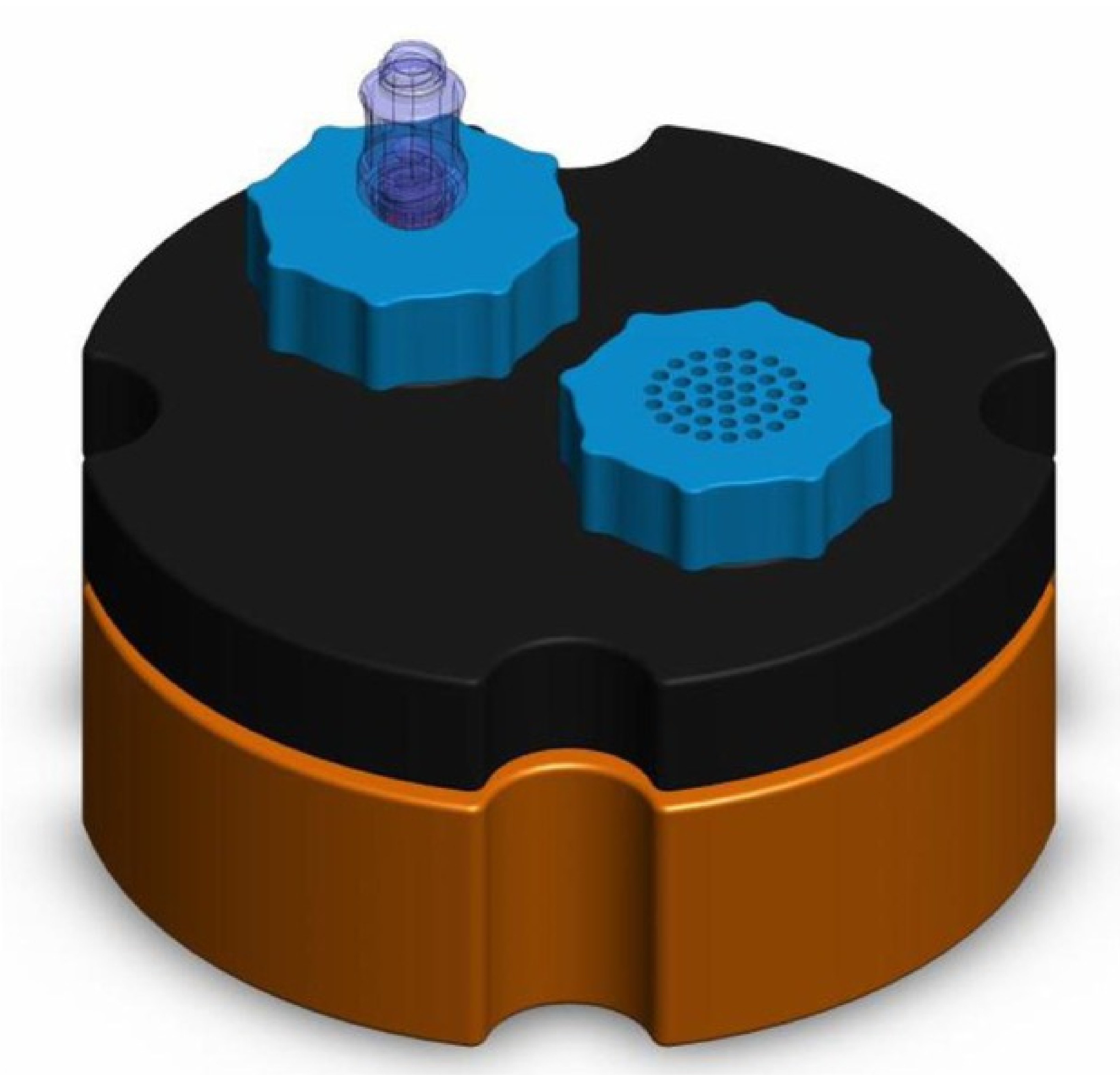
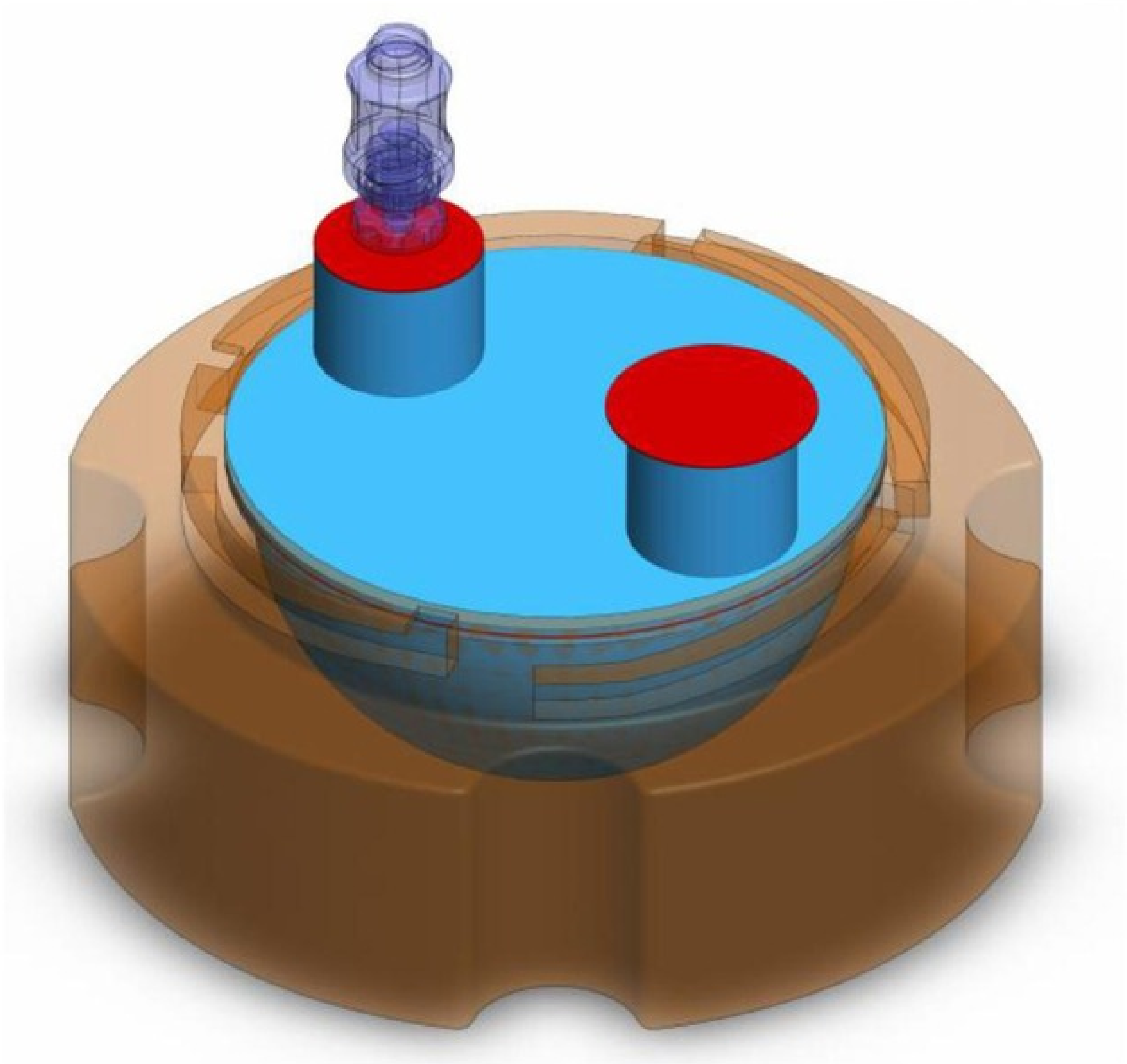
ARDONX PRIVATE LIMITED

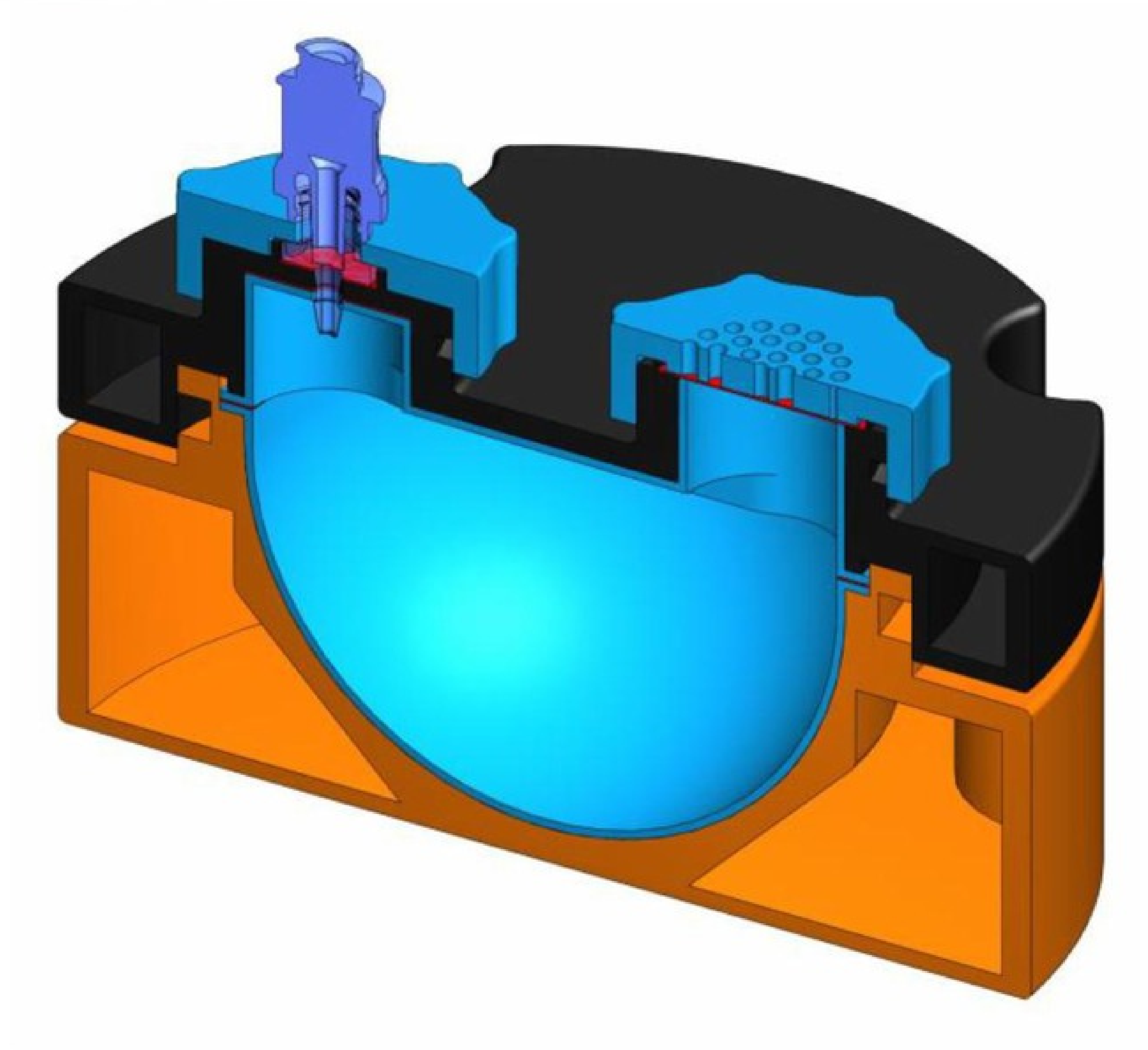
Efficient Hemispherical Bioreactor 3D Printable, Reusable, Modular, Optimized for Uniform Culture Growth and Gas Exchange

For

NASA Challenge "3D Printable Bioreactor for Deep Space Food Production"







PROJECT TITLE:
EFFICIENT HEMISPHERICAL BIOREACTOR 3D PRINTABLE, REUSABLE, MODULAR, OPTIMIZED FOR UNIFORM CULTURE GROWTH AND GAS EXCHANGE

PREPARED FOR:
NASA's SYNBIO PROJECT

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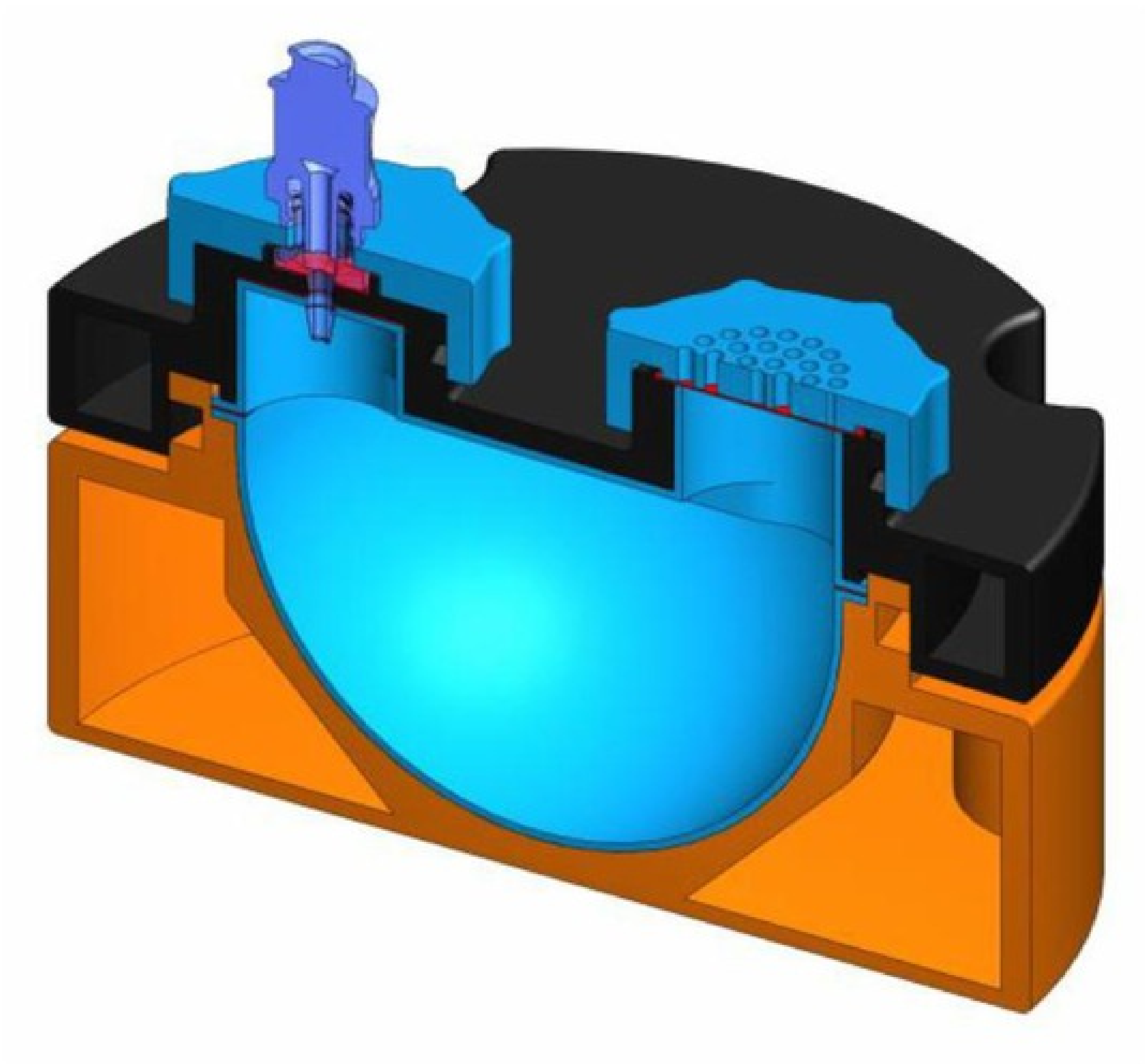
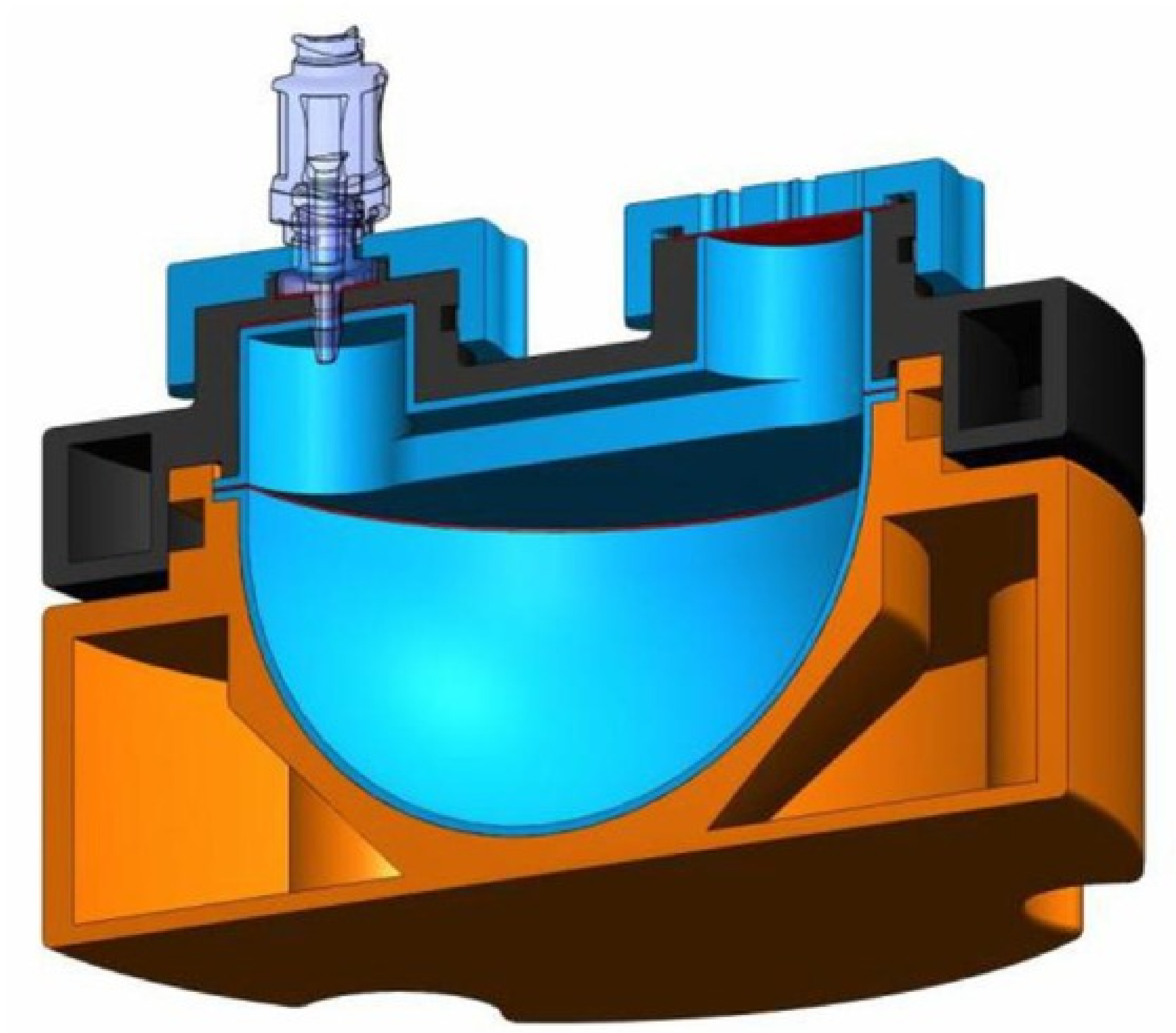
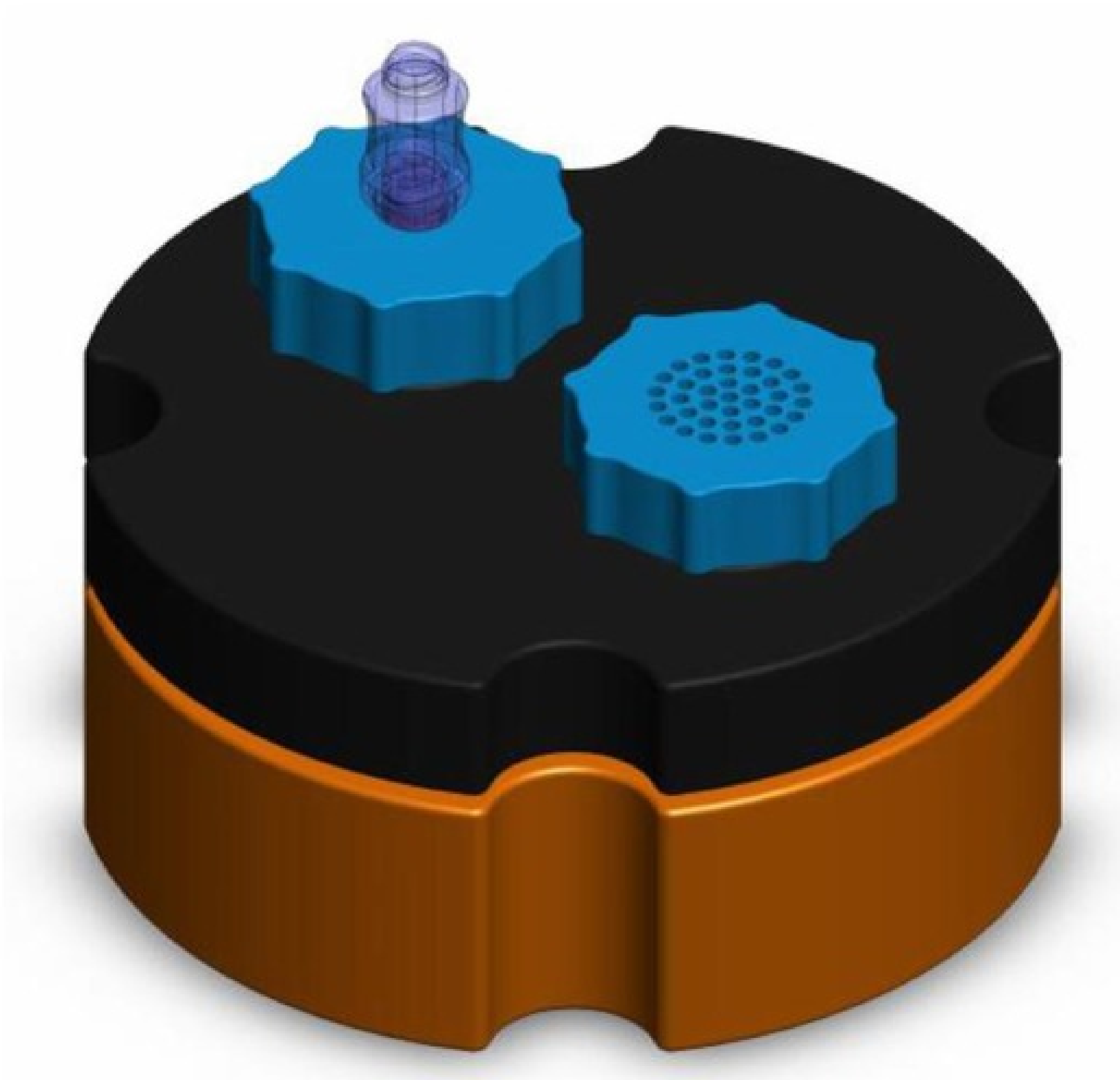
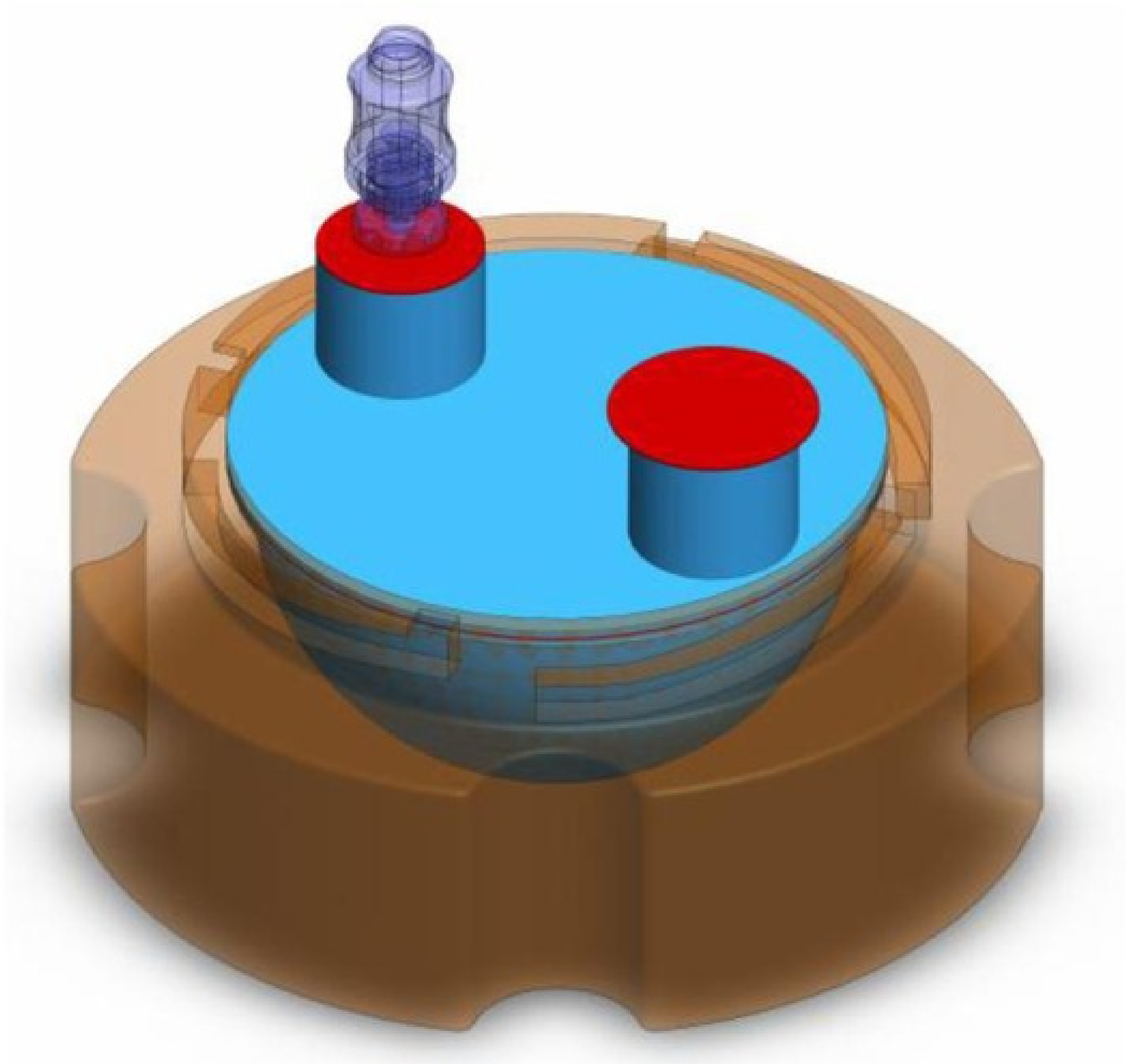
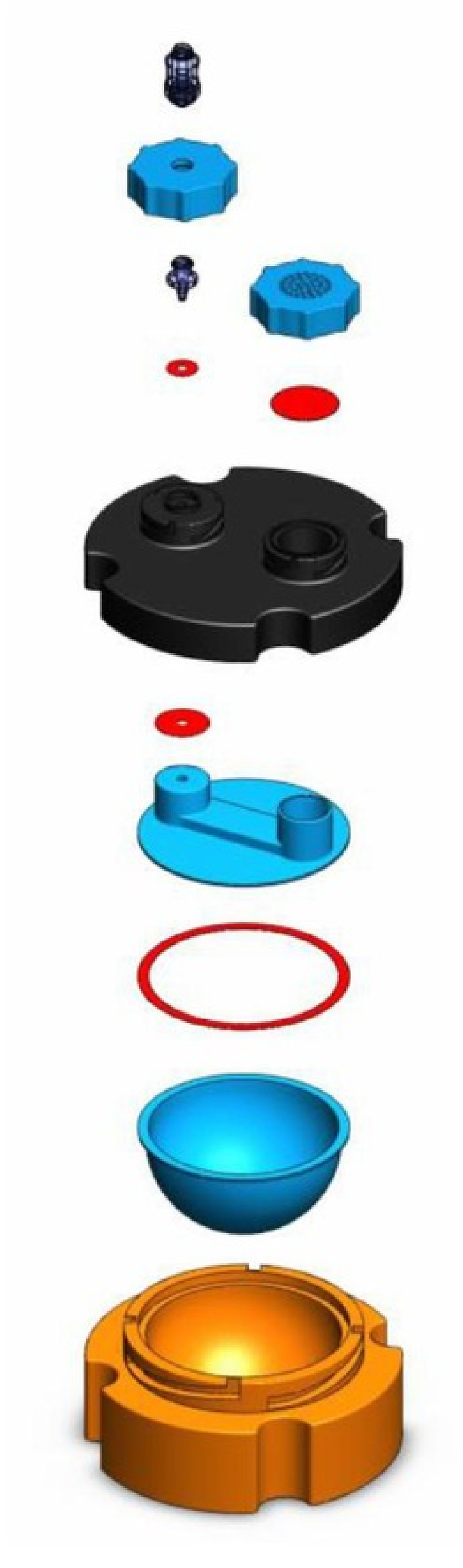
BIOREACTOR ISOMETRIC VIEWS

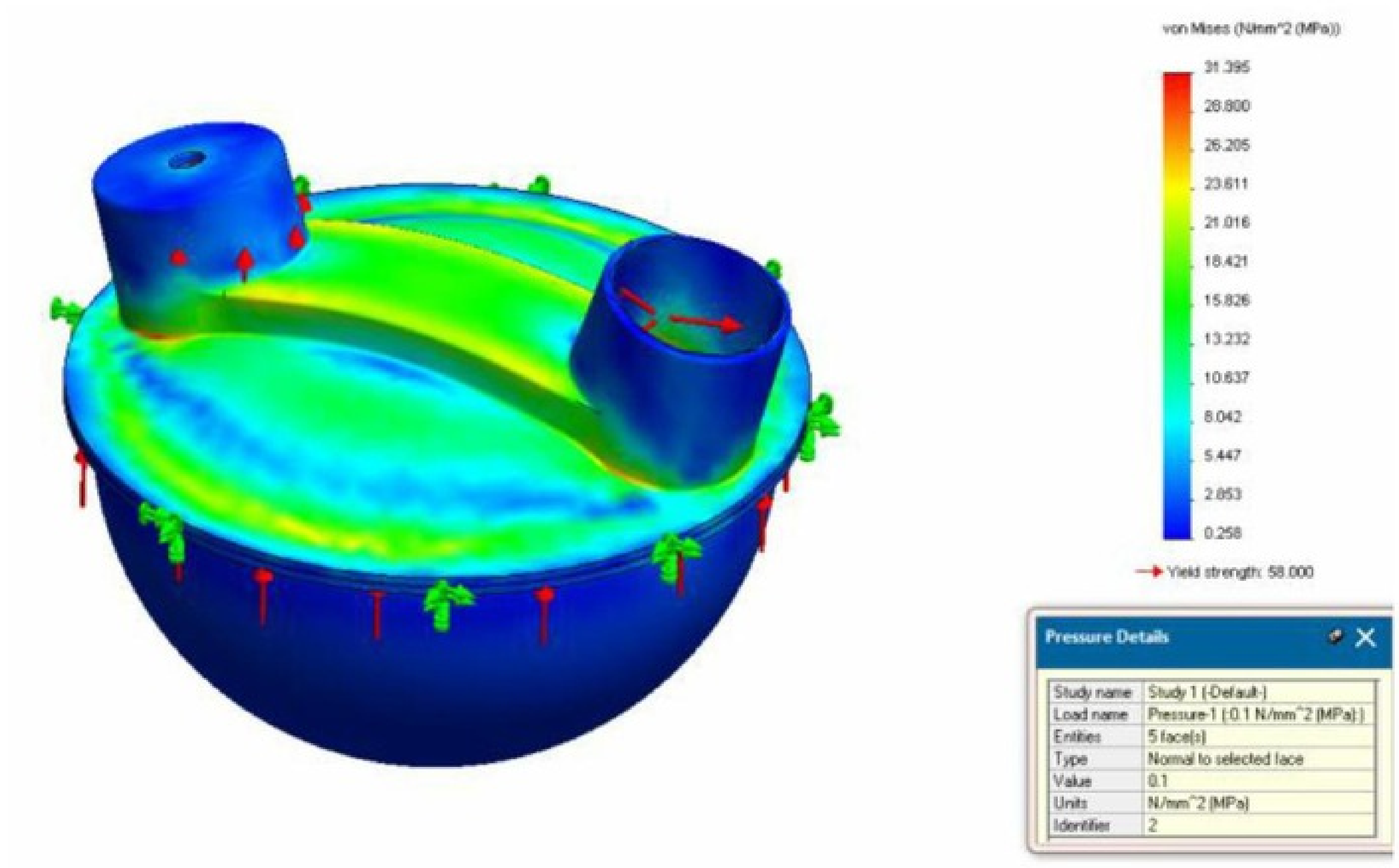


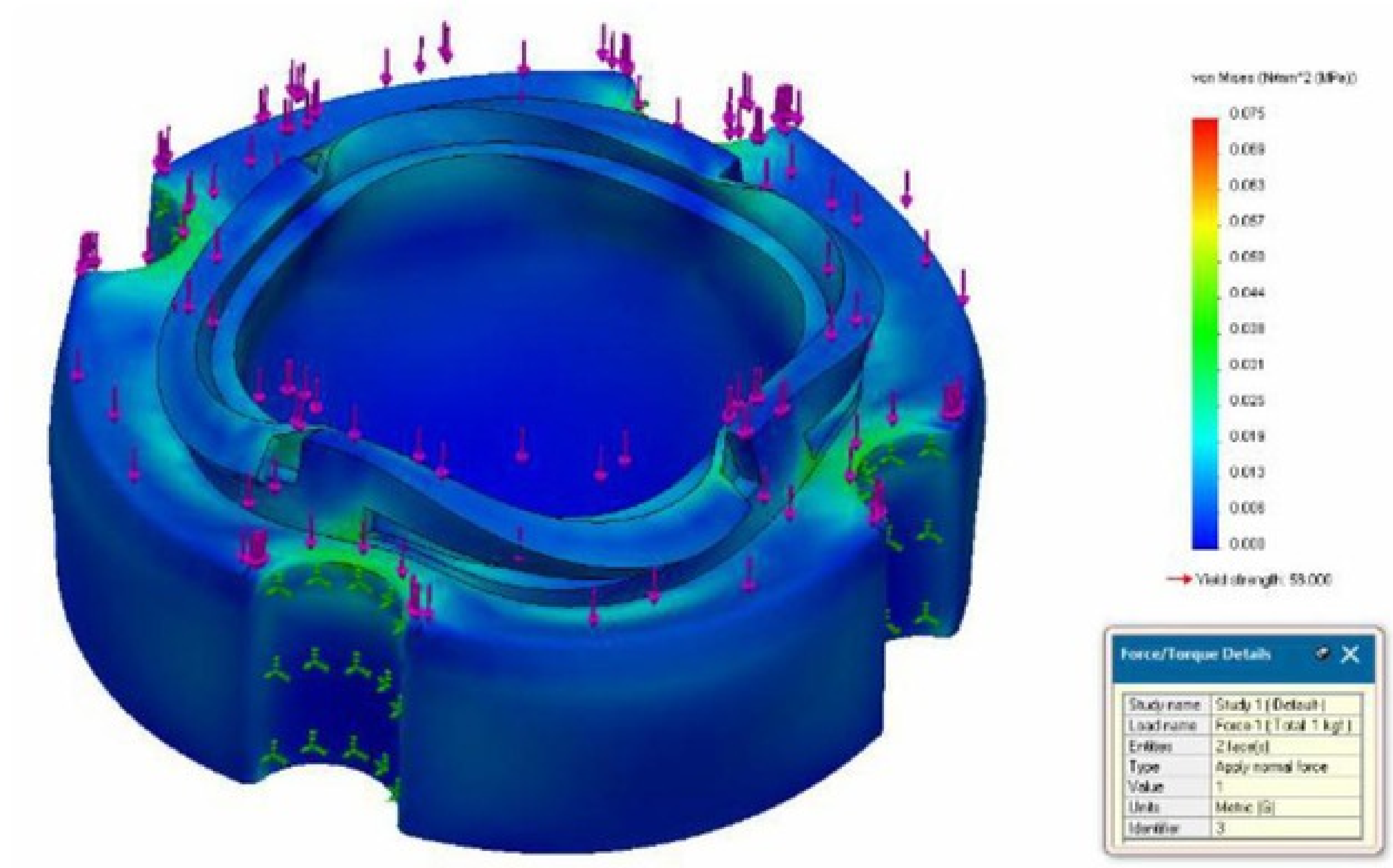












Overview of the Design Challenge

The NASA challenge focuses on the development of a 3D printable bioreactor capable of supporting food production in deep space environments. The bioreactor must be suitable for microbial culture growth, such as that required for fermentation-based food production, in a zero-gravity or microgravity setting. It must meet the requirements for food safety, space mission compatibility, and ease of manufacturing using advanced 3D printing technologies.

Importance of Sustainable Food Production in Space Missions

Deep space missions, such as those to Mars or beyond, will require sustainable, reliable methods for food production to support long-term crewed missions. Traditional food storage and resupply options are impractical due to the extended travel times and logistical constraints. Bioreactors capable of efficiently growing food on-demand using microbes or other biological systems are essential for ensuring crew health, providing critical nutrients, and minimizing waste.

Objective of the Bioreactor Design

The goal of this design is to create a 3D printable bioreactor that supports aerobic microbial growth, utilizes food-safe materials, is reusable, and is capable of recycling components for extended space missions. This design incorporates an efficient gas exchange system, modularity, and a robust sealing mechanism to ensure reliability, safety, and ease of operation.

Proposed Hemispherical-Shaped Culture Chamber Design Overview:

The proposed bioreactor features an efficient hemispherical-shaped culture chamber capable of holding liquid volumes ranging from 30 mL to 100 mL, excluding an additional 11 mL headspace, combined with this membrane, is sufficient for effective gas exchange, ensuring optimal microbial fermentation. The hemispherical shape optimizes fluid dynamics, nutrient distribution, and gas exchange while minimizing dead zones, ensuring uniform culture growth. To maintain aerobic conditions, the system includes an 18 mm diameter gas exchange port with a PTFE membrane, facilitating efficient oxygen intake and CO_2 removal. The reactor is reusable, modular, and specifically designed to meet NASA's stringent space mission requirements for food production.

DESCRIPTION

Bioreactor Structure

The bioreactor is designed as a modular, hemispherical-shaped culture chamber, providing uniform conditions for microbial growth. The hemispherical shape offers optimal surface area for nutrient exchange and gas diffusion, promoting efficient growth and minimizing potential contamination or pressure build-up. The chamber is made of PETG (Polyethylene Terephthalate Glycol), a high-performance polymer suitable for the harsh conditions of space. It is designed to be leak-proof and compatible with various interfaces for adding media, water, or extracting culture samples.

Material Selection (PETG and PTFE)

The bioreactor structure is primarily fabricated using 3D print **PETG (Polyethylene Terephthalate Glycol)**

- **Food-Safe:** Approved for food contact, making it ideal for bioreactor applications.
- **Mechanical Strength:** Offers good tensile strength, impact resistance, and durability for long-term use.
- **Thermal Properties:** Performs well at temperatures up to 80°C, with good heat resistance for most food production environments.
- **Chemical Resistance:** Resistant to a wide range of chemicals, suitable for use in food fermentation and bioreactor systems.
- **Clarity:** Offers transparency, allowing easy observation of the culture inside the bioreactor.
- **3D Printing Compatibility:** Easy to process with 3D printing, providing flexibility in manufacturing and customization.
- **Biocompatibility:** Food-grade material, ensuring safe and contamination-free use in biological environments.

PTFE (Polytetrafluoroethylene) is used for the gas exchange membrane and washers, ensuring controlled gas diffusion and leak-proof sealing.

Gas Exchange System

The gas exchange system is integrated into the bioreactor to facilitate the required aerobic microbial growth. A PTFE semi-permeable membrane, with a 0.45-micron pore size, is used for controlled gas exchange (oxygen intake and CO2 release). This ensures that the growth chamber maintains optimal aerobic conditions while preventing contamination or pressurization. The membrane allows the passage of gases while maintaining the integrity of the culture chamber.

Leak-Proof Interfaces and Sealing Mechanisms

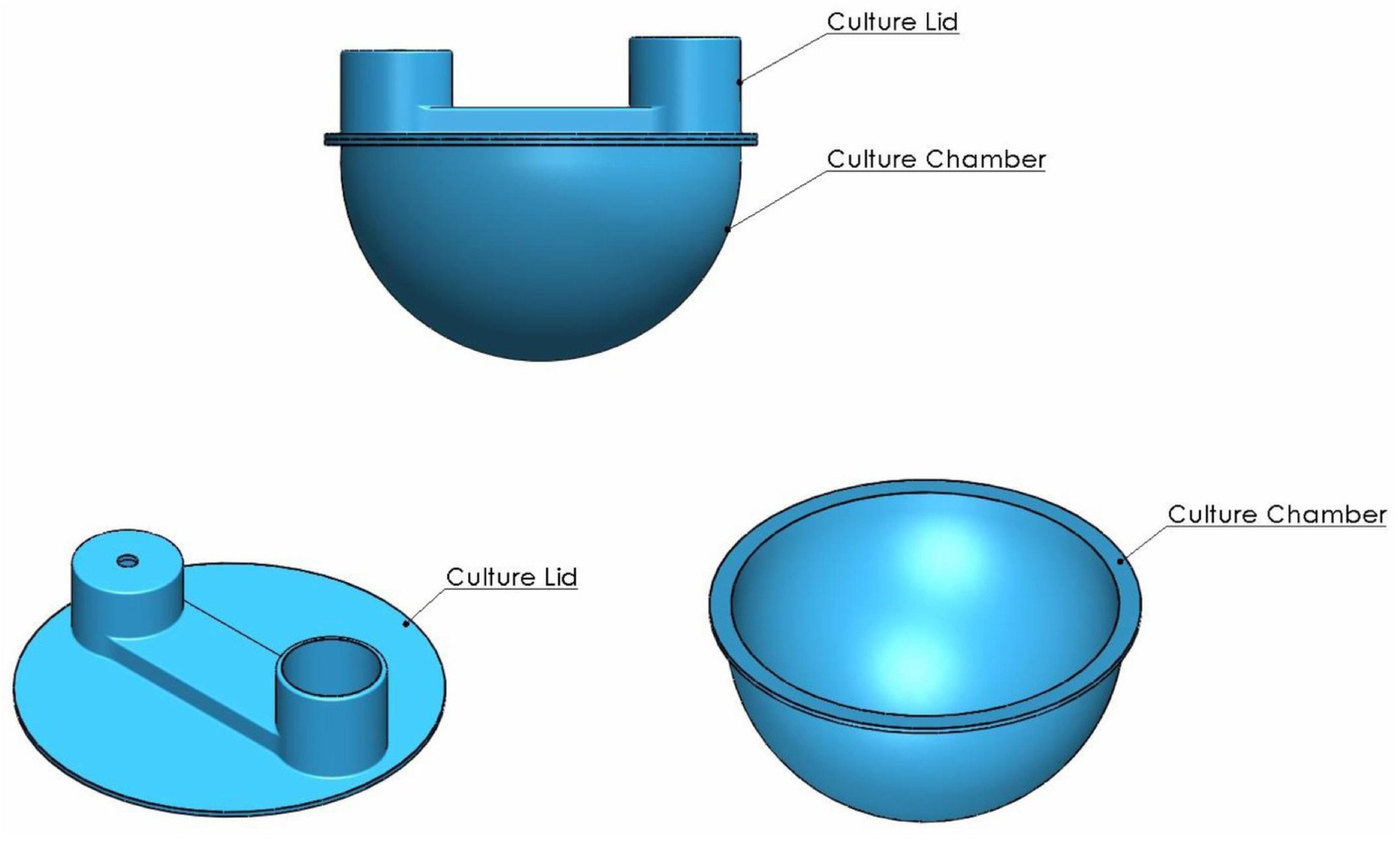
The bioreactor is equipped with luer lock-compatible ports to allow the safe introduction of media, water, and organisms, as well as the extraction of culture samples. PTFE washers, made of semi-permeable PTFE material with 0.45-micron pores, are used to ensure leak-proof sealing around these ports. The PTFE washers provide robust, reliable sealing while allowing the necessary gas exchange. This sealing mechanism ensures that the bioreactor remains sterile and contamination-free during use.

Modular Design and Reusability

The bioreactor is designed for easy disassembly and reassembly, promoting reusability in deep space missions. Components such as the culture chamber and lid are made from materials compatible with 3D printing, enabling the creation of new parts as needed, either on-demand or through recycling of older components. The modular design also allows for easy customization and adaptability to different space mission requirements.

Culture Chamber and Lid Recycling

The **culture chamber** and its **lid** are designed with recycling in mind. These components can be prefabricated using 3D printing, allowing for on-demand manufacturing. The materials used for 3D printing are selected for their durability, sterilization capabilities, and compatibility with microbial growth. Over time, worn or damaged components can be recycled and replaced, ensuring long-term functionality and sustainability.



HEMISPHERE-SHAPED CULTURE CHAMBER FOR OPTIMAL EFFICIENCY

The **hemisphere design** chosen for the **bioreactor project** is based on its unique geometric properties that offer several key advantages:

1. **Optimization of Fluid Flow**: The spherical shape minimizes resistance to fluid dynamics, promoting smooth and efficient circulation of gases and liquids, and reducing the risk of dead zones.

2. **Maximized Surface Area**: The design increases the surface area for microbial activity, ensuring enhanced biological processes.

3. **Effective Gas Exchange**: The hemispherical top provides ample surface area for the exchange of oxygen and carbon dioxide, crucial for aerobic reactions.

4. **Uniform Temperature and Nutrient Distribution**: The shape supports better heat retention and distribution, ensuring stable conditions for microbial growth.

5. **Structural Stability**: The design can withstand internal pressure fluctuations commonly found in bioreactors.

6. **Scalability and Space Optimization**: The compact and efficient shape makes it ideal for industrial-scale applications, ensuring easy maintenance and durability.

Overall, the hemisphere design **enhances the efficiency** and **sustainability** of the bioreactor's operation.

TECHNICAL SPECIFICATIONS

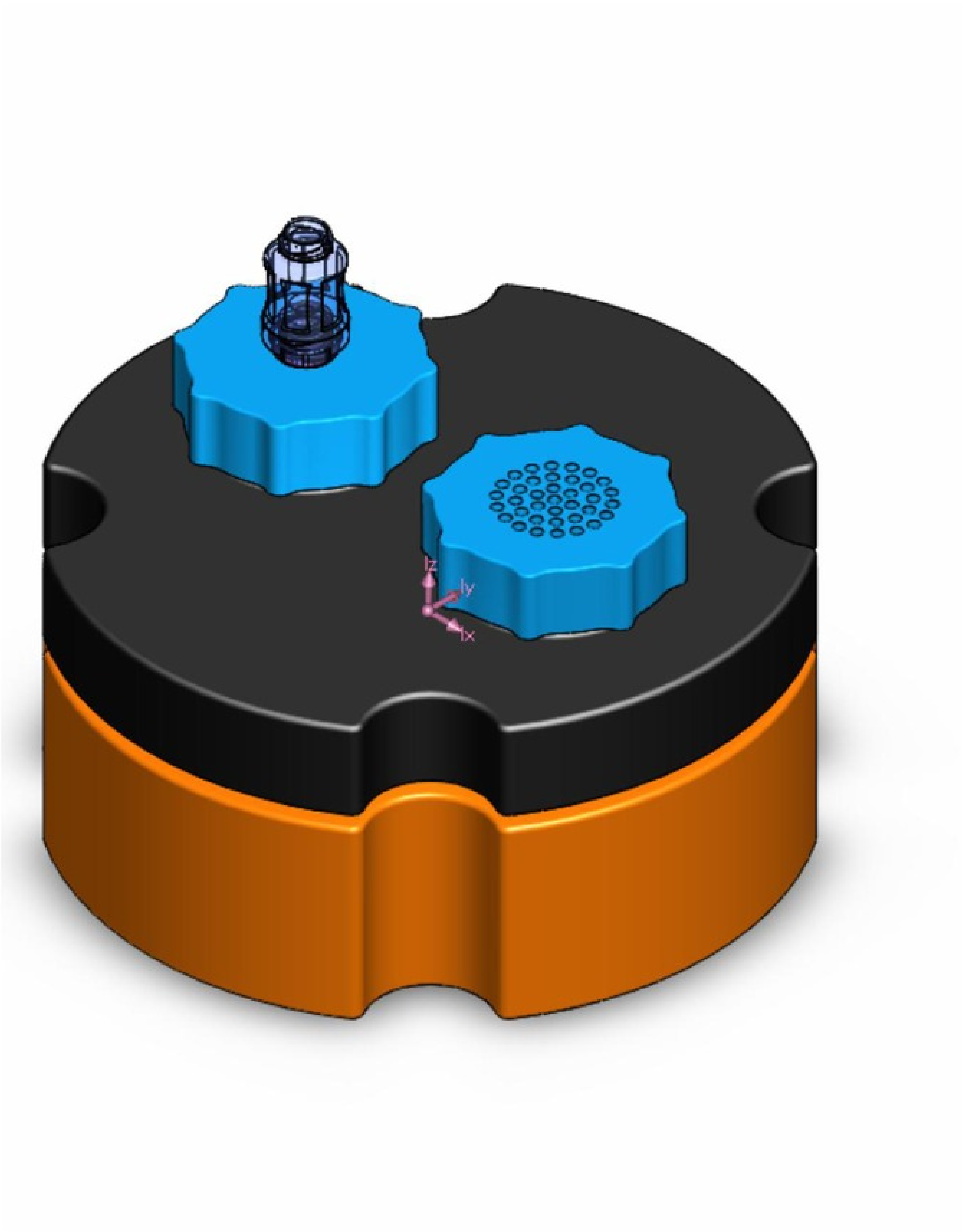
Material Details:

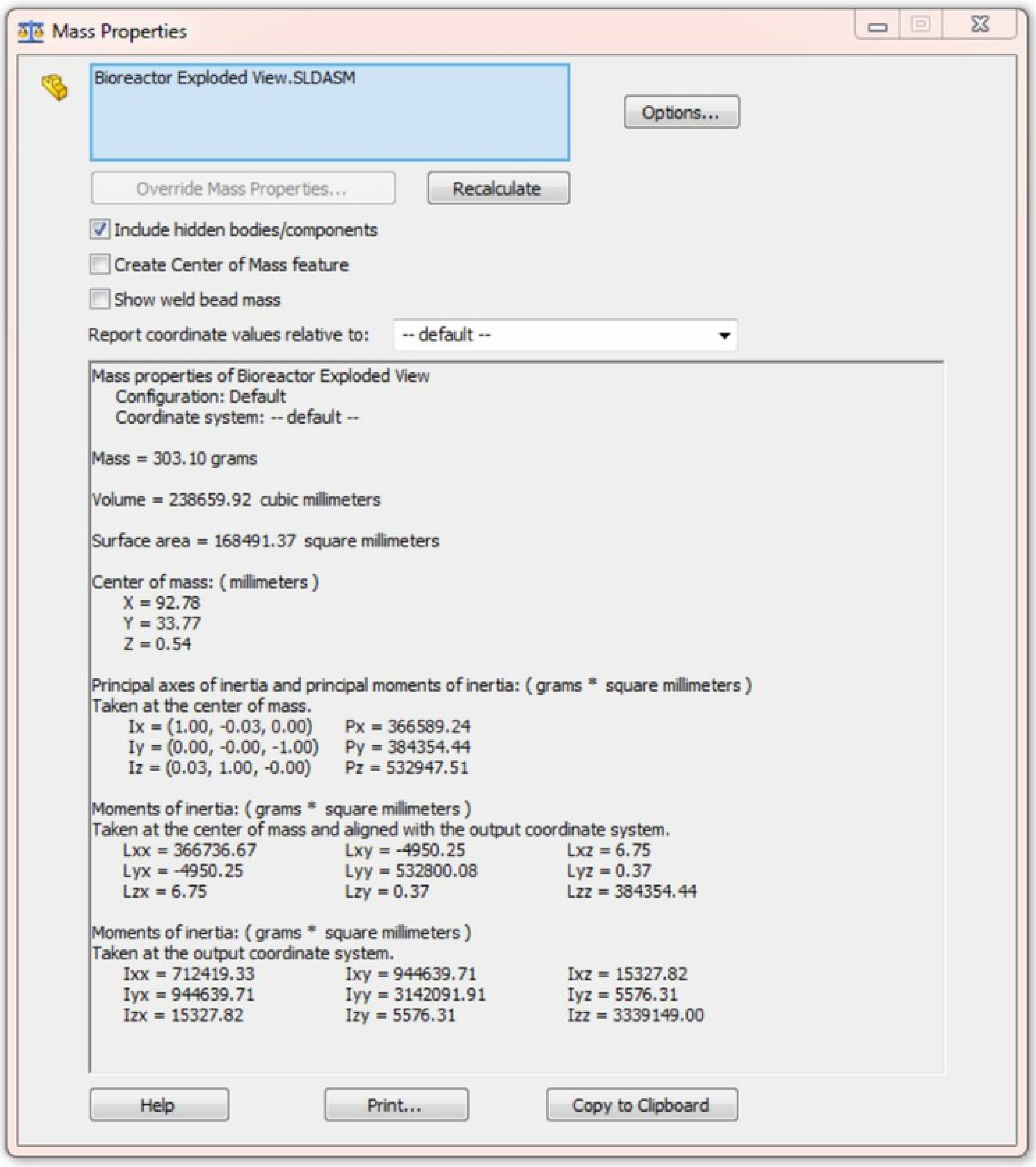
Material and Mechanical Properties:

- 3D Printing Material : PETG (Polyethylene Terephthalate Glycol)
- PETG Tensile Strength (YS) : 58 N/mm²
- Withstand Working Temperature: 80°C
- Density : 1.27 g/cm³
- pH range : 4 to 8 (suitable for food and fermentation environments)
- PTFE Membrane Pore Size : 0.45 Micron

Bioreactor Weight:

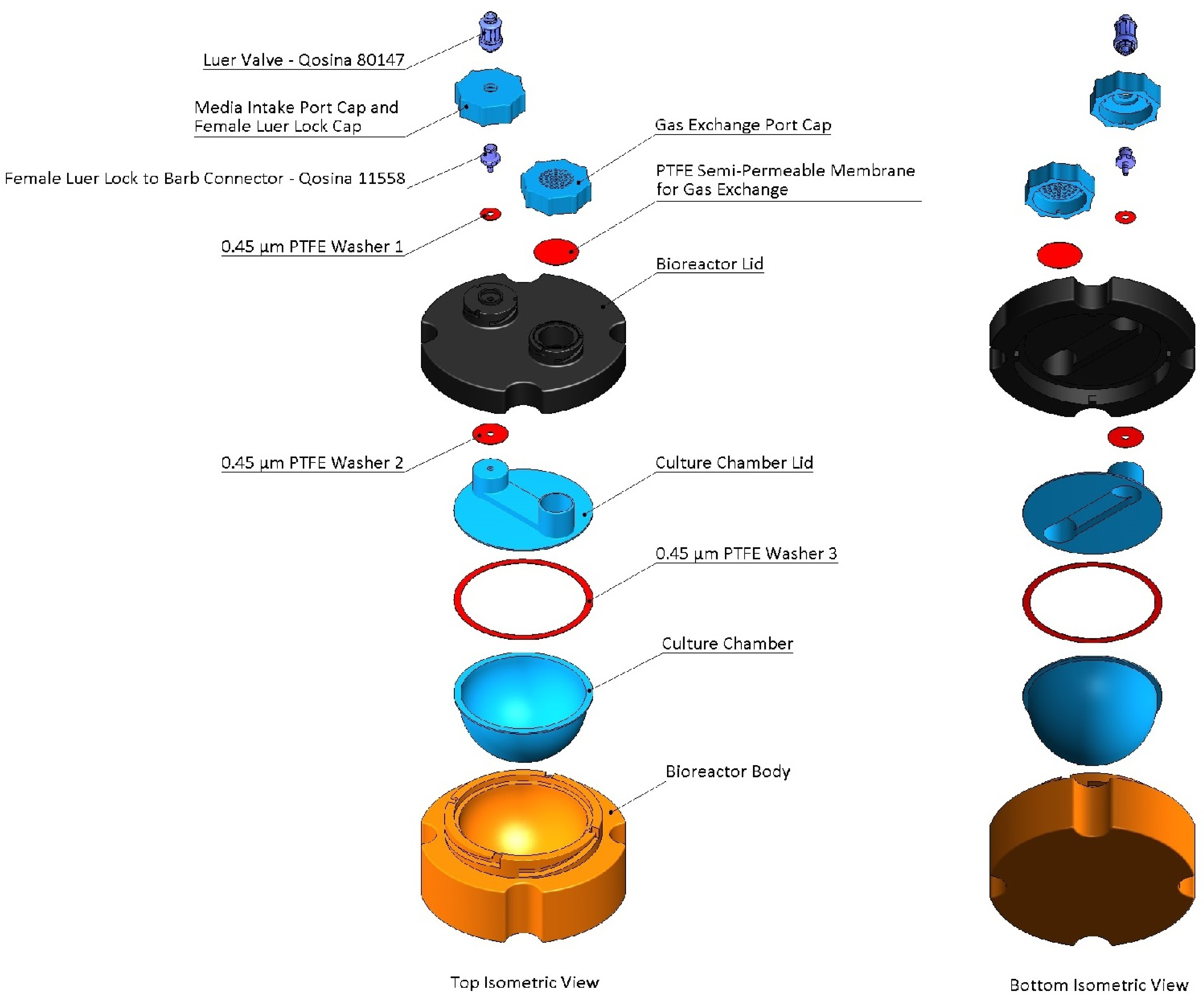
303 grams





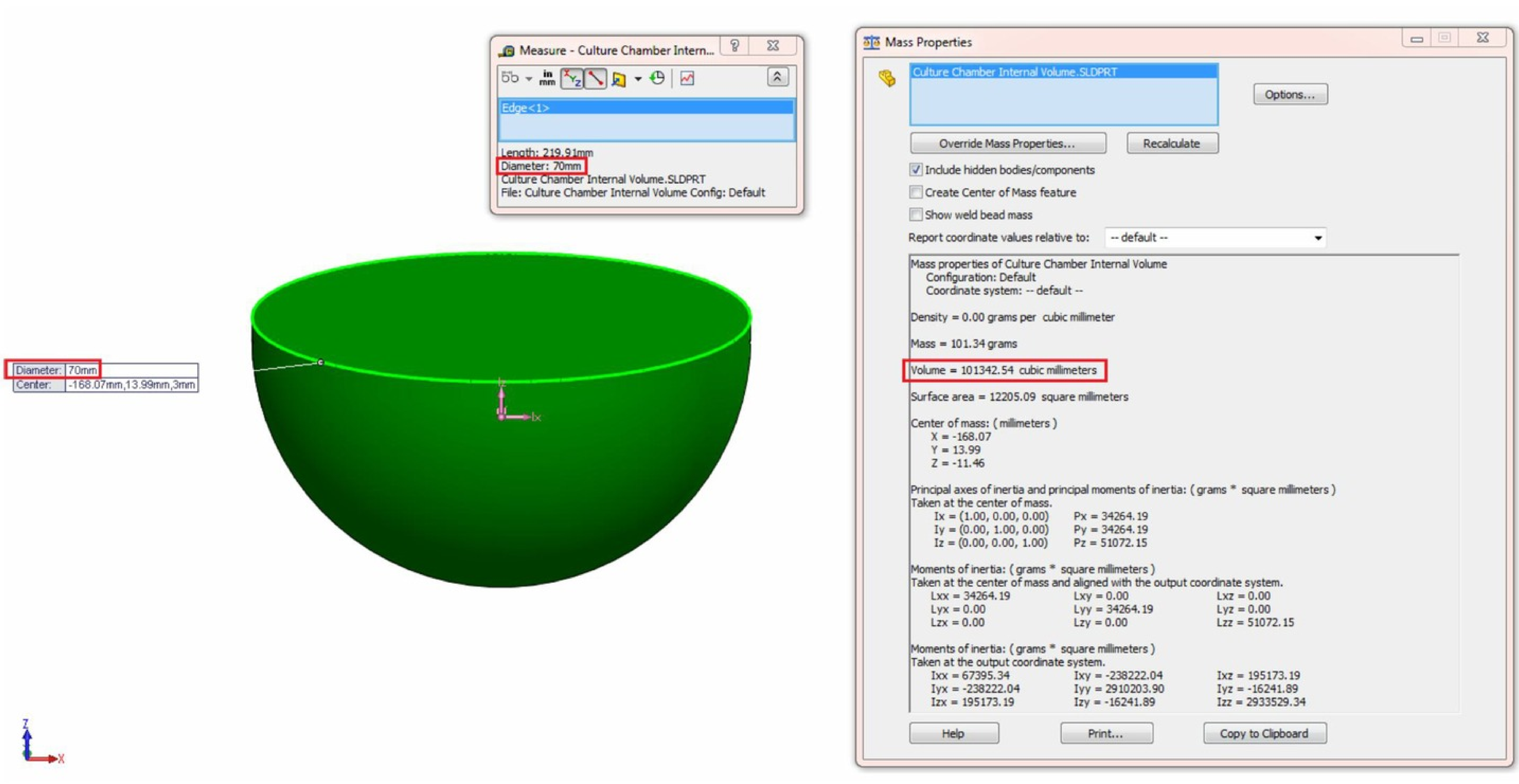
Bioreactor Major Parts and Weight:

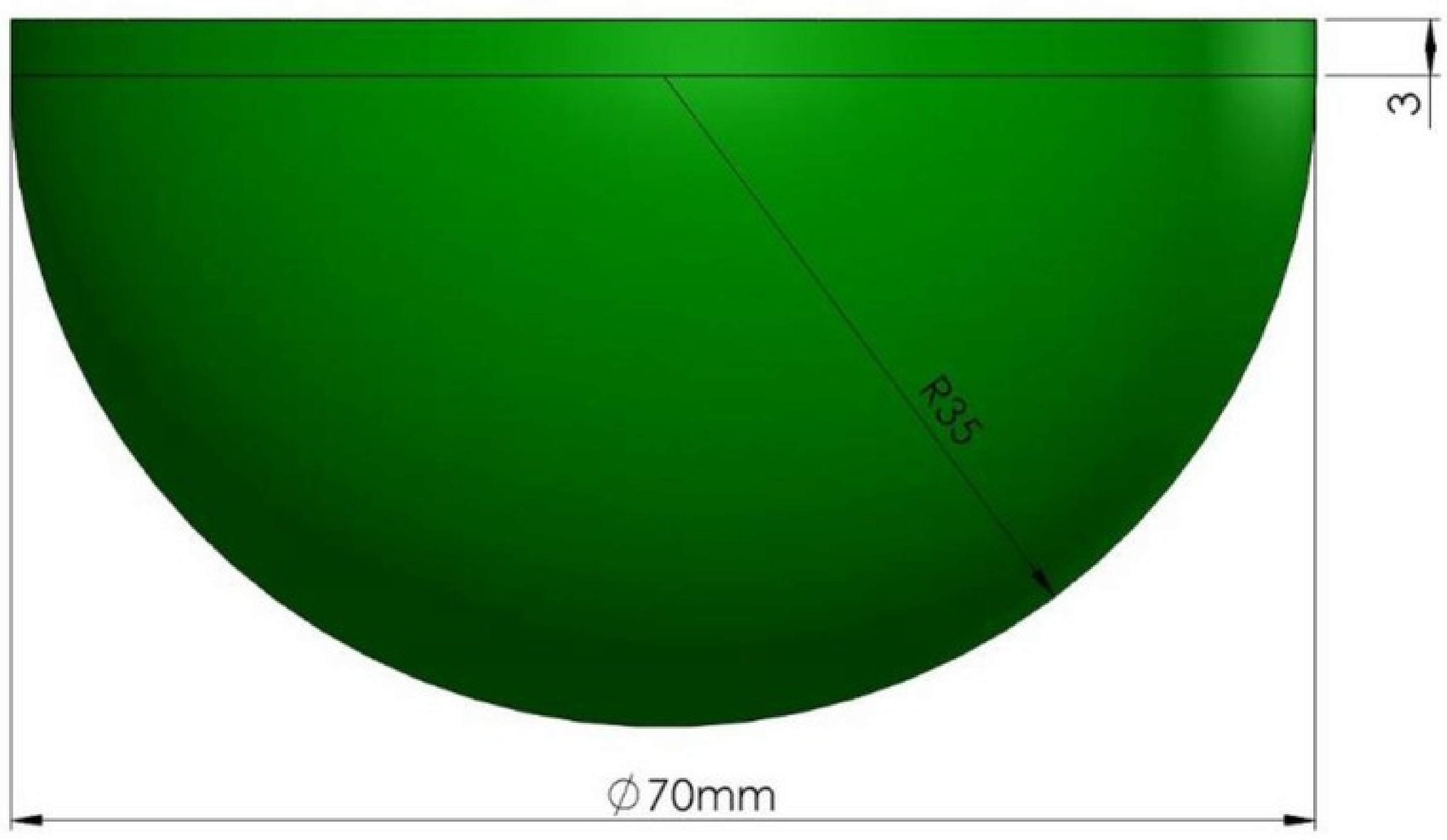
1. Bioreactor Body (158 grams)
2. Bioreactor Lid (103 grams)
3. Culture Chamber (12 grams)
4. Culture Chamber Lid (8.4 grams)
5. Gas Exchange Port Cap (8.1 grams)
6. Media Intake Port Cap (9.6 grams)
7. Luer Valve – Qosina 80147
8. Luer Lock Female Connector – Qosina 11558
9. PTFE Semi-Permeable Membrane Pore Size 0.45 Micron
10. PTFE Membrane Washer



Culture Chamber Internal Volume:

100ml or 100000 mm³





The total volume of the culture chamber is the combination of a hemisphere and a cylinder.

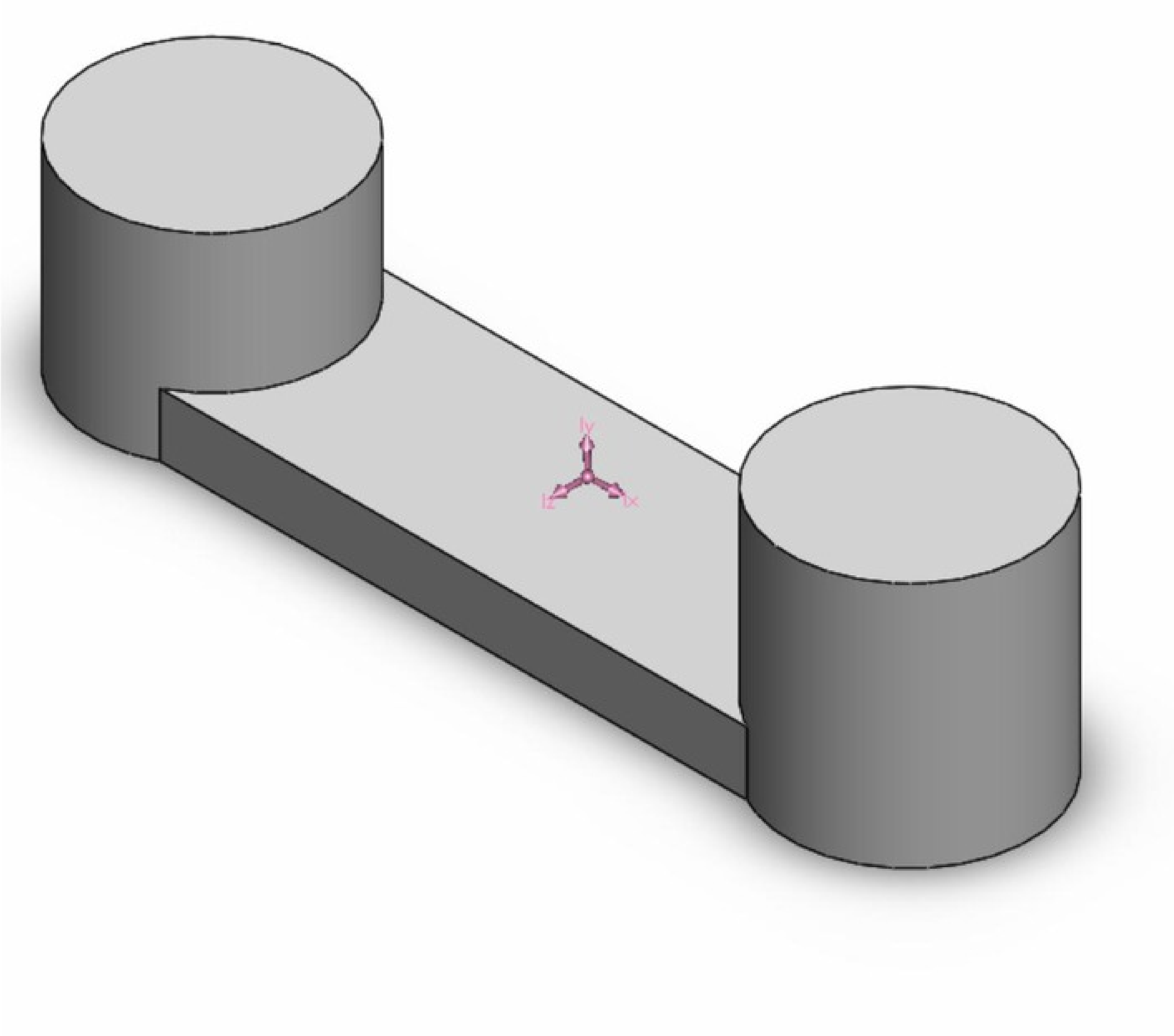
- **Hemisphere**:
  - Diameter: 70 mm
  - Volume: 89,759 mm³

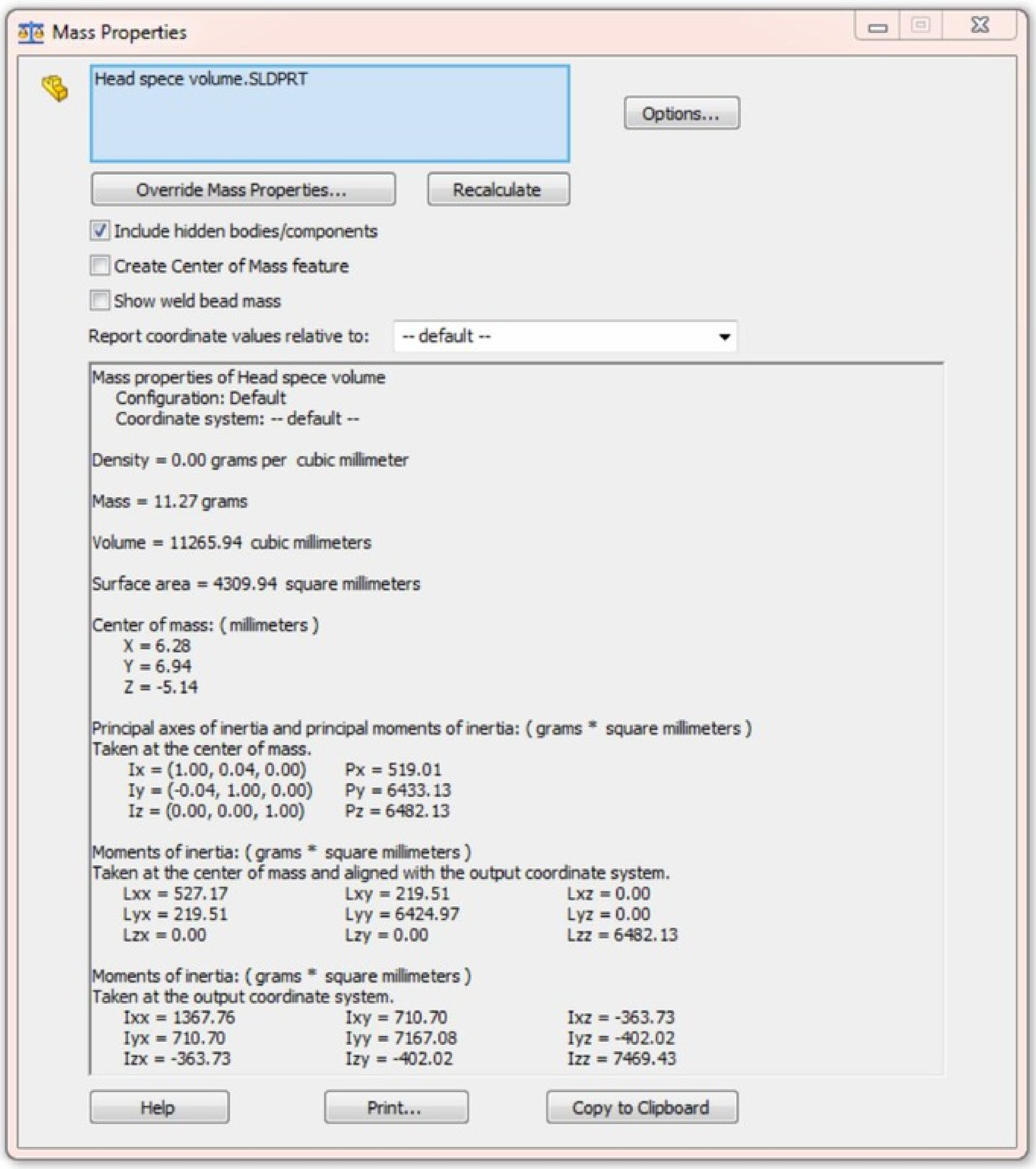
- **Cylinder**:
  - Diameter: 70 mm
  - Height: 3 mm
  - Volume: 11,549 mm³

Total Volume (Hemisphere + Cylinder): **101,308 mm³**

Headspace Volume:

11ml or 11265 mm³

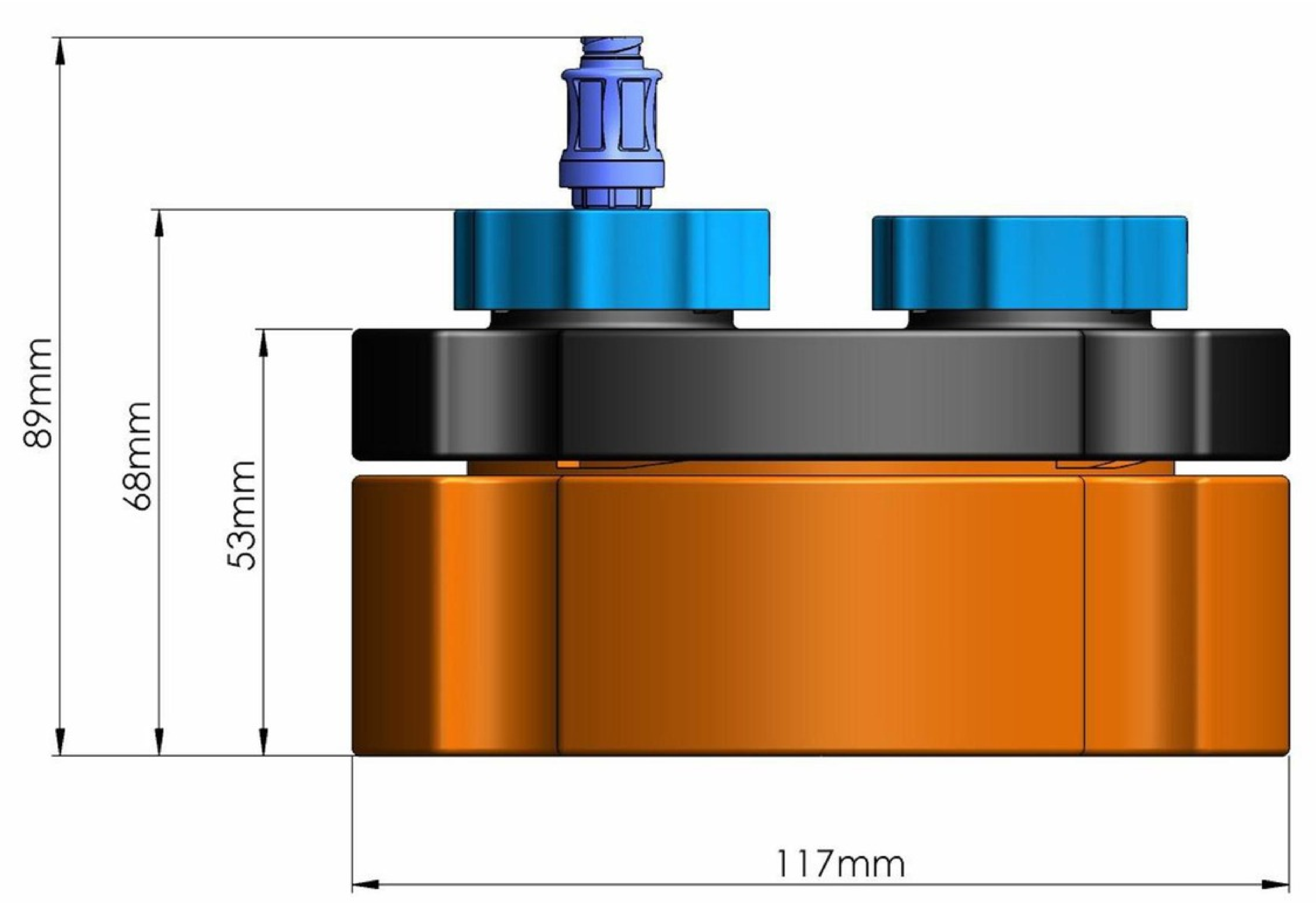




Dimension:

Height: 89mm

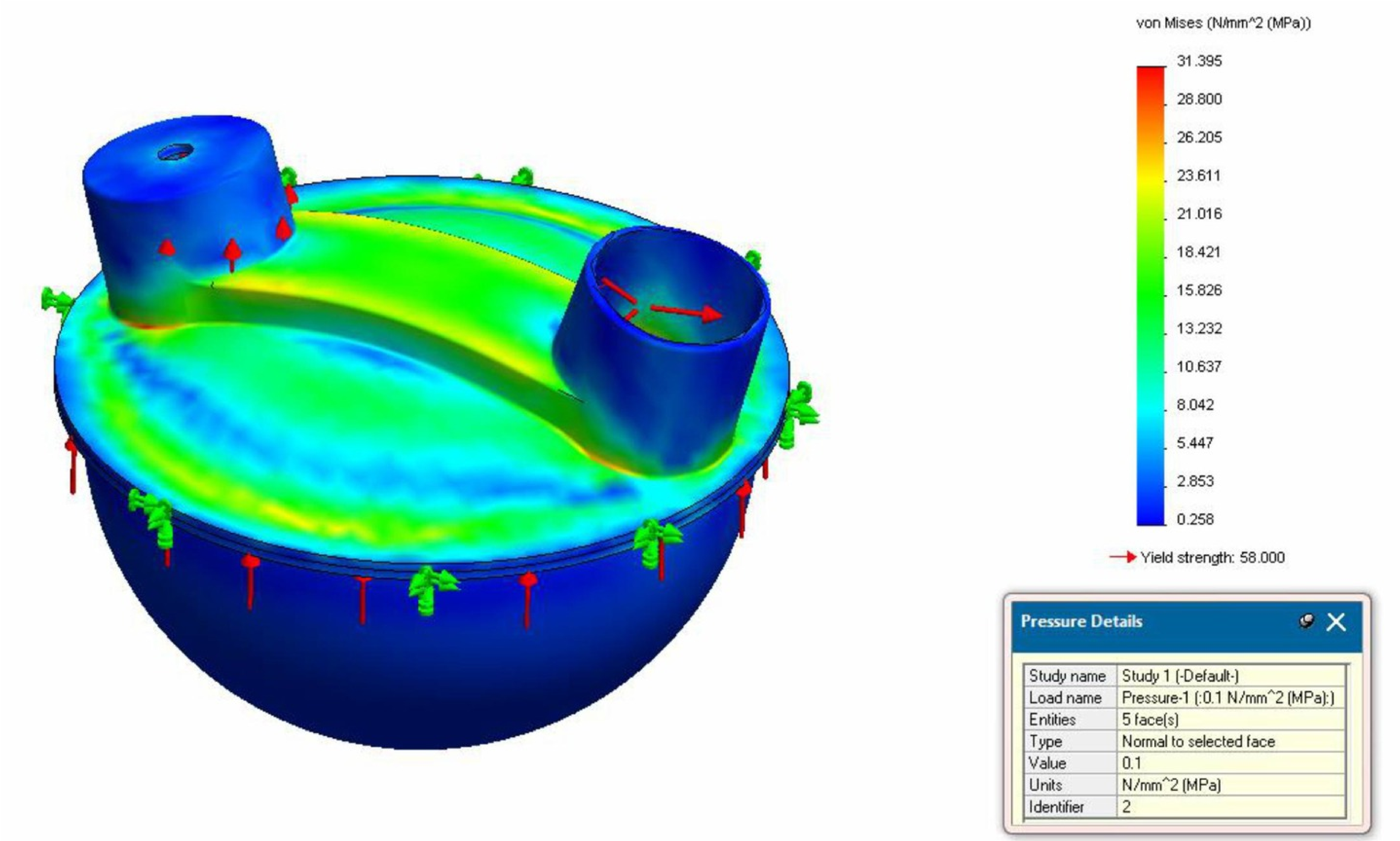
Diameter: 117mm



Gas Pressure in the Culture Chamber

The culture chamber operates under aerobic conditions with a 100 mL culture volume and 11 mL of headspace. A gas exchange port equipped with a PTFE membrane ensures efficient removal of CO_2 produced during microbial metabolism, preventing significant pressure buildup within the chamber. The PTFE membrane allows for the exchange of gases, maintaining a stable environment by venting excess CO_2 while facilitating oxygen intake, which is crucial for aerobic respiration.

Due to the gas venting mechanism, the pressure inside the culture chamber remains close to atmospheric levels, typically around **0.1 MPa (0.1 N/mm²)**, which minimizes stress on the chamber structure. As the microorganisms metabolize, CO_2 is produced but immediately vented through the PTFE membrane, preventing any significant pressure increase. This design ensures the culture chamber maintains near-atmospheric pressure, contributing to a stable and controlled growth environment while avoiding the pressure-related risks typically associated with sealed systems.



Internal Pressure Due To CO2 Gas: 0.1N/mm²

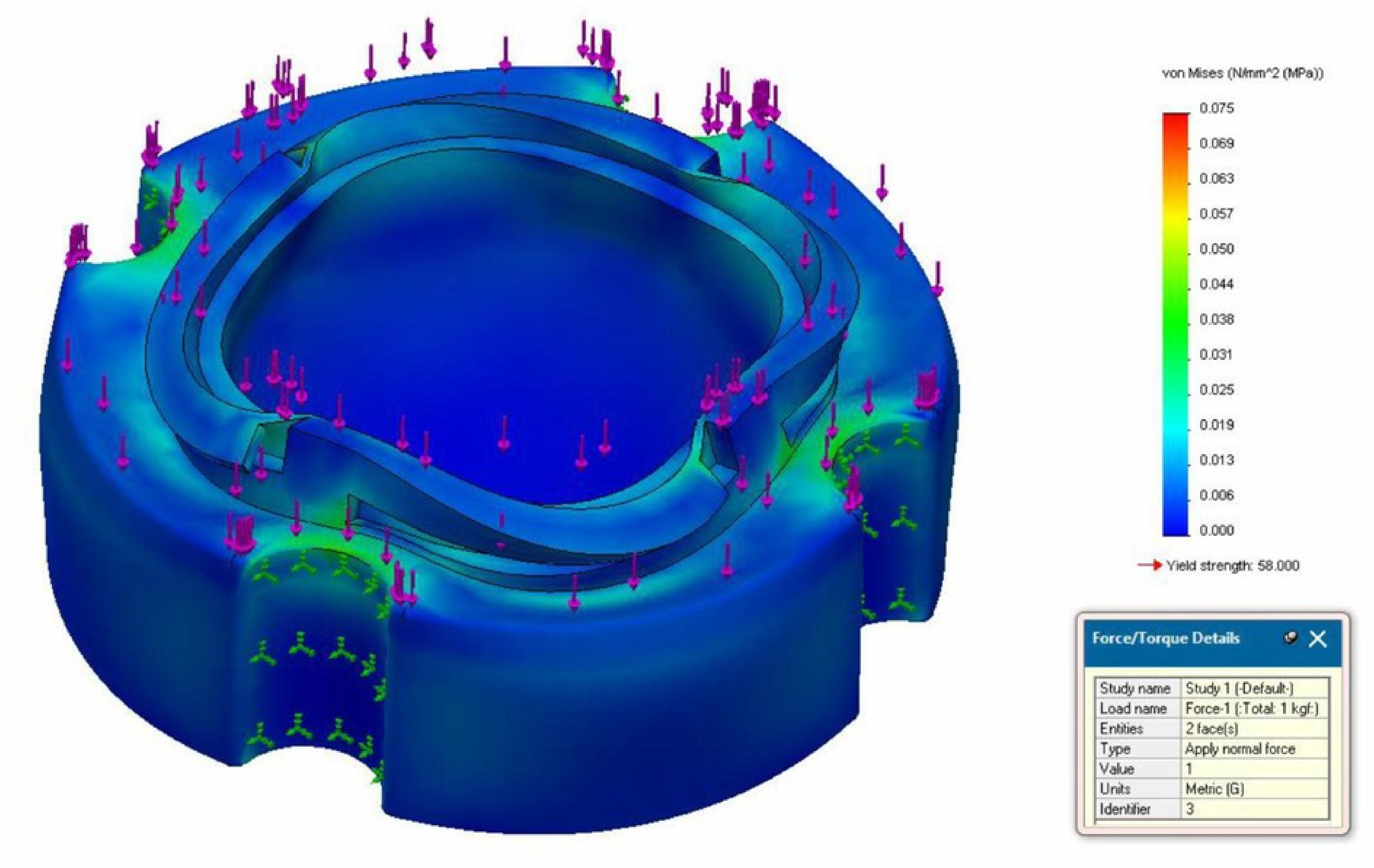
Von Mises Stress: 31.39 N/mm²

Factor of Safety: 1.84

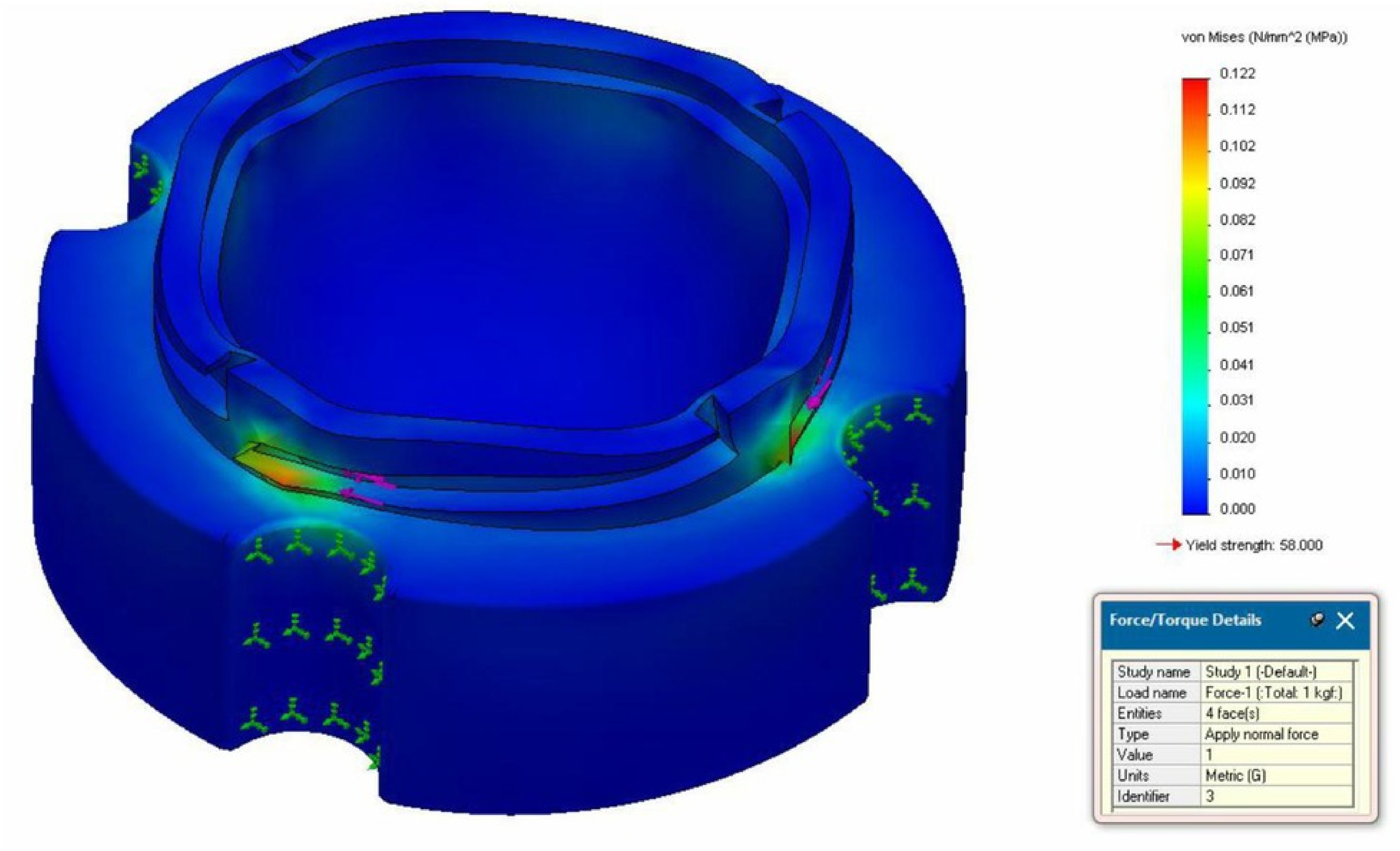
Culture Chamber Wall Thickness: 1mm

STRESS ANALYSIS OF BIOREACTOR BODY

Vertical Load: 1Kg
Von Mises Stress: 0.075
Factor Of Safety: 773



Lateral Load: 1Kg
Von Mises Stress: 0.122
Factor Of Safety: 475



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PTFE Membrane

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THANK YOU