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PERFORMANCE OF THE AN/GMD-2 RAWIN SET IN THE DENPRO SYSTEM

By

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PACIFIC MISSILE RANGE

Point Mugu, California

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SUMMARY

An analysis is performed of the velocity and altitude data derived from the AN/GMD-2 rawin set track of four flights of the density probe (DENPRO) vehicle made at San Nicolas Island in May and December 1964. Data from AN/FPS-16 radars are available for two of the flights and are used as a basis for evaluating the AN/GMD-2 data.

Slant ranges and vehicle velocities derived from the AN/GMD-2 compare favorably with those derived from the AN/FPS-16 data. Vehicle altitudes derived from the AN/GMD-2 are consistently lower than those derived from the AN/FPS-16. This was due to AN/GMD-2 rawin-determined elevation angles being lower than AN/FPS-16 radar-determined elevation angles by varying amounts, though the reason for this has not yet been determined.

It has been concluded (1) that the modified AN/GMD-2 is capable of tracking a rocket probe, (2) that AN/GMD-2 rawin-determined velocities may be expected to be within 1 per cent of AN/FPS-16 radar-determined velocities, and (3) that AN/GMD-2 rawin-determined altitudes are about 1 per cent lower than AN/FPS-16 radar-determined altitudes, up to an altitude of 400,000 feet.

INTRODUCTION

The purpose of this report is to present an analysis of the velocity and altitude data derived from the track by the AN/GMD-2 rawin set of density probe (DENPRO) vehicles launched from San Nicolas Island during May and December 1964. Six flights were made with a transponder telemetry system which provided data for the computation of vehicle velocity and altitude when tracked with a modified AN/GMD-2. There are no data available from one of these flights because of the failure of the telemetry system to function properly. One flight, flight operation 411176 of 1 May 1964, was evaluated by the U.S. Army Electronics Laboratories, Fort Monmouth, New Jersey (reference 1). The remaining four flights were evaluated by the Pacific Missile Range (PMR) and form the basis of this report. Of these four flights, two were tracked by AN/FPS-16 radar as well as by the AN/GMD-2, and the velocity and altitude data derived from these two sources are compared.

The DENPRO system consists of a pitot tube and a telemetry assembly payload carried aloft by a two-stage solid-propellant vehicle which consists of a SPARROW booster and a high-velocity ARCAS sustainer. During ascent, pitot-tube pressures are telemetered to the AN/GMD-2 which serves as the ground telemetry and tracking station. Minor modifications were performed on the AN/GMD-2 to permit the recording of data on magnetic tape and to permit the tracking of the DENPRO vehicle and the determination of its velocity and altitude.

The DENPRO system is fully described in references 1 and 2, and the reader is referred to them for the details of system theory and operation.

VEHICLE ACQUISITION

In order to permit the use of the DENPRO system in locations where only limited space is available, the system has been designed to operate with the AN/GMD-2 antenna located as close as possible to the vehicle launcher. As a result of the proximity of the antenna to the launcher the vehicle cannot be tracked from lift-off, because the antenna slew rates required to follow the vehicle are much greater than the slewing capability of the AN/GMD-2 antenna.

This problem is circumvented by aiming the antenna at a point along the vehicle's flight path and delaying the energization of the antenna drive circuits until the vehicle reaches a point where the antenna slew rates required do not exceed the capability of the AN/GMD-2. The time delay required will be smaller the more closely the AN/GMD-2 antenna can be placed to the vehicle launcher.

For the flight operations conducted from San Nicolas Island the AN/GMD-2 antenna was located 430 feet from the launcher at a bearing of 140 degrees. For this particular relationship of antenna to launcher, the antenna slew rates required at any time to track the vehicle were determined trigonometrically, by the use of predicted flight trajectory data. The time delay required after launch until the required antenna slew rates would fall within the capabilities of the AN/GMD-2 was determined to be 6 seconds, at which time the vehicle would be at an altitude of about 10,000 feet.

Angular settings required for the AN/GMD-2 antenna to intercept the vehicle at this 6-second point were computed with the aid of predicted flight trajectory data. The experience gained from these flights has shown that the antenna lock angles should be based upon the predicted resultant elevation and azimuth angles for the flight. That is to say, launcher settings could be completely ignored in computing the 6-second position of the vehicle.

In practice, acquisition of the DENPRO vehicle has posed no problems. Even with some large errors in predicted resultant azimuth angles, the field of view of the AN/GMD-2 antenna has been large enough to acquire the telemetry signal and to initiate tracking. Attempts to initiate track on ARCAS vehicles at about 6,000 feet (6-second time delay) have resulted in some failures. Even though the ARCAS vehicle is moving slower than a DENPRO vehicle at this point, apparently the smaller field of view requires a more precise prediction of vehicle position than can always be achieved.

SLANT RANGE

The range-change signal produced by the phase comparator in the modified AN/GMD-2 during a flight is recorded on magnetic tape at 60 inches per second. At the completion of the flight the tape is played back at a speed of 15 inches per second into a multichannel recording galvanometer with the paper speed set at 1 inch per second. Figure 1 is a sample of the range-change record obtained from a flight.

Each complete electrical cycle of range change represents a distance of 2,000 yards. The slant range is the total number of cycles multiplied by 2,000 yards, plus the original distance between tracking antenna and vehicle launcher.

A spin rate at sustainer burnout of about 7 revolutions per second is induced on the sustainer to help maintain low angles of attack during the flight. Since both the transmitting and receiving antennas are linearly polarized, a signal loss is suffered twice during each spin. And since the amplitude of the output of the phase comparator is sensitive to the strength of the received signal, the amplitude of the range-change signal is, in effect, modulated with a frequency twice that of the rocket spin rate.

The recorded range-change signal requires the least smoothing as it passes through electrical zero. These zero crossings give the most easily identifiable points for determining increments of range change. The zero line is placed midway between an approximately straight horizontal line connecting the positive peaks and an approximately straight horizontal line connecting the negative peaks of the range-change signal.

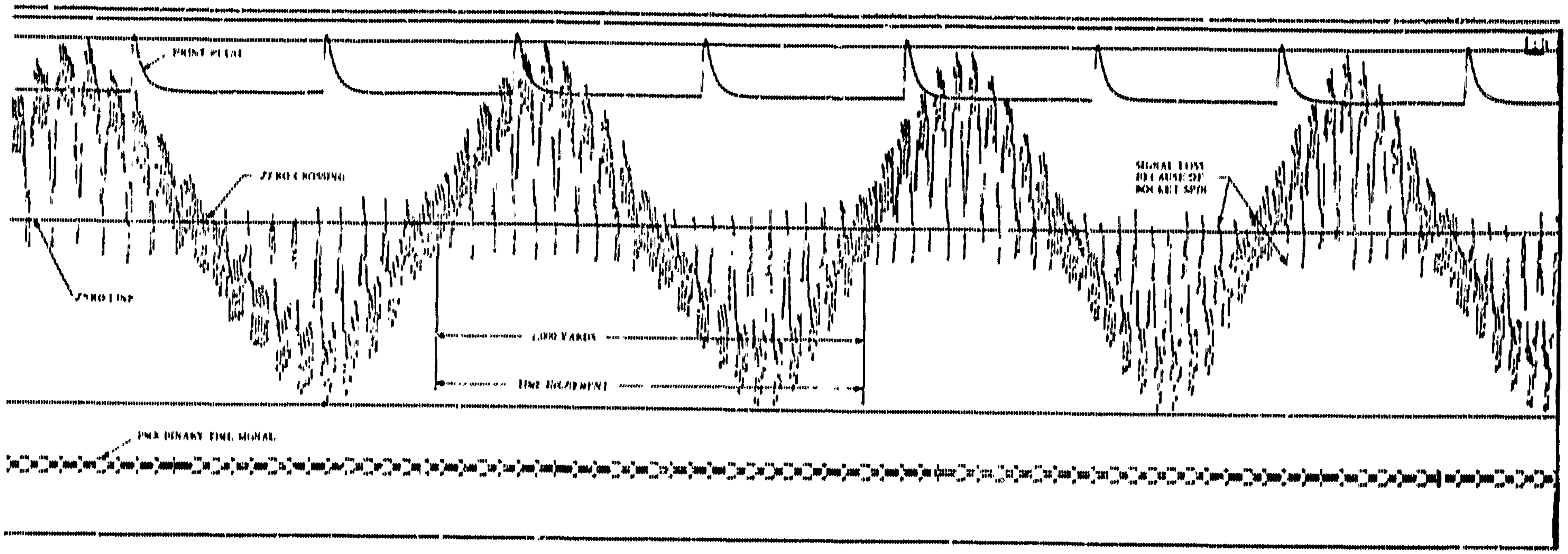

Figure 1. Sample of Range-Change Signal.

Print pulses (as shown in figure 1) are generated and recorded on the magnetic tape each time the AN/GMD-2 prints out antenna azimuth and elevation angles. These are used to establish a time correlation between the angular data and the range-change data.

Table 1 presents a comparison between the values of slant range versus time as obtained from galvanometer records and as determined by the AN/FPS-16. Flight operation 417104 shows good agreement between the AN/GMD-2 rawin-determined and AN/FPS-16 radar-determined slant ranges, with a root-mean-square difference of ±180 feet. The AN/GMD-2 rawin-determined slant ranges obtained for flight operation 417158B average 473 feet less than the AN/FPS-16 radar-determined slant ranges, with a root-mean-square difference of ±516 feet. However, the largest difference at any given time would account, in the first flight, for less than 500 feet of error in the altitude computations and, in the second flight, for less than 1,000 feet of error.

The galvanometer record for flight operation 417104 (figure 2a) shows a slow, smooth increase in range during the first 2 seconds of the flight. The record for flight operation 417158B (figure 2b) indicates a decrease in the range during the first 0.3 second of flight, which is not consistent with a reasonable flight path. Apparently, the effects of lift-off reduce in some way the time constant required by the airborne telemetry package to process the range-change signal, thus giving a false indication of a decrease in range. The galvanometer records indicate that this effect is temporary, with the time constant of the flight telemetry package returning to its original value as the stresses of lift-off decrease, thus re-establishing a proper range value.

The anomaly discussed above in the range-change signal has been noted on all flights except 417104. However, since the effect on the indicated range is apparently temporary, it does not provide an explanation for the systematic error observed in the slant ranges for flight operation 417158B. However, it is noted that the maximum range decrease of the anomaly is within about 50 feet of the value of the systematic error observed. No other source of systematic error of this magnitude is obvious within the DENPRO system.

VELOCITY DATA

Velocity computations were made using distances equivalent to a full range-change cycle. The velocity computed is the average value during the time increment required to travel this distance and is considered to have been the instantaneous value at the midpoint of the time increment. This assumption is valid since the acceleration of the vehicle is a smooth and very nearly straight-line function during the data-gathering portion of the flight (150,000 to 300,000 feet).

Table 2 presents AN/GMD-2 rawin-determined velocities and the differences between them and AN/FPS-16 radar-determined velocities. Table 3 presents AN/GMD-2 data for flight operations for which no radar track was obtained, and the differences are those about a smooth curve fit to the data points visually. With

Table 1. AN/GMD-2 Rawin-Determined Slant Ranges Compared With AN-FPS-16 Radar-Determined Slant Ranges

Time After Launch (Seconds)	AN/FPS-16 Radar-Determined Slant Range (Feet)	AN/GMD-2 Rawin-Determined Slant Range (Feet)	Δ Slant Range [a] (Feet)
A. Flight Operation 417104, 17 December 1964 [b]			
58.83	200,609	200,700	+91
60.86	209,535	209,500	-35
61.84	213,800	213,900	+100
64.88	226,919	227,000	+81
67.94	239,810	239,600	-210
71.85	255,894	255,900	+6
73.90	264,121	264,000	-121
77.89	279,829	279,900	-71
81.85	294,856	295,300	+444
B. Flight Operation 417158B, 17 December 1964 [c]			
45.68	126,121	125,750	-371
51.63	155,077	155,000	-77
59.78	193,018	192,500	-518
67.87	228,662	228,500	-162
72.82	249,461	249,000	-461
78.79	273,524	273,250	-274
84.77	296,576	296,000	-576
89.76	314,943	314,500	-443
97.75	342,844	342,100	-744
103.75	362,495	361,800	-695
109.77	381,232	380,750	-482
115.82	398,853	398,300	-553
119.88	410,043	409,250	-793

[a] AN/GMD-2 radar-determined slant range minus AN/FPS-16 radar-determined slant range.

[b] The root-mean-square difference for this flight is ±180 feet.

[c] The root-mean-square difference for this flight is ±516 feet.

one exception the root-mean-square variations of velocity for the four flights evaluated were between 25 and 35 feet per second. Flight operation 417158A of 17 December 1964, was by far the poorest flight, with a root-mean-square difference of nearly 82 feet per second. On this flight the failure of the nose cone to eject kept the 403-megacycle (Mc) receiver antennas stowed and caused a range-change signal of small amplitude. A major portion of the root-mean-square variation on all four flights can probably be attributed to the modulation imposed on the range-change signal because of rocket spin.

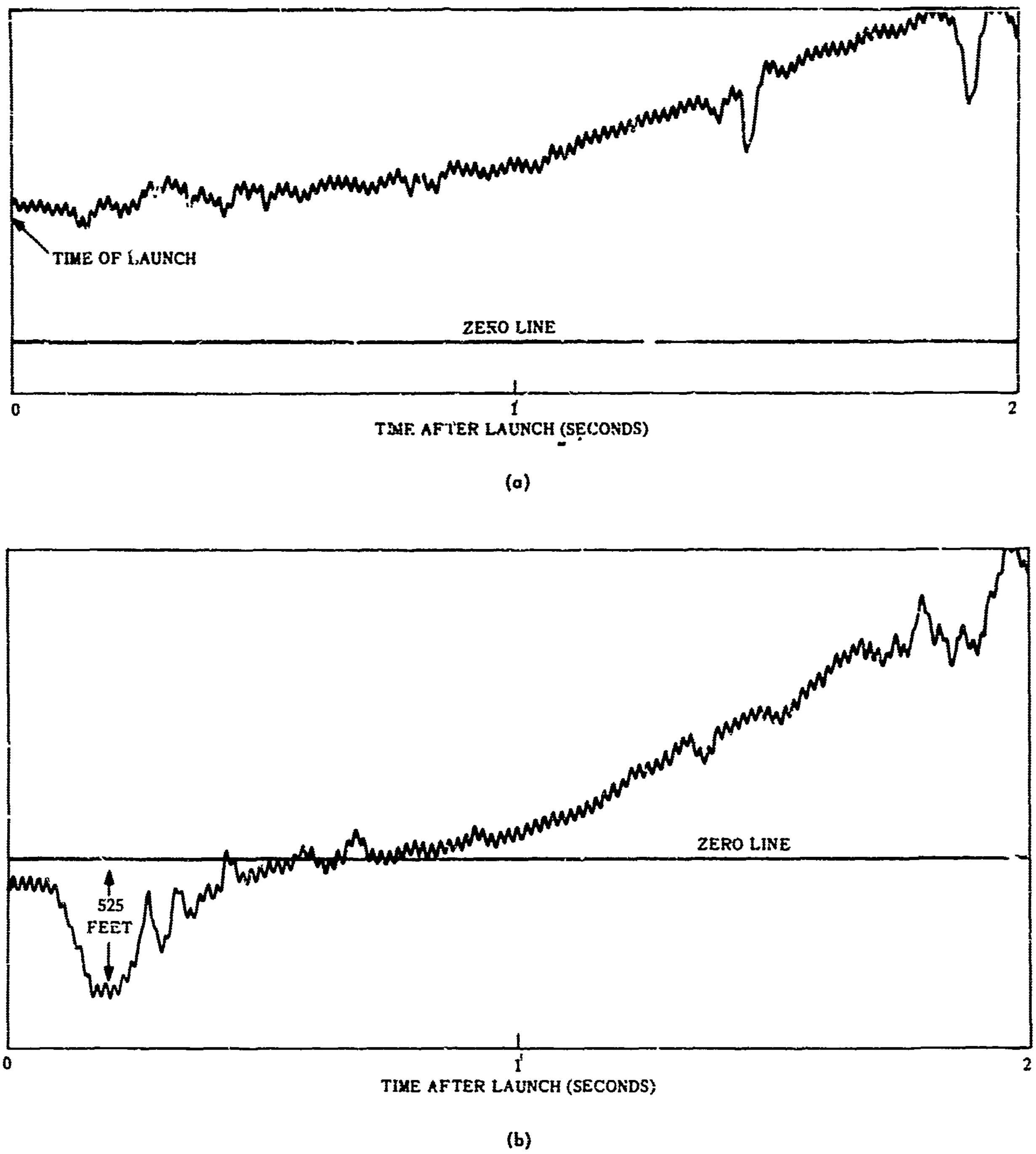

Figure 2. Galvanometer Records of First 2 Seconds of Flight Operations (a) 417104 and (b) 417158B.

When a curve that is fit visually to the data points is compared to AN/FPS-16 radar-determined velocities, root-mean-square differences on the order of 10 to 20 feet per second are obtained.

Table 2. AN/GMD-2 Rawin-Determined Velocities Compared With AN/FPS-16 Radar-Determined Velocities

Time After Launch (Seconds)	AN/GMD-2 Rawin-Determined Velocity (Feet Per Second)	Δ Velocity[a] (Feet Per Second)
A. Flight Operation 417104, 17 December 1964[b]		
46.0	4,838	-24
46.7	4,837	+2
47.3	4,820	0
47.9	4,780	-20
48.5	4,820	+35
49.2	4,780	+25
49.9	4,705	-30
50.4	4,705	-11
51.0	4,725	+27
51.8	1,705	+35
52.4	4,670	+18
52.9	4,650	+15
53.7	4,600	-10
54.3	4,580	-11
55.0	4,580	+8
55.6	4,580	+27
56.2	4,580	+45
56.9	4,580	+65
57.6	4,528	+33
58.2	4,460	-15
58.9	4,480	+25
59.5	4,460	+23
60.3	4,410	0
60.9	4,365	-27
61.6	4,318	-57
62.3	4,300	-52
63.0	4,318	-17
63.8	4,225	-82
64.5	4,270	-18
65.0	4,333	+64
65.9	4,315	+80

[a] AN/GMD-2 radar–determined velocity minus AN/FPS-16 radar–determined velocity.

[b] The root–mean–square difference for this flight is ±33.7 feet per second.

Table 2. (Continued)

Time After Launch (Seconds)	AN/GMD-2 Rawin-Determined Velocity (Feet Per Second)	Δ Velocity[a] (Feet Per Second)
B. Flight Operation 417158B, 17 December 1964[c]		
48.2	4,909	-11
49.1	4,902	+22
49.7	4,858	+7
50.2	4,842	+7
50.7	4,800	-17
51.4	4,761	-34
52.0	4,796	+18
52.6	4,762	+5
53.2	4,713	-22
53.9	4,754	+39
54.6	4,745	+50
55.2	4,665	-10
55.8	4,625	-27
56.5	4,646	+16
57.2	4,615	+5
57.8	4,646	+56
58.4	4,580	+10
59.2	4,494	-54
59.7	4,485	-45
60.5	4,485	-25
61.2	4,477	-11
61.7	4,501	+26
62.4	4,486	+34
63.2	4,423	-3
63.7	4,390	-20
64.5	4,340	-44
65.2	4,360	-2
65.7	4,375	+25
66.5	4,355	-29
67.2	4,260	-42

[a] AN/GMD-2 radar-determined velocity minus AN/FPS-16 radar-determined velocity.

[c] The root-mean-square difference for this flight is ±24.6 feet per second.

Table 2. (Concluded)

Time After Launch (Seconds)	AN/GMD-2 Rawin-Determined Velocity (Feet Per Second)	Δ Velocity[a] (Feet Per Second)
B. Flight Operation 417158B, 17 December 1964[c] (Cont'd)		
68.0	4,250	-30
68.7	4,265	+10
69.3	4,246	+12
70.2	4,222	+12
70.5	4,203	+8
71.3	4,165	-5
72.3	4,165	-15
72.8	4,135	+10
73.5	4,067	-33
74.2	4,055	-25
75.0	4,045	-11
75.5	4,029	-13
76.3	4,022	0
77.1	4,010	+10
78.0	3,930	-40
78.8	3,907	-44
79.5	3,915	-15
80.3	3,895	-2
81.1	3,895	+24
81.8	3,865	+10
82.5	3,855	+15
83.4	3,823	+8
84.3	3,780	-10
85.1	3,753	-7
85.8	3,725	-10

[a] AN/GMD-2 radar-determined velocity minus AN/FPS-16 radar-determined velocity.

[c] The root-mean-square difference for this flight is ±24.6 feet per second.

Table 3. Variation of AN/GMD-2 Rawin-Determined Velocities About Curve Fit

Time After Launch (Seconds)	AN/GMD-2 Rawin-Determined Velocity (Feet Per Second)	Δ Velocity[a] (Feet Per Second)
A. Flight Operation 411391, 8 May 1964[b]		
46.9	4,740	+21
47.6	4,718	+7
48.3	4,700	-12
48.9	4,680	-46
49.6	4,660	+180[c]
50.1	4,644	+7
50.8	4,625	-45
51.4	4,605	+45
52.0	4,588	-7
52.6	4,570	-5
53.4	4,546	+17
54.1	4,527	0
54.7	4,504	+24
55.3	4,489	+23
56.2	4,466	+29
56.6	4,451	-6
57.3	4,430	+13
58.1	4,406	+23
58.7	4,388	-39
59.4	4,368	+12
60.2	4,347	+34
60.8	4,322	-35
61.5	4,305	+10
62.2	4,285	+31
62.9	4,265	+23
63.6	4,240	0
64.3	4,220	+20
65.0	4,196	+3
65.7	4,180	-55
66.4	4,159	+6
67.2	4,137	-11
67.9	4,115	-47
68.7	4,090	+20
69.3	4,076	-6
70.2	4,048	+7
70.9	4,025	-51

[a] Difference between the AN/GMD-2 data points and the smooth curve fit to the data points.

[b] The root-mean-square variation for this flight is ±26.4 feet per second.

[c] Not used in computation of root-mean-square variation.

Table 3. (Concluded)

Time After Launch (Seconds)	AN/GMD-2 Rawin-Determined Velocity (Feet Per Second)	Δ Velocity[a] (Feet Per Second)
B. Flight Operation 417158A, 17 December 1964[d]		
46.1	4,996	-57
46.5	4,980	-10
47.1	4,960	+40
47.9	4,930	-121
48.4	4,910	0
48.9	4,890	+60
49.5	4,866	-125
50.3	4,851	-121
50.9	4,807	+157
51.4	4,782	+100
52.1	4,760	-120
52.7	4,731	-53
53.4	4,707	+52
53.9	4,690	-52
54.7	4,665	+31
55.3	4,648	+239[c]
55.9	4,628	-5
56.5	4,609	-70
57.2	4,589	+41
57.9	4,570	+155
58.4	4,554	-64
59.3	4,530	-76
59.9	4,512	+143
60.5	4,497	-22
61.1	4,477	-50
61.9	4,456	+59
62.5	4,438	-90
63.3	4,412	0
63.9	4,397	+91
64.5	4,378	+73
65.3	4,354	+28
65.9	4,333	0

[a] Difference between the AN/GMD-2 data points and the smooth curve fit to the data points.

[c] Not used in computation of root-mean-square variation.

[d] The root-mean-square variation for this flight is ±81.9 feet per second.

ALTITUDE DATA

The altitude of the DENPRO vehicle was determined using smoothed slant range and elevation angles measured by the AN/GMD-2. As with velocity, AN/FPS-16 radar-determined altitudes were used as a basis for comparison.

AN/GMD-2 rawin-measured elevation angles were plotted and graphically smoothed for use in the altitude computations. Figure 3 shows a typical plot of AN/GMD-2 rawin-measured elevation angles, the smooth curve drawn through them, and the corresponding AN/FPS-16 radar-measured elevation angles.

An extremely long smoothing period was used to eliminate the 10- to 15-second-period oscillations in the elevation angle data. Coppola (reference 1), suggests that these oscillations may be due to the effects of the 1680-Mc preamplifier on the sensitivity of the sine gain potentiometer in the AN/GMD-2. These oscillations are such as to require a somewhat subjective smoothing, which is a possible source of error.

The angular differences obtained on both flights for which radar data are available are of such a magnitude as to produce significant differences between AN/GMD-2 rawin-derived and AN/FPS-16 radar-derived altitudes. Table 4 presents the elevation angle differences and the resulting altitude differences. From the results of the slant range data it is evident that the altitude differences are due primarily to differences in the angular data.

The elevation angle differences appear to be due to an improper orientation of the antenna, which results in a systematic error, and some disturbance in the tracking circuits, which results in a varying amount of error. Table 4 indicates that there is some variable which causes the angular difference to vary as the flight progresses.

The introduction of a systematic error in the angular data could come about as a result of the physical configuration of the facilities which were available for orientation. Preflight orientation of the AN/GMD-2 antenna was accomplished by locking onto a 1680-Mc radiosonde transmitter located on a pole about 100 yards from the antenna. A survey had established an elevation angle of 7.25 degrees and an azimuth of 349.98 degrees from antenna to transmitter, and the printed angular readings of the AN/GMD-2 were adjusted to these values. However, optical sighting of the transmitter was not possible through the protective dome in which the antenna was housed.

A later check performed with the AN/GMD-2 showed that the orientation transmitter signal was sufficiently strong to permit the AN/GMD-2 antenna to lock-on with several side lobes. These lobes surrounded the electrical axis of the antenna, forming a cone with a central angle of between 2 and 4 degrees. Since the orientation transmitter could not be seen, it is possible that one of the several

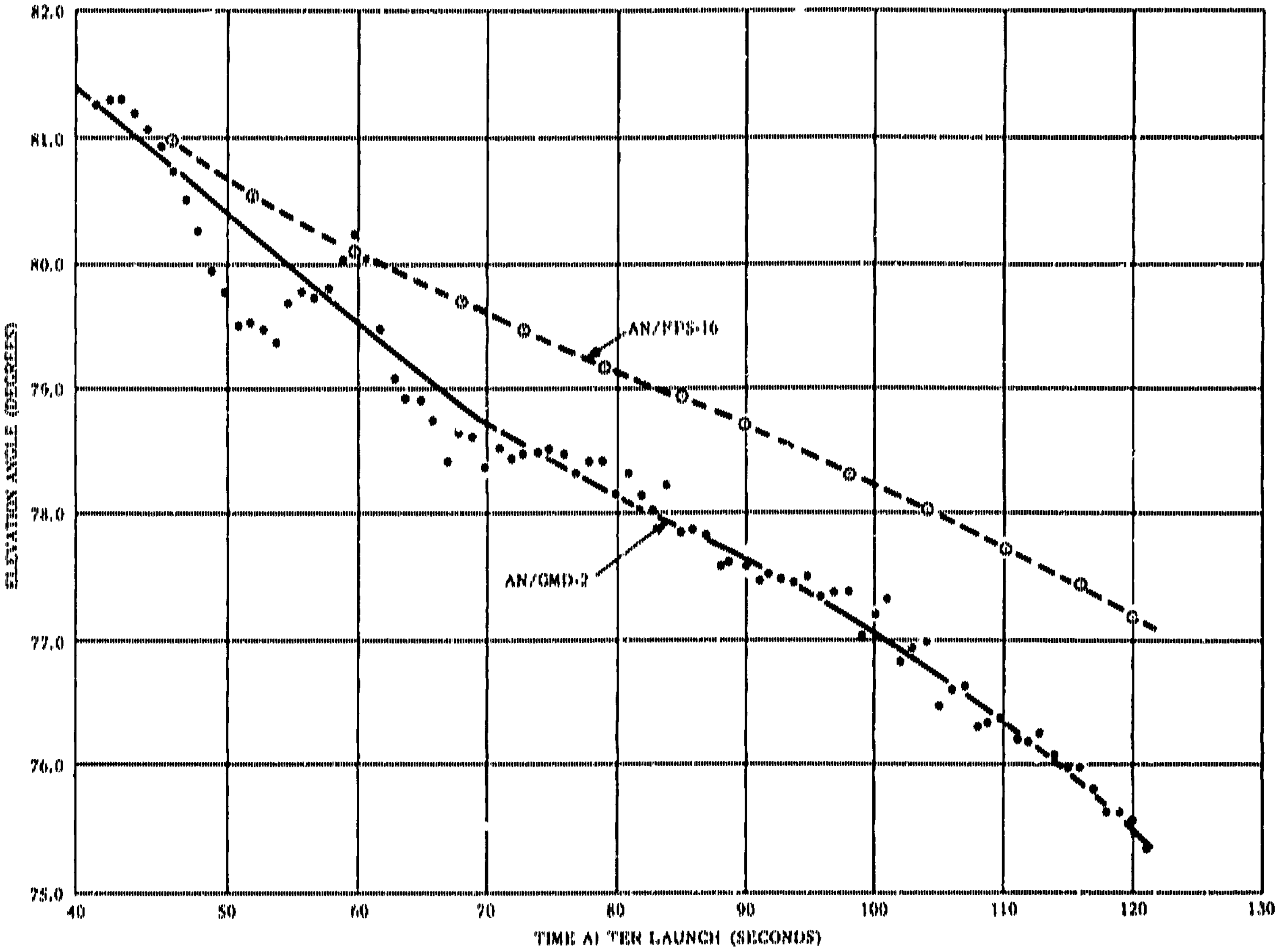

Figure 3. Elevation Angle Versus Time After Launch for Flight Operation 417158B of 17 December 1964.

Table 4 AN/GMD-2 Rawin-Determined Elevation Angles and Altitudes Compared With AN/FPS-16 Radar-Determined Elevation Angles and Altitudes

Time After Launch (Seconds)	AN/FPS-16 Radar-Determined Elevation Angle (Degrees)	Δ Elevation Angle[a] (Degrees)	AN/FPS-16 Radar-Determined Altitude (Feet)	Δ Altitude[b] (Feet)
A. Flight Operation 417104, 17 December 1964				
44.71	---	---	132,796	-252
47.78	---	---	147,321	-66
49.74	---	---	156,432	-49
53.75	---	---	174,637	-478
58.83	78.22	-0.96	197,043	-1,152
60.86	78.12	-1.01	205,747	-870
61.84	78.06	-1.02	209,896	-686
64.88	77.89	-1.06	222,600	-801
67.94	77.76	-1.14	235,083	-1,205
71.85	77.55	-1.19	250,604	-1,122
73.90	77.43	-1.25	258,579	-1,360
77.89	77.23	-1.23	273,668	-1,273
81.85	77.01	-1.25	288,157	-954
B. Flight Operation 417158B, 17 December 1964				
45.68	80.91	-0.19	125,079	-260
51.63	80.52	-0.32	153,686	-227
59.78	80.09	-0.56	190,877	-1,094
67.87	79.70	-0.78	225,718	-731
72.82	79.46	-0.90	246,007	-1,190
78.79	79.18	-0.97	269,449	-1,184
84.77	78.92	-1.00	291,824	-1,582
89.76	78.70	-1.06	309,626	-1,603
97.75	78.31	-1.15	336,554	-2,170
103.75	78.04	-1.29	355,484	-2,346
109.77	77.71	-1.38	372,341	-2,455
115.82	77.13	-1.55	390,157	-2,959
119.88	77.18	-1.60	400,758	-3,456

[a] AN/GMD-2 radar-determined elevation angle minus FPS-16 radar-determined elevation angle

[b] AN/GMD-2 radar-determined altitude minus FPS-16 radar-determined altitude.

side lobes of the AN/GMD-2 was locked onto the orientation transmitter, establishing a systematic error in the elevation angle readings. Therefore, it is possible that systematic errors of different magnitudes were established on each flight. A bias of this nature can be easily eliminated by improving the facilities available for prelaunch orientation.

A more disturbing feature of the elevation angle differences is their variation in magnitude with time, as can be seen in figure 3. Attempts were made to determine the source of this variation in the elevation angle differences, but proved futile. Investigated as potential sources of this variable difference in angles were the following:

1. The slew rates of the AN/FPS-16 and the AN/GMD-2 antennas, considered separately and in combination.

2. AN/GMD-2 antenna elevation angle.

Although no source of the varying differences was found, several items of interest were noted:

1. The angular difference increased rapidly as the actual slew rate of the radar antenna changed from positive (increasing elevation angles) to negative (decreasing elevation angles).

2. The angular differences decreased after apogee, which coincided with a marked increase in both AN/FPS-16 and AN/GMD-2 negative slew rates.

Since the source of the angular differences is unknown, it is not possible to apply any corrections to the AN/GMD-2 data. It is reasonable, therefore, to assume that what is true for the two flights for which radar data are available is also true for the two flights for which radar data are not available: That AN/GMD-2 rawin-determined altitudes are about 1 per cent lower than radar-determined altitudes.

CONCLUSIONS

Two major sources of error were present on all flights and must be eliminated before the DENPRO system can be considered operational. One was the disturbing effect of rocket spin on the range-change signal. This effect manifested itself in a larger root-mean-square variation in the velocity data than otherwise would have occurred. The other was the elevation angular differences which resulted in altitude differences 5 to 10 times greater at 300,000 feet than should be expected.

Nevertheless, certain conclusions can still be drawn from the results of the four DENPRO flights evaluated by PMR:

1. The AN/GMD-2, as modified for the DENPRO system, is capable of tracking a rocket-borne payload during the ascending portion of a flight.

2. AN/GMD-2 rawin-determined velocities may be expected to be within 1 per cent of AN/FPS-16 radar-determined velocities.

3. AN/GMD-2 rawin-determined altitudes are about 1 per cent lower than AN/FPS-16 radar-determined altitudes up to an altitude of 400,000 feet.

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