



**USAF INSTRUMENT PILOT INSTRUCTOR
SCHOOL**
Randolph Air Force Base, Texas

CONTROL-DISPLAY INTEGRATION PROGRAM

AD 74-654

LANDING WEATHER MINIMUMS INVESTIGATION

IPIS-TR-70-3

Lt Colonel D. L. Carmack

January 1972

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AIR FORCE FLIGHT DYNAMICS LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) USAF Instrument Pilot Instructor School Test and Evaluation Branch Randolph AFB, Texas 78148		2a. REPORT SECURITY CLASSIFICATION	
		2b. GROUP	
3. REPORT TITLE Landing Weather Minimums Investigation			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report (1964-1969)			
5. AUTHOR(S) (First name, middle initial, last name) Lt Colonel Donald L. Carmack			
6. REPORT DATE January 1972		7a. TOTAL NO. OF PAGES 170	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S) IPIS-TR-70-3	
b. PROJECT NO. CDG-PF-4			
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. DISTRIBUTION STATEMENT Approved for public release: distribution unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
13. ABSTRACT The low visibility environment presents a formidable challenge not only to pilots, but to the engineers, designers and planners who will develop hardware and establish procedures. The pilot, however, is in a unique position, since, in the final analysis, he is the ultimate decision maker whether or not he desires this role. Pilots must know and understand what they are being tasked to do. This report has been written to describe and explain from a pilot's point of view, the requirements and procedures for operating in the low visibility environment. This report represents the experiences acquired from over 250 low visibility approaches and landings in visibilities as low as zero-zero. These have been documented to describe what will be seen from the approach and landing environment and how what is seen may be used. The thoughts and opinions presented here on systems requirements, configurations and pilot interface are introduced to provide a germ for planning and development. It should be foremost in the minds of those in authority that control/display composition is equally important as a compatible guidance system or training requirements and crew procedures. As the aviation community moves closer to a solution to the low visibility landing problem, those concerned will find that each element must be given due consideration; if not, the ultimate decision maker must say, "no."			

1a

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Aircraft Flight Control and Instrumentations Meteorology Man-Machine Relationships Navigation and Guidance Landing Aids Runways Weather Flight Testing						

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To the
advancement
of
low visibility
flight

FOREWORD

The Landing Weather Minimums Investigation was conducted by pilots assigned to the United States Air Force Instrument Pilot Instructor School, Test and Evaluation Branch. Technical supervision was under Mr George Yingling, Chief, Systems Integration and Flight Experimentation Branch, Flight Control Division, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio. The original program was conceived in 1964 by Colonel W. E. Christian, Flight Division, Directorate of Operations, Plans and Programs (Hq USAF/AFXOPY) and Lt Colonel Donald M. Condra, Member of Test and Evaluation Branch, IPIS. Lt Colonel Condra discussed the idea with Lt Colonel E. P. Cullivan, Chief of Test and Evaluation Branch, and the program was initiated. Their insight, and the courage of many, including Colonel Robert D. Williams, IPIS Commander during the inauguration of the program, mollified the many problems inherent with such a research effort.

Project officers were Lt Colonels Edward P. Cullivan, Donald M. Condra, Edwin W. Johnson, James W. Lee, Larry M. Hadley, and Donald L. Carmack. Project pilots were Majors Benny J. Allen, Paul S. Lasen, Thomas E. Brand, Richard J. Adams, Michael G. Hoff and Roger K. Taylor.

Human Factors Engineering support was provided by The Bunker-Ramo Corporation -- Dr Charles McTee and Mr Gerald Armstrong.

Avionics Systems Engineering support was provided by Lear-Siegler Incorporated -- Mr Justin J. Bindner, Mr Jesse W. Martin and Mr Marshall J. Buckberry. Air Force Technicians were Mr Raoul G. Canamar and Mr Orrin C. Kopff.

This program was initiated during 1964 with inflight validation completed in March 1969.

This technical report has been reviewed and approved.


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ABSTRACT

The low visibility environment presents a formidable challenge not only to pilots, but to the engineers, designers and planners who will develop hardware and establish procedures. The pilot, however, is in a unique position, since, in the final analysis, he is the ultimate decision maker whether or not he desires this role. Pilots must know and understand what they are being tasked to do. This report has been written to describe and explain from a pilot's point of view, the requirements and procedures for operating in the low visibility environment.

This report represents the experience acquired from over 250 low visibility approaches and landings in visibilities as low as zero-zero. These have been documented to describe what will be seen from the approach and landing environment and how what is seen may be used. The thoughts and opinions presented here on systems requirements, configurations and pilot interface are introduced to provide a germ for planning and development. It should be foremost in the minds of those in authority that control/display composition is equally important as a compatible guidance system or training requirements and crew procedures. As the aviation community moves closer to a solution to the low visibility landing problem, those concerned will find that each element must be given due consideration; if not, the ultimate decision maker must say, "no."

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SECTION I
INTRODUCTION

LANDING WEATHER MINIMUMS INVESTIGATION

The idea of isolating the pilot from visual information by placing him under the hood was considered unrealistic for simulating "Real-World" flight conditions, if visual cues are available and usable in actual weather. Therefore, an effort to determine what visual information is available from outside the aircraft became a fundamental requirement for providing solutions in terms of satisfying piloting requirements. It was necessary to determine the effectiveness of these cues and to investigate the fog structures as they relate to the visual sequence to be expected during the landing profile. Also, the aircrew's procedural role must be defined when operating in this new and unfamiliar environment. Therefore, in the fall of 1965, using the knowledge and experience gained from the PIFAX studies, the Landing Weather Minimums Investigation was initiated to investigate the pilot's flight/control/display requirements and his role in the low visibility landing. It is believed any advanced flight control-display system/concept cannot receive pilot acceptance until the approach and landing problems have been resolved in terms of the actual weather environment.

Operational requirements for landing under low weather conditions are increasing; however, few pilots have had the opportunity of familiarizing themselves with runway visibility conditions below one-quarter mile. This type of inflight research was a needed departure from the normal validation/demonstration of automatic and manual control techniques in simulated conditions. The experience gained from such a program could permit a more realistic and valid assessment of the pilot's control-display information requirements and the determination of his ultimate role in the landing profile.

The USAF Instrument Pilot Instructor School has endeavored to investigate and assess the low visibility landing environment when under the influence of various fog structures. During the preliminary phase of the investigation, one hundred ILS approaches and landings were made at selected military airfields during weather conditions below 1600 RVR. These landing profiles were considered pre-experimental in that project pilots probed the uncertainties of the

new environment for the purpose of building an experience level for future exploration. This newly acquired knowledge and experience provided an adequate basis for improvements in the test aircraft's flight control-display configuration and for revision of aircrew procedures.

In the past two years emphasis has been placed on continued assessment of the instrument landing problem and the accumulation of data for documentation of the landing environment. Through the cooperation of the Federal Aviation Administration, permission was obtained to use selected Category II facilities in support of this investigation. Project pilots have flown an additional 150 approaches and landings in low weather at these installations. The knowledge gained has greatly enhanced our capability to authoritatively assess the landing environment, and has enabled the Air Force to share with the aviation community first-hand piloting experiences below existing landing minima.

Objectives: This project had the following objectives:

- a. Determine the visual information available from outside the aircraft during precision approaches and landings under varying environmental conditions.
- b. Determine the effectiveness of this information.
- c. Establish a systematic investigation of fog structures as they relate to the visual sequence to be expected during the approach and landing.
- d. Investigate the pilot's flight control-display information requirements for flying on instruments during a precision approach and landing.
- e. Develop optimum inflight procedures for use during approaches and landings in low weather conditions.

BACKGROUND

The USAF Instrument Pilot Instructor School, in conjunction with the Air Force Flight Dynamics Laboratory, has since 1962 been involved in a study entitled the "Pilot Control-Display Factors

Program" (PIFAX).^{1,2} The PIFAX program was an exploratory development program to define the pilot's flight control-display requirements and to demonstrate solutions for flying on instruments from letdown through approach and landing. The PIFAX program was under the sponsorship of the Federal Aviation Administration and the technical direction of the Flight Control Division of the Air Force Flight Dynamics Laboratory (AFFDL). Inflight validation was conducted by the USAF Instrument Pilot Instructor School using a cross section of pilots from the American flying community. This paper does not intend to discuss the findings of the PIFAX program; however, several concepts should be explained prior to discussing the Landing Weather Minimums Investigation.

Pilot in the Loop: The USAF has long contended that the flexibility and the decision-making characteristics of the pilot should be fully exploited if a total system is to have the capability of dealing with the many variables that could occur during an approach. Rather than be subservient to an automatic system the pilot should be an active control element; he should be in the control loop with the capability of making inputs as necessary. For the pilot to be in the control loop he must:

- a. Be provided the means of taking action in an easy and natural fashion without disengaging the autopilot, and
- b. Have access to the proper information to control the performance of the aircraft.

This integration of the pilot must serve to increase the precision of the total system. The PIFAX program demonstrated the feasibility of integrating the pilot with the automatic system with force wheel steering.

Control Concepts: Force wheel steering links the pilot to the control surfaces of the aircraft through the autopilot by placing electronic force sensing devices in the control column and rudder pedals. The

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1. Control-Display Pilot Factors Program, Instrument Evaluation
Project Nr 63-1, December 1963, USAF Instrument Pilot
Instructor School, Randolph Air Force Base, Texas.
 2. Control-Display Pilot Factors Program, Instrument Evaluation
Project Nr 62-1B, September 1966, USAF Instrument Pilot
Instructor School, Randolph Air Force Base, Texas

force wheel and pedals convert force applied by the pilot into electronic signals which are received by the autopilot computer-amplifier. The forces required for the pilot to make inputs with the force wheel are similar to those required to move the control surfaces through normal linkage. The force wheel is active any time the autopilot is engaged allowing the pilot to fly the aircraft independently or in conjunction with the automatic flight control system. Force wheel steering (FWS) allows the pilot to exercise his judgment and skill by making control inputs, through the aircraft's control column, to the autopilot. The pilot's inputs supplement the autopilot in refining the aircraft's position in relation to guidance information. The pilot, therefore, flies his aircraft with FWS and autopilot assistance, speeding up or slowing down guidance corrections, compensating for wind and wind shears, damping out guidance system errors and supplying the judgment, skill and determination which cannot be built into automatic systems. The human pilot is conditioned to make these corrections because he virtually flies each approach. His hands are always on the aircraft controls and he is psychologically and physically prepared to assume control to whatever extent necessary. Force wheel steering is not intended to replace automatics; it is a means of assisting the human pilot to fulfill his duties and at the same time incorporating the safety and precision of an automatic system.

Display Concepts: If the pilot is to use the maximum potential of the autopilot loop, he must have the ability to assess autopilot performance. This implies he must see what the autopilot is doing and have at his disposal quantitative and qualitative instrument information. Therefore, the autopilot was modified to eliminate the approach coupler. Circuitry was added so the autopilot could act on the same signals the flight director computer was using to drive the steering command bars. This, then, gave the pilot the means to view autopilot performance in relation to, first, the quantity and quality of corrections it was making, and, second, the raw guidance information. Advanced displays of expanded localizer, flight path angle, approach progress indications, instantaneous vertical velocity and radar rate information were added to complete the process. The loop was now closed. The pilot can use the autopilot, he can monitor autopilot performance and possess the means to inject his skill and judgment along with the automatic system.

These principles were used throughout the PIFAX study in an effort to define piloting requirements in terms of control and display for the final approach to touchdown and rollout under low visibility conditions. Several thousand hooded landings were made using instrument information only in efforts to validate the PIFAX concepts. The results of these

carefully controlled inflight studies demonstrated that the advanced flight control-display system permitted the pilot to make meaningful control inputs throughout touchdown, on instruments alone.

SECTION II
METHODOLOGY

RESPONSIBILITIES:

a. This project was conducted in accordance with the General Working Agreement for Instrument Pilot Instructor School Support of Flight Control Division (AFFDL) Research and Development Programs.

b. The Bunker-Ramo Human Factors Engineers assisted in oscillograph calibration, data reduction/analysis and final report preparation.

c. The LSi Service Corporation engineers calibrated and maintained project equipment and provided on-site technical assistance.

TEST AIRCRAFT

The test aircraft was modified by the addition of advanced control-display systems. A brief description of each system used for the project (excluding aircraft standard equipment) is presented below. Detailed descriptions and evaluations are contained in Section III, "Findings."

a. Lear-Siegler three-axis (each independent) autopilot with dual force wheel steering. Autopilot uses flight director computer steering as approach coupler.

b. Two highly-modified Collins CPU-27A flight director computers calibrated for optimum performance from middle marker through touchdown and ground rollout.

c. Two Sperry flight path angle computers for providing pitch augmented rate, flight path angle and reference signal to the flight director computer for flare.

d. Two Honeywell radar altimeters for absolute altitude and rate of closure information. Rate of closure information to base computation for flight path angle computer below 50 feet.

e. Two experimental attitude director indicators with flight path angle quantity readout to the left of the attitude sphere.

f. Two radar altitude/pitch augmented rate indicators provide qualitative radar height indications from approximately 200 feet to touchdown and anticipatory vertical velocity information.

g. Two radar altitude indicators for absolute altitude from 1000 feet to touchdown. (One unit used for camera recording of absolute altitude.)

h. Two lateral landing situation indicators for defining middle one-half of runway and lateral flight path limit information during approach and landing.

i. Two approach sequence indicators for monitoring approach progress and function tripping.

j. Automated Specialties angle of attack system with apexer.

k. Automated Specialties automatic throttle system.

TEST SITE SELECTION:

Selection of Air Force bases and civilian airports as test sites for this project was based on probability of obtaining low weather conditions, suitability of airport facilities and willingness of prospective sites to participate. Bases selected had the following facilities:

a. An FAA approved Category II ILS facility or an ILS with good demonstrated beam characteristics.

b. Precision Approach Radar (military bases).

c. Operating transmissometer.

d. Rotating beam ceilometer.

e. High-intensity runway lights with U.S. Standard (A) approach lighting at military bases, or Category II approach lighting system at civil airfields.

f. Instrument runway markings.

After initial airport surveys were conducted, liaison trips to the selected sites were made to solicit cooperation from airport authorities. If cooperation was indicated, a series of approaches to the selected sites were flown for the purpose of familiarizing project personnel with the quality of the ILS and GCA guidance, lighting systems, terrain, winds, ATC procedures, etc.

PROGRAM METHOD:

a. Training.

(1) Project pilots performed training approaches at Randolph AFB and/or other nearby airfields for developing and practicing crew procedures and task sequences required for automatic, semi-automatic, and manual ILS approaches.

(2) During the training approaches, system performance data were collected to provide baseline information in determining performance capabilities under the varied control modes.

(3) The system performance data recorded during the automatic approaches were compared to the data recorded during the semi-automatic and manual approaches.

b. Test Methodology.

(1) It is recognized that many factors -- including weather conditions and flight operational procedures -- preclude a complete statistical experimental design in a flight program of this sort; however, a suitable test methodology can produce meaningful information if the experimental conditions are controlled and the number of dependent variables are few.

(2) The independent variables included the following:

- (a) Test Site (ILS)
- (b) Project pilots and crew assignment
- (c) Approach and Runway Lighting Configurations
- (d) Approach and Runway Lighting Intensities

- (e) Runway markings
- (f) Ambient cockpit lighting
- (g) Environmental weather conditions
- (h) Day or night conditions

(3) Generally, these variables were uncontrolled for each test flight and test approach series. (A test flight consisted of at least one test approach series. A test approach series consisted of at least one automatic approach and one or more semi-automatic and/or manual approaches.)

(4) The data were sorted by test site (ILS), project pilots, and crew assignments prior to data analysis. In this manner, the approach and runway lighting configurations and runway markings remained constant for the analysis.

(5) The approach and runway lighting intensities were determined during the automatic approaches so as to be set to an optimum combination for the semi-automatic and manual approaches. The ambient cockpit lighting levels were determined by the day or night conditions and/or environmental weather conditions.

c. Data Recorded.

(1) The information listed below was recorded for each approach and landing.

- (a) Mission number
- (b) Approach number and type landing
- (c) Local time at glide slope intercept
- (d) Film type and magazine number
- (e) Camera f/stop and oscillograph number
- (f) Approach speed and control condition
- (g) Weather sequence report

- (h) Transmissometer RVR during landing phase
- (i) Type and location of transmissometer
- (j) Runway observer's RVR during landing phase
- (k) Location of Observer
- (l) Fog height reported by aircraft (radar altimeter)
- (m) Type fog structure (mature, shallow, etc)
- (n) Vertical and horizontal variability of fog from 200' AA
to touchdown
- (o) Approach lighting system contact height (radar altimeter)
- (p) Estimated ground visual segment at initial contact height
- (q) 500 ft ground visual segment contact height
- (r) Aircraft observer's visual segment at touchdown
- (s) Qualitative evaluation of approach lighting system and
runway visual aids
- (t) Type ILS
- (u) Rollout information
- (v) Automatic flight control system performance
- (w) Flight path (ILS) performance
- (x) Beam deviations at 100 ft above ground

(2) The dependent variables recorded included such variables as first visual cue (approach), approach light contact height, visual cues for landing, i. e., number of runway lights visible, runway markings visible, reference for visual call and others.

(3) Subjective workload scale values were obtained from each pilot after each approach. The workload scale used is as follows:

- (a) Very much less than normal workload (relaxed)
- (b) Slightly less than normal workload (unburdened)
- (c) Normal workload for manual ILS using standard USAF minimums 200 X 1/2 (busy)
- (d) Slightly more than normal workload (burdened)
- (e) Very much more than normal workload (saturated)

(4) Oscillographs were used for recording pilot control inputs and necessary flight control information. The following parameters were recorded on each approach:

- (a) Absolute altitude
- (b) Glide slope deviation
- (c) Localizer deviation
- (d) Course error
- (e) Event marker
- (f) Pitch attitude
- (g) Pitch rate
- (h) Pitch force
- (i) Roll attitude
- (j) Roll rate
- (k) Roll force

(5) A Pemco model 110, 14-channel one-inch magnetic tape recorder recorded pilots' heart rate through two Offner cardiachometer modules on some flights. The following parameters were recorded to measure pilot(s) activity and stress throughout the mission profile:

- (a) Electrocardiograph

- (b) Cardiometer
 - (c) Event marker
 - (d) Voice
- d. Crew Procedures (see Appendix D).

SECTION III

FINDINGS

THE LOW VISIBILITY ENVIRONMENT

Some people may believe that the process of flying an aircraft on instruments is relatively a mechanical act regardless of the weather conditions. However, this is not the case, since there are profound psychological and procedural considerations that pilots must physically and mentally adjust to depending on the operational environment. This section of this report will consider, from a pilot's point of view, the problems of operating in visibilities below those currently authorized.

Shallow fog:

One type of weather which produces extremely hazardous low visibility conditions is shallow fog, which for purpose of definition will be considered to exist to a height of not more than 200 feet above and down to the runway surface. The variables that exist in shallow fog are its depth, density and uniformity. Observations made during the Landing Weather Minimums Investigation (LWMI) have shown that visibilities in this type of fog can change very rapidly from several miles to 600 feet or less. While forming, shallow fog tends to be non-homogeneous (patchy) and wisps of fog may form along or down the runway that will restrict visibility at different positions on the runway. In its embryo stage, its height may be fifteen to twenty feet. Therefore, it's possible for a pilot's eye height to be above a fog level with the aircraft on the runway. As the fog matures, the visual segment decreases. Its height may reach several hundred feet and it may become homogeneous. Visual segments of 200 feet with a fog height of 150 feet have been noted along the runway after a period of thirty minutes.

Shallow fog conditions present an unusual challenge to pilots due to its insidious effect on visual cues. Pilots may be instilled with a false sense of confidence due to the abundance of visual cues during the early portion of an approach. The Approach Lighting System (ALS), strobes, and runway lighting may be visible as outer marker is passed and the pilot feels relaxed and confident. However, this is a fallacious impression. As the aircraft continues along the approach path, visual

cues become more obscure and a realization occurs to the pilot as he suddenly finds himself void of visual guidance. For a pilot to suddenly find himself in such a position there are but two alternatives. The first and most practical is a missed approach. The second is to continue in hopes of again becoming visual. This choice is like playing Russian Roulette with a completely loaded revolver. Generally, the pilot cannot expect to see visual cues until he is well into the flare; in fact, in a mature, homogeneous shallow fog, the visual segment may vary from two to four hundred feet -- this is definitely not enough to visually flare the aircraft and a difficult condition in which to control lateral alignment.

Psychologically, the pilot is faced with a deterioration of confidence and judgment -- confidence, because unwittingly a dangerous condition has developed, and judgment, because a clear course of action is not apparent. Should he continue on instruments, continue visually or execute a missed approach? If the pilot continues on instruments, he has only ten to fifteen seconds prior to touchdown. What do the instruments relate to the pilot -- how to precisely control the vertical and lateral path of the aircraft, when to initiate the flare, how to decrab, touchdown point, runway available? No, none of these parameters are available on the instrument panel in usable form. Pilots are familiar with their visual approach patterns and most of their knowledge and experience has been negated since there is very little on the panel that presents meaningful information in a manner comparable to a visual approach. During the low visibility approach, the pilot encounters an unfamiliar environment he must negotiate safely and routinely. These last few seconds of an approach must be considered as an element in itself, where control inputs are difficult to determine and an improper decision could be fatal. Acts must be concise and correct, for there is no second chance as every effort must be directed toward the successful approach and touchdown. Apprehension, anxiety and assimilation time are psychological barriers pilots must understand and be prepared to accept routinely if low visibility approaches and landings are to be performed.

Visibility Measurement:

How pilots become involved in such an untenable situation could be the subject of a paper in itself; however, only a short discussion will be presented to expose some of the problems of weather reporting. The science of weather reporting is indeed extremely sophisticated. Meteorologists use satellites, television, radio reports, pilot reports,

etc, to produce weather data as accurate as possible; and for pilots, the usual method is to receive a briefing on his destination weather prior to takeoff and update it during flight. As a pilot nears his destination and is channelled to approach control, he is again informed of his destination weather. The pilot receives reports on ceiling, visibility, restrictions to visibility, such as rain, fog, snow, etc, altimeter setting and the runway visual range, if available. Now comes the problem that has been unresolved for many years -- the weather, as reported by the controller, represents the most recent observation, which may be several minutes or as much as an hour old. If we examine the situation more closely, we find it is mandatory for controllers to report Runway Visual Range (RVR) if it is part of the criteria for an approach. This value is obtained automatically from a transmissometer (a device which projects a light source and measures the transmittance of the beam through the media) which may be located several hundred feet from the touchdown zone. This value may be in error by several hundred feet due to patchy conditions or because it is derived during a period of high background brightness or extreme darkness. In extreme darkness the photoelectric cell which is receiving the quantity of light will record a greater value of light indicating a higher than actual RVR reading. In daylight the emitted light blends with the natural light and again the transmissometer reading is not representative of the true RVR.

Category II Weather:

This, then, is responsible for some of the pilot's anxiety for the low visibility approach he is about to commence. The visual cues that will actually be seen depend on the facilities available at his destination. If the weather is reported as 100 feet obscured with fog and an RVR of 1200 feet, the visual segment will be less than reported due to a decreased slant range visibility and the aircraft's downward vision angle. Also, the effectiveness of the Approach Lighting System (ALS), Touchdown Zone Lights (TDZ), Centerline Lights and High Intensity Runway Lights (HIRL) will depend on the contrast between the lights and the brightness of the environment. At night, of course, the lights will be more distinguishable affording much better visual information. During daylight operations the lights will be less discernable and the visual segment will seem shorter; however, the cockpit is more conspicuous and the runway with its contrast and markings will be available. Certain periods of the day, such as sunset and sunrise will cause other problems which are not strictly associated with pure night or day operation. When the sun rises or sets, the light through the fog

causes refractive effects which create little contrast between the lighting systems and their background reducing the effectiveness of lights as visual cues. In some cases the lack of contrast may render completely ineffectual the use of lights as visual cues.

At night shallow fog conditions present a unique problem as the ALS segment and strobe lights will be visible through the fog structure during the early part of the approach. However, as the fog layer is entered, contact with the ALS may be lost, and the strobe lights cause a distracting or possibly blinding effect as their light is diffused through fog. The first usable cue for lateral alignment will probably be the 1000-foot bar and then in rapid succession will be the last 700 feet of the ALS, the red terminating bar 200 feet from threshold, the red wing lights, threshold lights, and then contact with the TDZ, CL and HIRL. It should be pointed out that as rapidly as these cues are perceived they will be lost as they pass out of the pilot's field of vision. The visual segment observed from the runway lighting environment should remain constant in a homogeneous fog condition. The pilot should see five to six HIRL's at each side of the runway and about a 1000-foot segment of the TDZ and CL lights. The visibility at decision or flare height will not be equivalent to the reported RVR, because the visual environment must be viewed at an angle through the fog. The actual visibility will be a slant range visibility which is usually less than horizontal visibility. Darkness also reduces the effectiveness of the touchdown zone, centerline and edge markings; in extreme darkness these markings will not be visible. Once visual contact with the TDZ, CL and HIRL's is achieved within a visual segment of 1200 feet, it is a matter of using the visual environment to control the lateral and vertical path of the aircraft. In the test Sabreliner there was no problem controlling either the lateral or longitudinal flight path in this condition.

One of the first visual responses is to determine lateral position through use of all available cues. At night project pilots used the TDZ and centerline lights to determine flight path, effect lateral control and decrab. Once initial lateral conditions were determined, a single row of lights may be sufficient to control lateral movements. After proper lateral path control is ascertained a pilot's attention must then focus on the vertical plane for flare control.

The pilot's visual expanse for flare initiation will be sharply limited by the lack of visual cues resulting from the 1200 foot segment. Training will be necessary to adapt to using this shorter visual segment. The TDZ and CL lights will have to be used to control flare attitude, although they do not provide good visual reference for depth perception.

The runway and its markings may not be visible at night, so the flare may be based totally on lighting cues. If proper lateral alignment was not ascertained at initial contact with the lighting cues, the pilot's control problems will be compounded since he has both flare and alignment to adjust and maintain.

The problems of lateral and vertical control will be deeply compounded at those installations without TDZ and CL lights. The ALS with its strobes, red terminating bar, red wing bars and threshold lights provide the same cues, but once these are no longer in the pilot's visual segment all that exist are the HIRL for lateral and vertical control. Roll, yaw and specifically pitch cues will be considerably less placing more emphasis on using instrumentation for flare and touchdown.

Imagine now descending into a black void with an RVR of 1200 feet at 140 knots. You have been flying instruments and suddenly you transition to outside visual cues at 75 to 80 feet above the ground. Your first visual impression will be of blackness. You will not see the runway outline or its markings, only two segments of HIRLs, two rows of five or six parallel lights moving toward, down and then past the sides of the aircraft; these will be your only cues for lateral and vertical control.

During the Landing Weather Minimums Investigation it was determined it requires about three seconds for the heads-down pilot to integrate the outside visual cues after becoming visual. It requires this length of time to adjust to the outside environment, to determine position with relation to the runway, determine cross-track rate and develop the knowledge to effect the control inputs necessary for visual control. A pilot's mind must function like a computer digesting information to determine actions. Until a history is known in relation to the visual cues, the proper control input cannot be derived. While this process is occurring the aircraft is moving forward about 225 feet per second and downward at 10 to 15 per second. The pilot's visual roll and pitch information is limited in this environment. Due to the short visual segment, a feeling of being high may exist, causing an instinctive lowering of the nose creating a false aiming point. Also, if the aircraft is at an angle to the runway centerline, the pilot's first impression may be perceived as a cross-track causing a roll input which produces an actual cross-track. The 1200-foot segment presents enough information to perform the flare maneuver; however, the horizon and usual background cues will not be visible. A different flare reference must be learned and a new set of values for judgment and confidence must be

part of the pilot's repertoire for approaches and landings in this environment.

Once touchdown is accomplished, the HIRLs will provide adequate cues to perform the rollout phase of the landing. Of course if TDZ and CL lights are available, cues from these sources will present better rollout information. Lighted distance-to-go markers along the edge of the runway should be adequate for braking; however, it would be better from a pilot's point of view to have in-runway lighting for distance remaining along the centerline of the runway. Attention could then be totally focused on the centerline for rollout and braking techniques.

Use of the landing lights has not been mentioned on these descriptions of night approaches. These lights produce a blinding effect, thus hindering both the heads-down and heads-up pilots. They will completely block out visual cues for the heads-up pilot and draw the heads-down pilot away from his instruments.

There are several significant factors that distinguish day operations from night in visual range of 1200 feet. Some of these are: the pilot's psychological feelings; the effectiveness of lighting systems; the use of cues from runway markings; and the discernibility of the runway.

Psychologically the pilot is more relaxed since the day visual segment contains more familiar cues and he can rely more on the past experiences he has developed from the visual environment. The runway, with its outline and markings, provides more tangible cues than lights in the darkness. Subconsciously, these are some thoughts that go through a pilot's mind. Realistically, however, the pilot is faced with a more difficult situation than he realizes.

In fact, there will be less lighting cues available for the day approach. On final the ALS and scrobe lights will be washed out, possibly faded to the extent they may not be visible from the cockpit. If some are visible, only the last few hundred feet prior to threshold will be found useful. In this case the runway markings and contrast will provide better guidance than the in-runway lighting system. The heads-down pilot, as he comes visual, will be drawn to the CL striping and touchdown zone markings more than the lighting systems. The markings will provide adequate lateral guidance for alignment and the visual segment should provide sufficient reference for flare. Some

TDZ and CL lights will be visible; however, they will be of secondary importance when the background behind the lights is bright. Runways without TDZ and CL lights may provide just as effective cues with the all-weather runway markings during day operations.

One of the most important aspects of the day approach is, then, the runway markings. It is imperative these cues be kept in excellent condition. If not, much of the visual information for lateral control will be obscured. Further, the TDZ and CL striping provide cues to acquire depth perception. If these cues are not in good condition, the flare perspective would be considerably reduced. The side striping also produces valuable position information for lateral guidance during the flare and rollout. The rollout can be accomplished with reference to CL striping. Distance-to-go information on centerline should be considered to avoid division of attention during rollouts.

There is an extreme variance between the cues used for day and night operation. Lights provide the dominant night cues, while the runway and its markings are best during daylight. During sunrise and sunset, both lights and markings provide significant cues.

Operations Below Category II:

When the visual range decreases to a value from 200 to 600 feet, a new problem develops where insufficient cues are available to flare the aircraft whether it is day or night. And, as the visibility approaches 200', recognition of lateral movement becomes extremely difficult with present lighting and marking systems. In this environment, the entire ALS can be considered ineffective for lateral control. The threshold, red terminating bar and wing lights may provide a cue to the heads-up pilot. However, the heads-down pilot will not see these cues since he must remain on instruments to touchdown. Therefore, the heads-down pilot requires refined lateral and vertical instrumentation in addition to flare information. The key, then, to a successful approach is the interaction of each pilot, with their proper execution of assigned responsibilities. The heads-up pilot will see cues from the TDZ, CL and HIRLs during night operation or the washed-out effect of the lighting system and runway markings during daylight operation. These cues provide a marginal visual segment for lateral alignment; the flare must be controlled by instruments.

Reaction Time:

Reaction time must be carefully considered when a transition is

made from a heads-down instrument environment to a low visibility real-world environment. To use a limited visual segment as a basis for suddenly establishing visual flight will require some time to interpret the visual environment. When cues are first seen, aircraft position is known, but what is not known at that instant, is exactly what the aircraft is doing with relation to the cues perceived. The time required to integrate and determine lateral movement depends to some extent on the length of a visual segment and the cues within a visual segment. Visual segments of 1200 feet generally presented project pilots with little difficulty determining lateral and vertical movement. However, as segments decreased toward 600 feet, visual perception of lateral movement (cross-track rate) became extremely difficult and pilots required normally 3 to 4 seconds to effectively interpret visual cues. One explanation of this observation would be that as the visual segment decreases, it does not present enough visual information within the pilot's visual field to rapidly determine cross-track movement. It would seem logical to assume that the shorter the visual segment became, the longer the time required to perceive lateral movement.

Time is an extremely important factor when operating in visibilities less than 600 feet. If an aircraft is moving forward at 225 feet per second and downward at 10 to 15 feet per second, the aircraft would be almost at touchdown before a pilot is alert to the geometry of the flight path. This fact directs, to some extent, complete instrument flight and the need for new instrumentation when operating with restricted visual segments. An analysis would indicate a need for lateral information relating to runway centerline presented and scaled in such a manner to be flyable and command corrections toward centerline. At night in a visual segment less than 600 feet, it is extremely difficult to acquire depth perception. A feeling may exist that the aircraft is sailing along several feet above the runway. Another visual effect may be of descending through a narrowing funnel. This illusion may be caused by fixation on a point source of light (Autokinesis). Daylight operation in the same weather allows some use of the runway surface for depth perception; however, the flare must be accomplished on instruments.

TRANSITIONING FROM INSTRUMENT TO CONTACT FLIGHT CONDITIONS:

Introduction:

In the low visibility environment, pilots will seldom experience a distinct transition from instrument to visual conditions during an approach in obscured weather. This type of weather presents pilots with a number of problems not encountered during an approach to a cloud base ceiling or one that is hooded. At the point where the hood is pulled or the aircraft breaks out below the ceiling, the visual cues used to control the aircraft are usually clear and distinct and there is instantaneous recognition of aircraft position with relation to the runway. With obscured or partially obscured conditions the reverse is usually true; visual cues are indistinct, easily lost and it is difficult to discern aircraft position laterally and vertically with relation to the runway. It is essential to consider every factor which might aid the pilot during the final stages of an approach and landing. The visibility, type of weather, expected visual cues and even crew procedures and coordination are some of the tangibles which require careful consideration. Preparation and understanding are the keys which will make the transition smooth and precise; and only through a thorough understanding of the weather environment and how it affects the availability and use of visual cues will the pilot be prepared to accomplish the low visibility transition safely and routinely.

Restrictions to Visibility:

There are many phenomena, such as rain, smoke, snow, haze, which restrict visibility; however, the most common restrictive element is fog, which may be encountered in a number of different forms, each with its own particular hazards. When visibility restrictions do exist and the sky is totally hidden from the observer, the sky is reported as obscured and the reported ceiling is the vertical visibility from the ground. If a pilot is executing an approach in an obscured condition, he will not normally see the approach lights or runway environment as he passes the level of the obscured ceiling. The pilot should be able to see the ground directly below him; however, the transition from instrument to visual flight will occur at an altitude considerably lower than the reported vertical visibility. In partially obscured conditions, vertical visibility is not reported since the ground observer can see through the obscuration or a portion of the sky is not hidden by the obscuring phenomenon. However, when clouds are visible with a

partial obscuration, their heights and amounts are reported. The amount (in tenths) of the sky or clouds obscured by a partial obscuration is included in the remarks section of weather reports. Although this may help clarify the reported conditions in many cases, it still does not provide an idea of the height which visual cues will be sighted or the slant range visibility. In some cases the partial obscuration can be associated with shallow patchy fogs so the pilot can expect to lose visual references once the fog condition is entered. Also of concern to the pilot is the visual range at which he will be able to discern visual cues for runway alignment and flare. The pilot must be aware that the reported runway visibility or runway visual range (RVR) may not be representative of the range at which he will sight the runway. In fact, the pilot's slant range visibility may be considerably less than the reported RVR. Another factor that must be considered is the decrease in the visual segment due to an aircraft's downward vision angle (angle from the pilot's eyes over the aircraft's nose measured from the horizontal). This also may be several hundred feet. Once these factors and the destination weather are understood, the pilot will possess the knowledge to effect a safe, smooth transition from instrument to visual flight.

a. Shallow Fog: This type of fog seldom exists to a height of over 200 feet and is usually associated with partially obscured conditions. Since the fog may be patchy, it is possible that the visual segment may vary considerably during the approach and rollout. Also, the pilot may be misinformed if RVR is measured by a transmissometer located in an area of good visibility. The most serious problem with this type of fog stems from the abundance of cues at the start of the approach. The shallow fog allows the pilot to view the approach lighting system and possibly even some of the runway environment, during the early stages of an approach. However, as the fog layer is entered, most or all the cues may be lost. If the pilot is not flying instruments, he may become confused and disoriented. During the early part of the approach, pilots should not rely entirely on visual cues for guidance. They can be brought into the cross-check to confirm position, but instrument flight must be maintained until the visual cues perceived can be kept in view, and the runway environment provides sufficient references for flare and alignment.

b. Deep Fog: Deep fog exists to a height of several hundred feet and is usually associated with obscured conditions. The pilot will not normally see cues during the early portion of an approach. More likely, he will view cues from only the last one thousand feet of the approach

lighting system. From a U.S. Standard A approach lighting system, the pilot will probably see cues from the thousand-foot bar, the last one thousand feet of the centerline approach lights, red terminating bar, red wing lights, green threshold lights and the high intensity runway edge lights. If operating at night and the strobe lights are on, these may produce a blinding effect. Care should also be taken when using landing lights as they may cause a blinding effect at night. The transition from a deep fog approach involves the integration of visual cues within the cross-check during the latter portion of the approach. The pilot should see identifiable portions of the ALS at decision height; however, cues to control lateral alignment and flare will occur well below decision height. Again, it is essential for the pilot to be thoroughly familiar with the approach lighting system to develop the proper perspective between these cues and the ensuing runway environment.

c. Cloud Base Fog: This type of fog usually forms above the surface of the runway and is associated with low ceilings, but since the fog forms more of a definite ceiling, a pilot can usually expect better visibilities once the ceiling is passed. Therefore, the transition from instrument to visual flight is sharper with more pronounced use of visual cues after passing the ceiling. Night approaches may produce the sensation the aircraft is high once the cloud base is passed. The pilot should continue on instruments, cross-checking visual cues to confirm runway alignment. During the flare the pilot may experience a sensation of descending below the surface of the runway. This will be especially pronounced at facilities with 300-foot wide runways. In either case, the pilot must avoid large attitude changes which might produce a duck-under or over rotation.

d. Sea Fog: In most fogs the pilot expects almost calm wind conditions and is not too concerned with side slip or de-crab procedures. Sea fogs, however, can present pilots with wind and turbulence problems not associated with other fogs. It will be more difficult to maintain good instrument flight if turbulence is present. Pilots can encounter sea fogs with characteristics similar to shallow, deep or cloud base fogs. The characteristics of the sea fog will be related to the wind speed, for as the wind speed increases the fog usually deepens. Wind velocities greater than 15 knots usually form a cloud base fog due to the lifting action of the turbulence. The pilot's best procedure is to be aware of the conditions which might be encountered and to integrate visual cues within the cross-check during the latter portion of the approach. Since cross winds do exist, the pilot must be especially prepared to de-crab while avoiding large attitude changes which might

produce an undesirable touchdown attitude. Also, airspeed must be more closely monitored because of the effects of turbulence and the de-crab.

c. Ice Fog: This type of fog is most common to the arctic region; however, it can occur in other areas if the air temperature is below about -25°F . It consists of a suspension of ice crystals in the air and is mainly an artificial fog produced by human activities when hydrocarbon fuels are burned. When there is little or no wind, it is possible for an aircraft to generate enough fog during landing or take-off to cover the runway and a portion of the field. Depending on the atmospheric conditions, ice fogs may persist for several minutes or days. The piloting hazards and procedures are basically the same as the other fogs, but careful preflight planning must be made if the conditions exist for its formulation.

f. Rain: Approaches and the ensuing transition to visual flight can be very hazardous as moderate to heavy rain conditions can seriously affect the utility of visual cues. Night approaches in these conditions are even more critical as the pilot may be blinded by flashing strobes or runway end identifier lights. The transition to visual flight can be severely hampered by the inability to adequately maintain aircraft control and interpret the instrumentation to gusty or turbulent conditions. The moderate or heavy rain condition can also render the rain removal equipment ineffective causing obscuration of visual cues at a critical time during the transition. In these conditions the pilot must be prepared with an alternate course of action and act without hesitation to prevent the development of an unsafe situation.

g. Snow: Blowing snow is accompanied by many of the same hazards as rain, such as turbulence, difficulties in reading the flight instruments, obscured visual cues and aircraft control problems. Of special interest will be a lack of visual cues to effect runway identification for the visual portion of the approach. The approach and runway lights will provide some identification; however, runway markings and the contrast with relation to its surroundings will be lost in the whiteness. Therefore, depth perception may be difficult to achieve, placing more emphasis on instrumentation for attitude control. It is extremely important to avoid large attitude changes during approaches in snow.

Visual Cues: Approach lights, runway markings, lights and contrast are the primary sources of visual cues. At some facilities touchdown

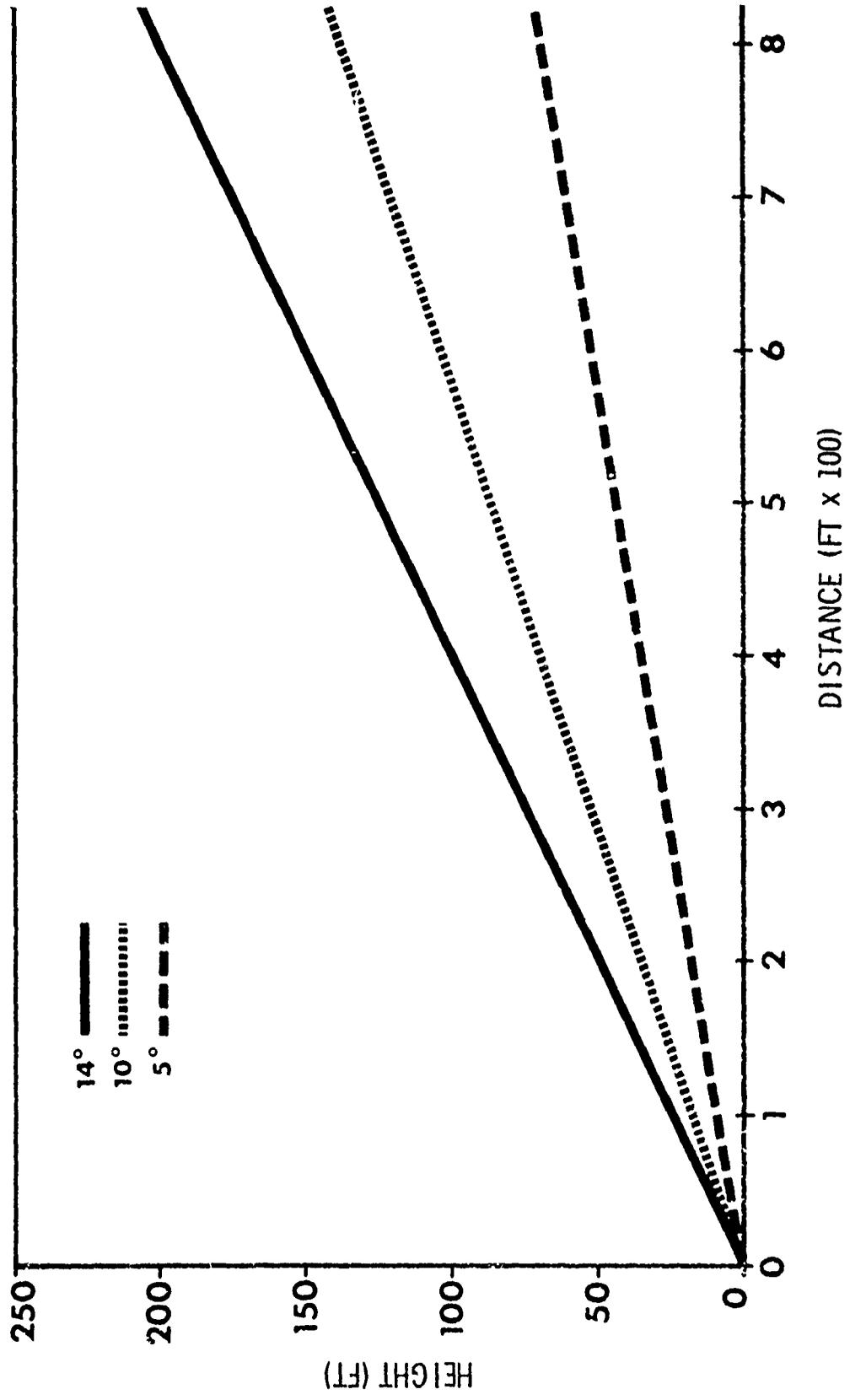


Figure 1. Downward Vision Angle Chart

zone and centerline lights may also be available. The pilot's responsibility is to become familiar with the lighting and marking patterns provided at his destination and to correlate them with the weather to be effectively prepared for the transition to visual flight. In minimum visibility conditions, the visual cues and references for flare and runway alignment are extremely limited compared to the normal references the pilot uses during a visual approach. Therefore, the aircraft's projected runway contact point will not be within the pilot's visual segment until considerably below decision height. Any abrupt attitude changes to attempt to bring the projected impact point into the pilot's visual segment may produce high sink rates and thrust/lift management problems at a critical time. These so-called duck-under maneuvers must be avoided during the low visibility approach.

Another type of duck-under is encountered when the pilot attempts to land within the first 500 to 1000 feet of the runway after breaking out of an overcast. In this case the pilot attempts to establish a visual profile similar to the one he uses most often. Establishing the visual profile usually involves reducing power and changing attitude to aim the aircraft at some spot short of the end of the runway. In this maneuver a pilot attempts to use as much of the available runway as possible and justifies the maneuver due to shortness of the runway or poor braking conditions. This type of maneuver is not recommended since high sink rates and poor thrust relationships can develop which may cause under-shoots or hard landings. The pilot should base his landing decision upon the normal touchdown point from the instrument approach and if stopping distances are insufficient proceed to an alternate.

Downward Vision Angle. There is area hidden by the nose of an aircraft which the pilot cannot see from the cockpit. If a line from the pilot's eye is projected over the nose of his aircraft, this line will form an angle with the horizontal determining an aircraft's downward vision angle (Figure 1). The area hidden from the pilot's view can then be determined from a trigonometric relationship based on aircraft elevation and downward vision angle. An aircraft with a 14° downward vision angle 100 feet above the surface will conceal about 400 feet beneath its nose. Consider an approach in 1600 feet visibility. This means the pilot's visual segment at 100 feet elevation with a 14° downward vision angle will be reduced to about 1200 feet. Other factors, such as a nose-high pitch attitude and a slant range visibility less than the RVR, can further reduce the pilot's visual segment.

APPROACH AND RUNWAY LIGHTING:

The touchdown zone (TDZ), centerline (CL) and high intensity runway edge lights (HIRL) provide adequate visual information for night operations in Category II conditions. The centerline lighting fixtures which emit at least 7500 candela are far superior to the 300 candela fixtures which can be considered inadequate. When the 7500 candela lights were placed at step 4 (approximately 30 percent of their maximum output) they were found to be marginal at night and unsatisfactory during day operations when the runway visual range (RVR) was 800 feet or less. When the runway lighting was set to step 3, the TDZ, CL, and HIRL were found to be inadequate for either day or night operation with RVRs of 800 feet or less.

One major deficiency was the use of the HIRLs for visual cues. These lights proved to be adequate in Category II conditions and marginal to unsatisfactory in visibilities below 800 feet. Also, it was noted that runway width reduced the effectiveness of HIRLs for visual cues. In similar fog conditions with RVRs close to 800 feet, three to four HIRLs along each side of the runway were barely visible on runways 150 feet wide; while on runways 300 feet wide, only two HIRLs were visible. Considerable effort should be expended to determine a more satisfactory peak intensity alignment which will allow the pilot to take advantage of their maximum of 50,000 candela.

Another major problem area during low visibility flights was the identification of runway threshold. Pilots are extremely interested in knowing their aircraft is over concrete. This mere fact instills confidence and assurance that the aircraft is indeed past the approach lights and properly aligned. This psychological feeling is extremely important since the approach lighting system may provide few or no cues relating to position with respect to threshold in low visibility. This fact is especially true at those military facilities flown which had flush-mounted lights in the overrun. This is not to advocate stanchion-mounted lights, but to simply express a desire for brighter flush-mounted fixtures.

Still another problem area is the possible misinterpretation of the centerline for runway edge lights. To investigate this possibility, a number of offset approaches were flown in Category II and visibilities down to 600 feet. There was no discrepancy noted until visibilities approached 800 feet. In these reduced visibilities, project pilots felt the potential existed to confuse the runway edge lights for the centerline

lights. Inflight photography taken of the offset approaches very vividly depicts the possibility of mistaking the HIRLs for centerline lights.

To prevent this occurrence, either the touchdown zone or centerline lights should be reconfigured or color coded. One possible solution would be to color code the HIRLs red. This would positively identify an unsafe condition while preventing any confusion between the touchdown zone and centerline lights.

Project pilots have had the opportunity to fly the Category II approach lighting system (ALS) installed on Runway 12R, San Antonio International Airport, and have found it far superior to the US Standard "A" for the following reasons:

- a. The strobe lights removed from the last 1000 feet of the ALS eliminated the blinding flashes on short final.
- b. The 500-foot white bar is a definite aid in determining distance and position from threshold.
- c. The parallel rows of red lights for the last 1000 feet of the ALS aid roll guidance and further define the transition from approach zone to touchdown zone.
- d. The stanchion-mounted green threshold lights clearly define the beginning of the runway. However, these 14-inch stanchions are not recommended for the overrun area or threshold use. Study should be directed toward developing a flush-mounted fixture of sufficient candela for these purposes. Recent studies conducted for TAC relating to flush-mounted threshold lights with 500-watt bulbs have indicated they are just as effective as 14-inch stanchion fixtures with 200-watt bulbs.

The flush-mounted 7500 candela minimum centerline lights provide outstanding rollout guidance in night Category II conditions. On step five project pilots were able to use the 7500 candela lights for rollout guidance in night visibilities as low as reported zero-zero. During day operations, it was found that runway centerline marks provide better references for rollout. The color coded centerline lights are extremely effective. All project pilots felt the color coded centerline lights in the last 3000 feet of runway were a definite help. Investigations with color coded centerline lights should continue. Perhaps a configuration where the first third of centerline lights are

green, the second third are amber and the last third are as presently configured would be a possible solution to identification of runway remaining and eliminate the possibility of confusing runway edge and centerline lights.

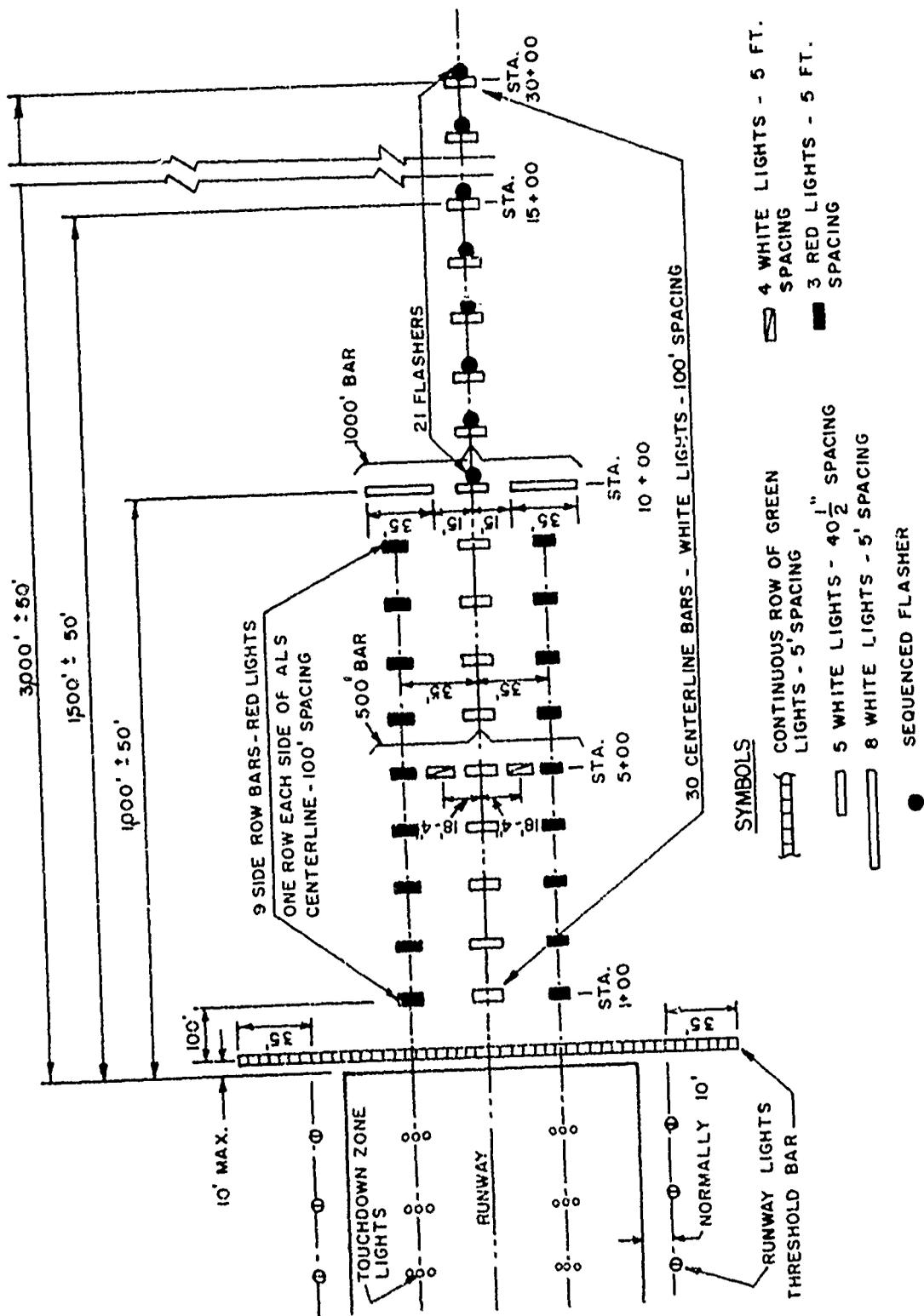


Figure 2. Category II Approach Lighting System

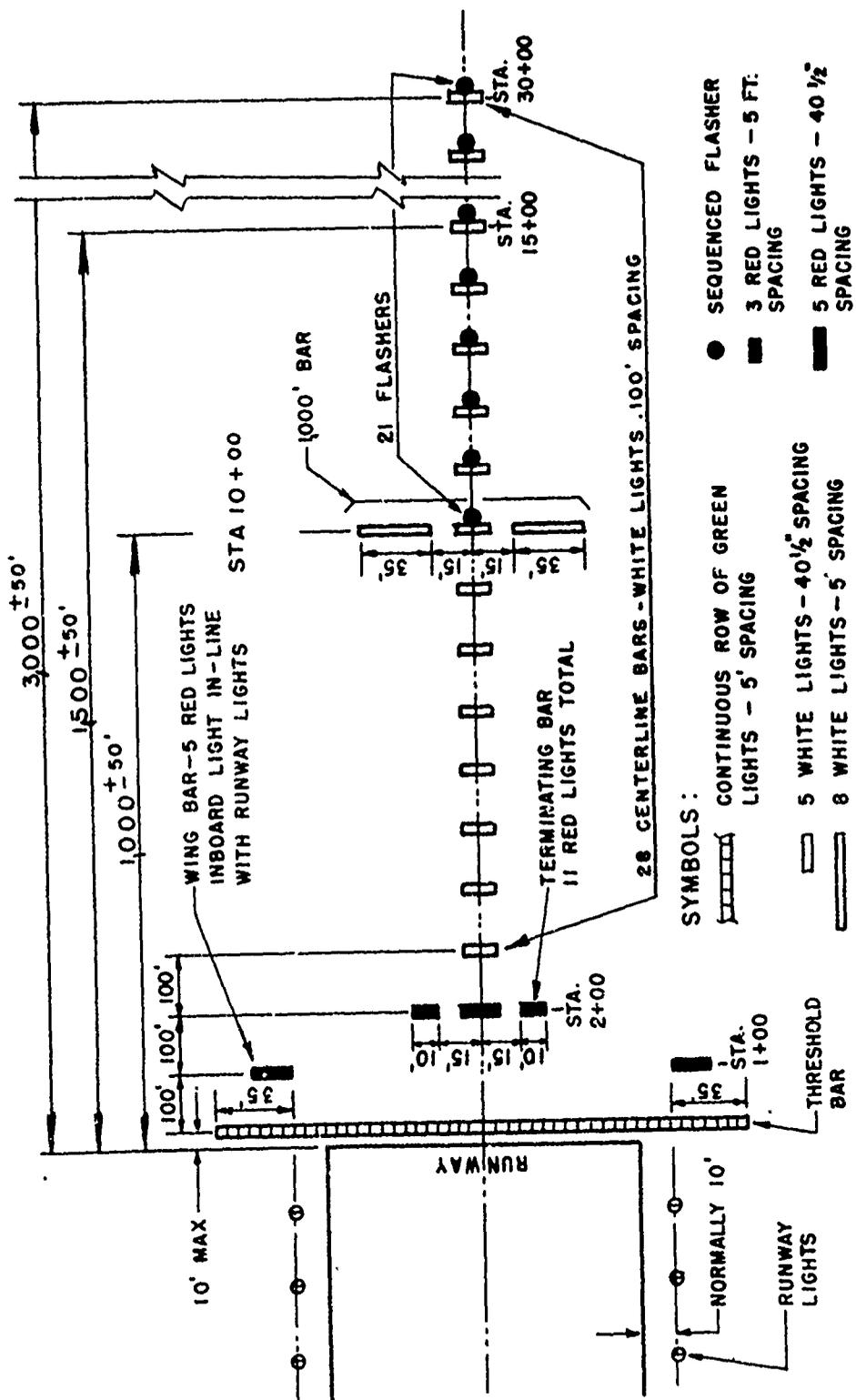


Figure 3. Category I Approach Lighting System

RUNWAY MARKINGS:

In low visibility weather runway markings assume extreme importance and in some cases, such as day approaches, may provide better visual references than centerline or touchdown zone lighting. It would be highly desirable then to provide marking patterns which could instinctively indicate information with respect to runway centerline and distance during both the takeoff and rollout.

The FAA's proposed 3-3-2-2-1-1 pattern (Figure 5) was evaluated by project pilots in April 1969 and at that time it was felt to be an inferior replacement for the present 2000 foot all-weather runway markings. The concept of a marking pattern for touchdown zone identification 3000 feet in length should be adopted if a suitable pattern can be determined. Of paramount concern were these negative features of the 3-3-2-2-1-1 pattern:

1. The touchdown aim points located 1000 feet from threshold do not provide a realistic aim point during low visibility landings. The normal GPIF associated with precision approaches can vary from 750 to 1250 feet. It is believed a bold touchdown identification marking in the touchdown zone would provide an erroneous aim point during low visibility approaches, possibly resulting in "duck-unders" or hard landings. Such a marking may well provide a "forcing function" during any type of landing. This problem is not associated with the present instrument runway marking system.

2. The proposed system degraded the concept of providing distance from threshold information by repeating marking patterns. The problem of identifying specific marks with distance from threshold was prevalent with a standard instrument marking pattern. Project pilots determined during the Landing Weather Minimums Investigation (LWMI) that a more interpretable system was necessary to ascertain touchdown point, and equally important was a need for identification markings which relate distance information for braking techniques at the stop end of the runway. Under low visibility conditions when only one runway marking can be seen, the determination of distance information using the proposed system would be impossible due to the repetition of patterns. It was also determined that the standard AF runway distance markers were not visible in visibilities of less than approximately 600 feet. Their utility is also reduced when vision is restricted by rain, snow, etc., on the windshield. Military requirements for distance information are apparently more critical than civil

because of takeoff criteria (acceleration, refusal, etc.) and stopping distances of high performance aircraft.

3. During visual conditions, the standard 4-3-2-1 pattern Figure 4) presents the pilot with a narrowing envelope directing his efforts toward runway centerline. To some degree, this concept has been retained with the proposed system. However, the envelope has been lengthened and duplicated thus reducing the effectiveness of the concept under low visibility conditions when possibly only one or two markings can be seen. This shortcoming was extremely apparent during the LWMI as many times it was difficult for project pilots to accurately determine lateral corrections (direction to correct to centerline) from the rectangular patterns. This fault has not been corrected by the proposed marking pattern.

4. A pilot over threshold at 50 feet with 1200 feet RVR will probably see only one set of markings on which to determine his lateral position. His downward vision angle (angle from the pilot's eye over the aircraft's nose measured with the horizontal) will cut off approximately 200 to 250 feet of visual cues reducing his visual segment to less than 1000 feet. A pilot in these conditions will find it impossible to determine lateral position on an offset approach (aligned with runway edge). Project pilots flew a number of offset approaches during the LWMI to investigate the effectiveness of the standard instrument runway markings. If the aircraft was aligned with the edge of the runway it was found the edge stripe and adjacent touchdown zone markings could be mistaken for the centerline and corresponding touchdown zone marking. This fault is common to the proposed marking pattern.

Every consideration should be directed toward establishing a fixed distance pattern with direction to centerline compatible for both visual and instrument conditions. Runway markings assume critical importance during low visibility approaches and have profound impact on the successful completion of an approach. In cases of high foreground brightness, the markings provide better visual cues than in runway lighting or runway edge distance-to-go information. Also, the touchdown zone markings provide critical cues to acquire depth perception during day low visibility approaches as the number and interval between markings present transitional and rate information for the flare and touchdown.

Careful study must be directed toward establishing a pattern which

provides the pilot with as much information as possible during the low visibility approach. The following minimum criteria should be considered in the development of an advanced instrument marking pattern:

1. Provide lateral guidance toward centerline.
2. Identifies left or right side of runway.
3. Relates distance from approach and stop end threshold with as little interpretation as possible.
4. Provides distance coding each 500 feet.
5. Identifies runway edge.
6. Identifies runway centerline.
7. System length is 3000 feet.
8. Identifies threshold.
9. Widen the gauge to reduce wear on the inner markings.

Figures 6 and 7 represent attempts to satisfy the stated criteria. Figure 6 shows a standard 2000-foot system modified to indicate runway side, direction to centerline, centerline diamonds, side barbs and distance remaining.

Figure 7 indicates a modified 3000-foot proposal to depict runway side and direction toward centerline. It also includes side barbs, centerline diamonds with distance remaining and directional triangles. As indicated by the large diamond, distance remaining is provided by numbers inside the diamonds which are viewable from one direction only.

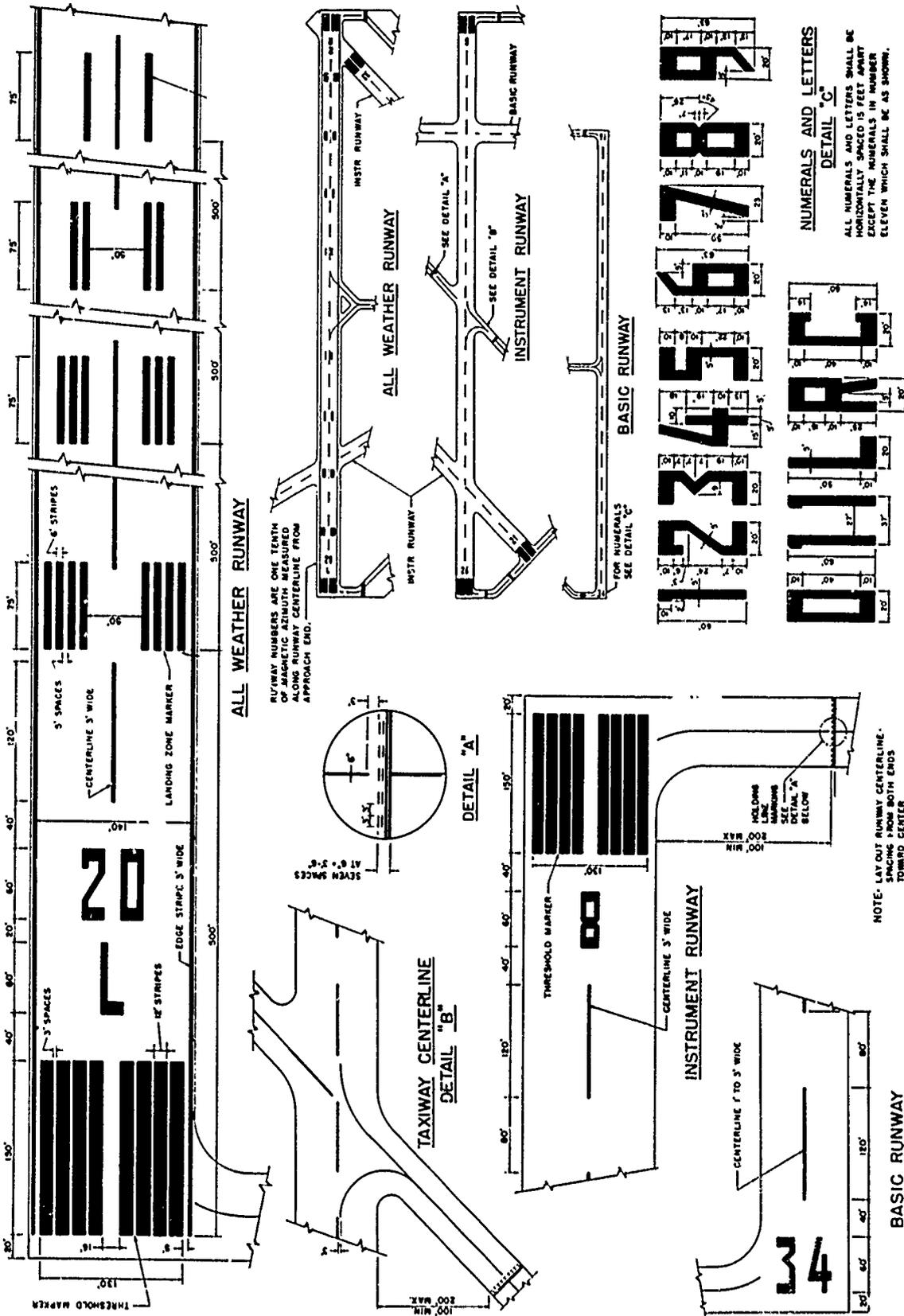


Figure 4. Runway and Taxiway Marking

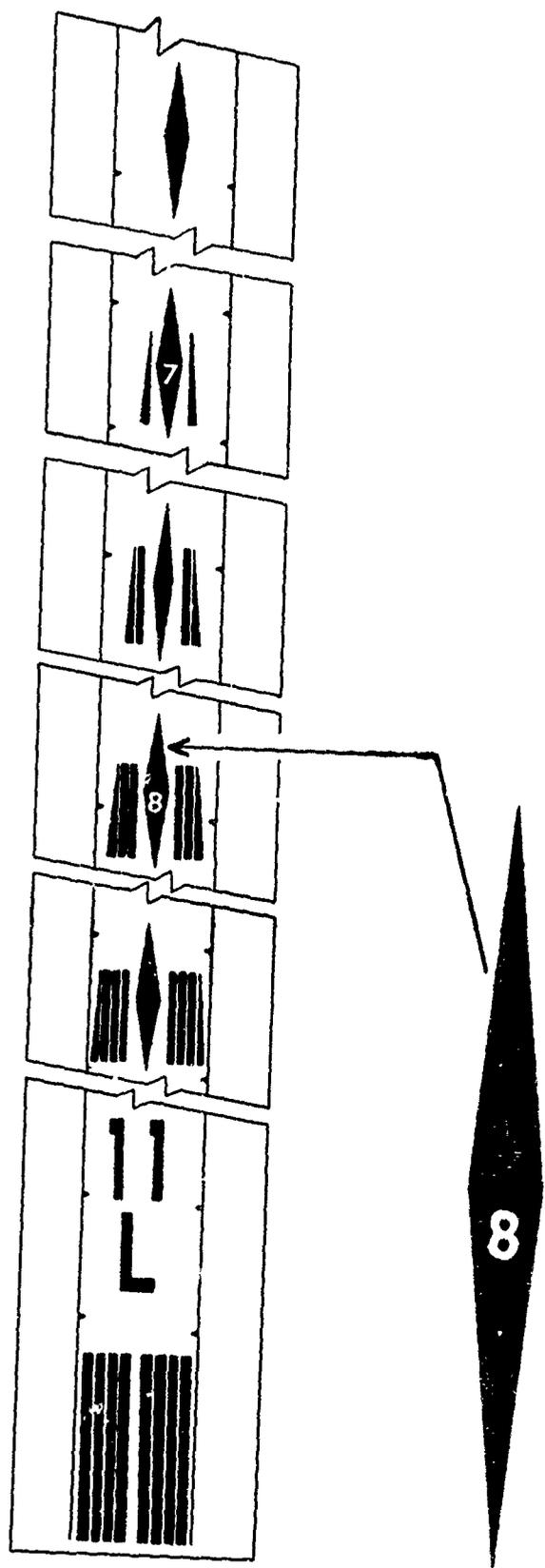


Figure 6. IPIS 2000-foot Instrument Runway Marking Pattern

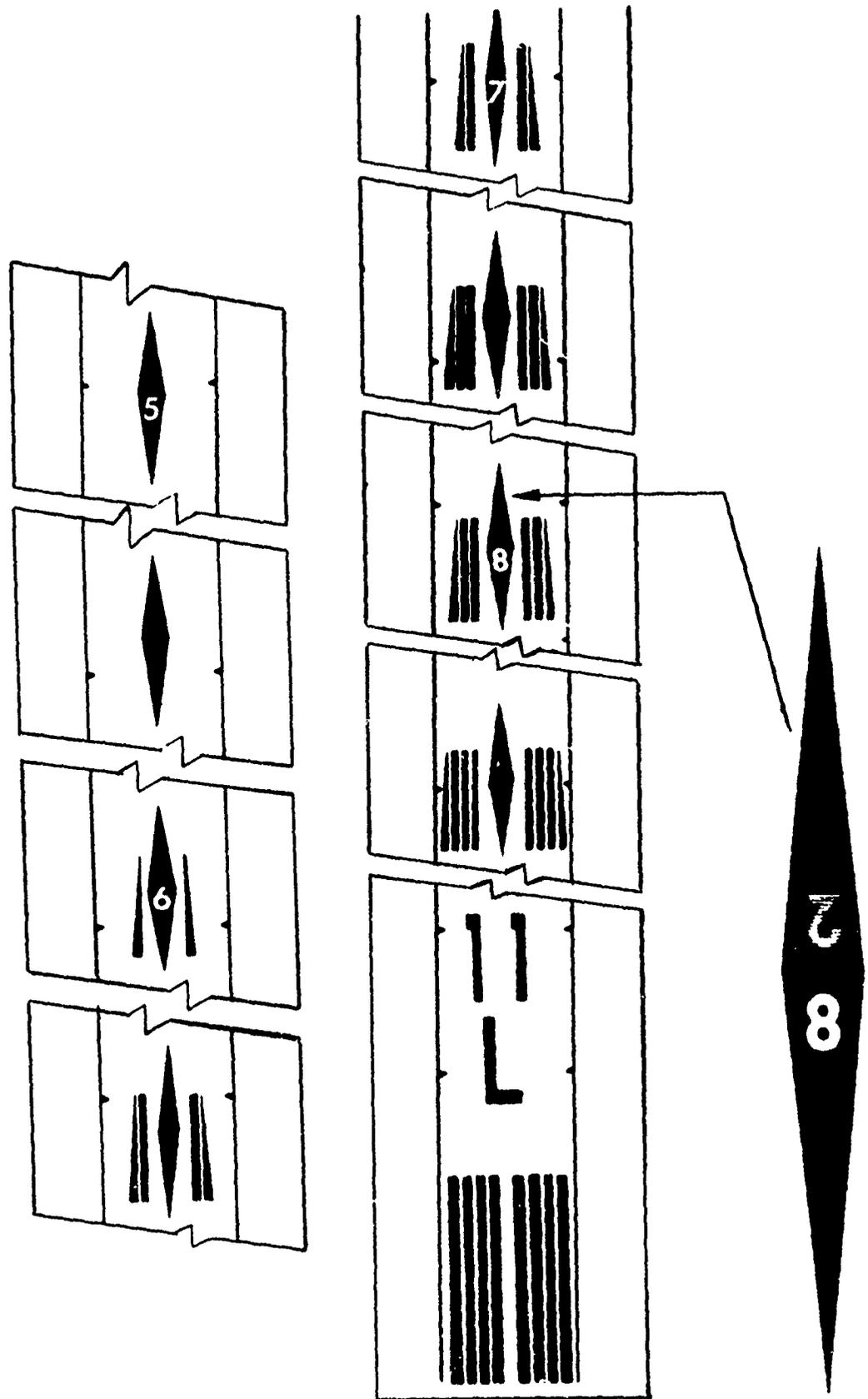


Figure 7. IPIS 3000-foot Instrument Runway Marking Pattern

CATEGORY II OPERATIONAL CONSIDERATIONS

Introduction:

Routine operation in the low visibility environment presents a formidable challenge to the aviation industry. Most assuredly engineers and designers will develop the required control, display and guidance hardware. What will then be the best piloting procedures to use the control/display equipment in the low visibility environment? One of the goals of the Landing Weather Minimums Investigation (LWMI) was to research crew procedures and suggest control/display configurations for low visibility landings. Over 250 low visibility landings were made and as experience was gained, these important realizations occurred:

1. The visibilities caused by fog were usually greater than Category I (200 feet DH and 1/2 mile visibility) or less than Category IIIA (700 feet RVR) meaning that the theoretical Category II operation very seldom existed.
2. Visual information is usually available from the approach lighting system and runway environment even though the weather is reported as zero-zero.
3. Pilots could use visual segments of 600 feet to maintain lateral alignment, but had insufficient visual information to flare.
4. The visual environment can present confusing and illusionary information.
5. At least three seconds are required for a pilot to orient himself in visibilities between 600 and 800 feet if a sudden transition is made to visual flight.
6. A visual segment of 200 feet was sufficient for rollout using cues from either the centerline lights or markings.

Pilot in the Control Loop:

The basic problem of low visibility landings is contingent upon the assigned role of the pilots. Basically two approaches can be taken. The first premise is that of a completely automated coupled approach. The second premise is that which includes the pilot as an active control

element and adjunct to the automatic system. If the first premise is accepted, then the pilot's role becomes that of a monitor and the success of the approach, touchdown and rollout rests with the automatic systems. The pilot in this sense is a detriment to the automatics and is there for passenger appeasement and to take control only if an emergency occurs. Aircraft equipment requirements become simplified since outside references and special displays and control systems will not be required. Therefore, the engineer and designer can concentrate on automatics and guidance systems to satisfy low visibility landing requirements.

The other premise accepts the pilot as a necessary adjunct to the automatic system. In this design, the needs of the pilot must be considered. Not only must the pilot have access within the automatic system, he must have the controls and displays to actively participate based on his judgment of approach progress. Therefore, he will need the display to effect a manual on instrument capability for the approach, flare, touchdown and rollout. This also requires the pilot be provided the unburdening qualities of automatic systems so he may be integrated into the total system. In this manner pilots would be able to participate in conjunction with the automatic system and an additional redundancy would be established with pilots in the control loop.

It is doubtful that the first premise would ever be appealing to the pilot populace due to the extremely stressful nature of the low visibility approach maneuver. There are extreme psychological as well as physiological forces which must be neutralized by satisfying the pilot's need to know. In this way, the displays will satisfy the requirement for approach progress information, the control systems allow the pilot to participate and automatics produce unburdening. In the final analysis, the pilot's role must be defined to add substance to the development of crew stations and assignment of procedures during the approach and landing.

Regardless of the level of automatics, it seems only reasonable to assume that the pilot will be the ultimate decision maker in the man/machine relationship. If the pilot is assigned the responsibility for the safe conduct of flight, then it is absolutely essential he be provided the tools to perform his job. There are those that contend the pilot would be a detriment to approach progress in low visibility conditions -- that the low visibility environment can create illusionary effects which could trap pilots into catastrophic situations. The issue here is a vital one and must be resolved by providing an on-instrument capability to touchdown. In this manner, not only can the low visibility environment

be safely flown, but a solution to the visual landing accident will exist. Pilots will have the means to follow instrument flight paths to a runway, thus eliminating the possibility of under or overshoots. If energy management displays are added to the scheme, then an on-instrument capability will exist to arrive on the runway at the proper position and speed.

The main question which arises is the procedural use of the on-instruments landing system. Will the pilot(s) be allowed access into the control system to assist the automatics with aircraft control or will they merely serve as monitors to take over only if an emergency occurs? During project flying in the LWMI, all project pilots agreed that it is absolutely essential that pilots be provided access into the automatic system with force wheel steering. They felt that only by being integrated as an active control element would the pilot be prepared to assist or assume active command as necessary. Therefore, to satisfy piloting requirements, the computer which operates the autopilot must also operate the command steering displays, the pilot must be integrated with the automatics with force wheel steering and finally, the pilot must have the displays to effect a manual on-instrument approach, flare, touchdown and rollout. In reality the process is one of maintaining instrument flight to touchdown or a closed instrument loop. How pilots can do this will be discussed next.

Closed Instrument Loop:

With the exception of the takeoff and landing pilots can maneuver an aircraft through its entire flight profile without visual reference to the real world. In fact, the real world is not necessary since all piloting tasks can be performed with reference to instrumentation within the aircraft. This, then, implies that instrumentation of a very sophisticated nature, to relate to the pilot all the visual information he needs from outside his vehicle plus parameters depicting aircraft position and performance are necessary for the takeoff and landing. One must not infer that parameters in themselves will supply the key to the solution. There are three essential interrelated aspects which must be considered collectively. These are the control, display and guidance elements. Without determining the requirements for all three, the instrument loop can never be closed.

Presently, the pilot is faced with parameters which do not relate to him his position with respect to runway centerline. He knows he is left or right of a final approach course and aiming somewhere down the runway, but he cannot determine exactly where since the quality

of the guidance is not designed to provide this information, and his displays are oriented to the guidance, not the runway. In the low visibility environment, present instrument displays are adequate to visibility minimums of approximately 1600 feet RVR with a decision height of 100 feet. For precision flying, however, present instruments do not display the information to perform the subtle corrections necessary below 1600 feet visibility. Also, the navigation displays are oriented to the guidance which was not designed to provide information to touchdown.

Therefore, the capability to maintain a closed instrument loop begins to deteriorate when descending through a height of 200 feet since the information does not relate to the runway centerline nor provide the means for the finite corrections required. The closed instrument loop starts to open (provide insufficient instrument information), then, around 200 feet with present guidance/display configurations. Thus supplemental information relating to flight path control must be derived from outside the aircraft at some theoretical altitude below 200 feet. This, to say the least, is extremely undesirable in adverse weather conditions since the pilot must divide his attention between the instrument displays and visual information from the real world. Almost certainly the pilot will place more emphasis on real-world cues which may not relate a true picture of approach progress and in some cases create illusions.

At present there is no way a pilot can maintain a closed instrument loop to touchdown. The process is one of supplementing instrument with visual information until a closed visual loop exists and a visual landing can be accomplished. It is this transition from one loop to the other that produces the potential hazard and must be eliminated.

The closed visual loop consists of using real-world cues supplemented with performance instrument information for aircraft control. When the pilot has the runway environment in sight, he can gauge his rate of closure with the touchdown point and has at his disposal all the information he needs to effect the finite roll, pitch, yaw and airspeed corrections necessary for a successful approach, landing and rollout. If weather obscures the pilot's aiming point, but allows cues for lateral control, he is faced with a partially closed instrument/visual loop (maintains lateral alignment visually and flares on instruments) and the integration of cues from both the visual and instrument environment. This form of control can be acceptable until the instrument or visual loop opens (either loop provides insufficient information

for aircraft control); if this occurs, the approach cannot be continued, and an extremely hazardous condition may exist.

The Category II Transition

The "see-to-land" process entails maintaining a closed instrument loop while attempting to establish a closed visual loop at decision height, or some point thereafter, and then transferring to the closed visual loop to complete the approach and landing. In reality, the visibility for a distinct transition from the closed instrument to the closed visual loop seldom, if ever, exists in actual low visibility conditions. If restrictions to visibility do exist, they are usually caused by total or partial obscurations which normally produce visibilities less than 1000 feet. The problem, then, doesn't involve a transition to visual flight, but a method to maintain lateral alignment and flare on instruments. To attempt the transition visually requires 3 to 4 seconds for the pilot to assimilate the visual cues, another second or so to determine a course of action, another second for the control input, after which the aircraft reacts to the control input. If we further examine this piloting task, we may find the pilot is not absolutely positive that the visual patterns developing define the aircraft's attitude and position. It was noted many times during the LWMI that the visual pilot, using outside visual references, had the sensation the aircraft was much higher than its actual altitude. This visual illusion could lead to a duck-under maneuver during a critical phase of flight. Another important aspect was the lack of a well-defined aiming point for touchdown. This causes the flare perspective to lack the fundamental characteristics apparent during an unrestricted visual flare. The pilot's visual segment may contain enough cues for lateral alignment; however, the visual perspective to flare the aircraft is lacking. This condition was encountered numerous times below 1200 feet RVR.

The conditions described above denote a phase of aircraft control which is a combination of both instrument and visual control or a partial instrument/visual loop, neither being closed. This situation develops when there are enough visual cues to provide some guidance, but not enough for total reliance. This condition is perhaps the most dangerous, due to the visual illusions, false sensations, lack of well-defined cues, pilot reaction time, etc, that could possibly exist. It is this partial loop, visual and instrument, which is neither desirable nor tolerable since there are insufficient cues from either source to provide a true picture for aircraft control. Also, the pilot is faced with an extremely hazardous situation if he elects to control his

aircraft in the low visibility environment with the present family of instruments, and if he relies solely on an automatic flight control system, there is no way to monitor the performance of the autopilot or assume control without proper instrumentation.

It is quite obvious the closed visual loop cannot be maintained for 100% of the approaches, landings and rollouts. Would it then be possible to develop an instrument system capable of displaying the information the pilot needs to maintain a closed instrument loop throughout the approach and landing profile? Also, could such a system be configured to produce more desirable information than the real world? The answers to these questions are yes, and this must be done to have a true low visibility landing capability.

Independent Landing Monitor

One of piloting's dilemmas is determining the integrity of an ILS localizer and glide path signal during low visibility conditions. This perplexing situation produces extreme psychological conflicts for a pilot. This attitude manifests itself in the fact that his past experiences have proven to him that electronic guidance has not been reliable enough to repeatably align his aircraft within the confines of a runway 150 feet wide. In some cases, beam bends and dips can be of such a sufficient magnitude to cause uncoupling of an autopilot. This salient fact exists in visual conditions; how, then, can a pilot have confidence in the integrity of an electronic beam during minimum visibility conditions?

Obviously, a device or system is absolutely essential to verify the integrity of the electronic guidance and also allay a pilot's psychological fears. Only through the use of an Independent Landing Monitoring (ILM) device will sufficient redundancy be realized to absolutely ascertain the safety required for operations in the low-visibility environment. To be totally effective, the ILM system must be completely independent of the electronic guidance used by the autopilot and that displayed on the navigation instruments. Its purpose, then, would be to either confirm or deny an acceptable lateral and longitudinal dispersion during the period from short final to touchdown.

To totally justify such an important component, it would seem apropos to design a multi-function display capable of relating critical information to the pilot throughout an entire mission profile. Since a majority of flight time is conducted during visual conditions, it

would seem completely essential to include display elements required in both the visual and instrument environment. Some of these parameters might include:

1. Pitch and Bank Attitude
2. Flight Path Angle
3. Angle of Attack
4. Limiting parameters such as pitch rate, acceleration rate, and "G" loading
5. Command Steering
6. Gunsight Information
7. Radar Altitude
8. Course Deviation
9. Heading
10. Failure Annunciation
11. Altitude
12. Terrain Avoidance Information

By now it may appear that the Independent Landing Monitoring System is taking shape as a collimated light display capable of projecting a wide variety of information. A desirable configuration would be a HUD (heads-up display) using a combining glass and images focused at infinity to delineate certain parameters for specific flight maneuvers. These, of course, would be selectable by the pilot.

In the case of the low-visibility landing, the display should depict the relationship of the aircraft to the runway centerline with qualitative parameters to indicate vertical and especially lateral deviation. Other useful information could include FPA (flight path angle), radar altitude, projected touchdown point, aircraft attitude, and distance from both threshold and far end of runway. It would seem desirable to project runway symbology in a form comparable to the visual perspective on

short final; that is, the runway symbol is not fixed on the display and both ends move laterally and fore/aft to provide an intuitive sensation of proper flight path and cross track rate. It is extremely important to stress at this point that the symbology must be representative of real-world cues and relate to the pilot the same information, as to position, he would see through the aircraft's windshield during a visual landing.

To generate this type of real-world display, it seems that a high resolution radar or infrared system may be necessary. These systems could be used to provide the necessary inputs to depict the runway symbology on a combining glass or possibly present the real world on a CRT. In either situation, the depiction would provide performance information relating to a pilot his aircraft's position with respect to runway centerline. It must be noted that this display is not anticipated as a command instrument; that is, one that directs the pilot to establish an altitude, attitude or heading on short final approach. However, it may have application as a terrain avoidance, low approach monitor and for other visual maneuvers.

Heads-Up Displays (HUD)

Project pilots did not have a heads-up display to evaluate; however, some pertinent observations were made concerning their utility and use during the Landing Weather Minimums Investigation. It is believed that a heads-up display would not have been any benefit to the heads-down (instrument) pilot. The instruments and displays on the instrument panels were the heads-down pilot's responsibility to monitor and use to fly the approach, make the touchdown, rollout, and takeoff. However, it is believed that a HUD display would have been of great benefit to the heads-up (visual pilot), since he came heads-up at approximately 200 feet to determine exactly what visual information was available from the approach lighting system and the runway environment. He was severely limited in his ability to monitor the progress of the approach with relation to the flight instrumentation inside the aircraft after he went heads up. It is believed that if the heads-up pilot had information on the wind screen in front of him, then he would be able to spend some of his time monitoring the performance of the heads-down pilot while integrating visual cues. A basic necessity for the heads-up pilot would be attitude information. This seems to be an extremely important parameter, especially in aircraft with a fairly long wing where the possibility of dragging a wing pod exists during a decrab maneuver. Attitude information in both the roll and

the pitch axis would seem a very basic requirement to monitor on short final. Also, the heads-up pilot would be vitally concerned with the quality of the tracking performance the heads-down pilot is attaining. So, it is also necessary to supply the heads-up pilot with information with respect to localizer error and what is being done to return the aircraft to the localizer course. Both raw and command steering information with respect to the localizer course are necessary. In the pitch axis, information with respect to aircraft position with relation to the glide slope and the performance of the heads-down pilot is necessary to properly monitor the approach. Airspeed information also seems to be a necessary parameter; not so much with respect to exact airspeed, but some type of on-speed information. Is the aircraft on-speed? If not, exactly what is the error, and is it within tolerances and at what rate is the speed increasing or decreasing, or is the trend toward an undesirable airspeed indication? These types of parameters should be monitored by the heads-up pilot. Also, it would seem almost essential for the heads-up pilot to have a separate source of guidance being supplied into his heads-up display as a method of cross-checking the primary guidance to the runway. This secondary guidance would also be with relation to the runway centerline and glide slope to allow monitoring of the performance of the aircraft with relation to the primary guidance system.

Pilots flying a low visibility approach may find it extremely difficult to focus their attention on a display which is located directly in front of them while attempting to see through the display to pick up visual cues from the approach lighting system or the runway environment. Will pilots have the ability to focus on two areas at the same time, and does it require a great deal of pilot concentration to monitor the instrument approach from the HUD in the precision manner that's necessary from 200 feet above the surface to the runway? All of the heads-down pilot's concentration will have to be channelled into maintaining the heads-down instrument display to attain adequate performance. At times, project pilots felt that possibly a heads-up display may be extremely distracting to a pilot who goes from flying cockpit instruments to looking outside for visual cues. Also, it may be that the symbology on the HUD could be confused with lighting from the runway or approach lighting system. At times, during the LWMI when the project pilots came heads up, it took 3 to 4 seconds to integrate the outside visual cues. In addition, it was difficult to pick up any type of trend from the visual cues when the RVR was down in the area of 6-800 feet. There was one time in particular when the runway edge lights produced an overpowering compulsion to fly the aircraft toward

these lights. Therefore, the feeling exists that possibly some type of lighted heads-up display in front of the aircraft might create this type of lighting illusion where the aircraft is misaligned. The pilot may inadvertently put the aircraft into an undesirable attitude in order to center or correct some type of lateral situation that doesn't exist.

There is absolutely no doubt that heads-up displays have merit; however, they must be evaluated in an actual weather environment to ascertain exactly what parameters should be put on the display, how they should be configured, scaled, and color coded. They would appear to have a tremendous amount of flexibility if pilots had the option to select the display that would most benefit his particular flight needs. In the scheme of low visibility approaches, it would seem also desirable for both pilots to have a heads-up display from the viewpoint that the all-weather systems design, in the final analysis, probably would have the capability of being flown from either the left or the right seat. In this manner, either pilot could act as the heads-down pilot flying the aircraft to touchdown while the other pilot acts as systems monitor.

Guidance Systems

Advanced guidance capability is a necessary adjunct for operating in Category II and III visibilities. In planning for a mix of conventional, STOL, and VTOL aircraft, on varying profiles in dense traffic, present and forecast, some desirable guidance capabilities emerge: a selectable glide slope; a glide slope and centerline signal without dips, bends or scalloping; a basis for ground monitoring of an aircraft's approach progress; high resolution distance information in the cockpit; flare guidance to touchdown 1000 feet to 1500 feet from threshold; compatibility with present instrumentation; self-monitoring with switching in case of failure. A most important concept is the linear definition of the approach path on short final. The advantages of the linear approach path are two-fold: sensitivity remains constant and instrumentation can relate aircraft position to runway centerline. Another important consideration is the design synthesis of new instrumentation capable of relating lateral rates and the means to control/adjust lateral rate.

Whenever beam interference is encountered, piloting workload increases at an alarming rate. Any over-correction made on final approach can create enough instability to cause a go-around. The aircraft must be stabilized in its landing configuration when the middle marker is reached. From this position to touchdown, there is very little that can be done to re-establish the dynamic stability necessary for the remainder of the approach.

CREW PROCEDURES

Instrument flight in any type of weather environment requires definition of piloting roles if operations are to be efficient. The weather environment will, to some extent, provide guidelines and restrictions to crew procedures and training requirements. If the different types of weather environments are examined, crew procedures may become evident which will be appropriate for all types of visibility conditions. Basically, three types of visibility categories may be encountered -- the cloud base ceiling, the zero-zero visibility condition, and the "quasi" condition. Also, it is possible that a combination of these conditions may exist. These three conditions and conceivable combinations will be investigated from the crew procedures viewpoint to determine possible piloting roles. Let us discuss these weather categories and how they affect crew procedures.

The cloud base ceiling can be defined as that meteorological condition where the aircraft descends through a definite ceiling. Once the ceiling is passed, visibility is usually unrestricted. Conditions such as rain, snow, etc, may exist, but there are still sufficient visual references to maintain composite flight, as previously defined. In this type of condition, pilots may use a number of different crew allocations. Some of these could include the co-pilot flying instruments until composite flight is possible and then either continuing visually to touchdown or relinquishing control to the aircraft commander. Another possibility could be the aircraft commander making the instrument approach and either continuing to touchdown or allowing the co-pilot to fly to touchdown once composite flight can be maintained. There could also be a split allocation concept with the pilot not flying instruments controlling the throttles to maintain airspeed. Another possibility could be a split axis concept with one pilot controlling pitch and power while the other has roll and yaw. Other combinations could also be arranged.

The cloud base ceiling offers no particular stressful challenge since visual references will be plentiful once the ceiling is passed. However, it is possible to enter into the "quasi" condition if composite flight is not strictly adhered to. If, for example, the approach is conducted at night in an area without many lights or at an austere facility, it is possible the visual references may not be reliable. Even though the entire approach and runway lighting system is in view, pilots have landed short of runways, in some cases up to five miles, simply because the visual references were insufficient for adequate

depth perception or created illusions leading to the errors. This could also be the case during approaches in snow, rain, etc, where the visibility is somewhat obscured. The solution to preventing these types of accidents is to maintain composite flight. Also, one pilot, in a dual aircraft, could be tasked to specifically monitor instrumentation. This type of task allocation could possibly prevent premature descents or large excursions from instrument flight paths when the visual references create illusions of false height or present ill-defined cues.

The reported zero-zero weather condition presents a situation where there are supposedly no visual references to control the aircraft. Therefore, at least one pilot must maintain instrument flight to touchdown, throughout rollout and during taxi. The other pilot could be either looking outside for visual cues or assisting passively or actively with instrument flight. The experiences acquired during the LWMI indicate that there may be visual references available even though the visibility is reported as zero. In fact, visibilities as great as 600 feet were noted and usually at least 200 feet visibility was available. These findings indicate that some visual information may be available to assess Category III approach progress. A great deal of caution must be exercised when interpreting and using cues in the low visibility environment. This does not mean these cues can be used for path control, only that visual confirmation of approach progress may be possible. Training will be required to use cues properly in the lower visibilities. The role of the pilots in the zero-zero environment could be to have one pilot maintain instrument flight to touchdown while the other pilot acts as the decision maker, based on the information acquired from the instrument displays, independent landing monitor or visual cues if available.

The "quasi" weather environment provides insufficient information to conduct visual flight although enough cues are available to positively confirm position. The "quasi" environment presents the greatest challenge to crew integrity since there will definitely be visual cues for interpretation and possible use for lateral alignment and flare. Let us look at the "quasi" environment, approach geometry, and the limitations inherent with cockpit design before discussing crew procedures in this environment.

Generally, the weather associated with the "quasi" environment is fog, which can be categorized as either shallow or deep. In either case the characteristics of each may vary considerably and pilots

have no meaningful information relating to them a true picture of the visibility conditions until they actually encounter the weather phenomena. In shallow fog, pilots generally expect to have visual cues until the top of the fog is encountered, then some or all cues may be lost until close to the flare height. In deep fog (fog several hundred feet thick), pilots generally expect cues close to decision height unless it's a deep, mature, homogeneous fog. In either case, if the theoretical 1200 foot RVR exists at decision height, the pilot's aiming point and runway threshold will not be in view, although sufficient visual references may be available for lateral alignment. The weather phenomena then dictates a requirement for continued instrument flight past the decision height. Therefore, one pilot must fly instruments while the other continues to evaluate the weather environment with respect to the visual patterns developing.

A second important consideration is the limitation imposed on the visual segment due to cockpit downward vision angle. In most aircraft of the transport category, this angle is approximately 14° , which means at decision height, 400 feet of the visual segment will be hidden by the nose of the aircraft ($100 \div \tan 14^{\circ} =$ approximately 400 feet). The pilot's visual segment, then, will not be 1200 feet at decision height, but 800 feet. This is the segment available at decision height which the pilot must use to evaluate his approach progress and make his landing or go-around decision. A visual segment of 800 feet is insufficient to consider as visual conditions, so the aircraft must be flown by instruments below decision height. Again, cockpit geometry dictates that one pilot is necessary to maintain instrument approach progress.

The third item for consideration is the approach geometry. At decision height with 1200 feet RVR, the runway environment (runway surface, touchdown zone, and centerline lights, markings, threshold and edge lights) and the pilot's aiming or touchdown point are not in view. This means instrument flight must be continued to some altitude below decision height. At fifty feet altitude, the aircraft should be at threshold and the pilot's visual segment is approximately 1000 feet ($50 \div \tan 14^{\circ} =$ approximately 200 feet) due to the downward vision cutoff angle. Thus, a visual pilot still cannot see his aiming or touchdown point, although there should be sufficient visual references for lateral alignment and control. However, there are marginal references for longitudinal path control.

A solution to the crew procedures question would be to assign

one pilot the responsibility for visual decisions and the other for instrument flight. As visual references become available, the visual pilot could use verbal cues to alert the instrument pilot about their identity, magnitude, and utility. In this manner instrument flight can be maintained to touchdown, confidence is instilled in the instrument pilot as he receives information relating to the visual environment. Also important, control integrity would not be sacrificed if a missed approach is necessary at or below decision height. To complement this crew concept, the visual pilot could assist as the visual environment allows, first in the lateral axis, then in the longitudinal axis and then take complete control at touchdown for the rollout and taxi.

The crew's roles should surely include the total integration of their efforts along with the unburdening aspects of an automatic flight control system with a flare and landing capability. Theoretically it would seem plausible, if not absolutely essential, to assume that both pilots should have at their disposal the flight control/display systems to singly or dually accomplish flight to touchdown solely with instrumentation. The basic act of aircraft control seems somewhat trivial, but the prerogative of command should ideally rest with the aircraft commander. The aircraft commander should be the decision maker while the other pilot is responsible for instrument flight. If a fault warning system is not included in the system's design, consideration should be given towards a third pilot performing this function.

The aircraft commander would normally be the overseer for the entire flight, directing the efforts of the crew, assigning duties and making critical decisions. In the case of the low visibility landing, the aircraft commander would assume a visual posture at some predetermined altitude, evaluate the visual environment and make the land or go-around decision. Since he would have access to the visual environment, he could assist with path control when able, or monitor the co-pilot during the entire approach and touchdown.

The instrument pilot would execute physical authority over the automatic flight control system (AFCS), assisting in the tracking function by inserting control inputs as necessary. His primary function would be the overt management of the AFCS through control inputs and selection of the proper automatic modes during the approach.

Until passing the final approach fix it is anticipated the aircraft

commander would direct, at his discretion, the accomplishment of communications and aircraft configuration procedures. However, once the final approach fix is passed, the aircraft should be in its landing configuration (to prevent instability problems on short final), and the visual pilot should assume full responsibility for radio communications. The reason for this assignment is two-fold. The visual pilot, since he is the overseer for the approach, would be alert to the total situation, both inside and outside the aircraft. This also permits the instrument pilot to concentrate on systems performance, assessing the need for control inputs, and exercising proper control over the automatic system without distraction.

Since the visual pilot is alert to the geometry of the approach profile and the status of the ground environment, he should naturally assume the role of the decision maker. In his role of decision maker, he would be responsible for the land or go-around decision and also for conveying information regarding the approach to the pilot flying the instrument approach. This concept was found extremely important during the LWMI and may have merit during routine low visibility landings. The following verbal procedures were used during the LWMI. The first call was "CUE", which meant that portions of the runway environment were coming into view, but insufficient visual information was available to control the aircraft. The second call was "LATERAL", meaning that the visual cues were sufficient to laterally align the aircraft with the runway centerline; however, insufficient visual information was available to flare the aircraft. Also, at the lateral command, the visual pilot exercised his prerogative and assisted with lateral axis control. It is extremely important to stress at this point that there was no transfer of aircraft control and the instrument pilot was still tasked to maintain instrument flight. When the visual pilot had sufficient references to visually control the aircraft he called, "VISUAL". At this time he could, at his discretion, aid with aircraft control with inputs into both the lateral and longitudinal axes. There was still no transfer of control. If the visual pilot wished to take complete control, he would state, "I have the aircraft", and assume complete control while the instrument pilot relinquished complete authority. It was anticipated that this command would be executed by the visual pilot only after the aircraft was safely on the runway, at which time he would assume active control for the rollout. The instrument pilot would then be responsible for configuring the aircraft for the rollout.

Another important decision that must be made is whether or not

to execute a go-around. This decision should be made by the visual pilot and executed by the instrument pilot on the verbal command, "GO-AROUND". The roles of the pilots should be exact and specific as the go-around is commanded. The instrument pilot should execute the maneuver since he has physical control of the aircraft. The visual pilot would be evaluating the weather environment on final approach and hence direct the appropriate command. When a go-around is made, the visual pilot reconfigures the aircraft, leaving the other pilot free to concentrate on the go-around maneuver. Again, the main principle is to unburden the aircraft commander, who would normally be the decision maker and visual pilot, while eliminating any transfer of control during the final approach, flare and landing.

SECTION IV

CONCLUSIONS

See-to-Land Concept

Twelve hundred feet RVR provides a marginal visual segment to control an aircraft's flight path. In effect, a decision height of one hundred feet allows only a visual segment of 600-800 feet for pilot use to determine his land or go-around decision. The effective visibility (slant range visibility) and downward vision angle must be carefully considered when assigning a visibility criteria for a visual takeover on short final approach. It is believed that 1600 feet is the lowest practical visual range that can be assigned to a decision height of 100 feet to safely maneuver visually for landing. Visibilities below 1600 should be approached with the philosophy of an on-instrument capability to touchdown. This includes an on-instruments flare capability.

Force Wheel Steering

Force wheel steering (FWS) is an absolute necessity as an unburdening tool for all flight operations and especially those in the low visibility environment. Force wheel steering must be a part of a low visibility approach system. The actual force levels and roll rate functions must be investigated, but it is appropriate to say that the final configuration should be active throughout the approach and touchdown. Using FWS on short final should not disengage or uncouple the autopilot; however, the pilot should have the means to uncouple the autopilot if desired while the FWS remains active.

Pilot in the Control Loop

This is the most powerful and convincing approach to the low visibility landing problem. The pilot must have access to the autopilot through FWS and the displays to evaluate the caliber of the approach. Only in this manner can the essential innate human qualities of judgment, evaluation and action be coupled with the precision and unburdening aspects of a finely tuned approach and landing system. The primary integrating factor of the pilot is the computer which drives both the command steering bars and autopilot. In this manner the pilot has at his disposal the performance of the autopilot with relation to the raw course information. The pilot can then evaluate autopilot performance and assist as the displays require.

Heads-Up (Visual) Procedures

The visual environment was found to provide useful information when the weather was reported as WOX0F (ceiling and visibility zero). Project pilots were able to use a 200-foot visual segment for rollout during both day and night low visibility conditions. Visibilities on the order of 200 feet will afford some information for the rollout only.

The heads-up pilot will be subject to visual illusions and possibly disorientation with ill-defined cues in Category II and III types of weather. Therefore, the heads-up pilot will have to rely heavily on instrumentation during the approach, flare and touchdown. In shallow fogs, the temptation to control the approach visually must be avoided to prevent an inadvertent excursion into instrument conditions while flying visually.

The role of the heads-up pilot is to monitor the instrumentation and visual environment making his landing/go-around decision based on the visual cues in view at decision height.

Heads-Down Procedures

The low visibility environment presents a serious challenge to contact aircraft control as visual segments decrease below 1600 feet. If the visual environment cannot provide sufficient information for aircraft control, the aircraft must be flown with reference to instrumentation during the final approach, flare, touchdown and rollout if necessary. The role of one pilot (the ace in the hole) should be to maintain aircraft control with instrumentation until the visual environment affords sufficient information for a visual landing.

Category III weather will dictate a continuance to touchdown on instruments even though there may be enough cues to ascertain lateral position. The heads-down pilot must be adequately trained to participate in conjunction with the autopilot to touchdown.

Radar Altimeters

The requirements for precision in Category II operations point to the need for an altimetry system with as much accuracy as possible. Even though the decision point is identifiable by a marker beacon crossing an electronic glide path, the accuracy and definition is unacceptable and can serve only to remind the pilot he has descended to

minimums. In a situation where the marker beacon receiver or transmitter fails, reliance on a barometric altimeter would be totally unacceptable.

Radar altitude also functions as a necessary parameter for inputs into the flare mode and other functions such as approach sequence information or gain tailoring.

Approach Lighting

The Category II approach lighting system should be adequate for approaches down to Category IIIa. In Category II and IIIa, the system should provide sufficient visual references to affirm or deny position with respect to runways. In Category IIIb and IIIc, approach lighting for visual cues would not be a significant factor since Category IIIb uses lights for taxi and possibly rollout while IIIc is not concerned with external visual references.

Runway Lighting

The 7500 candela in-runway lights are adequate for touchdown zone and centerline lights in Category II and IIIa weather. Either the centerline or runway edge lights must be reconfigured or color coded to allow absolute identification of either system during offset approaches. The flush-mounted threshold lights with 200-watt bulbs provide inadequate visual cues in Category II or IIIa conditions. Investigations should be made of 500-watt bulbs in flush-mounted fixtures to determine their effectiveness. Stanchion-mounted fixtures should not be used in the overrun area or for threshold lighting. The HIRLs are not adequate.

Guidance

The VHF guidance system is unreliable and subject to too many excursions, dips, scalloping, and outside influences to be an effective tool for operations in Category II or lower weather. It is believed a practical limit for the VHF ILS guidance is 100 feet.

A new type of guidance criteria as specified in this report is considered an absolute necessity for safe and consistent operations below a decision height of 100 feet. A new guidance system must supply linear information during at least the last three-quarters of a mile from threshold.

Heads-Up Display (HUD)

Heads-up displays do not appear to be the panacea for all-weather flight. Careful consideration must be given to their role in both a visual/instrument environment to determine their ultimate configuration. Before those proponents of HUDs are heeded a careful study must be made of the HUD in all types of weather to learn their uses and pitfalls. At this time HUDs would seem to have useful application to visual as well as tactical environments. However, caution must be exercised to prevent a rash of nonstandard, cluttered displays which would tend to be confusing in themselves.

Runway Markings

The runway markings presently in use are not adequate for low visibility landings. A new system must be developed to provide instinctive information to the pilot relating his position to centerline and distance from threshold. Distance information is especially important to determine both takeoff and rollout performance. One of the most important visual references during day low visibility landing are the touchdown zone and centerline markings. In fact, pilots will find the markings to provide more useful cues for day operations than either the touchdown zone or centerline lights.

Independent Landing Monitor (ILM)

A need exists to present a separate source of "how goes it" type of information to the pilot. This information would be completely independent from the guidance information. Only in this manner will pilots be able to ascertain that the guidance and automatic systems are indeed performing in an optimum and safe process. The ILM concept is extremely important as it supplies redundancy, which promotes safety, and can instill confidence in the pilot to relieve psychological pressures. The best type of display would be a real-world time pictorial display similar to what the pilot sees out the windshield of his aircraft.

Visibility Measurement

There are many variables which cause inaccuracies in the measurement of visibility. From the pilot's point of view, the visual segment at decision height, in the touchdown zone and during the rollout, are all of prime interest. The visibility at decision height would be a slant range

visibility relating to the pilot the furthest distance which may be seen. Knowing this distance, the pilot can subtract the cockpit cutoff distance and determine the length of the visual segment available for the landing or go-around decision. Another important use of slant range visibility would be the determination of the visual segment during flare. This particular information is extremely valuable in "see-to-land" operations. Different and degraded visibilities, especially in shallow fogs, were noted many times. The differences between visual segments at decision height and those in the touchdown zone must be accurately sensed and reported to provide valid information relating to the visual cues expected on short final.

The pilot's problems do not end with a successful touchdown since there is still the rollout, taxi and docking to complete. To be complete, the pilot must also be advised of visibilities during these phases of operation and systems developed to control the aircraft efficiently once it has landed.

Emergency Equipment

It is possible to foresee that situations may develop where ground or airborne emergency equipment is required to operate in the low visibility environment. Displays and procedures are necessary for the types of vehicles to operate routinely along the airport surface or at low altitudes to transition to and from emergency operations. Without a routine operational capability for emergency vehicles, there can be no low visibility operation for aircraft.

Training Requirements

The most difficult task of all will be to prepare the pilot for the low visibility landing. He can be taught to operate the equipment and shown the various cues available in the simulator, but there is always the fundamental overtone that the situation is not real. When the real situation occurs, there will be tremendous psychological and physiological pressures on pilots that no electronic simulation can adequately reproduce. Above all, pilots must have absolute confidence in themselves and both the ground and airborne equipment. This confidence can only be realized through everyday use and constant practice with equipment and procedures. In this way pilots will gain both confidence and proficiency.

There must also be realistic training programs established which

will put the pilot in the aircraft in conditions similar or equal to the weather environment he is being certified to operate in. Such a training program should include ground school to learn systems operation and the effects of restrictions to visibility on visual cues. Simulator time will put the training into motion and actual flight time will utilize the equipment in the actual or simulated environment. One method of simulating the low visibility environment would be to electronically time the approach and runway lighting with the movement of the aircraft. As the aircraft moves down final and along the runway, a segment of lights could be electronically keyed to illuminate and simulate the required visibility. If this type of training could be accomplished on a dark night, it could prove to be extremely effective.

APPENDIX A
TAPED COMMENTS

TAPED COMMENTS
SACRAMENTO METROPOLITAN AIRPORT
10 January 1969

Sacramento Metropolitan

P Maj Carmack
CP Maj Hadley
TP Maj Adams
ACM Armstrong

Runway 16

10 January 1969

APPROACH #1 (Osc #75) (Film #255)

-X1 1/16F/RVR 800

Automatic

Comments:

Major Hadley: This is a fairly shallow fog, but very mature in that you can't see through it until you get right at it. Our approach light contact height was about 200 feet. Our first cue was the approach lights. The number of approach lights visible were about three prior to the 1000-foot bar. They came through the fog quite well. Then I could see all of the approach lights at that point on. I did not notice the red terminating bar, or the wing bar lights or the threshold lights. I saw the touchdown zone lights very clearly. The centerline lights were not on. I could see about four to five hundred feet on the ground. We did not roll out because we did not have any centerline lights and the visibility was only 400 feet. The effectiveness of the lighting system was good once we got down in it; however, we didn't see the lighting until we entered the fog, at about 200 feet. The number of runway lights visible were two, which would mean we had four to five hundred feet. The runway markings were not overly apparent; of course, it's dark out there, but they are not in as good a condition as they were last year, not as effective. We did not go manual and we did not roll out very far.

Sacramento/10 Jan 69

APPROACH #2 (Osc #76) (Film #252)

-X1 1/8F, RVR 800

Automatic

Comments:

Major Hadley: This is a shallow fog, about 300 feet thick. It's getting a little thicker. It's a mature fog, you can't see through it. It's not the type that you can see trees and lights through it unless they are real bright. The first cue is the approach lights. That time I could pick up about six lights prior to the 1000 foot bar, saw the 1000 foot bar very clearly and all the lights the rest of the way in including the terminating bar. However, I did not see the green threshold lights. Approach light contact height is about 190 feet. I gave you the number of lights visible. At that time, I would say we had six to eight hundred feet forward visibility. The lighting system is very effective. I could see about eight hundred feet of touchdown zone lights. The runway markings are very ineffective at this point. I could have controlled the flare from the right seat; however, if I would have been coming heads-up, I'm not particularly sure that I could have at that point.

APPROACH #3 (Osc #77) (Film #248)

-X1 1/8F, RVR 800

Semi-Automatic

Comments:

Major Hadley: On our third approach, which was a semi-automatic approach, everything was about the same as last time. I could see about six to seven of the approach lights prior to the 1000' bar, which was the first cue.

The fog, is about 300' thick. Mature type fog, although it is not very thick at this time. Approach light contact height was 300'.

Sacramento/10 Jan 69

Number of approach lights visible were about six prior to the 1000' bar, and I could see the rest of them on in. The reference for cue was the approach lights. I'd say our visual segment is six to seven hundred feet. The lighting system is very effective -- everything is on step five. Runway lights visible -- I could see three. I could see about ten to twelve of the centerline lights as we went down the runway. Runway markings are not visible -- they are not very good at all in this type of weather, perhaps the effectiveness of the touchdown zone and centerline lights are blaring them out. They are not a bit effective. The pilot was semi-automatic that time and he flared through the automatics system; however, he wasn't coupled and I don't think he had any difficulty. We will let him make some comments at this time.

Major Carmack: I came off instruments between 100 and 50' when you said "visual". However, I didn't have a good flare reference. I could see about six TDZ lights in front of me there, and lost my reference for flare. When I eased back on the control column, I really didn't have full grasp of where the aircraft was relative to the runway and it could have developed into a dangerous situation. I didn't know how high above the runway I was as I had no depth perception. I had the sensation of floating above the runway at an undetermined height and I had a funny sensation when we were on the runway -- I knew we were on the runway, but had the feeling that I really wasn't on the runway. I had the feeling we were sailing along above the surface of the runway. I think, to suddenly go visual, is too much of a transition to make, especially at night. A lot of the information that I would like to see isn't accurately displayed on the instruments. I would like to see the instruments depict what the aircraft is doing in relation to the runway and what visual cues are available such as lights (centerline lights) for cross track rate and information to resolve crab angle. I would rather stay on instruments, at night, in this type of weather. It's better to stay on instruments.

Sacramento/10 Jan 69

APPROACH #4 (Osc #78) (Film # 237)

-X1 1/8F, RVR 800 (I don't think they quite have 800', it's more about 600')

Semi-Automatic

Comments:

Major Hadley: The fog is becoming more of a deep fog than a shallow fog. It's now 600 feet thick. I would have to call it a rather mature fog. Also, on the first cue, which is again the approach lights. I have been seeing about six lights prior to the 1000-foot bar, this time I saw only three lights prior to the 1000-foot bar. I can see the lights through it, but I can't get any directional control, because I can't actually see the light itself. So, the number of approach lights visible were three prior to the 1000-foot bar and I could see a total of about six as we got just slightly lower. Reference for visual call was the approach lighting system. The effectiveness of the lighting system is outstanding. It's very good at this step setting. The number of runway lights visible was a minimum of three that time. I would say our runway visibility at touchdown, is about 600'. The runway markings -- still not effective. It's starting to get a little lighter. I would think, perhaps, that we will be able to see them now. I could see all of the lights that time, including the terminating bar, wing bar lights and the threshold lights. They were all quite visible. Now, we did not go manual. The pilot, although flying semi-automatic, stayed heads down during that approach. He doesn't feel that he wants to come heads up and make the flare. I assisted, a little bit, in directional control on the rollout.

Major Carmack: I believe it's the night operation that causes gun barrel effect. I'm drawn right to the center of the ADI and pitch and bank steering bars as the necessary thing to do. When I become focused on a fixed area like that, I really have to concentrate to break the fixation. I have to force myself to come down to the LSI and to cross-check the ADI and the CDI and so forth. It seems like when I get a fixation it's like a lens of a camera that you have to reset the focusing and force yourself off. It is a manual effort.

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APPROACH #5 (Osc #79) (Film #262)

-X1 1/8F, RVR 800

Manual

Comments:

Major Hadley: The fog, now, on approach number 5, is quite thick. The visual cue is the approach lights. However, I did not see the 1000 foot bar. I only saw three approach lights before I saw the terminating bar, the green threshold lights and the wing bar lights. I did see them, again, but I did not make out or see them as early as I did before. The reference for the visual call was the approach lights. The lighting system, not nearly as effective since the fog seems to be thickening. Runway markings are not effective along with touchdown zone lights and centerline lights. We don't see them for much effectiveness. That was a manual approach. Manual all the way. He did a fine job of flying it. Had no problems, whatsoever, until I called "visual". At that time, he came heads-up and we developed a cross-track rate and we did go around. He probably could have landed the airplane. However, there's no point in trying to do it. In a T-39, he could have made it all right, although we did develop a rather sudden cross-track rate just as soon as he went heads-up. We drifted over to the left side quite rapidly. A big airplane would never have been able to control it, so we went around. Now standby for comments from the pilot.

Major Carmack: I would definitely say that it takes a considerable amount of time to integrate the outside visual cues. I think there is a big problem in this area. We developed the cross-track rate because I just do not have enough of an aiming point or enough references in the visual segment. I have enough visual references as long as the aircraft is stationary along the centerline or along the touchdown zone lights, but I just don't have enough visual reference to compute the amount of correction that is necessary to stop the cross-track rate, or determine the aircraft is drifting from left to right.

Sacramento/10 Jan 69

APPROACH #6 (Osc #80) (Film #439)

-X1 1/8F, RVR 800

Automatic

Comments:

Major Carmack: As you roll into the turn with the heading mode coupled to the bank steering bar and try to slew the aircraft around to a new heading the fast rate of roll with the autornatics doesn't feel natural. It is not the normal rate that a pilot would use. If it were the normal rate that a pilot would use it would be good, but the fast rate gives you the feeling that as well as turning you are descending. On short final approach the strobe light flashes, I don't look outside to see them, but I can see the lights flash up in front of the aircraft and this is bothersome.

Major Hadley: The fog now is a very mature fog. The fog height is about 700 feet. The first visual cue remains the same -- the approach lights. The approach light contact height that time was probably 250 to 300 feet. The approach lights visible -- I estimate about six prior to the 1000-foot bar. Reference for the visual call once again, was the approach lighting and for the visual call, also, was the entire runway environment. The IVALA lighting system continues to be good. I could see, at the touchdown point, only about two to three high intensity edge lights; however, as we rolled down the runway, I could see three to four runway lights. So, the visibility along the runway is varying a couple of hundred feet. The runway markings, even though it's getting lighter up here, it's still pretty dark down there, and they are not effective at all. I could see them, somewhat, but not, not very much. That was a full automatic approach and rollout so there are no manual comments to be made.

Major Carmack: On that approach it was fully automatic with auto-throttles; I tried to be more active in the autopilot on that particular approach. Anytime there was any deviation from the localizer or glide slope, I would add a correction to the automatics and try to correct back a little bit faster than the automatics make

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Approach #6 cont:

the correction. This gives me more of a feeling of flying the aircraft and I think it did make the approach more precise and it gives the pilot more of a feeling of being in the control loop. This is probably the way to go. In the past, I let the automatics make the corrections on its own at its own rate. I believe the way to perform these approaches, then, is to really participate in the control loop and make the approaches, making as many corrections with the automatics as the pilot possibly can.

APPROACH #7 (Osc #81) (Film #440)

-X1 1/8F, RVR 800

Semi-Automatic with auto-throttles

Comments:

Major Hadley: On that approach, the type fog is a deep fog. I don't believe it is quite as deep as it was before though. I'd say it is only five or six hundred foot thick now. The first visual cue was the approach lights. I am not calling "cue" until I can actually see the approach lights. The light flashing through the fog is a bit deceiving as it doesn't give you any directional control. The approach light contact height was a little lower that time, probably about 200'. I just checked with the third pilot. I haven't been calling "cue" until I could see the approach lights because the lights flashing through do not give you enough directional control to be absolutely certain where you are. When I call "cue" it means I can see the light itself for directional control and he said at that time it was only a few seconds later. Reference for visual call was the approach light. I could see not as much of them as I could on the last approach. I only picked up the approach lights at the 1000-foot bar and could see about four or five hundred feet. Lighting system very effective. Runway lights -- extremely effective. The touchdown zone lights and center line lights make it very, very nice. The runway markings, even though it's getting lighter

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Approach #7 cont:

out and we can see something down there, are extremely ineffective and I can't pick them up at all. That was a semi-automatic approach and the pilot came heads up when I called "visual" which was about flare and he had no difficulty at all flaring the airplane, at least I don't think he did.

Major Carmack: I still believe it's a blind visual flare. I can see the TDZ and CL lights. I know I'm properly aligned, but I don't really know or get the feel for aircraft attitude. I think what I'm doing, more or less, I'm not even really flaring the aircraft. I'm just maintaining the attitude I have and letting it touch down. I believe that time I looked outside and saw the center line lights, so I knew I was properly aligned and I was able to transition from instruments to outside cues, and I was coming back to look at air-speed. I believe this is a natural reaction any time you are in a flare attitude where you come back in to cross-check airspeed.

APPROACH #8 (Osc #82) (Film #446)

-X1 1/8F, RVR 800

Full Manual

Comments:

Major Hadley: On that approach, once again, a mature fog. The fog now is only about 500 feet thick. First visual cue -- the approach lights. I saw two approach lights prior to the 1000 foot bar, and about 5 or 6 beyond the 1000 foot bar. I think we had five to six hundred feet at that point. Lighting system is extremely effective. I could see four runway lights that time. The touchdown zone lights and centerline lights, although on step 4, remain very effective. Since it's getting lighter outside, I could see the runway markings that time. I didn't see the touchdown zone markings, but after we touched down, I could see the centerline marking quite well. That was a complete manual approach. A fine approach. He came visual

Sacramento/10 Jan 69

Approach #8 cont:

upon my call and after a few moments of orientation had no problem controlling the airplane. I have some doubts in my mind whether a large airplane can handle it with this visibility of about 800 foot RVR.

Major Carmack: We were about eighty feet above the surface there when I came heads up. It appeared it took, three or four seconds to properly orient myself. I had the feeling that time of looking down on the runway as if I was a lot higher than eighty feet. It felt like I was at least one hundred and fifty feet or about twice as high as we actually were. I felt as if I was looking down into a little funnel. Especially in manual, any type of beam scalloping or "s-ing", is very upsetting. Once the aircraft is stabilized, it just seems to make you work ten times as hard to get the aircraft back in a stabilized attitude. I know it was stabilized about seven or eight hundred feet above the surface and then we had a hump in the glide slope, around 500 feet and the airspeed dropped off and it's very burdening to regain stabilization.

APPROACH #9 (Osc \$83) (Film #282)

-X1 1/8F, RVR 800

Semi-Automatic

Comments:

Major Hadley: On that approach, the runway lights were on step four, as it becomes lighter, they become less effective. On the night approaches we have flown, it looks like the lower step settings, step four for example, is too bright; however, when it starts getting daylight we would like to have the higher step settings. On this next approach, we will have the lighting on step five. It should be more effective on this approach.

Sacramento/10 Jan 69

Approach #9 cont:

The fog height is about 500 feet. The first visual cue was the approach lights. The sun is coming up and it is obscuring the approach lights even though they are on step five. We picked them up at one hundred and ninety feet on the radar altimeter, which was a little higher, but weren't as good, they don't show through the fog at that height. The number of approach lights visible, I could see some before the 1000' bar, about six of them. Reference for the visual call, was the runway environment. Number of runway lights visible -- I could see four. Runway markings visible, I'm seeing the centerline markings, but I don't know if it's tunnel vision or what, but I'm not yet picking up the runway touchdown marks as we go down the runway.

Major Carmack: Now that it's becoming light outside, I have more visual references. That time I could pick up the runway as soon as Larry called "visual". Even though it's grey outside, I can still pick up the contrast of the runway from the surrounding environment.

APPROACH #10 (Osc #84) (Film #447)

-X1 1/8F, RVR 600

Automatic with auto-throttles

Comments:

Major Hadley: This will perhaps be our last approach for today as a fog dispersal aircraft is flying a mission. On approach number 10, which was our last approach, the fog was not nearly as thick; however, the height was about four or five hundred feet. The first visual cue was the approach lights. The approach light contact height that time was 130 feet. The approach lights visible were three lights prior to the 1000-foot bar. Reference for visual call

Sacramento/10 Jan 69

Approach #10 cont:

was the runway environment. The lighting system is not nearly as effective as the brightness increases. It's daylight outside and step five is adequate, and I think step five will be necessary for day operations. We could see six hundred feet on the runway -- three runway lights. I made a concerted effort to see the runway markings. I could see the last two touchdown zone markings. I suspect that the others are pretty obliterated with rubber. I could see the centerline markings, and side stripe markings quite visibly. I looked at all the environment of the runway. There is a definite contrast between the runway and side ground.

Major Carmack: The lighter it becomes, the more visual cues I perceive and the more visual reference I have to the runway. This is a great aid to the pilot. That time I could pick up the centerline lights, and the touchdown lights and the lights on outer edge of the runway. It seemed to me that I could pick up about three high intensity runway lights with an RVR of about 600 feet. I think my attention is drawn more to runway centerline lights than anything else. The secondary thing that draws my attention is the contrast of the runway with the surrounding ground environment.

<u>APPROACH #11</u>	(Osc #87)	(Film P	Maj Adams
		#253) CP	Maj Hadley
W1 1/16F, RVR 600		TP	Maj Carmack
		ACM	Armstrong

Fully Automatic

Comments:

Major Hadley: On approach number eleven, Sacramento Metropolitan. It is a very mature fog. The height of the fog is five to six hundred feet. The first visual cue was the approach lights. I did see the terminating bar, the wing bar, and the green threshold lights momentarily. With the brightness outside coming through the fog it is very, very difficult to see them. The approach lights visible, maybe, one or two, that was all. Reference for visual call was the threshold

Sacramento/10 Jan 69

Approach #11 cont:

lights. The visual segment, at that time, was marginal. I would say not more than two hundred feet. Visual segment at flare -- maybe four hundred feet; on the roll-out it reduced to two hundred feet. Now the lighting system is very ineffective. Runway lights visible--two. Runway markings -- centerline marking was visible. Could not see any of the touchdown zone marking. It was an automatic approach with touchdown in the center of the runway.

Visual Segment vs Height

Date 10 JAN 69
 Site SACRAMENTO
 Time 0541-0732
 App's IC
 WX WIXI/I6F

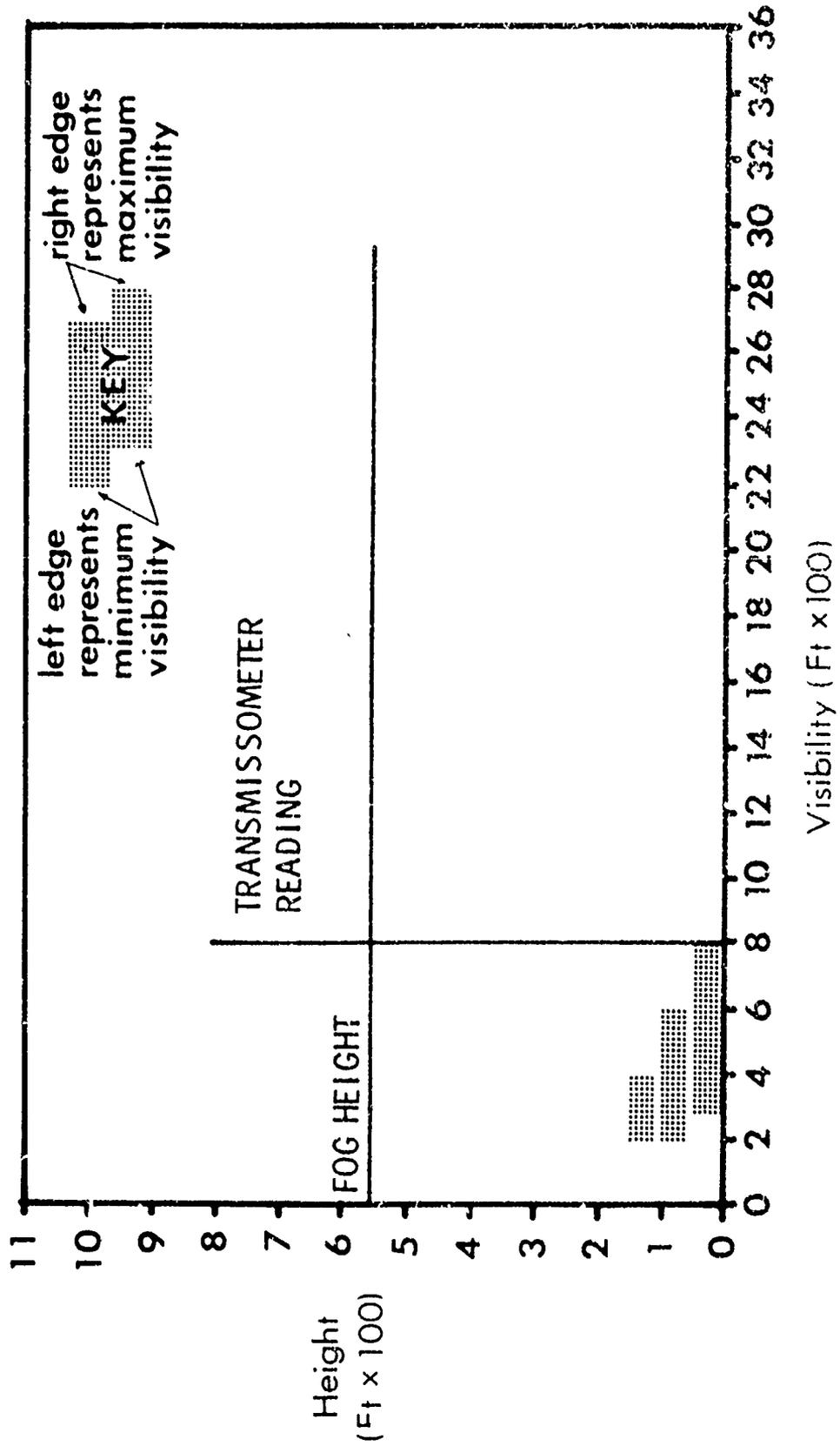


Figure 8. Visibility Chart for Sacramento, 10 Jan 69

TAPED COMMENTS
PORTLAND INTERNATIONAL AIRPORT
29 January 1969

Portland, Oregon

P Maj Carmack

Runway 16

CP Major Hadley

TP Capt Taylor

ACM

29 January 1969

APPROACH #1 (Osc #117) (Film #244)

1503 S-

Semi-Automatic

Comments:

Major Hadley: On the first approach, I did not make any cues or visual or for the first cue. I did not event -- I did not event at four hundred feet because the visibility is so good. There is some light snow. I could see the entire approach lighting system prior to the outer marker. All the lights were visible. I did not make a visual call because I was visual approximately four miles out. The runway markings are not visible because of the patchy snow. You can see very little of them. The approach lights are visible. We will go ahead and make a couple more approaches and take pictures of it, but probably will not make any comments other than this.

APPROACH #2 (Osc #118) Film #275)

1503/4S-, RVR 2600

Manual

Comments:

Major Hadley: On approach number two, I did not give any visual calls or any cue calls. I could see the entire lighting system at outer marker. The visibility was not quite as good on that or .. You could see all of the approach lighting system. The runway is getting fairly covered with snow. It's still patchy, but the braking

Portland, Oregon/29 Jan 69

Approach #2 cont:

action doesn't look like it would be too good. Runway markings are not visible except just an occasional mark that's not obliterated with the snow. It was a manual approach. The beam doesn't look like it's too good, although we did not have any problems. It brings you right down to the center of the runway. We will go ahead and make at least one more approach and see if the visibility might lower a bit.

APPROACH #3 (Osc #119) (Film #242)

-X23@3/4S-, no RVR given

Automatic with auto-throttles

Comments:

Major Hadley: We could see the entire approach lighting system at about nine hundred feet radar altitude. I think they must have the step setting turned down lower, because it wasn't near as bright as on the last approach. The wind has blown some of the snow off the runway -- and the runway markings look like they are in pretty good condition. We can see some now, more than we have been able to on the last few approaches. There is not enough snow to cause any distractions for the heads-up man at all. It's very light snow and I doubt if the camera is even picking it up.

APPROACH #4 (Osc #120) (Film #276)

-X3@1/2, RVR 2000

Fully Automatic

Portland, Oregon/29 Jan 69

Approach #4 cont:

Comments:

Major Hadley: We have now landed, refueled and the weather has moved in. Our weather is considerably worse. We were able to see from glide slope intercept on down. I could see ground straight down; however, our forward visibility was 14 to 1800 feet. The first visual cue was the approach lighting system. I could see most of the approach lighting system. I was able to see the thousand foot bar, the red terminating bar, and the wing bar lights. The green threshold lights stood out very well, and I could see about fourteen to eighteen hundred feet at flare. The visibility at the far end of the runway is not as good as the visibility at the approach end of the runway. It's not snowing very hard at the present time. The flakes are small and they do not distract the heads-up man in any way at the present time. Possibly they would be if the snow was heavier. The runway markings are pretty well covered up with snow. I could see some of them. They are in good condition when we can see them. Workload scale for the right seat man was very easy -- one, or two, I would say, two at the most, but, we had enough visual information compared to the fog, so it was no problem whatsoever. Let's see if the left-seat man has anything to say.

Major Carmack: We were fully automatic, auto-throttles engaged with very tight control. I was staying with the automatic flight control system, making corrections along with the automatic flight control system to keep the parameters as centered as possible. The system is working real well, keeping the aircraft on centerline and on localizer. However, our glide slope tracking isn't as good as we would like to see. It's deviation is up to one-half dot at times. Most of the time, it's deviating approximately a quarter of a dot which isn't too bad but it's distracting. There's quite a bit of wind shear and turbulence at the higher altitudes. It's causing the aircraft to buck around quite a bit and usually drops off about four hundred feet, then it stays smooth from there until landing. We will make a semi-automatic approach this time.

Portland, Oregon/29 Jan 69

APPROACH #5 (Osc #124) (Film #274)

30X1/2S, RVR 2000

Semi-Automatic

Comments:

Captain Taylor: Early on the approach when the radar tape unstowed, I had visual contact with the ground looking straight down to pick out a few differences in color, probably trees and there's some cleared dirt. Calling a mark four hundred, I was able to look up and pick up the approach lights in the snow. And the visual segment at this time was quite good, at least 2400 feet. The visual segment at flare and touchdown appeared to go down slightly to around 2000 feet and I would estimate we touched down 2800 feet down the runway, because I was able to look up and see the 5000 foot marker and could not look to the right and see the 6000 foot marker. My initial impressions coming across the threshold were that we were very high and very steep and if this was a full-stop landing with a stopping factor critical in a swept-wing aircraft, I think I probably would have aborted the approach.

Major Hadley: The first visual cue is the approach lights. I can see all of the approach lights, including the thousand-foot bar, the terminating bar, the wing bar lights, the threshold lights, and some runway lights. I would say that the visual segment, at that time, was about 2000 feet. Once we got down on the runway, the visual segment deteriorates to fourteen, eighteen hundred feet; it seems to vary along the runway. The runway lights available, seven to nine. The runway markings are not too good and there's quite a bit of snow on the runway. I could make out the centerline striping part of the time, and some of the touchdown zone markings, but that's all. That was a semi-automatic approach and the pilot went visual on the visual call, had no problems whatsoever, controlling the aircraft. He had plenty of time to acclimate himself. I do think, from an observation, that at night, this would be a bigger problem than it is in the daytime. In the daytime, even with say a couple thousand feet visibility, you've got the whole runway environment, which helps you out a lot. At night, with only the runway lights, I

Portland, Oregon/29 Jan 69

Approach #5 cont:

think it would become more of a problem. It might be interesting to get some snow approaches at night. The workload factor as far as the right seat man is concerned is very low. I would rate it as one.

Major Carmack: That approach was semi-automatic. That time we were not coupled to the glide slope, the auto-throttles were engaged. Pilot activity in this mode of flight is a lot more. It doesn't feel to me to be as natural as flying fully coupled to the guidance system when you're active in the control loop. In other words, I would rather have the aircraft coupled to the guidance system and be very active with the force wheel steering making my inputs along with the inputs from the automatic-flight control system. I came heads up that time when Larry called "visual". The visual range was at least twelve hundred and there's no problem at all with visual references. That time, I was able to cross-check inside, look at my flare reference on the pitch steering bar, outside, to the runway environment and cross-check between the two. I could do this because of the amount of visual range available to the pilot.

Captain Taylor: See Comments on Approaches #5 and 6 on page 82.

APPROACH #6 (Osc #125) (Film #272)

3X1/2S, RVR not given.

Manual

Comments:

Major Hadley: The first visual cue was the entire approach lighting system, although we could see the ground that time, in all areas. I'm not calling cue until I see something which has to do with the runway environment, which is not, perhaps, quite correct because we are seeing the ground, the river running underneath us, buildings, and what have you. I could see the entire approach lighting system. The visual segment, at that time, is 3000 feet, perhaps,

Portland, Oregon/29 Jan 69

Approach #6 cont:

even a little more. The lighting system is quite effective at step five. The number of runway lights visible through flare and touchdown ten or twelve. I would say we had about 2400 RVR, which is about what they called it. Runway markings are not too good because they are covered with snow. I think the in-runway lighting would be a big aid in a light snow like this. That was a manual approach. Major Carmack did a fine job flying it manual. There's quite a bit of noise on the glide slope which causes you to work pretty hard on a manual approach. The flare and everything at touchdown point was quite good. I don't think he's having any problem at all with the visual cues. We'll let him comment on that at this time. The workload, once again, one.

Major Carmack: We intercepted the localizer too close to the outer marker that time, which was rather distracting. The aircraft wasn't stabilized until we passed just about over the outer marker. Once we're inbound from the outer marker, any type of deviation, scalloping or beam bends in the localizer and glide slope, burden the pilot more than he should be in weather conditions. To get the aircraft stabilized, on course and on glide slope and then to repeat the control actions is very distracting. It's very burdening to get the aircraft back on course and back on glide slope. Coming visual that time, again, went inside the aircraft from outside to look at the flare reference and it's easier to make a flare inside the aircraft than it is outside.

COMMENTS ON APPROACHES #5 and 6

Captain Taylor: These will be comments on the last two approaches-- approach five and approach number six. Approach number five, the weather appeared to be a little better and all visual cues began to appear sooner. The touchdown point was a little closer to the threshold than the first approach. The last approach appeared to be absolutely no problem. Had approach light contact at 500 feet, very, very distinct and clear. And at that time, had I been head up, I think, it would have been very easy to continue on in and the runway began to appear very well proportioned, a lot of high intensity runway lights. I would

Portland, Oregon/29 Jan 69

Comments on Appr #5 & 6 cont:

estimate at least ten. I was not able to pick out the touchdown zone markings too distinctly because of the patches of snow. And on this approach we touched down about 1600 feet down the runway. The best touchdown of the three approaches in regards to nearness to threshold. Also, on the approach that was manual I though we had a much better touchdown airspeed for obtaining an optimum stopping distance.

Visual Segment vs Height

Date 29 JAN 69
 Site PORTLAND
 Time 1129-1416
 App's 6
 WX 3X 1/2 SNOW

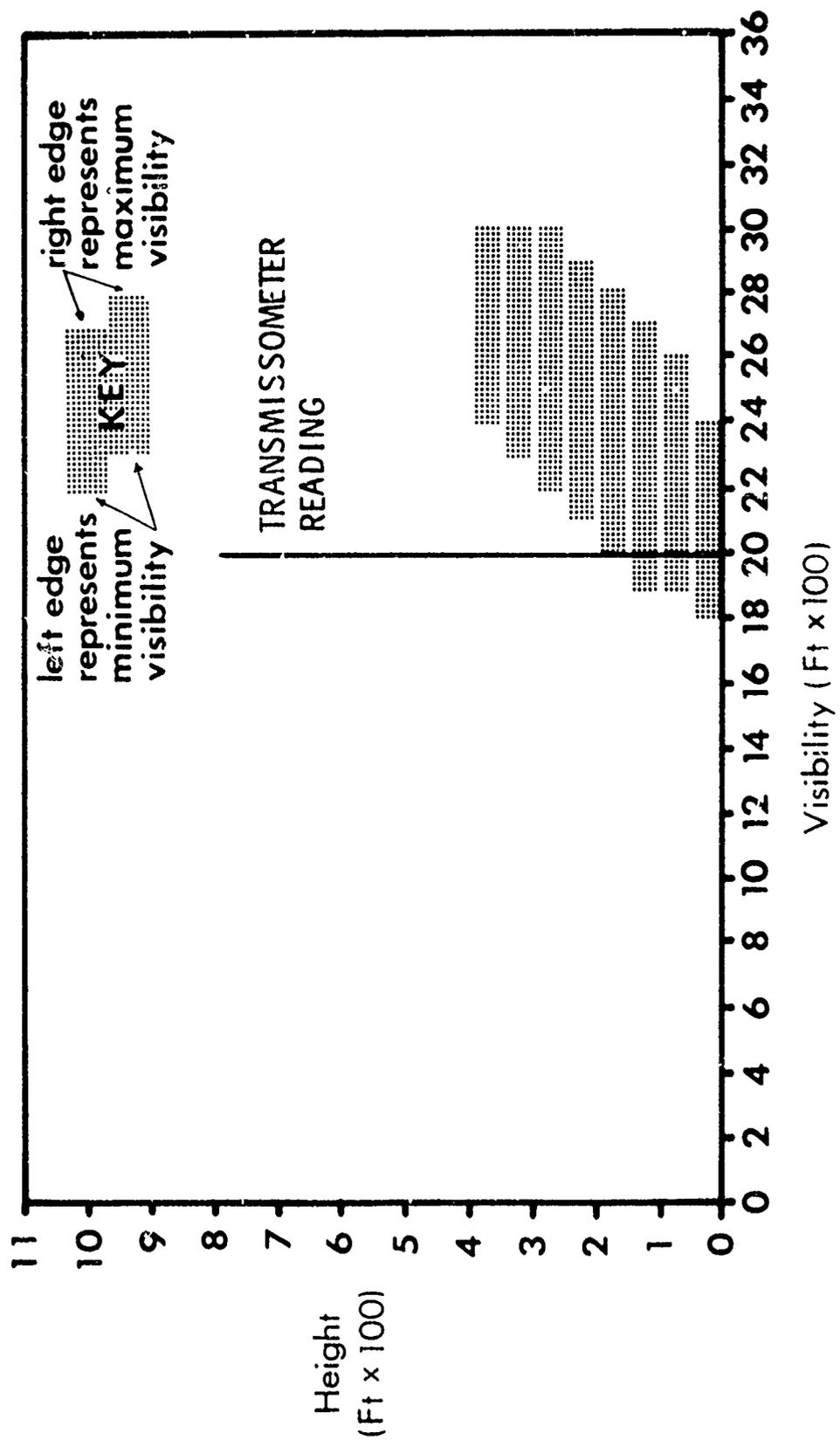


Figure 9. Visibility Chart for Portland, 29 Jan 69

TAPED COMMENTS
SAN FRANCISCO INTERNATIONAL AIRPORT

30 January 1969

San Francisco, California

Runway 28L

30 January 1969

P Maj Carmack
CP Maj Hadley
TP Capt Taylor
ACM

APPROACH #1 (Osc #129) (Film #239)

X1/8F, RVR 1000

Automatic

Comments:

Major Hadley: This is a very shallow fog. It's quite interesting in the fact that the height of the fog, I would say, is only about one hundred and fifty feet thick. I can see the first row of the approach lighting system where the sequence flashers start. Then it cuts off and I do not see any more approach strobe lights or approach lights until past the thousand foot bar. I did not see the thousand foot bar. Once we broke out we had about 6 to 700 feet at first cue. By the way, on that approach I did not call, "cue" or "visual"; I just simply forgot all about it, and I did not mark the oscillograph on the first approach. Number of approach lights visible at any time -- three, to possibly four on occasion. My reference for a visual call if I would have made it would have been the touchdown zone lights and the terminating bar and wing bar lights. I could see them all with a span of about 4 to 600 feet. The touchdown zone lights look very good. I did not see the green threshold but I saw all the other lights at that time. The thousand foot bar was not in view; however, I did see the approach lights quite well. They were good. The centerline lights appear to be a bit dim. I don't know what their candle power output is. It doesn't seem to be as bright as at Sacramento. Runway markings are in pretty good shape - I didn't see the four but I did see the three and the rest of them from that point on and I could see the centerline marking to a certain extent. I would have had difficulty flaring the aircraft manually, I think, on the first approach. I'll have better impressions on the next one. The left-seat man was heads-down so he shouldn't have any comments. Workload, I would rate on that one, was four.

San Francisco, California/30 Jan 69

Approach #1 cont:

Major Carmack: That was an automatic approach coupled in all axes, auto-throttles engaged; I was flying very tight control over the automatic system, making some inputs. The guidance system is such that it's almost "iron rail", localizer and glide slope. Very little effort is needed, on the pilot's part, to track this type of guidance system. So, I would say the workload is three.

APPROACH #2 (Osc #130) (Film #266)

X1/8F, RVR 1000

Semi-Automatic

Comments:

Major Hadley: The type fog is a shallow; it's rather non-homogeneous in that it's moving quite a bit. The height is only about one hundred feet thick. I did not call first visual cue that time or the approach lights, for the very simple reason I could see the approach lights, all of them, practically from the outer marker in. The fog is laying right on the end of the runway. My first visual cue call was the four marks of the runway, the runway markings. At that time I was still not visual. I called visual when I could see the touchdown zone lights and enough visual reference for Major Carmack to flare the aircraft. As I say, I could see all of the approach lights prior to and the terminating ones. The reference for the visual call was the runway markings. The visual segment, once you're on the runway, initially was about 800 feet, deteriorating down to 4 or 500 feet along the runway. This should be very interesting film. The IVALA lighting system was very good. It's very deceiving because you can see all of it. An aircraft, making an approach, not knowing what was on the runway, could get into serious trouble in this condition. I could see two to three runway lights while on the runway. It was worse on the far end of the runway than it was on the approach end of the runway.

San Francisco, Calif/30 Jan 69

Approach #2 cont:

The runway markings were very visible on that approach because it's just laying right on the end of the runway, they were quite effective. The pilot, Major Carmack, was flying a semi-automatic approach. Did a fine job. We'll stand by for his comments now. Workload, I would say, was a three.

Major Carmack: That was a semi-automatic approach. Not much increase in workload for semi-automatic compared to the fully coupled approach. That particular approach had some very subtle deviations in the localizer beam and it's almost a constant scalloping down final approach from about 300 feet above sea level on into touchdown. That time when Larry called "visual", I did come heads up and I could see first of all, the touchdown zone lights on the left-hand side of the runway and maybe through experience I'm getting to recognize cues more as I come visual. It didn't appear that there was any crosstrack rate and I didn't try to attempt to correct the aircraft back to the right. Just flared on the touchdown zone lights for touchdown. To me, it looked like a visual range of approximately 400 feet and that seems to be enough to flare this type of aircraft. On that particular approach, also, I was able to come back inside the aircraft, re-reference the flare presentation on the pitch steering bar and use that in conjunction with the outside environment, so this might be a possibility.

APPROACH #3 (Osc #131) (Film #261)

X1/8F, RVR 1400

Manual

Comments:

Major Hadley. A very shallow fog. The fog is moving. The height is approximately one hundred feet. Once again, I could see the entire approach lighting system, the thousand-foot bar, and I

San Francisco, Calif/30 Jan 69

Approach #3 cont:

could just see the red terminating bar. The approach light contact height was outside the outer marker and well above 1000 feet. I waited to call visual until I could see some of the runway itself. I did not want the man to come heads up until he had enough visual reference to land. I used the touchdown zone lights as well as the touchdown zone markings. These were quite apparent because the fog was laying on the end of the runway. They were reporting 1200 RVR. At one spot on the runway, they probably had 1000 to 1200 feet. At other places the visibility deteriorated to around 400 feet. I could see, at one point, about six runway lights, and then it would deteriorate down to two runway lights. Lighting system -- very effective. The runway markings are very good at San Francisco, quite effective. They show up very well in the daylight hours. Workload for that approach, I would rate as a three.

Major Carmack: I would rate that a bit higher. That's definitely more burdening than a semi-automatic approach. I would rate that as a four. When Larry called "visual", I came heads up and could see about three high intensity runway lights, touchdown zone and centerline lights were prevalent. Also was able to use the centerline striping for visual cues. They gave me very good lateral guidance. No problem flaring the aircraft. I saw we were slightly off to the right side of the runway on that particular approach. Didn't even bother to correct it, just flared and touched down using the visual cues. It still seems like there are some very subtle deviations in the localizer signal here at San Francisco. It causes the bank steering bar to oscillate very slightly back and forth. This is quite bothersome. On the automatic approach, it did not seem to do that as much, then when we get down to semi-automatic and manual, you can pick up these oscillations and if you go after them, you over-correct. Glide slope is outstanding. It's almost "iron rail". No problem controlling glide slope.

Captain Taylor: This is Capt Taylor, making a few comments on the approaches at San Francisco. The first approach caught me a little by surprise as I was pulling off my third pilot duties. I came heads up at about 100 feet and could pick up about three rows of approach lights and the terminating bar and the black hole just prior to threshold. The

San Francisco, Calif/30 Jan 69

Approach #3 cont:

visual segment improved through flare to touchdown to an estimated 500 feet based on three approach lights or so. Touchdown point-- the only way I could determine it was by a sense of time coming over the threshold, flaring to touchdown. I could not pick up anything on the runway to reassure me where we were touching down. The second approach was VFR or at least the approach lights in contact on the way down with a very good RVR going into the threshold. It deteriorated very rapidly at flare and touchdown back to the previously called or estimated 500 feet. Again, I could only judge the touchdown point on an elapsed time factor after crossing the threshold. The third approach of Don's that was manual. The only comment that I might have was that when Don came heads-up, we started a cross-track from left to right and at heads up he was well on the left side side of the runway and as he annotated the tape, here, he noticed that we were on the right side at touchdown but it did not concern him because the RVR was such that we were able to pick up the high intensity runway lights on both sides. I was checking the trim and trying to find a reason for this cross-track to the right, as it has been apparent in the previous films, but I could find nothing to re-affirm why it should occur. And that's about all my visual comments.

Major Carmack: In that type of shallow fog condition, I believe it's harder to mentally adjust yourself to flying the instrument approach. I feel more at ease if you are in the weather from outer marker on down to touchdown. It seems like, you are coming down and it's perfectly visual outside and you know you are going into a very shallow fog condition where the ceiling is sitting up there at about 100 feet or so and you can't get yourself really mentally adjusted. So, all of a sudden, you're in the weather. It seems like it's easier to fly instruments when you're in the weather at outer marker all the way to touchdown rather than to bust into it at 100 feet.

Major Hadley: I think that's probably true, Don. The heads-up man, perhaps, doesn't play the role as well as what we have outlined. Because I could see so much, I'm heads-up all the way, and I found myself tending not to monitor your performance as well as I should have been if we had been in the weather. Perhaps this is not the correct way to do it. I found myself checking at the last minute when normally I would be coming heads up about the time we start going in the fog when I would be looking to see if everything was all right. So, I think it's a good point.

Visual Segment vs Height

Date 30 JAN 69
 Site SAN FRANCISCO
 Time 0805-0830
 App's 3
 WX X 1/8F

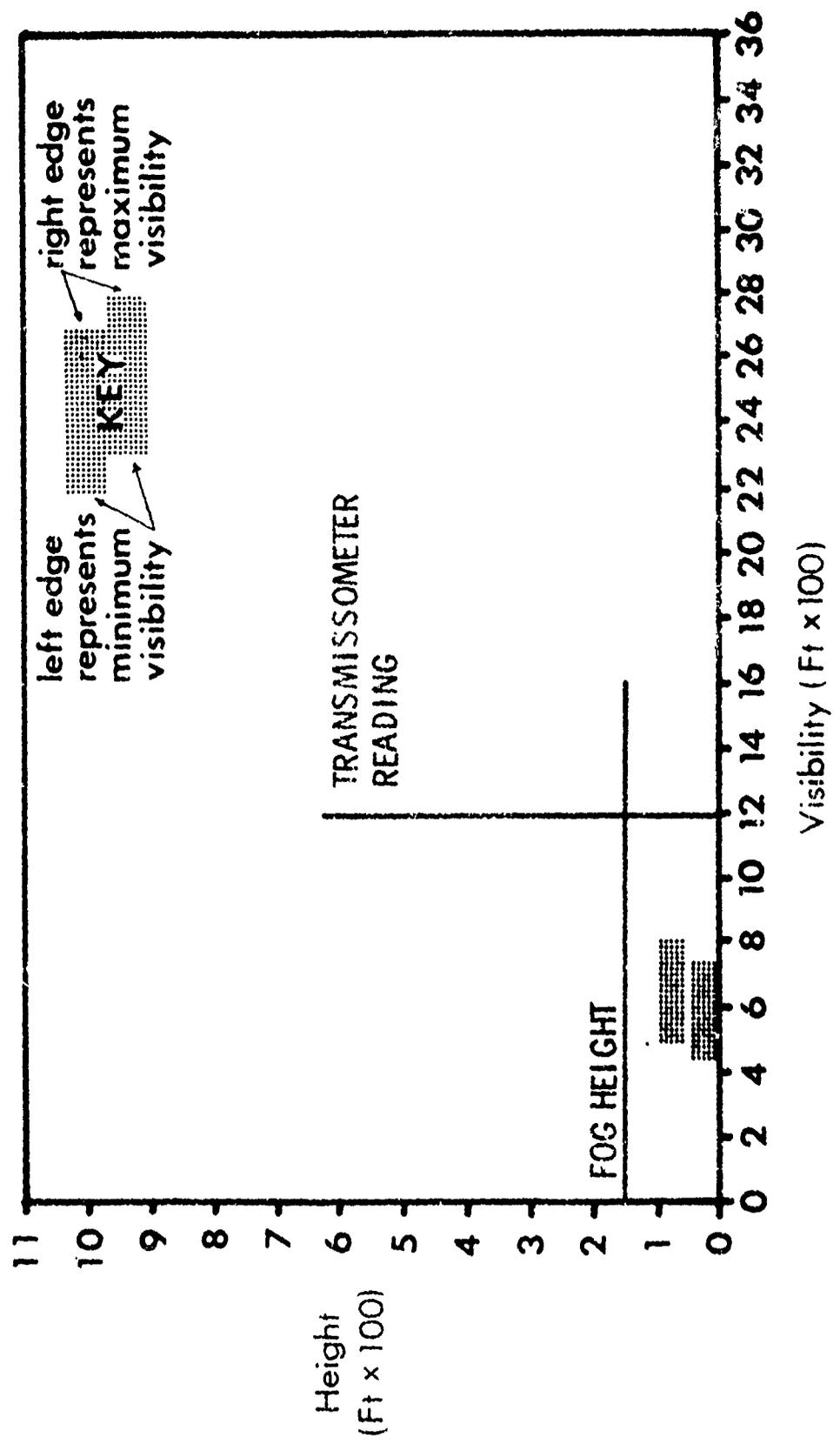


Figure 10. Visibility Chart for San Francisco, 30 Jan 69

TAPED COMMENTS
MATHER AIR FORCE BASE

31 January 1969

Mather AFB, Calif

Runway 22L

31 January 1969

P	Maj Carmack
CP	Major Hadley
TP	Capt Taylor
ACM	Mr Armstrong

APPROACH #1 (Osc #132) (Film #452)

2X3/16F, RVR 1000

Automatic

Comments:

Major Hadley: This will be the first time that we've flown this year at a facility that does not have the "in-runway" lighting. We'll be making comments comparing the contrast between a facility that has "in-runway" lighting and one that does not.

On the first approach, I didn't hit the camera switch so we did not get any film on the first approach. I will make some comments on the first approach in just a moment, but we will have to use the same film can over on the second approach. On the first approach, as I mentioned before, the camera did not turn on. I probably did not hit the switch hard enough. This is a shallow fog. We can see lights through it. We can see the glow of the approach lights quite a way out, but we don't actually pick up the approach lights until approximately 100 feet, radar altitude. The height of the fog is about 300 feet. The first visual cue was the approach lights. I did not see the 1000-foot bar. Approach light contact height, once again, 100 feet. The reference for the visual call was the high intensity runway lights on the side. The effectiveness of the lighting system is relatively effective in this type of fog with this approach lighting system. As low as the fog is, we did not see too much of the lighting system, although we could see the glow. The runway markings were not visible. We did not use the landing light on that approach. As we were rolling down the runway, by looking straight down, I could faintly see the centerline. On the rollout, Major Carmack turned on the landing light and this helped tremendously for finding the runway markings. I could see the centerline marking all the way. I would not have been able to flare the aircraft visually at that point.

Mather AFB, Calif/31 Jan 69

APPROACH #2 (Osc #133) (Film #452)

W2 1/16F, RVR < 1000

Automatic

Comments:

Major Hadley: I had some conversation with approach control on the first approach just inside middle marker. I am sure that this distracted somewhat from what I saw as heads-up pilot. It's a very shallow fog, the height of the fog was 300 feet. The first visual cue was the approach lighting system. The first thing I saw of the approach lights was the 1000-foot bar. I did not see any lights prior to the 1000 foot bar. Approach light contact height for "cue" was 100 feet. Number of approach lights visible following the 1000-foot bar were three or four. I did see the red terminating bar, the red wing bar lights, and the green threshold lights. The reference for visual call was the threshold lights and the high intensity runway lights. At touchdown point the RVR was approximately 600 feet. As we rolled down the runway the RVR was considerably more at one point. I would say up to 1000 feet in one place.

Normally three approach lights visible. The runway markings I could see, without the landing light on, were enough of the centerline stripe to give us directional control. I don't think this would be satisfactory if your eye height was higher above the surface. I would not have been able to flare the aircraft visually. As soon as you fly out of the approach lights it's very dark with no visual reference for flare, whatsoever. At the touchdown point, the directional control for the lateral guidance is not the problem, it's the pitch problem. I don't think either one of us could flare the aircraft visually at this point. I could see enough, and so could the third pilot, to identify the runway markings, number markings, distance remaining, on the side. So we've got a good 600 or 700 feet. End of comments on the first approach. Do you have any comments that you want to make, Don?

Major Carmack: The automatic system is tracking the beam real well now. Very little if any scalloping of the localizer beam. There is a little dip in the glide slope around 200 feet, but it's not too bad. As we enter into the fog the high intensity strobe light flashes disperse

Mather AFB, Calif/

Approach #2 cont:

through the fog, and have a blinding effect. This is rather bothersome. In cross-checking the instruments you can see this out of your peripheral vision. That time, I left the landing light out during the rollout and I had more visual reference using the high intensity runway edge lights. I was able to see 2 on each side of the runway as we were going down the runway, and I couldn't pick up all the centerline stripes. I think I was picking up about every other one. I believe this was due to the anti-collision light flashing below the aircraft. That time I couldn't have flared the aircraft visually. It's interesting to note that while I was on the pitch and bank steering bars, and I was able to bring the LSI into my cross-check and also the radar tape. Through my peripheral vision I could also look outside the aircraft during the flare and see the runway edge lights. Even though I was flying instruments and concentrating on instruments and watching airspeed, radar tapes, LSI, etc, I could see through my peripheral vision, the high intensity runway lights. We have a bad LSI on the left side, Larry. It was hanging on the right side of the element. That was very, very bothersome to me, but in cross-checking it with yours, which I shouldn't be doing, I could see that yours was all right.

Major Hadley: Mine looked real good at 200 feet, when I came heads up. Any more comments, Don?

Major Carmack: No, just if you see anything wrong with your LSI, be sure to let me know, as mine doesn't agree with yours at all. Mine's hanging on the right-hand side.

Mather AFB, Calif/31 Jan 70

APPROACH #3 (Osc #134) (Film #429)

W2 1/16F, RVR < 1000

Semi-Automatic

Comments:

Major Hadley: The type fog is a shallow, rather non-homogeneous as I'll describe when we get on the runway. The first visual cue that time was the red terminating bar. I did not see any approach lights. I could see the flashes coming up through the fog, but I could never visually distinguish any of the approach lights. Approach light contact height, no contact. Number of approach lights visible--none. The reference for the visual call was the red terminating bar. I saw the red terminating bar and the green threshold lights. At that point it becomes very, very black. I could see the runway high intensity lights. There is no visual reference for flare. We landed quite long on that approach. It was a semi-automatic approach and we landed very, very long. We were floating along about 15 feet in the air for a while and then gradually we came on down. As soon as we touched down, pretty much on the center of the runway, we started drifting to the left rather quickly. I did put an input in that time. I just asked Major Carmack and he said he didn't feel me come in with the rudder to bring us back and we started drifting back to the center at this time. Number of runway lights visible--only about 3 that time which would give us 400 feet. As we roll down the runway, the visibility increases. I could see at one point, 5 to 6 high intensity runway lights. So, at the departure end of the runway the visibility is much better than on the approach end of the runway. Of the runway markings visible the only thing at all I could see was the centerline stripe. On that approach again we did not use the landing light. We're going to use the landing light on this approach. This will be another semi-automatic approach. I'll go ahead and let Major Carmack make any comments at this time. Oh, one other comment before he starts with his discussion. The auto-throttle package did not turn that time, so there'll have to be a correction. I had said it would be automatic throttles and it was not, and I'm sure he'll have something to say about the workload factor.

Mather AFB, Calif/31 Jan 70

Approach #3 cont:

Major Carmack: The auto-throttles were not on that time, as Larry said. This takes quite a bit of the pilot's time to monitor power and also I'm looking at angle of attack and airspeed along with everything else. So, you have to really double up on airspeed, angle of attack, look at power position, and all these things. This takes quite a bit of your attention away from trying to maintain exact path guidance in both glide slope and localizer. Approaching about 200 feet and we again had a hump in the glide slope. I didn't go after it because I felt that we'd even it out if I just maintained the same rate of descent; however, we didn't do that. It seems to bend down a little bit and I'll have to go after it to maintain exact path guidance on the instrument display. I got my flare that time and I was trying to hold the pitch steering bar centered; however, it seems like we never got down to the runway toward the latter part there. It looked to me like we were riding about 10 feet high on radar. I just lowered the nose a bit below the flare command and I imagine we hit down at about 400 feet per minute, but it wasn't too much a jar. In this situation, flying semi-automatically, the pilot is exceedingly more burdened than he would be flying automatically. You don't have as much time to use any outside cues that you might have, so it's really a shock when you're on the runway and all of a sudden you look out. That time I could only see about one high intensity runway light on each side of the runway and I didn't have any visual reference to the centerline striping at all. It's very, very difficult to have any type of lateral control with that type of visual cues outside.

Major Hadley: Our workload scale for the pilot on that last approach was rated as four. I would rate it the same. After touchdown I'd have to rate it as five for directional control, but the approach itself is four. I haven't rated the other approaches which we've had. I would rate them also as four.

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APPROACH #4 (Osc #135) (Film #416)

W2 1/16F, RVR < 1000

Semi-automatic

Comments:

Major Hadley: This will be another semi-automatic approach. If our auto-throttles will work, it will be 1.3 with auto-throttles.

We still have a shallow fog about 300 feet thick. My first visual cue was 3 approach lights before the black hole. I did not see the 1000-foot bar. I did see the red terminating bar and the green threshold lights. Reference for visual call was passing the threshold lights and seeing the high intensity runway lights. We have a visual segment at threshold of about 500 feet. Effectiveness of the IVAALA lighting system--if you can't see it, it doesn't do you a bit of good. In a deeper fog than this, I don't think we would see it at all. We can see the glow coming through and I'm not calling cue on that glow because there is just no way of maintaining directional control from the glow. We can be one or two hundred feet left or right of center, I believe, and still see the glow. Number of runway lights visible in the touchdown zone was three to four, which gives us around 600 feet, again. Down the runway, once again, it breaks out a little bit. Major Carmack came heads up on the rollout that time. I gave him a call to come heads up and it didn't take him but just a second to adjust to the visual cues within his field of vision. I'll let him comment on that. Runway markings visible--none, except for the centerline marking. Unable to control the aircraft vertically. I would have been unable to flare the aircraft. Workload scale, once again, I would rate as four. It's still more than what you would expect for a normal approach as we're rating it. Now one very interesting comment. We turned the landing light on that time at the "visual" call. When the landing light came on, everything blanked out. It just glowed up in front of us. I lost any visual reference I had with the high intensity runway lights. I couldn't see anything. It also blinded the pilot badly. Both of us almost simultaneously called landing light off. And then again, it just takes your eyes a moment to

Mather AFB, Calif/31 Jan 69

Approach #4 cont:

get used to that landing light coming off. It's a very dangerous situation in this type of fog particularly. I would strongly recommend not using landing light at night in the fog. Stand by for the left-seat man's comments.

Major Carmack: Auto-throttles were operative on that semi-automatic approach, and that reduced the workload to the point where I was able to maintain path guidance much better. I had more time to concentrate on keeping our pitch and bank steering bars centered and maintaining path guidance. Went after the hump that time at about 200 feet in the glide slope. It takes a pretty bad dip at 200 feet and glide slope raw information drops down approximately one dot. However, our pitch is coupled such that we don't go after that full scale. It kind of averages out. As Larry said--we're coming down final approach and turn the landing light on at about 100 feet and it's just like somebody tood a bright search light and flashed it right in the cockpit. It also blanked out the instrument panel to me. I don't know whether it actually blanked it out, but it seemed like it did. Maybe it was because my attention was immediately drawn from the instruments to the light outside the aircraft, but it completely destroyed any contact I had with the instruments or the outside environment. I wasn't able to see anything at that particular instant and immediately called for the light out. We had a better flare that time. I think this is because the auto-throttles were on. I had no throttle action, whatsoever, but as we do get down into the flare the auto-throttles will retard the throttles somewhat. This helps quite a bit. I'm going to have to start retarding the throttles just a little bit on the semi-automatic and manual approaches. Otherwise we're going to be carried on down the runway like we did on the previous approach. That time no problem at all maintaining flare on the pitch steering bar with the auto-throttles. Outside visual cues, that time, I could see I'd say about 2 high intensity runway lights off the side of the runway.

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APPROACH #5 (Osc #136) (Film #304)

W1-1/16F, RVR < 1000

Automatic

Comments:

Major Hadley: The fog is still shallow with a height of 300 feet. First visual cues were 3 approach lights. Reference for the visual call was the approach lights. The IVALA lighting system was not effective, although we could still see the glow up through the clouds. The number of runway lights visible at flare and touchdown--3. That means that we're only seeing about 400 to 500 feet in that area. That time I saw some runway markings on the right side, one glimpse of one of the touchdown zone marking. I have no idea which one it was. I would assume it was probably 2 or a one stripe, but I don't know. I could see the centerline marking after we got on the runway. Unable, once again, to control the aircraft manually for flare. There's just no visual reference at all for flare. On the rollout we turned the landing light on again just to glimpse to see what it would do as we were rolling down the runway. It was extremely blinding. We immediately shut it off. It blanks out everything. I probably could still see some of the high intensity runway lights since we just turned it on momentarily, but it's not effective at all. I think we all feel the very same way about it; that it's very ineffective and a hazard. Comments from left-seat pilot.

Major Carmack: I rated that approach on our scale as a three. Larry says he rates that as a three also. Again, we're getting very subtle deviations in the glide slope which are quite distracting. Can't see the strobe lights flashing up through the fog now, so I'm not distracted as much from that source. Distractions within the cockpit are the deviations in the glide slope. Left side LSI is riding on the right-hand side of the element. This is very distracting. That time at "visual" once we had touchdown, I did come heads up and I could see approximately 3 high intensity runway lights on each side of the runway. Then as we were passing over the centerline striping, as the anti-collision light would flash, I could see the centerline striping. I

Mather AFB, Calif/31 Jan 69

Approach # 5 cont:

didn't have any visual reference that I could use for a flare on that approach. However I could have controlled the aircraft in a lateral plane with no flare reference. Let's try one manual.

APPROACH #6 (Osc #137) (Film #318)

W1-1/16F, RVR -1000

Manual

Comments:

Major Hadley: A shallow fog. It's beginning to get a little lighter outside. I saw the 1000-foot bar that time, and 4 or 5 of the lights from that point on. The height of the fog was 250 feet. The first visual cue was the 1000 foot bar and then the approach lights. Approach light contact height was 150 feet. My visual call was at 75 feet. Reference for the visual call was passing the green threshold lights, and the terminating bar which I could still see very well, and the high intensity runway lights. RVR in the touchdown zone was about 600 feet. Maybe a little better. Let's say 700 feet on that one. It is a little bit more than it was on the last approach. This may be because it's beginning to get a little lighter outside. The sun hasn't come up yet, but it's lighter than it was on the last approach. Runway markings visible -- I still cannot see the touchdown zone markings. I saw the centerline and side stripe markings that time. We landed on the right side, and I could see the right side stripe marking. The pilot came up and controlled the aircraft laterally, fine. I might have been able to flare the aircraft that time, but I'd have been searching for it. On the next approach, he's going to try to flare the aircraft when I make my visual call. Workload - 3.

Mather AFB, Calif/31 Jan 69

Approach #6 cont:

Major Carmack: I'd scale the workload on that approach as a 3, also. No problem at all controlling the aircraft in the lateral direction. Again, the big problem was in the vertical direction with the hump in the glide slope. It is quite bothersome. You don't know quite what to do at that particular time. You don't know how much to correct. You can see the raw information that went up, oh, I'd say, about a quarter of a dot, then it dropped down to about a half a dot and then it started coming back to center. When Larry called "visual" that time he wanted me to come heads up and I didn't want to. I was in the flare and I had the bar centered and it looked real good to me and I wanted to get the feel of the aircraft in the flare and retard the throttles at the same time. The radar tape was very prevalent in the cross-check. Something here that might be very interesting -- Through my peripheral vision I could see outside the aircraft some high intensity runway lights which gave me lateral guidance. So, here was a combination of lateral guidance outside the aircraft with peripheral vision and inside looking at the pitch steering bar for flare reference and radar tape and throttle control integrated together to give us what I thought was an excellent touchdown. Once we had touchdown, it was much easier to have lateral guidance from the high intensity runway lights, but I had lateral guidance before touchdown through my peripheral vision so it wasn't as great a transition.

APPROACH #7 (Osc #138) (Film #283)

W1X1/16F, RVR -1000

Semi-Automatic

Comments:

Major Hadley: On the visual call this time Maj Carmack is going to come heads up and try to make a flare. If he doesn't like it, he'll go back on the bar. I've got enough visual reference to maintain safety.

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Approach #7 cont:

It's a shallow fog; fog is about 150 to 200 feet thick. The first visual cue was the approach lights. This time I did not see the 1000-foot bar. I saw about three lights prior to the terminating bar and the green threshold lights. For some reason I'm picking up the green threshold lights a lot better than I have in previous flights this year. Maybe because I'm getting use to it and becoming more cognizant of everything which is below me. Anyway, I'm picking them up better, whatever the reason. IVALA lighting system--it's getting lighter outside; it's not as effective as it was. The glow we see still gives us no directional information whatsoever. It's no help on a cross track rate. Number of runway lights visible in the touchdown zone was about 3, which is still giving us 600 feet. Immediately after touching down, however, it opens up somewhat, and I would say our RVR is about 1400 feet in that area. As you roll down the runway it closes in to about 6 or 800 feet. Runway markings visible -- I'm still not picking up the touchdown zone markings. It's just not light enough yet for the touchdown zone markings. The pilot came up visual on my call and I heard him say, "I don't like it", but he did stay visual and make the flare and searched for the runway a little bit, but not much of a problem. It's getting lighter. I think probably in another one or two approaches he won't have any problems. It's the darkness that causes the problems for the vertical guidance.

Major Carmack: When Larry called "visual", I came heads up at that time. I didn't have much vertical reference to flare the aircraft. I could see approximately two lights out to the side of the aircraft. Then it was just like descending into a dark hole. I didn't have any depth perception relating to the runway once I came off instruments. I stayed up and touched down a little bit harder that time than we normally would. No problems were encountered with the lateral guidance. I could see almost instantly that we were aligned with the runway; however, in the vertical plane I had no guidance whatsoever.

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APPROACH #8 (Osc #139) (Film #456)

W1X1/16F, RVR -1000

Manual

Comments:

Major Hadley: I'm going to, if I can remember it, make a running commentary on tape as we make the approach. We have enough light down there now as the sun is just beginning to show up over the mountains, almost, but I'm going to try to make it. Major Carmack might tell me to shut up, but we'll try it anyway.

Major Carmack: You still got the tape on? I might make a comment on the lighting system in this airplane. It's pretty bad. For example, I can't see the LSI that well and I have no visual reference to DME information. Instruments are red and white lighted and there is no contrast between the instruments and the panel; they look like watch faces in the dark.

Major Hadley: We touched down that time about 2700 feet. I forgot to make a running commentary as we went along. Rolling down the runway now about midpoint in the runway and I can see about 900 feet. Touchdown RVR was about 600 to 700 feet. We're right on the centerline striping this time. I could see it quite well. It's getting lighter. OK, let's go around, Don. I did see some of the touchdown zone marks that time. I saw the 2 and the 1 go underneath us. Comments on the last approach. Still a shallow fog. It seems to be maturing, not in height, but in density. This probably is because it's getting a little lighter. It's almost daylight up above the clouds, not quite, the sun's not quite up over the mountains. The height of the fog is about 225 to 250 feet. It's not raising up any. First visual cue was the 1000 foot bar. I could see about 4 lights in sequence from that point on. Reference for the visual call was the same that I've been making before, the high intensity runway lights, but this time I did see some touchdown zone markings. I didn't identify the first ones I saw which probably were the three stripes. I didn't see the threshold markings. Then we passed over the touchdown zone marks at 1500 and 2000 feet and touched down about 2700

Mather AFB, Calif/31 Jan 69

Approach #8 cont:

feet down the runway. That was a manual approach and a manual touchdown with the pilot coming heads up on the visual call and making the landing. It's getting lighter and I don't think he had as much difficulty with his depth perception as he did on the last approach. Visibility in the touchdown zone was 600-700 feet and then it breaks out to 900 to 1000 feet and then closes in again far down the runway. Runway markings are more visible now. I would suggest that we try the landing light on the next approach, and see if the outside light of the sun and the landing light tend to blend a little bit and help us, although at this point we really don't need a landing light. We'll try it anyway. Workload on that approach -- 3.

Major Carmack: I'd rate that as workload 3 also. There still isn't enough of an aiming point to flare the aircraft. I could see about 2 high intensity runway lights on each side of the runway, but still didn't have enough reference to visually flare the aircraft although it is getting somewhat lighter. All I can see is the lights. I can't see the contrast of the runway yet. I believe that as soon as I can pick up the contrast of the runway, I'm going to be able to flare the aircraft. I feel more comfortable flaring the aircraft on the pitch steering bar. Coming back to the lighting system just a second; we have a heading deviation indicator within the LSI. I can't see that, so it's of no use to me. Also, our lighting is such that I can't pick up the top of the horizontal situation display where our range indicator, course selector window and heading marker are located. LSI is very effective at night, during the daytime it's not. Our lighting is such that we have red light intermingled with white light and different intensities of white light which is also very distracting. I feel it would be better if we had the whole panel lit up and could see the outline of the instruments and the panel and could easily read what was on the displays. Lighting should have a profound impact on the pilot's psychological feelings during these types of approaches. A different lighting concept is needed.

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APPROACH #9 (Osc #140) (Film #319)

WIX1/8F, RVR -1000

Automatic

Comments:

Major Hadley: Now we're coming down the approach I can not see any approach lights at all through the fog. Now the fog has matured in its density. We're coming up on about 200 feet at this time.

On the cue, I just saw some lights prior to the 1000-foot bar. Now I can see some strobe, but they're not apparent. There's the green threshold lights, but I didn't see the red terminating bar.

Probably that time we touched about 2200 feet. We touched down somewhat to the right side. Our visibility at the touchdown point, because of the brightness, is deteriorating again. I could only see about 4 or 500 feet that time. The approach lights just weren't bright at all, even though they're on step 5. We're rolling down the runway now. It's light outside. We can see the side stripe markings. I can see several of the side lights, about 4 or 5, centerline light. Going around at this time.

Fog height remains the same. First visual cue, the 1000-foot bar, then I lost contact with the approach lights, then I picked them up again. I didn't see the terminating bar that time but I saw the red wing bar lights and the green threshold lights. I don't know why I didn't see the terminating bar. Perhaps because I was talking. When you're talking like this, you tend not, perhaps, to see as much, and I think this verifies the fact that the less conversation you have in the cockpit, the better, although it didn't apparently bother the left seat man too much. The visual segment at touchdown was about 600 feet. The lighting system, now is very ineffective. We don't see it at all on final approach and then when we do see it, it's very, very dim. The high intensity runway edge lights appear very dim; threshold lights, terminating bar, everything is dimmer than before, and I contribute

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Approach #9 cont:

this only because it's getting light outside and it destroys the effectiveness of the lights. The visibility increases as we roll down the runway and it decreases about the time we start going around. Runway markings -- I could see them fine that time. I could see the three, two and one TDZ markings, side stripe markings and centerline markings. As for workload that time, I'd rate it as 2. No, I'll change that to 3, because of the light. I was a little bit concerned because of the dimness of the approach lights.

Major Carmack: I wanted to find out something about that particular approach. I maintained loose control on that automatic approach. Auto-throttles were engaged, we were coupled. Then at about 150 feet, I disconnected everything and took over complete manual control of the aircraft. So, I went from a very loose automatic control to trying to maintain a very tight manual control, and I just wasn't in the control loop on that particular approach. I'm going to try an automatic approach this time, uncoupling about 150 feet, only this time I'll have real tight automatic control and see if that doesn't help.

APPROACH #10 (Osc #141) (Film #234)

WX1/8F, RVR -1000

Automatic

Comments:

Major Hadley: Now we're coming up on 200 feet. Can't see approach light, one. I'm going heads-up this time. There they are. I just lost them again. I'm picking them up again -- 1000-foot bar, the approach -- wing bar, threshold. OK, I was busy talking to Don that time. We were quite high that time. I didn't make a "cue" call or a "visual" call. I'll comment on that later. The fog is mature, but the height, at least on the approach end, is only about

Mather AFB, Calif/31 Jan 69

Approach #10 cont:

200 feet. It's higher on the other end of the runway. The sun is causing the fog to become more dense and more mature. We can't see nearly as much as we did about 30 minutes ago as far as the runway lights are concerned. Approach lights that time -- I saw them quite early -- I saw them briefly before the thousand foot bar, then I saw the thousand bar, then I lost them momentarily, then I picked them up again. Once again I looked for the terminating bar and didn't see it, but I saw the wing bar lights. I think it was because of our nose high attitude at that time. I saw the green threshold lights on our side. Lighting system -- not nearly as effective as it has been in the past, because the sun is up over the mountains now and it's daylight outside. Number of runway lights visible -- were 2 to 4, about 600 foot visual range, then it deteriorated down the runway. At one time I could only see 2. Runway markings are showing up pretty good. The white markings show up good in the daylight hours. We landed very long on that last approach. Standing by for comments. Workload on that one, once again, I'll say 3.

Major Carmack: We were fully automatic, auto-throttles engaged, tracking just beautifully and uncoupled at 150 feet. Information to me was all centered, and it surprised me when you said we were high because everything that I could see on the instruments said we were right where we were supposed to be. Kept the bar centered, came on down and saw flare height -- again kept the bar centered. I just don't know how we could be that high.

Major Hadley: Well, I don't see how either. That's why I think we should try an automatic approach on this one and see how they come out -- but we really were high. Possibly we didn't rotate when I thought we did, but nevertheless we really sailed down the runway for some reason. I don't know what it is, so, why don't you make an automatic and let's check it this time. Also on that last approach I didn't event on cue or visual because I was talking to Don. Now this conversation in the cockpit, although we're doing some of it, we would highly recommend that the normal approach in this type of weather configuration that you not make these comments. We're doing it because we're becoming pretty familiar with the approach;

Mather AFB, Calif/31 Jan 69

Approach #10 cont:

we're sure of what we're doing, but every time that I start talking, I forget something. I've done it almost on every approach. This could be serious if an emergency would arise or something of this nature, so I'm going to quit talking during the approach unless it's of an emergency nature.

APPROACH #11 (Osc #142) (Film #268)

WX1/8F, RVR -1000

Automatic

Comments:

Major Hadley: Comments on the last approach of the day, which was the 11th approach. Type of fog now--a mature fog, although it's not a tremendous amount thicker. No contact with the approach lights at all. I saw one glimpse early on the approach and I saw some approach lights -- I saw the thousand-foot bar, then I lost them again and then they came back in again and I saw 2 or 3 more. Then I saw to the right side the wing bar lights and the right of the threshold lights. I did not see the red terminating bar. We're having little problems with the automatic system and I think we're rotating early and the nose of the aircraft probably is cutting off the red terminating bar. The lights are extremely ineffective. At touchdown that time I think our RVR was maybe 200 or 400 feet. I don't think it was much more than that, do you Don? Like I say, the lighting system is extremely ineffective. I think the RVR is going to stay quite low for another hour at least. Runway markings are visible. I could see them but not quite as well as I could earlier. This is due to the reduced visibility in the fog, I'm sure. We landed that time long, I'd say 3400 to 3500 feet.

Major Carmack: Coming down the final approach, fully automatic, the instruments look real good. We are coupled - flare mode came in-- we did get our rotation. Went back to the pitch steping bar throughout the flare. It might be just that the aircraft is getting down to about 2000 pounds of fuel now and we're so light, we're just extending our flare on out. That might be the reason for this.

Visual Segment vs Height

Date 31 JAN 69
 Site MATHER
 Time 0513-0720
 App's 11
 WX IX 1/16F

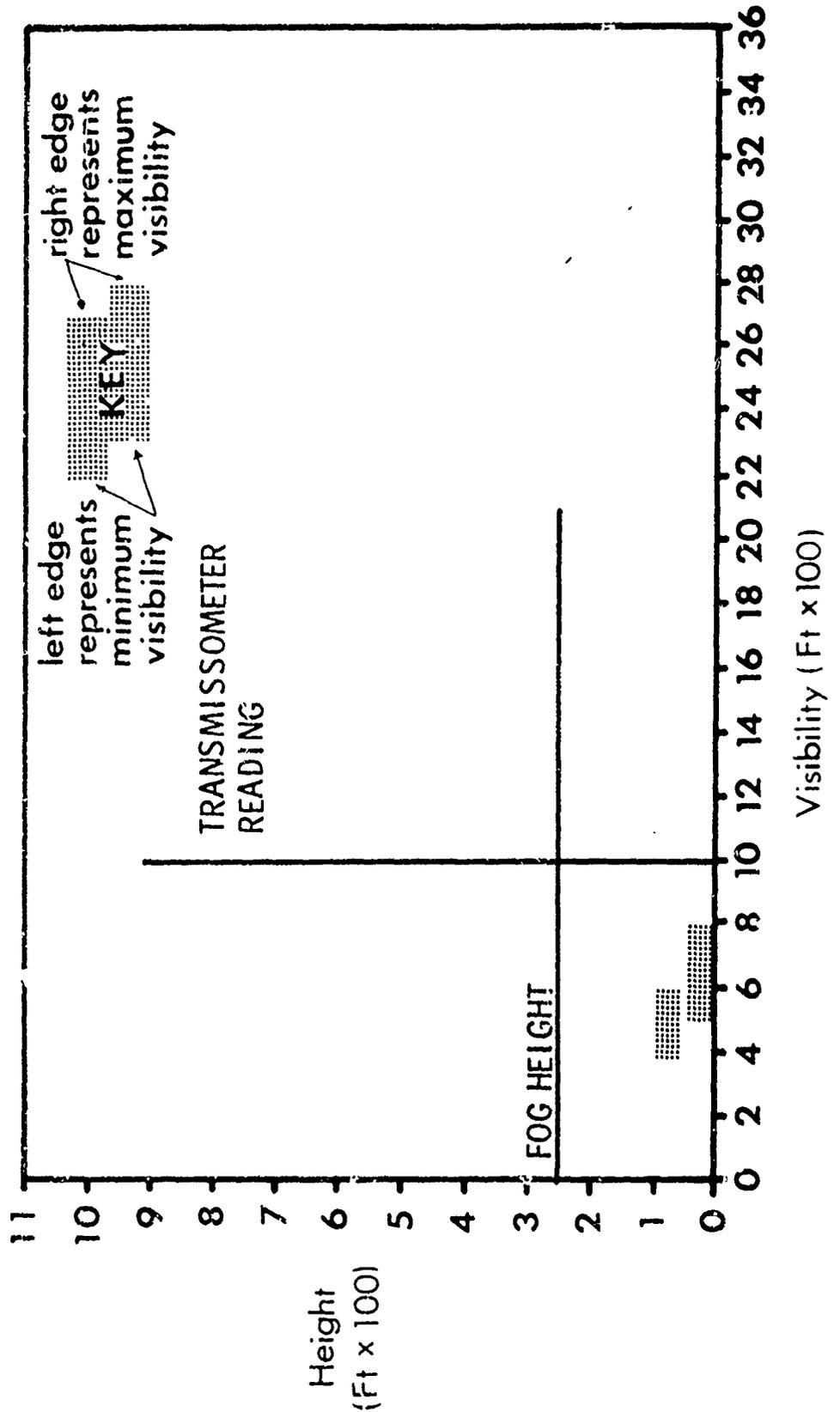


Figure 11. Visibility Chart for Mather AFB, 31 Jan 69

TAPED COMMENTS
SACRAMENTO METROPOLITAN AIRPORT
3 February 1969

Sacramento Metropolitan Airport, California

P

Maj Hadley

Runway 16

CP

Maj Carmack

TP

Capt Taylor

ACM

Mr Armstrong

3 February 1969

APPROACH #1

(Osc #145)

(Film #280)

X03/16F

Automatic

Comments:

Major Carmack: Approach number 1 at Sacramento Metropolitan Airport. The fog condition is a shallow type fog. The top of the fog height is approximately 150 feet. Coming down final approach, I can see the entire approach lighting system underneath the fog, putting out a glare and you can see the strobe light flashes below the fog, although you can't see the actual lights themselves. You can see the reflection from the lights and the strobe lights have a blinding effect as we continue down final. The first visual cue that time occurred at approximately 100 feet, where we did pick up some of the approach lighting system. The thousand foot bar was visible, also the red wing bars and green threshold lights. As we went into flare our visual segment, was approximately 1000 feet. Had contact with 600 feet of the touchdown zone lights, the centerline lights and about 3 high intensity runway edge lights on the side of the runway. At touchdown, I could see about 3 high intensity runway lights on each side of the runway. I would say our visual range was approximately 600 feet. Our reference for the visual call was the runway environment itself, consisting of the touchdown zone lights, centerline lights and high intensity runway lights. The lights give us real good lateral guidance in this particular type of fog. 500 foot visual segment height was approximately 100 feet. The VASI lighting system is not too effective until we get down to about 100 feet. Once we do get down there, then it is very effective. That time I could see some runway markings and the touchdown zone markings. I would say we touched down a little over 1500 feet down the runway. I would say that I could have taken manual control of the aircraft at 100 feet and landed the aircraft.

Sacramento Metro, Calif/3 Feb 69

APPROACH #2 (Osc #146) (Film #320)

X03/16F

Automatic

Comments:

Major Carmack: Again, our fog height is about 150 feet. The entire approach light system is visible through it. However, you can't see the lights per se, but you can see the length of the lighting system as the light from the system is dispersed up through the fog. That time they did not have the strobe lights on. I don't know whether Larry noticed that or not, but the strobe lights were not on during that approach and it was not necessary that they be on. In fact, I think it was better that they were off, for they didn't provide the blinding flashes up through the fog which tends to blind the pilot. At least they tended to blind me somewhat when I was flying the left seat. The first visual cue that time was contact with the approach lights, where I could see the actual approach lights themselves and not the light being dispersed through the fog, and this occurred at approximately 100 feet again. Number of approach lights visible, I could see about, I'd say, 500 foot of approach lights up to the thousand foot terminating bar. It's interesting to note that we did pick up the approach lighting system. I did have visual cues at this time, but once we passed the 1000-foot bar the lights were not visible anymore; if I would have gone visual at this particular time, I would have lost my visual reference with the lighting system for approximately 3 to 4 seconds until I picked up the touchdown zone, centerline, and high intensity runway lights. At flare engage, we had approximately 1000 feet visual range and at touchdown our visual range drops off to about 600 to 800 feet. Number of runway lights visible was approximately 4. At that time I believe I could have taken control of the aircraft, at approximately 75 feet, and could have flared the aircraft manually. Perhaps Larry would like to make some comments now.

Major Hadley: I did come heads up after we were on the ground. That was the only time I did, although during flare I could see the touchdown zone lights out of my peripheral vision. I had no trouble

Sacramento Metro, Calif/3 Feb 69

Approach #2 cont:

at all. I could have controlled the aircraft once I was on the runway laterally. This is going to be a semi-automatic approach, so I'll have more comments to make following this approach.

APPROACH #3 (Osc #147) (Film #449)

WX--none given

Control Condition--none given

Comments:

Major Carmack: Larry had no problem flying the aircraft that time and putting the aircraft on the runway. Again, we could pick up the entire approach lighting system -- I'd say about 800 feet above the surface. It's curious that the fog is such that we can pick up the first 2000 feet of the approach light system up to about the 1000 foot terminating bar and the fog is more dense after that particular point. After we pass the 1000 foot terminating bar it's completely blacked out -- the runway is, and as you progress on for about another 2 or 3 seconds; then you can pick up the red wing bars and the terminating bar and the runway lighting environment. Visual segment at flare that time was approximately 1000 feet. Touchdown point, about 1800 feet down the runway. At touchdown we had good contact with the runway lighting system. I could see about 5 to 6 high intensity runway lights, giving us a runway visual range of 1000 to about 1200 feet. Our first visual cue that time was the approach lighting system and the visual cue call that time was based upon seeing green threshold lights, threshold markings and the touchdown zone and centerline high intensity runway lights.

Major Hadley: I came heads up that time at the visual call. At the visual call it took me just a moment to take everything into focus since we had quite good visibility. I flew the aircraft manually

Sacramento Metro, Calif/3 Feb 69

Approach #3 cont:

without looking at the bars at all. Had very little trouble, at least I didn't think I did. I may have landed a little long but no trouble at all controlling the aircraft either laterally or in the vertical plane at flare. I agree with Don, that the visibility on the runway... the visual range on the runway, probably was about 1000 feet at touchdown and during the rollout. We tried the landing light that time after we were on the runway and with the brightness of the touchdown zone lights and the centerline lights had very little trouble. However, the landing lights were a hindrance at military airfields without the in-runway lighting.

APPROACH #4 (Osc #148) (Film #417)

-X1/4F

Semi-automatic with auto-throttles

Comments:

Major Carmack: Our weather conditions remain relatively the same. Our fog type is a shallow fog -- it's non-homogeneous in nature as it's thicker in some areas than it is in others. As we come down final approach we can pick up about 2000 feet of the approach lighting system. This is contact with the glare or reflection of the lights through the fog. We could pick up the entire approach lighting system up to about the thousand foot terminating bar since the fog is non-homogeneous in nature. Then, as we approach touchdown and pass over the thousand foot bar we lost contact with the approach lighting system; then about 2 or 3 seconds later I was able to pick up the red terminating bars, the red wing bars, and the green threshold lights, plus the runway environment, consisting of the high intensity runway lights, touchdown zone and centerline lighting system. At flare engage, about 50 feet, we were able to pick up about 5 high intensity runway lights for our RVR -- I'd say about 1000, maybe up to 1200 feet. I believe that at approximately 75 feet, when I had contact

Sacramento Metro, Calif/3 Feb 69

Approach #4 cont:

with the runway environment consisting of the lighting system I could have flared the aircraft... taken over the control of the aircraft manually with the lighting system. And then as we continue to touchdown, the runway visual range drops off, I would say to somewhere between 800 and 1000 feet, then it will vary somewhat as we rollout on the runway, it will increase or decrease somewhat. The lowest visual range we had on that particular approach was probably close to 700 feet, then it opened up to about 1000-1200 feet as we go on down the runway. Larry would like to make some comments now.

Major Hadley: Once again, on that approach, I came visual at his call. It was no problem recognizing the entire runway environment with the in-runway lighting system. It's a tremendous aid in picking up the runway outline, so to speak, as we know what to expect. I did say that I had no problem controlling the aircraft either laterally or vertically. I think I would have vertically if I didn't have in-runway lighting. With that much RVR of about I would say touchdown, about 7-800 feet and then as Don said, down the runway maybe a thousand to 1200. There is just no difficulty at all. We're picking up some noise on the glide slope. I don't know if it's in our equipment or the glide slope transmitter itself. There's quite a bit of jiggle in the bar -- we're going to talk to Buck about it when we get back in.

APPROACH #5 (Osc #149) (Film #448)

-X1/4F

Manual

Comments:

Major Carmack: Maybe I have given a false impression. We can pick up the entire approach lighting system around 800 feet, but it's a

Sacramento Metro, Calif/3 Feb 69

Approach #5 cont:

glare through the fog condition. As we come on down to about 200-250 feet somewhere in this area, we start to pick up the first 2000 feet of the approach lighting system through the 1000 foot bar. On that particular approach, it was a little bit more than that. We could see beyond the thousand foot bar about another one to two hundred feet and the homogeneous fog makes it very difficult to see anything beyond that particular point. Then, as we progress on down, at possibly 100 feet, we pick up the red terminating bar, red wing bars, green threshold lights and some of runway environment. At about 100 feet, I believe I called cue, had contact with the touchdown zone lights, high intensity runway lights and so forth and about 75 feet could see the runway environment with a visual range of approximately 1000-1200 feet. I could have taken over and flared the aircraft manually using the lighting system. At touchdown I would say our visual range was approximately 1000-1200 feet, possibly a little bit more than that. Any comments you want to make, Larry?

Major Hadley: I came heads up on that manual approach at your visual call. At that time everything was clearly outlined. Once again, just no problem at all controlling lateral and vertical plane. I agree with Don of his evaluation of the RVR. I want to try something a little different on this one. When he calls cue I'm going to take a look and, if I think that I've got enough for lateral guidance, I'm going to go ahead to be in and out on his cue call, so he'll be backing me up very closely, making sure that we are aligned and what have you.

Sacramento Metro, Calif/3 Feb 69

APPROACH #6 (Osc #150) (Film #460)

W1/4GF

Manual

Comments:

Major Carmack: Let's sum up this flight this morning. I'd say the weather that we encountered here in Sacramento is very indicative of what would be encountered under a 100-foot condition, with a 1200 foot runway visual range, and possibly it could get some pilots in trouble if they came visual at about 200-250 feet. At that particular altitude, we had contact with the glare from first 2000 feet of the approach lighting system -- it is evident. You shouldn't use it for lateral guidance. As you continue to about 150 feet the fog becomes more dense and you lose the lateral guidance that you're getting from the lighting system. At 100 feet you start to pick up the runway lighting system and you have good lateral control and guidance. The runway lights, centerline lights do give you the ability to control the aircraft in a lateral plane and also the vertical plane with this type of visual range. The effectiveness of the lighting system is very good. Any well-trained pilot should be able to come heads up at approximately 100 feet in this type of RVR and land.

I want to make a correction on this tape -- do not use oscillograph number 150, film can number 460. Approach number 6 was cancelled at Sacramento Metropolitan because the fog seeder aircraft was making approaches over the runway at about 500 feet. Approach #5 will be our last approach.

Visual Segment vs Height

Date 3 FEB 69
 Site SACRAMENTO
 Time 0532-0619
 App's 5
 WX WOXI/4F

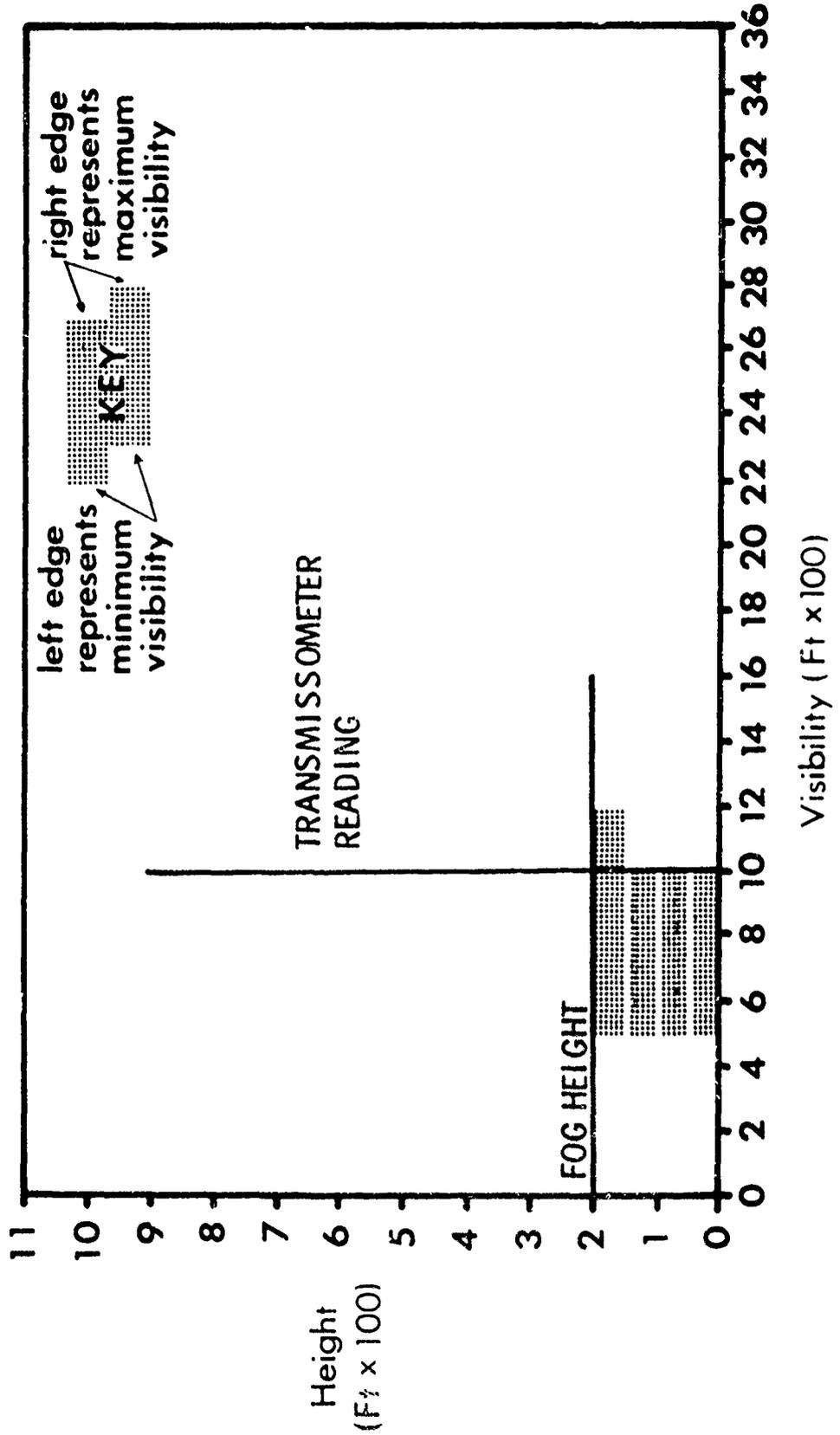


Figure 12. Visibility Chart for Sacramento, 3 Feb 69

TAPED COMMENTS
CASTLE AIR FORCE BASE

4 February 1969

Castle AFB, California

Runway 30L

4 February 1969

P	Maj Hadley
CP	Maj Carmack
TP	Capt Taylor
ACM	Mr Armstrong

APPROACH #1 (Osc #150) (Film #460)

Wx2 3/8

Automatic

Comments:

Major Carmack: Let's try a different procedure on final approach. There will be three calls. There will be a "cue" call which means that we have some visual cue. There will be a "lateral" call when the right-seat man thinks he has enough visual cues or visual segment to control the lateral axis of the aircraft. Then a "visual" call when he feels that the left-seat man could come heads up at that time and take over visual control of the aircraft with the outside environment. We have a deep fog condition existing today. Our fog height is approximately 800 feet. Coming down final approach that time, called first visual cue picking up the approach lighting system. I could see about 1000 feet of the approach lighting system. They are very effective -- still bright. I could have used the approach lighting system for lateral guidance at that time. Approach light contact height was approximately 200 feet. Called "lateral" at approximately 150 feet. I could see approximately 1000 foot visual range out in front of the aircraft. At the time I called "visual" we were about 75 feet in the air, I figure we had about 1000-1200 feet RVR. The high intensity runway edge lights are very effective in this type of weather. And the visual segment down the runway in the flare and rollout improved to, I'd say, anywhere from 4 to 5 thousand feet.

Castle AFB, Calif/4 Feb 69

APPROACH #2 (Osc #151) (Film #271)

W2 3/8, The visual range is reported as 2200 feet.

Semi-Automatic

Comments:

Major Carmack: Deep fog conditions -- the fog height approximately 800 feet above the ground. The first visual cue on that approach was the approach lighting system. I could pick up two or three of the barettes, then approximately a 1000-foot segment of the barettes. Approach light contact height that time was approximately 200 feet. As we progressed on down, called "lateral" at about 120 feet. At this time I had contact with the 1000 foot bar, green threshold lights, red wing lights and terminating bar. I could pick up about 5 or 6 high intensity runway edge lights on each edge of the runway. Touchdown zone markings were in view, also. And the centerline striping. There is no problem whatsoever from 100 feet on down maintaining lateral control; if I would have taken over, I could have visually controlled the aircraft. Runway visual range, looked like it dropped off just a little bit on that approach over the previous one. Runway visual range in the touchdown zone at flare, I'd say was about 1500 feet, then, as you progress down to the runway and land the runway visual range opens up to about 4000 to 5000 feet.

Major Hadley: I came heads up that time on his "lateral" call. At that time I had no difficulty at all telling lateral and just a few seconds later was able to go visual in just the length of time that it took me to focus my eyes. With visibility like this, around 2000 or 2200 at this point, there would be no problem at all for the man to come heads up and assume visual. I think that point probably deteriorates someplace down below 1000 feet. We will have to get some more data to be sure.

Castle AFB, Calif/4 Feb 69

APPROACH #3 (Osc #152) (Film #281)

2W3/8, RVR 2400

Manual

Comments:

Major Carmack: We have a deep fog condition. It is about 800 feet thick. The first cue that time, at 200 feet, was the approach lighting system. At this time I could recognize 500 feet of the approach lights and I would have been able to maintain visual contact with the approach lights all the way to the runway and touchdown. They could be used effectively to laterally control the aircraft. However, you don't have any feeling of depth without the approach lighting system in visual contact. Approach light contact height was about 200 feet. At about 100 feet, I did pick up the green threshold lights, the red terminating bar, red wing lights, and the 1000-foot bar was plainly visible. At 100 feet I'd say our visual segment was about 800 to 1000 feet, so, it looks like we're going down a bit more. At flare engage, I would estimate the runway visual range to be about 1200 feet. Once we get on the runway, the visual range opens up quite a bit and gives us about 4000 to 6000 feet. That time, again, the runway markings were visible. I could have used the touchdown zone markings and runway centerline striping to laterally control the aircraft. Doesn't seem to be any problem at all controlling the aircraft when you have a runway visual range of about 1000 to 1200 feet. Not for the flare or for the touchdown or, of course, the rollout either.

APPROACH #4 (Osc #153) (Film #275)

W2X1/8, RVR 5000. Runway Visual Range now reported as 1100 feet.

Automatic

Castle AFB, Calif/4 Feb 69

Approach #4 cont:

Comments:

Major Carmack: Our fog seems to be mixing a little bit now. I'd call it a non-homogeneous type fog. It becomes a little thicker and then it will open up, then become thicker as we progress down the runway. Still a deep fog condition. Fog is about 800 feet thick. Our first visual that time was the approach lighting system. It was picked up at approximately 200 feet. At that time we had about a 500 foot visual segment at first cue. The first cue was the approach lighting system. As we progress on down at approximately 100 feet, called "lateral". At lateral, I was able to pick up the red terminating bar, the red wing bars, green threshold lights. And about 4-5 high intensity runway lights along the edge of the runway, so I would say that at "lateral" I had approximately 800 to 1000 foot runway visual range. At "visual" call we were approximately 75 feet. At this time our runway visual range was approximately 1000 feet. I was able to see the entire runway environment, the contrast between the runway and the outskirts of the runway, position of the grass, tetrahedron, little buildings, and things such as this. I would say the workload scale for the approach was probably a "two". On the second and third approaches, probably also a "two", on the first approach, probably a "three."

Major Hadley: Comments on the workload scale on the four approaches. On the first two approaches, I would call them, probably "two". The first one being an automatic, the second one a semi-automatic. The third one, which was a manual, even though we had fairly good weather, I would rate it as standard, about a "three". I contribute this to having to pay attention to airspeed control, adjusting the throttles, and what have you. I found that the alpha indicator, even though it's quite a bit out of the field of vision, is easier for me to see and interpret than the airspeed is. Also, the apexer, here once again, is out of the field of vision, up on top of the windshield, is still not bad because it's right in line with my eyes and I only have to flick up there and then flick right back down. It's very easy to interpret and very easy to see. The last approach, being an automatic approach, workload scale would be "two".

Castle AFB, Calif/4 Feb 69

APPROACH #5 (Osc #154) (Film #253)

2Wx3/8F, RVR 2200

Semi-automatic

Comments:

Major Carmack: We are going to change the control condition on this approach. When the right seat pilot calls "lateral" he will assume control of the lateral axis. The left seat pilot will stay heads down and control the vertical axis. Auto-throttles will be controlling airspeed.

We have a deep fog condition here on Approach #5 at Castle AFB. The thickness of the fog is still approximately 200 feet. It seems to be maturing now. It's a non-homogeneous type of fog. It seems to open and close somewhat as we rollout. Our first visual cue, first time was the approach lighting system. It is very effective. That time the visibility and visual segment increased as we approached the runway. At the "cue" call we had a visual segment of approximately two to three hundred feet. Visual cue was called at approximately two hundred feet, possibly a bit lower, about 150 feet. As we approached 75 feet, we pick up the green threshold lights, the red wing bars and the red terminating bar. We could see approximately 3 to 4 high intensity runway lights. I would estimate the visibility at flare to be about six to eight hundred feet. At "lateral" call the right-seat pilot took over lateral control of the aircraft. There was no problem whatsoever controlling the lateral axis with this... about six to eight hundred foot runway visual range. In view that time were the touchdown zone markings, centerline marking and the runway environment in relation to the edge of the runway. The distance-to-go markers are readily visible from the cockpit of the aircraft with about three to four hundred foot visual range and it is light enough outside. We can pick these things up and use them for distance-to-go. As we progress on down the runway, the runway visual range seems to open up to about three thousand feet. Then as we progress on down the runway it opens up to about two or three thousand feet. The fog, being non-homogeneous in nature, it opens up to about four to five thousand feet on a clear part of the runway.

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APPROACH #6 (Osc #155) (Film #246)

2XW3/8F, RVP 1200

Manual

Comments:

Major Carmack: We still have a deep fog condition existing at Castle AFB. It seems that it is maturing more. The fog is getting thicker, it's more mature and dense. The call for first visual cue was the approach lighting system. Could pick up at first visual cue about two or three barettes. The strobe lights do help, somewhat, to give you path for lateral guidance. However, it's not enough. I called "cue" at approximately 200 feet and started maintaining a lateral directional control and, as we progressed on down at approximately 100 feet, called "lateral". At that time I could see the threshold lights, red terminating bar, red wing lights, and I could see about two or three high intensity runway lights along the edge of the runway. Runway visual range at the "lateral" call was approximately two to six hundred feet, but I did not feel there was enough visible at that time to call "visual". There was enough visual range to laterally control the aircraft and maintain it on the runway. However, there weren't enough cues to control the vertical axis of the aircraft. As we came down and got into flare, I called "visual" at approximately thirty or forty feet.

At that time our runway visual range opened up to approximately 600-800 feet, and I felt that I had enough cues at this time to visually and manually take control of the aircraft at flare. As we come on down to the runway, the runway visibility opens up quite a bit, somewhere to one thousand to twelve hundred feet. Then as we progress throughout the rollout, it opens up to two or three thousand feet. So, the fog is getting more dense, more mature. You can use the centerline striping to maintain lateral directional control and this is what I would be using at the "Lateral" call. The high intensity runway edge lights also give us lateral guidance; however, I have enough visual contact with the centerline striping to use this and it gives me a better reference for lateral control.

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Approach #6 cont:

The workload on that approach was a little more for the right-seat pilot, about a three. This is because the runway visual range is dropping off. I have to concentrate more on picking up cues for lateral guidance.

Major Hadley: On that approach, when he called "lateral", I came heads up, as we had discussed prior to the approach. At this time, it took me a moment to pick up the lateral guidance cues. The high intensity runway lights didn't strike me as being nearly as apparent as they had been before; consequently, I drifted somewhat to the right as soon as I came visual. Also, at that point, I had just a little difficulty with pitch control. I didn't have good depth perception at all, and it took me several seconds and descending more before I was able to establish satisfactory flare. I went momentarily back on the instruments to center the bar for the flare and then looked outside again. After we had descended the visibility had improved somewhat. It's really interesting that even in daylight, which it is now and with decent visibility, which we have, as Don had told you in that particular area, depth perception still becomes a problem. The lateral control doesn't appear to bother much, but the depth problem, even with this type of visibility is not easiest thing in world. If we had been sitting higher, in a higher cockpit, I would have had depth perception problems all the way down to touchdown. I would rate that as a three.

APPROACH #7 (Osc # 156) (Film #247)

W2X3/8, RVR 1400

Manual

Comments:

Major Carmack: We still have a deep fog condition. Fog thickness is about 800 feet. Getting more mature, it's more dense. That time our first visual cue was the strobe lights. We were able

Castle AFB, Calif 4 Feb 69

Approach #7 cont:

to pick up the strobe lights at approximately 150 feet. At this time, I would say our visual segment was about 200 feet. As we progressed on down to about 150 feet, I was able to pick up the approach lighting system as well as strobe lights. The strobe lights were the first ones that were visible.

As we progressed on down to approximately 75 feet, I called "lateral". I say at this time that I had enough visual cue in the lateral direction to laterally control the aircraft, but definitely not enough to vertically control the aircraft. At this time, the visual segment, at 75 feet, was approximately two to three hundred feet. I called "visual" at approximately forty feet. At this time I could see about four to six high intensity runway lights indicating runway visual range of about 800 to 1200 feet. At this time, I would have had no problem at all taking control of the vertical and lateral axis.

Again, the runway markings are visible. The touchdown zone, the centerline, side stripes, etc, are visible and are very effective visual cues for lateral control of the aircraft. At that time, when I did call "visual", it seemed like the left seat pilot came heads up and seemed like he wanted to bank the aircraft a little bit to the left; however, I did come into the lateral axis and prevent this action because we were just about on centerline. Perhaps he was attempting to get the aircraft back to centerline.

Then, as we progressed on down the runway, the runway visual range did open up. After about travelling, I'd say 3000 to 4000 feet, the runway visual range opened up to 2000 to 3000 feet. It's not a fixed range for and will close and open up.

Left Bank: When I came heads up that time, I didn't see the runway markings and I guess I probably did turn to the left slightly. I could see the left side of the runway lights. Although I could see both sides I seemed to automatically kind of home in on the lights so I would have good reference. When I did come heads up, I didn't have a good reference as I would have liked to have had, particularly in patch. As we went down a little lower, I began

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Approach #7 cont:

to pick it up, but I yo-yoed a little bit to find the runway. This is a little unusual with this type of RVR, I think, but as the sun comes up and it gets brighter outside, the lights just don't seem to help me quite as much. Once again, no problem laterally, although I did turn to the left slightly. More of a problem in pitch. Workload scale--3.

Major Carmack: I would rate that, from a right side point of view as a 2.

APPROACH #8 (Osc #157) (Film #277)

W2X3/8, RVR 1200

Fully Automatic

Comments:

Major Carmack: We still have our deep fog condition. The fog is now about 900 feet thick, fully matured. I would say a homogeneous fog; it's just about as stable and homogeneous as a fog can get. First visual cue that time occurred at approximately 150 feet above the surface and the first visual cue was the approach lighting system. Visible this time were the strobe lights as well as segments of the approach lighting system. At this time I could pick up about 2 to 3 barettes of the approach lighting system. I just didn't feel that I had enough to use for lateral guidance. As we progressed on down to approximately 100 feet, I called "lateral". At this time I could pick the overrun markings, the red terminating bar, green threshold lights, and the red wing lights. At this time I could see about 2 to 3 high intensity runway lights and a runway visual range of about 400-600 feet. I thought I had enough to laterally control the flight path of the aircraft in those axes; however, it was not enough of a vertical reference to control the aircraft in the vertical plane. As we continued

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Approach #8 cont:

to about 40 feet, the RVR picked up to 800 to 1000 feet and I felt that I then had enough at this time to vertically control the aircraft, and I could have taken over both the vertical, as well as the lateral axis to complete the landing. The centerline striping gives very effective cues when the runway visual range is about 400 to 600 feet, when it is daylight. I could go ahead and laterally make corrections with the centerline striping. Also visible out to the sides of the aircraft were the side stripes. After progressing about 3000 feet from the approach end of the runway, the RVR opened up to about 1200-1400, maybe 5-1600 feet RVR based on the number of high intensity runway lights that were visible at that time. It seemed to me like Larry was searching a little bit in the lateral axis when I called "lateral". I was not making any control inputs but I was damping out his control actions. I don't know if Larry felt me in the lateral axis or not.

Major Hedley: I came heads up that time when you called "lateral" and definitely did not have enough for pitch control. A little shaky on lateral control at that point. Also, I did uncouple at 200 feet which didn't appear, at least to me, to cause any problems. I imagine that the control input to the left was due to when I went down in pitch, and in doing this, I may have crept in the lateral plane. Then, I came heads up again when he called "visual", and at that time I did have enough visual reference for flare and lateral control.

Major Cernack: It is interesting to note that when I call "lateral" with about 400 to 600 feet and I have enough cues to control laterally, but not the vertical plane. I felt the same way in the vertical plane, although laterally I did have enough cues to control the aircraft in the lateral axis. I would rate that as a two. I was very relaxed and, from about 150 feet on, I had visual cues. I knew the aircraft was on centerline of the runway from looking at the approach lighting system, strobe lights, and that we were not in lateral difficulty by seeing the overrun markings, thousand foot terminating bar, 300 foot red terminating bar, and red wing lights. I knew what the aircraft's position was. I was very relaxed on that

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Approach #8 cont:

particular approach, and then when I picked up the high intensity runway lights I began to relax in the right seat. Larry said he would also rate that approach as a two. --

Major Hadley: Notice any tendency for rolling motion that time when we uncoupled?

Major Carmack: No.

Visual Segment vs Height

Date 4 FEB 69
 Site CASTLE
 Time 0630-0758
 App's 8
 WX W2X3/8F

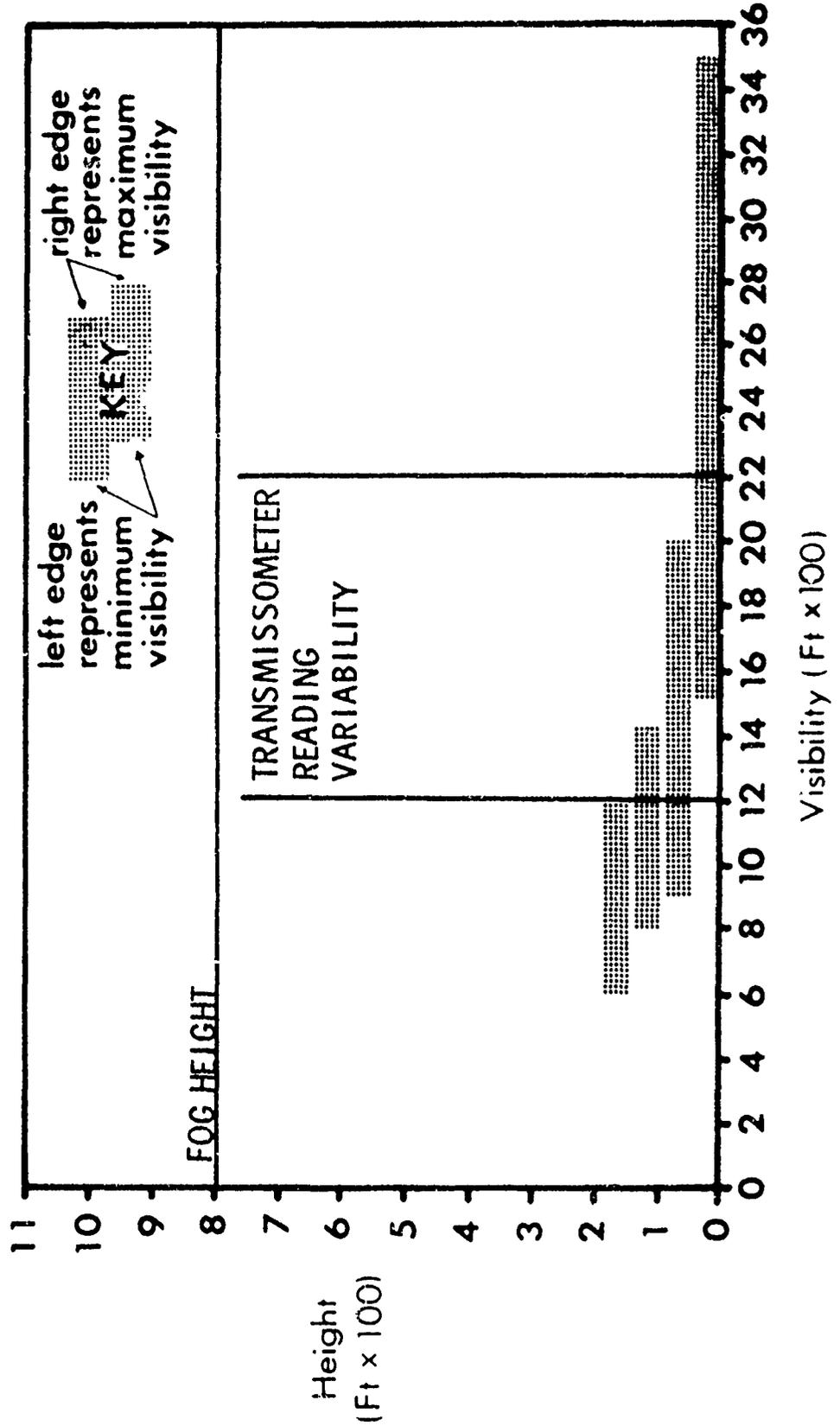


Figure 13. Visibility Chart for Castle AFB, 4 Feb 69

APPENDIX B
PROJECT AIRCRAFT SYSTEM CONFIGURATION

PROJECT AIRCRAFT SYSTEMS CONFIGURATION

Mode Selection:

The project aircraft was equipped with independent controls for Flight Director mode selection, autopilot engaging, and autopilot axis coupling. The Flight Director mode selector consisted of push button selection annunciation for different modes. Each mode was labeled as to its function and illuminated upon selection. Mode selection in the longitudinal axis provided selection of altitude hold, flight path angle (FPA) or flight director computer (FDC) longitudinal off. The lateral modes consisted of heading, capture, track and FDC lateral off. A dimming switch was also included on the mode selection panel. The mode selection panel was located on the center of the forward instrument panel allowing project pilots optimum access. The selection of a mode completed the circuitry to the appropriate computers (FPA or FDC) so each would display their respective information to either or both the pitch and bank command steering bars. Each display received computed information from a separate computer.

The autopilot engage switches were located below the FDC mode selection unit and consisted of three magnetically held switches. Each switch was independent of the other allowing yaw, roll, or pitch axes selection as desired. Whenever the autopilot roll axis was activated, roll FWS was available to both pilots. Whenever the pitch axis was engaged, pitch axis force fade was available allowing neutralization.

Systems Analysis:

The control configuration and switching arrangements created no particular problems during the weather flying. However, project pilots generally felt optimum use of the systems was not obtainable with the established configuration. While the right FDC provided redundant display elements, its use during the final approach profile was severely limited. It was felt both computers should have the capability of operating the autopilot independently or in conjunction with one another. For example, one computer supplying roll and yaw inputs while the second furnishes pitch inputs into the autopilot. This control scheme allows complete use of both computers and provides the necessary flexibility in event of radio or computer failures.

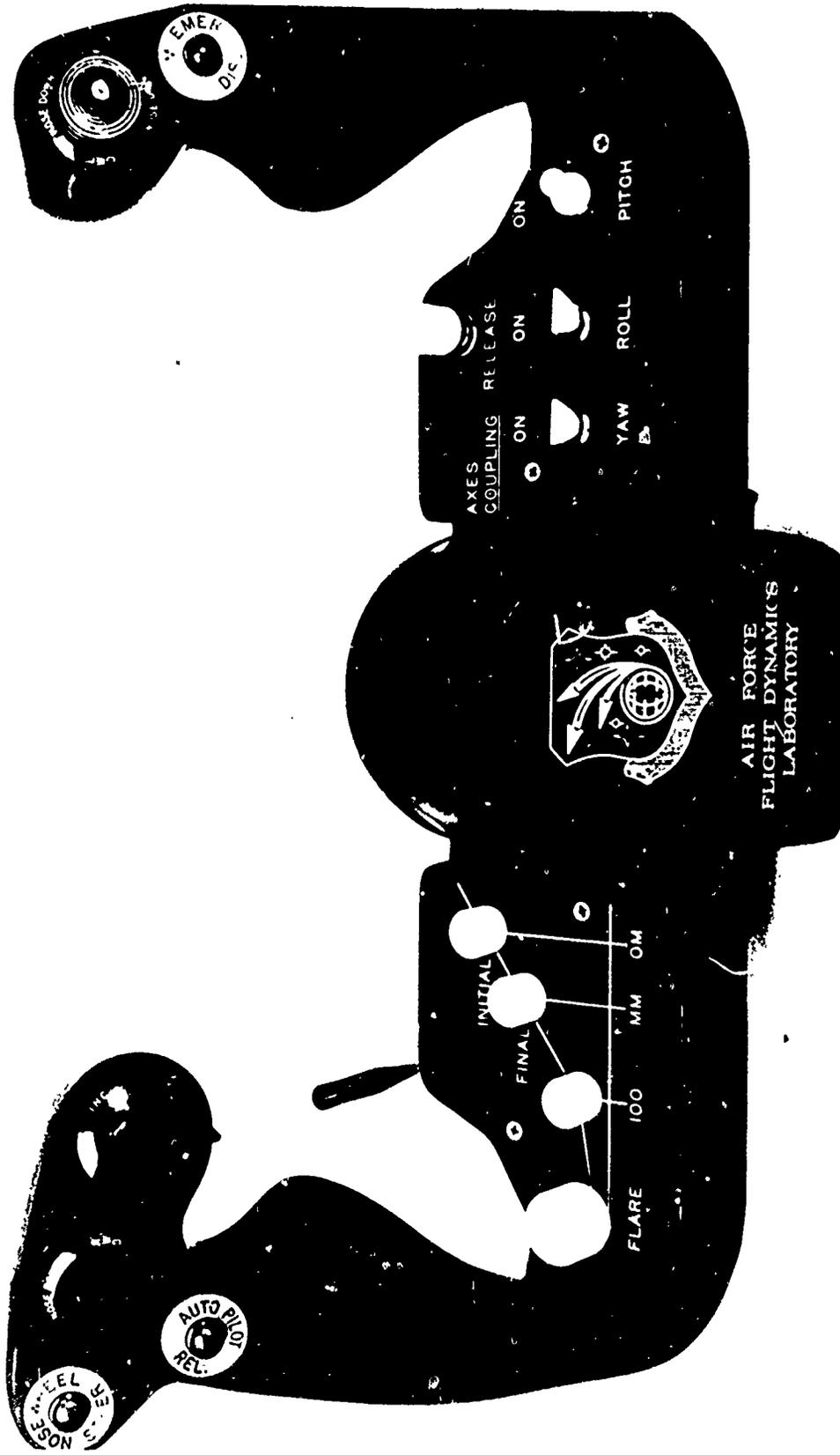


Figure 14. Pilot's Control Wheel

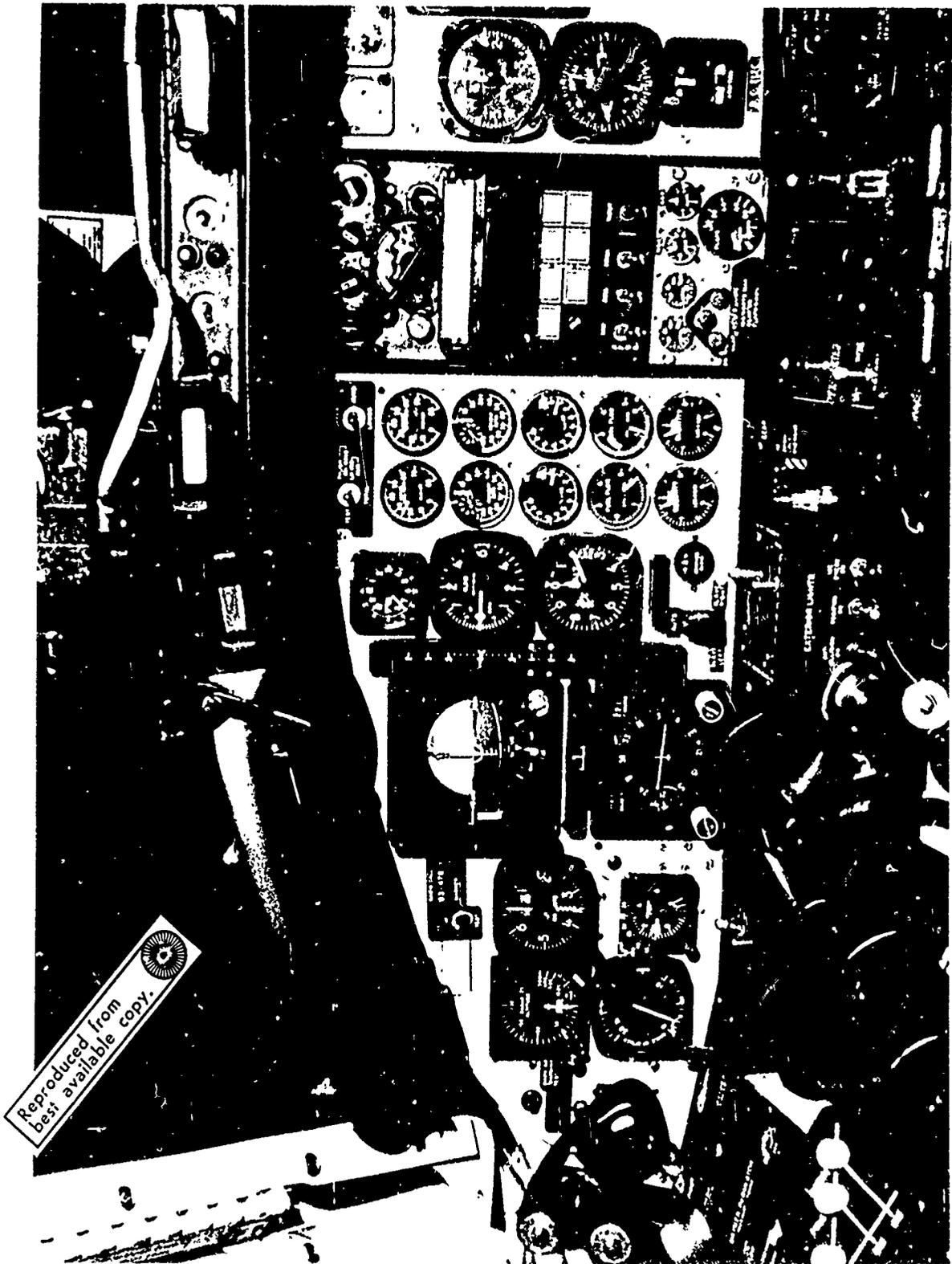


Figure 15. Pilot's Instrument Panel

In addition, increased capability could have been obtained through the inclusion of longitudinal slew control. The control function could be included with the lateral slewing switch with an up and down motion providing the slewing function. This function should provide for a compatible rate of change of the selected parameter, i. e., FPA, altitude or vertical velocity. A slewing switch should also be provided to select command airspeed or mach. Pitch attitude should also be incorporated as a longitudinal mode and could be used during climb, penetration, and other instrument maneuvers requiring constant pitch attitude. This mode should also have a slewing capability.

The lateral modes in the project aircraft included localizer and heading displays from the FDC with the capability for autopilot coupling. Project pilots indicated a strong preference for the heading mode during all phases of flight. Aircraft coupling in conjunction with the slewing function reduced pilot workload considerably; however, it was felt the system lacked the desired flexibility since no provisions were incorporated in the computer or slewing switch for TACAN/VOR course slewing or coupling. The next major change then should include logic design in the computer for TACAN/VOR selection and the ability to slew course changes in the course selection window of the HSI. Wind and course error logic would be included in all navigation modes.

Computer Functions:

The modified CPU-27 computer installed in the project aircraft was insufficiently refined in its heading, capture, and track modes to perform optimum tracking tasks. In the heading mode, the slewing mechanization was set to provide an approximate one degree heading change with a click of the switch. Adjustment is necessary for an exact one-half degree change. If held left or right for more than 3 seconds, heading changes were commanded until release of the switch. Project pilots view the selected heading in conjunction with the heading marker and received command steering from the Bank Steering Bar (BSB). The initial turning rate produced by the coupled system was uncomfortable to project pilots and needed filtering within the computer to prevent an excessively high initial roll rate. Project pilots felt any abnormal rate of movement was extremely distracting during any phase of flight.

The capture mode of the FDC provided automatic localizer capture

by establishing a 45° intercept heading and beam capture upon localizer sensing. The capture mode maintained localizer until glide slope intercept. Usually, altitude hold was selected and used during the capture phase of the ILS approach. At glide slope intercept, the glide slope beam sensor would establish the track mode, automatically switching altitude hold off and establish glide slope coupling. This particular switching function was smooth in the transition from altitude hold to glide slope. The gains between capture and track for localizer steering were different producing an uncomfortable transient during the switching process. Other factors contributing to the transient were the absence of wind circuits in the capture mode, the need for switching at GS intercept, the gain variance and lack of turn rate circuitry to smooth the transition.

Once the transition to track (ILS final approach mode) mode was accomplished, autopilot localizer tracking was extremely tight with very little or no deviation of the BSB. It should be made clear the autopilot was coupled to the BSB and PSB command signals allowing pilot observance of autopilot performance in relation to raw localizer and glide slope information. Absolute localizer deviations occurred due to beam scalloping and noise; however, these excursions were small and damped easily by project pilots with FWS.

Glide slope coupling was not as tight as project pilots desired allowing deviations about the glide slope of $\pm 1/4$ dot. Project pilots found the deviation of raw glide slope extremely distracting during project flying. This concern for glide slope tracking was traced to the need for absolute zeroing of the raw information during project weather flying for approach confidence. Pilots were active during the coupled approaches damping autopilot roll inputs and assisting in the pitch axis.

Flare Command:

The flare presentation occurred at fifty feet and consisted of a fly-up command on the pitch steering bar. Other indications were a change of FPA on the tape within the ADI, the flare light on the approach sequence indicator illuminated and an attitude change was apparent on the ADI. The logic for the flare command was based on a change of FPA from -2.5 to -1° . At one hundred feet, glide slope signal fading began simultaneously with the fade in of a FPA signal equal to a negative 2.5 degrees. At a radar height of 50 feet the transition from glide slope to FPA was completed. Also at this time, radar height initiated the flare mode.

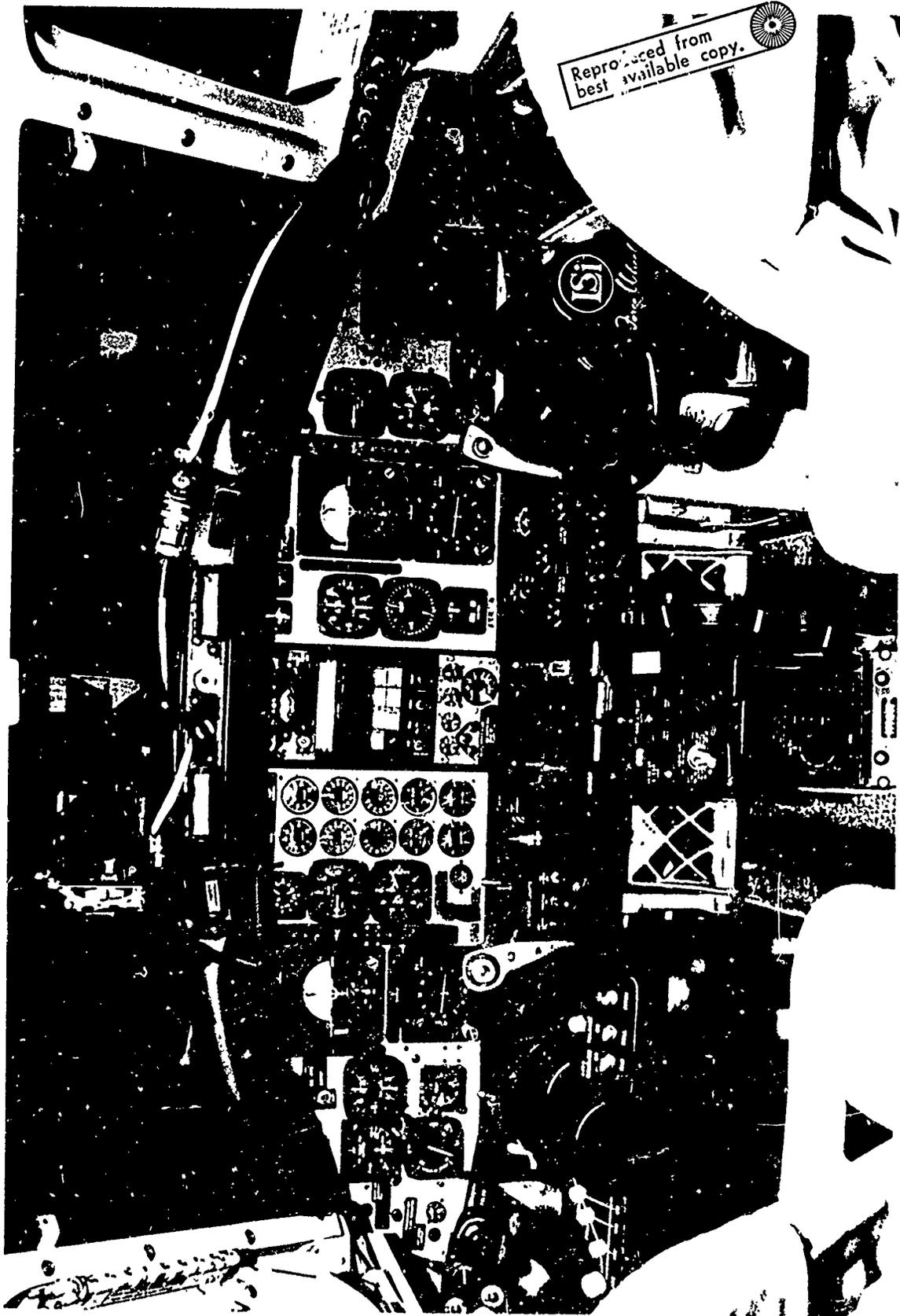


Figure 16. Pilot's and Co-Pilot's Instrument Panel

The flare was based on an FPA signal consisting of radar for \dot{h} (vertical velocity) and IAS for the horizontal signal. This arrangement provided an optimum flare for the test aircraft regardless of the level of automatics. Project pilots found the one-step flare command easy to follow and felt an exponential command would have been more difficult to maintain. A problem was encountered with longitudinal dispersion based on the level of automatics. It was found that completely automatic approaches resulted in consistent performance, while uncoupled approaches led to floating and several hundred feet dispersion. Also it was felt path guidance should be ground based to allow beam following to the ground. Therefore, it was determined the guidance system should provide a multi-angular approach path with the on-board computer sorting signals to provide a bi-angular approach path including final approach and flare angles compatible to the type aircraft. It may be desirable to use tri- or multi-angular approach paths for some aircraft.

Attitude Director Indicator:

The Attitude Director Indicator (ADI) consisted of the conventional display of sphere and fixed miniature aircraft. Command steering was presented by vertical and horizontal pointers for bank and pitch respectively. The attitude sphere was color coded with blue for sky or pitch up corrections and a light brown for ground or pitch down indication. An added feature was the Flight Path Angle tape on the left side of the instrument. This parameter will be discussed in another section.

The color coded attitude sphere presented a more realistic formulation of pitch information. The elimination of the horizon line on the sphere and the contrast of colors serving as the horizon reference produced an overall improvement in the attitude display. The one degree pitch references between \pm ten degrees of pitch were difficult to interpret and might be better defined with an indication every two degrees and a larger indication at \pm five degrees.

The thinner command steering bars allowed better vision of the pitch references. The most desirable feature of the display was the separation of the bank and pitch commands into two entities. The multiple cue presentations allowed more precise control of either axis without interference. During short final, finite corrections are required in both axes and it was particularly important to interpret and establish the proper command without upsetting the other axis.

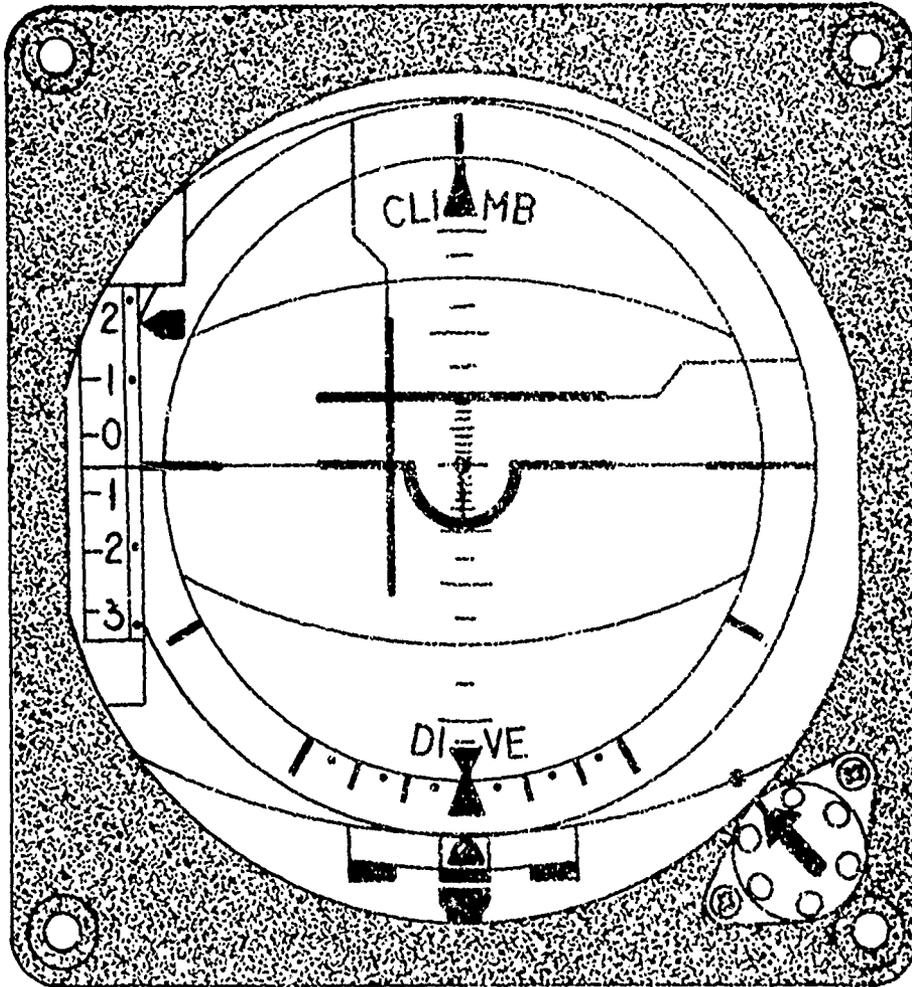


Figure 17. Attitude Director Indicator

During the LWMI it was determined the cues for pitch and bank commands must be separate to allow optimum control of each axis. The most critical period exists from 100 feet to touchdown with the flare presentation being established at 50 feet. At this crucial time it was imperative the command steering be definitive with reference to the proper flare and heading command. A single cue presentation during this period would produce distracting effects and proper path control would be more difficult to maintain.

It is recommended that the FPA tape be configured to display pitch attitude. The scaling of the tape should remain the same with the tape color coded to present blue and brown indications for climb and descent. With this display, pilots of high performance aircraft would be provided expanded information for their specific needs at high altitude and mach numbers. This parameter is also needed to provide qualitative information throughout the low speed profile. An additional requirement is the inclusion of an attitude readout window for attitude slewing, coupling, and command readouts when required.

Landing Sequence Indicator:

This display was located above the ADI and presented approach progress information to the pilot. The display was activated at outer marker and presented mode and function annunciation to touchdown. The modes presented were: outer marker, middle marker, 100 feet, flare and go-around. The go-around mode, although present on the display, was inoperative.

The display was extremely valuable for "how goes it" type information. The 100-foot presentation provided information that glide slope gain changing had occurred, therefore, was one of the critical terms on the display. The other critical term was flare annunciation and confirmed proper system operation at the flare altitude. The outer marker and middle marker modes were less critical modes, but confirmed operational status during the approach profile.

The system could be reconfigured to provide more useful information during the approach. Of primary interest to the pilot at any time during the approach is the quality of system performance. The same basic display should be used with more emphasis placed on defining flare engage and decision height. Fundamental to the display and of critical importance is the presentation of go-around command. This command must have over-riding emphasis over any other command.

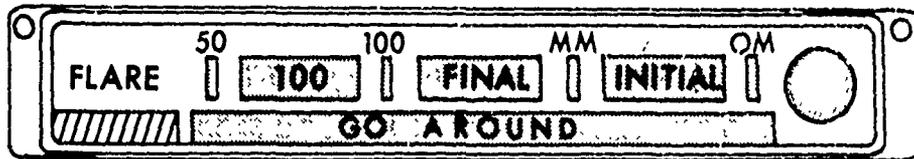


Figure 18. Landing Sequence Indicator

The go-around command should also be in line with the aircraft's monitor system to alleviate the necessity for a decision at a critical time. To prevent an adverse reaction from the pilot, it is suggested the go-around annunciation start by flashing on and off, and then remain on steady when the go-around command is satisfied.

Lateral Displacement Indicator:

The Lateral Displacement Indicator (LDI) located between the ADI and HSI presented a correlation between the bank steering command bar and the raw localizer information. Its presentation represented localizer expanded five to one compared with raw information. Its display consisted of an element 40 millimeters in width, an index, and a heading error indication. The instrument was configured so the element would represent the center one-third of a ten-thousand foot runway at threshold if the element's outer edge was in line with the index. The heading error indication was engineered to represent a maximum of 15° deviation from approach heading and consisted of a triangular indication which moved in the direction of heading error.

The instrument was used by project pilots to ascertain localizer tracking performance for short final approach and touchdown. Also, the element factuated the decision to continue or execute a missed approach from 100 feet throughout the remainder of the approach. If for any reason the index was not within the limits of the element, localizer tracking performance was unsatisfactory, and a missed approach was executed.

The movement of the element was not damped sufficiently to provide good performance indications. Also, no provisions were incorporated in the display to compensate for runways of various width and length. Project pilots also had adverse comments on the heading error display as it was difficult to see during day operation and could not be seen at night. The instrument was not internally lighted. The left LDI was configured so the heading error indication was 10° full scale while the right represented 15° of heading error at full scale. Also, the magnitude of the deviation could not be read since no scale was incorporated into heading error display. However, it was felt an exact magnitude of heading error was not necessary if pilots could establish a trend and direction from the indications.

The two LDIs were damped differently also; the left was overly active, while the right was sluggish. This produced different



Figure 19. Lateral Displacement Indicator

magnitudes of error between the two displays and was one of the most distracting features of the displays. Reliance on these displays for absolute tracking performance in relation to runway centerline was not possible for the above reasons.

A lateral displacement display should be incorporated with the pilot's instrument displays in the form of a command instrument to depict proper runway alignment and command information to runway centerline. Also, trend information (departure rate from centerline) should be depicted to allow for corrections back to centerline. The pilot must be presented actual position, trend and command back to centerline to adequately control lateral deviations on short final. At present, this information is not available for an instrument approach. It is believed error information could be better presented as moving runway symbology.

Vertical Velocity - Absolute Altitude Indicator:

This display was located to the right of the ADI and consisted of both augmented vertical velocity and radar height. The index for the display was located on a line horizontal through the center of the ADI. This configuration provided a desirable cross-check reference for vertical velocities and an appropriate index to view closure with the runway.

The conceptual design of augmented vertical velocity included accelerometric and vertical gyro inputs for anticipatory terms and static pressure for stability. These terms were mixed in the flight path angle (FPA) computer for display on a triangular pointer moving with relation to a fixed scale. The parameter lacked the needed reliability for consistent interpretation and use by project pilots. They felt the conceptual philosophy had extreme merit, but needed better mechanization for pilot acceptance.

In most cases the parameter was unstable, consistently indicated erroneously, or was stuck at some random position. In dual installations the parameters very seldom indicated equal values or moved at the same rate. Project pilots felt these discrepancies must be corrected and a change incorporated in the display principles before optimum use of the instrument can be obtained.

Radar height was presented as a white tape along the right side of the display. The tape unstowed at 1000 feet absolute altitude and

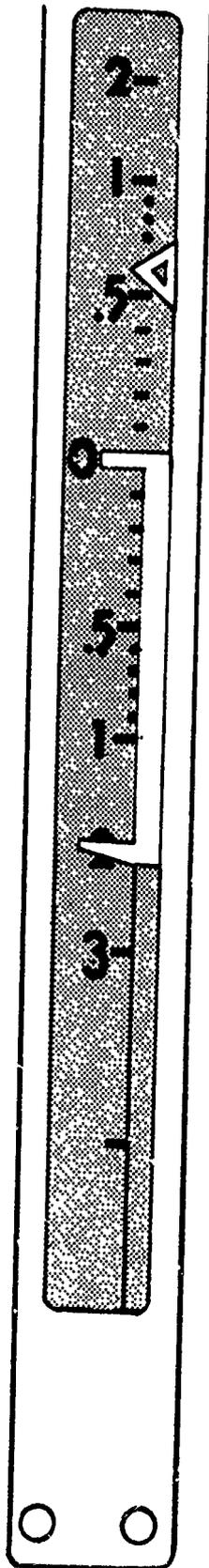


Figure 20. Vertical Velocity-Absolute
Altitude Indicator

began moving towards the index at a height of 240 feet. As the aircraft descends, the area of white tape exposed is reduced by the tape moving upward giving the pilot a visual sensation of descent. Since the only scale was for augmented vertical velocity, unfamiliar pilots were confused when trying to determine radar height from the tape.

It is believed the instrument could better aid the pilot if augmented vertical velocity was presented on a color coded tape -- blue with white numerals for climbs and brown with white numerals for descents. Radar height could be presented in the same manner with respect to a scale along the right side of the tape. The movement and dynamics of the tape should remain relatively the same as project pilots found these items most distinctive and natural. Consideration should be directed toward finishing instrument cases with a crinkle grey paint to prevent the distracting contrast of the black case on the grey instrument panel.

Flight Path Angle:

Flight Path Angle was included as a display element in the form of a moving tape on the left side of the ADI. This parameter used IAS and h' (vertical velocity) to present an aircraft's flight path through the air mass with relation to the horizontal. The tape is color coded -- grey with black numbers for positive angles and black with white numbers for negative angles -- for easy interpretation. The numbers are approximately one-quarter inch apart for ease of reading.

Flight path angle mode selection was included for presenting FPA on the pitch steering bar. This allowed project pilots to select the desired FPA within the limits of ± 25 degrees and the pitch steering bar displays the angle when centered. If desired, the pitch axis of the autopilot could be coupled to the FPA displayed.

Flight Path Angle was also used as the basic flare reference for the test aircraft. At 100 feet absolute altitude, glide slope signal fading began and was replaced with FPA signals so at 50 feet the pitch steering bar displayed a negative 2.5 FPA. At 50 feet radar altitude the barometric h' was replaced with radar h' and the flare maneuver to a minus one degree FPA established. This maneuver produced a one-step flare with indications seen on the pitch steering as a fly up indication, the FPA tape would change from -2.5 to -1.0 degrees, and the flare annunciation would appear on the Approach Sequence Indicator (ASI). If coupled in the pitch axis automatic

rotation to flare attitude occurred.

Project pilots felt the one-step flare produced a much more desirable indication than an exponential display. The indications were easy to interpret and the flyability of the pitch steering bar was excellent throughout the flare maneuver. Project pilots felt the exponential flare presentation would be undesirable since it would be difficult to interpret and would require constant corrections and attention to produce satisfactory results.

The FPA system uses inputs from indicated airspeed (IAS) and an altitude rate sensor for its normal indications. Radar rate sensing may replace the barometric altitude rate sensor on short final for more accuracy. Using IAS for the horizontal component of FPA causes erroneous indications. A better system should be developed. It is recommended that a CADC be used to produce clean parameters for the vertical and horizontal terms. During approach modes, radar supplies the needed vertical term. The horizontal term should be supplied through inertial, DME, or Doppler means to provide an accurate display. The tape should be color coded brown and blue to match the coding of the attitude sphere. It is suggested the tape be moved from the ADI to a vertical tape and a readout window be used in conjunction with a command indication for slewing and monitoring. In this configuration FPA would be used as desired throughout the flight profile.

Automatic Throttle System:

Project pilots found the auto-throttle system to be extremely unburdening and expressed the unanimous opinion that auto-throttles should be standard equipment for any low approach or landing system. The configuration in the test aircraft maintained 1.3 Vs until passing the flare initiation height of 50 feet. Radar was used at 50 feet as the tripping function to establish a new speed reference of 1.2 Vs during the flare and touchdown.

The auto-throttles could be activated by a switch located on the forward center instrument panel adjacent to the autopilot engaging switches. The system could be deactivated by the same switch, overpowering the throttles, pressing the auto-throttle disengage switch on the right throttle, or pressing the autopilot disengage switch on either pilot's control wheel.

The system consists of a computer, two amplifiers, interfacing and two actuators. The inputs into the system consist of angle of attack signals summed from left and right conical probes, a normal accelerometer and two actuators. The inputs into the computer consisted of summed and averaged angle of attack signals, normal acceleration and elevator position. The angle of attack signal is the primary control function with the normal accelerometer providing a damping function. The elevator position signal was used to provide angle of attack change anticipation.

Project pilots found that they were able to completely eliminate power instruments from their cross-check. They were aware of throttle movement since their hand was on the throttles and could determine the resulting performance of the auto-throttle system from the airspeed and angle of attack display. When the system was first installed, throttle movement was extremely sensitive causing RPM changes from 60 to 95 percent to maintain 1.3 Vs in light turbulence. Desensitizing the angle of attack and elevator position signals by approximately 50 percent of their original values resulted in an extremely stable and usable system. Project pilots felt the original system was extremely burdening because of the throttle activity and the need for monitoring. However, after the system was desensitized, RPM changes in the order of \pm five percent were obtained, which resulted in smooth throttle action and airspeed control within \pm 2 knots.

The angle of attack display was calibrated in units which went from zero to thirty. The approach angle of attack, which corresponded to 1.3 Vs, was approximately 14 units and this approach index was positioned at the 3 o'clock position on the dial. Indices were also included to correspond to maximum range, endurance lift/drag, buffet and stall. Project pilots felt the unit's scale was not meaningful. Pilots should be presented meaningful angle of attack displays which depict the performance of their aircraft with respect to total performance capability aircraft.

The most meaningful display seems to be the normalized scale which presents to the pilots the percentage of lift being used on a scale from 0 to 100 percent. This depiction presents information on the lift being used with relation to lift in reserve. Project pilots felt this type of display would have been more meaningful throughout the entire flight profile.

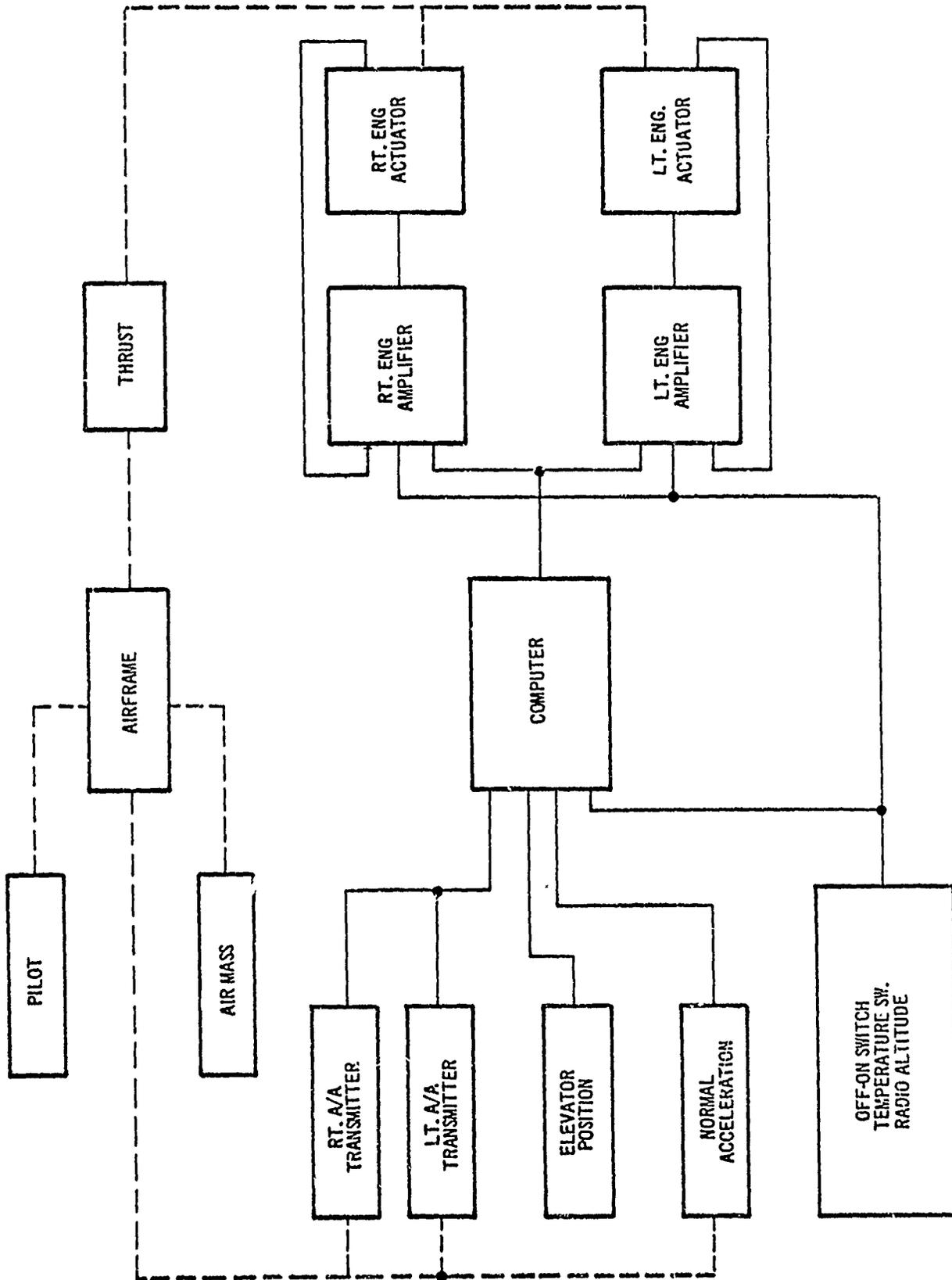


Figure 21. Automatic Throttle System

APPENDIX C
AIRCREW AND AIRCRAFT CRITERIA

AIRCREW AND AIRCRAFT CRITERIA

The nature of the Landing Weather Minimums Investigation demands certain aircrew and aircraft limitations that will ascertain flight safety throughout the mission profile. The following is established to define aircrew and aircraft acceptable performance criteria during weather approaches:

1. The pilot flying the aircraft understands he is committed to land the aircraft after passing middle marker. He is mentally/physically prepared to fly instruments to touchdown, throughout rollout and takeoff. The only deviation from this procedure will be as previously stated in the test plan under Cockpit Procedures and Voice Terminology.
2. Pilots flying weather will conduct at least their first approach with full automatic assistance. Other levels of automatic assistance will be used at the discretion of the crew after the first approach.
3. An immediate initial action is necessary if any malfunction occurs after passing the middle marker. The initial action will be a missed approach. Further approaches may be executed if the crew's analysis determines flight safety is not compromised in any manner.
4. The following criteria will be used by pilots to define tracking limitations on final approach:
 - a. Outer marker to middle marker
 - G/S -- 0.50 dot
 - LOC -- 0.25 dot
 - A/S -- \pm 3 knots
 - b. Middle marker to touchdown
 - G/S -- 0.25 dot
 - LOC -- 0.50 CDI width
 - LSI -- Captured to touchdown
 - A/S -- \pm 3 knots
 - c. Maximum crosswind component -- 5 knots

APPENDIX D
T-39 FLIGHT PROCEDURES

LANDING

WEATHER

MINL MS

INVESTIGATION

T-39 FLIGHT PROCEDURES

USAF INSTRUMENT PILOT INSTRUCTOR SCHOOL
Randolph AFB, Texas

LANDING WEATHER MINIMUMS INVESTIGATION

T-39 FLIGHT PROCEDURES

AIRCREW PROCEDURES

1. Each flight during this investigation will consist of a minimum crew of three fully-qualified project pilots. A flight test engineer will be aboard the aircraft whenever possible, serving in the capacity of systems advisor. Each crew member will accomplish sufficient training at his position so each task will be instinctive and natural. Practice approaches, including emergency procedures, will be performed at the test site prior to actual weather flying. A human factors specialist (Bunker-Ramo Corp) will also accompany the crew whenever possible to help formulate and control data resulting from the project flying.

2. Aircrew procedures are established herein as the result of experience gained during the pre-experimental flying phase. Whether the aircraft commander should perform as a "heads-down" pilot during the approach and landing remains a matter of diverse opinion. The format established here is a test; as experience is gathered, different combinations of control and monitor tasks will be investigated.

NOTE: For this test, the heads-down pilot will normally be in the left seat, heads-up pilot in the right seat.

a. Head-down pilot's tasks and responsibilities:

- (1) Crew and aircraft safety.
- (2) Remain heads down during the approach and landing phase, flying manually or in conjunction with the automatic flight control system. Integration of control tasks will be determined by the aircraft commander.
- (3) Landing or go-around decision.
- (4) Perform emergency procedures as required.
- (5) Aircraft, Automatic Flight Control System configurations and Flight Director Mode selection.

(6) Maintains aircraft control (heads down) during rollout and takeoff after landing.

(7) Executes go-around if:

(a) Commanded by heads up or third pilot.

(b) An emergency occurs.

(c) ILS flight path limits are exceeded.

(d) Radar flight path limits are exceeded.

(e) A system failure occurs.

b. Head-up pilot's tasks and responsibilities:

(1) Crew and aircraft safety.

(2) Perform emergency procedures as required.

(3) Operate measurement and recording equipment.

(4) Monitor AFCS's control and flight path performance to a designated altitude (normally 150 ft above ground).

(5) Perform heads up function at designated altitude (normally 150 ft above the ground).

(6) Manually fly aircraft heads down when directed.

(7) Assume control of all axes and execute an immediate go-around if:

(a) Commanded by the heads down pilot.

(b) An emergency occurs.

(8) Assumes control of the aircraft when sufficient visual cues are available to effect a safe landing. This condition would be implemented under controlled conditions when ground visual segments are adequate for see-to-land.

(9) Touch-up control axes during the landing and rollout phases (if necessary) at times when the heads-down pilot is flying the aircraft. These corrections would be made subsequent to visual cue verification that an unacceptable path excursion is taking place.

(10) Radio calls.

(11) Execute inflight project equipment checklist.

c. Third Pilot's tasks and responsibilities:

(1) Monitor all functions being performed by the pilots and AFCS.

(2) Read aircraft and project equipment checklists.

(3) Monitor tape recorder and oscillograph for proper operation.

(4) Assist heads-up pilot in recording and evaluating visual cues obtained from outside the aircraft.

(5) Monitor engine and flight instruments.

(6) Call approaching 400', 400', approaching 300', 300' (absolute altitude obtained from radar altimeter).

(7) Command go-around if:

(a) ILS or radar flight path limitations are exceeded.

(b) An emergency occurs.

(c) A system failure occurs.

d. General:

(1) All pilots will record visual cues on tape giving absolute altitude and nature of cue.

(2) Any abnormality will immediately be brought to the attention of the other pilots.

AIRCRAFT CONFIGURATION

1. Fuel--The fuel load will provide two (2) hours local flight time with sufficient reserve to reach a suitable alternate.
2. Airspeed--ILS pattern 180 kts; final approach 1.3Vs.
3. Flaps--100% for all approaches except single engine, 66%.
4. Complete Landing Checklist prior to glide slope interception.
5. Type landing will be determined by the aircraft commander.

COCKPIT PROCEDURES AND VOICE TERMINOLOGY

1. Downwind:
 - a. Heads-down pilot will:
 - (1) Fly aircraft.
 - (2) Perform FDC and AFCS mode changes.
 - (3) Perform radio calls.
 - b. Heads-up pilot will:
 - (1) Accomplish inflight project equipment checklist.
 - (2) Record pertinent data from last approach and landing on tape recorder.
 - c. Third pilot will:
 - (1) Read aircraft checklist and assure that tape recorder and oscillograph are operational.
 - (2) Prepare 16mm camera slate for next approach.
 - (3) Prepare third pilot card for next approach.
 - (4) Monitor instruments and AFCS.

2. Base to Outer Marker:

a. Heads-down pilot will:

- (1) Accomplish Before Landing checklist.
- (2) Fly aircraft in conjunction with AFCS.
- (3) Perform mode and coupling changes.
- (4) Hold slate in front of 16mm camera (inflight checklist).

b. Heads-up pilot will:

- (1) Complete inflight project equipment checklist.
- (2) Perform radio calls.
- (3) Monitor localizer intercept maneuver.

c. Third pilot will:

- (1) Read aircraft checklist.
- (2) Monitor engine and flight instruments.

3. Outer Marker to Touchdown:

a. Heads-down pilot will:

- (1) Fly aircraft with AFCS or manually.
- (2) Make landing or go-around decision; predicated on instrument displayed information.
- (3) Perform emergency procedures.
- (4) Execute go-around if:
 - (a) Commanded by heads-up or third pilot.
 - (b) ILS flight path limits are exceeded.

(c) Radar flight path limits are exceeded.

(d) An emergency occurs.

(e) A system failure occurs.

b. Heads-up pilot will:

(1) Operate camera, oscillograph and tape recorder.

(2) Monitor AFCS's performance.

(3) Come heads up at 150 ft AA.

(4) Make go-around decision, if required. This action would be predicated on visual cue verification.

(5) Uses following terminology:

(a) CUE -- Heads-up pilot has some portion of approach lighting or runway in view.

(b) LATERAL -- Heads-up pilot has sufficient cues to control aircraft laterally.

(c) VISUAL -- Heads-up pilot has sufficient visual cues to land aircraft.

(d) GO-AROUND -- Directs heads-down pilot to execute missed approach.

(e) I HAVE THE AIRCRAFT -- Heads-up pilot assumes control of all axes.

c. Third pilot will:

(1) Monitor engine and flight instruments.

(2) Log appropriate entries on third pilot card.

(3) Call approaching 400', 400', approaching 300', 300' radar altitude.

(4) Monitor sequence indicator, i. e., final, 100', flare lights. Call any lights which do not trip.

(5) Observe visual cues from outside the aircraft. This information will be recorded prior to commencing the next approach (see #2).

(6) Command a go-around if:

- (a) ILS flight path limits are exceeded.
- (b) Radar flight path limits are exceeded.
- (c) An emergency occurs.
- (d) A system failure occurs.

4. Touchdown:

a. Heads-down pilot controls aircraft in conjunction with AFCS.

b. Heads-up pilot will touch-up control axes as required, or assume control of the aircraft if an unacceptable excursion is taking place. Sufficient visual cues must be available prior to commencing a transfer of control authority.

5. Rollout:

a. Heads-down pilot controls aircraft in conjunction with AFCS.

b. Heads-up pilot will:

(1) Touch-up control axes as required, or assume control of the aircraft if an unacceptable excursion is taking place. Sufficient visual cues must be available prior to commencing a transfer of control authority.

(2) Execute project equipment checklist.

(3) Call for touch-and-go condition.

(4) Configure aircraft for takeoff (flaps, trim, etc).

6. Takeoff from touch-and-go:

a. Heads-down pilot will fly aircraft manually or in conjunction with AFCS.

b. Heads-up pilot will monitor touch-and-go progress visually until cues are obscured then monitor flight instruments.

c. Third pilot will:

(1) Monitor engine and flight instruments.

(2) Ascertain that camera switches and tape recorder are turned off.

(3) Read checklist as required.

(4) Monitor aircraft performance.

7. Missed approach procedures:

a. Heads-down pilot will fly aircraft manually or in conjunction with AFCS.

b. Heads-up pilot will:

(1) Monitor flight instruments.

(2) Perform radio calls.

c. Third pilot will:

(1) Monitor engine and flight instruments.

(2) Read aircraft checklist as required.

(3) Ascertain that camera switches are turned off.

APPENDIX E

WAIVERS

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR TRAINING COMMAND
Randolph Air Force Base, Texas 78148

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Reply to

Attn of: ATOOS-O

20 July 1967

Subject: Request for Deviation from AFM 60-16 (Randolph (VCR) Ltr, 16 Jun 67)

To: Randolph

Request contained in referenced letter is approved. The provisions of paragraphs 8-4b, 8-6a, 8-9 and 8-15, AFM 60-16, are waived for instrument flights in support of the landing minimums investigation. Waiver applies to project aircraft and to the designated project pilots of the IPIS, Instrument Evaluation Branch.

FOR THE COMMANDER

(signed)

ROBERT D. CURTIS, Colonel, USAF
Acting DCS/Operations

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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Washington, D. C. 20590

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In Reply
Refer to: RD-322

Department of the Air Force
USAF Instrument Pilot Instructor
School (ATC)
Randolph Air Force Base, Texas 78148

Attention: Colin J. N. Chauret, Colonel, USAF; Commander

Dear Colonel Chauret:

We have been discussing the proposal outlined in your June 30, 1967 letter regarding the in-flight research program at selected Category II civilian airports with the various FAA Services and airport authorities. At this time, we can report that your request has been favorably received. There are, however, additional negotiations required before a firm commitment can be made. We hope this can be achieved by the week of August 21, 1967, and reported to your staff during the discussions to be held here that week. We would like to confirm our request for your staff to make a presentation of your low weather minima films here during the same week.

With regard to the legal technicalities regarding your proposed in-flight research program, the following information has been supplied by the FAA Flight Standards Operations Division.

"There are no applicable Federal Aviation Regulations (except Part 159 'National Capitol Airports') from which a waiver or exemption is necessary for the operations proposed. The Category II rules of Parts 61 and 91 apply only to civil aircraft; military aircraft operations are not affected by those rules.

Section 91.117 governs other landing and takeoff weather minimums. However, the paragraphs of the section pertinent to takeoff and landing

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do not apply to military aircraft. Section 91.117(c), 'Landing minimums', does not apply to 'military aircraft of the United States'. Section 91.117(d), 'Civil Airport takeoff minimums', does not apply to aircraft other than those operating under the civil air carrier rules of Parts 121, 129, or 135. Section 91.117(h), 'Descent below landing minimums', applies to the 'applicable minimum landing altitude'. Since no minimum landing altitude is applicable to military aircraft of the United States under paragraph (c), this paragraph would not apply to your proposed aircraft operations."

Additionally, development of air traffic procedures will be required by the Air Traffic Control Service for your mission. We will coordinate this and the negotiations with the various airport authorities prior to the meeting of August 21, 1967.

Sincerely yours,

(signed David J. Shaftel)

Alexander B. Winick, Chief
Navigation Development Division
Systems Research and
Development Service

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APPENDIX F
TEST SUPPORT REQUIREMENTS

LANDING

WEATHER

MINIMUMS

INVESTIGATION

TEST SUPPORT REQUIREMENTS

USAF INSTRUMENT PILOT INSTRUCTOR SCHOOL
Randolph AFB, Texas

LANDING WEATHER MINIMUMS INVESTIGATION

APPROACH CONTROL/GCA DATA INSTRUCTIONS

1. Transmit latest record weather observation prior to the aircraft passing over the Outer Marker.
2. Notify the pilot to execute a missed approach if the aircraft exceeds the PAR safety limits (not applicable at civil airfields unless PAR is available).
3. Notify the weather observer (representative observation site) when the flight crew calls touchdown or missed approach.