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Memorandum

To: Dr. Busch-Vishniac

From: Robert McMahan TEXAS UNIV (AUSTIN)

Date: February 19, 1993

Re: Specification List and Function Structure for a Full-Body Dynamometer to be Used Aboard Space Station Freedom

This memorandum presents a specification list and a function structure to help clarify the design task of producing a full-body dynamometer to be used by NASA on space station Freedom and perhaps on the space shuttle. Both the specification list and the function structure have accompanying explanations. Also, there is an introduction, conclusion, and reference list to further aid in clarifying the design problem.

(NASA-CR-195508) SPECIFICATION LIST AND FUNCTION STRUCTURE FOR A FULL-BODY DYNAMOMETER TO BE USED ABOARD SPACE STATION FREEDOM (Texas Univ.) 11 p

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Introduction

NASA has a need for a machine which can be used as an exercise device and as an instrument to measure an astronaut's muscle performance. The purpose of the exercise device is to work various muscle groups of the astronaut to prevent muscle atrophy, the loss of muscle strength and mass from prolonged exposure to a micro gravity environment. The measurement part of the machine will be used to collect data on the strength and power of the astronaut's muscle groups to be used in studies examining the effects of prolonged space inhabitation.

The principle device used in this machine to both exercise and measure muscle performance is the dynamometer. The dynamometer converts electrical energy to mechanical energy and mechanical energy to electrical energy or signals. The task of the designer will be to incorporate a dynamometer into a device which can meet all of the needs discussed above.

This memorandum has two sections which clarify the design task: to produce a full-body dynamometer. The first section is a specification list. The specification list provides the requirements that the designer must meet in his/her design. The second part is a function structure. The function structure shows graphically the flow of material, energy, and information through the machine. These two items will be used by the designer in the design process for the full-body dynamometer.

NASA	Specification List	
D/W	Requirement	Verify
	Geometry	
D	Integrated mountings to stably attach to station	Dynamic analysis
D	Maximum dimension: 8 feet	Measure
D	Fit in standard NASA research device transportation module	Measure
D	Maximum mass: 800 lbm	Weigh
D	Fit within NASA space station work module	Measure
	Kinematics	
D	Ability to move at fixed rotational speed	Test prototype
D	Ability to hold position & measure torque	Test prototype
D	Perform exercises/tests for:	
	Knee	
	Extension/Flexion Sitting	
	Extension/Flexion Supine	
	Extension/Flexion Prone	
	Shoulder	
	Flexion/Extension Supine	
	Abduction/Adduction Side	
	Flexion/Extension Adduction Supine	
	External/Internal Rotation Neutral	
	External/Internal Rotation 45 d Abducted	
	External/Internal Rotation 90 d Abducted	
	External/Internal Rotation 90 d Flexion Sitting	
	Flexion/Extension Sitting	
	Abduction/Adduction Sitting	
	Elbow	
	Flexion/Extension Supine	
	Flexion/Extension Sitting	
	Ankle	
	Dorsi/Plantar Sitting Straight Knee	
	Dorsi/Plantar Sitting Flexed Knee	
	Dorsi/Plantar Supine Straight Knee	
	Dorsi/Plantar Supine Flexed Knee	
	Dorsi/Plantar Prone Straight Knee	
	Dorsi/Plantar Prone Flexed Knee	
	Dorsi/Plantar Kneeling	
	Eversion/Inversion	
	Wrist	
	Flexion/Extension Supinated	
	Flexion/Extension Pronated	
	Radial/Ulnar Deviation	
	Supination/Pronation	

	Hip	
	Abduction/Adduction	
	Flexion/Extension	
	Flexion Adduction/Extension Abduction	
	External/Internal Rotation Prone	
	Back	
	Flexion/Extension Standing	
	Flexion/Extension Sitting	
	Forces	
D	Withstand 3.3 g accelerations	Dynamic analysis
D	Withstand 20 g decelerations	
D	Withstand shuttle launch vibrations	Dyn analys
D	Withstand 0 atm to 1.5 atm pressures	Pres test
D	Withstand torques up to 450 ft-lbf	Test prototype
D	Measure torque exerted	
	Energy	
D	Operate on 160 V DC external power	Power test
D	Power usage: less than 1 kW	
D	Withstand storage temperatures of -40 F to 160 F	Test proto
D	No escaping electromagnetic signals to interfere with station operations	Operate & measure
	Signals	
D	Electronic output compatible with station computers	Computer check
D	Measurement accuracy within +/- 5 % of reading	Dynamic test
D	Input/output signals will not interfere with station operation	Test proto
D	Send output of all readings to station computer	Test proto
	Safety	
D	Provide emergency halt	Test proto
D	No sharp edges	Inspection
D	No off gassing of harmful contaminants	Test proto
D	Flame retardant materials	Material data
	Ergonomics	
D	Means to secure astronaut to device	Test proto
D	Device does not irritate skin	Matl data
D	Maximum exercise set up time: 5 minutes	Test proto
D	Adjustable to humans within 95th percentile	Measure
D	Reasonably comfortable to operate	Test proto
W	Padded surfaces	Inspection
W	Measure user's pulse rate	Test proto
W	Measure user's blood pressure	Test proto

W	Measure user's body temperature	Test proto
	Operation	
D	Fully functional in 1 micro-g environment	Dynamics
D	Noise limit: 55 dB	Measure
W	Noise limit: 40 dB	Measure
	Maintenance	
D	MTTF greater than 30 years	Experience
D	Average maintenance: less than 1 hr/month	Experience
D	Modular design to facilitate easy replacement of parts	Inspection
	Costs	
D	Total cost less than $500,000 U.S.	Records

Specification List

The purpose of the specification list is to provide a framework of demands and wants for the designer to work in. The specification list is divided into ten design areas. Each of these areas is briefly discussed in this section.

Geometry: The purpose behind the geometry specifications is the need for the device to be used aboard a space station. The requirements follow NASA regulations on size and lift limits. The device should be able to affix firmly and stably to the station to not produce unwanted movements.

Kinematics: The kinematic specifications all involve the primary function of the device. The ability to control speed is critical to strength assessments. The list of tests to be performed is according to those NASA wishes to see examined.

Forces: During storage and transportation to the space station, the device will go through accelerations, vibrations, and pressures that it must withstand. The numbers shown are extremes to what the device will go through to get to the space station. The maximum torque shown is the maximum torque provided by the strongest astronaut on the highest torque rated exercise.

Energy: The station provides power at 160 Volts DC, so the device must be able to use this energy. Also, the device should not use over ten percent of the power available at a research node on the space station, which is 10 kW. To get to the space station, the device might undergo the extremes in temperature shown on the specification sheet.

Signals: A reliable device of this kind should be accurate to within 5 percent of a reading. More accuracy is not important since the nature of the measurement, human muscle action, is not exact and tends to vary from time to time.

Safety: Safety is always important, and in a closed environment extra care must be taken not to allow foreign particles into the air.

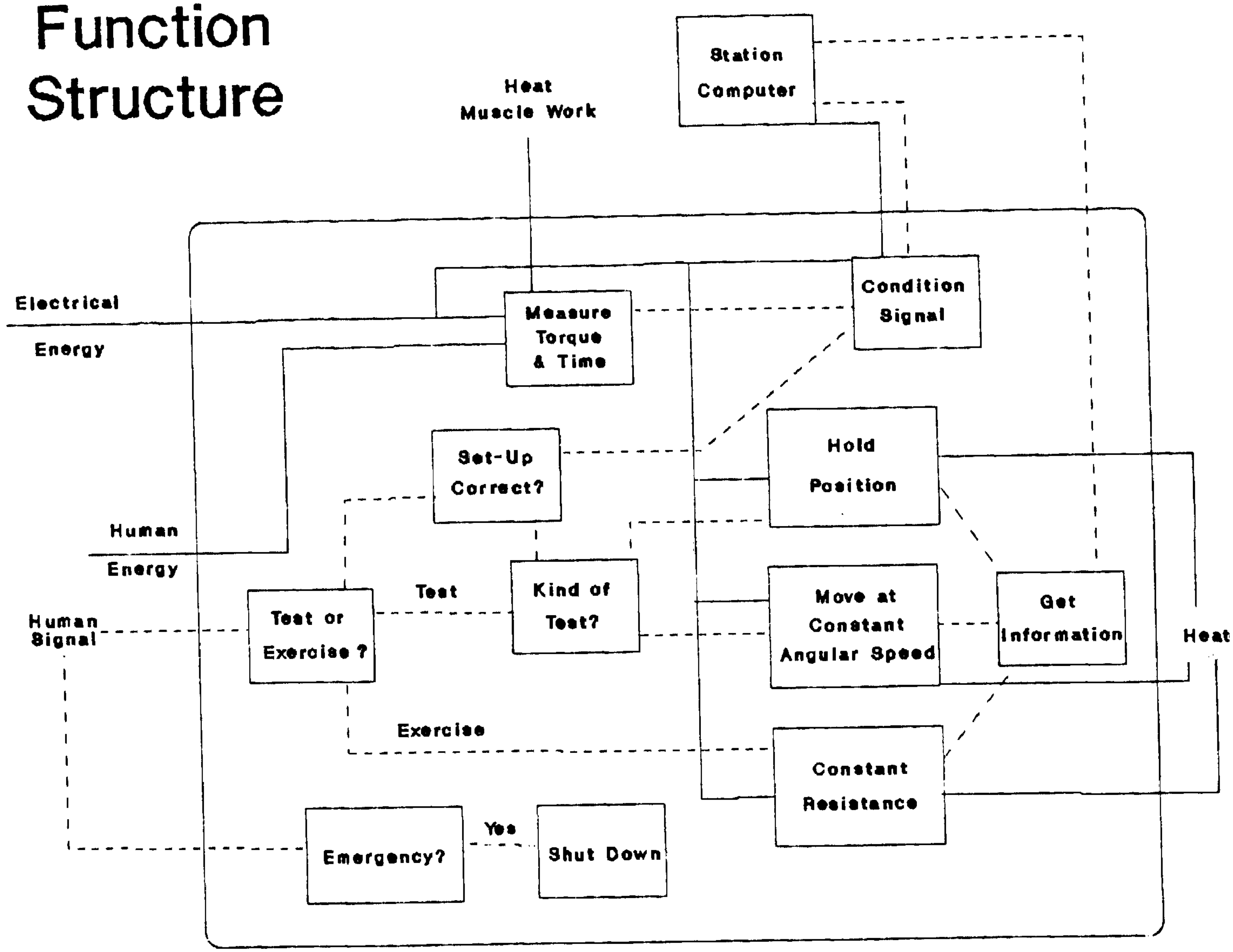
Ergonomics: A time of five minutes to switch exercise set-ups is reasonable in a micro-g environment. A shorter time is not necessary in this non critical device and a longer time would imply a unnecessarily complicated device. If the device could also measure other physiological factors (pulse, blood pressure, and temperature), it could be an aid in gathering information on the physical fitness of the astronauts; but these functions are not the primary purpose of the device.

Operation: A noise level of 40 dB (reference 20E-6 Pa) is approximately equivalent to a refrigerator. The operating of the device should not be louder than this aboard a closed wall station. Actually, a quieter operation level (closer to 30 dB) would be preferred.

Maintenance: The device must have a lifetime at least as long as the space station, which is 30 years. It should also require little to no maintenance (1 hr/month at most) because of the value of man-time in space.

Costs: The cost of 500,000 dollars is a NASA estimate of how much they are willing to pay for a device capable of the specifications laid out here.

Function Structure



Function Structure

A function structure depicts graphically the flow of material, energy, and information through a system. It allows the designer, and other interested parties, to observe the major functions and sub-functions of the device quickly. The function structure can be a great aid to the designer in the conceptual phase of the design where a 'picture' of the function flow of the device is of primary importance. What follows is a short description of the function structure for the full-body dynamometer (presented on the previous page).

This function structure has no material flow through it. The human doing the work might be thought of as a material but he/she is not going through or being transformed by the machine. Therefore, I have chosen to keep the 'human material' out of the system. The human is depicted on the left hand side and there are three inputs from the human user into the system. The first is an energy input. This represents the energy the human puts into the system by doing an exercise or test with the device. The next input is an information flow giving various parameters to the system. The third information flow is the emergency switch. This flow represents the activation of some type of emergency mechanism on the device which immediately shuts down the device.

The energy paths through the system are short. All the human energy is put through the subfunction which measures the torque applied. The mechanical torque from the human is 'burned' at this location, exiting the system as waste heat and energy put into the human (body temperature, blood pressure, muscle exercise). The electrical energy from the station flows through the system in three ways. The electrical energy is used in the dynamometer to measure the torque applied. It is also used to condition and boost the output signal from the device to the station's computer. The last way the electrical energy is used is to control the dynamometer depending on the test or exercise being performed. The energy is used to either hold the device steady, move it at a constant angular velocity, or create a constant resistance to the human torque.

The information flow to the system comes from both the human and the station computer. The station computer stores data on individual astronaut performances, amount of exercise needed and accomplished, strength levels, test results, and so on. The information from the human is used the determine the type of test or exercise to be performed and to retrieve information from the station computer for the particular user. The three larger sub-function boxes to the right on the system are the three tests/exercises done by the device. The sub-functions on the left determine the type of test/exercise to be performed and checks to see if the device is set up correctly for the particular test/exercise to be done. If not, an alarm is sent to the station computer warning the user of the problem.

From the function structure we see information flows going both to and from the station computer. The information leaving the system contains new information just obtained (torque ratings on a test for example), requests for information, and alarms. The information coming into the system is historical data on the specific user currently using the device and records for the amount of exercise and tests needed. This information is needed to determine how the device should implement each test or exercise since each user will have different needs and routines.

Conclusion

The specification list gives as much freedom as possible to the designer so as to allow the greatest openness in which to design. The necessity of designing a device to work and be compatible with a space station in no small task though, so many specifications are necessary to insure a proper design. The function structure shows that this device is mainly an information gathering device. There is no material being transformed in the system and the energy is used primarily to facilitate the gathering of the information. These two items, the specification list and the function structure, are tools used to clarify the design problem. The use of these tools will greatly aid the designer and the design process by giving the designer a better grasp on the problem presented.

References

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