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ATMOSPHERIC PHENOMENA AT HIGH ALTITUDES

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ABSTRACT

Six grenade Aerobees to be fired at Fort Churchill in July and August were prepared. Some design changes were incorporated. The data from Aerobee SM1:01 were partially reduced. Analyses of samples from sampling Aerobees SC 34 and 35 were nearly completed. The study of the dynamics of rarefied gases continued.

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1. INTRODUCTION

This is the eighth in a series of quarterly reports on Contract No. DA-36-039 SC-64659. The purposes of the contract are:

a. to adapt the rocket-grenade experiment for use in the Arctic during the International Geophysical Year,

b. to collect and analyze upper-air samples, and

c. to engage in the general investigation of problems relating to upper-air research.

2. GRENADE EXPERIMENT

2.1. MECHANICAL DESIGN

The major effort during the quarter was directed to the redesign and fabrication of the rockets scheduled for the summer firings. To improve the rocket performance over the 44 miles accomplished in November of 1956, two approaches were tried. The first, aimed at reducing drag, required the cooperation of another agency, BRL, to reduce the drag of the DOVAP antennas. The other, aimed at reducing weight, was largely within the control of the design group.

Drag reduction was accomplished by reducing the angle of the nose cone from 30 degrees included angle to 25 degrees, and by a joint effort of BRL and the University personnel to redesign the antennas. Although this redesign was undertaken primarily to reduce drag, the final antenna also was lighter by approximately 50%.

Functionally, the warhead design was proved in two ground firings and one rocket flight during the latter part of 1956. So that the benefit of this prior service test would not be lost, the design changes were limited to those which would reduce weight without altering the functional characteristics of the successful 1956 warheads.

The 30-degree wooden nose cone of the 1956 rocket was redesigned in sheet aluminum for a weight saving of approximately 50%. For improved drag characteristics, the angle was reduced to 25 degrees. This caused a weight increase which was felt to be a profitable compromise since it would account for 3 to 4 net additional miles of altitude. The net weight saving was approximately 40%. The grenades fired in 1956 were considered to be overly large for the lower altitudes of the initial launchings. Therefore the outer circle of 12 grenades was reduced from 4 lb of explosive per grenade to 2 lb. Because this change permitted shortening the mortars and the grenade section skin, additional weight saving was accomplished.

The grenade section of the rocket was shortened, and lightened internally also. This was made possible by the reduced length of the 2-lb grenades. Lighter mortar bases and fewer and lighter section bulkheads were incorporated in the design. Elimination of the grenade-ejection indicator system provided the space and the weight allowance for one additional grenade, which was added. The instrument section was lightened by substituting a magnesium nose extension for the previously used aluminum extension. Internally, the section was extensively redesigned to make the installation of electronic components more convenient. The structural design remained virtually unchanged.

The net weight reduction totaled 50 lb, of which 20 lb represents the reduced explosive load and 30 lb the weight trimmed from the warhead structure. The payload carried by the rocket was reduced from approximately 220 to 170 lb.

The firing mechanism used to detonate the grenades was weight-trimmed by reshaping the outside of the housing. Although this change saved something over a quarter of a pound per rocket, which was desirable, the primary goal was reduction of shrapnel. Tests with reduced load production grenades indicated satisfactory shrapnel reduction with no change in functional characteristics.

When the decision was made to reduce the first 12 grenades per rocket to 2 lb of explosive each, it was also considered desirable to change only the high explosive charge. Additional tests with dynamically identical dummy grenades were scheduled and run to compare lanyard dynamic loads of the 2-lb and 4-lb grenades. The 2-lb grenades eject at higher velocity and cause higher lanyard forces when the firing pin is pulled. The difference in pull force is largely academic, however. The pull force for the 2-lb grenades averages perhaps 10 lb more than the 4-lb grenades, but the spread of test points is such that considerable overlap of the two groups exists. The experimental error is greater than the average group difference. Both groups, 2-lb and 4-lb grenades, test well below the static strength of the lanyard material.

To improve the time required for preflight check-out under field conditions, preliminary checks on the complete rocket and warhead were scheduled to be run at The University of Michigan. To provide for these tests, the rockets were routed to the University instead of the launching site.

2.2 SM1:01 DATA REDUCTION

2.2.1. DOVAP Data.—Two copies of the DOVAP film were obtained from the Ballistic Research Laboratories early in February. The DOVAP cycles were counted independently by two persons in accordance with procedures described in a previous report. The count was carried out and recorded at half-second intervals up to 100 seconds of flight. The time spent on the cycle count was 12 working days (for 5 receiving stations). This checks closely with the estimate of 18 days for 8 receiving stations for 95 seconds of flight.

The quality of the record was very good, except that in one copy of the film regions of changing film speed were encountered. These regions were somewhat difficult to count. Fortunately, the regions affected were only a small part of the film. The grenade explosions registered as disturbances about 40 msec long. (The nature of the disturbance is discussed below.) The disturbed regions were counted by interpolation, that is to say, the opening of the dividers for pacing the disturbed region was set as an average of appropriate divider openings to the left and to the right of the disturbed region. The dividers are set to count 5 or 10 cycles. It is thought that no loss of accuracy results since the dividers, if started pacing prior to the disturbed interval on the null-points, always fall on the null-points at the end of the disturbed interval.

Spin corrections were carried out and precomputations prepared for the MIDAC computer. The initial position of the missile was taken at 1-sec range time. This was done because the DOVAP cycles in the region from the "wire-break" up to 1-sec range time were rather difficult to read. The missile position at 1-sec range time was calculated, assuming a constant thrust and a linearly changing mass of the propellant. The magnitude of the thrust was computed from the mean acceleration between "lift-off" and the "wire-break." The tilt of the tower was taken to be: South - 141 mils and East - 60 mils, as given in the "Meteorological Report SM1:01" by the Meteorological Branch, Fort Churchill Division, White Sands Signal Corps Agency. Possible wind effects on the position of the missile from the time the rocket leaves the tower up to 1-sec range time were neglected in computing the position at 1-sec range time.

The first MIDAC computation of the trajectory was rejected because of errors in typing the punched tape input to the computer. After the trajectory at half-second intervals up to 100 sec was computed on the MIDAC for the second time, it was discovered that an error occurred at 27.5 sec in typing one number on the punched tape. The error affected three out of the four different combinations of the receiving stations from this point on. Inasmuch as the MIDAC facility was closed down at the beginning of April, it was impossible to re-run the problem on the computer. It was decided to hand-calculate the sixteen grenade-explosion points only and let the computation of detailed trajectory at half-second intervals await the availability of an IBM 650 program. The hand calculation of the explosion points was carried out by the data-reduction group at the Willow Run Laboratories. The computed coordinates of the explosion points were communicated to the Signal Corps. Rather large deviations exist between solutions based on the different combinations of the receiving stations. The differences between the different solutions are as large as 65 ft in the vertical direction and as large as 250 ft in the horizontal directions. An investigation of this situation will be carried out.

2.2.2. Times of the Explosions.—The times of the grenade explosions were determined previously from the DOVAP slow-speed telemetry record as noted in a previous report. Subsequently, a high-speed (20 in./sec) telemetry record was obtained from BRL. The sound-ranging record, which was received from the Signal Corps, includes two channels recording the output of two ground flash-detectors (galvanometers 0-125 cps, 64% critical damping), and a DOVAP telemetry channel (galvanometer 0-300 cps, 64% critical damping). Thus four more records with the times of the explosions were available.

It was noted that the beginning of the distrubance in the DOVAP cycles occurred at about the same time as the times of the explosions as determined from the above mentioned records. The disturbance starts as a discontinuity in the DOVAP cycles. The individual DOVAP cycles can be distinguished for about 5 msec, but the cycle pattern is irregular. In the second phase of the disturbance no individual cycles can be distinguished, and it can be said that noise completely predominates. This phase lasts about 8 msec. In the third phase the DOVAP cycles can again be distinguished. The pattern changes from irregular to regular, but the length of individual cycles changes somewhat more rapidly than in the neighboring undisturbed region. This phase lasts for 20 to 30 msec.

It should be noted that this description applies especially to the first explosions. Thi disturbance changes markedly between the first and the last grenades, undoubtedly due to the orders of magnitude difference in ambient density. The second phase is practically absent for the higher grenade explosions.

The early part of the disturbance can be explained by a multiple path of propagation effect. Apart from the usual direct path transmitter-missile (and missile-receiver), propagation path transmitter-explosive ball-missile (and missile-explosive ball-receiver) is possible, because the explosion shock wave consists in its early stages of highly ionized gases, from which the DOVAP waves are reflected. On this indirect path of propagation, the explosive ball acts as a virtual receiving (and transmitting) antenna. As a result, the signal at the receiver is the sum of four signals arriving through four different propagation paths. Hence the phase shift, which varies with the relative movement of the explosive ball and the missile. The second phase can be explained by the arrival of the shock wave at the DOVAP antennas. The ionized gases of the shock wave effectively short-circuit the antennas and black out the missile reception and transmission. In the third phase the antennas are no longer inside a highly ionized medium. The missile is probably above the shock wave. Multiple path propagation can possibly occur, or the propagation can take place through the "ionosphere" from the explosion. The propagation through this expanding ionized sphere takes place at higher phase velocity; hence a changing phase-shift effect.

The fact that the disturbance comes at the time that the flash detectors signal the flash indicates that the explosive ball in its very early stages (diameter of probably about 1 meter) is large enough to provide a multiple path propagation effect. The disturbance in DOVAP can thus be taken as a source of information about the time of the explosion.

The times of the explosions were determined from all the above sources. The results are presented in Table I. Of the two ground flash detectors, one consistently gave an earlier flash signal than the other, the difference being about 1 msec. Only the times from the wide cone No. 4 flash detector, giving the earlier signal, are given in the table. The times are specified in range-time. The time from "lift-off" can be determined by adding 0.1256 sec to the range time.

2.2.3. Angles of the Sound-Wave Arrivals.—The sound-wave times of arrival at the geophones were read off the sound-ranging records obtained from the Signal Corps. Most of the arrival times could be read with an accuracy of 1 msec. Difficulty was encountered in reading off the arrivals from grenade No. 15. The arrivals will be read again by a second person.

It appears from the sound-ranging records that the SM1:01 trajectory, except for its low peak, was very favorable from the point of view of geometry. The arrivals from the grenades Nos. 9 and 10, approximately median grenades, were almost directly vertical.

A method for computing the directional cosines of the arriving wave at the center geophone was developed for the Churchill array. The method consists of computing first the partial derivatives $\partial T/\partial X$ and $\partial T/\partial Y$ at the center geophone, where T is the time of arrival at a theoretical microphone that can move around in accordance with our mathematical fancy, and where X and Y are the distances along the axis of the array. From $\partial T/\partial X$ and $\partial T/\partial Y$, the directional cosines can be computed. This method will be used to compute the angles of arrival by hand computation and the results will be compared with the results obtained by the Signal Corps from the IBM 650 program.

The method is thought to be much simpler for hand computation. It utilizes the information obtained from the times of arrival at all the geophones.

2.3. TRAJECTORY CALCULATIONS

The peak altitude of Aerobee SM1:01 was about 50,000 ft lower than the predicted peak, as reported in the previous report. In the predicted tra-

TABLE I

GRENADE-DETONATION DATA FROM DIFFERENT SOURCES (RANGE-TIME)

Grenade No.	Seconds				
	T_1	T_2	T_3	T_4	T_5
1	41.745	41.745	41.745	41.744	41.744
2	45.204	45.205	45.206	45.204	45.204
3	48.663	48.664	48.664	48.663	48.663
4	52.188	52.190	52.190	52.188	52.188
5	55.651	55.651	55.651	55.649	55.650
6	59.081	59.082	59.082	59.080	59.081
7	62.561	62.561	62.562	62.560	62.561
9	69.527	69.528	69.529	69.527	69.527
10	72.945	72.946	72.947	72.945	72.945
11	76.463	76.464	76.464	76.463	76.463
12	79.955	79.956	79.957	79.955	79.955
13	83.370	83.371	83.372	83.371	83.371
14	86.873	86.873	86.874	86.873	86.873
15	90.373	90.374	90.375	90.373	90.373
16	93.837	93.837	93.838	93.837	93.837
17	97.350	97.351	97.351	97.350	97.350

Notes: T_1 = Explosion time as determined from BRL DOVAP telemetry low-speed record.

T_2 = Explosion time as determined from BRL DOVAP telemetry high-speed record.

T_3 = Explosion time as determined from Signal Corps DOVAP telemetry record.

T_4 = Explosion time as determined from the Signal Corps record of a ground flash detector No. 4.

T_5 = Explosion time as determined from the disturbance in DOVAP cycles.

All times are given in range-time.

jectory the drag effect of the DOVAP antennas was not included.

A drag-coefficient-versus-Mach-number curve for Aerobee SM1:01, which takes into account the departure of the nose cone from the standard ogive and the effect of the DOVAP antennas, was prepared in accordance with suggestions by the Aerojet General Corp. Using the drag coefficient from this curve, a new SM1:01 trajectory was computed in a step-by-step hand calculation. The steps were 0.2 sec during the boost period, 1 sec during the sustainer motor operation, and 2 sec during the free flight up to the point where the drag acceleration became less than 1 ft/sec^2. From this point a vacuum trajectory was used.

The calculated trajectory was compared with the actual SM1:01 trajectory as obtained from DOVAP data. On the basis of point-by-point comparison of accelerations in the two trajectories, it appeared that the peak of the drag-coefficient-versus-Mach-number curve (around Unity Mach number) is too high.

A new drag-coefficient-versus-Mach-number curve (with peak value $C_D = 0.86$ instead of 0.97) was prepared. The SM1:01 trajectory was recalculated, using the modified drag-coefficient curve and with some other minor changes. This final calculated SM1:01 trajectory checked very closely with the actual (DOVAP) trajectory. On this basis the low performance of SM1:01 can be explained.

Using the same technique, and allowing for a payload smaller by 52 lb (initial weight of the rocket: 1708 lb) and improved DOVAP antennas, which were developed by BRL, a trajectory for SM1:02 was calculated. The predicted peak velocity is 4120 ft/sec and the predicted peak altitude is 310,000 ft.

2.4. THEORETICAL INVESTIGATION OF SOUND VELOCITY AT ALTITUDE OF 95 KM

Confirmation has been obtained from Prof. Lindsay concerning the basic correctness of calculations which tend to indicate that the group velocity of sound waves for frequencies lower than 50 cps at 95-km altitude should not depart by more than 0.1% from the velocity under the conditions of same temperature and sea-level pressure.

3. AIR SAMPLING

During the quarter three runs were completed on upper atmosphere sample B-10 with associated ground air and control checks. The system was serviced and the ion gage was replaced in preparation for the analysis of C-23-B upper atmosphere sample. The new ion gage was calibrated with ground air and the first sample of C-23-B was checked for condensables and analyzed.

3.1. COMPLETION OF THE ANALYSIS OF B-10 UPPER AIR SAMPLE

Preliminary ground-air runs and the first run on bottle B-10 were reported during the last quarter. The analysis went smoothly, and two more analyses were made before the storage vial containing the balance of the sample was sealed off the system. The B-10 gas remaining in the connecting tubing was then analyzed and found to check with the three previous runs. This test indicates that the sample contained in the vial was not changed in helium, neon, and nitrogen composition and proportion by seal-off, and that the sample in the vial is a valid one. The results of all B-10 analyses are recorded in Table II.

3.2. B-10 CONTROL CHECKS

After completion of the analyses of B-10, a series of control checks were run. These tests were devised to show the effects of töplering and adsorption on the upper air sample.

In the first test the gas remaining in the bottle from the previous töplering was transferred to the analyzer and analyzed in the standard manner. The results are recorded in Table II under B-10 residue. It should be noted that the high helium content may be due to gas permeating the graded seal. This information was reported during the last quarter; however, it is recorded in the chart for completeness.

The second check consisted of an analysis of gas baked out of the bottle by heating it to temperatures within 20°C of those at which the bottles were originally prepared for flight. The töpler pump was operated during baking. The results, given in Table II, show large quantities of condensables with only relatively small quantities of helium and neon baked out.

The third control check was intended to show the quantity of gas adsorbed on the walls of the bottle. To prepare the bottle, it was baked out while connected to the diffusion pump. A measured amount of ground air was introduced into the bottle while still hot. The bottle was allowed to cool and the ground-air sample was extracted by the töpler pump in the usual manner. This gas was analyzed twice. The results are shown in Table II.

The fourth control check was a repetition of the third control check.

3.3. PREPARATION OF THE ANALYZER FOR SAMPLE C-23-B

In preparing the analyzer for analysis of C-23-B, maintenance service was performed. It was noted that the mercury control pot on one of the fractionation columns appeared dirty. The pot was removed and it and the mercury

TABLE II

SUMMARY OF RESULTS

Sample	Run	CCNTP of Gas After Oxidation, with Dry Ice Trap	$\frac{\text{He Upper Air}}{\text{He Ground Air}}$	$\frac{\text{Ne Upper Air}}{\text{Ne Ground Air}}$	% Gas Lost on Hot Filament	Condensable Matter, %			
						Before Oxidation		After Oxidation	
						Vol.* Lost Liquid N_2	Vol. Lost Dry Ice	Vol. Lost Liquid N_2	Vol. Lost Dry Ice
				Ground Air					
17	1	0.00563	1.00	1.00	19.0	--	--	--	0.62
17	2	0.0071	1.00	1.00	18.4	--	--	--	0.5
17	3	0.01084	1.00	1.00	19.0	--	--	--	0.1
17	4	0.0195	1.00	1.00	19.9	--	--	--	1.2
17	5	0.00523	1.00	1.00	19.1	--	--	--	0.3
17	6	0.00240	1.00	1.00	18.8	--	--	--	0.28
17	7	0.00465	1.00	1.00	18.0	--	--	--	0.75
17	8	0.00777	1.00	1.00	17.7	--	--	--	0.62
17	9	0.00216	1.00	1.00	17.3	--	--	--	0.42
				Upper Atmosphere					
B-10	1	0.00656	1.52	1.13	36.0	2.3	--	12	10
B-10	2	0.00528	1.50	1.10	35.4	--	--	--	8.7
B-10	3	0.00393	1.45	1.09	37.0	--	--	--	8.0
B-10	4	0.00259	1.45	1.10	36.5	--	--	--	7.3
B-10 residue	5'	0.00193	4.68	1.00	50.5	--	--	--	2.3
B-10 hot residue	6"	0.0101	0.058	0.0177	-7.8	62.3	2.7	82.9	7.0
				First Ground Air Introduced in B-10					
17 in B-10	1	0.01633	0.986	1.012	~0.9	4.0	1.06	3.6	1.3
17 in B-10	2	0.00253	1.01	1.02	~0.9	--	--	--	0.95
				Second Ground Air Introduced in B-10					
17 in B-10	1	0.00829	0.988	0.978	~0.0	2.9	0.42	2.9	0.42
				Leaked or Outgassed Material					
Before B-10 opening	1	0.000102	7.75	0.214	~0.0	~63%	4	--	--
				Ground Air					
18	1	0.00853	1.00	--	18.1	--	--	--	0.81
18	2	0.00564	1.00	1.00	18.8	--	--	--	0.67
18	3	0.00365	1.00	1.00	18.7	--	--	--	0.61
18	4	0.00769	1.00	1.00	19.0	--	--	--	0.81
				Leaked or Outgassed Material					
Before C-23 opening	1	0.00069	4.56	0.117	7.41	83.5	46.7	92.5	50
				Upper Atmosphere					
C-23-B	1	0.00544	1.26	1.04	0.1	3.3	0.76	4.1	1.3

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*Measured with McLeod gage.

were cleaned and replaced. The ion gage, which had given considerable service, was replaced for safety.

3.4. C-23-B PRELIMINARY CHECKS

Bottle C-23-B was attached to the system. The system was then pumped and baked out. Two leak checks of the bottle coupling were made, the first for one day and the second for nine days seal-off from the system. After a series of ground-air checks, the "leaked" gas from this section was analyzed. The results shown in Table II compare favorably with leakage of B-10 bottle coupling.

The new ion gage showed slightly less sensitivity than the original tube, but calibrated well.

3.5. C-23-B ANALYSIS

After the system ionization gage was calibrated and the "leakage" tests performed, the bottle gas was given its first analysis. The results differed from previous bottles. This bottle shows smaller relative quantities of helium and neon compared to B-15 and B-10. No conclusions are drawn from these results until further analyses have been made.

3.6. FUTURE WORK

In the next quarter, the analysis of C-23-B will be completed. A trip to visit Prof. Paneth at Mainz is planned to discuss in detail the results of his recent analyses of upper air samples. Following this, a systematic review and study of the results of SC-34 and 35, which have been prevented by the necessity of analyzing the samples expeditiously, will be made.

4. RAREFIED GAS-FLOW ANALYSIS

In the last quarterly progress report, a model for treating rarefied gas-flow problems was proposed. The iterative calculation starts with results of the classical free-molecule flow as the first iterate. To obtain the second iterate, we take into account the aerodynamic effect contributed by the first collisions between the incident and the reflected families of molecules. The distribution of the reflected molecules depends on the interaction between the incident molecules and the solid surface of the object. The mechanism of this interaction phenomenon is determined by such factors as the smoothness and temperature of the surface, molecular structure and temperature of the incident gas molecules. In general, the reflection-mechanism is partly specular and partly diffuse.

As a test model for the theory, a plate normal to the stream is used. The calculations for the case of specular reflection had been made and described in the last report. To continue the analysis, we assume that the molecules are reflected diffusely. The procedure of calculations is practically the same as for the specular reflection case except that the probability distribution function of the reflected molecules is different. In diffuse reflection from the surface, the incident molecules are reflected from the surface in an absolutely random manner. All traces of their past history having been lost, they obey a cosine law similar to that of a surface emitting radiant energy. The incident molecules may have made several collisions in the interstices of the surface during which they can exchange momentum and energy with it.

The computations for the case of diffuse reflection are much more involved than those for the specular reflection. The results of drag-coefficient calculations for a plate normal to the stream show the same qualitative trend with respect to Mach number and Knudsen number as those reported last for the specular case. Again, it should be mentioned that the results are considered preliminary and subjected to refinement as far as the idealization of the model is concerned.

5. LABORATORIES VISITED

The following places were visited during the quarter:

Ballistics Research Laboratories,
Evans Signal Laboratory,
National Northern Division.

6. FUTURE PROGRAM

During the coming quarter, grenade Aerobees SM1:02 and SM1:03 will be fired. The reduction of data from A robee SM1:01 will continue. A visit to the Max Planck Institute für Chemie will be made. The study of rarefied gas dynamics will continue.

7. ACKNOWLEDGMENT

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