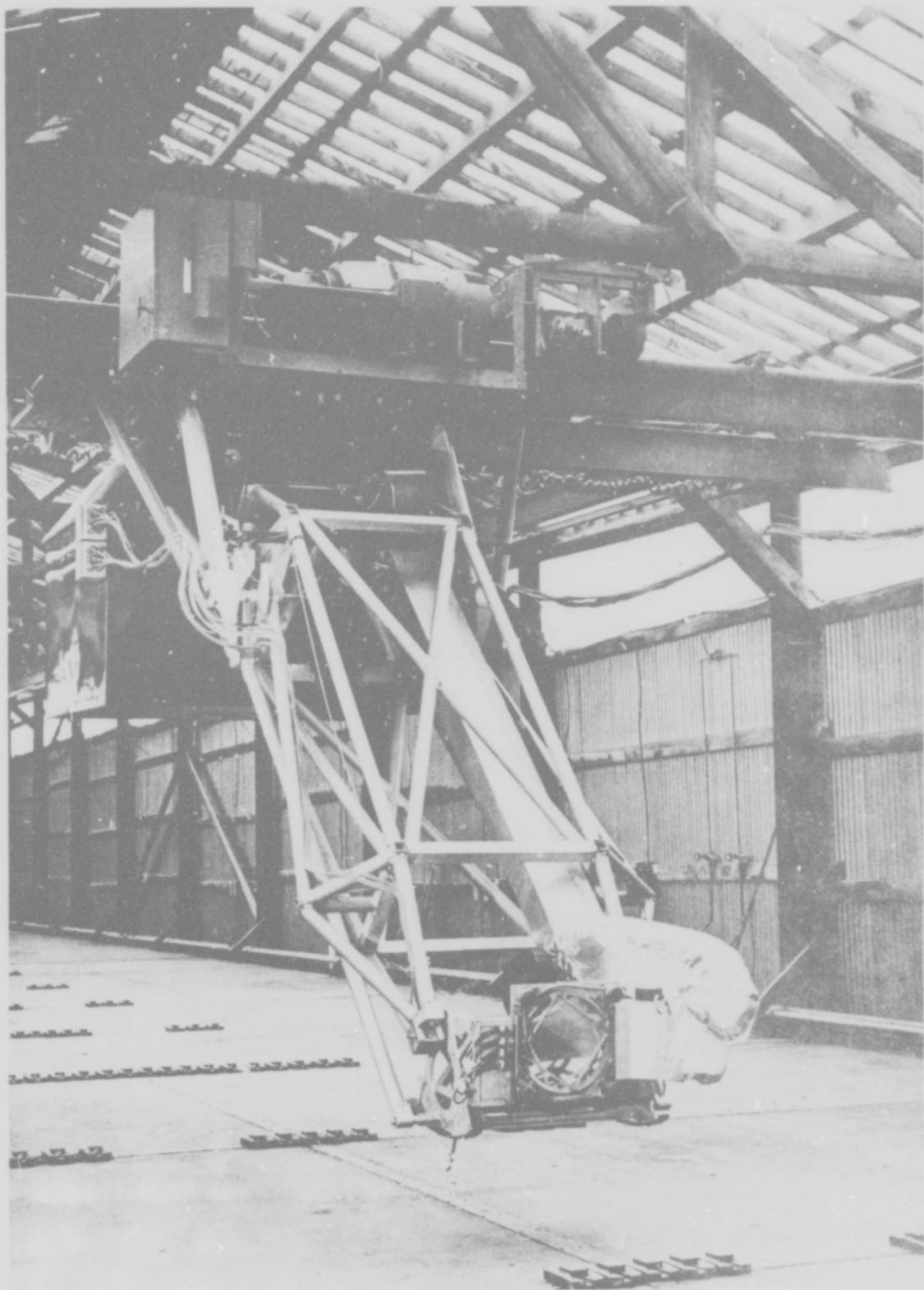


Fig. 5. Lower limit of vertical travel of camera boom.

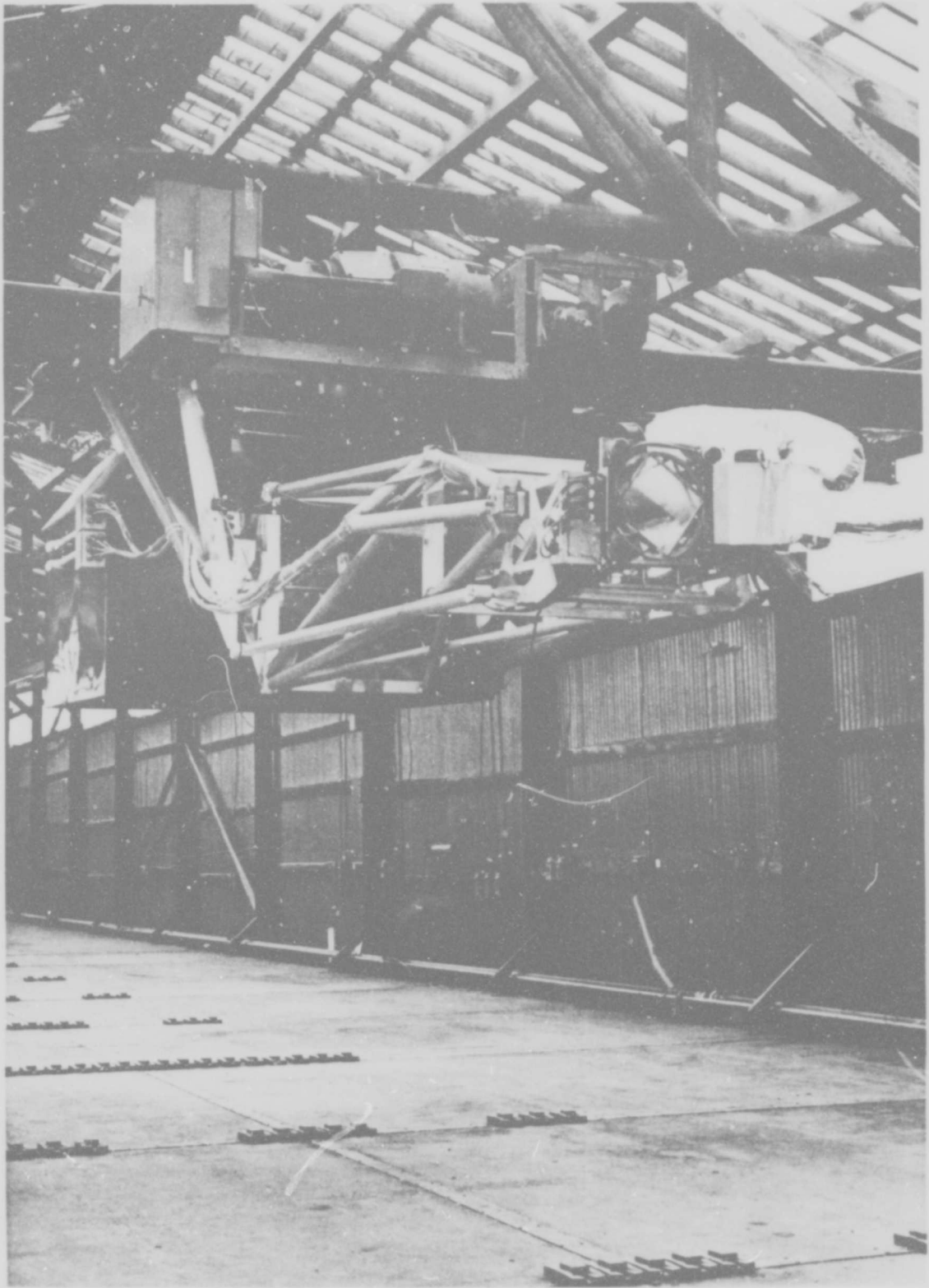


Fig. 6. Camera boom in position parallel to 2-1/2' glideslope.

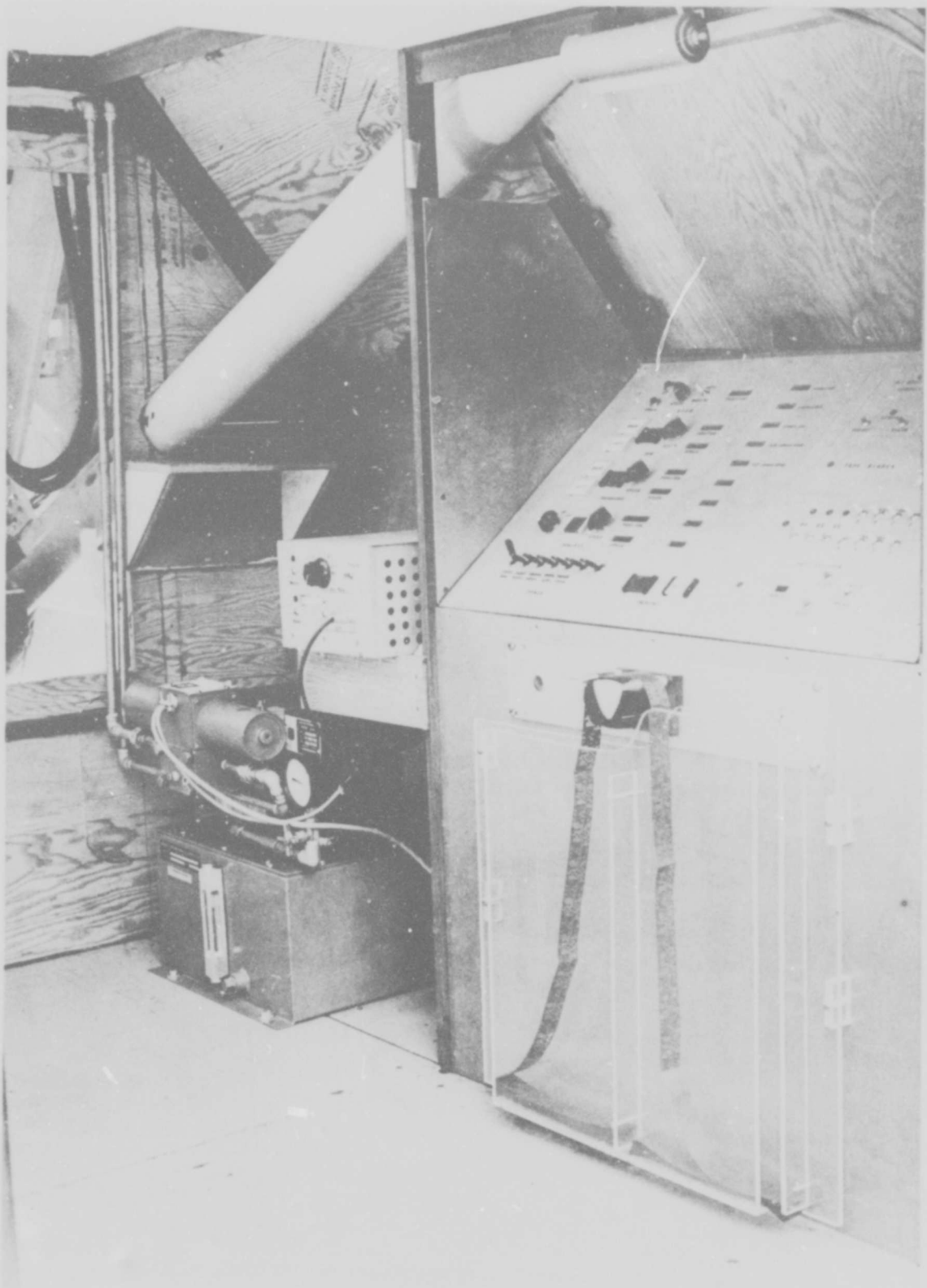


Fig. 7. Interior of cockpit showing hydraulic pump for boom operation, and control panel with tape reader.

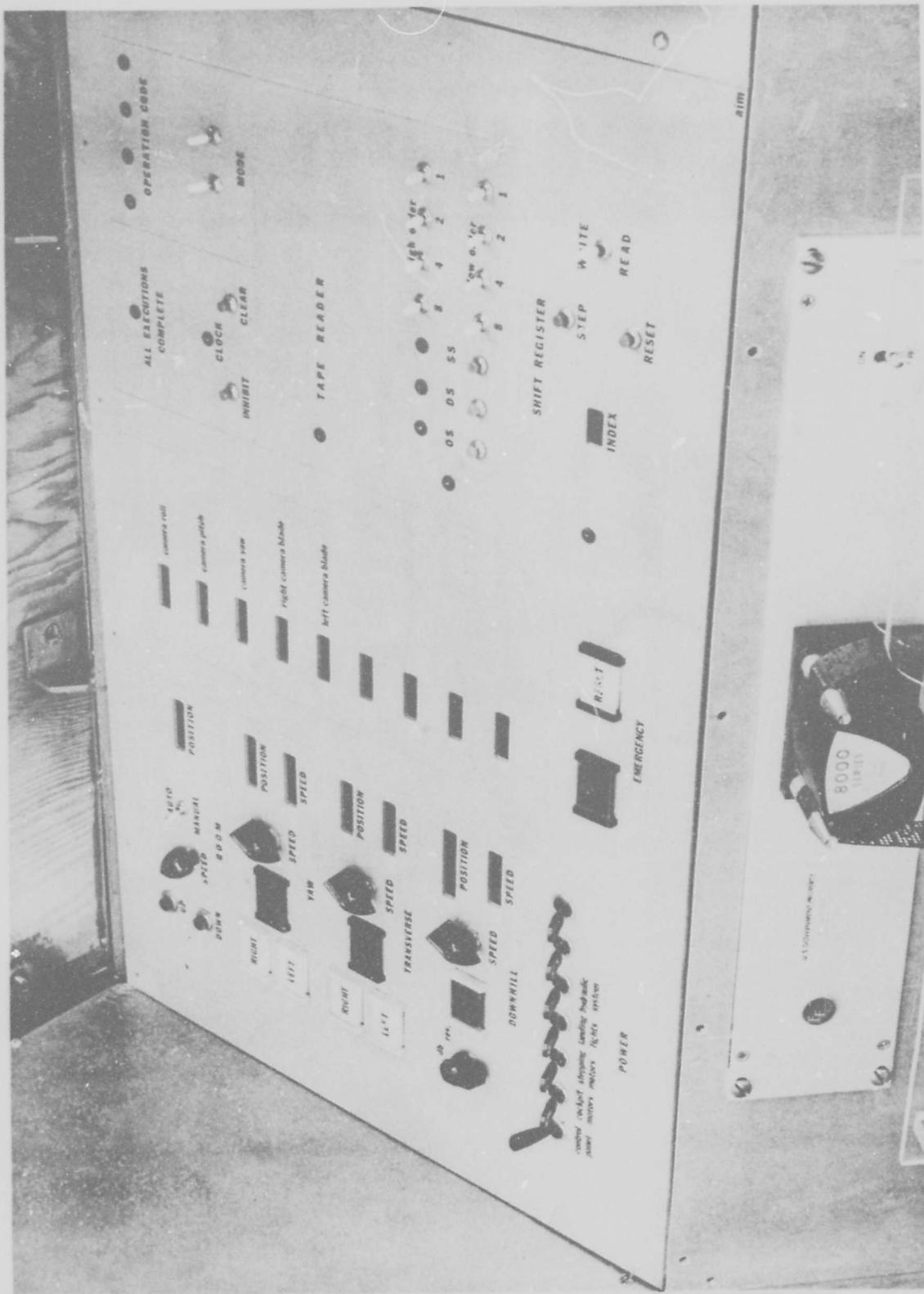


Fig. 8. Control console and tape reader for automatic flight path.

Weight was not a consideration in the design of the original camera mount. By sawing out the center portions of individual structural elements of that mount and by drilling lightening holes in other pieces, the weight of the camera mount with the smaller stepping motors was reduced from 60 pounds to 25 pounds. This reduction in weight was necessary to reduce the weight in the boom counterbalance. The modified camera mount is shown in Fig. 9.

The supplementary blade assembly previously used in filming to block out the sides of the Fog Chamber from the view of the camera was large and heavy. In the original installation it was mounted some distance in front of the camera outside the cockpit. A revised smaller model was built to achieve a weight saving of 20 pounds and dimensions commensurate with the ability to mount the unit in close proximity to the camera lens. The positioning of the translucent-to-clear blades to provide the necessary perspective view of the runway was achieved by stepping motors operated by the electronic control system. The old and new blade assemblies are shown in Fig. 10. Fig. 11 shows the camera mounts and supplementary blade assembly mounted on the boom. The plastic bag on the upper left is a part of the air blower system used to keep the glass face of the supplementary blade assembly free of water droplets.

### C. Revisions to Fog Control System

Based on the past performance of the automatic fog control system, extensive modifications were necessary to insure acceptable performance for this program. Many problems with the old fog control system had been found in the years of working with it. Specific modifications to the system were designed to eliminate these known problems. To clarify the reasoning for these modifications, it is necessary to give a brief description of the way in which that automatic system worked.

The fog control system consisted of 21 identical independent units. Each unit controlled the fog in a small section of the building. The fog transmission in each section was monitored with a transmissometer consisting of an unmodulated infrared light source at one end and a phototransistor light receiver at the other end. The sensed signal was proportional to the total amount of light seen by the phototransistor. This DC signal was then used to control the rate pulses of fog pumped into the building. The control system was built so that sufficient fog was injected into the building to maintain a fixed 2 microampere signal from the phototransistor. The normal mode of operation was to establish a uniform setting for all sections. The fog level was modified by changing the intensity of the light source. The higher the light intensity, the more fog was needed to attenuate the light beam so that only the fixed 2 microampere signal was detected.

The major difficulties experienced with this fog control system were caused by the unmodulated infrared light source and the lack of amplification in the light receiver. Using a continuous unmodulated infrared light source meant that there was no way to distinguish between the signal received from the light source and any signal received from background brightness of the fog. This created no problem during nighttime conditions. However, in some daylight conditions it was found that the background brightness of the fog yielded sufficient signal to cause the system to produce fog pulses even when the light sources were turned off. The lack of signal amplification required that the control system sense extremely small currents. Electrical leakage in the wiring system was found to create erroneous signals larger than the pulse control.

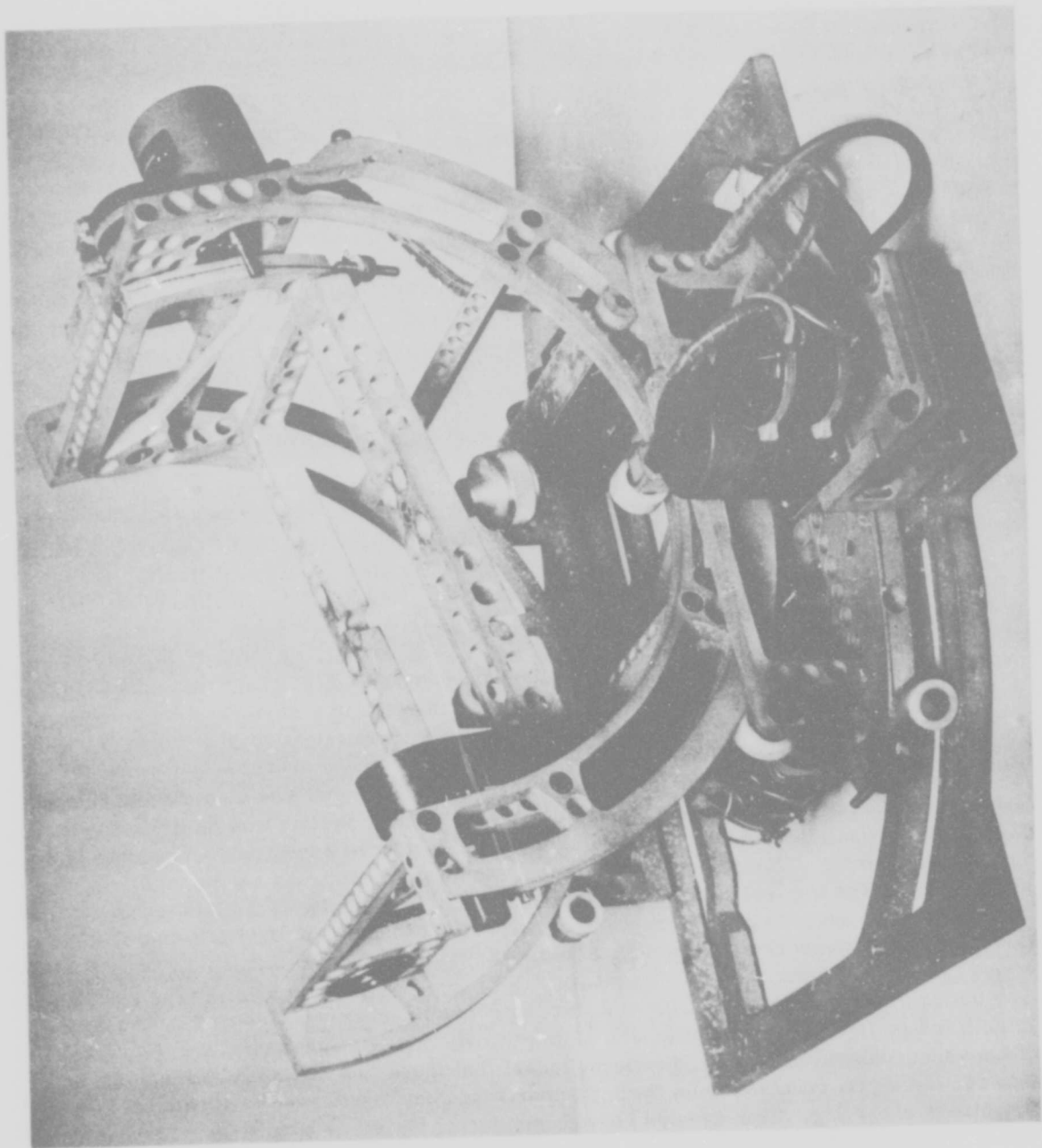


Fig. 9. Modified camera mount for pitch, roll and yaw movements.

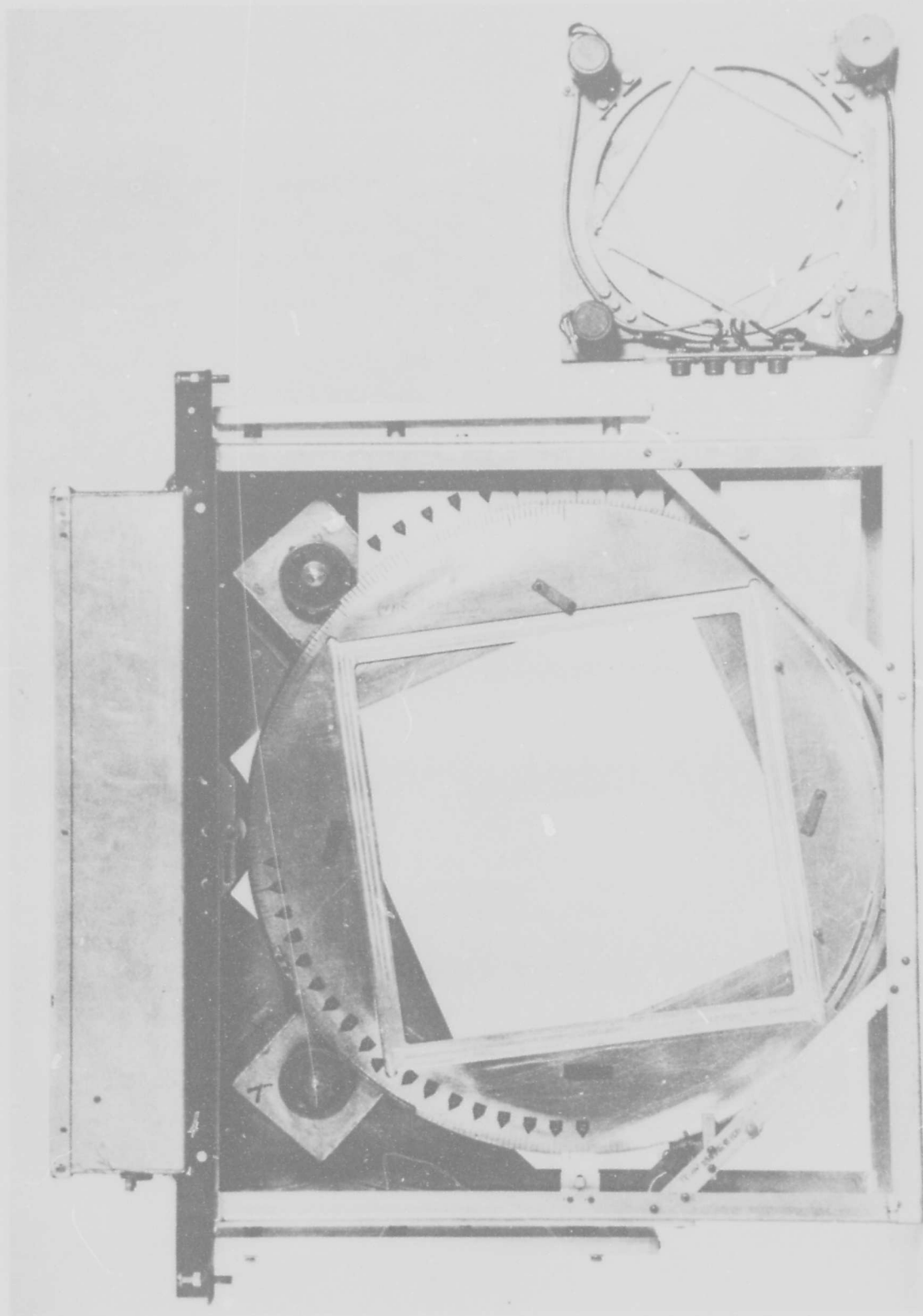


Fig. 10. Old (left) and new (right) blade assembly.

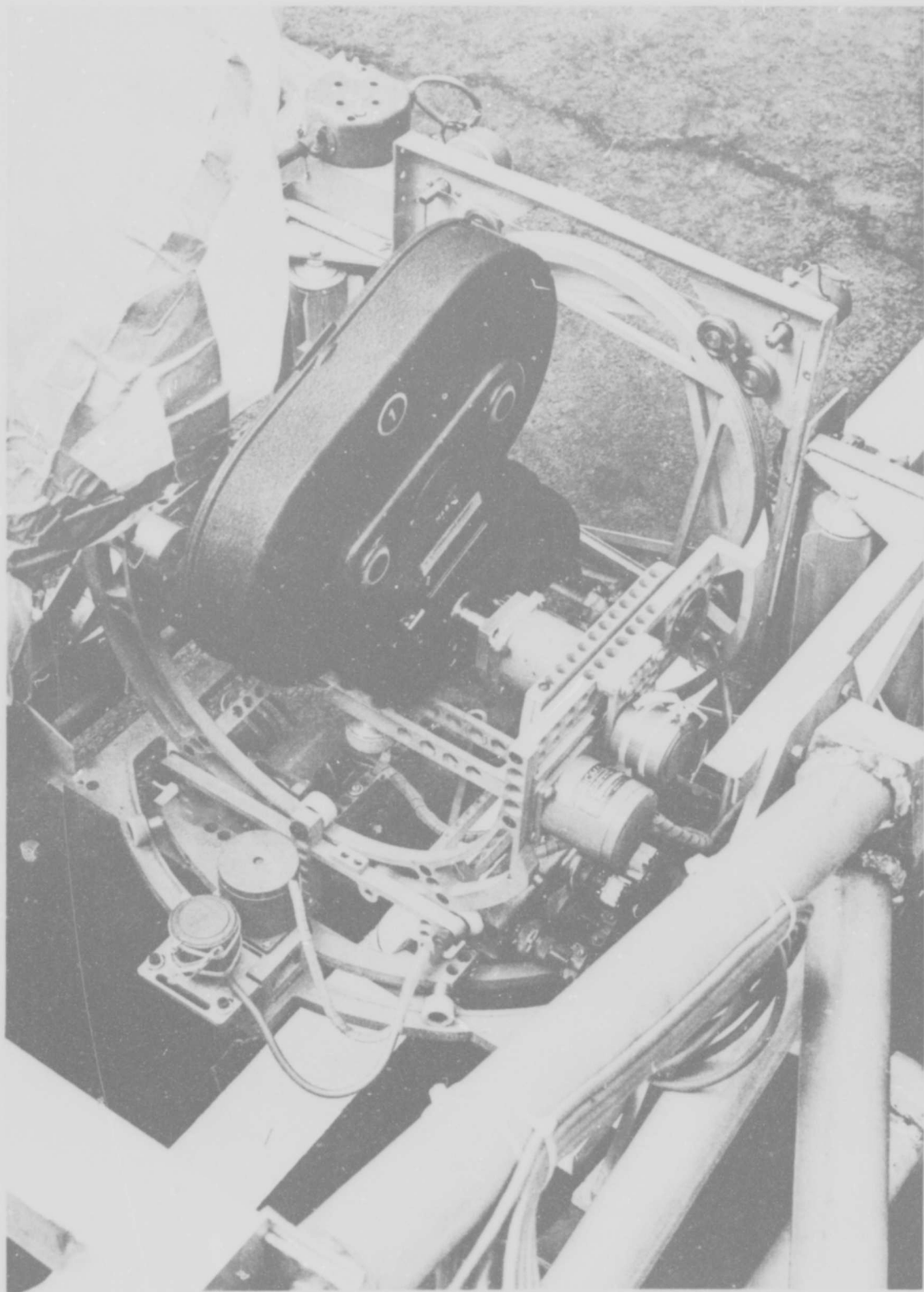


Fig. 11. Camera mount and blade assembly with blower system to reduce water droplet formation on glass.

The modified fog control system still uses the 21 sections, but also utilizes light sources which are modulated at 1100 Hertz (Infrared) and light receivers which contain two stages of amplification for the phototransistor sensor. The light receiver preamplifier is designed as a bandpass filter, allowing only signals of frequencies from 1050 to 1150 Hertz to pass. This narrow bandpass feature eliminates receiving any interfering signal caused by the background brightness of the fog and also eliminates receiving any signal which would be due to modulation of the source light signal by turbulence in the fog caused by the continuous injection of air. It was found that the maximum frequency of the turbulence was about 500 Hertz.

The pulse control system was also extensively modified to incorporate several features, including:

1. The ability to individually monitor the signal level from any fog control section, thereby allowing the operator to obtain accurate transmission data for the particular fog condition established.
2. The electronics for each section contains a variable gain amplifier which is used to calibrate the signal in that section to a 100% transmission level. This feature allows the automatic monitoring system to accurately assess the absolute transmission in each section.
3. The electronics for each section also contains a second variable gain amplifier, the purpose of which is to set the transmission of that section. This allows the transmission of each individual section to be established independently through a 100 to 1 range. This permits the development of nonuniform as well as very uniform fog densities throughout the entire Fog Chamber.
4. The electronic controls are capable of accurate adjustment to control within  $\pm 10\%$  of the desired setting (i.e.,  $\pm 70$  ft in a simulated 700 ft fog) without resorting to interim manual adjustment.
5. By providing a higher resolution, the new system extends the fog control to scale visual ranges of more than 5000 ft (500 ft real fog density). The old system could not accurately control fogs with scale visual ranges beyond 2000 ft (200 ft real fog density).
6. By elimination of all possible error signals and the addition of amplification to the light receiver, it is possible for the new fog control system to maintain lower transmission levels. It is now possible to control scale visual ranges down to 400 ft (i.e., 40 ft real fog). The lower limit of uncontrolled continuous fog in the Chamber produces fogs of 70 ft scaled visual range (i.e., 7 ft real fog).

Fig. 12 is a functional diagram of a section of the new fog control system.



#### D. Electronic Control of Camera, Boom and Canopy

The basic premise in the development of the electronic control system for the camera, boom and canopy was to provide movements of the viewing axis of the camera which would duplicate a line of sight along the flight vector of the aircraft. Thus, any track changes would be viewed just as the pilot would view them from the correct eye position in a real cockpit. This flight vector may be "flown" at any scaled speed as long as the framing rate of the camera is consistent with aircraft position; when the films are projected at normal rate, 24 frames per second, the action then resembles the actual flight with acceptable accuracy, particularly with regard to airspeed.

The control system built into the tramway canopy was designed to control up to 11 functions, of which 8 have been used during this program. These functional motions are:

- Transverse canopy motion
- Boom altitude
- Camera roll
- Camera pitch
- Camera yaw
- Camera frame rate
- Right supplementary camera blade
- Left supplementary camera blade

The automatic system controls both the speed and position of each of these motions except that the camera frame rate is dependent only on the simulated approach speed. In normal operation, the control system enters a complete instruction set for all motions every foot of travel of the canopy longitudinally down the building. A function designator is provided in 4 bits of an 8-bit binary number. The other 4 bits of that binary number sets the speed at which the function travels. An additional 8-bit binary number describes the position to which that specific function is to travel. For ordinary operation, speed and position instructions may be entered manually with switches. Under controlled operation, a pre-programmed flight path is obtained by means of punched paper tape. The system has been built so that a memory system may be added in the future to allow immediate programming of standardized flight paths. For normal paper tape operation, the sequence of control operations is as follows:

The control system receives a pulse from the rail encoder which identifies each one-foot increment of longitudinal travel of the canopy. Upon receiving this pulse, the control system steps the paper tape reader to the next instruction and reads an 8-bit binary word, 4 bits of which are operation code and 4 bits are a speed instruction. The operation code number of 5 or larger signifies one of the 11 possible functions. When the control system reads one of these operation codes, it switches the multiplexing system to the coded function. After completing this operation, it steps the paper tape reader and reads the next 8-bit word. It enters this 8-bit word as the position instruction for the same function. This completes the sequence of operations necessary to update the speed and position instructions for one function. This same sequence is repeated until the instructions for all functions are updated.

The next operation code will be a code number of 2, 3, or 4. Operation code 2 will instruct the control system to wait for the next one-ft mark from the rail encoder. When the foot mark pulse is obtained, the instruction updating sequence will begin again. An operation code of 3 instructs the control system to switch an oscillator onto the main clock line. This will cause the various motions to move to their coded positions without longitudinal movement of the canopy. This mode is used to initialize positions at the beginning of a run. In this mode, when all functions have come to the correct positions, an "all executions complete" light will turn on and from this signal, the control system will step the paper tape reader once. It should then find an operation code of 2 and at this point the operator may initiate the run. Operation code 4 signifies that the run has been completed and instructs the control system to stop all motions. Operation codes 0 and 1 are codes used internally for sequence timing.

Fig. 13 is a block diagram of the control system.

## 1. Individual Components

### a. Longitudinal Distance Encoder

A key element in the control of the individual components is the longitudinal position encoder. This device consists of a friction driven wheel running on the steel track of the tramway. The wheel has a circumference of exactly 12.00 inches, so one revolution is one ft of movement of the canopy. Attached directly to the wheel axle is a 3-segment encoder which emits 128, 16, and 1 pulse per revolution. The pulses are monitored separately to effect the control functions as previously described.

### b. Camera Drive

A stepping motor drive system was built to replace the DC motor drive system of the 35 millimeter Arriflex camera. This was done so the camera function could be run in a single frame mode. This makes it possible to frame the camera at a programmable number of frames per foot of travel of the canopy longitudinally down the building. Synchronizing the camera framing with longitudinal position allows the operator to drive the canopy at any speed or even stop the canopy without affecting the apparent flight speed of the projected film. The formula for frame rate is

$$\text{Frame rate} = \frac{142.2}{(\text{speed in knots})} \quad \text{frames/foot}$$

when the final projection is to be at 24 frames per second, and provides allowance for the Fog Chamber scale factor of 10 to 1.

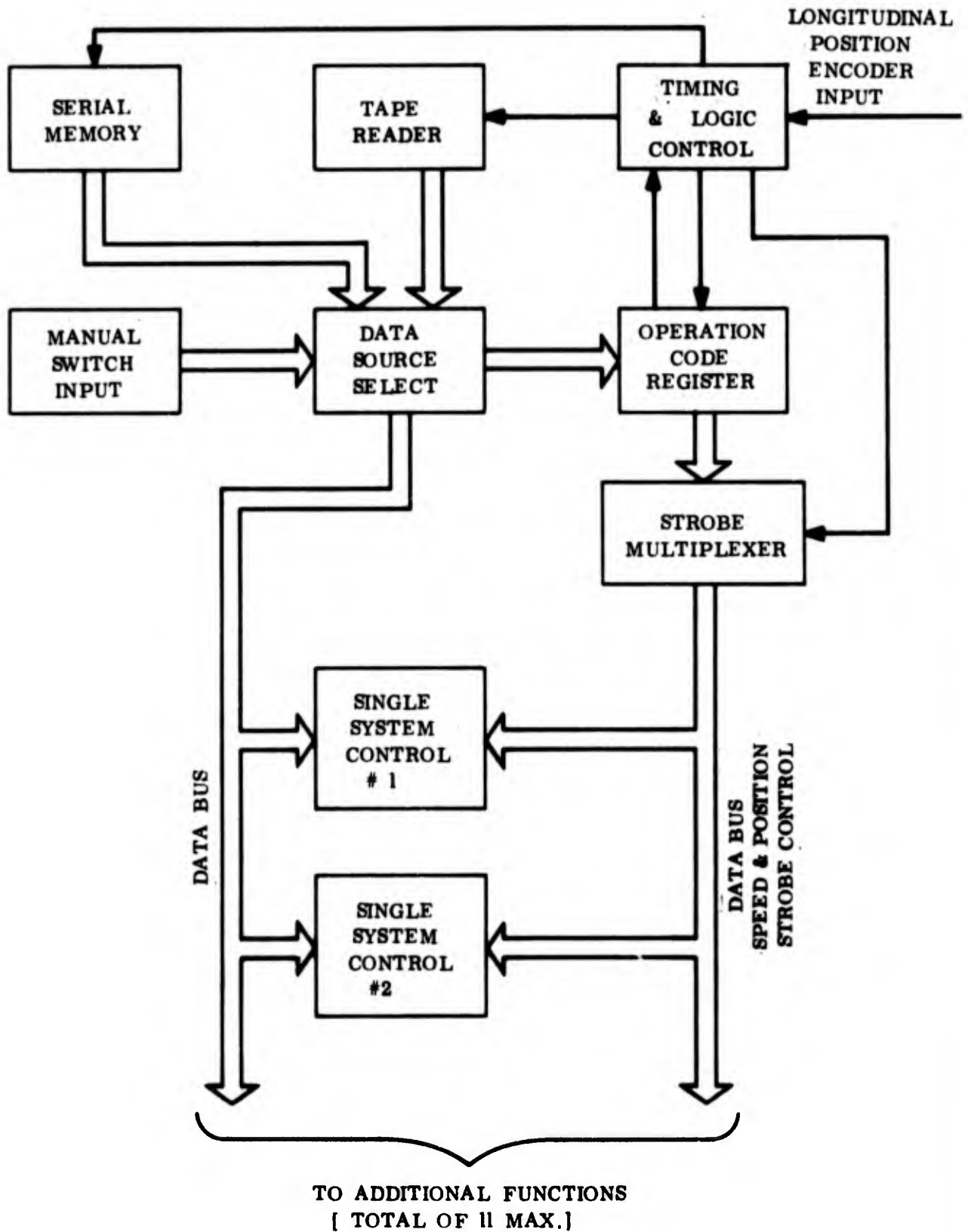
The camera frame rate is programmed with an 8-bit instruction number and utilizes the 128 pulse per foot encoder line for any synchronization. With N defined as the decimal equivalent of the 8-bit instruction number, the formula for the camera frame rate is

$$\text{Frame rate} = \frac{128}{N} \quad \text{frames/foot}$$

Combining these two formulas yields the formula for N based on the desired speed:

$$N = .900 \times \text{speed in knots}$$

The 135 knot approach speed used in the filming, therefore, requires an instruction number of 122.



**BLOCK DIAGRAM  
ELECTRONIC CONTROL SYSTEM**

Fig. 13

The electronics built to drive the camera stepping motor were built as a separate unit from the electronic control system in the canopy. This was done so that the single frame filming technique could be used elsewhere. It was built to run from either internal or external control. Operating from internal control, the camera may either be single frames from a pushbutton or run at a constant frame rate from its own internal oscillator. When switched to external control, the camera accepts a 5 volt control pulse, framing once for each pulse. When filming an approach and landing from the canopy, these control pulses are supplied by the electronic control system in the canopy.

Under normal loading and at constant pulsing, the stepping motor will not start or stop at a sufficiently high speed for this application. It was necessary to design the camera drive electronics to accelerate and decelerate the stepping motor for each frame. When the motor is signalled to move the film one frame, the electronics start the stepping motor at a rate of 150 steps per second and accelerates it to 1800 steps per second. The motor is run at this speed through most of its cycle, then decelerated and stopped. This operation is accomplished in .150 seconds. While the shutter of the camera is open, the motor is maintaining the constant 1800 step per second speed. This insures that whatever the frame rate, the film exposure time will be the same.

A block diagram of the camera drive system is shown in Fig. 14.

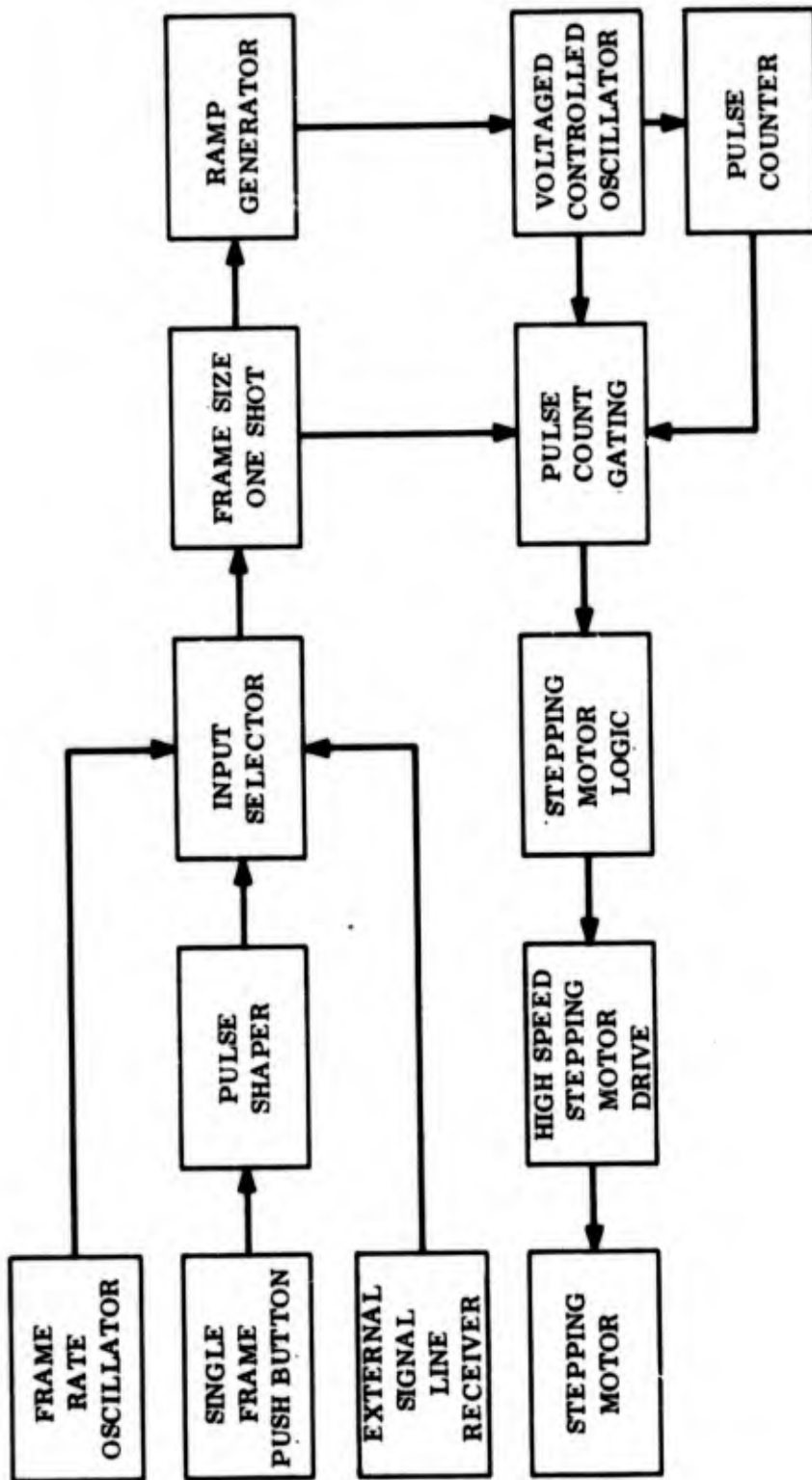
c. Camera Mount Drives and Camera Blade Drives

The electronic control systems for the camera roll, pitch and yaw stepping motors and for the right and left supplementary camera blade stepping motors are all identical systems. The following description is correct for all of them.

The position of the function is monitored with a potentiometer attached to the stepping motor drive train. The voltage signal output from this potentiometer is sampled by an analog-to-digital converter, the output of which is an 8-bit binary number. This binary number describes the actual position of the function. The electronic control system compares this number with the desired position, which is another 8-bit number stored in the position register by the main control electronics. The output of the compare operation instructs the motor drive system as to which direction to run the motor to match the actual and desired positions.

A 4-bit number stored in the speed register is used as a divider of the pulse train from the 16 pulse per foot encoder line. The output of this is a pulse frequency of between 1 and 16 pulses per foot which may be varied by changing the 4-bit number in the speed register. This output pulse train is fed to the motor control logic as the motor speed control, the stepping motor making one step for each pulse in the direction determined by the compare operation.

When the motor has been driven to the point for which the actual and desired positions match, the compare circuit instructs the motor drive logic to stop the motion. This position will be maintained until a different desired position is entered into the position register by the main control system. Both position and speed instructions may be changed at each one foot increment of travel of the canopy longitudinally down the building.



BLOCK DIAGRAM  
ELECTRONIC CAMERA MOTOR DRIVE SYSTEM

Fig. 14

Utilizing the longitudinal rail encoder for the speed base insures that the motions of the camera will occur at the correct positions and with the correct speeds relative to the motion of the canopy longitudinally down the building. The instructions for any of these motions (including camera frame rate, boom altitude and transverse canopy position) are the positions they must attain at particular locations down the building.

Because this type of speed base has been used, the speeds of the various motions are in degrees per foot or feet per foot of longitudinal travel down the building.

A block diagram of this control system is shown as Fig. 15.

d. Vertical Boom Drive

The vertical boom drive operates very much like the camera mount stepping motor drive. It uses the same potentiometer and analog-to-digital converter position measuring system. Direction of motion is determined by the same type of compare circuitry; however, for the boom drive the outputs of the compare circuitry are used to control the hydraulic solenoids.

The principal difference of the boom drive is in the speed control. It uses the same type of speed register and divide circuit; however, it utilizes the 128 pulse per foot encoder line rather than the 16 pulse per foot line. The output pulse train from the divide circuit serves as the output to a frequency-to-voltage converter. The result is a current which is proportional to the desired boom speed. The current output is used to drive a hydraulic flow control valve, which has the characteristic that it maintains a flow of hydraulic fluid proportional to its drive current. This hydraulic flow rate serves as the boom speed control. To stop the boom motion, the direction control solenoids are de-energized.

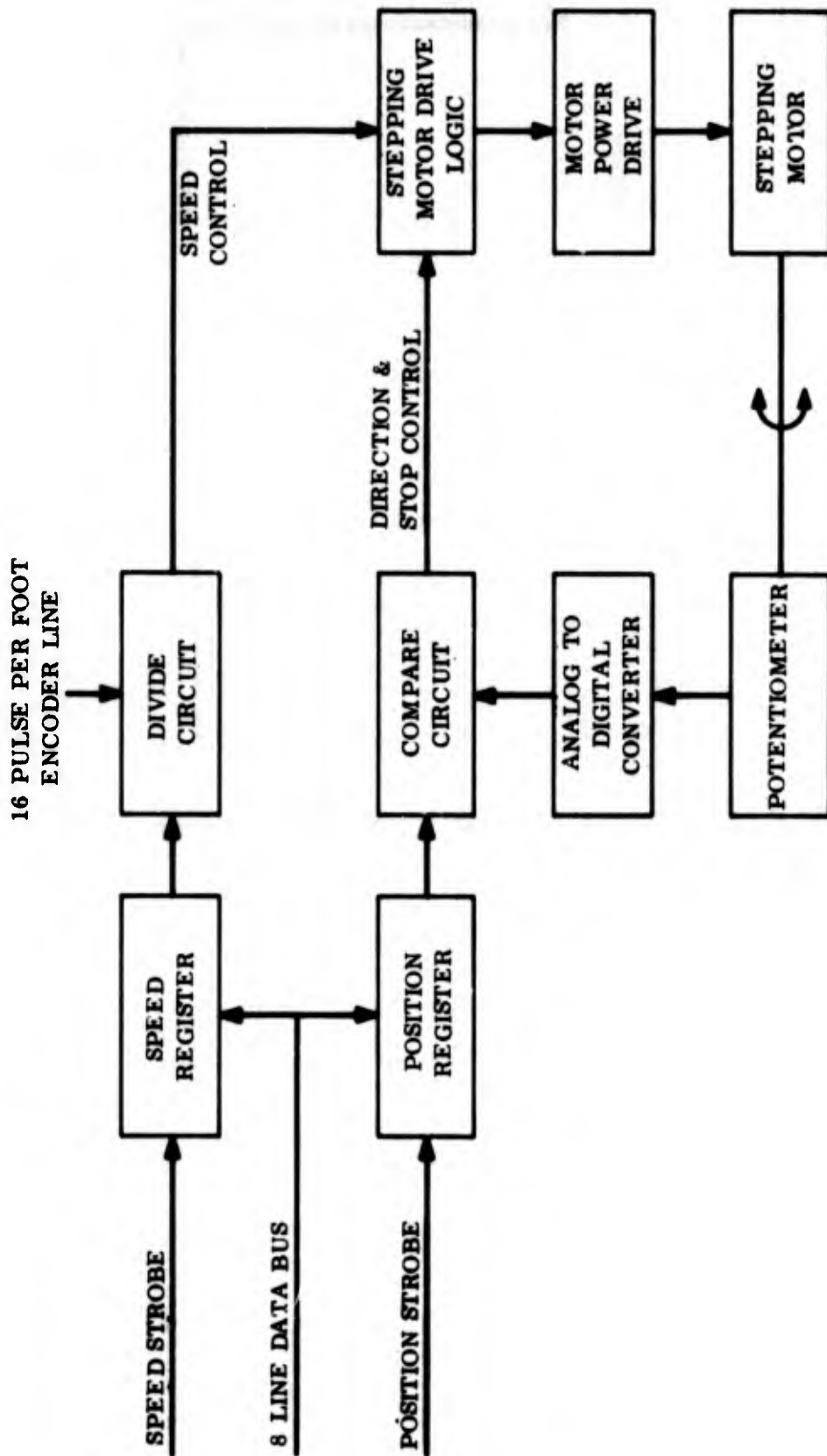
Manual control of the boom is also possible, both in direction and speed. A block diagram of this system is shown as Fig. 16.

e. Lateral Traverse Control and Drive

The lateral canopy control electronics are nearly identical to the vertical boom control electronics. The lateral canopy direction control requires one extra signal, a stop signal. The stop command is a signal output of the position comparing circuits.

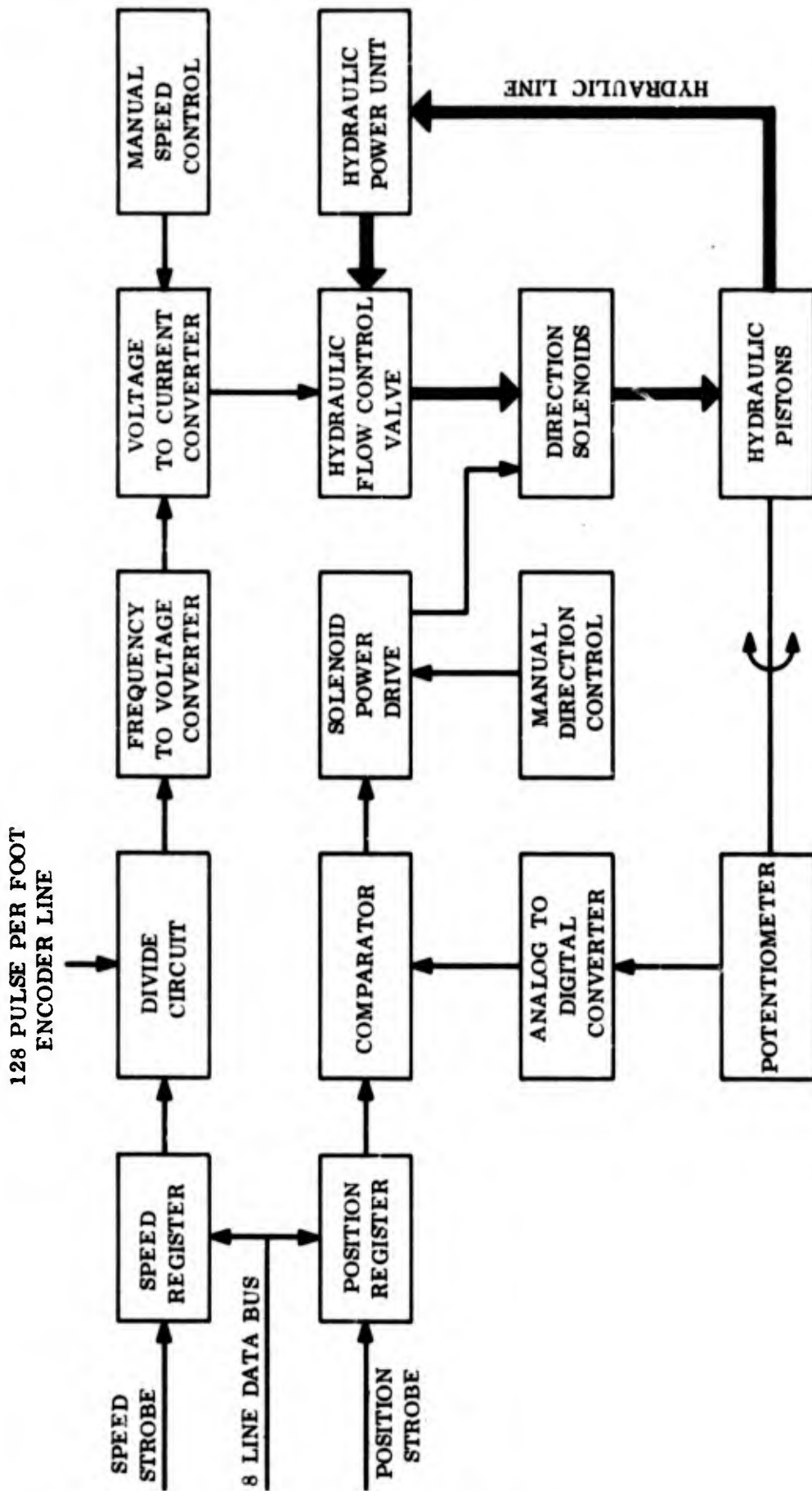
Lateral canopy motion is driven by a Boston Gear E-100 motor controller rather than a hydraulic system as used by the boom. Smooth operation of the lateral motion when direction changes from left to right were required could not be attained with this Boston Gear motor controller. A stepping motor should be used.

Manual operation is also permissible for this canopy motion by means of left, right and stop pushbuttons and a speed control knob. A block diagram of this system is shown as Fig. 17.



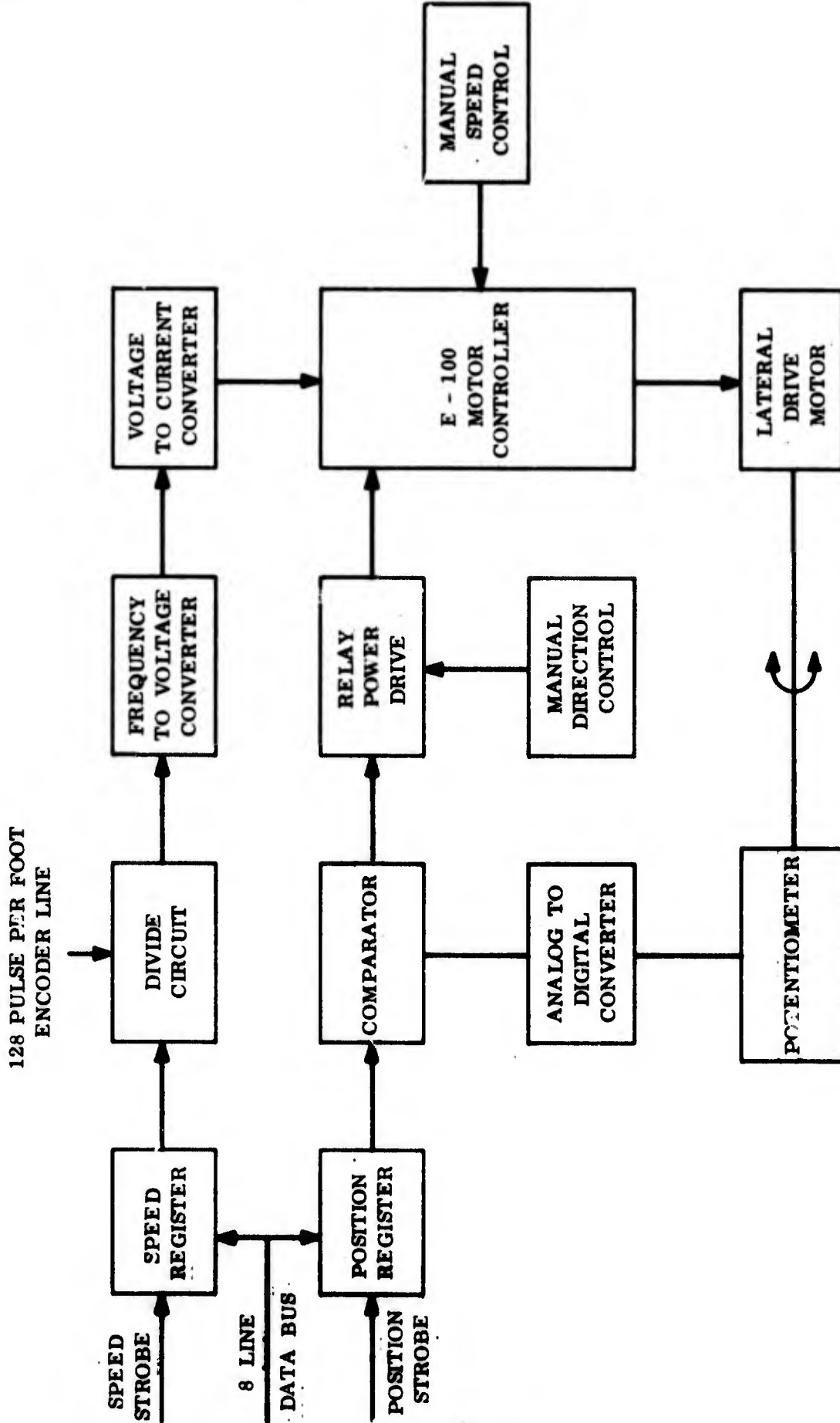
**BLOCK DIAGRAM  
STEPPING MOTOR ELECTRONIC CONTROL FOR ANY FUNCTION**

Fig. 15



BLOCK DIAGRAM  
ELECTRONIC CONTROL OF VERTICAL BOOM DRIVE

Fig. 16



BLOCK DIAGRAM OF LATERAL TRANSVERSE DRIVE  
ELECTRONIC CONTROL OF LATERAL TRANSVERSE DRIVE

Fig. 17

#### f. Computer Program for Producing Flight Trajectory Tape

Input data for the computer program consists of a set of fixed input parameters and a list of the positions the various degrees of freedom are to have at particular locations of the canopy longitudinally down the building. The fixed input parameters describe the 8-bit and 4-bit position and speed numbers equivalent to the true positions and speeds of the various functions. These algorithms are used to derive the binary coded numbers to be punched on the paper tape.

For a particular function, the program takes two successive positions and their respective longitudinal locations and calculates the position and location changes. It divides these to yield the speed required of that function for that portion of the run. Using the fixed input parameters, the program codes these speeds and positions into the binary numbers to be punched into the paper tape. Using the transverse and altitude position profiles, the program calculates the camera blade angles required and codes these angles into position and speed numbers. The speed and position numbers for all degrees of freedom for each foot of travel is punched onto the paper tape as a block of information. The blocks of information are separated by the appropriate operation code.

The actual positions and speeds to be coded onto the paper tape usually do not have exact binary equivalents. For position, the program picks the nearest binary number. For speed, the program picks the nearest slower binary speed. This is done to insure that the motions will be continuous. If a faster speed were allowed, the motor would arrive at the new position before the next instruction was issued, resulting in a jerky appearance of the motion.

Table I is a listing of the fixed input parameters. A typical position-location instrument set is given as Table II. The extra 2-1/2 degrees pitch up at the beginning of the run is that which is necessary to compensate for the pitch down caused by the slope of the tramway rails.

#### E. Pan American World Airways Flight Training Simulator Photography

##### 1. General Description

The Pan Am flight training simulator is a replica of the cockpit of a Boeing 707 aircraft. All three positions of Captain, Co-Pilot and Flight Engineer are provided. All controls and instruments are also provided. Flight conditions are simulated through computer controlled servo systems. Pilot adjustments to carry out specific tasks show on the flight instruments. The Simulator can be "flown" with two degrees of freedom to the cockpit, pitch and roll, or the cockpit can be in a fixed position and only the instruments activated for simplicity. The latter mode of operation was used throughout the filming sequences.

The Captain's seat and control wheel were removed to permit the placement of the 35 mm Arriflex camera on its tripod in the proper position to view the flight instruments as though from the pilot's eye position. In this position, the field of view of the camera, even with a wide angle lens, does not duplicate that of the binocular vision of the human eyes. The camera is limited to 60° in the horizontal direction, about 40° in the vertical. Binocular vision includes at least 130° and with recognition of movement beyond this. The limited field of view by the camera to some degree substitutes for the ability of the human eye to concentrate on a small area.

TABLE 1

NUMERICAL EQUIVALENTS OF SPEEDS & POSITIONS

DEGREE OF FREEDOM	POSITION ALGORITHM			SPEED ALGORITHM		
	0	N	255	0	R	15
CAMERA ROLL	$N = 4.88 (26.1 + P)$ P In Degrees Left Defined as Negative			$R = (.418) / S$ S In Degrees / Foot		
CAMERA PITCH	$N = 5.67 (22.5 + P)$ P In Degrees Down defined as Negative			$R = (.360) / S$ S In Degrees / Foot		
CAMERA YAW	$N = 6.57 (19.4 + P)$ P In Degrees Right defined as Negative			$R = (.313) / S$ S In Degrees / Foot		
CAMERA BLADES	$N = 2.60 (P)$ P In Degrees Vertical Defined as Zero			$R = (.790) / S$ S In Degrees / Foot		
CAMERA FRAMING	$N = .900 (Q)$ Q Is Simulated Speed in Knots					
COCKPIT TRANSVERSE	$N = 127.5 (P)$ P In Feet Left defined as Negative			$R = (.400) / S$ S In Feet / Foot		
BOOM ALTITUDE	$N = 129 + 2.57 \sin^{-1}$ $(.134 P - .01)$ P In Feet			$R = .200 \cos$ $(-50.3 + .389N) / S$ S In Feet / Foot		

N = Decimal Equivalent of Binary Position Number

R = Decimal Equivalent of Binary Speed Number

P = Actual Position

S = Actual Speed (All Speeds in Degrees Per Foot or Feet Per Foot of Longitudinal Travel)

TABLE II

INSTRUCTION SET TAPE NO. 18	ROLL		PITCH		YAW		
	D	P	D	P	D	P	
APPROACH SCENES #2	0.0 1000.0	0.0 0.0	0.0 330.0 344.0 380.0 394.0 410.0 490.0 510.0 520.0 565.0 1000.0	+3.0 +3.0 +3.4 +6.6 7.0 +7.0 +4.5 +4.5 +4.3 0.0 0.0	0.0 250.0 310.0 610.0 650.0 1000.0	0.0 0.0 +1.0 +1.0 0.0 0.0	
DESCRIPTION 50 Ft. Right Offset							
CONDITIONS 700, 1200 Ft. RVR							
THRESHOLD 350 Ft.							
TRANSVERSE		BOOM		CAMERA		OPERATION INST.	
D	P	D	P	D	Q	D	P
0.0 260.0 310.0 470.0 610.0 650.0 1000.0	+5.0 +5.0 +4.8 +2.5 +0.4 0.0 0.0	0.0	0.0	0.0 600.0 890.0 940.0 1000.0	135 135 80 60 60	980.0	Op. Code "4"
<u>SUPPLEMENTARY CAMERA BLADES</u>							
Internal computer programming produces the proper blade angles.							

TYPICAL POSITION-LOCATION INSTRUCTION SET  
FOR PREPARING PUNCHED TAPE

A 25 mm focal length lens was selected to give increased size to the flight instruments in the projected view. To further emphasize the instruments, the lower portion of the field of view which contained the rudder pedals was masked off by black drapery material. The camera was positioned 34" from the Flight Director. The Flight Director was also used as the center of the field. Since this instrument is positioned only slightly below the glare shield, a small portion of the Captain's window was also included. By keeping this minimal, the need for moving mask composites was avoided.

Lighting for the instrument panel was provided by several 100 watt incandescent light bulbs which operate at approximately 3500° Kelvin. The principal object was to provide flat, even illumination without reflections from the various instrument faces, bezels, or control knobs. Where necessary, on the latter two, flat black poster paint or black photographic masking tape was used to eliminate unwanted reflections. The level of illumination was, of course, several hundred times that of the usual cockpit lighting. In normal cockpit operation at night, flight instruments and tell-tales are back lit. For the filming, the current to the bulbs was raised to the permissible maximum, but they did not have sufficient self-illumination to photograph well.

Two levels of overall flat lighting were used during the filming, 650 ft Lamberts to represent daylight cockpit conditions and 450 ft Lamberts to represent nighttime cockpit conditions. These values were read on a Taylor-Luckiesh spectral light meter.

All filming was done on Eastman Kodak 35 mm #5254 color negative film which has a film speed of approximately 100 ASA. No filter is required for night filming.

All processing of film was performed by Film Effects of Hollywood, using Technicolor Laboratories facilities. From the #5254 color negative, prints are made on Eastman #20 color positive film. The principal problem as is usual with experimental photography is to get the proper color balance and exposure in the printing. The technically correct procedure is to print to the best rendition of the color from the technician's viewpoint, not actually what was "seen" by the camera. Close cooperation with Mr. Don Weed of Film Effects made it possible to achieve good color balance and exposure even when negative material was not always consistent as to exposure, due to light fluctuations. This was particularly true of Fog Chamber photography. Further detail on methods of compositing are given in the section on Fog Chamber filming.

## 2. Pan Am Filming Technique

In the Pan American World Airways, Inc., training simulator, the filming technique was kept as simple as possible. With the simulator operational, the pilot, controlling from the right or co-pilot's position, performed a simulated approach. As the instruments would indicate a certain altitude and aircraft position, the camera would be turned on, filming at 24 frames per second. The camera would continue the exposure until the instruments indicated that the aircraft had completed the desired maneuver. Then it would be stopped. Then the pilot would return the simulator to the proper altitude and attitude for the next approach in the series.

The validity of the approach was, of course, a function of the pilot's ability to control the simulator. Just as in a real aircraft, certain maneuvers are near the limits of the aircraft and the simulator. To perform good approaches, the pilot must understand and be able to "fly" the simulator close to these limits. Anytime the pilot felt that he had not been able to follow the prescribed flight trajectory, a re-run would be made immediately.

Each "approach" flown on the simulator was carefully planned in advance and the pilot worked from a scenario. This scenario was prepared by Capt. James I. Fleming, former Senior Pilot with Pan American World Airways, Inc. His great skill and experience in flying and previous work at Pan American in the training of pilots was most valuable in establishing the specific parameters for the flight trajectories. In addition to preparing the scenario, Capt. Fleming viewed the finished films on a frame-by-frame basis and plotted the resultant flight trajectories in graphical form. These graphs were then translated by computer programming into punched paper tape. The paper tape then, as previously described, was used to "fly" the camera on a matching trajectory in the Fog Chamber. A total of 32 approaches were flown by Capt. William Ballinger of Pan American World Airways. Of these 14 were selected for inclusion in the Film Library. The filming scenario and typical log sheets are given in Appendix A. Table III identifies the cockpit simulator material in the Film Library. (Page 35)

#### F. Fog Chamber Filming

The filming techniques used in the UC-FAA Fog Chamber were kept as simple as possible. The 35 mm Arriflex camera mounted on the boom was controlled by the electronic system previously described. Film used was Eastman Kodak #5254 color negative. The following sections give more detail of certain portions of the filming procedures and results.

##### 1. General Comments

Fog Chamber filming was done with the Arriflex 35 mm camera with the 25 mm lens, using an effective shutter speed of 1/30th of a second and High Speed Ektachrome color negative film #5254. For all daylight filming, the lens was stopped down to f8 with no filter. For all night filming, the lens was set at f3.5. For dusk shots, optimum results were obtained using a lens stop of f9.5 and a number 85 Kodak daylight filter. Because of the rapid transition from daylight to dark, no satisfactory results were obtained by filming dusk approaches under actual dusk conditions.

##### 2. Limits of Motion

Table IV is a summary of the limits of motion of the various degrees of freedom used during the filming.

TABLE IV

Motion	Limits
Camera Frame Rate	1.11 knots to 284 knots (simulated speeds)
Camera Roll	26° right to 26° left
Camera Pitch	12° down to 17° up
Camera Yaw	12° down to 12° left
Boom Altitude	60" down to 46" up
Transverse (canopy)	7.5' right to 7.5' left

TABLE III

COCKPIT SIMULATOR FILM CATALOG

Legend

Scene No.	Take No.
Date of Filming	Movie Scene
Head Frame	Tail Frame

APPROACH NUMBER	APPROACH DESCRIPTION Note: All Approaches at 135 Knots Air Speed	SCENE CATALOGING			
		NIGHT COCKPIT		DAY COCKPIT	
1	Start 800 ft Alt-Heading 281° -cross 100' Alt point with PDI indicating 100' Right of Centerline. Execute missed approach at 80' continue to 300' Alt Heading 281°.	301 12-21-61 E55X93825	2 1A 93945	601 2-8-72 E58X44228	1  44349
2	Start 400 ft Alt-Heading 281° -cross 100' Alt point with PDI indicating 50' Right of Centerline, at 80' start left turn to heading 275°.	302 12-21-71 E55X94074	1  94173	602 2-8-72 E58X44350	1  44414
3	Start 400 ft Alt-Heading 281° -cross 100' Alt 100'. Left Centerline at 80' initiate right turn to 295° prior to TD. Execute missed approach on Heading 295° to 300' Alt.	303 12-21-71 E12X29723	1  29794	603 2-8-72 E58X44483	2  44556
4	Start at 800 ft Alt-Heading 281° -on localizer and Glide Slope continue to TD & Rollout to 60 knots.	304 12-21-72 E12X29798	1  29943	604 2-8-72 E58X43823	1  43980
5	Start 400 ft Alt-Heading 281° -on localizer 50' below Glide Slope - Terminate at touchdown short of runway.	305 12-21-71 E12X29947	1  30018	605 2-8-72 E58X44557	1  44627
5A	Start 400 ft Alt-Heading 281° -on localizer Aim point at leading edge of ground segment resulting in "Teaspoon or Duckunder" approach. Terminate in TD short of Runway.	305 12-21-71 E12X30021	2  30071	None	
6	Start 400 ft Alt-Heading 269° (12° crab angle) on localizer and Glide Slope-at 80' adjust heading to 281° by yawing aircraft. Prior to TD execute missed approach on Heading 281° to 300'.	306 12-21-71 E58X45042	1  45116	606 2-8-72 E58X43982	1  44053
7	Start 400 ft Alt-Heading 269° (12° crab angle) on localizer and Glide Slope - continue to just prior to TD - de-crab, land and continue rollout to 60 knots.	307 12-21-71 E58X45120	1  45210	607 2-8-72 E58X44053	1  44121

Additional Film Strips

607R, 2-28-72, Day-P.A. -C-165° f 8. - 25 mm lens  
Touchdown & Rollout to Stop. P.A., E58X44122 - 44173

701-1, 2-28-72, Exposure Selection - P.A. -C-165° f see below, 25 mm lens  
Captain's Windshield - Exposure f. 5.6-8-11-16-22.

Of these, the drive systems for camera roll, pitch and yaw and transverse canopy position were built prior to this program and their limits of motion could not be changed without extensive modifications. It would have been preferable to increase the position limits of the transverse motion. However, completion of the necessary modifications was not within the scope of this program. A more precise control of transverse speed would also have been preferable; however, this too could not be accomplished within the scope of this program. The design criteria leading to the limits of motion for boom altitude and camera frame rate have been discussed in previous sections of this report.

As mentioned previously, the degree of precision which could be obtained from the transverse motor control was not satisfactory. The transverse motor control was not adequate for some of the more complex approaches filmed. Improvement was made by re-programming the approach paths to reduce the precision required, but even then a somewhat jerky motion was easily seen in the finished film. To improve the results would require replacement of the motor control system and motor and possibly the motor drive train. Good results could be obtained for the simpler approaches requiring transverse motion by careful flight path programming and careful adjustment of the transverse motor controller just prior to the run.

### 3. Schedule of Films and Conditions

Filming of the Fog Chamber approach scenes began on May 9, 1972 when the basic control system was complete and the simplest of the approach paths could be simulated. As the control systems for other motions were completed, the filming schedule was expanded to include more complex approach paths. The first scenes shot were used as tests of the electronic and mechanical systems and of the photographic parameters. Changes were made to solve these problems and after 31 unsuccessful takes, the first useful scenes were filmed on June 1, 1972. During May, June and July, a total of 162 takes were filmed to obtain the final 68 approaches to comprise the Film Library. 23 work shifts and approximately 11,000 ft of film were used to complete the Fog Chamber filming. Table V gives the Fog Chamber scenes which are included in the Film Library. Complete graphical descriptions of 14 approach paths as prepared by computer analysis are shown in Figs. 18-31. The numerical list indicates 18 approaches. Number 1 and number 2 are identical except for boom height adjusted to the 45' eye height. Approaches 3, 4 and 5 are static scenes taken from a point directly over the 800 ft bar of the approach lighting system. The movement depicted in each of these three scenes was manually controlled. The 800 ft bar which gives an eye height altitude of 91.4 ft or a wheel height altitude of 75.4 ft, was chosen for good appearance of the remaining approach system, threshold and runway.

### 4. Film Library Composition and Utilization Procedures

The film library consists of a total of 85 positive print film sections -- 17 Pan American cockpit simulator scenes and 68 Fog Chamber scenes. The former are listed in Table III the latter in Table V. In each of these tables, the format is similar. The approach path is identified, a description of the approach is given, the conditions of the filming (i.e., day, night, visibility, etc.) and the scene is identified as to number, take, date of take, and the film footage numbers of head and tail frame. This latter number is the footage number of the negative and is used in identifying the film to be printed by Film Effects of Hollywood.

TABLE V

SCENES USED TO COMPILE FILM LIBRARY

Legend

Scene No.	Take No.
Date of Final Take	Movie Scene
Head Frame	Tail Frame

Approach Path No.	Description	Scene Cataloging (See Legend)							
		Day 1200' VR		Day 700' VR		Night 1200' VR		Night 700' VR	
1	Approach, ICAO 16 ft. Eye Ht.	020	2	024	2	009	8	014	4
		6/26/72	I-1A	6/22/72	-	6/1/72	I-1A,3	6/22/72	-
		E63X48238	E63X48316	E63X43458	E63X43520	E59X35440	E59X35518	E55X27673	E55X27731
2	Approach, ICAO 45 ft. Eye Ht.	021	1	029	1	012	3	013	4
		6/22/72	-	6/26/72	-	6/1/72	I-3A	6/22/72	-
		E55X87602	E55X87680	E55X28377	E55X28455	E59X35355	E59X35433	E55X27595	E55X27666
3	Static Pitch, ICAO	039	2			005	4		
		6/26/72	-			6/1/72	I-2		
		E63X49191	E63X48208			E55X94725	E55X94748		
4	Static Yaw ICAO	040	2			007	3		
		6/26/72	-			6/1/72	I-2A		
		E63X48213	E63X48231			E55X94755	E55X94780		
5	Static Transverse ICAO	041	3			006	3		
		6/28/72	-			6/1/72	I-2B		
		E63X43209	E63X43221			E55X94781	E55X94818		
6	Approach With Roll, ICAO	022	2	030	2	010	3	015	3
		6/26/72	-	6/22/72	-	6/1/72	-	6/22/72	-
		E63X47140	E63X47218	E63X43525	E63X43587	E59X35526	E59X35605	E63X47963	E63X48017
6	Approach with Roll, Centerline Lights	050	2	036	2	011	2	016	2
		6/26/72	-	6/26/72	-	6/1/72	-	6/1/72	-
		E63X47438	E63X47529	E55X28301	E55X28370	E55X81440	E55X81518	E55X81283	E55X81354
7	Approach With Yaw, ICAO	023	2	031	2	026	3	018	3
		6/26/72	-	6/22/72	-	6/29/72	-	6/22/72	-
		E63X47223	E63X47301	E63X43593	E63X43672	E63X47857	E63X47935	E63X48027	E63X48099
7	Approach With Yaw, Centerline Lights	051	2	037	2	069	2	017	3
		6/26/72	-	6/26/72	-	6/29/72	-	6/29/72	-
		E55X28143	E55X28222	E55X28228	E55X28296	E63X47773	E63X47851	E63X47620	E63X47687
8	Oscillating Transverse Approach, ICAO	052	2	032	1	028	3	027	4
		6/29/72	-	6/22/72	-	6/29/72	-	6/29/72	-
		E55X27934	E55X28012	E63X43680	E63X43758	E58X72838	E58X72915	E63X47540	E63X47615

TABLE V. SCENES USED TO COMPILE FILM LIBRARY (continued)

Approach Path No.	Description	Scene Cataloging							
		Day 1200' VR		Day 700' VR		Night 1200' VR		Night 700' VR	
8	Oscillating Transverse Approach, Centerline Lights	052	3	038	4	075	2	059	1
		6/29/72	-	7/5/72		6/29/72		6/15/72	-
9	Roll, Yaw, Transverse Combination, ICAO	E55X28018	E55X28096	E58X73118	E58X73191	068	3	E63X49828	E63X49899
						7/20/72	I-4A		
9	Roll, Yaw, Transverse Combination, Centerline Lights					E63X48927	E63X48989		
						077	1		
10	Out of Limits Missed Approach 75' R. of Δ, ICAO	043	2	033	2	060	1	054	1
		6/26/72	-	6/22/72	-	6/6/72	II-1	6/6/72	-
11	Within Limits Landing, 50' Right of Δ, ICAO	E55X87685	E55X87710	E63X43766	E63X43787	E57X05677	E57X05703	E57X05643	E57X05699
						067	1	057	2
12	Excessive Track Change Missed Approach, ICAO					6/15/72	II-2	6/15/72	-
						E60X71727	E60X71797	E63X49597	E63X49667
13	Teaspoon Approach ICAO	046	2			062	4		
		6/29/72	-			7/20/72	II-3		
14	Approach 50 feet Below Glideslope, ICAO	E55X27806	E55X27851			E63X48867	E63X48894		
		047	3			063	1		
14	Approach 50 feet Below Glideslope, U. S. Standard	6/29/72	-			6/15/72	-		
		E55X27855	E55X27901			E60X71808	E60X71881	079	1
15	Incorrect (Early) Yaw Alignment, ICAO					064	2	7/25/72	II-4
						6/29/72	II-4	E63X49094	E63X49146
						E58X72985	E58X73035		
						076	1		
						7/20/72	II-4		
						E63X48817	E63X48862		
						065	4		
						7/20/72	II-5		
						E63X48898	E63X48923		

TABLE V. SCENES USED TO COMPILE FILM LIBRARY (continued)

Approach Path No.	Description	Scene Cataloging							
		Day 1200' VR	Day 700' VR	Night 1200' VR	Night 700' VR	Day 700' VR	Night 700' VR		
16	Correct Yaw Alignment ICAO	049	2			066	1		
		6/26/72	-			6/1/72	II-5A		
		E63X47304	E63X47383			E55X94637	E55X94716		
17	Early Yaw Alignment with Correction & Landing, ICAO	044	1	034	1	061	1	055	2
		6/28/72	-	6/28/72	-	6/15/72	-	6/15/72	-
		E63X43310	E63X43387	E63X43060	E63X43131	E60X71575	E60X71646	E63X49750	E63X49815
18	Excessive Track Change missed Approach, ICAO	045	3	035	1	062	3	056	1
		6/29/72	-	6/22/72	-	6/29/72	-	6/22/72	-
		E55X27774	E55X27802	E63X43796	E63X43824	E58X72922	E58X72950	E55X27490	E55X27518

TABLE V (Continued)  
 ADDITIONAL APPROACHES FILMED

Approach Path No.	Description	Scene Cataloging		Lighting & Fog Condition
1	☐ Approach, ICAO 16 ft. Eye Ht.	053	1	Day, 2000 Foot V. R.
		7/5/72 E58X72434	- E58X72512	
1	☐ Approach, ICAO 16 ft. Eye Ht.	074	1	Dusk, 1200 Foot V. R.
		7/5/72 E58X72517	I-1A E58X72595	
1	☐ Approach, ICAO 10 ft. Eye Ht.	073	1	Dusk, 900 Foot V. R.
		7/5/72 E58X72600	- E58X72681	
1	☐ Approach, ICAO 16 ft. Eye Ht.	072	2	Dusk, 600 Foot V. R.
		6/26/72 E55X28460	- E55X28527	
1	☐ Approach, ICAO 16 ft. Eye Ht.	078	1	Night, Clear Weather
		7/20/72 E63X48756	I-1 E63X48813	
1	☐ Approach, ICAO 16 ft. Eye Ht.	019	2	Night, 2000 Foot V. R.
		6/1/72 E55X94826	E55X94905	
13	Teaspoon Approach ICAO	070	2	Night, 1600 Foot V. R.
		6/22/72 E55X27371	II-4 E55X27425	
14	Approach 50 Feet Below Glideslope ICAO	071	1	Night, 2000 Foot V. R.
		6/22/72 E55X27430	- E55X27484	

APPROACH PATH NUMBER 1

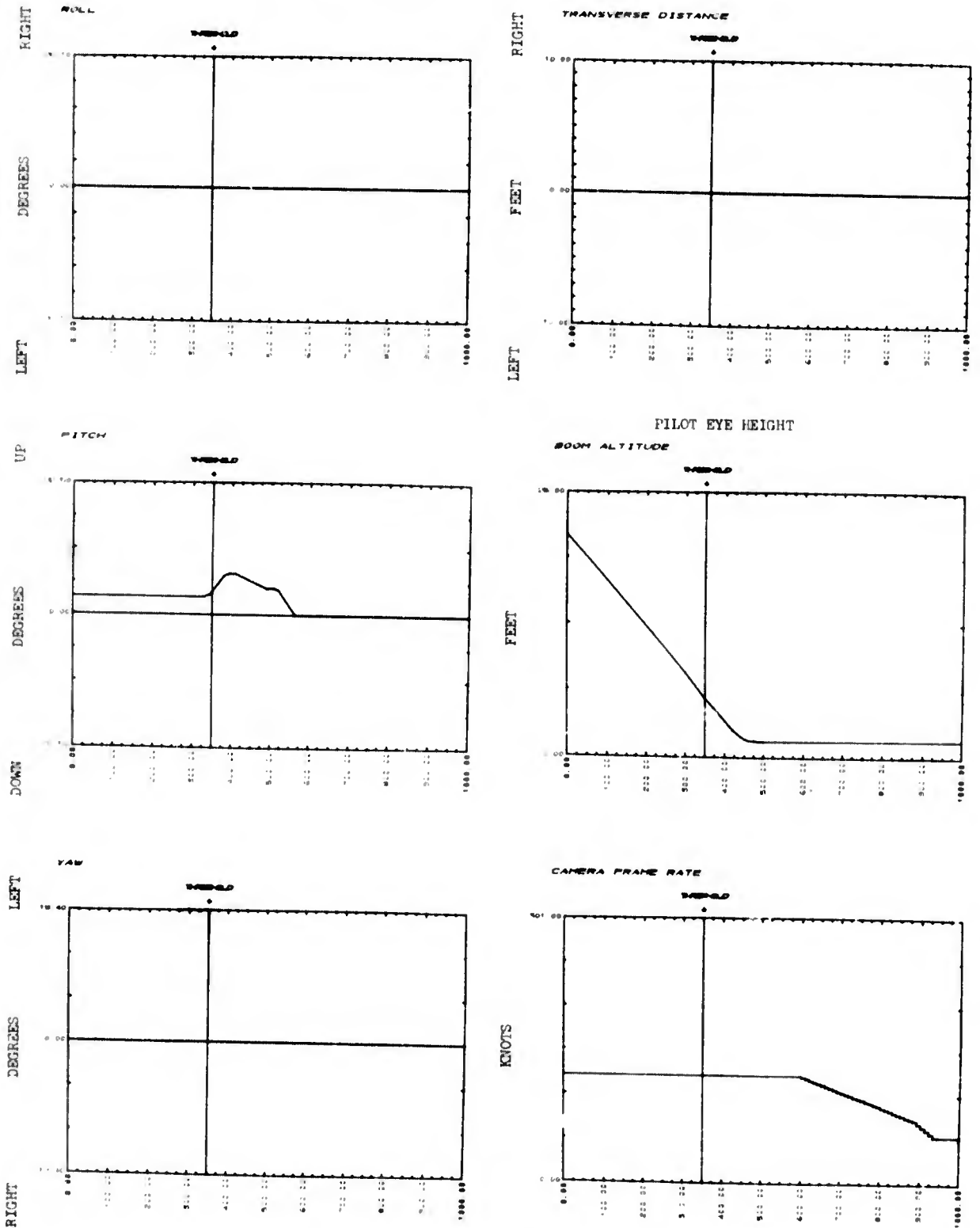


Fig. 18. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 6

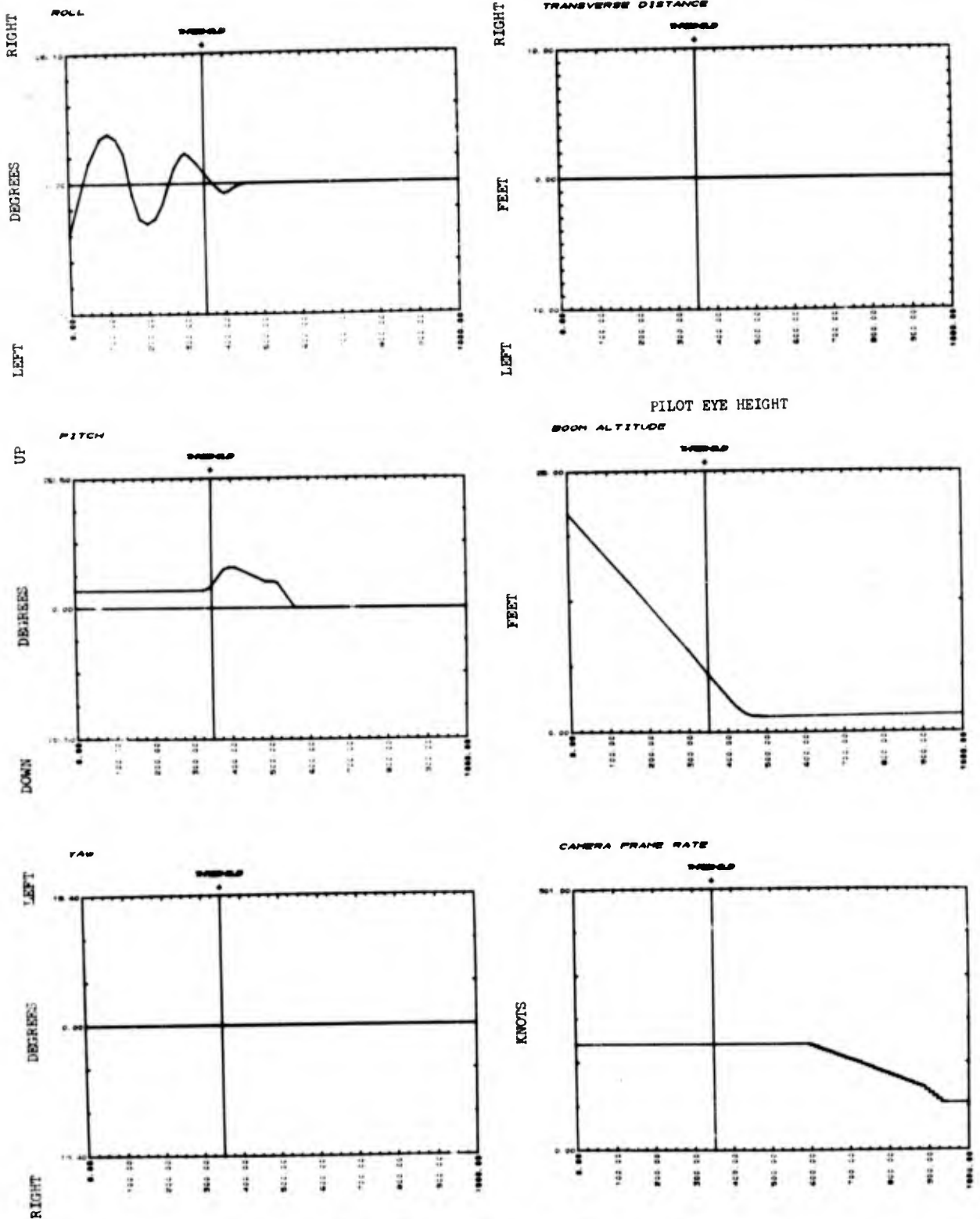


Fig. 19. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 7

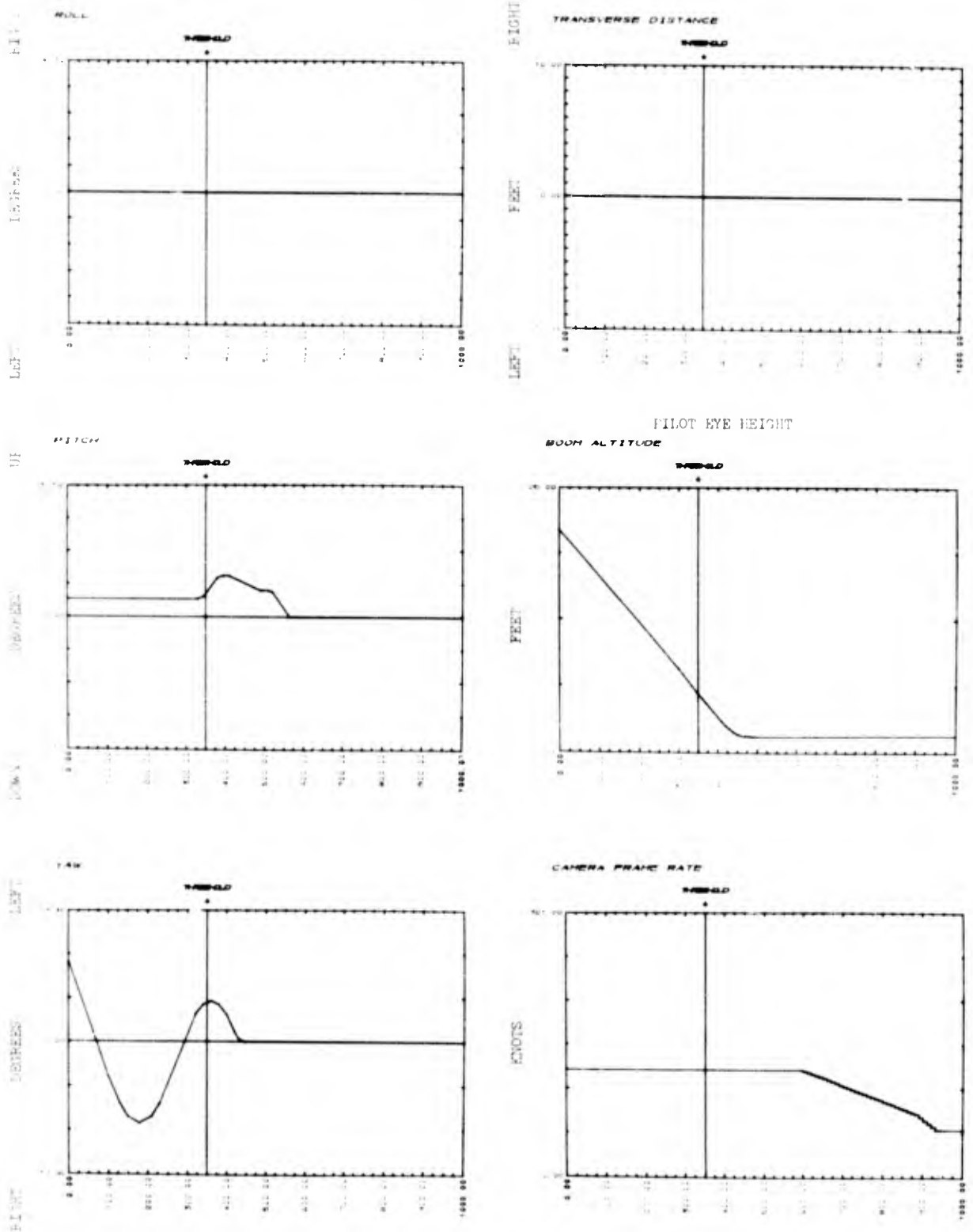


Fig. 20. Computer Print-out of Flight Trajectory as shown on Pan Am Simulator.

APPROACH PATH NUMBER 8

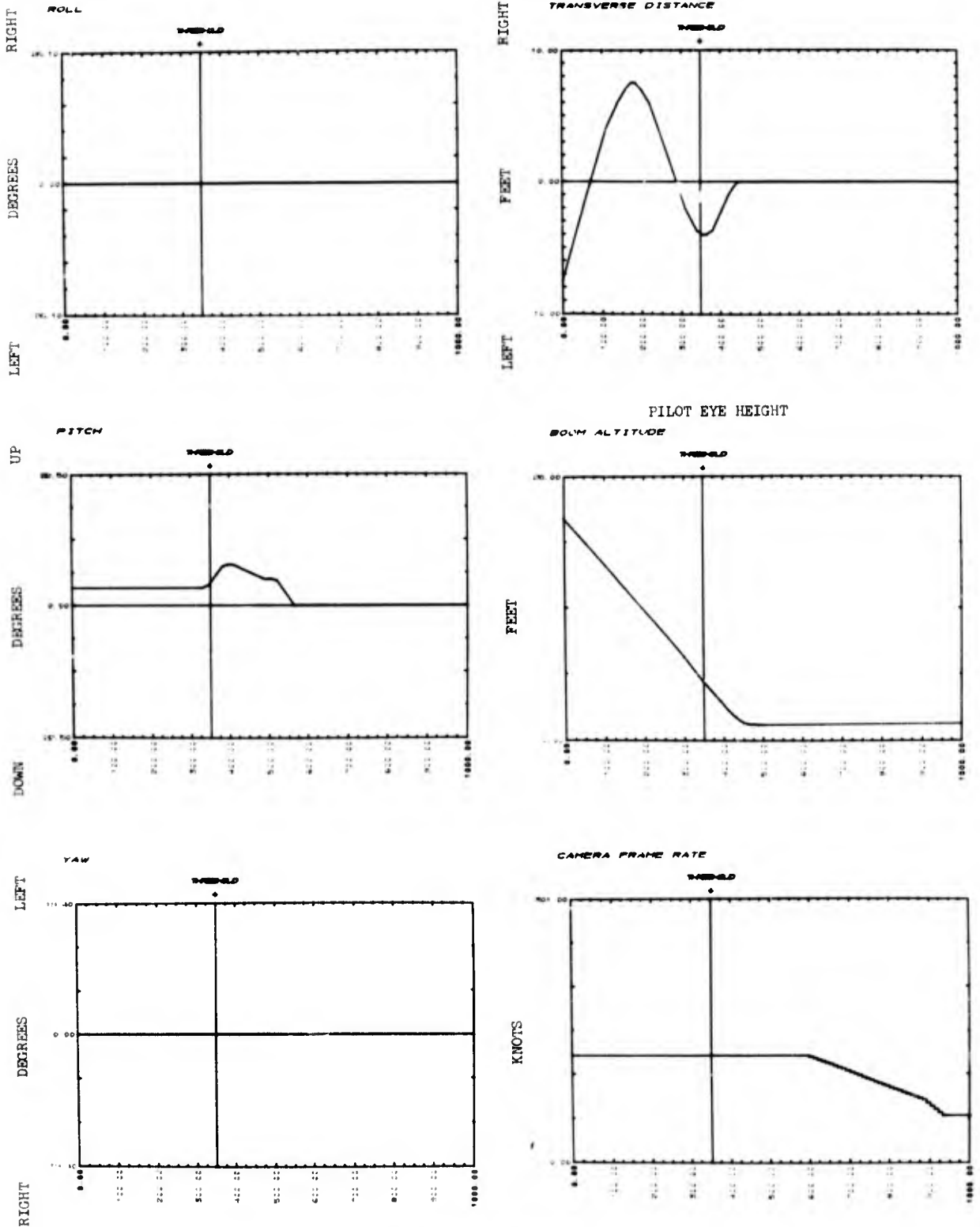


Fig. 21. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 9

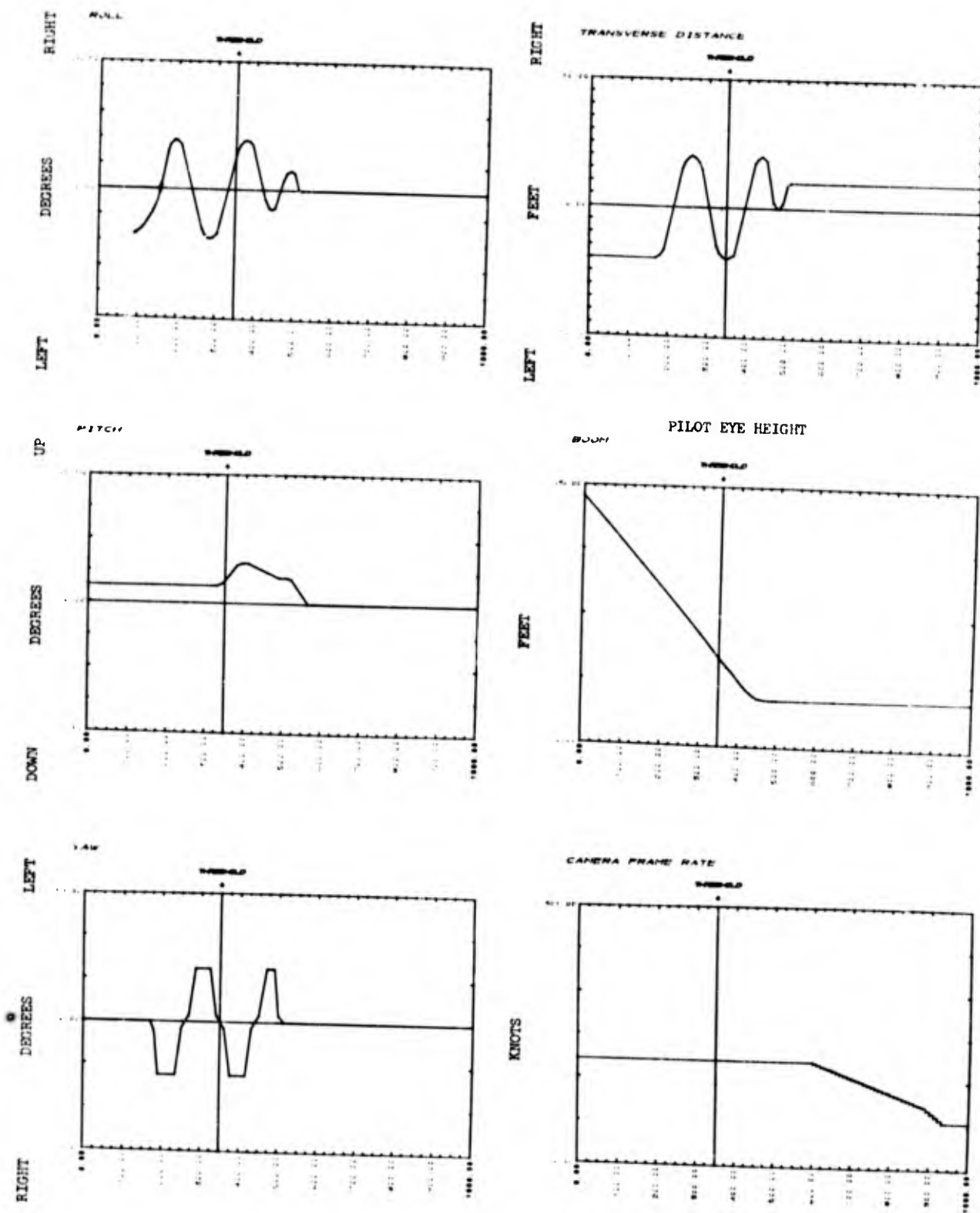


Fig. 22. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 10

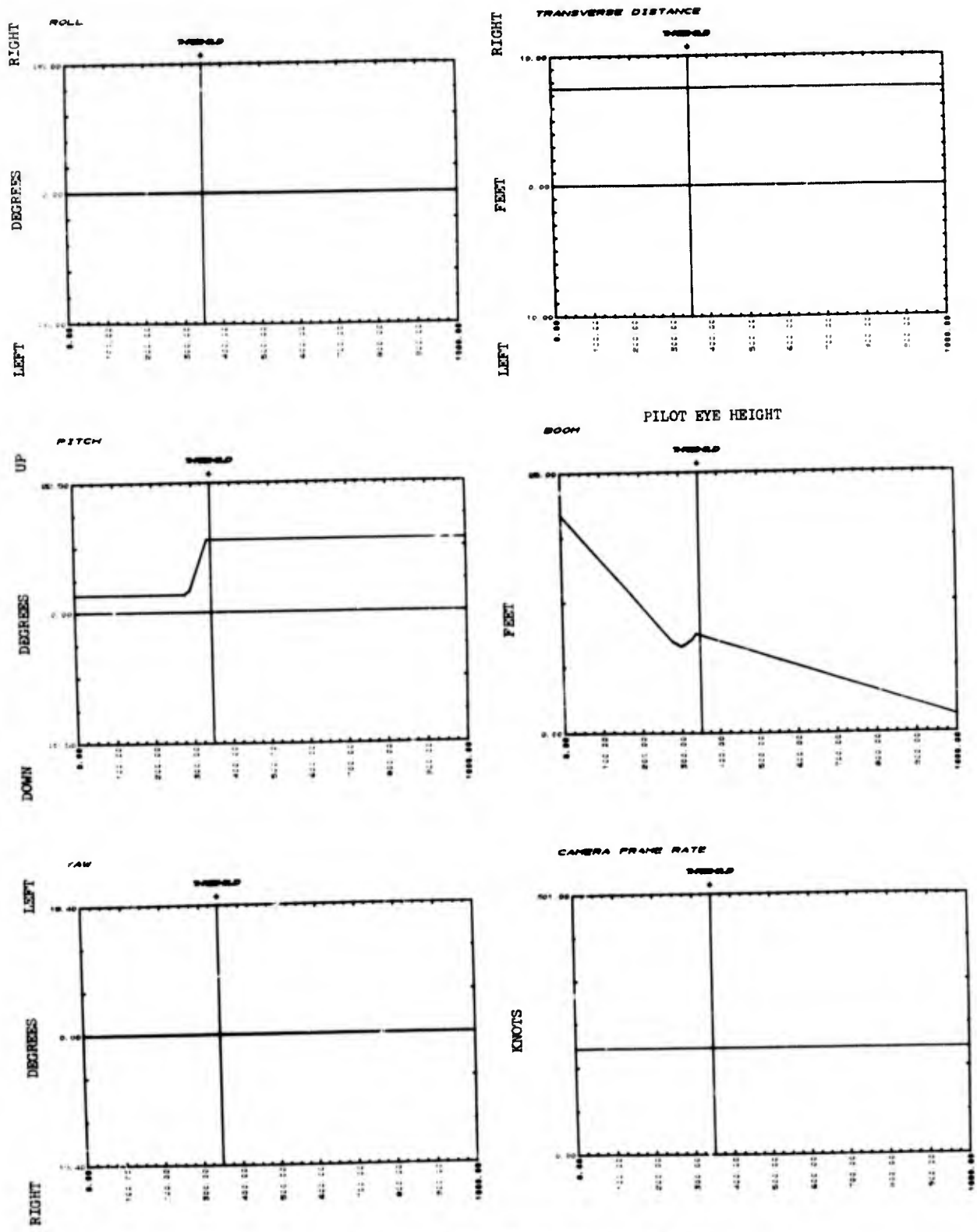


Fig. 23. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 11

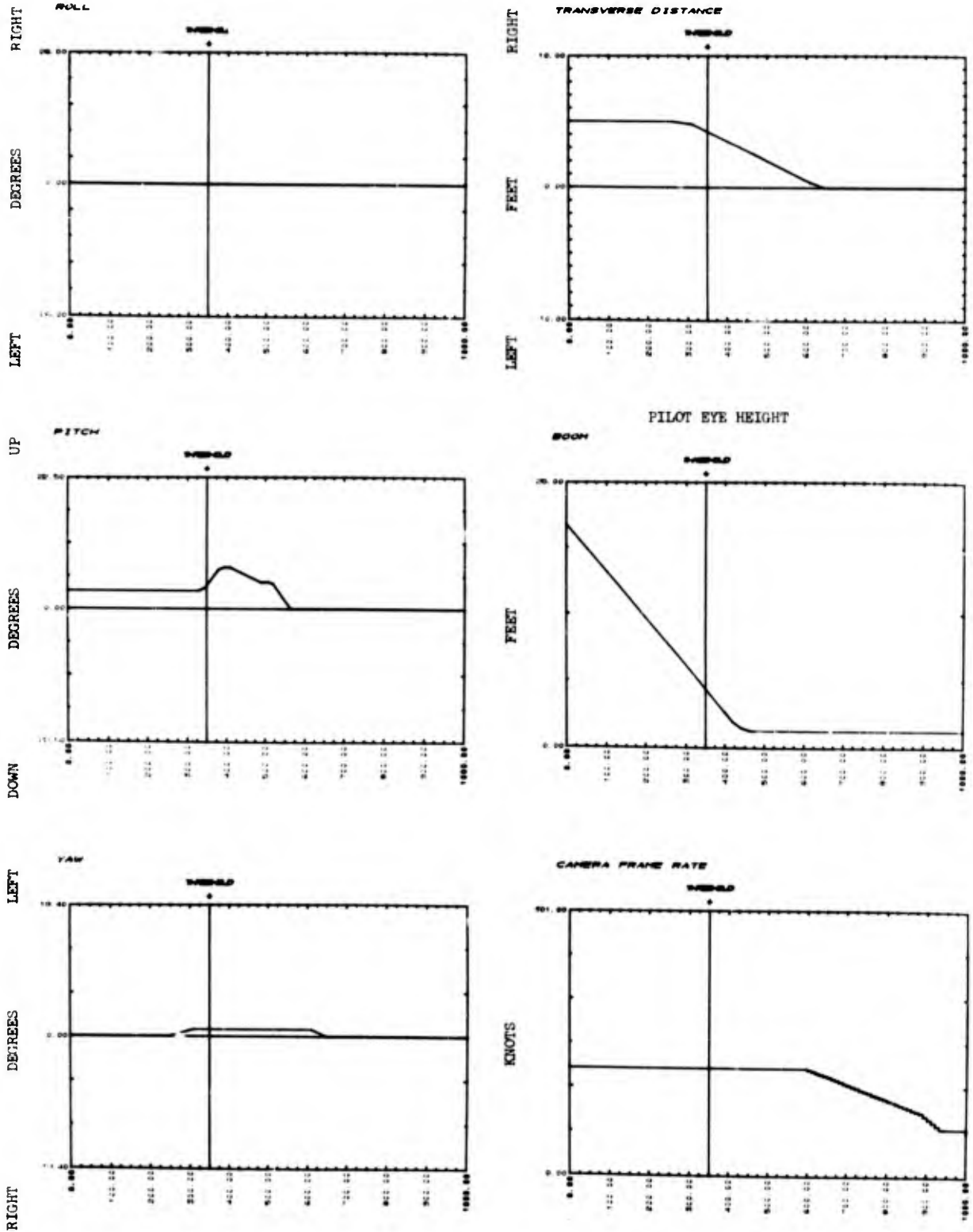


Fig. 24. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 12

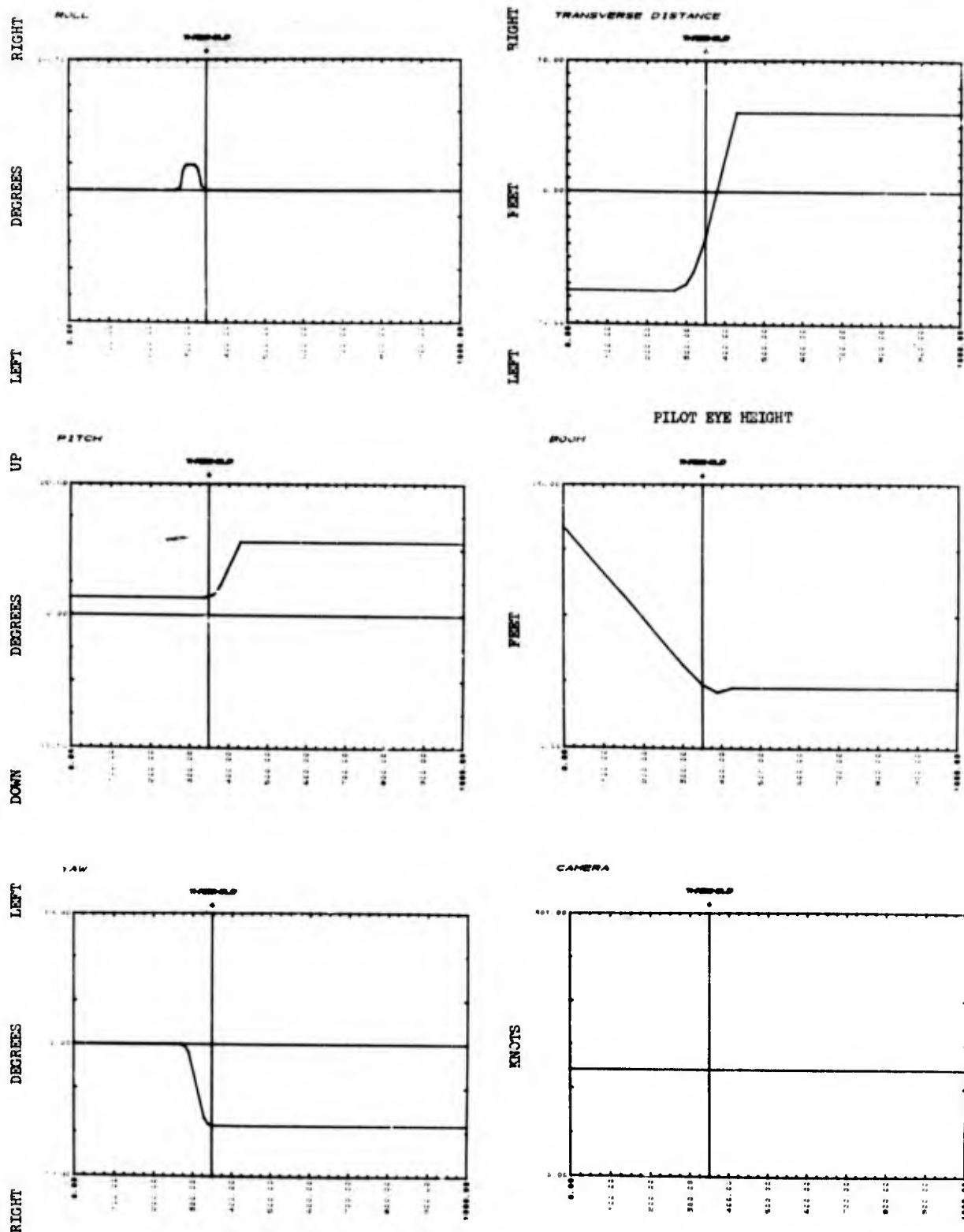


Fig. 25. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 13

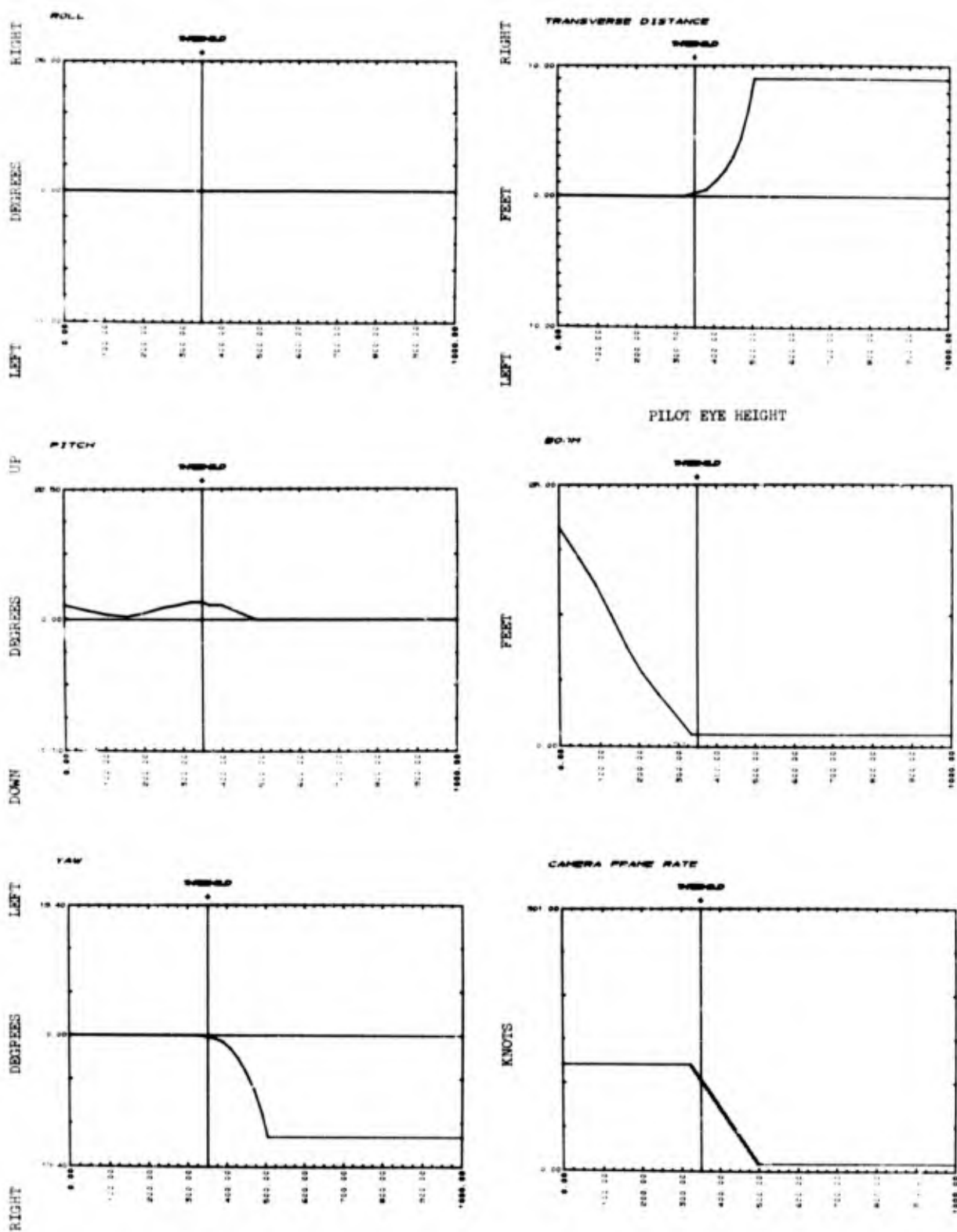


Fig. 26. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 14

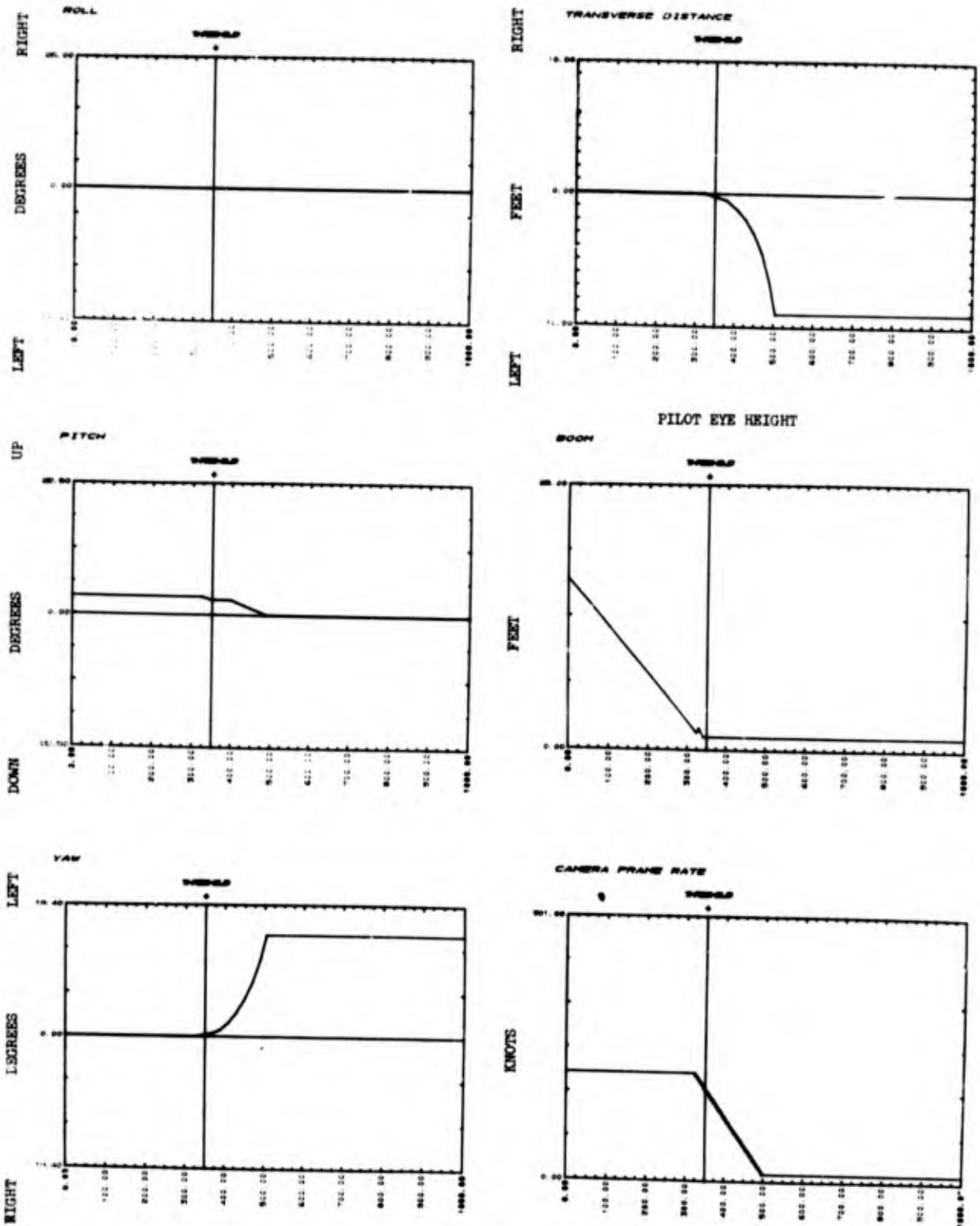


Fig. 27. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 15

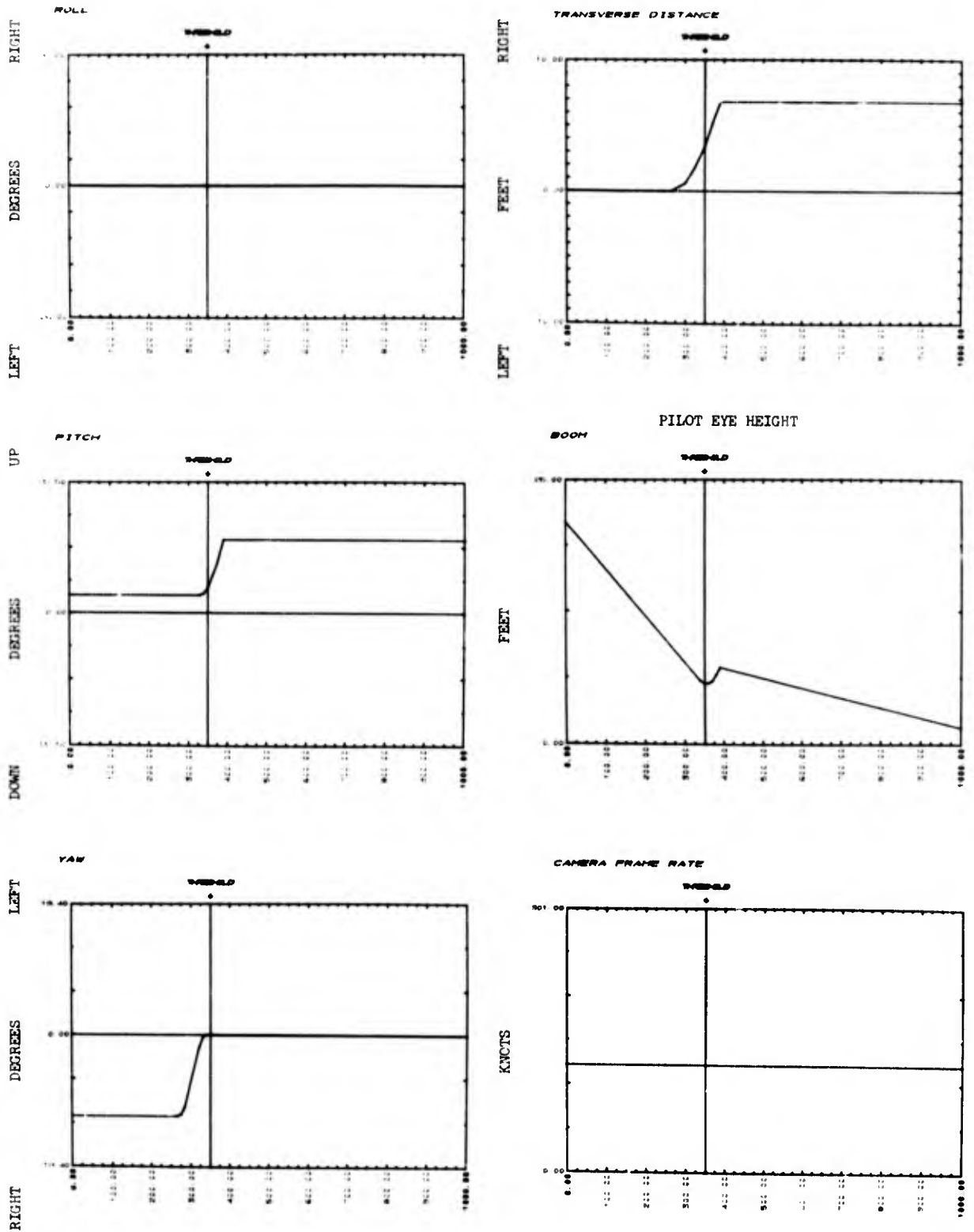


Fig. 28. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 16

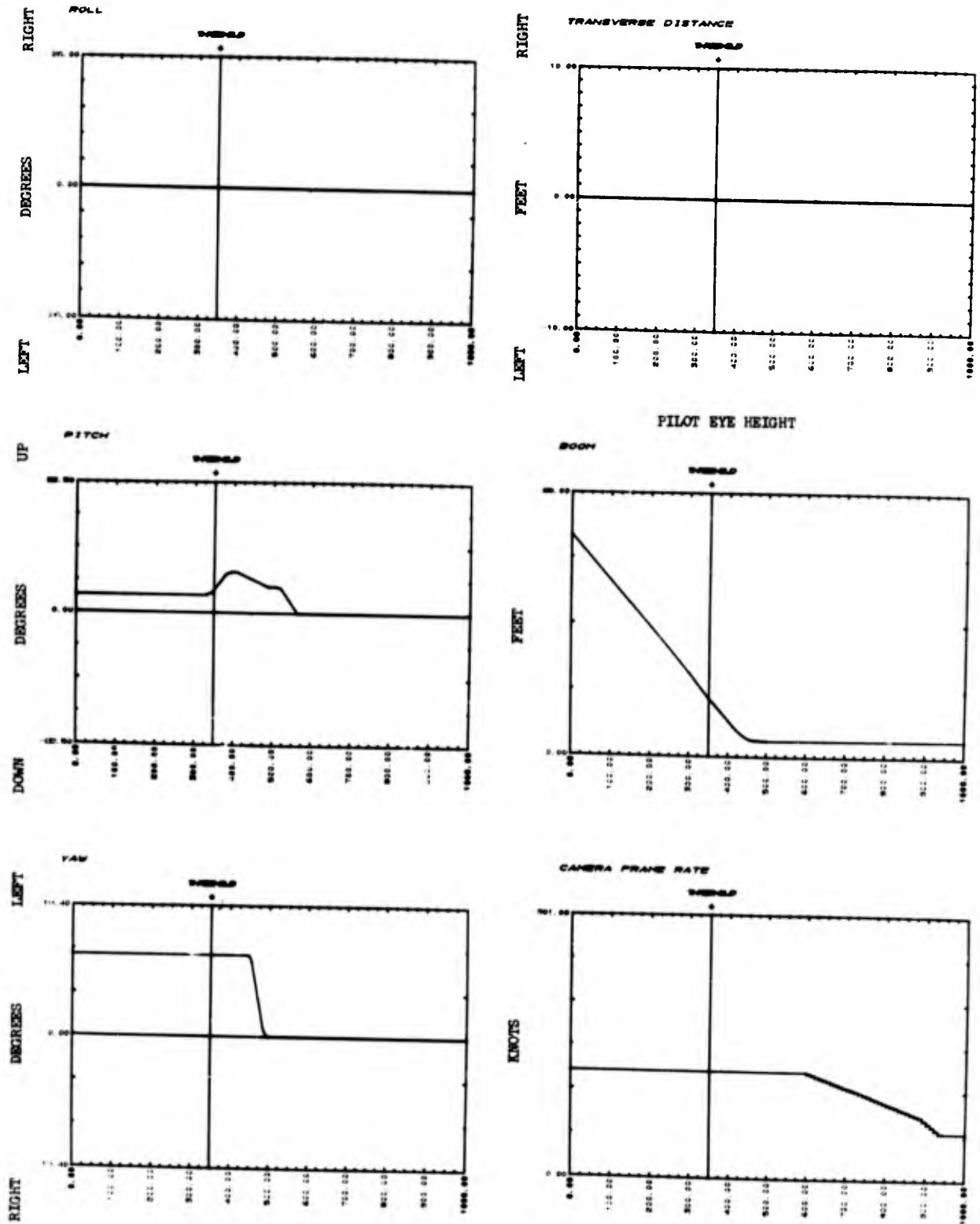


Fig. 29. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 17

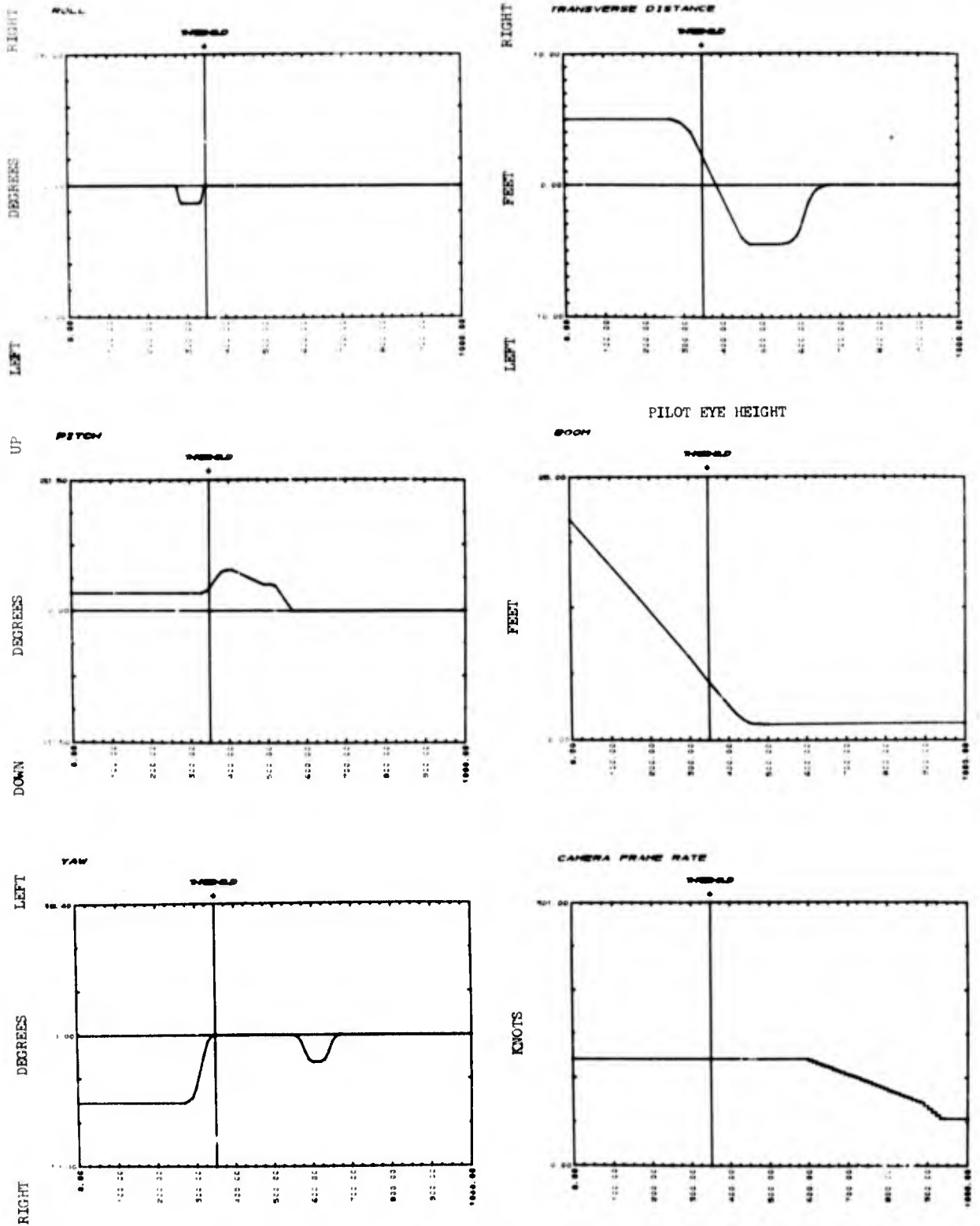


Fig. 30. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

APPROACH PATH NUMBER 18

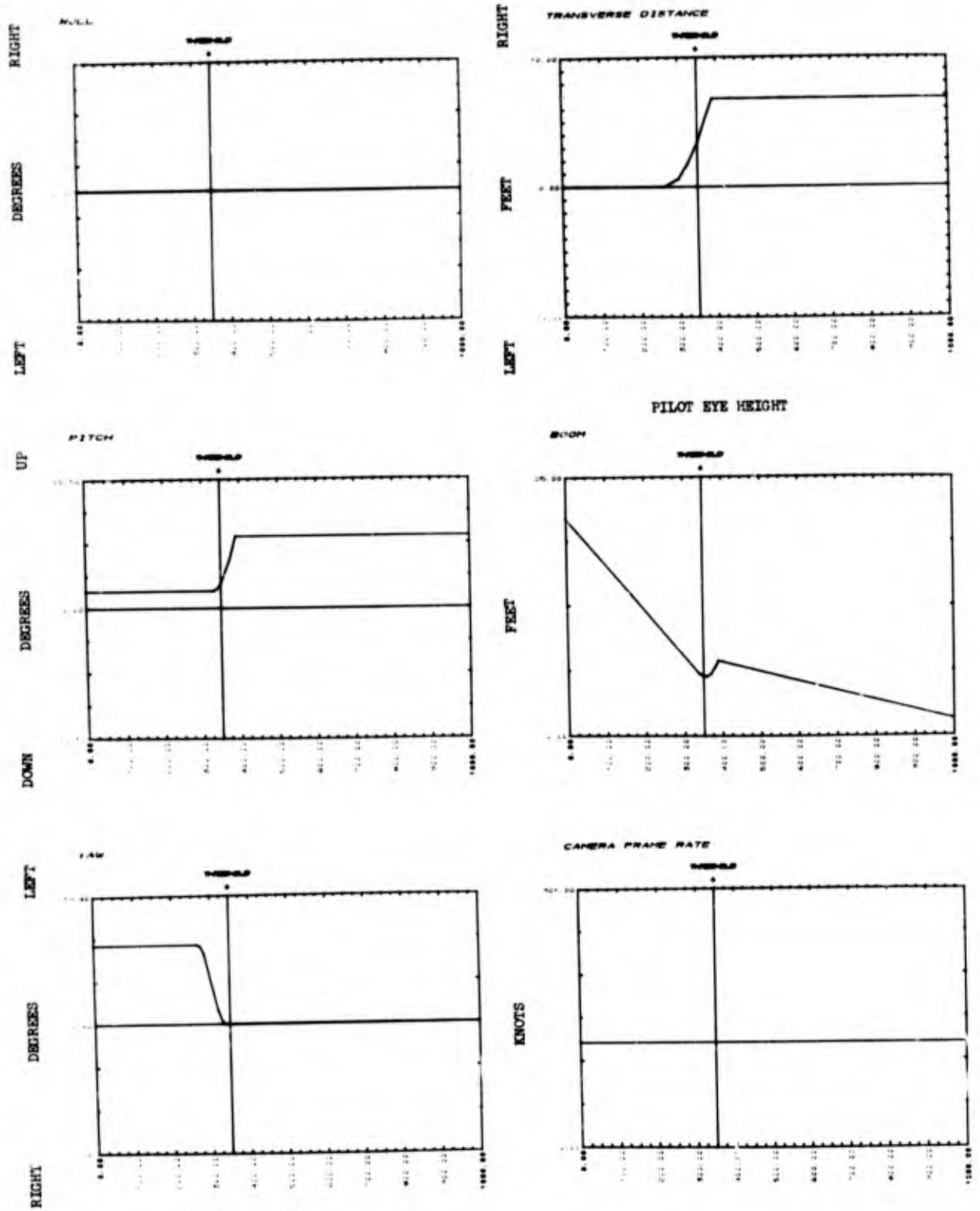


Fig. 31. Computer Print-out of Flight Trajectory as flown on Pan Am Simulator.

To utilize the Film Library, the following procedure was used in the preparation of the film "Pilot Orientation in Low Visibility Landings." Following the scenario given in Appendix A, individual scenes were selected and the proper frame identified by the method outlined on Fig. 32. From this a composite print was obtained. This print was then compared to the filmed sequence taken in the Pan Am simulator. An experienced pilot, following procedures frequently used to familiarize pilots with proper flying techniques or coupled approaches, selected the proper points for inserting sections of the composited approach film into the cockpit instrument scenes.

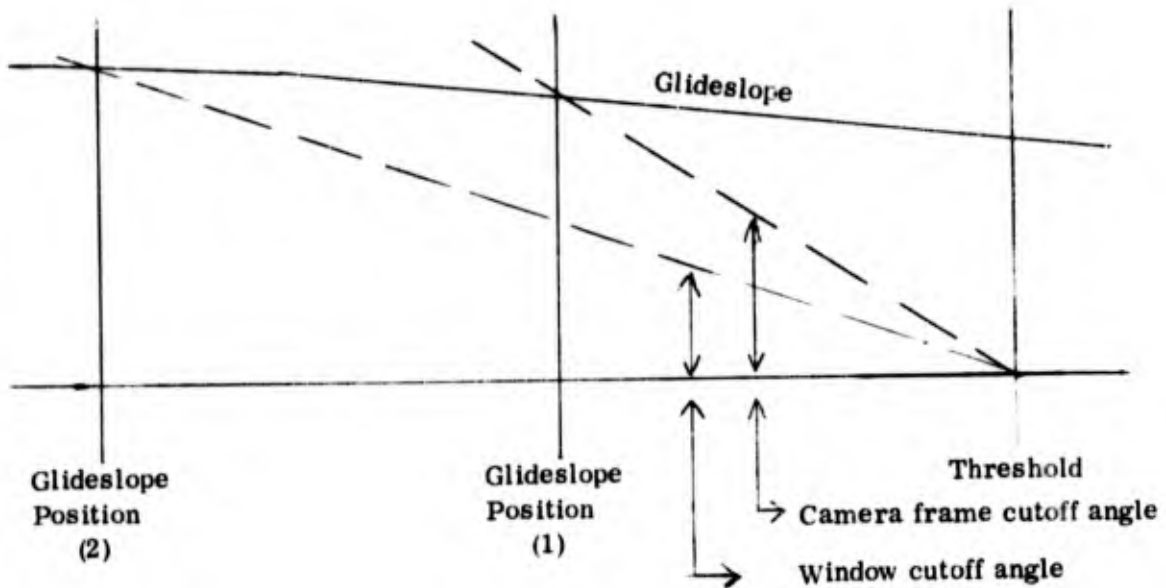
Great care was exercised to make sure the aircraft position as seen in the composite was correct with respect to the instruments in the cockpit (i.e., centerline to the left when instruments indicated this position of the aircraft). The balance between looks to the outside and watching the instruments in the cockpit was critical. When far out on the approach with nothing to see except blank fog, the interval was short. As lights became visible, the looks outside were lengthened. In most cases, the time span used was longer than a pilot would normally take to effect the shift from instruments to outside and return. This was necessary because the pilot observing the action did not initiate the eye movement and it takes the eye and brain a fraction of a second longer to adjust to the new scene under these circumstances.

Wherever necessary, appropriate diagrams were made up and filmed to explain technical points, such as relation of visual ground segment to pilot eye height, the relationship of cockpit cutoff angle to visual ground segment, or the effect of changing the aim point from the normal point to the leading edge of the visual ground segment. Appropriate titles were also filmed and the entire film spliced together, after which a complete new print was made. Since the spliced workprint contained the film footage numbers, the film processor could match negative segments precisely and no difficulty in shift of scenes was experienced.

From a 35 mm print of a composited scene, single frame slides were cut. An entire sequence, frame by frame, could be constructed in this manner. Since all of the 35 mm. films were taken in stop action or lapsed time mode, the individual frames are in sharp focus and no blurring of the lights is apparent. These slides can be used to pinpoint any feature that needs visual emphasis.

Additionally, these individual slides can be printed into color photos of sufficient size to be easily observed and the individual scenes desired for visual emphasis presented for close study. A separate Appendix of mounted 5 x 7 color photos has been provided to FAA and is not considered to be a part of this report.

Thus, the Film Library presents the opportunity for developing a wide variety of visual training aids--35 mm or 16 mm motion pictures, 35 mm single frame slides, and color photos.



#### METHOD OF DETERMINING COMPOSITE MASK PLACEMENT

- A. Using a scene from the Fog Chamber Film Library, find the frame with threshold (or other appropriate light bar) at the lower frame line. Since camera attitude and camera angular field of view <sup>\*(1)</sup> are known, they determine the angle of camera frame cutoff relative to the horizontal. By triangulation, the glide slope position (1) for this frame can be calculated.
- B. Calculate the cockpit cutoff angle from aircraft characteristics (i.e., Boeing 707, 14.25°) and camera attitude (i.e., 5° nose up, or whatever from the flight trajectory graphics). Again, by triangulation calculate the glide slope position (2) at which the threshold (or other appropriate light bar) is at that cockpit cutoff angle.
- C. Calculate the number of frames between glideslope positions (1) and (2) at 9.6 feet per frame. (86.4 ft = 9.0 frames)
- D. Count back from frame (1) found in A the required number of frames. This new frame is the glide slope position (2) and is the frame in which the threshold (or other appropriate light bar) is at the correct cockpit cutoff angle adjusted for the view through the cockpit windshield. This frame is appropriately marked for identification.
- E. The film processor using this marked frame (2) places the cockpit mask over this frame. The threshold (or other appropriate light bar) should cross the center of the windshield lower frame exactly. With this alignment the film can be run to the start and printed to create a composite view.

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<sup>\*(1)</sup> Camera field of view with 25 mm lens: 45.2° Vertical, 60° Horizontal.

Fig. 32

## Conclusions and Recommendations

The UC-FAA Fog Chamber modifications permit accurate and realistic viewing of the approach, touchdown and rollout of an aircraft in low visibility conditions, either by an observer or by filming techniques. The addition of the precise control of the six degrees of freedom of normal flight, together with the ability to follow a prescribed flight trajectory, makes the Fog Chamber a useful tool. The improved fog control adds credibility to the visual appearance of the fog.

The films prepared under this contract create the beginnings of a comprehensive film library of simulated approaches and have been combined into a film for "Pilot Orientation for Low Visibility Landings" which can be useful as a visual aid in the training of pilots in low visibility conditions.

It is recommended that continued efforts be made to exploit the techniques developed by this filming method to prepare films, slides and photos suitable for pilot orientation.

## APPENDIX A

December 3, 1971

MEMO TO DON O. HORNING

1. 707 Simulator work required for Visual Aids Orientation Scenes 1 through 4A.
  - a. Film of left windshield support structure and glare shield showing instrument panel down to the middle of the artificial horizon to be used for all compositing for night-time conditions. (The last scene on the recently taken test film closely approximates that needed except that the instrument lighting should be subdued somewhat.)
  - b. Same as a. except at a background brightness suitable to meet the requirements of Visual Aids Orientation Scene 1A and all other compositing requirements for day-time conditions which may be desired at some future date.

NOTE: Since instruments are not read in these scenes, filming should be done with the cab stationary.

2. 707 Simulator Work required for Approach Scenes 1 through 5A.
  - a. For all Approach Scenes use a runway heading of 281° M and to simplify altimetry, use an elevation of sea level.
  - b. Film all Approaches with nighttime instrument lighting conditions designed to match the nighttime view of the windshield support structure, glare shield, etc.
  - c. For possible future use, repeat b. with daytime or appropriate higher background brightness conditions.
  - d. Note that certain simulator approaches may serve the requirements of several Approach Scenes.
  - e. Since many parameters automatically follow, approaches are described without use of the forms provided. The forms are not required to explain objectives to pilots.
  - f. Have thought more about your concern as to the lateral direction of the camera approximating the pilot's direction of view. Believe it a valid point; however, with the prepared film being nighttime scenes and for the most part in low visibilities, I think one direction of filming for all scenes will not be unrealistic. (Sure hope so; if not, we are in deep trouble.)

Along this same line but with a solution (though costly) at hand is the showing of some portion of the windshield when flight instruments are being viewed. During these portions of instrument flight when lights or objects (even fog) are visible out the windshield the pilot is aware in some degree that they exist. Therefore, if an unrealistic condition arises, as a result of this, those portions of the instrument scenes affected could be composited.

J. L. Fleming

**APPROACH #1 (Day and Night Lighting)**

Starting at 800 ft altitude, approach on an approximate heading of 281° so as to cross the 100 ft altitude point with a PDI deflection indicating about 100 ft right.

At 80 ft, initiate a missed approach and continue to an altitude of 300 ft on a heading of 281° approximate.

Camera: Start at 800 ft and end during the missed approach at 300 ft.

Use the nighttime approach for these two for:

Approach Scene 1 (1200 ft VR)

**APPROACH #2 (Day and Night Lighting)**

Starting at 400 ft altitude, approach on an approximate heading of 281° so as to cross the 100 ft altitude point with a PDI deflection indicating about 50 ft right.

At 80 ft start a left turn to a heading of 275° approximate. Terminate just prior to touchdown.

Camera: Start at 400 ft and end just prior to touchdown.

Use the nighttime approach of these two for:

Approach Scene 2 (1200 ft VR)

**APPROACH #3 (Day and Night Lighting)**

Starting at 400 ft altitude, approach on an approximate heading of 281° so as to cross the 100 ft altitude point with a PDI deflection indicating about 100 ft left.

At 80 ft, initiate a right turn to approximately 295° and just prior to touchdown start a missed approach on a heading of 295° and continue to 300 ft.

Camera: Start at 400 ft and end during missed approach at 300 ft.

Use the nighttime approach for these two for:

Approach Scene 3 (1200 ft VR)

APPROACH #4 (Day and Night Lighting)

Starting at 800 ft altitude, approach on an approximate heading of 281° and approximate on localizer and G/S. Continue to touchdown and rollout to 60 knots.

Camera: Start at 800 ft and end at 60 knots.

Use the nighttime approach of these two for:

Approach Scenes 4 (2600 ft VR) and other rollout requirements.

APPROACH #5 (Day and Night Lighting)

Starting at 400 ft altitude, approach on an approximate heading of 281° and approximate on localizer, but roughly 50 ft below G/S. Terminate at touchdown.

Camera: Start at 400 ft and end at touchdown.

Use the nighttime approach of these two for:

Approach Scenes 4 (1200 and 700 ft VR - 50 ft and 1200 ft VR - 50 ft with U. S. Standard approach lighting system).

APPROACH #6 (Day and Night Lighting)

Starting at 400 ft altitude, approach on an approximate heading of 269° (12° crab angle), approximate on localizer and G/S. At 80 ft, adjust heading to 281° approximate by yaw. Just prior to touchdown execute a missed approach on a heading of 281° to 300 ft.

Camera: Start at 400 ft and end at 300 ft during missed approach.

Use the nighttime approach of these two for:

Approach Scene 5 (1200 ft VR)

APPROACH #7 (Day and Night Lighting)

Starting at 400 ft altitude, approach on an approximate heading of 269° (12° crab angle), approximate on localizer and G/S, and continue to just prior to touchdown, at which time de-crab, land, and continue rollout to 60 knots.

Camera: Start at 400 ft and end at 60 knots.

Use the nighttime approach of these two for:

Approach Scene 5A (1200 ft VR)

FILM LOGGING SHEET

Scene No. \_\_\_\_\_ Date \_\_\_\_\_

Location \_\_\_\_\_ Time of Day \_\_\_\_\_

Operators: \_\_\_\_\_ Weather Condition \_\_\_\_\_

Camera \_\_\_\_\_ Fog Control \_\_\_\_\_

Logging \_\_\_\_\_ Cockpit \_\_\_\_\_

Camera Set Up: \_\_\_\_\_ Film \_\_\_\_\_

Shutter \_\_\_\_\_ Filter \_\_\_\_\_

Lens \_\_\_\_\_ ASA No. \_\_\_\_\_

Frame Speed \_\_\_\_\_ Position \_\_\_\_\_ " from Flight Director

\_\_\_\_\_ " from Floor

\_\_\_\_\_ " Side Window

Take No.		1	2	3	4	5	6
Camera	Focus						
	Aim Point						
	f Stop						
	Program Tape						
	Type of Approach						
	Footage						
Visual Range Actual/Camera							

Notes: \_\_\_\_\_

\_\_\_\_\_

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