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FLIGHT TESTS OF THE AN/APN-67 AUTOMATIC NAVIGATOR USING SPACE DUPLEXING

C. R. Grant, E. F. McClain,
and W. R. Ferris

Radio Astronomy Branch
Atmosphere and Astrophysics Division

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NAVAL RESEARCH LABORATORY
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ABSTRACT

The AN/APN-67 Automatic Navigator using "space duplexing" has been flight tested for a total of 27,597 nautical miles. During the early flight tests, covering 41 navigational flights for a total of over 10,000 miles, the average distance error was one half of one percent. Due to an inaccurate heading reference the average heading error was 1.84% and the average position error was 2.06%.

The space-duplexed antenna system proved to be completely reliable and trouble free.

There was no significant difference in the accuracy of over-water flights compared to over-land flights as long as the sea state was Beaufort 1 or greater.

There was no deterioration in accuracy up to 12,000 feet, the highest altitude tested, even though the receiver did not employ frequency-following filters.

After approximately 800 hours of operation, including extensive laboratory as well as airborne testing, mechanical wear in the computation system caused a measurable reduction in accuracy.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

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INTRODUCTION

The AN/APN-67 Automatic Navigator is a self-contained electronic device which automatically accomplishes the dead reckoning necessary to navigate an aircraft. It continuously indicates position, true ground track, drift, velocity, and heading. The ground speed and drift are obtained by measuring the doppler frequency shift from two signals which have been reflected from the surface of the earth. The system and early flight tests are described completely in NRL Report 4051.[1]

In a practical system it is necessary to isolate electromagnetically or duplex the transmitter and receiver. Several methods have been evolved making use of phase or polarization relations in the microwave circuits. Two separate antennas may be employed to accomplish the desired result and, if properly designed, superior operation may be obtained.

The hybrid ring duplexers in the system described in the above-mentioned report have been replaced with "space duplexers." This report describes the flight tests of the space-duplexed system.

ANTENNA SYSTEM

Previous flight experience with phase-duplexed systems employing hybrid rings or magic tee's has indicated that these systems are inherently unstable and microphonic due to their null type operation. That is, the transmitter power is nulled out at the receiver terminals by a proper phasing arrangement in the microwave plumbing. Such systems in addition to the above objections are characterized by a theoretical sensitivity loss of 6 db which is inherent in the duplexing bridge. Laboratory tests indicated that practical systems exhibited an additional loss of about 8 db due to side slope detection of FM noise in the transmitter. These difficulties are easily overcome by employing separate antennas for transmission and reception but the space required for such an installation is prohibitive.

Accordingly an effort has been made to employ a single 24-inch aperture for both transmission and reception. A single 24-inch parabola was separated into two halves by means of a metallic septum (Fig. 1). Feed horns were located on either side of the septum so that one half of the surface was used for transmission and the other half for reception. Such an arrangement obviously reduces the gain 3 db on transmission and 3 db on reception so that the system sensitivity is reduced 6 db. The theoretical sensitivity then is the same as the phase-duplexed system. Laboratory and flight tests indicate an actual improvement of about 8 db as a result of the elimination of the FM to AM conversion. Of equal importance is the extreme reliability of the space-duplexed system as evidenced by several weeks operation with no adjustment whatsoever to the radar portion of the system. The antenna units were packaged in sealed-beam fashion (Fig. 2) for installation in the aircraft.

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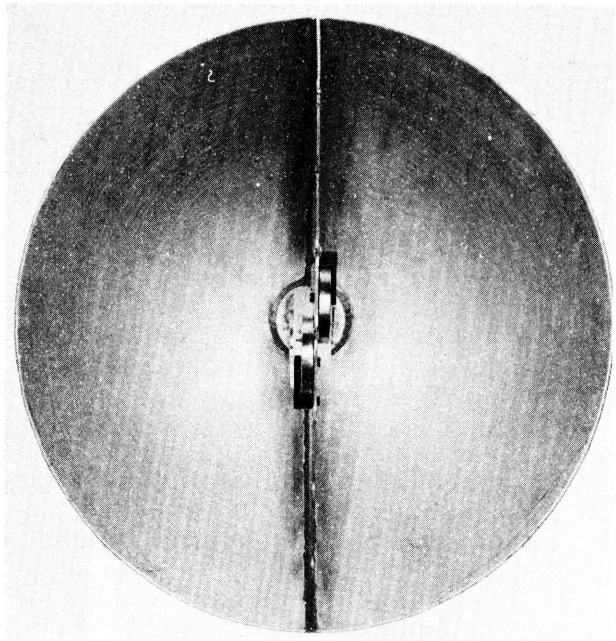
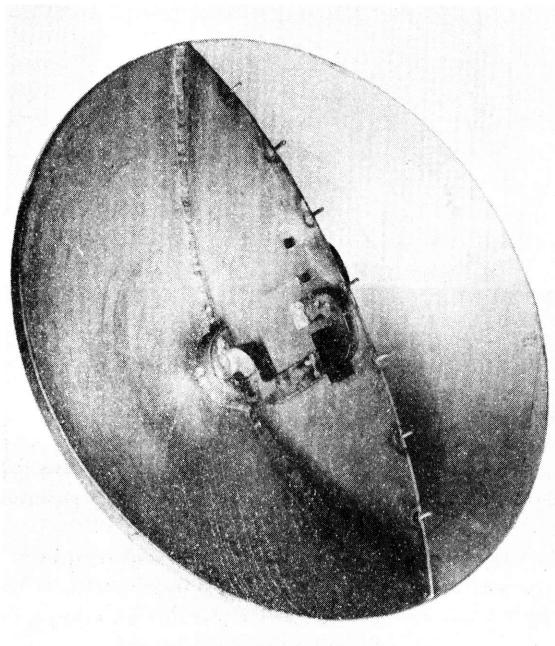
[1]McClain, E. F., Giles, R. C., Dewey, D. L., and Ferris, W. R., "The AN/APN-67 Automatic Navigator," NRL Report 4051 (Confidential), 24 October 1952



(a)



(b)

Fig. 1 - Space-duplexed antenna showing septum and feed horns

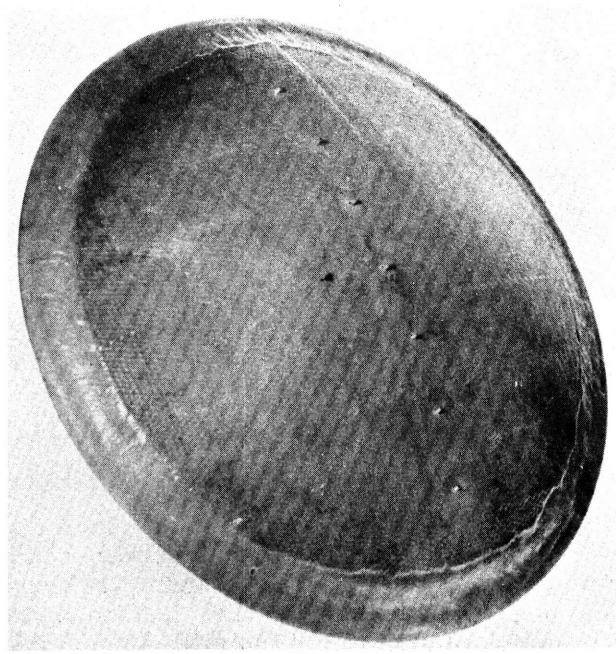


Fig. 2 - Space-duplexed antenna with radome in place before sealing

SUMMARY OF FLIGHT TESTS

The space-duplexed AN/APN-67 Automatic Navigator was flight tested on 122 flights for a total of 27,597 nautical miles. These flights have been separated into four categories:

	Nautical Miles
10 Miscellaneous testing flights	3350.4
15 Calibration flights	2520.3
14 Uncompleted navigational flights	3179.9
83 Completed navigational flights	18,546.4

To determine the errors on a navigational flight the latitude and longitude of the end point indicated on the AN/APN-67 are compared with the actual latitude and longitude (Fig. 3). The position error is the total error. Since these flights were flown in as nearly a straight line as possible, this total error can be broken down into two components—a distance error in the direction of the course flown and a heading error in a direction normal to the course. All these errors are expressed as a percentage of the course distance.

The flight tests have been divided into two groups for analysis because of an obvious deterioration in the system during the latter part of the flight test program. This deterioration is probably due to wear in the navigational computer which has had about 1000 hours of operation.

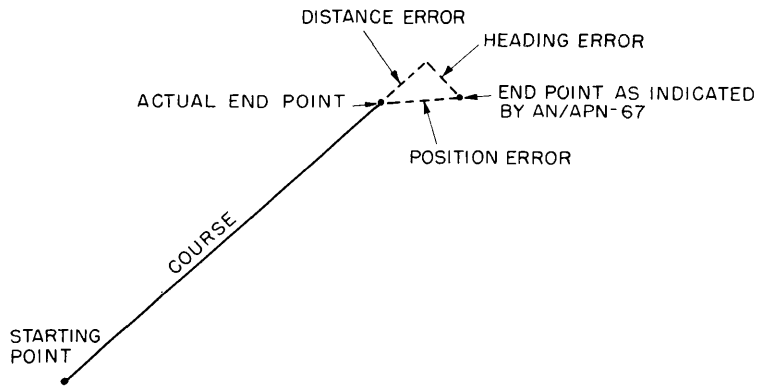


Fig. 3 - Diagram showing method of resolving errors

During the early flight testing period there were 80 flights for a total of 21,827 nautical miles. Of these, 41 flights for a total of 10,419 miles were completed straight-line navigational flights on which the errors can be separated. The average distance error was 0.50%. Comparisons were made between the drift indications on the AN/APN-67 and drift readings on a gyro-stabilized drift sight (Table 1). Since it takes several seconds to adjust and read the drift sight, it is believed that drift may be determined more accurately with the AN/APN-67 than with the gyro-stabilized drift sight.

TABLE 1
Correlation of AN/APN-67 Drift Indication with Gyro-Stabilized Drift Sight

Number of Comparisons	Percent of Total Number of Comparisons	Difference between AN/APN-67 and Drift Sight (degree)
56	44.4	0
43	34.2	1/2
24	19.0	1
2	1.6	1-1/2
1	0.8	2

On these same flights the average heading error was 1.84%. This relatively large heading error was due to inaccuracies in the G-2 compass system used as a heading reference and cannot properly be charged to the AN/APN-67. Since the position error is the resultant of the distance and heading errors, the inaccurate heading reference also causes a large position error. The average position error was 2.06%.

During the later flight testing period there were 42 flights for a total of 5770 nautical miles. Of these, 34 flights for a total of 4745 miles were completed straight-line navigational flights on which the errors can be separated. The average distance error was 1.48%,

the average heading error was 3.72%, and the average position error was 4.24%. In the case of these flights the over-all accuracy of the navigator has deteriorated due to wear in the computation system. As in the earlier flights, the heading errors are much greater than the distance errors due to inaccuracies in the heading reference.

ACCURACY OVER WATER VS. OVER LAND

As long as the sea state is Beaufort 1 or greater the automatic navigator operates satisfactorily over water. Out of 24 over-water navigational flights, mostly in the Caribbean area, there were three during which seas smooth enough to cause a reduction in accuracy were encountered. On all three of these flights, during the same week in September 1953, the loss of signal over smooth water caused intermittent operation of the automatic navigator and a decrease in accuracy. The distance errors on these three flights were from 2% to 7% instead of less than 1% as is usually obtained. Memory circuits which could take over whenever the signal is lost would have greatly reduced these errors.

A comparison of the errors on the over-water flights with a Beaufort 1 or greater sea with errors on over-land flights shows no significant difference (Table 2).

TABLE 2
Comparison of Flight Errors Over Land and Over Water

Test Period	Type of Flight	No. of Flights	Total Distance (naut. mi.)	Avg. Distance Error (%)	Avg. Heading Error (%)	Avg. Position Error (%)
First	Over land	32	7107.3	0.51	1.71	1.95
	Over water	9	3312.2	0.46	2.28	2.46
	All flights	41	10,419.5	0.50	1.84	2.06
Second	Over land	22	2353.7	1.52	4.32	4.78
	Over water	12	2391.7	1.42	2.63	3.24
	All flights	34	4745.4	1.48	3.72	4.24

The accuracy of a doppler navigator is affected by water motion on over-water flights. There are three effects which must be considered: the motion of the entire body of water resulting from ocean currents, the motion of the gravity waves, and the motion of the capillary waves or ripples. An ocean current will cause a direct error in indicated velocity, but since the ordinary velocity of ocean currents is only one or two knots this error is not serious for a fast aircraft. Theoretical[2] and experimental[3,4] investigations have shown that the doppler frequency does not depend on the velocity of the gravity waves, which

[2]Hulbert, E. O., "The Doppler Frequency Change in Radiation Reflected From the Waves of the Sea," NRL Report H-2422, 19 December 1944

[3]McClain, E. F., and Ferris, W. R., "Reflectivity of Sea Surface for Doppler Radar," NRL Report R-3418 (Confidential), 16 February 1949

[4]NRL ltr C-F42-5 (390Ga) of 9 August 1945 to Chief, BuAer

move at near wind speed, but rather on the velocity of the capillary waves which usually move at less than 10% of the wind speed. Consequently, the error caused by wave motion, while significant, will not necessarily be serious.

On December 15, 1953 an attempt was made to measure the error due to wave motion on an over-water navigational flight (Table 3). Two round trips were flown between Miami, Florida, and Nassau, Bahama Islands—one at 4000 feet and the other at 8000 feet. Surface winds of 20 to 30 knots were in such a direction that they were tail winds on the Miami-to-Nassau run and head winds on the return trip. These flights show a difference of nearly 2% in the measured distance between the head wind runs and the tail wind runs, the tail wind distance being short while the head wind distance is long. This wave motion error does not exceed 6.2% of the wind velocity for the 4000-foot run and 8.5% of the wind velocity for the 8000-foot run.

TABLE 3
First Test Period—Effect of Wind on Accuracy as a Result of Wave Motion

Altitude (ft)	Tail Wind Run		Head Wind Run		Measured Distance Corrected for Wave Motion Error (naut. mi.)	Estimated Surface Wind Velocity (knots)	Error due to Wave Motion (knots)
	Measured Distance (naut. mi.)	Time (min)	Measured Distance (naut. mi.)	Time (min)			
4000	165.9	51	169.1	55	167.4	30	1.8
8000	165.6	46	168.6	60	166.9	20	1.7

More flights were made over this same course in March 1954 at altitudes of 1000, 4000, 8000, and 12,000 feet (Table 4). The accuracy of the navigational computer had deteriorated by this time so consequently the errors are larger and should not be charged entirely to wave motion. On these later flights the wind was from the opposite direction so that head winds were encountered on the Miami-to-Nassau run and tail winds on the return trip. Again, the distance measurement was consistently longer on the head wind runs than on the tail wind runs.

TABLE 4
Second Test Period—Effect of Wind on Accuracy as a Result of Wave Motion

Altitude (ft)	Tail Wind Run		Head Wind Run		Measured Distance Corrected for Wave Motion Error (naut. mi.)	Estimated Surface Wind Velocity (knots)	Error (knots)
	Measured Distance (naut. mi.)	Time (min)	Measured Distance (naut. mi.)	Time (min)			
1000	168.3	53	173.7	59	170.9	15	2.8
4000	169.9	50	171.1	54	170.5	13	0.7
8000	167.7	49	172.0	50	169.8	15	2.6
12,000	168.8	48	174.6	52	171.6	15	3.5

ACCURACY VS. ALTITUDE

The amount of flight test data obtained was not great enough to permit an exact determination of the effect of altitude on the accuracy of the AN/APN-67. Available data indicate that any altitude effect up to 12,000 feet, the highest tested, is so small that it is completely masked by the other errors. There were no frequency-following filters in this laboratory model of the automatic navigator. The use of such filters should give a four-to-one improvement in the altitude capabilities of the system. The average distance error for each altitude flown during the flight test program is given in Table 5.

TABLE 5
Effect of Altitude on the Distance Error

Test Period	Altitude (ft)	No. of Flights	Total Distance (naut. mi.)	Average Distance (Error (%)
First	2000	4	1085.0	0.17
	2500	3	1052.2	0.31
	3000	1	276.6	0.98
	4000	19	5007.7	0.45
	5000	7	1089.7	0.81
	7000	1	312.0	0.29
	8000	3	759.2	0.44
	10,000	1	264.7	1.02
	12,000	2	536.4	0.48
Second	1000	2	342.0	1.79
	1500	2	244.6	1.78
	2000	1	175.8	0.57
	3000	1	99.0	2.93
	4000	4	860.7	0.92
	5000	7	786.8	1.37
	6000	12	1383.4	1.43
	8000	3	509.7	1.76
	12,000	2	343.4	2.04

ACCURACY VS. DISTANCE TRAVELED

Not enough data were obtained to determine an exact expression for the distance error as a function of the distance traveled. If all the errors are random, the error should theoretically be proportional to the one-half power of the distance traveled.

The absolute distance error on each of the 41 flights during the first test period have been plotted against the length of flight in Fig. 4. The solid line is the least squares solution of the data. The broken line is the theoretical curve of error proportional to the one-half power of the distance. The dotted line would result if the error were proportional to the first power of the distance. (These two have been normalized to the least squares solution at the 100-mile point.) A comparison of these curves shows that the least squares solution of the data falls very close to the theoretical curve of error proportional to the one-half power of the distance. The systematic errors are due mainly to an uncertainty

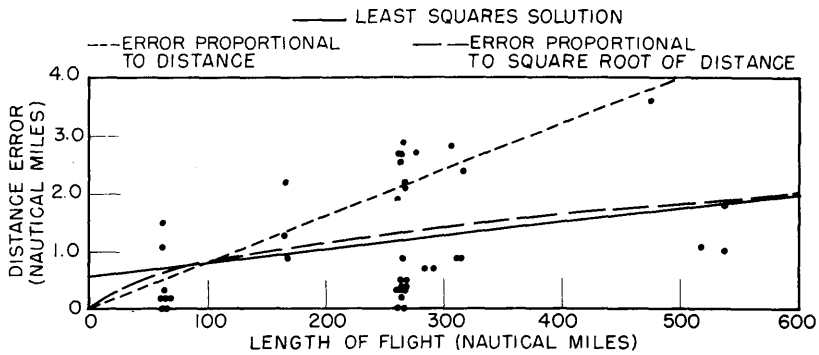


Fig. 4 - Distance error vs. length of flight

in the setting and reading of latitude and longitude on the navigational computer of about plus or minus 0.5 nautical mile. This possible source of error exists regardless of the length of the flight.

CONCLUSIONS

The space-duplexed AN/APN-67 Automatic Navigator proved to be extremely reliable and resulted in about 8 db improvement over the phase-duplexed system previously tested. The system operates satisfactorily over water provided the sea state is Beaufort 1 or greater, and with the addition of memory circuits it should be possible to navigate over even smoother water without excessive error.

If a compass with accuracy comparable to that of the AN/APN-67 were available it should be possible to make routine navigational flights over land and water with an average position error of 0.5% to 1.0% of the distance traveled.

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