Convoluted Nozzle Extension

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Theme

THIS paper reports the experimental development of a new extendable nozzle concept. The convoluted nozzle is a sheet metal nozzle extension that is formed with a portion of the nozzle convoluted (i.e., turned inside out) to reduce the installed nozzle length to one third of the deployed length. The nozzle is extended to the operating position by simple roll-through of the convoluted section. The resulting plastic deformation of the rolled section produces a rigid final structure that requires no additional support to react the operating thrust and dynamic loads. The convoluted nozzle (CN) can therefore be self actuated with the addition of a jettisonable exit closure and simple internal pressurization (to a low pressure level, e.g., 15 psi) will extend the nozzle to the operating position. Upon deployment, the CN becomes a conventional, sheet metal nozzle extension and therefore the equal of a fixed nozzle in reliability, performance and weight.

The analytical approach to the design of the convoluted nozzle is described. Self-alignment and rolling pressure prediction are discussed. The prototype CN design and deployment test setup is described. Six convoluted nozzles of stainless steel and columbium were successfully deployed. Symmetrical, self-aligning rollout to good final alignment and position was demonstrated. Deployment pressures and roll geometry are shown to correlate well with values and characteristics determined by analysis. This work reduced to practice the fundamental ideas of rolling metal extendable nozzle design with high temperature materials and self-actuation by internal pressure (patent applied for).

Contents

The characteristic increase in fixed bell-nozzle length with nozzle expansion ratio forces upper-stage rocket engine design into a tradeoff with envelope limitations, vehicle bending moments and interstage structure weight. The resulting compromise nozzle expansion ratio does not make the full-performance potential of the engine available to the vehicle. One basic method of circumventing this compromise is to install a large expansion ratio nozzle in a reduced length, nonoperating configuration that does not effect rocket stage design. During or after stage separation, this type of nozzle is extended to operating configuration to provide the maximum engine performance available with an optimum nozzle expansion ratio. Several forms of extendable nozzles have been previously investigated. However, the most promising concepts have involved operating reliability compromises such as a requirement to close a hot gas seal during extension of a rigid nozzle or to cool and stabilise a flexible nozzle.

The convoluted nozzle is an otherwise conventional welded sheet-metal extension that is formed with the mid-portion of the nozzle turned inside out so that this convoluted portion occupies a mirror image position from its deployed condition as shown in the prototype design drawing of Fig. 1. This prototype CN was designed for small engine geometry (e.g., nominally 1000-lb thrust at 380 psi chamber pressure) and no provision was made to demonstrate technically straightforward or conventional aspects of the convoluted nozzle. The deployment control structure was therefore formed by simply pouring a low melting point alloy into the convolution cavity and the nozzle exit seal was a manually removed cover, comprising bolt-on flanges and a rubberized nylon fabric diaphragm.

The flight type CN exit closure is a similar low pressure diaphragm of rubber sealed cloth with provision for automatic jettisoning. The convoluted nozzle is deployed to the fully extended position by internal pressurization to a low-pressure level. This low pressure, acting over the large nozzle area, produces relatively large forces which roll the convoluted section through itself from the larger diameter to the smaller diameter. Since the local force required to roll the convoluted section is directly proportional to the local roll-through angle, the nozzle is self-aligning during deployment. Any cocking tendency produces a restoring force couple because cocking, by definition, requires the leading side to advance into large roll angles and simultaneously reduces the roll angle on the lagging side. The rolling section of the CN includes a short cylindrical portion as shown in Fig. 1. This cylindrical section provides axial translation to adjust for the local nozzle diameter growth produced by rolling around a small but finite roll radius and is sized to align the deployed contour with the fixed section contour. An integral roll stop surface at the end of the fixed section provides positive control of the final alignment of the rolled section with the fixed section.

The convoluted section of the flight type CN is backed by a lightweight deployment control structure to counteract buckling loads produced by internal pressurization. The control structure is segmented and spring loaded to provide

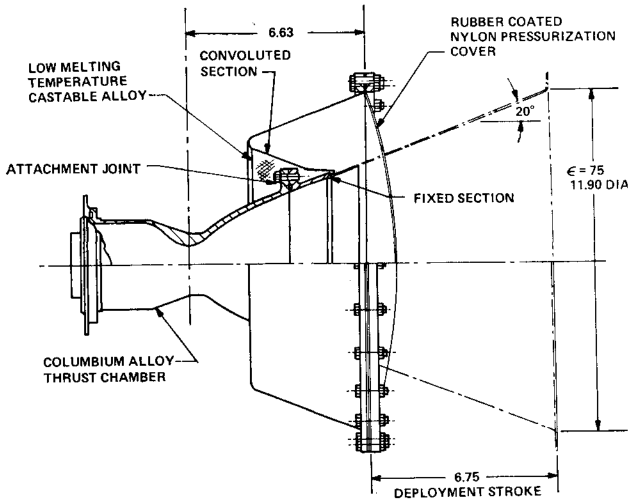

Fig. 1 Prototype convoluted nozzle design.

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automatic jettisoning of this structure after deployment. This deployment control structure is trapped between the convoluted section and the fixed portion of nozzle during fabrication (similar to Fig, 1). Roll-through of the convoluted section during deployment releases the deployment control structure for automatic spring ejection. The flight type exit seal is a high-strength cloth cover that seals against the nozzle exit stiffening hoop and is secured by a retaining ring. The exit seal is jettisoned by the internal pressure after the convoluted nozzle is fully extended. The seal can be released for pressure ejection by explosive cutting of a seal retaining ring or cable. At this point, the convoluted nozzle is extended and ready for engine operation as shown in phantom on Fig. 1. The advantages of this extendable nozzle concept are summarized in Table 1.

Four nozzles were fabricated from 347 stainless steel and two from columbium alloy C-103 sheet metal. All six nozzles were satisfactorily deployed on a simple nitrogen pressurized blowdown rig. The first CN in each material was deployed at slow rates to permit roll geometry measurements.

The remaining nozzles were deployed at fast rates (1.6 to 0.2 sec) to evaluated real time deployment characteristics. High rate deployment in a total time of 0.2 sec was demonstrated with both stainless steel and columbium nozzles. Symmetrical, self-aligning rollout to good final alignment and position (within 0.3° of exact) was also demonstrated with both columbium and stainless steel convoluted nozzles. Two of these prototype nozzles are shown in Fig. 2. This photograph compares the installed and extended configurations of the CN. The cloth exit cover is removed from the stowed nozzle to reveal the internal metal configuration. The extended nozzle is shown in the fire-ready configuration after separation of the exit cover. The extended contour is a

Table 1 Convoluted nozzle advantages

A	Lightweight pressure deployment	
	1	simple reliable deployment—self actuated
	2	deployment equipment jettisoned after extension
B	Conventional metal nozzle after deployment	
	1	maximum reliability—no hot gas seals
	2	maximum life—radiation cooled columbium
	3	simplicity—rigid shell structure
	4	low weight—high structural efficiency
C	No interaction with engine or vehicle design.	
	1	replacement nozzle for existing engines
	2	no thrust vector control changes required

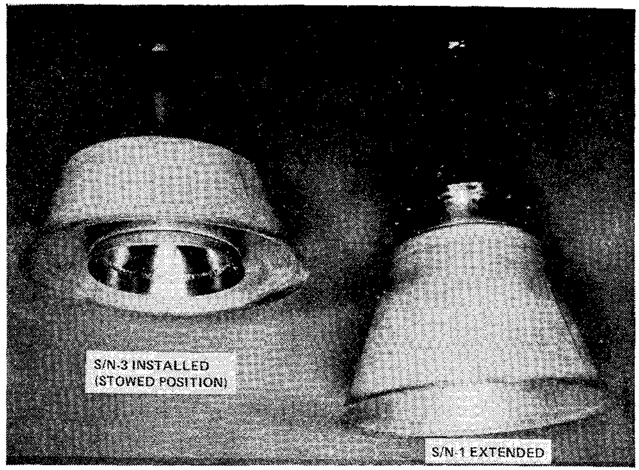

Fig. 2 Convoluted nozzle extensions.

smooth and symmetrical mirror image reproduction of the fabricated contour, with the single exception of a step (of approximately .030 in.) located at the juncture of the fixed and extended sections of the nozzle as shown in Fig. 1.

This extendable nozzle, upon deployment, becomes a conventional, rigid sheet metal nozzle extension that can be designed for any thickness required for structural stability margins over the firing loads. This, together with the high-temperature service life of the columbium material selection and the absence of moving hot gas seals, indicates that maximum operating reliability can be achieved. In addition, high-deployment reliability is available through simple extension by internal pressurization (that is by attaching an exit closure the nozzle becomes its own actuator). This convoluted nozzle and extension simplicity also produces a very lightweight and low cost extendable nozzle system. The CN extended length is the same as the equivalent fixed nozzle extension and the stowed length will be 33% to 39% of this value. The flight weight of a convoluted nozzle for any application can be assumed to be equal to the weight of the equivalent fixed nozzle for the purposes of preliminary design. The jettisoned deployment equipment weight will vary with the expansion ratio and pressurization source but 50% of the CN weight will suffice for a first estimate of the performance benefit obtainable with a Convoluted Nozzle Extension.