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USAF INSTRUMENT FLIGHT CENTER
Randolph Air Force Base, Texas

DULLES CATEGORY IIIA ILS EVALUATION

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The Category IIIA ILS guidance system is designed to provide a VHF/UHF localizer and glide slope with increased performance and a backup capability. The overall flyability of the systems must be superior to a Category I or II system due to the lower minimums (700 feet RVR) authorized for the approach. Since the radiated signal is in the UHF/VHF frequency band, it is subject to the same errors and limitations caused by ground or airborne vehicles. The success, then, of a Category IIIA approach depends on the control of interference factors and capability of the aircraft and pilot to maintain the localizer and glide path.

1

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ii

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DULLES CATEGORY IIIA

ILS EVALUATION

CDG-PF-9

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May 1972

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111

FOREWORD

This evaluation of the Dulles Category IIIa ILS guidance system was conducted by pilots assigned to the Research and Development Division of the Instrument Flight Center.

Data collection and analysis was performed by The Bunker-Ramo Corporation--Dr A. C. McTee. Data reduction was performed by Carol Berryhill, Bunker-Ramo.

It is important to note that this evaluation was under the direction of both Headquarters USAF and FAA and represents a cooperative effort to bring into focus some of the problems of operating within the lower visibilities. Major John D. Seaton, XOOTFC, Headquarters USAF, was Air Force project officer and Commander James F. McCarthy, OP-4, Headquarters FAA, was FAA project officer.

This technical report has been reviewed and approved.

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ABSTRACT

The Category IIIA ILS guidance system is designed to provide a VHF/UHF localizer and glide slope with increased performance and a backup capability. The overall flyability of the systems must be superior to a Category I or II system due to the lower minimums (700 feet RVR) authorized for the approach. Since the radiated signal is in the UHF/VHF frequency band, it is subject to the same errors and limitations caused by ground or airborne vehicles. The success, then, of a Category IIIA approach depends on the control of interference factors and capability of the aircraft and pilot to maintain the localizer and glide path.

TABLE OF CONTENTS

SECTION		PAGE
	FOREWORD	iv
	ABSTRACT	v
	CONTENTS	vi
I	PROJECT NUMBER AND TITLE	1
II	PROJECT OFFICER	1
III	AUTHORITY	1
IV	PURPOSE OF PROJECT	1
V	INTRODUCTION	1
VI	TEST AIRCRAFT	2
VII	TEST METHODOLOGY	4
VIII	RESULTS AND DISCUSSION	7
IX	CONCLUSIONS	11
X	RECOMMENDATIONS	12

I. PROJECT NUMBER AND TITLE: CDG-PF-9, Evaluation of a Category IIIA ILS at Dulles.

II. PROJECT OFFICER: Lt Colonel Donald L. Carmack, member, Research and Development Division, USAF Instrument Flight Center (IFC), Randolph AFB, Texas 78148.

III. AUTHORITY: AFR 53-12; and letters of approval from Hq USAF/XOOTFC and Hq ATC/DOTA.

IV. PURPOSE OF THE PROJECT:

A. Determine the flyability of a Category IIIA ILS guidance system both manually and automatically.

B. Record the magnitude and direction of transients during switching and interference with guidance systems.

C. Determine magnitude and direction of dispersions from localizer/glide slope during approach, flare and rollout.

D. Determine pilot subjective opinion of operating to the runway surface both automatically and manually.

V. INTRODUCTION:

Category IIIA operations will be extremely demanding of both ground-based and airborne equipment. An additional consideration will be the role of pilots and their ability to function to this lower minimum. Looking realistically at the task, we see that the intention to land has been made after carefully assuring that all systems are functioning routinely and that a go-around will only be made if a failure of a required system occurs prior to alert height. The task for the pilots (depending on system configuration, pilot preference, and operational requirements) becomes one of either managing the automatics or participating as an active control element while flying the aircraft throughout the approach, flare and touchdown.

In this early "look see" at a Category IIIA guidance system, the primary objective was the determination of "flyability" -- which in turn tests the guidance signal quality and the effects of signal transients during switching from one guidance system to another. Other areas of interest were maximum/minimum dispersions during approach, at touchdown, and during rollout. Since pilots may have to "take over" for failed systems, it was felt extremely important to perform both manual as well as automatic approaches and obtain subjective as well as objective data concerning each. This project, then, was conducted in an atmosphere as realistic as possible to produce data representative of a Category IIIA environment.

VI. TEST AIRCRAFT:

The primary test aircraft (60-3478) has been modified by the addition of advanced control-display systems, allowing either coupled, manual or attitude stabilized modes of flight to touchdown. A brief description of each system (excluding aircraft standard equipment) is presented below.

A. Independent three-axis autopilot with dual rate/displacement force wheel steering. Autopilot uses same signals driving pitch and bank steering bars from flight director computer as approach coupler.

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

C. Two flight path angle computers to provide instantaneous vertical velocity, flight path angle and flare reference signal.

D. Two radar altimeters for absolute altitude, rate of closure and vertical flight path angle term below 50 feet.

E. Two experimental color-coded attitude director indicators with flight path angle quantity readout in degrees to the left of attitude sphere.

F. Two radar altitude/IVSIs to provide qualitative radar height and anticipatory vertical velocity information.

G. Two radar altitude indicators to provide absolute altitude readout from 1000 feet to touchdown. One unit is for camera recording of absolute altitude.

H. Two expanded localizer indicators for defining lateral flight path limits during final approach and landing.

I. Two approach sequence indicators for monitoring approach progress and systems operation.

J. Angle of attack system with apexer.

K. Automatic throttle system set for $1.3V_s$ during approach and $1.2V_s$ reference at flare engage.

<u>Automatic Systems Configuration</u>: The test aircraft was equipped to perform instrument approaches to touchdown in three different modes: coupled; uncoupled with attitude stabilization; and manual control linkage. In the coupled mode, the flight director computer (FDC) served as the approach coupler, i.e., the same signal operating the command steering information operated the autopilot. This arrangement placed the pilot in the control loop since he could interpret between the performance of the autopilot and guidance beam tracking by observing the relationship of command and raw localizer/glide path signals. If, for example, the command steering continues to be centered, but the raw localizer continues to indicate that the aircraft is off course and not correcting, then the autopilot system is <u>not</u> tracking properly. The pilot can correct this tracking error by adding a course correction through the control wheel, since his control inputs will be summed along with those from the FDC. Also, the coupled mode allows localizer beam following through rollout by use of ailerons, rudder and nose wheel steering at the slower speeds.

The attitude stabilization mode provides the pilot the use of the autopilot even though coupling is not accomplished. In this mode the autopilot is on and attitude stabilized to the wings level position (dynamically stable), until a control wheel input is made. When the pilot applies a control wheel force to bank the aircraft, the force applied displaces the aircraft from a wings level attitude; the greater the force, the greater the bank angle. The test aircraft is equipped with this form of displacement attitude stabilization to $\pm 10^{\circ}$ of bank. Once 10° of bank is surpassed, roll force is synchronized to maintain the angle of bank when the force used to establish the roll rate is stopped. Thus, angles of bank between 10 and 30 degrees will be maintained once established. The aircraft is attitude stabilized in longitudinal axis to maintain the pilot established pitch attitude.

In the manual control mode, the normal aircraft control linkage is used to maneuver the aircraft. In all these modes, instrument displays would depict identical information to both pilots for either monitoring or manual control.

VII. TEST METHODOLOGY:

Site: This series of approaches was flown to the Category III ILS installed on Runway 01R at Dulles International Airport.

Approaches: Sixty-four ILS approaches were flown hooded to touchdown or to takeover by the safety pilot. The approaches were flown, eight per sortie, in a racetrack pattern with radar vectoring for intercept of the ILS course two miles or more outside the outer marker. Coupled and manual control were used on alternate approaches (see Table 1).

Crew Coordination: The left-seat pilot flew the aircraft, heads down, on each approach, to touchdown or to a point where the safety pilot felt it advisable to assume control. The right-seat pilot handled all communications, and flew the aircraft on the downwind leg.

The pilots changed seats and roles after the fourth approach of each sortie.

The systems engineer operated the CEC 5-119 oscillograph installed on the aircraft, and monitored performance of aircraft systems.

An observer was stationed in the Dulles Control Tower cab to monitor the approaches, and to coordinate procedures and ground system switching. A log was kept of touchdown and switchover times, plus notations of any potential sources of interference with the guidance -- taxiing aircraft, takeoffs and localizer overflights, and vehicles operating near the runway or guidance sites.

Guidance Switching: The approach plan (Table 1) was used as a guide for the timing of switchovers from primary to standby guidance. Actual switching was performed by one of the FAA engineers in the equipment room of the Dulles Tower, at phone command from the observer in the tower cab. Exact GMT for the switchover was logged by the observer when the alarm sounded in the tower cab, for later correlation with the oscillographic records taken on board the aircraft.

Data Collection: Records of relevant information were collected at three locations: in the cockpit, on the airborne oscillograph, and in the tower cab.

Pilot comments were recorded on the inflight data card. This card provided for each sortie a reminder of the sequence of manual and automatic approaches, and blanks for the recording of a general description of weather conditions, specific information for each landing (lateral and longitudinal touchdown distances, heading), and comments if the pilot desired.

Oscillographic recordings were made for each approach, recording eight parameters: glide slope, pitch steering bar, pitch attitude, pitch rate, roll attitude, localizer, bank steering bar, and radar altitude. These records were made on a CEC 5-119 oscillograph, operating at a speed of one inch/second, from just outside the outer marker through touchdown, rollout and takeoff, in order to cover the entire approach, landing and rollout.

Observer records taken in the tower cab have been mentioned already. These included GMT times for marker passage (taken from the cab radar scope), touchdown, rotation, localizer overflight, and any other occurrence which might affect the guidance signal. These occurrences included the switchovers, plus other aircraft approaching, landing, or taxiing, and vehicles on or near the runway or antennas. Observer records of touchdown times were relatively accurate during day approaches, but night touchdowns could not be determined precisely.

Data Reduction and Analysis. The oscillographic records were developed, then digitized at one-second intervals for 100 seconds back from touchdown. A Benson-Lehner OSCAR was used to accomplish the digitizing.

Means, absolute averages, and standard deviations were computed for the pitch steering bar, bank steering bar, and localizer; these were felt to reflect most accurately the flyability of the system. The glide slope trace was not analyzed because of the aircraft system, which progressively replaced glide slope with flight path angle from 100 feet marker to touchdown.

Day	1								1								2								2							
Flight	Day								Night								Day								Night							
Aircrew	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	1	1	1	1
Condition	M	A	M	A	M	A	M	A	A	M	A	M	A	M	A	M	M	A	M	A	M	A	M	A	A	M	A	M	A	M	A	M
Flyability	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
T_1																	x	x				x								x		
T_2																									x							x
T_3																					x					x			x			
I_1																		x					x							x		
I_2																			x							x					x	
I_3																						x					x					x

Day	3								3								4								4							
Flight	Day								Night								Day								Night							
Aircrew	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	1	1	1	1
Condition	M	A	M	A	M	A	M	A	A	M	A	M	A	M	A	M	M	A	M	A	M	A	M	A	A	M	A	M	A	M	A	M
Flyability	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
T_1		x							x	x				x							x	x				x						
T_2				x	x							x					x							x					x			
T_3	x				x	x						x					x								x					x		
I_1			x							x					x							x					x					
I_2						x					x							x												x		
I_3		x		x			x					x		x					x					x		x					x	

Code

T_1 - Transient - Outside Middle Marker
T_2 - Transient - Middle Marker to Flare
T_3 - Transient - Flare Through Rollout

I_1 - Interference - Aircraft on Runway
I_2 - Interference - Aircraft at No. 1 Position
I_3 - Interference - Vehicular
O - Full Stops

TABLE I. Approach Conditions

VIII. RESULTS AND DISCUSSION:

Flyability: The Category IIIA ILS guidance proved to be very flyable during both manual and coupled approaches. Dispersions from localizer proved to be negligible during coupled approaches. The apparent reason for this exceptional beam tracking was the high quality of the generated localizer course. From a purely subjective point of view, the beam was straight. No bends were noticeable in the localizer during either coupled or manual approaches. It should be mentioned that dispersions during manual approaches were usually small and those observed could be attributed to such things as pilot reaction time, wind shear, turbulence and display interpretation.

Table II shows the mean and variability of the dispersions for three recorded parameters. Note that deviations are small in all cases; the slightly greater means and standard deviations for the second series of 32 approaches may be attributed to an exceptionally severe crosswind condition, up to 30 knots. For this reason, it is not advisable to attempt direct comparison of performance for the two series. It may also be seen that manual and automatic approaches do not differ significantly, both showing exceptional tracking accuracy.

There were some noticeable deviations of the glide slope during both coupled and manual approaches. These dispersions were generally small and located at two points on the glide slope. The first and smallest anomaly (glide slope) occurred at approximately 900 feet radar altitude. At this position, vertical velocity increased one to two hundred feet per minute, a power reduction was necessary, and pitch attitude decreased approximately one to two degrees. The deviation from glide slope was approximately one-eighth to one-quarter dot, or about 20 to 40 feet. Another dispersion occurred at approximately 300 feet AGL. This glide slope anomaly resulted in deviations up to one-quarter dot and was more severe than the one at 900 AGL. Neither, however, was of a magnitude sufficient to create instability during final approach or produce an adverse effect on flare entry.

Flyability by Sortie Period: Two sorties flown at Dulles were night missions starting at approximately 0500 local time. The sky conditions were clear and wind and turbulence were negligible during these two sorties consisting of 16 approaches; no glide slope anomalies were apparent. The localizer was straight. During the rollout, there was no noticeable localizer scalloping as the transmitter was approached.

PARAMETER	STATISTIC	APPROACH SAMPLE: All Approaches Manual	All Approaches Auto	First Series Manual	First Series Auto	Second Series Manual	Second Series Auto
Pitch Steering Bar	Mean	0.78	1.06	0.91	1.08	0.66	1.04
* (Barwidths)	Absolute Avg	1.52	1.87	1.57	1.85	1.68	1.90
	Standard Dev	2.12	2.55	1.71	2.61	2.44	2.48
Localizer	Mean	0.10	0.11	0.07	0.08	0.12	0.13
(Dots)	Absolute Avg	0.16	0.15	0.15	0.15	0.17	0.14
	Standard Dev	0.18	0.13	0.19	0.14	0.16	0.11
Bank Steering Bar	Mean			Lost Data		-0.43	-0.45
* (Barwidths)	Absolute Avg			by recorder		1.56	0.82
	Standard Dev			malfunction		2.32	1.57

* One Barwidth equals 0.03 inch at the display

TABLE II. Mean, Absolute Average, and Variability for Recorded Parameters

The second series of 16 approaches was flown between 0900 and 1100 local time. During these approaches the maximum crosswind component was 5 knots; sky conditions were clear and turbulence was negligible. The localizer quality remained excellent with no noticeable beam bending. The glide slope, however, seemed to deteriorate with the daylight conditions for no apparent reason. There were no identifiable geographical features which could cause sufficient up or down drafts to create dispersions from glide slope.

Glide slope scalloping occurred at approximately 900 and 300 feet radar altitude. Neither dispersion was so severe or abrupt as to promote aircraft instability, but either would be a definite negative psychological factor for aircrews during a Category IIIA approach. The localizer signal was excellent during approach and rollout.

The next series of 16 approaches was flown between 1100 and 1300 local time. Localizer quality was, as in other series, excellent. The glide slope quality was approximately the same as seen in the approaches flown during the 0900 to 1100 time period. Of special interest were the turbulence and strong crosswinds during these sixteen approaches. Crosswinds were in the magnitude of 15 to 25 knots which made aircraft control extremely difficult. Project pilots felt that the maximum comfortable crosswind component for autoland and pilot takeover for rollout during 700 feet RVR (Category IIIA) would be about 10 knots. This figure (10 knots of direct crosswind) must be clarified within the context of the test profile and aircraft capability. Project pilots felt that if they could have remained coupled to the guidance system to touchdown, or had flown instruments to touchdown, including an automatic or manual decrab, then have the heads-up pilot take over for rollout after touchdown, a safe landing may have been difficult. The seriousness of this last statement must be inspected.

First of all, the project aircraft had no de-crab mode or displays, meaning that directional control would be extremely difficult at the initial transfer of control from the heads-down to heads-up pilot during manual flight. Until rudder and aileron forces have been properly applied, a possible out-of-control situation may exist, making transfer of control at this point potentially dangerous. There is a very definite possibility that a Category IIIA manual approach in strong crosswinds will require heads-up pilot activity in the lateral axis prior to touchdown. The concept is for the heads-up pilot to assist with lateral control while cross-checking the visual environment during the latter stages of the approach. In this manner the heads-up pilot will be alert to the control forces required to compensate for crosswind during rollout. This speculative concept will be investigated during a program now being conducted by the IFC, R&D Division.

The last sixteen approaches were flown between 1500 and 1700 in crosswinds of 3 to 5 mph; turbulence was light. No problems were encountered with aircraft control in either manual or automatic modes. Flyability and tracking of the localizer during approach, touchdown and rollout were excellent. The glide slope had the same problems previously mentioned.

Switching transients: A number of localizer and glide slope transmitter switchings were conducted to determine the effect on autopilot tracking and navigation displays. These switchings were accomplished at different positions on final approach to simulate failure of the primary system and automatic changeover to the backup system. To determine the effects of these changeovers, switchings were made between outer marker and middle marker, middle marker and flare engage (50 feet) and flare engage throughout rollout. The autopilot did not have any adverse reactions to guidance changeovers of glide path, localizer, or both. The navigation displays (command steering bars, course deviation indicator and glide slope indicator) did not show any noticeable deflection during switching. Switchover indications on the recorded traces were typically deflections of perhaps 0.2 dot of raw guidance information, decreasing to zero in 0.2 second or less.

Effects of Interference: For the first test series, there were no planned interference factors except for vehicular traffic consisting of a large fire truck. All other interference factors (aircraft) were random movements. The vehicular traffic was stationed adjacent to runway 01 right at various taxiways. Even though the truck was rather large, it did not produce any noticeable scalloping of the glide path or localizer beam.

Random aircraft factors consisted of a sampling of all types of aircraft from a large turbojet to smaller two engine jet aircraft, and light aircraft. Interference factors were greatest when aircraft passed over the localizer transmitter site. Aircraft on final approach or rollout caused some interference, but did not degrade the quality of the localizer or glide path to make them unflyable. It's interesting to note that these interference factors were the smallest ever encountered from the random aircraft movements. More controlled investigations must be accomplished to determine exact magnitude of interference at different locations during approach and rollout.

Marker Beacons: All marker beacons were functioning in a normal manner.

Station Identifier: The station identifier was functioning in a normal manner.

Radar Height: The alert height had not been defined for the test aircraft. However, the basic principle of defining an alert height seems somewhat vague if based on radar altitude since most of the final approach zone must be surveyed to compute a specific height requirement. The test aircraft was equipped with both a gross (0-1000 feet) and qualitative radar display. The qualitative radar display could be read to 5-foot increments below 50 feet. Project pilots found the qualitative display extremely beneficial during the latter part of the approach (flare and touchdown). The gross radar altimeter served as a good approach progress monitor and also to ascertain barometric altimeter reliability during passage of middle and inner markers.

Range Information: One important parameter missing from the Category IIIA approach profile is range information. Not only must the pilot be able to determine distance from threshold, he must know his position on the runway to plan braking performance or missed approach. The Category IIIA flight profile requires an instrument approach and flare, but neglects the critical requirement of distance-to-go information for the visual rollout.

Crew Procedures: The IPIS believes that in dual piloted aircraft the role of one pilot is to remain heads down assisting the automatics or manually controlling the aircraft with reference to instruments to touchdown.[1] The role of the other pilot is to be the decision maker; to monitor approach progress both by instruments and visually and to take over at touchdown for the rollout.

IX. CONCLUSIONS:

A. The localizer was flyable to touchdown. The glide slope was flyable to 100 feet where the glide slope was replaced by flight path angle for the flare presentation in the test aircraft.

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1. IPIS-TN-71-4, "Crew Duties, Mode and Function Study," which is available from the US Department of Commerce, National Technical Information Service, AD-740 502, covers this subject in detail.

B. The backup system was equally as flyable as the primary system.

C. Changing from the primary to backup system did not affect tracking performance and was not noticeable in the cockpit or by the automatic flight control system.

D. The localizer and glide slope appeared to be affected in a lesser manner by interference than other ILS systems project pilots had flown.

E. The localizer signal provided a usable rollout signal the length of the runway. No bends were noticeable during coupled rollouts.

F. The investigated ILS can safely be flown to Category IIIA minimums when crosswinds are less than 10 knots.

X. RECOMMENDATIONS:

A. That improved runway markings be developed to provide position and distance information for Category IIIA operations. IPIS Technical Note 71-2 (AD-884 902), "Runway Markings Improvement Study" deals with this subject in detail.

B. That controlled interference studies be conducted to determine specific magnitudes of dispersions resulting from interference factors.

C. That crosswind limitations of 10 knots be applied to manual approaches in Category IIIA visibilities.

D. That future studies include gradual localizer and glide slope beam shifting to the point of guidance system switching to the secondary system.