Survivability of NASA's 10k RDRE

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Rotating detonation rocket engines (RDRE) have widespread global industry and academic interest. Lessons learned in survivability is critical to furthering this technology. To support RDRE development, NASA hot-fire tested several 10k lbf thrust class thrust chamber assemblies with various propellent combinations including liquid oxygen/ liquid methane, liquid oxygen/ liquid hydrogen, and liquid oxygen/RP-1. The thrust chamber assemblies include injectors, inner bodies, and outer bodies that were additively manufactured (AM) laser powder bed fusion (L-PBF) GRCop-42. This paper will cover hardware damage identified in the 2023 and 2024 RDRE testing campaigns and lessons learned to improve survivability for future RDREs. Particularly notable were the findings concerning the number of detonation waves formed and their effects on the bolted interface and its sealing.

I. Introduction

II. LOx/LCH4 Hot-Fire Testing Observations

Three injectors were tested with varying stiffnesses and element densities under the LOx/LCH4 2023 campaign: MSFC 75%, MSFC 50%, and Venus 75%. Three inner bodies were tested with varying area ratios: AR 1.0, AR 1.0 R2, and AR 1.13. Four outer bodies were tested with varying area ratios: AR 1.0, AR 1.3, AR 1.7, and Stub. The components tested and mainstage duration during each test is shown in Table 1.

Table 1. LOx/LCH4 hot fire testing summary [1].

Test Identifier	Cycle Duration	Mainstage Duration	Total Cycles	Component		
				Injector	Inner Body	Outer Body
IGN GBD001	9.2	-	-	MSFC 75%	AR 1.0	AR 1.0
IGN FBD001	10.9	-	-	MSFC 75%	AR 1.0	AR 1.0
LBD-001	22.7	-	-	MSFC 75%	AR 1.0	AR 1.0
HF001	-	37.2	1	MSFC 75%	AR 1.0	AR 1.0
HF002	-	23.8	1	MSFC 75%	AR 1.0	AR 1.3
HF003	-	24.9	1	MSFC 50%	AR 1.0*	AR 1.3*
HF004	-	-	-	MSFC 50%	AR 1.0_R2	Stub
FBD001	8	-	-	MSFC 50%	AR 1.0_R2	Stub
HF004	-	1.1	1	MSFC 50%	AR 1.0_R2	Stub
HF005	-	4.2	1	MSFC 50%	AR 1.0_R2	Stub
HF006	-	30.1	1	MSFC 50%	AR 1.0_R2	Stub
HF007	-	60.3	2	MSFC 50%	AR 1.0_R2	AR 1.0

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HF008	-	18.8	1	MSFC 50%	AR 1.0_R2*	AR 1.7
HF009	-	48.8	2	MSFC 50%	AR 1.13	AR 1.0
FBD002	33.1	-	-	Venus 75%	AR 1.13	AR 1.0
HF010	-	30.2	1	Venus 75%	AR 1.13	AR 1.0
HF011	-	152.9	1	Venus 75%	AR 1.13	AR 1.0
HF012	-	251.5	1	Venus 75%	AR 1.13	AR 1.0

*Loss of Hardware

Detailed visual inspection and documentation was completed after each hot fire test. However, the paper will focus on indications observed after hot fire tests #3 and #8. The inspection report post-hot fire test #3 included significant blanching all around the outer body hot wall at the throat, inner body hot wall burn through between 3-5 o'clock at the throat, seal damage between the three components, fusing around the bolt holes of the three components, bolts loosening, and outer body hot wall instrumentation port cracking.

The C-seal between the inner body and injector shattered and the rubber O-ring burned through shown in Figure 1. The fusing around the bolt holes between the injector and outer body is shown in Figure 2. The outer body hot wall static pressure port cracking is shown in Figure 3.

Figure 1. Injector to inner body seal damage post-hot fire test #3.

Figure 2. Injector to outer body fusing around bolt holes post-hot fire test #3.

Figure 3. Outer body hot wall static pressure port cracking post-hot fire test #3.

The inspection report post-hot fire test #8 included inner body hot wall burn through between 1-4 o'clock at the throat, seal damage between the three components, fusing around the bolt holes of the three components, and bolt loosening.

The fusing around the bolt holes between the injector and inner body is shown in Figure 4.

Figure 4. Injector to inner body fusing around the bolt holes post-hot fire test #8.

Borescope inspection was completed after testing of both inner bodies which showed significant internal damage as shown in Figure 5. In inner body AR 1.0, six of the nose cone support struts fractured off and two of the struts exhibited cracking in AR 1.0 R2. All four exit ducts AR 1.0 had cracking around the base, three of which were through cracks. In AR 1.0 R2, three exit ducts had cracking around the base, one of which was a through crack. The exit duct with a through crack, rotated and a hole was observed on the exit duct wall.

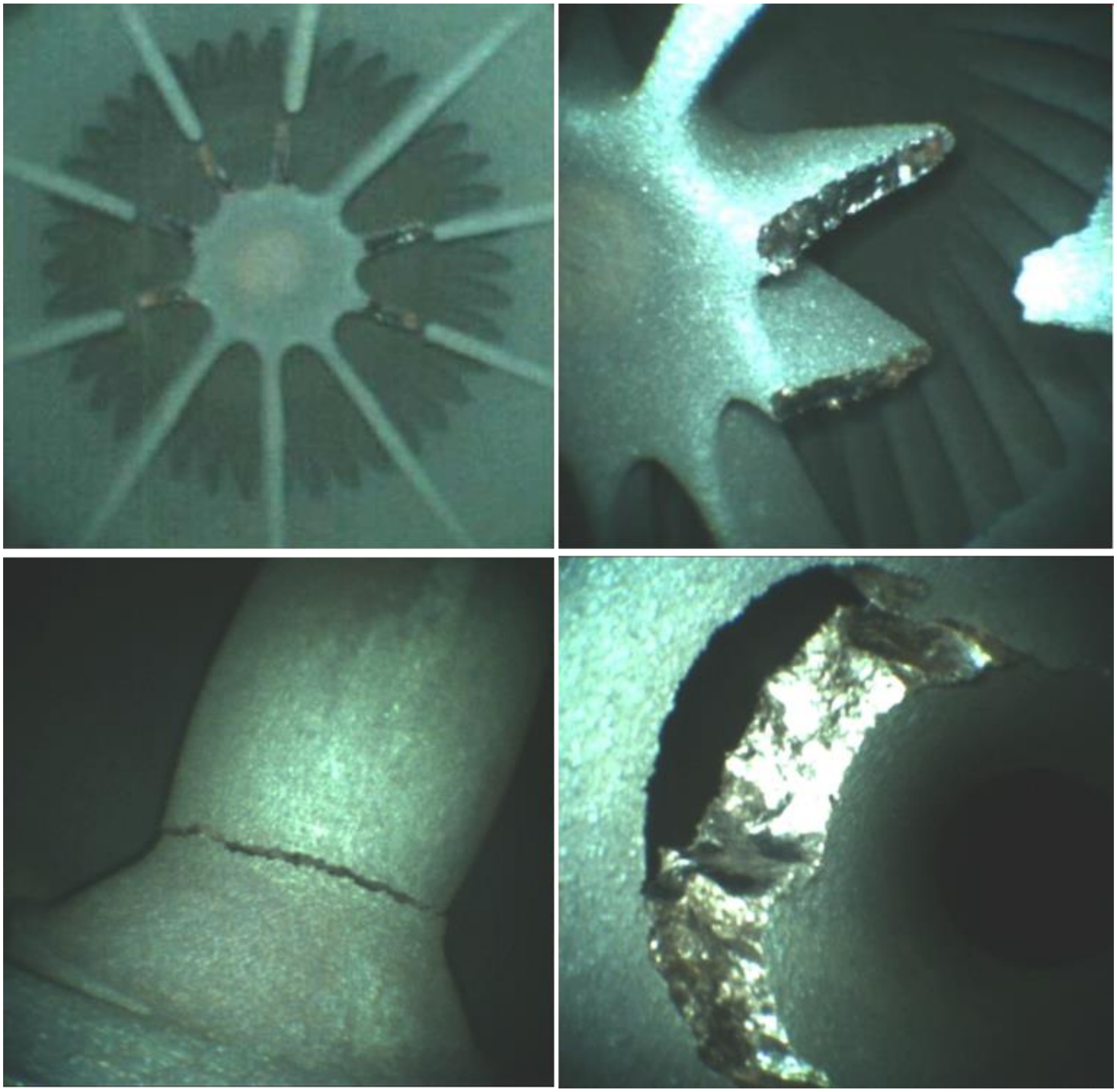

Figure 5. Inner body internal damage. Nose cone support stuts fractures (top), exit duct cracking (bottom left), and hole in exit duct (bottom right).

III. LOx/LH2 Hot-Fire Testing Observations

The LOx/LH2 2024 campaign tested the same hardware from the LOx/LCH4 2023 test campaign. The LOx/LH2 test campaign used the MSFC 50% injector, AR 1.13 inner body, and AR 1.0 outer body. The components tested and the mainstage duration during each test is shown in Table 2. The first and last test of the campaign saw the end of life for the inner body.

Table 2. LOx/LH2 hot fire testing summary

Test Identifier	Cycle Duration	Mainstage Duration	Total Cycles	Component		
				Injector	Inner Body	Outer Body
LBD001	22.7	-	1	MSFC 50%	AR 1.13	AR 1.0
HF001	-	34.8	1	MSFC 50%	AR 1.13*	AR 1.0

Borescope inspection of inner body AR 1.13 showed hot wall static pressure port damage, shown in Figure 6. The support strut of the instrumentation port had completely fractured off and fell out of the inner body after test and the base of the instrumentation port near the closeout of the channels exhibited cracking.

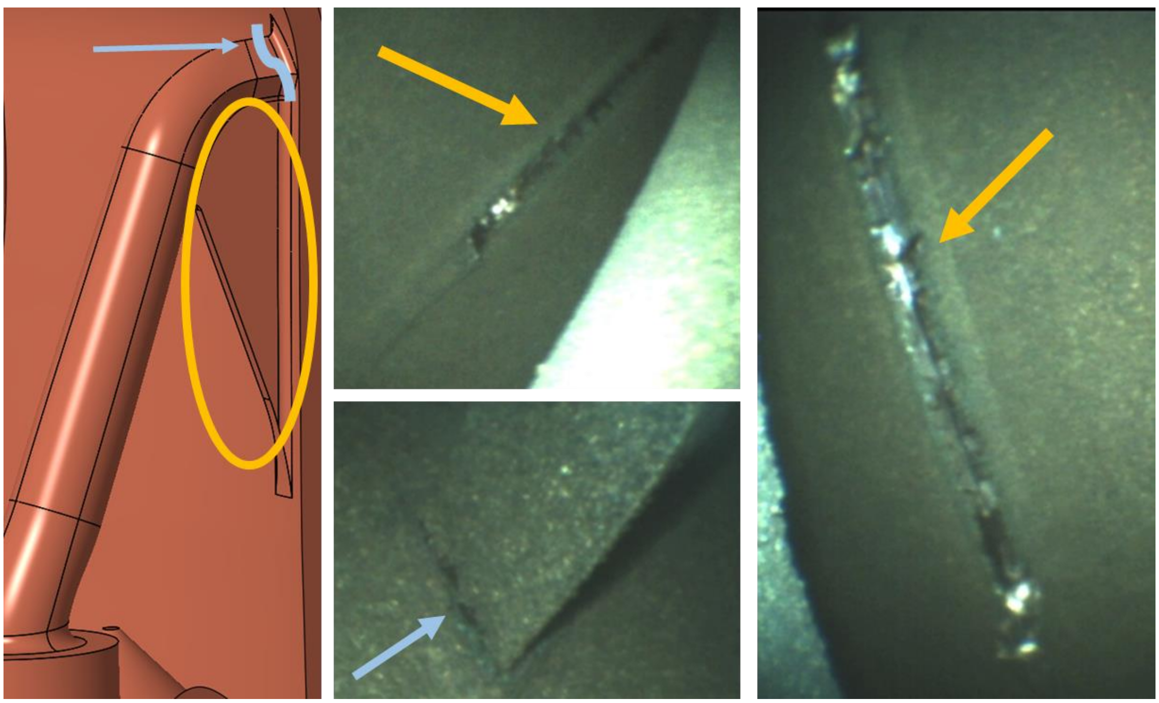

Figure 6. Inner body hot wall static pressure port internal damage post-hot fire test #1.

IV. LOx/RP-1 Hot-Fire Testing Observations

V. Fractography

VI. Conclusions

VII. Acknowledgements

VIII. References

[1] T.M. Fedotowsky, S. Skinner, B. Cook, C. Katsarelis, T.W. Teasley, Investigating the Design, Development, and Survivability of NASA's Full Scale RDRE, in: JANNAF, 2024: pp. 1–26.