Selection and Maintenance Program for Astronauts For the National Aeronautics and Space Administration

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OVER the past ten years, through the stimulation of the U. S. Air Force Research and Development Command,† the Lovelace Foundation has developed a program of special examination and evaluation procedures for determination of the state of the physical, mental, and social well-being of preselected and highly experienced test pilots. Far more than the absence of disease has been determined. The long-range objective of this program has been to ascertain whether or not a particular pilot has the capacity to live, observe and do optimal work in the environment of space and return safely to earth. In contrast to classical medicine—where the stressing agent on the body is disease—in aviation and space medicine, the stressing agent on the normal subject is the environment. Knowledge of congenital or pathological conditions that may be incompatible with the hazards of a particular type of mission are assessed from the standpoint of the individual's physiological and psychological ability to withstand the specific stresses involved in a particular space mission. It has been accepted that some compromises will be necessary between the physiological and environmental parameters, but Lovelace and Crossfield[1] feel these will be within an acceptable margin of safety. In the past, pilots have undergone exhaustive test procedures prior to the selection of those with the best overall tolerances and capabilities for flights involving unusual stress in very high performance aircraft such as the X-15.

In 1959, the staff of the Lovelace Foundation and Clinic were asked by the National Aeronautics and Space Administration to consider conducting an examination program for potential space pilots. The final details of the examination procedures used for the astronaut candidates were determined by the members of the Special Committee on Life Sciences to the National Aeronautics and Space Administration, meeting together with representatives of the armed services at the Langley Research Center, Virginia. Close liaison was maintained with the Aerospace Medical Laboratory, the Air Force School of Aviation Medicine and the Navy School of Aviation Medicine as well as the Armed Forces-National Research Council Committee on Bio-Astronautics established by Dr. Detlev Bronk, President of the National Academy of Sciences.

Graduates of service flight test schools were

From the Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico.

Presented at the Second International Symposium on Submarine and Space Medicine, Stockholm, Sweden, August 18, 1960.

Analysis of the data from this program was done in Colorado Springs, Colorado, and was made possible by a grant from the El Pomar Foundation. This work was initially supported by a contract with the U. S. Air Force and subsequently by the National Aeronautics and Space Administration in 1959.

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†The authors wish to express their gratitude to Brig. General Don D. Flickinger, M.D., USAF, whose stimulating and administrative guidance was largely responsible for this work.

selected as potential space crew members because of their high intelligence, versatility, knowledge of the problems of hazardous and difficult test flying, and their flying and engineering experience with attendant frequent exposure to noise, altitude, vibration, orientation and navigation problems, acceleration and combinations of the above stresses. They have demonstrated repeatedly their ability to withstand stress. Pilots of this type are stable, mature, highly motivated, accustomed to making decisions rapidly and have a capacity for making and documenting observations concerning the environment around them and the effect of a hostile environment on themselves and their vehicles.

PHASES OF PROGRAM

The examination of the astronaut candidates for Project Mercury was done under the auspices of the NASA in four phases.

The first phase of the selection program was to review the records and qualifications of jet pilots under 40 years of age, less than 71 inches in height (180.34 cm.), who were in excellent physical condition, graduates of an Air Force or Navy flight test school with a university or college degree in one of the engineering or physical sciences and with at least 1500 hours of flying time—much of this time to be in jet aircraft. Out of 100 test pilots who met the above qualifications, 69 were then briefed on the plans for Project Mercury in Washington, D. C., by representatives of the NASA. Fifty-five volunteers were interviewed and given psychological tests, written examinations, and had a review of their past experiences and accomplishments. Of this group of volunteers, 31 very outstanding men were selected to proceed in the program. They ranged from age 27 to 38 with an average age of 31.3.

The second phase of the program consisted of determining each candidate's history and the medical and physiological tests done by the Lovelace Foundation staff.

The third phase, at the Aero Medical Laboratory at Wright-Patterson Air Force Base, concentrated on determination of tolerances to meaningful physical stresses such as could be encountered in space flight.

The fourth phase, also done at the Aero Medical Laboratory, was concerned with psychiatric and psychological evaluations.

MEDICAL AND PHYSIOLOGICAL PROGRAM AT THE LOVELACE FOUNDATION

Woodbury[2] has emphasized that all of the life sciences have the following in common: That something is observed, something is selected for recording (sampled), something is recorded in some form or other (coded), something is done to it (analysis), or it is put away for further use (store), and in most cases used later (retrieval). A major reason for slow utilization of the revolutionary improvements in data handling in the life sciences has been lack of personnel familiar with the use of such equipment and with what type of processing is appropriate once the computer stage is reached.

All the information concerning each one of the astronauts was placed on color-coded machine mark sense cards (IBM) designed by one of us (A.H.S.).[3] The use of these cards free more of the physician's time and talents for diagnosis and study, and insure accuracy and comparability of records, as well as ready accessibility to the data. Marks are made on the cards with a special electrographic pencil. As the cards pass through a machine, which has small metal brushes, electrical contact is made across the pencil mark causing a hole to be punched automatically just under it. Duplicate cards can then easily be made and a number of studies can thus be made simultaneously if desired. Such copies can also be sent to other medical groups as was done in this case when copies were sent to the Wright Aero Medical Laboratory. Because the pertinent information is recorded by the holes, these cards are easily interpreted without the necessity for a code or key providing physicians and others the information they require. The process of automatically punching holes in the original pencil-marked cards and providing five duplicate sets of cards

on each of six candidates seen every week took approximately two hours.

Any system adopted for the machine processing of astronaut data should be of great utility from many aspects because of the capability to recall or retrieve information promptly and completely. Among the uses are the following:

1. Complete review of all pertinent medical and physiological characteristics.
2. Comparison of present status with past status in regard to any chosen characteristic.
3. Assessment of current status of qualification for a given mission task.
4. Rate of progress compared to norms or averages.
5. Study of individual alterations which might result from repeated space flights, aging deterioration, pathological processes and the like.
6. Prediction of future career limitations from evidence indicating a deterioration pattern in some significant characteristic.
7. An idea of the rate of physiological aging rate (PAR) as compared to chronological age.

The personal, past, and family medical history, the aviation history, and the physical examination, together with the many medical specialists' examinations and the laboratory and radiological procedures were considered in the nature of a static test of the human body at rest. These provide a history of the patient's past and the current status of his physical condition. This is the extent of most medical examination procedures.

It was believed desirable to determine the maximum physical effort that could be safely exerted by these individuals and the efficiency of these efforts. This dynamic testing was done in connection with the physiological tests for pulmonary function and physical competence performed by one of the authors (U.C.L.). These tests had been validated by over 600 past determinations to establish the normals and the range of variation by sex, age group, body type, and also for certain pathological conditions.

All examinations of these flying personnel were carried out under the direction of the Department of Aviation and Space Medicine, headed by a flight surgeon (A.H.S.). This department was responsible for briefing the pilots concerning the purposes and techniques of the tests; scheduling and integrating the numerous tests; and for guiding and orienting toward the medical and physiological problems of flight in the atmosphere and in space the numerous specialists in the different branches of medicine and surgery as well as the paramedical personnel who performed the different examinations. The candidates were examined in groups of six and each group was at the Foundation for a week. A typical schedule is given in the Appendix to this article.

A complete history was taken. Particular attention was given to a complete family history and to the attitude of the immediate family toward hazardous flying; the subject's growth and education; hobbies; recent travel to areas where parasitic diseases are endemic; food intolerances; the effects of loss of sleep, excessive smoking, previous exposure to extremes of heat and cold and any disorders precluding pressure inflation of the lungs, ears or sinuses. The history cards (Fig. 1) and the Cornell Medical Index Health Questionnaire may be completed by the individual who may ask questions of a nurse or physician as he proceeds with this task.

The aviation history covers the individual's experience in flying. One of six of these machine record cards (Fig. 2) indicates how numerical information, as distinct from "Yes" and "No" type of information, may be recorded in a readily understandable form. The total number of flying hours including the average altitude flown in respect to both ambient altitude and cabin altitude was obtained. The type of aircraft flown was recorded from previous coded lists. Military experience, both in peace and war time, was also obtained and war experience was recorded on the basis of number of missions, combat hours, and type of missions. All aircraft accidents, either major or minor, including any injuries, based on a coded system of type and anatomic location, were recorded. Experience with the ejection seat was recorded in

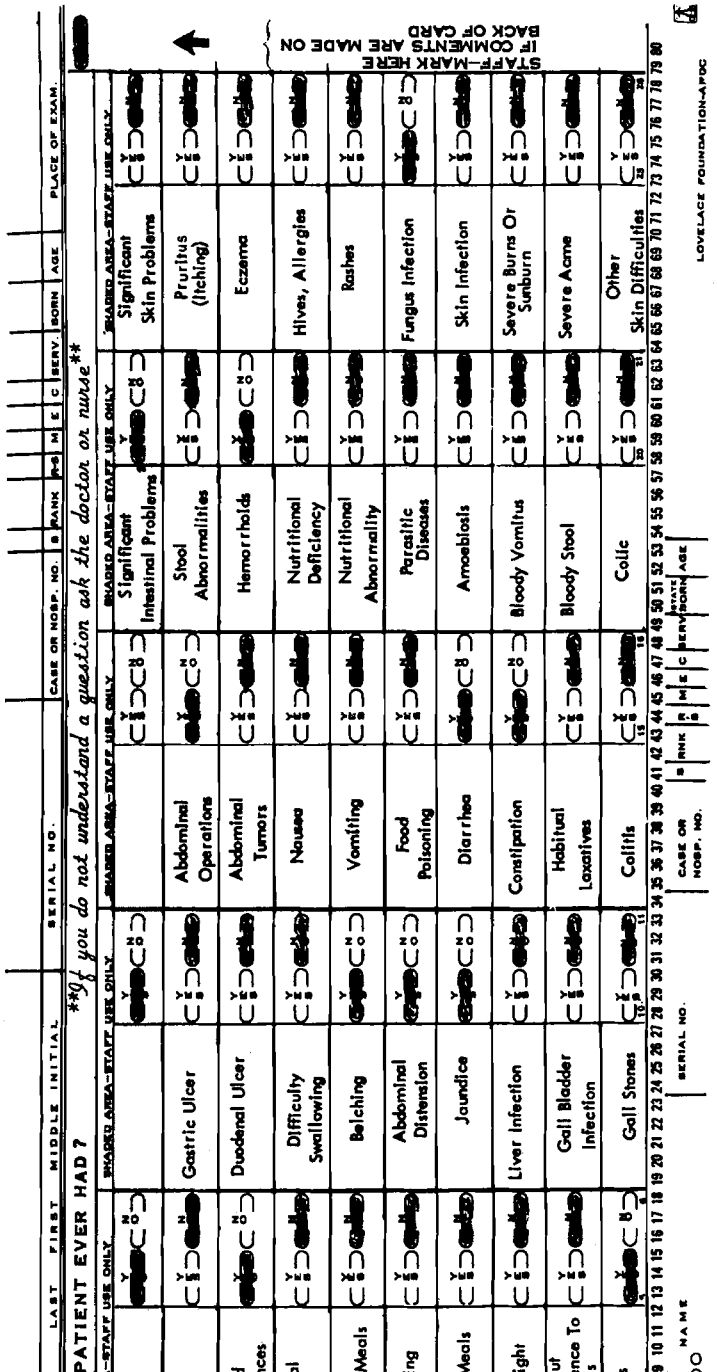

Fig. 1. Medical History (one of nine cards). Can be filled out by patient with assistance of a nurse. Reviewed by physician and indicated in shaded area.

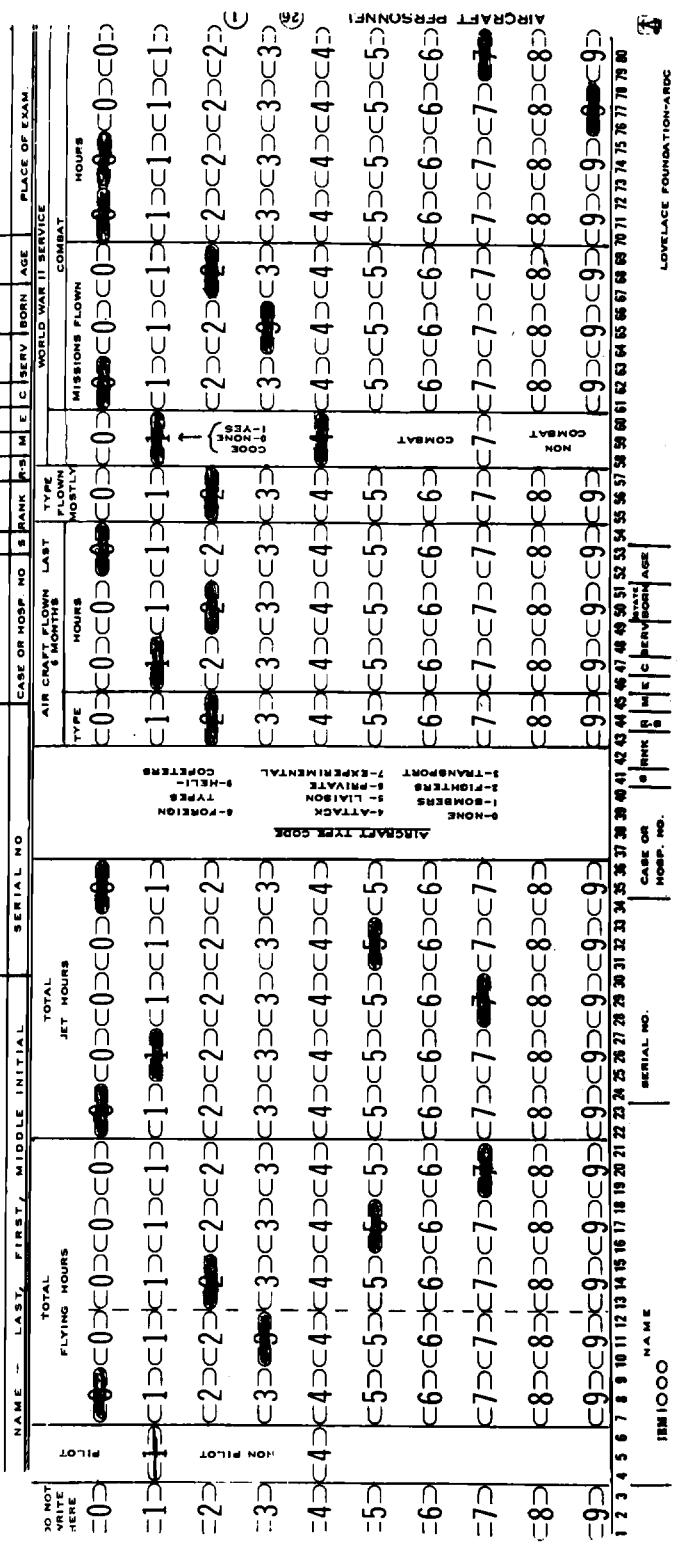

Fig. 2. Aviation Background (one of six cards). Provides all essential information on the individual's flying experience.

detail. Altitude chamber results, intentional and operational explosive decompressions, and experience with partial pressure or full pressure suits were recorded.

PHYSICAL EXAMINATION

A complete physical examination was done by a physician who is both an internist and flight surgeon (R.R.S.). The physician records his findings on physical examination mark sense cards. It should be emphasized that pertinent comments may be written on the back of the cards in ink. The presence of such remarks on the reverse side is indicated by a mark in the upper right-hand corner of each card. These comments may be copied by hand or typewriter on the backs of duplicate cards but as yet are not recorded automatically.

As soon as the initial history and physical examinations were completed, the findings were reviewed with the object of directing special attention to certain organs or systems. There were a number of examinations performed on each candidate by specialists in their respective fields, such as proctosigmoidoscopy by a surgeon.

After a special history the following examinations were done in the ophthalmological section by Dr. E. H. Wood: The eyes were refracted, using a cycloplegic; visual fields were done on each eye, and a gross binocular field study made. The red lens test was used for this purpose. Tonometry was done, together with slit lamp studies, depth perception and dynamic visual acuity. The dynamic visual acuity used was a determination of the visual acuity in each eye on a moving visual acuity test target within 10 seconds of time. For this test, an American Optical Stereo Orthopter was used for which special Snellen Test cards were made. The acceptable standard for this test was reading through the 20/40 line within 10 seconds. In general, for the eye examinations, the United States Air Force standards were used with due consideration being given to the age and experience of the candidates. Dark adaptation studies were made in the usual manner after 30 minutes of dark adaptation in a totally dark room, and using the Radium Plaque Night Vision Tester developed by the Wright Field Aero Medical Laboratory. Finally, a color photograph was made of the conjunctival and retinal vessels after a careful inspection of the eye and an ophthalmoscopic study.

The otolaryngological tests consisted of the standard examinations of the ear, nose and throat performed by Drs. H. W. Merideth and D. E. Kilgore, Jr., including visual inspection, indirect laryngoscopy and nasopharyngoscopy. In this connection one of the totally unexpected findings was a benign tumor 4 mm. in diameter on a vocal cord. This was removed, and the candidate was permitted to continue in the program. Complete audiometric threshold study and speech reception and discrimination tests were done in a specially constructed soundproof room constructed by the Industrial Acoustics Company for the Foundation. Allison Audiometric Equipment was used together with Vicon High Fidelity Sound Recording Equipment for recording normal speech. For this purpose, a special paragraph, prepared by Van Riper,[4] was read by each candidate. It contained all the test sounds usually found in the English language and read as follows:

> You wish to know all about my grandfather. Well, he is nearly 93 years old; he dresses himself in an ancient black frock coat, usually minus several buttons; yet he still thinks as swiftly as ever. A long, flowing beard clings to his chin, giving those who observe him a pronounced feeling of the utmost respect. When he speaks his voice is just a bit cracked and quivers a trifle. Twice each day, he plays skillfully and with zest upon our small organ. Except in the winter when the ooze or snow or ice prevents, he slowly takes a short walk in the open air each day. We have often urged him to walk more and smoke less, but he always answers, "Banana Oil!" Grandfather likes to be modern in his language.

Tests of labyrinth function were done by the standard caloric method. The external canals were carefully cleansed of all wax. Then 30 cc. of water at a temperature of 10 degrees Centigrade was directed against the membrane tympani in 30 seconds. The average duration of

nystagmus is approximately 100 seconds, plus or minus 20 seconds. The rate of onset of nystagmus and the equality of response bilaterally is also considered in evaluating this function.

Examinations by a cardiologist, Dr. J. K. Conrad, included the use of the tilt table test in conjunction with the staff of the Physiology Section. After a control period of five minutes in the supine posture, the subject was tilted to an angle of 65 degrees for 20 minutes and then returned to the supine position for a final five-minute period. Measurements of heart rate and blood pressure were taken each minute and the electrocardiogram recorded every five minutes. Such a change in posture calls for immediate and sustained circulatory adjustments to insure adequate cerebral blood supply by counteracting the pooling of blood in the dependent parts of the body. Most individuals show an increase in heart rate and minor changes in blood pressure. Poor circulatory reactivity becomes apparent in a greater rise in heart rate with narrowing of the pulse pressure which may lead to collapse that is immediately reversible on return to the supine posture. The test provides information on the stability of the pressor-reflex mechanisms and the effectiveness of vasomotor control by the autonomic nervous system. The test has also been recommended to detect relative coronary insufficiency from the electrocardiogram. Lack of sleep or adequate rest and recent acute illness influence the results so much that re-examination may be necessary.

Electrocardiograms, using the standard thirteen leads, were made as were the double Master's[5] two step tests. Vectorcardiographs, phonocardiographic and ballistocardiographic studies were also made. The machine record card used by the cardiologist for recording the electrocardiographic findings is illustrated (Fig. 3).

A test was done to detect the existence of minute openings between the right and left chambers of the heart that are too small to cause symptoms or give clinical signs. This is important because of the possibility of explosive decompression with resultant aeroembolism. The presence of an atrial septal defect or patent foramen ovale can be detected by the method of Lee and Gimlette[6] without performing cardiac catheterization. A continuous recording was made of the arterial oxygen saturation with an ear oximeter. The patient performed a Valsalva maneuver by blowing against a 40 mm. mercury column for 20 seconds. The Valsalva maneuver produces characteristic pressure changes in the chambers of the heart resulting in a transient right-to-left gradient in the atria immediately after the pressure maneuver. In the presence of a defect between the right and left atria, some venous blood will be transferred to the arterial system and a transient reduction in oxygen saturation is registered on the oximeter placed on the ear lobe.

A neurological examination was done by Dr. B. T. Selving including: Testing of the reflexes and coordination; and determination of the normalcy of the cerebellar function and the position sense along with other sensory tests. The conduction velocity of the right ulnar nerve between the elbow and wrist was measured using an electronic stimulator of the constant voltage type. The stimulator was used to trigger the sweep of an oscilloscope beam so that the latency period and response could be photographed, analyzed and measured. Also, an electromyographic examination of the right hypothenar muscles was performed by Dr. L. D. Amick with a coaxial needle electrode. Electrical activity occurring in the muscles on voluntary activity and denoting motor unit action potentials was observed on an oscilloscope. All the values were well within normal limits.

A standard electroencephalographic test, using both monopolar and bipolar readings, was performed with the Grass eight-channel instrument. Activation procedure with hyperventilation was used in addition to the routine recording. In flight electroencephalograms, after the method of Sem-Jacobsen,[7] may be done later.

RADIOGRAPHIC EXAMINATION

Reduction of radiation exposures to less than half of the usual levels was accomplished by the

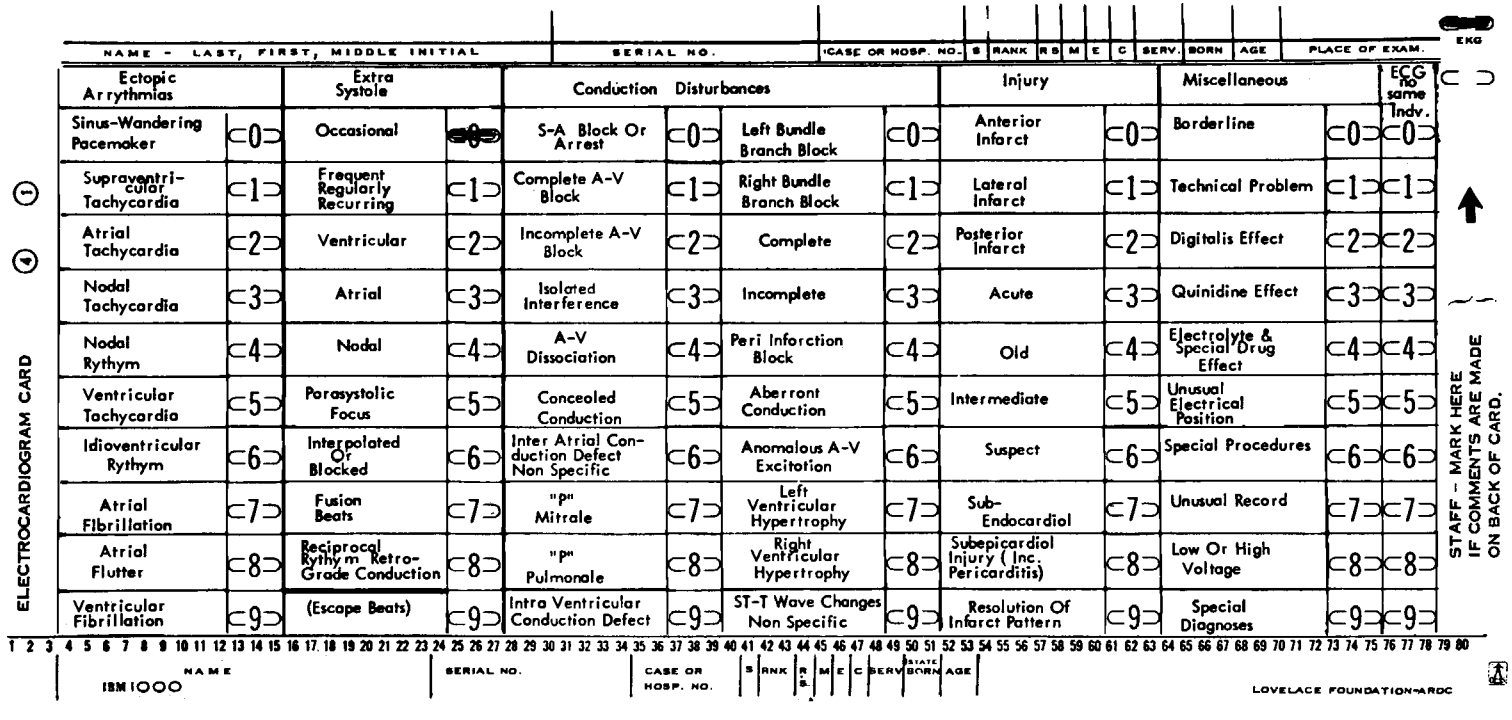

Fig. 3. SPECIAL EXAMINATION (one of seventeen cards). This Electrocardiogram card is representative of others on Ophthalmology, X-ray, Audiology, Dental, Physical Competence, et cetera.

use of supersensitive intensifying screens and shielding, as well as ultra fast x-ray film. Roentgenograms were taken of the chest posteriorly-anteriorly in inspiration and expiration, and right laterally. Bullae on the lungs were looked for in all candidates. An x-ray moving picture of the heart was studied by the usual technique using the image intensifier for fluoroscopy. A special colon examination was made using the barium enema and an image intensifier for fluoroscopy and spot films. Lumbosacral spine roentgenograms were made using anterior-posterior and lateral views routinely and oblique views when indicated. The teeth and sinuses were x-rayed for possible pathological processes. All radiological results were reviewed and evaluated by a radiologist, Dr. J. W. Grossman.

POSITIVE CLINICAL FINDINGS
(31 Candidates)

Ophthalmolgic

Static visual acuity 20/25 or less	5
Convergence weakness	2
Exophoria	2
Borderline night vision	2

Otolaryngological

Sinusitis and sinus cyst	7
Hearing loss, more than 15db upper range	19
Allergic rhinitis	6
Pharyngitis, chronic	1
Cervical adenitis	1
Deviated septum with obstruction	8
Hyperactive caloric response	1
Small eustachian tube openings	2
Vocal cord tumor	1
Betahemolytic strep carrier	3

Cardiovascular

Hypertensive vascular disease	1
Vasomotor instability on tilt table	2
Increased carotid sinus sensitivity	1

Gastrointestinal

Retroceal appendix	1
Inverted caecum	1
Dilated external inguinal rings	3
Diverticulosis	2
Fissure and pruritus ani	1
Hemorrhoids	5
Abnormal stool specimen	2
(1 Endolimax nana, 1 Endamoeba histolytica)	

Genitourinary

Abnormal urethral meatus	2
Varicocele	2
Orchitis, inactive	3
Testicular atrophy	2
Prostatitis	1
Glycosuria	1

Orthopedic

Abnormal dorsal spine	3
(1 mild dorsal kyphosis, 1 dorsal scoliosis, 1 old fracture)	
Abnormal lumbosacral spine	5
(1 loose annulus, 3 spondylolisthesis, 1 sacralization)	
Tight hamstrings	1
Osteochondritis dissecans, left elbow	1

Neurological

Borderline electroencephalogram	1

Dermatology

Acne	1
Epidermophytosis	1
Seborrhea	2

Defects in Final Seven Astronauts

Static visual acuity 20/25 or less	1
Hearing loss, more than 15 db upper range	5
Vocal cord tumor	1
Abnormal lumbosacral spine	1

LABORATORY EXAMINATIONS*

The laboratory work included the following tests which were done on all candidates. The normal range of values used at the Lovelace Clinic will be given.

Hemoglobin was estimated by the Cyanmethemoglobin; the normal sea level values for patients are 14 to 17 grams per/100 ml. Hematocrit determinations were done using the micro hematocrit method. The normal values for patients are 42-50. Leukocyte total count was done by the standard dilution method. Three differential blood counts were made by the usual techniques using the Wright Stain. Special hematology smears were made using Wright Stain and examined by Dr. S. L. Painter, a hematologist. Sedimentation rates were determined using the Wintrobe method, with normal values

*These examinations and their evaluation were done under the direction of Dr. T. L. Chiffelle, Dr. P. V. Van Schoonhoven, Dr. B. B. Longwell and Dr. W. E. Clapper of the Department of Pathology.

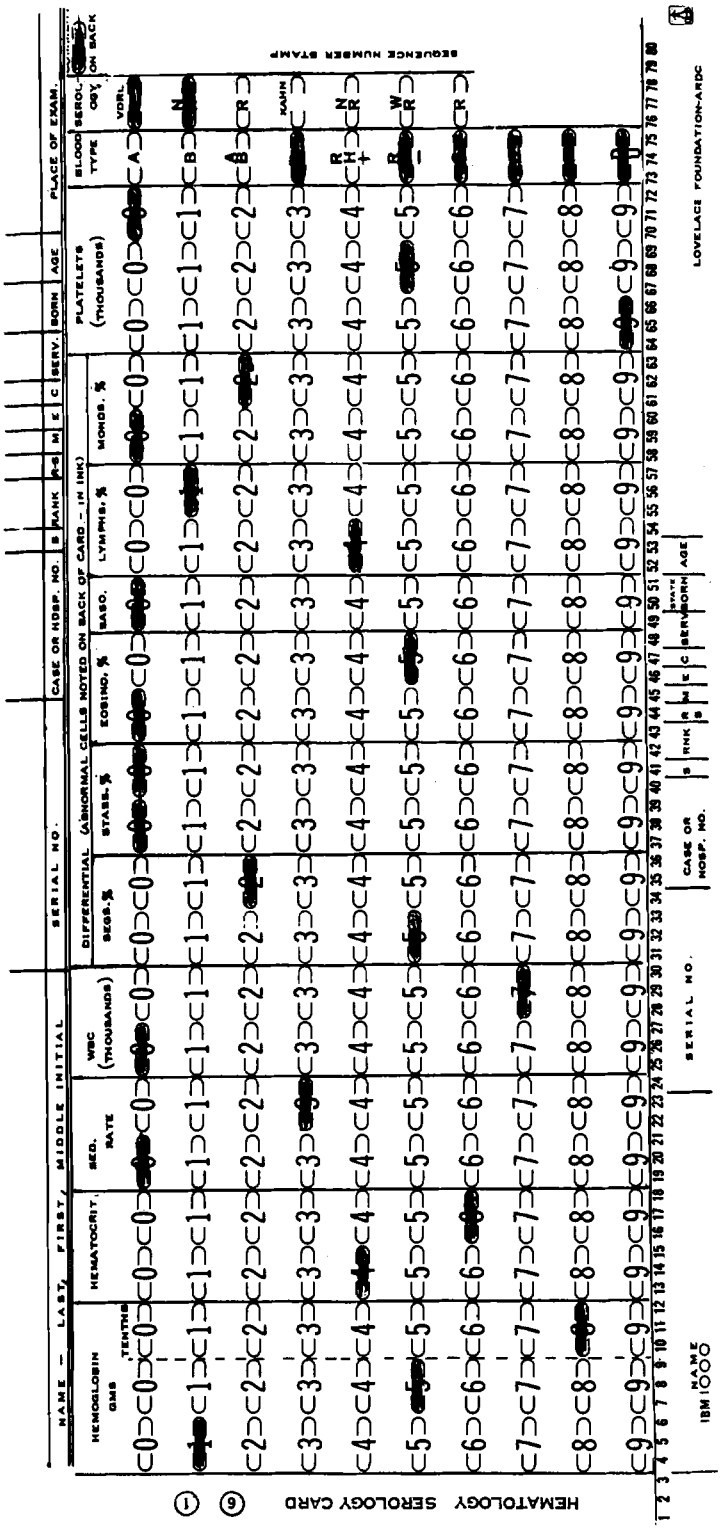

Fig. 4. Laboratory Tests (one of seven cards). Other cards are for Gastric Analysis, Urinalysis, Parasitology, Blood Chemistry, Glucose Tolerance.

for patients being 0-9 mm/hr. Fasting blood sugar was determined using the Folin-Wu method. Normal values for patients have been 80-120 mg/100 ml. Cholesterol determinations were done. For patients any value over 250 mg/100 ml. is considered abnormally high. Blood grouping studies were done using the Standard ABO system of classification. Serology studies were done using the standard Kahn and Venereal Disease Research Laboratory (VDRL) tests.

One of the laboratory cards (Fig. 4) shows hematological and serological findings. These findings are simply and easily recorded and as readily understood once the general plan is explained.

Electrolyte studies: Sodium and potassium determinations were done with the flame photometer. Manometric procedures were used for serum carbon dioxide content determinations. For chloride determination the Schales and Schales Mercurimetric procedure was used. Average values for patients are: serum sodium 137 to 149 mEq/1; serum potassium 3.8 to 5.8 mEq/1; serum carbon dioxide 21 to 28 mEq/1; serum chloride 95 to 110 mEq/1.

Urea clearance on blood and urine by a urease procedure was followed by nesslerization. The average value is 74 ml/min. Blood urea nitrogen tests were done. The average value for patients is 10 to 20 mg/100 ml. Catecholamine was determined by modification of the ferricyanamide oxidation procedure, Sobel-Henry method. The average is up to 14 mcg/100 ml. It is believed useful in estimating individual stress response, based on early work by the Aero Medical Laboratory.

Protein bound iodine determinations were made using the Strickland procedure. Normal values for patients are 3.6 to 7.4 micrograms/100 ml.

Protein electrophoresis was done by the standard electrophoresis method in barbiturate buffer pH 8.6, followed by staining with Ponceau R2 dye, followed by eleution with sodium hydroxide. Dye quantity was determined by use of the Beckman Model B spectrophotometer. This gives the proportion of the major protein fractions. This was done mainly for future reference. The standards are: Albumin 58 to 76 per cent of total; Alpha 1 Globulin 1.5 to 5.5 per cent of total; Alpha 2 Globulin 4.3 to 10.4 per cent; Beta Globulin 5.1 to 12.9 per cent and Gamma Globulin 8.6 to 17.8 per cent.

The blood volume is estimated by dividing the total circulating hemoglobin by the venous hemoglobin concentration. The average normal blood volume is 78 ml/Kg. of body weight. The total circulating hemoglobin was determined by Sjostrand's[8] carbon monoxide method.

Basal blood carbon monoxide levels were determined. These are higher in those who smoke. A small, precisely measured volume of pure carbon monoxide is added to the oxygen rebreathed in a closed circuit. After a period of 20 minutes, the amount of carbon monoxide taken up by the blood stream, and for the major part attached to hemoglobin, can be measured. Normal values are 10 to 11 gms. of hemoglobin per kilogram of body weight.

The total body water determination was done by the tritium dilution method as developed by Pinson and Langham, et al[9,10] at the Los Alamos Scientific Laboratory. A tracer dose of 1.5 millicuries of tritiated water (HTO) in 250 ml. of warm water is given early in the morning to the fasting subject. At half-hour intervals for three and a half hours, urine samples are collected and a final sample obtained at approximately four and a half to five hours. The urine samples are decolorized by filtration through activated charcoal and the tritium activity assessed by a liquid beta-scintillation technique, using a Packard Tri-Carb liquid scintillation spectrometer. A standard is obtained by processing a spiked sample of the subject's urine obtained before the start of the test. The technique follows closely that described by Langham and his associates. The degree of dilution of the ingested HTO, after equilibrium is reached, indicates the total body water volume which can be expressed as a percentage of total body mass. The mean total body water was 41.3 Kg. and the range 36.3 to 47.2 Kg.

Most of the values we have obtained on young healthy men have been between 52 per cent and 60 per cent, which is somewhat lower than the values published by Pinson and Langham,[9] and the average value of 61.8 per cent obtained by Scholoerb[11] and his associates using deuterium oxide, but are in agreement with results obtained recently at Los Alamos.

Throat cultures were made using blood agar and chocolate agar plates, both incubated in carbon dioxide at 37 degrees centigrade, and further subculture tests were done as indicated to differentiate the organisms found. Sensitivity studies of these organisms to antibiotics were also made.

Direct smear stool examinations as well as Faust and DeRivas concentration were done.

LABORATORY TESTS

Test *Fasting Specimen	Male Astronaut Candidates (31)		Male Astronauts Selected (7)	
	Mean	Range	Mean	Range
*Hgb-gm/100 ml	16.0	14.5-17.9	16.6	14.5-16.2
Total circ. hgb-gms	756.5	565-1127	857.2	674-1120
*Leucocytes-1000/mm³	8.1	4.7-15.3	7.7	5.0-10.0
*Sed rate-mm/hr	5	0-32	4	2-6
*Cholesterol-mg/ml	225	150-320	238	184-280
*Na in mEq/l	142	139-147	143	141-144
*K in mEq/l	4.6	3.4-5.5	4.7	4.0-5.5
*Cl in mEq/l	105	103-110	105	103-108
*Co_2 in mM/l	26	22-30	26	23-30
*Sugar-mg/100 ml	102	84-112	100	88-108
*PBI-micrograms/100 ml	5.8	4.2-10.4	5.5	4.9-6
*BSP-% retention (45 min)	3	0-7	3	2-4
17 KGS-mg/24 hrs	19.1	8.8-29	18.3	11.1-23
17 KS-mg/24 hrs	13.7	8-22.6	13.3	9.9-17.5

The percentage body water can be used to estimate the fat-free body mass by assuming values for the percentage of water in fat and in the lean body mass, but there is considerable uncertainty about these estimates.

A liver function test was done using bromsulphalein dye (5 mg. of dye per Kg. of body weight). In patients, less than 5 per cent of the dye should be obtained in the serum 45 minutes after injection. Gastric analysis was done using the standard alcohol meal and 1 cc. of Histalog was given, if indicated. The analysis was done using the standard titration method.

Urine analysis including tests for reducing agents and a 4 per cent sulfosalicylic acid for protein was done. For 24-hour urinary steroid excretion, 17-ketogenic steroids were determined using the Noremburski method. Normals are 9 to 25 mg/24 hrs. for the male. Using the Zimmerman reaction, 17-ketosteroids were determined colorimetrically. The normal values are 9 to 22 mg/24 hrs. for the male. Urine concentration test (Fisher modification) should give a concentration of 1.025 or higher.

Iron hematoxylin stains were done when indicated.

Total sperm counts were done together with a determination of proportion of motile forms and pathological forms on stained slides. Normal count was taken as 100 to 150 million per cubic centimeter.

The results of the laboratory tests in consolidated form are shown in the accompanying table.

Of special interest were the studies done at the Los Alamos Scientific Laboratory by Langham and his associates. They included total body radiation count and potassium determination. The total body radiation is a base line determination which will be repeated from time to time. The body potassium is of importance in determining lean body mass since most of this is in the muscle tissue. These tests are made in the whole body counter developed by Anderson, Schuch, Perrings, and Langham.[12] The average total potassium derived from the K^{40} count is approximately 150 grams, or about 2 grams per kilogram of body weight. In this series, the total

mean K^{40} was 168.8 gms. and the range 142 to 204 gms.

PHYSICAL COMPETENCE AND VENTILATORY EFFICIENCY TESTS

Darling[13] (1947) defined fitness as the ability of the organism to maintain the various internal equilibria as closely as possible to the resting state during strenuous exertion and to restore promptly after exercise any equilibriums which have been disturbed.

PHYSIOLOGIC DATA

Test	Male Astronaut Candidates (31)		Male Astronauts Selected (7)	
	Mean	Range	Mean	Range
Height-cm	176	167-180	177	170-180
Weight-Kg	73.4	61-87	75.3	70-87
Body surface area-m^2	1.9	1.7-2.1	1.9	1.8-2.1
Lean body mass-Kg	63.9	55-71	66.8	59-71
Total body potassium—gms	168.6	142-204	175.4	167-199
Total body water—liters	41.3	36-47	41.5	37-45
Blood volume—liters	4.92	3.33-6.91	5.40	4.35-6.91
Total circ. hgb-gms	756.5	565-1127	857.2	674-1120
Total lung capacity—liters	6.82	5.36-8.19	7.02	6.34-8.02
Functional residual capacity—liters	3.22	2.25-4.23	3.41	2.96-4.23
Vital capacity—liters	5.49	4.35-6.91	5.54	5.11-6.02
Residual volume—liters	1.32	0.83-2.00	1.48	1.13-2.00
Maximum breathing capacity—liters	180	149-247	191	156-247
Nitrogen clearance equivalent	11.1	9.3-13.0	10.9	9.2-12.0
Final O_2 uptake during exercise—l/min	2.41	1.90-2.84	2.60	2.07-2.84

The physical competence tests were done by one of the authors (U.C.L.) and will be reported in detail in a later publication. These tests give an estimate of the subject's general physical condition and cardiopulmonary competence. P.O.[14] and I. Åstrand,[15] Balke,[16] Lundgren,[17] and v. Döbeln, [18,19] have carried out extensive experiments for the determination of the physical working capacity on personnel in the same age group as the Astronauts. Graded work is performed on v. Döbeln's[20] bicycle ergometer ranging from 300 mkg/min. to about 1200 mgk/min. The test proceeds until a heart rate of 180 beats/min. is attained or other signs of approaching overload are evident. Measurements were made each minute of the heart rate, blood pressure, and the respiratory volume and gas exchange. These were recorded at frequent intervals. The oxygen consumption attained during the highest workload is used as the criterion of aerobic work capacity. The mean value was 2.41 1/min. and the range was 1.9 to 2.84 1/min. Each individual was rated with regard to standard values based on age, height and weight. The milliliters oxygen uptake for the final minute of exercise per kilogram of lean body mass is one of the correlation studies now being done in the physical competence determination. The normal ranges have not yet been fixed.

Density of the body was determined by weighing the nude body in water after exhaling a measured amount of air from maximal inspiration. The amount of air remaining in the lungs was obtained by deducting the amount exhaled from the total lung capacity which was determined previously with the nitrogen clearance method. The mean value for the group was 1.066 g/cm^3 ranging from 1.047 to 1.092. The mean body surface area was 1.90 m^2 and the range 1.70 to 2.06 m^2.

PULMONARY FUNCTION TEST

Measurements were taken of the total lung capacity and its relative subdivisions and the efficiency of ventilation determined by continuous recording of the dilution of nitrogen while the subject was breathing 100 per cent oxygen. The maximal breathing capacity was measured and the ventilatory response to light exercise. The steps were as follows:

1. Measurements of total lung capacity and subdivisions of lung volume by direct and indirect spirometry. The mean total lung capacity was 6.82 liters and the range 5.36 to 8.19 liters.

2. Timed vital capacity and maximal breathing capacity. The mean vital capacity was 5.49 1. and the range 4.35 to 6.91 1. The mean maximal breathing capacity was 179.5 1/min. and the range 149 to 247 1/min.

3. Nitrogen clearance study with continuous recording of expired nitrogen concentration and respiratory volume to calculate the nitrogen clearance equivalent as a measure of ventilatory efficiency in intrapulmonary mixing and distribution. The nitrogen clearance equivalent mean was 11.1 and the range 9.3 to 13.

4. Standard exercise test (walking at 2mph for three minutes) with measurement of respiratory gas exchange and ventilation equivalent for oxygen.

The procedures provide information regarding the size of the lungs and the range of respiratory excursions relative to estimated normal values for each individual. It is possible to detect restrictive or obstructive impairment and estimate the efficiency of breathing at rest and during mild exercise.

PERSONALITY EVALUATION

There are certain features in the make-up of all individuals which require contact with them by experienced observers before an evaluation can be made. Motivation, sense of humor, emotional maturity, inter-personal relations, ability to make a satisfactory adjustment in a new environmental situation, ability to grasp complex instructions and to carry out acts based on the understanding of such instructions, constitute a small part of this complex. In a formal atmosphere much as exists during a clinical evaluation, it is impossible to see some of the finer shadings of these qualities. Ideally a qualified observer should live with these individuals and see them in a wide variety of circumstances (truly a flight surgeon's responsibility); however, informal social gatherings under relatively relaxed circumstances certainly aids in gathering this valuable information. On at least two or more occasions three or four of the Foundation staff spent an evening under informal circumstances with each group of pilots and arrived at independent opinions about their personality traits. Also, selected responsible individuals from a wide variety of the clinical, radiology and laboratory departments of the Clinic submitted notes on observations of the candidates especially noting traits which appeared favorable or unfavorable under the circumstances of the particular evaluation being carried out.

BOARD MEETING AND FINAL SUMMARY

At the conclusion of the examinations, all the machine record data cards were gathered together each week and assembled in decks, one for each examinee. Each subject was evaluated on the basis of physical, mental and social well being, by a board consisting of four flight surgeons and a physiologist with extensive high altitude experience. From these a summary of all significant findings was prepared and this—together with a copy of the machine record cards—was sent to the Aerospace Medical Laboratory, Wright-Patterson Air Force Base prior to the stress tests.

AEROSPACE MEDICAL LABORATORY-WADC

At the Wright Air Development Center Aerospace Medical Laboratory, the following tests were done. The techniques and results are given in detail by Wilson[22] and his associates.

Psychiatric interview; Rorschach test; positive and transverse g profile; anthropometric studies; heat test; Harverd step test; Flack and Valsalva overshoot test; treadmill test; MC-1 partial pressure suit test; tilt table test; equilibrium chair test; high-energy sound test; and a cold pressor test as modified by McGuire. A candidate evaluation committee ranked all the candidates on the basis of total performance and then rated each of the candidates as outstanding, highly recommended, or not recommended.

FINAL SELECTION

The final selection of astronauts was done at Langley Field by representatives of both medical and technical fields from the National Aeronautics and Space Administration, the Aesospace Medical Laboratory and the Lovelace Founda-

tion. The seven ultimately selected were chosen because of their exceptional resistance to mental, physical, and psychological stresses, and because of the particular scientific discipline or specialty each presented. Their average intelligence quotient was 135. Their average total flying time was 3300 hours and of this 1514 were jet hours. Their average age was 34.1, with ages ranging from 32 to 37. All of these men were married.

MAINTENANCE PROGRAM

There are five main objectives ideally in the continuing medical maintenance phase of the astronaut program:

1. Constant and continuing medical observation and attention to even minor or minute medical problems as they arise. This requires a flight surgeon to be assigned to this particular responsibility. (Dr. W. Douglas)

2. Continuing observation on intangible problems such as morale and motivation.

3. Periodic more intensive medical evaluation to insure a continuing good state of general health. The records of each individual are evaluated, determination is made of the physical changes according to increasing age and the early diagnosis of potential chronic illnesses and cancer with prompt treatment and follow-up is established. A major objective is to prevent sudden, acute illness or death in an individual thought to be in good health. Another objective is to insure the maintenance of the same type of response and physiologic reserve for which they were originally selected.

4. Re-evaluation of all physiological and psychological testing procedures on which selection was made in order to insure continuing high caliber performance.

5. Continuing evaluation of the entire program in relation to the physiological and psychological demand to be placed on the individual and correlation with their known demonstrated qualities. This is quite necessary since technical engineering advances in equipment may change the physiological and psychological demands.

At the time of the periodic examinations an interval history is obtained and the relevant laboratory and roentgenologic examinations performed after the physical examination is done. The routine examination includes:

1. A summary from their flight surgeon regarding interval medical problems and current personality evaluation, especially any change of motivation or mental capacities.

2. A complete interval history covering the period since their last visit and a physical examination is done. Insofar as possible, they see the same physician they saw before, and this means they will see him two or three times during their two day stay.

3. Laboratory data include: complete blood count and smear, non-protein nitrogen, sedimentation rate, serology, blood sugar, cholesterol, urinalysis.

4. Included every year will be a chest radiograph, a double master two step electrocardiogram and a vectorcardiograph and a proctoscopic examination.

5. The stomach radiograph which is done the first year will be repeated the second year in patients over 40 years of age, as will the gastric analysis, and will be done every other year after the age of 40. In other words, the stomach radiograph will be done the first year, the second year, fourth year, sixth year, and so on, after age 40. Before age 40, it will be done every four years.

6. The colon radiograph will be done the first year and will be done every other year after age 40. This will mean that following the original examination the colon and stomach will be done alternate years after age 40 and every four years before age 40.

7. The gallbladder radiograph will be repeated every third year following the original examination after age 40 and every five years before age 40.

8. The physical competence test is done each year and the lean body mass determined, as are the blood volume, total body water, total circulating hemoglobin, and the pulmonary function

test is done every third year following the original examination.

At the conclusion of the above procedures, the patient is informed of the results and requested to ask any questions concerning information he does not fully understand. His future health program and advice regarding work and recreation is outlined.

A detailed summary with recommendations is sent to the responsible medical officer, since constant maintenance is the goal.

It is clear that data obtained in all phases of the astronaut training and maintenance program can readily be recorded in a form suitable for machine processing. The method should be extended to include such areas as training progress, rate of progress, pertinent operational experience, re-examination results, radiation exposure history and the like. For example, each individual could have a Radiation Summary Card, on which items such as the following would be serially recorded subsequent to each significant exposure:

Individual identifying information
Significant medical conditions
Accumulative radiation dosage to date
Current exposure data
  Date of exposure
  Source of exposure
  Type of radiation
  Radiation dosage—physical units
  Type of body exposure
  Net effective exposure—in rads
  Effects of exposure
  Therapeutic measures required
New accumulative body dosage
Precautionary instructions
Future career requirements
  Present stage of proficiency
  Special limitations
  Remaining tolerable dosage limit
  Space missions to date
  Maximum number of space missions allowable
  Maximum number of missions remaining

APPENDIX

SUNDAY

On arrival	Complete Cornell Medical History Forms and IBM Forms. Collect first stool specimen Sunday night or Monday morning.
12:00 midnight	Nothing to eat, drink or smoke after midnight until after completion of laboratory tests on Monday morning.

MONDAY

Nothing to eat, drink or smoke on arising.
Collect first stool specimen Monday morning if not collected Sunday night; turn in stool specimen to Laboratory Control Desk.

8:00 a.m.	Report to Laboratory Control Desk on first floor of Lassetter Laboratory Building for tests listed below:	
	Complete Blood Count	Sedimentation Rate
	Special Hematology Smear	Cholesterol
	Blood Sugar	Blood Grouping
	Non-Protein Nitrogen	Rh Factor
	Serology	Urinalysis
9:00 a.m.	Report to flight surgeon, third floor of Clinic Building, for general history and physical examination.	
10:30 a.m.	Report to receptionist for referral for ECG; also, obtain instructions for preparation for proctoscopic examination Monday afternoon.	
12:00 noon	Lunch	
1:30 p.m.	Report to Clinic Emergency Room for proctoscopic examination.	
2:00 p.m.	Report to receptionist for referral for dental and sinus x-rays.	
3:00 p.m.	Report to receptionist for referral for vector-cardiograms.	
Evening	No restrictions on eating, drinking or smoking.	
12:00 midnight	Nothing to eat, drink or smoke after midnight.	

TUESDAY

Nothing to eat, drink or smoke on arising.
Collect second stool specimen Tuesday morning if not collected Monday night.
Turn in stool specimen at Laboratory Control Desk.
Collect entire urine specimen for radiation physicist.

7:00 a.m.	Report to radiation physicist in Radiation Therapy Building for total body water determination. Turn in urine specimen to him.
11:00 a.m.	Report to Laboratory Control Desk for BSP liver function test.
12:00 noon	Start 24-hour urine collection
	Lunch
1:30 p.m.	Report to Cardiology, first floor of Clinic Building, for tilt-table tests.
3:00 p.m.	Report to receptionist for referral for lumbar-spine x-rays.
4:30 p.m.	Report to receptionist for instructions for preparation for gastric analysis and the colon x-rays on Wednesday morning.
Evening	No restrictions on eating or drinking. Do not smoke after 7:00 p.m. until after blood volume determination Wednesday afternoon.
12:00 midnight	Nothing to eat, drink or smoke after midnight.

WEDNESDAY

	Nothing to eat, drink or smoke on arising. Do not smoke until after completion of blood volume determination, Wednesday afternoon.
8:00 a.m.	Report to Laboratory for gastric analysis.
9:30 a.m.	Immediately following gastric analysis, report to X-ray Department for colon x-rays.
12:00 noon	Turn in 24-hour urine collection at laboratory control desk.
	Lunch.
1:30 p.m.	Report to Physiology Department, first floor of Clinic building, for blood volume determination.
2:30 p.m.	Report to Ophthalmology Department, second floor of Clinic building, for ophthalmological examination.
Evening	No restrictions on eating, drinking or smoking this evening.
12:00 midnight	Nothing to eat, drink or smoke after midnight, until after completion of stomach x-rays on Thursday morning.

THURSDAY

	Nothing to eat, drink or smoke on arising.
8:00 a.m.	Report to receptionist for referral for stomach, chest and esophagus x-rays.
	Upon completion of x-rays, you may eat breakfast if time permits.
10:00 a.m.	Report to Carco Air Service for flight to Los Alamos.
11:00 a.m.	Total body counter—K^{40} determination.
3:30 p.m.	Report to Physiology Department, first floor of Clinic building, for pulmonary function testing.
	No restrictions on eating, drinking or smoking this evening.
	Wash hair before going to bed; do not re-apply oil, spray, or anything on hair until after completion of electroencephalograms on Friday afternoon.

FRIDAY

	You may eat a light breakfast.
8:00 a.m.	Report to Physiology Department, first floor of the Clinic building, for hydrostatic weighing.
8:30 a.m.	Report to Physiology Department for exercise tests.
9:30 a.m.	Report to receptionist for referral for audiograms.
10:30 a.m.	Report to Physical Medicine Department, second floor of Clinic building, for neurological examination.
12:00 noon	Lunch.
1:30 p.m.	Report to receptionist for referral for electroencephalograms.
4:00 p.m.	Report to Otolaryngology Department, third floor of Clinic building, for ENT examination.
Evening	No restrictions on eating, drinking or smoking this evening.

SATURDAY

	You may eat breakfast.
9:00 a.m.	Report to flight surgeon, third floor of Clinic building.

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