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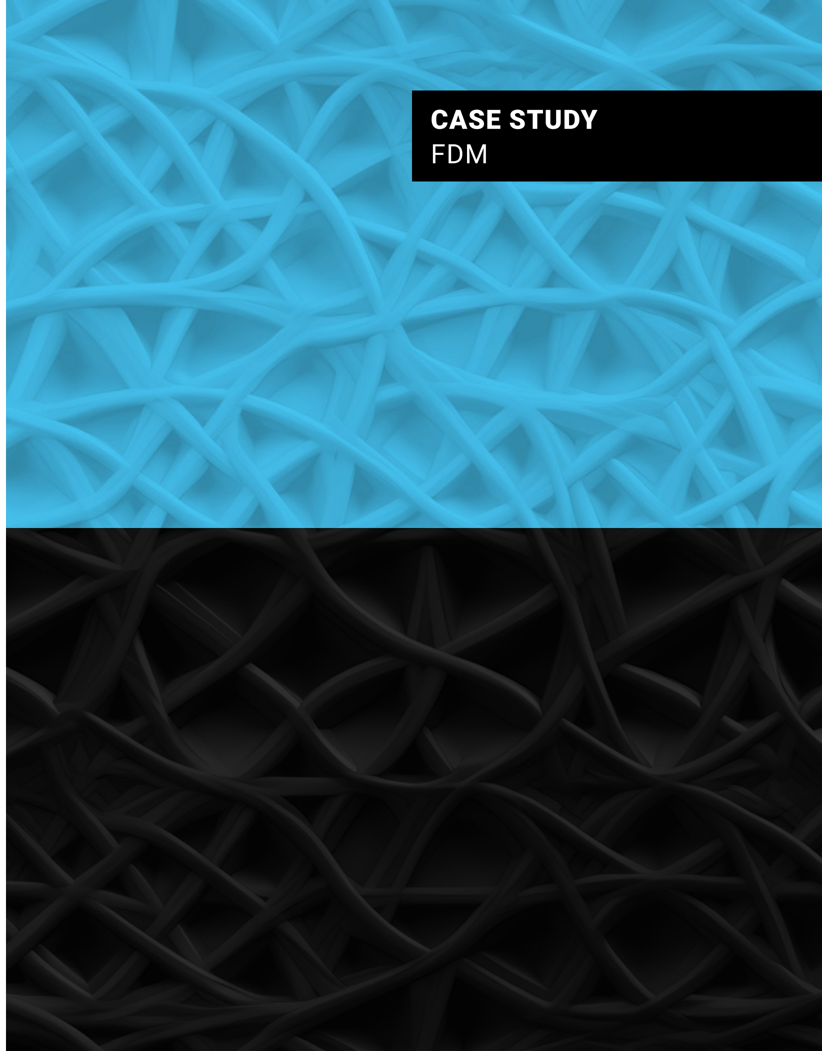


CASE STUDY
FDM

Redefining Manufacturing Tooling in Aerospace

How Northrop Grumman changed the tooling paradigm to cut rocket motor development time.

One of the most famous rocket motors ever designed almost didn't get off the ground. Engineers developing the Apollo Saturn V's F-1 rocket engines were perplexed by a problem causing their engines to explode on the test stand. Only when the team devised a new approach – a new way of thinking – to the standard design of the fuel injector system did they achieve combustion stability and success, ultimately allowing humanity to reach the moon.

Fast-forward sixty years, and another rocket motor developer, Northrop Grumman, is taking a similar fresh-approach mindset to overcome challenging production obstacles. This time, the problem is the excessive lead-time within the tooling supply chain, which puts excessive drag on new rocket motor development. Rather than accept the status quo, the team at Northrop Grumman forged a new path and used additive manufacturing (AM) to replace the metal tooling causing the delays in new development. The result was a dramatic reduction in tooling production time and the creation of a new rocket motor in less than a year.

Supply Chain Disruptions Drive Delays

Northrop Grumman Propulsion Systems has a rich history of solid rocket motor development, providing lift capability for defense, civil, and commercial rocket applications for over 60 years. The Northrop Grumman team there even provided rocket motors for the Apollo moon missions. Success at this level relies on innovation and a healthy supply chain to meet the technical, cost, and schedule challenges that face any product development program. But supply chains are fragile, a fact underscored by the COVID pandemic, although that's not the only cause. Political tensions, trade wars, and similar geopolitical challenges are constant threats to stable supply chains, highlighting the value of on-shoring or near-shoring strategies. Specific to rocket motor development, one of the weak links is the procurement of new tooling used to mold the solid rocket propellant inside the motor casing to meet mission objectives. For Northrop Grumman, the aforementioned supply chain realities can push out tooling lead times for over a year for some projects.

Chase Smaellie, Northrop Grumman tooling engineer, is all too familiar with procurement delays that impact project plans: "During COVID, lots of different suppliers were shut down, and we really struggled, and still struggle, getting in large forgings, castings and weldments. It takes much longer than it should to get some of these larger tools into the company."

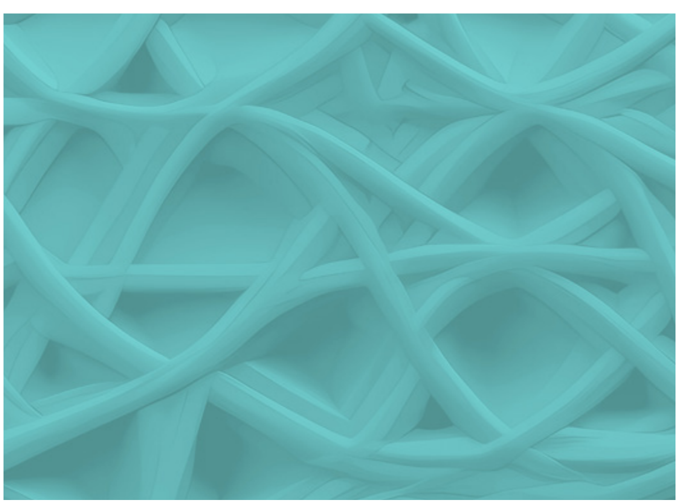
The ramifications of supply chain disruptions go beyond time-related delays. As any manufacturer knows, production pauses mean the product gets to market later rather than sooner. In a competitive industry, this can ultimately result in missed business opportunities. Process delays hamper the ability to react swiftly to changing market conditions, new customer requirements, or emerging trends. They also negatively impact delivery schedules, leading to unmet customer expectations, erosion of the company's dependability, and lost sales.

A SMART Approach to New Solutions

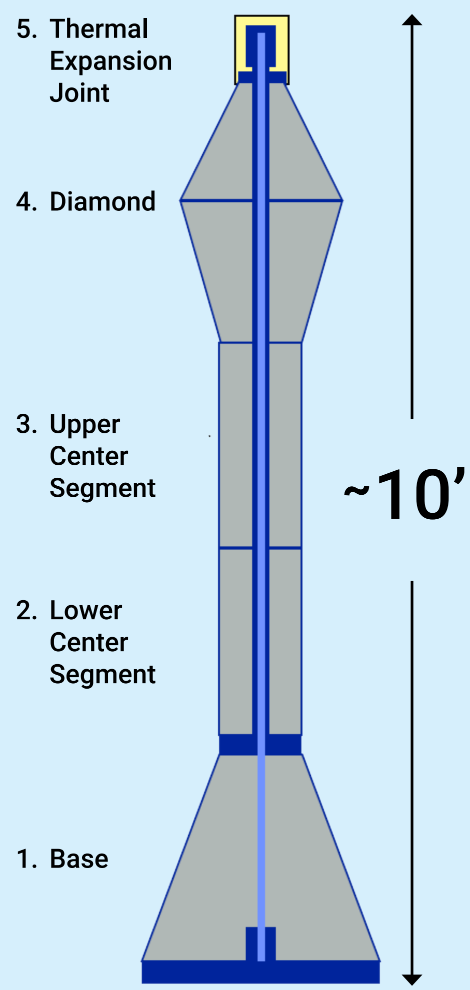
To offset these difficulties, Northrop Grumman took an innovative approach. The company developed the Solid Motor Annual Rocket Technology Demonstrator, or SMART Demo for short. It's an annual program to advance rocket motor development in tooling, materials, and design to meet specific industry and customer needs, and address process challenges.

One aspect of the 2023 SMART Demo struck at the heart of the long-lead-time tooling issue. Instead of relying on the traditional metal tools to cast the rocket motor propellant, Northrop Grumman used its in-house Stratasys FDM® AM technology to accelerate the process and 3D print the complex-shaped tooling. The result was a mold tool completed in a fraction of the time it would take to procure metal tooling. Emphasizing the value of additive manufacturing over traditionally sourced materials, Smaellie says, "It's needed. In-house, large-scale fabrication is advantageous. We're cutting a year of fabrication time down to six weeks."

However, beyond validating AM as a solution for supply chain disruptions, the 2023 SMART Demo highlighted the significance of polymer technology as a replacement for metal. Rocket motor propellant is cast at high temperatures, so any additive polymer material used to mold the propellant must withstand these conditions. Based on the successful results, particularly the reduction in tooling cycle time, the 2023 SMART Demo confirmed the value of the polymer-for-metal approach. From these results, the expectation is that additive technology will contribute to decreased lead times and faster fabrication of new solid rocket motors.



> "It's needed. In-house, large-scale fabrication is advantageous. We're cutting a year of fabrication time down to six weeks." - Chase Smaellie



The SMART Demo rocket motor core dimensions; sections 1 through 4 were 3D printed with Antero PEKK-based material.

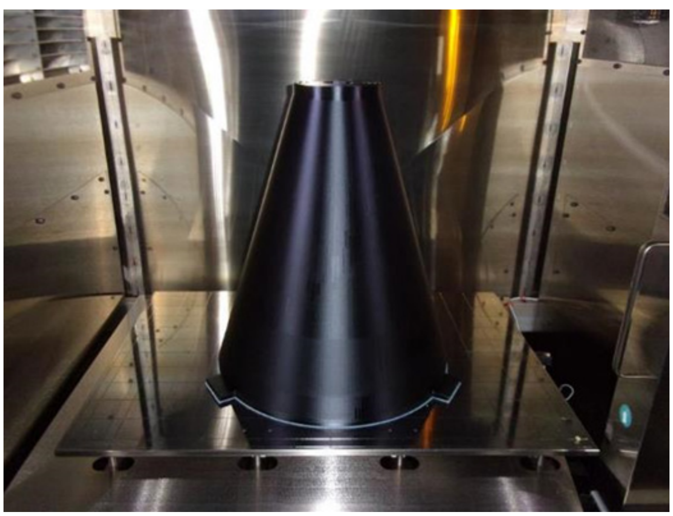
A New Way of Thinking About Polymer AM Tooling

For several decades now, AM adopters have used the technology as a faster and less costly way to make jigs, fixtures, and other common manufacturing tools typically made from metal. But for some manufacturers, using polymers instead of metal, particularly for higher-requirement tooling applications, is not even in the realm of consideration. This usually stems from an unawareness of polymer AM's capabilities. However, Northrop Grumman chose a different course, exhibiting confidence that polymer additive technology can be an effective alternative to metal, especially for rapid development efforts.

For the company's 2023 SMART Demo, an essential requirement for using additive was finding materials with suitable application properties. The rocket motor mold tooling had to be compatible with the propellant and cleaning solvents. It must also be electrically grounded to prevent static buildup and accidental discharge that could catastrophically ignite the propellant.

The AM material choices that met these requirements came down to ABS-ESD7™, an electrostatic discharge-safe ABS plastic, and Antero® 840CN03, a high-strength PEKK-based polymer with excellent chemical resistance and ESD properties. "We down-selected to Antero. We went with the Antero because of its mechanical properties as well as its resistivity to solvents. We clean our cores and the tooling with solvents. (Antero) resisted that," Smaellie relates.

Antero's ESD properties offered another significant benefit. "A lot of our processes are geared toward preventing sparks, either through metal-on-metal contact or through conductivity issues with insulators," says Smaellie. "Our internal safety documents drive us to find non-sparking conductive materials, and Antero fits that bill. The material properties were attractive for safety purposes," Smaellie adds.



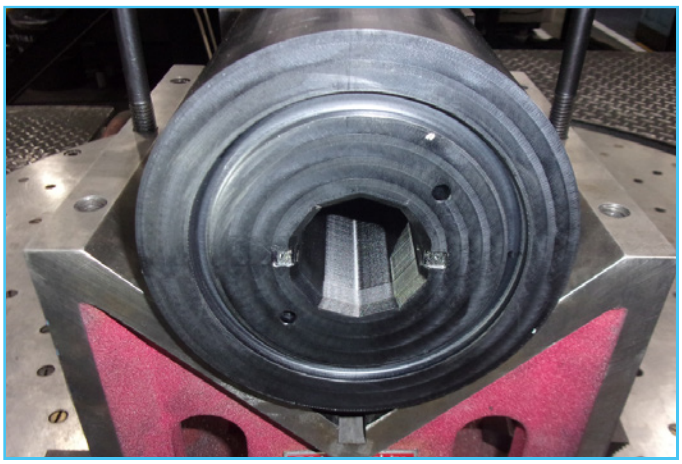
A part of the tool being 3D printed with Antero 840CN03.

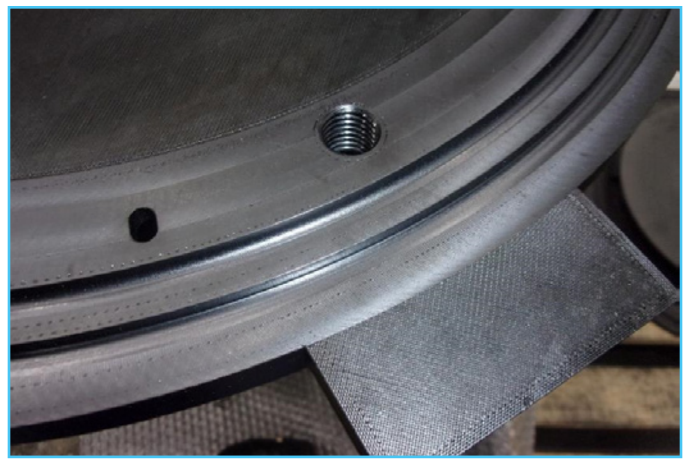
Tooling size was another issue Northrop Grumman engineers had to deal with. The rocket motor's core design was roughly 10 feet long. Making the core's mold tool meant printing it in several large pieces. This required a 3D printer with sufficient volume to build each large section. Ultimately, Northrop Grumman printed the core in four pieces on the company's Stratasys F900 printers. According to Smaellie, the advantage of the F900 included "the large build volume and the accuracy." Print reliability was also a consideration since the build time for each section was extensive.

Weight reduction was another advantage of printing the tool instead of using conventional metal tooling. Printing with a custom infill (a non-solid, honeycomb-like internal structure) provided the necessary structural integrity while minimizing weight. 3D printing's design freedom also enabled built-in workholding fixtures to aid in post-print machining required on the core sections' mating surfaces.

Polymer AM Tooling Opens New Opportunities

If there's a takeaway for other AM users from Northrop Grumman's 2023 SMART Demo experience, it's that there's a broader horizon for polymer AM tooling and a corresponding favorable payback for its application. Although the ESD-capable Antero material was initially developed for spacecraft parts, Chase Smaellie and the Northrop Grumman team recognized its potential for a tooling application. The result was a dramatically shortened lead time that helped produce a new rocket motor in a much shorter timeframe. And that 'think-outside-the-box' approach continues to pay dividends, giving the team the knowledge to achieve further gains with the subsequent annual SMART Demonstrators.



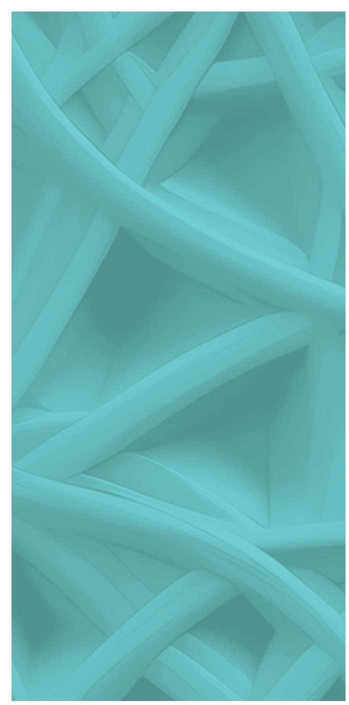


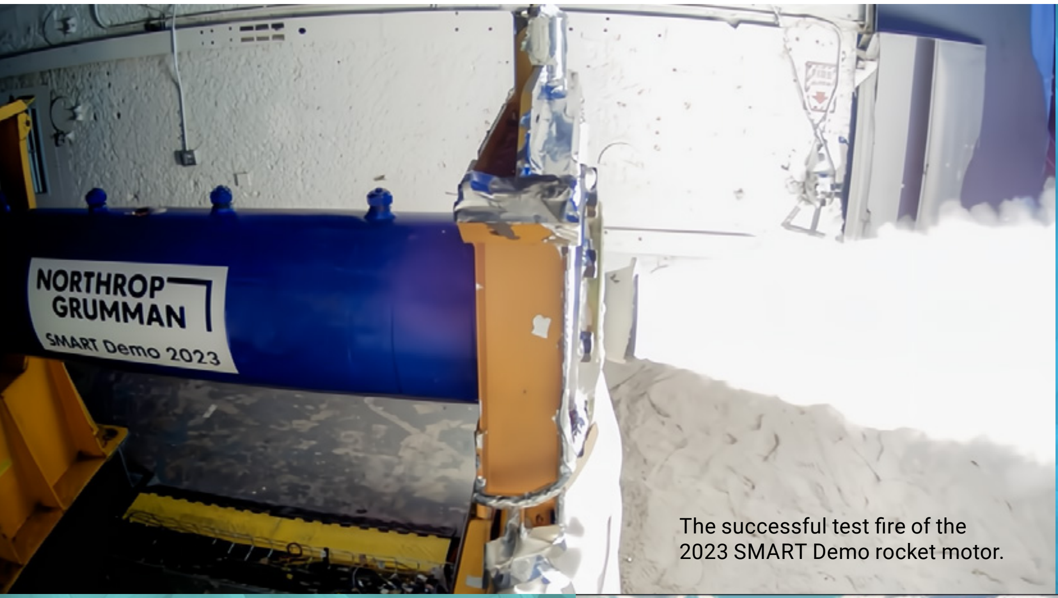
A view of the 3D printed center and base sections machined for threaded inserts, O-ring grooves, locating holes, and flat sealing faces.

The polymer-for-metal trade obviously hinges on a part's structural requirements. But the availability of high-performance polymer materials opens new doors, providing opportunities to avoid the costly and time-consuming process of multi-axis metal machining. "Where 3D printing will really come into its own is when we're able to replace large forgings and complex five-axis machine parts with Antero," says Smaellie. "We're seeing that now with other components we're making with Antero, as well as future cores. And that's where we start seeing the upfront dollars-and-cents savings on these parts, in addition to speed and long-term value," he adds.

There's no magic bullet to remedy all the problems that can develop in a complex supply chain. The solutions can be as varied as the causes themselves. However, additive manufacturing has proven it can put a significant dent in lead-time delays, particularly for tooling. And the availability of high-performance and specialty polymers like Antero makes unique tooling applications possible.

In the end, however, what matters most are the business opportunities that additive technology unlocks. Chase Smaellie highlights the shorter development cycle benefits AM provides: "When we're looking at delivery and payment from a customer, meeting our deadlines and obligations, and how that affects our business, that's huge." He goes on to say, "There are dollars in there that we are winning back by meeting deadlines and going faster by using new processes. Just by casting a motor and firing it in a year for the SMART Demo project, that's opened doors for our company."





The successful test fire of the 2023 SMART Demo rocket motor.


The Northrop Grumman rocket motor test facility.

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