Semi-Annual Report

November, 1966

NASA Grant NGR-10-007-028

RESEARCH IN ATMOSPHERIC MEASUREMENT TECHNIQUES

submitted to

Office of Space and Applications
National Aeronautics and Space Administration
Washington, D. C.

by

School of Environmental and Planetary Sciences
University of Miami
Coral Gables, Florida

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The program of research funded by NASA Grant NGR-10-007-028 has had three general aims: (1) to apply the laser technique to a study of the influx of interplanetary dust into the earth's atmosphere; (2) to apply the laser technique to the detection and study of other particulate matter in the atmosphere (i.e., aerosols, cloud particles, etc.) and to make measurements of atmospheric density itself; and (3) to make use of particular absorption regions in the electromagnetic spectrum by atmospheric gases and develop, if possible, laser techniques which may be applicable to meteorological satellites. This report describes progress along all three objectives.

1. Systems Analysis

Firstly, we have completed now the systems analysis, first reported in March 1966, which optimizes the laser experiment to detect interplanetary dust. As discussed in our report of March 1966, the experiments by Fiocco and Smullin give positive results while those of Wright, et al, give negative results. In Appendix I, we present a concise summary of the systems analysis, brought up-to-date in the light of experience since March 1966, to show to what extent we have been able to improve on the effectiveness of the laser experiment. It can be seen also that great benefit would be derived by the acquisition of a light-collecting mirror having a diameter of 40 or more inches. We have efforts underway to obtain such a mirror, possibly on a no-cost loan basis.

2. Measurement of Atmospheric Density at High Altitudes

A reading of the systems analysis given in Appendix 1, together with the atmospheric scattering cross-section (in cm^2/cm^3) shown in Appendix 2, makes it evident that atmospheric density and atmospheric density changes can be measured by use of the laser technique. If it should become possible to obtain a mirror of 40" or even 112" in diameter, then we would be able to carry out routinely atmospheric density measurements in the region of the earth's ionosphere and, of course, at all altitudes below 100 km. This would transform our laser experiment into a powerful tool for studying the upper atmosphere in a continuous and routine manner. It should be noted that this region of the atmosphere is inaccessible to direct measurements with balloons nor is it accessible to direct measurements with satellites. It is accessible, of course, to direct measurements with small sounding rockets but, because of their expense, such soundings can only be performed infrequently.

3. Meteorological Satellite Application

In considering the application of lasers to meteorological satellites, we have tried to develop an application which makes use of peculiar absorption properties of atmospheric gases. It turns out that the absorption produced by molecular oxygen can be utilized with spectacular results, and we believe it is possible to develop a method for measuring the atmospheric surface pressure from a meteorological satellite. This would represent the solution of a problem of the greatest importance to meteorological satellite scientists and may supplant the need for an expensive system of floating buoys in the World Weather System. Our approach is based on the use of a laser operating in the region of 7640 Å. We have devised a conceptual design based on the ruby laser and a Raman shifter, and have carried out a complete systems design and error analysis to show that it is possible to measure the differential pressure to better than 10 millibars over cloud-free regions of the earth. An abstract of a paper presented recently is attached as Appendix 3. A full report is now being prepared for publication.

We have at the present time no funds nor plans to carry out a test of this concept. However, the instrumentation being constructed for the interplanetary dust experiment can easily be adapted for the purposes of such a test, simply by adding the appropriate Raman shifters. We anticipate that, in a follow-up to this contract, we may be able to carry out this task.

4. Theoretical Studies of Dust Influx

An extensive program of theoretical studies has been conducted during the past half-year to put limits on the interplanetary dust influx into the earth's atmosphere. As is well known, the zodiacal light has been explained in terms of a distribution of interplanetary dust; however, the interpretation is not unique, and indeed, many different models have been put forward to explain the zodiacal light. These models lead to quite different predictions concerning the dust influx into the earth's atmosphere. Furthermore, the satellite studies of dust impacts on microphones as well as direct collection experiments in the upper atmosphere have given information which has sometimes been in conflict with the zodiacal light data.

We have based our approach on the idea that a dust model must be consistent not only with the zodiacal light data but also with the influx data derived from the study of radioactive aluminum which has been detected in deep sea cores. In this way, we have been able to conclude that the most likely model of interplanetary dust is the one proposed by van de Hulst and Allen, and refined by Öpik. Nevertheless, in our theoretical studies, we have also made use of a quite different model first proposed by Ingham and refined by Giese and Weinberg. The latter model has a sharply varying distribution of particle sizes and extends to particles of about 0. 1 of a micron in size, while the earlier model has a flatter distribution and is made up mainly of particles in the order of tens of microns. A summary of the distribution functions for zodiacal dust is given in Appendix 4A.

The theoretical studies which we have conducted deal with the braking of smallparticles in the earth's upper atmosphere. Then, because of a conservation of flux, the concentration of particles must increase as their velocity decreases. At each level of the atmosphere, the smallest particles will have been braked and will be drifting downward while larger particles may still be travelling with their original impact velocity. This rather complicated picture has been reduced to a computational scheme and results have been obtained giving the concentration of particles of different sizes at all altitudes in a quiescent atmosphere (it should be kept in mind, however, that vertical air currents can produce large perturbations in these distributions).

This work has now been completed and is in the process of being written up for publication. However, in advance of publication, we give in Appendix 4B some graphs which show the echo area; i.e., the cross-section in cm^2/cm^3, as a function of altitude. Both a flat model having a population index of 3.0 and a steep model having a population index of $p = 4.0$ are given. It can be seen that, even though the mass influx under the steep model is much less, the echo area is higher by about two orders of magnitude.

We believe, from the results of our calculations, that the back-scattering from the Rayleigh scattering of the atmosphere may dominate. In that case, the layers which have been observed by Fiocco and Smullin must be due to particles which have not been taken into account in the zodiacal dust model but must be of a different origin. We hope to be able to verify this point in the actual experiment.

In the course of this work, it became obvious to us that it would be highly desirable to conduct an analogous laser experiment, but at a much lower frequency, i.e., at a longer wavelength. The suggested wavelength would be 10.6 micron, corresponding to the existing CO_2 laser wavelength. We are in the process of making a systems analysis of such an experiment, but it is apparent even now that the Rayleigh scattering of the atmosphere would be reduced by a factor of 10^5 so that any dust component would immediately stand out. This method of a multi-frequency laser experiment can be used to distinguish conclusively between Rayleigh scattering and geometric scattering.

Another theoretical study has concerned itself with tracing a possible time variation in the influx of interplanetary dust. This time variation would arise because of the eccentric orbit of the earth around the sun. In December, when the earth is closest to the sun (perihelion) and moves most rapidly, it will be overtaking the interplanetary dust particles which are thought to be in circular orbits. Because of this effect, which leads to an asymmetry of influx, we should observe then a diurnal variation with a maximum influx at 6:00 a.m. local time and a minimum influx at 6:00 p.m. local time. A corresponding but inverse effect takes place in June, thus causing a seasonal variation as well as a diurnal variation. This work has now been completed and is being prepared for publication. In advance of publication, we enclose as Appendix 4C some graphs, giving some of the major results of the study. We believe that this morning-to-evening asymmetry effect experimentally detected can be used to draw additional and important information about the nature and distribution of dust in interplanetary space and about its influx to the earth.

SYSTEMS STUDY OF LASER ATMOSPHERIC BACKSCATTER EXPERIMENT

(Updated from March 1966 Semi-Annual Report

Introduction

Our previous report presented the derivation of the basic design equations for a back-scatter experiment in the atmosphere, based on a ruby laser. Relevant system parameters were brought out and typical values were given to them. These were based, however, on an idealized conception of a simple system.

Now that the project has gone a long way towards actual measurements, it is appropriate to update our previous results by considering, on the one hand, the improvements we were able to introduce and, on the other, a more realistic estimate of probable losses.

The Equations

It was shown in our previous report that a pulsed laser aimed at the zenith and finding volume-distributed targets in its path would originate backscattered photons that would arrive back at the ground at the rate:

$$N = 6 \times 10^{31} \lambda E_o A_r \alpha \frac{T^2(z,\lambda)}{Z^2} n \sigma \qquad \frac{\text{counts}}{\text{sec}} \qquad (1)$$

where λ is the wavelength of the laser in meters and E_o its energy-content per pulse in joules; A_r is the area of the collecting mirror in square meters; Z is the altitude of the target in meters; $T(z,\lambda)$ is the transmission of the atmosphere at the wavelength λ and up to altitude z, and $n\sigma$ is the backscattering cross-section per unit volume of the distributed target, in square meters per cubic meter. α is the overall efficiency of the system.

In order to obtain a valid comparison with our previous calculations, let us assume the same experimental conditions external to the instrument. Namely, we will consider our target at an altitude of 100 km, and take for its cross-section the value $n\sigma = 3 \times 10^{-11} \frac{m^2}{m^3}$. Let us take for granted that our wavelength can be approximated by $\lambda = 0.7\,\mu = 7 \times 10^{-7}$ m, which now determines $T^2(z, \lambda) = 0.7$.

With these values, equation (1) becomes

$$N = 8.8 \times 10^4 E_o A_r \alpha \quad \frac{\text{counts}}{\text{sec}} \tag{2}$$

where the rate at which signal photons are received is expressed in terms of circuit parameters only.

On the other hand, the sky background contributes to our photon count in a measure given by the following equation, where it is assumed again that $\lambda = 7 \times 10^{-7}$ m.

$$N_b = 2.1 \times 10^9 A_r \Omega B \alpha \quad \frac{\text{counts}}{\text{sec}} \tag{3}$$

where Ω is the field of view in steradians and B, the receiver bandwith in Å.

Now the number of laser pulses that have to be added and averaged over in order to yield a measurement of 10 times the fluctuations is:

$$u = 100 \frac{N + N_b + N_d}{\tau N^2} \quad \text{pulses} \tag{4}$$

where N_d is the dark count of the phototube and τ the integrating interval in seconds (if greater than the pulse length).

We shall now re-assess the system parameters that come into equations (2), (3), and (4) and compare the resulting values with those anticipated in our previous report.

Evaluation of System Parameters

E_o, the energy content of the laser pulse, was taken from nominal specifications as 5 joules. However, since we will mostly operate the laser without the saturable cell, it appears that the energy may be as much as twice the nominal value. We may then safely assume E_o = 8 joules.

The main mirror of our receiving telescope has an area $A_r = 0.164$ m^2. We shall also calculate, however, the performance with a 40" mirror, a size we proposed in our semi-annual report (March 1966). Also, since a 112" mirror is in existence elsewhere and might conceivably be used, we will calculate the improvement it would produce.

In assessing the overall efficiency α, it is found that the main sources of loss are:

1) The photomultiplier, whose performance should be measured by its quantum efficiency α_{pht}.
2) The interference filter, which attenuates appreciably even at the peak of its response curve. Its transmission at that wavelength we call α_F.
3) Reflections and losses on all optical surfaces. We shall express their effect by their compound efficiency, which we designate α_o.

Obviously, the overall efficiency is the product of all three: $\alpha = \alpha_{pht} \times \alpha_F \times \alpha_o$.

Our choice of photomultiplier has changed from the RCA C70038D tube (α_{pht}= 5.3%) to the EMI 9558QA tube (α_{pht} = 2.5%), mainly because we can improve the performance of the latter by a factor of 4 by subjecting the light-beam to successive reflections within the tube window. Therefore, we shall take $\alpha_{pht} = 0.1$.

For the interference filter, we can now go from nominal to specific values, since we have it on hand. Its bandwidth is 19 Å, its peak transmission, 0.78. In order to show the effect of the various parameters, we will also consider, in one case, a hypothetical filter with a 5 Å bandwidth and 0.25 peak transmission.

The optical losses are of three kinds. At air-glass interfaces of lenses; flats and prisms, we shall assume a transmission of 0.985, which is typical for coated surfaces. At mirror surfaces, we must recognize that the reflection coefficient varies rather rapidly with time; as a consequence, we will not take an optimum value, but rather a more conservative one: 0.85. Finally, we must take into account the obscuration factors in both telescopes. The transmitting scope will probably have a main mirror of 20.3 cm (8") and an obscuration circle of 3.15 cm diameter; hence an obscuration factor of 0.024 or a transmission of 0.976. The receiving telescope, in turn, has a main mirror diameter of 284.5 cm and an obscuration circle of 7.75 cm diameter, whence a transmission of 0.971.

The next parameter to consider, the field of view, is determined by the aperture stop used in the receiver, it being understood that the transmitted beam-width is equal to or smaller than the received one. Small fields of view are desirable, but how small they can be made depends on the quality of the mirror.

Also, for reasons of cost, the larger the mirror, the poorer its quality. Therefore, we have assumed a beamwidth of 1 milliradian for use with our astronomical mirror (then, $\Omega = 7.85 \times 10^{-7}$ sr) while for the 40" mirror, we expect a beamwidth of 2.8 mr, which makes $\Omega = 6 \times 10^{-6}$ sr. With the 112" mirror, we will stretch the beamwidth to 10 mr ($\Omega = 7.85 \times 10^{-5}$ sr), as explained below.

The last parameter to consider is the tube dark current. Although it may be reduced by as much as a factor of 1000 by cooling the tube, it does not necessarily become negligible in comparison to other signal components. Furthermore, manufacturers do not give values for tubes under cooling. In the absence of other information, then, we shall adopt the value published by R. Wright *, for the EMI 9558A cooled with cold nitrogen gas, namely, $50 \frac{\text{counts}}{\text{sec}}$. At room temperature, we would take the value given by the manufacturer; i.e., $4400 \frac{\text{counts}}{\text{sec}}$.

System Comparison

We now proceed with our comparison, whose results are shown in the attached Table. As was done in our Semi-Annual Report (March 1966), the yardstick used to measure the relative merits of each oombination is the number of laser pulses required in a statistical analysis, as given by equation (4).

The first system considered is R. Wright's, as reported in 1965 *. Although the system parameters coincide with those we had quoted in our previous

* "A Study of the Feasibility of Measuring Atmospheric Densities by Using a Laser-Searchlight Technique," B. R. Clemesha, G. S. Kent and R. W. H. Wright, University of the West Indies, A. F. -A. F. O. S. R. -616-64, May 1965.

report, the result differs appreciably, because we have now taken into account the optical losses of his system, which we could not previously assess.

The original estimate for our own experiment is repeated without change and labelled: theoretical. The optical efficiency was taken as 1, under the assumption that optical losses would be negligible in comparison to those in the photomultiplier and filter. The paraters of the latter are nominal, and the phototube considered is the C70038D. The laser power is also nominal.

The same system is then re-assessed in the column marked "design." The laser energy, though reappraised, is still not a specific figure. Values for our individual filter are given and the phototube is changed.

In calculating the optical efficiency, all air-glass interfaces in our final design were counted: there are 15 of them. There are also four mirrors. Then, ~~adding~~ the obscurations, we have

$$\alpha_o = 0.985^{15} \times 0.850^4 \times 0.976 \times 0.971 = 0.39$$

The next system is presented on the assumption that a 40" mirror of sub-astronomical quality can be obtained at a moderate price. The field of view then has to be enlarged, but the other parameters are left unchanged. It will be noticed, however, that the optical efficiency is slightly greater than before. This is merely because, with this larger mirror, the obscuration in the receiving telescope becomes quite negligible, provided the same secondary mirror considered above is used again here. Then

$$\alpha_o = 0.985^{15} \times 0.850^4 \times 0.976 = 0.406$$

Next, a 112" mirror is considered. Now the signals gathered by such a large collector are so much stronger than before, that two important simplifications can be introduced into the system. First, the beamwidth is extended to 10 milliradians, which is the divergence of the laser beam. This makes it pointless to employ a transmitting telescope; the laser itself can just be mounted vertically and made to shine at the zenith. As a consequence, the optical efficiency improves markedly. Only 13 interfaces and two mirrors have to be considered, thus

$$\alpha_0 = 0.985^{13} \times 0.850^2 = 0.59$$

Secondly, because the signals and background are so intense, the dark current becomes negligible, whether or not the tube is cooled. It is then assumed at room temperature, and its noise estimated accordingly.

Finally, the same system is re-examined with a very narrow bandwidth filter. All parameters are left unchanged except the peak transmission and bandwidth of the filter, which are again nominal values.

Conclusions

The results in the Table fully confirm the findings of our Semi-Annual Report (March 1966); namely, that in this kind of backscatter experiment, measurements are obtained only by pulse-to-pulse averaging and that the system parameters that are most effective in reducing the required number of pulses are those that contribute directly to enhance the signal - mainly the size of the collector.

This is true even if the background also increases, even in proportion to the signal. While in Wright's experiment the background is only about 1% of the signal, in our design, it is 4%, and for the 112" mirror, it would be more than 4 times the signal and yet the required number of pulses decreases from each example to the next. In fact, reducing the background in comparison to the signal is not necessarily an advantage, as can be seen in the last column.

In our previous report, we stated that "accepting a large background may result in an improvement if the size (of the collector) is increased enough to reduce the overall fluctuation as compared to the total count." Now, since the fluctuation is the square root of the count, the greater the latter, the smaller the former becomes in comparison.

Thus, the main criterion is indeed the obtention of a large signal count. And this explains why the use of a narrow filter in conjunction with the 112" mirror does not help, even though the background seems outrageous with the 19 Å filter. The catch is in the three-fold decrease in the filter transmission.

We can draw here two practical conclusions regarding an experimental layout. One is that the background should be minimized only by minimizing factors not affecting the signal. It is then best to operate with the smallest possible field of view and, regarding the filter, peak transmission should not be sacrificed to narrow bandwidth.

Secondly, it pays to cool the phototube when its noise would otherwise be a prominent component of the total count. But when the noise is a small component, it may not be worth the effort. For example, if the tube is used at room temperature with the 40" mirror (dark count going up from 50 to 4400 counts/sec), the required number of laser pulses only rises from 760 to 898, which certainly would not materially affect the experiment. This is because the signal count is 17,676; if the same thing were done in our design, where the signal count is only 3463, the required number of pulses would be doubled.

COMPARISON OF EXISTING AND PROPOSED SYSTEMS, SHOWING

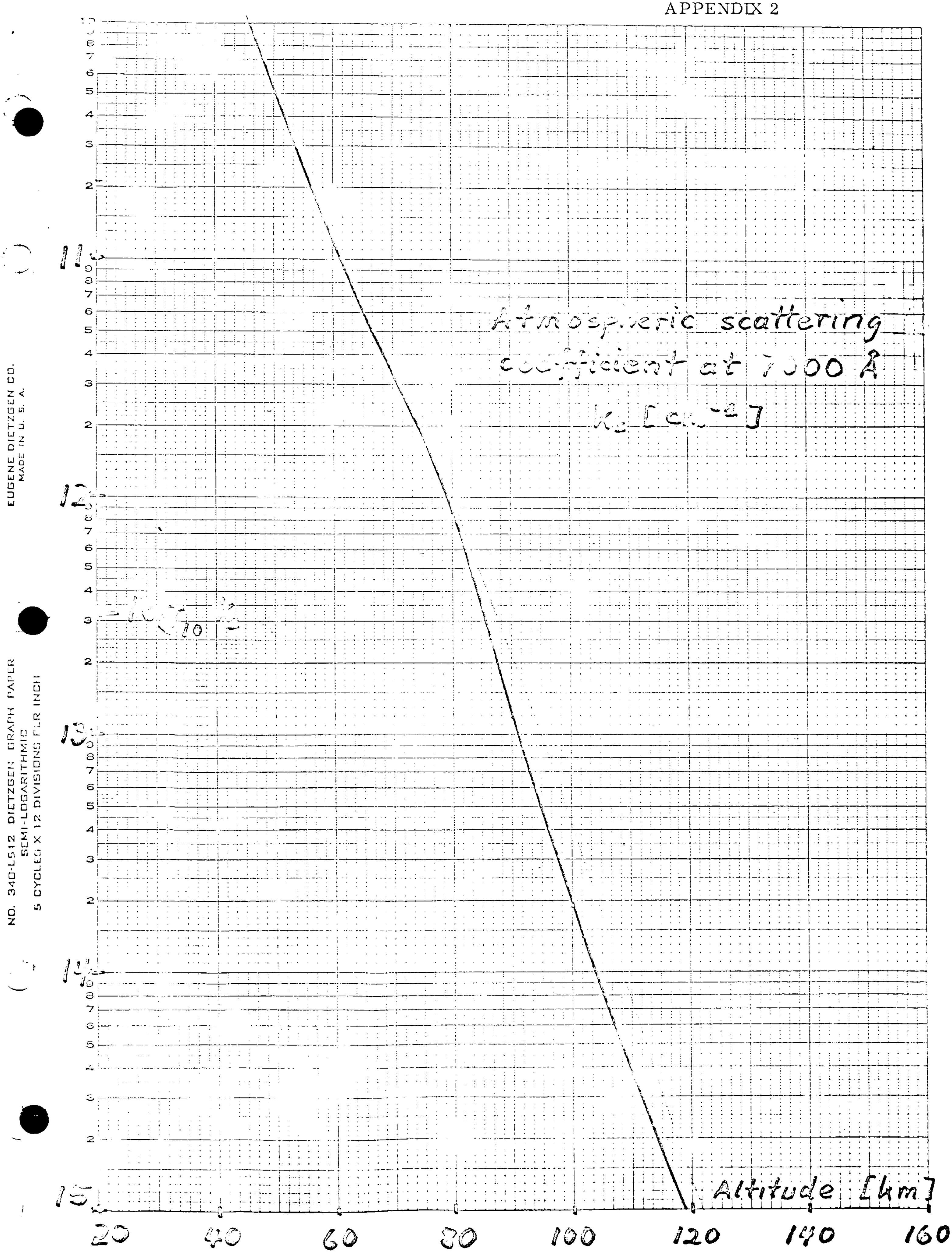
PARAMETER	UNITS	U. of West Indies R. Wright	UNIVERSI Astronomical Mirror Theoretical	Astronomical Mirror Design
Laser Energy, E_0	Joules	5	5	8
Mirror Area, A_r	m^2	0.2	0.164	0.164
Beamwidth, φ	mr	0.4	1.0	1.0
Field of view, Ω	sr	1.26×10^{-7}	7.85×10^{-7}	7.85×10^{-7}
Optical Effic. α_0	–	0.44	1	0.39
Filter Bandwith, B	Å	20	20	19
Filter Transm., α_F	–	0.6	0.5	0.78
Phototube	–	9558 A	C 70038D	9558 QA
Quantum Effic. α_{pm}	–	0.025	0.053	0.1
Overall Effic. α	–	0.007	0.026	0.030
Signal Count N	counts/sec	616	1890	3463
Background N_b	counts/sec	7	143	154
Dark Count N_d	counts/sec	50	200	50
No. of Pulses υ	pulses	17,750	[illegible]	3038

1

THE EFFECT OF DESIGN PARAMETERS

TY OF	MIAMI	
40-inch Mirror	112-inch Mirror	Narrow-band filter
8	8	
0.81	6.35	
2.8	10	
6×10^{-6}	7.85×10^{-5}	
0.406	0.59	
19	19	5
0.78	0.78	0.25
95580A	95580A	
0.1	0.1	
0.031	0.0[illegible]	0.0[illegible]5
17,676	205,638	67,05[illegible]
6,007	914,55[illegible]	78,480
50	4,400	[illegible],420
760	266	333

2


Atmospheric scattering
coefficient at 7000 Å
Altitude [km]
20
40
60
80
100
120
140
160
11
12
13
14
15
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APPENDIX 3

AMERICAN GEOPHYSICAL UNION
WESTERN NATIONAL MEETING

FORM FOR SUBMISSION OF ABSTRACTS

Section of Meteorology

Time required 15 minutes   Projection equipment required 3 x 4" slides

Please submit original and two carbon copies. Carbon copies may be on plain bond paper. Abstracts should be as brief as possible, preferably under 200 words. They should be informative rather than indicative; references are not appropriate. Do not underline. Capitalize first letters only. Continue on separate page if necessary.

NAME(S) OF AUTHOR(S). SHOW INSTITUTIONAL AFFILIATION, AND CITY AND STATE, IN PARENTHESES. DOUBLE SPACE.

S. Fred Singer

(University of Miami)

(Coral Gables, Florida)

TITLE OF PAPER. DOUBLE SPACE.

Possibility of Atmospheric Pressure Measurements from a Meteorological Satellite

ABSTRACT. DOUBLE SPACE. IDENTIFY SYMBOLS.

By using a pulsed laser operating in and just outside of the O_2 absorption region near 7460 A[1], it is possible to make simultaneous measurements of pressure and geometric altitude at any reflecting surface in the atmosphere. The pulse delay gives the actual distance to the surface; the absorption depends on the total content of O_2 above the surface, thus giving the amount of overlying atmosphere. The precision obtainable appears to be adequate to measure pressure differences of 10 millibars over cloud-free regions on the surface of the ocean and possibly over land surfaces. Of particular interest is the measurement of altitude and pressure depth in the atmosphere of a cloud top. Using infrared emission in an atmospheric window, it is possible to measure also the temperature, thus giving pressure, temperature, and altitude at a particular location in the atmosphere, for the first time.

[1] D. Q. Wark and D. M. Mercer, Applied Optics, 4, 839 (1965)

Furnish your complete mailing address on the reverse side of this form to ensure receiving a schedule in advance of the meeting.

Table 1. Properties of zodiacal dust models. The model is characterized by a size distribution $n(a) = C a^{-p} da$, extending from a minimum radius $a_<$ to a maximum radius $a_>$ (in microns). The particle density is δ (in $gm\text{-}cm^{-3}$). The number concentration N and mass concentration M in space are in units of (km^{-3}) and (10^{-22} $gm\text{-}cm^{-3}$), resp. The accretion rates A_u (in tons/day) are given for geocentric velocities $u = 2$ km/sec and 5 km/sec. (1 ton/ day over the earth corresponds to 4.4×10^{17} gm/cm^2-sec)

Table 1

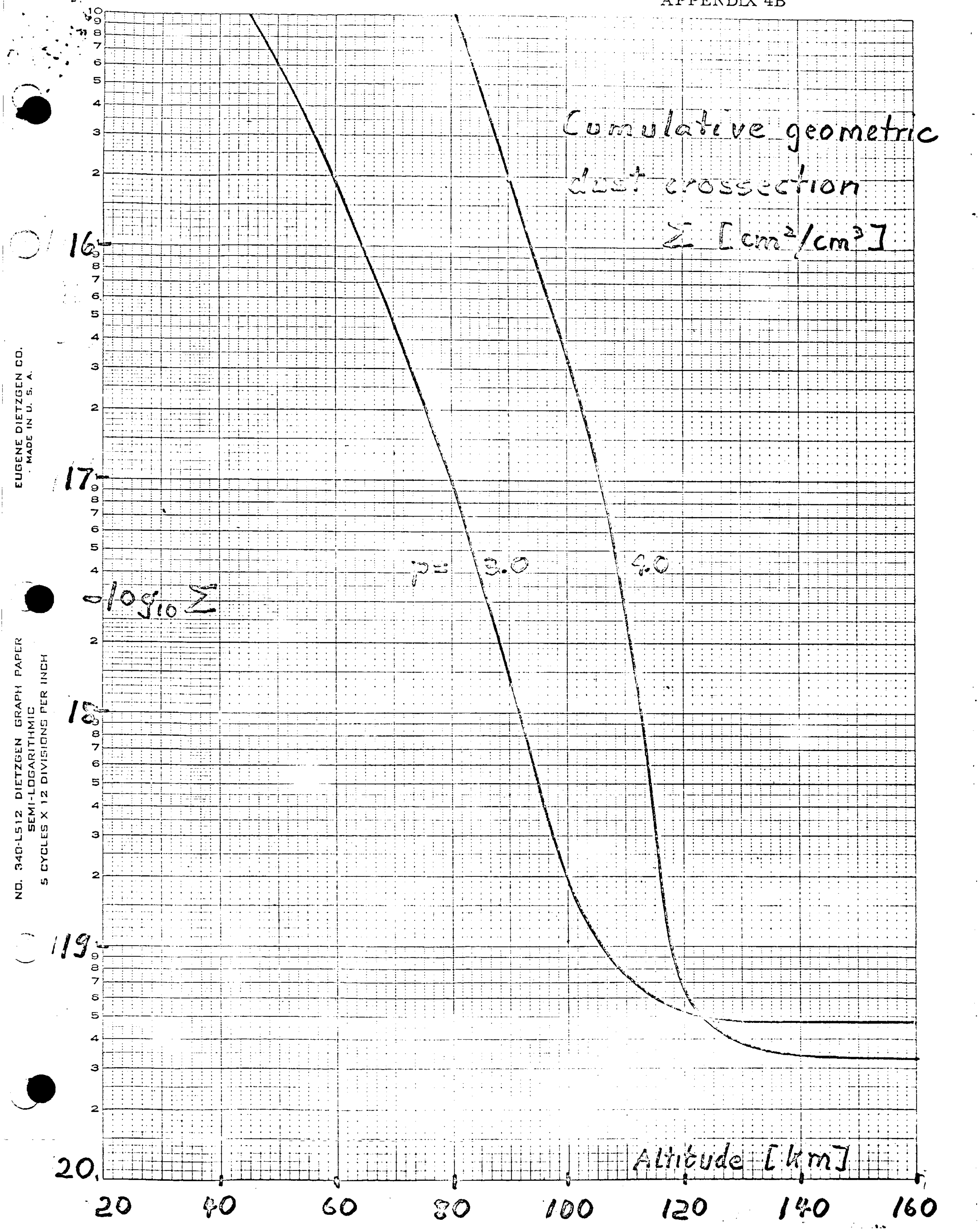
Author	Ref.	C	p	$a_<$	$a_>$	δ	N	M	A_2	A_5
v. d. Hulst (1927)	(1)	3.5×10^{-20}	2.6	1	350	3.5	55	34	2100	1000
Elsässer (1955)	(4)	1.0×10^{-18}	2.0	1	100-1000	3.5	10	90	5700	2700
Allen-Öpik (1956)	(3)	1.0×10^{-21}	2.6	1	350	3.5	50	50	3100	1500
Siedentopf (1955)	(5)	1.4×10^{-21}	2.85	3.2	320	3.5	150	4	250	120
Ingham (1962)	(8)	2.5×10^{-26}	4.0	0.4	840	2	130	0.021	1.3	0.63
Giese (1962)	(9)	1.0×10^{-20}	2.5	1.6	6.4	3.5	3	1.4	88	42
		plus 7.4×10^{-26}	4.0	0.16	4.1	3.5	6000	0.035	2.2	1.0
		plus 2.2×10^{-26}	4.0	0.16	4.1	7.8	1800	0.023	1.4	0.69
Weinberg (1965)	(10)	7.4×10^{-26}	4.0	0.17	4.4	3.5	5300	0.035	2.2	1.0

Main Results of a Calculation of Expected Echo Areas from Different Models of Zodiacal Dust

Terminal Speed: This would be the speed of a spherical particle, very much smaller than the atmospheric mean-free-path, if gravity and atmospheric drag balanced each other.

Cross-Section: After the general braking has occurred, all particles fall according to their respective terminal speeds which are approximately proportional to the inverse of the atmospheric density. The concentration, therefore (as well as the cross-section), follows the atmospheric density fairly closely below the braking altitude, regardless of the particular dust model in question. Above the general braking altitude, the variation is considerably steeper (than the atmospheric density variation) and the steepness depends on the dust model in a sensitive fashion. However, both models are seen to follow the atmospheric density variation below approximately 100 km.

All computations were based on data taken from the 1962 U. S. Standard Atmosphere.


Cumulative geometric dust crossection
Σ [cm²/cm³]
-log₁₀ Σ
16
17
18
19
20
p = 3.0
4.0
Altitude [km]
20
40
60
80
100
120
140
160
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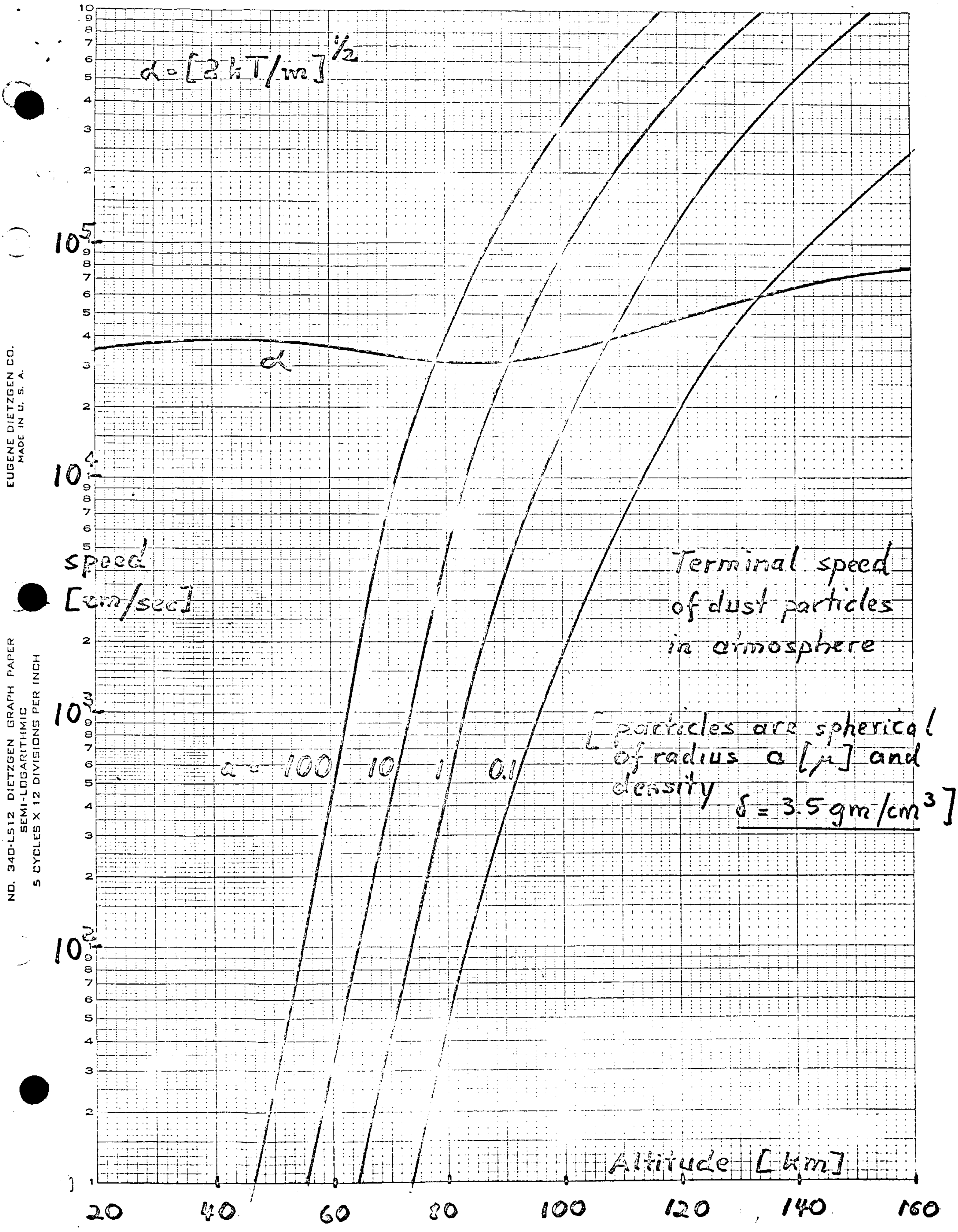
α = [2kT/m]^½
α
speed [cm/sec]
Terminal speed of dust particles in atmosphere
[particles are spherical of radius a [μ] and density δ = 3.5 gm/cm³]
a = 100
10
1
0.1
Altitude [km]
20
40
60
80
100
120
140
160
10⁵
10⁴
10³
10²
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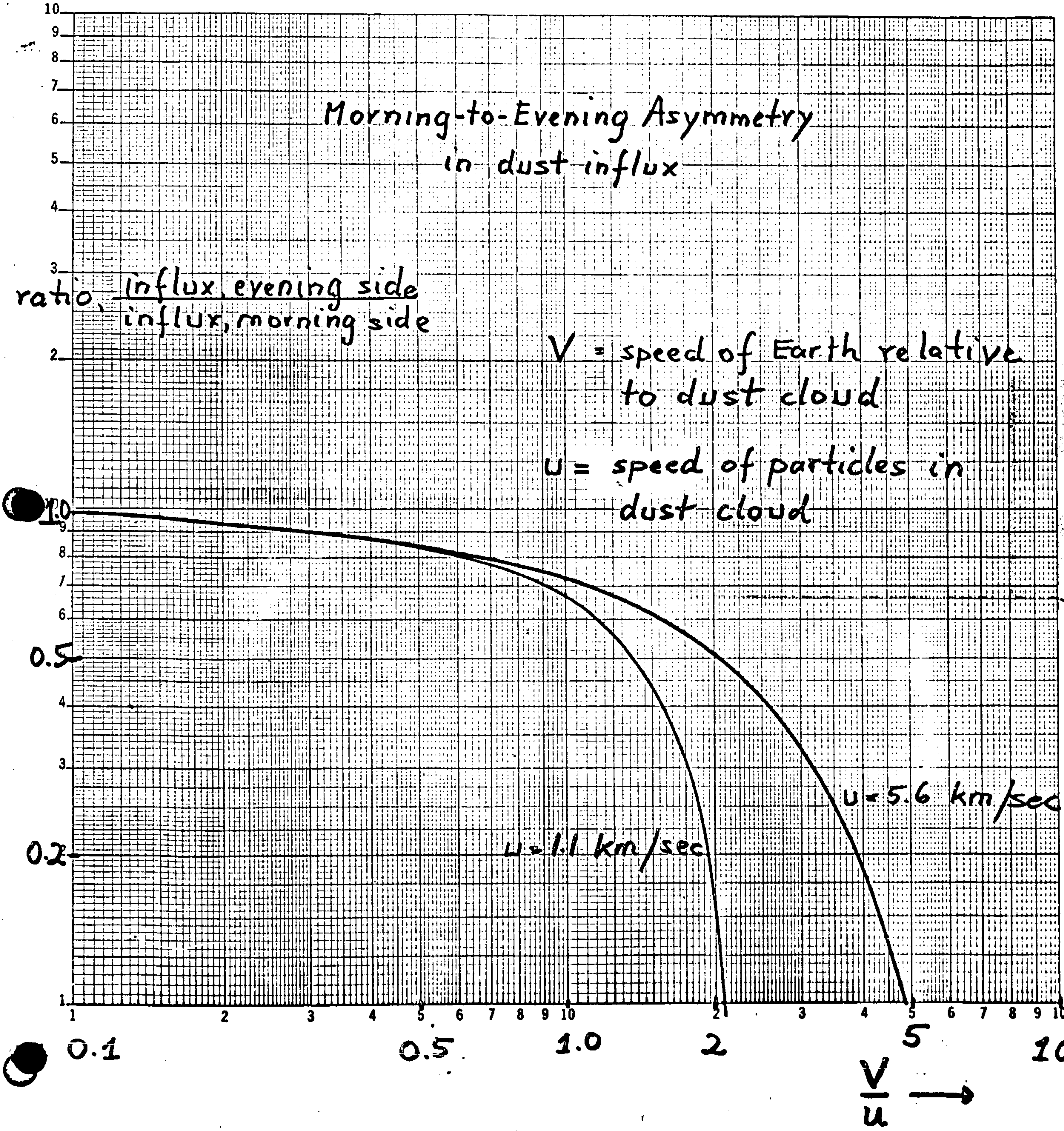
Main Results of a Calculation of Morning-to-Evening Asymmetry

The main results are the calculation of the morning-to-evening asymmetry in the dust influx into the earth's upper atmosphere. It is seen that the ratio depends on the speed of the earth relative to the dust cloud and, therefore, on the season of the year. A good working bet for the expected result is 0.5 corresponding to a variation in the dust influx between morning and evening of a factor of 2.



Logarithmic 2 x 2 Cycles