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Technical Comments

Comment on "Method for Reducing Stagnation Pressure Losses in Segmented Solid Rocket Motors"

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JOHNSTON[1] examined total pressure losses in segmented motors for *undeformed*, zero-burnback grains when the port flow area change across the slots $\Delta A_{port} \leq 0$, found they were reduced when $\Delta A_{port} = 0$, and commented on performance improvements associated with total pressure loss reductions. However, we showed in Ref. 2 (Johnston's Ref. 3) the following facts.

1) Total pressure losses, when the grain(s) are *deformed*, determine head end pressure.

2) Motor performance predictions require *coupled* internal ballistic and grain deformation analyses.

3) Sharp-edged slots with $\Delta A_{port} < 0$ are particularly prone to large, flow-induced, inward deformations, and total pressure losses, and represent poor design practice.

4) Slots with $\Delta A_{port} > 0$ and a large radius (i.e., aerodynamic smoothing) on the segments leading edge (termed a Ritchy radius) minimize flow-induced deformations and represent good design practice. (Castor II's over-pressure problems were "fixed" with $\Delta A_{port} > 0$ and a large Ritchy radius at the *critical* slot. A Ritchy radius significantly reduces grain deformation per unit slot to port pressure difference relative to an "identical," sharp-edged grain.)

It is intriguing that any segmented solid rocket motor (SRM) would have utilized performance penalizing grain arrangements that enhanced the potential for Castor II type overpressure failures.

Figure 1 illustrates possible segment arrangements and relates them to real motor situations. In Fig. 1a, port geometry and slot flow effects combine to exacerbate the "aerodynamic" pressure force deforming the downstream grain and the total pressure loss; grain deformation directly aggravates these effects. In Fig. 1b, the deforming pressure force and total pressure loss are initially due solely to the slot/port flow interaction. However, grain deformation directly aggravates the process and Fig. 1b becomes like 1a. In Fig. 1c, total pressure losses may be increased, the aerodynamic pressure force is reduced, and grain deformation does not directly aggravate the deformation until it is large.

Johnston's study did not examine $\Delta A_{port} > 0$ arrangements.[3] However, if the slot flow turned and filled the downstep region, free expansion losses would be reduced and *so would mixing losses*! Therefore, total pressure loss minimization *may* be compatible with Ref. 2 good design practices. Clearly, there is a "best" way to arrange (and design) a motor's segments, it is probably motor dependent, and Johnston's article does not deal with it.

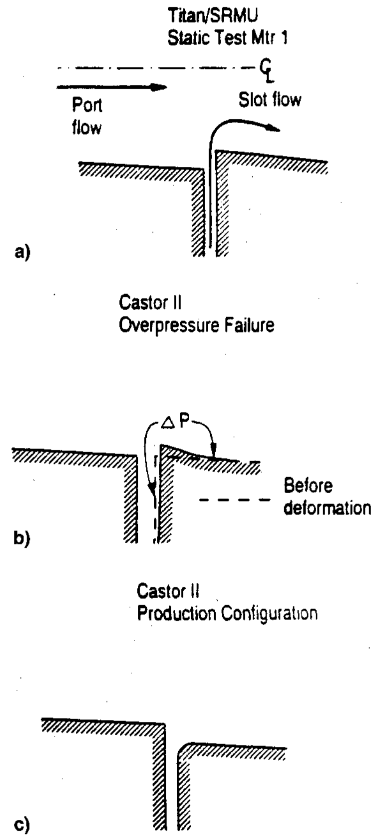

Fig. 1 Solid rockets with circumferential slots—problems occur when merging flows produce pressure drops capable of deforming a grain to restrict port flow: a) grain designs with port contractions promote pressure drop and propellant deformation into the port flow stream; b) ports that are initially uniform can contract when pressure drops deflect the grain towards the centerline; and c) downstep and/or aerodynamic tailoring reduces pressure drop and avoids port contraction.

Johnston's Fig. 2 shows slot total pressure losses account for roughly half of Titan/SRMU's *undeformed* total pressure loss. Therefore, based on Johnston's Titan SRM calculation, elimination of Titan/SRMU's slot flow losses would provide a specific impulse improvement of approximately 0.4%—significant relative to Titan/SRMU's 6.2% thrust increase over Titan.[4] Johnston's current computational tools can examine these designs with coupled grain deformations.[3] Therefore, motor performance with *optimal* segment arrangements (and segment designs) could be examined.

In summary, 1) Castor II and Titan/SRMU[4] overpressure failures show that segmented SRM designs *must* consider aerodynamically induced grain deformations, 2) *coupled* internal ballistic and structural analyses are required for performance analyses, 3) grain slump and launch acceleration loads must be included, and 4) performance optimization must consider $\Delta A_{port} \geq 0$ to be realistic.

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[1]Johnston, W. A., "A Method for Reducing Stagnation Pressure Losses in Segmented Solid Rocket Motors," *Journal of Propulsion*

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[2]Glick, R. L., Caveny, L. H., and Thurman, J. L., "Internal Ballistics of Slotted-Tube Solid Propellant Rocket Motors," *Journal of Spacecraft and Rockets*, Vol. 4, No. 4, 1967, pp. 525–530.

[3]Johnston, W. A., personal communication, Los Angeles, CA, June 18, 1992.

[4]Boyer, W., "SRMU Test Firing Proves Successful," *Space News*, June 15–21, 1992, p. 3, 21.

Reply by the Author to R. L. Glick and L. H. Caveny

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THE author wishes to thank Glick and Caveny for their interest in his Note,[1] and to comment briefly on the issues which they raise. In their Comment, Glick and Caveny make two points. First, and most important, they emphasize that an internal ballistic analysis of a solid rocket motor (SRM) ought to be coupled to a grain structural analysis to properly analyze SRM performance, since grain deformation can significantly alter the internal geometry. Second, they suggest that it may be possible to create more efficient segmented SRM designs than the simple modification proposed in Ref. 1, where alternate segments are installed in the motor upside down (relative to the usual orientation of segments in SRMs). Their prime candidate appears to be a design in which all of the segments are installed upside down (see Fig. 1c of Glick and Caveny's Comment), and the individual segments are tailored so that the resulting port flow area increase across slots is filled by the flow which emerges from the slots.

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In regard to the second point, I would agree with Glick and Caveny that the design change proposed in Ref. 1 will not necessarily optimize an SRM from the standpoint of reducing the initial stagnation pressure loss or reducing the danger of catastrophic grain collapse. The idea in the original Note was that a simple rearrangement of the segments would improve the motor in both of these respects, and that this could be achieved with the propellant segment shapes currently in use.

Concerning their first point, that a coupled flow/structural analysis is required to properly analyze SRM performance, I would also agree with Glick and Caveny on this matter. The fixed grain geometry calculations, for which results were presented in Ref. 1, are only valid if the propellant deformation is small, due either to a stiff (high modulus) propellant or to the nature of the design. And the standard SRM design (Ref. 1, Fig. 1a), which has forward propellant segment corners that jut out into the bore flow and experience large aerodynamic loading, is a design which by its very nature is prone to deformation. In cases where the grain deformation is not small, such fixed geometry calculations can only provide a preliminary assessment of SRM performance. A coupled flow-structural interactive calculation is needed in the final analysis. It should be added however, that my modified design (Ref. 1, Fig. 1b), and Glick and Caveny's alternate design (their Fig. 1c), are both less prone to deformation under the expected aerodynamic loading, as are chamfered (i.e., Ritchey radius) designs.

Finally, I would mention that, in addition to the pioneering work done by Glick and Caveny in this area,[2] a coupled flow/structural numerical procedure for SRMs has recently been developed which addresses these concerns.[3] This computer code simultaneously models the developing flowfield and the associated propellant grain deformation during the ignition transient period of SRM operation.

References

[1]Johnston, W. A., "A Method for Reducing Stagnation Pressure Losses in Segmented Solid Rocket Motors," *Journal of Propulsion and Power*, Vol. 8, No. 3, 1992, pp. 720, 721.

[2]Glick, R. L., Caveny, L. H., and Thurman, J. L., "Internal Ballistics of Slotted-Tube Solid Propellant Rocket Motors," *Journal of Spacecraft and Rockets*, Vol. 4, No. 4, 1967, pp. 525–530.

[3]Johnston, W. A., and Murdock, J. W., "Flow-Structural Interaction Inside a Solid Rocket During Ignition Transient," The Aerospace Corp., ATM-92(2530-03)-12, Los Angeles, CA, Jan. 1992.