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A COMPUTER STUDY OF THE WIND FREQUENCY RESPONSE OF UNGUIDED ROCKETS

by

Edward M. D'Arcy

ATMOSPHERIC SCIENCES LABORATORY
WHITE SANDS MISSILE RANGE, NEW MEXICO

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ABSTRACT

The wind frequency response of several unguided rockets was studied using data collected by simultaneous releases of a jimsphere and a standard 100 gm balloon. Results show there can be large differences in the predicted rocket impacts using the two balloons. High wind frequencies are shown to affect the rocket only to a small degree and can be ignored in real-time rocket impact prediction applications. Averaging winds over a fifty-foot layer gives results comparable to the best Fourier smooth and binomial filter.

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INTRODUCTION

Many people have asked questions regarding the wind frequency response of unguided rockets. This study was made in an attempt to answer some of these questions. The report actually contains three different studies: (1)compares predicted rocket impacts by using data obtained from a jimsphere and a standard 100 gm balloon (2) compares a Fourier smooth with a binomial filter and (3)shows the effect of averaging each wind profile through six different layer thicknesses.

From the standpoint of impact prediction by high-speed computer, one can only analyze the effect that a certain wind profile has upon a given rocket trajectory. Wind data were obtained from a standard 100 gm balloon and a jimsphere released simultaneously. The data were smoothed by a Fourier series and by a binomial filter. The wind frequencies to be smoothed were determined from a paper published by Manuel Armendariz (1). The cutoff frequencies were chosen to eliminate balloon noise and to destroy as few as possible of the wind frequencies to which the rocket might respond.

The data were collected at three-foot intervals by cine-theodolites and rocket trajectories run on these original wind profiles. Since this requires tremendous amounts of computer storage, the data were also averaged through layers 24, 51, 99, 198, 498 and 999 feet thick to save storage space and to determine the effect of averaging on rocket impact accuracy.

Due to the large amount of computer time necessary for one complete analysis, the data for only four rockets are presented. These are, however, thought to be representative of most unguided rockets and hopefully all conclusions can be applied to other unguided rockets.

DISCUSSION

Two balloons, released simultaneously, were used to obtain the wind profiles. One was a standard 100 gm balloon and the other was a jimsphere. Armendariz (1), using the method used by Rogers and Camnitz (2), ran a power spectrum on these and other pairs of wind profiles. Figure 1 is a representative graph of the spectral density (after Armendariz). In all cases observed, on the jimsphere curve there was a flat spot between about .03 and .15 cycle/sec, representing a wave number of .002 and .01 cycle/foot respectively. A secondary peak at about .20 cycle/sec, representing .0133 cycle/foot,

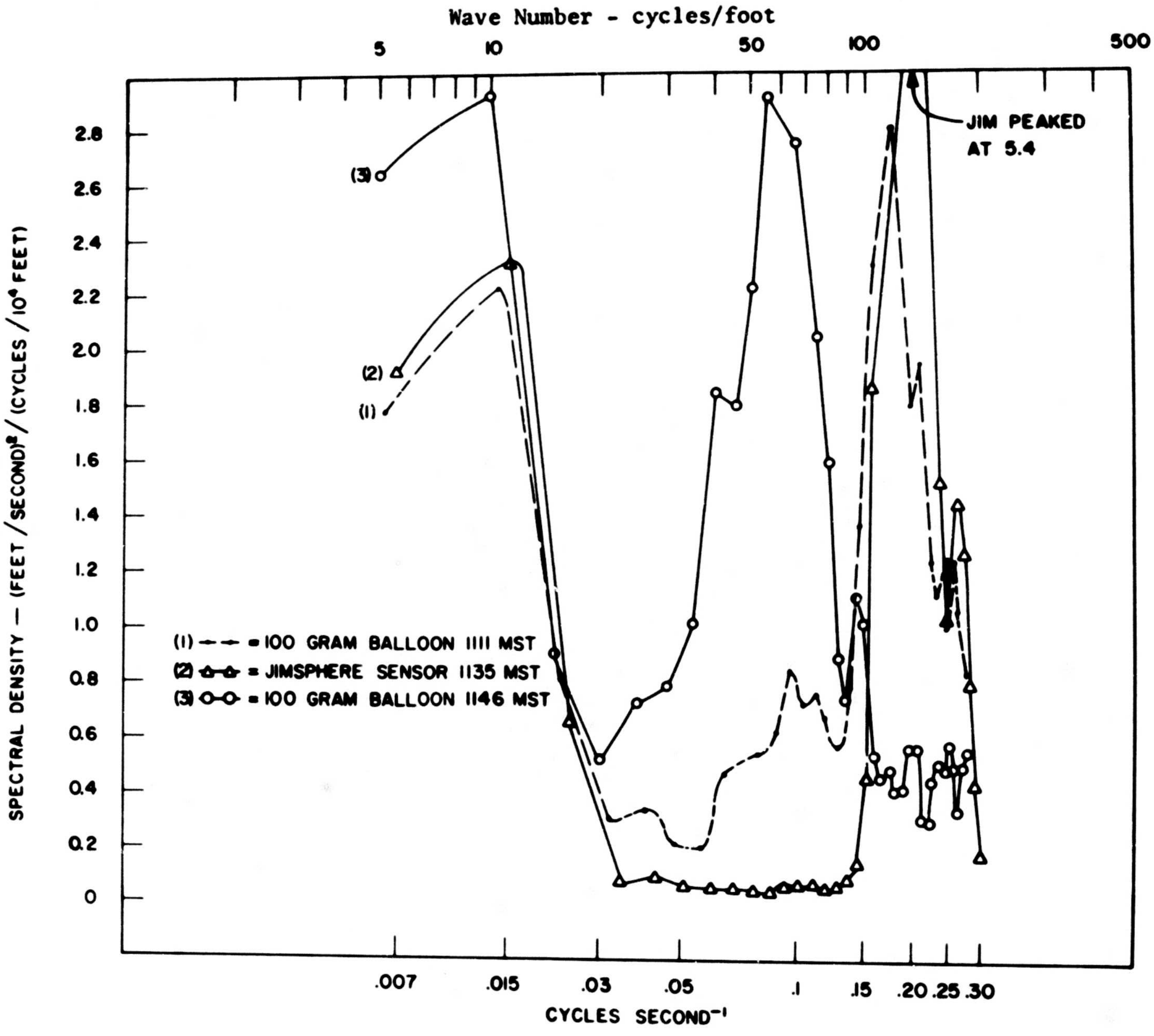

FIGURE 1 EXPERIMENTAL SPECTRA OF THE MERIDIONAL WINDS

is attributed to balloon noise. The standard 100 gm balloon shows a minimum frequency at about .03 cycle/sec, representing .002 cycle/foot, with several secondary peaks attributed to balloon noise, scattered between .05 and .30 cycle/sec, representing space frequencies of .0033 and .02 cycle/foot. These power spectra give us a starting point for our truncation of unwanted wind frequencies.

To eliminate the balloon-induced noise and still maintain a representative wind profile, one can truncate the wind frequencies above .01 cycle/foot on the jimsphere and see how this affects the predicted impact of the rocket. The truncation of the wind frequencies was accomplished by two methods: a Fourier series was fitted to the unsmoothed original data, and the unwanted frequencies in the wind profile were eliminated; and a binomial filter was used. An 83 point smoothing technique eliminated wind frequencies above .004 cycle/foot and a 167 point smoothing technique eliminated wind frequencies above .002 cycle/foot. Each of these truncated wind profiles was impressed on the trajectories of the four missiles, a 150-lb. payload Aerobee 350, a 500-lb. payload Aerobee 350, an Athena and a Nike-Apache. These three rockets were chosen because they cover a wide range of unguided missiles used for research. The Aerobee 350 is 50 feet long and weighs about 7000 pounds, the Athena is about 51 feet ong and weighs 16,000 pounds, and the Nike-Apache is 26 feet long and weighs 1700 pounds at launch. Tables I-VIII present the empirical results of this study.

First observe only the rocket impacts listed in the tables for the wind layer thickness of three feet. In the unsmoothed original data, one will immediately notice the large differences between the predicted rocket impact obtained from the jimsphere and that of the standard 100 gm balloon. It is not clear which is the more accurate; however, it is thought by most authorities in the field that the jimsphere will give a more representative wind profile (1).

The Fourier smooth of the three-foot data for the jimsphere shows only a small amount of the rocket's response is lost by truncating the wind frequencies at .01 cycles/foot. A much larger amount of response is lost if the wind frequencies above .002 cycle/foot are truncated. Truncation of any lower wind frequencies would result in larger errors in predicted rocket impact. Another example of this can be seen by observing each set of rocket impacts from the three-foot to the one-thousand-foot averaging intervals. The unsmoothed original three-foot data were averaged over layers of the different noted thicknesses. As larger layers are averaged the same effect as truncating the short wavelengths is observed.

The binomial filter did not work as well as the Fourier series, but here again the 83 point filter gave better results than the 167 point filter showing that the rocket does indeed respond to wavelengths of less than one-hundred feet.

To eliminate the balloon noise of the standard 100 gm balloon the Fourier series was truncated at .03 and .015 cycle/sec, which is equivalent to .002 and .001 cycle/foot. Here again the .002 cycle/foot shows greater agreement with the unsmoothed original data than does the .001 cycle/foot pointing out the rockets response to high wind frequencies. Again with the binomial filter the 83 point filter gave better results than the 167 point filter. It is rather difficult to say which method is better; however it appears as though the Fourier series truncated at .01 cycle/foot is the best method for the jimsphere, and the 83 point binomial filter is best for the standard 100 gm balloon. This is probably due to the different response characteristics of the two balloons.

Several things had to be considered to make the computer study valid. The rocket trajectory is composed of a series of points calculated from an integration procedure. The program used (3), contains checks to assure that the errors obtained in the Runge-Kutta integration do not get too large. It is possible to obtain a series of different predicted rocket impact points by simply changing the time constant of the integration. In other words, a rocket trajectory with an integration interval of one second will give a different impact point than one constrained to a maximum integration interval of one-tenth of a second, even though the change may be only a few feet. Since the unsmoothed original data are profiles with points every three feet, the integration interval must be forced to three feet or less for the rocket to "see" the higher wind frequencies. For this study the wind profile covered the first 10,000 feet of the rocket trajectory, and the integration interval was adjusted to meet the maximum velocity obtained during this portion of the rocket trajectory. This extremely small integration interval, on the order of .001 second, causes the trajectory to take six or seven minutes to run where under normal integration intervals it would run in one and a half or two minutes. For real-time applications the higher wind frequencies can be eliminated without too great a loss in rocket impact prediction accuracy, and at least four minutes of trajectory calculation time would thus be saved. Also one can see that a high resolution profile necessitates a large number of data locations in the computer. At one point per three feet this would necessitate the allocation of about 250,000 data locations for wind alone in a profile for an Athena firing. Fortunately, the 51 foot averaged wind profiles are not very different from the three foot unsmoothed original data. An earlier study (4), has shown that if one starts with 50 ft. layers at the end of the launcher, the layer thickness can be increased toward the top of the wind profile with only small losses in predicted rocket impact accuracy.

CONCLUSIONS

It appears safe to say that the jimsphere gives a more representative wind profile than the standard 100 gm balloon. If the secondary peaks observed in Fig. 1 are truely balloon noise, then the Fourier truncated wind profile and the 83 point binomial filter should give better results than the unsmoothed original data.

There is no doubt, in this study, that the rocket does respond to the higher wind frequencies. However, assuming the majority of the energy observed past .002 cycle/foot is due to balloon noise and observing the relatively small change in rocket impact due to smoothing, one can assume that these high wind frequencies affect the rocket only slightly. For very accurate theoretical studies the high wind frequencies can be used if desired, however for real-time purposes where time and storage considerations in the computer must be met, the higher frequencies can be ignored as can any extensive filtering of the data. Averaging the wind data through a layer is fast and, if the proper layer thicknesses are chosen, gives results comparable to a smoothed, high-resolution profile.

Although the above conclusions are based on data obtained from a mathematical simulation, it is thought that a true aerodynamic study would yield similar results.

TABLE I

AEROBEE 350-150 Lb. PAYLOAD

Jimsphere

Layer Thickness (feet)	X(feet)	Y(feet)
	Original Data	
3	-93804	1140401
24	-93185	1138690
51	-92830	1137761
99	-89606	1139772
198	-86943	1142287
498	-75211	1139879
999	-55903	1139002
	Fourier Smooth .01	
3	-92506	1144638
24	-92570	1140803
51	-91669	1140108
99	-89098	1141925
198	-85749	1143473
498	-75163	1140812
999	-55846	1139087
	Fourier Smooth .002	
3	-90704	1154423
24	-90371	1151500
51	-89841	1148937
99	-88817	1148671
198	-85176	1145181
498	-75016	1142361
999	-55749	1139511
	Binomial Smooth 83 Pt.	
3	-84397	1142210
24	-83573	1143215
51	-83136	1142909
99	-80881	1144106
198	-77087	1143904
498	-65930	1141480
999	-51262	1139864
	Binomial Smooth 167 Pt.	
3	-73891	1144696
24	-73188	1144876
51	-72026	1147203
99	-70747	1144601
198	-67974	1142871
498	-58519	1141066
999	-49131	1142765

TABLE II

AEROBEE 350-150 Lb. PAYLOAD

Standard 100 gm Balloon

Original Data

Layer Thickness (feet)	X(feet)	Y(feet)
3	-85377	1120410
24	-86877	1123878
51	-88572	1123321
99	-84264	1122429
198	-88168	1122234
498	-70639	1129645
999	-54183	1133501
	Fourier Smooth .002	
3	-87585	1123911
24	-87603	1123960
51	-87868	1123391
99	-88108	1122536
198	-85048	1125464
498	-70483	1129502
999	-54254	1133608
	Fourier Smooth .001	
3	-87991	1147068
24	-87974	1146912
51	-87785	1145385
99	-86909	1140487
198	-84060	1133974
498	-70132	1132632
999	-54135	1134930
	Binomial Smooth 83 Pt.	
3	-81507	1117419
24	-82371	1117037
51	-83388	1118164
99	-83242	1121494
198	-76052	1124346
498	-62235	1129928
999	-50387	1135182
	Binomial Smooth 167 Pt.	
3	-78394	1128020
24	-76774	1128299
51	-75836	1128932
99	-73574	1130032
198	-67593	1131592
498	-57187	1136449
999	-48329	1137399

TABLE III

AEROBEE 350-500 Lb. PAYLOAD

Jimsphere

Original Data

Layer Thickness (feet)	X(feet)	Y(feet)
3	-57704	868673
24	-59298	861367
51	-59034	859814
99	-56565	862240
198	-54301	863445
498	-45470	862863
999	-31275	862005

Fourier Smooth .01

3	-58888	866386
24	-58804	862205
51	-58108	861786
99	-56201	863779
198	-53527	864930
498	-45411	863515
999	-31242	862084

Fourier Smooth .002

3	-57365	873708
24	-57118	869894
51	-56795	869138
99	-55738	866185
198	-53104	866208
498	-45216	863497
999	-31111	861376

Binomial Smooth 83 Pt.

3	-52679	864166
24	-51989	864143
51	-51611	863837
99	-49819	864504
198	-46959	865438
498	-38645	864534
999	-28171	862177

Binomial Smooth 167 Pt.

3	-44574	866048
24	-43937	865268
51	-42904	865421
99	-42063	865007
198	-39935	864078
498	-33096	862849
999	-26912	861764

TABLE IV

AEROBEE 350-500 Lb. PAYLOAD

Standard 100 gm Balloon

Original Data

Layer Thickness (feet)	X(feet)	Y(feet)
3	-53413	847063
24	-54366	848542
51	-55668	849006
99	-52331	848601
198	-55458	848839
498	-42331	855328
999	-30059	856924
	Fourier Smooth .002	
3	-55224	850351
24	-55225	850553
51	-53906	854970
99	-55494	848431
198	-53193	851562
498	-42106	854683
999	-30167	858137
	Fourier Smooth .001	
3	-55143	868696
24	-55193	869383
51	-52667	872532
99	-54334	863960
198	-52199	859202
498	-41835	857789
999	-30040	858036
	Binomial Smooth 83 Pt.	
3	-50511	845621
24	-51083	844434
51	-51872	846405
99	-51815	849174
198	-46297	850375
498	-35863	854206
999	-27533	859194
	Binomial Smooth 167 Pt.	
3	-48099	854025
24	-46888	854827
51	-46143	855217
99	-44392	855541
198	-39706	857251
498	-31972	857426
999	-26257	859228

TABLE V

ATHENA

Jimsphere

Original Data

Layer Thickness (feet)	X(feet)	Y(feet)
3	1594284	-1744913
24	1593861	-1744627
51	1593979	-1744296
99	1592572	-1743482
198	1593237	-1746626
498	1592616	-1746359
999	1602055	-1739926
	Fourier Smooth .01	
3	1593592	-1744153
24	1593828	-1744593
51	1595353	-1746579
99	1593593	-1745183
198	1592340	-1745172
498	1592998	-1746008
999	1602284	-1739707
	Fourier Smooth .002	
3	1594024	-1745634
24	1592445	-1743881
51	1593641	-1745323
99	1594160	-1746340
198	1592398	-1745233
498	1593357	-1745509
999	1603779	-1740480
	Binomial Smooth 83 Pt.	
3	1594359	-1745567
24	1593269	-1744428
51	1593185	-1744777
99	1593191	-1744776
198	1593079	-1745277
498	1595637	-1745297
999	1605642	-1739457
	Binomial Smooth 167 Pt.	
3	1593062	-1744497
24	1592970	-1744481
51	1592837	-1744459
99	1593429	-1745976
198	1592445	-1744125
498	1600637	-1743517
999	1607093	-1736878

TABLE VI

ATHENA

Standard 100 gm Balloon

Layer Thickness (feet)	X(feet)	Y(feet)
	Original Data	
3	1590694	-1750412
24	1590632	-1750022
51	1590956	-1749598
99	1591798	-1748082
198	1593024	-1749894
498	1594129	-1746604
999	1601587	-1743687
	Fourier Smooth .002	
3	1592387	-1749370
24	1592196	-1749197
51	1592577	-1749723
99	1591089	-1748279
198	1592592	-1750496
498	1593826	-1747524
999	1601608	-1743657
	Fourier Smooth .001	
3	1589845	-1752583
24	1589031	-1751629
51	1589694	-1752351
99	1589542	-1751921
198	1590664	-1752076
498	1593515	-1747348
999	1601754	-1741124
	Binomial Smooth 83 Pt.	
3	1591509	-1751260
24	1591002	-1750409
51	1591536	-1750347
99	1590973	-1750076
198	1591156	-1750269
498	1593397	-1748433
999	1602738	-1740822
	Binomial Smooth 167 Pt.	
3	1589894	-1749503
24	1590353	-1749941
51	1591201	-1750514
99	1590120	-1749394
198	1590590	-1749357
498	1597272	-1745766
999	1604326	-1738027

TABLE VII

NIKE-APACHE

Jimsphere

Layer Thickness (feet)	X(feet)	Y(feet)
	Original Data	
3	36135	126665
24	35536	126997
51	34605	128174
99	34191	128047
198	34550	126873
498	33754	125812
999	32941	120733
	Fourier Smooth .01	
3	34775	127441
24	34742	127469
51	34624	127402
99	34504	127135
198	34270	127304
498	34085	125777
999	33053	120656
	Fourier Smooth .002	
3	34489	127327
24	34507	127434
51	34499	127420
99	34477	127439
198	34300	127033
498	34052	125652
999	33071	120448
	Binomial Smooth 83 Pt.	
3	35425	127045
24	35161	127316
51	34950	127259
99	34985	127808
198	34770	127420
498	34543	126134
999	33654	120342
	Binomial Smooth 167 Pt.	
3	35058	127453
24	34924	127632
51	34432	127836
99	34408	127535
198	34463	127334
498	34494	125706
999	33898	120903

TABLE VIII

NIKE-APACHE

Standard 100 gm Balloon

Layer Thickness (feet)	X(feet)	Y(feet)
	Original Data	
3	31198	125820
24	31285	125395
51	31615	125181
99	31490	123083
198	33446	123218
498	33823	123152
999	32762	119974
	Fourier Smooth .002	
3	33375	123377
24	33382	123385
51	33372	123276
99	33451	123414
198	33653	123410
498	33871	123295
999	32754	119746
	Fourier Smooth .001	
3	32891	124208
24	32892	124214
51	32898	124204
99	32930	124192
198	33039	124082
498	33476	123050
999	32301	119698
	Binomial Smooth 83 Pt.	
3	31247	125389
24	31267	125145
51	31450	124418
99	32498	123754
198	32934	123615
498	34354	122632
999	33601	119089
	Binomial Smooth 167 Pt.	
3	31311	125157
24	31334	124853
51	31495	124589
99	32111	124338
198	33194	122328
498	34363	121876
999	33867	119650

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13. ABSTRACT

The wind frequency response of several unguided rockets was studied using data collected by simultaneous releases of a jimsphere and a standard 100 gm balloon. Results show there can be large differences in the predicted rocket impacts using the two balloons. High wind frequencies are shown to affect the rocket only to a small degree and can be ignored in real-time rocket impact prediction applications. Averaging winds over a fifty-foot layer gives results comparable to the best Fourier smooth and binomial filter.

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