

What is the Potential of 3D Printing Technology When Integrating with Aerospace Engineering?

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ABSTRACT: This study investigates the potential of integrating 3D printing technologies into aerospace engineering to address challenges such as high production costs, material waste, environmental impact, and vulnerability of spacecraft to orbital debris. Various 3D printing materials, including plastics, nylon, and metal filaments, were evaluated for suitability in different spacecraft components based on strength, flexibility, heat resistance, and weight. Simplified rocket and satellite models were designed in CAD, fabricated via 3D printing, and tested in a custom wind tunnel to simulate debris collisions, with polymer simulations conducted in Material Studio. Results show that lightweight, additively manufactured structures can withstand repeated impacts while offering advantages in cost efficiency and sustainability. Although constrained by school-level equipment and limited access to industrial materials, the project demonstrates the feasibility of applying additive manufacturing concepts in aerospace. It highlights opportunities for further research under realistic space conditions.

KEYWORDS: Aerospace Engineering, 3D Printing, Additive Manufacturing, Spacecraft Materials, Orbital Debris Collision Testing.

Aim

To investigate whether 3D-printed materials and design choices can improve the durability and sustainability of aerospace structures, with a focus on reducing damage risk from simulated orbital debris impacts.

Objectives

1. **Identify the key limitations** of current rockets and satellites (cost, waste, environmental impact, lifespan, and debris vulnerability) and define success criteria for an improved approach.
2. **Review candidate 3D-printing materials** (plastics, nylon, metal filaments) and justify how their properties could map to different spacecraft functions (shell protection, wiring, high-temperature regions).
3. **Design scale models** of a representative rocket and satellite (based on Long March 5 and GPS IIIF) using CAD/Blender, simplifying geometry to match printer constraints.
4. **3D print and assemble prototypes**, adjusting scale and print orientation for reliable manufacturing, then apply **colour-coding** to indicate proposed material allocation by component.
5. **Construct a transparent wind-tunnel test rig** (fume cupboard + acrylic screens) that safely contains debris while enabling clear video recording.
6. **Select and prepare debris analogues**, and justify the final choice (spillage-kit absorbent) based on safety, hardness, and flight distance under airflow conditions.
7. **Conduct controlled collision tests** under two impact modes:
 - 7.1 Horizontal impacts driven by airflow (hairdryer), optimizing distance and angle;

- 7.2 Vertical impacts by releasing debris above the model, improving consistency over a sieve method.
8. **Record and evaluate outcomes** using slow-motion video, comparing surface damage/structural integrity after repeated impacts to judge feasibility and limitations.
 9. **Support the experimental work with simulation** (Material Studio/Forcite geometry optimization) to demonstrate polymer modelling workflow and connect material behaviour to design decisions.
 10. **Reflect on limitations and improvements**, including realism of debris/space environment conditions and equipment constraints, and propose next steps for higher-fidelity testing.

Purpose & Background (Examples)

1.1. The Drawbacks of Current Aerospace Equipment (On Earth):

1. **Expensive:** Rare but crucial rocket construction material can drive prices to skyrocket. Moreover, substantial maintenance costs may be a significant factor, as returning the equipment to Earth for maintenance can increase the number of launches. For example, the new StarShip rocket, made of sheet steel, costs approximately \$130,000. Additionally, the price of a 3D-printed alloy engine is approximately \$30,000; however, a rocket has six engines, so the total cost of the engines is \$180,000.
2. **Lifespan:** Most rockets are reusable only once per mission. Satellites typically operate for 5 to 15 years before malfunctioning. They may become space junk and a long-term problem when they lose control.
3. **Waste and efficiency:** While the number of rockets using current technologies is increasing, a proportion of components must inevitably be separated. Therefore, debris may enter unknown regions that are difficult to detect or become space debris. And the components will become waste. A large piece of space junk recently washed up on a remote West Australian beach, likely a solid rocket motor casing (**Figure 1**). This has a negative social impact, as it may pose risks to public health and instill fear in the community. Moreover, the payload capacity of current rockets is limited, whereas the missile size is often colossal.



Figure 1. Spacecraft waste debris.

4. **Pollution:** Toxic gas emissions during the combustion process of the engine and fuel. Therefore, it may degrade air quality, which is already poor in some regions. (Can list primary and secondary problems)
5. **Further environmental problems:** Climate change, crippling the atmosphere and ozone layer (risk to humanity, as ozone protects the Earth from harmful UV radiation), acid rain, altering weather patterns, and ecosystems (For example, it may become a

disturbance to the migration of birds). Additionally, alumina and black carbon will trap long-wavelength radiation emitted by Earth and prevent it from escaping. This can warm the stratosphere, thereby accelerating the chemical reaction and leading to faster ozone depletion. Additionally, rocket launches generate between 50 and 75 tons of CO₂ per passenger.

6. **Hazards and Risks:** Extreme temperatures cause explosions or malfunctions, and high pressure may cripple the equipment. On 28 June 2015, an explosion happened during the Falcon 9's launch. The Dragon capsule tumbles into the ocean. Two structures supporting a single tank failed, resulting in elevated pressure and loss of structural integrity (**Figures 2.1 & 2.2**).



Figure 2.1 & 2.2. Explosion of Falcon 9.

7. **The difficulty of construction:** The material may proliferate during construction, thereby increasing construction duration and the number of required labourers. It will take about 5-15 years to design and build a rocket.
8. **Sustainability:** Many current aerospace materials are finite and may be depleted in the future. Therefore, we may need to collect resources from asteroids or other planets.

1.2. Toxic Gases and Pollutants List:

- o Methane CH₄
- o Carbon monoxide CO
- o Black carbon (BC, soot) can persist for over a century.
- o Nitrogen Oxide NO_x
- o Alumina Al₂O₃
- o Hydrochloric acid HCl
- o Hydroxyl OH (depletion of ozone)
- o Water vapour H₂O

1.3. The Drawbacks of Current Aerospace Equipment (On Space):

1. Be Vulnerable in Front of Orbital Debris:

This space debris can pose a hazard to aerospace equipment despite its size, as it often moves rapidly (research indicates that space equipment typically moves at 8 km/s, while space debris can travel at even higher velocities, around 10 km/s). If they collide with spacecraft and satellites, this may result in financial losses and casualties. Furthermore, if the broken equipment does not burn entirely in the atmosphere, it can threaten human life on Earth.

Real-life incidents involving unintentional high-speed collisions between active satellites and orbital debris have been documented.

- o The Mission-related debris (1977- 062C, 13475) collided with Kosmos 1934 in 1991.
- o On the 18th of March 2021, there was a serious collision between Yunhai-1 02 and the orbital debris, the rocket body of the Kosmos 2333 satellite (a Tselina-2 satellite) launched in 1996. It was predicted that the debris from the collision would rapidly fill the outer atmosphere.

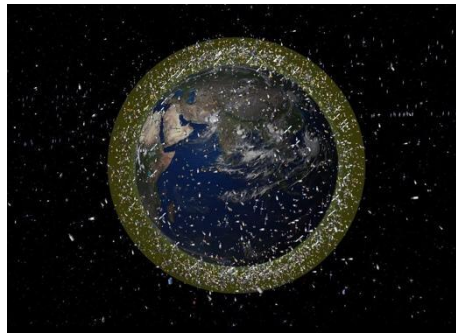


Figure 3. Space junk in Earth's orbit.

Throughout these three accidents, we can sum up these two problems of current aerospace equipment and those from the past century:

- o Despite the dramatic technological breakthrough, the potential dangers posed by orbital debris remain unaddressed.
- o The short lifespan of space equipment can cause it to become larger-sized space debris alongside existing debris.

2. The orbital debris is from the space equipment itself.

- o In 2009, the Iridium 33 communications satellite and the derelict Russian Kosmos 2251 spacecraft collided, destroying both satellites. It is also noteworthy that this accident is the first to involve a collision between 2 satellites. However, Kosmos-2251 had already gone out of control in 1995, making it space debris at the time of the incident. After the accident, NASA estimated that more than 1000 pieces of space debris, larger than 10cm, and smaller fragments had been created within 10 days (**Figure 4**).

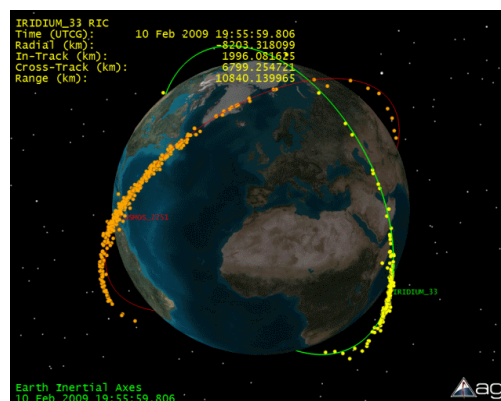


Figure 4. Space debris monitoring by NASA.

Hypothesis

Our project aims to address the problems identified by our team. Among a host of them, we can summarise them into two parts of the problem:

- **Internal issues:** The rocket or other space equipment itself has many flaws that can cause potential problems, such as high expenditures, crippling the Earth's environment, generating waste, and low efficiency.
- **External threats:** Rockets and other space equipment may be vulnerable to space debris orbiting Earth. If they collide, the equipment may be destroyed, become new space debris, and pose an additional hazard.

To address these problems, mitigate accident risk, and reduce existing issues, we must change the equipment's materials, enhance its structure, and modify or refine the overall manufacturing process.

As 3D printing technologies have gained global attention in recent years, our team members recognized their potential to address the problem we have identified and to make a breakthrough in aerospace engineering. Therefore, in the next section of our article, we will formulate hypotheses to inform solutions to the problems, such as the use of 3D printing technologies. Moreover, we will elaborate on the evidence supporting the use of 3D printing technologies.

2.1. The Advantages and Disadvantages of Manufacturing Using 3D Printing Technology:

Edges:

- **Reduce Material Waste:** Most 3D printers require only a small amount of material for manufacturing (e.g., plastic or metal powder). This can effectively reduce waste and resource consumption, lower material costs, and be environmentally friendly.
- **Convenient and Easy to Access:** Compared with traditional manufacturing methods, 3D printing requires less equipment. This can ensure quick responses to production needs, urgent repairs, and prototype adjustments. This is vital for saving time in production.
- **Lightweight:** The cost of launching satellites and other space equipment is significantly higher due to the size and weight that require more fuel. Consequently, space exploration is accessible only to wealthy nations or global powers. However, 3D printing enables the construction of lightweight structures (E.g., Plastic is a lighter material than steel or other metals), thereby reducing weight. As a result, fuel efficiency is enhanced, thereby reducing costs and greenhouse gas emissions.
- **Innovative Design:** More design possibilities are offered by 3D printing, which enables engineers to push boundaries in structure and geometries. 3D design software, particularly SolidWorks and Blender, offers considerable freedom and design options.
- **Longevity and Efficient Maintenance:** A Specific section can be 3D-printed and integrated into the existing structure rather than replacing the entire part. This prolongs the components' life cycle and minimises waste, which offers environmental benefits.

Drawbacks:

- **Limited Materials:** A notable drawback is the scarcity of suitable materials. Currently, the aviation sector relies on 3D printing, which imposes design limitations that may affect the safety and performance of satellites.
- **High Investment Cost:** The high cost of 3D printing technology impedes small businesses' access to this technology. It is also unsuitable for countries lacking financial and technological competencies (E.g., Most developing nations).
- **Climbing Unemployment Rate:** The process in manufacturing, characterised by a high degree of automation, can cause skilled workers to lose their jobs and cause massive social problems, such as unemployment. This can lead to tumult and unrest.
- **Size limitations:** It is challenging to use 3D printing technology to manufacture substantial structural components, thereby limiting the types of objects that can be produced.
- **High Level of Accuracy and Precision Requirement:** Because 3D printing has size limitations, as noted above, one approach to assembling small components is to weld them together. Although this method is convenient and cost-effective, we must ensure that our equipment and the components produced are accurate and precise for assembly.

Across these properties, it is evident that 3D printing has the potential to enhance space equipment and manufacturing processes. However, we must also consider its drawbacks and identify the most effective means of mitigating their significance. We now elaborate on the benefits and drawbacks of the available materials for 3D printing.

2.2. Comparison of Different 3D Printing Materials:

Table 1. The Advantages and Disadvantages of Different Types of 3D Printing Material (Reference 1).

Filament	Advantages	Disadvantages	Cost Per Kg
ABS	Tough, impact-resistant, Common, Non-toxic, water- and chemical-resistant, it is remarkable for preserving its colour	High melting point; Unpleasant fumes	\$20 to \$50
PLA	Easy to print with; Biodegradable	Prints degrade over time; Rough texture	\$20 to \$50
PVA	Water soluble; Fairly easy to print	Expensive; Risk of toxic fumes	>\$100
Nylon	Tough; Inexpensive	High temperature requirement	\$18
HDPE	Easy to dissolve; Lightweight	High temperature requirement	\$30
T-Glase/PETT	Food-safe; Glass-like look	Slow to print; Heated printing bed needed	\$30
Wood Filament	Attractive wood-like look	Finicky to use; Requires sanding	\$60 to \$100
Metal Filament	Attractive metal-like finish	Finicky to use; Expensive	\$75 to \$120

Carbon Fibre Mix	Mimics carbon fibre's lightweight strength	Tough on extruders; Expensive	\$50 to \$120
Flexible Filament	Produces flexible prints	Requires tinkering with the printer	\$50 to \$120
Conductive Filament	Conducts electricity; Similar to PLA	Expensive; Still experimental	\$70 (for a 100g reel)

As shown in the table illustrating the properties of different 3D printing materials, there are five main types of available filaments: synthetic, metal, wood, flexible, and conductive. Synthetic filaments can be further divided into two categories: plastic and nylon.

We now anticipate how to translate the properties of different materials into the enhancement of space equipment such as satellites and rockets, while mitigating their drawbacks in application. We will substantiate these assumptions in our subsequent practicals.

- **Plastic:** Plastic can become a central component of the surface protection of space equipment, thereby reducing vulnerability to friction and collisions while minimizing weight and reducing launch costs. However, a plastic protection surface can only be used to cover the parts of the space equipment that do not come into direct contact with a high-temperature source, such as sunlight, which is the most common heat source we will face, as modern technology is not advanced enough to let most of the spacecrafts and satellites travel out of the range where sunlight can reach.

Plastics such as ABS (Figure 5) exhibit remarkable toughness. Therefore, our team hypothesizes that it could be used for reinforcement to mitigate collisions with space debris. Moreover, in addition to ABS, plastics such as PLA, PVA, and T-Glase/PETT have extremely high melting points, according to our research, enabling them to withstand extreme conditions, such as the temperatures in outer space. Additionally, plastic is relatively affordable compared with other filaments, making it accessible to firms and nations with limited financial resources.

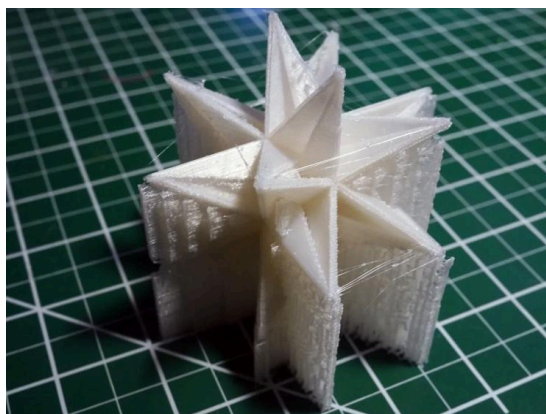


Figure 5. ABS.

Moreover, plastics such as HDPE (Figure 6) have a significant advantage: they are lightweight. According to the official website ([Reference 2 & 3](#)), the cost of launching space equipment to orbit can vary from US\$ 2009 - \$2343/kg to even US\$ 10000 - \$20000/kg due to the complexity and reusability. As a result, the lightweight attributes of plastic can be instrumental in reducing transportation and launch expenditure.



Figure 6. HDPE.

However, the flip side is that plastic can emit toxic gases during combustion, leading to environmental degradation. Moreover, this can endanger human health and even lives. Consequently, plastic is not an appropriate material for constructing the spacecraft engine system.

In addition, the exceptionally high melting point of plastic can be a double-edged sword. Although plastic is a practical material for constructing the spacecraft's outer shell due to its high melting point, it can also pose manufacturing challenges, as higher temperatures are required to reform plastic. This can put a financial burden on the firms and authorities.

- **Nylon:** This can be used as the primary material for electrical wires and other components of space equipment that require high elasticity and flexibility. However, nylon must also be combined with metal for maximum security.

Nylon's (**Figure 7**) use as a 3D printing material is relatively new, but it is becoming popular because its prints are very tough and resistant to damage. Most importantly, nylon exhibits remarkable elasticity and flexibility. Therefore, nylon is widely used in electrical and industrial wires.



Figure 7. Nylon.

As a result, our team proposes applying nylon 3D printing technology in aerospace engineering, particularly for electrical wires in space equipment, because it offers toughness, strength, elasticity, flexibility, and UV resistance. Moreover, nylon is relatively affordable for large-scale industrial production and is a lightweight material compared with its commercial alternatives, with strong physical properties.

Apart from that, nylon, which is a polymer made from alkene, is very stable to chemical reactions, so it can provide more security when the space equipment is traveling in space, as the wire will not be easily affected or crippled by other chemical substances.

Another key fact to remember is that nylon is an excellent electrical insulator (**Reference 6**), meaning electric currents cannot readily pass through the wire. Therefore, a nylon-wire surface can ensure the stability of the electrical transition. However, to make it even more stable, we must also mix nylon with metal filaments, which is also a perfect electric insulator (**usually metal is an electric conductor, but metal filaments for 3D printing are not, and we will explain the reason behind that later**) to provide the capability to the electric wire to function well.

However, nylon requires high printing temperatures (e.g., 250 °C), which many extruders cannot achieve. It is more difficult to adhere to the print bed than with ABS or PLA. Generally, nylon requires both a heated print bed and white glue to stick. In contrast, printing, which can further complicate the production process and require additional energy to maintain a high-temperature environment, entails energy waste that is detrimental to the planet and can increase expenditure.

In addition, although nylon is heat-resistant, with a melting point of 220 °C (Reference 4), this is still insufficient to withstand the harsh conditions in the universe. Although sunlight in cosmic regions near Earth's atmosphere can reach temperatures of up to 120 °C (Reference 5), other heating factors, such as the tremendous aerodynamic drag experienced as the rocket passes through the atmosphere, can also contribute to extremely high heat. Therefore, in addition to using nylon as the primary material, the electrical wires of space equipment must also incorporate a moderate amount of metal to ensure safety and maintain reasonable production costs.

- **Metal Filament:** Can be versatile and can be applied to a variety of parts of space equipment. In general, we can combine it with plastic to construct a more impregnable protection cover. On the other hand, metal can be combined with nylon to enhance the durability and stability of electric wires in space equipment. Moreover, it can be used in the rocket engine due to its high melting point.

Metal filaments (**Figure 8**) are made of fine ground metals combined with PLA and a polymer glue. This means they print like PLA but have the look and feel of metals when polished. They are compatible with any standard printer that supports PLA filament. Therefore, producing metal-containing materials is more cost-effective because we do not require complex, advanced industrial equipment.



Figure 8. Gold ingot, which is one of the most expensive metal filaments.

Available versions include steel, brass, bronze, and copper particles to create the look and feel of those respective metals. The addition of the metal does change how they print, though, so experimentation is required to find the correct settings on your 3D printer. These filaments also require sanding or polishing to create a metallic look. Immediately after printing, they generally resemble ceramics, but brushing with steel wool or metal polish reveals the metal particles, creating a metallic appearance. As sanding and polishing are already well-developed techniques in industrial production, they can reduce production costs while ensuring the aesthetic appearance of space equipment and preserving the original metal material, which is a very expensive option.

For the durability enhancement of the protection shells on the spacecrafts and satellites, our group members decided to opt for metal as the material apart from plastic since it has a very high melting point, which means it is highly heat resistant even to the extreme temperature created by sunlight, friction, or other cosmic radiations. Therefore, it is an ideal material for the rocket engine. Moreover, metal is malleable and ductile, which facilitates production: we can easily shape steel into the desired structure or form without requiring expensive methods.

To enhance the toughness and stability of electrical wiring in space equipment, our group members opt to use copper, in addition to nylon, because, like steel, copper has a high melting point that ensures heat resistance. Most importantly, copper is a highly flexible metal with a high tensile strain. Therefore, copper can be combined with nylon to enhance the elasticity of electrical wires. **Additionally, because the PLA and glue bind the metal particles, these filaments do not conduct electricity; therefore, they can be used to ensure the electrical stability of the wire when combined** with nylon.

Additionally, metal filaments are less dense than solid metal; therefore, a print of a statue with a bronze filament will not weigh as much as a cast bronze version. Consequently, we can reduce launch expenditures or load the rocket with additional essential supplies, given the diminishing payload mass.

However, metal is a costly material, with prices ranging from \$75 to \$120 per kg ([Reference 1](#)), and it also requires experimentation to determine optimal print settings, which can increase production costs and make the process time-consuming. Accordingly, we must balance the amount of metal used on space equipment.

Research Plan & Practical

To prepare for our upcoming practical, we must contemplate four factors.

1. The method our group will use to illustrate our ideas.
2. The prototype of the space equipment we intend to demonstrate.
3. The procedure for conducting experiments and testing our hypothesis.
4. The risk assessment is what makes us competent to cope with unprecedented outcomes.

3.1 The Methods:

As our project concerns practical design associated with 3D printing, our primary approach is to use a 3D printer to produce a simple model that clearly demonstrates our idea (**Figures 9.1 & 9.2**). We can then illustrate the material we will apply to various space equipment components, such as rockets and satellites, by colour-coding; this will serve as **our experimental evidence**.

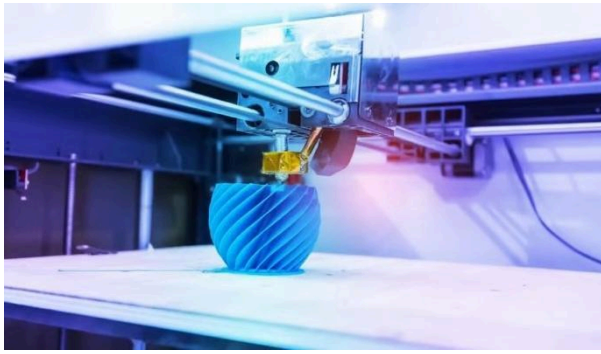


Figure 9.1. 3D printing.



Figure 9.2. Advanced 3D printer.

The reason is that, although it is not impossible, it is still arduous to use a 3D printer to render colour directly on the model, which is also a drawback when access to highly advanced equipment is limited. Moreover, this can become a potential challenge for small companies and firms. (e.g., one 3D printer that can manufacture a large-sized product while having an integrated colour coding function can cost over £10000)

Moreover, we can use Material Studio software to modify the structures of materials suitable for 3D printing, such as plastics and metals. Furthermore, we can also demonstrate the collision between the material and the particles through this software. **This will be our theoretical evidence.**

To investigate how 3D printing could improve aerospace structures, we applied several practical and analytical approaches throughout the project:

1. We used 3D printing to illustrate and test our ideas, producing scale rocket and satellite models that allowed different materials to be mapped onto spacecraft components through colour coding.
2. We designed and built simplified working prototypes of space equipment using CAD software and physical assembly to demonstrate how material selection and structural design influence durability under simulated debris impacts.
3. We conducted controlled-collision experiments in a custom-built wind tunnel to simulate horizontal and vertical debris impacts, thereby enabling evaluation of whether printed structures could withstand repeated strikes.
4. We supported experimental work with computer-based material simulations, using Material Studio to explore polymer structure optimisation and relate material properties to impact resistance.
5. We conducted a structured risk assessment prior to experimentation, identified hazards such as debris escape, tool handling, and heat sources, and implemented mitigation measures, including protective shields, PPE, and controlled test

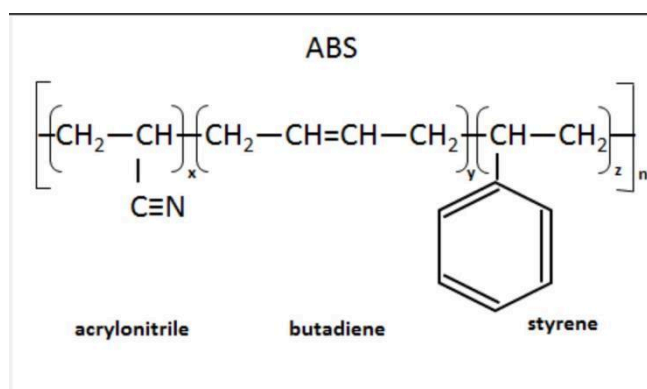
procedures.

6. We iteratively refined experimental setups, adjusting debris materials, airflow angles, and distances to improve the consistency and reliability of collision testing.

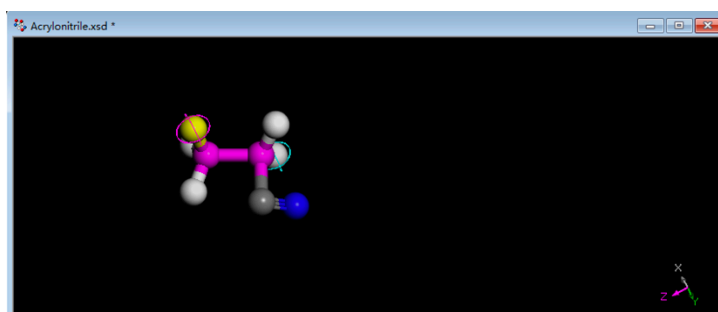
These combined approaches allowed us to move from theoretical investigation to practical demonstration, ensuring that our project integrated research, design, experimentation, and safety planning.

3.2. The Theoretical Online Material Illustration:

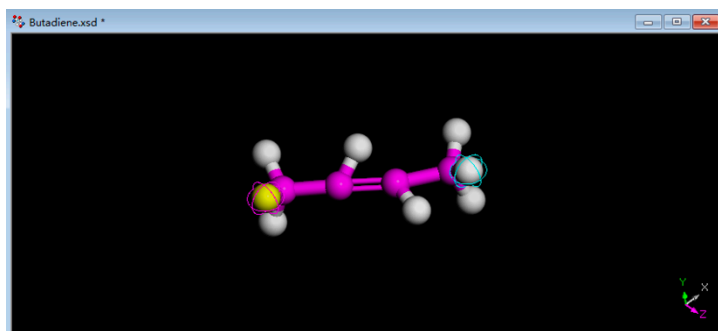
1. Construct the ABS structure in Material Studio.



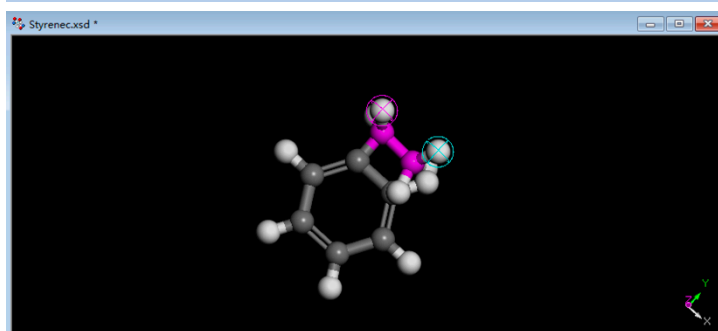
2. Build the structure of Acrylonitrile, butadiene, and styrene separately.



Acrylonitrile



Butadiene



Styrene

- Click Build Polymer, then select Build Random Copolymer. We decided to use a chain length of 10 and 3 chains; the following figure shows the result.

Random Copolymer

Polymerize | Probabilities | Reactivity Ratios | Advanced | Branches

Define repeat units

Repeat Unit	Invert	Flip
Acrylonitrile	0.0	0.0
Butadiene	0.0	0.0
Styrenec	0.0	0.0

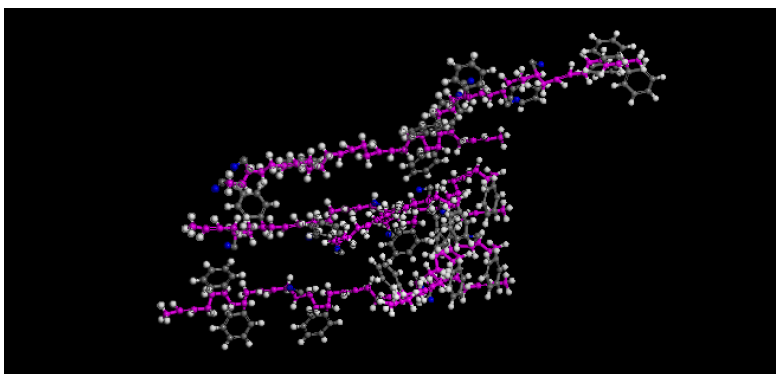
Propagate using:

☒ Probabilities ☐ Reactivity ratios

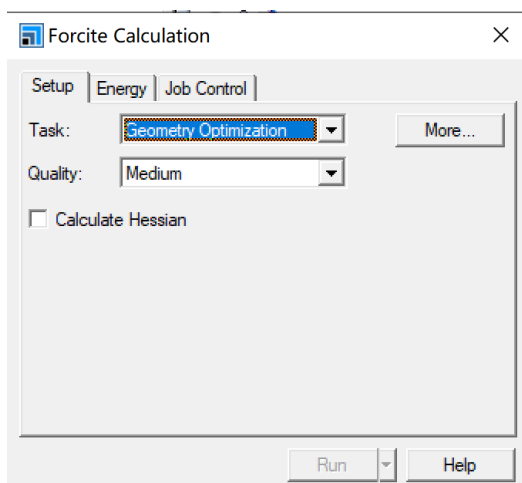
☐ Force concentrations

Chain length: 10 Number of chains: 3

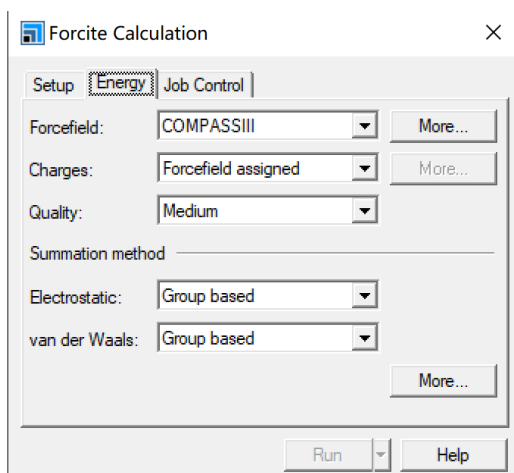
Build Help



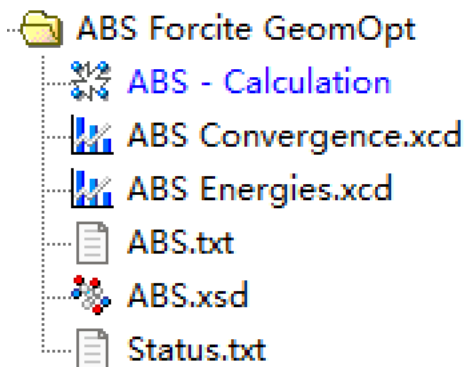
4. Rename the polymer to ABS, as a file with a name that is too long cannot be calculated.
5. The ABS structure lacks geometric precision. We need to use the classical simulation tool Forcite to refine it. It relies on a force field to represent atomic interactions, defined by mathematical functions of distance, angles, and atomic types.
6. Click Forcite on the Modules toolbar and select calculation from the dropdown list.
7. Choose the task of geometry optimization.



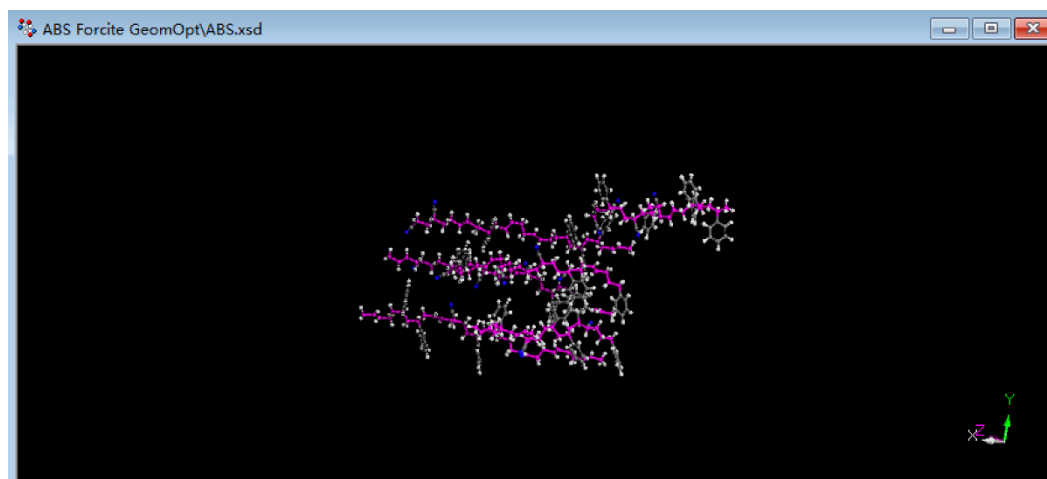
8. On the Energy tab, choose COMPASSIII.



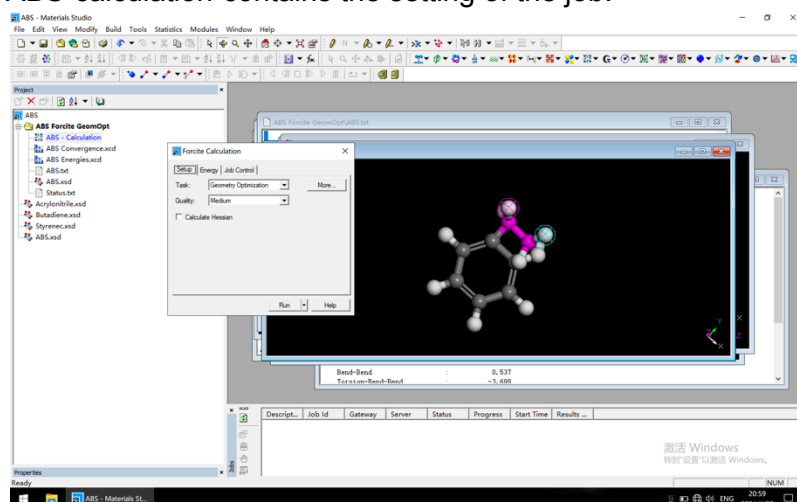
9. COMPASS is a thoroughly tested force field featuring its charges. Selecting COMPASS automatically adjusts the charges option to Forcefield assigned. The non-bond setting typically defaults to the Atom-based setting.
10. Click run
11. A new folder is created called ABS Forcite GeomOpt.



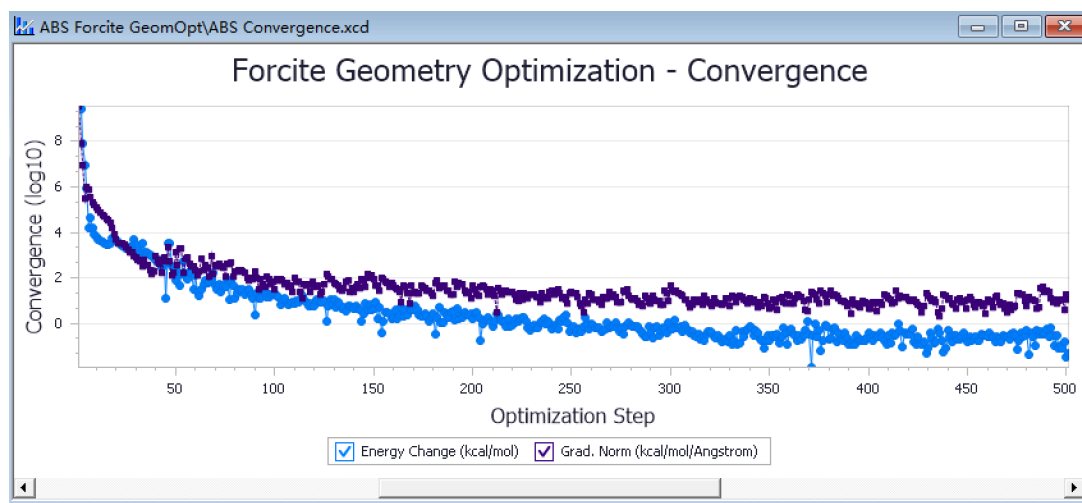
12. ABS. xsd- contains the optimised geometry of the initial structure.



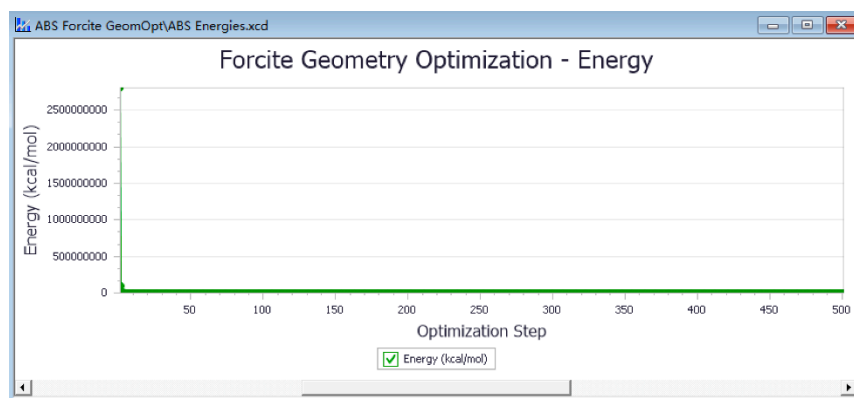
13. ABS-calculation-contains the setting of the job.



14. ABS convergence.xcd- plots the evolution of the energy change and gradient normal change.



15. ABS Energies.xcd- plots the evolution of the enthalpy. There is a dramatic drop, indicating that the initial base geometry was successfully refined.



16. Status.txt- contains the live status.

```

Forcite
-----
Task       : Energy
Version    : 2020
Build date  : Oct 18 2019
Host       : APPLE3B95
Threads    : Scalar
Operating system : Windows
Task started : Wed Apr 17 16:44:45 2024

---- Energy parameters ----

Forcefield      : COMPASSIII (Version 1.0)
Charges         : Forcefield assigned
Electrostatic terms:
  Summation method      : Atom-based
  Truncation method      : Cubic spline
  Cutoff distance        : 12.5 A
  Spline width           : 1 A
  Buffer width           : 0.5 A

Van der Waals terms:
  Summation method      : Atom-based
  Truncation method      : Cubic spline
  
```

Cutoff distance : 12.5 Å
Spline width : 1 Å
Buffer width : 0.5 Å

---- Current structure ----

Total energy : 151.837349 kcal/mol

Contributions to total energy (kcal/mol):

Valence energy (diag. terms) : 215.638

Bond : 54.514

Angle : 119.038

Torsion : 36.089

Inversion : 5.997

Valence energy (cross terms) : -87.485

Stretch-Stretch : 3.981

Stretch-Bend-Stretch : -9.706

Stretch-Torsion-Stretch : -4.331

Separated-Stretch-Stretch : 3.241

Torsion-Stretch : -95.508

Bend-Bend : 0.684

Torsion-Bend-Bend : -4.556

Bend-Torsion-Bend : 18.710

Non-bond energy : 23.685

van der Waals : 88.566

Electrostatic : -64.881

Task terminated : Wed Apr 17 16:44:46 2024

Total CPU time used by Forcite: 1 seconds (0.52s)

Termination status : Normal

17. ABS.txt- shows a text version of the initial settings, and a breakdown of energies for the initial and final structure.

Task : Geometry Optimization
Version : 2020
Build date : Oct 18 2019
Host : APPLE3B95
Threads : Scalar
Operating system : Windows
Task started : Tue Apr 30 18:31:06 2024

---- Geometry optimization parameters ----

Algorithm : Smart
Convergence tolerance:
Energy : 0.001 kcal/mol
Force : 0.5 kcal/mol/Å
Maximum number of iterations : 500
Motion groups rigid : NO

---- Energy parameters ----

Forcefield : COMPASSIII (Version 1.0)
Charges : Forcefield assigned
Electrostatic terms:
Summation method : Group-based
Cutoff distance : 12.5 Å
Spline width : 1 Å
Buffer width : 0.5 Å

Van der Waals terms:
Summation method : Group-based
Cutoff distance : 12.5 Å
Spline width : 1 Å
Buffer width : 0.5 Å

---- Initial structure ----

Total energy : 2805966172.816242 kcal/mol

Contributions to total energy (kcal/mol):

Valence energy (diag. terms) : 7182.877

Bond : 2691.195

Angle : 4153.467

Torsion : 338.215

Inversion : 0.000

Valence energy (cross terms) : 1118.025

Stretch-Stretch : 128.968

Stretch-Bend-Stretch : 81.180

Stretch-Torsion-Stretch : 18.225

Separated-Stretch-Stretch : 93.320

Torsion-Stretch : 582.837

Bend-Bend : 2.295

Torsion-Bend-Bend : 195.398

Bend-Torsion-Bend : 15.801

Non-bond energy : 2805957871.914

van der Waals : 2805957907.847

Electrostatic : -35.933

rms force : 5.128E+08 kcal/mol/A

max force : 3.504E+09 kcal/mol/A

---- Final structure ----

Total energy : 229.564300 kcal/mol

Contributions to total energy (kcal/mol):

Valence energy (diag. terms) : 147.066

Bond : 49.513

Angle : 94.288

Torsion : -1.639

Inversion : 4.904

Valence energy (cross terms) : -85.348

Stretch-Stretch : 4.049

Stretch-Bend-Stretch : -9.442

Stretch-Torsion-Stretch : -4.436

Separated-Stretch-Stretch : 3.299

Torsion-Stretch : -95.259

Bend-Bend : 0.537

Torsion-Bend-Bend : -3.698

Bend-Torsion-Bend : 19.603

Non-bond energy : 167.846

van der Waals : 63.172

Electrostatic : 104.674

rms force : 7.406E-01 kcal/mol/A

max force : 1.191E+01 kcal/mol/A

WARNING Convergence criteria are not satisfied.

Task terminated : Tue Apr 30 18:31:11 2024

Total CPU time used by Forcite: 4 seconds (3.81s)

Termination status: Normal

Employing Forcite calculations facilitates the prediction of various properties, including density, diffusion, mechanical properties, and solubility parameters. These insights can inform subsequent investigations, such as assessing molecular compatibility among polymers, small molecules, and surfaces. Additionally, it enables the study of properties such as the diffusivity of small molecules in polymer matrices and the glass transition temperature.

However, due to the lack of professional software, equipment, and ideas on the actual proportion of the polymer. We only did a simple Forcite calculation to gain insight into the material studio.

3.3. The Prototype:

In practice, we must develop two models: the rocket and the satellite. To determine the most probable scenario the spacecraft will encounter in practice, our team conducted research on the most widely used model of space equipment.

For the rocket, our team has agreed to use the Long March 5, one of China's most advanced rocket series (**Figure 10**). As Chinese space engineering technology has advanced rapidly in recent years, China's space industry and exploration projects have become a major focus worldwide. Therefore, many countries have predicted that China's space equipment and its government will play an increasingly significant role in global space development.



Figure 10. China's Long March 5.

To streamline our procedure, our group simplified the rocket model design (Figure 11) because it is easier to recreate in 3D design software.

For the satellite, our group selected the most modern U.S. model, GPS III, and the upcoming GPS III F (**Figure 12.3**). This is because our daily lives are increasingly technology-driven, and state-of-the-art devices such as GPS are indispensable for navigation.

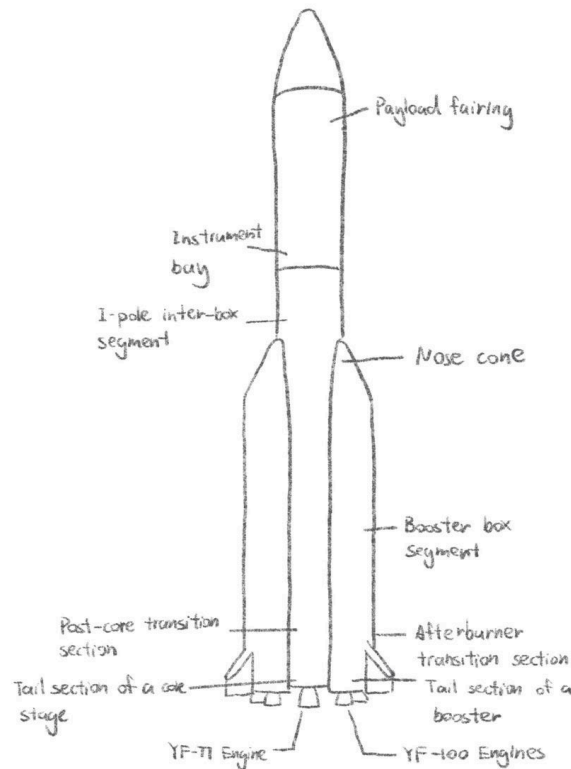


Figure 11. Rocket model prototype.

Therefore, according to the official statistical website of American GPS **(Reference 4) & (Figures 12.1 & 12.2)**, 31 GPS satellites are orbiting around the Earth in contemporary time. Therefore, we must prevent them from colliding with space debris traveling at velocities exceeding 8 km/s.

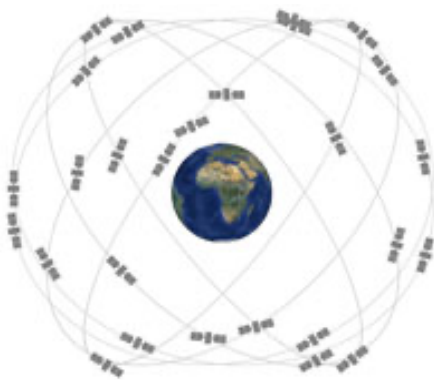


Figure 12.1. GPS satellites that are in the Earth's orbit.

LEGACY SATELLITES		MODERNIZED SATELLITES		
BLOCK IIA	BLOCK IIR	BLOCK IIR-M	BLOCK IIF	GPS III/IIIF
0 operational	6 operational	7 operational	12 operational	6 operational
- Coarse Acquisition (C/A) code on L1 frequency for civil users - Precise P(Y) code on L1 & L2 frequencies for military users 7.5-year design lifespan - Launched in 1990-1997 - Last one decommissioned in 2019	- C/A code on L1 - P(Y) code on L1 & L2 - On-board clock monitoring 7.5-year design lifespan - Launched in 1997-2004	- All legacy signals 2nd civil signal on L2 (L2C) LEARN MORE - New military M code signals for enhanced jam resistance - Flexible power levels for military signals 7.5-year design lifespan - Launched in 2005-2009	- All Block IIR-M signals 2nd civil signal on L5 frequency (L5) LEARN MORE - Advanced atomic clocks - Improved accuracy, signal strength, and quality 12-year design lifespan - Launched in 2010-2016	- All Block IIF signals 4th civil signal on L1 (L1C) LEARN MORE - Enhanced signal reliability, accuracy, and integrity - No Selective Availability LEARN MORE 15-year design lifespan - IIIF: laser reflectors; search & rescue payload - First launch in 2018

As of July 3, 2023, there were a total of **31 operational satellites** in the GPS constellation, not including the decommissioned, on-orbit spares.

Figure 12.2. Types of GPS satellite systems.

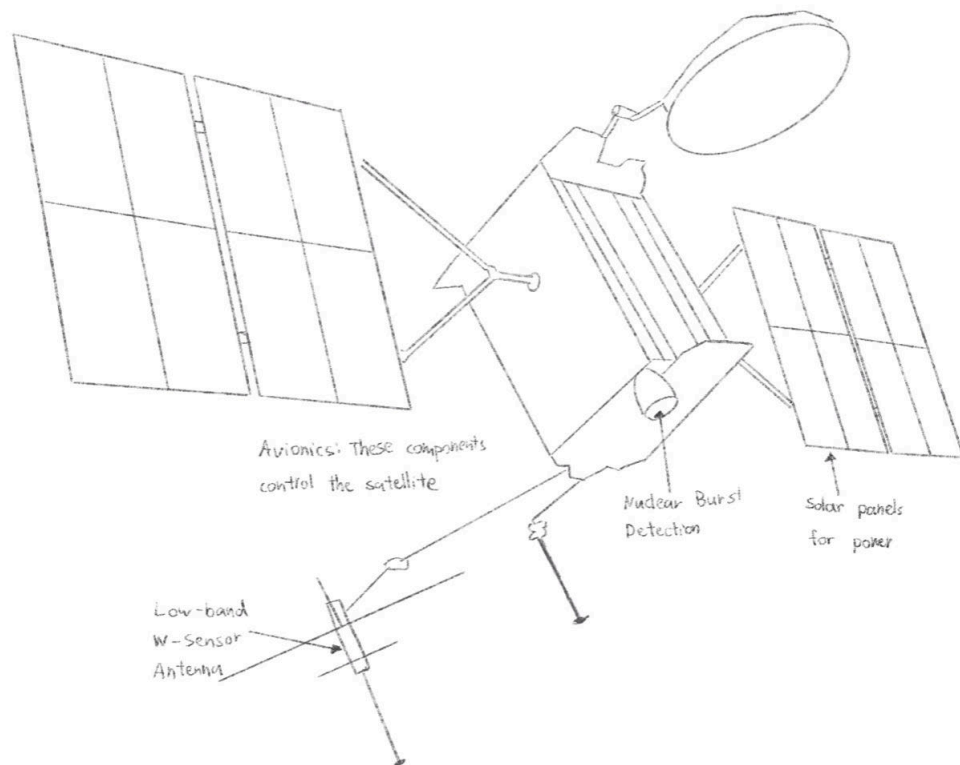


Figure 12.3. Satellite model prototype.

Our team must conduct two practical tests to evaluate our hypothesis regarding the use of the desired material on the various components of rockets and satellites. It is because we must modify and illustrate whether the proposed solutions are practical and feasible.

In terms of our practical planning, our teams decided to divide them into several parts.

3.4. Procedure:

Equipment List:

- A2 acrylic cardboards: As a result, our group members have decided to use an alternative plan, namely, a medium-sized transparent fume cupboard as the main structure. To block the side, our group opted for two transparent safety screens to construct two walls, preventing paper debris from being blown out of the wind tunnel and providing support for our video cameras. To block the top, our group used cardboard to create a 'roof'.
- Transparent tape x1:
- Large cardboards x2:
- Toilet paper x1:
- 3D rocket model x1 (Printed by 3D printer, use different colours of paint markers to demonstrate different rocket materials.): If a 3D printer is not available in our school, we must buy the 3D printed models online.

- 3D satellite model x1 (Printed by 3D printer, using different paint markers and colours to demonstrate different rocket materials)
- Tripod x1:
- Metal gauze x1:
- Hairdryer x1: Available to lend from our school.
- Video camera x1 (We will probably use our own iPhone camera)

Part 1: Constructing the Wind Tunnel

- Construct a wind tunnel using an acrylic board, tape, and a glue gun to hold the boards together and consolidate the structure of the wind tunnel.
- Overall, our team has decided that the wind tunnel should be a square tube because it is easier to construct and to hold the satellite model on the ground.
- Moreover, we chose an acrylic board as the tube material because it is transparent, thereby enabling more explicit and effective video recording. Moreover, acrylic is less hazardous as it does not break as easily as glass and is more affordable than other transparent materials.
- Then, we must seal the 5th side of the wind tunnel with a square piece of cardboard.
- In the subsequent stage, we must cut cardboard into long rectangles and place them on the opening side of the square tunnel to create a platform for placing small debris representing space junk that could collide with space equipment.

Part 2: Collision Test

After successfully constructing the wind tunnel, we must modify the collision model between the satellite and space debris by conducting a collision test. To achieve the most accurate and realistic simulations, our teams have decided to separate the collision direction into two components: horizontal and vertical.

Horizontal: Use a blow dryer to generate mighty wind and make the debris accelerate. A wind tunnel or an acrylic tube can prevent debris from splashing everywhere.

Vertical: Modify the vertical collision by pouring the debris onto the satellite model. Surround the model with a wind tunnel or an acrylic tube to prevent debris from splashing.

- While conducting both tests, we will let one team member use a camera to monitor and record the processes and results. The reason for choosing a video camera is that it provides a clear visual record and greater accuracy, as we can rewatch the video at any time.

3.5. Risk Assessment:

Before conducting our practical, we must first organise a risk assessment. This can not only provide an advantage during the experimental process but also equip us to address unforeseen outcomes.

Part 1: Wind Tunnel Construction

Hazard: Material Handling and Assembly

Risk: Risk of injury from handling acrylic boards, tape, glue gun, and sharp tools during assembly.

Control: Provide appropriate personal protective equipment (PPE) such as gloves and safety glasses. Ensure all team members are trained to handle materials and tools safely.

Action: If an injury occurs, immediately stop work, provide first aid as necessary, and seek medical attention. Investigate the cause of the incident to prevent future occurrences.

Hazard: Structural Stability

Risk: Risk of collapse or instability of the wind tunnel structure during construction or operation.

Control: Ensure proper reinforcement and secure bonding of acrylic boards with tape and a glue gun. Regularly inspect the structure for any signs of weakness or instability.

Action: If instability is observed, evacuate the area and secure the experiment site. Investigate the cause of instability and reinforce or repair the structure as necessary.

Part 2: Collision Test Preparation

Hazard: High-Speed Debris

Risk: High-speed debris propelled by blow dryers may cause injury or damage if not controlled.

Control: Ensure proper safety measures, including the use of appropriate PPE and positioning the wind tunnel to contain debris. Use caution when operating the blow dryer.

Action: If debris escapes containment, immediately stop the experiment, secure the area, and provide medical assistance if necessary. Review safety protocols and adjust containment measures as needed.

Hazard: Pouring Debris

Risk: Pouring debris onto the satellite model may result in spillage or unintended impacts.

Control: Use a controlled-pouring technique and ensure that the wind tunnel effectively contains debris. Keep the surrounding area clear to minimise the risk of tripping or slipping.

Action: If spillage occurs, stop pouring immediately and clean the area to prevent further hazards. Assess any damage to equipment or models and make repairs as necessary.

General Risks

Hazard: Fire Hazard

Risk: Using a hot glue gun and blow dryer poses a fire risk if not handled properly.

Control: Keep fire extinguishers nearby and ensure all team members are trained in fire safety procedures. Avoid flammable materials near heat sources.

Action: If a fire occurs, evacuate the area, activate fire alarms, and use a fire extinguisher to suppress flames. Contact emergency services if necessary and follow evacuation procedures.

Hazard: Chemical Exposure

Risk: Exposure to fumes from the glue gun or acrylic materials may cause respiratory irritation.

Control: Ensure adequate ventilation in the work area. Use respiratory protection if necessary. Limit exposure time to minimise risk.

Action: If exposure occurs, remove affected individuals from the area and provide fresh air. Seek medical attention if symptoms persist or worsen. Review ventilation measures to prevent future exposures.

3.6. Practical Process:

After planning comprehensively, we are now finally able to commence on our practical, whose procedure is divided into four parts:

- Model Design
- 3D Printing & Colour-coding
- Wind Tunnel Construction
- Collision Test

Part 1: Model Design

As STEM students with prior experience with Blender, we chose to use it to design our own rocket and satellite model. Overall, we use the Long March 5 and GPS IIF as our design references, incorporating some of our personal preference designs (**Figures 13.1 & 13.2**).

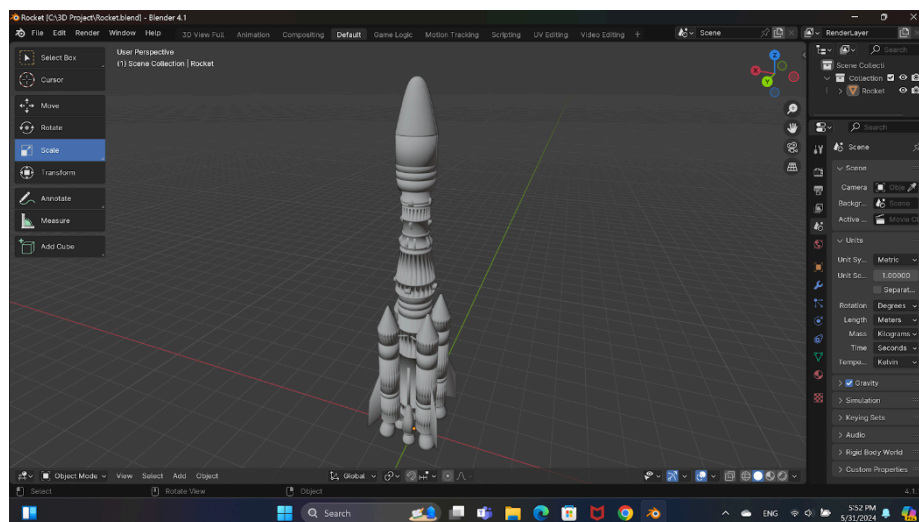


Figure 13.1. Rocket model CAD designer via Blender.

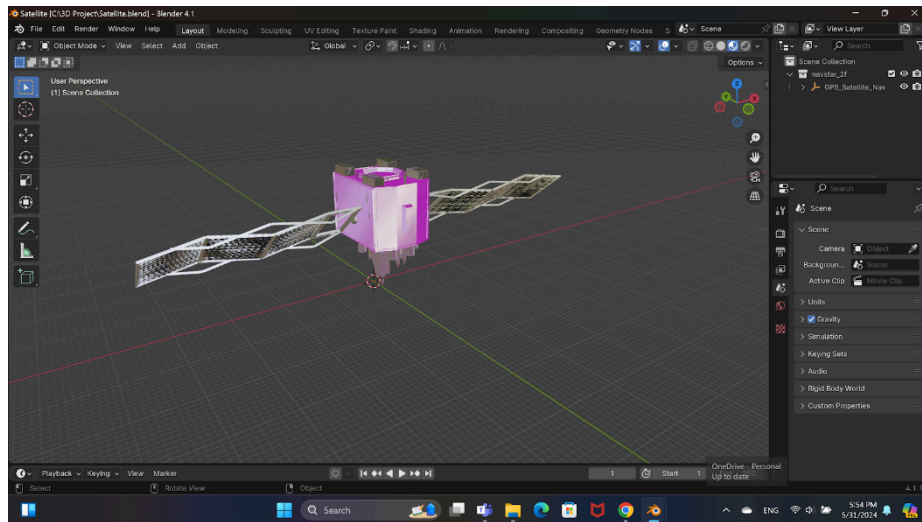


Figure 13.2. Satellite model CAD design via Blender

Part 2: 3D Printing & Colour-coding

After completing the design of our 3D models, we used CAD and our school's 3D printers to fabricate them. Due to the size limitations of the 3D printers, we used CAD software to scale our models (length, width, and height were all within 20 cm) and to adjust the printing angle to ensure a smoother process. Moreover, because the satellite featured numerous intricate components, our group divided the models into several parts and printed them separately. In the subsequent stage, we use a glue gun to assemble different components (**Figure 14.1-14.8**).

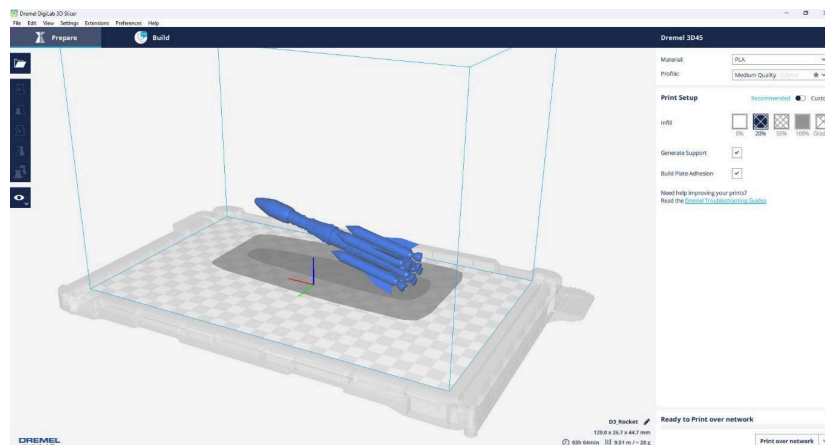


Figure 14.1. The rocket model was ready for 3D printing.

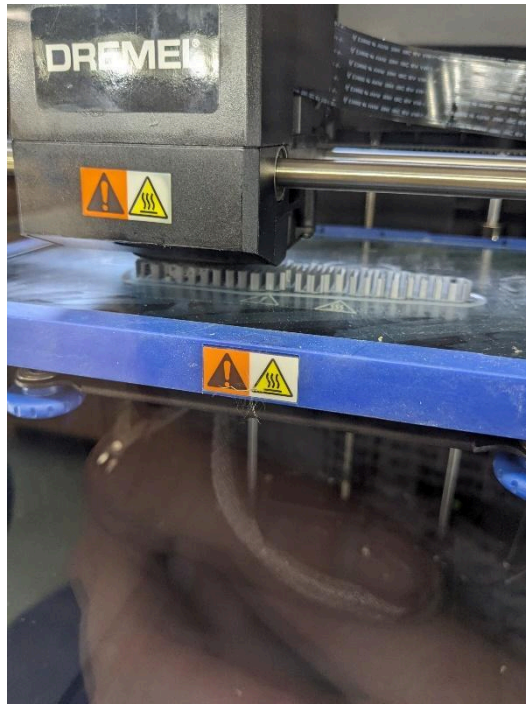


Figure 14.2. The rocket model was printing.



Figure 14.3. The rocket model was printing.

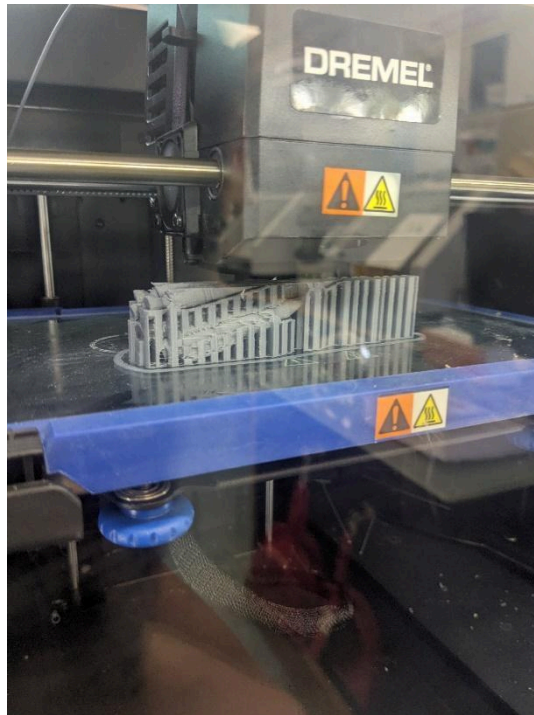


Figure 14.4. The rocket model was printing.



Figure 14.5. The rocket model was printing.

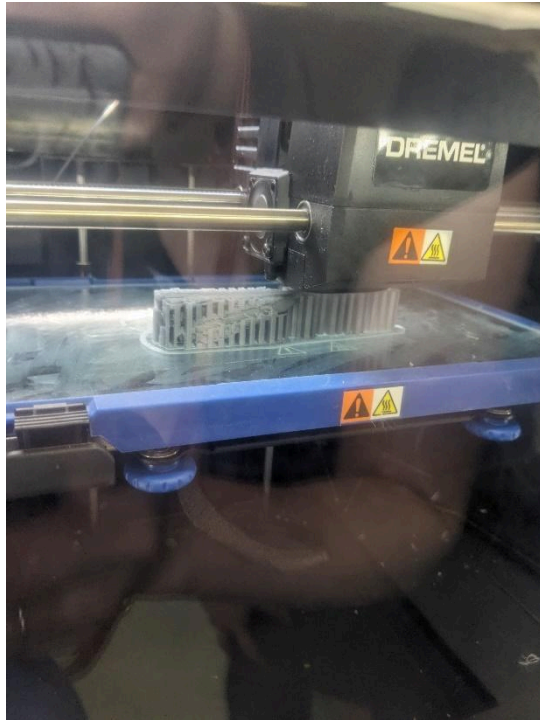


Figure 14.6. The rocket model was printing.



Figure 14.7. 3D-printed rocket model.

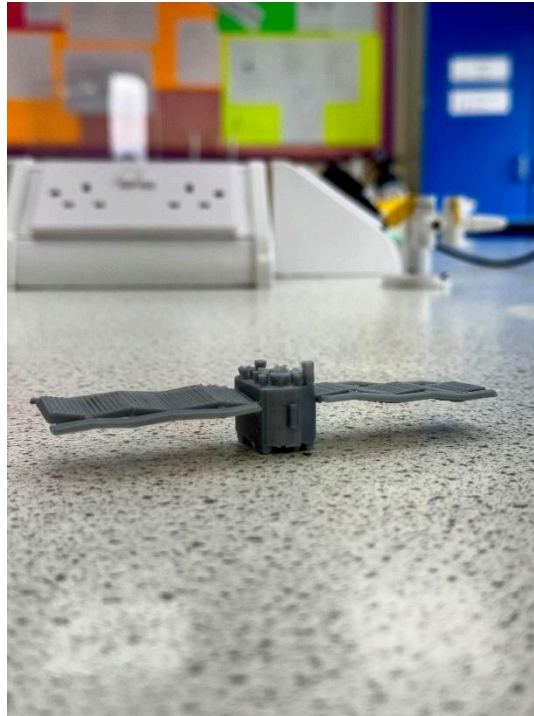


Figure 14.8. 3D-printed satellite model.

Next, our team decided to use a colour-coding technique to identify the most suitable 3D printing material for different parts of the space equipment. As it is challenging and expensive to colour-code the space equipment solely through a 3D printer, we opt to use paint markers, such as acrylic paint, one of the best media for painting plastic, which is also the material of our illustrating models.

As a result, our team members decided to use the following colours (**Figures 15.1 & 15.2**):

Red: Plastic

Yellow: Metal and metal filaments

White: Nylon

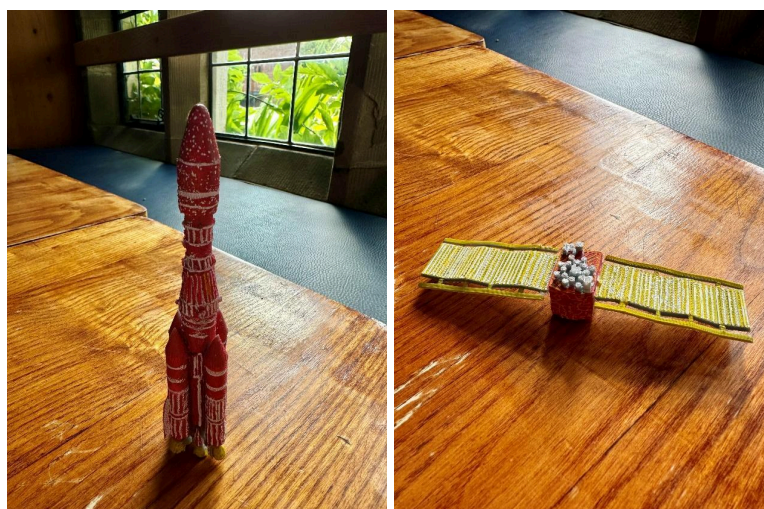


Figure 15.1 & 15.2. Colour-coded rocket & satellite model.

Part 3: Wind Tunnel Construction

Due to the lack of availability of some tough and strong materials, such as metal plates and carbon fibers, on top of the requirement of visibility for video recording, our team opted to use the large fume cupboard (for meeting the requirements of a long distance for the wind to flow) and a three-sided screen protector to construct a simple wind tunnel. Furthermore, we used cardboard and books, some common materials found in our laboratory and classroom, to seal the gap between the fume cupboard and the screen protector to minimise the uncertainty that might arise in our experiments. Moreover, we cut cardboard into several rectangles to create platforms for placing debris, which will be used in the collision test.

For the debris and space junk used in our collision test, we initially decided to use either toilet paper or polystyrene balls, as their shapes can be readily modified. However, as it is very time-consuming to tear down the paper and polystyrene to make numerous small debris pieces, which would be used in the later experiment, and these materials are too soft and cannot have a sufficiently long flight due to the large drag force they would experience, we decided to use a more rigid material that is already small. Consequently, we decided to use the spillage kit absorbent, an ordinary, safe material commonly found in laboratories. Moreover, sufficient absorbent hardness ensures that they remain airborne after being blown by the hairdryer (**Figures 16.1–16.7**).

Finally, we mounted our illustration model on the tripod at an optimal orientation to withstand as many collisions as possible.



Figure 16.1. Spillage kit absorbent.



Figure 16.2. The simplified version of a wind tunnel.



Figure 16.3. Debris was placed on the cardboard platforms.



Figure 16.4. The rocket model was mounted on a tripod platform made of gauze and cardboard.



Figure 16.5. Creating wind and turbulence by using a hairdryer.



Figure 16.6. Debris was placed on the cardboard platforms.



Figure 16.7. The satellite model was mounted on a tripod platform made of gauze and cardboard.

Part 4: Collision Test

For the horizontal collision test, our group members first placed the 'debris' we had already produced on the cardboard platform, while ensuring that the sizes of the debris were evenly distributed to make our collision test as close as possible to the realistic situation. Moreover, we determined the optimal incline angle of the hairdryer and the distance between the hairdryer and the debris after several trials: 15 degrees upward and 1 metre, respectively.

On the other hand, in the vertical collision test, although using a metal sieve appeared effective initially, the limited space of our wind tunnel made it difficult to control the amount of debris introduced into the demonstration model with each shake. Moreover, using a sieve may introduce discontinuities and alter collision intensity. Therefore, our group decided to use our hands to release the debris.

Consequently, the result was satisfactory, as our rocket and satellite model withstood vigorous collisions from all angles without sustaining scratches or surface damage. Moreover, we recorded the crash process using our iPhone's slow-motion camera, which allowed us to rewatch the collision test and reduce random errors and uncertainties.

Ethical Considerations and Responsible Practice

4.1. Ethical Considerations and Responsible Practice:

In directing this project, we considered not only experimental safety but also ethical responsibilities in conducting and reporting scientific work. All collision tests, including those that did not produce clear or expected outcomes, were recorded and included in our lab documentation. No results were excluded to improve the appearance of the findings, ensuring honest and transparent data reporting throughout the investigation.

We also considered the wider societal implications of aerospace research. Space debris poses risks to all space users, including communication, navigation, and climate-monitoring satellites on which modern society depends. By exploring how additive manufacturing could contribute to stronger and lighter spacecraft structures, our project supports long-term efforts to reduce satellite failures and debris generation, thereby helping maintain safer access to space for all nations and industries.

In addition, the project emphasizes sustainable manufacturing practices, as 3D printing can reduce material waste compared with traditional subtractive methods. Considering environmental impacts and responsible resource use guided our material discussions and design decisions.

By combining safe laboratory practice with ethical data handling and consideration of societal benefits, we aimed to conduct our project responsibly while contributing ideas that may support safer and more sustainable future aerospace development.

Time Scale and Challenges

5.1. Project Sections:

Our project can be divided into several sections, each of which took us a significant amount of time:

- Whole project: around 1 year
- The problems of current space equipment: 1 month
- The properties of different 3D printing materials: 2 months
- Deciding which material is suitable for a specific part manufacturing: 1 month
- Research planning: 1 month
- Collision simulation: 1 month
- 3D design and printing: 2 months
- Wind tunnel construction: 2 months
- Collision test: 2 months

The writing of our research essay was synced with the process, which also takes roughly 1 year to complete.

5.2. Encountered Challenges:

During our project, our team members have encountered several challenges that we have had to overcome:

1. The investigation of the properties of different 3D printing materials relied solely on online resources, without conducting experiments to validate the findings. Moreover, the space environment differs from Earth's.

Although our investigation on different 3D printing materials was comprehensive, it was not proven by any tests or practical experience. As it was challenging and expensive to obtain all those materials, including metal filaments and nylon, we created a 3D collision simulation to test whether a specific material can withstand such a strong collision in the universe.

However, because some materials exhibit different properties in extreme and vacuum environments in space, we must continue to investigate this topic further.

2. The fume cupboard was too short to accommodate a larger opening, and its opening was too small to accommodate our cardboard platform.

When constructing our wind tunnel, the fume cupboard was the most suitable material that we could find, as it was made of transparent acrylic boards and was almost perfectly sealed. Therefore, it created an ideal environment for photographing and filming during the collision test. However, although we could block the gaps with books, the opening of the fume cupboard was too small because the acrylic surface blocked half of it.

Therefore, our group decided to lift it vertically to achieve a broader opening and increase the cardboard surface area. Although it worked, it did so at the expense of the fume cupboard's total length. To resolve this problem, we decided to install two transparent screen protectors on the side of the fume cupboard to extend its length.

3. The production of debris was too time-consuming, and they could not achieve a sufficiently long flight or a sufficiently powerful collision.

Initially, our group members decided to use toilet paper as space debris because our school laboratory lacked more durable materials, such as stones. We attempted to make them into small spheres. However, the process required excessive time and effort. Therefore, our guiding teacher offered an alternative: polystyrene balls. Although the process of breaking them down was much quicker with the cheese and vegetable grater, the polystyrene sphere still could not provide a sufficiently long flight, even though the hairdryer was extremely close to them.

Therefore, after reviewing all materials available in our school laboratory, we identified the most suitable material for our collision test: the spillage kit absorbent, as it was not only small enough to act as a debris collector but also safe and durable. Moreover, it could experience a long flight with just low wind power. Therefore, this material has resolved our issue.

4. The blowing angle and the distance between the hairdryer and the debris.

This was the pivotal issue our team encountered, as it was challenging to ensure that a single hair dryer could dislodge all debris from all 3 cardboard platforms and that particles could achieve a random, extended trajectory to strike the 3D model.

To resolve this problem, our team members have tested different angles of the hairdryer and several distances between the hairdryer and the cardboard platform. Consequently, we found that 15 degrees upward and 1m from the cardboard platform were the best options to balance power and affected range.

Consequently, during our practical, all particles were allowed to flow long enough to reach the 3D rocket and satellite model and to undergo a vigorous collision with it.

5.3. Reflection & Future Improvements:

Through this project, we developed practical skills in problem-solving, experimental design, and resource-constrained adaptation. We also strengthened our understanding of materials science and gained experience in integrating aerospace engineering concepts with additive manufacturing methods. Constructing our own testing setup and modifying procedures when materials or equipment were unavailable improved our creativity and teamwork.

However, several aspects of the project could be improved in future work. The collision tests were limited by available equipment and did not fully replicate realistic space conditions. In a future investigation, we would aim to secure access to university or professional laboratory facilities to perform higher-energy impact simulations and more accurate material testing. We would also conduct pilot tests using varying mixtures of plastic, nylon, and metal filaments to determine which combinations best balance strength, weight, and cost.

Additionally, instead of relying primarily on published material data, we would plan controlled experiments to directly measure properties such as impact resistance and thermal behaviour of printed samples. More systematic testing, including repeated trials and quantitative measurements, would improve reliability. We would also schedule prototype testing earlier in the project timeline to allow design adjustments before final printing.

By improving experimental realism, collecting more quantitative data, and refining material selection through repeated testing, future versions of this project could provide stronger evidence for the application of 3D printing technology to aerospace engineering challenges.

Results Evaluation & Implications

6.1. Implications For Space Debris Risk & Spacecraft Safety:

If scaled for industrial use, 3D printing could support spacecraft designs that are more damage-tolerant and easier to iterate. Engineers could rapidly prototype protective housings, shielding concepts, or internal supports and test them early, thereby reducing the likelihood that structural weaknesses would be introduced into flight hardware. In the long term, improving durability and extending satellite lifetimes could help slow the growth of debris by reducing premature failures that create additional defunct objects and fragmentation risk.

6.2. Implications For Cost & Launch Efficiency:

A key advantage of 3D printing is the ability to produce lighter structures and complex geometries while minimizing material waste. Reducing mass can lower launch costs and increase payload capacity for the same launch vehicle, which is particularly important for satellites. In addition, additive manufacturing supports modular repair or part replacement (printing specific components rather than replacing entire assemblies), which could reduce maintenance costs and decrease downtime for satellite constellations.

6.3. Environmental & Societal Implications:

Additive manufacturing typically uses only the material required for the part, thereby reducing manufacturing scrap and improving resource efficiency. If this approach reduces the number of launches needed for replacements and enables longer satellite lifetimes, it may also lower the indirect environmental burden associated with frequent production cycles and launch operations. More affordable and reliable satellites can benefit society by strengthening systems on which modern life depends—such as navigation, communications, climate monitoring, and disaster response—while improving safety by reducing the probability of uncontrolled failures.

6.4. Limitations and next steps:

Our results should be interpreted as evidence of early-stage feasibility. Real debris impacts occur at much higher velocities than can be replicated in a school wind tunnel. Future work should test higher-energy impacts, vacuum/thermal cycling, and a broader range of aerospace-grade printable materials. Nevertheless, the project demonstrates a practical pathway: use fast, low-cost testing to inform safer spacecraft designs, then progress to higher-fidelity validation as resources allow.

Conclusion

Our results suggest that additive manufacturing can contribute to more resilient and sustainable aerospace structures when materials are selected strategically and designs are optimized for strength-to-weight performance. In our impact tests, the 3D-printed rocket and

satellite models withstood repeated horizontal and vertical “orbital-debris” collisions without visible surface damage, indicating that lightweight printed structures can tolerate repeated particulate impacts under controlled conditions. While this experiment does not replicate the full severity of real hypervelocity collisions, it provides evidence that prototype-level testing can quickly screen design concepts and highlight which geometries and materials are more robust.

To cut a long story short, our project can be deemed a success, thanks to the rigorous investigations and analyses we conducted, along with two compelling collision tests, both virtual and physical. These provided valuable insights and validated much of our theoretical research. However, one of the main challenges we faced was the limited accuracy and precision in our practical work, due to the absence of advanced, professional equipment typically found in research laboratories rather than school laboratories. Despite these obstacles, overcoming them greatly enhanced our problem-solving and critical-thinking abilities, skills that are indispensable for any STEM student or researcher. We learned to adapt and innovate with the resources available to us, which will undoubtedly be an asset as we advance in our academic and professional careers.

Furthermore, this project deepened our understanding of materials science as we explored the properties of various materials. This knowledge will give us a distinct advantage when we pursue more advanced research at the university level. The interdisciplinary nature of our team was another key element of our success, as we benefited from each member’s unique expertise. Kelvin’s background in aerospace engineering and Lulu’s specialisation in materials science were pivotal to the integration of these two fields. This collaboration enabled us to embark on an innovative research journey, learning from one another and expanding our knowledge into areas we might not otherwise have encountered.

Finally, this project has been an exhilarating experience for all of us, sparking an even deeper passion for STEM. The opportunity to engage with such a revolutionary topic has reinforced our enthusiasm and determination to pursue further research and exploration in this field. We are proud of the work we have accomplished and motivated to continue pushing the boundaries of what’s possible in the world of science and technology.

Team Composition

- Whole Project: Kelvin Cheung & Lulu Shen
- Online Research: Kelvin Cheung & Lulu Shen
- Essay Writing: Kelvin Cheung
- 3D Collision Simulation: Lulu Shen
- 3D Model Design % Production: Kelvin Cheung
- Collision Test: Kelvin Cheung & Lulu Shen

References

1. 3D Printing Materials: The Pros and Cons of Each Type. [Online] Available at: <https://www.tomsguide.com/us/3d-printing-materials.news-24392.html> [Accessed 12 June 2025]
2. How Much Does It Cost to Launch a Rocket? [Online] Available at: <https://spaceinsider.tech/2023/08/16/how-much-does-it-cost-to-launch-a-rocket/> [Accessed 12 June 2025]

3. Cost of space launches to low Earth orbit. [Online] Available at:
<<https://ourworldindata.org/grapher/cost-space-launches-low-earth-orbit>> [Assessed 12 June 2025]
4. GPS.gov: Space Segment. [Online] Available at: <<https://www.gps.gov/systems/gps/space/>> [Assessed 12 June 2025]
5. What is nylon? All about its properties and common uses. [Online] Available at:
<<https://europas.com.vn/en-US/blog-1/what-is-nylon-all-about-its-properties-and-common-uses>> [Assessed 12 June 2025]
6. nylon is a good conductor or poor conductor - [Brainly.in](https://brainly.in/question/10589749). [Online] Available at:
<<https://brainly.in/question/10589749>> [Assessed 12 June 2025]
7. The Temperatures Of Outer Space Around The Earth. [Online] Available at:
<<https://www.sciencing.com/temperatures-outer-space-around-earth-20254/>> [Assessed 12 June 2025]
8. Satellite Bus Showdown: Legacy Titans vs. NewSpace Mavericks (2024–2033). [Online] Available at:
<<https://ts2.tech/en/satellite-bus-showdown-legacy-titans-vs-newspace-mavericks-2024-2033/>> [Assessed 12 June 2025]