2-P
m1X

NASA TECHNICAL MEMORANDUM

NASA TM X-62,187

NASA TM X-62,187

INITIAL FLIGHT AND SIMULATOR EVALUATION OF A HEAD UP DISPLAY FOR STANDARD AND NOISE ABATEMENT VISUAL APPROACHES

Kent Bourquin, Everett Palmer, George Cooper, and Ronald Gerdes

Ames Research Center
Moffett Field, Calif. 94035

February 1973

(NASA-TM-X-62187) INITIAL FLIGHT AND SIMULATOR EVALUATION OF A HEAD UP DISPLAY FOR STANDARD AND NOISE ABATEMENT VISUAL APPROACHES (NASA) 39 p CSCL 01B G3/02

N73-18021

Unclas
63441

39

INITIAL FLIGHT AND SIMULATOR EVALUATION OF A HEAD UP DISPLAY FOR STANDARD AND NOISE ABATEMENT VISUAL APPROACHES

Kent Bourquin, Everett Palmer, George Cooper, and Ronald Gerdes

ABSTRACT

A preliminary assessment was made of the adequacy of a simple Head Up Display (HUD) for providing vertical guidance for flying noise abatement and standard visual approaches in a jet transport. The HUD featured gyro-stabilized approach angle scales which display the angle of declination to any point on the ground and a horizontal flight path bar which aids the pilot in his control of the aircraft flight path angle.

Thirty-three standard and noise abatement approaches were flown in a Pan American World Airways Boeing 747 aircraft equipped with a Sundstrand Head Up Display. The HUD was also simulated at Ames Research Center in a research simulator. The simulator was used to familiarize the pilots with the display and to determine the most suitable way to use the HUD for making high capture noise abatement approaches.

Preliminary flight and simulator data are presented and problem areas that require further investigation are identified.

INTRODUCTION

Jet transport noise is a continuing concern to airport communities, the airline industry, and the Federal Government. One method of reducing the noise perceived by the aircraft community is to modify the approach flight path so that the aircraft use less power and is higher above the ground during most of the landing approach.

The NASA and the FAA have demonstrated the noise reduction potential of the two-segment approach (refs. 1 and 2). In the two-segment approach, the aircraft approaches on a higher-than-normal glide slope and then makes a transition to the standard glide slope in time to stabilize prior to the landing. In order to fly these approaches accurately, a pilot requires glide slope guidance for the upper segment as well as for the lower segment. The FAA, in an experimental program, has demonstrated the feasibility of using Distance Measuring Equipment (DME) and barometric altimeter signals for establishing an upper segment glide slope (ref. 2). NASA and American Airlines have recently completed a flight evaluation demonstrating the feasibility of using area navigation equipment for establishing the upper segment glide slope (ref. 3). These avionics systems, however, require ground navigation aids to provide the required guidance.

Recent aircraft display research at Ames Research Center indicates that a simple Head Up Display might allow two-segment approaches to be flown with no ground navigational aids. One study (ref. 4), evaluating an Independent Landing Monitor (ILM) display which produced a perspective image of the runway showed that the runway image alone provided inadequate glide slope guidance. A second study (ref. 5) showed that adding a "glide slope reference" bar parallel to and 3° below the true horizon allowed the pilot to precisely track a 3° glide slope to the runway aim point. The only drives to this symbol were aircraft pitch and roll attitude. A third study (ref. 6) of STOL visual approaches, showed that a simple Head Up Display (HUD) presenting the same type of symbology as on the ILM display resulted in a large improvement in tracking a 7-1/2° glide slope as compared to visual approaches made without the HUD. The ability of a simple HUD to provide accurate guidance for any glide slope angle to any point on the ground suggests the application of the type of HUD for providing the guidance for both upper and lower segments of a visual two-segment approach.

Pan American World Airways recently evaluated such a Head Up Display in a Boeing 747 aircraft as a safety aid during conventional approaches (ref. 7). In a cooperative program, the Director of Flight Operations Technical Services, of Pan American, arranged for NASA/Ames test pilots to make ten approaches in the B-747 to evaluate the HUD for making noise abatement approaches. NASA/Ames provided precision radar tracking data of the aircraft for all approaches to aid Pan American in their evaluation of the HUD. NASA/Ames also provided a research simulation which incorporated the HUD symbology. This simulation was then used to familiarize both Pan Am and NASA pilots with the display and to define the flight test program.

In this report, the simulation and flight test are discussed and some results on vertical profiles, potential noise reduction, and pilot commentary and reactions are presented. Finally, problem areas are identified which could be investigated in a future program.

HEAD UP DISPLAY

The Head Up Display installed in the B-747 aircraft and simulated at Ames was manufactured by Sundstrand Data Control, Inc. It is referred to by the manufacturer as a Visual Approach Monitor or VAM. The display employs collimating optics so that the symbology appears superimposed on the real world visual field. The symbology is illustrated in figure 1; it consists of two vertical approach angle scales and a horizontal bar. The approach angle scales are driven by pitch attitude so that the zero on the scale is always superimposed on the horizon. The approach angle scales indicate the angle of declination to the respective point superimposed on the ground. The horizontal bar can be used in three different modes; the gamma mode, the delta gamma mode; and the fixed bar mode. The mechanization of these modes is illustrated in figure 2.

Gamma Mode - In the "gamma" mode, the bar defines aircraft flight path angle with respect to the ground. It is computed using the estimated ground speed from the INS and the rate of sink as estimated by a complementary filter that has vertical acceleration and altitude rate inputs. The intersection of the bar with the ground is where the aircraft would impact if it maintained its present flight path angle.

Delta-Gamma Mode - In the delta-gamma mode the bar displays the deviation of actual aircraft flight path angle (γ) from the desired flight path angle during approach (-3° in this evaluation) multiplied by a gain (g) and biased to the desired flight path angle. In this mode the bar acts as a flight director. Controlling the aircraft so that the bar overlays the desired runway aim point causes the aircraft to fly to and then along a 3° glide slope to the aim point.

Fixed-Bar Mode - In the "fixed-bar" mode, the bar is slaved to the numerical approach angle scales at the desired glide slope angle. The pilot makes pitch attitude changes to adjust the aircraft's flight path angle so that the bar is superimposed on the runway aim point. Since the bar is slaved to the vertical approach angle scales, it does not provide direct information of the aircraft's flight path angle. A fixed aircraft symbol (—┐┌—) was added to the symbology for this mode to explicitly display aircraft pitch attitude.

SIMULATION EVALUATION

Simulation Facility - For expediency, an existing research simulator was used for this evaluation. The column, wheel, and rudder pedals were spring loaded. The throttle levers were mounted on an overhead panel. Representative aircraft instruments displayed sink rate, airspeed, altitude, and power. Digital read-outs of distance to a Distance Measuring Equipment (DME) transmitter located 4000 ft down the runway from the threshold and radar altitude were also displayed.

The visual system consisted of a collimating lens system and a 21" cathode ray tube (CRT) display. A general purpose computer graphics system was programmed to display a perspective night view of San Jose Municipal Airport and its surrounding terrain. Figure 3 shows the pilots view of the airport and VAM display in its delta-gamma mode during an approach.

The simulated VAM display was programmed to function the same as the one installed in the aircraft except that perfect signals were used for altitude rate, ground velocity and pitch. The display symbols were drawn directly on the CRT by the computer graphics system and the actual VAM computer and displays were not used.

Dynamics of a four-engine transport of the DC-8, 707 class were programmed into the simulator computer. Flaps and gear were always down. The pilot could either control power manually or select an autothrottle mode.

The simulation contained random gusts and the headwind profile shown in figure 4. Data on range, altitude, airspeed, and power was taken every 200 meters from 12,000 meters to touchdown.

Simulation Program - The simulation program was divided into two parts. The first part was restricted to an evaluation by Pan American and NASA pilots of the delta-gamma mode. The second part was used to determine the most promising HUD modes and trajectories for noise abatement approaches that could be evaluated in flight. Only the NASA research pilots were used in the second part of the simulator program.

The pilots flew a number of approaches for training and familiarization with the VAM display and then one or more sets of eight specified approaches in which display and task variables were varied. The set of eight specified approaches are listed below.

Condition	Display	Throttle	Winds	Approach
1	VAM	Auto	Calm	Normal
2	VAM	Auto	Turbulent	Normal
3	NO VAM	Auto	Calm	Normal
4	NO VAM	Auto	Turbulent	Normal
5	VAM	Auto	Calm	High Capture
6	VAM	Auto	Turbulent	High Capture
7	VAM	Manual	Calm	High Capture
8	VAM	Manual	Turbulent	High Capture

On the normal approaches, the pilot was instructed to maintain an altitude of 458 meters (1500 ft) and start his descent 0.2 miles before intersecting a 3° glide slope. The DME read-out was programmed to flash at the push over point. On the high capture approaches, the pilot was instructed to maintain an altitude of 916 meters (3000 ft) and start his descent .32 kilometers (0.2 miles) before intersecting a 5° glide slope. On the NO VAM approaches, the VAM was turned off and the pilot used only the runway scene and head down instruments (without glide slope information) to stay on the 3° glide slope. However, the DME position and altitude fix was used to initiate the approach. The number of sets of approaches flown by each pilot is listed in Table 1.

The vertical profiles recorded during this study are illustrated in figure 5 for the so-called normal approaches. It is seen from figure 5 that the approaches flown with the VAM in its "delta-gamma" mode (conditions 1 and 2) are more precise than those made without the VAM display (conditions 3 and 4). Mean and standard deviation performance data for altitude and airspeed error at a range of 1000 meters (3280 ft) from the runway aim point are shown in Table 2. The standard deviation of altitude error for conditions 1 and 2 was 1.0 and 2.0 meters, where as for conditions 3 and 4, the standard deviation was 13.1 and 8.8 meters. The use of the VAM display in the simulation reduced altitude variability by a factor of four. If a DME position and altitude fix had not been used to establish the aircraft on an initial 3° glide slope angle the dispersion without the VAM might have been even greater.

Figure 6 shows the vertical profiles for the high capture approaches with and without turbulence and with and without the autothrottle. Note the long curved trajectory that resulted with the display in the delta-gamma mode. The angle of declination to the runway aim point is 5° at the push over point. The declination angle then reduces gradually to 3° at an altitude of about 50 meters (150 ft). The altitude error data in Table 2 shows only a slight increase in variability between the normal 3° approach with the VAM and the high capture noise abatement approach with VAM (for example, see VAM manual condition). Note the small altitude variability on the high capture approaches with the VAM.

After flying the above set of eight approaches, all of the pilots were debriefed and four of the pilots answered a debriefing questionnaire. The pilot responses to the questionnarie indicated that: (1) One pilot felt the VAM should present some form of airspeed error; (2) Two pilots felt an autothrottle would be desirable on the high capture approaches; (3) All four pilots felt that workload with the VAM was slightly lower than the workload during an ILS approach; and, (4) Three pilots felt the workload with the VAM was less than on a standard VFR approach without a VAM but the fourth pilot felt it was more difficult due to the added eye scan required for the VAM. In the debriefing, a few Pan American pilots complained about making control reversals. The reason for these reversals is that in the delta gamma mode when the flight path bar is above its reference (the runway aim point), the proper pilot response is to pitch down. This response is opposite to a flight director command, if the bar is above its reference the proper response is to pitch up. After several approaches, these pilots were able to interpret the commands correctly.

The NASA pilots participated in the second part of the simulator study to determine the most promising HUD display modes and trajectories for noise abatement approaches to be evaluated in the Ames portion of the 747 flight test. Variations of the three basic modes; gamma, delta-gamma, and fixed bar, were evaluated. A plot of the vertical profile and airspeed error was presented to the pilot at the end of each run. These plots were used to help the pilots select the procedures and displays to be evaluated in flight.

As a result of this study, three noise abatement procedures using the HUD were selected for flight evaluation. A brief description of these three procedures follows:

1. High Capture using the Delta-Gamma Mode.- The pilot maintains an altitude of 915m (3000 ft) until a DME position fix or until a 5° declination angle to the runway aim point is indicated on the VAM approach angle scales. The aircraft will be then located at the approach initiation point as shown in figure 7 on a 5° glide slope to the runway aim point and also conveniently on a 6° glide slope to the end of the approach lights, which are 4000 ft short of the runway aim point. At the approach initiation point, the aircraft is pitched down until the horizontal bar intersects the runway aim point. Flying the aircraft so the horizontal bar remains on the aim point resulted in the curved trajectories shown in figure 8(a). These approaches were easy to fly. However, disadvantages are: (1) the curved path required continual small increases in power; (2) the flight path sinks below the upper segment of the nominal two-segment approach; and, (3) the initial flight path angle is steeper than -6° for the first part of the approach.

2. Two-Segment Approach Using the Modified Delta-Gamma Mode. At the approach initiation point, the pilot pitches the aircraft down until the horizontal bar is positioned at -4.5° on the approach angle scales. This will actually result in a flight

path angle of -6°. The pilot then maintains the horizontal bar at -4.5° until it is superimposed on the runway aim point at which time he reverts to the normal usage of the delta-gamma mode, i.e., maintains the bar on runway aimpoint. This procedure prevents initial commanded flight path angles from exceeding -6° and allows the aircraft to be trimmed to a constant speed and flight path angle during the upper part of the approach. Trajectories resulting from using this approach procedure are in figure 8(b).

3. Two-Segment Approach Using the Fixed Bar Mode.- In the fixed bar mode, the end of the approach lights is used as an aim point for the upper glide slope. To fly along the upper glide slope the pilot controls the aircraft so that the fixed bar, which is slaved to -6° on the approach angle scale, overlays the end of the approach lights. The aircraft symbol (—┐┌—) aids the pilot in making proper pitch and flight path corrections to stay on glide slope. Transition to the lower 3° glide slope is initiated when the approach angle scales indicate a 3.5° declination angle to the runway aim point. The aircraft, is then rotated and flown to the aim point along the 3° glide slope using the aircraft symbol and the -3° marks on the approach angle scales. This mode is very simple and straightforward. Only pitch attitude is required to drive the display. Disadvantages are that the pilot has no explicit display of flight path angle to help him cope with turbulence and wind shear as in the other two modes. Trajectories resulting from this approach procedure are in figure 8(c).

FLIGHT EVALUATION

The flight evaluation was conducted on March 10, 1972, at the Stockton Metropolitan Airport using runway 29R. The runway aim point was two white painted marks situated 1200 feet from the threshold. The middle marker building, located 5000 feet before the runway aim point, served as an aim point for the upper segment glide slope during some of the two-segment approaches.

A Pan American World Airways Boeing 747 number N750PA was used for the flight test. Aircraft gross weight varied between 510,000 and 400,000 lb during a six-hour flight. V_{ref} was set at 140 knots for a 25° flap final approach. VAM displays were installed on both the captain's and first officer's glare shields. Both displays had a 12° vertical field-of-view. The cockpit layout with the pilot's VAM display, is shown in figure 9.

The overall flight test situation at Stockton is illustrated in figure 10. A high precision ground radar was used to measure the aircraft position. The ground noise caused by the over-flying aircraft was measured at six sites underneath the approach path. Communication existed between the aircraft, the tower, and the radar. The radar also had communication with the noise measurement stations. Pilot and project participation are shown in Tables 1 and 3.

There were a total of thirty-three (33) approaches starting at 10:00 AM, and concluding at 2:30 PM. The visibility was marginal at about 4 miles for the first 7 approaches. For approaches 8 through 33, the visibility was greater than 6 miles and the runway aim point was visible at the push over point. Each of the approaches was one of the 6 nominal profiles shown in figure 11. Profile 1 was a standard 2.5° ILS approach. Profiles 2, 3, 4, and 5, were flown using the Delta-Gamma mode in a conventional manner but were initiated from different positions as shown in figure 11. Profile 6 is a two-segment approach using the modified delta-gamma mode and fixed bar modes as described in the previous section. Pan Am pilots flew profiles 2 (low), 3 (normal), and 4 (high). NASA pilots flew only profiles 5 and 6. Profiles 5 and 6 closely approximated the 6°/3° two-segment approaches flown in the NASA/American Airlines program (Ref. 3) and was steeper than the high capture approach flown by the Pan Am pilots.

The main results of the flight test can be seen in the radar vertical profile plots shown in figures 12 and 13. The profile plots are referenced with respect to the position of the VAM in the cockpit.

Figure 12 contains the radar profiles of the normal, high, and low approaches flown by the Pan American pilots for their VAM evaluation. These approaches were all with the VAM in the $\Delta\gamma$ mode providing guidance to a 3° glide slope. The numbers on the figure are approach numbers which are in chronological order. In figure 12a, note how the approach precision increases below an altitude of 300 ft as the pilot is better able to select a precise aiming point on the runway and tighten his control as he approaches the runway. The high capture (fig. 12b) approaches were initiated for an above-beam capture after overshoot of 3° beam. Note that the VAM display in the delta-gamma mode allowed the pilot to capture the three-degree glide slope with very little undershoot. On the low capture approaches, the VAM was not used until about the spot marked by an "•" on each profile.

The NASA pilots and a consultant pilot evaluated the high capture approaches using the delta-gamma mode (profile 5) and two-segment approaches using the modified delta-gamma and the fixed-bar modes (profile 6). Radar profiles of these approaches are shown in figure 13. The approaches all started at a 3000 foot altitude with approach initiation intended to occur just before reaching a 5° angle of declination to the runway aim point. Approaches 17 and 18 are not plotted since the VAM could not be used due to poor visibility.

The results obtained during the flight evaluation of these procedures are discussed below in terms of the approach initiation, the upper segment and the lower segment.

Approach Initiation.- Two techniques were used to initiate the approach. One technique was to initiate the pushover when the VAM indicated angle of declination to the runway aim point was 5°. The other technique was to use a DME position fix for pushover initiation. Approaches 19, 22, 23, 24, 25, 26, 27, 28, and 29, were initiated using the VAM; whereas, runs 20 and 21, were initiated using the DME. Future work is planned to determine which technique is preferrable for given conditions of visibility, navigation aids, etc.

Upper Segment.- The evaluation pilots felt that all three procedures were adequate for flying the upper segment of the approach. Delta-gamma was perhaps the easiest because the pilot did not have to change aim points as in the fixed bar mode or change the manner in which he used the horizontal bar as in the modified delta-gamma mode. As previously indicated, a disadvantage of the delta-gamma mode was that the aircraft was never completely trimmed due to a continuously changing trajectory. The advantage of the two-segment approach using the fixed bar and the modified delta-gamma mode that was identified in the simulation study, was that the aircraft can be trimmed on the upper segment of the approach since it is a straight line segment. However, this trimmed condition advantage could not be achieved on the B-747 flight because the aircraft drag characteristics were low, requiring idle power on the -6° flight path angle at 25° flaps. Using 30° of flaps (which could not be used on this flight) or a less steep upper segment should allow the trimmed condition to be achieved.

Lower Segment Capture.- As shown in figure 13a, b, and c, the NASA pilots consistently dipped below the lower 3° glide slope. This undershoot of the lower glide slope was not encountered in the simulator studies (figs. 6 and 8) or in the approaches made by the Pan Am pilots (fig. 12b). The cause of this discrepancy has not been completely resolved but it has been determined that the undershoot occurred only when there was significant deceleration during the transition to the lower glide slope. The NASA pilots flew the steep approaches (5 and 6) at V_{ref} + 20 knots for two reasons. One was to reduce the requirement for an abrupt thrust increase when transitioning from 6° - 3°. The second was the lack of a deceleration capability at 6°. Transition from 6° - 3° was therefore accompanied by an abrupt deceleration to V_{ref}. It is conjectured that the longitudinal deceleration interacted with the VAM dynamics in such a way that the VAM display was in error. An attempt to validate this will be made on a future flight.

The NASA pilot comments and the pilot questionnaire are summarized in Appendix A and B.

Noise measurements were obtained on all the approaches (ref. 8) and certain ones are summarized in figure 14 where smooth curves have been passed through the average data points. The high capture profile noise data summarized was obtained from those approaches that the radar tracking confirmed were nominally profiles 5 and 6. At 18,000 feet from runway threshold, the average noise during a high capture approach was 13 EPNdB less than the noise measured during a standard 2.5° ILS glide slope approach. At 18,000 ft from the runway threshold, a 3° approach resulted in 5 EPNdB reduction from the -2.5° approach.

CONCLUDING REMARKS

The following observations were made on the normal -3° approaches:

1. Simulation data showed a four-fold increase in precision when the VAM was used on a visual approach.

2. Flight results showed acceptable capture and tracking of the 3° glide slope for normal, low, and high approaches.

3. Some pilots complained of a tendency to "reverse control" in the delta-gamma mode. Alternate symbology is being investigated.

The following observations were made on the high capture noise abatement approaches:

1. Simulation results suggest that the high capture approaches can be flown with the VAM with considerably more precision than non-ILS visual approaches with no VAM.

2. Current HUD hardware symbology is suitable for high capture noise abatement approaches.

3. The best means or conditions for initiating the approach, VAM or DME position fix, remains to be determined although either may be acceptable.

4. The 747 aircraft drag characteristics were low, requiring idle power on the -6° flight path angle at 25° flaps. Future work will be done using 30° flaps and a shallower (-5°) flight path angle if necessary.

5. On those approaches in which the aircraft decelerated during the 6° to 3° transition there was a tendency to undershoot the 3° glide slope. This appears to be related to display errors, not piloting errors and is being investigated. This, of course, was not a problem for standard 3° approaches.

REFERENCES

1. Quigley, H.C.; Snyder, C.T.; Fry, E.B.; Power, L.J.; and, Copeland, W.L.: Flight and Simulation Investigation of Methods for Implementing Noise Abatement Landing Approaches. NASA TN D-5781, 1970.

2. Chubboy, R.A.: An Operational Evaluation of the Two-Segment Approach for Noise Abatement. FAA Report No. FAA-RD-71-21, April 1971.

3. Denery D.G.; Bourquin, K.R.; and Drinkwater, F.J.: Preliminary Results on Two-Segment Noise Abatement Studies. NASA TMX-62,098, September 1971.

4. Wempe, T. and Palmer, E.: Pilot Performance With a Simulated Pictorial Landing Display Including a Different Conditions of Resolution and Update Rate. Proceedings of the Sixth Annual Conferenct on Manual Control, Air Force Institute of Technology, April 7-9, 1970, pp. 47-81.

5. Palmer, E. and Wempe, T.: Pilot Performance With a Simulated ILS-Independent Pictorial Display. Proceedings of the Seventh Annual Conference on Manual Control, University of Southern California, May 1971, (forthcoming NASA SP).

6. Palmer, E. and Croun, F.W.: Head-Up Displays for STOL Visual Approaches. Presented at the STOL Technology Conference, NASA/Ames Research Center, October 17-19, 1972.

7. Elson, B.M.: "Visual Approach Monitor Being Certified," Aviation Week and Space Technology, April 3, 1972, pp. 37-38.

8. Tanner, C.S. and Glass, R.E.: Noise Measurements Obtained During Visual Approach Monitor Evaluation in 747 Aircraft. NASA CR 114478, May 1972.

TABLE 1.- PILOT PARTICIPANTS

Pilot	Organization	Simulation	Flight
		Number of sets of 8 approaches	Approach Number
MHM	PAA	0	1, 2, 3, 4, 5, 33
IRA	PAA	2	6, 7, 8, 9, 32
JMM	PAA	0	10, 11, 12, 13,
HGE	PAA	0	14, 15, 16
JLF	PAA	0	30, 31
PR	PAA	1	- - -
RMW	PAA	2	- - -
GEC	NASA	2	17, 18, 19, 20, 21
RG	NASA	2	22, 23, 24, 25, 26
AW	Al White & Associates	1	27, 28, 29

TABLE 2.- MEAN AND STANDARD DEVIATION SIMULATOR PERFORMANCE DATA AT 1000 METERS FROM THE RUNWAY AIM POINT

SIMULATION	CONDITION				Pilots	Condition	Repeats	ALTITUDE			AIR SPEED	
	Display	Throttle	Winds	Approach				Mean	Mean Error	Stan. Dev.	Mean Error	Stan. Dev.
								m	m	m	m/s	m/s
Part 1	VAM	Auto	Calm	Normal	Pan Am and NASA	1	10	50.3	-1.9	1.0	0.0	0.1
	VAM	Auto	Turb.	Normal		2	10	49.1	-3.1	2.0	-.3	1.2
	No VAM	Auto	Calm	Normal		3	10	58.8	6.6	13.1	.2	.2
	No VAM	Auto	Turb.	Normal		4	10	53.2	1.0	8.8	-.7	1.2
	VAM	Auto	Calm	High		5	10	54.8	2.6	1.8	-.2	0.1
	VAM	Auto	Turb.	High		6	10	53.2	1.0	2.3	-2.0	1.0
	VAM	Manual	Calm	High		7	10	55.6	3.4	2.4	.6	2.2
	VAM	Manual	Turb.	High		8	10	52.4	.2	2.7	-2.0	2.5
Part 2	delta gamma	Manual	Calm	High	NASA	1	6	55.7	3.5	.7	-.4	.7
	mod delta gamma	Manual	Calm	High		2	6	56.6	4.4	1.2	0.0	.8
	Fixed Bar	Manual	Calm	High		3	6	52.8	0.6	3.0	-.2	.6

TABLE 3- PROJECT PARTICIPANTS

Program Management	Pan Am, NASA
VAM Responsibility	Sundstrand Data Control Corp.
Noise Measurements and Data Reduction	Hydrospace Research Corp.
Ground Radar Measurements	Bell Aerospace Corp.
On-Board Data Recording	NASA

Appendix A. NASA Pilot Comments.

1. General.

NASA pilot comments relate to the flight evaluation of the VAM display aboard the B-747 (N750PA), at the Stockton Municipal Airport on March 10, 1972. The average gross weight was about 425,000 pounds with Vref set at 140 knots, for a 25° flap final approach. The approaches were initiated at 3000 feet and completed with a low approach at 100 feet as follows:

	Pilot C	Pilot G
a) Standard Delta Gamma	#17	#24
b) Modified Delta Gamma	#18,#19,#20	#25,#26
c) Fixed Bar	#21	#22,#23

2. Approach Initiation

2.1 Pilot C

I planned to use DME for the steep approach initiation in order to validate this procedure, but was only able to do so on the last 3 runs. My first descents were initiated prematurely when because of poor visibility and concentration on loclizer alignment, I responded to the safety pilots cue without waiting for the desired DME indication. My subsequent impression was that DME would provide a precise method for identifying the steep descent initiation.

With the bar locked on 6°, the steep descent initiation point was clearly identified from the bar location with respect to a ground aiming point near the end of the approach lights. (middle marker "shack") After seeing other accurate pushovers subsequently obtained using the VAM, no clear cut superiority was evident. Either method, therefore, appears suitable at this time, with perhaps the method to be used depending on whether the steepened descent is initiated IFR or VFR.

2.2 The sight was used to initiate all pushovers by waiting until the touchdown point coincided with the desired sight angle. This was done with a fair degree of consistency on all five approaches by pushing over when the touchdown point was coming up on-5°. Power was brought back to idle in most cases to reduce overspeed (velocity). In the two-segment fixed-bar cases, pitch attitude was adjusted to keep the middle marker "shack" at 6°. In the Delta - Gamma run, the bar was "pushed" down to track the touchdown point, while the -4 1/2° mark was the target for the modified Delta - Gamma runs. The sight provided an excellent reference for executing this pitch-over maneuver with ease and minimal overshoot tendency.

3. Steep Flight-Path Segment Tracking

3.1 Pilot C.

The standard delta gamma mode was quite easy to use, with the task being merely to hold the bar on the visually identified touchdown point. I noted some tendency, however, to overconcentrate on the bar and its movement and this detracted somewhat from my visual scan and reference to descent angle and airspeed. This combined with the constantly changing flight-path-angle left me with a feeling I did not have full situation information.

In simulating a -6°/-3° approach using the modified delta gamma mode, I inadvertantly pushed over beyond -6° on one run because I momentarily forgot that the -4 1/2 position on the scale identified a -6° path. The effect on the path was minor but it suggested that steep approach reference marks at -4 1/2° or the appropriate scale position would be desireable. The steep portion required idle thrust to maintain Vref. I chose to use Vref +15 or 20 knots throughout this portion because more thrust modulation was available and the additional speed would be helpful for transition to a 3° path. There was some feeling of "open loop" tracking because the task of holding the bar on the -4 1/2° scale marks was not directly related to an identified ground reference. This was not particularly disturbing, however, on the run in which I made the descent initiation at the desired precise DME point. Tracking data, however, revealed the aircraft closely followed constant 6° paths.

In the fixed bar mode, with the bar fixed at -6° and using the aircraft symbol for pitch control, I was favorably impressed by the ease of interpretation and a feeling of increased precision and situation information. This was no doubt due to the fixed-path reference and readily identified aim point on the ground. While some objection could be raised against an aim point short of the runway, it must be remembered that this is a visual task and the pilot is merely using the steepened descent to get down to the lower path segment reasonably close to the runway. Variations in the initial aim point will merely determine the altitude at which transition to the lower segment occurs. If a positive pushover is established by DME or a reference VAM scale intercept with VAM scale intercept with the touchdown point, the steep descent aim point can be identified after pushover (if one exists). Over water or untextured terrain. Some wander in the steep path segment might be expected.

3.2 Pilot G

The airplane symbol, which was added during the flight and somewhat hard to distinguish, was used for the major longitudinal tracking task on the fixed bar and modified Delta - Gamma runs, that is sight angle to the middle marker "shack" was observed and the aircraft symbol pitch angle was changed to correct any error. For example, I ended up too steep (late pushover) on the second fixed-bar approach and tried to correct by pushing the nose down to -11° on the pitch scale. The radar profile shows that I overshot and got shallow. I felt at home using this mode because of previous experience with the C-8A and the HUD simulation runs. A big disadvantage, of course, is the dependence on a target that is short of the runway. (middle marker "shack")

The Delta - Gamma run was straight forward and quite comfortable to perform. The radar profile showed a classical approach (just like the HUD simulation). The bar was easy to "fly" and as mentioned above, surprisingly steady.

By the time I got around to my last two approaches (modified Delta - Gamma), I had enough practice to get on to the -6° segment with surprising accuracy (within 60 feet), using the sight alone. I held the bar at -4 1/2° and simply monitored the progess of the touchdown point as it progressed up the sight pitch scale from -5° to -3°. There must have been very little wind, because the aircraft tracked beautifully down the -6° segment. The task was simple, but workload was increased a little over the straight Delta-Gamma mode since touchdown point "progress" had to be monitored.

4. The Capture of -3° Glide Slope

4.1 Pilot C

Transition with the standard delta gamma mode was slow and easy to accomplish, yet revealed some minor objectionable features. First was a tendency to focus too much attention on the bar. Based on the simulation experiments, I think that splitting the bar and allowing an open section in the center might alleviate this. Second, the continuous change in flight path requires a gradual increase in thrust, which becomes most noticeable about the time one approaches the -3° path.

With the modified delta gamma display, I actually preferred the more positive shorter transition which the two-segment approach enables. I also prefer to maintain a higher airspeed during the steep segment in order to eliminate any requirement for an abrupt increase in power or tendency to get below Vref. On one run, I was conscious of dropping below the 3° path because of not starting transition soon enough but speed control was not a problem.

With the fixed bar mode, the use of reference marks at -3° (or the desired lower segment angle) on the scale would likely help and could simplify the display even further. Automatic movement of the fixed bar from -6° to -3° at transition would accomplish this but adds complexity which may be unnecessary. The airplane symbol provided an excellent reference for making and interpreting pitch corrections. It provides a natural interpretation of the symbology and I was surprised at how easy this mode was to use. The airplane symbol was too dim and difficult to see particularly on the final segment when superimposed on the white runway. Once you knew where to expect it on the scale, it becomes even more helpful. This was quickly resolved, however, after making a couple of flight path corrections.

4.2 Pilot G

Here is where I had my biggest problem; I consistently "dished-out" low on all five -3° segments. I was surprised to see this on the radar profiles because this tendency was not apparent to me during the flight except on my second run where I called out -2 1/2° at 100 feet. I would expect some misjudgement of the -3° segment using the fixed-bar technique, but even the Delta - Gamma profile was low at -3°.

I didn't find the two-segment technique uncomfortable dispite the fact that the B-747 was about twice as big as anything else I had previously flown. There was some concern felt at about 1200 feet that "it was getting time to start rotating to -3°", but I found myself doing this on the HUD simulation as well. This brings to mind an important aspect of VAM. It is a definite aid to the pilot as a judgement device. There exists a sense of confidence in the transition maneuver (despite the size of the aircraft and relatively low transition altitude) when viewed through the sight because qualitative flight path information is clearly displayed as the nose rotation maneuver for the transition is executed. (immediate-qualitative feedback). Here is where the sight really lives up to its name: visual approach monitor. For example, it is an excellent aid for preventing landing short.

5. Final Flight-Path Segment Tracking

5.1 Pilot C

The records indicated that the final path was shown lower than I felt was apparent from the display. With the standard Delta - Gamma mode, my only problem was in over concentration on the bar. I wanted to focus on the runway rather than the bar, hence, my recommendation for splitting the bar and leaving an open center. The same comment applies to the modified Delta - Gamma runs, also. If it is important to always use the same angles (-6 and -3° for example) it might be desirable to provide special identifying marks, (split bar over scale only) at those locations as an assist to peripheral viewing, otherwise the scale reference as used would be acceptable. With the fixed bar approach, the lack of reference marks at 3° (bar remained at 6°) left me with a feeling of not being constrained to 3°. This is perhaps a desirable condition, but I merely felt that reference marks at the desired lower segment angle would make the pilot more conscious of his flight path situation.

5.2 Pilot G

There was little time to evaluate tracking on the -3° segment. Most of my transitions were too low and completed at an average altitude of about 350 feet. There was, thus, about 15 to 20 seconds tracking time down to the go-around altitude of 100 feet. A review of my comments indicates that I was pretty much satisfied with -3° tracking performance, and felt pretty much squared away on all runs except for the second one where I called out -2 1/2°. I can attribute some misjudgement of the -3° segment in the fixed-bar cases to lack of a reference bar at the -3° point on the pitch scale. The HUD simulation indicated a pronounced improvement of -3° segment tracking in the fixed-bar case when two fixed bars were used. I found the VAM to be an excellent reference for "setting up" the aircraft over the threshold for landing. In most cases, though, I was too fast for a touchdown at the touchdown point due to speed buildup and poor power management.

6. Pilot Preferences

6.1 Pilot C

The visual approach monitor (VAM) flown is a highly desirable method of giving a pilot flight path information for visual approaches of any type. I had mixed feelings as regard to preferences, however. Both of the Delta Gamma modes and the fixed bar mode provides needed, useful information for VFR approaches particularly under dark night, or poor horizon visibility conditions. While major benefits would be realized where no electronic or visual glide slope (VASI) information is available, benefits would also be realized from the increased time the eyes can be kept out of the cockpit.

The simplicity of the standard Delta Gamma mode has a certain appeal for the purely VFR approach. While I had no reversal tendencies, I would recommend a further look at minor changes in symbology. It appears to me that the modified Delta Gamma mode, however, also has potential application for accurate steep descents (2-segment) approaches which are initiated under IFR conditions but completed under VFR conditions. The fixed bar mode is only applicable to the full VFR condition. I preferred it slightly over the Delta Gamma modes for the clearly VFR situation. For marginal VFR conditions, a Delta Gamma mode would be preferred.

6.2 Pilot G

In general, I was favorably impressed with the VAM as a flight path situation monitor in the B-747, and feel it has good potential as a safety device as well as a flight path director or reference for executing multiple segment noise abatement profiles. The Delta-Gamma mode is simple to fly but confuses some pilots when trying to use the bar for anything other than touchdown point tracking due to the gain factors involved. This might suggest a mode selector to switch from "fixed bar" to "Gamma" to "Delta-Gamma". From a tracking workload standpoint, I did prefer the Delta Gamma mode to others. There was less to do, and pilot judgement requirements were at a minimum. Workload, with respect to power management, was not assessed because of the requirement to throttle back to idle due to high L/D. It was almost a "toss-up" as to my preference for the two-segment approaches. I felt that I could do almost as well using the fixed-bar technique as compared to the modified Delta-Gamma. I found the aircraft symbol to be a real asset in judging the magnitude of aircraft pitch attitude correction required to get onto the desired flight path. Without this symbol, the fixed bar tracking workload would have increased considerably as indicated during the HUD simulation evaluation. It was also valuable in helping to judge aircraft pitch rate during the transition. In either case (Fixed Bar or modified Delta Gamma) tracking workload was increased over straight Delta-Gamma, because the pilot must monitor 6° segment progress, anticipate approach to the -3° segment and perform the transition based on line of sight assessment of aircraft position. The modified Delta-Gamma has the advantage of keeping you on a -6° flight path without reference to a ground "target" but not necessarily on the desired segment itself. Tracking precision during the transition and -3° segment is improved with the modified Delta-Gamma mode. Thus from a tracking workload standpoint, I preferred the modified Delta-Gamma mode for two-segment profiles, although I could do almost as well with fixed bar.

APPENDIX B

Pilot Questionnaire for NASA and Pan Am Pilots

1. Did you have any tendancy to overconcentrate on the bar?

   C. A little but much less than on simulator.

   G. I did at first in order to get "on target," but after being established in the approach, I was able to start a pretty good scan. Checking other instruments as well as checking my actual sight angle to the touchdown point.

   W. No.

   JMM. Yes - a little - when flying the bar below 300 to 400'.

   MHM. Yes.

2. Did you have time to cross check your primary flight instruments?

   C. Yes - but should have done more.

   G. Yes - but only the essential ones and my basic scan pattern was: HUD-AIRSPEED-POWER-ALTITUDE. Spent about 75% of the time on the HUD.

   W. Yes.

   JMM. Yes.

   MHM. Yes.

3. Did you have time to cross check your glide slope angle on the scales?

   C. Yes.

   G. Yes - I did this consistently and with natural ease. Primarily due to HUD simulation and C-8A experience with fixed bar work.

   W. Yes.

   JMM. Yes.

   MHM. Yes.

4. How did the workload with the VAM compare to a

   (1) Standard ILS approach?

   G. Less - A VFR task in general but we did not perform any 3° VAM approaches with which to get a quantitative assessment.

   W. Less.

   JMM. Increased - due to extra - monitoring.

   JHM. Same

   (2) VFR approaches?

   G. Little more - extra workload involved in tracking the desired sight picture. Although workload was a little lighter - the sight apprehension over the threshold point.

   W. Same, maybe slightly less.

   JMM. Increased due to extra monitoring.

   JHM. More.

5. What other information, if any, would you like displayed on the VAM?

   C. Major scan was to airspeed. So IAS or speed error signal might be helpful. But display complexity must be kept minimal.

   G. Fixed airplane (permanent) and another fixed bar capability. (Increase versatility for two-segment also.)

   W. A/S or speed error.

   JMM. IAS or CAS if anything is to be added.

   MHM. None.

6. On high approach did the higher-than-normal sink rate concern you?

   C. No.

   G. Not at first, but at about 1200 ft, I found I became concerned of my altitude and noted my particular altitude at that time.

   W. No.

JMM. Yes - because of the necessity for scanning the VAM to maintain a specific G/S angle.

MHM. Yes.

7. Did you have trouble making transition from level flight on the High approach?

C. No - once I found the proper timing on power cut.

G. Yes - there is a basic problem here in the resolution at the pushover point. It is somewhat hard to estimate 1/2 increments, etc. This is why fixed bars are desirable for specific angles rather than trying to estimate.

W. No.

JMM. No.

MHM. No.

8. How did you feel about the curved trajectory you flew on the high approach?

C. Somewhat disturbing - because you don't feel real confident as to position.

G. OK, but I feet it is easier to get squared away on a straight line segment than one that requires a gradually changing pitch attitude and power setting.

W. Not aware that it was a curved path.

JMM. No real problem with or <u>without</u> the VAM so long as visibility is adequate and TDZ markings clearly outlined.

MHM. OK.

9. Was throttle control a problem?

C. Somewhat - even though requirement exists for series of throttle changes (increases) - considered acceptable.

G. Somewhat - on idle most of the time. Bring up the power on the 3° segment did not present too much of a problem.

W. Can't say - throttle was at idle most of the time until 90-around. On Fixed Bar throttle control was not a problem at the 500 ft transition.

JMM. No.

MHM. No.

10. Do you feel an auto throttle is necessary?

C. No.

G. Did not use A/T in 747. Simulator showed A/T reduced pilot workload considerably. Nothing else is <u>essential</u> for the high approaches.

W. Desirable perhaps but not essential. (Might cause noise.)

JMM. Essential - no - desirable - perhaps.

MHM. No.

11. On high approaches, do you feel that you were stabilized on the 3° approach for an adequate amount of time before touchdown?

C. On the good 6 - 3 yes. On regular $\Delta\gamma$ it was acceptable but not as long as desirable. Wasn't as sure when I was on 3° as with mod $\Delta\gamma$ or F.B.

G. No - apparently (after seeing profiles) I was going low on the 3° segment. Felt rushed. Never really felt stabilized.

W. No, but not the fault of the system. In 2 of 3 approached, I did not start down soon enough.

JMM. No.

MHM. No.

12. Did you fly VAM simulator at Ames. If so, who did it compare with that you saw in flight?

C. Yes - Very good correlation. Lower brighten in flight was a help.

G. Yes - Simulator experience - extremely valuable in getting the max out of the 747 approaches. Felt "at home" in the use of the sight.

W. Yes - Too much trim change due to speed change in simulator.

JMM. No.

MHM. Yes - good simulation.

13. Other comments?

C. F.B. last so more at home in A/C. Even so, it was the easiest to adapt to. During first mod $\Delta\gamma$ I inadvertantly put bar on 6° first. Then remembered to go to 4.5. Would need identifying marks to eliminate this problem. Found DME more precise than VAM for start.

G. Sight very useful as an approach path monitor as well as a guidance devised for execution of desired flight path profiles. Transition altitude for two-segment approach should be increased somewhat (750 - 1000 ft).

W. Parallax. Not much difference in displays. No problem with fixed bar. No problem with transition.

JMM. Tendency to correct in the wrong direction when first viewing flight path bar. Somewhat less with later approaches.

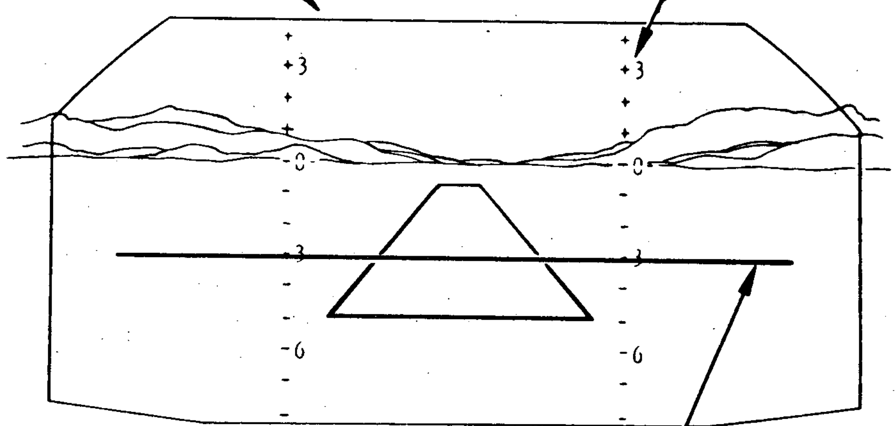
MHM. Tendency to correct in wrong direction.

Viewing Lens

Fabricated of optically ground and coated acrylic plastic – folds down automatically when the unit is stowed, extinguishing the display lighting. The display is self-calibrating.

Approach Angle Scales

Display vertically – one on each side of the lens. Numbers on the scale above zero are in plus (+) degrees, those below zero are in minus (–) degrees. Slope angle to the runway aiming point is read off directly.



Horizontal Bar

Extends horizontally across the width of the lens. In use, it is aligned between the pilot's eyes and the runway. Maneuvering the aircraft to hold the bar on the runway aiming point will cause the aircraft to intercept and maintain a –3° flight path to the TDZ.

Figure 1.- Visual Approach Monitor Display Symbology.

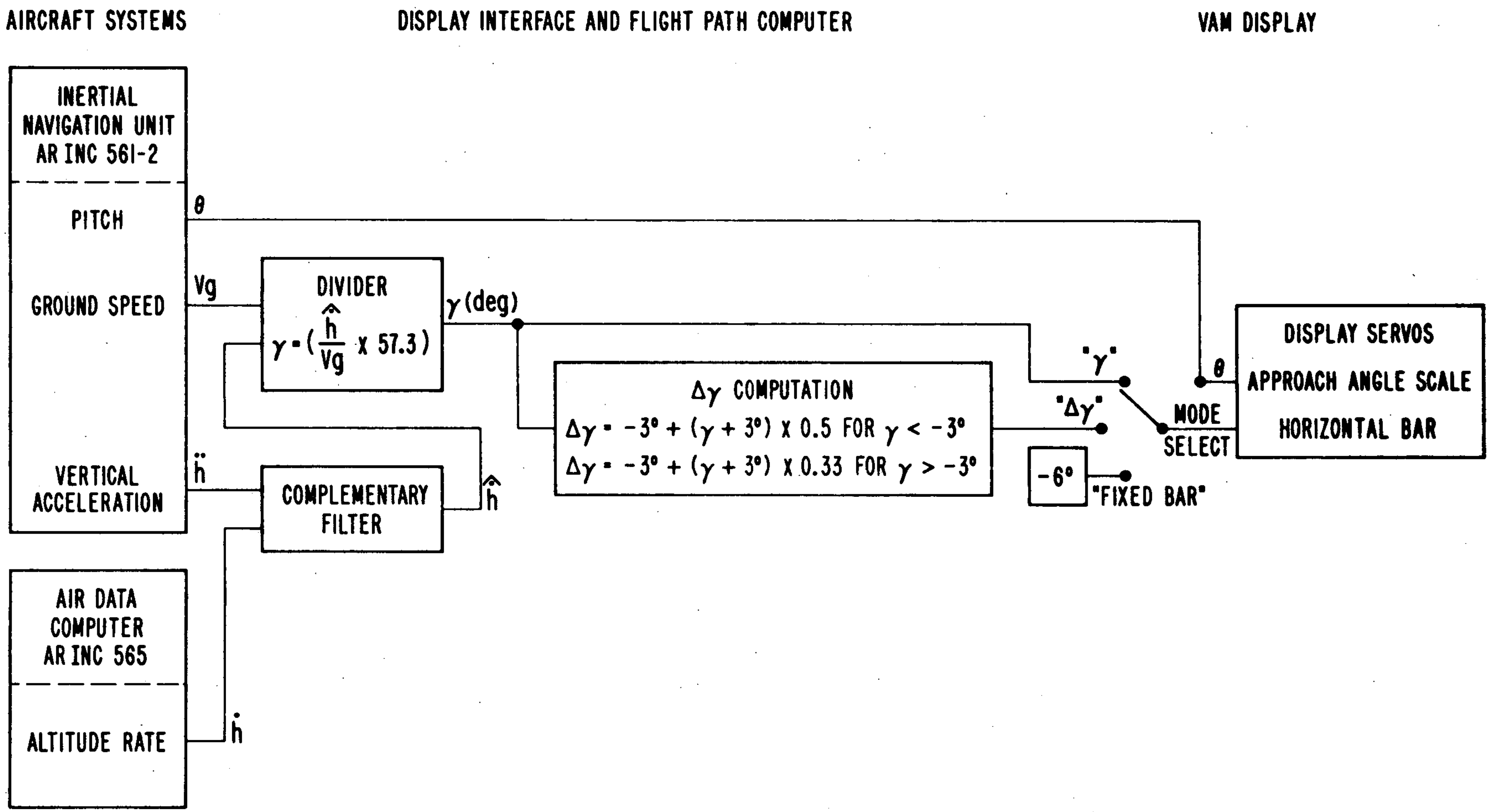


Figure 2.- Interface between the Aircraft Avionics and the VAM display.

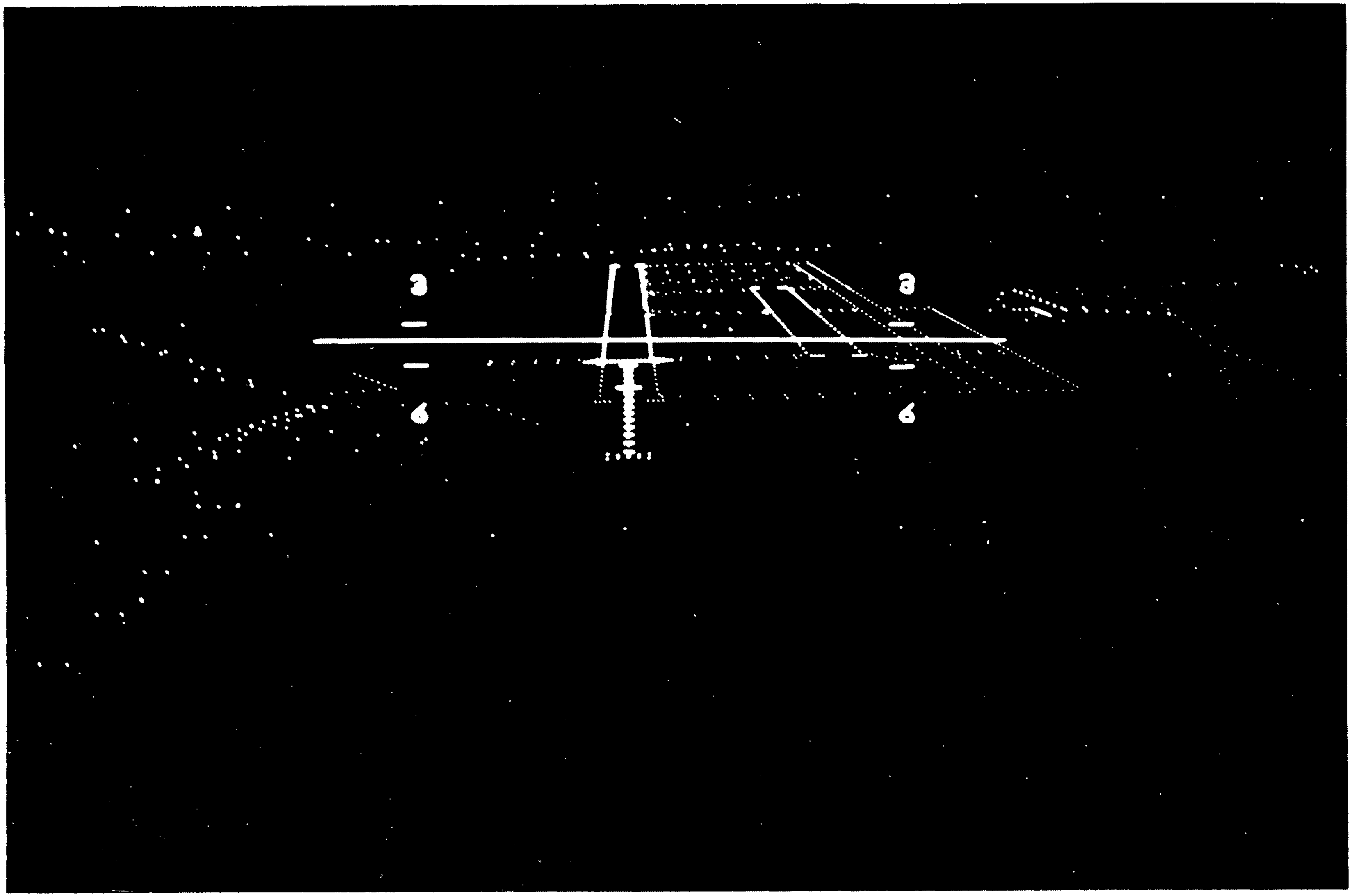


Figure 3.- Simulated night scene of San Jose Municipal Airport and Visual Approach Monitor (VAM).

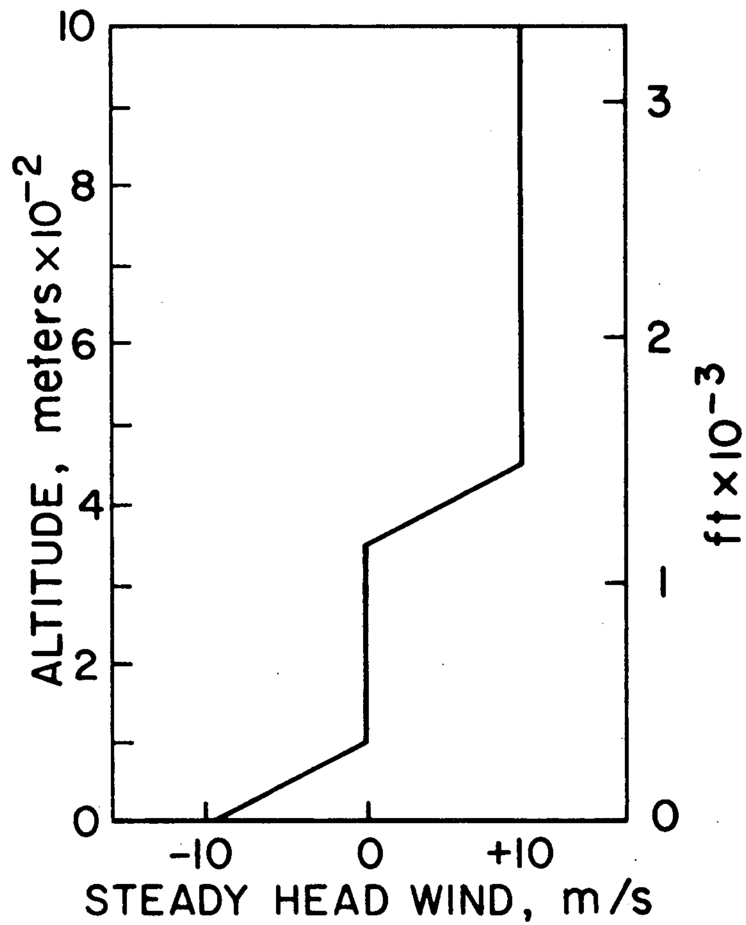


Figure 4.- Head wind profile used during the simulated runs with turbulence.

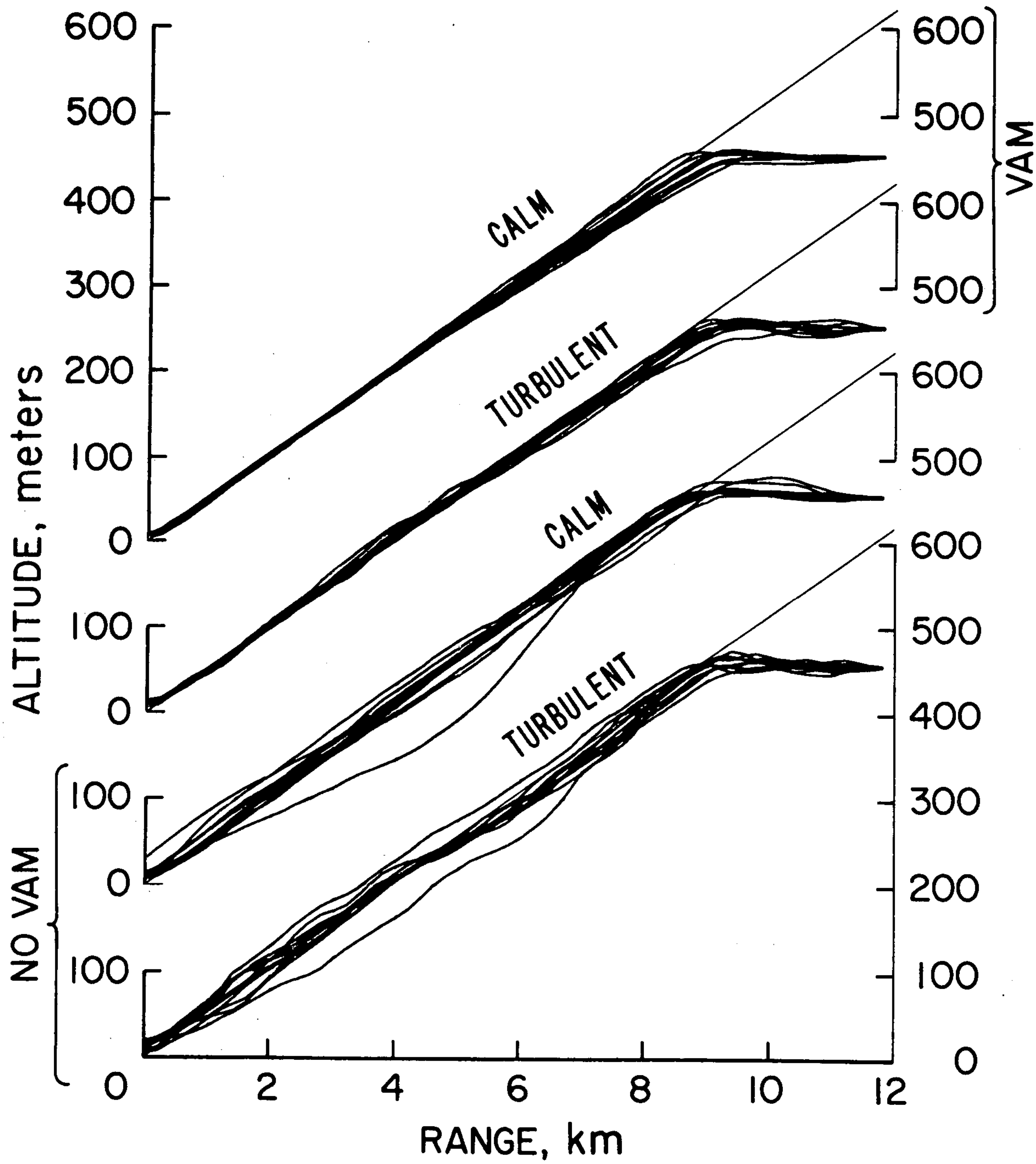


Figure 5.- 3° approaches in flight simulator - all with autothrottle.

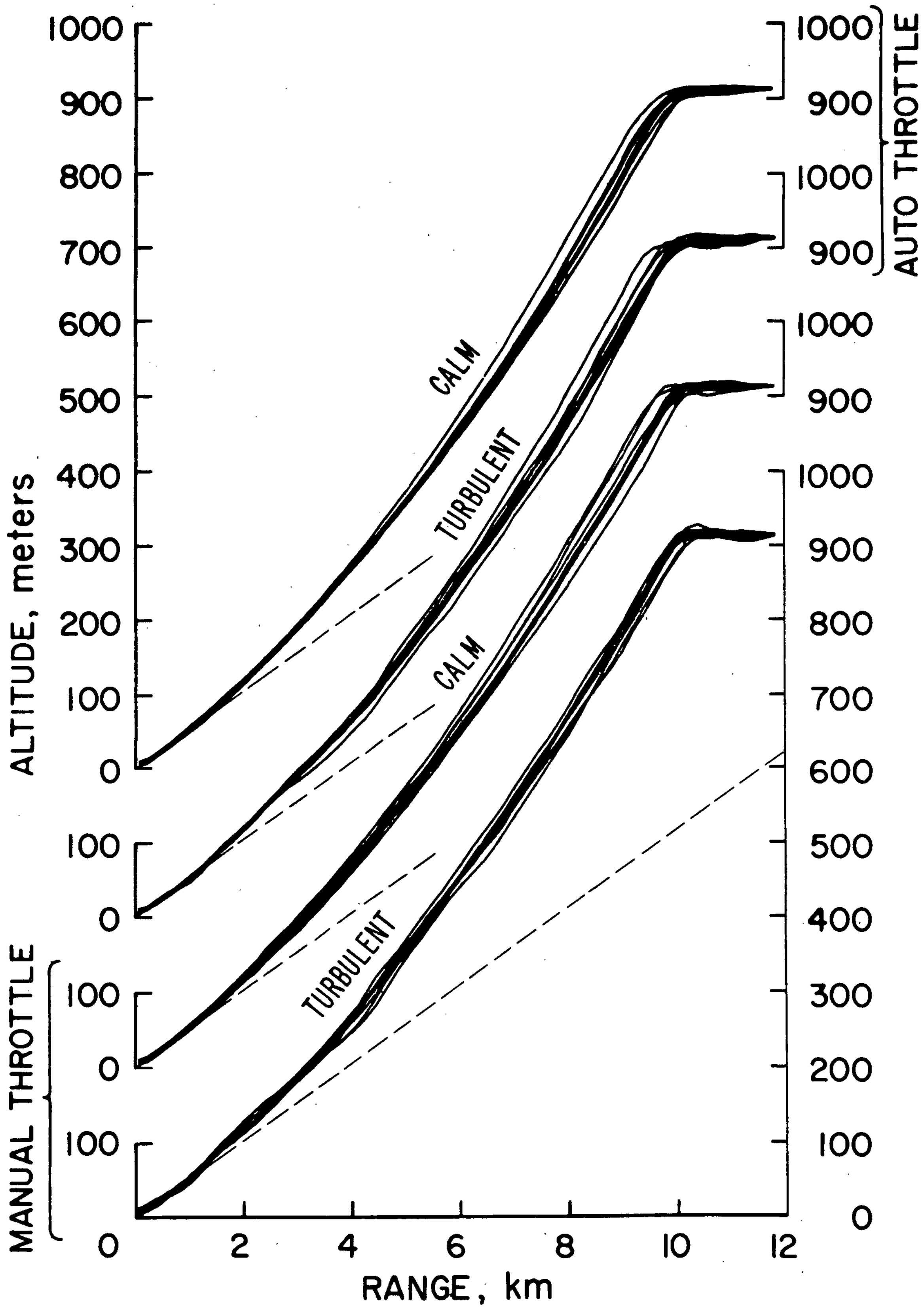


Figure 6.- High capture noise abatement approaches with VAM in $\Delta\gamma$ mode in flight simulator.

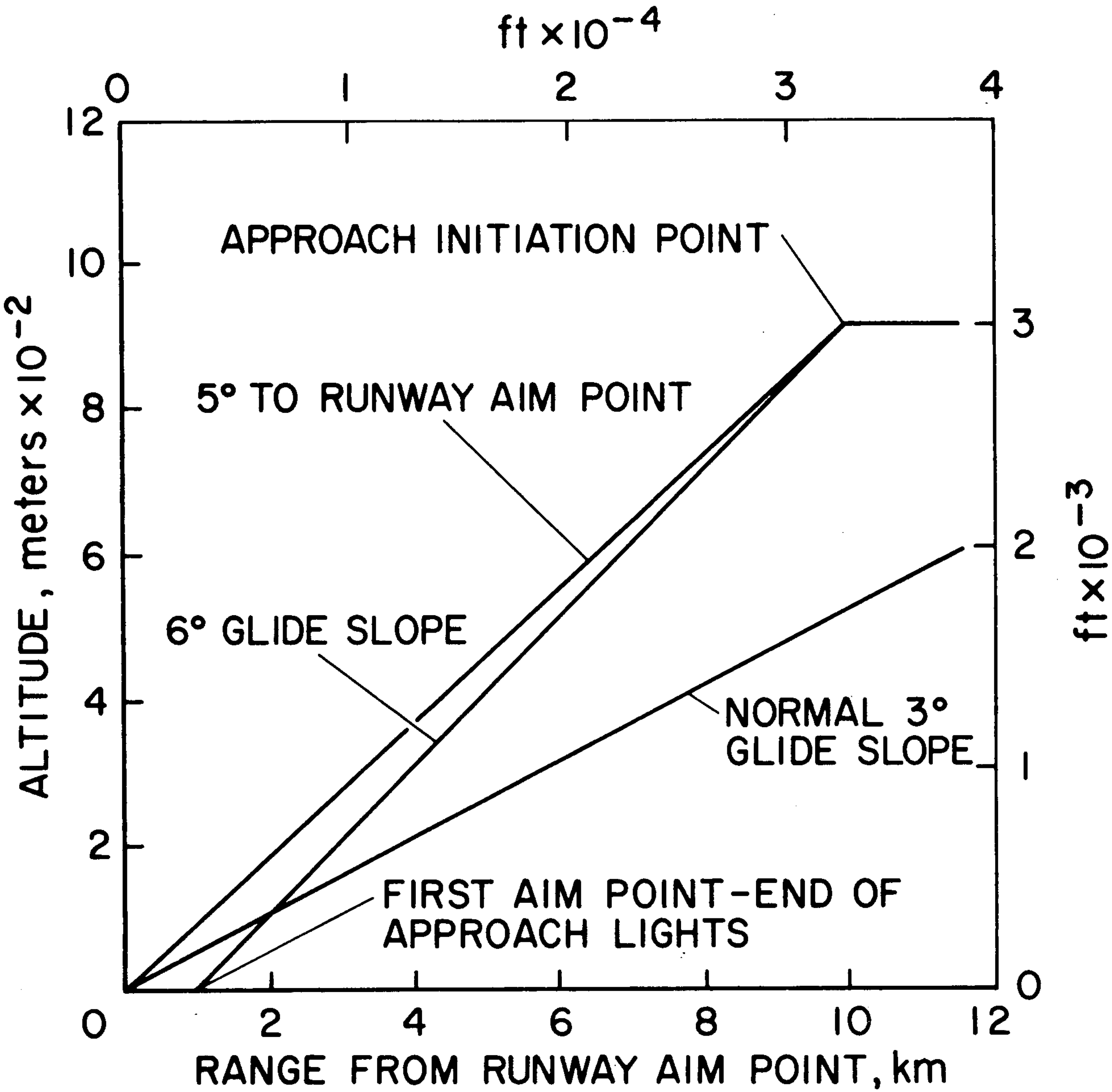


Figure 7.- Nominal Approach Trajectories.

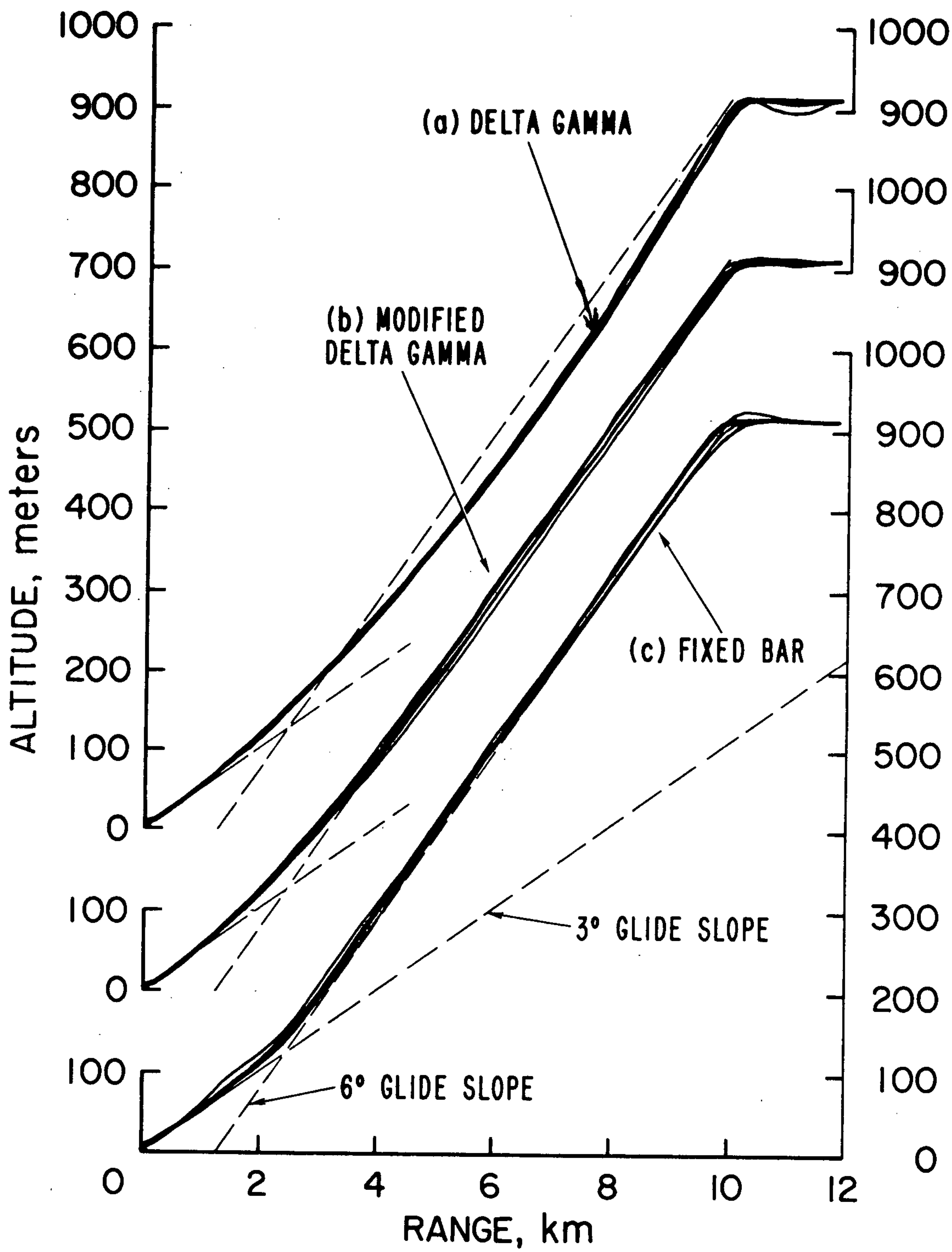


Figure 8.- High capture approaches in flight simulator used to develop procedures for the B 747 flight test. Two NASA pilots - 3 runs each. All with manual throttle and calm air.

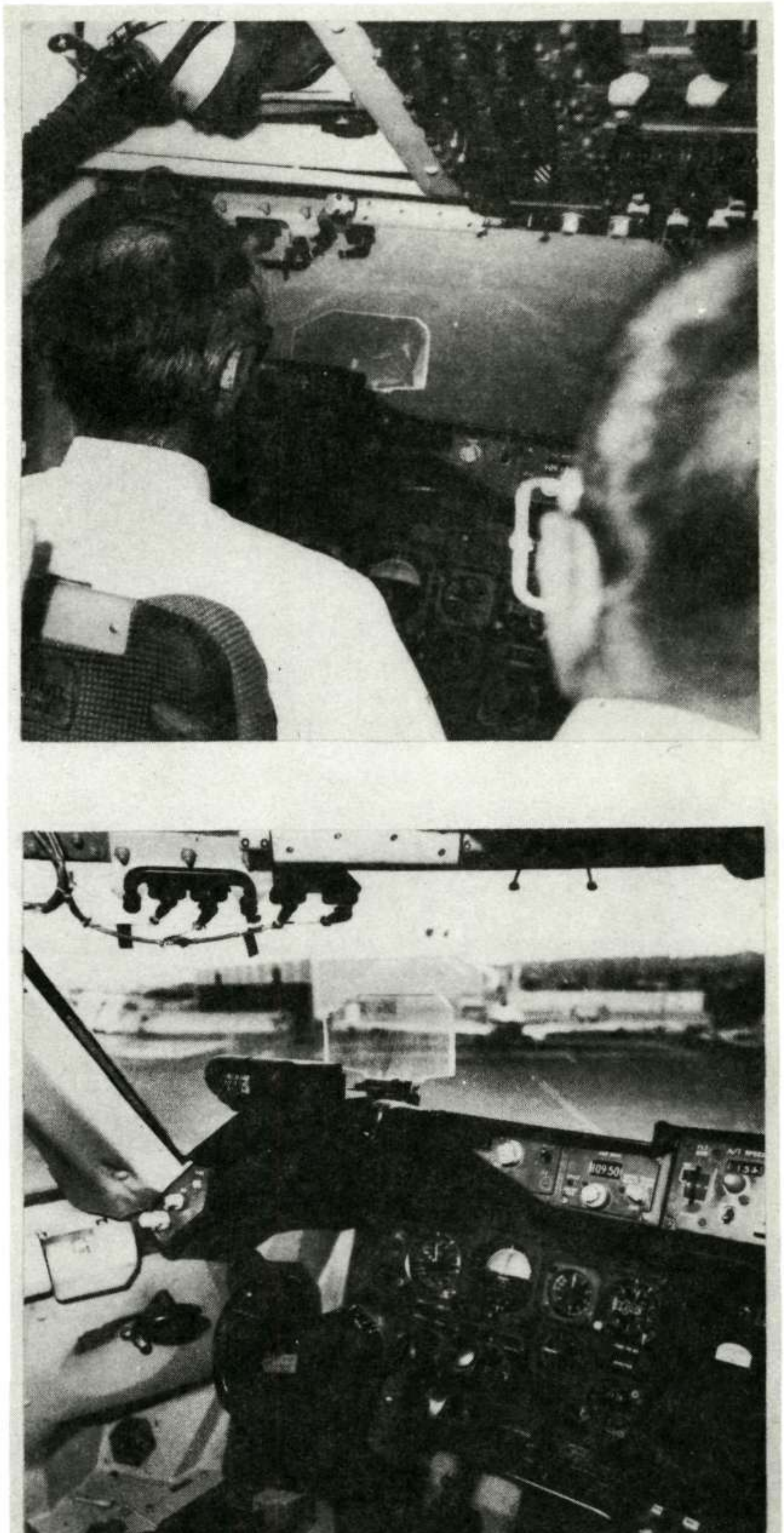


Figure 9.- Cockpit layout with the pilots VAM display.

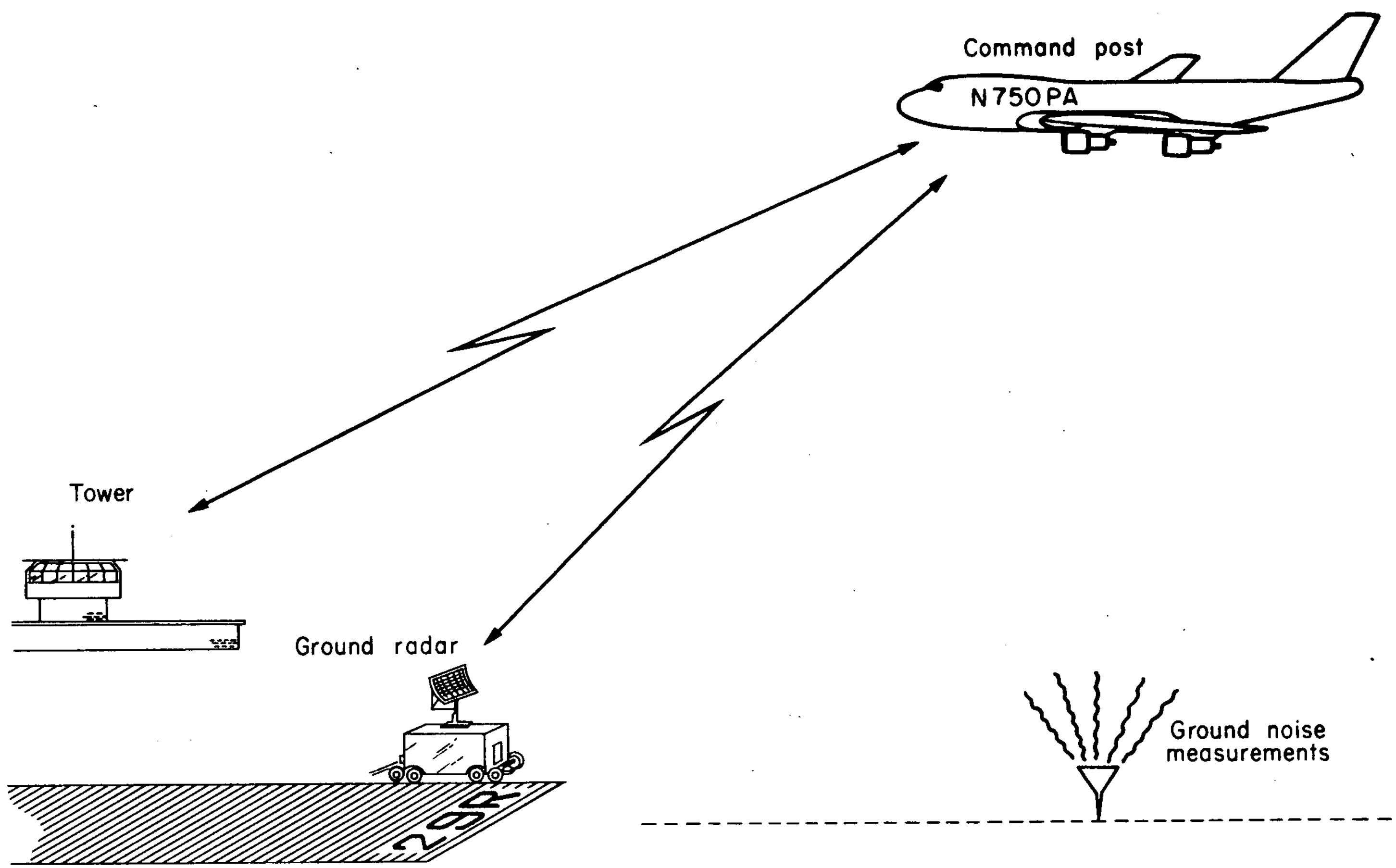


Figure 10.- Elements of Flight Test Program.

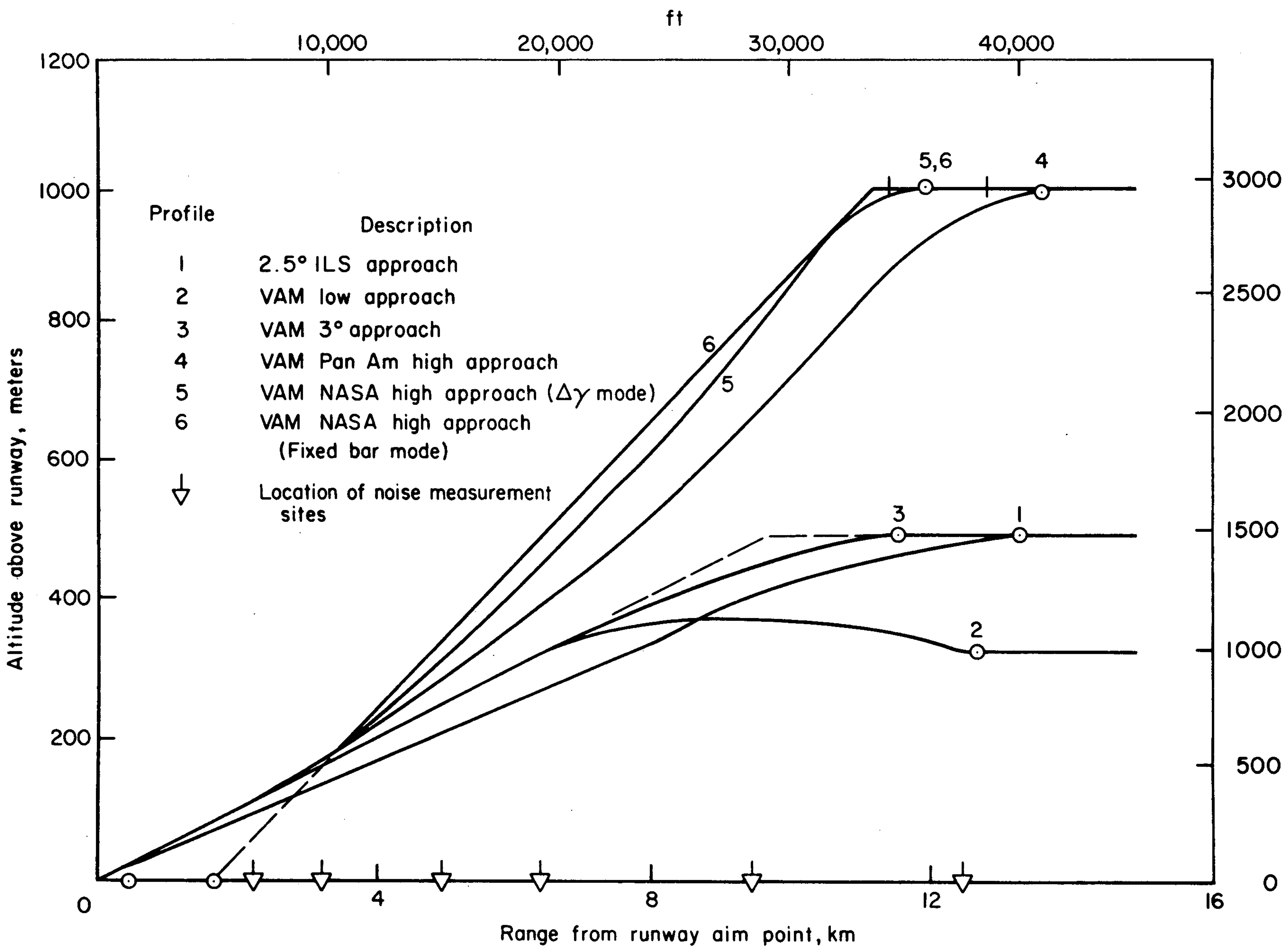


Figure 11.- Flight Profiles.

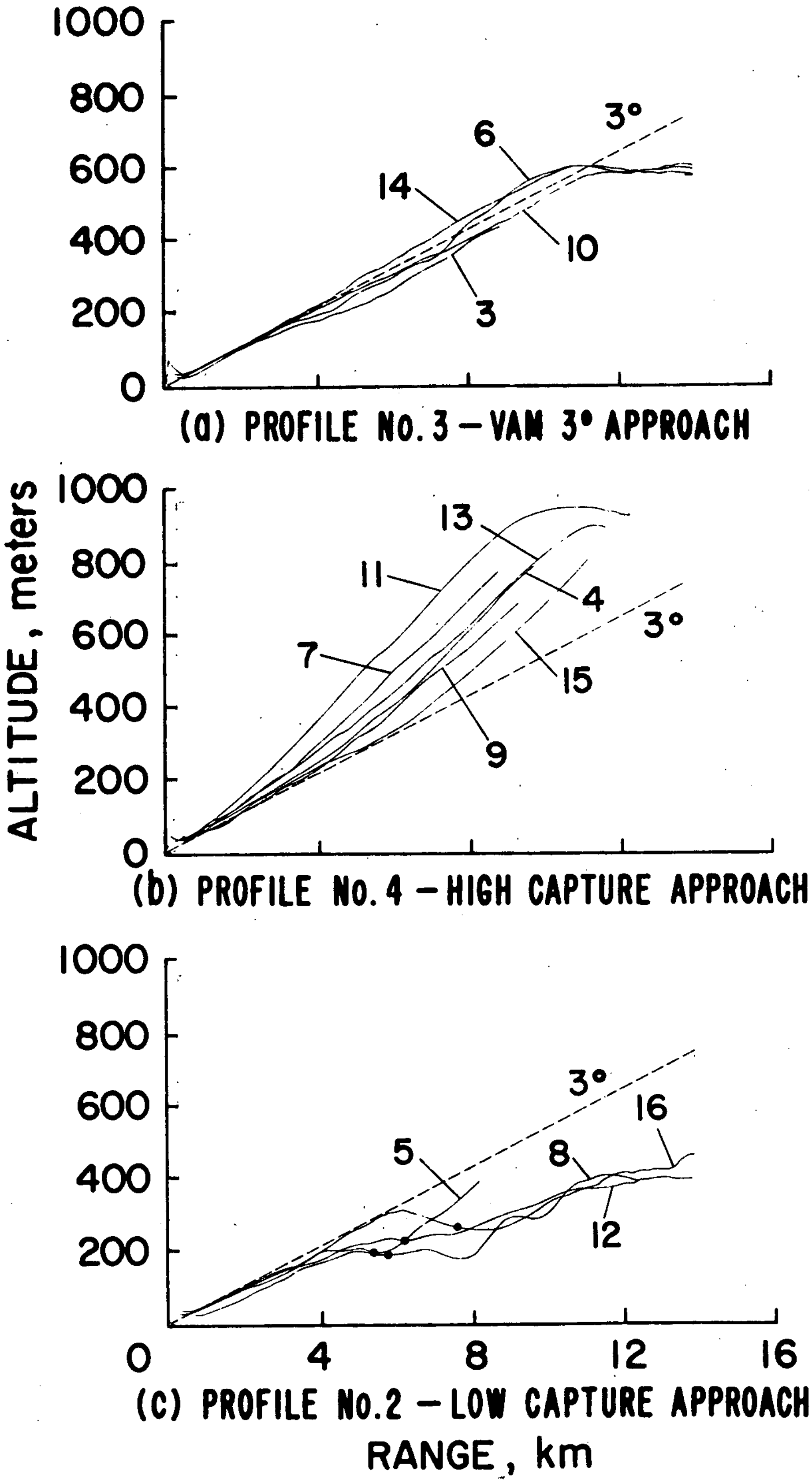


Figure 12.- Radar profiles of VAM delta-gamma approaches flown by Pan Am pilots.

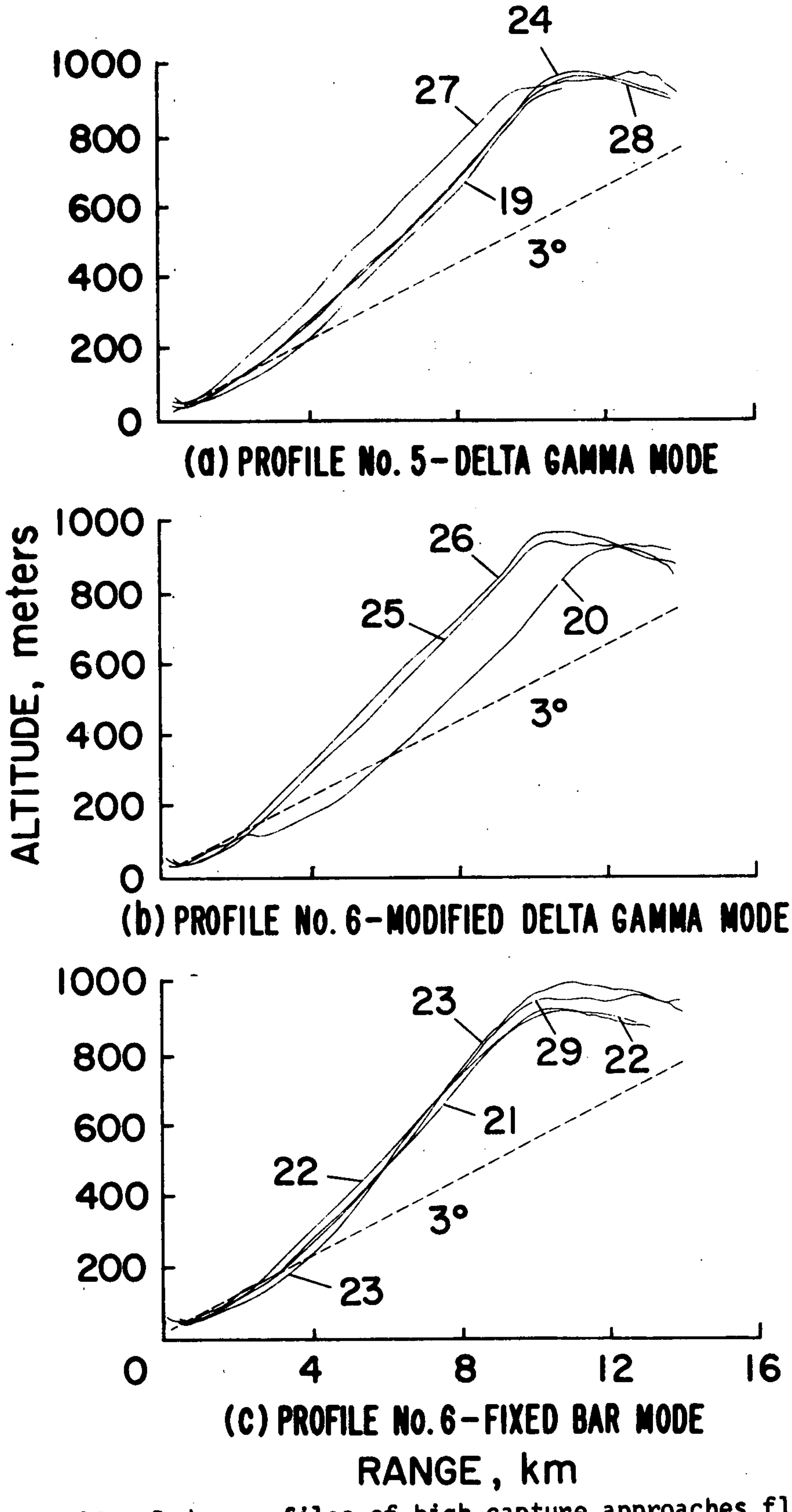


Figure 13.- Radar profiles of high capture approaches flown by NASA pilots.

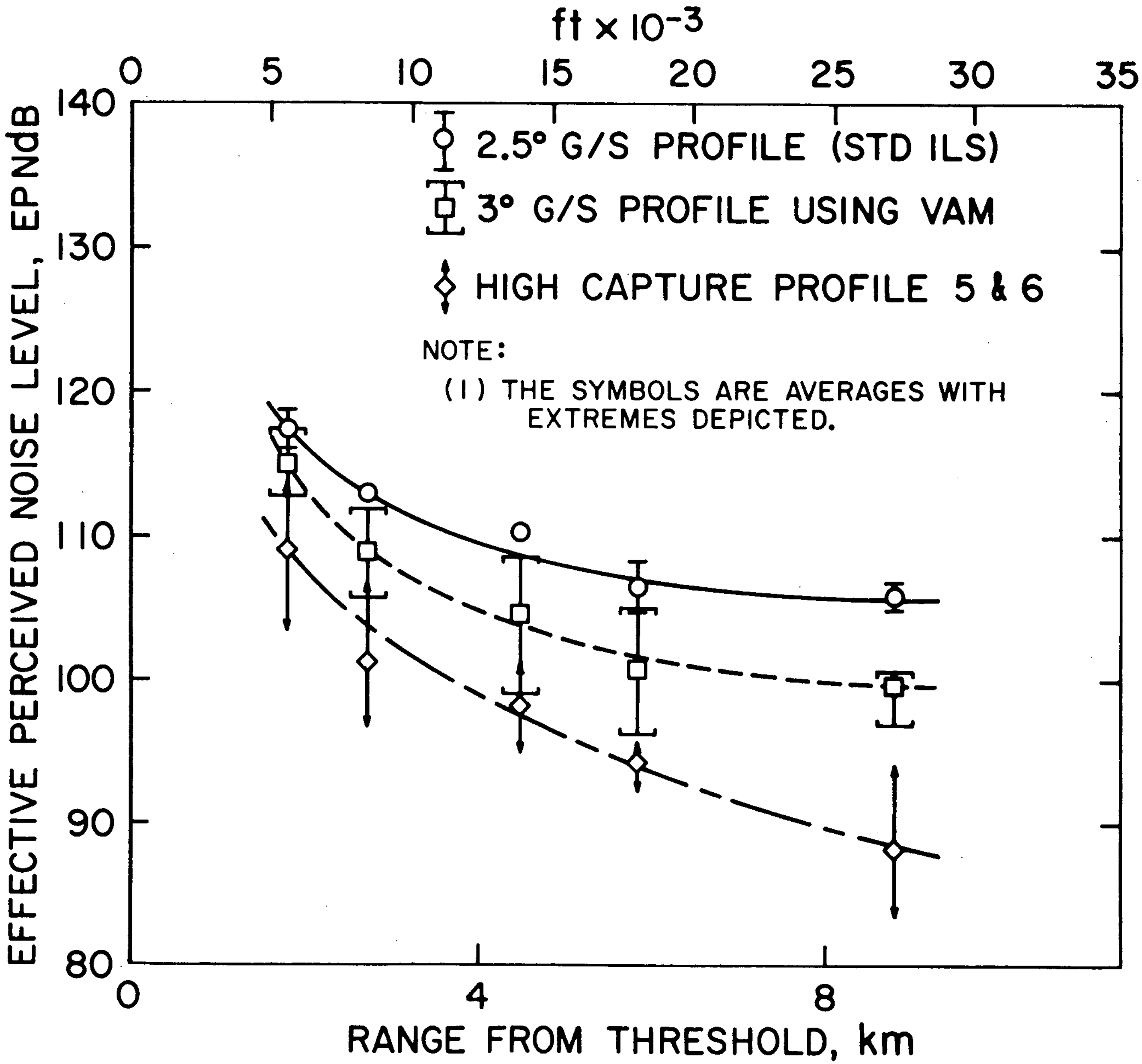


Figure 14.- Summary of Noise Data.