# Multivariate Dynamical Modeling to Investigate Human Adaptation to Space Flight: Initial Concepts

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***Abstract* — The array of physiological changes that occur when humans venture into space for long periods presents a challenge to future exploration. The changes are conventionally investigated independently, but a complete understanding of adaptation requires a conceptual basis founded in integrative physiology, aided by appropriate mathematical modeling. NASA is in the early stages of developing such an approach.**

## I. Introduction: The Human Body in Space

When humans go into space, many physiological changes take place in response to multiple environmental stressors (weightlessness, altered light/dark cycles, radiation exposure, isolation and confinement) [1]. The changes affect most every system in the body (sensorimotor, cardiovascular, muscle, bone, immune), with different magnitudes and time courses, and can have adverse consequences for health and performance (including psychological and behavioral issues). Furthermore, these various systems interact with each other in ways that we do not fully understand. Nevertheless, the body adjusts to this assault with a set of adaptive adjustments, resulting in a new equilibrium known as “space normal.”

A large amount of research over many years has provided a good understanding of many of these individual adaptive adjustments. Although many contributing factors have been identified, which help establish the context of the human in a larger overall system [2], the individual physiological systems and their responses to the environment have often been explored in an ad hoc fashion and rarely as an *integrated* system. An overall conceptual framework is needed, by which we might better understand how the organism as a whole responds to space flight [3]. The problem is that even the most basic of interactions quickly leads to incredible complexity.

## II. Conceptual Approaches

Several features of the humans-in-space model make it uniquely suited for an integrated approach: 1) the population of astronauts is relatively homogeneous, highly trained, and well-characterized; 2) the environment is well understood and constantly monitored; 3) the ability exists (within limits) to make multiple simultaneous measurements in each person.

Initial questions to be pursued with a modern modeling approach include: 1) does space-normal represent an attractor of a dynamic system, or a driven state maintained by chronic perturbation with dissipative costs? 2) is there a “common currency” to describe the systems and their interactions? 3) can the human response to space flight be characterized by bidirectional interaction with the environment?

One possible methodology is based on small-world networks [4]. A set of highly-interconnected nodes leads to a system that self-organizes and is robust in the face of perturbations. This may describe the body in space, where the various physiological systems correspond to network nodes, and self-organization reflects adaptation. If this conceptual approach is fruitful, it might provide an understanding of how current countermeasures work across systems (e.g., exercise is a successful countermeasure for bone loss and muscle deconditioning, but also may have benefits for immune function and psychological health). This understanding could in turn lead to more targeted and efficient countermeasures.

## III. Advantages to the Approach

Benefits include insight into complex interconnected systems in extreme environments, and establishment of a conceptual basis for understanding how humans adapt to space flight. Practical aspects include improving the approach to space-flight countermeasures: a small number of interventions focused on critical nodes in a physiological network, for example, might have widespread effects and thus replace a large number of interventions each focused on an individual response. Given the severe constraints on mass, power, and crew time inherent to space flight, the creation of more efficient countermeasures would be a significant benefit.

## IV. Initial Efforts

A subset of interconnected physiological systems must be identified for initial work. To this end, we are implementing a set of tools to visualize and quantify linkages between disciplines covered by the NASA Human Research Program, based on publication records. These initial results will provide the basis for dynamic modeling as described here.

## References

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* Supported by the NASA Human Research Program.
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