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Quarterly Report

ATMOSPHERIC PHENOMENA AT HIGH ALTITUDES

(November 1, 1956 to January 31, 1957)

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Project 2387

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ABSTRACT

Aerobee SM1:01 was successfully fired at Fort Churchill. The data reduction on this flight was begun. Air sample bottle B-15 and control samples associated with bottle B-15 were analyzed. Various repairs were made to the analyzer. A new method of attack for solving rarefied gas-flow problems is being developed; the results of a sample calculation using this method are presented.

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1. INTRODUCTION

This is the seventh 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. PRE-FIRING OPERATIONS AT FORT CHURCHILL

The pre-firing operations conducted up to November 1, 1956 are described in the last quarterly report, No. 2387-19-P. On November 1, 1956, the total weight and center of gravity of the missile were determined. Figure 1 shows the missile being placed on the scales. The missile as weighed was complete except for fuel, oxidizer, helium, grenades, and Prima-cord detonator block.

Table I contains a summary of weight and center of gravity information for Aerobee SM1:01. The total length of the missile was 210.7 inches; the forward 70.15 inches consisted of the nose cone, grenade section, and instrumentation section, and the rear 140.56 inches was the standard AJ 10-25 Aerobee power plant and tail cone.

The missile was placed in the launching tower on November 9, 1956. Figure 2 shows the missile as it is being raised up into the tower. The first vertical check was held the same day. In this check everything worked properly except the transmitter for the AN/DRW-3 cut-off receiver. The transmitter malfunction was corrected and a second vertical check was successful in all details on November 10, 1956. At this time the final firing schedule was set up; however, the exact firing time could not be set because of the heavy cloud cover. On November 11 at about 4 p.m. examination of weather charts revealed

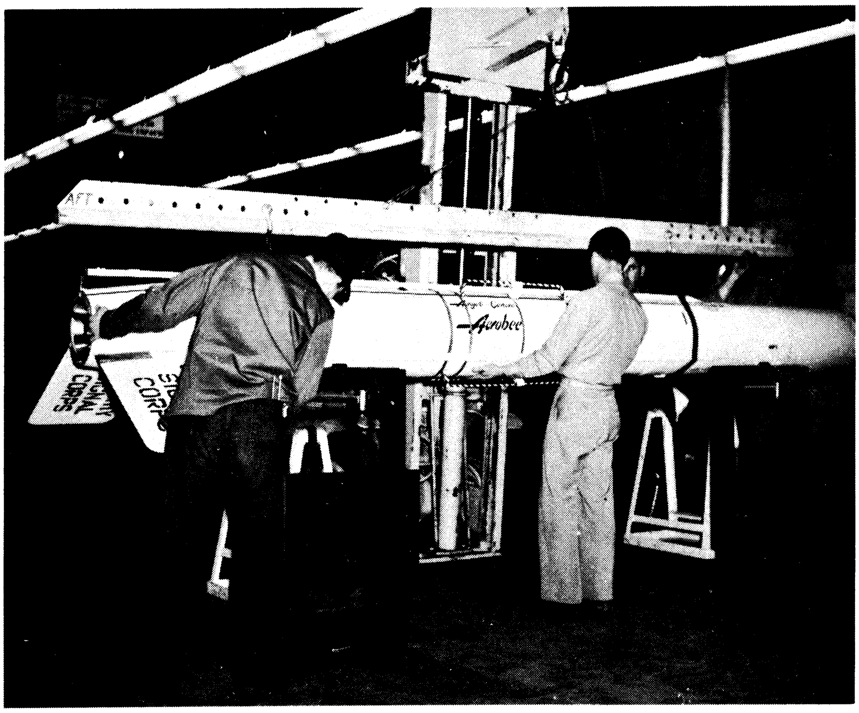

Fig. 1. Placing Aerobee SM1:01 on scales (in preparation for making weight and center of gravity measurements).

TABLE I

WEIGHT AND CENTER OF GRAVITY INFORMATION FOR AEROBEE SM1:01

	Before Firing	After Burnout	After All Grenades Ejected
Dry weight of missile (power plant, tailcone, and fins), lb	287	287	287
Payload (nose cone, grenade section, instrumentation section, wiring, antennas, and Prima cord), lb	220	220	130
Helium, lb	5	---	---
Aniline, lb	181	4	4
Oxydizer, lb	497	---	---
Total, lb	1190	511	412
Center of gravity (inches from nose tip)	113.5	81.4	90

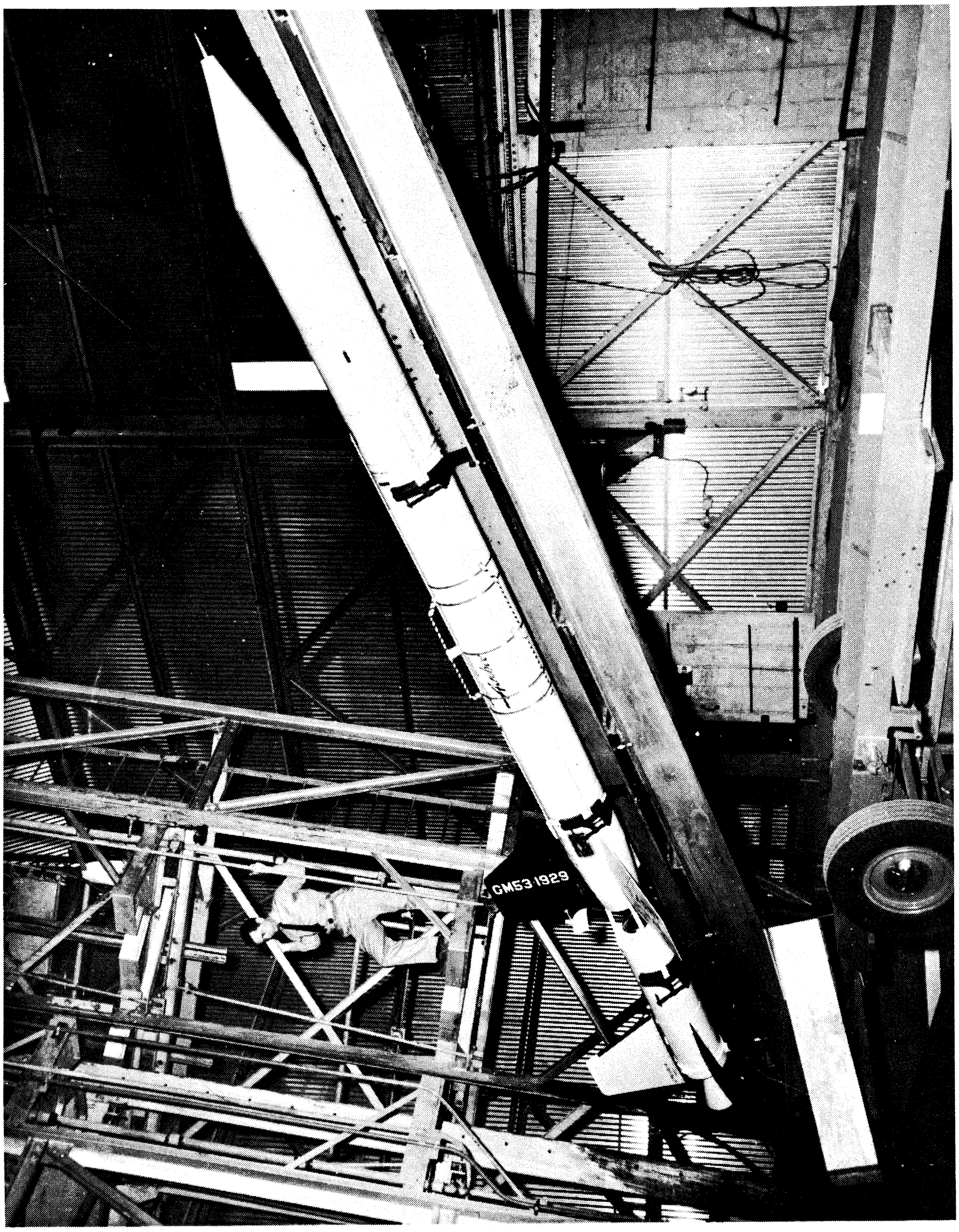

Fig. 2. Aerobee SM1:01 being raised up into launching tower.

that the sky would begin to clear sometime during the early morning hours of November 12. It was decided to schedule the firing for about 4 a.m. of November 12.

The pre-firing operations proceeded smoothly except for some difficulty in grenade loading. Grenades No. 8 and 18 could not be threaded completely into their sockets. The grenade that was first tried in the No. 8 position was removed and successfully inserted into another position. This indicated that the thread at the bottom of the grenade mortar was at fault rather than the thread on the grenade itself. Another grenade was then tried in the No. 8 position, but also could not be threaded completely into the socket. Moreover, in attempting to force this grenade into position, it was jammed into the socket. At this time it was decided that an attempt to remove this grenade forcefully might result in shearing the shear rivets at the bottom of the grenade. If this happened, the grenade would become dangerous to the grenade loading personnel, and therefore it was decided to leave this grenade as it was. A similar situation was encountered in the case of grenade No. 18. Because of its short lanyard, grenade No. 18 is potentially more dangerous in the case of sheared rivets than the other grenades. Accordingly it was decided to leave this grenade as it was.

At the time of grenade loading it was not certain that these two grenades were threaded far enough into their sockets to enable the microphone plug to mate with its jack. Because of this uncertainty and because grenade No. 18 was designed to explode within the nose cone, thereby destroying all unejected grenades, another short lanyard grenade should have been installed in position No. 17. However, under the pressure of the situation, this was not done. (See 2.7 for further discussion of this difficulty.)

At about 4 p.m., the sky began to clear and helium pressurization was begun. Except for a hold due to the failure of the radar-transmitter motor-generator set and some difficulty with the Twin Lakes ballistic camera-shutter operation indicator, the remainder of the firing operations proceeded without difficulty.

2.2. PERFORMANCE OF AEROBEE SM1:01

The missile was fired at 5:47:47 a.m. on November 12 (see Fig. 3). The performance of the booster and Aerobee sustainer motors was about normal, although the burning time of each of these units was longer than usual. Booster burnout (from booster separation) occurred at 2.729 seconds after lift time and the sustainer motor burnout (from launch station maximum radial velocity) occurred at 36.2 seconds. The normal burning times for booster and sustainer motor are 2.5 seconds and 34 seconds, respectively.

Preliminary data from radar and DOVAP are the following:

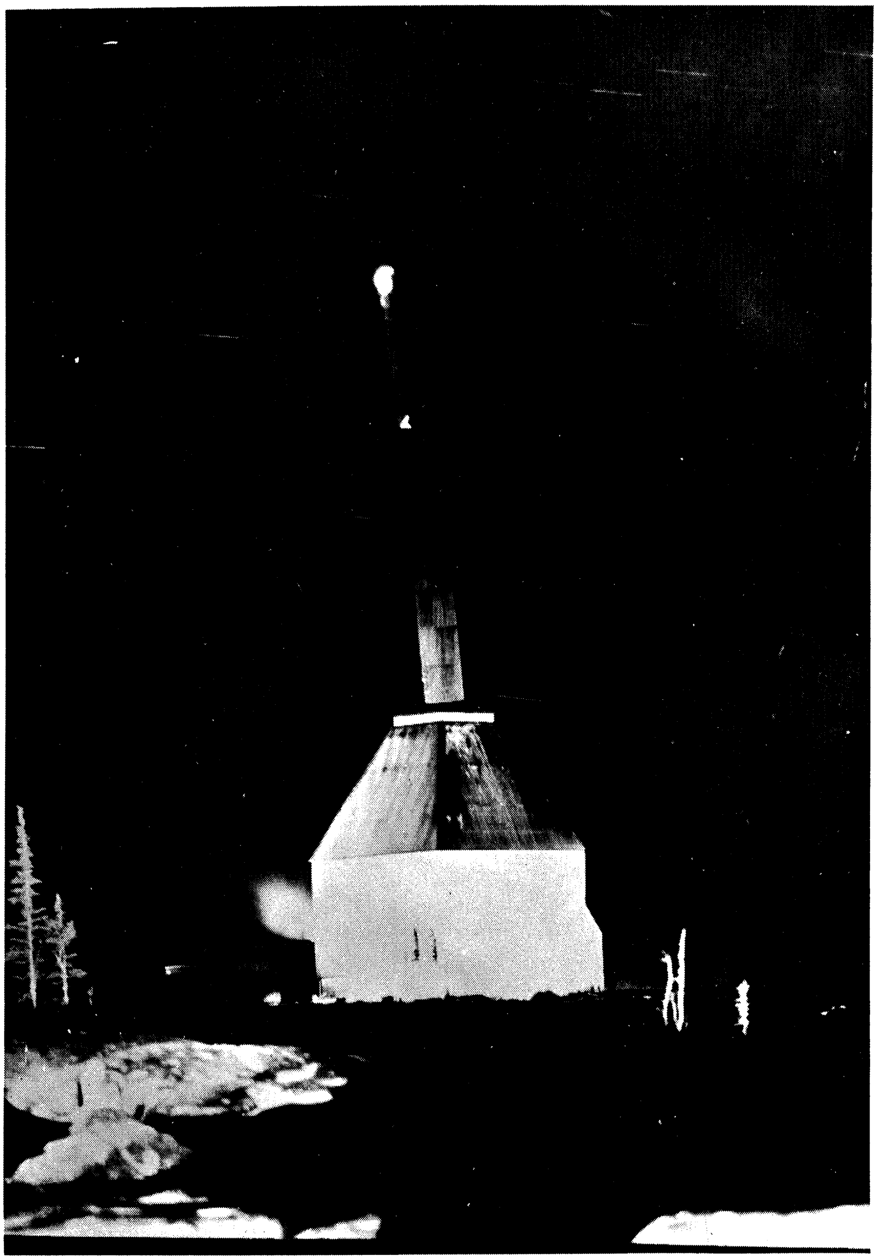

Fig. 3. Aerobee SM1:01 leaving Aerobee launcher (1/100-second exposure).

Maximum velocity, 3250 ft/sec (DOVAP-initial data)
Peak altitude, 222,700 ft (Radar plot)
Peak time, 135 seconds (DOVAP).

The predicted performance of Aerobee SM1:01 was:

Maximum velocity, 4200 ft/sec
Peak altitude 274,530 feet.

The discrepancy between the predicted and actual performance of Aerobee SM1:01 has not been completely resolved as of this date; however, it appears that the low maximum-velocity and low peak-altitude of Aerobee SM1:01 was due to the drag of the DOVAP antennas. This drag was not allowed for in predicting the peak altitude of Aerobee SM1:01.

2.3. PRELIMINARY RESULTS OF THE GRENADE EXPERIMENT ON AEROBEE SM1:01

All the grenade-experiment instrumentation on Aerobee SM1:01 appears to have worked very satisfactorily.

Before firing, all equipment was operated on external batteries, then transferred to internal batteries without difficulty. All monitor signals were normal.

The program timer started at booster separation and went through its timing sequence properly. Sixteen grenades were ejected at the proper times. The two grenades which failed to eject did so because of the loading difficulty described above.

DOVAP cycle counts were recorded at all stations, starting shortly after the missile left the tower and continuing on to what appears to be the impact time. DOVAP telemetering worked very well. The telemetering record will yield the grenade explosion times and all the details of the timer operation. The missile-borne flash detectors, whose signals were transmitted by the DOVAP telemeter, appear to have worked as desired.

The tracking radar ground station and DPN-19 missile unit performed very well; a plotting board record which covers the complete trajectory was obtained.

Although the range-safety officer did not find it necessary to cut down the missile, it appears that the AN/DRW 3 cut-off receiver was working properly and would have performed the cut-off function properly.

The ground equipment of the Signal Corps Engineering Laboratories worked very well. All nine microphones in the sound-ranging array received each grenade signal. The microphone signals, ground flash detector signals and DOVAP telemetry signals were successfully recorded on one oscillograph record at Twin Lakes, along with range-timing signals. The ground meteorological data necessary for the grenade experiment were also recorded by SCEL personnel at the Twin Lakes site.

Pibal wind observation runs and high-altitude radiosonde runs were made by personnel of the White Sands Signal Corps Agency group at Fort Churchill. The pibal wind observations provided data used to set the tower tilt for the desired rocket trajectory. The high-altitude radiosonde runs were made at approximately 3:25 a.m., 5:15 a.m., and 8:15 a.m. of the firing day. On these runs, data were recorded of 34000 ft, 62000 ft, and 102000 ft, respectively. The meteorological data from the last run will cover the low altitude range of the data from the grenade experiment.

2.4. IMPACT PREDICTION FOR AEROBEE SM1:01

The impact prediction work for Aerobee SM1:01 was carried out by personnel of the Meteorological Branch, Fort Churchill Division, White Sands Signal Corps Agency. Their data are summarized in "Meteorological Report for Aerobee SM1:01," by Lloyd White.

The desired trajectory for Aerobee SM1:01 was due south from the launcher over Twin Lakes. Impact was desired to be south of Twin Lakes. The trajectory was planned so the grenade ejections would be made on the upleg of the trajectory as directly as possible over the Twin Lakes sound ranging array.

The rocket ballistic factors, unit wind effect, tower tilt effect, and coriolis displacement were calculated by the WSSCA personnel. Because of low ceiling and poor visibility all pibal wind observation balloons were not tracked to 2040 feet as desired; however, three of the runs did obtain this altitude. On the basis of the data obtained, the tower tilt was set at 60 miles east and 141 miles south. With this tower tilt and the prevailing winds, the rocket impact was predicted to be 21 miles due south of the launcher (azimuth 180°). The actual impact was 33 miles from the launcher at 200 degrees azimuth.

Although the trajectory was a suitable one in that it satisfied the technical requirements of the grenade experiment, the fact that the impact prediction was in error was of some concern to the range-safety officer. In his words,[1] "While well within the range limitations or boundaries, this impact too closely approached the boundary." Because of the concern of the range-safety officer, an attempt will be made to determine the reason for the error in predicted impact.

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[1] See "Report on the Pre-IGY Firings Conducted at Ft. Churchill, Manitoba, Canada," Jan. 10, 1957, by Jack Siwert, Capt. Ordnance Corps., Range-Safety Officer, Ft. Churchill IGY Rocket Project.

2.5. DOVAP TELEMETER RECORD

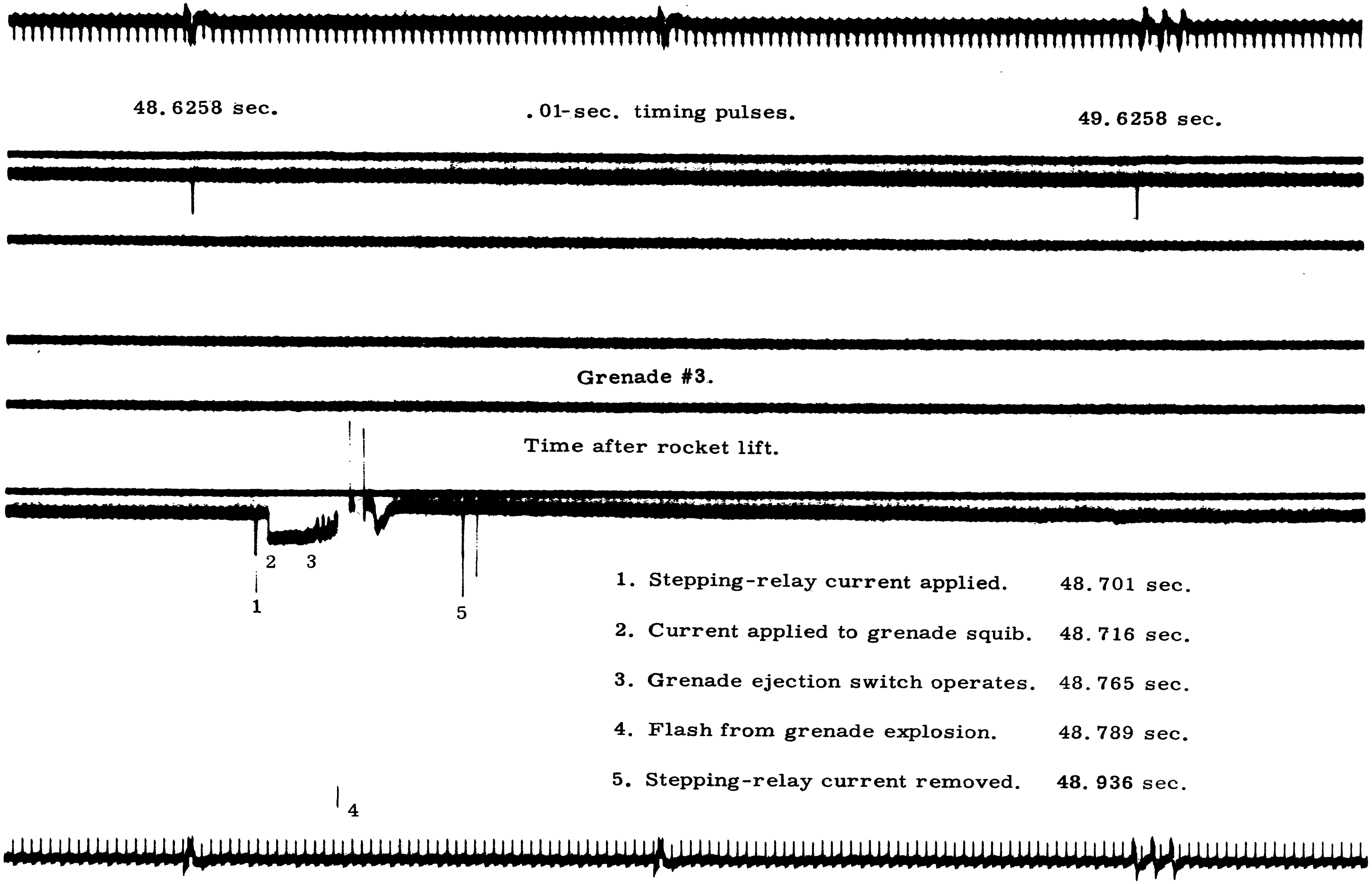
The DOVAP telemeter record for SM1:01 has been received from BRL. This record is a real time oscillographic recording (6.9 in./sec paper speed) of the first 205 seconds of rocket flight.

Figure 4 is a photograph of a portion of this record, showing the sequence of events covering the one-second interval during which grenade No. 3 was ejected and detonated. The legend indicates the meaning of the telemeter signals. The times T_1, T_2, T_4, and T_5 were easy to read; however, the time T_3 is not indicated with the desired clarity. The signal at this point indicates qualitatively whether or not the grenade ejection switch has operated; however, the exact time is difficult to determine.

This time sequence of events for all eighteen grenades is given in Table II. The times T_4 are of primary importance to the grenade experiment. It is believed that these times are accurate to ± 0.001 second. T_2-T_1 is the time interval between the time at which current is applied to the stepping relay and the time at which current is applied to the grenade squib. This time interval is approximately the same for all grenades. The time interval T_5-T_1 during which current is applied to the stepping relay, is the time during which the timer microswitch is actuated by the grenade firing cam. This time interval depends on the width of the notch in the cam and on the motor speed. The relatively large value of 0.270 second for the first grenade indicates that the motor was operating at a lower than normal speed at this time.

The time interval T_3-T_2 tells how much time elapsed between application of current to the squib and the operation of the ejection switch. The time interval T_4-T_3 between operation of the ejection switch and the grenade flash is an indication of how far the grenade traveled before it was detonated. Since the accuracy of the time T_3 is somewhat poor, the time T_4-T_2 is also given for reference. Consideration of these three intervals indicates that grenades 1, 2, 3, 10, 13, and 16 probably did not travel the full length of lanyard before they were detonated.

This recording of the DOVAP telemeter data was made with the use of a wide-band discriminator capable of resolving a 30 Kc subcarrier deviated plus and minus 40%. The discriminated signal was filtered by a 3 Kc low-pass filter and recorded on film using a galvanometer having a 600 cps damped frequency response. The time delay of this combination to a pulse modulation signal with 5 microsecond rise time has been measured to be 160 microseconds. The limiting factor in the time accuracy of the determination of grenade flash time from this recording is the paper speed of 6.9 in./sec. Accordingly a request has been made to have the first 100 seconds of this record played back at a paper speed of 20 inches per second. The signals will be read again. It is hoped that a greater reading accuracy will be obtained.



1. Stepping-relay current applied. 48.701 sec.
2. Current applied to grenade squib. 48.716 sec.
3. Grenade ejection switch operates. 48.765 sec.
4. Flash from grenade explosion. 48.789 sec.
5. Stepping-relay current removed. 48.936 sec.

Fig. 4. DOVAP telemeter record for Aerobee SM1:01.

TABLE II

GRENADE EJECTION AND DETONATION DATA FROM 6.9 IN./SEC RECORDING OF AEROBEE SM1:01 DOVAP TELEMETER

Grenade Number	T_1 (sec)	T_2 (sec)	T_3 (sec)	T_4 (sec)	T_5 (sec)	T_2-T_1 (sec)	T_3-T_2 (sec)	T_4-T_3 (sec)	T_4-T_2 (sec)	T_5-T_1 (sec)
1	41.790	41.802	41.854	41.871	42.060	.012	.052	.017	.069	.270
2	45.229	45.243	45.300	45.330	45.452	.014	.057	.030	.087	.223
3	48.701	48.716	48.765	48.789	48.921	.015	.049	.024	.073	.220
4	52.194	52.208	52.272	52.314	52.398	.014	.064	.042	.106	.204
5	55.658	55.671	55.722	55.777	55.869	.013	.051	.055	.106	.211
6	59.091	59.105	59.156	59.207	59.319	.014	.051	.051	.102	.228
7	62.571	62.584	62.626	62.687	62.783	.013	.042	.061	.103	.212
8	66.067	66.082	--	--	66.271	.015	--	--	--	.204
9	69.536	--	69.604	69.653	69.750	--	--	.049	--	.214
10	72.979	72.992	73.031	73.071	73.205	.013	.039	.040	.079	.226
11	76.469	76.484	76.554	76.589	76.688	.015	.070	.035	.105	.219
12	79.972	79.985	80.032	80.081	80.173	.013	.047	.049	.096	.201
13	83.442	83.455		83.496	83.660	.013	--	--	.041	.218
14	86.891	86.904	86.950	86.999	87.118	.013	.046	.049	.095	.227
15	90.382	90.394	90.445	90.499	90.598	.012	.051	.054	.105	.216
16	93.889	93.902	93.955	93.963	94.093	.013	.053	.008	.061	.204
17	97.365	97.378	97.424	97.476	97.580	.013	.046	.052	.098	.215
18	100.820	100.832	--	--	101.048	.012	--	--	--	.228

NOTES: T_1 = Time at which stepping relay current was applied.

T_2 = Time at which current was applied to the grenade squib.

T_3 = Time at which grenade ejection switch operated.

T_4 = Time of the flash from the grenade explosion.

T_5 = Time at which the stepping relay current was removed.

All times are given with respect to the time of rocket lift.

Accuracy of reading flash time is ± 0.001 second.

An examination of the full 280 seconds of the telemetering record is desired to check for possible malfunction of the equipment after grenade ejection. Accordingly a request has also been submitted for a playback of the complete DOVAP telemeter record at a paper speed of 4 inches per second.

2.6. DATA REDUCTION

The work on the DOVAP trajectory for Aerobee SM1:01 did not start during this quarter. Neither the cycle count films nor the ground station coordinates had been received, although they were expected to arrive early in February, 1957.

2.7. DISCUSSION OF GRENADE INSTALLATION DIFFICULTY

During the loading of the rocket with grenades, difficulty was encountered with grenades No. 8 and No. 18. The grenade in mortar No. 8 did not seat properly and another was substituted which also did not seat properly. The threads seemed unusually tight, making the grenade difficult to seat or to remove. The loading personnel surmised, incorrectly, it turned out, that the grenade was installed into the mortar socket sufficiently far to make the necessary electrical contacts. Number 18 grenade gave similar difficulty.

After all eighteen grenades were in place the nose cone was installed and the tower was cleared of personnel to permit pressurizing the helium tank, the last operation before firing.

Consultation by the loading personnel with personnel more intimately acquainted with the grenade and mortar assembly brought to light the fact that electrical contact had not been made on grenades Nos. 8 and 18. Pressurization of the rocket had already started and it seemed advisable to continue with the firing preparations with two doubtful grenades rather than risk the possible adverse effects of de-pressurization for the sake of removing or examining these grenades.

The rocket was launched successfully with sixteen grenades firing as planned. As predicted, grenades Nos. 8 and 18 did not fire.

Several factors contributed to the malfunction of grenades 8 and 18. The aluminum castings from which the grenade bulkheads were made did not possess the machinability which was claimed for them. As a consequence the threads were not as smooth as desired. The grenade installation wrench was too long to be used conveniently in the tower and was shortened in the field. This field modification necessitated leaving off the torque handles. With the torque handles off, the person installing the grenades lost his previously acquired sense of feel of the limiting torque to be applied. Since the lack of torque handles would indicate an apparent torque higher than actual, it is quite possible that these two grenades would have seated properly if an additional safe amount of torque had been applied. The most important factor, however, was the lack of proper organization of field operations. Personnel were present at the launching site who knew the grenade rocket assembly intimately and who could have taken the necessary action immediately. In this case such action would have been to determine if the grenades were impossible to seat properly and if so, to remove them from the rocket and fly without them.

The following actions have been undertaken to prevent any such occurrence again:

1. Tighter specifications on materials and inspection of grenades and mortars.

2. Redesign of installation wrench to facilitate reading proper torque limits under tension of field conditions.

3. Arrangement of field operations so that a person with intimate knowledge of the grenade and rocket assembly will have excellent communication with those installing the grenades.

2.8. GRENADES

Two grenades were fired at Churchill from individual mortar tubes as reported in the last quarterly report. In addition sixteen grenades were fired successfully from the rocket as reported elsewhere in this report. Counting 46 previous grenade launchings attempted with 44 successes, the total launchings attempted is now 64 with 62 successes for an indicated reliability of this grenade lot of 97%. Two grenades in the rocket which were improperly installed and which were specifically predicted by number as unlikely to be fired were not counted in arriving at this reliability figure. If only those grenades fired at Churchill are considered the reliability figure is 100%.

2.9. MISFITS OF PARTS

For the November firing at Churchill, The University of Michigan provided the complete warhead for the Aerobee rocket plus the handling of the subcontract for the reconditioning of the rockets and for the notch antenna installation. Prior to the arrival of the various rocket components at Churchill, no attempt was made to mate all these components. Despite the fact that these components were all supposed to be jig-fitted before shipment from the factory, difficulty was encountered in attempting to mate physically major components. Such mating was impossible in at least one case due to substantial misalignment of screw holes.

Further, it was necessary to manufacture some electrical and mechanical parts in the field which could not be prefabricated without having the rocket present.

Because repairs are difficult or often impossible in the field where facilities and materials are limited, it is desirable to complete all fabrication work and all possible inspection and repair work before the rocket and instrumentation leave the States. To avoid these difficulties in IGY firings, the Aerobees will be shipped to Ann Arbor for pre-fitting of components prior to shipment to Churchill.

2.10. TRANSPORTATION AT CHURCHILL

Although transportation at Churchill normally would not be considered a proper subject for this report, the lack of adequate transportation at Churchill definitely interfered with the operation of preparing and firing rockets. For the IGY firings it is planned to take a vehicle to Fort Churchill for the use of University of Michigan personnel.

3. AIR SAMPLING

During the quarter the final run on upper-atmosphere sample bottle B-15 was made. The apparatus was prepared and ground-air samples were made and analyzed in preparation for the analysis of upper-air sample B-10. The effects of coolants on various samples were investigated. Difficulties with breakage in the fractionating column and failure and replacement of the charcoal oven were encountered.

3.1. RESIDUAL GAS IN BOTTLE B-15

Results of the analysis of bottle B-15 were reported in the previous quarterly report. Following these analyses a series of tests was undertaken, designed to show any discrepancies in the results arising from the steel sample bottle or its connecting tubing.

First, approximately 80% of the bottle gas was pumped into the system. This gas consisted of residual gas not previously transferred, plus any gas which may have leaked into the bottle or any gas which may have outgassed from or permeated through the walls of the connecting tubing. Included are the soft-glass-to-hard-glass graded seal, the glass-to-Kovar seal, and the copper tubing and its flare-fitting connection.

An analysis was made of this extremely small sample. The helium content was quite different from the samples previously examined, i.e., the samples B-15, runs 1-2-3, and "residual" in Table III.

3.2. GROUND-AIR SAMPLE ADMITTED TO BOTTLE B-15

After a short pumping, 0.021 cc of gas from ground-air sample No. 13 was introduced into the bottle. This sample was toeplered out the same day in a manner similar to the pumping of the original sample. This gas was then analyzed, and the results are indicated under 13-1X in Table III. It will be noted that the helium content as compared with normal No. 13 ground-air samples is 1.322 times higher. The neon content is near normal, and the oxygen content is very low.

The bottle was flushed with No. 13 ground air, pumped for about 2 hours by the system mercury-diffusion pump to a good vacuum. A second sample of gas from ground-air sample No. 13 was introduced into the bottle. This sample was then toeplered out as before, and preparation for analysis was made. The oxygen cell was operated, and this sample showed even less oxygen than the first sample. At this point, a system breakage necessitated admitting air. The control ground air was lost, so no further analyses were made. In the table, the data obtained are listed under 13-2X.

3.3. COMMENTS

With these data, certain conjectures can be made. First, consider gas cleaned up on the copper filament. Metal surfaces within the bottle appear to react readily with the oxygen in the air sample. It therefore appears unlikely that the upper-atmosphere sample contained appreciable oxygen. This seems to be consistent with the results of analyses made previously by both Dr. Paneth at Durham and our own control samples over several years.

If a gas other than oxygen is assumed, it must then be a gas which will react readily with either the hot copper filament or the equally hot copper oxides which form on the filament. The most likely gas appears to be hydrogen, which would then reduce the copper oxides on the filament to form water. Actually, the filament appears to be cleaned up slightly when operated with the upper-atmosphere samples in the cell as might be expected with hydrogen.

It is hoped that the gas from one of the samples can be examined with a mass spectrometer to verify this deduction.

The gas, whatever it may be, can be assumed to have (1) been present in the upper air, (2) leaked in or outgassed from the bottle, or (3) leaked in or outgassed from the connecting tubing.

TABLE III

SUMMARY OF RESULTS

Sample	Run	Quantity Gas before Oxidation (cc NTP)	He upper air / He ground air	Ne upper air / Ne ground air	% Gas Loss on 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				
13	1	0.0089	Calibration Run		19.6	---	---	---	---
13	2	0.0042	"	"	--	---	---	---	---
13	3	0.0074	"	"	--	---	0.95	---	---
13	4	0.0106	"	"	18.7	---	---	---	0.81
13	5	0.0074	"	"	19.08	---	---	---	1.8
17	1	0.007	"	"	19.0	---	---	---	0.62
17	2	0.0087	"	"	18.4	---	---	---	0.5
16	1	0.0058	"	"	17.4	---	---	---	0.5
					Upper Atmosphere				
B-15	1	0.0082	1.64	1.12	23.2	2.9	---	---	---
B-15	2	0.0061	1.64	1.14	23.7	---	---	---	2.2
B-15	3	0.0036	1.67	1.13	24.2	---	---	---	2.0
B-15	Residual	0.0018	5.25	1.22	25.6	3.3	---	3.4	0.78
B-10	1	0.0102	1.52	1.13	36.0	2.3	---	12.0	10.0
					Ground Air Introduced into B-15				
13	1X	0.0053	1.32	1.06	2.8	---	---	---	1.0
13	2X	0.0049	--	--	0.35	---	---	---	0.5
					Leaked or Outgassed Material				
B-10 not open Connecting tubes only.		0.0001285	7.75	0.214	~0	63	04	---	---

*Measured with McLeod gage.

Later checks have shown that no gas is cleaned up from a small sample collected for 48 hours in the connecting tubing. Possibility (2) is being considered. There is some possibility of hydrogen permeation of the steel bottles. This will be investigated further during the coming quarter.

3.4. HIGH HELIUM CONTENT IN 13-1X

Ground air from No. 13 sample was introduced into the bottle in an attempt to discover whether or not any separation of the upper-atmosphere sample gases occurs in the bottle. It was surprising to find a high helium content in the extracted gases. The explanation of this effect is not immediately apparent. However, in preparing the system for opening bottle B-10, a check analysis was made of gases collected over a two-day period in the connecting tubings. Although the sample was very small, the results of the analysis are considered reliable. The gases contained a large proportion of helium compared to ground air. From these data it seems likely that any increase in helium in Bottle B-15 residual, after toeplering and while still attached to the system, was due to helium permeation of the connecting tubing.

This helium leakage is not high enough to account for the amount of helium in 13-1X. The same checks will be run on B-15 with No. 17 ground air to further clarify this point.

Although the helium content in the connecting tubing is increased, it should be noted that the sample is very small. If the whole sample of B-10 were contaminated with the gas collected during two days, the

$$\frac{\text{He upper-air}}{\text{He ground air}}$$

ratio would be changed less than 2%, and B-15 changed less than 2.6%. The pumping time is only about 7 hours; consequently, the error from this source is less than 1% on each bottle and is not considered significant.

3.5. CONDENSABLES

Some data were collected showing the amount of sample reduction when a trap cooled to various temperatures. In addition, this cooling was done both before and after removing gases on the hot filament. It should be noted that several gases have sufficiently high boiling points to be condensed at the temperature of liquid nitrogen. In all cases, the trap volume comprised only a small portion of the total volume containing the sample. It is estimated to be on the order of a few percent. The results appear in the table and no comments will be made on them at this time. All readings are based on the change of pressure in a fixed volume. The pressures were measured with a McLeod gage.

During this period several breaks occurred in the capillary-tubing fractionating column. Delays were encountered while the breaks were repaired. One piece of capillary, which was particularly persistent in its breakage, was finally replaced before the work could be continued.

The charcoal oven also caused delay. The heating element burned out, and it became necessary to construct a new oven before proceeding with the analyses.

The apparatus is now working well, and bottle B-10 analysis should be completed during the next month.

3.6. BOTTLE B-10

Preparations were made for opening B-10. Prior to the opening several checks for system tightness were made. Breakage on the column caused the loss of some ground-air samples. Ground-air sample No. 16 was analyzed once before breakage and loss. Ground-air sample No. 17 was analyzed as a control. Results are noted under 17-1 in the table.

The upper-atmosphere sample B-10 was then opened. To date only one run has been completed on this sample. The helium and neon ratios appear to be slightly lower than B-15. The results are listed under B-10-1 in the table.

An additional control sample was run. The results are given in 17-2 in the table.

We have now analyzed gas from bottles with 1- and 2-inch orifices.

From the data now available, it may be concluded that the separation shown is not caused by either supersonic velocity at sampling or by the dynamics of the sampling orifice.

4. RESEARCH INVESTIGATIONS - PROGRESS REPORT ON RAREFIED GAS-FLOW RESEARCH

One of the drawbacks of the aerodynamic methods of upper atmosphere measurements is the lack of satisfactory theory of predicting the aerodynamic effect of flow around a body in the rarefied gas, such as atmospheric air at an altitude of 100 Km. The properties of the atmosphere at this altitude can be characterized as a medium with a mean free path comparable in order of magnitude to the size of the body about which the aerodynamic effect is of interest. Results of low-density wind-tunnel tests corresponding to these flow conditions have been meager and perhaps unreliable due to unresolved experimental difficulties involved in the tests.

The classical theoretical analysis of the problem boils down to the solution of Boltzmann's collision equation. Attempts have been made along this line for solving various rarefied gas problems by Chapman, Enskog, Grad, Uhlenbeck, and Chang, to mention a few. However, due to the immense mathematical difficulties involved, only modest success has been achieved. Satisfactory results have been obtained mostly in the field of diffusion problems such as those described in the treatise by Chapman and Cowling (The Mathematical Theory of Non-Uniform Gases, Cambridge University Press, 1952, 2nd ed.).

The present approach offers a new line of attack. The general principle of which can be briefly described.

When the mean free path of the medium is much larger than the characteristic size of the object, the so-called free molecule flow region prevails in which collisions between the molecules of the medium may be neglected as compared with those with the object. The theory of free molecule flow has been well developed except for the uncertainty concerning the nature of reflection of the gaseous molecules from the solid surface of the object. As far as this interaction is concerned, at least two different types of mechanisms of reflection are possible, depending on the state and nature of the surface, the kind of gas, the density of the impinging stream, and the respective temperatures of the gas and the solid surface. These are specular reflection and diffuse reflection. In specular reflection, the component of the molecular velocity tangent to the surface remains unchanged but the component normal to the surface reverses its sign. In the diffuse reflection, the 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 usually make several collisions in the interstices of the surface during which time they can exchange momentum and energy with the surface. Review of progress in recent research concerning the interaction between gaseous molecules and the solid surface is given by Schaaf (Heat-Transfer Symposium, University of Michigan Press, 1952). It can be said that the free molecule flow theory, which describes the characteristics of flow in extremely rarefied gas, will be established once the uncertainty of this interaction phenomenon is cleared.

The attempt, initiated here, is made to take collisions into account so as to obtain a better approximation to the aerodynamic effect of the flow for which the characteristic size of the object is not entirely negligible compared to the mean free path of the medium. It can be considered as a second approximation to the aerodynamic force, while the result of the free molecule flow constitutes the first approximation for which the effect of molecular collisions has been neglected.

It is plausible to assume that the chance that a reflected molecule collides n times near the object is obviously less than if it collides m times, if $n > m$. Thus we start the analysis by taking into account those molecules that collide once in the gas near the object. This is here considered as the second approximation. Theoretically speaking, the nth approximation can be obtained by calculating the effect of n collisions.

In the scheme of successive kinetic calculation, we define $D^{(1)}$ as the correction term to the first order of approximation of the aerodynamic force (the free molecule flow theory). In obtaining $D^{(1)}$, we take into account the contribution to the aerodynamic force on the object due to the collisions between the incident and reflected molecules in the first round.

As a sample to test the workability of the basic idea just described, we chose a very simple model which consists of a flat plate moving in a direction normal to its plane in a monatonic gas of hard, spherical molecules. Specular reflection is assumed.

The results of the calculation of the drag coefficient of the flat surface at various ratios of mean free path and plate diameter are plotted in Fig. 5. The results presented here are considered preliminary because they are obtained on the basis of very crude assumptions concerning the molecular behavior. Nevertheless, the results of the sample calculation already indicate that the present idea is promising when considered as a working model for solving rarefied gas-flow problems.

A technical report dealing with the present method of attack on the rarefied gas-flow problems will be issued as soon as sufficient sample calculations are completed.

5. LABORATORIES VISITED

During this quarter, visits were made to the following places.

a.) Fort Churchill, Manitoba, Canada
b.) Air Force Cambridge Research Center
c.) Evans Signal Laboratory
d.) Defense Research Board, Ottawa, Ontario.

6. FUTURE PROGRAM

During the next quarter, work on the project will include the following:

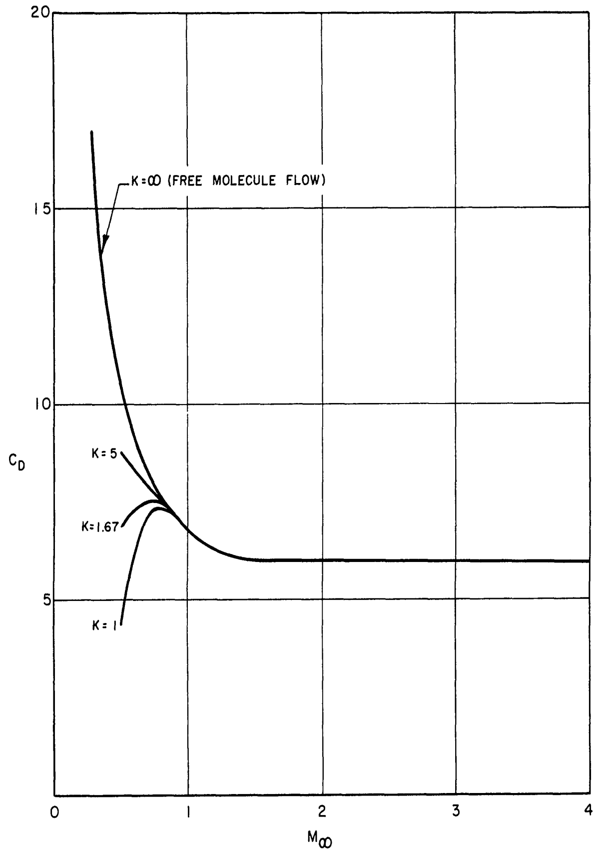


Fig. 5. Drag coefficient of a flat surface,

$$C_D = \frac{\text{drag}}{\pi a^2 \frac{\rho}{2} V_\infty^2},$$

for specular reflection.

$$K = \frac{L_M}{2a} : \text{Knudsen number, } \frac{\text{mean free path}}{\text{plate diameter}} .$$

6.1. GRENADE EXPERIMENT

a.) Data reduction for Aerobee SM1:01.
b.) Re-design of Aerobee instrumentation for IGY grenade experiments.
c.) Construction of a prototype "modular" instrumentation section.
d.) Analysis of Aerobee SM1:01 rocket performance.
e.) Rehabilitation of Aerobee rockets by the Aerojet-General Corporation.
f.) Construction of Aerobee instrumentation for IGY grenade experiments.
g.) Analysis of method of impact prediction.

6.2. AIR SAMPLING

Bottle B-10 will be analyzed and the analysis of control samples will continue.

6.3. RESEARCH INVESTIGATIONS

The method of attack on rarefied gas-flow problems introduced above will be applied to other sample problems.

7. ACKNOWLEDGMENTS

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d.) The Fort Churchill Section of WSCCA for Radar Tracking, Range Safety Impact Prediction, and Communications;
e.) BRL, DOVAP, and Ballistic Camera Groups;
f.) Commander Diehl and the Aerobee launching Team;
g.) The field crew of NMAMA;
h.) The field representatives of the Aerojet-General Corporation.

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