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FLIGHT PERFORMANCE OF THE TCV B-737 AIRPLANE
AT KENNEDY AIRPORT USING TRSB/MLS GUIDANCE

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SUMMARY

On December 4-13, 1977, the Terminal Configured Vehicle (TCV) B-737 airplane was flown at John F. Kennedy International Airport in New York in support of the Federal Aviation Administration (FAA) demonstration of the U.S. candidate Time Reference Scanning Beam (TRSB) Microwave Landing System (MLS). The objective of the National Aeronautics and Space Administration (NASA) participation in the TRSB/MLS demonstration program was to demonstrate practical utilization of MLS guidance for curved, noise-abatement approaches and at the same time acquire useful pilot operational experience. The formal demonstration flights at JFK consisted of 41 automatic approaches. The demonstration flights were preceded by other manual and automatic checkout flights to verify the acceptability of the processed MLS parameters, and to evaluate the performance of the airplane along several candidate curved-path approaches. On the basis of results from these checkout flights a constant-descent version of the VOR Rwy 13L (Canarsie) approach with a 0.44 n. mi. final segment was selected for demonstration. The report presents a summary of the flight performance of the TCV airplane during the demonstration automatic approaches and landings while utilizing TRSB/MLS guidance. Detailed analyses of the performance data are not presented herein.

INTRODUCTION

The NASA Langley Research Center's Terminal Configured Vehicle (TCV) program operates a highly modified Boeing 737 airplane which contains a second research cockpit in addition to a large amount of experimental navigation, guidance, and control equipment for conducting flight research on advanced avionics systems and displays. The FAA requested that NASA use the TCV B-737 to provide demonstrations of the TRSB/MLS being proposed by the United States as a new international standard landing guidance system to replace the presently used Instrument Landing System (ILS) and Precision Approach Radar (PAR). The first such demonstration was conducted at the FAA's National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey in May 1976 for members of the International Civil Aviation Organization (ICAO), industry and government officials, and representatives of the news media. The flight results from the NAFEC demonstration are documented in references 1 and 2 which also include descriptions of the TCV airplane equipment, MLS processing, and control laws. The latter were modifications of the original ILS control laws, since insufficient time was available to develop new control laws designed for MLS. Similar demonstrations were subsequently requested for Buenos Aires, Argentina in October 1977, for New York in December 1977, and for Montreal, Canada in March 1978.

This report summarizes the flight performance results of the TCV airplane during the demonstration automatic approaches and landings conducted at the John F. Kennedy International Airport in New York. The TRSB system demonstrated at JFK was installed on runway 13L and consisted of the Basic Wide azimuth subsystem, the Basic Narrow elevation subsystem, and a precision L-band DME (reference 3). Observers carried on these demonstration flights included representatives of the U.S. Congress, Air Line Pilots Association (ALPA), Air Transport Association (ATA), foreign embassies, New York civic groups, and various news media. References 4 and 5 are pertinent magazine articles describing the MLS demonstration flights at JFK.

ABBREVIATIONS AND SYMBOLS

CAT II	Category II Landing Minima {30.5m (100ft) decision height, 366m (1200ft) runway visual range}
CAT IIa	Category IIa Landing Minimum {runway visual range 213 m (700 ft)}
CWS	Control Wheel Steering
DELTH	Vertical error signal input to autoland control law
DELTY	Lateral error signal input to autoland control law (negative of crosstrack error)
DME	Distance Measurement Equipment
EADI	Electronic Attitude Director Indicator
EHSI	Electronic Horizontal Situation Indicator
FAF	Final Approach Fix
GPIP	Glide Path Intercept Point
HER	Vertical error signal input to RNAV control law (negative of altitude error)
IDD	Inertial and dual DME area navigation mode
IDX	Inertial and single DME area navigation mode
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IXX	Inertial area navigation mode
MLS	Microwave Landing System

NCDU	Navigation Control and Display Unit
NCU	Navigation Computer Unit
PAR	Precision Approach Radar
RNAV	Area navigation
R_{Rhumb}	Rhumb line distance from MLS azimuth antenna (60 X Δ latitude ÷ cosine of the course angle from true North)
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
TRSB	Time Reference Scanning Beam
VOR	Very high frequency Omnidirectional Range
$\hat{X}$	Estimated position along runway centerline extended from MLS azimuth antenna
XTK	Lateral error signal input to RNAV control law
$\hat{Y}$	Estimated perpendicular distance from runway centerline extended
Δh	Altitude above local terrain
ΔHER	Change in HER at conventional/MLS RNAV transition
$\overline{\Delta t}$	Mean time interval between events
ΔXTK	Change in XTK at conventional/MLS RNAV transition

TCV RESEARCH AIRPLANE

The TCV Program operates a Boeing 737-100 airplane (Figure 1) to conduct flight research aspects of the program. The airplane is equipped with a special research flight deck, located about 6m (20 feet) aft of the standard flight deck. An extensive array of electronic equipment and data recording systems is installed throughout the former passenger cabin (Figure 2).

The airplane can be flown from the aft flight deck using advanced electronic displays and semi-automatic or automatic control systems that can be programmed for research purposes. Two safety pilots located in the front flight deck are responsible for all phases of flight safety and most traffic clearances. Two research pilots usually fly the airplane from the aft cockpit during test periods, which can last from takeoff through landing. The only normal flight systems that cannot be controlled from the aft flight deck are the landing gear and the speed brakes, which are operated by the safety pilots in response to annunciators. The safety pilots can take control of the airplane at any time by overpowering the aft flight deck controls or by disengaging the aft flight deck.

The aft flight deck (Figure 3) includes three monochromatic Cathode Ray Tube (CRT) displays that are available to each research pilot. The lower display is the Navigation Control and Display Unit (NCDU) which allows each pilot to control and monitor the airplane's navigation computer. The computer can access airway, Standard Instrument Departure (SID), Standard Terminal Arrival Route (STAR), and runway data for the geographic area of interest.

The center display is an Electronic Horizontal Situation Indicator (EHSI) that provides each pilot with a pictorial navigation display of the airplane's position relative to desired guidance path, flight plan waypoints, and selectable local points of interest such as airfields, obstructions and radio navigation aids.

The top display is an Electronic Attitude Director Indicator (EADI) that provides the pilots with a display of the airplane's pitch and roll attitude for instrument flight. Other symbols for flight path acceleration, flight path angle (actual and commanded), lateral and vertical guidance, and speed error are integrated into the EADI display format. A forward-looking, low-light-level television image (from a TV camera located in the airplane's nose) can be presented on the EADI in registration with the symbols. A computer-generated runway drawing, showing the true perspective of the runway (based on navigation position estimates) can also be displayed during approach and landing.

The TCV airplane's navigation, autoland and autothrottle systems permit the plane to fly complex two-, three-, and four-dimensional (position and time control) flight paths. The flight plan can either be programmed before takeoff or developed and modified in flight through the navigation computer's keyboard. An on-board data acquisition system records pertinent flight information for analysis after a test. Information can also be transmitted to a ground station within a range of 50 n. mi.

CANARSIE APPROACH INTO JFK

The Canarsie approach over Jamaica Bay and the Shore Parkway is a route designed for avoiding traffic conflicts with La Guardia Airport to the northeast (Figure 4) and for reducing the impact of aircraft noise over heavily populated residential areas (reference 3). The published approach chart is shown in Figure 5. It requires at least a 244m (800 ft) ceiling and 2n. mi. visibility. The visual portion is defined by high intensity flashing lead-in lights on the ground which are located along an arc of 4511 m (14800 ft) radius. An MLS volumetric coverage precision guidance system could allow similar approaches under Instrument Meterological Condition (IMC).

The TRSB/MLS demonstration approach profile chosen followed the ground track of the published approach to runway 13L, as shown in Figure 6, from Canarsie VOR (CRI) inbound. A constant 3.15-degree glide path was followed. The dashed line indicates the ±60-degree azimuth coverage about the runway centerline provided by the MLS. The turn is of constant radius and requires a nominal bank angle of about 8 degrees. The straight-in portion was 0.44 n. mi. to the displaced threshold. The MLS ground configuration for the TCV B-737 flight demonstrations at JFK is shown in Figure 7. The control law schedule of the TCV B-737 during the automatic Canarsie approaches is depicted in Figure 8. The average elapsed time between Autoland engagement and decrab for the demonstration flights was only 3.4 seconds which illustrates the demanding nature of the Canarsie-type approach.

FLIGHT RESULTS AND DISCUSSION

The flight performance data obtained during the TRSB/MLS demonstration flights of the TCV B-737 at JFK are presented in Table I. These data are presented in chronological order for selected points along the approach and landing path: at conventional/MLS RNAV transition, the final approach fix, the CAT II decision height, and at touchdown. The final approach fix data are shown as determined from both the navigation computer and the flight control computer. At this point the lateral axis was still being controlled by the RNAV system, and the longitudinal axis was in the Autoland glide path tracking mode. The data therefore represent flight technical error of the RNAV system in the lateral axis, and of the Autoland system in the longitudinal axis. Only eight of the forty-one automatic approaches resulted in manual landings from the forward flight deck, the others were successful automatic landings. The manual landings were mostly caused by the inability of the RNAV control system to consistently deliver the aircraft to the final approach fix as accurately as required for the very short final approach leg, but two were caused by equipment malfunctions.

The winds presented in Table I were derived from the onboard inertial navigation system. The conventional presentation format is followed; the first pair of numbers is the compass direction from which the wind is blowing expressed to the nearest 10-degree increment (e.g. 08 = 80 degrees) and the second pair is the wind speed expressed in knots. The mean values and estimated standard deviations of the wind speed along the approach are shown at the bottom of the table, along with similar statistics on the flight technical errors.

Typical Approach Data

Representative data for one of the approaches are presented in Figure 9 showing the cross track and elevation deviations from the planned curved approach path according to the received MLS signals. These data do not indicate performance of the MLS, but rather performance of the airplane's guidance system utilizing MLS. However, analysis of photo-theodolite tracking data from reference 1 indicates that the MLS guidance accuracy is comparable to the photo-theodolite accuracy and therefore the MLS-derived position errors DELTH and DELTY are good indications of path following error.

These data are annotated to indicate various discrete events along the approach corresponding to the control law schedule shown in Figure 8. The winds derived from the navigation computer are shown for three way-points along the approach path. At TRSB enable the airplane changes guidance from conventional RNAV (dual DME) to MLS RNAV. Under RNAV guidance the airplane on its constant curved 3.15-degree descent approaches the 3.15-degree planar glide path from above. The switch from RNAV to Autoland vertical guidance occurs when the airplane comes within 0.108 degrees of the planar glide path. The switch from RNAV to Autoland guidance in the cross track (lateral) direction occurs approximately 0.44 n. mi. from runway threshold, when the airplane comes within 9.8 m (32 ft) of runway centerline with a bank angle of less than 3 degrees and a ground track within 0.27 degrees of runway heading. This left very little time for the Autoland guidance system to reduce any RNAV guidance delivery errors. Decrab occurs at 45.7m (150 ft) altitude provided lateral guidance is in the Autoland mode. Flare occurs at variable altitudes based on the airplane's sink rate and radar altitude.

Conventional/MLS RNAV Transition Offsets

Figure 10 presents a summary of the TRSB-derived position $\hat{X}$, $\hat{Y}$ at the time of TCV B-737 airplane transition from conventional RNAV guidance to MLS RNAV guidance. The location of this transition point was dependent upon valid MLS azimuth and elevation data being received on the airplane for 10 seconds and subsequent pilot-initiated switchover at his discretion after receiving an MLS valid annunciation. This transition offset is recognized as an area which deserves additional research since the flight maneuver to correct navigation errors upon entry to MLS coverage should be as smooth as possible. Also it is undesirable for large path corrections to be required close to the runway threshold. For the TCV B-737 demonstration flights at JFK the conventional/MLS RNAV transition offset statistics (Table I) were:

	Mean, m	Est. Std. Dev., m
ΔXTK	-169.1	± 204.3
-ΔHER	-35.8	± 35.5

The airplane was generally to the left of and slightly below the intended track at transition from conventional RNAV guidance to MLS RNAV guidance. The large mean offset in XTK appears to have been due mainly to an error in the geographical location of the JFK VORTAC in NCU bulk data storage, which was not updated to reflect a relocation of that navaid during earlier construction at the airport. The component of VORTAC position error in the XTK direction was -184.3 m.

The altitude offset, as may be seen in Figure 11, appeared to be a function of position. It should be noted that the path geometry was such that almost all transitions to TRSB guidance occurred outside the specified coverage of the elevation antenna, and the mean altitude offset was approximately zero as the coverage boundary was approached near waypoint INTER (Figure 10). The isolated point with the large positive altitude offset differed from the previous run by +143 m. A possible explanation for this anomaly may be that the pilots re-initialized the NCU prior to this run and failed to re-enter the current altimeter setting. In this case the standard setting of 29.92 inches of mercury would have been used. Interpolation from weather maps for the flight period indicates the correct setting was 30.33 inches of mercury, which would result in an error of +125 m. The curve through the data is a second-order polynomial obtained by using the method of least squares (without considering the previously mentioned suspect data point).

Automatic Approach and Landing Criteria

Figure 12 schematically depicts the FAA certification criteria for automatic approaches and landings using ILS guidance. Also shown is the localizer mode capture threshold at the final approach fix that was used for the TCV B-737 approaches. The flight performance data from Table I are compared with these criteria in Figures 13 to 16 in order to provide some quantitative measure of the TCV B-737 approach and landing performance utilizing MLS guidance in lieu of conventional ILS guidance.

Final Approach Fix Delivery Errors

Figures 13 and 14 present the autopilot guidance errors at the final approach fix as determined from the navigation computer and the flight control computer, respectively. The localizer track mode is engaged when the airplane comes within 9.8 m (32 ft) of runway centerline with a bank angle of less than 3 degrees and a ground track within 0.27 degrees of runway heading. As indicated in Figure 14 five of the automatic approaches did not result in automatic landings but were completed manually by the safety pilots located in the Forward Flight Deck. Four other approaches shown were not within the localizer mode capture range with the airplane at the location of the final approach fix but were shortly thereafter.

CAT II Decision Height Delivery Errors

Figure 15 presents the TCV B-737 approach performance data at the CAT II decision height altitude of 30.5 m (100 ft). The FAA autopilot certification criteria (2σ) for CAT II and CAT IIIa conditions are ±19.5 m lateral and ±3.7 m vertical deviation from localizer and glide path track, respectively (references 6 and 7). As shown in the figure the TCV flight performance data easily met these criteria (2σ) with ±8.6 m lateral and ±2.3 m vertical errors. The mean value of the data was 0.8 m above the glide path and 0.4 m to the right of the extended center. For comparison purposes the scale of the airplane is also shown in the figure.

Touchdown Performance

Touchdown times were assumed to be the earliest of the times at which the right landing gear strut squat switch closed or either main gear wheel speed reached approximately 60 knots. These events are indicated by the value of data bits which are output 20 times per second by the flight control computers. The TRSB-derived latitude and longitude at touchdown time was used to calculate the rhumb line distance from the azimuth antenna. This method was used because data system problems caused the TRSB-derived values of $\hat{X}$ to be lost on some runs. A comparison of the rhumb line distances with $\hat{X}$ for all the runs where the latter was available showed that the mean R_{Rhumb} was 4.3 m greater than the mean $\hat{X}$, and the estimated standard deviation was 0.3 m greater for R_{Rhumb}. The values of DELTY were not affected by the data recording problem.

Figure 16 presents a summary of the touchdown performance data for the TCV B-737 automatic landings at JFK. These data are compared with the FAA certification criteria (2σ) for Autoland Systems, 457 m footprint distribution down the runway and ±8.2 m from centerline (reference 8). In the figure this footprint is arbitrarily located with respect to the Glide Path Intercept Point (GPIP). The TCV B-737 landings easily met the above criteria with a touchdown dispersion (2σ) of 146.8 m along the runway and 2.4 m across the runway. The mean value of these touchdown data is located 2701 m from the MLS azimuth antenna, which corresponds to 81 m beyond the GPIP (see Figure 7), and 0.7 m left of runway centerline.

CONCLUDING REMARKS

The NASA TCV B-737 participation in the TRSB-MLS demonstration at JFK proved the capability of MLS for providing adequate guidance for flying curved automatic approaches with short finals. During the TCV B-737 automatic MLS approaches at JFK no piloting problems were identified.

REFERENCES

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5. Kocivar, Ben: We Fly the New, Safer Microwave Landing System. Popular Science, May 1979, pp. 84-88.

6. FAA Advisory Circular No. 120-29: Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operations, September 1970.

7. FAA Advisory Circular No. 120-28B: Criteria for Approval of Category IIIa Landing Weather Minima, December 1977.

8. FAA Advisory Circular No. 20-57A: Automatic Landing Systems, January 1971.

TABLE I. - SUMMARY OF FLIGHT PERFORMANCE OF THE TCV B-737 AT JFK AIRPORT USING TRSB-MLS GUIDANCE

DATE	FLT/RUN	CONVENTIONAL/MLS RNAV TRANSITION (1) (ref. figures 10 and 11)				FINAL APPROACH FIX (1) (ref. figure 13)		
		$\hat{Y}$, m	ΔXTK, m	-ΔHER, m	WINDS	XTK, m	-HER, m	WINDS
12/4/77	205/8	9861.2	- 6.1	- 36.6	2713	-12.2	- 3.7	2908
	/8R1	9808.2	-170.7	- 43.9	3011	- 3.2	- 4.7	2711
	/8R2	10242.8	73.2	- 43.9	2813	-11.2	- 3.7	2808
12/5/77	206A/3	8790.4	-246.3	- 37.8	1038	- 9.8	- 3.6	0717
	/3R1	8583.2	-270.7	- 32.9	1237	- 9.2	- 2.4	0620
	/3R2	9495.4	-352.3	- 29.3	1138	- 4.1	- 3.7	0815
	206B/3	8826.4	-387.7	- 46.3	1136	-21.9	- 2.4	0619
12/6/77	207A/3	4298.0	-109.7	2.4	2621	- 5.5	- 1.6	2515
	/3R1	3992.6	-142.6	1.2	2830	0.2	- 2.3	2614
	/3R2	4396.1	-206.0	13.4	2824	-52.4	- 1.2	2715
	207B/3	6650.1	-354.8	4.9	2930	2.4	0	2716
	/3R1	7626.4	-309.7	14.6	2927	3.2	- 3.7	2717
12/7/77	208A/3	8710.6	-195.1	- 35.4	3035	- 8.4	0.4	2513
	/3R1	7789.8	-331.6	- 71.9	2930	- 7.3	2.0	2616
	/3R2	10266.0	-199.9	- 43.9	2934	2.1	1.2	2716
	208B/3	-------	-124.4	- 29.3	3030	-----	----	2920
	/3R1	-------	-142.6	- 26.8	3036	6.8	1.9	2911
	/3R2	7034.5	-328.0	- 20.7	2931	- 1.2	3.7	3017
12/8/77	209A/3	7714.5	-268.2	- 46.3	3315	- 4.8	2.4	3307
	/3R1	8795.3	-295.0	- 46.3	3313	-----	----	3506
	/3R2	8326.2	-213.4	- 43.9	3411	-13.2	3.7	2702
	209B/3	8457.3	412.1	- 70.7	3110	- 7.9	4.6	3603
	/3R1	8225.6	-482.8	- 32.9	3209	- 1.0	- 1.2	3204
	/3R2	8133.6	-309.7	- 43.9	3210	-10.2	2.4	3004
12/9/77	210A/3	4922.5	-264.6	- 23.2	2332	0.4	2.4	2114
	/3R1	6100.0	-291.4	- 12.2	2334	0	- 1.2	2218
	/3R2	5489.8	-529.1	- 8.5	2435	2.5	- 0.6	2325
	210B/3	5499.2	-246.3	- 4.9	2628	2.4	- 0.9	2422
	/3R1	5582.1	-336.5	3.7	2832	6.1	2.4	2721
	/3R2	6174.9	-321.9	- 59.7	2824	-22.9	1.2	2619
12/12/77	212A/3	11557.4	- 51.2	- 84.1	2407	- 6.0	0	1412
	/3R1	11608.0	- 61.0	- 97.5	2407	- 9.8	1.2	1511
	/3R2	10763.7	26.8	- 85.3	2107	- 7.6	0.5	1510
	212B/3	9374.4	-256.0	- 76.8	2408	4.1	0	1609
	/3R1	9658.2	-115.8	-100.0	2609	- 6.4	0.3	1611
	/3R2	10881.4	23.2	- 69.5	2404	- 0.5	2.4	1508
12/13/77	213A/3	9158.6	376.7	- 56.1	2906	- 9.8	1.2	1205
	/3R1	3728.9	36.6	86.6	0704	- 9.8	1.2	0908
	213B/3	5997.9	- 26.8	- 42.7	1905	-11.6	0.3	1008
	/3R1	6123.1	234.1	- 53.6	1909	- 9.8	0.2	1109
	/3R2	-------	------	------	1806	- 1.8	1.2	1009
MEAN (5) EST. STANDARD DEVIATION			-169.1 ±204.3	-35.8 ±35.5	20.5 ±12.2	-6.4 ±10.2	0 ±2.3	12.5 ±5.7

NOTES:
1. FROM NAVIGATION COMPUTER
2. FROM FLIGHT CONTROL COMPUTER
3. VALUE OF $\hat{Y}$ INSTEAD OF -DELTY
4. VALUE MAY BE LIMITED ($DELTY_{LIM} \sim 13.6$m)
5. VALUE FOR WINDS REFERS TO SPEEDS ONLY

TABLE I. - CONTINUED

FINAL APPROACH FIX (2) (ref. figure 14)		CAT II DECISION HEIGHT (2) (ref. figure 15)			TOUCHDOWN (1) (ref. figure 16)		REMARKS
-DELTY, m	DELTH, m	-DELTY, m	DELTH, m	WINDS	-DELTY, m	R_{Rhumb}, m	
- 3.1	0.1	- 3.0	1.7	3106	-3.0	2724	
5.3	-0.7	0.4	-0.3	2910	-3.1	2640	
- 3.5	0.5	- 1.5	2.1	2807	-0.6	2633	
- 1.0	0.8	- 1.3	1.0	1014	-0.9	2793	
- 0.4	1.5	2.8	2.7	1014	-1.1	2791	
2.8	0.3	- 1.2	1.1	1010	-0.5	2579	
-15.8 (3)	1.5	-10.8	1.0	0614	-2.3	2740	
- 0.1	1.6	1.8	1.0	2810	-0.9	2632	
11.0	1.0	8.8	1.1	2609	-1.5	2716	
-48.1 (3)	3.5	-----	----	2619	----	----	NO LOC. MODE CAPTURE
15.3 (3)	3.7	-----	----	2716	----	----	NO LOC. MODE CAPTURE
7.9	0.6	5.9	-0.1	2717	-1.4	2713	
- 1.0	0.3	4.1	-0.1	2818	0.2	2650	
1.7	1.5	3.6	-0.9	2520	-2.7	2748	
7.5	0.8	4.3	1.8	2714	-.3	2485	
-----	----	-----	----	2822	----	----	MLS RECEIVER FAILURE
15.4 (3)	1.4	-----	----	2911	----	----	NO LOC. MODE CAPTURE
8.5	2.6	5.3	-0.7	3017	-0.7	2590	
3.8	1.8	2.3	1.9	3307	0.9	2628	
-----	----	-----	----	3505	----	----	DME RECEIVER FAILURE
- 6.9	3.0	- 4.0	2.4	0500	-2.8	2612	
2.5	4.1	- 1.5	0.1	0502	-0.2	2733	
5.5	-1.2	4.2	0	2705	-1.0	2664	
- 4.5	3.0	0.2	0.7	2704	0.1	2676	
6.0	1.7	2.7	-1.1	2011	0.9	2744	
11.8	-0.5	2.9	-1.1	2308	1.2	2723	
8.9	-1.0	7.5	-0.5	2325	0.4	2659	
13.5 (4)	-0.6	-----	----	----	----	----	NO LOC. MODE CAPTURE
13.3 (4)	2.0	-----	----	----	----	----	NO LOC. MODE CAPTURE
-13.4 (4)	1.0	-11.4	1.5	2615	-2.1	2644	
3.4	0.6	1.0	-1.7	1407	0.7	2779	
- 2.8	0.9	- 1.6	-0.9	1307	-2.4	2770	
1.4	0.1	1.5	-0.4	1505	1.0	2766	
14.8 (3)	-0.1	-----	----	1709	----	----	NO LOC. MODE CAPTURE
0.6	0.1	- 1.6	0	1405	-0.8	2758	
7.3	2.4	2.0	-1.6	1608	0	2780	
0.5	0.9	1.3	0	1204	0.2	2768	
- 1.4	1.6	1.1	-0.1	1007	-0.4	2766	
- 2.8	0.5	- 0.9	1.5	1010	0.5	2739	
- 0.1	0.5	- 0.6	0.7	1109	-0.1	2755	
5.5	0.8	0.6	1.4	1109	-0.3	2723	
1.8 ±10.9	1.1 ±1.3	0.8 ±4.3	0.4 ±1.2	10.5 ±5.7	-0.7 ±1.2	2701 ±73.4	

Figure 1. - NASA TCV B-737 Research Aircraft.

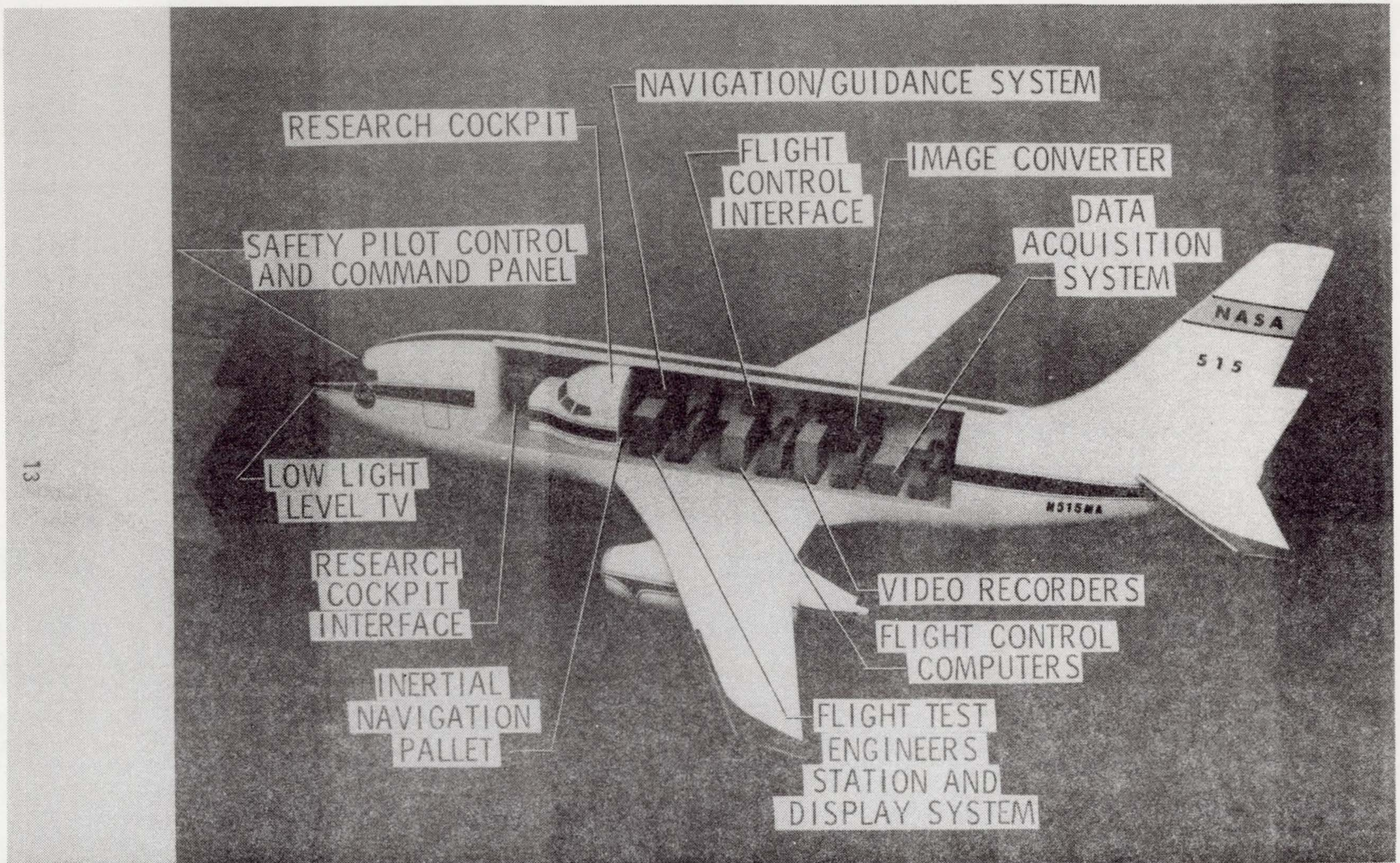


Figure 2. - NASA TCV B-737 Research Aircraft (Internal Arrangement).

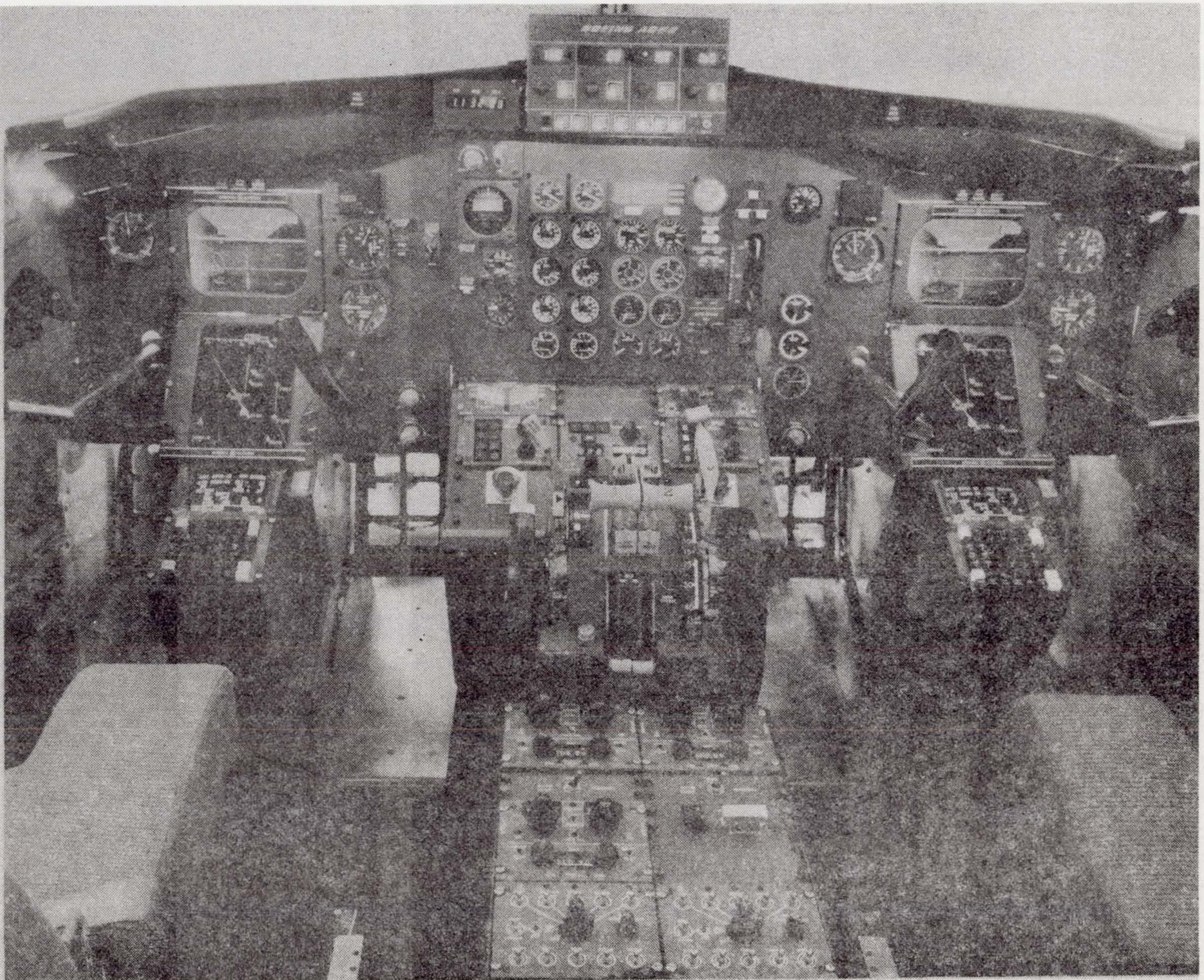


Figure 3. - Aft Flight Deck Display Arrangement.

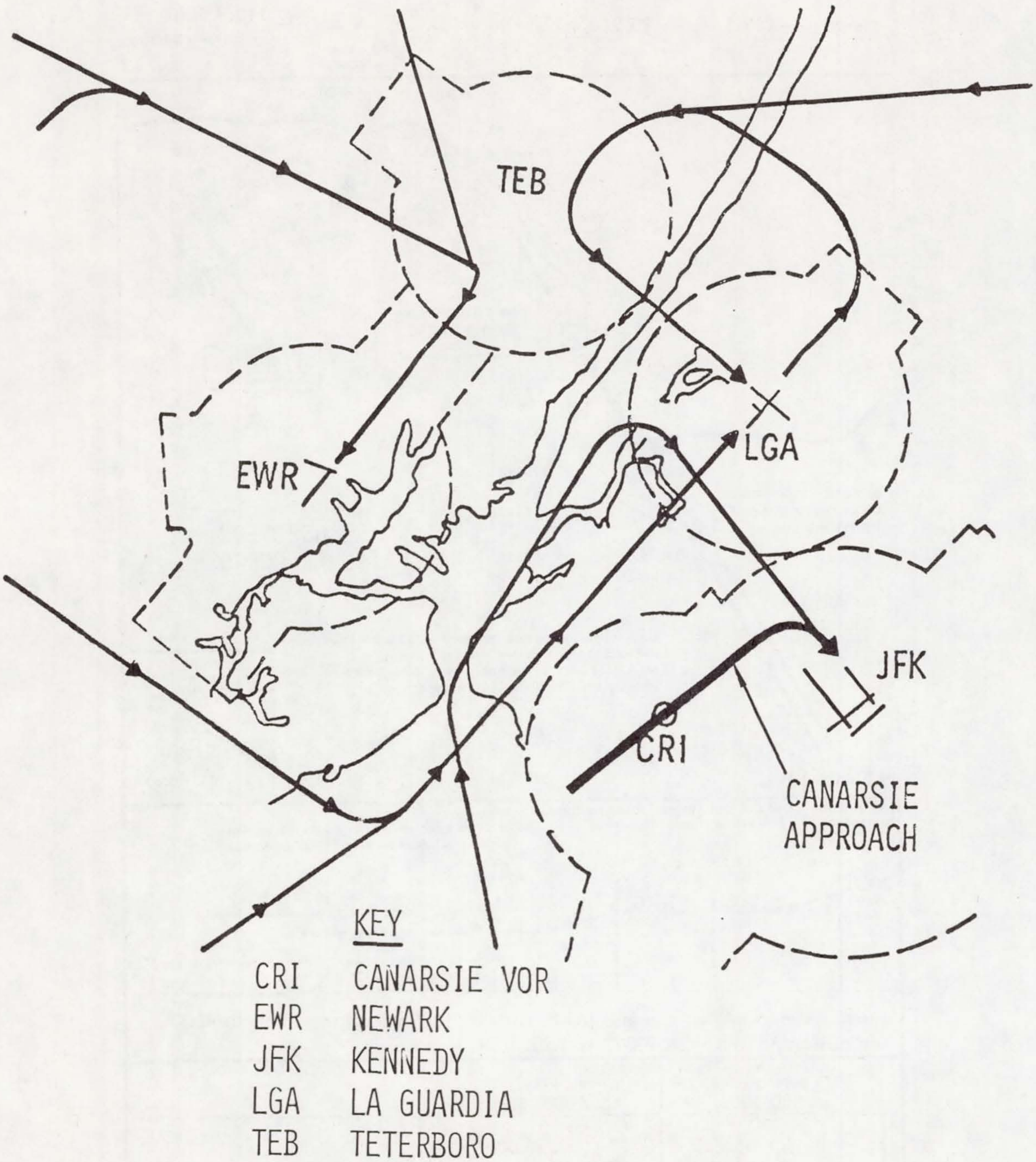


Figure 4. - New York Terminal Area Route Structure.

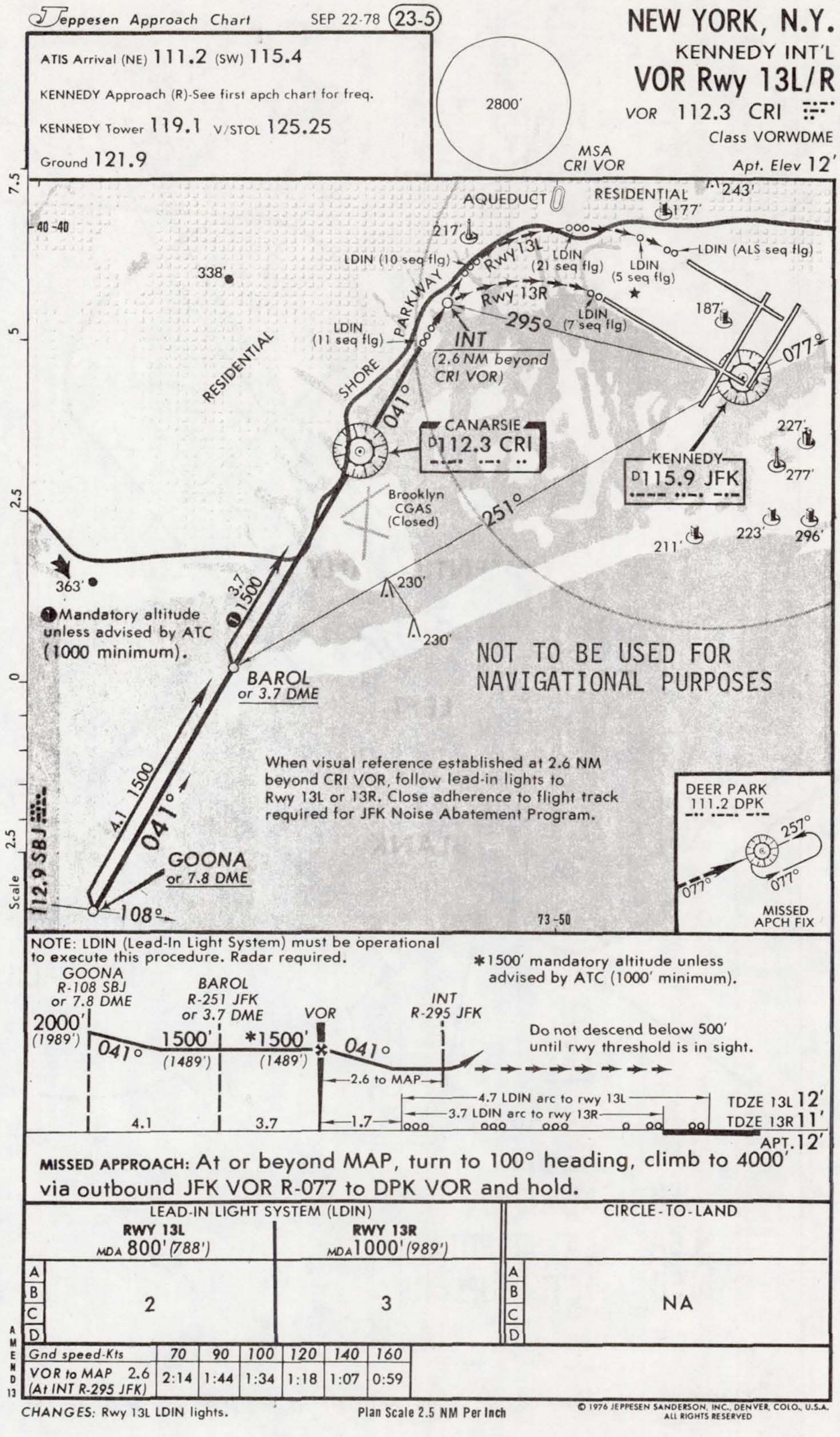


Figure 5. - VOR Runway 13L/13R Approach to JFK.

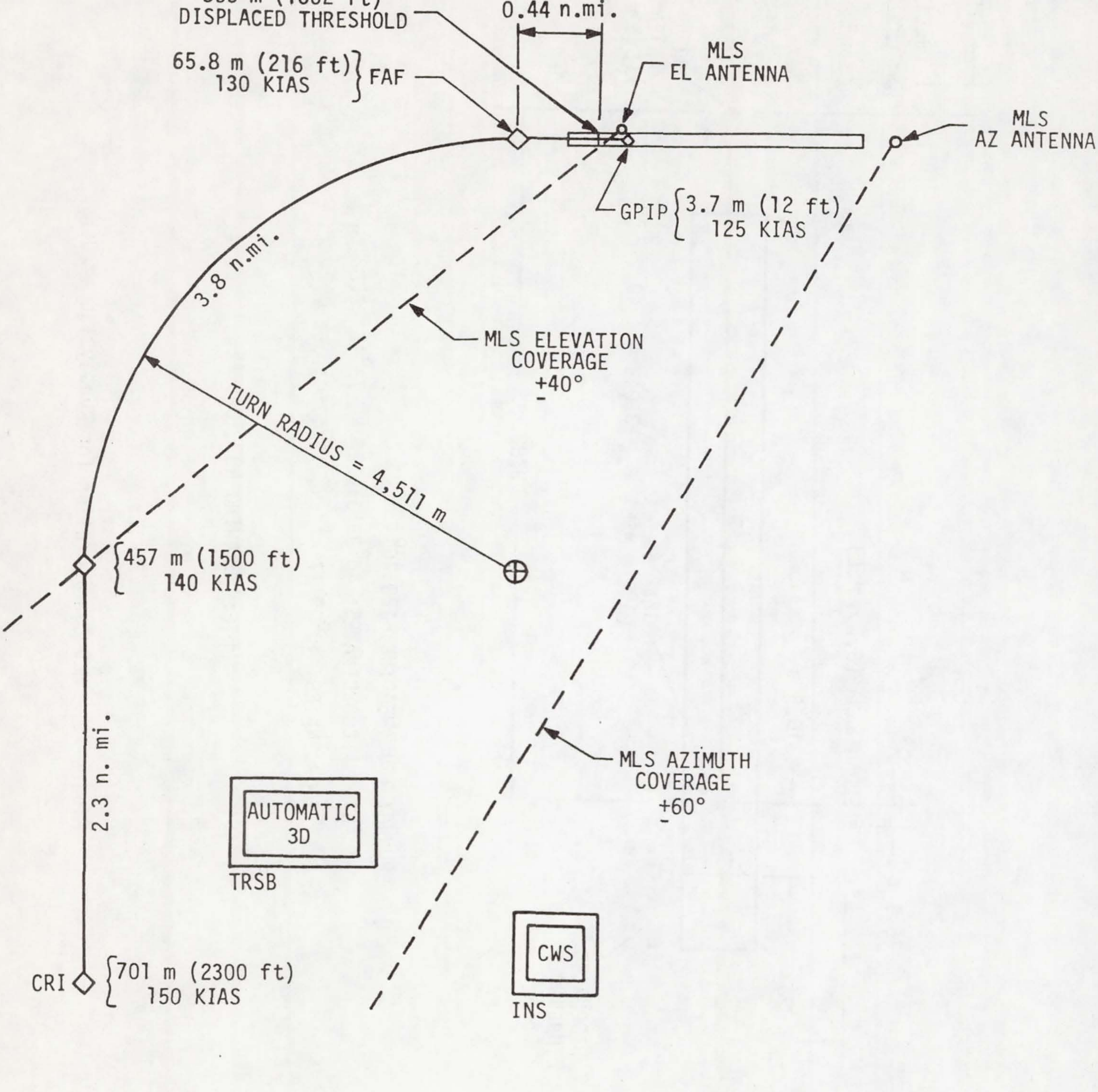
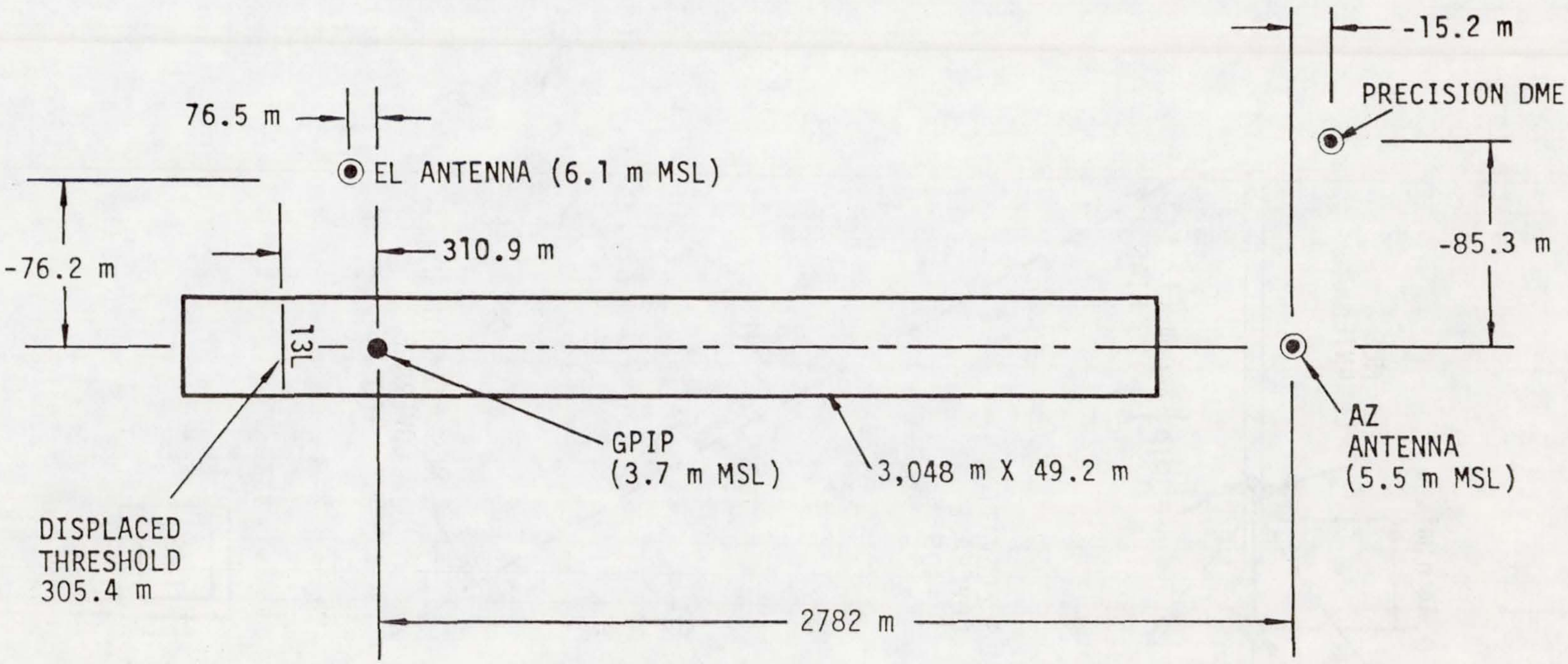


Figure 6. - MLS Approach to JFK from Canarsie VOR (CRI).



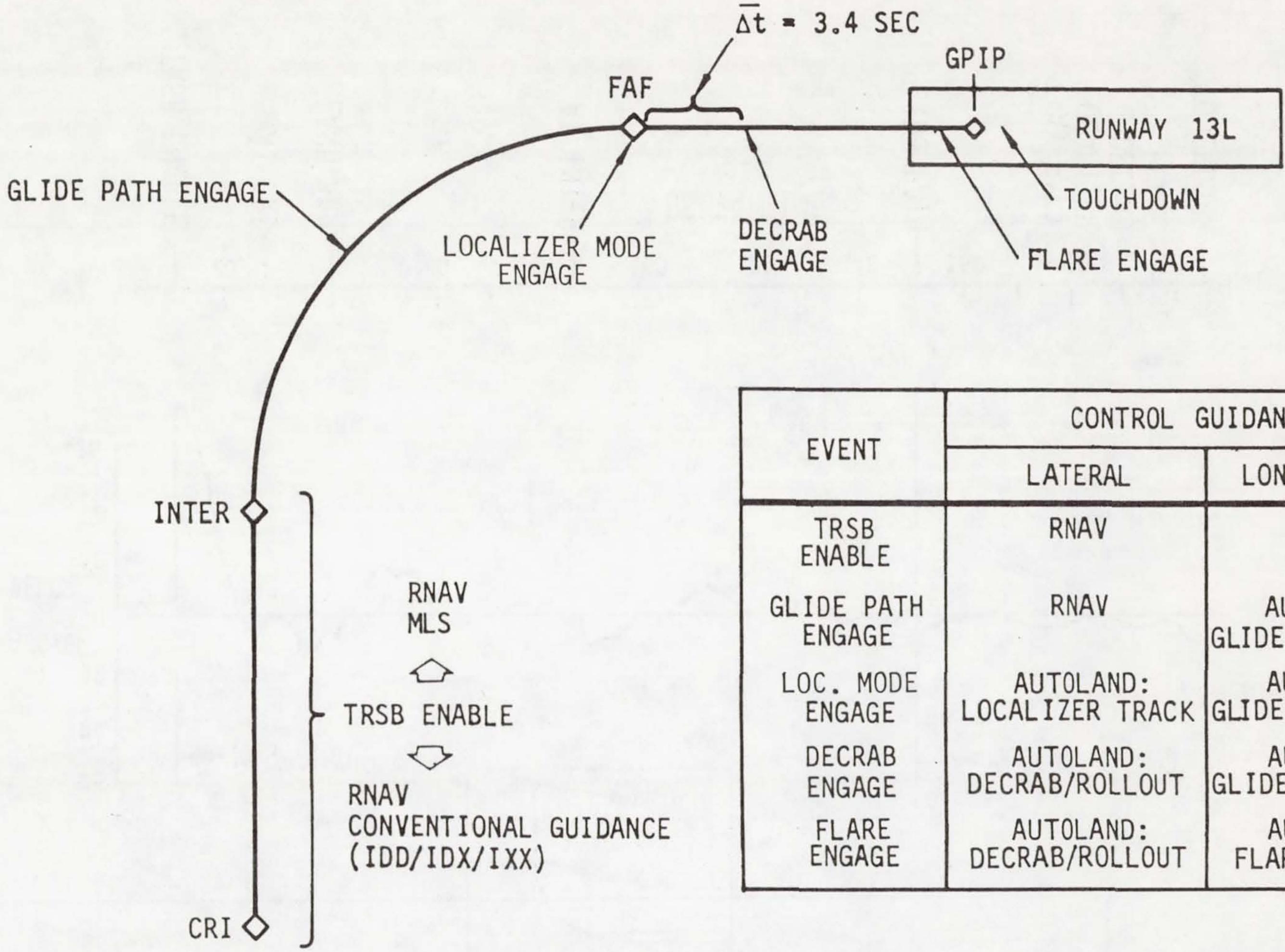
RUNWAY TRUE HEADING: 120.76°

AZ ANTENNA COORDINATES: 40°38'31.32" N, 73°45'22.32" W

GPIP COORDINATES: 40°39'17.44" N, 73°47'04.06" W

NOTE: DRAWING NOT TO SCALE

Figure 7. - MLS Configuration for Runway 13L at JFK.



EVENT	CONTROL GUIDANCE	
	LATERAL	LONGITUDINAL
TRSB ENABLE	RNAV	RNAV
GLIDE PATH ENGAGE	RNAV	AUTOLAND: GLIDE PATH TRACK
LOC. MODE ENGAGE	AUTOLAND: LOCALIZER TRACK	AUTOLAND: GLIDE PATH TRACK
DECRAB ENGAGE	AUTOLAND: DECRAB/ROLLOUT	AUTOLAND: GLIDE PATH TRACK
FLARE ENGAGE	AUTOLAND: DECRAB/ROLLOUT	AUTOLAND: FLARE/ROLLOUT

Figure 8. - TCV B-737 Control Law Schedule for JFK Automatic MLS Approaches and Landings.

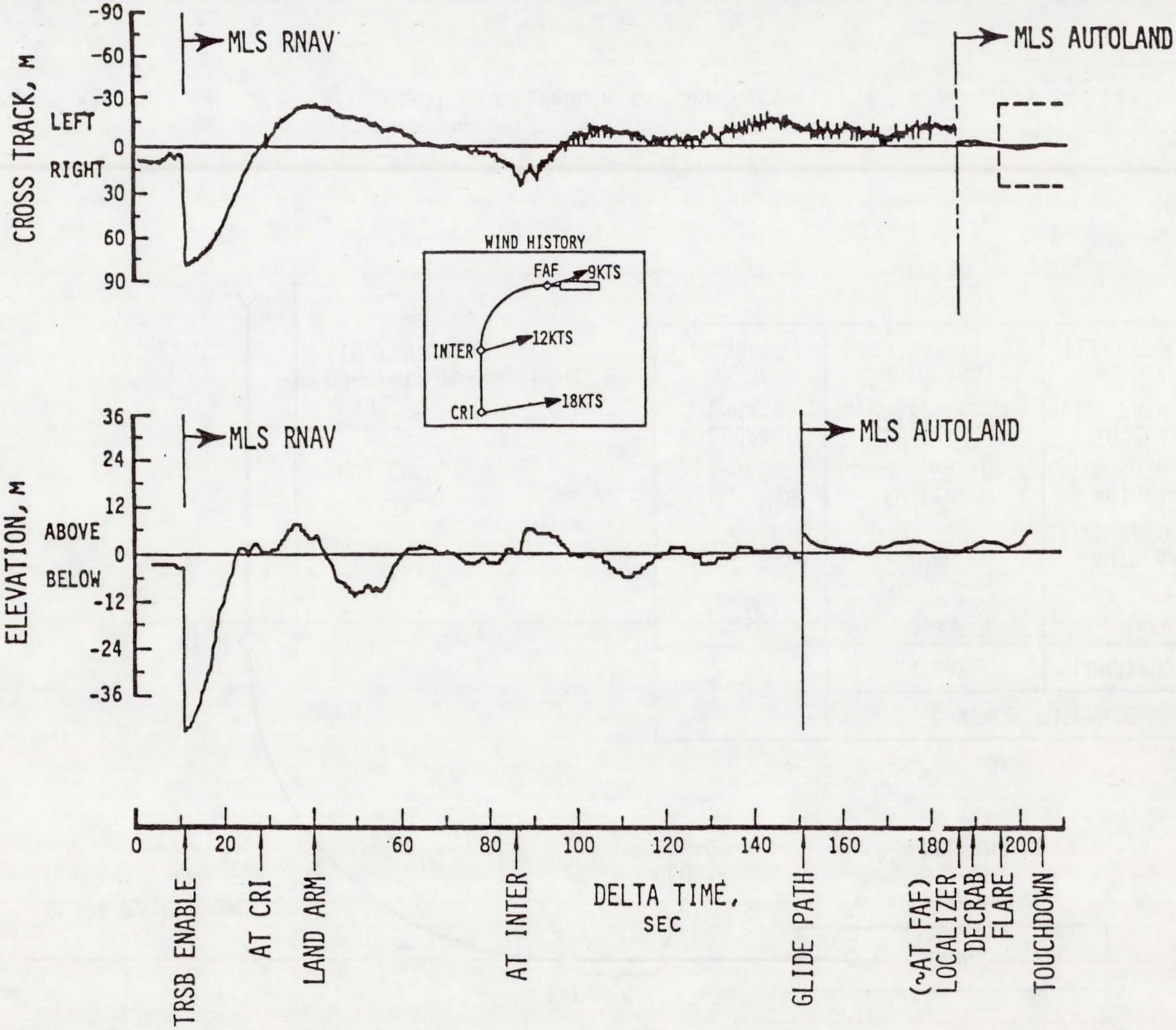


Figure 9. - Flight Technical Errors for Typical Automatic MLS Canarsie Approach.
(Flight/Run No.: 205/8R2)

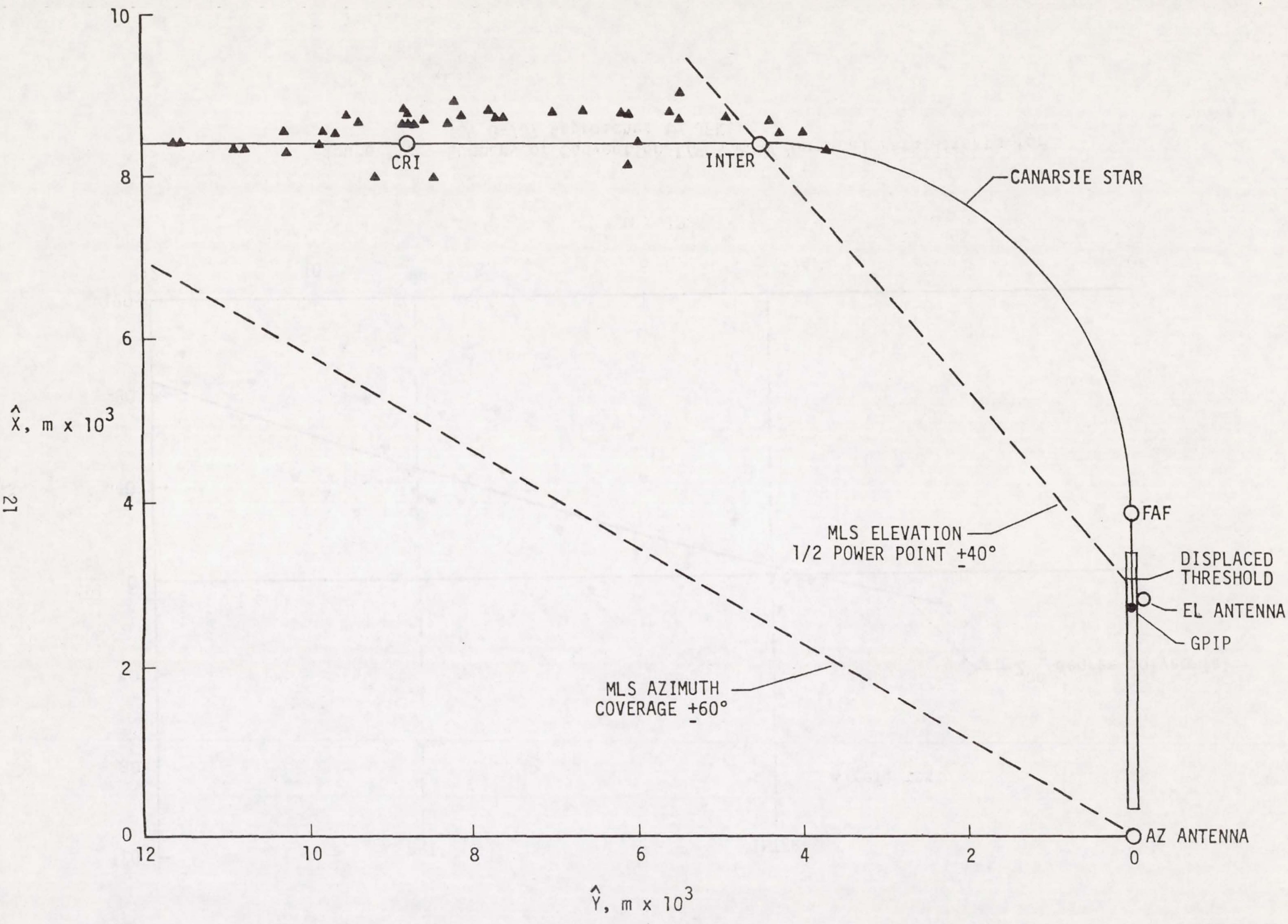


Figure 10. - Summary of Conventional/MLS RNAV Lateral Path Offsets for TCV B-737 Approaches to JFK.

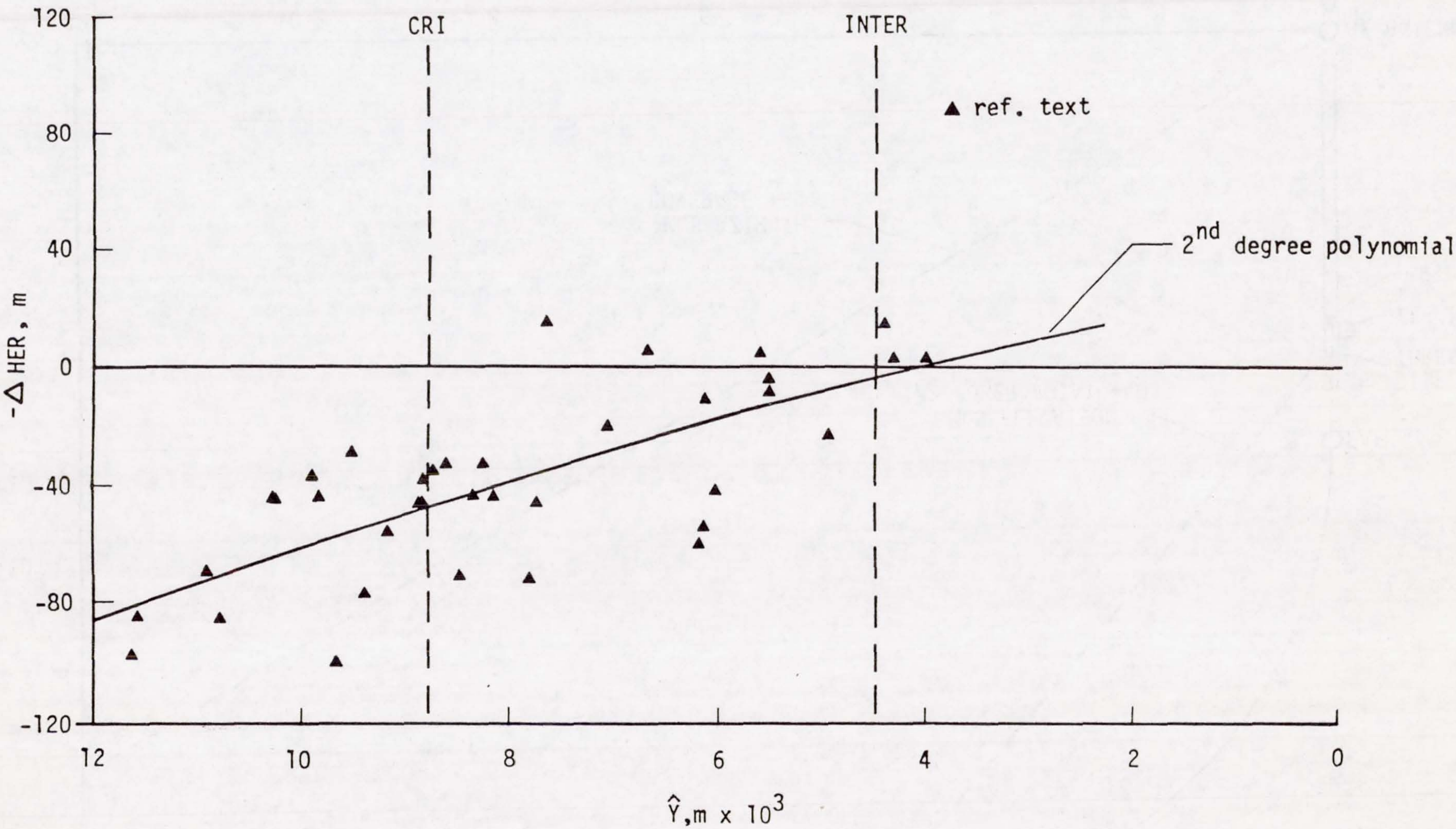


Figure 11. - Summary of Conventional/MLS RNAV Vertical Path Offsets for TCV B-737 Approaches to JFK.

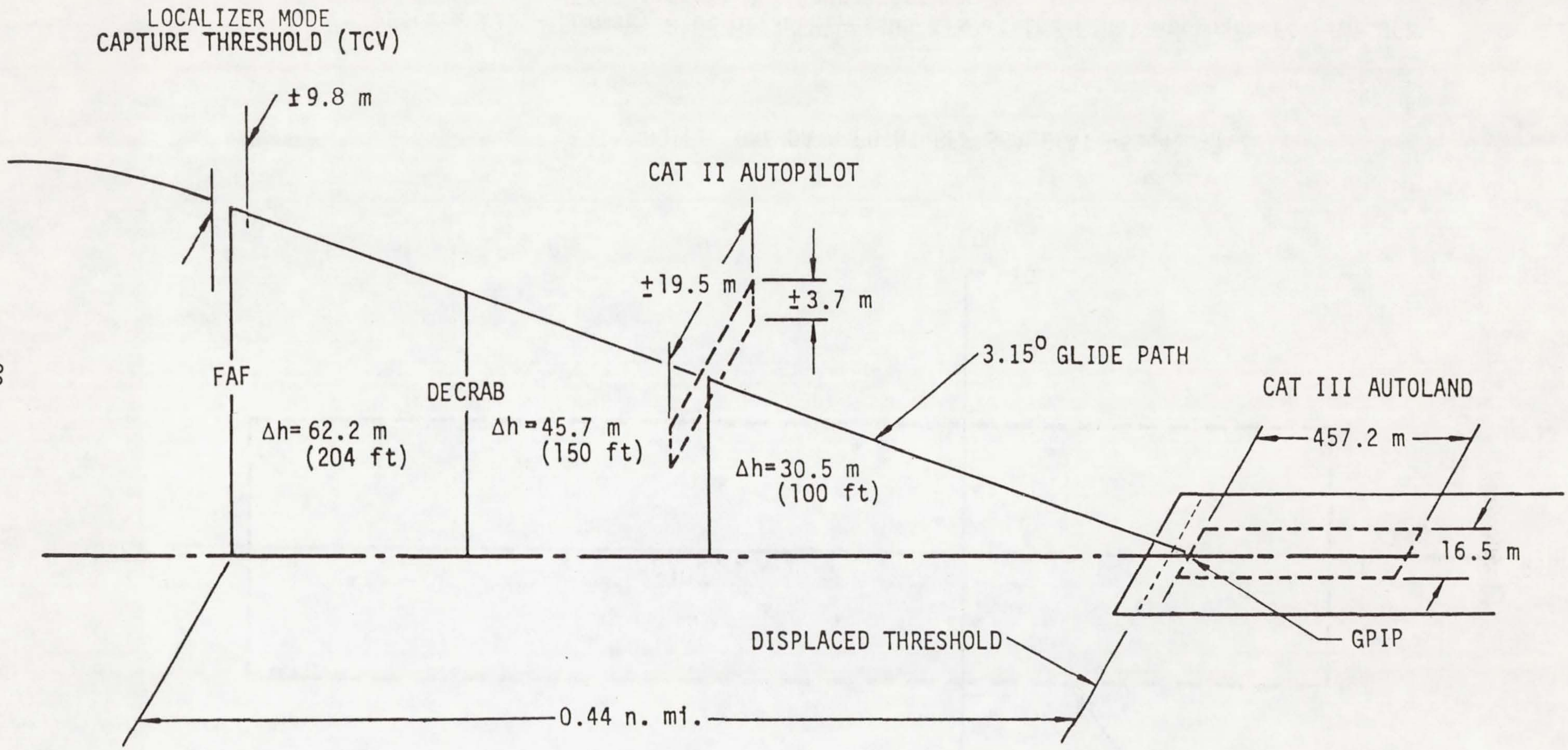
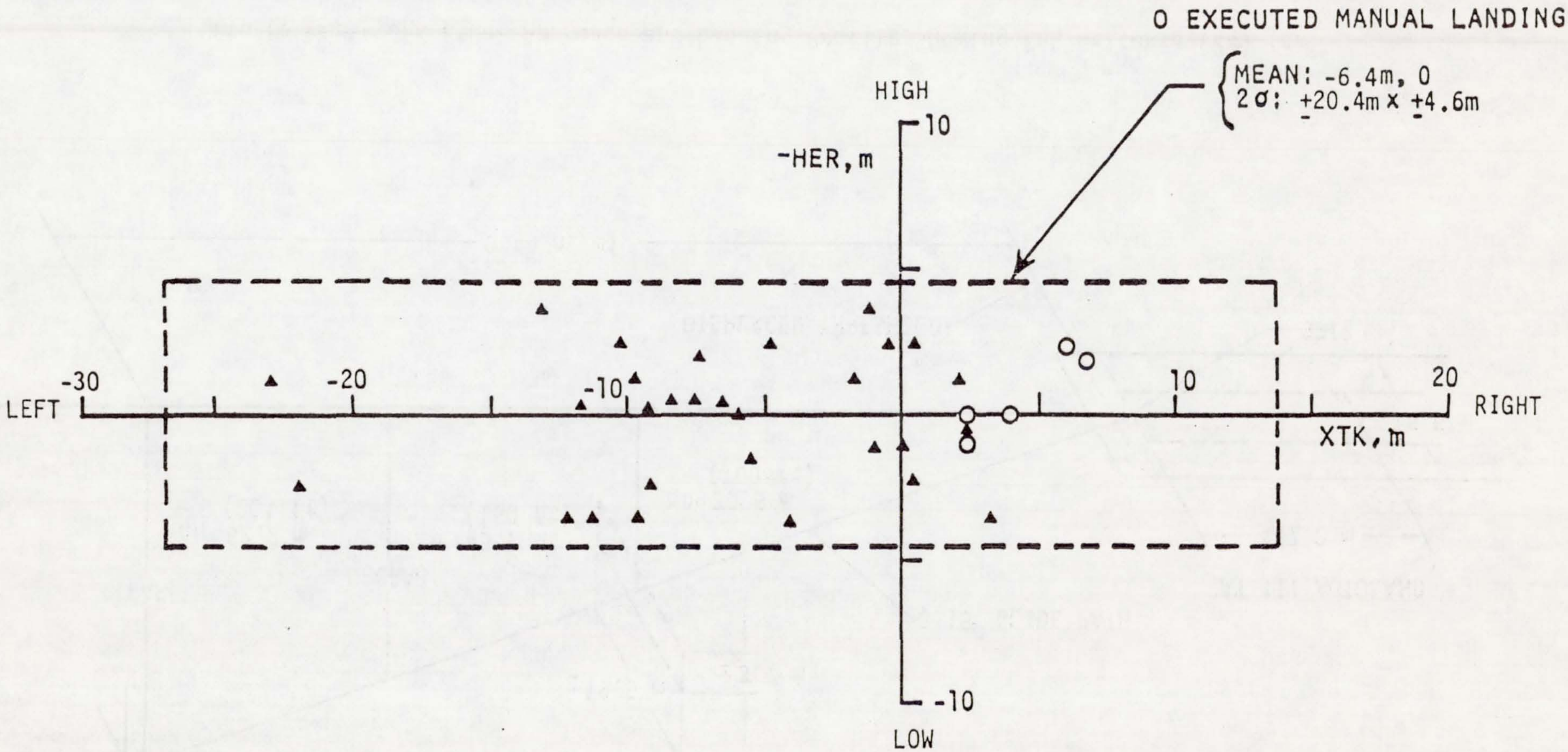
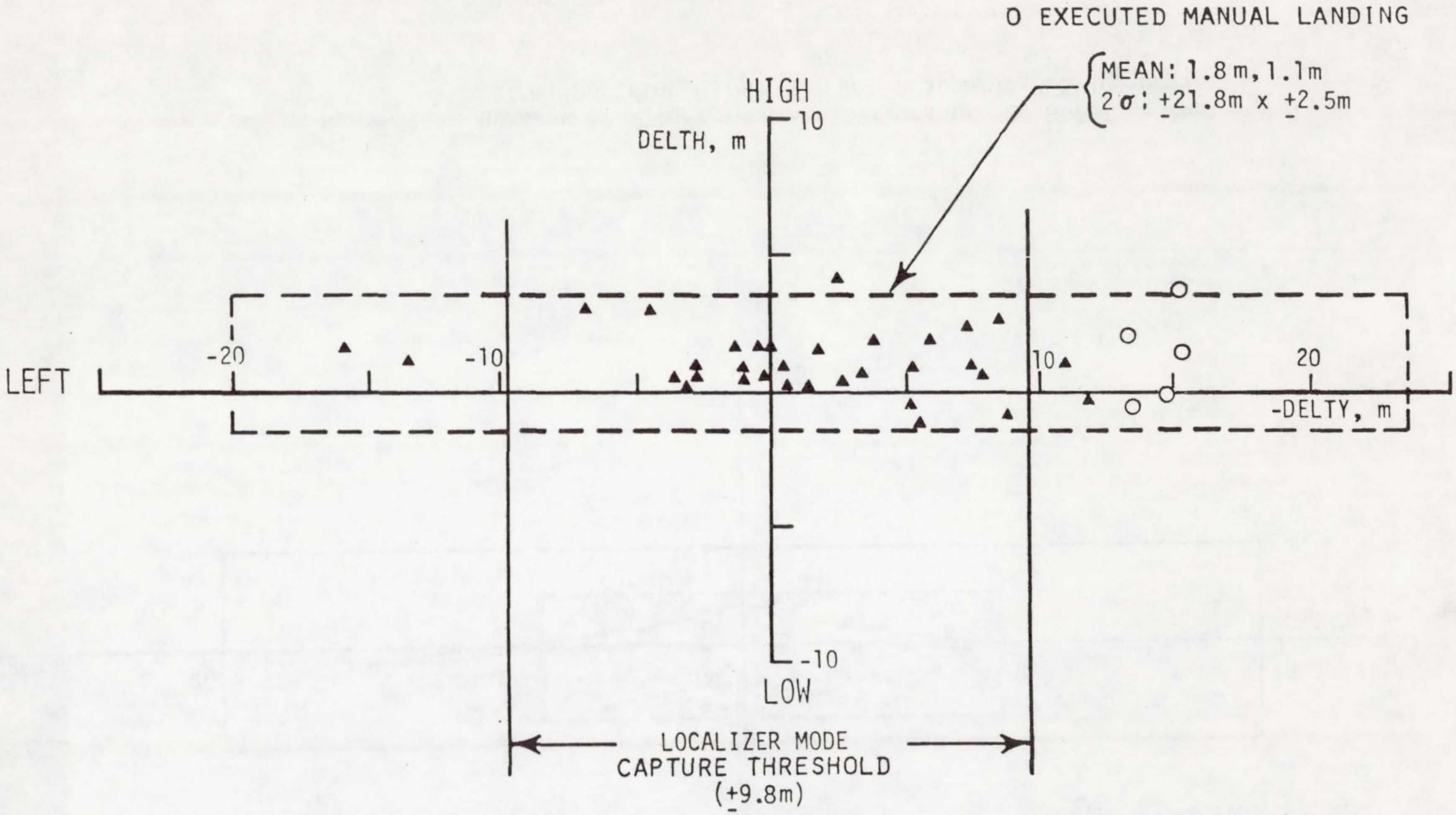


Figure 12. - JFK Final Approach and Landing Profile Showing FAA Criteria (2σ) for Automatic Systems.



NOTE: ONE DATA POINT OFF SCALE AT -52.4, -1.2

Figure 13. - Summary Plot of -HER versus XTK at the Final Approach Fix for JFK
JFK Automatic MLS Approaches.



NOTE: ONE DATA POINT OFF SCALE AT -48.1, 3.5

Figure 14. - Summary Plot of DELTH versus - DELTY at the Final Approach Fix for JFK Automatic MLS Approaches.

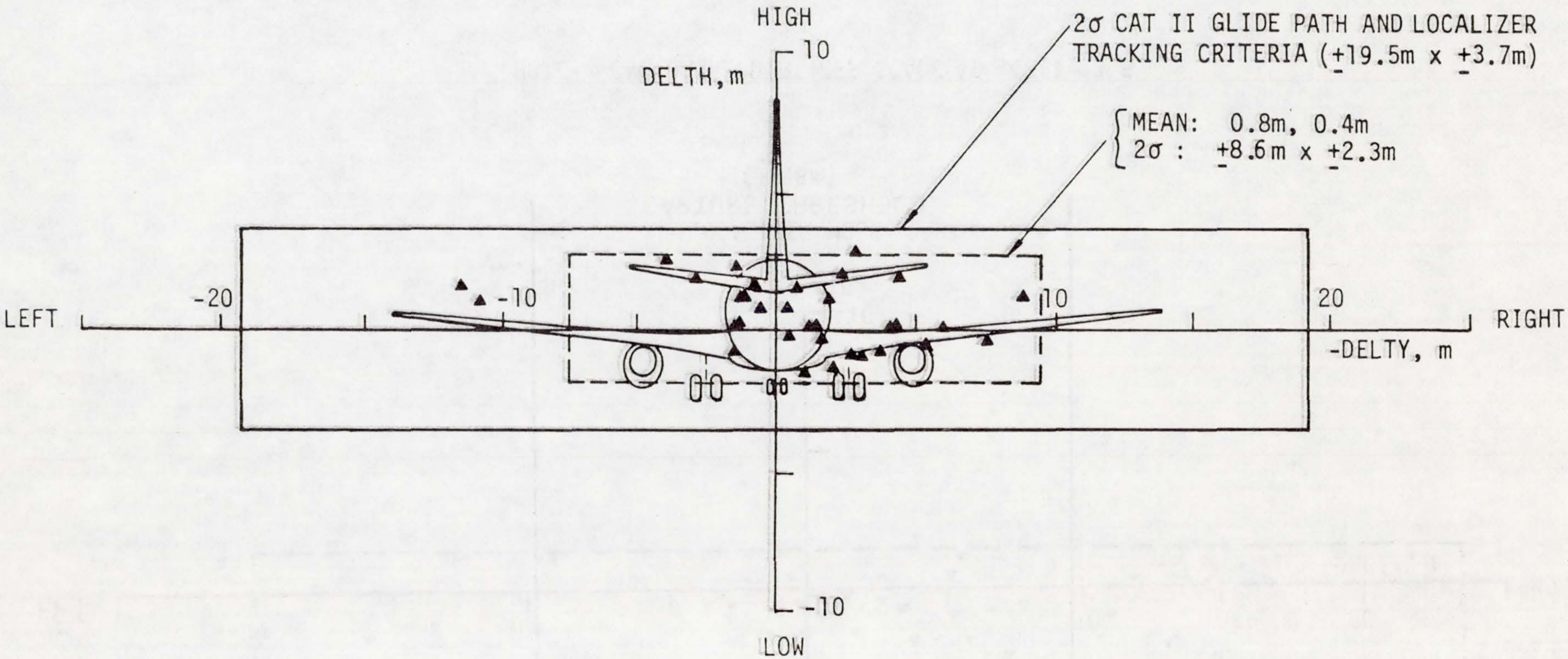


Figure 15. - Summary of Flight Technical Errors of TCV B-737 at the CAT II Decision Height for JFK Automatic MLS Approaches.

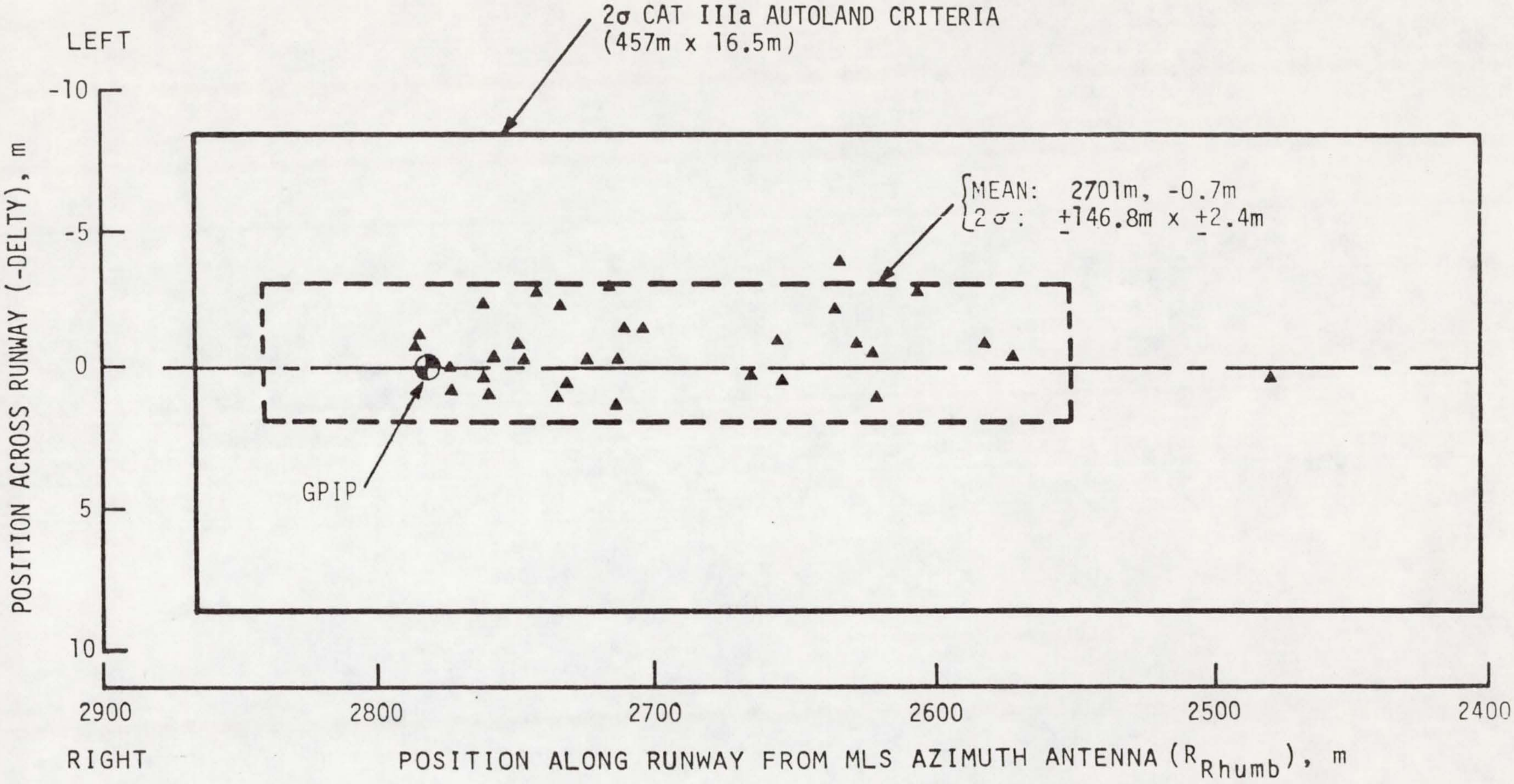


Figure 16. - Summary of Touchdown Performance of TCV B-737 for JFK Automatic MLS Landings.

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15. Supplementary Notes

16. Abstract

The NASA Terminal Configured Vehicle B-737 was flown at John F. Kennedy International Airport in December 1977 in support of the world-wide FAA demonstration of the Time Reference Scanning Beam/Microwave Landing System. This report presents a summary of the flight performance of the TCV airplane during the demonstration automatic approaches and landings while utilizing TRSB/MLS guidance. The TRSB/MLS was shown to provide the terminal area guidance necessary for flying curved automatic approaches with short finals.

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