NASA TECHNICAL NOTE

NASA TN D-2347

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by Kenneth H. Crumbly

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JULY 1964

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SUMMARY

Recent efforts in obtaining optical data from reentry vehicles have resulted in a spectrogram of the fourth and fifth stages of a Trailblazer IIb rocket reentering at 8.1 and 10.9 km/sec, respectively. These data were obtained by a ground-based slitless spectrograph equipped with a 400 groove/mm transmission grating which gives a line resolution of approximately 10 A. The fourth-stage reentry ablative elements were identified as iron, magnesium, chromium, calcium, sodium, manganese, and nickel. The fifth-stage reentry ablative materials were identified as aluminum, magnesium, and aluminum oxide. A short discussion is presented on various radiometric aspects of the two reentries.

INTRODUCTION

An intensive research program has been established by the Langley Research Center in cooperation with the Massachusetts Institute of Technology Lincoln Laboratories to study the physical phenomena of reentry of various materials and shapes at intercontinental-ballistic-missile (ICBM) reentry velocities; the vehicles used in this program are identified as Trailblazer. Optical and radar signatures of reentries are measured from the ground to gain some understanding of the aerodynamics, physics, and chemistry of the reentry phenomena. In order to determine the luminous efficiency at velocities within the range of natural meteors, one Trailblazer vehicle was modified such that a small particle would reenter at a velocity nearly twice that associated with ICBM reentries. This vehicle was designated Trailblazer IIb.

Trailblazer IIb was a six-stage solid-fuel rocket system with the six stages being arranged in tandem fashion. The first and second stages acted as boosters to gain altitude for the velocity package. The third-, fourth-, and fifth-stage motors along with the sixth-stage shaped-charge accelerator were enclosed in a structure to form the velocity package which faced rearward at launch. During the boost phase of powered flight, the velocity package was spin-stabilized so that after apogee the attitude of the velocity package was nearly vertical. The stages were fired in rapid succession to achieve the high reentering velocity.

The Trailblazer IIb rocket was fired on the night of May 5, 1962, and four stages of the velocity package were observed to reenter. Of prime interest, from the data obtained, was a spectrogram of two stages reentering at velocities of 10.9 and 8.1 km/sec. In addition to the spectrogram, radar signature studies were made and the visible reentry of the four stages in the velocity package were photographed by ballistic cameras situated at three locations on the East Coast. In addition, various other optical instruments recorded one or more stages reentering.

The purpose of this report is to identify materials found in the spectrogram by identification of wavelength and, with microphotometer traces of the fourth stage, to provide an indication of energy distribution as a function of wavelength and energy variations with altitude. A detailed analysis of the spectrogram is not given. Altitude as a function of velocity and slant range for the fourth and fifth stages is also given.

LAUNCH VEHICLE AND TRAJECTORY

The basic Trailblazer II launch vehicle is composed of four stages, two boosters or elevating rockets and two accelerators. The first stage is a Castor with two Recruits and the second stage is a Lance. The third stage is an Altair and, along with the fourth stage, Cygnus 15, is enclosed in a velocity package.

The Trailblazer IIb rocket used this same configuration with the addition to the velocity package of a fifth stage, Cygnus 5, and a sixth-stage shaped-charge accelerator. The assembled rocket stood over 50 feet in height. These six stages were arranged in tandem fashion with the third, fourth, fifth, and sixth stages enclosed in a structural shell identified as the velocity package and facing in a rearward direction at launch.

The fourth and fifth stages and the sixth-stage container are pictured in figure 1; this assembly is known as the reentry package. The sixth-stage shaped-charge accelerator was developed by the Air Force Cambridge Research Laboratories to accelerate a 2-gram stainless-steel disk.

The Trailblazer IIb vehicle was launched at 05:41:00 G.M.T. May 6, 1962, from NASA Wallops Station on an azimuth of 150°. The second-stage motor ignited at about 36 seconds from launch. At launch time t plus 62 seconds, the velocity package separated from the second stage. During the firing of the second stage, the canted fins of the second stage spun the configuration to about 10 revolutions per second. This was sufficient to stabilize the vehicle attitude to 68° with the horizontal. After apogee, approximately 300-km altitude and t + 290 seconds, the third stage fired at t + 330 seconds. Since the velocity package and reentry stages operated the greater part of the flight above the earth's atmosphere, three spin motors were provided which fired at third-stage burnout to stabilize the remaining stages.

The fourth stage fired at t + 370 seconds with the fifth-stage firing at t + 377 seconds. The shaped-charge accelerator fired at t + 382 seconds and, in so doing, broke the fifth-stage motor into several pieces.

REENTRY TRAJECTORY

The disk or artificial meteoroid reentered at about t + 390 seconds and a velocity in excess of 11.5 km/sec. The reentry was recorded on ballistic plates but no spectrum was obtained of this reentry by NASA ground equipment. Several pieces of the fifth-stage motor and the remains of the shaped-charge accelerator reentered at about t + 399 seconds at an altitude of about 72 kilometers. The visible trail lasted until an altitude of almost 56 kilometers. The fourth-stage motor reentered at about t + 402 seconds slightly south of the fifth-stage reentry. It was visible at an altitude range between 75 kilometers and 30 kilometers. These two reentries were very close together in time and most of the optical recording equipment and cameras recorded both reentry streaks. Altitude is presented as a function of velocity for the fourth and fifth stages in figures 2 and 3, respectively. Altitude is presented as a function of slant range for the fourth and fifth stages in figures 4 and 5, respectively.

GROUND-BASED OPTICAL EQUIPMENT

An aerial K-24 camera (fig. 6) was modified to accept a 127- by 178- by 1.6-mm photographic glass plate. The camera was equipped with an f/2.5 lens of 177.8-mm focal length. The camera has 127-mm square format. A transmission grating was placed in front of the objective lens thereby constituting a slitless spectrograph. The grating was oriented with the grooves parallel to the expected reentry trace. The grating is 84 mm square with 400 grooves/mm and blazed for a wavelength of 5000 A in the first order. The emulsion used on the glass plate was a high-speed panchromatic type and the shutter was open continuously about 45 seconds with no mechanical chopper employed. The plate was developed for 7 minutes at 20° C.

CALIBRATION AND DATA REDUCTION PROCEDURES

The spectrogram shown in figure 7 and sketched in figure 8 was taken at the Optical Tracking Station located at latitude 35°15'44" N., longitude 75°33'53" W., near Coquina Beach, North Carolina. The camera was oriented to an azimuth of 85° and an elevation of 12°. In order to reduce this spectrogram, it was necessary to obtain certain spectral calibration plates. The procedure used to obtain these calibration plates was that of photographing a line source effectively placed at infinity by using a large collimating mirror. The camera was alined in the collimating system so that the zero order of the spectrum was in the same position on the plate as the original spectrogram.

The reduction of the spectrogram and the calibration plates was accomplished by making microphotometer traces of each and then comparing the measurements from these traces.

All the microphotometer traces were made from the zero order through the first order on both the original and the calibration plates. Since the wavelengths of the lines on the calibration plates are known, a comparison of the microphotometer traces will give the desired wavelength on the original. Once a series of lines on the original trace was identified, a dispersion calibration was determined and used to determine wavelengths of the remaining lines; the resolution was estimated at 10 A except for the band spectrum.

A series of 10 microphotometer traces was made of the spectrogram at different altitudes to insure measurement of all lines. The wavelengths of the lines from each microphotometer trace were recorded and grouped together by wavelength. The numerical average of the wavelengths of the line was taken from these readings. These wavelengths were then compared with wavelengths in reference 1, in order to determine which elements were detected.

In figure 9, four typical microphotometer traces are shown. Figure 9(a) shows a trace at an altitude of 60 km; figures 9(b), (c), and (d), at altitudes 58, 50, and 42 km, respectively. Figure 9(a), shows several lines belonging to the fifth-stage motor. These lines are identified on the trace as to their wavelength.

RESULTS AND DISCUSSION

A sketch of the spectrogram is shown in figure 8, to the same scale as figure 7. The identification of the zero orders for the fourth and fifth stages is shown as well as the major emitting species for that portion of the spectrogram which contains the overlapped spectra. The wavelength scale given is for the fourth stage; the same dispersion scale holds for the fifth stage, but is displaced to the left by the distance between the two zero orders.

Fifth Stage

The fifth-stage spectrum shows the characteristic aluminum doublet at 3944 A and 3961 A. This doublet appears high in altitude and lasts until a final burst of energy at an altitude of about 60 km; at this burst the aluminum oxide bands appear. At an altitude of about 70 km, the fifth stage emits radiation from magnesium in the two triplets at 5167 A, 5172 A, 5183 A, and 3827 A, 3832 A, 3838 A. A summary of the results as compared with references 2, 3, and 4, is given in table I (where λ_{meas} is the measured value of wavelength and λ_{std} is the standard value of wavelength).

The bands and lines of the fifth stage are overlapped with the spectrum of the fourth stage as may be seen in figures 7 and 8.

Fourth Stage

The fourth-stage results are tabulated in table II. The most predominant radiation is emitted by the element iron. Traces of chromium, copper, calcium, aluminum, and nickel were also found. Strong radiation from magnesium and sodium is also present.

In table II, an asterisk in the remarks column indicates that the line is a relatively positive identification. The asterisk is used where there is good agreement as to the spacing between two lines as well as to the measurement of the line's wavelength.

The spectrogram as a whole contains other information not contained in a table or readily evident when one looks at a microphotometer trace. It is evident that the radiation intensity of the reentry of either the fourth- or fifth-stage fluctuates with time and altitude. Also, the radiation does not remain in a steady state as regards the spectral region of emission. In other words, different elements are emitting radiation at different times.

The fourth-stage radiation starts and ends rather abruptly, maintaining a fairly constant intensity during the reentry except for the burst of energy at an altitude of about 50 km. Following this burst, there is a rapid cooling-off process which is indicated by the change in distribution of energy to the red end of the spectrum.

The elements which were found in the spectrogram were those expected for these reentry vehicles. The magnesium is present in heavy concentrations in the rocket nozzle and shows up in both spectra. Most of the other elements are known to occur in slight percentages in either the fourth- or fifth-stage motor. Sodium has been recorded in almost every reentry spectrum and is often used as a standard with which to measure other wavelengths.

A small amount of radiation was recorded in the second order of the spectrogram, but no significant contribution to this report was obtained by reducing the second-order spectrum. Radiation from certain molecules of atmospheric constituents was not recorded. Neither was radiation recorded outside of 6300 A, the film cut-off, or below 3700 A. The short cut-off wavelength is believed due to a combination of atmospheric and optical transmission losses. These cut-offs prevented any order overlap.

Figure 9 shows energy fluctuations as a function of wavelength at different altitudes for the fourth-stage reentry. In figure 9(a) the two sharp lines identified as "Al, 3944 A, 3961 A," are due to the overlapping spectra of the fifth stage. The energy in figures 9(a) and (b) is, for the most part, from line spectra. In figures 9(c) and (d) most of the radiation appears to be continuum, particularly in figure 9(d).

These microphotometer traces are the actual traces, and normalizing of these traces as to reciprocity failure, writing speed across the film, wavelength sensitivity, and so forth has not been done. These figures give only an indication of how the energy fluctuates from the violet to the red end of the spectrum and are characteristic of the energy fluctuations caused by temperature changes from a high to a low value. The overall energy picture then is one of a temperature decrease with an altitude decrease for the visible portion of the spectrum.

CONCLUDING REMARKS

A study of the reentry spectrogram from two stages of Trailblazer IIb resulted in the identification of certain elements and molecules. The spectrogram showed energy fluctuations as the reentry vehicle decreased in altitude. Altitude plotted against velocity and slant range were also given for the fourth- and fifth-stage reentries. The major elements and components were listed.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., March 14, 1964.

REFERENCES

1. Zaidel', A. N., Prokof'ev, V. K., and Raiskii, S. M.: Tables of Spectrum Lines. The Macmillian Co., 1961.

2. Harrison, George R., compiler: Massachusetts Institute of Technology Wavelength Tables. John Wiley & Sons, Inc., 1956.

3. Pearse, R. W. B., and Gaydon, A. G.: The Identification of Molecular Spectra. Second ed., John Wiley & Sons, Inc., 1950.

4. Harrison, George R., Lord, Richard C., Loofbourow, John R.: Practical Spectroscopy. Prentice-Hall, Inc., c.1948.

TABLE I.- WAVELENGTHS AND RADIATING SPECIES FOR FIFTH STAGE

λ_{meas}, A	λ_{std}, A (refs. 2 to 4)	Element	Remarks
3828	3829.350	Mg I	*
3834	3832.306	Mg I	*
3834	3838.258	Mg I	*
3947	3944.032	Al I	*
3966	3961.527	Al I	*
4027	4030.76	Mn I	------------
4663	4672.0	AlO	Band spectra
4825	4842.1	AlO	Band spectra
5098	5102.1	AlO	Band spectra
5179	5167.34	Mg I	*
5179	5172.70	Mg I	*
5179	5183.62	Mg I	*

*Identification by comparison with fourth-stage spectrum.

TABLE II.- WAVELENGTHS AND RADIATING SPECIES FOR FOURTH STAGE

λ_{meas}, A	λ_{std}, A	Element	Remarks
3737	3737.133	Fe I	--------------------
3744	3745.564	Fe I	*
3799	3798.513	Fe I	*
3828	3829.350	Mg I	*
3834	3832.306	Mg I	*
3834	3838.258	Mg I	*
3844	3840.439	Fe I	--------------------
3856	3856.373 3858.301	Fe I Ni I	Both lines probably present
3871	3872.504	Fe I	--------------------
3874	3878.021	Fe I	--------------------
3884	3886.284	Fe I	--------------------
3900	3902.915 3902.948 3902.963	Cr I Fe I Mo I	All three lines probably present
3922	3922.914	Fe I	--------------------
3931	3933.666	Ca II	*
3947	3944.032	Al I	*
3966	3961.527	Al I	*
	3968.468	Ca II	Probably present also
4008	4005.246	Fe I	
4031	4030.755	Mn I	*
4040	4045.815	Fe I	--------------------
4064	4063.597	Fe I	--------------------
4068	4071.740	Fe I	*
4140	4143.871	Fe I	*
4151	4147.673	Fe I	Weak
4155	4157.791	Fe I	Weak
4199	4199.099	Fe I	--------------------
4207	4210.352	Fe I	--------------------
4229	4226.728	Ca I	Weak
4261	4254.346	Cr I	--------------------
4269	4271.764	Fe I	--------------------
4278	4274.803 4282.406	Cr I Fe I	Possibly both lines
4287	4289.72	Cr I	--------------------
4303	4305.453 4305.455	Cr I Fe I	Possibly both lines
4308	4307.906	Fe I	--------------------
4316	4315.087	Fe I	--------------------
4336	4337.049 4337.566	Fe I Cr I	Possibly both lines
4354	4352.737 4351.770	Fe I Cr I	Weak possibly both lines present
4384	4383.547	Fe I	*
4398	4401.547	Ni I	--------------------
4402	4404.752	Fe I	--------------------
4409	4407.716	Fe I	--------------------
4417	4415.125	Fe I	--------------------

*Relatively positive identification.

TABLE II.- WAVELENGTHS AND RADIATING SPECIES FOR FOURTH STAGE - Concluded

λ_{meas}, A	λ_{std}, A	Element	Remarks
4440	4442.343	Fe I	---------------
4455	4454.383	Fe I	---------------
4459	4459.121 4459.037	Fe I Ni I	Possibly both lines present
4465	4466.554	Fe I	---------------
4474	4476.022	Fe I	---------------
4573	4580.056	Cr I	Weak
4700	4707.281	Fe I	Weak
5179	5183.618	Mg I	*
5270	5269.541	Fe I	---------------
5277	5281.799	Fe I	---------------
5291	5287.922	Fe	Weak
5324	5324.182	Fe I	---------------
5337	5339.938 5341.026	Fe I Fe I	---------------
5342	5339.938	Fe I	Weak
5351	5348.319	Cr I	Weak
5402	5404.148	Fe I	---------------
5413	5415.207	Fe I	---------------
5420	5420.362	Mn	Weak
5435	5434.527	Fe I	---------------
5443	5446.920	Fe I	---------------
5474	5476.906	Ni I	---------------
5521	5525.553	Fe I	?
5525	5528.461	Mg I	?
5544	5546.490	Fe I	Weak
5576	5576.106	Fe I	---------------
5605	5602.956	Fe I	---------------
5645	5650.130	Mo	---------------
5666	5662.525	Fe I	---------------
5694	5694.730 5694.998	Cr I Ni I	Possibly both lines present
5720	5722.735	Mo	Weak
5767	5763.011	Fe I	---------------
5857	5857.755	Ni I	---------------
5897	5889.953 5895.923	Na I Na I	*
5927	5928.882	Mo	---------------
5936		----	---------------
5961		----	---------------
6003	6003.034	Fe I	Weak
6032	6030.662	Mo	---------------
6091	6086.290	Ni I	Weak
6127		----	Weak
6184	6176.814	Ni I	---------------
6196	6191.186	Ni I	---------------
6215		----	Weak
6251	6256.365	Ni I	---------------
6270		----	---------------
6279		----	---------------
6289	6290.743	Mo	---------------
6326	6330.101	Cr I	---------------

*Relatively positive identification.

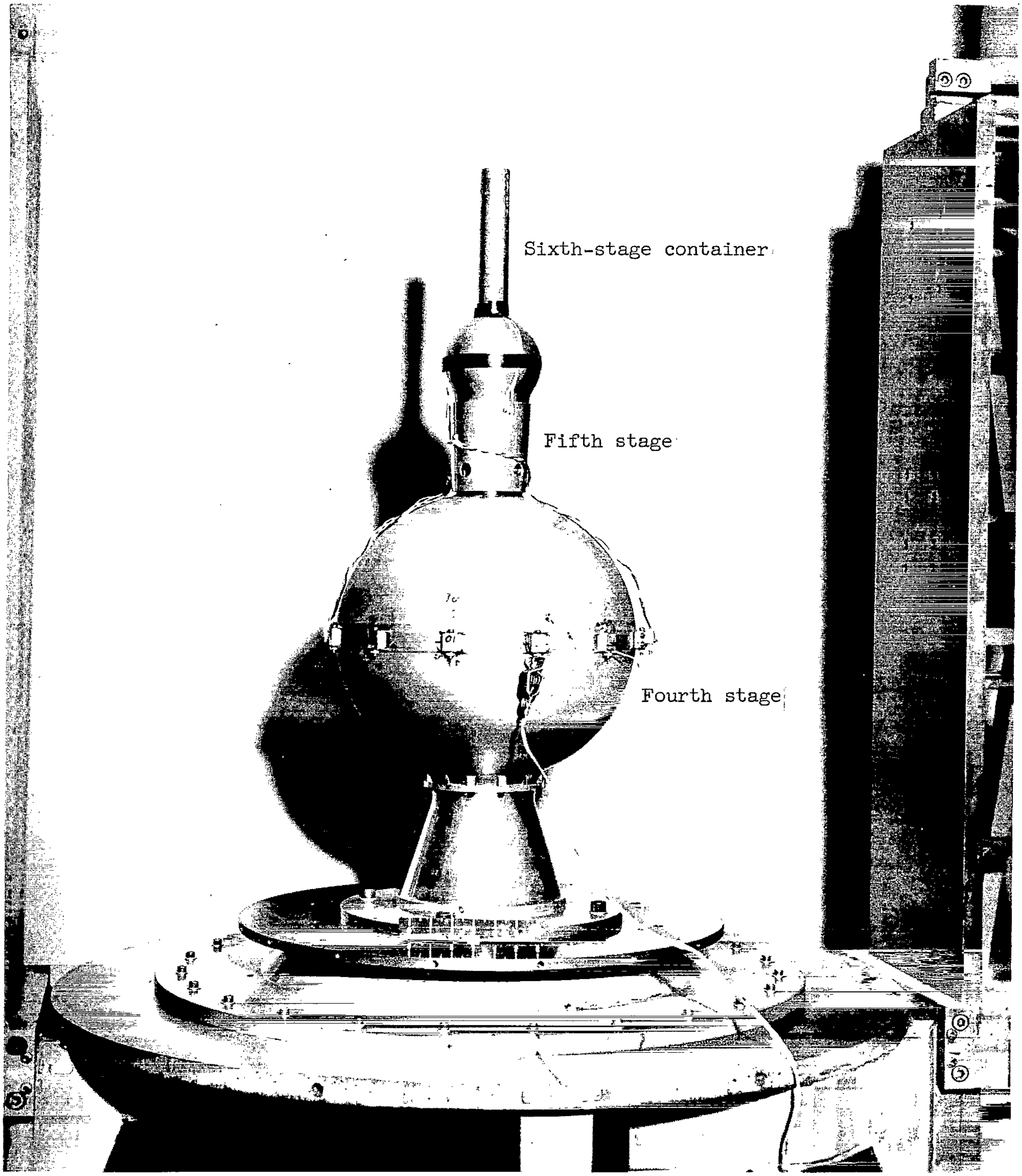


Figure 1.- Reentry package, Trailblazer IIb. L-62-3614.1

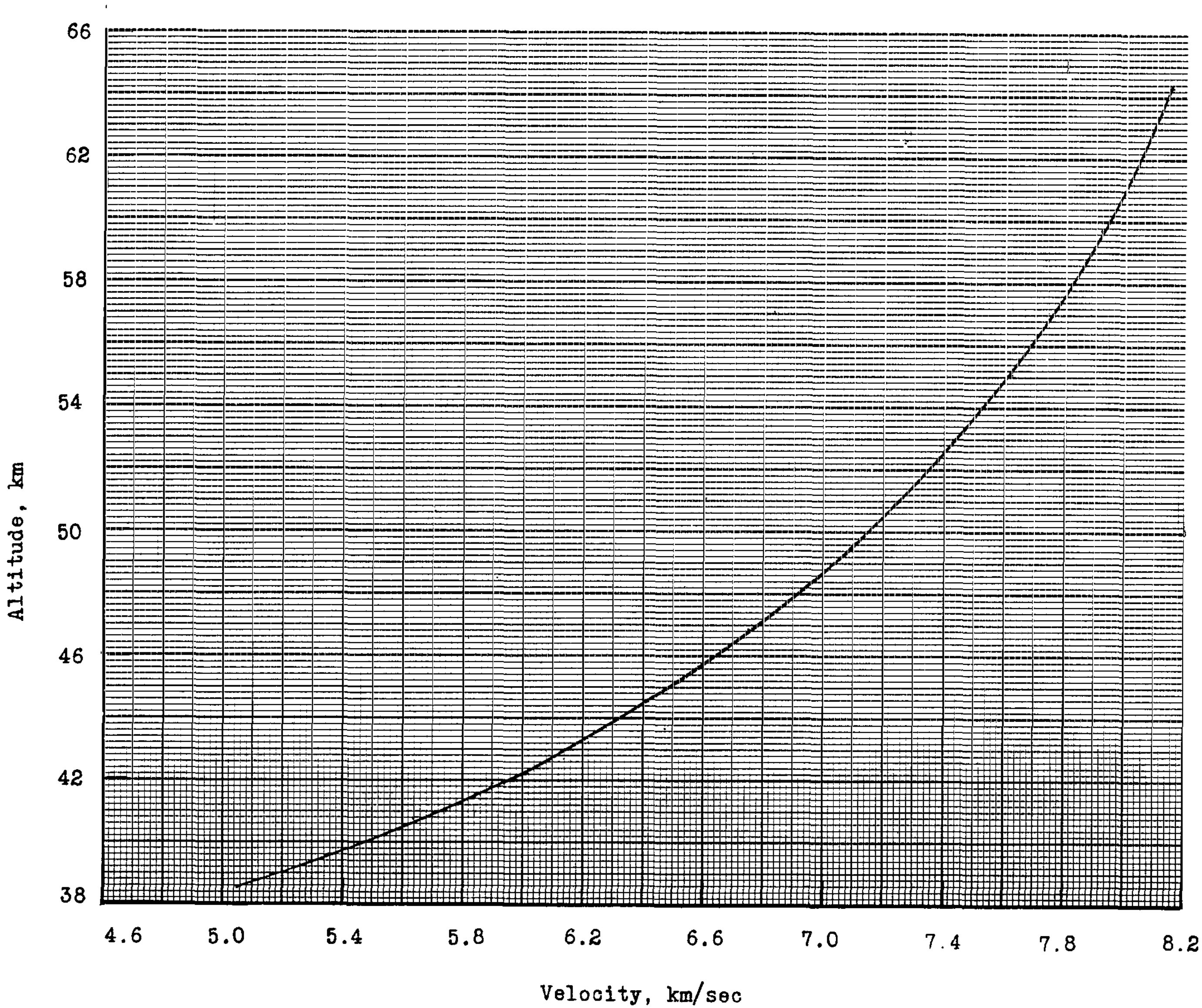


Figure 2.- Altitude as a function of velocity for fourth stage.

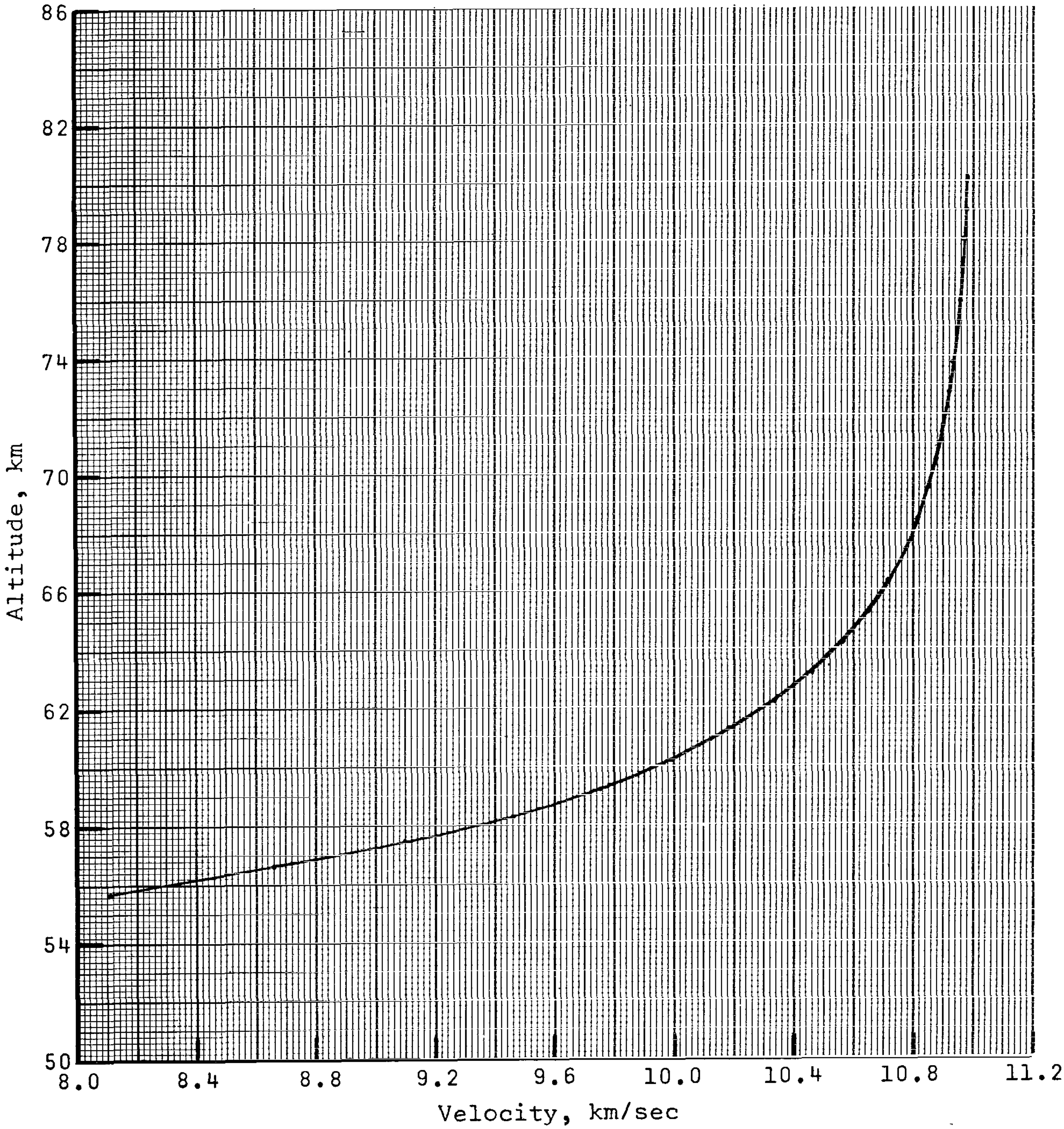


Figure 3.- Altitude as a function of velocity for fifth stage.

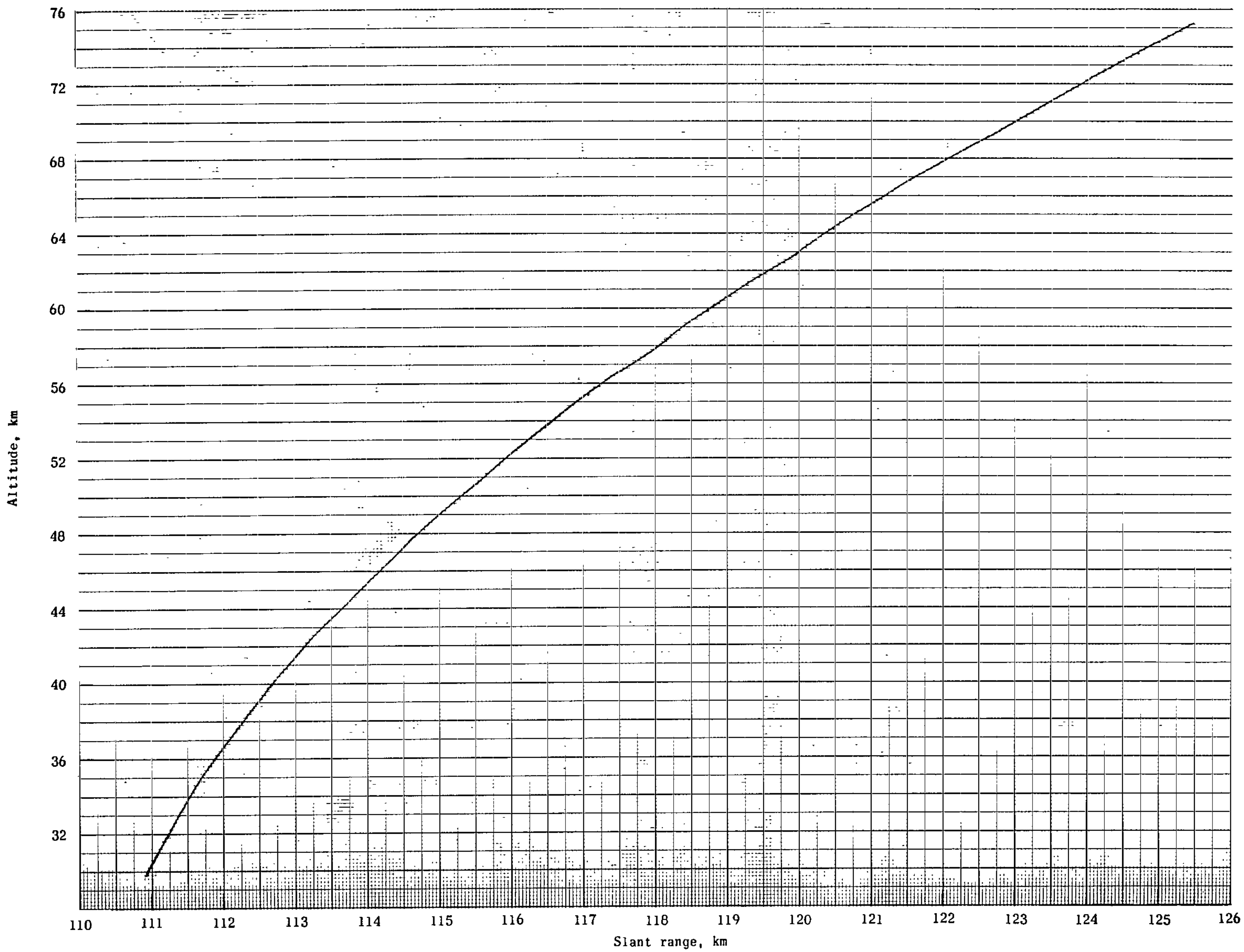


Figure 4.- Altitude as a function of slant range for fourth stage.

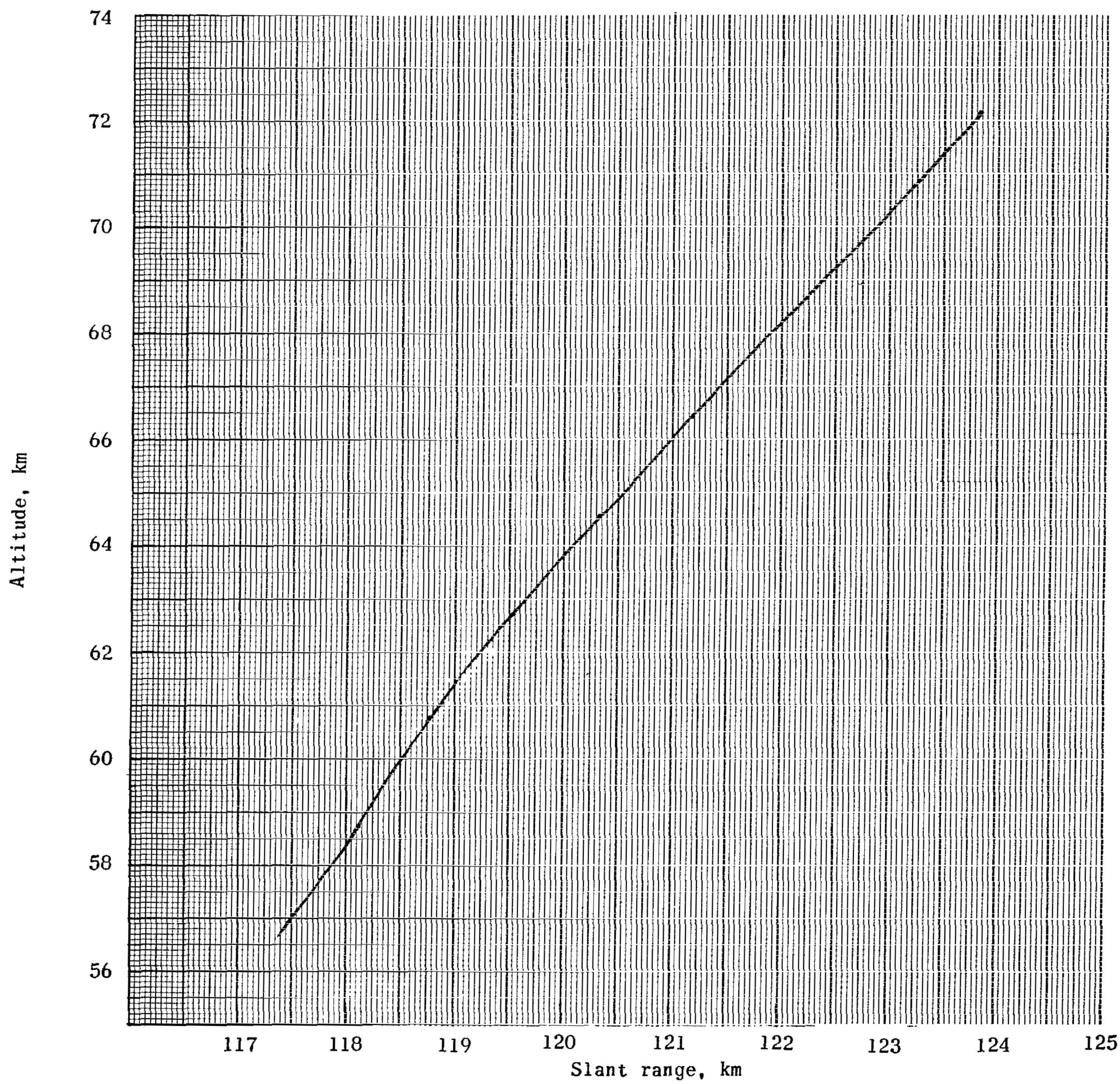


Figure 5.- Altitude as a function of slant range for fifth stage.

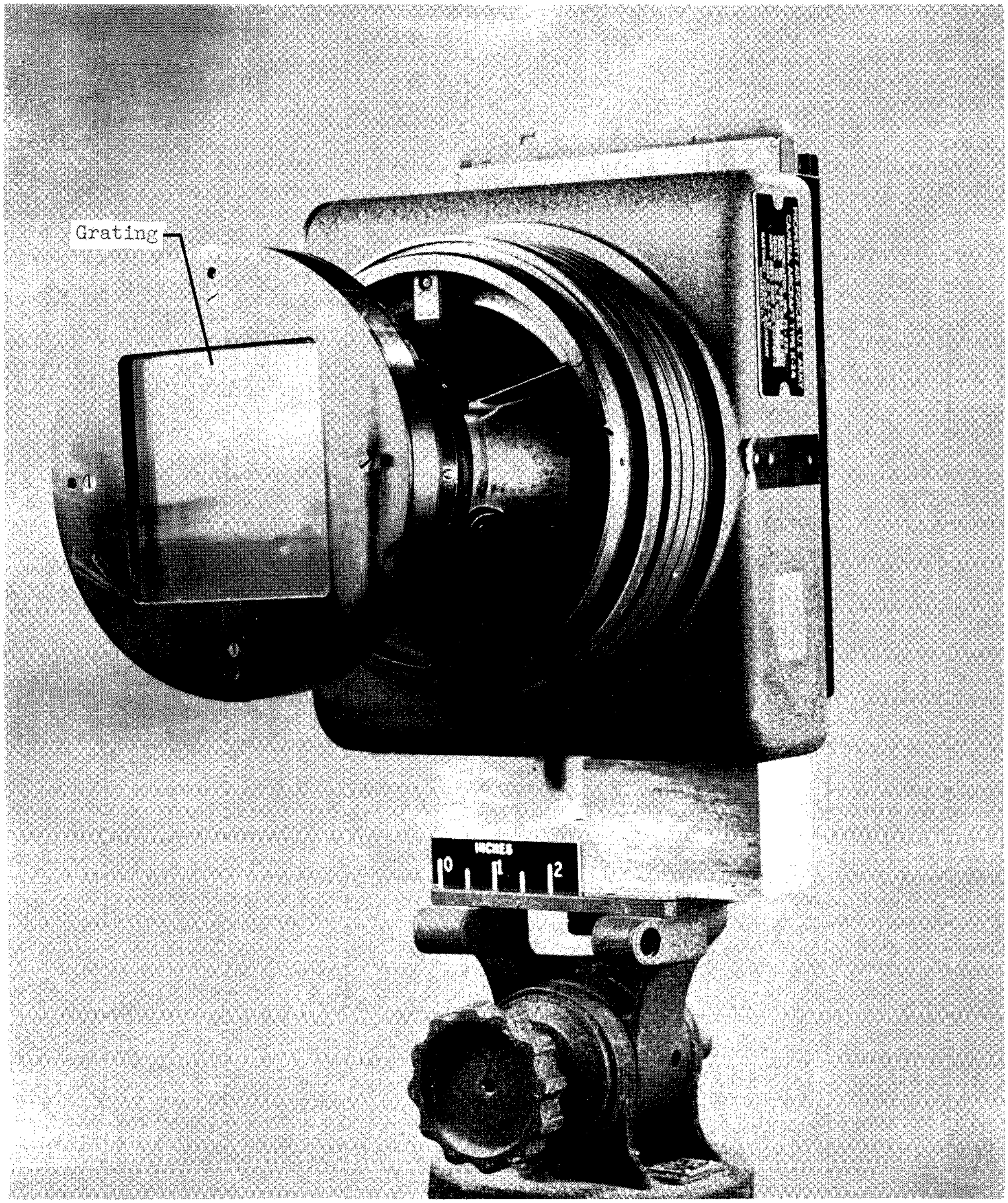


Figure 6.- Slitless spectrograph. L-62-5897.1

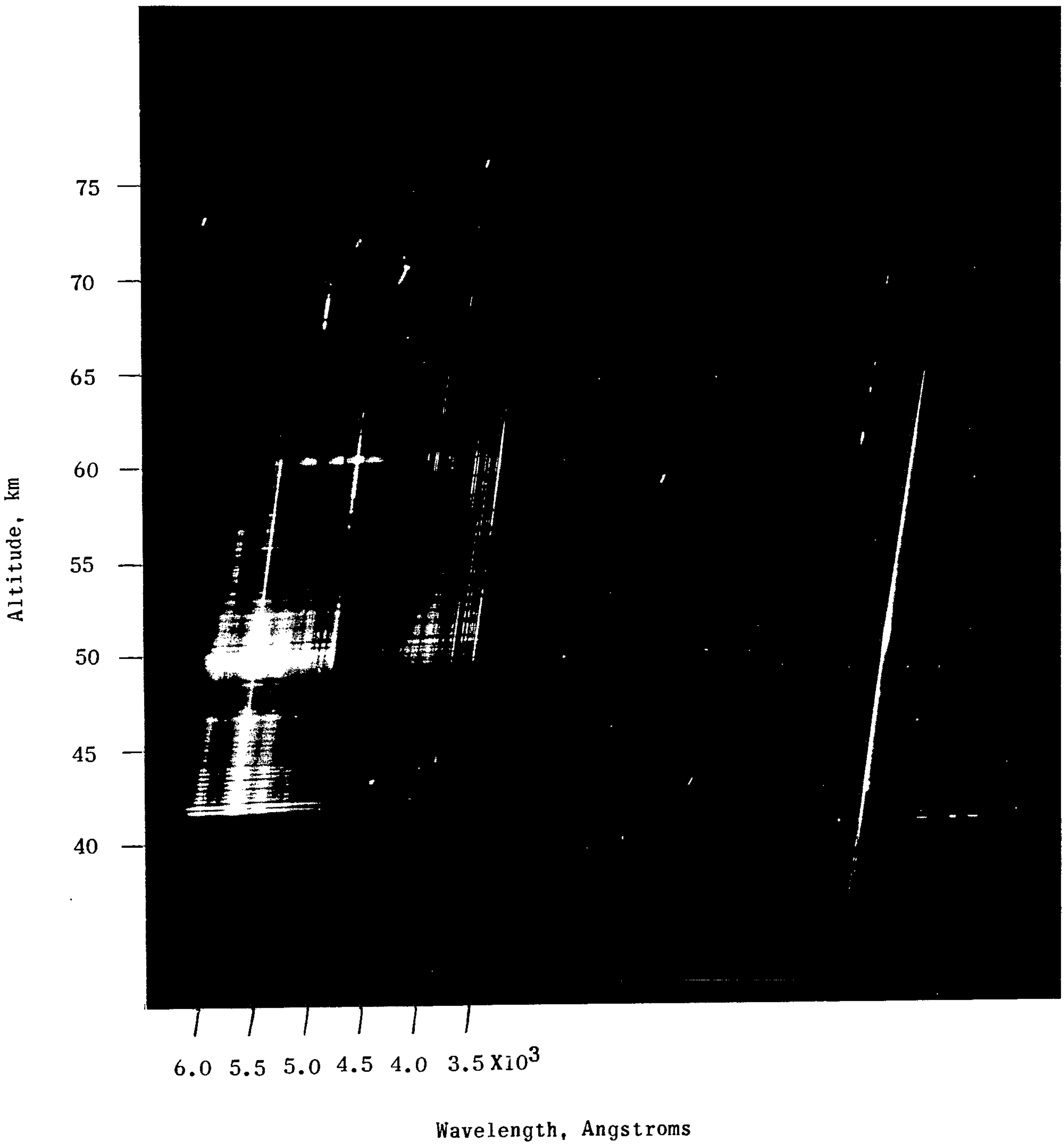


Figure 7.- Spectrogram of fourth and fifth stages. L-64-3016

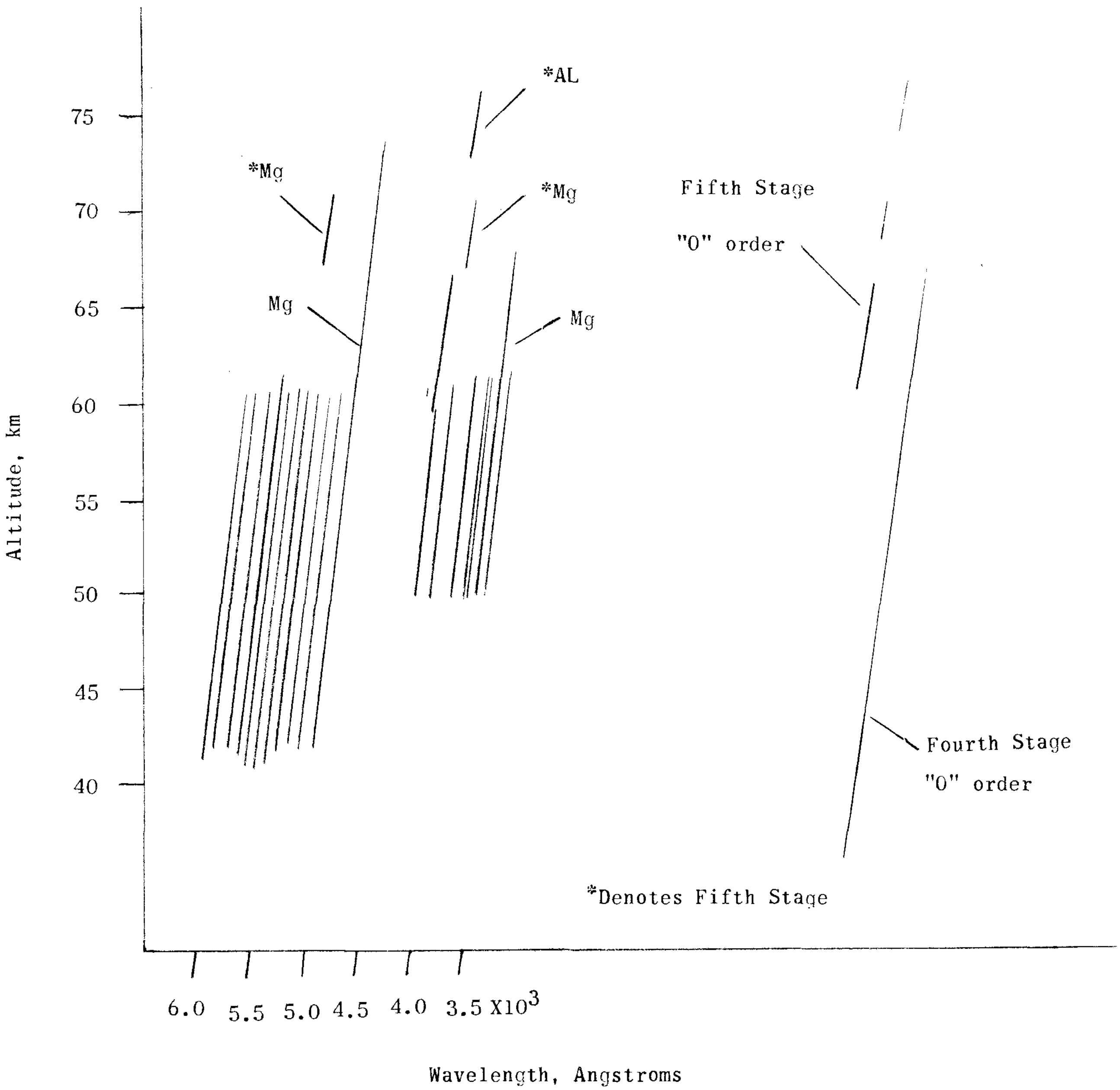
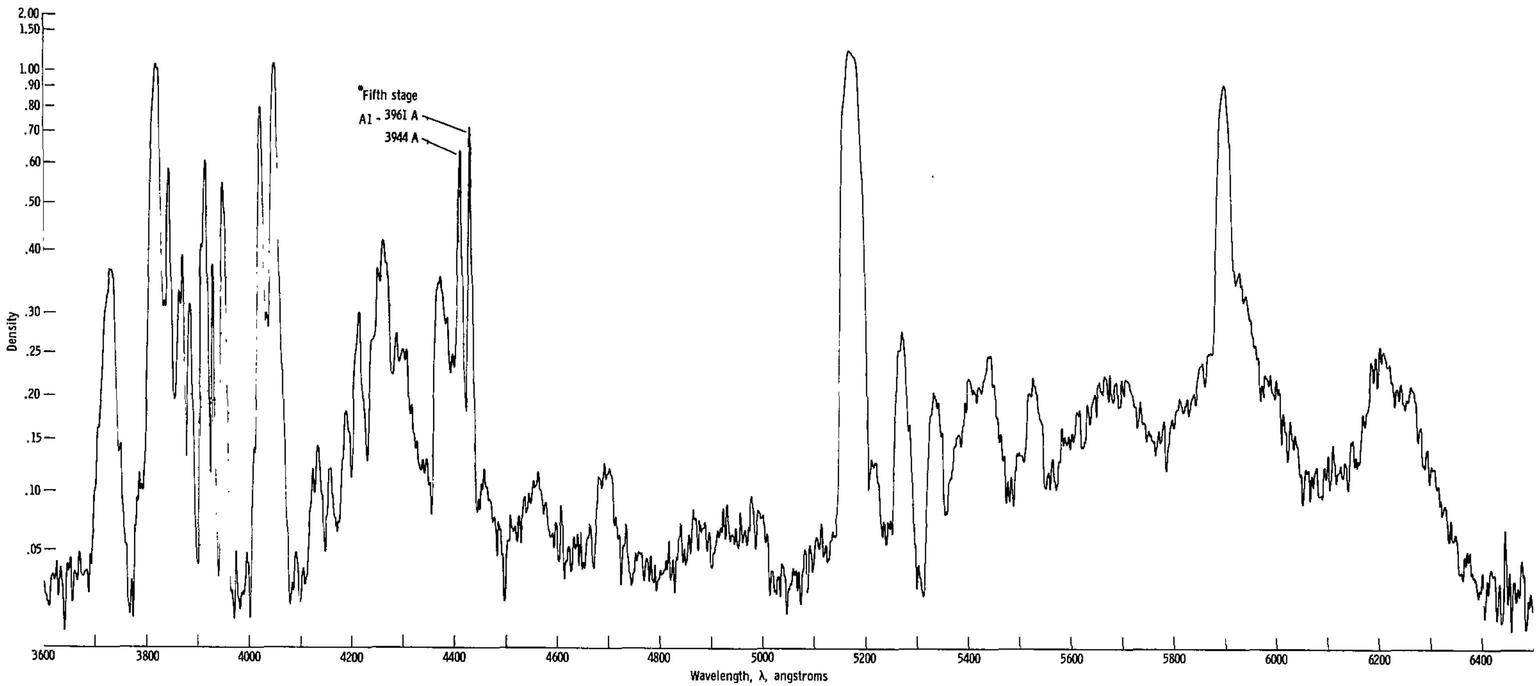
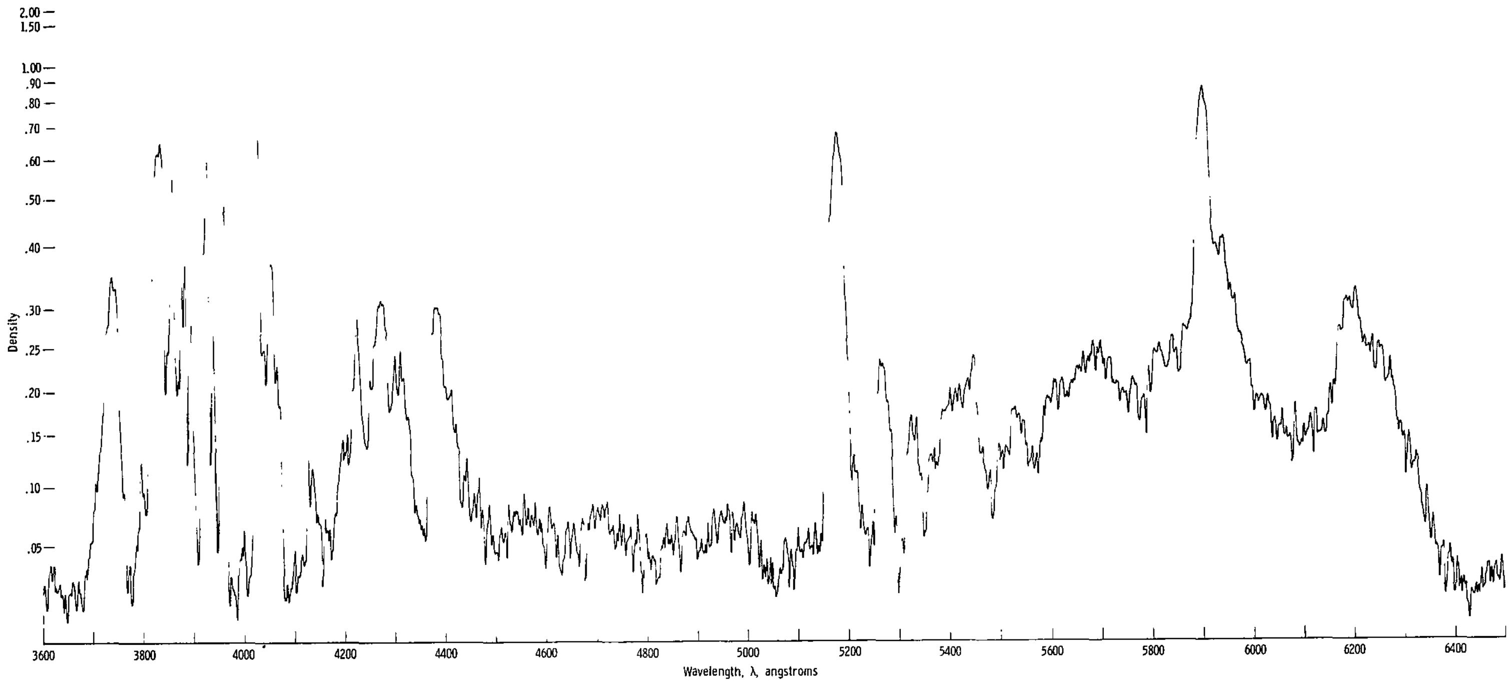


Figure 8.- Sketch of spectrogram of fourth and fifth stages.



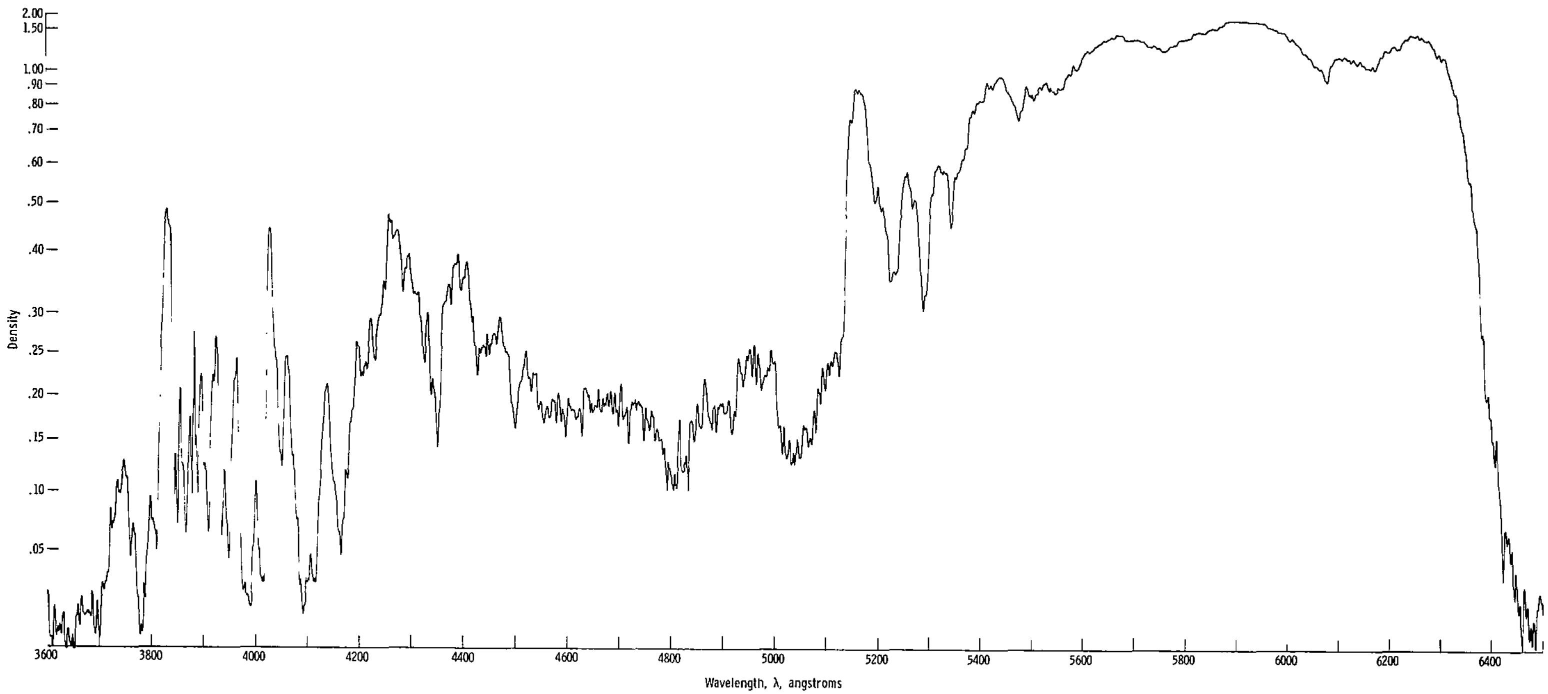
(a) Altitude, 60 km.

Figure 9.- Density as a function of wavelength for fourth stage.



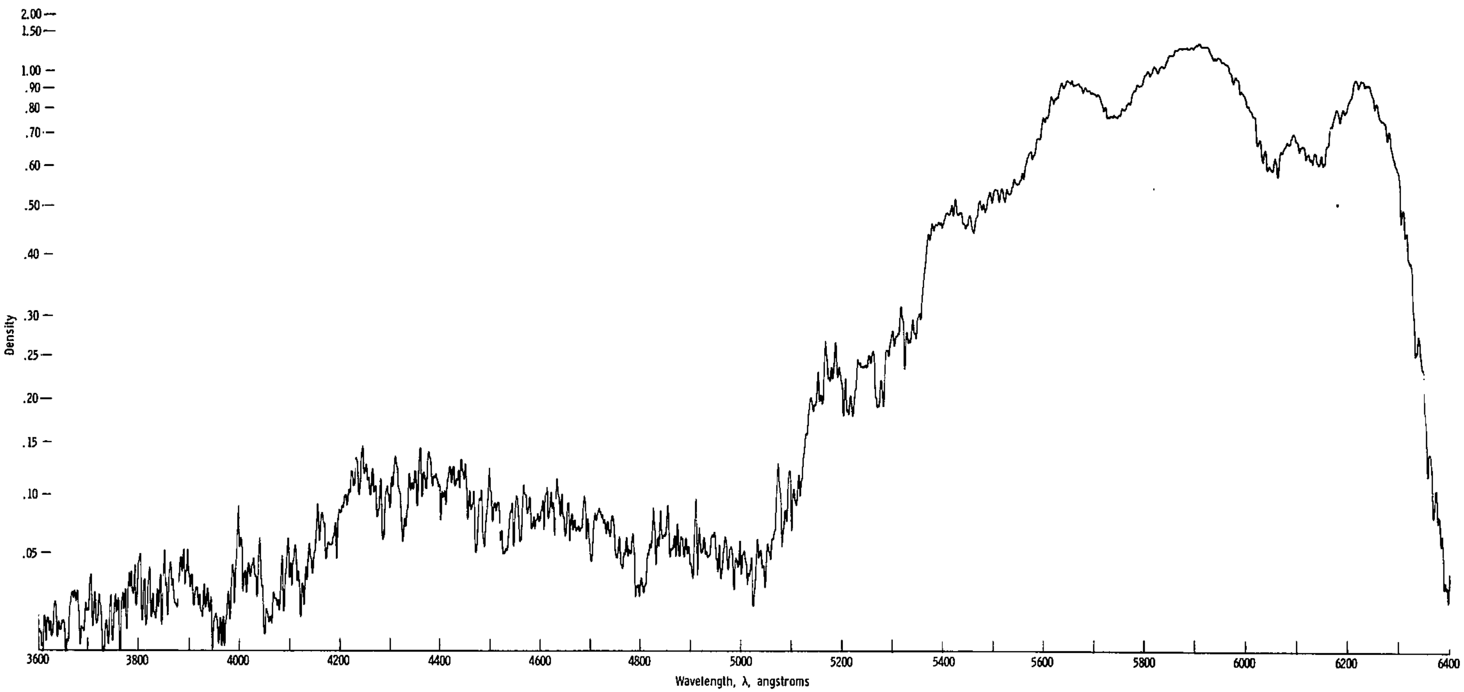
(b) Altitude, 58 km.

Figure 9.- Continued.



(c) Altitude, 50 km.

Figure 9.- Continued.



(d) Altitude, 42 km.

Figure 9.- Concluded.

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