CHARACTERIZATION OF FLUID PHYSICS EFFECTS ON CARDIOVASCULAR RESPONSE TO MICROGRAVITY [G-572]

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The investigation of cardiovascular adaptation to space flight has seen substantial advancement in the last several years. In-flight echocardiographic measurements of astronaut cardiac function on the Space Shuttle have documented an initial increase, followed by a progressive reduction in both left ventricular volume index and stroke volume with a compensatory increase in heart rate to maintain cardiac output. To date, the reduced cardiac size and stroke volume have been presumed to be the consequence of the reduction in circulating fluid volume within a few days after orbital insertion. However, no specific mechanism for the reduced stroke volume has been identified. The following investigation proposes the use of a hydraulic model of the cardiovascular system to examine the possibility that the observed reduction in stroke volume may, in part, be related to fluid physics effects on heart function. The automated model is being prepared to fly as a GAS payload within the next year.

Many factors influence the filling of the heart during diastole. These factors include (1) the atrial pressure, (2) the inertia of the blood as it enters the ventricle, (3) the transmural pressure difference, (4) the myocardial compliance including myofibril passive, elastic recoil, and (5) the gravitational acceleration-dependent hydrostatic pressure difference that exists in the ventricle due to its size and anatomic orientation. This pressure gradient, which can be estimated to be 6660 dynes/cm^2 ($\approx$ 5 mm Hg) in an average adult, acts to augment the diastolic filling of the heart. The investigators have hypothesized that the absence of this contribution to the ventricular filling process in the microgravity environment of space flight may account, in part, for physiological factors that would act to reduce cardiac filling and consequently result in a reduced stroke volume.

The experimental apparatus to investigate this issue consists of a pneumatically actuated, elliptical artificial ventricle (UTAH-100 human version left ventricle) connected to a closed-loop, hydraulic circuit (Penn State) with adjustable compliance and resistance elements to create physiologic pressure and flow conditions. A 40% glycerin in water solution is used in the hydraulic circuit to simulate the viscosity of blood. The ventricle is powered by a miniaturized controller (Symbion, Heimes® Portable Heart Driver) originally developed for use with clinical artificial heart recipients. Ventricular instrumentation includes high-fidelity, acceleration-insensitive, catheter-tip pressure transducers (Millar Instruments) in the apex and base to determine the instantaneous ventricular pressures and ΔP_{LV} across the left ventricle (LVP_{apex} - LVP_{base}). The ventricle is also instrumented with pressure transducers (Millar Instruments) immediately upstream of the inflow valve and downstream of the outflow valve, and an ultrasonic transit-time flow probe (Transonic Systems) downstream of the outflow valve. Acceleration of the experiment will be sensed by a miniature piezoresistive accelerometer (Endevco) and the temperature at three locations in the experiment will be sensed and recorded by an ambient temperature recording unit (NASA/ARC ATR-4). Heating elements (Minco) are incorporated into the hydraulic circuit to establish and maintain the temperature in the operational range of 20° to 40° C. The experiment is thermally insulated by an external sleeve of multiple layers of aluminized Mylar with a Beta cloth cover (NASA/JSC). A bidirectional roller pump is used to inject or withdraw fluid from the hydraulic circuit to create different preload conditions for the artificial ventricle. The experiment is microprocessor controlled (Campbell Scientific, CR-10) with analog signals stored on a seven channel FM data tape recorder (TEAC, HR-30) which can provide up to three hours of continuous recording. Power for the experiment is provided by an array of alkaline batteries (Duracell) in a sealed battery box.

On-orbit performance of the experimental protocol will be initiated once the operational temperature range has been established. By experimentally varying the circulating fluid volume in the hydraulic circuit, ventricular function can be determined for varying preload pressures at a regulated, fixed afterload pressure of 95 mm Hg. This variation in preload condition will permit the construction of ventricular function curves for the microgravity environment for comparison to ventricular function curves constructed from data recorded in the 1-G environment. Eight developmental experiments on board the NASA KC-135 aircraft have demonstrated proof-of-concept and provided early support for the proposed hypothesis. Developmental progress on the GAS version of this experiment will be presented. The schematic layout of the experiment package is presented below.