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Flight Evaluation of STOL Flare and Landing During Night Operations

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NOTATION

$d\gamma/du$	change of flightpath angle with airspeed for constant thrust
EADI	electronic attitude director indicator
F_c	column force
GW	gross weight
HSI	horizontal situation indicator
$\dot{h}_{TD}$	touchdown sink rate
IFR	instrument flight rules
MFD	multifunction display
m	aircraft mass
N_H	high-pressure engine rotor rpm
T_R	roll mode time constant
T_S	spiral mode time constant
$t_{0.5\Delta\gamma_{max}}$	time to 50% of the peak flightpath response to a step change in throttle
VFR	visual flight rules
V_{c_0}	initial calibrated airspeed
w	perturbation vertical velocity
X_{TD}	touchdown distance from runway threshold
Z_w	vertical velocity damping, $\frac{1}{m}\,\partial Z/\partial w$
$(\Delta u_{ss}/\Delta\gamma_{ss})_{\Delta T}$	ratio of change of steady-state airspeed to flightpath due to a change in thrust (constant pitch attitude)
$\Delta u_{ss}/\Delta\theta_{ss}$	ratio of change of steady-state airspeed to pitch attitude (constant thrust)
$\Delta\beta/\Delta\phi$	ratio of peak sideslip to peak bank angle occurring during a turn entry maneuver
$(\Delta\gamma_{max}/\Delta\gamma_{ss})_{\Delta T}$	ratio of peak to steady-state change of flightpath angle due to a change in thrust (constant pitch attitude)

$\Delta\gamma_{max}/\Delta\theta_{ss}$	peak change in flightpath angle in response to a step change in pitch attitude
$\Delta\gamma_{ss}/\Delta\theta_{ss}$	ratio of change of steady-state flightpath angle to pitch attitude
δ_f	flap position
δ_w	wheel position
ζ_d,ω_d	damping ratio and natural frequency of the Dutch roll mode
ζ_{sp},ω_{sp}	damping ratio and natural frequency of the short period mode
$\dot{\theta}$	pitch rate
θ_{max}/θ_{ss}	ratio of peak to steady-state change in pitch attitude
ν	nozzle position
$\dot{\phi}$	roll rate
ϕ_{max}/ϕ_{ss}	ratio of peak to steady-state change in bank angle
ω_E	natural frequency of the engine dynamic response to throttle

SUMMARY

Flight experiments have been conducted with the Augmentor Wing Research Aircraft to evaluate flying qualities for the STOL flare and landing during night operations. The experiments were carried out at Ames Research Center's experimental flight facility at the Crows Landing Naval Airfield using a baseline lighting configuration comparable to that of Transport Canada Ottawa-Montreal STOL Demonstration Project. Simulated instrument approaches were made to Category I minimums followed by a visual landing on a 100 x 1700 ft STOL runway. Data was obtained for variations in the aircraft's flare response characteristics and control techniques and for different combinations of aircraft and runway lighting and a visual approach slope indication.

With the complete aircraft and runway lighting and visual guidance as used in the Transport Canada Program, no degradation in flying qualities or landing performance was observed compared to daylight operations. Elimination of the touchdown zone floodlights or the aircraft landing lights led to somewhat greater pilot workload; however the landing could still be accomplished successfully. Loss of both touchdown zone and aircraft landing lights led to a high workload situation and only a marginally adequate to inadequate landing capability

INTRODUCTION

A substantial amount of flight experience has been obtained concerning the factors that influence control of the flare and landing for STOL aircraft. Flight research programs at the Ames Research Center with the Augmentor Wing and Quiet Short Haul Research Aircraft (refs. 1-5), at Princeton University with the variable stability Navion (refs. 6,7) and by Systems Technology, Inc. using this aircraft (ref. 8), have provided considerable information about the characteristics of flightpath response to a powered-lift STOL aircraft's thrust and pitch attitude controls and the extent to which these characteristics influence control of the landing flare. A good deal of experience has also been obtained from specific operational and prototype STOL aircraft such as the de Havilland DHC-6 Twin Otter and Dash 7 aircraft, the Breguet 941, the Boeing YC-14 and the McDonnell-Douglas YC-15 STOL transports. Most of this information from the research and operational programs has been obtained during day VFR or simulated IFR landing approaches to a specified decision height followed by a visual flare and touchdown. Only the Twin Otter, Dash 7, and Breguet 941 have had exposure to night operations. The Twin Otter was involved in the Transport Canada Ottawa-Montreal STOL Demonstration Project to determine the technical, operational, and regulatory requirements and operational feasibility of an intercity STOL air transportation system. A number of observations and recommendations came out of this program, including airfield facilities and operational criteria (ref. 9) and the projects pilots' impressions of the operational aspects of the program (ref. 10). Dash 7 exposure to night operations has accumulated in conjunction with its air carrier operations, and the Breguet 941 was briefly evaluated during a U.S. Air Force program conducted in 1963.

With this experience as a background and, specifically, considering the design criteria developed for control of the flare and landing during day operations, it was of interest to determine the extent that night operations and airfield lighting configurations might influence these design criteria. Consequently, flight experiments were conducted on the Augmentor Wing Research Aircraft to evaluate the flare characteristics of selected flightpath control configurations during daylight and night conditions and to determine the effect of variations in the runway lighting arrangement and visual approach slope guidance. The flightpath response configurations were selected from previous experimental programs to include those which use either pitch attitude or thrust as the primary flare control and which encompass flare response characteristics that were assessed to range from fully satisfactory to marginally adequate during day landings by the project evaluation pilots.

This report describes the night landing experiments, including the research aircraft and airfield facilities, and presents the results of the pilots' evaluations of the effects on the flare and landing of the various lighting conditions.

DESCRIPTION OF THE FLIGHT EXPERIMENT

Research Aircraft

The flight experiments conducted during this research program were performed with the NASA Ames Research Center's Augmentor Wing Research Aircraft. This aircraft, as shown in figure 1, is a de Havilland C-8A Buffalo, modified to incorporate a propulsive lift system by The Boeing Company, de Havilland of Canada, and Rolls Royce of Canada. In this program, capabilities for altering its basic lift and drag characteristics, as described in reference 1, were used to represent selected configurations for evaluation of flare control characteristics. Pitch, roll, and yaw stabilization and command augmentation were also provided to insure satisfactory attitude control for these experiments. Cockpit displays and other instrumentation described in reference 1 were also included. For night operation, external landing lights and cockpit interior lights were added to the aircraft; three 250 watt scaled-beam lights were attached to the aircraft's main landing gear and nose gear as shown in figure 2.

Airfield Facility

Approach and landing operations were conducted at Ames Research Center's experimental flight facility at the Crows Landing Naval Airfield. A STOL runway is laid out on the surface of runway 35 as shown in figure 3. This runway has dimensions of 30 x 518m (100 x 1700 ft), and is located about half way along the length of the main runway.

For night operations, this runway was lighted as shown in figure 4. This arrangement was intended to represent that used in reference 9 and did so to a major extent. White runway edge lights of 30 watts power lined the length of the runway. Green touchdown zone edge lights of 204 watts intensity extended for the length of the touchdown zone, which was 92m (300 ft) in this instance instead of 61m (200 ft) as used in the daylight landings of reference 1. In addition, the touchdown zone was floodlit by 500 watt lamps, spaced 15m (50 ft) apart, 6.1m (20 ft) from the edge of the runway. The photograph in figure 4b shows the complete lighting arrangement although the quality of the picture is insufficient to show the extent to which the floodlights illuminate the touchdown zone. In fact, the entire zone from runway centerline to both edges was fully lighted.

Photographs and detailed drawings of the individual light elements are shown in figures 5 and 6. For this experiment, their installation was intended to be portable. As a consequence, they all were mounted on wooden frame footings and were restrained by sandbags to prevent them from being displaced by the aircraft's wake. The drawings illustrate the permanent design installation used in reference 9.

Measurements were made of the intensity of illumination of the touchdown zone. Readings were obtained from a Pritchard Photometer (Model 1970-PR) located 1.45m (4.75 ft) above the runway surface and aimed at the runway at a depression angle of 16 degrees. Figure 7 shows the locations of the aim points at which the photometer readings were taken and presents a tabulation of these values.

Precision electronic landing guidance was provided by a prototype microwave system (MODILS). A Fresnel Lens Optical Landing System was used for visual guidance to the glide slope during the final segment of the approach below decision height and during the initiation of the flare. This device is shown in figure 8 and is described in detail in reference 11. It gives an indication of deviation from an optical glide slope using a light source focussed through the Fresnel lens and referenced to a horizontal datum bar of green lights as shown in figure 4b. For this experiment, the optical glide slope was offset from the 7.5 degree MODILS glide slope by a vertical distance corresponding to the pilot's eye position in the cockpit with the aircraft in its nominal landing attitude so that the visual and electronic indications of glide slope deviation were in agreement. The runway intercept points for the MODILS and optical glide slopes are indicated in figures 3 and 4.

For this experiment, data was obtained through tape recording on board the aircraft and telemetry of a pulse code-modulated (PCM) data stream. The airborne data included aircraft attitudes, angular rates, linear acceleration data, approach path deviations, engine performance, control positions, and digital control system discrete and computed variables. Ground-based three axis, radar tracking data was merged with that obtained from telemetry and recorded for post flight analysis of approach path tracking and landing performance.

Experiment Matrix

Flare control configurations were adopted from references 1 and 2 and represented extremes of variations in the pilots' assessments of flare control with pitch attitude and thrust from those programs. Their essential characteristics are reviewed in table 1. They include (A) the basic Augmentor Wing Aircraft (config. 11 from ref. 1) that utilizes pitch rotation as the primary control, with assistance as required from thrust; (B) a configuration from reference 2 that augments flightpath response to pitch to the extent that pitch alone is used for the flare; (C) a configuration with inadequate path response to pitch that requires that thrust be the primary flare control (config. 14 from ref. 1); and (D) a configuration similar to (C) but with quickened path response to throttle. They were first reassessed in daylight operations to confirm the pilots'original judgments. Then, all four were evaluated under night conditions with all runway lighting elements and the Fresnel lens guidance turned on. Following this series of landings, configurations A and D were evaluated with the floodlights off, and configuration A was assessed with landing lights off, the Fresnel lens off, and both floodlights and landing lights off. Landings were not performed with degraded lighting for configuration C, whose characteristics were only marginally adequate under the best lighting conditions

DISCUSSION OF RESULTS

Review of Daylight Landing Characteristics

Before night operations were initiated, each of the experimental configurations were re-evaluated under daylight conditions to familiarize the pilots with their flare characteristics and to establish a baseline from which to assess the influence of night operations and the aircraft and airfield lighting conditions. Following the familiarization flights, both pilots concurred with the ratings that were given to these configurations during the landing evaluations of references 1 and 2. As noted in table 2, configuration A (config 11, ref 1) was considered to have adequate flare capability when pitch rotation is used as the primary control to modulate the flare and thrust is used as required for gross sink rate corrections at flare entry and to prevent floating out of the touchdown zone. Pilot ratings ranged from 3-1/2 to 5 in this case. Configuration B with augmented heave response (ref. 2) could be flared with pitch control alone and was considered to have fully satisfactory flare capability. Pilot ratings for this configuration were 2 to 3. For configuration C (config 14, ref 1) which had inadequate heave response to pitch, the flare was performed primarily with thrust. Because of the relatively sluggish flightpath response to the throttles associated with low vertical velocity damping (Z_w = -0.21 sec^{-1}) and somewhat slow engine acceleration characteristics (ω_E= 2.7 rad/sec), the flare capability with thrust was considered to be just adequate and was rated from 5 to 6 by the pilots. When the effective engine response was quickened substantially (ω_E= 10.4 rad/sec) for configuration D, the flare capability was considered to be clearly adequate or even marginally satisfactory and was given ratings from 3 to 4-1/2.

Effect of Night Lighting Conditions

Full lighting configuration - With the complete aircraft and airfield lighting configuration described in the previous section, the pilots considered the flare and landing capability for all four flightpath response configurations to be the same or only slightly degraded in comparison to daylight operations. At the most, pilot B's ratings changed only by one-half rating unit. The floodlit landing zone used in this program, provided cues for judgement of sink rate and touchdown point that were equivalent to those available in daylight. In some cases the pilots were more conscious of the touchdown zone than during daylight conditions. Runway surface detail was discernible prior to flare initiation and depth perception was considered to be good. The aircraft landing lights illuminated the dark runway surface ahead of the touchdown zone and provided some indication of the visual aim point for flare initiation.

Flare profiles for configuration A are shown in figure 9 that offer a comparison of day and night operations with complete runways and aircraft lighting available. Considering the sink rate profiles in figure 9a, the character of the flare is quite similar for day and night conditions, particularly the altitude for flare initiation and the amount of sink rate arrestment. The use of pitch rotation for flare control is nearly identical as well and, as illustrated in figure 9b, the rotation from flare initiation to touchdown is steady with no apparent oscillatory tendencies. Some control with thrust, coordinated with the pitch rotation, may be noted in figure 9c, and is consistent with the flare technique used for this configuration in reference 1. A comparison of landing performance, presented in figure 10 shows similar touchdown point and sink rate dispersions for day and night conditions. The difference in mean sink rates is not considered to be significant and any difference is most likely due to the absence of turbulence during night operations. The fact that the mean touchdown point was well within the touchdown zone for the night landings, as compared to somewhat longer daylight landings is considered to be a consequence of the incentive to land within the lighted area, the enhanced definition of the touchdown zone provided by the floodlights, and the lack of a well defined visual aim point for the daylight landings. Consequently, it should be possible to reduce or eliminate this difference by providing a compelling visual aim point on the runway for daylight landings.

For configuration B, landing flare profiles presented in figure 11 also show comparable behavior for day and night landings. The flare commences with a pitch rotation at altitudes from 40 to 50 feet and a gentle rotation is carried to the point of touchdown. Because the aircraft's heave response to pitch is quickened and follows the pitch rotation well in the long term, quite precise sink rate control can be achieved with this configuration. Limited touchdown performance data were obtained for night landings with configuration B and are shown in figure 12. These data fall within the range of results for touchdown distance and sink rate that were obtained during daylight operations and corroborate the pilots' impressions that fully satisfactory landing performance can be achieved with this configuration.

Profiles for configuration C are presented in figure 13. Flare initiation appears to occur at similar altitudes at night as in daylight, when the full lighting array is available. The same vigorous use of thrust is also evident is both cases. Although landing performance data for night operations are not sufficient for statistical significance, the results, shown for comparison in figure 14, as well as the pilots' impressions of precision of flare control indicate that acceptable landing performance can be achieved.

Results from landings with configuration D show similar characteristics of flare control to those of configuration A for both day and night landings. Figure 15 illustrates the flare profiles for night operations and presents a few examples from day landings as well. Sink rate profiles are comparable for day and night conditions and, referring to figure 9a, to those for configuration A during night landings. Thrust control is similar for the day and night examples shown and it is worth noting that except for the final application of thrust to arrest the sink rate, the magnitude of thrust control activity is considerably less for this configuration with quickened thrust response, particularly compared to configuration C (fig. 13b) that has substantially longer thrust response time to the throttles. Landing performance results are presented in figure 16 and, with the exception of one landing short of the touchdown zone, are comparable to those for configuration A.

Touchdown zone floodlights off - Landings without the touchdown zone floodlights were performed with configurations A and D. While there are nearly as many cues available with the floodlights off as with them on, there is less awareness of the touchdown zone location with these lights off. The landing lights did not illuminate the runway surface until the aircraft descended to about 60 feet above the surface. Although the green edge lights along the touchdown zone are distinctive enough during the approach to the flare, the pilot tends to lose sight of them during the flare as he concentrates on the touchdown point ahead of the aircraft.

The same situation exists regarding the touchdown zone stripes during daylight landings. While the absence of touchdown zone lighting had some adverse effect on the pilots' evaluations of flare control for these two configurations, the degradation was minimal. For configuration A, the change was one-half rating unit or less, for configuration D the decrement was one unit. Although touchdown zone floodlighting was clearly desirable, the landing could be performed adequately for either of these configurations in their absence.

Flare profiles for configuration A are included in figure 17 and, in comparison to the envelope of profiles with the floodlights on (fig. 9), show essentially no difference in sink rate, pitch or thrust control characteristics. While it appears that there may be some tendency to initiate the flare with the pitch rotation at slightly higher altitudes with the flood lights off, the pilots made no specific comments in this regard, and the data available are insufficient to be conclusive on this point. Landing performance data shown in figure 10 are also not statistically significant; however they indicate an ability to make precise landings at low sink rates in the absence of touchdown zone floodlights.

Similar comments may be made for configuration D. Figure 18 shows flare profiles that are quite similar to those obtained with the floodlights on. Again, it appears that the altitude for initiation may have been slightly higher with the floodlights off; however, the primary application of thrust for final sink rate arrestment is still not initiated until altitudes of 20 to 30 feet are reached. Landing performance shown in figure 16 compares well with that for the floodlit touchdown zone.

Aircraft landing lights off - When all the airfield lighting was on and the aircraft landing lights were turned off, the degradation in flare control capability was also minimal. This lighting configuration was evaluated only with configuration A. The pilots missed the runway illumination provided by the landing lights as the aircraft approached the touchdown zone and noted that visual cues for flare initiation were poor until the aircraft was nearly into the zone. Some concern was also expressed about floating beyond the zone without benefit of landing lights to illuminate the runway surface. Thus, aircraft landing lights are clearly preferred and an aircraft would certainly be equipped with them. However, it is reasonable to expect that adequate landing capability could be achieved should the landing lights fail to operate. Pilot ratings degrade only about one-half unit for configuration A under these circumstances.

For the examples of flare control shown in figure 19 for configuration A, sink rate and pitch profiles are comparable to those with the landing lights on that are represented by the crosshatched envelope. Again, a tendency to initiate the maneuver at a slightly higher altitude is suggested by these examples. Limited landing performance results still indicate capability to achieve precise landing performance (fig. 10).

Visual landing guidance off - When the Fresnel lens visual landing aid was turned off, essentially no difference was noted in flare control capability. With the touchdown zone floodlit and landing lights to illuminate the runway approaching the zone, the pilots felt they had adequate visual guidance to the flare after breaking off from MLS guidance prior to flare initiation. Furthermore, with the lens located 116 feet laterally from the runway centerline (66 feet to the side of the STOL runway) and 33 feet before the visual aim point, the pilots tended to lose sight of the glide-slope light and could not make much use of it during the flare. Essentially no difference in pilot rating was found to exist in this case. This is not to say that an optical display of the glide slope is of no value. For conducting an approach under visual conditions or for completion of an instrument approach to landing when visibility is poor below the stated instrument minimums, a ground-based visual display or an on-board, head-up presentation are both acknowledged to be useful in guiding the pilot to the point of flare initiation.

Floodlights and landing lights off - A substantial difference in flare control capability was noted by both pilots when the touchdown zone floodlights and aircraft landing lights were inoperative. Only configuration A was evaluated under these conditions. Perception of height above the runway surface and sink rate were poor and, as a consequence, control of the flare for a precise touchdown position and sink rate was difficult. Both pilots tended to initiate the flare earlier and establish a more gradual descent to the runway. They felt they could land at reasonable sink rates but at the expense of unacceptable touchdown dispersions, at least for the runway dimensions for this program. As a result, flare control was judged to be inadequate for this configuration under these lighting conditions.

The flare control examples shown in figures 20 for configuration A illustrate the gradual flare maneuver the pilots felt compelled to use when the floodlights and landing lights were both off. In this case, sink rate arrestment begins around 75 feet, initiated by pitch rotation and an increment of thrust. The shallow approach is carried until touchdown is assured and is terminated with a final check of sink rate at about 10 feet above the runway. Landing performance reflects this technique and touchdowns at low sink rates well beyond the landing zone may be noted in figure 10.

CONCLUSIONS

Flight experiments have been conducted with the Augmentor Wing Research Aircraft to evaluate flying qualities for the STOL flare and landing during night operations. The experiments were carried out at

Ames Research Center's experimental flight facility at the Crows Landing Naval Airfield using a baseline lighting configuration comparable to that of the Transport Canada Ottawa-Montreal STOL Demonstration Project. Simulated instrument approaches were made to Category I minimums followed by a visual landing on a 100 x 1700 ft STOL runway. Data was obtained for variations in the aircraft's flare response characteristics and control techniques and for different combinations of aircraft and a visual approach slope indication. Aircraft response characteristics ranged from fully satisfactory to marginally adequate flightpath response to either the pitch attitude or thrust controls. Airfield lighting included white edge lights for the length of the STOL runway and green edge lights along the touchdown zone. The touchdown zone could also be floodlit. Visual approach slope indication was provided by a Fresnel Lens Optical Landing System.

For the range of flare response characteristics with the complete airfield and aircraft lighting arrangement, the pilots considered the flare and landing capability to be nearly the same for night as for day operations. Touchdown zone floodlighting and aircraft landing light illumination of the runway surface ahead of the touchdown zone were elements of the lighting arrangement most appreciated. When either the floodlights or landing lights were turned off, the landing could still be accomplished successfully although the pilot's workload was increased somewhat. Without flodlights and aircraft landing lights, the flare capability was considered to be inadequate even for aircraft configurations having good flare response characteristics.

Therefore, it may be concluded that all of the runway lighting elements examined in this program that are not ordinarily incorporated in an airfield lighting array (touchdown zone edge and floodlights and a visual approach slope indicator), are considered to be highly desirable for night STOL landings. Failure of any one of these particular elements or the aircraft landing lights does not prevent adequate STOL landing performance from being achieved; however, this performance might be marginally adequate for poor visibility or runway surface conditions or for aircraft flare response characteristics that are unsatisfactory, although adequate. Failure of both of the important elements (floodlights and landing lights) produces conditions under which adequate landing performance cannot be achieved.

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TABLE 1.- CONTROL CHARACTERISTICS OF EVALUATION CONFIGURATIONS

CONFIG.	RESPONSE TO PITCH				RESPONSE TO THRUST		
	$\frac{\Delta\gamma_{max}}{\Delta\theta_{ss}}$	$\frac{\Delta\gamma_{ss}}{\Delta\theta_{ss}}$	$\frac{d\gamma}{du}$ deg/knot	$\frac{\Delta u_{ss}}{\Delta\theta_{ss}}$ knots/deg	$\left(\frac{\Delta\gamma_{max}}{\Delta\gamma_{ss}}\right)_{\Delta T}$	$t_{0.5\Delta\gamma_{max}}$ sec	$\left(\frac{\Delta u_{ss}}{\Delta\gamma_{ss}}\right)_{\Delta T}$ knots/deg
A CONFIG. 11 REF. 1	0.53	–	0.19	-2.4	1.03	2.5	0.4
B γ-V SCAS REF. 2	1.2	1.2	-1.1	0.55	–	–	–
C CONFIG. 14 REF. 1	0.29	–	0.57	-1.0	1.2	3.8	-0.3
D	0.29	–	0.57	-1.0	1.2	3.0	-0.3

FLIGHT CONDITION

GW = 19,520 kg (43,000 lb)

N_H = 95%

δ_f = 65°

V_{c_o} = 70 knots

ν = 80°

PITCH SCAS RESPONSE

$\frac{\dot{\theta}}{F_c}$ = 0.4 deg/sec/lb

$\frac{\theta_{max}}{\theta_{ss}} = 1.0$

$\zeta_{sp} \doteq 0.7$

$\omega_{sp} \doteq$ 2.2 rad/sec

ROLL-YAW SCAS RESPONSE

$\frac{\dot{\phi}}{\delta_w}$ = 0.33 deg/sec/deg

$\frac{\phi_{max}}{\phi_{ss}} = 1.0$

$\zeta_d = 0.8$

$\frac{1}{T_R} = 2.28\ sec^{-1}$

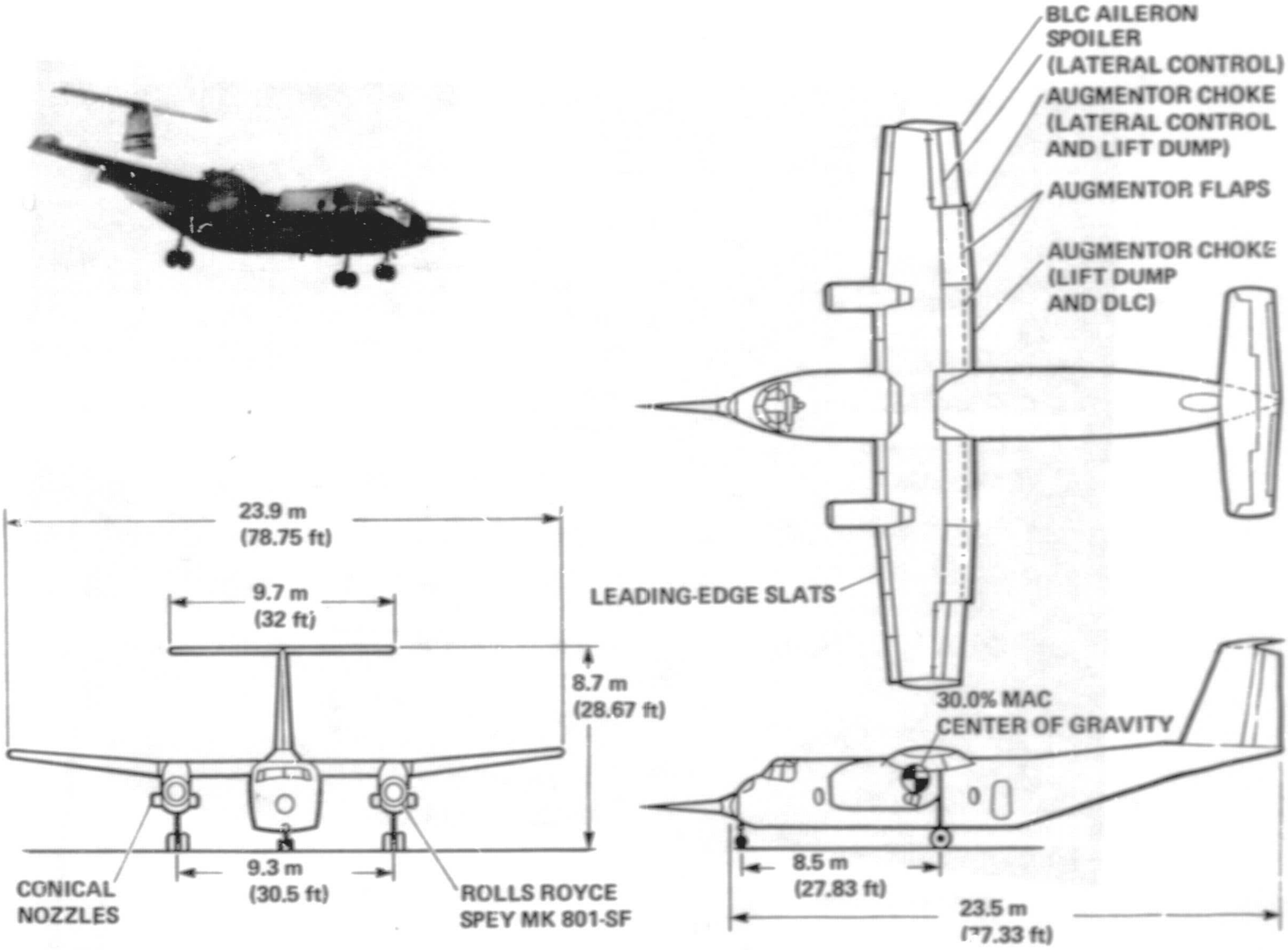
ω_d = 1.54 rad/sec

$\frac{1}{T_S} = 0.55\ sec^{-1}$

$\frac{\Delta\beta}{\Delta\phi} = \leq 0.1$

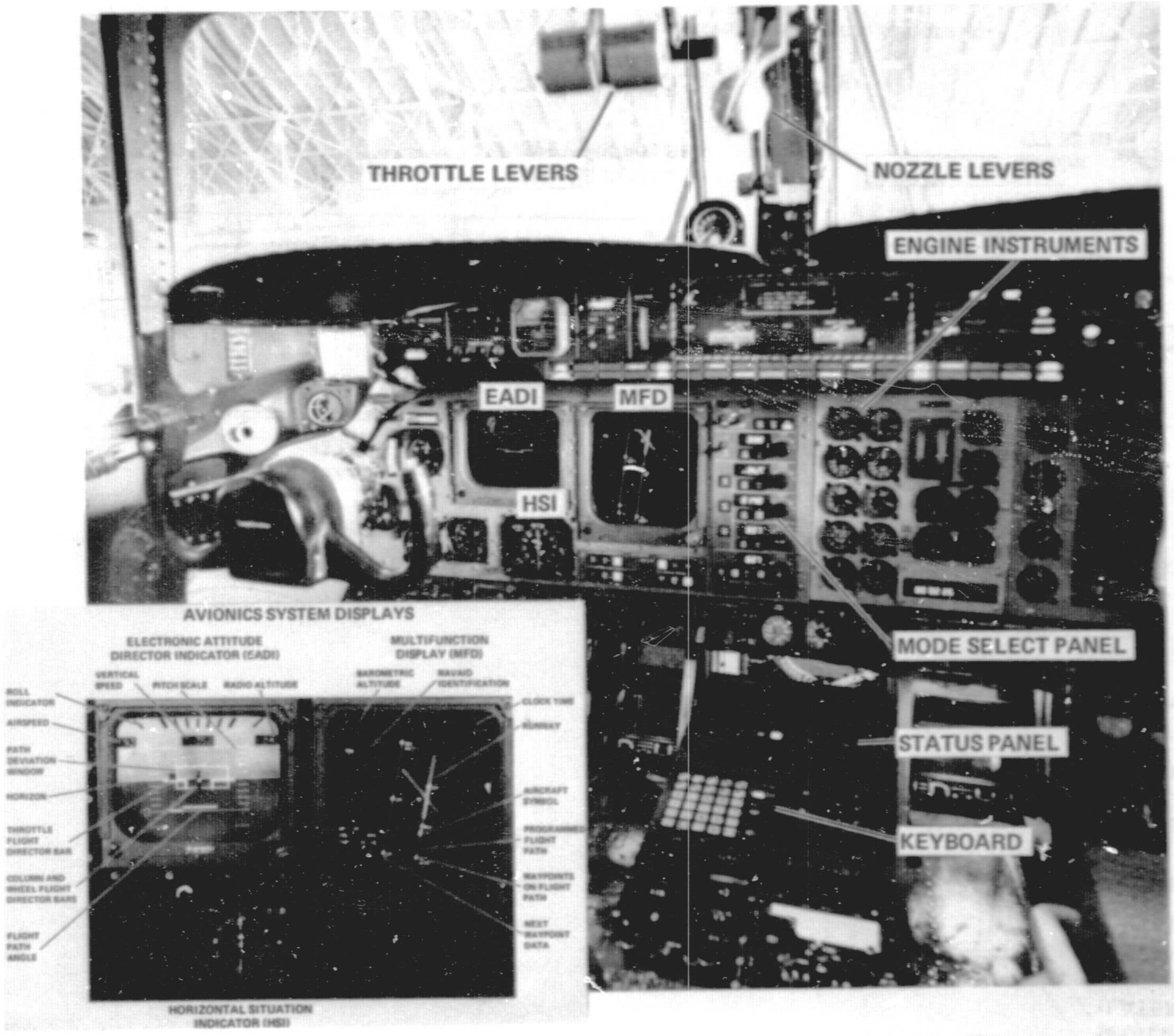
TABLE 2.- SUMMARY OF PILOT RATINGS

FLARE CONTROL CONFIG	FLOODLIGHTS	LANDING LIGHTS	FRESNEL LENS	PILOT RATING	
				A	B
A	DAYLIGHT			3.5	3–3.5
	ON	ON	ON	3.5	3.5–4
	OFF	ON	ON		4–4.5
	ON	OFF	ON		4–4.5
	ON	ON	OFF		3.5–4
	OFF	OFF	ON	INADEQUATE	INADEQUATE
B	DAYLIGHT				3
	ON	ON	ON		3–3.5
C	DAYLIGHT			5.5–6	5
	ON	ON	ON	5.5–6	5–5.5
D	DAYLIGHT			4.5	3–3.5
	ON	ON	ON	4.5	3.5–4
	OFF	ON	ON		4.5–5



(a) Aircraft three view.

Figure 1.- Augmentor Wing Research Aircraft.



(b) Cockpit control and instrument arrangement.

Figure 1.- Concluded.

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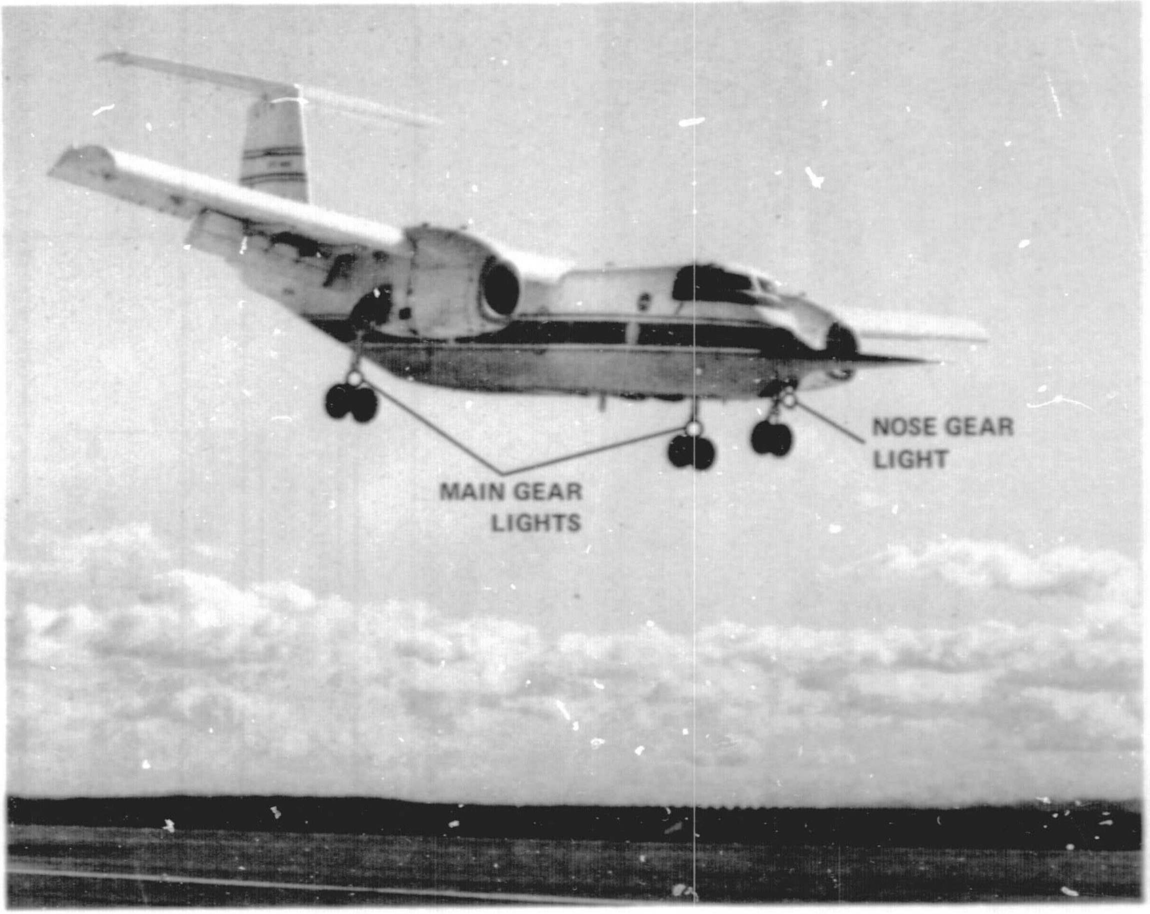


Figure 2.- Augmentor Wing Research Aircraft landing light arrangement.

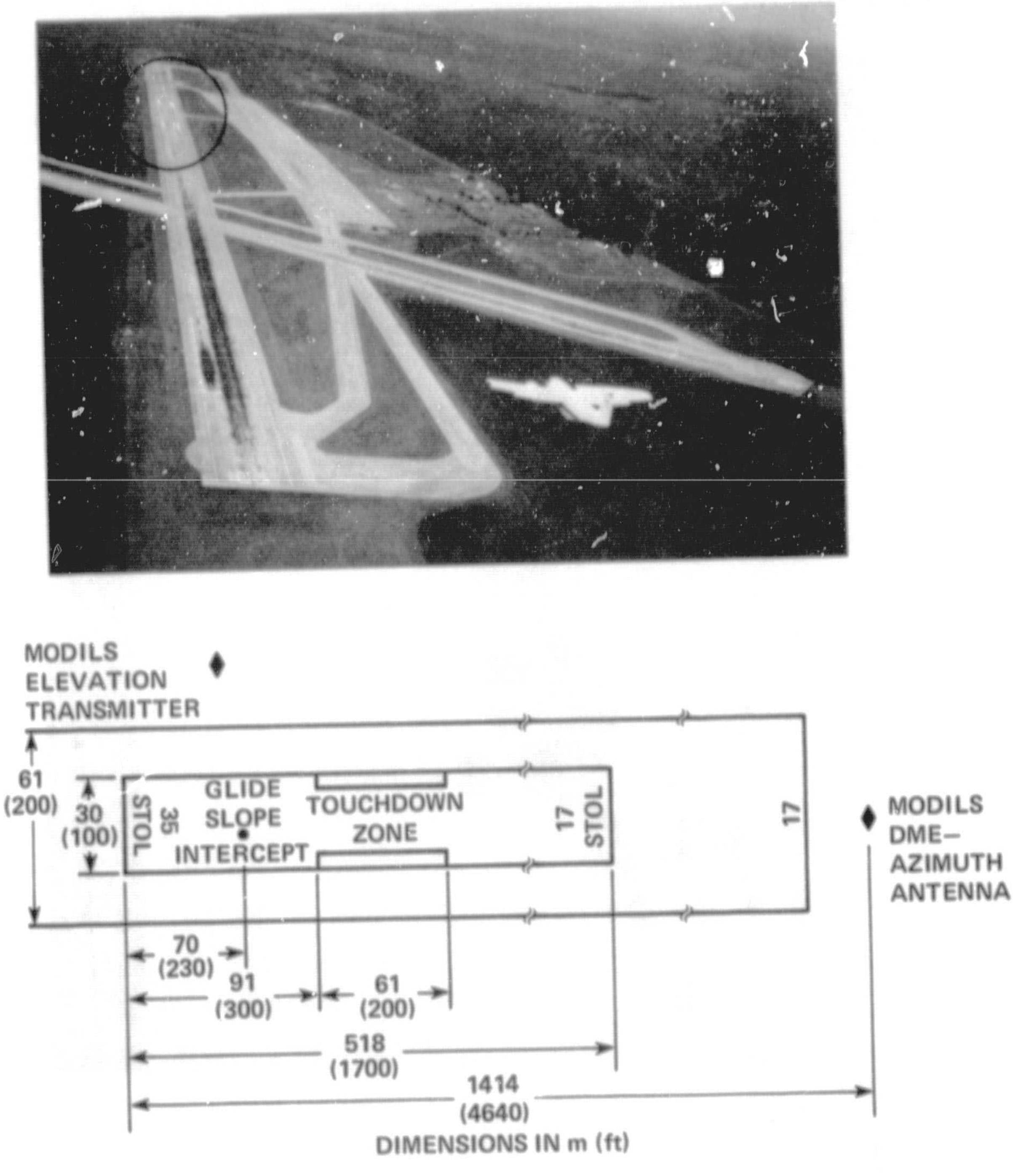
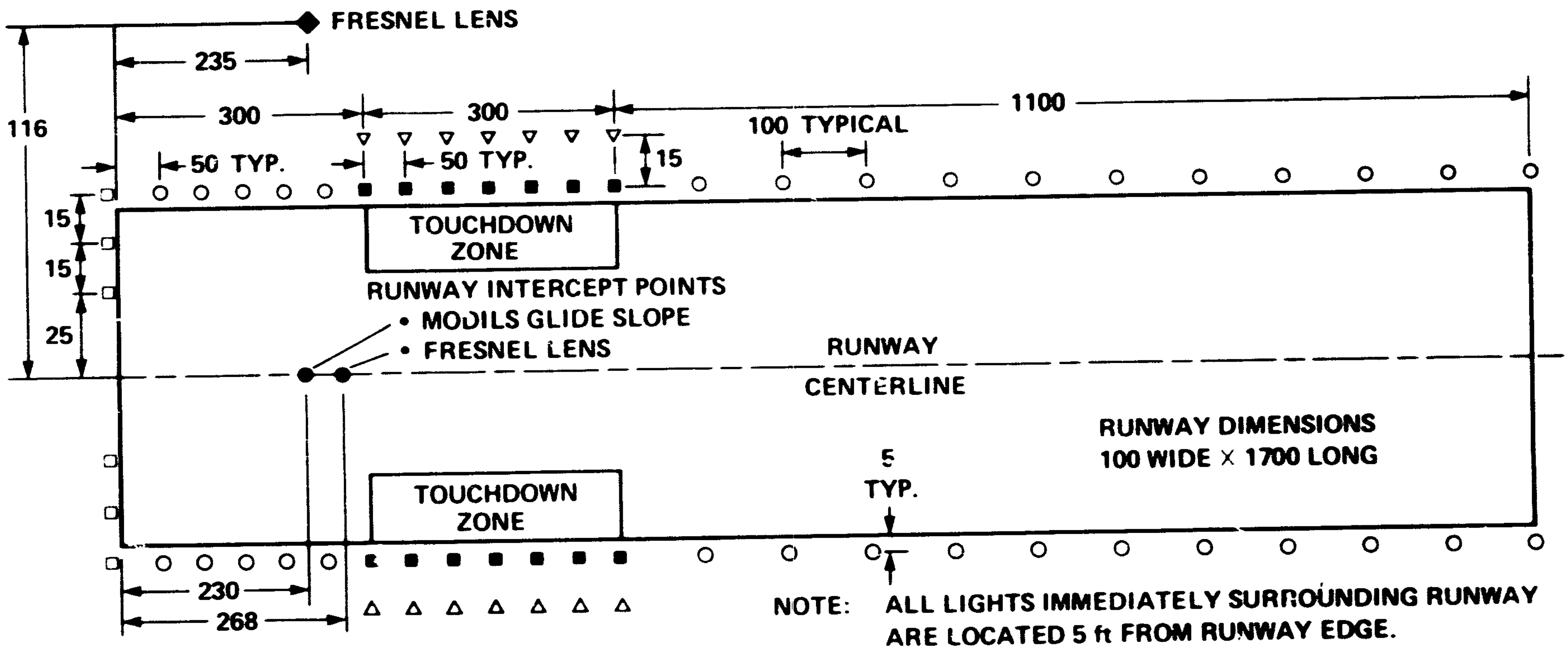


Figure 3.- Crows Landing Flight Research Facility and STOL runway layout.

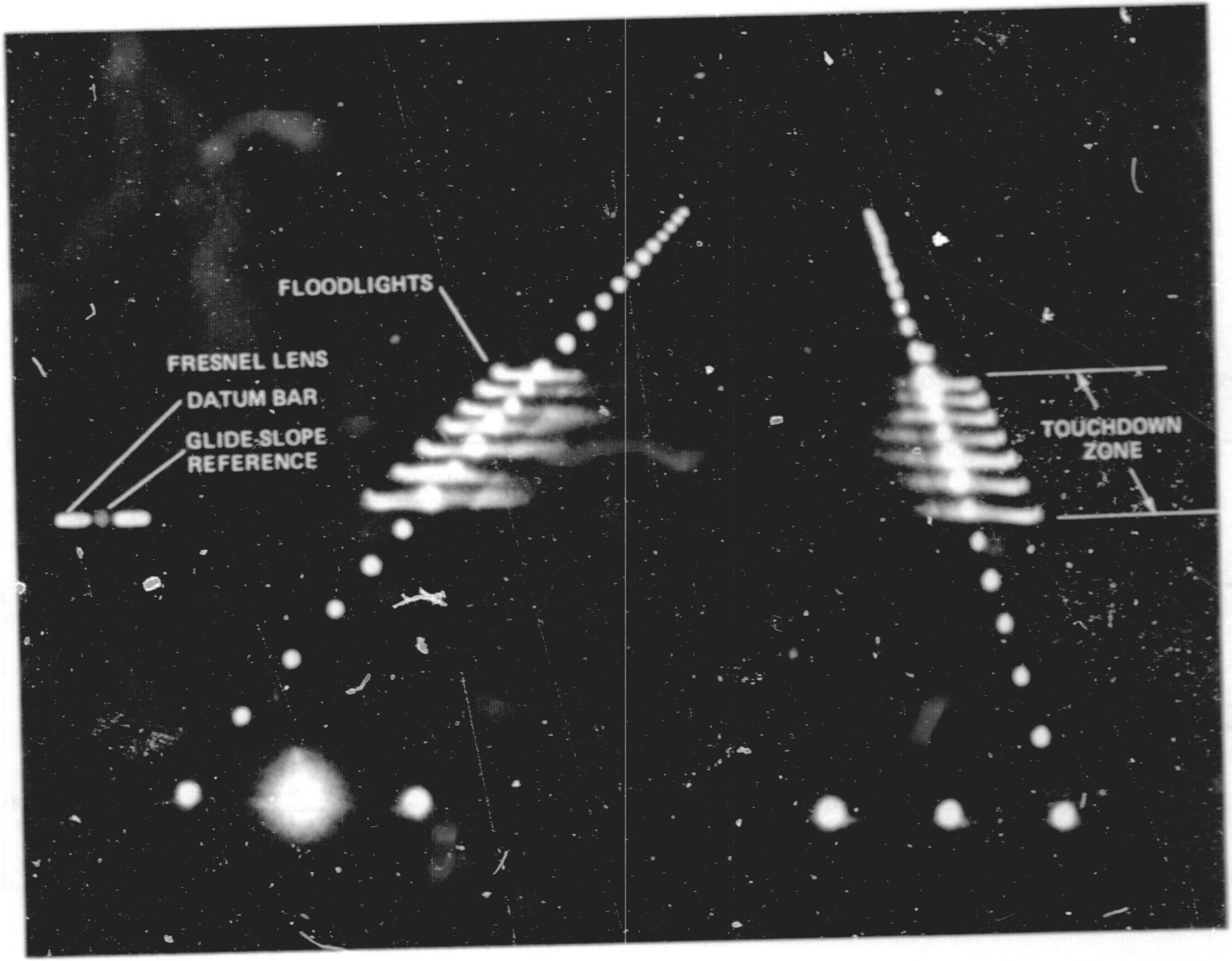


KEY:			
○	MEDIUM INTENSITY	30 WATT LAMP	32 REQUIRED WITH CLEAR LENS
□	HIGH INTENSITY	204 WATT LAMP	6 REQUIRED WITH CLEAR LENS
■	HIGH INTENSITY	204 WATT LAMP	14 REQUIRED WITH GREEN LENS
△	FLOOD LIGHT	500 WATT LAMP	14 REQUIRED

SCALE NOTE: NOT DRAWN TO SCALE
SEE DIMENSIONS AND NOTES
DIMENSIONS IN ft

(a) Lighting diagram.

Figure 4.- Runway lighting arrangement.



(b) Photograph of runway at night.

Figure 4.- Concluded.

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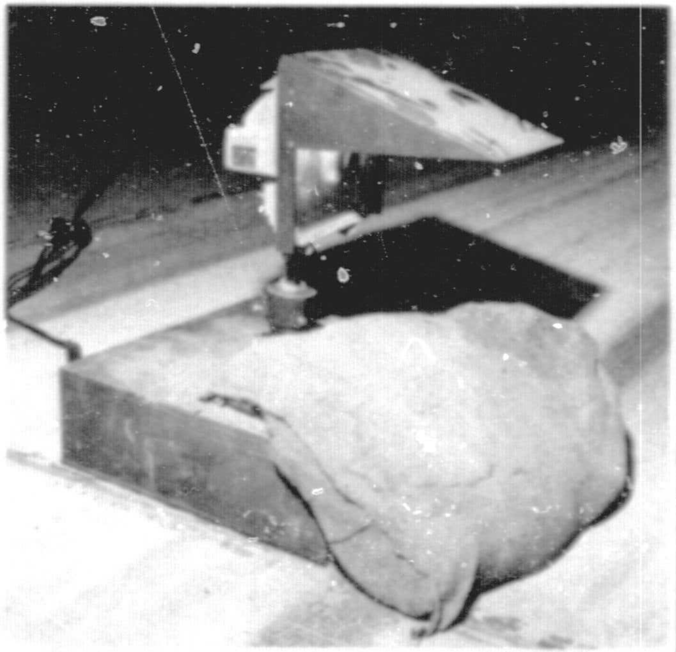


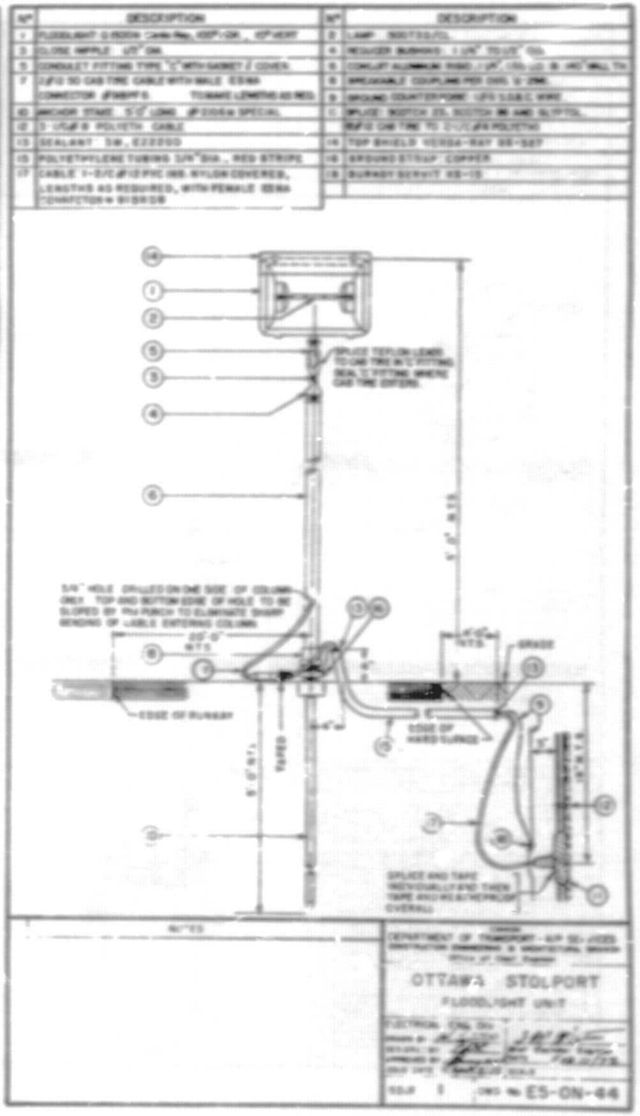
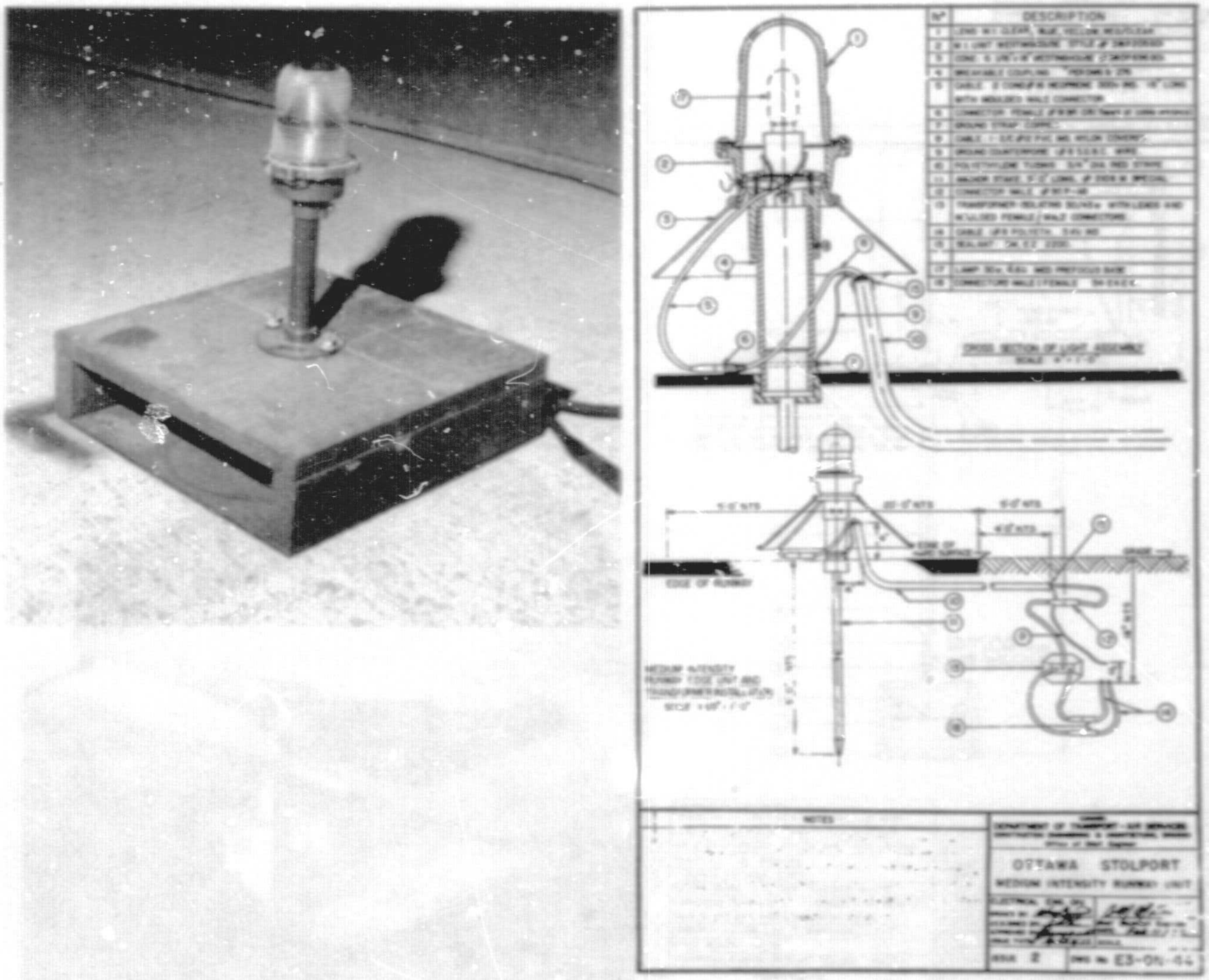
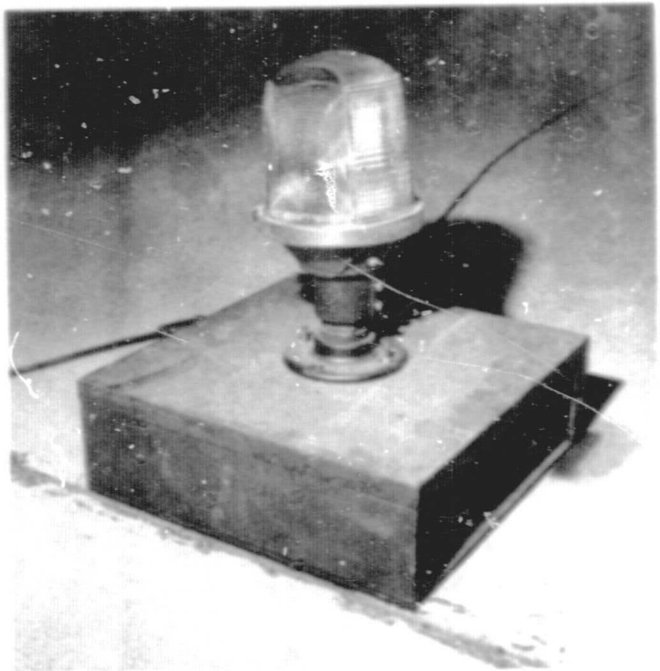


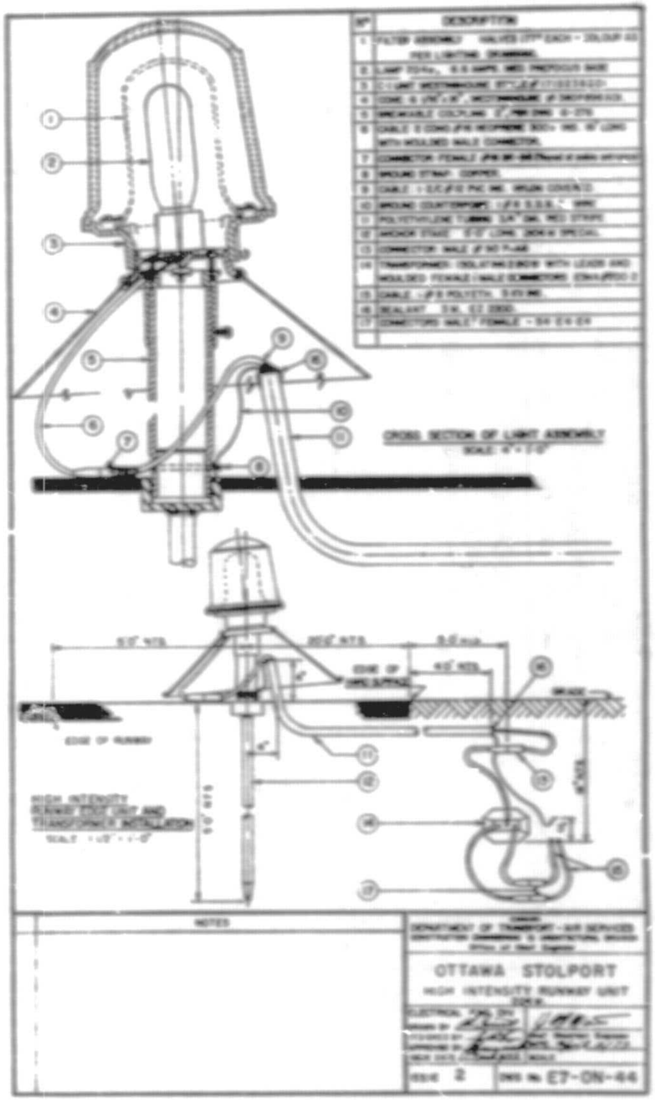
Figure 5.- Touchdown zone floodlight.



(a) 30 watt edge light.

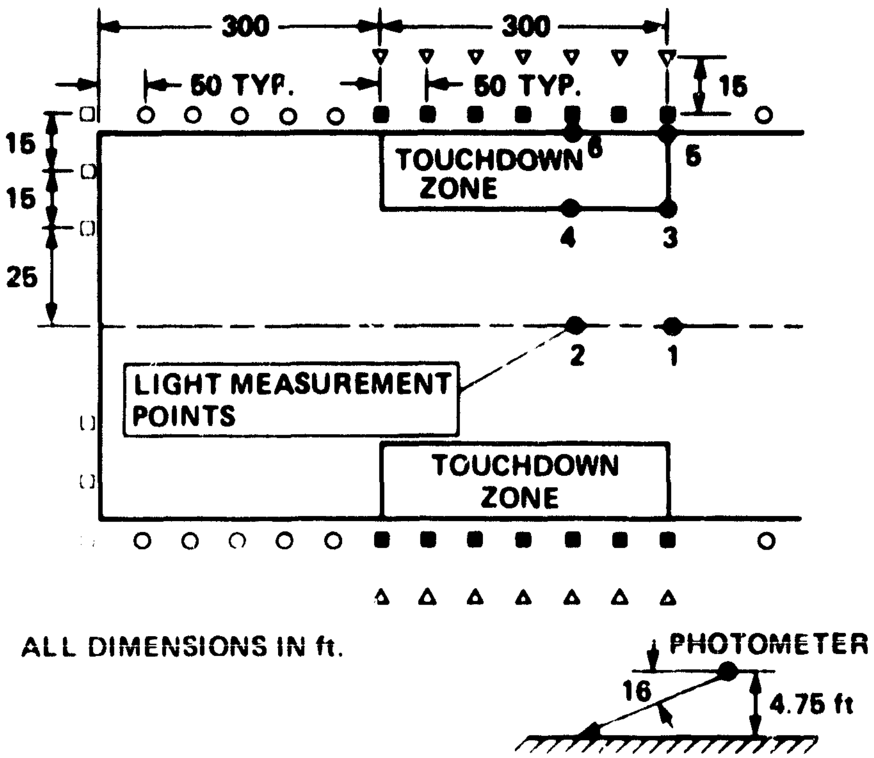
Figure 6.- Runway edge lights.





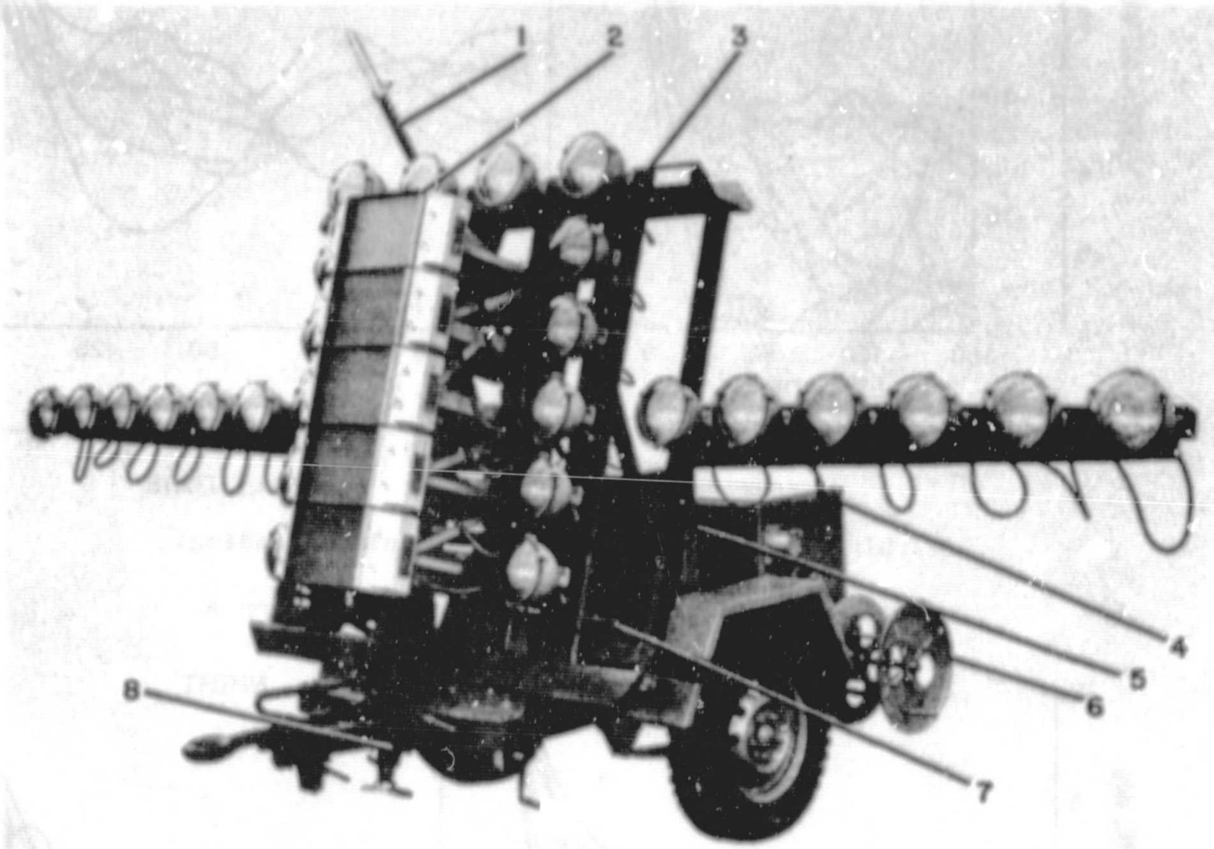
(b) 204 watt touchdown zone edge light.

Figure 6.- Concluded.



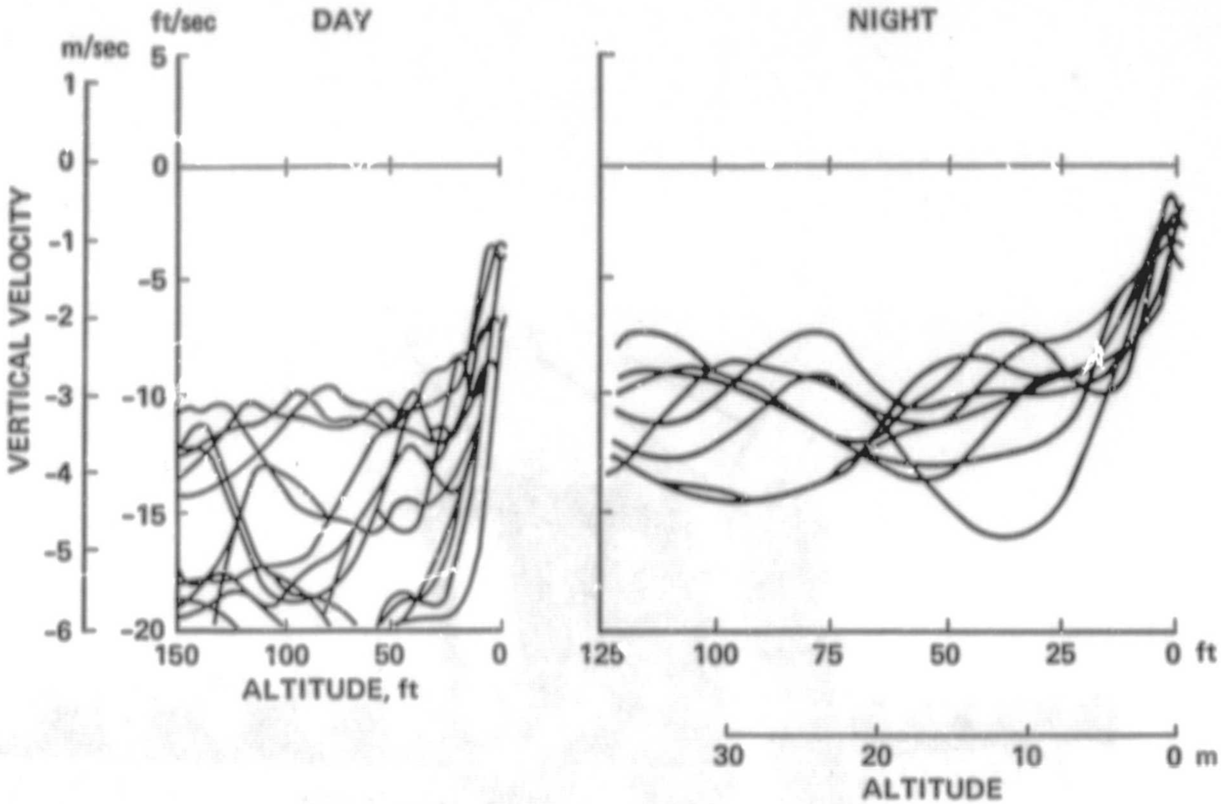
RUNWAY SURFACE LIGHT MEASUREMENT POINT	PHOTOMETER LIGHT MEASUREMENT, ft.-L
1	0.09
2	0.10
3	1.26
4	2.02
5	1.67
6	1.01

Figure 7.- Runway surface illumination measurements.



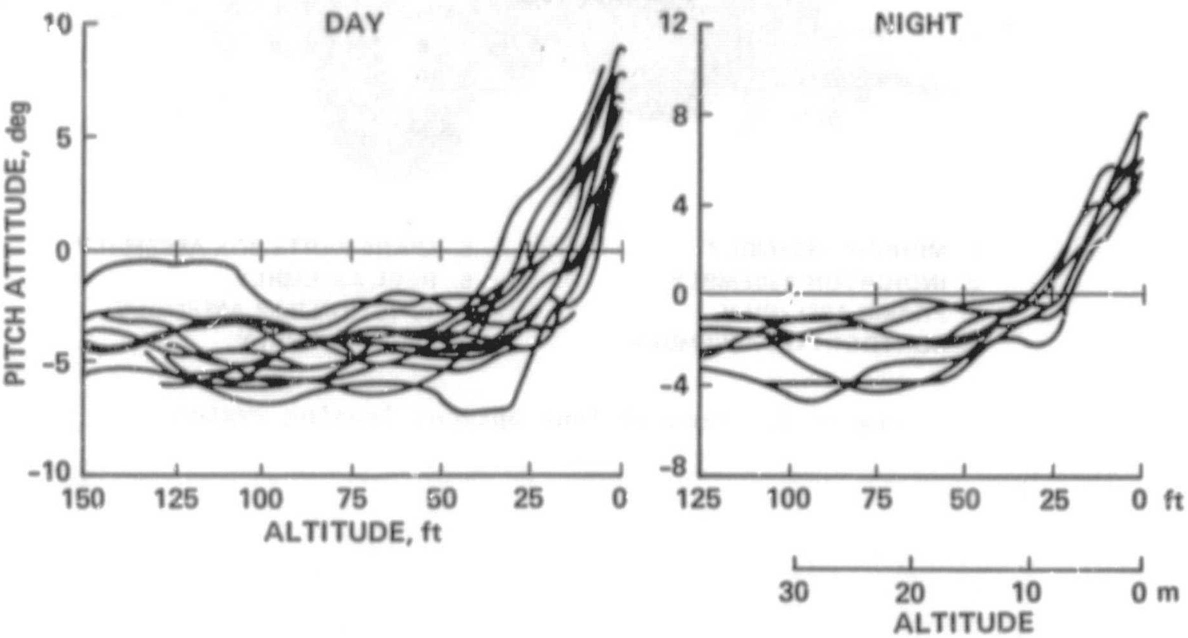
1. MIRROR ASSEMBLY
2. INDICATOR ASSEMBLY
3. FRAME ASSEMBLY
4. CONTROL BOX ASSEMBLY
5. SPARE PARTS BOX ASSEMBLY
6. REEL ASSEMBLY
7. JUNCTION BOX ASSEMBLY
8. JACK ASSEMBLY

Figure 8.- Fresnel lens optical landing system.



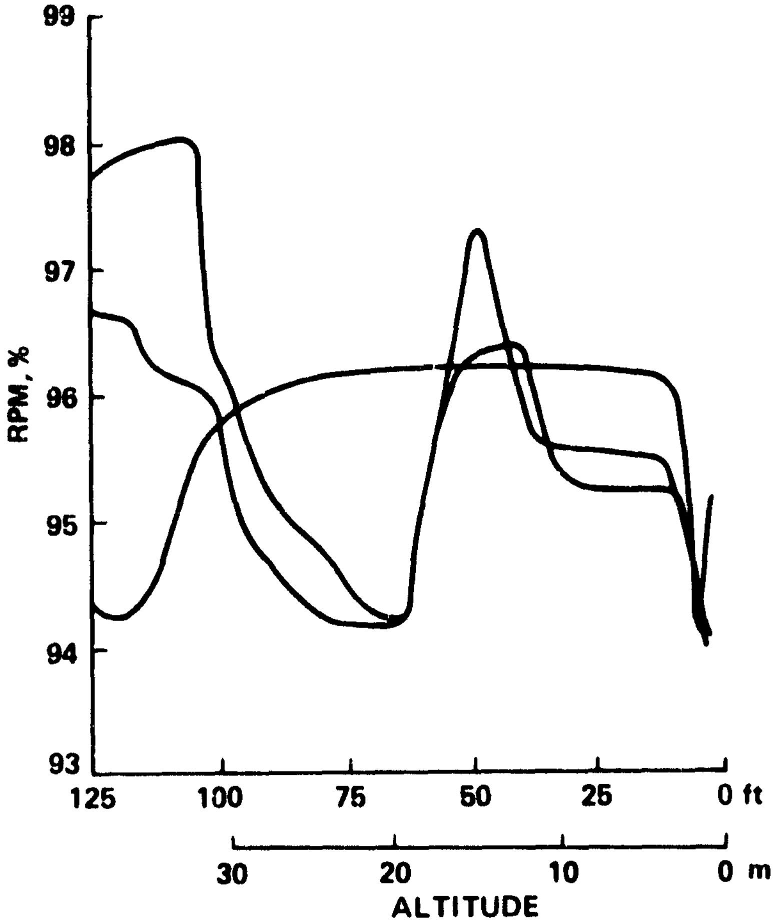
(a) Sink rate profiles for day and night landings.

Figure 9.- Flare profiles for configuration A.



(b) Pitch attitude profiles for day and night landings.

Figure 9.- Continued.



(c) RPM profiles for night landing.

Figure 9.- Concluded.

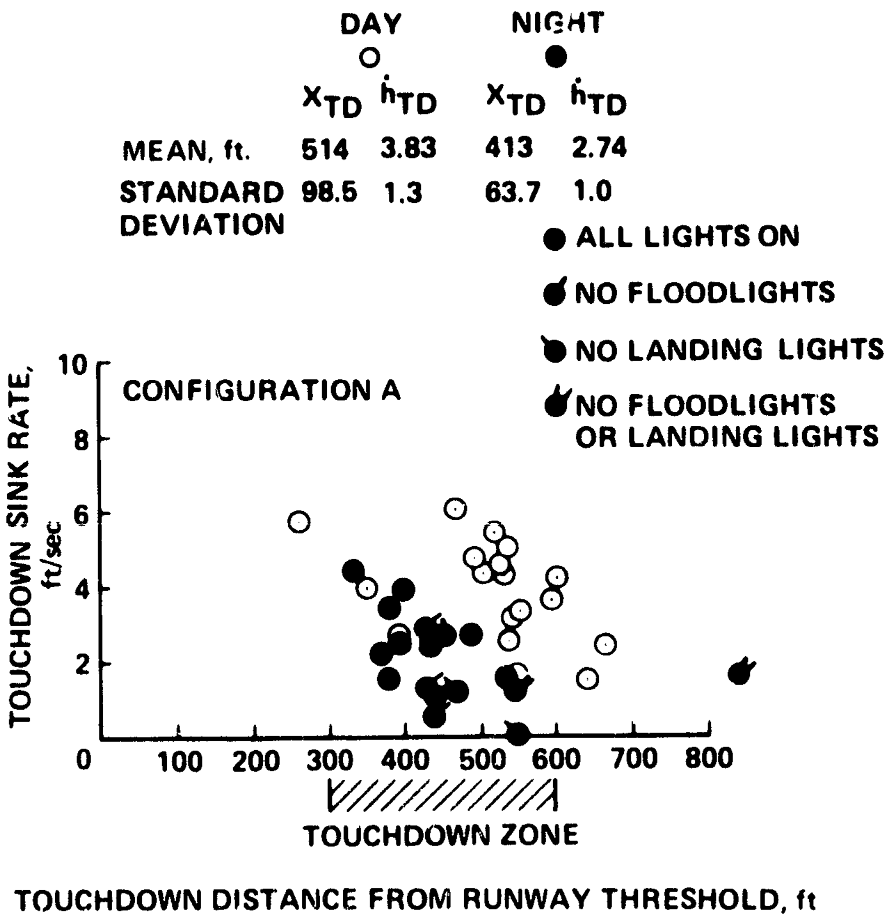
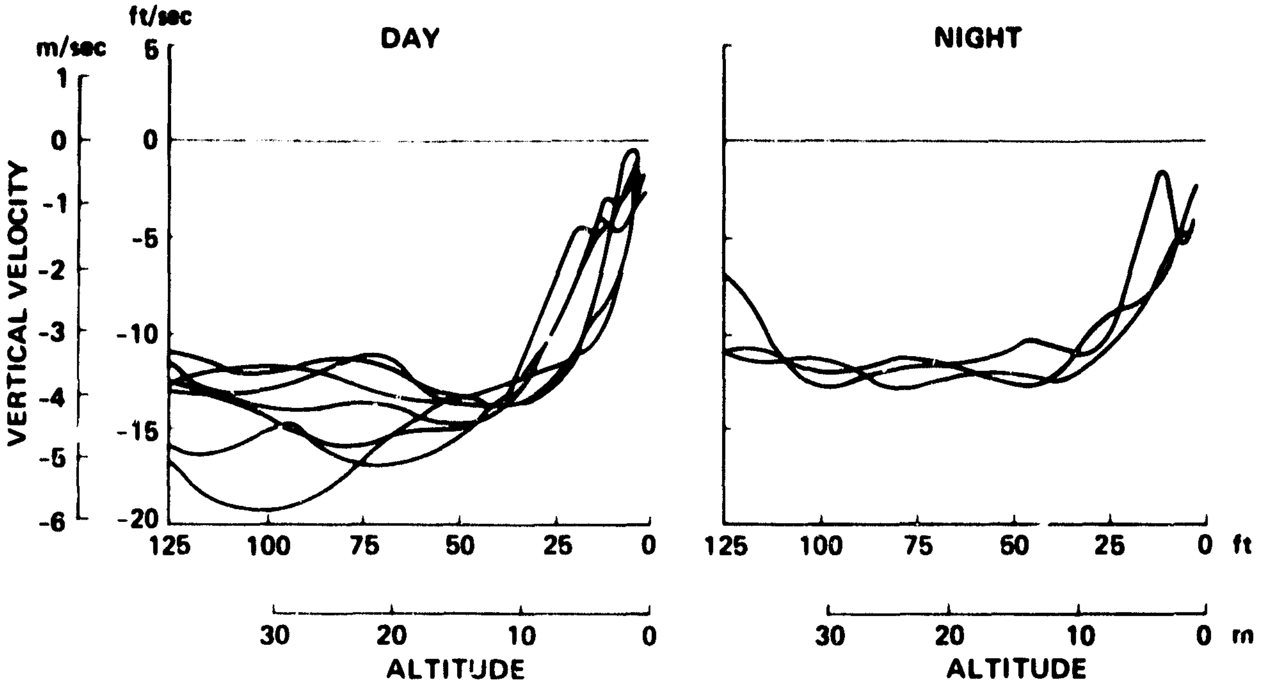
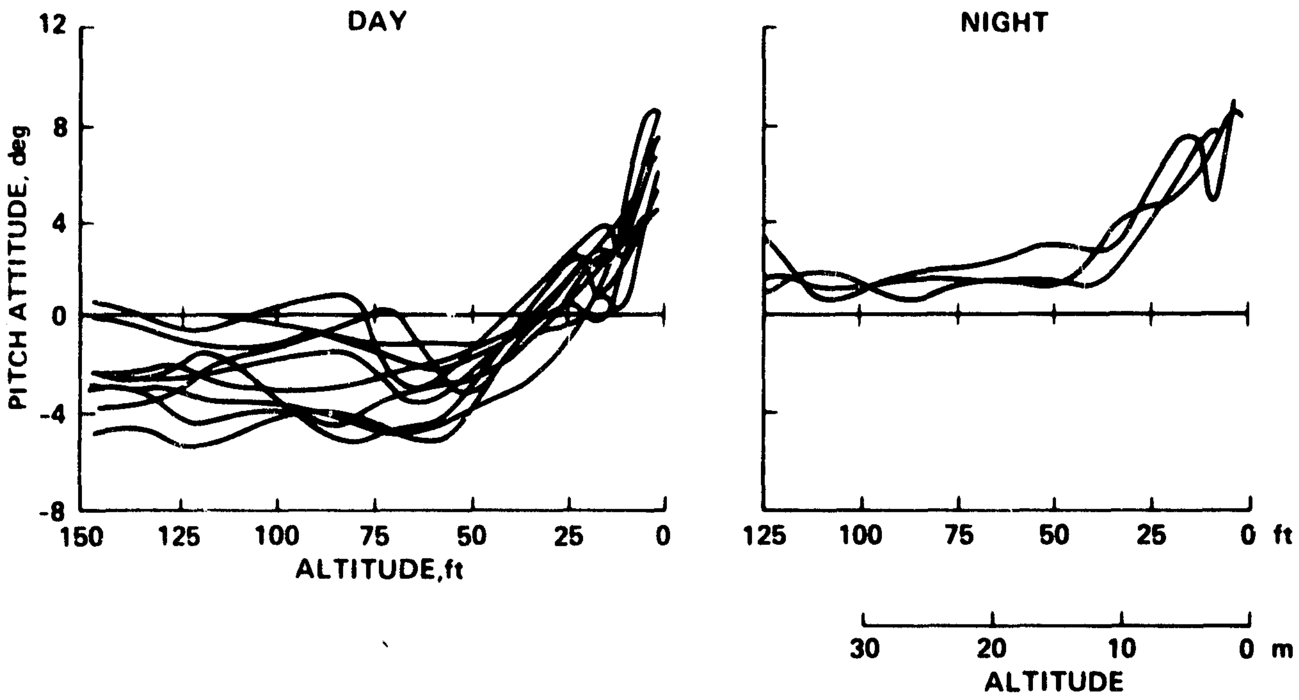


Figure 10.- Landing performance for configuration A.



(a) Sink rate profiles for day and night landings.

Figure 11.- Flare profiles for configuration B.



(b) Pitch attitude profiles for day and night landings.

Figure 11.- Concluded.

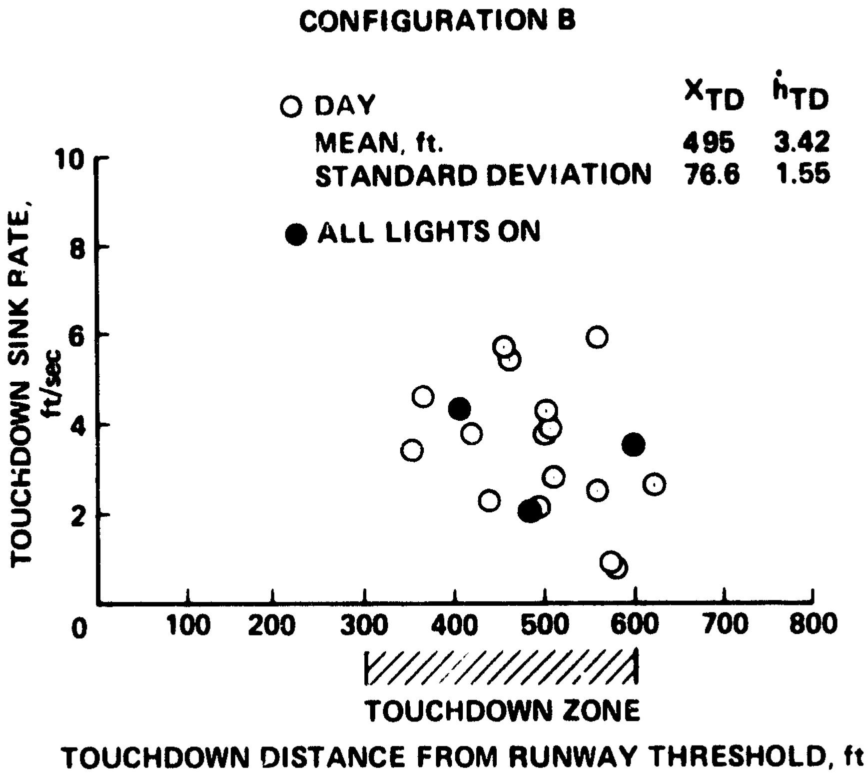
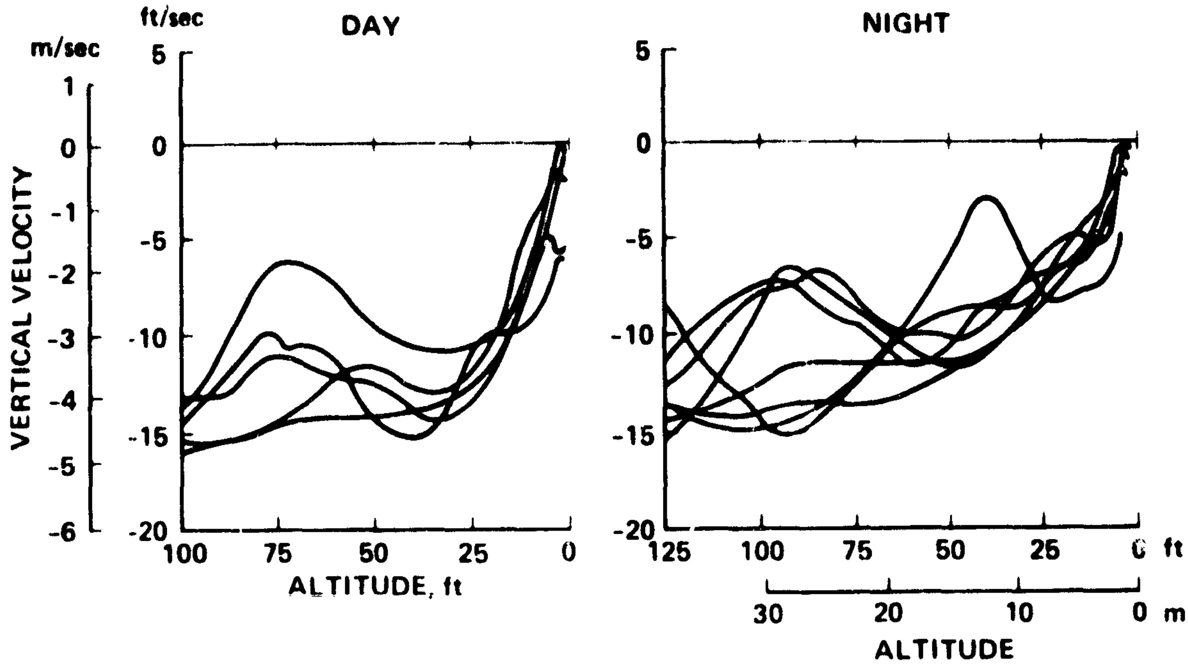
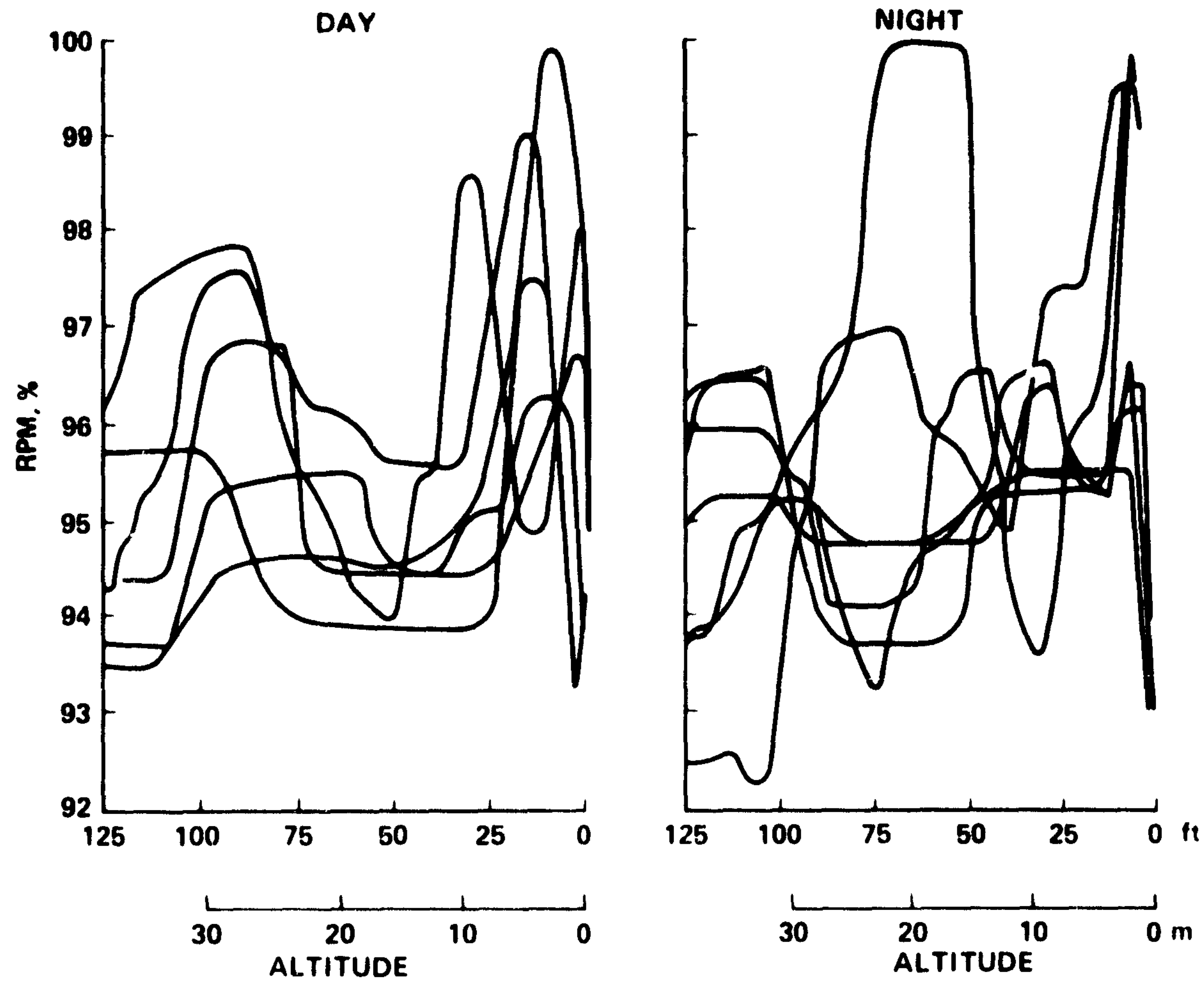


Figure 12.- Landing performance for configuration B.



(a) Sink rate profiles for day and night landings.

Figure 13.- Flare profiles for configuration C.



(b) RPM profiles for day and night landings.

Figure 13.- Concluded.

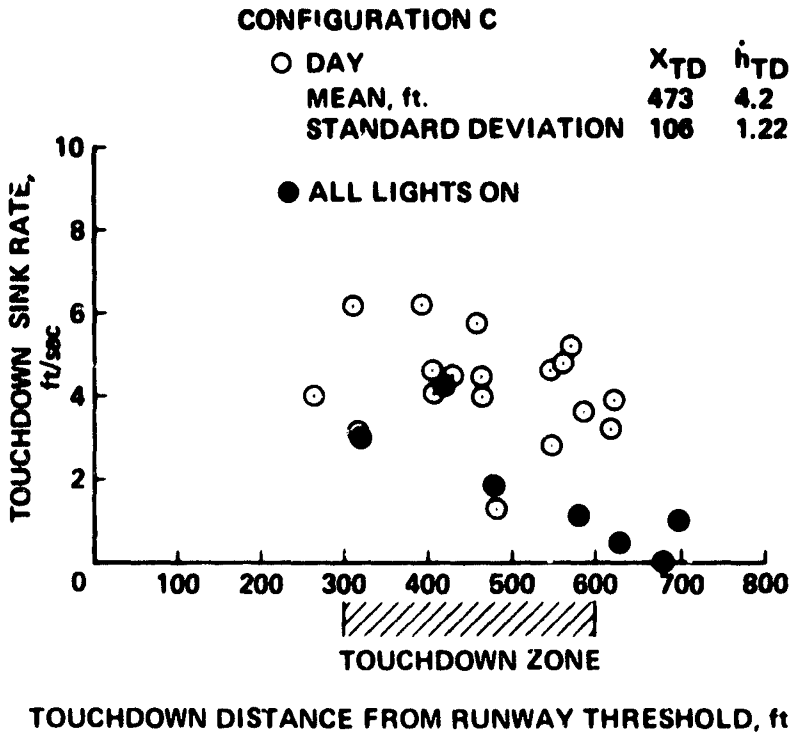
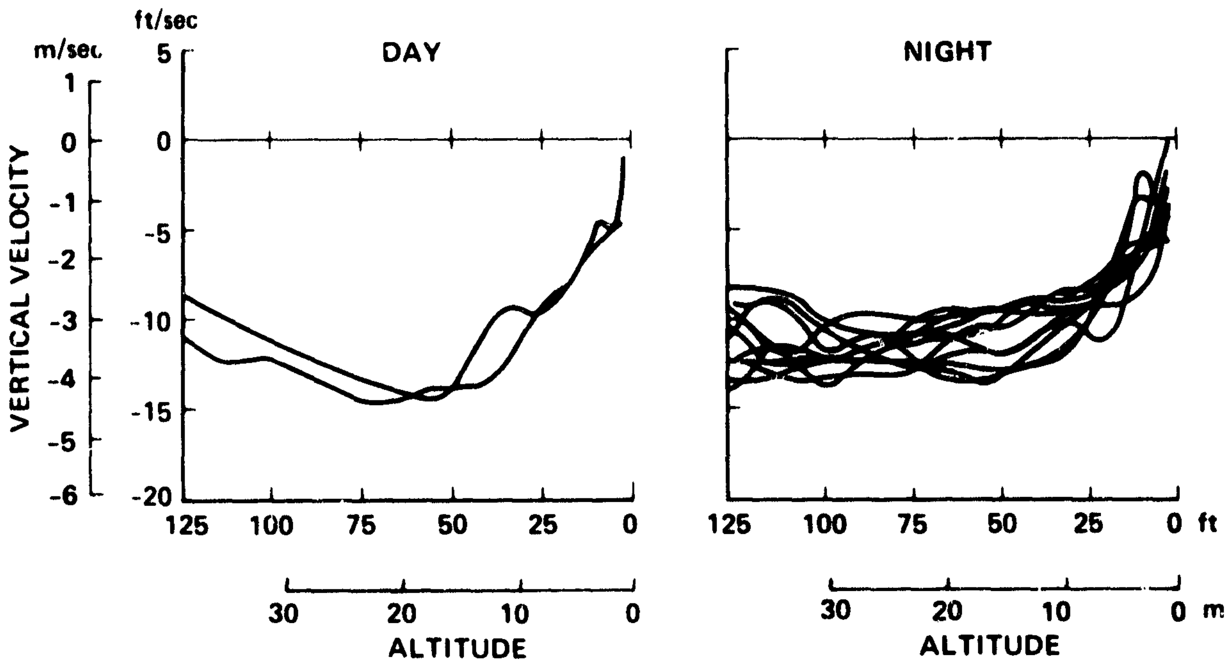
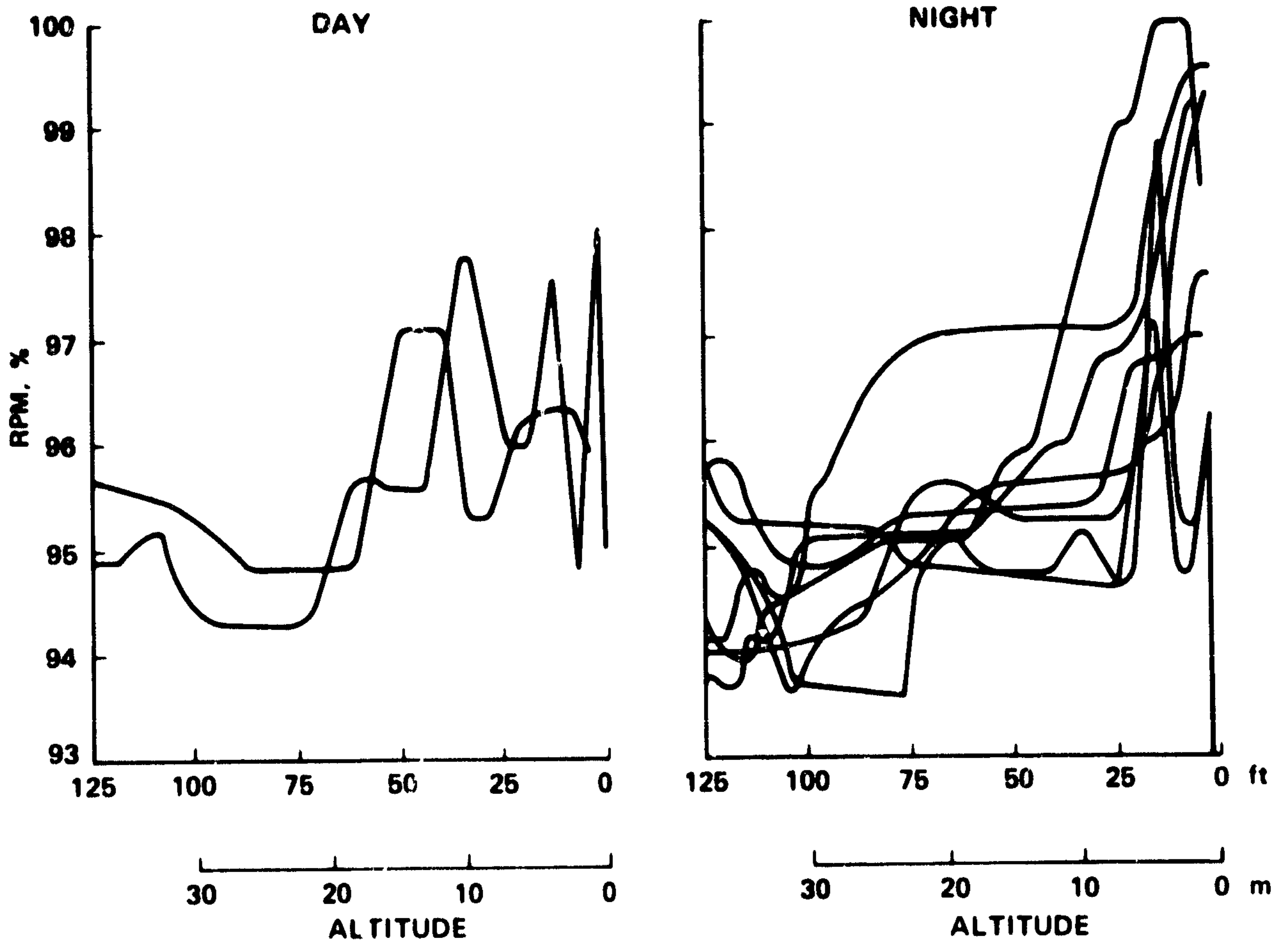


Figure 14.- Landing performance for configuration C.



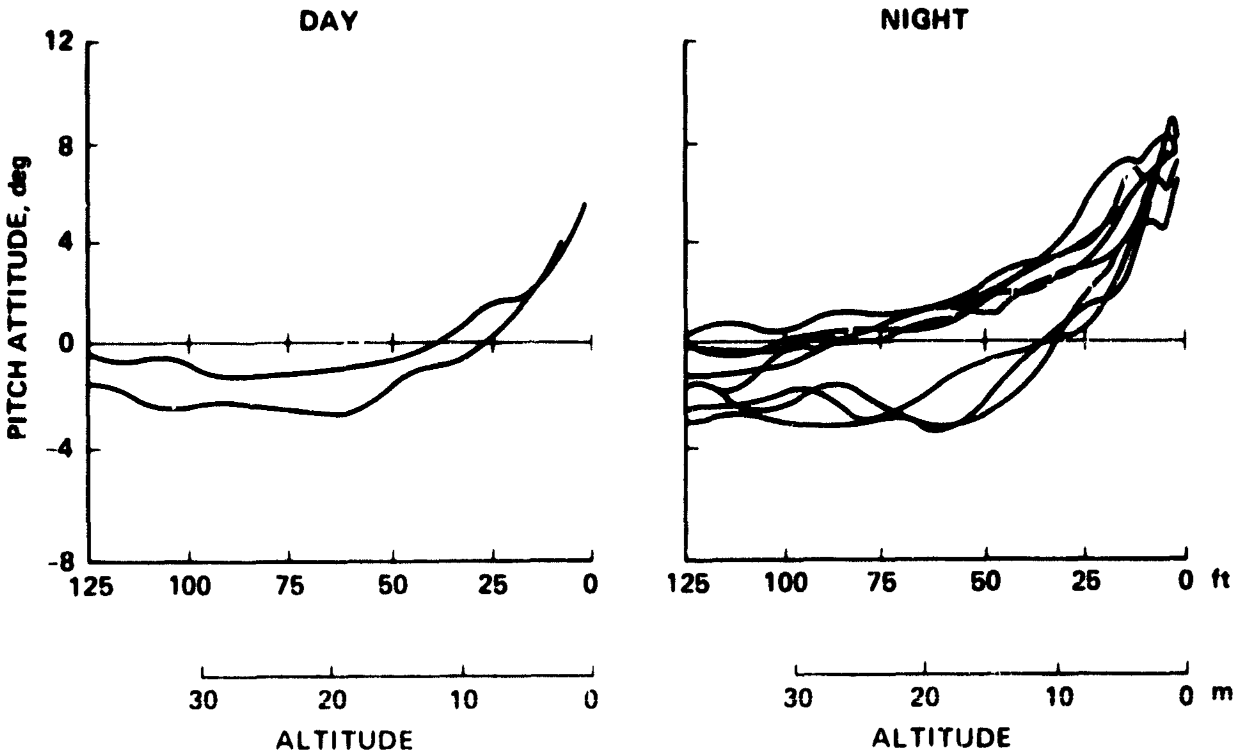
(a) Sink rate profiles for day and night landings.

Figure 15.- Flare profiles for configuration D.



(b) RPM profiles for day and night landings.

Figure 15.- Continued.



(c) Pitch attitude profiles for day and night landings.

Figure 15.- Concluded.

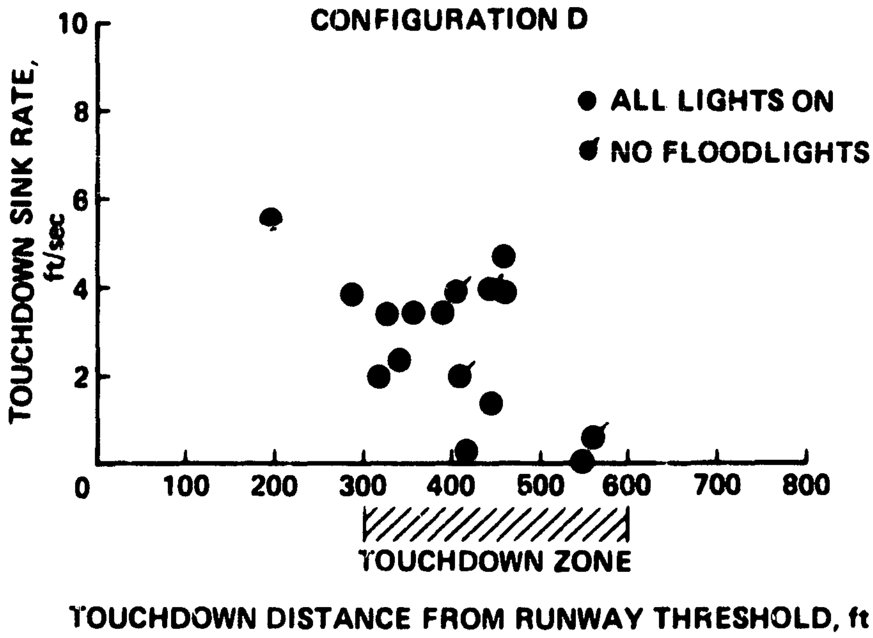
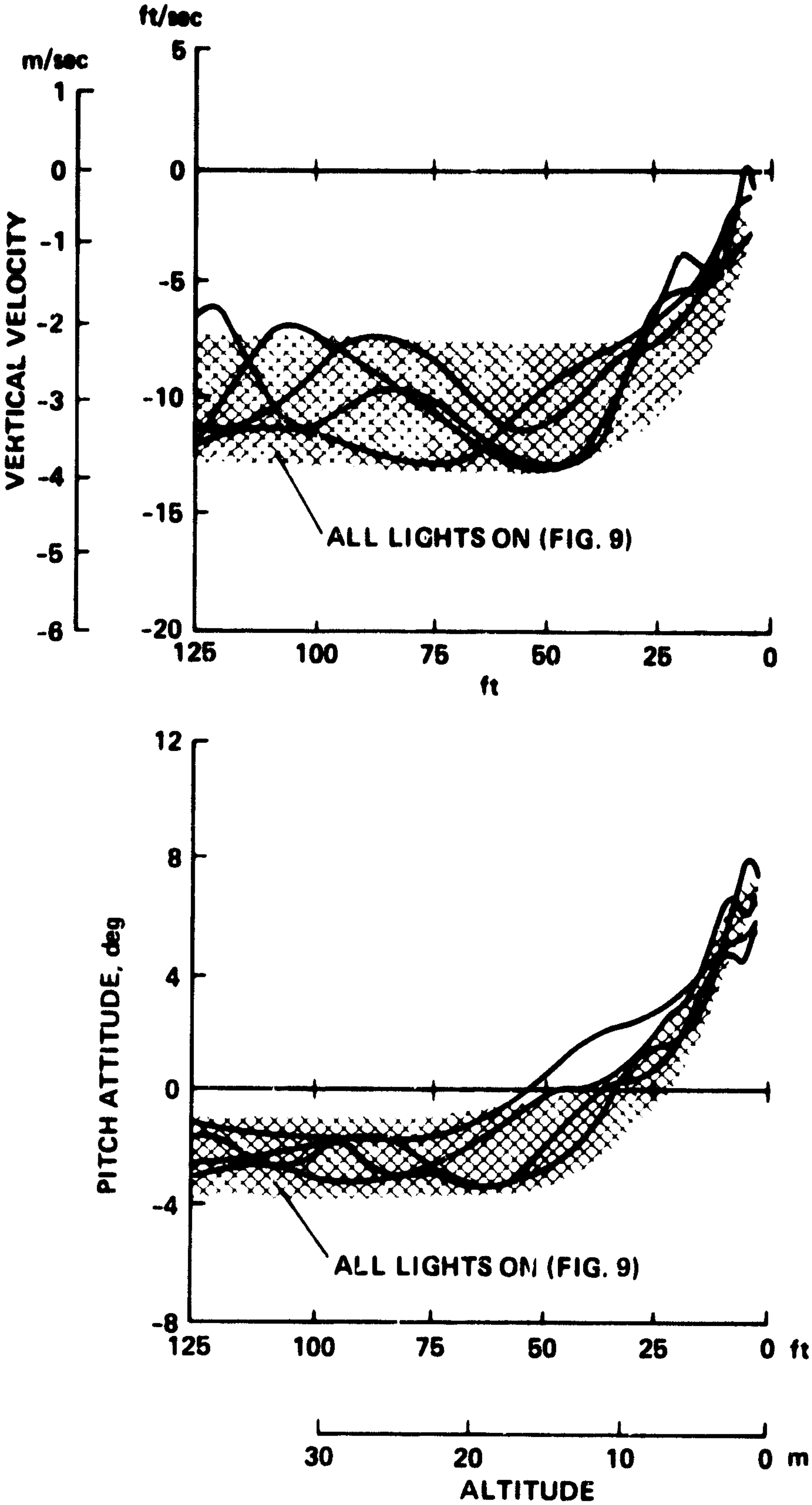
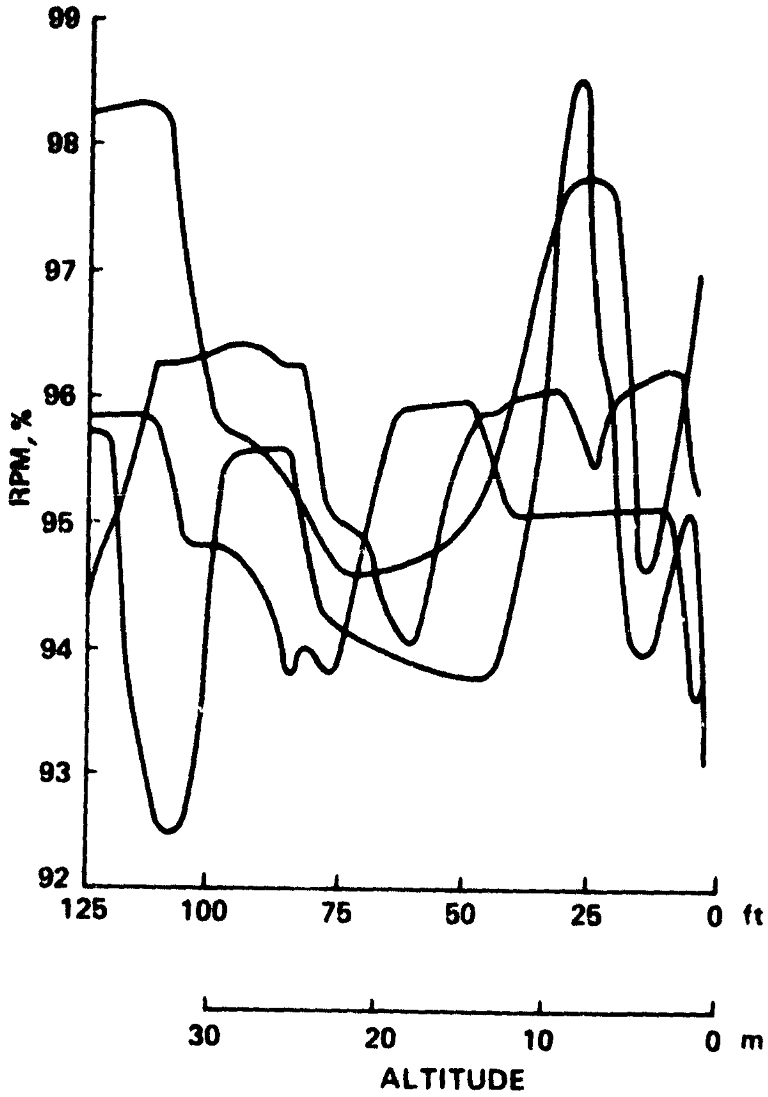


Figure 16.- Landing performance for configuration D.



(a) Sink rate and pitch attitude profiles.

Figure 17.- Comparison of flare profiles for configuration A with touchdown zone floodlights on and off.



(b) RPM profiles.

Figure 17.- Concluded.

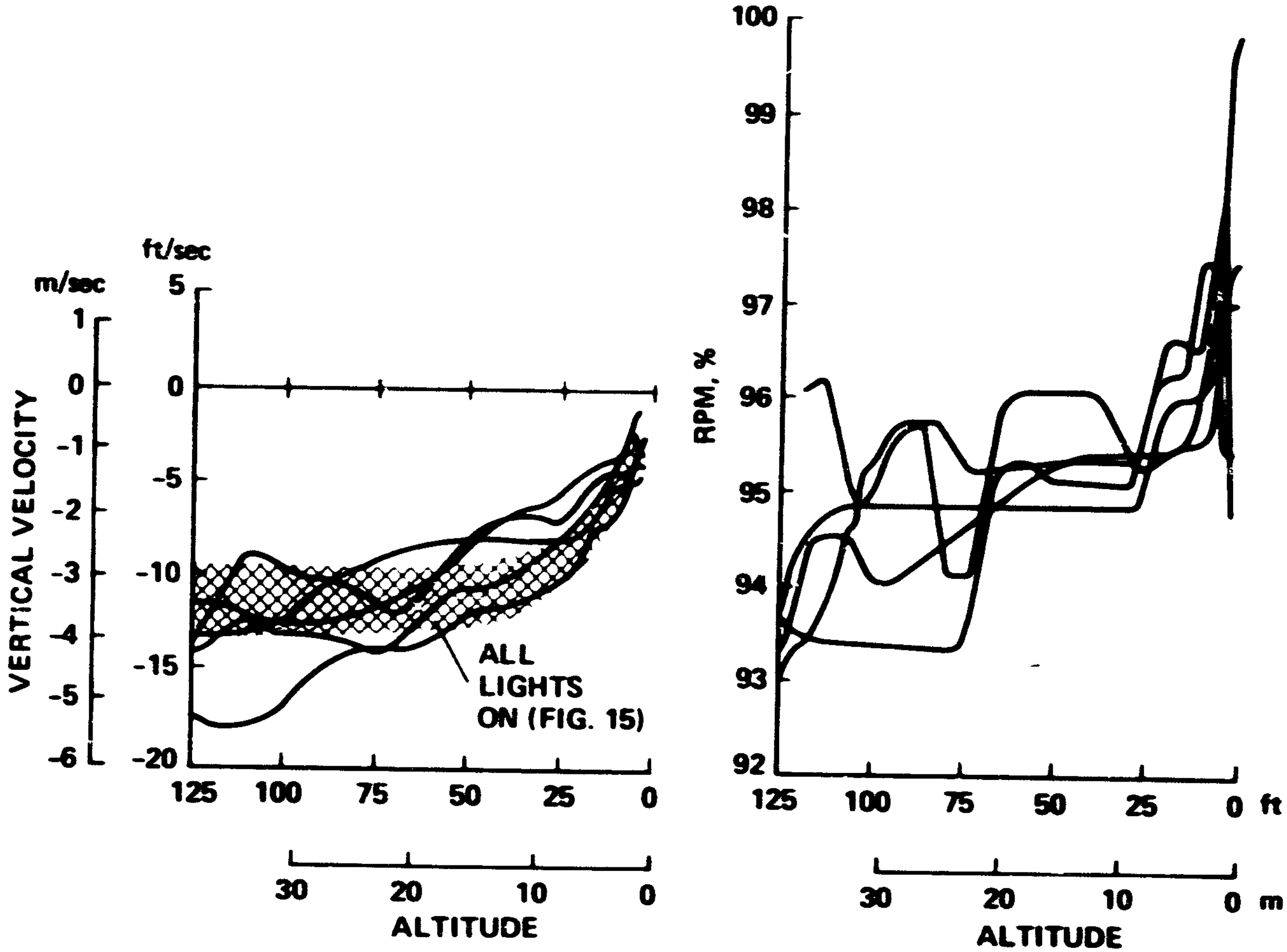
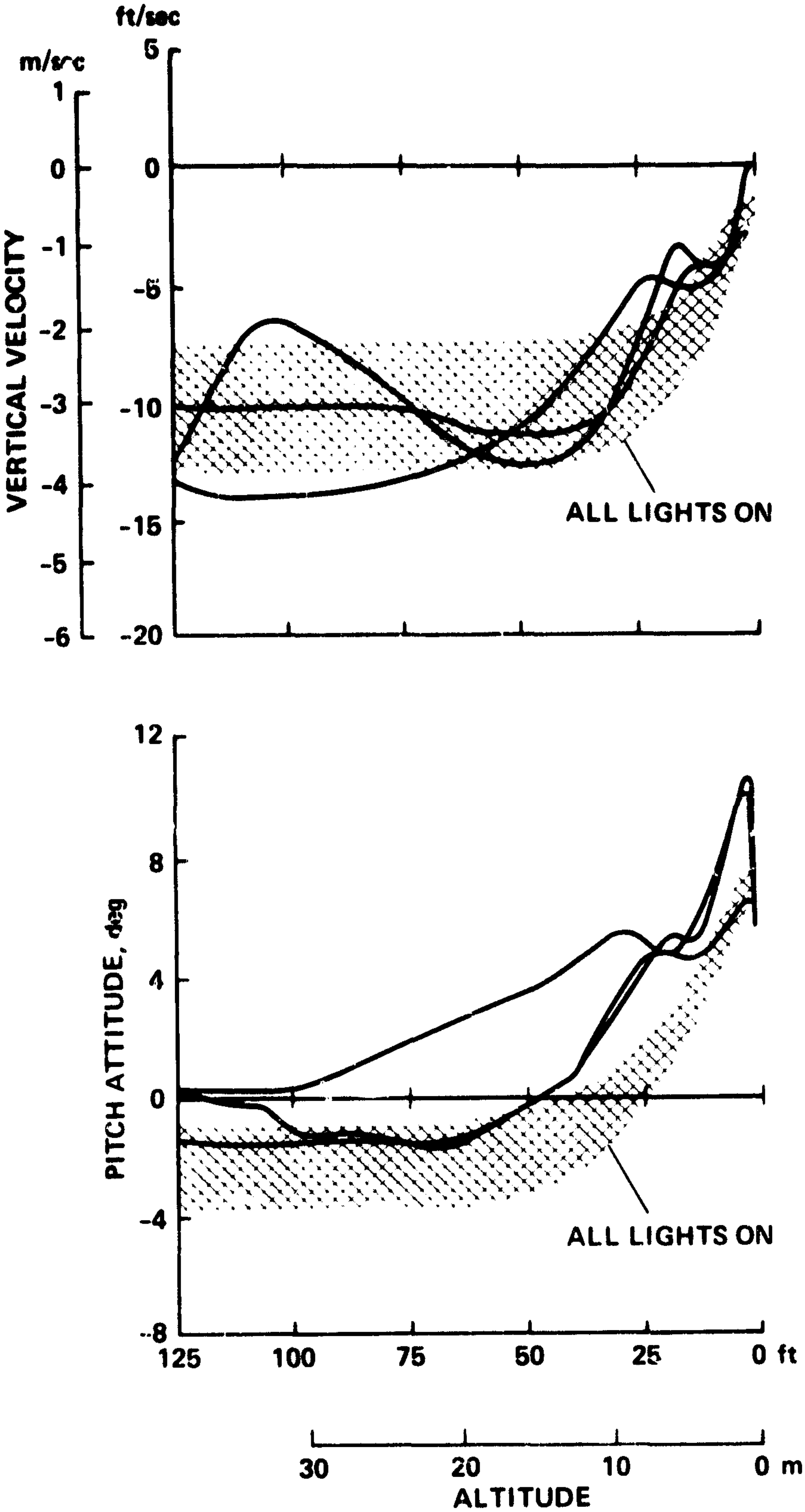
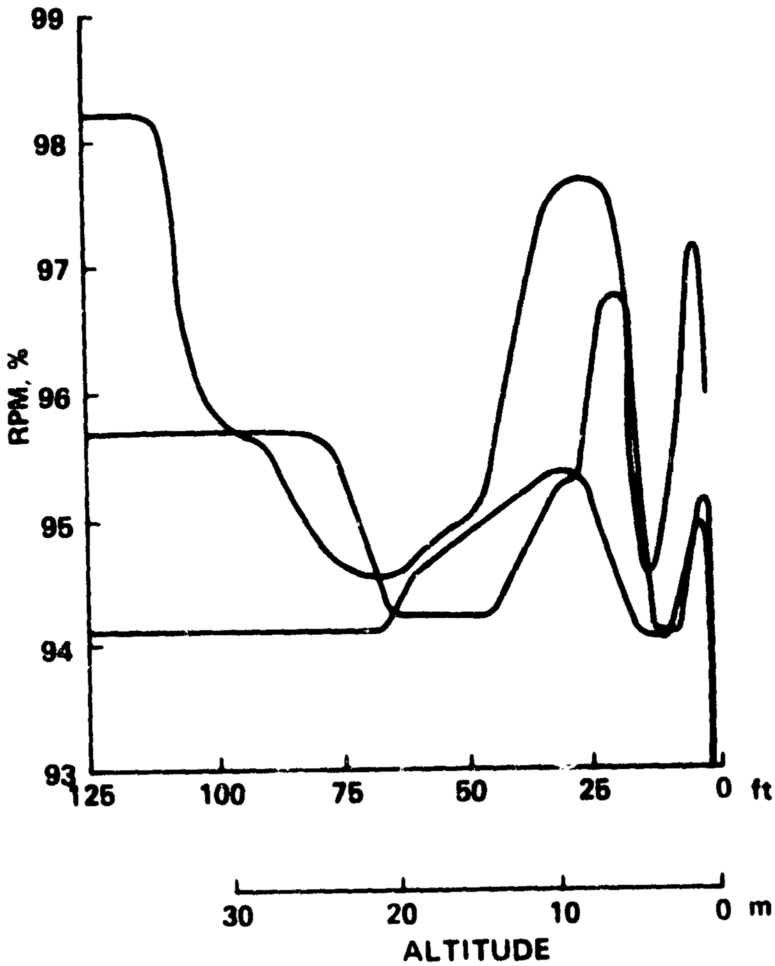


Figure 18.- Comparison of flare profiles for configuration D with touchdown zone floodlights on and off.



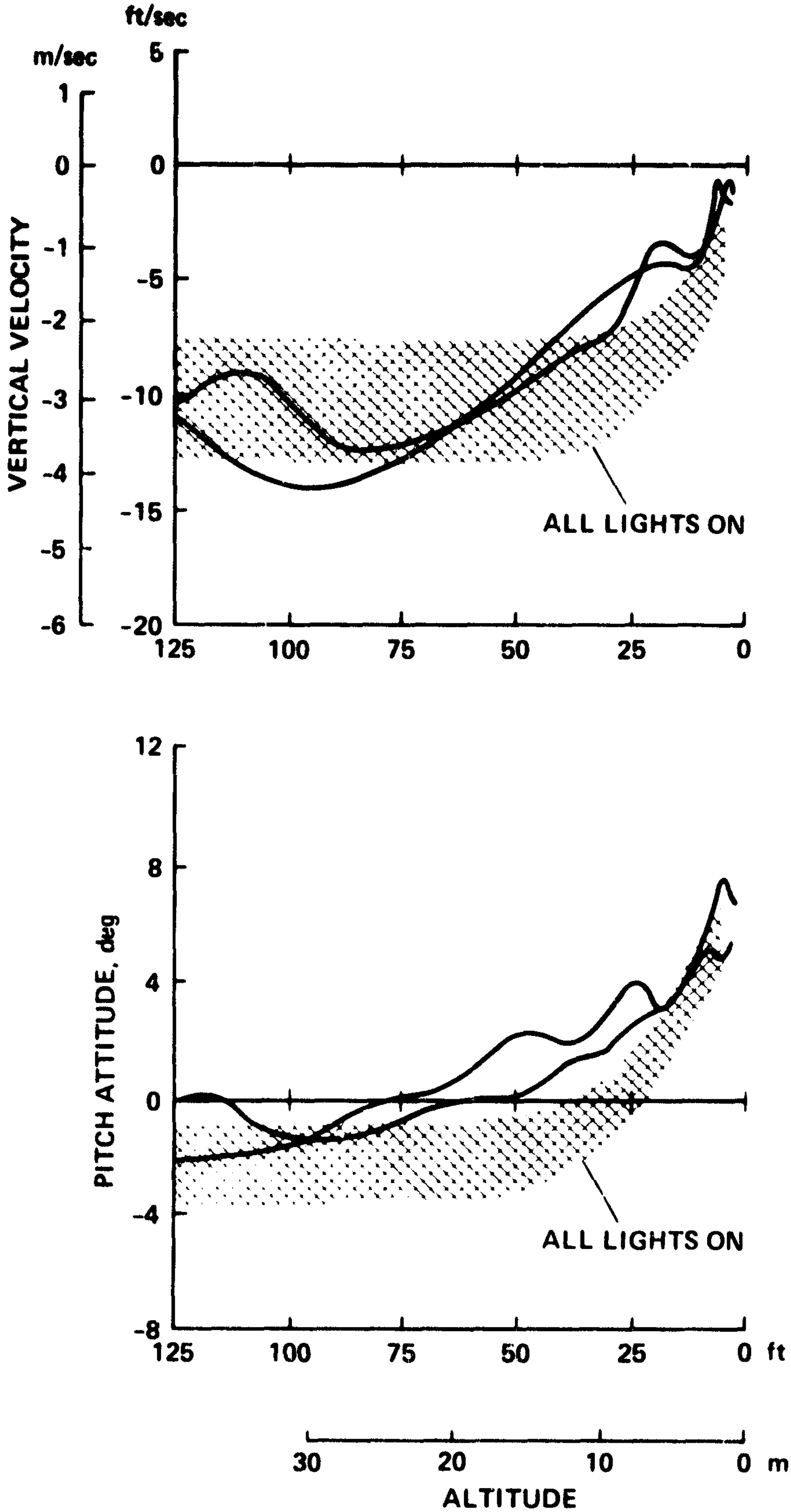
(a) Sink rate and pitch attitude profiles.

Figure 19.- Comparison of flare profiles for configuration A with aircraft landing lights on and off.



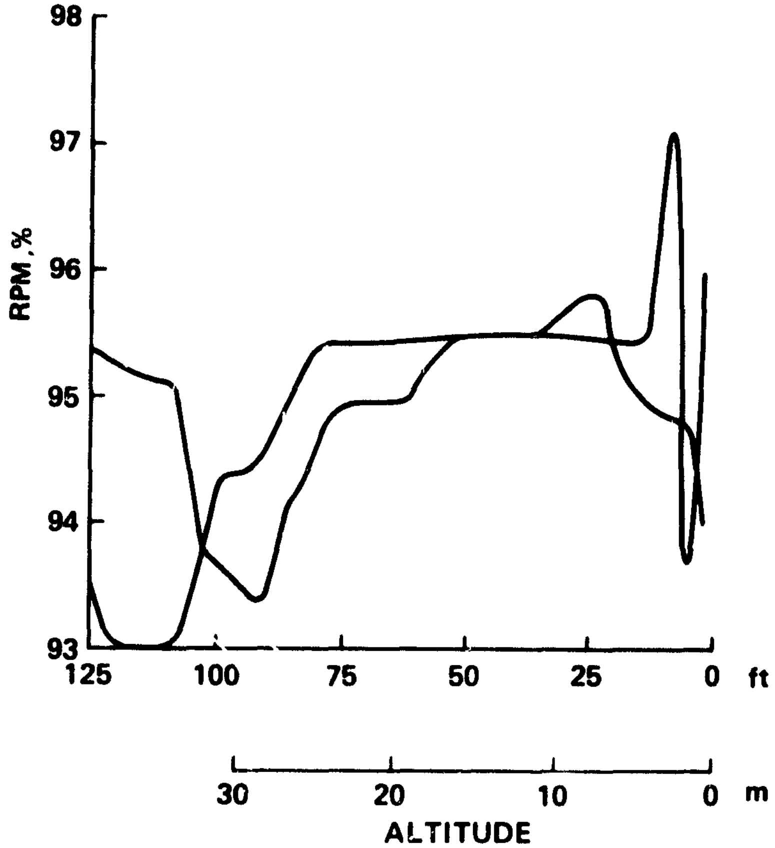
(b) RPM profiles.

Figure 19.- Concluded.



(a) Sink rate and pitch attitude profiles.

Figure 20.- Comparison of flare profiles for configuration A with floodlights and landing lights on and off.



(b) RPM profiles.

Figure 20.- Concluded.