Exhaust Nozzle for a Multitube Detonative Combustion Engine

Pressures at outlets of combustor tubes are approximately constant.

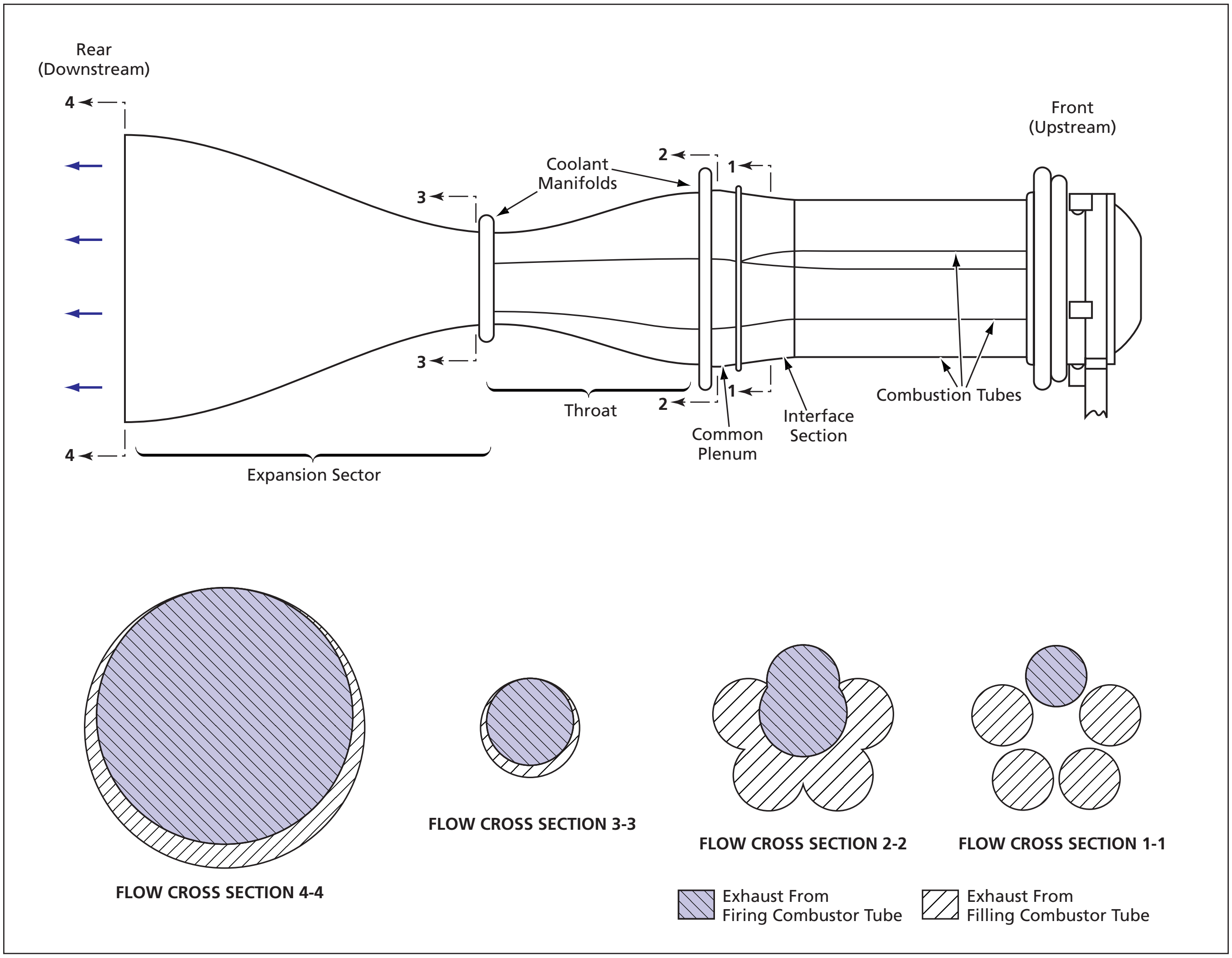
Marshall Space Flight Center, Alabama

An improved type of exhaust nozzle has been invented to help optimize the performances of multitube detonative combustion engines. The invention is applicable to both air-breathing and rocket engines used to propel some aircraft and spacecraft, respectively.

In a detonative combustion engine, thrust is generated through the expulsion of combustion products from a detonation process in which combustion takes place in a reaction zone coupled to a shock wave. The combustion releases energy to sustain the shock wave, while the shock wave enhances the combustion in the reaction zone. The coupled shockwave/reaction zone, commonly referred to as a detonation, propagates through the reactants at very high speed — typically of the order of several thousands of feet per second (of the order of 1 km/s). The very high speed of the detonation forces combustion to occur very rapidly, thereby contributing to high thermodynamic efficiency.

A detonative combustion engine of the type to which the present invention applies includes multiple parallel cylindrical combustion tubes, each closed at the front end and open at the rear end. Each tube is filled with a fuel/oxidizer mixture, and then a detonation wave is initiated at the closed end. The wave propagates rapidly through the fuel/oxidizer mixture, producing very high pressure due to the rapid combustion. The high pressure acting on the closed end of the tube contributes to forward thrust. When the detonation wave reaches the open end of the tube, it produces a blast wave, behind which the high-pressure combustion products are expelled from the tube.

The process of filling each combustion tube with a detonable fuel/oxidizer mixture and then producing a detonation is



Sequentially Pulsed Exhaust Streams from multiple combustion tubes are channeled in such a manner as to maintain a nearly steady back pressure needed for refilling the combustion tubes with fuel/oxidizer mixture.

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.

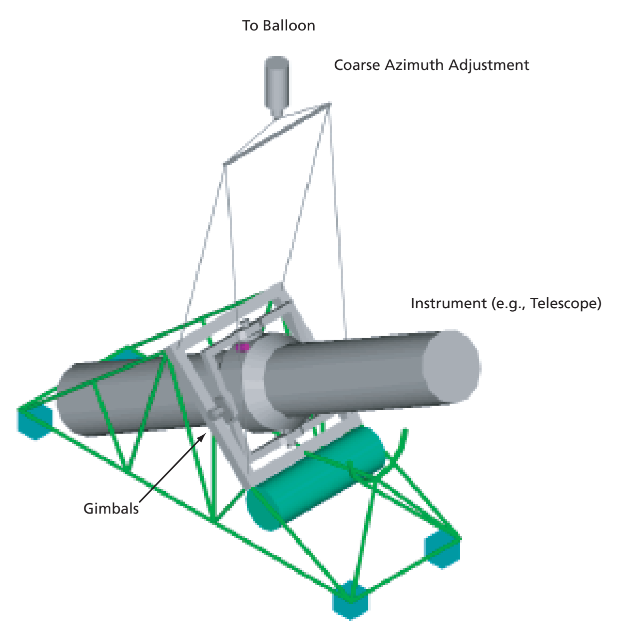
Goddard Space Flight Center, Greenbelt, Maryland

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.