repeated rapidly to obtain repeated pulses of thrust. Moreover, the multiple combustion tubes are filled and fired in a repeating sequence. Hence, the pressure at the outlet of each combustion tube varies cyclically. A nozzle of the present invention channels the expansion of the pulsed combustion gases from the multiple combustion tubes into a common exhaust stream, in such a manner as to enhance performance in two ways:

(1) It reduces the cyclic variations of pressure at the outlets of the combustion tubes so as to keep the pressure approximately constant near the optimum level needed for filling the tubes, regardless of atmospheric pressure at the altitude of operation; and

(2) It maximizes the transfer of momentum from the exhaust gas to the engine, thereby maximizing thrust.

The figure depicts a typical engine equipped with a nozzle according to the invention. The nozzle includes an interface section comprising multiple intake ports that couple the outlets of the combustion tubes to a common plenum. Proceeding from its upstream to its downstream end, the interface section tapers to a larger cross-sectional area for flow. This taper fosters expansion of the exhaust gases flowing from the outlets of the combustion tubes and contributes to the desired equalization of exhaust combustion pressure.

The cross-sectional area for flow in the common plenum is greater than, or at least equal to, the combined cross-sectional flow areas of the combustor tubes. In the common plenum, the exhaust streams from the individual combustion tubes mix to form a single compound subsonic exhaust stream. Downstream of the common plenum is the throat that tapers to a smaller flow cross section. In this throat, the exhaust gases become compressed to form a compound sonic gas stream.

Downstream of the throat is an expansion section, which typically has a bell or a conical shape. (The expansion section can be truncated or even eliminated in the case of an air-breathing engine.) After entering the expansion section, the exhaust gases expand rapidly from compound sonic to compound supersonic speeds and are then vented to the environment.

The basic invention admits of numerous variations. For example, the combustion tubes can be arranged around the central axis in a symmetrical or asymmetrical pattern other than the one shown in the figure. For another example, the flow cross-sectional area(s) of one or more of the intake ports in the interface section, of the common plenum, the throat, and/or the expansion section can be varied, either symmetrically or asymmetrically, to adjust dynamics of the exhaust stream or to direct the thrust vector away from the central axis.

This work was done by Thomas E. Bratkovich, Kevin E. Williams, Thomas R. A. Bussing, Gary L. Lidstone, and John B. Hinkey of Adroit Systems, Inc., for **Marshall Space Flight Center**. *Further information is contained in a TSP (see page 1).*
MFS-32032

Arc-Second Pointer for Balloon-Borne Astronomical Instrument

A notable innovation would eliminate effects of static friction in bearings.

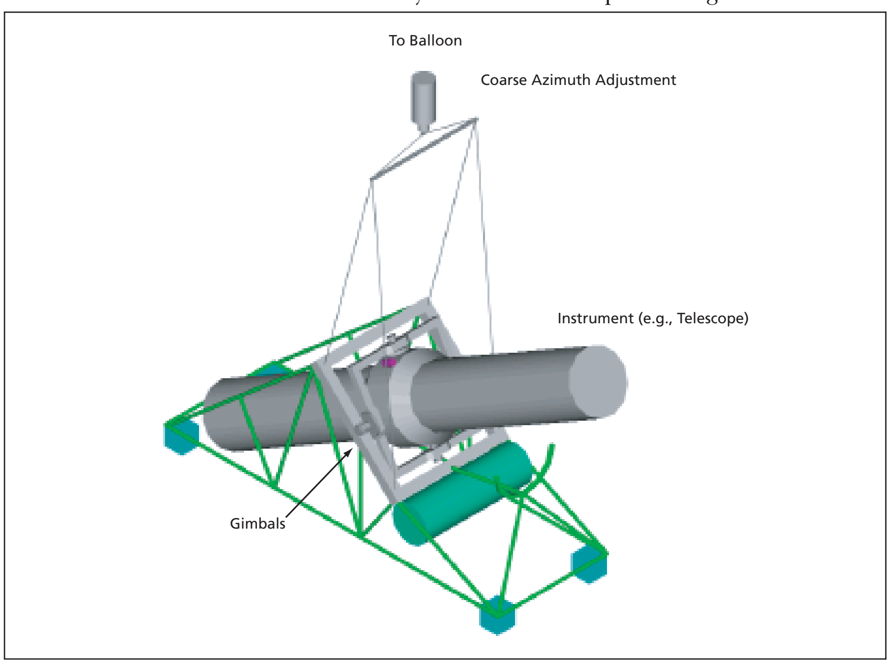
Goddard Space Flight Center, Greenbelt, Maryland

A control system has been designed to keep a balloon-borne scientific instrument pointed toward a celestial object within an angular error of the order of an arc second. The design is intended to be adaptable to a large range of instrument payloads. The initial payload to which the design nominally applies is considered to be a telescope, modeled as a simple thin-walled cylinder 24 ft (≈7.3 m) long, 3 ft (≈0.91 m) in diameter, weighing 1,500 lb (having a mass of ≈680 kg).

The instrument would be mounted on a set of motor-driven gimbals in pitch-yaw configuration. The motors on the gimbals would apply the control torques needed for fine adjustments of the instrument in pitch and yaw. The pitch-yaw mount would, in turn, be suspended from a motor mount at the lower end of a pair of cables hanging down from the balloon (see figure). The motor in this mount would be used to effect coarse azimuth control of the pitch-yaw mount.

A notable innovation incorporated in the design is a provision for keeping the gimbal bearings in constant motion. This innovation would eliminate the deleterious effects of static friction — something that must be done in order to achieve the desired arc-second precision.

Another notable innovation is the use of linear accelerometers to provide feedback that would facilitate the early detection and counteraction of disturbance torques before they could integrate into significant angular-velocity and angular-position errors. The control software processing the sensor data



An **Instrument Would Be Suspended** below a balloon on motor-driven gimbals at the lower end of a set of cables. The motors would apply torques to correct pointing errors.

would be capable of distinguishing between translational and rotational accelerations. The output of the accelerometers is combined with that of angular position and angular-velocity sensors into a proportional + integral + derivative + acceleration control law for the pitch and yaw torque motors. Preliminary calculations have shown that with appropriate gains, the power demand of the control system would be low enough to be satisfiable by means of storage batteries charged by solar batteries during the day.

This work was done by Philip R. Ward and Keith DeWeese of Wallops Flight Facility for **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
GSC-14715-1

Compact, Automated Centrifugal Slide-Staining System

Small quantities of different liquids would be displaced at different centrifuge speeds.

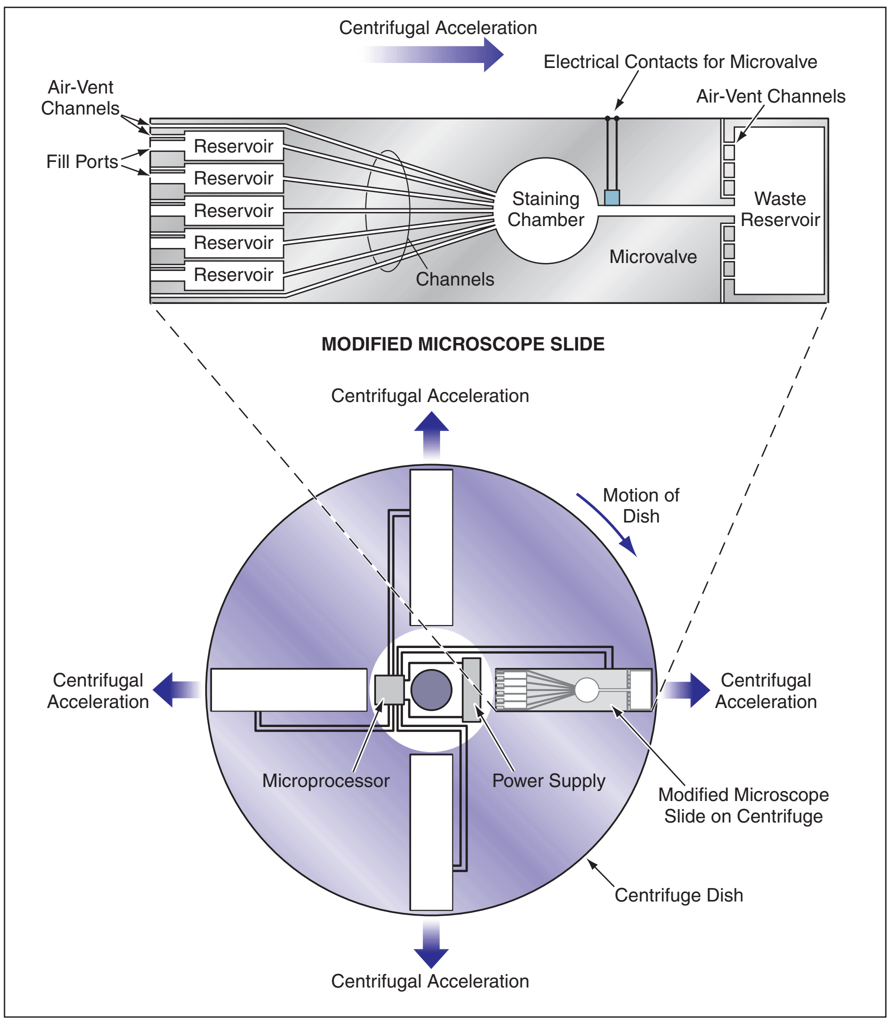
Lyndon B. Johnson Space Center, Houston, Texas

The Directional Acceleration Vector-Driven Displacement of Fluids (DAVD-DOF) system, under development at the time of reporting the information for this article, would be a relatively compact, automated, centrifugally actuated system for staining blood smears and other microbiological samples on glass microscope slides in either a microgravitational or a normal Earth gravitational environment. The DAVD-DOF concept is a successor to the centrifuge-operated slide stainer (COSS) concept, which was reported in "Slide-Staining System for Microgravity or Gravity" (MSC-22949), *NASA Tech Briefs*, Vol. 25, No. 1 (January, 2001), page 64. The COSS includes reservoirs and a staining chamber that contains a microscope slide to which a biological sample is affixed. The staining chamber is sequentially filled with and drained of staining and related liquids from the reservoirs by use of a weighted plunger to force liquid from one reservoir to another at a constant level of hypergravity maintained in a standard swing-bucket centrifuge.

In the DAVD-DOF system, a staining chamber containing a sample would also be sequentially filled and emptied, but with important differences. Instead of a simple microscope slide, one would use a special microscope slide on which would be fabricated a network of very small reservoirs and narrow channels connected to a staining chamber (see figure). Unlike in the COSS, displacement of liquid would be effected by use of the weight of the liquid itself, rather than the weight of a plunger.

The channel from each reservoir to the staining chamber would be made so narrow that the combination of surface tension of the liquid and friction between the liquid and the channel surface would suffice to prevent the flow of liquid from the reservoir to the staining chamber in the absence of hypergravitational centrifugal acceleration below a specified level. Downstream of the staining chamber, there would be channel for draining each fluid from the staining chamber into a waste reservoir after use; this channel would be wider than the other channels so that draining could be accomplished at a centrifuge speed much lower than that needed for filling the staining chamber from a reservoir. Flow in this channel would be restricted by an electrically actuated microvalve controlled by a microprocessor on the spindle of the centrifuge.

By suitable choice of width of each channel, taking account of properties and amount of each liquid, the threshold centrifugal accelerations for moving the liquids from the reservoirs to the staining chamber would be set at successively



Liquids Would Be Contained in Small Reservoirs on a modified microscope slide. Different liquids would be transferred into the staining chamber at different centrifuge speeds.