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REPLY TO ATTN OF: 70-FM22-137

AUG 14 1970

MEMORANDUM TO: Informal Distribution

FROM : FM2/Landing Analysis Branch

SUBJECT : A summary of availability and accuracy of landing aids for shuttle applications

References:

1. Navigation Systems for Aircraft and Space Vehicles, T. G. Thorne, 1962.

2. Planning and Design of Airports, R. Horonjeff, 1962.

3. Radar Techniques for Tracking and Navigation, W. T. Blackband, 1966.

4. Radio Navigation Systems for Aviation and Maritime Use, W. Bauss, 1963.

5. Advanced Scanning Beam Guidance System for All Weather Landing, Feb. 1968, Federal Aviation Administration, Summary report No. RD-68-2.

6. Apollo Operations Handbook - Lunar Module, Vol. I LMA790-3-LM7, Feb. 1, 1970, Grumman Aerospace Corp.

7. Application of Inertial Navigation and Modern Control Theory to the All-Weather Landing Problem, MIT report R-613, June 1968.

This memorandum is written to share some thoughts on the landing of the shuttlecraft, and to list the capabilities of a variety of navigational aids.

It appears that if the shuttlecraft is to possess an anytime abort capability, landings at any of a large number of airports must be within the ability of the shuttle's landing system. This means that the system must be able to utilize the conventional navigational aids in an emergency or backup mode whenever more sophisticated equipment is not available or operational. With this in mind, it is proposed that the shuttle's landing system, including man-display interfaces, be capable of using position and bearing information from a variety of sources for either manual aircraft type landings or for incorporation into an inertial automatic system. Differences in operating frequencies, transmitter/receivers, antennas, decoding, etc., must be traded off against weight, reliability, usefulness and gain in flexibility before a navigation aid capability is added to the system design.

Errors associated with some of the long and medium range navigation aids are given in table I. The position errors of most of the long range systems are large enough to degrade a well functioning inertial navigation system but could be used for gross checks on the accuracy of the primary system or in a backup emergency mode. Position information from some of the long and medium range systems might be improved by onboard data processing and filtering not now part of the current system setup. Use of Doppler radar and processing in the Decca system is largely responsible for the accuracy of the system. The TACAN and VOR systems would have sufficient accuracy to vector the shuttle to the vicinity of the landing area, where other landing aids could provide the closer tolerances required for the landing approach.

Table II lists the errors for a small number of airport landing systems. Most of the conventional ILS sites appear unable to support zero-zero landing due to their large lateral errors and beam path interference. However, some have ILS systems capable of supporting landings down to CAT II conditions (200 ft. decision height, 2600 ft. runway visibility). The British BLEU automatic landing system improves the conventional ILS with the addition of magnetic cables to provide accurate lateral control near the runway. Standard deviations computed from 4000 landings define the accuracy of the BLEU system. The PAR system is a scanning beam radar system possessing more path stability (less distorting interference) and greater accuracy than the conventional ILS. AILS are advanced ILS systems using scanning beam radars and show a marked improvement in accuracy. These systems should be capable of supporting landings in near zero-zero conditions. The AILS have been tested but are not operational yet and probably would not have sufficient distribution to support shuttle landing at all airports. However, use of the AILS system at preselected shuttle landing sites should be given further study.

Studies have shown (ref. 7) that optimal mixing of conventional ILS and inertial state information can produce an accurate navigation system. In this system the high frequency noise of the ILS and the low frequency errors of the inertial unit can be filtered out. However, a capability for the high glide slope landings necessitated by an unpowered shuttlecraft have not been demonstrated with the ILS glide slope beam.

Table III contains data on the Apollo LM rendezvous radar system. It is possible that a similar radar system incorporating a low cost transponder at candidate airports might prove very useful and inexpensive as a navigational aid. Bearing and range information from the RR could also be used to update the inertial system. Doppler radars are currently being used in some aeroplane navigation systems and could be used to provide velocity and wind information for the shuttle. Altitude information from an Apollo type landing radar is less desirable than radar type derived altitude information as the landing radar suffers from terrain effects.

In summary, it appears that there is a necessity to include some of the currently operational navigational aids in the shuttle equipment if emergency landings at almost any airport are attempted. There are a variety of navigational aids available some of which have enough accuracy to vector the shuttle to the landing area and perform a guided approach. However, at present, there is no system that has demonstrated guided landings at the large glide angles necessitated by an unpowered shuttle landing. In addition, it appears that a transponder type RR set right at the landing site could help vector the shuttle in an emergency or serve to update the inertial system.

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WMB WB

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Distribution:
(See attached list)

NOTATIONS

AILS	advanced instrument landing system
BLEU	blind landing experimental unit
DECTRA	Decca tracking and ranging
DH	decision height
DME	distance measuring equipment
ILS	instrument landing system
KC	kilo-cycle
LM	lunar module
LORAN	long range navigation
m	mile
n. mi.	nautical mile
MC	megacycle
PAR	precision approach radar
RR	rendezvous radar
TACAN	tactical air navigation
VOR	very high frequency omni-direction range

TABLE I

NAVIGATION AID ERRORS

System	Range	Error	Comments
Long Range			
Loran A	750 m.	1 n. mi.	Operates 2 mc.; gives position fix over the oceans; range over land limited to about 75 miles.
Loran C	1000 m.	~several hundred feet	Operates 100 KC/sec carrier frequency; gives position fix.
DECTRA	~2000 n. mi.	5 n. mi.	Used with Decca system; 70 KC.
Medium Range			
TACAN-DME	195 - 300 n. mi.	.1 n. mi. $.75^{\circ}$	Overall system errors; 962 - 1213 mc bearing and range information.
VOR	~220 n. mi.	$\pm 1.7^{\circ}$	Standard deviation; works on same frequency as ILS, 100 mc 3σ errors are about $\pm 5.1^{\circ}$ considering all VOR stations.
GEE	Line of sight	$\frac{1}{2}$ to 1 n. mi.	Use master/slave stations to produce hyperbolic position grid.
DECCA	250 m.	$\frac{1}{4}$ to 1 n. mi.	Use doppler information and processing.

TABLE II

LANDING AIDS

SYSTEM	ERRORS	REMARKS
ILS	$1/3^{\circ}$ on localizer = 60 ft. lateral error at threshold	Conventional glide and localizer beams 100 mc on localizer 300 mc on glide
BLEU	$1/2^{\circ}$ heading; .9 fps; 10 ft. lateral; 220 ft. range	Automatic landing system, standard deviations
PAR	.1 n. mi. range, .05 n. mi. lateral	Errors at 30 n. mi.; 3CM wavelength errors at 3/4 m. are $\sim$ 200 ft. range 20 ft. lateral
REGAL	$.05^{\circ}$ elevation	Elevation scanning beam ILS
AILS	$.03^{\circ}$ elevation, $.05^{\circ}$ azimuth, 75 ft. range	Standard deviation scanning beam ILS ± 5 ft. error at 100 ft. DH

TABLE III

APOLLO RENDEZVOUS RADAR

range	80 ft. to 400 n. mi.			
range rate	$\pm$4900 fps			
beam width	$\pm 3.5^\circ$ transmitter/reciver $\pm 60^\circ$ transponder			
range error	bias	$\pm$120 ft. for ranges < 50 n. mi.		
	random	80 ft or 1% ranges 80 ft to 5 n. mi. 300 ft or 1/4% range above 5 n. mi.		
range rate error	bias random	1 fps 1 fps	3σ	
angular error	range	bias	random	
	200 n. mi.	8 mr	4.8 mr	
	5 n. mi.	8 mr	4.7 mr	
	80 ft	8 mr	10 mr	
frequencies	9832.8 mc transmitter 9792 mc transponder			