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Work, Exercise and Space Flight
III. Exercise Devices and Protocols

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Introduction

It has been shown that lack of usual work and exercise in space leads to adaptations of the musculo-skeletal, cardiovascular-respiratory, and neuro-muscular systems which are incompatible with normal function in 1-g (1). To prevent or minimize such adaptation, exercise must be supplied on orbit. This requires quantitative knowledge of the nature of work and exercise in terms of physics (forces, time, distance, etc.). Rather than try to generate *de novo* exercises and devices for space, existing exercise and devices will be examined in physical terms and matched to actual work and exercise usually done on earth. Finally, devices which can operate in weightlessness will be derived or designed, their performance determined in the physical terms and protocols designed to replace, as necessary, the original quantities lost. This brief analysis follows such plan.

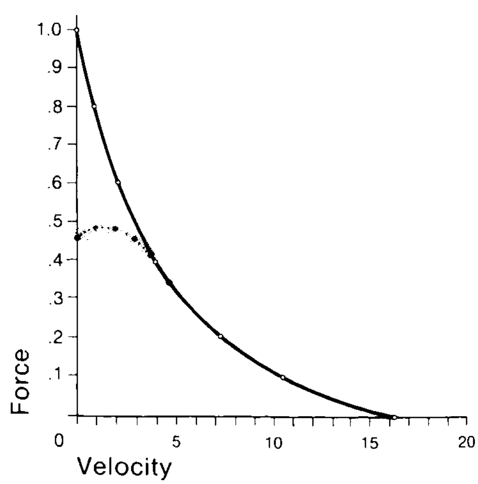


Fig. 1.- Force velocity curves from an isolated muscle fibre, dark line with open circles (A. V. Hill), and from intact limb segments measured isokinetically, dotted lines and solid circles (J. Perrine). The force-velocity ratios have been normalized in the isokinetic curve such that the final portion lies on the isolated preparation curve to illustrate the large amount of neurological inhibition present in intact neuro-muscular systems at zero and low velocities (shaded area). *From Perrine.*

Characterization of work and exercise - The primary function of muscle is to generate force and movement, hence external work and exercise can be defined in these quantities as a function of time. The generalized force-velocity curve for muscle is shown in Fig. 1. While it has long been recognized that force development of a muscle is velocity dependent (2), it is too often overlooked in practice, especially in measurement. A second characteristic is endurance which is dependent upon muscle training.

There is another crucial factor in exercise and work that is often overlooked, the nature and effect of external forces on muscle. The following is a description of commonly encountered forces. They are illustrated by a series of cartoons in Figs. 2 to 3.

1. $Force_g = Constant_{gr}$ (in magnitude and direction). F_g

Static weight is the outstanding example of this in which (Weight = mass · gravity), ideally isometric exercise is another.

2. $Force_G$ = mass · accleration. F_G

Such inertial force is seldom encountered in pure form on earth but is the predominant force in weightlessness.

3. $Force_R = Velocity^n \cdot constant_R$. F_R

This is a true resistive[a] force such as one encounters in wind resistance or rowing a boat. Typically n = 2

4. $Force_{Fr} = Constant_{Fr}$ velocity >0. F_{Fr}

[a]All external forces are still typically called 'resistance' by workers in exercise. Such generalities preclude rigorous treatment.

Frictional force such as sliding a load along a surface. Constant Fr is a function of forces between opposing surfaces.

5. $Force_{Sp} = Constant_{Sp}$ Displacement. F_{Sp}

This is the relation for spring forces which are only occasionally encountered in nature but are frequently used in exercise devices.

6. $Force_{IK}$ = muscle capacity
where velocity $\geq$ selected constant F_{IK}

This is isokinetic force which is seldom encountered except in testing or exercise devices.The force is small at all velocities below the selected limited velocity.

In practice, the muscle loads are usually some mix of the above, e.g. the archetypical muscle load is movement of a weight in 1-g where:

$$Force_{wt} = Force_g + Force_G = mg + ma$$

An understanding of these forces in exercise devices is as essential for success in design and application of exercise devices as is understanding of force magnitudes and kinesiology. Space is not available to describe the effect of these force types upon muscle beyond a few observations (3); type of force has great effect on endurance, i.e. forces cannot be equated on the basis of magnitude alone. Adequate inertia as part of the load is especially important. The locomotor exerciser ('treadmill') flown on Skylab 4 [Sect. 1, Fig. 9] was a friction device producing leg forces less than those developed in walking but which caused the legs to fatigue very rapidly. Cause of such rapid fatigue probably has to do with sustained force generation by the myofibrils, in contrast to brief bursts of force in normal walking or running where a major part of the energy is supplied to inertia. This 'stored' energy is released over the rest of the cycle while the fibrils rest prior to another burst of activity. Such flywheel action is somewhat analogous to that in an internal combusition engine in which the energy of a brief impulse is stored and released between impulses. The practical importance of this is that it is cheap and easy to develop forces by friction or viscous devices. Unfortunately, there are many bicycle ergometers and rowing machines and many other attempted substitutes for weights without significant inertia, all of which have major deficiencies. Such devices cannot be successfully substituted for the forces they try to mimic. It is a special temptation to try to use such devices in space flight for they are light in weight and simple but inadequate.

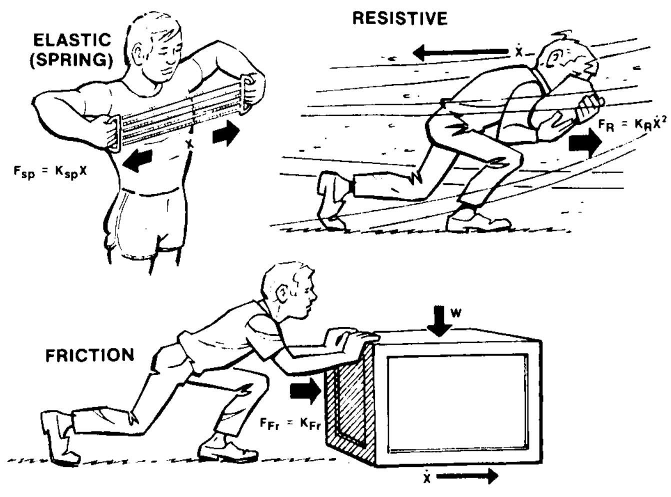


Fig. 3.- Other common forces include spring forces and true resistive forces. The latter directly dissipate energy.

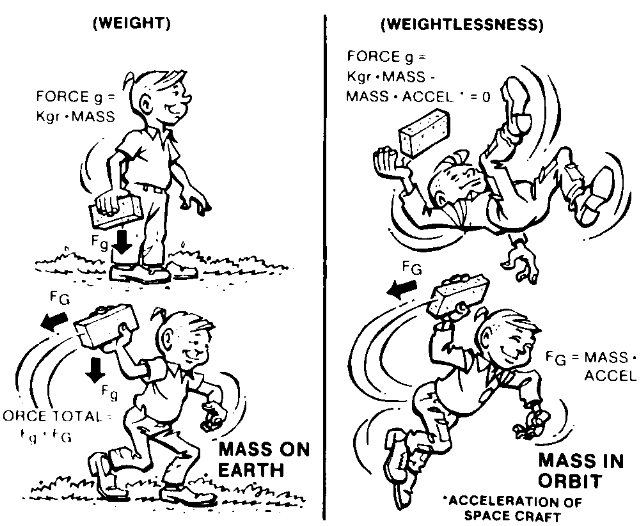


Fig. 2.- Illustrations of forces associated with mass on earth and in flight. Orbital acceleration, i.e. centrifugal force, balances weight in flight.

Arm and Upper Body Exercise - There is great variabiity from individual to individual; however, manipulation of weights remains the archetype of all work and exercise. A wide range of other forces and motions is also encountered.

The range of arm work and exercise in 1-g is simply too extensive and variable to describe adequately. It is also individually variable in the Astronaut Office ranging from a number of competitive weight lifters to runners who do virtually no arm exercise. The archetype of arm work and exercise is movement

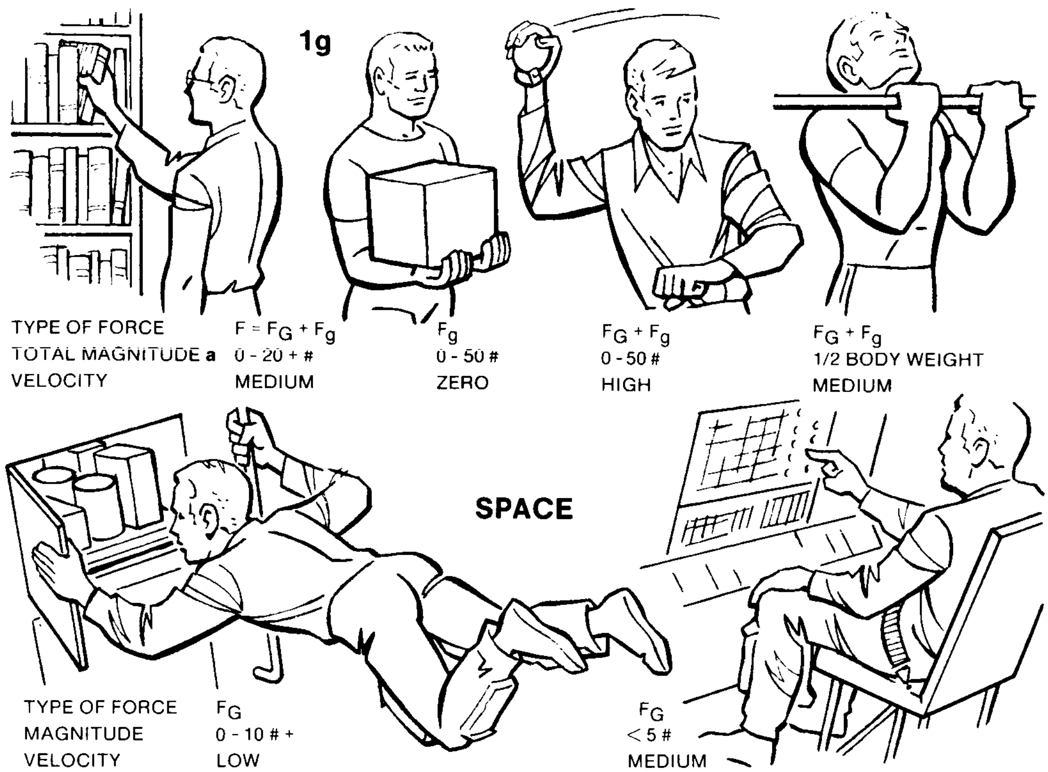


Fig. 4.- Illustrations of common arm forces with estimates of magnitudes on earth and in space. No large forces or rapid motions are usually generated in space.

of weight, albeit often only arm weight. Other common forces are carrying or holding weight and pushing or pulling, often times against friction or resistive forces. Throwing, frequently at large or near maximum acceleration rates, is also common. [Fig. 4].

In space, the usual arm force is fixing and maintaining body position by holding and stabilizing it with one arm, leaving the other free to manipulate objects. Arm activity is much greater in space than on earth but maximum and mean force loads are reduced. EVA operations are an exception to this and must be separately considered.

Truncal Work and Exercise - On earth, trunk[1] and vertebral muscles take part in locomotion, posture, and in supporting upper body and arm forces. Forces imposed on these muscles are often large. In weightlessness, these muscles are used but never with the loads or as frequently as in 1-g.

Arm/Trunk Exercise Devices - Rather than try to make a variety of arm and trunk exercise devices, the following arrangement is proposed as a general solution to the problem. A universal force generator -measurement unit [Fig. 5] will transmit forces to the subject through cable and pulley to handle or other means [Fig. 6]. The variety of exercise is only limited by users' imagination. Such force generation and measurement are made possible by a servo system in which the nature and magnitude of the force are controlled by electrical elements in a selectable series of feedback circuits (4). These circuits allow the system to generate exact analogs of forces normally generated by physical elements such as weights, etc. This includes an isokinetic mode. By monitoring internal signals such as force and displacement, the performance of a subject may also be monitored. Other trunk and arm exercises are considered later in this paper.

Leg Exercise - Locomotion (walking, jogging, running) is the primary exercise on earth. Forces, repetitions, and metabolic loads are briefly described in Section II, Figs. 2 thru 8. Kinesiology is relatively complex. Variants of locomotion are the games played by

[1]This does not consider the shoulder girdle muscles which are considered as arm muscles here.

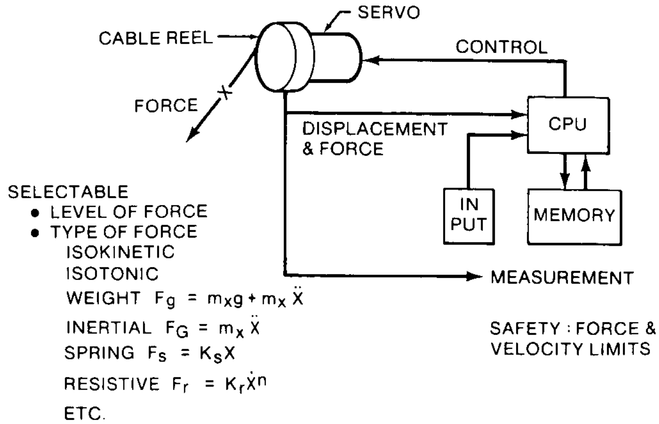


Fig. 5.- A force synthesizer made possible by efficient servo motors and feedback control. The latter is shown as a digital unit. Magnitude of the quantities such as equivalent mass and other constants plus equations of force may be set into the unit. Measurement of subject performance is accomplished from signals generated by and essential to its operation of the apparatus.

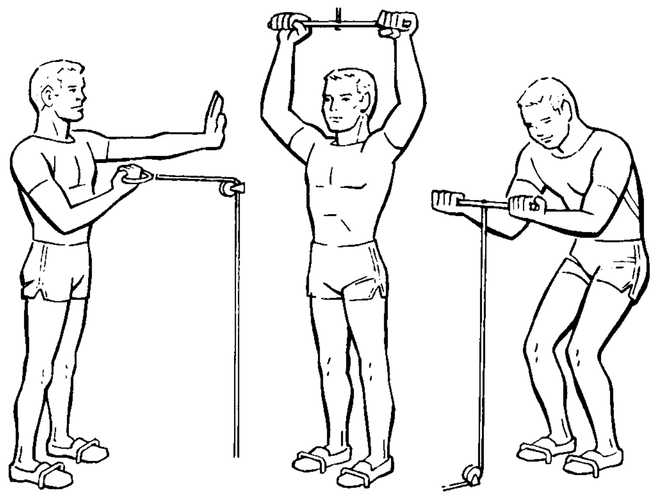


Fig. 6.- Only three of an infinite variety of exercises in space made possible by the force unit in Fig. 5 plus the necessary cable, pulleys, and restraints are shown here.

many, such as basketball and various other court and ball games. In these, action is more intermittant than in locomotion; hence, mean metabolic loads are lower but muscle involvement is more complex with occasional higher force loads.

Locomotor Exercise Devices - Currently, for a variety of reasons, replacement of locomotor exercise with a treadmill seems to be the only solution. A wide variety of leg exercise devices has advocates but when quantitatively examined without accompanying locomotor exercise, the often extravagant claims are not sustained in practice in one or more important areas. There is no currently available device which allows such a large number of repetitions at such large loads and also generates large metabolic demands.

Some of the current devices advocated are:

	Max (Usual) Peak Force Loads[b]	Similarity of Kinesiology[c]	Maximum Metabolic Loads
	X Body Weight		% Max[a]
Bicycle Ergometer$_m$	0.3 (.2)	Poor	~100%
Rowing Machine$_m$	0.5 (.3)	Poor	>100%
Continuous Stepper$_m$	~2.0 + (.8)	Poor	~100%
Simulated Skiing$_e$	1.0 + (1.)	Fair	≧100%
Climbing$_e$	1.0 + (.8)	Poor	≧100%
Treadmill$_m$			
Walk	1.8 + (1.8)	Almost exact	100%
Jog	3.0 + (3.0)	Almost exact	100%
Run	8 (3-5)	Almost exact	100%

[a]Referred to treadmill
[b]One leg
[c]Referred to walking/running in 1-g.

m measured
e estimated

A well-designed treadmill in 1-g allows almost perfect reproduction of locomotion [Fig. 11]. The problem is to produce a similar device in weightlessness. Major concerns are size, weight, power, and vibroacoustic properties. An additional problem in weightlessness is provision of constant vertical forces to replace weight: methodology is illustrated in Figs. 8, 9, and 10. The following is a brief description of it.

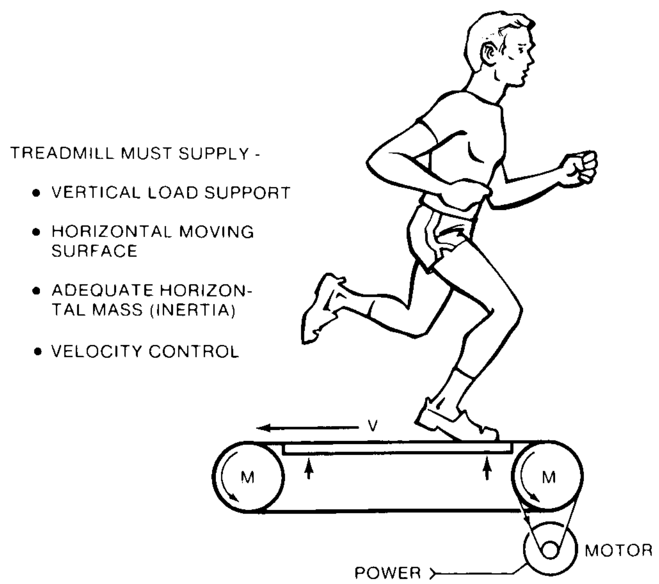


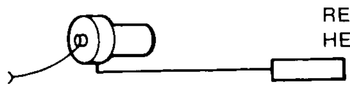
Fig. 7.- A well-designed treadmill with adequate vertical support and adequate inertia (or instantaneous power) to prevent changes in speed with the accelerations-decelerations on foot fall allows almost exact replication of locomotion on earth. This is usually provided by a belt supported by a rigid surface, a large motor (often 3-5 HP) and some form of belt speed control.

GENERATION OF CONSTANT FORCES ($F = K$)

- CONSTANT FORCE (NEGATOR) SPRINGS

HEAVY, LIMITED LIFE

- CONSTANT FORCE MOTORS



REQUIRE POWER, HEAVY, COMPLEX

- APPROXIMATION OF CONSTANT FORCE WITH ELASTIC CORDS — (BUNGEES)

$F = KX \quad F + \Delta F = K(X + \Delta X) \qquad$ FOR ΔF TO BE SMALL $\Delta X << X$

Fig. 8.- Three means of generating constant forces. Of these, bungees (springs) are the simplest but must be long for a good approximation.

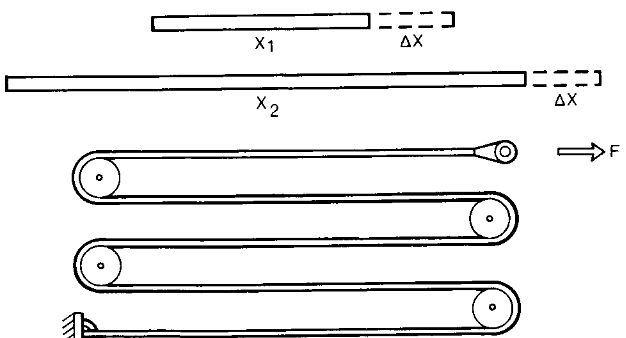


Fig. 9.- Generation of almost constant forces by elastic cords (bungees). Motion (changes in length) must be small compared to cord length as in X_2 in practice length is achieved by "folding" with pulleys.

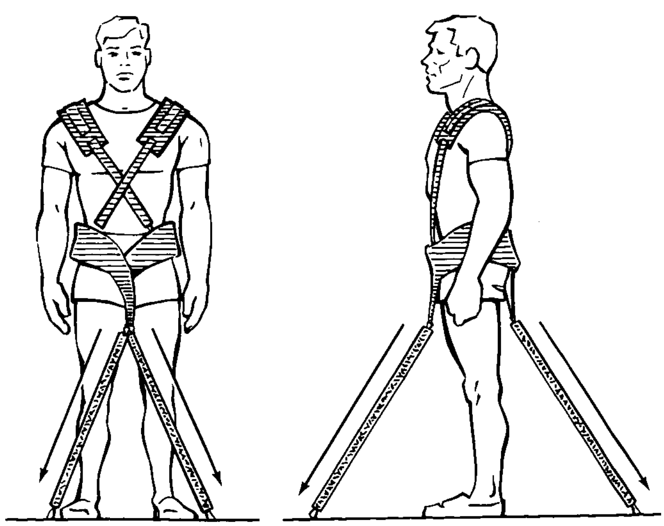


Fig. 10.- Currently used harness arrangement to provide equivalent weight on a subject. The bungees are longer and 'folded' [Fig. 9].

An initial treadmill was made for Shuttle and regularly flown since the third flight but severely constrained by size, weight, and funding. It can provide the basis for a proper design [Fig. 11].

A light rigid structure was fabricated from aluminum. The tread, which was constrained by considerations of space available is built from folded rectangular sheet metal sections running on precision ball bearing rubber shod wheels in a precision track to minimize friction. Adequate inertia is provided by a flywheel coupled to the tread by a high-ratio gear system. Speed control is provided by a centrifugally controlled mechanical brake which may be set to one of seven positions corresponding to 2.6 to 4.8 MPH. Weight equivalent force is closely approximated by four elastic bungees [Fig. 9] and a hip and shoulder harness [Fig. 10]. Force is individually adjusted to 1-g equivalent BW by setting the lengths of the straps which couple the bungees to harness at preset locations. By keeping the total length (X) of the bungee large as compared to changes in length (ΔX) during the step cycle changes in force (F) are small:

$$\Delta F \alpha F \cdot \Delta X \cdot X^{-1}.$$

1. TREAD
2. PULLEYS
3. FLYWHEEL
4. BRAKE
5. SPEED CONTROL
6. SPEEDOMETER
7. CONTROL
8. TACHOMETER GENERATOR

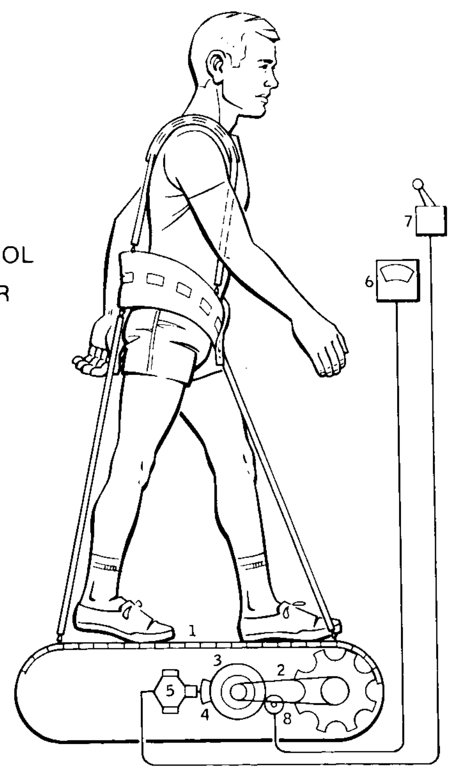


Fig. 11.- Schematic of original Shuttle Treadmill showing bungees and harness plus major components. Tread surface was 12. × 32.". It has been replaced by a smaller unit with a tread surface of 12. × 34.5", and with longer 'folded' bungees for more constant force.

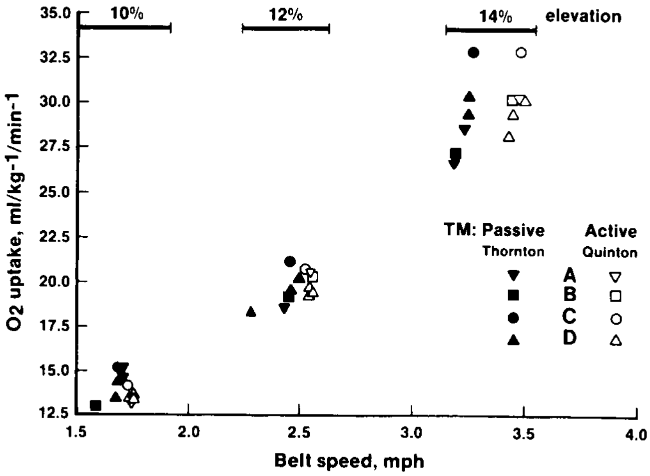


Fig. 12.- Comparison of metabolic costs for four astronauts running on an active treadmill (open symbols) and the subject driven Shuttle treadmill (filled symbols) in 1-g. The slightly increased costs on the Shuttle unit are probably caused by the small running space available resulting in extra muscular activity to stay within the area. Elevations were 12%, 14%, and 16% grade, increasing with speed.

A major point of confusion for many life scientists and even some engineers is the difference between motor driven and subject driven treadmills even to the point of causing them to make such statements as "We must have a motor driven treadmill which will not (unduly) tire the astronauts." A rough demonstration of the equivalence of active and passive treadmills is shown in Figure 12. There is no difference between well-designed motor driven and passive treadmills except at zero grade. At zero elevation, the subject's net external work is zero [Fig. 13]. At all other elevations, the subject inputs mechanical work to the treadmill, i.e. he drives the treadmill and not vice versa, whether passive [Fig. 14] or motor driven [Fig. 15]. This may be seen in motor driven treadmills by a reduction in motor power with increasing treadmill elevation. The real purpose of the motor in common treadmills is to provide the power to drag the belt over its support, to control speed and to provide inertia. A low friction arrangement such as we have on the Shuttle is more expensive to make than a belt, motor, and electric power and is not seen in the commercial market. A treadmill with no friction and adequate inertia could be run at zero grade after a starting transient in which the subject must push against a support to apply horizontal reactive forces to the tread. In practice in 1-g, the passive treadmill must be elevated to a point where the external work done in climbing is equal to the resistance losses which dissipate this work.

The gravity gradient of the elevated treadmill on earth is replaced by a slight forward tilt of the long axis of the subject to the treadmill surface in weightlessness [Fig. 16]. This is allowed by the elastic

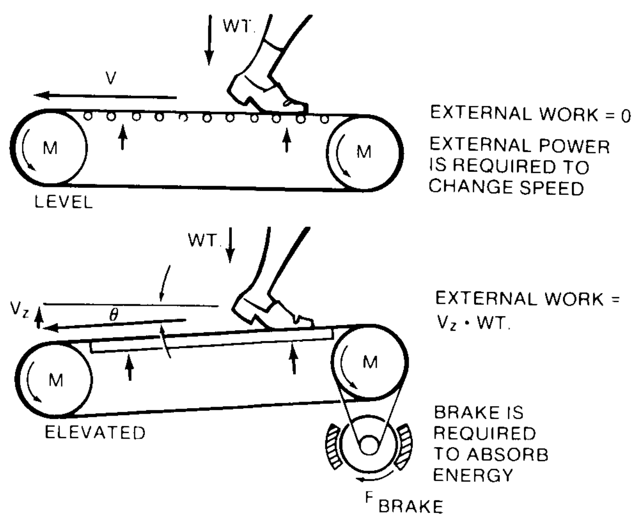


Fig. 13.- In human locomotion, the horizontal component of ground force is first negative, i.e. instantaneous deceleration followed by acceleration at each foot fall but the net force is zero. Only during changes in speed or with elevation is a net external force imparted. The external work done in climbing a grade is the vertical component of velocity V_z multiplied by the subject weight. This component is given by V_z $V \sin\theta$ and the external work, which must exactly equal energy dissipated by friction, is W_{ext} $Wt \cdot VEL \sin\theta$.

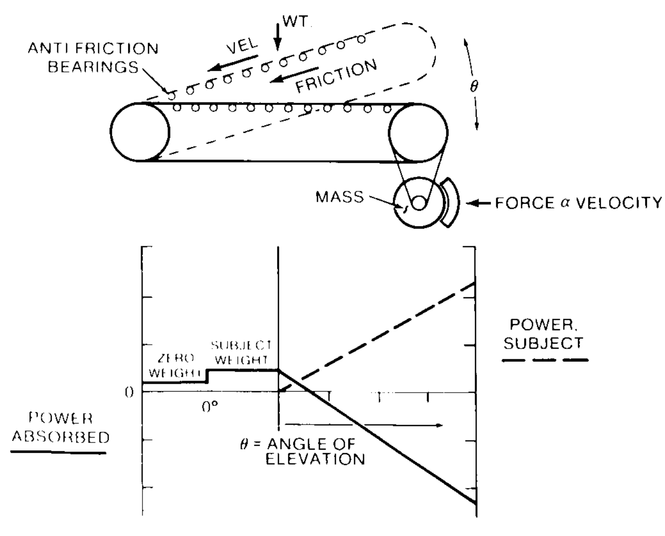


Fig. 14.- Power absorbed by the treadmill is shown by the solid line in the plot. Subject weight slightly increases the friction and at zero level can only be overcome by the subject pushing against some external object. As the elevation angle θ is increased, power into the treadmill (broken line) is increased until it equals frictional loss. Above this critical deviation, speed must be controlled by additional friction which is provided by a brake on the flywheel actuated when velocity exceeds one of seven levels (speeds) set into the brake mechanism.

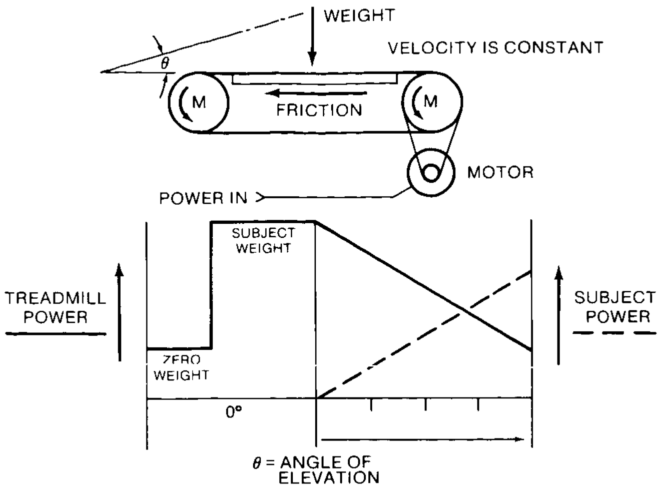


Fig. 15.- The external work relationship holds for a motor-driven treadmill but internal friction, usually a belt dragged over a support plate, is high, especially when the subjects' weight is on the tread, shown in the diagram by the step function in the power (solid line). As the angle is increased, subject input power (broken line) is increased and motor input is decreased but never below that required to overcome frictional losses.

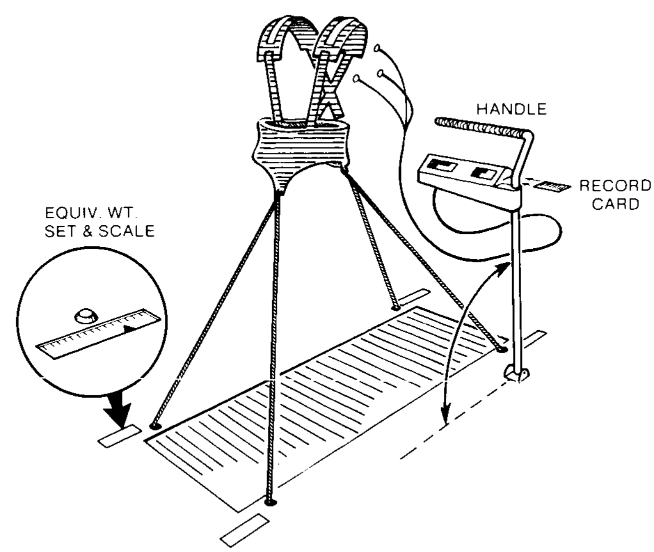


Fig. 17.- Drawing of prototype Space Station Treadmill currently under construction. Active tread area is 14 × 42".

bungees, with excellent stability. The angle is determined only by the mean force imparted to the tread, hence grade and speed are not independent on this device. While speed is controlled in 7 steps from 2.6 to 4.8 mph, this in turn requires a minimum force input at each velocity which sets the equivalent grade.

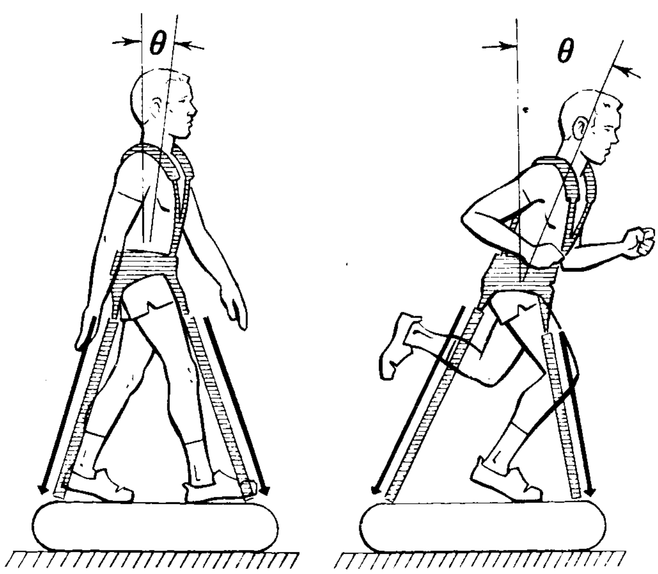


Fig. 16.- Subject on treadmill in weightlessness at two different speeds and treadmill loads. The treadmill is driven by the force parallel to the tread and this is developed by tilting the mean force vector opposite to the direction of tread movement. The tilt is handled nicely by compliance of the bungees whose expansion/contraction produces the necessary tilted force.

A prototype of the treadmill suitable for use in Space Station is currently under design and construction but is hampered by lack of adequate funding [Fig. 17]. It should have an adequate tread, be flush with the floor surface, have a range of speeds from 2 to 6 mph, provide subject loading equivalent to body weight of 100 to 225 lbs., and be easily adjustable and accurately measured, have low noise, with vibration isolation from the space craft and means of monitoring, displaying, and recording speed, heart rate, and subject equivalent weight. It also has provision for a motor drive to allow operation at zero equivalent elevation.

Other Devices - The universal force generator system and treadmill should provide the core exercise for usual purposes but there are two other categories to be considered: 1) maintenance of condition for suited (EVA) operations and 2) optional exercises. Suited operations have special demands which include resistance and elastic recoil on many motions with elasticity of gloves which tire hands and fingers as well as occasional large metabolic loads. Endurance is required for good operator function. While the demands of the metabolic load may be met by training with cardiovascular-respiratory exercise, there are no exercises at this time for musculoskeletal demands of the suit. It is the feeling around the Astronaut Office, which is consistent with EVA experience on Skylab 4, that so long as usual physical condition is maintained by routine exercise, no special requirements are necessary. A possible exception is hand exercise which could be provided by a special device with multiple but individual finger loading. Should this not be the case, an exercise suit with gloves which could be pressurized to the usual differential, might be the most efficient way to maintain condition when there are significant periods without EVA activity. This applies only to those crewmen trained for EVA operations.

Other optional exercise devices might include any small personal preference items, e.g. hand grip devices, etc. In addition, we are almost certain to have a bicycle ergometer to meet the needs of investigators. It is an excellent cardiovascular-respiratory exercise when used properly but is almost worthless for leg exercise. Another favored device is the rowing machine. There are a wide variety of such devices commercially available which range from simple resistance loads without inertia to excellent simulation of rowing. No objective biomechanical information on rowing or simulators was available so I instrumented an ergometer which closely simulates rowing force. Two members of our office made some time/force records with it. A composite of one such record is shown in Fig. 18. The work level was maximum, i.e. a brief sprint, but note that maximum individual leg forces developed are ~ 100 lbs. or 0.5 BW for this subject. Arm and back loads are relatively high but the arm loads are primarily passive tension. There is some literature on metabolic loading by this

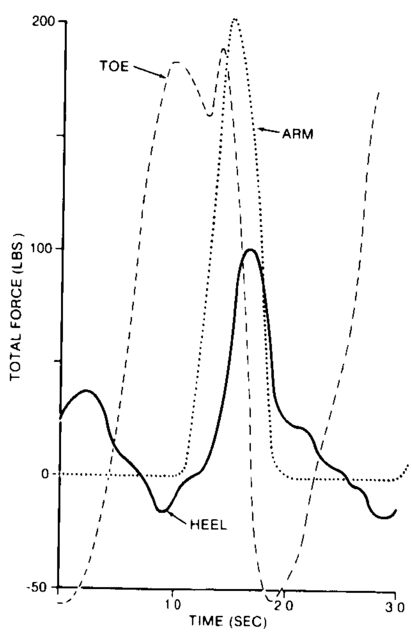


Fig. 18.- Measured forces developed at maximum effort on a rowing ergometer by 200 lb. subject in good condition. These forces are for both legs and both arms.

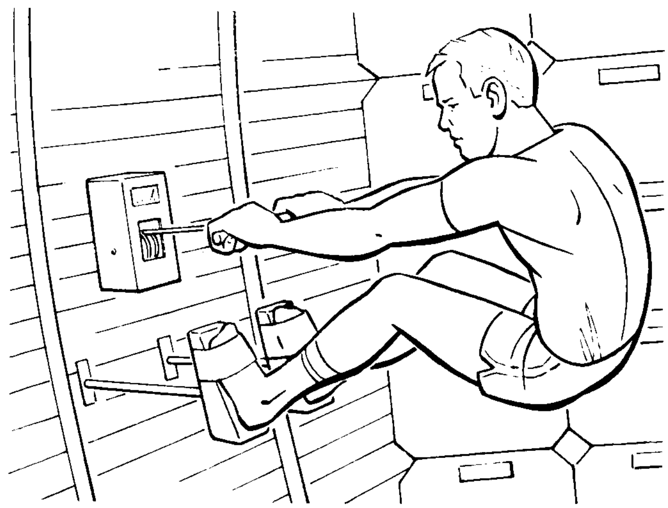


Fig. 19.- Conceptual sketch of rowing machine in use in weightlessness. Load generator has been built and is in test. Preparation for 'zero-G' flight testing is underway.

device which shows that it performs well in that regard. These characteristics make it attractive as an occasional alternative to treadmill and weights. N.B. Leg loads of both this and especially the bicycle make them useless for maintenance of locomotor capacity, hence they cannot be used as alternatives.

Sketch of a prototype rowing machine conceived by the author is shown in Figure 19. This used a load generator system we developed for a clinical bicycle ergometer years ago. We are in the process of testing a prototype unit which will be demonstrated here later today. The load generator can be coupled to pedals and used as a bicycle ergometer or to a cable and handle and used as a rowing machine, i.e. a dual purpose device is possible. The load consists of inertia plus a resistive load of the form;

$$F = K \cdot \text{Velocity}.$$

One aspect of force exercise which has been largely ignored, is the maintenance of strength at rapid angular rates. The Russians have found that strength is lost more rapidly at high than at low rates. (5). Maintenance of such fast twitch ability may be important to normal 1-g functions. Sprints on the treadmill should cover this concern for legs but it might be desirable to add such fast exercises to cover the arms and trunk. One possibility is use of light weights in a series of motions equivalent to the Heavy Hands_R programs on earth (6). A punching bag, with certain concessions, should function in space as should tethered balls. Hopefully we can produce some competitive exercises which might be based on a closed space with struck objects which are at least partially free.

Since Space Station is years away and should then have a life of many years hence devices should not be inseparably tied to the Station, rather they should be replaceable with improved items which are sure to develop (Fig. 20).

Protocol - The first step in development of a protocol (dosage if you will) is determination of level of capacities to be preserved. To do this successfully, the individual's work and exercise regimen on earth must be known as well as his capacities. Again, it will not be practical, even if possible, to maintain extreme capacity, e.g. marathon level or 'body builder' muscle strength. Taking the guidelines in Section II as a minimum, inflight exercise should be tailored to the individual to maintain as much of his 1-g capacity as possible. On-orbit work will at least partially preserve arm capacity. Conversely, muscle capacity of the legs is not preserved at all; and in the same process, cardiovascular-respiratory capacity will be sharply reduced. Based on this, treadmill exercise must take priority. It has to be performed at the subject's equivalent weight and should be equivalent to his locomotor exercise on earth, if possible.

The following concept will be tested in bed rest to determine if it will maintain musculoskeletal and cardiovascular-respiratory level. This also represents my best estimate of times and level required to date. The mean daily time and distance of locomotor exercise in 1-g will be determined. For example an individual might be running 2.5 miles at a rate of 8 minutes per mile or 20 minutes. Also, a count of average walking steps will be determined and their effect will be reproduced at a higher force load but reduced number by:

$$\sum_{\substack{\text{earth}\\ \text{Peak force} > 0.8\ \text{BW}}} \text{number of steps} \cdot \text{peak force} \cdot \text{step}^{-1}$$

$$= \sum_{\substack{\text{space}\\ \text{Peak force} > 0.8\ \text{BW}}} \text{no. of steps} \cdot \text{peak force} \cdot \text{step}^{-1}$$

A typical example might be 2500 steps $\times$ 1.8 BW = n $\cdot$ 3.0 BW or 1500 steps when running[a]. This could typically result in an additional 9 minutes of running. It would be preferable to divide this into two daily sessions. It may be possible to reduce this time especially if several fast sprints are part of the regimen. The above protocol should certainly maintain cardiovascular-respiratory capacity. It should also maintain leg strength in all areas but should testing reveal that it does not, then and only then should additional mandatory specific exercises be instituted.

Arm and trunk exercise should also be individually determined. For those who routinely do reasonable amounts of such exercise, an equivalent protocol in space would be appropriate. For those who do not, some standard program to maintain strength and endurance adequate to assure successful completion of escape maneuvers will be required.

It is obvious that neither time nor loads can be standard, rather they will be a function of individual history and capacity. Unlike many medications which depend only upon exceeding some threshold with a wide range of tolerance, exercise produces results in proportion to its 'concentration'; and its upper limit is constrained by time available and facilities, i.e. one cannot shotgun here. To ensure that 'dosage' is correct, results must be measured, i.e. periodic tests must be conducted inflight and levels changed as necessary. This is discussed in the next section.

The described regimen for core exercise should be augmented with time available for personal preference exercises which could include bicycle or rowing ergometry, 'speed' exercises, 'weights', etc., but it will be a serious mistake to confuse these with core exercise. Also, an approach in which a bit of everything is included will almost ensure failure. The goal must be to know and replace what is lost in the absence of 1-g work and exercise.

Exercise Evaluation - It is crucial to understand that success or failure of this program is absolutely dependent upon the individual who is exercising. The best insurance of success is to make this individual responsible for his own well-being. He must understand what is required and be given the means to ensure it is done. The first person to be aware of exercise test results should be this person. He should be provided with the knowledge, the exercise apparatus and time, and a means to evaluate his efforts. In addition, he must be a partner in any higher level monitoring by Life Sciences. A general plan for monitoring of any effort follows.

The first step is sufficient objective monitoring of a crewman's 1-g activities to establish an individual baseline. The subject and medical officer should collaborate on this exercise profile. Data would include measurement of locomotor activity with logging of arm exercises plus recorded estimates of other activity such as significant manual labor, sports, etc. Appropriate interactive performance testing of capacities would be done, e.g. O_2 uptake, strength and endurance testing of significant muscle groups, especially those

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[a]Running produces forces of ~ 3 BW versus 1.8 BW walking.

involved in emergency maneuvers. This would be administered by the physician and made jointly available to physician and subject. From this, a recommended baseline exercise plan would be developed with flight surgeons and subject using the guidelines developed and tested. In flight, routine monitoring and storage of all exercise data on an individual basis should be available with on-line monitoring and onboard facilities for display of the individual's stored data. A periodic self-evaluation test program should be provided which allows the subject and physician to follow significant parameters on a 'how goes it' basis. At longer intervals, physiological performance testing would occur. These results would be available to the subject. This would be an interactive program in which monitoring and test results could be modified to achieve desired levels of capacity. Any research or investigation which alters the usual protocol should be labelled and clearly understood by all involved.

Summary - The following is my estimate of a protocol based on experience to date.

Preservation of locomotor capacity by earth equivalent, exercise in space is the crucial component of inflight exercise. At this time the treadmill appears to be the only way possible to do this. Work is underway on appropriate hardware but this and a proposed protocol to reduce exercise time must be tested. Such exercise will preserve muscle, bone Ca^{++} and cardiovascular-respiratory capacity. In addition reasonable upper body exercise can be supplied by a new force generator/measurement system—optional exercise might include a rowing

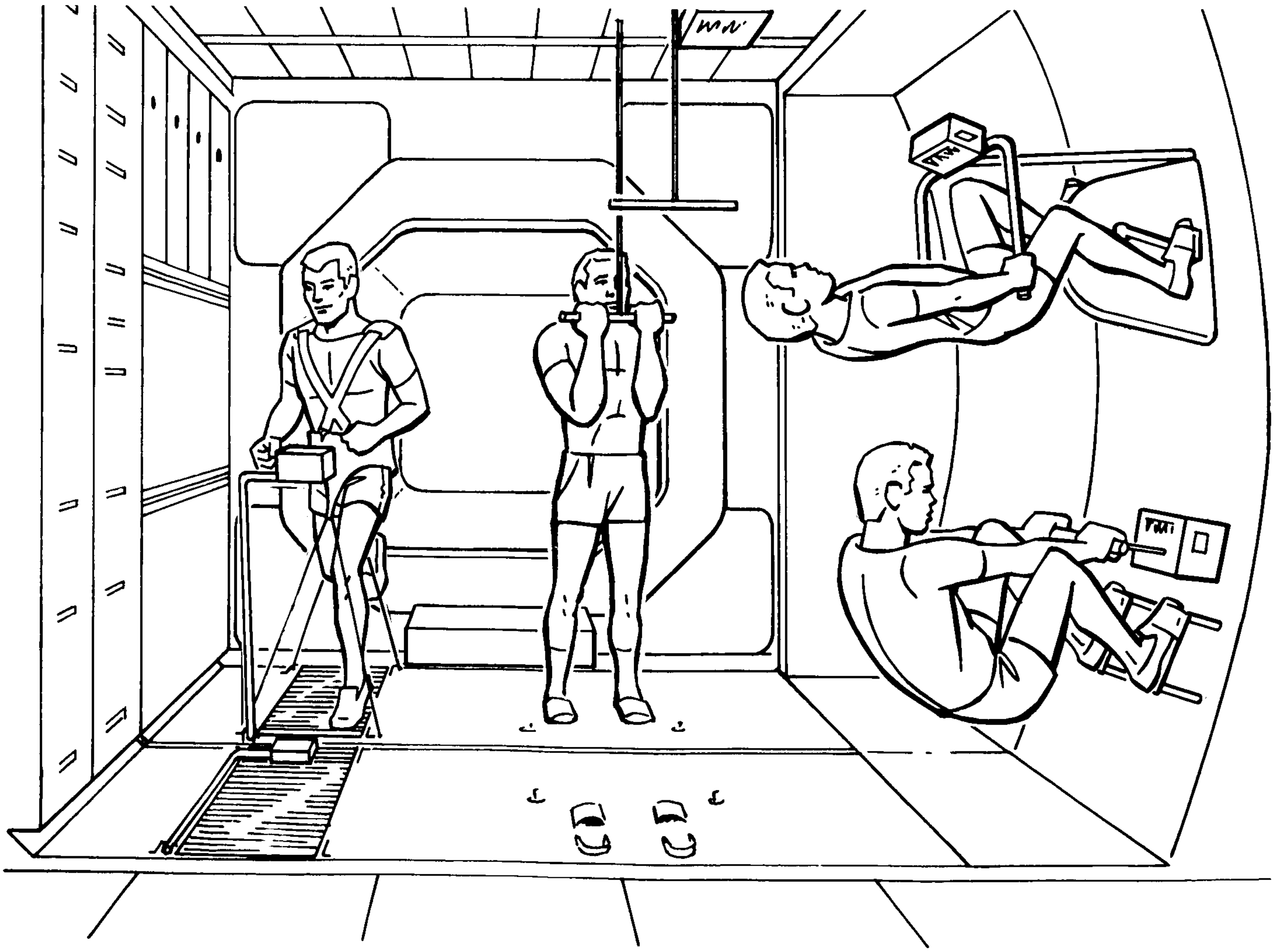

Fig. 20.- Conceptual sketch of exercise area (gym) in current space station layout. Dual treadmills, multipurpose arm-trunk ergometers, bicycles and rowing machines are available. All devices have individual crew recorders.

machine and bicycle ergometer. A subject centered monitoring-evaluation program will allow real time adjustments as required. Absolute protection for any astronaut will not be possible and thóse with hypertrophied capacities such as marathoners or weight lifters will suffer significant loss however the program described should return the crew to earth with adequate capacity for typical activity on earth including immediate ambulation and minimal recovery time and without permanent change. An understanding of the practical mechanics and biomechanics involved is essential to a solution of the problem.

Day	Exercise and Time[1,2]			Evaluation		
	Min-Mean-Max					
	Locomotor	Trunk & Arm	Optional	Mon.	Eval.	Test
1[3]	10 - 20 - 30		5 - 15 - 25	All		
	10 - 20 - 30		5 - 15 - 25	All		
2	10 - 20 - 30	5 - 15 - 25		All		
	10 - 20 - 30	5 - 15 - 25		All		
3	10 - 20 - 30		5 - 15 - 25	All		
	10 - 20 - 30		5 - 15 - 25	All		
4	10 - 20 - 30	5 - 15 - 25		All		
	10 - 20 - 30	5 - 15 - 25		All		
5	10 - 20 - 30		5 - 15 - 25	All		
	10 - 20 - 30		5 - 15 - 25	All		
6	10 - 20 - 30	5 - 15 - 25		All		
	10 - 20 - 30	5 - 15 - 25	All			
7	10 - 20 - 30		10 - 20 - 30	All		
	10 - 20 - 30		5 - 15 - 25	All		
8	30				Per	
	30				Per	
22						CVR
23						MS
31					Per	
					Per	

Cycles repeat in above order

NB at least 15 minutes cleanup must be allowed at each session.

[1]Time in minutes
[2]This is a function of subject's 1-g evaluation.
[3]Two sessions/day
Per - Physical Performance - strength, endurance - every 8th day
CVR - Cardiovascular Respiratory
MS - Musculoskeletal
Mon - Monitor

The foregoing is an estimate which will surely change with results from bed rest studies, further Shuttle and possibly Russian studies, and certainly on orbit; however, it has an objective basis.

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