particularly when available flux in the middle ultraviolet is low and considerable long wavelength background is present.

The curves of fig. 7 include the third category, vacuum ultraviolet photodetectors. Phototubes made by Sommer at RCA having cathodes of copper iodide, curve 3, and cesium iodide, curve 2, have a very strong rejection of

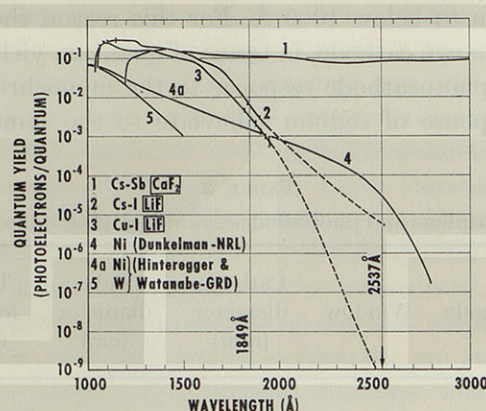

Fig. 7. Spectral response curves of a variety of photocathodes showing the high rejection of some of the iodide compounds at longer wavelenghts. The advantage of the relatively high yield composite photosurface over the lower yield pure metal is also evident.

all middle and near ultraviolet wavelengths but a large response at the short wavelengths around 1200 Å.* Also shown for comparison are two total cathode responses: nickel and tungsten, and the flat response of cesium antimony in the phototube with CaF_2 window mentioned above.

Fig. 8 shows some of the photomultipliers examined at our laboratory. The ASCOP tube, third from the left, with the LiF window, and the CBS tube, at the far right, with sapphire window, are both commercially available "solar blind" photomultipliers using Cs-Te photocathodes.

Additional data on specific phototubes is included in table 2. A recent paper prepared by the authors [13] describes in more detail properties of spectrally selective photocathodes.

3. Calibration

Calibration of photocathodes has been divided into two phases. In the

* The large quantum yields shown for these tubes represent an early measurement. Subsequent measurements of Cs-I and Cu-I cathodes show that in general a peak quantum efficiency of 10 % to 20 % is more typical with Cs-I, which in turn has been three to five times more sensitive than Cu-I at the Lyman α wavelength (1216 Å).

first phase the relative cathode spectral response is determined from measurements taken at the exit beam of the Cary 14 double monochromator and the 1 meter McPherson vacuum monochromator. A hydrogen arc light source is used with both instruments. The quantum yield of fluorescence of sodium salicylate is taken to be constant throughout the wavelength region from above 3300 Å down to below 1000 Å. For this reason the relative spectral response of the unknown cathode, in terms of quantum yield, can be obtained by comparing the photocathode response to the monochromator beam with the fluorescent response of sodium salicylate to the same beam.

TABLE 2

Commercial photomultipliers and photodiodes examined at Goddard Space Flight Center

Tube	Cathode	Window	Cathode diameter (mm)	Tube diameter (cm)	Tube length (cm)	Quoted dark currents at gains of 10^6 * (amps)
Photomultipliers						
EMI						
6256B	CsSbO	Quartz	10	5.1	10.7	10^{-9}
6255S	"S"	Quartz	42	5.1	12.0	6×10^{-9}
CBS						
CL1050	Cs-Sb	Sapphire	19	5.1	16.8	3×10^{-9}
CL1067	Cs-Te	Sapphire	42	5.1	15	not available
RCA						
1P28	Cs-Sb	9741	8 × 23 **	3.3	8.0	5×10^{-8}
C70128	Cs-Te	LiF	12	1.9	8.9	not available
ASCOP ***						
541F08	Cs-Te	LiF	10	3.2	12.7	2×10^{-11}
541F05M	Cs-Te	Sapphire	25	3.2	11.4	1×10^{-10}
Photodiodes						
CBS CL1051	Cs-Sb	Sapphire	12 **	2.5	7.0	
RCA c70126	Cs-Te	LiF	11	1.9	4.4	
ITT FW 156	Cs-Te	LiF	11 **	1.9	3.8	
ASCOP 540F	Cs-Te	LiF	8	1.9	6.3	
Westinghouse	Cs-I	LiF	12	1.9	6.3	

* Much lower dark currents have been measured in our laboratory for all of these tubes. A dark current of 2.5×10^{-12} amps at a gain of 10^6 has been observed for a Cs-Te photomultiplier.

** Opaque cathode deposited on a metal substrate.

*** Tubes potted with resistor chain in place.

Second, the relative quantum yield is put on an absolute basis by optical bench measurements. In general, use is made of a calibrated 2537 Å line of the mercury arc. On some occasions, the 2138 Å line of a zinc arc and the 1849 Å line of the mercury arc are also employed.

The mercury arc used is a small pencil-like septum lamp described by Childs [14]. This lamp has a flux at one meter of about 2 μW/cm^2 for a specified axial position and is relatively insensitive to ordinary changes in line voltage or room temperature. The mercury arc 2537 Å line calibration is based on the use of three calibrated ultraviolet intensity meters, each consisting of a cadmium photocell and simple electrometer amplifier. These intensity meters were manufactured by the Lamp Development Laboratory of the General Electric Company. The meters were calibrated by the General Electric Company and are frequently compared against each other in our laboratory. We estimate the accuracy to be within 5 %. These meters are used as a laboratory calibration reference and are employed each time a photosurface yield is measured against a mercury arc lamp. Thus reliance is placed on photosurfaces rather than on discharge sources. These meters have had their calibrations checked by comparison with National Bureau of Standards sources: first against an NBS mercury source by means of an NBS tantalum cell; then in our laboratory against an NBS standard carbon filament lamp by means of a gold black Golay cell.

4. Geophysical and astronomical applications

To date, middle ultraviolet astronomy [15] has been limited to preliminary surveys of the sky from unguided rockets. Most of these sky-survey type

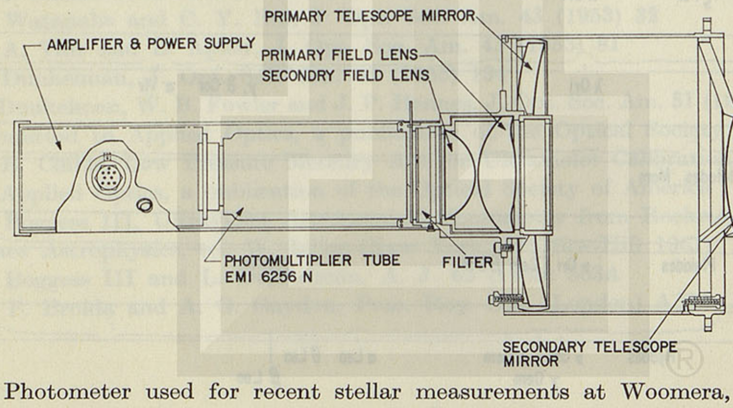

Fig. 9. Photometer used for recent stellar measurements at Woomera, Australia. The objective mirrors are modified cassegrainian with a concave parabolic primary and a spherical secondary. The field lenses are quartz. The filter cavity contains filter pieces of diameters ranging from 2.8 mm to 4.2 mm centered over the entrance aperture.

measurements have been made from White Sands, New Mexico [16] and Wallops Island, Virginia using American Aerobee vehicles. More recently southern sky measurements have been made from Woomera, Australia using U.K. Skylark rockets. Although filter limitations have allowed only broad-band photometry in certain special spectral regions, these surveys are nevertheless of considerable value for comparison with predicted ultraviolet intensities and intelligent planning of more sophisticated experiments.

A typical photometer is shown in fig. 9. These photometers may be mounted in pairs, triplets, etc. with parallel optical axes. With each photometer sensitive to a different band, multicolor observations can be taken. Direction of orientation is such that during observation the combined precession and rotation of the rocket causes the photometers to scan a large portion of the sky. To increase the area of the sky that is covered, sets of photometers may be pointed at several angles with respect to the rocket axis. On recent flights instruments have been mounted 105, 90 and 75 degrees from the longitudinal axis of the rocket.

Fig. 10 shows, as an example, selected portions of a telemeter record for one photometer and demonstrates the heretofore unavailable data which may be obtained from simple middle UV techniques. In this case the photometer optical axis was inclined 75 degrees from the rocket axis. During the portion of the flight represented by the upper trace, the rocket was rising

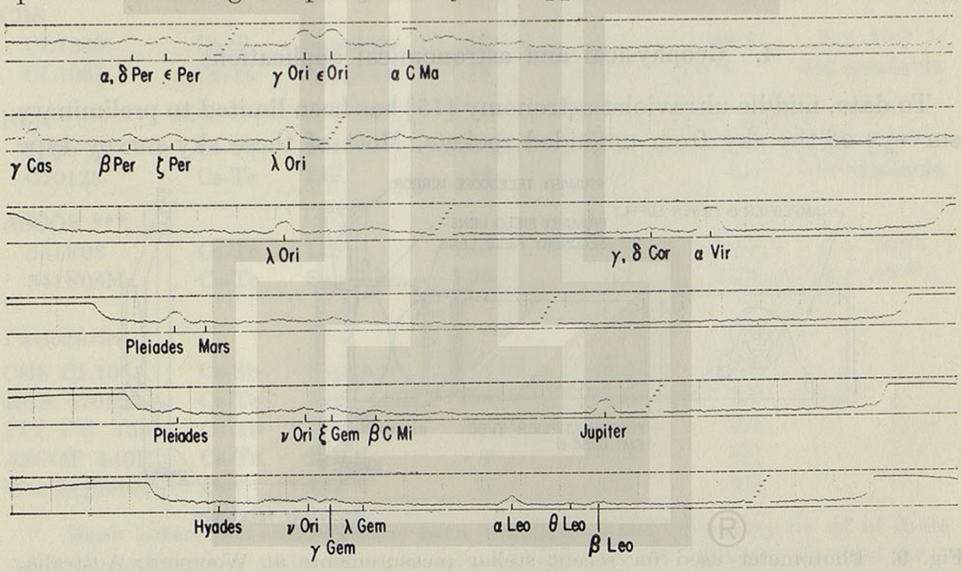

Fig. 10. Telemeter record of 2700 Å photometer. Saturated signals at the ends of the trace are due to the airglow horizon. Each trace is of 12 sec duration. Telemeter calibrations indicate 1 volt steps.

out of the airglow layer and the stars may be seen superimposed on a decreasing airglow signal. In the lower traces the rocket was above the emitting layer and the strong saturated signal at the edges of the trace is due to the bright airglow "horizon."

The ultraviolet airglow is of interest in its own right. Broida and Gayden [17] found that the Herzberg bands of molecular oxygen were the dominant feature in laboratory produced air afterglow between 2500 and 3000 Å. Rocket measurements have shown this layer to be between 85 and 120 km with ozone absorption evident up to 50 km.

The solar blind photocathodes described in previous sections of this paper may be used in photomultipliers for many conventional applications. In addition to these uses, work has begun on image converter tubes which will be selective to the middle and vacuum ultraviolet. Using such devices in a monocular or binocular system an astronaut might survey for astrophysical or geophysical effects.

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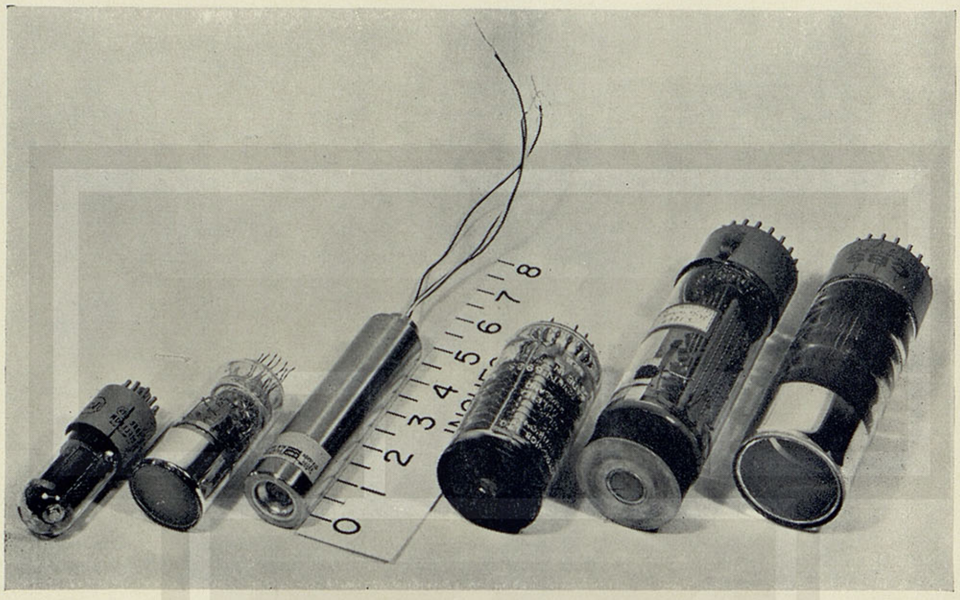

Fig. 8. Some of the photomultipliers examined at the Goddard Laboratory. Left to right: RCA 1P28, Cs-Sb cathode, 9741 glass envelope; RCA 7151c (Ruggedized version of 6199 tube); ASCOP 541F, semi-transparent Cs-Te cathode, LiF window (potted with resistor chain in place); EMI 6256B, semi-transparent Cs-Sb cathode, fused silica window; RCA (A. H. Sommer experimental tube), Cs-Te cathode, LiF window; CBS CL 1067, semi-transparent Cs-Te cathode, sapphire window.

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ULTRAVIOLET PHOTOGRAPHY AND SPECTROSCOPY USING A SPECTRALLY SELECTIVE IMAGE CONVERTER

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ABSTRACT

Laboratory and space research have both benefited from the new spectrally selective ultraviolet photodetectors. Large band-gap photoemitters, such as cesium telluride, having high quantum efficiencies in the ultraviolet and very low yields at longer wavelengths are now available. An image tube with such a cathode combines the advantages of spectrally selective photo-emission with the flux-integrating property of photographic emulsion. Observations can thus be made at selected ultraviolet wavelength regions, either photographically or visually, even in the presence of strong long wavelength backgrounds. Visual measurements with a Cs-Te image converter, having a sapphire faceplate and a green phosphor, were made with the following results: (a) cathode quantum efficiency at 2537 A is 0.016, which is expected to improve in future tubes; (b) minimal detectable converted 2537 A irradiance is 4 x 10^{-5} ergs cm^{-2} sec^{-1}; and (c) tube background is undetectable. Mercury spectra obtained with this tube demonstrate the expected high rejection of visible light. Tables are included which list the brightnesses of several extended ultraviolet and visible sources of interest in the space sciences. The luminance of visible sources; the radiance of ultraviolet sources; and the relative brightness, on a photon basis, of spectrally converted ultraviolet sources along with visible sources are tabulated.

There is a continuing need in spectroscopy and photography, in both laboratory and space research, for spectrally selective ultraviolet photodetection techniques. Photomultiplier detectors containing large band-gap photo-emitting cathodes now exist which effectively discriminate against long wavelengths.[1][2] An image tube with such a cathode can combine the advantages of spectrally selective photoemission with either the flux-integrating property of photographic emulsion or the synthesizing ability of a human observer. This paper includes a brief discussion of some of the considerations to be given to the choice of window and photocathode materials, extent of image intensification, etc. in converter design. Typical examples are given of the kinds of extended UV sources of astrophysical or geophysical origin which an astronaut might observe and photograph in various ultraviolet regions.

IMAGE TUBE CONSIDERATIONS

McGee[3] and Morton[4] have recently provided excellent surveys of image tube development; accordingly, here we will include discussions of only those image tube parameters unique to ultraviolet detection.

Figure 1 shows spectral response curves of some of the photocathodes used for ultraviolet photodetection. These emissive materials have been used in phototubes with appropriate ultraviolet transmitting faceplates such as LiF, CaF_2, sapphire, fused silica, etc. The conventional Cs-Sb photoemitter is sensitive to visible light and is frequently not useful as an ultraviolet detector because of the presence of long wavelength straylight. The spectrally selective cathodes Cs-Te and Cs-I are both relatively insensitive to longer wavelengths and make excellent UV detectors. Metal photocathodes, such as tungsten, are insensitive in the visible and have low yield in the middle ultraviolet (3000-2000A), but reach about 10% quantum yield at 1000A. Also shown is the relative quantum yield of Eastman 103a-0 spectroscopic film adapted from the Kodak handbook.[5] The response curves show that if a weak ultraviolet source must be observed in the presence of a strong visible background, then one must employ either spectral filtering or one of the spectrally selective cathodes, and occasionally both.

Figure 2 shows a variety of available ultraviolet transmitting windows whose short wavelength cutoffs range from λλ1050A (lithium fluoride) to λλ3000A (Corning 0-54, glass). In general, these windows may be employed as the actual image tube faceplate. However, in practice it is usually easier to employ as the faceplate either an alkali halide, sapphire, fused silica or vycor material and provide for additional short wavelength cutoffs by using either the appropriate material shown in Figure 2 or some other crystal, glass, gas cell, predisperser, etc. as desired by the user.

In this paper, we report on an ITT ultraviolet image tube with a cesium-telluride cathode and a sapphire faceplate. However, in Figure 3 there is shown a few of many other combinations which are practicable, the spectral sensitivity curves being formed by combining the cathodes of Figure 1 with the windows of Figure 2. Note the relatively narrow spectral response of Cs-I with sapphire window; this region of λλ1400 to 2000A might be of interest in the study of the Schumann-Runge O_2 bands in the upper atmosphere. Note also the K-Br cathode with LiF window yielding a response from λλ1050 to 1500A for observing, for example, stellar or nebular fluxes. In many cases one would surely wish to exclude the strong Lyman α hydrogen emission in the upper atmosphere; here one could employ a CaF_2 window or filter.

Figure 4 indicates three of many types of imaging systems. The top sketch, for example, shows a system which might be used by an astronaut for making both photographic and visual surveys of geophysical or astronomical objects such as airglow, nebulosities, stellar and planetary sources, earth albedo, etc.(6)-(11) In this case, the image tube acts as a spectral filter and a wavelength converter. Conventional photographic film would be used rather than fragile ultraviolet sensitive spectroscopic films. The middle sketch demonstrates an objective grating spectrograph to observe and obtain, for example, stellar or planetary spectra; whereas the bottom sketch would be a useful scheme for observing a spectral energy distribution of airglow, nebulosities and aurorae. Since so little is known of the dynamic properties of ultraviolet aurorae, a movie camera might be substituted for the still camera depending on whether one were interested in maximizing the observations of spatial or spectral distributions. Additional discussion on the expected radiances of celestial objects is given in a later section.

The spectral selectivity of an ultraviolet image tube having a cesium telluride photocathode, is demonstrated by the photographs in Figure 5. A tube manufactured by the ITT Industrial Laboratories in Fort Wayne, Indiana has been compared with a standard 7404 image tube with an S-13 cathode. Both are electrostatic, monovoltage tubes with identical imaging structures. The tubes were used to photograph a mercury arc spectrum in an arrangement similar to that illustrated in Figure 4 (bottom). The photographs show that although both tubes are equally sensitive to ultraviolet light, the Cs-Te ultraviolet tube is not affected at all by visible lines or stray light.

Figure 6 is a photograph of a display of electro-optical binoculars and the image tubes described in this paper. The upper right hand corner shows a pair of infrared binoculars which use standard infrared image tubes with cesium-silver-oxygen photocathodes. The image tubes shown are from left to right an RCA 7404 (Cs-Sb cathode with vycor window); an ITT UV tube (Cs-Te cathode with sapphire window); and an RCA far-UV tube (Cs-I cathode with LiF window). The image tube binocular, shown on the left with oculars and rubber shields removed, is equipped with quartz-CaF_2 doublet objective lenses with a 10.8 cm focal length shown in the detached barrels. The image tubes, housed in the central cylinders of the main body of the binocular, are powered by a 12 kilovolt miniature power supply. Monoculars rather than binoculars would be used in manned space observations since extra-terrestrial observations would not appreciably benefit by double vision, certainly stereopsis is not involved here. Future developments of ultraviolet image tubes can include better collection optics and more sophisticated features such as multi-stage image intensification, magnetic focussing, simultaneous electronic readout, color translation, etc. One or more additional stages of image intensification (over the usual 30 or 40 gain in these single stage tubes) will be necessary in the cases of some of the interesting dim phenomena discussed in the next section.

The quantum efficiency of the photocathode of the Cs-Te tube reported here is 0.016. In 1958, when the first rubidium or cesium telluride photomultipliers were assembled the quantum efficiencies were even lower.

Currently produced UV photomultipliers have yields of 0.05 or better and it is expected that this will be achieved with the image converters. Using our present tube, which has a green phosphor, as a converter we found that the minimal 2537A irradiance detectable by the eye was 4×10^{-5} ergs cm^{-2} sec^{-1}. With the f/5 objective the minimal detectable 2537A radiance of an extended source was 0.01 erg cm^{-2} sec^{-1} $ster^{-1}$. With this tube, the non-irradiated portion of the phosphor (the background) was black. This is what would be expected from large band-gap photoemitters which have negligible thermionic emission.

THE ULTRAVIOLET SCENE FROM SPACE

With reference to Table I, one can note the large variety and intensity range of extended (rather than point) source celestial objects of interest. These can be observed only from a vantage point above the ozonosphere (which absorbs the entire middle ultraviolet λ2000-3000A); or better still, at or above manned space altitudes (160 Km or more) to minimize absorption by oxygen. The table is divided into 3 sections, the first relates to phenomena in the visible region and is intended to provide (1) a convenient reference to objects fairly well known and whose observations are within our normal experience and (2) a means with which one can compare ultraviolet with visible sources. In the first section the luminance (brightness) of each source is given in cd cm^{-2}. In the second section of the table, there is listed again a wide variety of celestial UV sources all of which have been measured from above the ozonosphere. Here the radiance (brightness) is given in ergs cm^{-2} sec^{-1} $ster^{-1}$. Finally, in the third section, some of these sources are listed relatively on a brightness scale. The ultraviolet fluxes have been converted to the corresponding 5500A fluxes on a one-for-one photon basis.

With fast collection optics and higher cathode efficiencies, ultraviolet sources of radiance as low as 10^{-4} ergs $cm^{-2} sec^{-1} ster^{-1}$ should be visually detectable with only single stage image converters. This radiance level includes most of the sources listed in Table I. Less bright sources will require further amplification stages to be detectable. High amplification of very dim sources will not necessarily increase the information content for visual detection since photon statistical fluctuations at low flux levels limit image recognition[(4)]. Intensification of moderate brightness sources will, of course, make visual observation more comfortable. Intensification of both weak and strong sources will reduce exposure times for photographic recording. This latter effect can be an important consideration in rocket as well as in manned space observations.

TABLE I

PHENOMENON	LUMINANCE (candles cm^{-2})
Milky way, dimmest region, near Perseus	1×10^{-8}
Gegenschein	1.6×10^{-8}
Visible night glow (zenith)	2×10^{-8}
Milky way brightest region, near Carina	4×10^{-8}
Zodiacal light, (30^{o} elongation)	1.2×10^{-7}
Visible night glow (edge-on)	6×10^{-7}
Great Orion nebula M42	5.6×10^{-6}
Full Moon	4×10^{-1}
Fluorescent lamp 4500 white	4×10^{-1}

PHENOMENON	RADIANCE (ergs sec^{-1} cm^{-2} $ster^{-1}$)
Middle UV night glow (nadir), 2600A	2×10^{-5}/100A
Orion nebulosity (mean), 1225-1350A	6×10^{-5}/100A
Orion nebulosity (most intense part), 1225-1350A	4×10^{-4}/100A
Middle UV nightglow (edge-on), 2600A	5×10^{-4}/100A
Hydrogen lyman-alpha glow (mean), 1216A	3×10^{-3}
UV Aurora, Wallops Is. 22 Nov. 1960 (zenith), 1700-1800A	10^{-2}
UV Aurora, Wallops Is. 22 Nov. 1960 (zenith), 1300-1800A	10^{-1}
Sunlit earth albedo (nadir), 2600A	5×10^{-1}/100A

TABLE I (continued)

PHENOMENON	RELATIVE BRIGHTNESS (Photon flux)
Middle UV nightglow (nadir), 2600A	0.03
Orion UV nebulosity (bright portion), 1225-1350A	0.3
Milky way (mean)	0.7
Gegenschein	0.8
Middle UV nightglow (edge-on), 2600A	0.8
Visible nightglow (zenith)	1
Hydrogen lyman-alpha glow (mean), 1216A	2
Aurora IBC-I	3
Zodiacal light (30^{o} elongation)	6
Visible nightglow (edge-on)	30
UV Aurora, Wallops Is. 22 Nov. 1960 (zenith), 1300-1800A	100
Great Orion nebula M42	300
Sunlit earth UV albedo (nadir), 2600A	800
Aurora IBC-IV	3000
Full moon	2×10^{7}

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FIGURE CAPTIONS

Figure 1: Spectral Response of Typical UV Photocathodes. These curves are taken from reference 1. The relative response of type 103a-0 film is from reference 5.

Figure 2: UV Optical Materials. Transmittance curves, uncorrected for surface reflections, are shown for materials of thickness: 1-1.2 mm; 2-1 mm; 3-1 mm; 4-1 mm; 5-2.5 mm; 6-3 mm; 7, 8, and 9 are each about 2 mm.

Figure 3: Spectrally Selective UV Photodetectors. These curves are produced by combining some of the cathodes and filters from Figures 1 and 2.

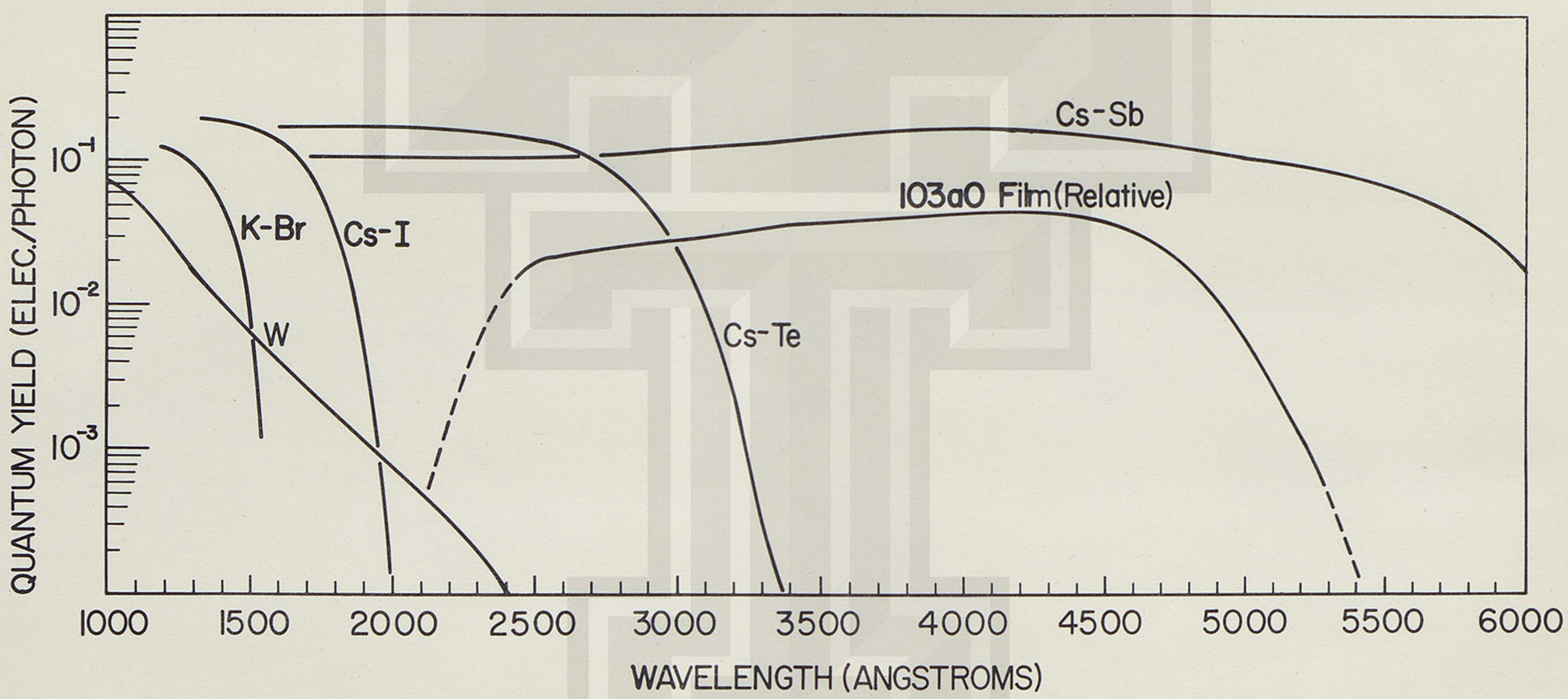
Figure 4: UV Imaging Systems. Various possible optical systems for use with an image converter are shown. Either visual or photographic observation are represented in the top picture.

Figure 5: Hg Spectra With A UV Image Tube. An RCA 7404 image tube (Cs-Sb cathode, vycor window) is on the left and an ITT UV Tube (Cs-Te cathode, sapphire window) is on the right. The UV tube has a slightly smaller cathode area.

A. The spectrum of the Hg lamp is shown on both tubes. The extreme left line is 3650A, the extreme right line is the green 5461A. Next to the first order green line is the second order 2537A line. Between the 2537A and the first order 3650A line are various blue and ultraviolet lines. Note that with the UV tube only the 2537A line and a very faint 3650A trace are recorded. The visible and near UV lines do not appear at all.

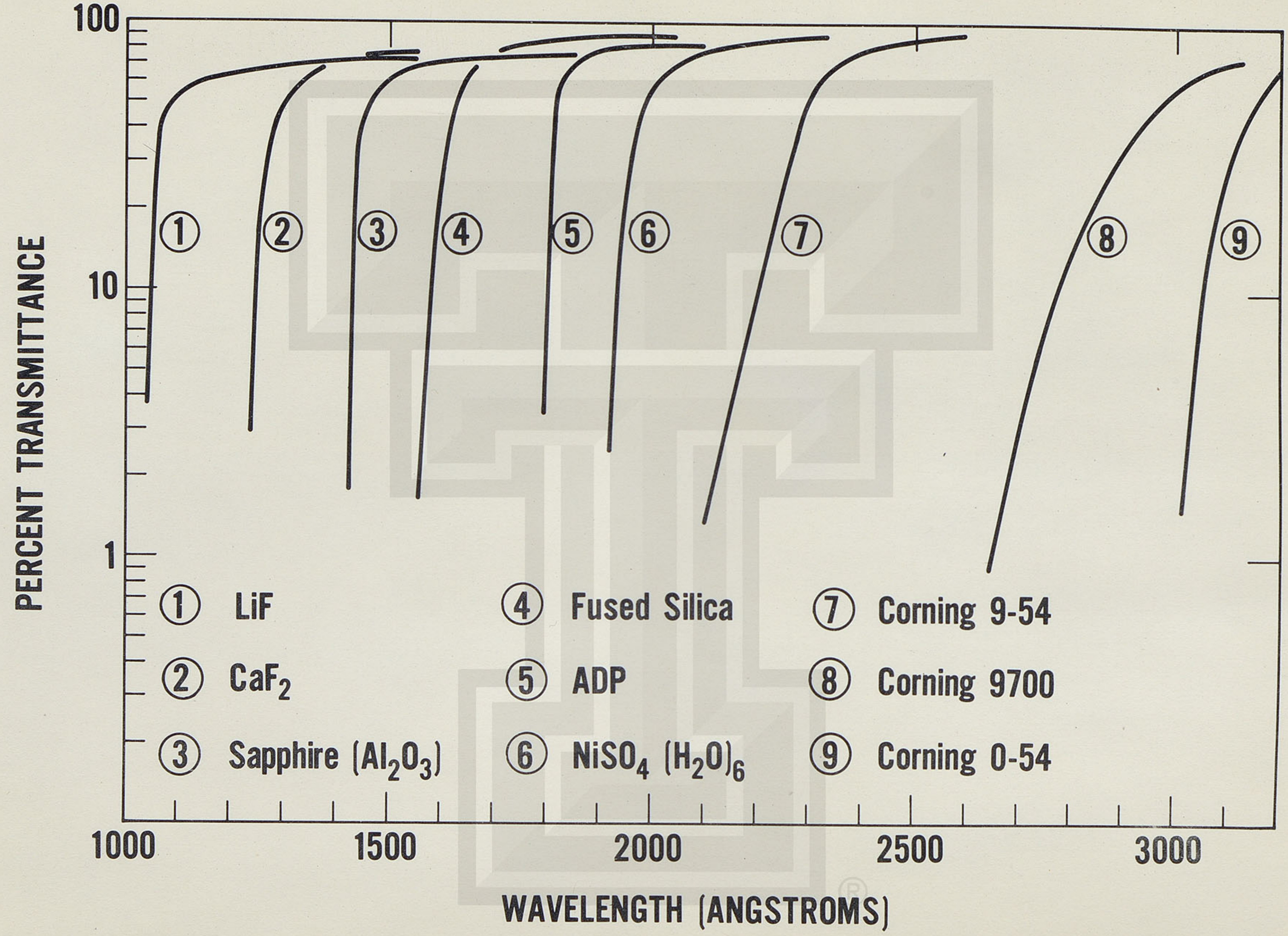
Figure 5: B. The spectrum of a Hg lamp in the presence of a strong continuum background (tungsten lamp) are recorded on both tubes. The visible image converter spectrum is almost washed out while the UV tube spectrum is the same as in part A.

Figure 6: UV Image Tubes and Binoculars. (See text)



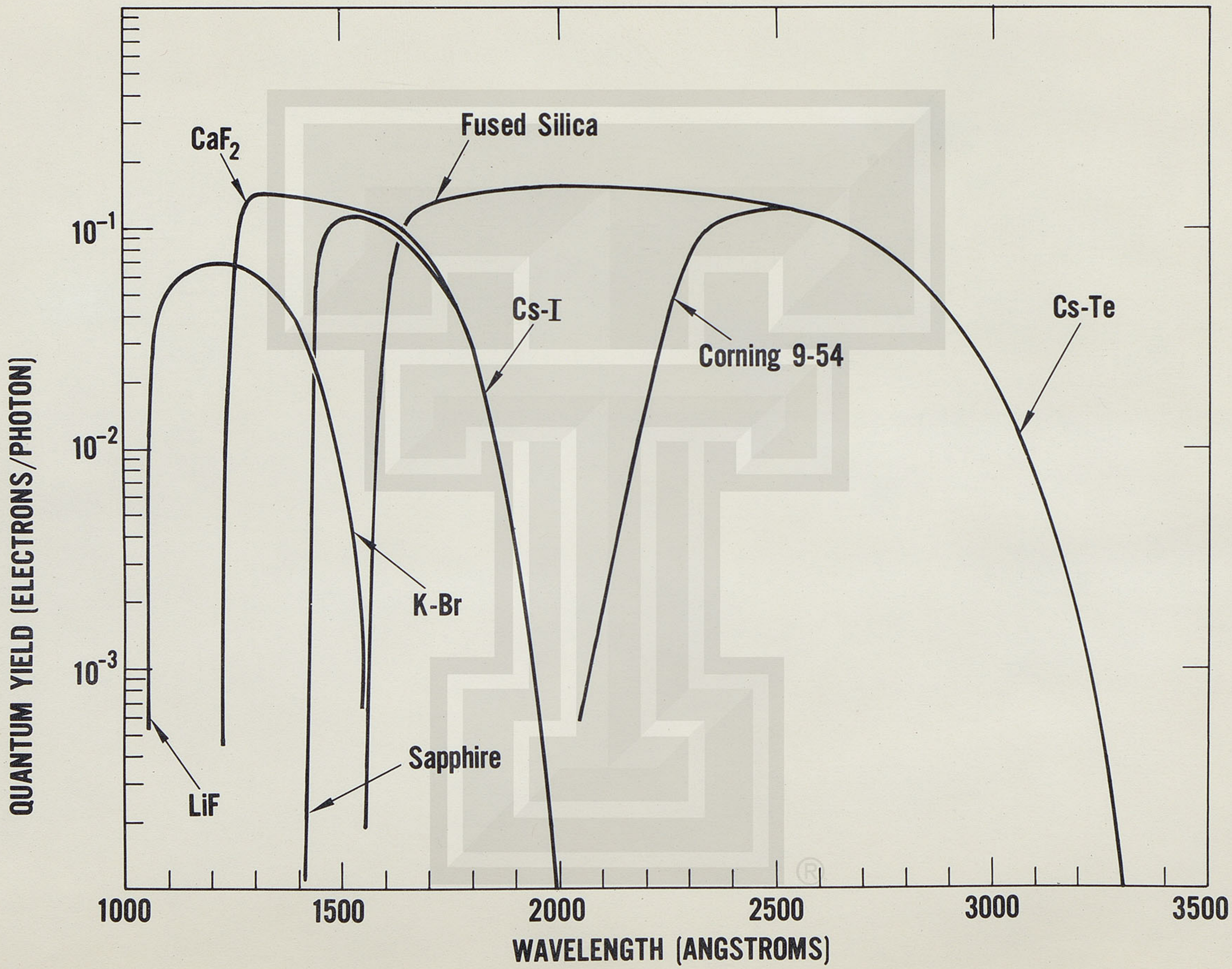
QUANTUM YIELD (ELEC./PHOTON)
10^{-1}
10^{-2}
10^{-3}
Cs-Sb
103aO Film (Relative)
K-Br
Cs-I
W
Cs-Te
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
WAVELENGTH (ANGSTROMS)

FIGURE 1



100
10
1
PERCENT TRANSMITTANCE
1000
1500
2000
2500
3000
WAVELENGTH (ANGSTROMS)
① LiF
② CaF$_2$
③ Sapphire (Al$_2$O$_3$)
④ Fused Silica
⑤ ADP
⑥ NiSO$_4$ (H$_2$O)$_6$
⑦ Corning 9-54
⑧ Corning 9700
⑨ Corning 0-54

FIGURE 2



CaF2
Fused Silica
Cs-I
Corning 9-54
Cs-Te
K-Br
Sapphire
LiF
QUANTUM YIELD (ELECTRONS/PHOTON)
10^-1
10^-2
10^-3
1000
1500
2000
2500
3000
3500
WAVELENGTH (ANGSTROMS)

FIGURE 3

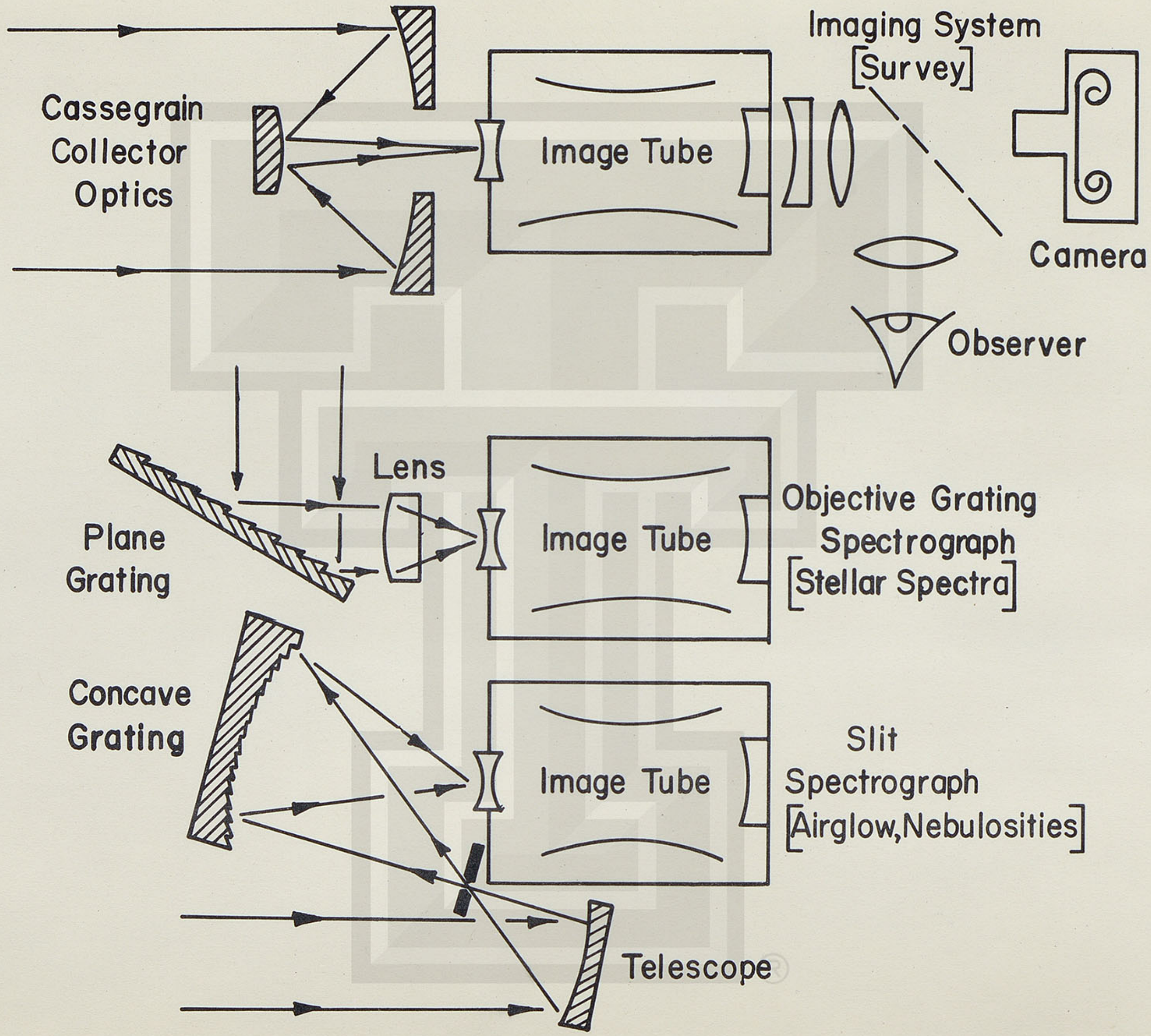

Imaging System
[Survey]
Cassegrain
Collector
Optics
Image Tube
Camera
Observer
Lens
Image Tube
Objective Grating
Spectrograph
[Stellar Spectra]
Plane
Grating
Concave
Grating
Image Tube
Slit
Spectrograph
[Airglow, Nebulosities]
Telescope

FIGURE 4

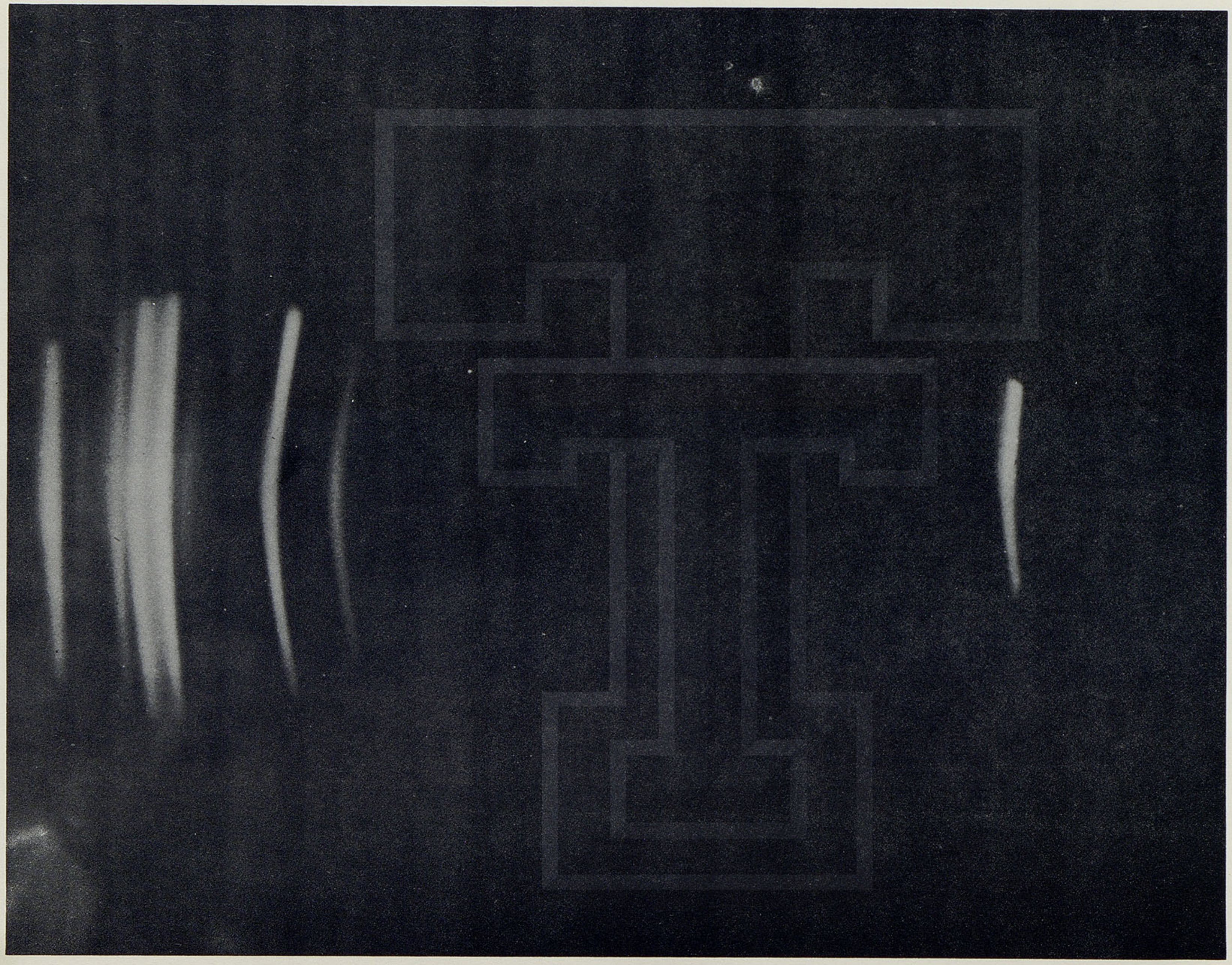


FIGURE 5A

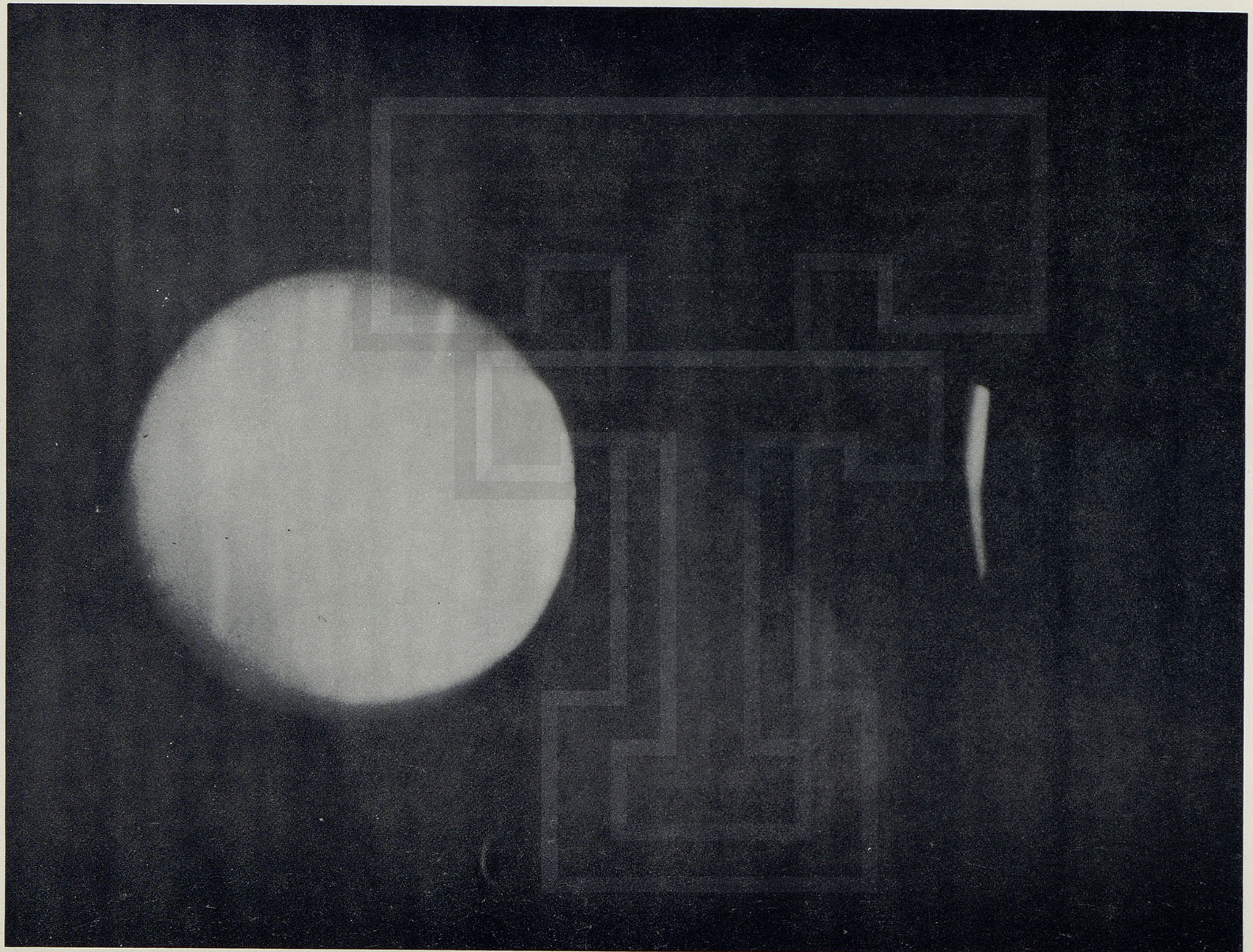


FIGURE 5B

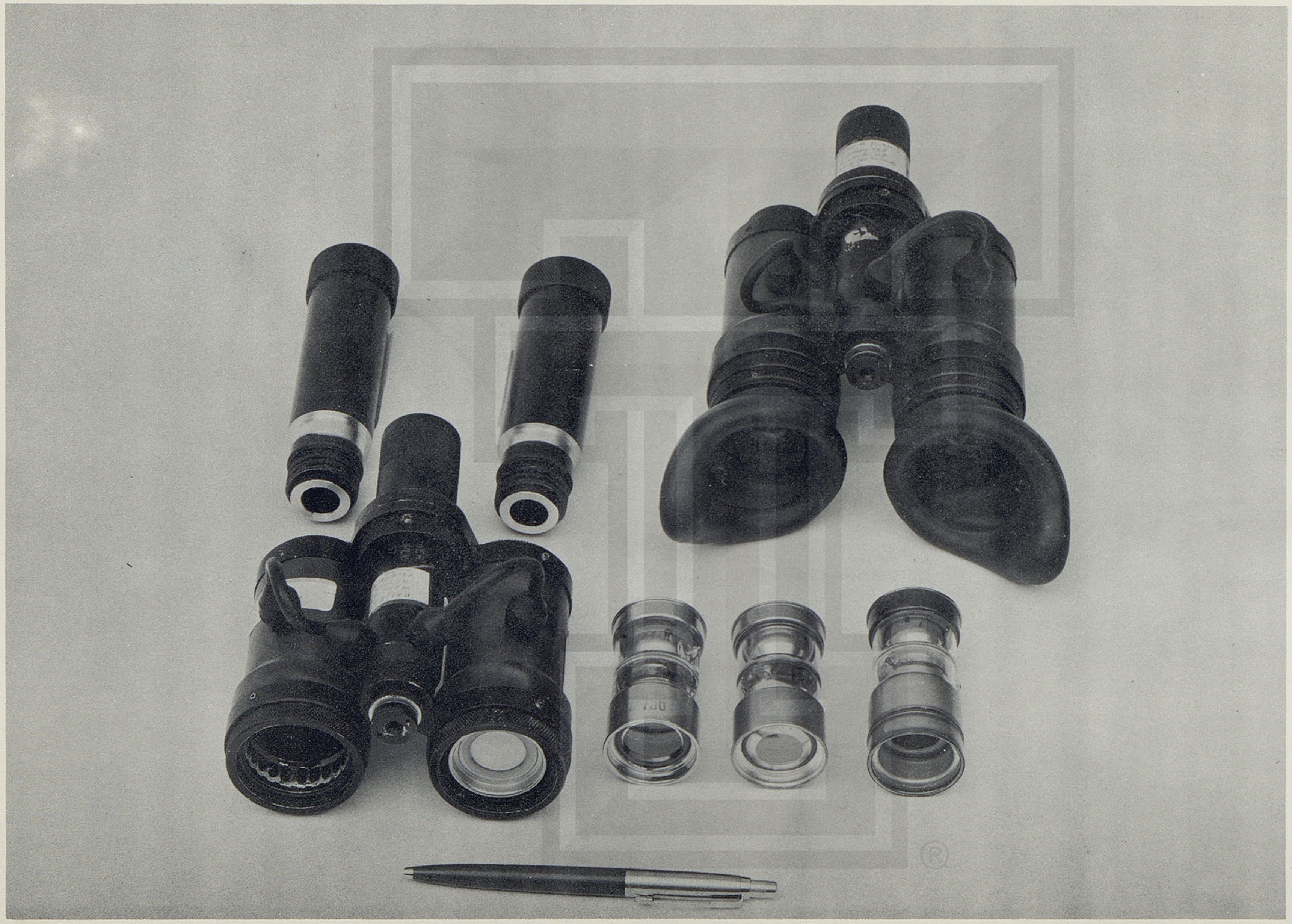


FIGURE 6

UNIVERSITY OF KENTUCKY LEXINGTON, KENTUCKY 40506
CENTENNIAL 1865-1965

FILE

MEDICAL CENTER
DEPARTMENT OF PHYSIOLOGY AND BIOPHYSICS

October 22, 1964

Dr. S. P. Vinograd
Directorate of Space Medicine
NASA
Washington, D. C. 20546

Dear Sherm:

I hope your "course" at George Washington went on successfully. I have my paper in final draft but will not be able to send it to you until I return from Japan November 10. In the meantime if there are instructions about format please send them to me.

Sincerely,

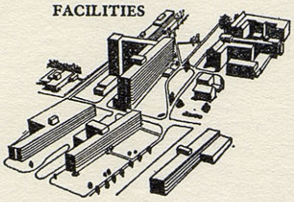
Loren

Loren D. Carlson
Professor and Chairman

LDC/s

NASA Mail Sec. OCT 26 1964
TO: MM -
☑ FOR ACTION ☐ FOR INFORMATION
ACTION COPY TO
INFORMATION COPY TO

THE HEALTH CENTER
FACILITIES



Department of Medicine

THE OHIO STATE UNIVERSITY

UNIVERSITY HOSPITAL
410 WEST 10TH AVENUE
COLUMBUS 10, OHIO

October 21, 1964

S.P. Vinograd, M.D.
Directorate of Space Medicine
N.A.S.A.
Washington 25, D.C.

Dear Sherm:

I thoroughly enjoyed taking part in your course on Monday and hope that I covered the material in the fashion that you desired. I will be interested to hear how the course goes and only wish that I could hear some of the other presentations.

I presume that George Washington is going to take care of the expenses involved for the visitors. Mine were as follows: $54.92 air travel, $14.00 hotel, $6.00 meals, and $6.00 taxi and airport transportation, for a total of $80.92.

Sincerely yours,

James V. Warren, M.D.
Professor and Chairman
Department of Medicine

JVW/sjk

UNIVERSITY of PENNSYLVANIA
PHILADELPHIA 4

The Graduate School of Medicine

Department of Physiology
~~and Pharmacology~~

October 21, 1964

Dr. S. P. Vinograd
Directorate of Space Medicine
Chief, Medical Science & Technology
Office of Manned Space Flight
National Aeronautics & Space Administration
Washington, D.C., 20456

Dear Sherm:

I hope the talk on the 20th was what you had in mind. It was very difficult to judge the audience ahead of time and I changed a lot in the middle.

My expenses totaled $46.00 as follows:

$24.14	PRR Parlor Car
13.00	Hotel Willard
5.05	Cabs and Parking (it really is 0.90 from Willard to GWU)
1.55	Tips
2.26	2 Meals
$46.00	

My readjusted manuscript will be along.

Sincerely,

Robert E. Forster, M.D.

REF:mbg

MAYO CLINIC
ROCHESTER, MINNESOTA

October 20, 1964

Dr. S. P. Vinograd
Director, Medical Science and Technology
Space Medicine Directorate
Office of Manned Space Flight
National Aeronautics and
Space Administration
Washington 25, D. C.

Dear Sherm:

The following is an itemized account of the expenses incurred in traveling from Rochester, Minnesota to Washington, D. C. to participate in the Symposium on the Engineering Aspects of Space Flight on October 20, 1964.

Air fare (round trip, Minneapolis-Washington) (stub enclosed)	$140.96
Private car (round trip, Rochester-Minneapolis) (180 miles)	18.00
Parking (Minneapolis airport)	1.50
Hotel bill - Roger Smith (receipt enclosed)	12.48
Telephone call (Rochester to Washington)	1.50
Meals	1.00
Taxi fares:	
National to Roger Smith	2.50
Roger Smith to George Washington University	1.00
George Washington University to Air Terminal	1.00
Air Terminal to Dulles Airport	2.50
Tips	.50
Total	$182.94

It was a pleasure to see you and enjoyed the discussion with the group.

Sincerely,

Earl

Earl H. Wood, M.D.

EHW:Fdk

Enclosures

OUTLINE OF PRESENTATION FOR SYMPOSIUM ON ENGINEERING ASPECTS OF SPACE MEDICINE

R.E. FORSTER October 20, 1964

ASPECTS OF HUMAN RESPIRATORY PHYSIOLOGY PERTINENT TO SPACE ENGINEERING

I. Introduction: Respiratory and circulatory systems compensate for the long diffusion paths in larger animals. Effects of variation in gravity are not all predictable and may be extremely subtle. Chemical activity [proportional to partial pressure] of respiratory gases in the cells is the important property.

II. Composition of inspired gas.

General difficulties of determing detrimental effects.

A. O_2: Body adapts remarkably, but there are definite upper limits, and growing evidence of more strict lower limits.

B. CO_2: Again body can adapt, but there are definite upper limits.

C. Inert gases: Toxic effects are produced at higher pressures. Presence of an inert gas in alveoli needed to prevent atalectasis.

III. Respiratory function on lungs divided for discussion into four steps.

A. Mechanics: considering lung as bellows; normal values.

B. Distribution of exchanging blood in relation to gas flow:

C. Diffusion exchange of gas between alveolar air and capillary blood:

D. Circulation of blood through capillary bed of lungs and thence to tissue capillary beds: normal values.

A. Mechanics of respiration

1. Normal physiology: diaphragmatic action: pleura and intrapleural pressure: Spirometry and lung volumes: Airway resistance: Compliance

2. Possible effects of changes in gravity

a. change in lung volumes

b. change in airway resistance

B. Distribution of blood and gas flow

1. An important problem: A major dysfunction in disease: Extreme case with all blood flow to one lung and all gas flow to the other. Ratio of alveolar ventilation to capillary blood flow is the important factor.

2. Concept of respiratory dead space as wasted ventilation experimentally hard to measure. May have same effect on gas exchange as non uniform ventilation blood flow.

3. Several known regulatory mechanisms to maintain a balance between capillary blood flow and alveolar gas ventilation at the microscopic level.

4. Effect of space flight on distribution problems: Increased gravity produces extreme distortions: Decreased gravity will alter mechanical balance in lungs.

C. Circulation: discussed mainly elsewhere.

1. Pulmonary circulation is low pressure and more susceptible to changes in surrounding pressures, particularly intrapleural and atmospheric.

2. O_2 carried in blood bound reversibly to haemoglobin: CO_2 as bicarbonate.

3. Hydrostatic pressure differences in living lung limits gravitational force man can tolerate.

IV. Control of respiration.

A. Effect of arterial P_{CO_2} and pH on medullary respiratory centers.

B. Effect of arterial Po_2 on the chemoreceptors in the aortic arch and bifurcation of the carotid.

C. Cerebrospinal fluid pH and Pco_2.

D. Reflexes and sensation from elsewhere in the body.

E. Temperature

F. Higher centers in the central nervous system.

G. Possible derangements with changes in gravity. In zero G, reduction in sensation may lower respiratory minute volume to dangerous level, particularly during sleep.

V. Self cleansing actions of the lung

A. Cough: expells larger bodies from upper airway. Ineffective in lower airways.

B. Mucus sheet: propelled by the rythmic beat of cilia from the respiratory bronchiole to the pharynx. Effects of changes in gravity on this system are unknown. Extremely important in removing finer particulate matter from the lung.

Dr. Earl H. Wood
200 FIRST STREET SOUTHWEST
ROCHESTER, MINNESOTA

NORTHWEST
AIR MAIL
COAST TO COAST • ALASKA

ROCHESTER
PM
OCT 20
1964
MINN.

8¢
U.S. AIR MAIL

NASA Mail Sec. OCT 22 1964

TO: MM

FOR ACTION

ACTION COPY TO

INFORMATION COPY TO

Dr. S. P. Vinograd
Director, Medical Science and Technology
Space Medicine Directorate
Office of Manned Space Flight
National Aeronautics and
Space Administration
Washington 25, D. C.

ISSUED BY
NORTHWEST AIRLINES, INC.

SOLD SUBJECT TO CONDITIONS OF CONTRACT ON PASSENGER'S COUPON

If the passenger's journey involves an ultimate destination or stop in a country other than the country of departure, the Warsaw Convention may be applicable and the Convention governs and in most cases limits the liability of carriers for death or personal injury and in respect of loss of or damage to baggage.

PASSENGER TICKET AND BAGGAGE CHECK
PASSENGER'S COUPON

AIRLINE 012 FORM 24 SERIAL NUMBER 2553079

DATE OF ISSUE

ORIGIN

DESTINATION

ISSUED IN EXCHANGE FOR

DATE AND PLACE OF ORIGINAL ISSUE

PASSENGER NAME: DR. E. WOOD — NOT TRANSFERABLE

VALID UNTIL | TICKET DESIGNATOR | ACCT. DEPT. USE ONLY

NOT GOOD FOR PASSAGE

FROM	FARE BASIS	CARRIER	FLIGHT	DATE	TIME	STATUS	ALLOW.
MPLS / STP	FX	NW	F 70	10/19	520 P	OK	
(NATIONAL) WASH. D.C. (DULLES)	FJO	NW	FJ 77	10/20	105 P	OK	
MPLS / STP							

BAGGAGE CHECKED / UNCHECKED — PCS. — UNCK. WT. — WT.

FARE 134.25 — TAX 6.71 — TOTAL 140.96 — EQUIV. AMT. PD.

ROUTE CODE — CPN. — TICKET NUMBER

FOR ISSUING OFFICE ONLY

FROM/TO	CARRIER	FARE CALCULATION
MSP		
WAS	NW	64.55
MSP	NW	69.70

FARE 134.25

318 NWA 318
OCT 19 1964
ROCHESTER
318 MINN. 318

DATE AND PLACE OF ISSUE OF THIS TICKET

CONJUNCTION TICKET(S)

FORM OF PAYMENT

ENDORSEMENTS

012 24 2553079

CONDITIONS OF CONTRACT

(1.) As used in this contract, "Convention" means the Convention for the Unification of Certain Rules relating to International Carriage by Air, signed at Warsaw, October 12, 1929, or that Convention as amended by The Hague Protocol, 1955, whichever may be applicable to carriage hereunder, "ticket" means "Passenger Ticket and Baggage Check", "carriage" is equivalent to "transportation", and "carrier" includes the air carrier issuing this ticket and all air carriers that carry or undertake to carry the passenger or his baggage hereunder or perform any other service incidental to such air carriage; "damage" includes death, injury, delay, loss or other damage of whatsoever nature arising out of or in connection with carriage or other services performed by carrier incidental thereto. Carriage to be performed hereunder by several successive carriers is regarded as a single operation.

(2.) (a) Carriage hereunder is subject to the rules and limitations relating to liability established by the Convention unless such carriage is not "international carriage" as defined by the Convention. (See carrier's tariffs, conditions of carriage for such definition). Carrier's name may be abbreviated in the ticket, the full name and its abbreviation being set forth in carrier's tariffs, conditions of carriage, regulations or timetables; and carrier's address shall be the airport of departure shown opposite the first abbreviation of carrier's name in the ticket; and for the purpose of the Convention the agreed stopping places (which may be altered by carrier in case of necessity) are those places, except the place of departure and the place of destination, set forth in this ticket and any conjunction ticket issued herewith, or as shown in carrier's timetables as scheduled stopping places on the passenger's route.

(b) To the extent not in conflict with the foregoing, all carriage hereunder and other services performed by each carrier are subject to (i) applicable laws (including national laws implementing the Convention or extending the rules of the Convention to carriage which is not "international carriage" as defined in the Convention), government regulations, orders and requirements, (ii) provisions herein set forth, (iii) applicable tariffs, and (iv) except in transportation between a place in the United States and any place outside thereof, and also between a place in Canada and any place outside thereof, conditions of carriage, regulations and timetables (but not the time of departure and arrival therein) of such carrier, which are made part hereof and which may be inspected at any of its offices and at airports from which it operates regular services.

(c) Unless expressly so provided, nothing herein contained shall waive any limitation of liability of carrier existing under the Convention or applicable laws.

(3.) Insofar as any provision contained or referred to herein may be contrary to a law, government regulation, order or requirement, which severally cannot be waived by agreement of the parties, such provision shall remain applicable and be considered as part of the contract of carriage to the extent only that such provision is not contrary thereto. The invalidity of any provision shall not affect any other part.

(4.) Subject to the foregoing: (a) Liability of carrier for damages shall be limited to occurrences on its own line, except in the case of checked baggage as to which the passenger also has a right of action against the first or last carrier. A carrier issuing a ticket or checking baggage for carriage over the lines of others does so only as agent. (b) Carrier is not liable for damage to passenger or unchecked baggage unless such damage is caused by the negligence of carrier. (c) Carrier is not liable for any damage directly and solely arising out of its compliance with any laws, government regulations, orders or requirements, or from failure of passenger to comply with same. (d) Any liability of carrier is limited to 250 French gold francs (consisting of 65½ milligrams of gold with a fineness of nine hundred thousandths) or its equivalent per kilogram in the case of checked baggage, and 5,000 such French gold francs or its equivalent per passenger in the case of unchecked baggage or other property, unless a higher value is declared in advance and additional charges are paid pursuant to carrier's tariffs or regulations. In that event the liability of carrier shall be limited to such higher declared value. In no case shall the carrier's liability exceed the actual loss suffered by the passenger. All claims are subject to proof of amount of loss.

(e) Any exclusion or limitation of liability of carrier under these conditions shall apply to agents, servants or representatives of the carrier acting within the scope of their employment and also to any person whose aircraft is used by carrier for carriage and his agents, servants or representatives acting within the scope of their employment.

(5.) Checked baggage carried hereunder will be delivered to the bearer of the baggage check upon payment of all unpaid sums due carrier under carrier's contract of carriage or tariff.

(6.) When validated, this ticket is good for carriage from the airport at the place of departure to the airport at the place of destination via the route shown herein and for the applicable class of service and is valid for one year from the date of commencement of flight except as otherwise provided in carrier's tariffs or regulations. Each flight coupon will be accepted for carriage on the date and flight for which accommodations have been reserved; when flight coupons are issued on an "open date" basis, accommodations will be reserved upon application subject to availability of space.

(7.) Carrier undertakes to use its best efforts to carry the passenger and baggage with reasonable dispatch, but no particular time is fixed for the commencement or completion of carriage. Subject thereto, carrier may without notice substitute alternate carriers or aircraft and may alter or omit the stopping places shown on the face of the ticket in case of necessity. Times shown in timetables or elsewhere are approximate and not guaranteed, and form no part of this contract. Schedules are subject to change without notice. Carrier assumes no responsibility for making connections.

(8.) The passenger shall comply with all government travel requirements, present all exit, entry, and other documents required by the law, and arrive at the airport by the time fixed by carrier or, if no time is fixed, sufficiently in advance of flight departure to permit completion of government formalities and departure procedures. Carrier is not liable for loss or expense due to passenger's failure to comply with this provision.

(9.) No agent, servant or representative of carrier has authority to alter, modify or waive any provision of this contract.

(10.) No action shall lie in the case of damage to baggage, unless the person entitled to delivery complains to the carrier forthwith after the discovery of the damage, and, at the latest, within seven days from the date of receipt; and in the case of delay, unless the complaint is made at the latest within 21 days from the date on which the baggage has been placed at his disposal. Every complaint must be made in writing and dispatched within the times aforesaid. Where carriage is not "international carriage" as defined in the Convention, failure to give notice shall not be a bar to suit where claimant proves that (i) it was not reasonably possible for him to give such notice, or (ii) that notice was not given due to fraud on the part of carrier, or (iii) the management of carrier had knowledge of damage to passenger's baggage.

(11.) Any right to damages against carrier shall be extinguished unless an action is brought within two years reckoned from the date of arrival at the destination, or from the date on which the aircraft ought to have arrived, or from the date on which the carriage stopped. The method of calculating the period of limitation shall be determined by the law of the court seized of the case.

SOLD SUBJECT TO TARIFF REGULATIONS

PRICE OF THIS TICKET IS SUBJECT TO CHANGE PRIOR TO COMMENCEMENT OF TRAVEL.

ISSUED BY NORTHWEST AIRLINES, INC., ST. PAUL, MINNESOTA, 55111, U. S. A.

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The ROGER SMITH MOTOR HOTEL	White Plains, N. Y.
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Rochester Minn
27590
67056

10/20 **Roger Smith**
HOTEL
PENNSYLVANIA AVE. AND 18TH ST., N.W.
WASHINGTON 6, D. C.

WHITNEY DUPLICATING CHECK CO., NEW YORK 1, N. Y.

MEMO.		DATE	EXPLANATION	CHARGES	CREDITS	BAL. DUE
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E ROGER SMITH HOTEL E
WASHINGTON, D. C. E
Earl H Wood

We hope your stay has been satisfactory and that we will see you again soon. Thank you.
ROGER SMITH HOTEL

ACCOUNTS PAYABLE WHEN RENDERED

C 1094 COMMUNICATION CONTROL RECORD
REPLACES IN THE USAF DD FORM 278 WHICH MAY BE USED.

AF FORM 388 FEB 59 ☆ GPO : 1962 - 647819

FROM R.E.Forster

SUSPENSE DATE NR

DATE recvd 5 Oct 64

NUMBER 1384/4

SUMMARY

GW U outline on "Aspects of Human Respiratory Physiology Pertinent to Space Engineering"

TO	TO	TO	TO	TO
Vinggrad				
DATE	DATE	DATE	DATE	DATE
5 Oct 64				

ACTION TAKEN *(Answered or other)*

COMMUNICATION CONTROL RECORD

REPLACES IN THE USAF DD FORM 278 WHICH MAY BE USED.

C 1094

GPO : 1962 - 647819

AF FORM 388 FEB 59

FROM	SUSPENSE DATE
Dr. D. E. Beischer, Nav Sch of Med	16 Oct
DATE	**NUMBER**
9 Oct 64	1416/4

GRR - GW Greene
Form letter already answers questions — sent out 10-12-64

SUMMARY

Requesting info re mtg of 23 Oct 64 on travel and location

TO	TO	TO	TO	TO
Vinograd				
DATE	**DATE**	**DATE**	**DATE**	**DATE**
14 Oct 64				

ACTION TAKEN *(Answered or other)*

AIR TERMINAL SERVICES, INCORPORATED

00106 Minneapolis - Saint Paul Airport Parking

SOLD BY ____ DATE 10-20 19 64

NAME ____

ADDRESS ____

REG. NO.	AMT. RECD.	ACCT. FWD.

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G.W. Course

U. S. NAVAL SCHOOL OF AVIATION MEDICINE
U. S. NAVAL AVIATION MEDICAL CENTER
PENSACOLA, FLORIDA 32512

IN REPLY REFER TO
32/mjj
9 October 1964

Dr. S. P. Vinograd, Director
Medical Science and Technology
Space Medicine Directorate
Office of Manned Space Flight
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Doctor Vinograd:

I forgot to ask you during my last visit if you plan to send me travel authorization to the meeting on the 23rd. If possible, I would also appreciate more precise information about the building in which the meeting will take place.

Sincerely yours,

D. E. Beischer

D. E. BEISCHER, Ph. D.
Head, Chemical Sciences Division

GW Course

9 October 1964

Colonel James E. Henry, USAF
DCS Personnel
AMD
Brooks Air Force Base
San Antonio, Texas

Dear Colonel Henry:

In accordance with our telephone conversation yesterday, I would like to request authorization for travel for Colonels John P. Stapp and James P. Henry. They have been invited to appear as guest lecturers for a post graduate course called "Engineering Aspects of Space Medicine" given by the George Washington University School of General Studies in Washington, D.C., October 19 through October 30, 1964. Colonel Stapp's lecture is scheduled for the afternoon of Monday, October 26 and Colonel Henry's for Thursday afternoon, October 22. Travel will be reimbursed by the school unless either or both of them will be here on official business anyway.

Both Colonel Henry and Colonel Stapp have responded affirmatively to their invitations. I am enclosing a copy of the form letter of request which was sent to all invited participants, together with a brochure of the course. Unfortunately, you will not find Colonel Henry's name among the list of guest lecturers outlined in the brochure. This is a result of changes which became necessary after the publication of the pamphlet.

Your kind attention to this matter is very much appreciated.

Sincerely yours,

/S/

S. P. Vinograd, M.D.
Course Instructor
Director, Medical Science and Technology
Office of Space Medicine

Enclosures

FILE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON 25, D.C.

IN REPLY REFER TO:
MMD

9 October 1964

Dear Faculty Member:

Please accept my appreciation for your lecture outline for the George Washington University course on Engineering Aspects of Space Medicine. The program seems to be shaping up very well, and alterations of the schedule have not had to be extensive as you will note from the enclosure.

I am happy to report that I am now able to give you the following particulars:

(1) The course will be held in Room 200 (Auditorium V), Tompkins Hall of Engineering on the GWU campus. The address is 725 23rd Street, N.W. As many of you know, this is a relatively short cab ride from almost any downtown hotel, although the Roger Smith Hotel on 18th and Pennsylvania Avenue, NW, is probably the closest. Should you need any assistance in making hotel reservations, you may get in touch with the Office of Dr. Robert Eller, Assistant Dean, College of General Studies, GWU, Washington, D.C., 20006.

(2) Payment for your travel will be by reimbursement upon your arrival at the school. Since this is tax exempt travel, please fill out a U.S. Government Tax Exempt certificate for your use at the time you purchase your ticket. The name of the institution for this form is, of course, the George Washington University. Needless to say, those of you who are already in Washington either by virtue of the fact that this is your place of business or that you will be here on other business anyway need not be concerned with this procedure.

Should some of you find that this arrangement is unsatisfactory in any way, please contact Dean Eller's office and they will make every effort to accommodate your individual needs.

(3) The syllabus of outlines will, unfortunately, not be ready in time for a copy to be mailed to you, but you will find one earmarked for you upon your arrival.

(4) The times given on the enclosed schedule are best approximations at this point. It will be important, however, that the 11:30 a.m. and 4:30 p.m. panel discussion periods take place at or earlier than these times, and that we start the morning and afternoon sessions on time. Within this time frame, allowances can be made where required. In general, we will want to allow a five or ten minute break between lectures, and also in the middle of the few 2-hour lectures appearing on the schedule.

(5) According to present estimates, the enrollment will be approximately 35 to 50 students.

(6) Visual equipment will include 35 mm and 3x4 inch slide (lantern slides) projectors, view graph projector, 16 mm sound motion picture projector, and a blackboard.

Should any questions or problems arise, please feel free to communicate with me or with Dean Eller's office, as the case may be.

Once again, thank you for your cooperation and participation. I am confident that we can all look forward to an effective course of which we can all be proud.

Sincerely yours,

S. P. Vinograd, M.D.
Course Instructor
Director, Medical Science and Technology
Office of Space Medicine

Attachment
Revised Schedule

This letter sent to all names on attached schedule
12 Oct 64

ENGINEERING ASPECTS OF SPACE MEDICINE
SCHEDULE

1ST WEEK

Monday, 19 October

AM
8:00 Introduction
G.P. Vinograd, MD
8:15 NASA Organization
W.Randolph Lovelace,II,MD
8:45 DOD Organization
B/Gen. B.A.Strickland,Jr., (MC) USAF
9:15 Introduction to Manned Space Flight
George M. Knauf, MD
9:45 Cardiovascular Physiology
Loren D. Carlson, Ph.D.
11:30 Questions - Panel Discussion
PM
1:00 Clinical Aspects of Cardiovascular Function
James V. Warren, MD
2:00 ECG
Capt. N.W. Allebach, (MC) USN
4:30 Questions - Panel Discussion

Tuesday, 20 October

AM
8:00 Respiratory Physiology
Robert E. Forster, MD
9:45 Research Aspects of Cardio-Respiratory Physiology as Applied to Space
Earl H. Wood, MD
11:30 Questions - Panel Discussion
PM
1:00 Genl. Metabolism & Endocrinology
Herbert Pollack, MD
2:00 Fluid & Electrolyte Balance
G. Donald Whedon, MD
3:15 Biochemistry
L/Col. Edward C. Knoblock, USA (MSC)
4:30 Questions - Panel Discussion

Wednesday - 21 October

AM
8:00 Genl. Neurology & EEG
Maitland Baldwin, MD
9:30 Vestibular Function
Ashton Graybiel, Capt., (MC) USN
10:30 Special Senses
John Lott Brown, Ph.D.
11:30 Questions - Panel Discussion
PM
1:00 Genl. Psychology
Ross A. McFarland, Ph.D.
2:15 Space Flight Habitability
Joseph F. Kubis, Ph.D.
3:30 Man-Machine Integration
Milton A. Grodsky, Ph.D.
4:30 Questions - Panel Discussion

Thursday, 22 October

AM
8:00 Physiological Factors in the Selection of Spacecraft and Spacesuit Atmospheres
John Billingham, MD
10:00 Food, Water, and Waste Systems
John Billingham, MD, Presenter
11:30 Questions - Panel Discussion
PM
1:00 Future Trends in ECS and Spacesuit Development
Michael Del Duca, Ph.D.
2:30 Physiological Aspects of Weightlessness
James P. Henry, Ph.D.
4:30 Questions - Panel Discussion

Friday, 23 October

AM
8:00 Space Radiation and Magnetic Field Environment
Wilmot N. Hess, Ph.D.
9:15 Radiation Biology
Douglas Grahn, Ph.D.
10:30 Radiation Shielding in Space
Warren Keller, MS
11:30 Questions - Panel Discussion
PM
1:00 Physiological Effects of Magnetic Fields
D. E. Beischer, Ph.D.
2:15 Visible Light, Ultraviolet and Infrared Energies
John A. Buesseler, MD
3:30 Circadian Rhythms
Franz Halberg, MD
4:30 Questions - Panel Discussion

2ND WEEK

Monday, 26 October

AM
8:00 Weightlessness
Sigfried Gerathewohl, Ph.D.
10:00 Acceleration
B.F. Burgess, Cdr.,(MSC) USN
11:30 Questions - Panel Discussion
PM
1:00 Impact
John P. Stapp, Col.,(MC), USAF
2:15 Noise and Vibration
Henning E. vonGierke, Ph.D.
3:30 Development Aspects of Biodynamics Protection
Gerald J. Pesman, MS
4:30 Questions - Panel Discussion

Tuesday, 27 October

AM
8:00 Toxic Hazards of Space Flight
Samuel Natelson, Ph.D.
9:15 Environmental Control System, Spacesuit, and Survival Equipment Development
Edward L. Hays, BS
11:30 Questions - Panel Discussion
PM
1:00 Lunar Hazards
G. Timothy Orrok,PhD
2:15 Living Conditions and Standards in Multiman Spacecraft
Saul B. Sells, Ph.D.
3:45 Human Standards
H. Grady Wise, L/Col., USAF
4:30 Questions - Panel Discussion

Wednesday, 28 October

AM
8:00 Bioinstrumentation Development
Wayne Holt, BS
9:15 Telemetering and Storage of Information
Marvin Rosenbluth, BS
10:30 Advanced Considerations in Bioinstrumentation and Communication of Information
Otto H. Schmitt, Ph.D.
11:30 Questions - Panel Discussion
PM
1:00 Gemini Inflight Medical Experiments
S. P. Vinograd, MD
2:15 Ground Based Medical Experiments
Lawrence F. Dietlein,MD
3:30 Simulations
Edward J. McLaughlin, Ph.D.
4:30 Questions - Panel Discussion

Thursday, 29 October

AM
8:00 R&D Aspects of Crew Medical Selection & Training
A.H. Schwichtenberg, MD
9:30 Occupational Medicine in Space Technology
David H. Stoddard, MD
John E. Boysen, MD
11:30 Questions - Panel Discussion
PM
1:00 Flight Crew Medical Operations
~~D. Owen Coons, MD~~
2:15 Flight Crew Training
Donald K. Slayton, BS
3:15 Ground Crew Medical Operations
A. Duane Catterson, MD
4:30 Questions - Panel Discussion

Friday, 30 October

AM
8:00 Space Flight Medical Operational Dynamics
Charles A. Berry, MD
9:30 Data Retrieval and Analysis
J.F. Lindsey, Ed.D.
John C. Townsend, Ph.D.
11:30 Questions - Panel Discussion
PM
1:00 ORL Concepts
Maurice Raffensperger, MS(EE)
2:00 MOL
A. I. Karstens, Col.,USAF (MC)
2:45 Unmanned Biological Flights
~~Orr Reynolds, Ph.D.~~ CARL W. BRUCH, PH.D.
Dale W. Jenkins, Ph.D.
4:30 Questions - Panel Discussion

UNIVERSITY OF SOUTHERN CALIFORNIA
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SCHOOL OF MEDICINE
DEPARTMENT OF PHYSIOLOGY

RICHMOND 8-2311
EXT. 581 OR 582

7 October 1964

Dr. Sherman Vinograd
Chief Medical Science & Technology Branch
Office of Manned Space Flight
HQ, NASA
Washington 25, D.C.

Dear Sherman:

Thank you for the invitation to contribute to the course on engineering aspects of space medicine. I enclose a copy of the section on the effects of weightlessness that I have written for the book on the Biomedical Aspects of Space Flight. This as yet unpublished work was done privately under contract for Holt, Rhinehart and Winston for a high school space series sponsored by NASA. Jim Bernardo of the NASA office of Education Programs and Services, whose Washington number is 382-8166, knows about this and would no doubt help you get approval to use this write-up should you need it and should such approval be necessary.

I also enclose a copy of a paper on weightlessness written a couple of years ago. Finally, there is, as I told you on the phone, a write-up in Schaefer's Bioastronautics.

I'll try to make the talk a little different from the material. It's always pretty sad to have the lecturer recapitulate the notes he has precirculated.

Best regards to Jim Nolan et al.

Sincerely,

Jim

James P. Henry, M.D.
Department of Physiology

JPH/br

Encl.

Effects of Weightlessness in Ballistic And Orbital Flight

A Progress Report

James P. Henry, M.D., Ph.D.; William S. Augerson, M.D.; Richard E. Belleville, Ph.D.; William K. Douglas, M.D.; Marvin K. Grunzke, M.A.; Richard S. Johnston, B.S.; Patrick C. Laughlin, M.D.; John D. Mosely, D.V.M.; Fred H. Rohles, Ph.D.; Robert B. Voas, Ph.D. and Stanley C. White, M.D.

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Effects of Weightlessness in Ballistic And Orbital Flight

A Progress Report

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THE MAIN biological interest in the achievement of orbiting space flight centers about the controversial question of the effects of the weightless state.[1] To date, there has been no difficulty in tolerating the noise, vibration, and acceleration associated with launch and with reentry.[2-4] For example, as can be seen in Figure 1, none of the accelerations in the various Mercury flights exceeded limits eminently tolerable for the supine posture. Launch values, with the exception of the escape rocket firing in MR-2, were less than 8g and reentry less than an 11g peak with a maximum time above 6g of no more than 45 seconds. Even with the unscheduled escape rocket firing of the MR-2, the momentary 17g launch and subsequent 15g reentry peaks were well tolerated. The oscillatory accelerations were, in all cases, less than 1.0g through the entire frequency range, including those from 1 to 20 cycles per second. Sound levels at no time exceeded tolerance, and impacts on the ocean using the pneumatic bag deployed with the heat shield were so mild that the protective crushable honeycomb structure under the couch remained uncompressed.

The normally functioning spacecraft environmental control system maintained suit inlet temperatures at less than 75° F. throughout flight. The only significant heat stress was after landing when the heating effect of the fan caused suit inlet values to rise above the already warm (75-85° F.) ambient air of the tropical ocean. This air has a high humidity and will, at these temperatures, maintain heat balance only in resting conditions. Radiation has been no problem in the Mercury flights to date, for the capsule no more than skims the atmosphere far below the Van Allen zones. It is not surprising then that the results of the postflight physical examinations and the evaluation of pilot performance have been negative.[2-4] It is important to note that the data on Figure 1 refer only to the Mercury-Redstone and Mercury-Atlas spacecraft-booster combinations. Another larger vehicle could have different and, perhaps, less tolerable launch acceleration, vibration, and noise characteristics. The characteristics of the environmental control system employed, including its freedom from toxic gases is also peculiar to these particular systems. Nevertheless, it can be stated that the Mercury environmental stress data is fully compatible with normal pilot performance. This leaves the question of the effects of the weightless state, a question which was first raised in the closing days of World War II by Gauer and Haber.[1]

The present paper will review what has been learned about the effects of weightlessness, now that manned orbiting spacecraft are realities. Gauer and Haber's original paper, which was written in 1946,[2] remains a classical summary of the possible effects of the weightless state. In it, they speculated concerning the possible consequences of day to week-long exposures such as would be met during a flight to the moon or even Mars. Their concern centered about the

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From the Life Systems Division, NASA-Manned Spacecraft Center, Houston, Texas.

Presented at the Aerospace Medical Association Meeting April 12, 1962 in Atlantic City, New Jersey.

questions of orientation. Postulating an individual free to float, they argued that vision would then provide the only means of orientation. There would be grossly altered and deficient information from the joints, tendons, muscle, and skin, i.e., the kinesthetic sense would be disturbed. The labyrinth would provide none of the usual orienting information from the otoliths in the utricle. Gauer and Haber[1] and later Haber and Gerathewohl[5] predicted difficulties because of the gross discrepancy anticipated between vision and the sensations from the labyrinth. It was thought that the utricular receptors might over-respond to the small inertial effects of head movement when there was no overriding force of gravity to pin them down.

Furthermore, since the actual relation between the gravity force and the sensation experienced by the organism had not been determined experimentally, Gauer and Haber chose to cite the Weber-Fechner law, which states that the sensation experienced by the organism is not directly proportional to the intensity of the particular stimulus but to its logarithm. Haber and Gerathewohl extrapolated the Weber-Fechner relationship to values below 1g, using this value as corresponding to zero sensation.

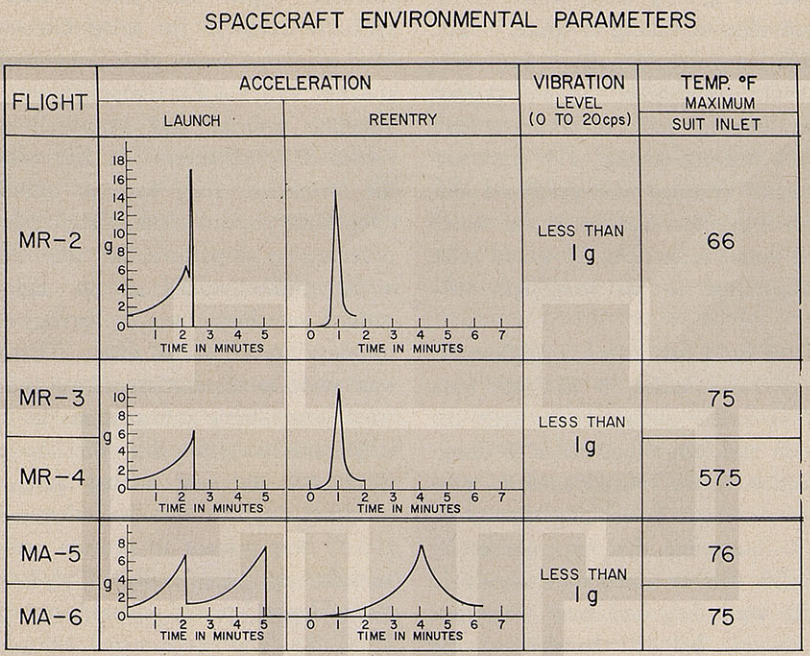

Fig. 1. Chart indicating Mercury spacecraft environmental parameters.

Gougerot immediately challenged these contentions arguing that the threshold for null sensations[6] of gravity would not be 1g but would probably change with reduced gravity to which he thought the organism would adapt rapidly, setting a new threshold as is the case with a continuous background of sound. However, as Haber and Gerathewohl themselves pointed out,[5] "the analysis of phenomena in a gravity free state had of necessity, to depend on assumptions and conclusions by analogy and only experiments will decide." Subsequent work with exposures to weightless flight in aircraft, lasting for no more than 30 seconds, have confirmed Gougerot's idea of adaptability. Thus, Simons reports the rapid reorientation of a man walking with "sticky" Velcro on his feet along a strip on the roof of the cabin. To these subjects, the erstwhile ceiling now appeared to be down;[7]

and, in a later study, Gerathewohl has concluded that it was probable that only small changes in sensations were produced at values below **1g.**[8]

The early speculation further assumed that "in the absence of gravity there would necessarily be a sensation of falling in space."[1] But, as Gerathewohl has recently pointed out,[9] even the brief aircraft experiments did not support this. Both Gerathewohl[9] and Von Diringshofen[10] report merely a floating feeling. Nor have aircraft experiments revealed the predicted difficulty with hand-eye coordination in the seated pilot with full visual references. It would seem that rapid adaptation to the weightless state occurs.

Because of the brief periods of weightlessness available in aircraft studies, it has not been possible to differentiate accurately between the effects of vision and kinesthetic sense in determining orientation. Such refined analysis must await more careful tests in orbiting spacecraft. However, it is interesting that experiments by Gerathewohl with cats in which they were held on their backs until they had been weightless for several seconds led to abolition of the righting reflex.[11] The impression was gained that they relied on vision for orientation.

Destruction of the labyrinth before exposure to the weightless state in the celebrated turtle experiment of von Beckh[12] prevented the onset of confusion in the animal when suddenly exposed to weightlessness. Having already lost his gravireceptors, the labyrinthectomized animal experiences no new situation to which he must suddenly accommodate. Von Beckh's normal turtles missed their target when suddenly weightless, but the labyrinth damaged animal showed no reduction in accuracy unless he was deprived of vision by hooding.[12]

Early Studies with Ballistic Rockets.—Ten years ago, the first results of a four-year, nine-flight investigation of the physiological and performance effects of the subgravity state during rocket flight were published by a team of American investigators and engineers in this journal.[13] The work, in which Dr. Gauer collaborated as an advisor, was in part an attempt to answer Gauer and Haber's questions concerning the subgravity state.[1] Monkeys and mice were used, first in captured V2's and later in Aerobee upper atmosphere research rockets specially assigned for these biological studies. The monkeys were placed in chairs and on couches and the electrocardiogram, respiration, systemic arterial and venous pressure were recorded by telemetry. It was concluded that the weightless state had no significant effect upon these physiological indices. Motion picture observations of performance were also made on a labyrinthectomized mouse and upon one trained to climb over a barrier in a slowly rotating, smooth-walled drum. Thus, an attempt was made to disassociate visual and kinesthetic from labyrinthine information: in one case by labyrinthectomy; in the other by providing a perch for the one animal and no possible orienting support for the other. As long as gravity was present to provide orientation, the animals behaved normally. With loss of gravity, the suddenly deprived animal became disoriented. Thus, the labrinthectomized animal did better than his normal control and the animal provided a perch did not display random behavior as did the one without foothold in the drum.

The results were promising, but ballistic rockets offered too short a period of weightlessness to justify further studies and the project was terminated with the above mentioned report which concluded that "the weight of evidence suggested that in currently attainable durations of two to three minutes, the subgravity state will not lead to any serious psycho-physiological difficulties. Investigation of the effects of subgravity states lasting for hours or days must await the development of orbital rockets." Since this event was still several years away, the group turned to other studies after sketching out the requirements for a long-term experiment using a mouse drum.[14]

Subsequent to this first group of V2 and Aerobee ballistic rocket studies, Russia has accomplished further work using dogs. In a review article by Galkin, et al,[15] results are presented from fourteen dogs, some alert and some anesthetized, which were submitted to dynamic weightlessness for a few minutes. The conclusion was drawn that, during weightlessness, the pulse rate and respiration of the alert animals were stimulated by the launch to high levels but decreased after the first two to three minutes of weightlessness and within four to five minutes had returned to their preflight levels. Significantly, in the anesthetized animals, pulse rate, respiration, and blood pressure did not differ during the period of weightlessness from their resting control values.

There were four American ballistic rocket flights of biological interest with a few minutes of weightlessness in the late 1950's. Two were with unanesthetized mice[16] and two with monkeys.[17] No performance data were obtained, but it was observed that the pulse and respiration rates approached prelaunch values during the weightless state.

Orbiting Flights other than the Mercury Series.—Workers in the USSR have successfully recorded data from at least six dogs in two 90-minute and four 24-hour orbital flights. In addition, they have reported the orbiting flight experiences of four men. How far do these hour-to-day-long flights go toward answering Gauer and Haber's questions?

Sisakyan[18] reviewed the data on the alert trained dogs and reported that following the emotional arousal of launch; pulse, respiration, and blood pressure settled to "normal values"; and, in ninety minutes, the pulse and respiration were "comparable to preflight data." During weightlessness, "all physiological functions approached the original level" and it was concluded that this "condition could be tolerated for as long as a day." A food and water supply was provided and body movements were monitored, both by actuation of a counter and by television.[19] Beischer[20] quotes the Russian investigators as observing that "no noticeable deviation in the condition and regulation of the main physiological functions from the usual level recorded under laboratory conditions occurred in the animals." However, in a recent article, Gazenko and Yadovsky do make a passing reference to "a certain unstability of the pulse rate and respiratory pattern suggesting a mild autonomic disturbance."[21]

The first human subject to be in orbit remained there for one and one-half hours. During this time, he reported no difficulties "in the sensory or motor sphere."[21] The second subject made several observations that relate to Gauer and Haber's original questions.[1] He described the usual sensation of tumbling at booster cut-off, prior to initiation of the weightlessness state. Despite this evidence of normal labyrinthine response, he reports no falling sensation during weightlessness. He had no difficulty with hand movements or the use of controls. He ate three meals successfully and slept, at first fitfully, then for several hours. He was able to perform exercises, write notes, and remain, according to his account, clear-headed and cognizant of his situation.[22]

However, after the sixth orbit, the subject reported "unpleasant" sensations of vestibular character which were felt stronger and stronger, especially when he sharply turned his head."[21] After some sleep, these symptoms decreased but did not disappear before the beginning of the "reentry overloads." It is further stated that "the sensation of some discomfort accompanied a considerable portion of the flight and resembled seasickness."[21]

In evaluating the severity of the symptoms, it is worth noting that, according to his account given to the press, the subject ate breakfast, considered shaving, discussed problems connected with reentry, and elected to parachute instead of staying with the capsule.[22] Nevertheless, the first subject's sensations raised interesting questions which, according to the accounts given to the press have had light thrown on them by the four and three-day orbiting flights of the Vostok 3 and 4. The reports from these flights describe the subjects' freedom from any symptoms, attributing this to a "new" "diversified" training program. It was stated that they had no nausea or other symptoms suggestive of motion sickness throughout these prolonged flights. Their condition at recovery was described as excellent and the pilot of Vostok 3 states that he "did everything during flight as though he was on the ground." The reports point to no major incapacitation by periods of weightlessness lasting up to four days.

Methods in the Mercury Flights.—The techniques employed to gather biological data during the Mercury flights have been described in the individual flight reports MR-2 and MA-5 (23), MR-3 (2), MR-4 (3), and MA-6 (4). To be considered are two animal and three manned flights. Three were ballistic firings, each yielding about six minutes of weightlessness (MR-2, 3 and 4) and two were orbital (MA-5 and 6), giving about 180 and 270 minutes, respectively. The first of the animal flights preceded the two manned ballistic shots and the other preceded the first manned U. S. orbital flight. Because the purpose of the animal flights was to verify the life support systems for the man, at attempt was made to use the same biosensors, and the animal couch was substituted for the pressure suit in the Mercury environmental control system.[23] The bioinstrumentation techniques employed are described in the individual flight reports[2-4,23] as well as in a special report by Wheelwright.[24]

Performance of the astronauts was determined by analysis of the voice records, by study of the onboard camera films, and by analysis of the manner in which the various tasks assigned them were accomplished. These included the working of the hydrogen peroxide jets controlling capsule attitude.[2-4] Behavior of the chimpanzee was assessed by means of operant behavior techniques. In the ballistic flight, a complex avoidance task, using two levers, was employed.[25] This consisted of the Sidman[26] avoidance procedure which required the subject to respond by pressing one lever continuously, or at least every fifteen seconds, to avoid an electric shock, and a discriminated avoidance task in which the animal was required to press a second lever within five seconds following presentations of a blue light, in order to prevent the occurrence of shock. This provided a measure similar to reaction time.

In the orbiting flight, a multiple schedule was employed which included three additional components:[27] a fixed ratio procedure in which the chimpanzee responded 50 times to obtain a pellet of food; a differential reinforcement of low rate procedure[28] which required the animal to pace his responses at least twenty seconds apart in order to obtain a water reward. An odd symbol discrimination task was used in which the animal selected the odd of three symbols (triangle, circle, square) (18 sets) displayed to the animal. Performance on the latter procedure was reinforced by shock.[29]

Results of the Mercury Flights.—Although the duration of weightlessness in the three ballistic flights (MR-2, 3 and 4) under consideration was only six minutes, this was already ten times as long as had been routinely achieved in aircraft weightless studies.

The animal data from the MR-2 flight showed his unimpaired efficiency.[23] Respiration rate returned to normal preflight values during weightlessness, after the rise which followed firing of the escape rocket at the end of the powered phase of flight. Heart rate followed the same pattern and returned towards normal resting values during the six minutes of weightlessness, as was described by the Russian workers.

Reactions to the four blue lights, presented during weightless flight, were all well within the preflight range. On the Sidman avoidance task, the subject responded at his normal rate of approximately once a second until at the 18g peak escape-loading acceleration, when he received a shock for failure to respond within the twenty second period. During the entire weightless state, his rate was normal, falling off only after the reentry acceleration. Postflight recovery examination revealed nothing that could be attributed to the weightless state.[23]

The human results suggested that pulse and respiration actually reverted towards normal during weightlessness. Performance was unaffected and control accuracy was unimpaired.[2,3]

Neither the human nor the animal data in the ballistic flights showed any impairment as a result of the weightless state.[3,23] What then of the animal and manned orbital flights? Does the longer duration of exposure lead to symptoms?

hours of weightlessness, falls back to prelaunch on-the-pad values. Further comparative studies have been made of this animal on the centrifuge. It appears to have developed vascular hypertension during the months preceding flight[23] and will be studied further. Pulmonary arterial

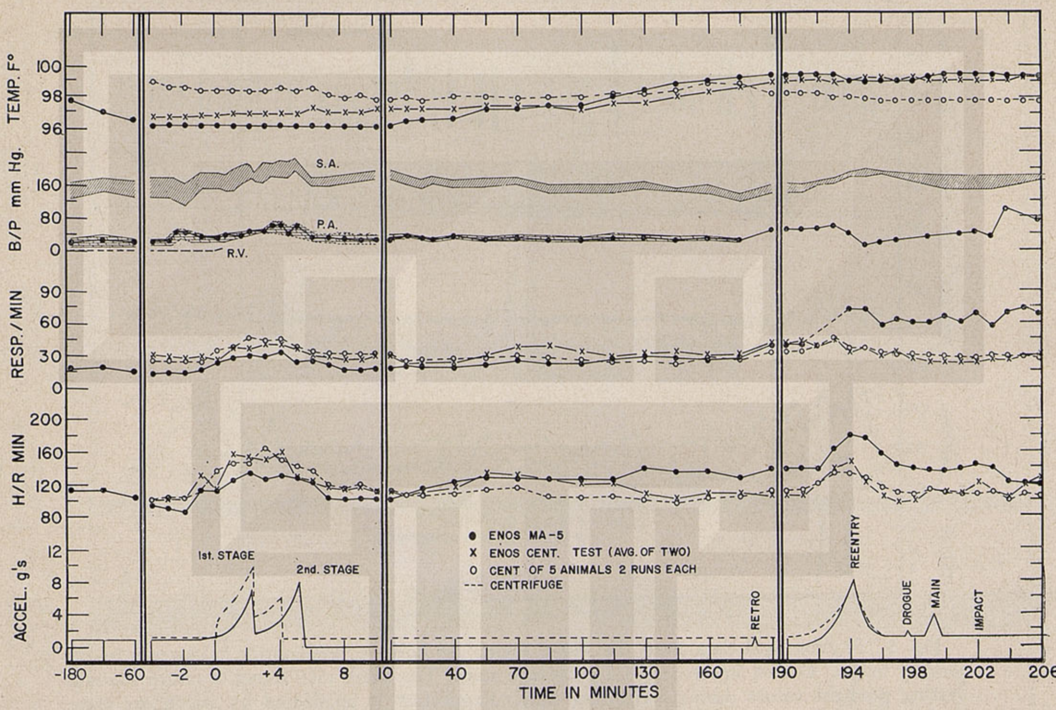

Fig. 2. Physiological data from the MA-5 chimpanzee flight. At the bottom: acceleration transverse to the subject in g's. Dotted lines represent centrifuge trials. The heart rate, in beats per minute, shows the parallelism of centrifuge and flight data. Respiration shows an increase during and after reentry, possibly due to the oscillation of the spacecraft. PA shows mean values (solid circles) and pulse pressure in the pulmonary artery. RV represents the pressure in the right ventricle during diastole which was obtained during countdown and, briefly, during flight. SA represents systemic arterial pressure as recorded by direct catheterization. Note high values during three hour control period prior to launch. Temperature during flight approximately parallels centrifuge experience.

Mercury Orbital Flight Data.—Figure 2 shows the cardiovascular and respiratory data obtained during the animal orbiting flight.[23] They are compared with control values determined on the centrifuge during simulated Atlas orbiting flights.

Body temperature remains well within acceptable limits, only reflecting moderate changes in inlet and capsule wall temperatures. Systemic arterial pressure is high in this animal, but this is a sustained high resting value as the three hours of on-the-pad record indicates. It rises further following launch but, with the three pressure runs at slightly elevated values and is not changed by weightlessness.

Premature ventricular contractions occurred during orbiting flight. As is discussed by Henry and Mosely,[23] the presence in the right ventricle and orifice of the pulmonary artery of a fine polyethylene tubing, intended to measure thoracic inferior vena caval pressure, was probably responsible for these events, which were without effect upon the animal's performance.

Respiration rate is unchanged by weightlessness, but rises following reentry in comparison with centrifuge data. This rise may represent a response to apprehension engendered by the oscillations of the capsule during reentry and when on the descending parachute; these oscillations were not reproduced in the centrifuge runs.[4] Pulse rate, like respiration, is relatively unaffected during launch and the first hour of weightlessness.

Figure 3 shows the comparable data from the manned orbital flight of MA-6.[4] The flight data are again contrasted with those from centrifuge studies in which the subject and other astronauts participated. Blood pressure, as measured with the autosphygmomanometer, is presented for the subject's centrifuge run by the open bar data and for the orbiting flight with a solid bar.[4] The mean systolic and diastolic values for the six astronauts tested on the centrifuge is represented by the continuous envelope. The rather large pulse pressure during orbiting flight is interesting, but not outside the range of normal physiological variation. It may in part represent a warming of the body with consequent vasodilation of the skin. Body temperature records are clearly within tolerable limits. Respiration is quite uneventful and the pulse rate, during the flight, shows the acceleration over control values that might be expected in view of the significance of the flight. It is interesting that the reentry acceleration does not lead to the highest pulse rate, as might have been expected if the prior four and one-half hours of weightlessness were having an adverse effect. Rather, the peak pulse rate is during the ensuing period of oscillation of the spacecraft on the drogue chute.

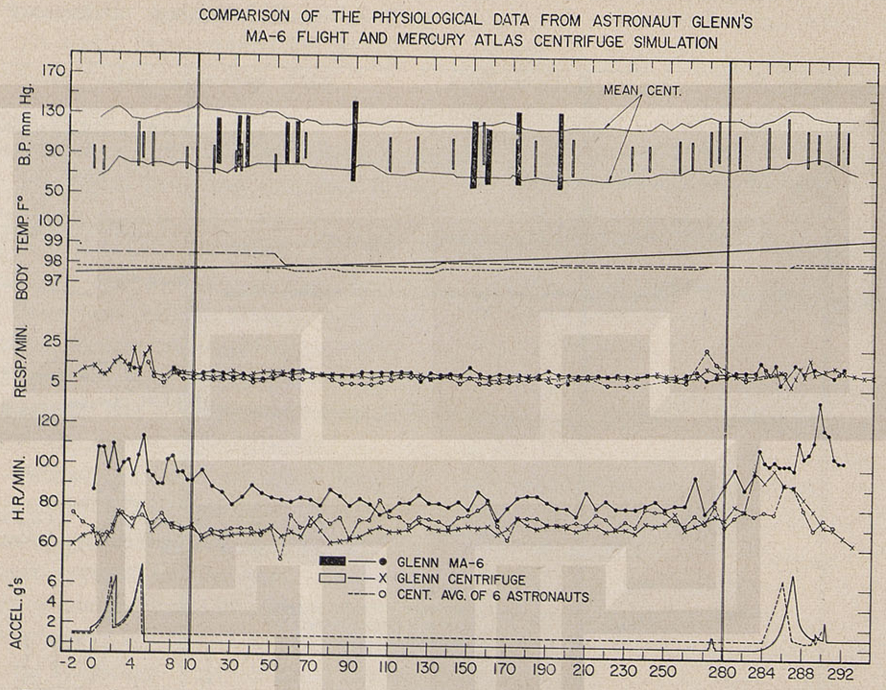

Fig. 3. Physiological data from the MA-6 flight. At bottom: acceleration transverse to the subject in g's. Dotted line represents centrifuge runs. The heart rate shows a return towards resting preflight values during weightless state. Respiration is unaffected by weightless state. Body temperature stays within normal values during flight (solid line). Blood pressure during the flight (solid bars) differs from centrifuge controls (open bars) showing a greater pulse pressure. Continuous lines represent mean of systolic and diastolic centrifuge blood pressure observations on six astronauts.

Performance of the animal during the orbital flight is shown in Figure 4 which summarizes the detailed reports of Rohles, Grunzke and Reynolds on the MA-5 flight.[23,30] The five components of the performance schedule are shown in relation to the accelerations of launch, the period of zero g, and the reentry acceleration. The sequence of presentation of each of the performance tasks is presented here, as well as "time out" or rest periods, indicated by the vertical arrows. The inflight mean (heavy horizontal line) is overlaid on the animals preflight performance. The shaded band represents one standard deviation on either side of the preflight mean and is based on many hundreds of measurements on this animal. It will be observed that the inflight mean falls within one standard deviation of the preflight mean, for all performance measures. The degree of control maintained over the animal is indicated by the absence of responding during "time out" periods.

With regard to the motivational status during flight, it can be stated that no major alterations in behavior occurred, whether the performance was reinforced by food, water, or aversive stimuli. It is also of interest that performance on schedules such as fixed ratio and DRL, in which the animals' own responses play a major role in maintaining the behavior, is not adversely affected by the weightless state in which proprioceptive and other internal stimuli are presumably altered.

Figure 5 shows the performance of the astro-

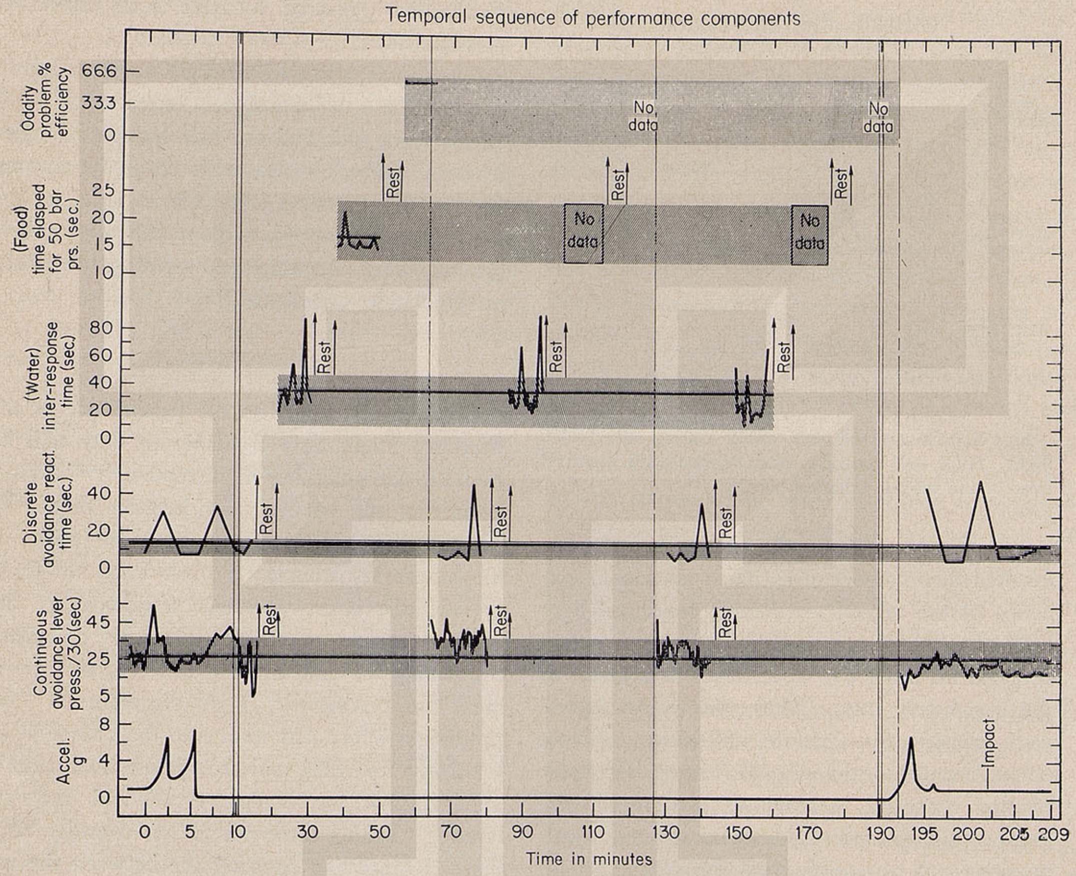

Fig. 4. Performance data obtained during MA-5 chimpanzee flight. At bottom: Acceleration transverse to the subject in g's. For each of the performance tasks indicated on the ordinate, the shaded bands indicate one standard deviation in each direction from the preflight mean. Transverse heavy line is arithmetic mean of flight performance. Time out periods are shown by two vertical arrows.

naut during the period of manual control systems check of the orbiting vehicle.[3] It is evident that he was performing within the standard attained in his previous experience with the simu-

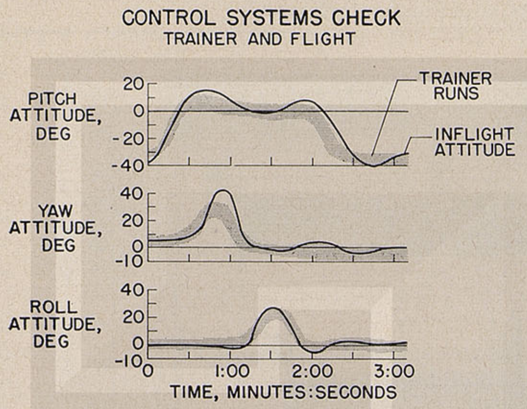

Fig. 5. Control systems check during the MA-6 flight. Solid line contrasts performance with mean of runs in the trainer (shaded bands).

lator as represented by the shaded band.[4] The detailed flight report gives much additional evidence of the orbital astronaut's continued high level of performance, and his clear introspection revealed no subjective disturbance as a result of the weightless state. Thus, the voice reports were consistently accurate, confident, and coherent throughout the weightless state. The voice quality conveyed a sense of continued wellbeing. His prompt responses to ground transmissions and to sounds from the spacecraft indicated that he experienced no decrement in hearing ability. Visual acuity was maintained, and the fact that his reports of visual perceptions were accurate was confirmed by in-flight photographs.[4]

The weightless state was associated with no disturbances in spatial orientation. Voluntary, rapid head-turning movements induced no unpleasant sensations suggestive of vestibular disturbance. This, despite the fact that the report of a brief sensation of tumbling forward occurring after sustainer engine cutoff and a feeling of backward acceleration with retrorocket firing, showed that his vestibular sensitivity was not abnormally depressed. Weightlessness did not disturb the act of food chewing and swallowing or micturition. Indeed, to the MA-6 astronaut, the four and one-half hours of weightlessness were described as a "pleasant" sensation and his physiological functions and performance during the period appeared to have been essentially undisturbed.[4]

The results of the MA-7 flight confirmed those of the MA-6. The subject experienced no ill effects from four and one-half hours of weightlessness. Indeed, he was relieved of the discomfort of the pressure suit. He experienced no nausea, ate and drank without difficulty and, in general, found the weightless aspects of the flight an enjoyable experience.[31]

DISCUSSION

Detailed comments on the significance of the Mercury Flight data available to date will be found in the individual flight reports.[2-4,23] When evaluating the results, consideration should be given to the fact that the primary objectives of the pioneering Mercury project were not those of scientific data collection. Furthermore, the closing remarks of Graybiel and his associates concerning the difficulties of this type of experiment are pertinent.[17] They comment on "the prodigious effort that went into the collection of relatively few data and the almost innumerable opportunities for human error and material failure." Taking these points into consideration, there is gratifying concordance between the results that were achieved and the data of other workers, both in the United States and Russia. There is also very satisfactory correlation between the performance information and the physiological data. This has often been missing in the past, even in experiments conducted under far more favorable circumstances.

It is important to recognize the potential limitations of the data from the Mercury studies due to the fact that they have been carried out in subjects that were firmly held in place and, consequently, had good spatial orientation and kinesthetic sense of their position. Furthermore, they were excellently oriented by visual sense being thoroughly familiar with the capsule interior and, in the case of the animal, with the pressurized couch. However, when combined with the work of the past fifteen years with humans and with animals, in parabolic aircraft flights[8-11] with water immersion tanks,[32-36] and with ballistic rockets,[13,20] the work with orbiting rockets has made it possible to frame a further interim answer to the questions raised by Gauer and Haber[1] and to say that no significant disturbance has occurred in properly oriented subjects subjected to the weightless state for periods up to hours. Indeed, the subjects of the Vostok III and IV appear to have practiced acts of fine hand-eye coordination such as threading a needle when floating detached in the spacecraft: it appears that orientation is feasible even when not firmly held into a seat.

Conceptual analysis of the weightless state has suggested several problems which may be encountered during and following a prolonged exposure to zero g which lasts longer than the periods that have, so far, been available to us. Answers are being found to these problems as the capability for prolonged flight rapidly develops. The first condition suspected is that of "space sickness" due to changes in utricular afferent information and to conflicting visual and proprioceptive stimulation. Whether problems of this nature will develop and whether adaptation will occur is currently receiving energetic attention.[37-39] The slow rotating room is being employed by Graybiel for investigating the Coriolis effect that arises when an attempt is made to replace gravity by radial acceleration.[38-41] Since acclimatization to labyrinthine disturbances due to wave motion occurs within a few days, it is reasonable to hope for a similar acclimatization to any disturbing influences of weightlessness. Reports of the three and four-day Russian flights support this thesis with their statement of freedom throughout from any symptoms such as nausea or loss of appetite.

Another question that has been raised is that of the possible "hypodynamic" effects of weightlessness on the circulatory system and the extent to which it may lower tolerance to subsequent reentry acceleration.[35,36] Disturbances of this nature would not occur immediately but would take several days. Hopefully, the effects will not differ significantly from those accompanying prolonged bed rest or the use of a water tank, but a major immediate objective should be to determine ways of preventing any deterioration by means, for example, of pressure cuffs on the limbs,[42] or pressure breathing. In actual flights, determination of the changes should be readily observable by using simple cardiovascular performance tests. However, the loss of blood volume and the changes of vascular reactivity that may accompany the weightless state would not necessarily lead to a significant disturbance in the tolerance of the transverse acceleration of reentry; for, in this condition, the hydrostatic columns are effectively in abeyance. The limiting condition is rather the blood distribution in the lungs. Here again the reports of the Vostok III and IV flights are of interest. It appears that reentry accelerations after three and four days of weightlessness were tolerated without loss of consciousness. Tolerance was attributed to preflight centrifuge training, regular in flight exercises and "special" exercises during the orbit just preceding reentry.

It has also been suggested that the digestive processes may become disturbed during the weightless state.[43] This certainly is an area of interest which must be followed closely. Tests of function of the gastrointestinal tract need not be elaborate in order to detect gross disturbances. It should only be necessary to be sure that all food given is eaten, to record symptoms such as malaise or loss of appetite, to follow nitrogen and inorganic ion balance, and the course of excretion of a marker pill such as carbon black and a non-metabolized sugar such as Xylose, in order to have reasonable clinical assurance whether this system has or has not functioned properly in the weightless state. It is significant that the Xylose absorption test carried out in the MA-6 flight showed normal results.[4] The available reports of the three and four-day Vostok flights support the briefer Mercury experiences. The Russians were reported as eating solid food at regular "mealtimes" throughout the flights without nausea or other digestive upset or loss of appetite.

As the duration of weightlessness extends from days to weeks, further questions concerning the effect of the prolonged condition upon the bones and muscles arise. As Lawton[44] points out, adequate exercise of the muscles should not only keep this system in tone but also, by the stimulating pull exerted on the bones, should prevent atrophy. Future studies carried out in prolonged flights will show whether this is indeed the case.

Another area of interest, in which it has been proposed that the weightless state might lead to disturbance, is the question of restful sleep and the diurnal rhythm that plays so large a part initiating it. The mechanisms of sleep have received much attention recently. The work of Jouvet[45,46] and Candia, Favale, Guissani and Rossi[47] suggests two fundamental phases: light sleep characterized by EEG synchronization, moderate muscular tonus and a resting waking blood pressure level; and rhombencephalic or "deep" sleep characterized by EEG desynchronization, complete muscular relaxation and a marked decrease of the blood pressure. There is evidence that dreaming occurs during "deep" sleep and that a certain amount of dreaming is important to the organism.[48] It would be of great interest to determine whether the weightless state in any way disturbs this sleep pattern and the diurnal rhythm associated with it. The statements in the press that the pilots of the last three Vostok flights "slept well in outer space" and on schedule for approximately seven hours each day "without disturbing dreams" suggests that for periods up to four days the weightless state does not grossly disturb this function.

While it would seem probable that weightlessness, per se, would not pose any threats to life, it may lead to subtle, or perhaps gross, changes in efficiency at the behavioral level. It is unknown whether there would be increased susceptibility in the weightless state to the sensory deprivation syndrome[40] were the subject left relatively unoccupied and, perhaps, floating for days or even months.[50] It is unlikely that man in space will, in the immediate future, be faced with situations in which there will not be the distraction of compelling tasks to prevent the development of symptoms. However, the development of behavioral techniques requires extensive study, not only for the prevention of symptoms, but for constructing an environment which will support optimum functioning and efficiency.

Hence, while not overlooking the possible disadvantages of zero gravity, it should be the aim of research, not so much to dwell on its deleterious effects nor merely to record the effects of passive exposure to it, but to design experiments in which our subjects interact with it so as to explore its unforeseen advantages—advantages which the first orbiting explorers have so vividly recounted.

SUMMARY

1. Data on weightlessness from work with aircraft and ballistic and orbiting rocket flights is briefly evaluated and described in relation to the results of the Mercury MR-2, 3, 4, MA-5, 6, and 7 flights. It is concluded that:

(a) A person firmly attached to his work place can carry out complex visual-motor coordination tasks proficiently for prolonged periods.

(b) Orientation is little problem if visual or tactile references are present.

(c) Respiration, digestion, eating and micturition appear to be unaffected by exposure to the weightless state for periods of hours to days.

(d) Weightlessness does not cause gross changes in the circulation within the course of a few hours and reentry has been tolerated after several days.

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The results presented in this report comprise a complex team effort that required, in addition to those cited as authors, the collaboration of a large number of people in the most varied branches of engineering and biological sciences.

Acknowledgment of some of those responsible is to be found in the technical documents describing the individual flights. It is only possible

to say that the unstinting cooperation of the entire group is remembered with appreciation as one of the most stimulating features of the Mercury project.

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EFFECTS OF WEIGHTLESSNESS

Definition

The weightless state is not merely attained when the vehicle is so far away from a heavenly body such as the sun and planets that there is no longer any significant gravity pull Fig 11. It ~~is~~ can be achieved in orbit because the force with which the earth pulls an object towards itself is countered with another equal and opposite force -- the force of inertia or the centrifugal force resulting from the fact that the vehicle is moving constantly in an circle around the earth and hence must constantly change direction. The gravity pull required to induce this change in direction exactly balances the force of inertia tending to keep the vehicle flying straight. (~~Fig~~). So not only does the space vehicle float weightless in space but also all objects within it float free of the supporting floor. This is different from the state of the man who tries to imitate weightlessness by floating in luke warm water. In this case although he himself may float, a heavy object within his body is pulled down on the wall of the cavity containing it by the force of gravity. Thus a steel ball swallowed by a man when in the weightless state will drift about freely within his stomach but if swallowed while he is floating in water the ball continues to press on the stomach wall. The tiny otoliths in the semicircular canals are like this steel ball. In weightlessness they float free and the organism receives different information when these parts of the balancing apparatus in the labyrinth do not experience a force exerted on them from a gravitational field. This is one reason why floating in water does not form a perfect equivalent for weightlessness. Weightlessness can be produced for about half a minute by making an airplane follow the ~~same~~ path ~~that~~ of a stone ~~would if~~ thrown upwards ~~in the atmosphere~~ and allowed to fall freely without atmospheric resistance. Throughout the period of free fall there will be no pressure of