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DESIGN STRATEGIES FOR THE INTERNATIONAL SPACE UNIVERSITY'S VARIABLE GRAVITY RESEARCH FACILITY

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ABSTRACT

A variable gravity research facility named "Newton" was designed by fifty-eight students from thirteen countries at the International Space University's 1989 summer session at the Universite Louis Pasteur, Strasbourg, France. The project was comprehensive in scope including a political and legal foundation for international cooperation, development, and financing; technological, science, and engineering issues; architectural design; plausible schedules; operations, crew issues, and maintenance. Since exposure to long-duration zero gravity is known to be harmful to the human body, the main goal was to design a unique variable gravity research facility which would find a practical solution to this problem, permitting a manned mission to Mars. The facility would not duplicate other space-based facilities and provide the flexibility for examing a number of gravity levels including lunar and martian gravities. Major design alternatives included a truss versus tether based system which also involved the question of docking while spinning or despinning to dock. These design issues are described. The relative advantages and disadvantages are discussed including comments on the necessary research and technology development required for each.

INTRODUCTION

The 1989 International Space University (ISU) convened July 1st in Strasbourg, France at the University of Louis Pasteur. One hundred twenty five students from twenty-five countries came to interact, study, and participate in a multinational, multidisciplinary educational experience in all aspects of space. An international faculty presented core lectures in eight space disciplines: Architecture, Business and Management, Engineering, Life Science, Policy and Law, Resources and Manufacturing, Satellite Applications, and Physical Science, providing a common base of knowledge for all the students. Advanced and plenary lectures from reknowned experts in each of the eight disciplines provided specialized study in each student's particular area of interest.

To promote interdisciplinary interaction and integration, two design projects were chosen whose goals were to utilize the talents and creativity of the students. Each project included mission objectives, design, organization, finance, implementation, and operation for peaceful international use. The selected design projects for 1989 ISU were a lunar polar orbiter and a variable gravity research facility. The names for these projects selected by their participants were Artemis and Newton, respectively. Faculty served as expert advisors. Department assistants who were 1988 ISU students provided additional support. The focus of this paper is to present the design alternatives for the variable gravity research facility, Newton, studied by the design team listed in Table 1. The required cooperation, collaboration, and understanding of the diverse student participants in research, analysis, decision-making, and complilation of the concluding design makes this project a remarkable achievement not only for its technical merit and feasibility but as a working example of outstanding international cooperation.

ISU STUDENTS

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Crawley, Ed	USA	Lemke, Larry	USA	Tolyarenko, Nikolai	USR

Table 1. Names of all individuals and their countries of citizenship who worked on the Variable Gravity Research Facility project during the 1989 Summer Session of the International Space University.

MISSION STRATEGY AND TIMELINE

Prolonged exposure to micro-gravity is known to be harmful to the human body. Some of the major problems are loss of heart and lung capacity, inability to stand upright, muscular atrophy, and loss of bone calcium. These debilitating effects of long duration-reduced gravity exposure must be minimized or counteracted for any long term human space travel such as the mission to Mars. Creation of artificial gravity in a rotating centrifuge or spacecraft is believed to be one possible way of combating these long term effects. The gravity level, spin rate, and duration that are compatible with human survival and efficient engineering design must be determined before a long duration mission to Mars can be undertaken. The variable gravity research facility, Newton, will find a practical solution, as soon as possible, to the problem of human adaptation to artificial gravity so that humans can go to Mars and return safely. It will provide the flexibility for examining a number of gravity levels including lunar and martian gravities and will not duplicate other space-based facilities.

The anticipated Mars mission development drove the end-point decision for Newton's operational lifetime. The scenario presented in the figure below seemed reasonable considering the extensive international development and cooperation required. The international organization consists of the U.S.A. and the U.S.S.R. as the primary partners with E.S.A., Canada, and Japan being secondary partners. The anticipated time-line of Newton is illustrated in Fig. 1 below.

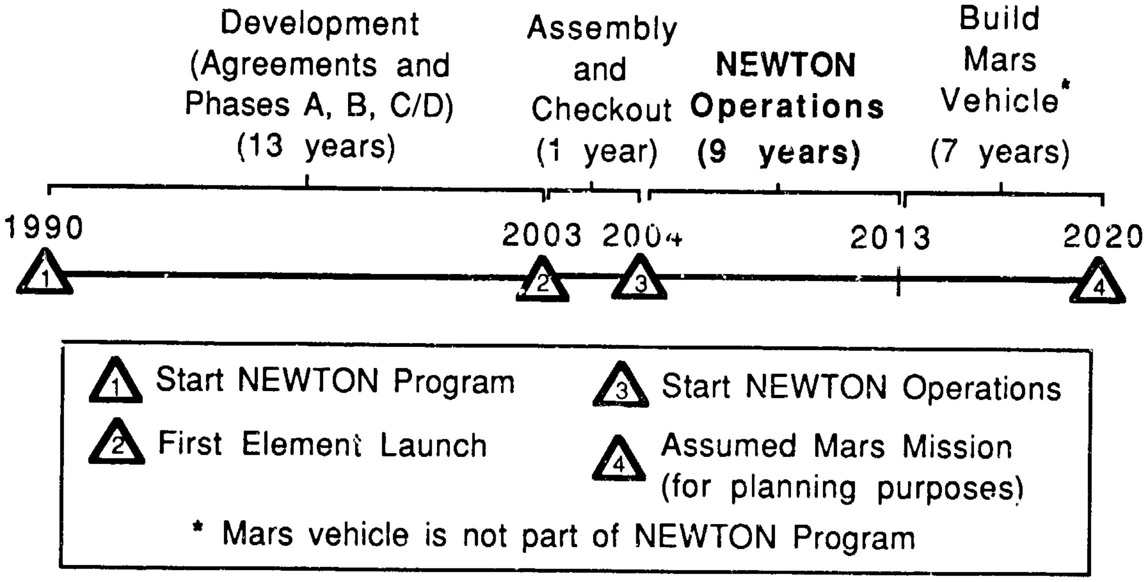

Fig. 1. Newton Time-line

FUNCTIONAL REQUIREMENTS DRIVING SYSTEM DESIGN

Certain assumptions were adopted to facilitate program design. They were as limited as possible in accordance with generally accepted projections for the timeframe listed above. The organizational structure assumes that the two major space-faring nations, the United States of America and the Union of Soviet Socialist Republics, will maintain the improving relations that have been demonstrated over the past few years. Furthermore, it is assumed that no major political problems will arise between or among the U.S.A., the U.S.S.R., or any of the other three partners. It is assumed that Newton will be constructed with technologies and launch vehicle capabilities that are currently in existence, which allows development costs and time requirements to be kept to a minimum. A notable exception to this is that Shuttle C, the future heavy-lift variant of the current U.S. Space Shuttle, is expected to be available when construction begins. Although international co-operative projects offer the benefit of shared costs, the price of Newton will be expensive for each of the partners. It is assumed that each partner has the necessary resources to build this facility, and the political motivation to do so. The U.S.S.R. and the U.S.A. will launch all required components and supplies for the Newton facility.

The functional requirements that were foremost in driving the design of Newton were as follows:

a) Newton must be capable of independently varying both spin rate and gravity level.
b) Newton must provide discrete gravity levels ranging between 0.1g and 1.0g including Martian and lunar gravities.
c) The maximum radius of rotation provides 1g of acceleration at 3rpm.
d) Newton will despin while docking.
e) Newton must accomodate a crew of six.
f) Newton design must permit phased development to allow replacement of modular lab racks and potential upgrade, such as replacing the counterbalance mass for laboratory/habitat modules. It will not be designed to permit additional mass at the end points.

DESIGN CONFIGURATIONS

Two major design alternatives were considered: a truss-based configuration illustrated in Fig. 2 and a tether-based design shown in Fig. 3. Both systems permit implementation of the functional requirements of Newton. A brief description of each system follows and then a comparison of the advantages and disadvantages.

Truss-based Configuration

The truss-based facility contains three major hardware sections: the module section, the despun section, and the counterweight section. The module section includes all of the pressurized habitation and laboratory modules, airlocks, escape vehicles, structural support hardware, and utility runs to provide continuous safe operation of the facility for up to six months. After six months the facility will be despun and resupplied through logistics modules. Long duration life support systems, thermal control systems, and meteoroid/space debris/radiation shielding are provided for the safe operation of Newton. The module section also includes a small reaction control system to provide control and maneuverability during zero gravity and artificial gravity conditions.

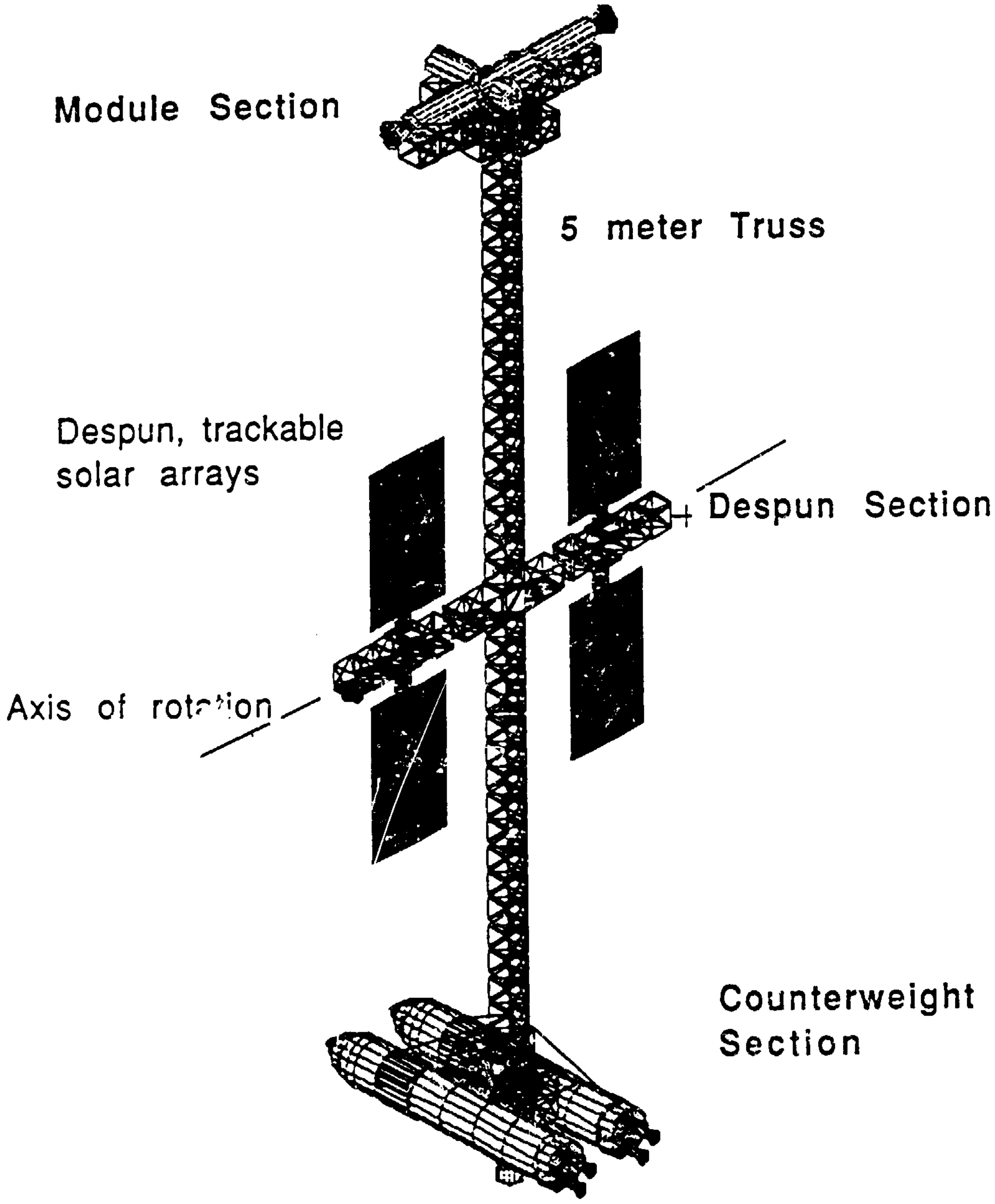
Module Section
5 meter Truss
Despun, trackable solar arrays
Despun Section
Axis of rotation
Counterweight Section

Fig. 2. Newton

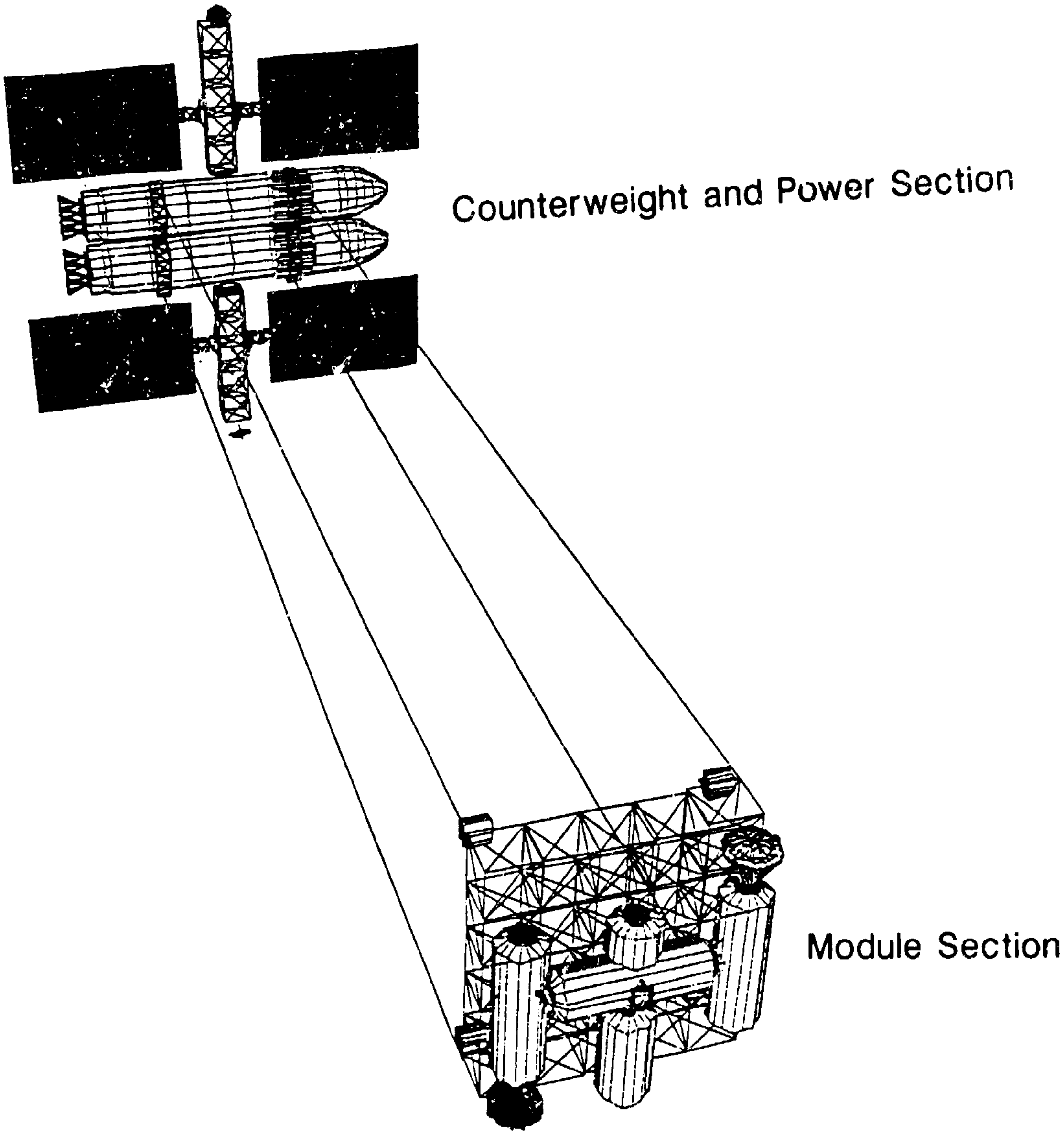

Fig. 3. Tether-based Newton

The despun section provides the power and external communication interfaces for Newton. Seventy-five kilowatts of continuous electrical power is provided through four solar array wings located on twin despun towers; each array is thus at zero gravity and capable of efficiently tracking the sun while the remainder of the facility is rotating. The twin communications antennae have the capablitiy to provide constant tracking of geostationary communication satellites. The despun section is mounted on a movable pallet to permit the section to remain at the center of gravity during radius or mass changes. A front view of Newton in Fig. 4 illustrates the despun section components.

The counterweight section balances the mass of the module section with a pair of spent Energiya core vehicles which have been orbitally outfitted with special mounting hardware to the truss assembly. The counterweight section is also capable of being moved to a new radial position by a mobile servicing unit. The variation in spin rate as a function of the movement of the counterweights is illustrated in Fig. 5. A larger reaction control system is located at the outer radius of the facility, and is capable of providing spinup and spindown thrust as well as boosting capability to higher orbits.

The truss assembly has been designed around a 5 m erectable bay, similar in size and composition to Space Station Freedom's truss structures. Fig. 6 illustrates the required 200 m truss structure necessary for Newton. Freedom is ~80 m in length not including the solar power modules. The struts used in Newton have a 3 cm radius and 2 mm wall thickness compared to the 2.54 cm radius and 1.83 mm wall thickness of Freedom's struts. The increased size of the struts is designed to account for material fatigue due to the rotation and hence induced structural tension.

Tether-based Configuration

The tether-based facility contains two major hardware sections: the module section and the counterweight/power section, as illustrated in Fig. 3. During operation, the dominant load on the structural connection between the two ends of Newton is the tension load due to the centrifugal force. The load would be carried by a system of tethers or cables. Four tethers provide redundancy and torsional stability. The tethers can be reeled in and out from four pulley systems located at the habitat end. Rigid spacers would be placed between the tethers at regular intervals to minimize the free-floating length of a ruptured tether. Such a tether system would require location of the solar arrays on the core stages at the end of the facility. To enable the system to track the sun, the arrays have two degrees of freedom with alpha and beta joints as in the truss-based design. As the power system is located on a rotating end of the facility, the arrays are gravitationally loaded and need to be designed accordingly.

To facilitate control, it would be necessary to reel in the tethers prior to despinning. Alternatively, it is possible that docking could be accomplished without despinning by reeling out the tethers until the rotation rate becomes so slow that docking is possible directly at the module. This would require at least a kilometer of length and is only possible with a tether-based system. The decision to despin prior to docking was based primarily on safety considerations.

TRUSS VERSUS TETHER: A COMPARISON

Four major design issues which must be discussed to assess the advantages and disadvantages of each system are: structural characteristics, assembly/deployment, operational use, and control.

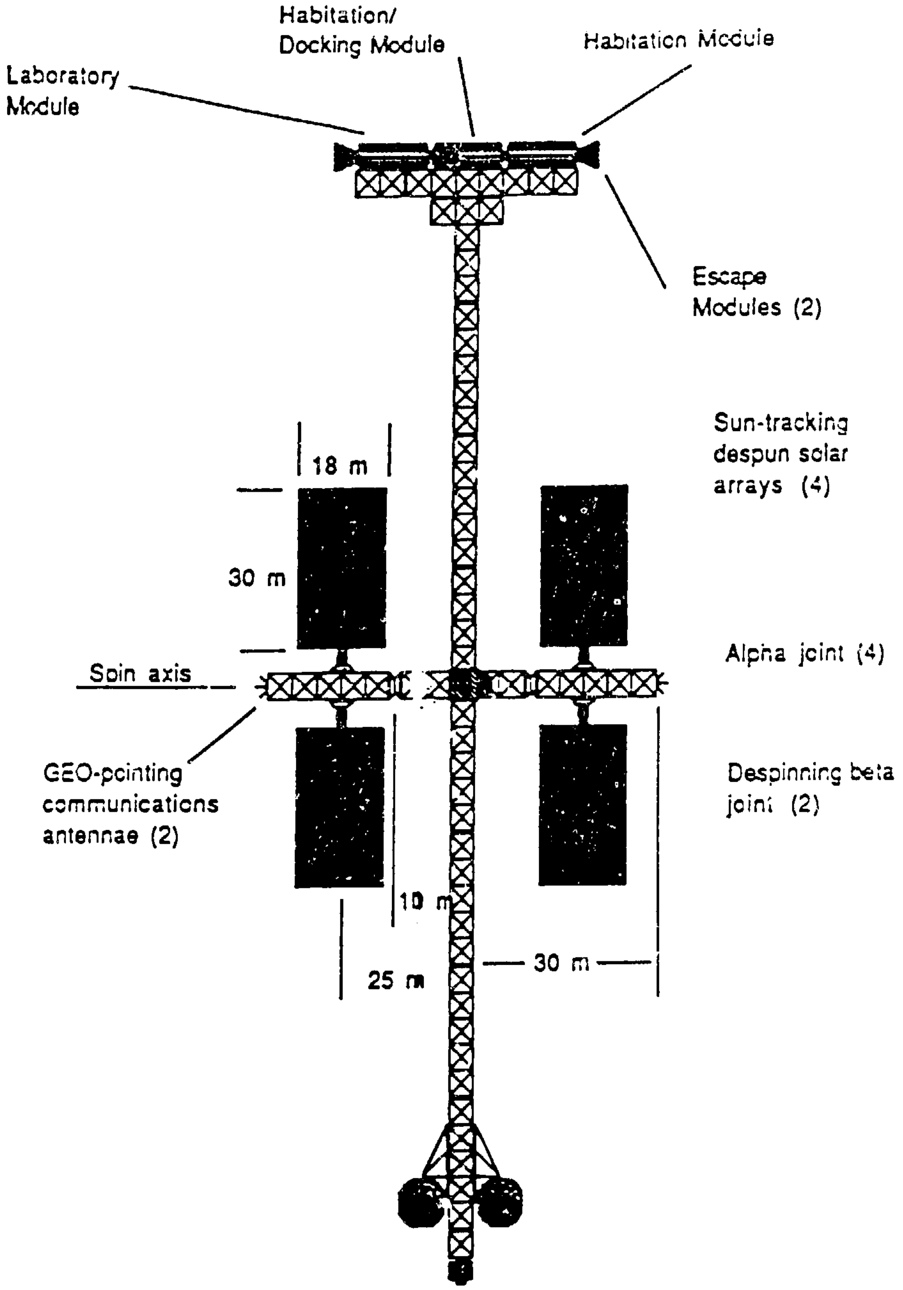

Fig. 4. Front View of Newton

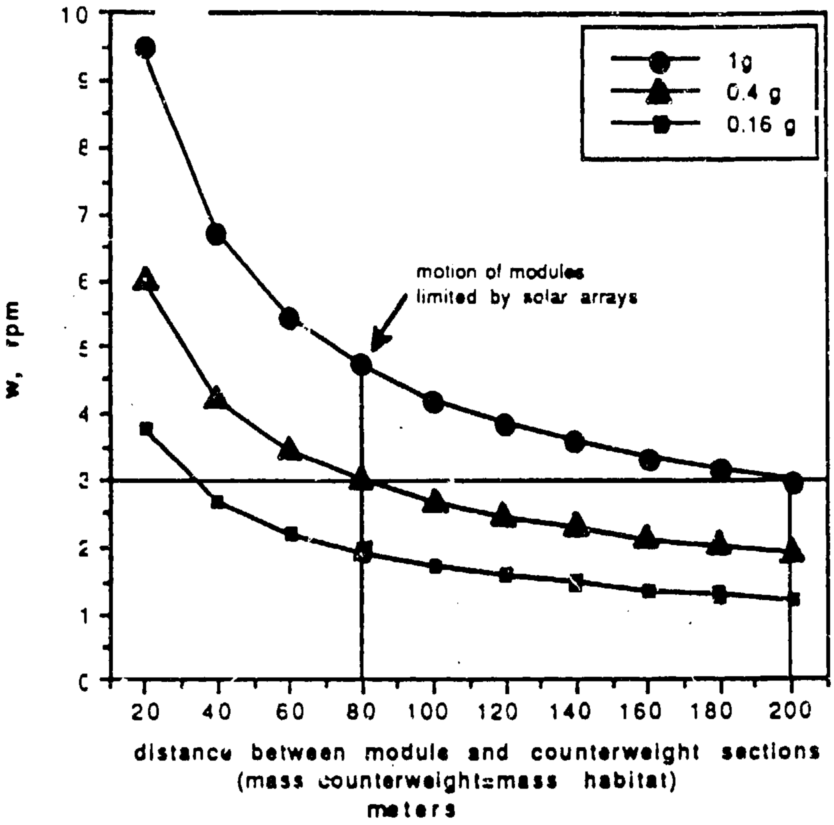

Fig. 5. Variation in spin rate for movement of the counterweights

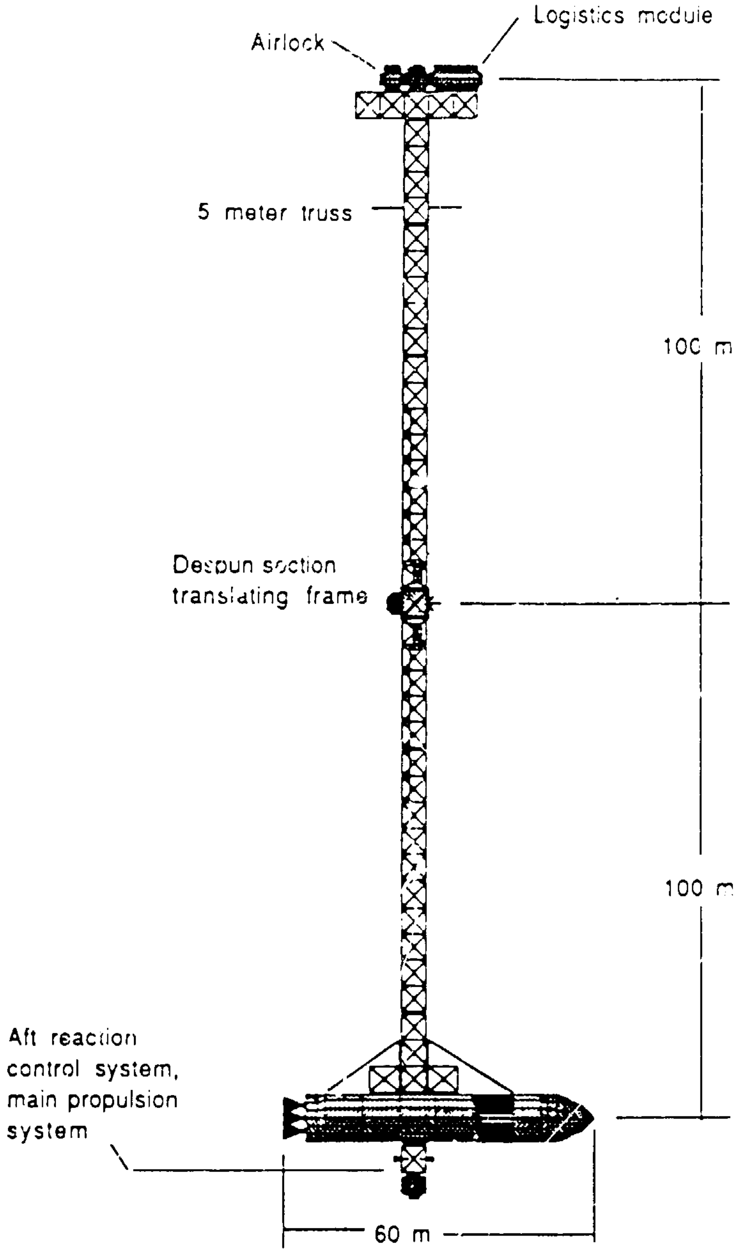

Fig. 6. Side View of Newton

CONCLUSION

A summary of some important considerations appear in Table 2. A truss structure clearly wins if more than two simultaneous gravity levels are required or for small radius structures where the added stiffness of a truss simplifies control. However for ease of gravity level variations permitting a variable radius rather than despinning, a tether system is preferable. Both systems permit phased development; however, a tether system excludes the possibility of expanding to simultaneous gravity levels. It is possible that a tether system would result in a total lower cost for a variable gravity research facility, however principally for safety reasons Newton was designed with a truss structure.

TETHERS	TRUSS
Best in tension	Not optimal in tension
Higher strength to mass ratio (Kevlar)	Lower strength to mass ratio (Al/C composite)
Minimum volume to mass ratio (small rolled volume)	Higher volume to mass ratio
Continuous	Beams must be connected
Not rigid when not rotating	Always rigid
Easily deployable (quick)	Must be erected (time consuming)
Easy and quick length change by reeling	More complicated length change
Limited knowledge of deployment (Agena; Shuttle 1991)	Better knowledge of deployment (Freedom 1995)
No knowledge of dynamic behavior under rotation	No knowledge of dynamic behavior under rotation

Table 2. Tethers versus Truss: A Comparison

REFERENCES

1. "NEWTON: A Variable Gravity Research Facility, Volume I", The International Space University, 1989.

2. "NEWTON: A Variable Gravity Research Facility, Executive Summary", The International Space University, 1989.

Structural Characteristics

The limiting factor on a truss's strength is the strength of the joints. An increase in the number of joints increases the potential failure points. A tether can be regarded as a homogenous, uniform tensile structure with a significant advantage in the strength to weight ratio under tension. Tethers do not have any static stiffness. Truss type structures have both static and dynamic stiffness. Some damping is thought to be initially present in both truss and tether systems. Active damping is greater in a truss [illegible] structure and requires active control. Damping considerations are particularly important during docking. In general it is easier to integrate utilities and power systems into a truss type structure. Power distribution requires significantly longer transmission lines in the tether system.

Assembly/Deployment

Tethers are likely to require significantly less EVA than either deployable or erectable truss structures. However, the construction of Freedom will result in a gain of considerable experience in erectable truss assembly. A tether structure would be significantly simpler than a truss assembly to deploy. The tether also facilitates radius changes, whereas an erectable truss structure requires major operations to change the radius or system geometry. Tethers are most suitable when configured for two separate masses.

Operational Use

Safety and reliability are of prime concern in considering a design choice. Whereas there is a lack of knowledge concerning the dynamic behavior under rotation of both a 200 m truss or tether, it is clear that tethers lack static stability. During assembly, they should be reeled together and then spun out. The major concern regarding tethers is maintaining control during spinup and spindown operation. If the facility were designed to continue spinning while docking tethers would be capable of being lengthened to permit a lower centripetal acceleration at the modules. This would permit docking directly with the module rather than to a central hub mechanism located at the center of gravity. Both structures are suitable for central docking, however eliminating the central hub docking facility and elevator transportation to the modules would increase the safety factor and reduce the complexity of the design. Tethers would have the further advantage of being able to absorb docking impacts by reeling out to absorb momentum and slowly retracting as oscillation subside. The truss system whether spinning or despun will use active control if there is any impact upon docking.

Control

A finite element model of Newton's truss indicated that the fundamental frequency of the truss under worst case loading is approximately 0.8 Hz (this assumes a pinned constraint at each end of the facility). While tethers can approach this dynamic stiffness under worst case loading, their dynamic stiffness decreases with the square of the tensile loading, thus dramatically diminishing their controlability. A tether system would require a greater number of control systems than a truss structure. However it should be remembered that a long thin truss will also be very flexible. If the line of action of thrust through the end mass is not through the center of mass, there will be a resulting torque on the structure. The inherent stiffness in a truss structure will help to reduce the effect of this torque although a damping control system will be necessary. A more complex system will be required for a tether structure.