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COMPARATIVE ANALYSIS OF DIFFERENT 3D PRINTED IGNITER CHARGES ON INTERIOR BALLISTIC PROPERTIES

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Abstract: *This paper aims to show how different designs of igniter charges affect interior ballistic properties. Different geometries were achieved with 3D printed technology. All igniter charges were prepared with an identical number and amount of pyrotechnic compositions to ensure consistency in released chemical energy. The experiments were conducted in experimental rocket motor with fixed and identical free volume as a flight rocket motor. To accurately monitor combustion behavior, operating pressures were measured at two points with the test setup using calibrated pressures transducers. The collected data were analyzed to assess the influence of geometric variations on ignition efficiency, pressure increase time and maximum pressure values.*

Keywords: *igniters, 3D printing technology, rocket motor*

1. INTRODUCTION

With the development of new additive manufacturing technologies, particularly 3D printing [1-2], it has become possible to create components with complex geometries that were previously economically viable only in mass production. Traditional manufacturing methods often required expensive tooling for each geometry, making small-batch or prototype production inefficient. In contrast, 3D printing allows rapid prototyping and cost-effective fabrication of custom parts without the need for molds or tooling, making it especially valuable in research and development environments. Ideas can be quickly transformed into physical components, tested, and iterated with minimal delay.

Additive manufacturing is increasingly utilized in the defense and aerospace industries across the globe [3-4]. In modern warfare conditions, 3D printing enables field-level production of urgently needed components, directly supporting operational readiness and logistical flexibility. Rapid on-site fabrication reduces downtime and increases system reliability in mission-critical applications.

One of the most critical components in a solid rocket propulsion system [5] is the igniter housing. The igniter must ensure precise and consistent initiation of combustion without damaging the propellant grain or nozzle throat [6]. Therefore, the housing must be mechanically robust, thermally stable, and capable of withstanding a wide range of environmental stressors—such as impact, vibration, and thermal cycling—that occur throughout the rocket's operational life cycle [7].

Another essential requirement for igniter housings is hermetic sealing and safe handling. In large-scale production scenarios, igniters are assembled and installed by trained personnel under standardized procedures. Therefore, the housing must not only guarantee performance but also meet stringent safety standards during storage, transport, and integration.

Before finalizing a design for mass production, several iterative prototypes must be tested under identical operating conditions to those of the final application. For this purpose, all igniters in this study were tested in experimental rocket motor with a fixed and controlled internal free volume.

Additive manufacturing enables the use of a wide range of materials with varying densities, thermal tolerances, and mechanical strengths [8-9].

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In this work, igniter housings were produced using a Creality K1C 3D printer (Figure 1), capable of printing high-performance polymers reinforced with carbon fiber, and supporting extrusion temperatures up to 300°C. The printer's build volume is 220 × 220 × 250 mm, with a maximum print speed of 600 mm/s, allowing for rapid and scalable prototyping.



Figure 1. Creality K1C 3D printer

2. DESIGN

Two different igniter housing models were designed using SolidWorks. Each housing consisted of three separate parts to allow for easy loading of pyrotechnic compositions and visual inspection before final sealing. The STL models were processed in the Creality slicing software (Figure 2), where part orientation, material selection, layer thickness, and print resolution were configured. Based on the slicing parameters, the estimated print time for a complete igniter housing was approximately 45 minutes. The selected material was 1.75 mm PLA filament, with a temperature resistance of up to 260°C.

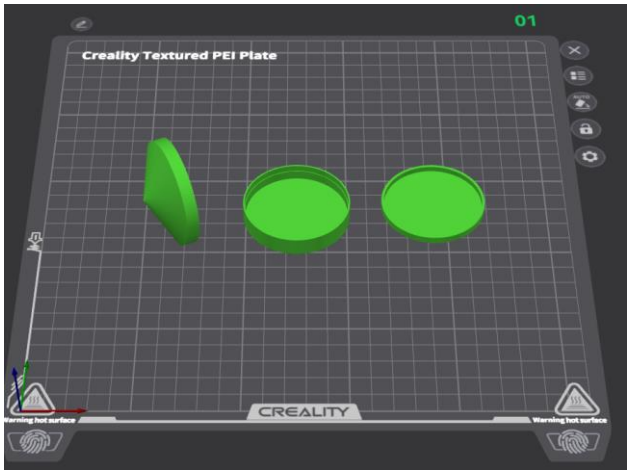


Figure 2. Creality slicing software – geometry 1

Both housing designs featured identical internal free volume to allow consistent loading of pyrotechnic compositions [10]. A total of six igniters were fabricated, with three for each housing geometry. All igniters were hermetically sealed and subjected to dimensional and mass control verification.

The internal architecture of each housing consisted of a primary cylindrical chamber (60 mm diameter) containing the initial ignition mixture—black powder with a pyrotechnic initiator cap and Composition No. 1. To this base structure, a second modular chamber of varying geometry was added. In Geometry 1 (Figure 3), this second chamber took the form of a regular conical shape containing Composition No. 2.

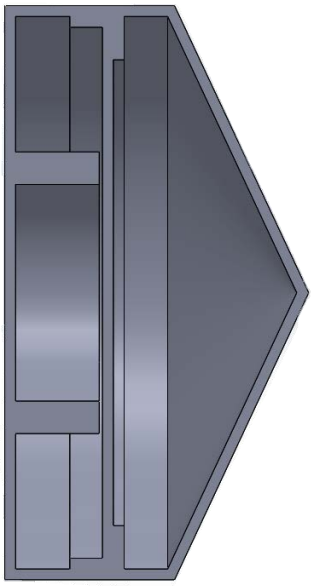


Figure 3. Geometry 1

In Geometry 2 (Figure 4), the second chamber featured an inverted conical cavity with a 60-degree angle, also housing Composition No. 2.

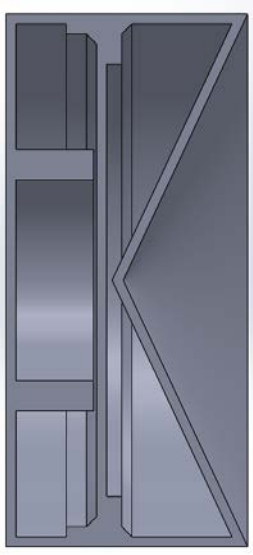


Figure 4. Geometry 2

The wall thickness of all printed housings was 1 mm. The free volume of Chamber 1 was 0.026 dm^3, while Chamber 2 had a volume of 0.042 dm^3.

For the third test configuration, the same pyrotechnic composition was loaded into an ethyl cellulose pouch, without a rigid printed housing structure. This configuration served as a control to observe the ignition behavior of the composition in a less confined environment. The results were not presented in this paper.

The used pressure transducers are designed for measuring static and dynamic liquid and gas pressures. They are available in various measuring ranges, from 1 to 3000 bar. Transducers with the 0 to 3000 bar measuring ranges work according to the strain gage principle. The strain gage application is located on the side of the tube away from the measurement medium in a hermetically sealed reference chamber. This protects it from environmental influences.

3. EXPERIMENT

All igniter charges were tested in experimental rocket motor (Figure 5) equipped with a calibrated pressure transducers P3IC up to 200 bar.

The transducers housings are made from stainless steel and hermetically seal the measurement system to protect it against any harmful external influences, so that even if the operating conditions continue to be rough, the reliability and precision of the transducer are not impaired.

The resulting data were acquired and visualized as pressure-time (P-t) diagrams. Accurate pressure measurement is important in interior ballistic testing, and uncertainty was minimized through calibration, thermal compensation, and signal filtering. Remaining uncertainties were evaluated using standard measurement uncertainty analysis.

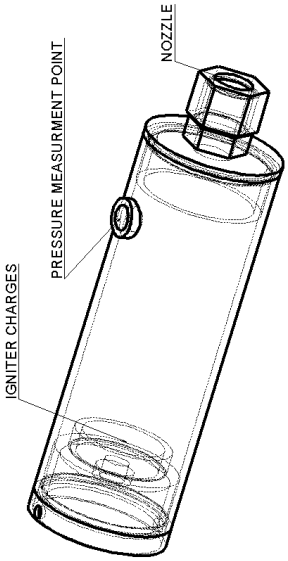


Figure 5. Experimental rocket motor

The pressure-time diagram for Geometry 1 (Figure 6) shows a maximum pressure of approximately 31 bar (y-axis), with moderate variation between trials.

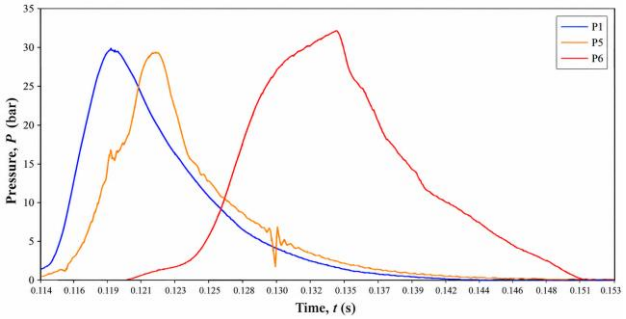


Figure 6. The pressure-time diagram for Geometry 1

The results presented in Table 1 include the maximum pressure and effective operating time.

Table 1. Geometry 1 test results

Igniter #	P	P (bar)	t (s)
#1	P1	30	0.014
#2	P5	29.8	0.013
#3	P6	31.6	0.016

The corresponding diagram for Geometry 2 (Figure 7) reveals a slightly higher maximum pressure—around 10% higher than Geometry 1—under otherwise identical conditions.

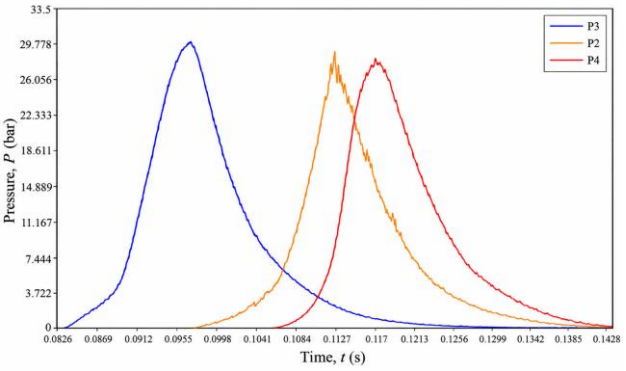


Figure 7. The pressure-time diagram for Geometry 2

The results presented in Table 2 include the maximum pressure and effective operating time.

Table 2. Geometry 1 test results

Igniter #	P	P (bar)	t (s)
#4	P2	27.5	0.014
#5	P3	29.8	0.015
#6	P4	27.3	0.014

These results show that internal geometry, even with identical pyrotechnic mass and free volume, can significantly affect pressure generation and combustion dynamics. The effect is likely related to localized flame propagation, gas flow paths, and the surface-area-to-volume ratio, all of which influence the rate of pressure increase.

Furthermore, the study demonstrates the efficiency and repeatability of 3D printing in the design, fabrication, and testing of igniter housings. Additive manufacturing offers a rapid and cost-effective method for prototyping and even low-rate production of components with complex internal geometries. It enables functional validation before mass production, reduces lead times, and allows for immediate modifications.

3. CONCLUSION

The results of this study confirm that internal geometry of igniter housing has a significant role in effect on interior ballistic behavior, even when the pyrotechnic composition and free volume remain constant. Among the tested configurations, Geometry 2—featuring a recessed conical cavity—demonstrated a ~10% increase in maximum pressure compared to Geometry 1. While the overall impulse remained comparable across designs, the rate of pressure increases and flame propagation dynamics were noticeably affected by structural differences.

These findings validate the hypothesis that optimized igniter geometry can enhance ignition efficiency and combustion control in solid rocket motors. Moreover, the successful application of 3D printing technology for rapid prototyping of complex igniter housings highlights its practical value in both research and low-volume production environments. The use of carbon-fiber-reinforced and high-temperature-capable filaments provides an adequate balance of mechanical strength, thermal stability, and manufacturing speed.

Future work will focus on numerical simulations (finite element methods or CFD analysis) of thermal and gas-dynamic processes within the igniter chamber to correlate experimental findings with predictive models. Additionally, further optimization of geometry, material selection, and surface finish could lead to improved safety, repeatability, and ignition performance under operational conditions.

Acknowledgments

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