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**SOME CONSIDERATIONS OF MANNED  
EXTRAVEHICULAR ACTIVITIES IN  
ASSEMBLY AND OPERATION OF  
LARGE SPACE STRUCTURES**

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## SUMMARY

Concepts are formulated by which man's extra-vehicular activities in assembly and operations of space structures can be placed into perspective.

Man's outstanding capability of adaption, intelligent anticipation and dexterity are identified as primary components of his usefulness in this function. These capabilities are considered in view of their use in specific phases of space programs, varying from the initial development phases to the operation of matured systems.

## I. INTRODUCTION

This work was prompted by the current interest in manned extravehicular activities in space (EVA) and was conducted as a portion of a study related to the design and operation of large sized, textured space structures.

The use of man in the deployment, assembly, and alignment of large space structures must be guided by an analysis of the significant and pertinent features of man's capability as opposed to that of inanimate mechanisms. These features must be evaluated in view of the physical characteristics of deployable, assembleable, and adjustable structures (i.e., "variable geometry" structures).

There does not appear to be available at present a universally recognized body of literature that provides a unifying and generally acceptable theory for the selection of man-systems in this area of structural design and operation. It seems pertinent, therefore, to review the features of both man and variable geometry structures briefly in an attempt to identify their systems interaction on a fundamental level.

This study constitutes an initial attempt at formulating some of the basic concepts and problems involved in this aspect of manned activities in space. The detailed, analytical treatment of these problems is relegated to future studies.

## II. DISCUSSION

### 1. Capability of Man

Many attempts to justify manned space systems on economic or technological grounds have failed in the past where a purely mechanical and deterministic view was taken of man's capability. The reason for this becomes quite clear from a review of the pertinent literature. Where predictable sequences of events or observations are to be performed, automatons ("robots") can almost invariably be shown to be more effective. It is a natural tendency of traditional engineering approaches to develop systems towards full predictability and deterministic control. Hence, the desirability for man's physical presence tends to diminish as the total system matures during its operational development. The tendency to automate industrial processes, quality control laboratories, and even certain types of "research" activities, (data processing, etc.), bears witness to this trend. At the same time, even fully automated production and assembly lines almost invariably require supervision by man in preventing minor and random malfunctioning to result in catastrophic consequences. This points to the proper place for man in an otherwise self-contained system, namely, in the role of providing adaptive redundancy (repair of unforeseen damage) which is required to obtain acceptable systems reliability.



Another example is illustrated by the need for pilot interaction in landing an aircraft at a relatively fixed point on a runway with tolerable vertical and horizontal velocity components, or, similarly, the docking of ships and spacecraft. These tasks require adaptive observation, extrapolation of such observation, and decision making based upon experience-able courses of events, i.e., the capability for anticipation and intelligent decision making.

Finally, man's role in judging the perfection of an evolving process by sensory feedback, i.e., dexterity, is in many instances, not readily replaced by automata.

From this discussion, it becomes clear that there are three distinct domains of activity in which man's contribution to a system must be considered; namely,

- (a) Sensory - involving adaptive observation of unforeseen (or unforeseeable) events;
- (b) Mental - involving anticipation and decision guided by experience; and
- (c) Physical - involving execution of physical functions requiring dexterity.

As applied to the construction and operation of variable geometry space structures, these domains of activity can be further defined as discussed below:

### 1.1 Sensory Domain of Activity

This may be regarded in terms of "adaptive instrumentation", i.e., the qualitative and quantitative observation of unforeseen events. Such observations may involve, for instance, orbital tests for deployment mechanisms that are neither fully deterministic nor capable of being fully tested in ground-based laboratories due to structure size, effect of gravity, etc. Because malfunctioning may be of unpredictable nature, full instrumentation for all contingencies will likely be inordinately costly.

### 1.2 Mental Domain of Activity

This involves all areas of adaptive control, where anticipation of events and decision for corrective action to counteract random disturbance is required. Such functions are typically those involving rendezvous (landing, docking, etc.), i.e., the function of bringing originally disconnected structural subsystems into physical contact for joining (see later discussion of "topological discontinuity"). Others are supervision of multiple event deployment sequences where certain dynamic motions must be suppressed before reaching disastrous magnitudes. Examples include "dead beat" of coriolis pitch accelerations of large structures during deployment, and critical speed phenomena in spin deployed structures. In other instances the danger of imminent snagging, or accidental collision

of structural components during a partially random assembly and deployment process needs to be anticipated and prevented by appropriate adaptive control.

### 1.3 Physical Domain of Activity

Physical activity as opposed to the sensory and mental activity, as discussed above, requires, unequivocally, that man be placed in contact with the structure in a direct, physical sense, in addition to the transmission of information and control signals from a more or less remote point. Hence, this activity will normally be "extravehicular" in a more specific sense even though the required protective space suits may possess many characteristics of a "vehicle" (propulsion, life support, servo-mechanisms, etc.). Activities in this area are primarily those of "repair". Those may take the form of correcting observed malfunctioning of a mechanism during initial assembly or deployment, or of performing final adjustments and alignments of deformable structures that require precise contour characteristics. Examples for such structures are, optical and radio telescopes. Another form of "repair" is that of maintenance and refurbishing during intervals of operation (for instance, repair of micrometeorite damage to the structure). Here, the physical presence of man provides adaptive rather than passive redundancy, and may be instrumental in insuring a required level of systems reliability.

Another area of physical activity is the retrieval of physical objects (such as meteorite panels) for examination in ground-based laboratories. Here the physical activity of sample retrieval is corollary to the desired observation and evaluation of scientific experiments.

## 2. Variable Geometry Space Structures

A general theory of variable geometry structures involves departures from traditional concepts of structural design and analysis. The reason for this is that the kinematic and topological aspects of structures that are not normally the concern of structural design come into the foreground during the deployment, assembly, and alignment phases. A multitude of concepts can be and have been conceived, varying greatly both in complexity and in their need for adaptive control, repair, and/or dexterity provided by man.

A basic distinction can be made between structures that require assembly in space from their individual components and those which do not. In mathematical terms, the former undergo topological changes in the direction of increasing connectivity (components at one time not connected are later connected), while the latter are topologically invariant (all connections remain).

An extreme example for a topologically variable structure is one which is assembled from components placed into orbit by several boosters, brought into contact by rendezvous and joined in site, such as the recent Agena-Gemini experiments.

An example for a deployable structure with topological continuity is the ECHO-balloon project, in which a thin membrane structure is erected by inflation to a shape predetermined by the membrane's geometrical characteristics (tailored gores) and the inflation gas' tendency to occupy the maximum volume permitted by the geometrical constraints of the membrane.

Between these extremes, many forms of intermediate variability in the deployment-assembly-alignment process can be considered. These range from simple flexures and hinge joints to universal or ball joints to sliding mechanisms to systems requiring pinning or joining after the deployment process.

A quantitative measure for the complexity of the kinematic process is the number of kinematic independent degrees of freedom (or generalized coordinates) required to describe the position of the structure at each instant during deployment. Another quantitative measure of distinct nature is the number of possible interference positions ("topological accidents") that the structural mechanism can assume during the

process. A simple example may serve to illustrate this distinction. Consider an accordion-folded assembly of four panels connected by three hinges (or flexures) as shown in Figure 1. The relative position of the four panels can be fully described by the three hinge angles  $\theta_1$ ,  $\theta_2$ ,  $\theta_3$ , hence, in the absence of additional constraints, three independent kinematic degrees of freedom exist (in addition to the obvious six "rigid body" degrees of freedom that locate the structure with respect to an external reference).

Depending on the dimensions of the individual panels "topological accidents", i.e., collisions can occur, placing portions of the structure into unintentional contact with each other. Such accidents may be tolerable in certain instances. The snag-free deployment of a tightly packaged spherical membrane (ECHO II) with large quantities of discrete elasto-plastic flexure hinges that move simultaneously during the deployment is an example. In the case of an open mesh construction, however, interpenetration of fiber loops into meshes can occur. This may cause such topological accidents to be catastrophic ("snagging"). A theory of snagging can be developed based upon the following criteria:

- (1) A necessary condition for snagging is, (a) if the kinematic properties of the structure are such that two surfaces which are not intended to contact each other are not positively constrained from such contact with each other (Figure 1); and (b) if, in

the event of accidental contact, the deployment force generates a positive normal pressure between the contacting surfaces.

(2) A sufficient condition for snagging is, if the ratio of the normal contact force component to the tangential contact force component exceeds the friction coefficient of the contacting surfaces (Figure 2).

Another catastrophic consequence could be cold-welding at undesired points of accidentally contacting components, which could effectively destroy the kinematic mobility required for full deployment. Finally, collision may result in structural damage, if relative impact velocities are not kept at tolerable levels.

Clearly, the larger the number of independent degrees of freedom is, the higher is the probability for such accidents. Reducing the number of independent degrees of freedom reduces mobility but provides better control. Reduction to a single degree of freedom provides "positive control" in which case the probability of collision in the absence of malfunctioning is either zero or unity and no randomness of events remains (full predictability). In the example shown in Figure 1, such positive control can be achieved, for instance, by

mutual gearing of the three hinges by a chain and sprocket arrangement as shown schematically in Figure 3. Such a gearing arrangement enforces a condition  $\theta_1 = \theta_2 = \theta_3 = \theta$ , effectively reducing the degree of kinematic freedom to one. If the mechanism is provided with appropriate stops (i.e., intentional points of contacts), the probability of accidental collision becomes zero. Stops can be designed to be snag and cold-weld free by appropriate choice of geometry and materials.

Such "gearing" can be accomplished by the very simple mechanical means shown in Figure 3. More complex cases may require electronic, pneumatic, or hydraulic actuators and associated straight or "feed-back" control systems.

Thus, randomness of motion can be eliminated at the cost of additional components, weight and complexity. Such complexity however introduces a different source of randomness, namely, that associated with the probability of component failure. This is particularly true in the case of moving components and electronic circuitry, which have been the subjects of many intensive studies related to systems reliability.

A very similar treatment can be given to the problem of alignment: Alignment can be provided by stops, metric constraints, etc., built into a variable geometry structure. These can hold a final shape within the limits of random fabri-



cation tolerance and of random distortions caused by unpredictable environmental effects. Compensation can be supplied by active control mechanisms, which are capable of sensing such random deviations from desired contour and of providing correction by means of actuators. Here, inherent randomness in final contour is reduced, again at the cost of additional complexity and the risk of component failure.

### 3. Man-Structure Systems Interaction

From the previous discussion it becomes clear that there are at least three distinct phases in which man's adaptability should be considered in supplementing a structural system:

- (a) In the development phase of a structural system, for instance, where adaptive observation of orbital deployment sequences is necessary to provide the desired insight into the nature and origin of non-anticipated failure sequences. Here, man plays the role of intelligent observer, aiding in the gathering of the technological experience required for successful ultimate systems development;
- (b) In providing adaptive control for deployment-alignment sequences which are simple but non-positive and therefore contain an inherent

randomness of the kinematic process. Here, man's interaction is that of intelligent anticipation and prevention of the fundamental consequences of the second law of thermodynamics (Entropy - i.e., disorder in a non-intelligent system - must increase);

- (b) In providing adaptive redundancy (repair and refurbishment) of well matured design configurations where lifetime requirement and inherent complexity erects a reliability barrier. Here, man is cast in the somewhat unexpected role of counteracting "Murphy's law" (if something can be done wrong, then somebody will). This becomes possible by judicious selection of the individual to whom this function is entrusted (Astronaut vs. Murphy).

A representation shown in Figure 4 summarizes man's interaction with structural systems in graphic form.

### III. CONCLUSIONS AND RECOMMENDATIONS

This study indicates three classes of extravehicular activities in which a meaningful role can be played by man in the deployment and operation of large space structures. These involve observations, decision, and repair as specific and distinct activities geared to man's capability of adaptation.

A quantitative analysis of the value of such intelligent interaction with the physical processes involved should be performed whenever such an interaction is a significant portion of a planned space program. Further, applicable literature should be reviewed and indexed with regard to its pertinence to the distinct areas of mans adaptive functions.

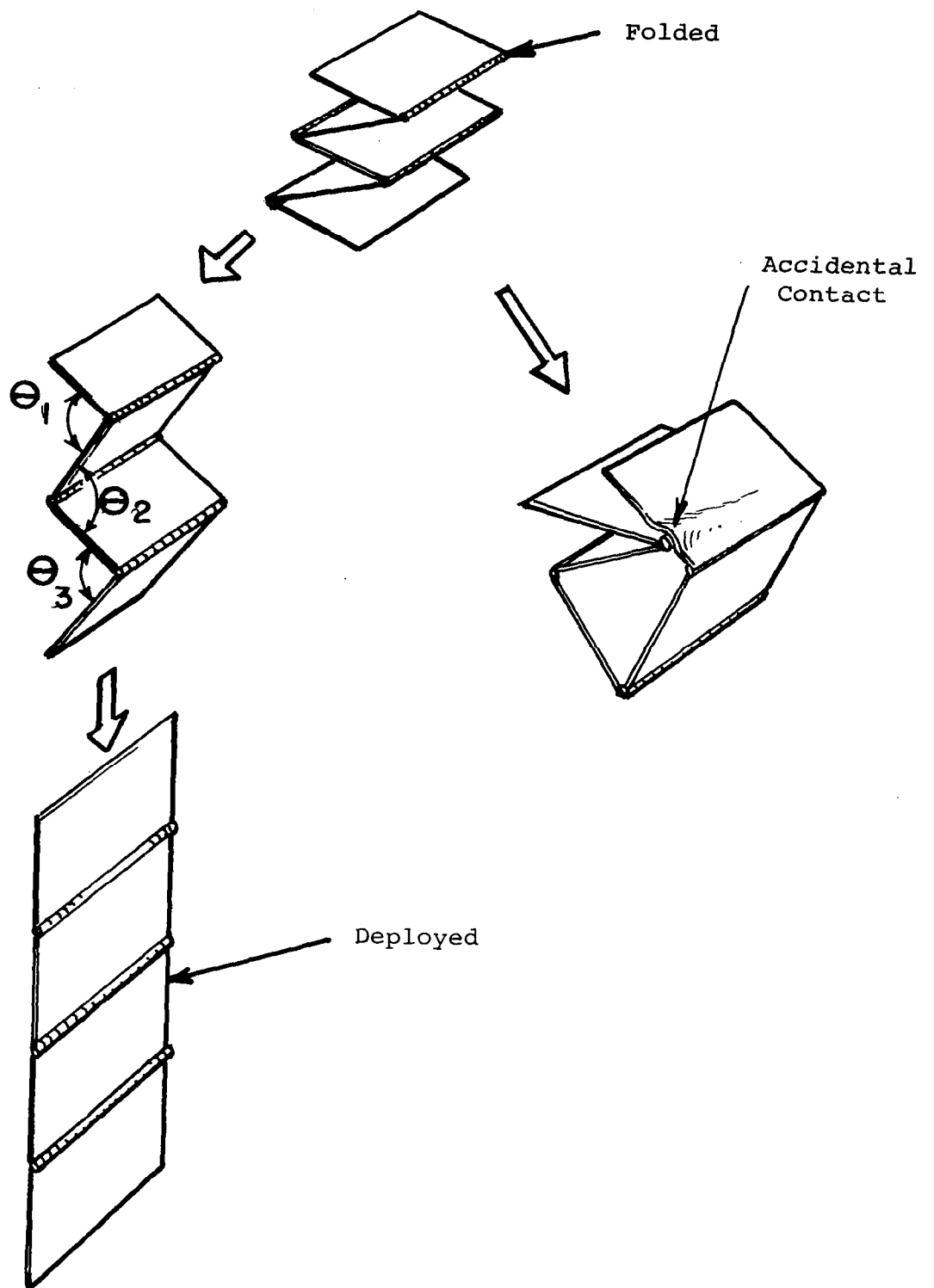


Figure 1

Topological Accident of  
Deployment Sequence

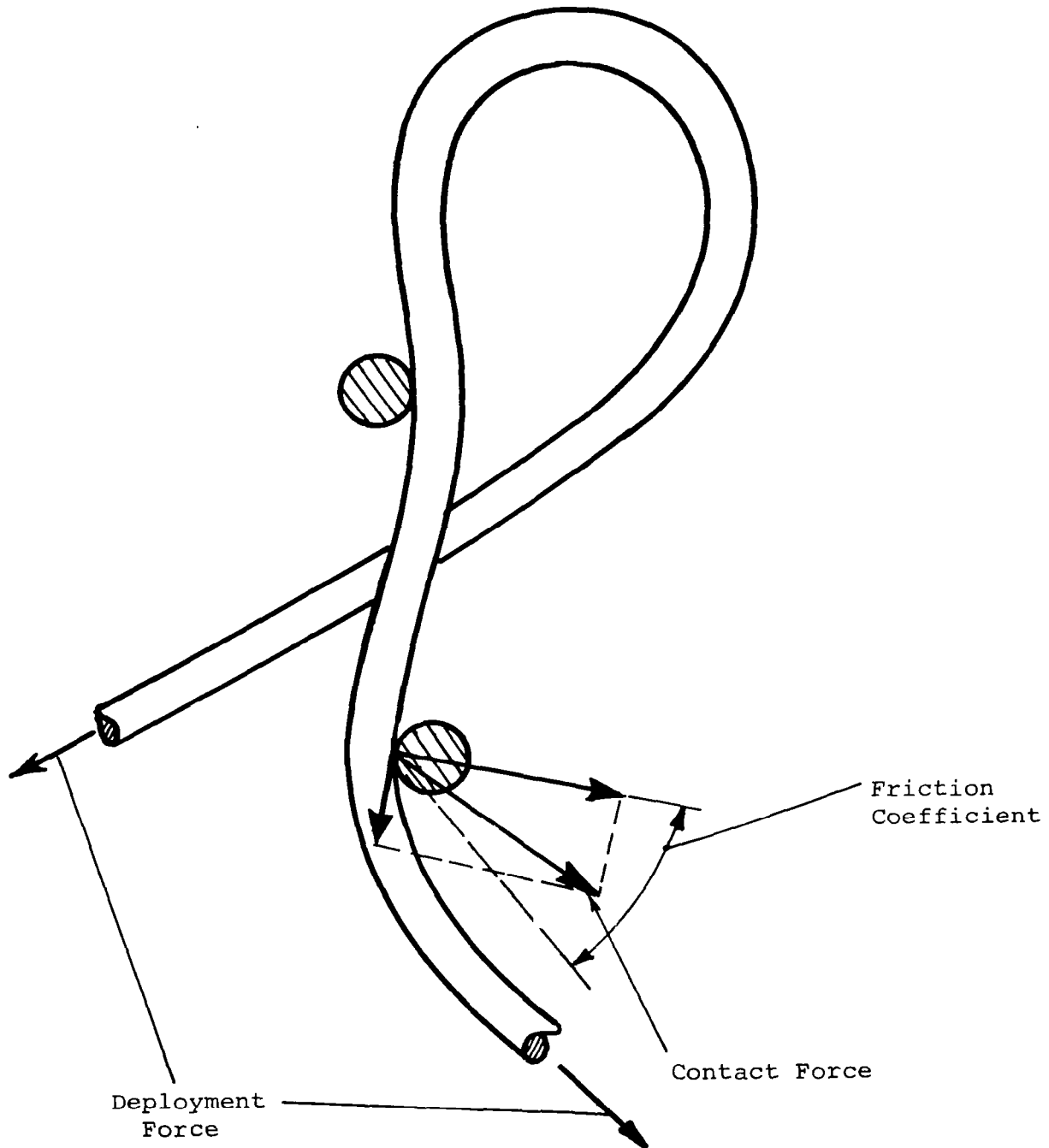


Figure 2

Snagging Condition for Interpenetrating Loop

*"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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