# 3D-Printed Satellite Brackets

Subjects: Materials Science, Composites

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Brackets are the load-bearing components in a satellite. The current age of satellites comprises specific brackets that set out as a link between the bodies of the satellite, reflector parts, and feeder facilities mounted at its upper end. Brackets are used to carry loads of the satellite body frame, supporting elements, batteries, and electronic goods. Additive Manufacturing (AM) is a process in which a 3D solid object is built by adding the material layer-over-layer. The success of making the product using AM technology requires greater experience in Design for Additive Manufacturing (DFAM) which makes use of the design of freedom of AM. Owing to the various advantages of AM and DFAM, it is easy to create high strength-to-weight ratio products. This is an important contribution to aerospace industries in meeting the unabated demand for lightweight and strong structural applications.

additive manufacturing (AM) | Selective Laser Melting (SLM) | bracket | Ti-based materials | satellite | DFAM

## 1. Introduction

Brackets are the important components of space vehicles. Brackets serve the purpose of carrying loads and supporting the structures. Mounting brackets are found in large numbers in aerospace vehicles and satellites. Due to their lightweight and thermal conductivity, these are generally used in satellites. Various brackets are used to carry loads of electronic goods, cameras, batteries, antennas, and various satellite components. One of the applications of a bracket used on the outer surface of the satellite is shown in **Figure 1**. Depending on the application, the shapes of the mounting brackets can be hanging type or supporting type [1]. On the other hand, a suitable, sturdy bracket or stand is necessary for the proper functioning of the satellite dish [2]. A sturdy wall bracket prevents the structure from being damaged. The usage of a suitable bracket has advantages like ease of assembly, optimal reception, and easy alignment in the required direction. Although a sturdy and strong bracket is required for the applications, the weight of the bracket can be a major concern, especially in the case of aerospace and satellite applications. A high strength-to-weight ratio is essential as every kilogram carried into space will add to the total cost of the flight depending on the carrier system and the orbit to be reached. Weight minimization in every aspect adds great value to the design of bracket structures used in space vehicles. Weight reduction of the part can be addressed in three ways: material selection, material design, and material processing. The favorable choice of materials for making satellite and aircraft brackets are the advanced functional materials like Al-based, Ti-based, stainless steel, NiTi-based and composite materials. The material design is considered depending on the loading conditions and also on the structure, and thus, structure optimization of the part should is of great importance. Finally, the choice of material processing technology has a vital role to play as it decides the total cost of the project. For a finalized choice of material, the focus would be on the integration of structure optimization and processing of the material chosen. The resultant complex geometries are extremely difficult to process by conventional manufacturing techniques. Brackets constructed by conventional metal cutting do not fulfill the desire of achieving a high strength-to-weight ratio in parts produced because conventional metal cutting may not optimize the component's weight and stress factor [3]. Hence, there arises a need for efficient processing techniques that can accommodate complex geometries in addition to structural optimization. One of the best ways to achieve this is through Additive Manufacturing (AM). Owing to the design freedom and also the capability of processing complex geometries, the world is seeing greater interest in the processing of mounting brackets through additive manufacturing technologies [4].

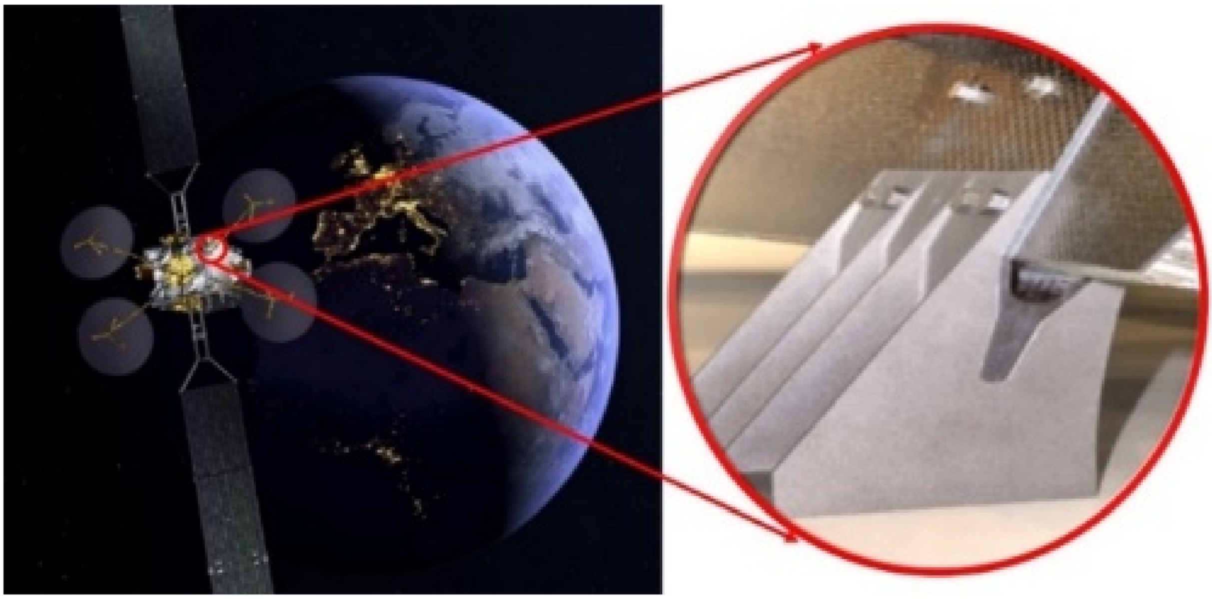

**Figure 1.** AM-made titanium brackets are used in satellites [5].

Additive Manufacturing (AM) is a process in which a 3D solid object is built by adding the material layer-over-layer [6][7][8]. The schematic of the AM steps is shown in **Figure 2**. A sliced 3D CAD model is directly converted into a solid model on the building platform of the machine. Hence, the process is also called 3D printing. During the making of the product, the material is added and consolidated into solid-phase layer-by-layer in the height direction. Hence the name layered manufacturing process. The most attractive aspect of AM is its ability to process complex geometries easily which is known as a solid free-form manufacturing process [9].

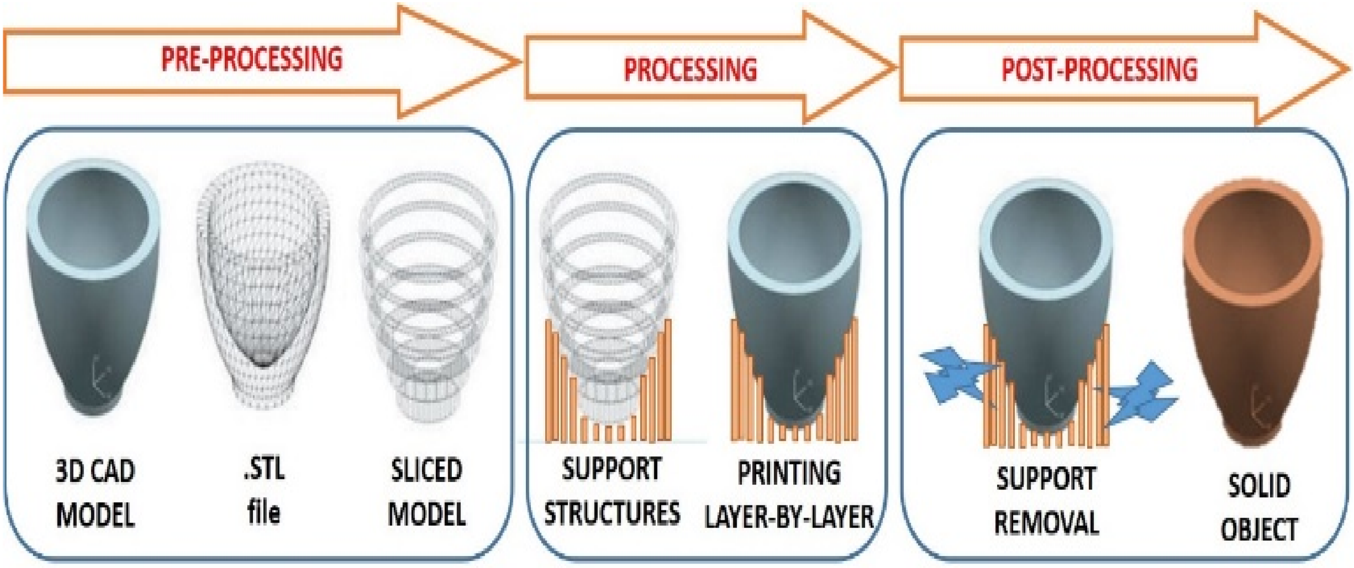


**Figure 2.** Schematic of AM process flow diagram.

AM is a recent technology and the alternatives to AM are the traditional manufacturing process that includes Subtractive Manufacturing (SM) and Formative Manufacturing. The SM uses a material removal approach, In contrast to AM, the part in SM is prepared out of the solid material block by removing the part of material using material removal processes like cutting, grinding, planing, shaping, drilling, milling, and slotting, etc. The AM technology was first attempted in 1981 by a Japanese Hideo Kodama for processing a photo-hardening polymer. Later in 1983, Charles W. Hull printed a teacup using the Stereolithography Apparatus SLA-1. In the initial days, the technology was imagined for making the prototypes of the products during the product development [10]. It was a solution for quickly making the products which otherwise consumed a huge amount of time and eventually added huge product development costs. With this technology, prototypes were quickly prepared and it was known as Rapid prototyping. The technology was evolving and attempts were made to process metals, ceramics, and other materials [11]. After about 12 years, the first powder bed has been developed by MIT using inkjet print heads and the term 3D printing began to be used [12]. In 1997, AeroMat produced a Metal 3D printer that used a laser to fuse Titanium powders, the process was called Laser Additive Manufacturing (LAM). As of today, the technology is matured to a greater extent and the world has witnessed the processing of almost all kinds of materials viz., polymers, metals and alloys, ceramics, composites, concrete, chocolates, sand, bio-materials, etc., using this technology. AM offers several advantages over traditional manufacturing technologies. The various advantages are explained below.

(I) Omission of smaller part assembly: During the designing procedure, various smaller parts can be replaced by a single part which allows researchers to print the complete part at once. Whereas in traditional manufacturing; first, all the components are manufactured individually and then assembled to create the final part [13].

(II) Minimization of Material waste: Advanced software like topology optimization calculates the best shape for a part and removes unnecessary material without compromising the structural integrity. This helps engineers to design and produce a lightweight part by advancing the material distribution, which leads to minimizing material waste. For example, Siemens uses generative design software in 3D printing to develop its gas turbine blades. General Motors also uses 3D printing with generative design and topology optimization software, and it aims to reduce the weight of a vehicle by exploring various options for material distribution within a component [14].

(III) Can easily create highly complex parts: AM overcomes most of the traditional manufacturing limitations to create almost every complex part with enhanced functionality. For example, the cooling channel of injection moulds in the traditional manufacturing method is mostly straight, which leads to slow and inconsistent cooling of a moulded part. The cooling channel in 3D printing is more advanced and can be re-designed according to the requirement, which provides a more homogeneous heat transfer that results in enhanced cooling characteristics [15].

(IV) Flexibility of material choice: AM process can print almost using any material available; this opens up the possibilities for material innovation. Engineers can explore the limitless option for the better properties of the product. For example, 3D printing of high-performance thermoplastics can replace some metal parts, and it is also low cost and lightweight [16].

(V) Minimized support structure: Like material innovation, 3D printing also opens up the possibility for unique support structure design. By choosing the best part orientation, the post-processing time and cost can be reduced. Though the supporting system can’t be removed completely, it is very much necessary that a minimum support system should be provided to the 3D model as it can reduce cost prominently. An optimized number of support systems should be provided while designing [17].

(VI) Lightweight product: Topology optimization provides the advantage to design and manufacture a product for a specific function, and with a made-to-measure feature, for example, unnecessary materials are removed by advanced design and complicated mathematical calculation; therefore, the product part is lightweight and cost is minimized [18].

(VII)Multimaterial Products can be manufactured: Another crucial advantage of 3D printing is multiple materials can be simultaneously printed into a solid. This solves one of the vital limitations of the conventional manufacturing method [19].

Although AM is evolving gradually, technology has gained tremendous interest in the last decade. As a part of industrial revolution 4.0, digital manufacturing involving AM appears to be the leading technology for manufacturing products on customized and mass levels. The current world is witnessing a revamp in manufacturing industries due to the implementation of AM [20]. The choice of suitable AM technique for making products mainly depends on (a) the material to be processed, (b) the size and shape of the product, and (c) the end characteristics of the product [21]. The success of making the product using AM technology requires greater experience in Design for Additive Manufacturing (DFAM) which makes use of the design of freedom of AM. DFAM mainly aims to optimize the product design by decreasing the total amount of support structures and the support material; decreasing the total mass of the product by incorporating lattice structures, print consolidation, and part orientation, eventually decreasing the total print time and total cost. Hence, the implementation of DFAM plays a vital role in making products using AM. Owing to the various advantages of AM and DFAM, it is easy to create high strength-to-weight ratio products. This is an important contribution to aerospace industries in meeting the unabated demand for lightweight and strong structural applications. Again, the applications of AM are spread on a large spectrum of industrial domains that include, automotive, healthcare, electronics, durable goods, cosmetics, architecture, etc.

## 2. Materials Used in Brackets

Material selection is a critical aspect of the aerospace component and system design cycle. It affects many of the performance factors of aircraft such as payload, flight performance, safety, reliability, structural efficiency, energy consumption, disability, lifecycle cost, and recyclability. The material for aerospace structural applications must consist of mechanical, physical, and chemical properties, such as rigidity, high strength, damage resistance, fatigue durability, high thermal stability, low density, excessive corrosion, and oxidation resistance. The material selection depends on various operating conditions like loading conditions, temperature, moisture, corrosion, noise, etc., of that particular component or system. For the brackets used in the wings of an aircraft that sustains bending during service along with torsion, vibration, tension, and fatigue, a material possessing high tensile and compressive strength, stiffness, vibration modes, and buckling strength will be suitable. Similarly, the combustion chamber always interacts with the fluid which is subjected to high temperature and pressure. So, the material for this should have oxidation resistance and principally thermal properties [22]. Despite matching the primary service requirements, the improvement of structural capability in aerospace structural design becomes remarkably important because the function of lightweight arrangement provides an exponential boost in aircraft performance wherein AM plays a significant role in meeting such unique demand. Another effective and more advanced way to achieve lightweight material is structural optimization. In this method, the material is distributed to reduce material, and structural performance is enhanced [23][24][25]. In addition to structural capability, improved acceleration performance, energy efficiency, flight endurance, payload, and decreased life cycle cost and greenhouse gas emissions can also be achieved by the application of DFAM [26]. The various materials used for making brackets and their processing using AM techniques are discussed below.

### 2.1. Al-Based Alloys

Al6061 is a lightweight material yet high in strength as compared to other aluminum alloys. The important factors to be considered are deflection and stress distribution. In general, good ductility and corrosion resistance, relatively high basic strength and rigidity, low price, and simple manufacturability and durability make advanced aluminum alloys an excellent choice of lightweight materials in many aerospace structural applications such as upper and lower wing skins, wing stringers, and fuselage skin, etc. [27]. On their first human-crewed flight in 1903, Al was the first choice for the engine components and cylinder block for the Wright brothers. For the first time, an Al-alloy was heat-reinforced, a discovery that set Aluminium's dominance in aerospace engineering [28][29]. The aluminum added substance layer manufactured (ALM) section saves weight and decreases the making time. More prominent solidness gives better guiding exactness toward mounting receiving wires. Airbus Defence and Space in the UK attempted its first space-qualified aluminum 3D printed segments. The optimized antenna bracket for TMTC is shown in **Figure 3**. The 3D printed segments being created by the UK group are high-performance structures that cannot be manufactured by conventional techniques. The advanced structural bracket made of Al-alloy was installed in Eurostar E3000 broadcast communications satellites. The bracket is a single-piece laser liquefied part weighing 35% less than the conventionally manufactured part that consists of four sections and 44 rivets. In addition, the ALM section is 40% stiffer. Further, as compared to the part processed using conventional machining techniques, the least wastage is observed. The section is used for mounting the telemetry and telecommand (TMTC) reception apparatuses onto the satellite. From the flight qualification testing of the structure, it was found fit to be flown on an impending satellite [30]. The innovative design in the 8 U Cube Satellite included DFAM-based lattice structures to improve the protection. Some of the latest developments include alloying additions such as Gd, La, Sm, and Yb to improve the high-temperature performance and corrosion resistance of cast Mg alloys [31][32].

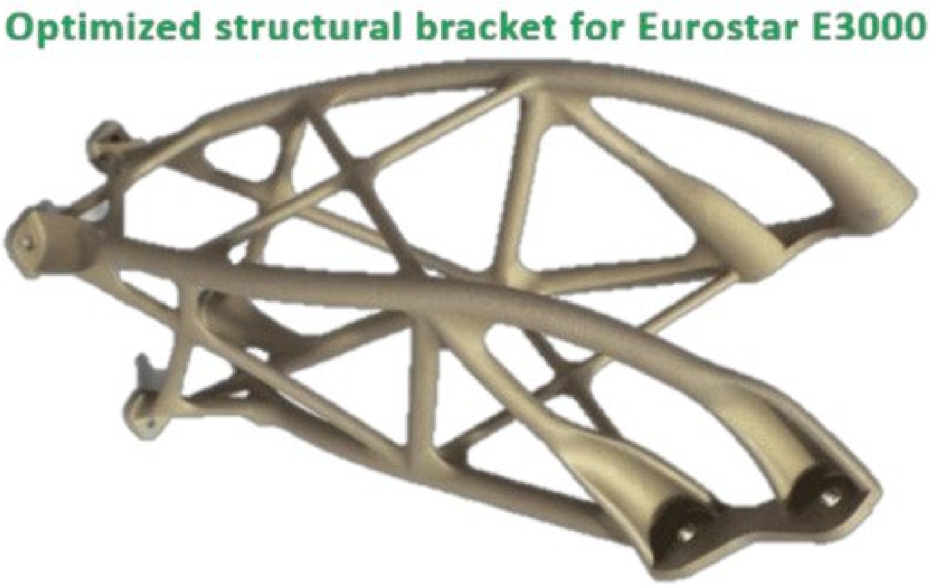


**Figure 3.** AM-made optimized bracket used for mounting the TMTC antennas onto the E3000 satellite [33].

## 2.2. Ti-Based Alloys

Titanium alloy is a preferred choice of engineering material after aluminum to manufacture aircraft frames and engine components. Although It has paved its way into the aerospace industry manufacturing Ti products have challenges. Firstly, the high cost of alloy, which is nearly eight times that of Al-alloys used in industries. Secondly, machining Ti-alloy is quite a difficult and expensive process due to its high strength and hardness. Hence, an adaptation of Ti alloys is considered only in critical components of aircraft. They are preferred where high strength, corrosion resistance, and space constraint are the deciding parameters for designing components, and also cost of the product must not be that crucial. In general, Ti-alloys are used mainly in manufacturing engine components and the mechanical structure of aircraft. Titanium combinations have a boundless edge over different metals. It has high rigidity, great crack strength, and fatigue resistance, with some erosion resistance, heat resistance, cryogenic embrittlement restriction, and low thermal coefficient. This makes the Ti-alloy an appropriate alternate choice for steel and Al-based compounds used in aircraft applications. **Figure 4** shows a simple design of the additively manufactured Ti-alloy bracket. The processing of Ti-alloy-based brackets using AM is also challenging. Benedetti et al. [34] found high porosity and surface roughness along with poor fatigue properties in the Ti-6Al-4V-alloy-made components processed by Selective Laser Melting (SLM). The relationship between porosity, microstructure, and mechanical properties is also analyzed in terms of process parameters and then improving the processing parameters to achieve 99.5% relative density in CP-Ti-made components [35]. Atar et al. [36] reported improvement in compressive strength, toughness, and tensile strength for SLMed structure. Sample production of Ti-6Al-4V alloy using Selective Laser Sintering (SLS) followed by hot pressing was attempted by Das et al. [37]. The Ti alloy structure processed by SLM provides the best strength-to-weight ratio and is about half as heavy-duty steels or Ni-based superalloys. The vast majority of aircraft frames today are made of Ti-alloys. These alloys have a very specific reinforcing body and can suppress the development of weakness on these grounds; they are considered an ideal replacement for steel and aluminum in frames. To prevent catastrophic fatigue, they are used as thin, narrow bracket rings around the aircraft fuselage of aluminum, similar to the belly bar. One of Ti alloys' main applications in the aerospace industry has been the use of (α + β) Ti3Al2.5V for hydraulic pipes, aircraft floors, piping systems, etc. [38]. Ti-6Al-2Zr-2Sn-2Mo-2Cr-0.25Si is being produced for US F-22 aircraft and joint strike missile projects. Ti alloys such as Ti-3Al-8V6Cr-4Mo-4Zr (β-C) and Ti-15V-3Cr-3Sn-3Al are preferred for generating sources for multi-aircraft activation systems [39]. Currently, Boeing has created 200 unique parts for ten aeroplane stages utilizing AM, and it has delivered around 20,000 sections for military and business aeroplanes, including 32 distinct segments for its 787 Dream liner planes. General Electric, the world's biggest fly motor provider, produces fuel spouts for a great many fly motors that are processed to have 25% less weight and multiple times more solidness than best-in-class parts, which were recently made by welding 20 unique parts. SLM is considered the most solid AM strategy that can deliver lightweight parts for aviation applications with diminished $CO_2$ discharge. Tomlin and Myer have demonstrated the useful suitability of the Electron Beam Melting (EBM) technique for making Airbus A320 nacelle pivot section segments. The utilization of Ti instead of steel brings about a 63% weight decrease.

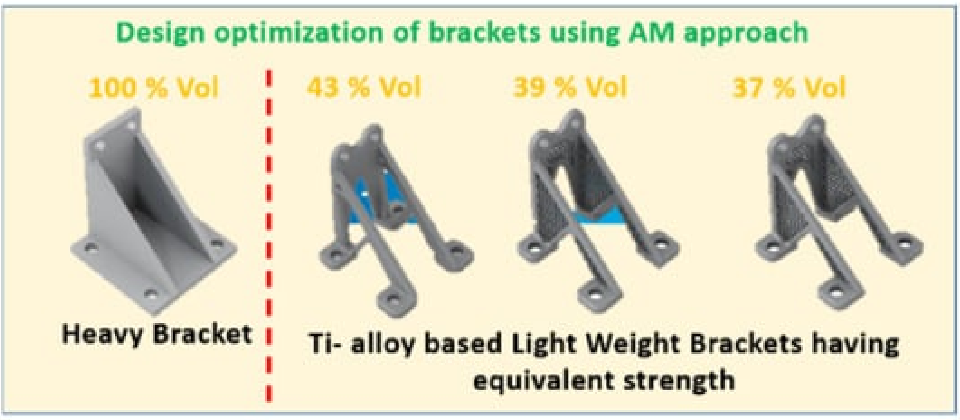


**Figure 4.** Schematic of Ti-alloy bracket processed by AM [5].

## 2.3. Stainless Steel

Steel is the most popular and commonly used material in almost every industry due to its easy availability and has high strength and stiffness, low cost, and good dimensional properties at high temperatures. It is still used in only 5% to 15% of the weights of a commercial aeroplane because of its limitation like high density and vulnerability to corrosion and embrittlement. For safety components where extremely high strength and stiffness are required, high-strength steel is the only choice. Another application of high-strength steel in aerospace is bearing, gearing, and undercarriage application [40]. All the AM-processed satellite wall brackets are made of high-quality stainless steel, making them resistant to all weather conditions and have a very high lifespan. The Cab Mount Bracket developed from powder-covered, heavy-gauge steel with vibration isolators offers the ideal solution for long-term outdoor use and is intended for robust support and durability [41].

### 2.4. NiTi-Based Alloys

NiTi smart materials are available in the form of a plate, thin film, or bar used to actuate the component whereas AM-made NiTi smart materials are available in any form [42]. In **Figure 5**a NiTi plate and an attachable flexible heater are part of the SMA damper module used to facilitate NiTi phase transformation. The SMA damper is also stowed together when the tape spring hinge is stowed in shape, as shown in **Figure 5**a. The tape spring is in an in-elastic condition at the stowed shape, but the NiTi plate is evidently in a plastic state; it recovers if its temperature is more than that of the austenite phase transformation temperature ($A_f$). Consequently, if the torque needed for NiTi plate plastic-like deformation is greater than the torque of a tape spring hinge, the deployment behavior could be regulated by the rate of NiTi phase transformation. The SMA damper module can minimize the accompanying latch-up shock without regard to functional requirements. The SMA damper module has no detrimental effect on the tape spring hinge and is a typical flexible deployment device for a satellite module's deployment torque since the phase transformation mechanism is similar to the steady release of the deployment angle restriction. Instead, when a deployed position (shown in **Figure 5**b) unexpectedly becomes stuck, the SMA damper module will serve as an emergency actuator because of its high recovery stress. Concerning deployed stiffness, it is clear that certain stiffness can be supplied by the SMA damper module [43].

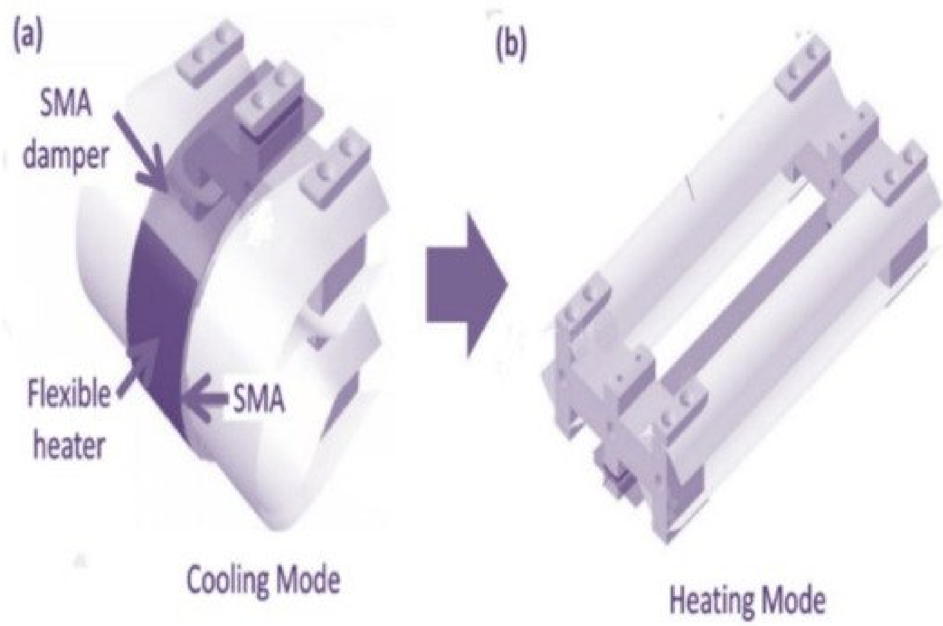


**Figure 5.** SMA damped tape spring hinge. (**a**) Stowed position; (**b**) Deployed position.

## 3. Emerging Applications of Satellite Brackets

### 3.1. Antenna Brackets

The German Center for Aerospace reports in the year 2016 that the space exploration mission's costs per kg of the payload are above €20,000 [44]. The variation in each gram of a load of a component may lead to a significant rise in the cost of launching the vehicle. Although optimization of process parameters for conventional manufacturing methods is possible, it is very difficult to reduce the load of the components [45]. AM provides greater freedom for the design of the bracket [46]. A Swiss research group, RUAG, investigated the optimization of the antenna bracket design using AM process and found that by adopting AM process, the optimum combination of strength and weight is achieved for the structure of its antenna bracket [47]. Similarly, using EOS M400, a 40 cm long antenna bracket was fabricated by Citim, GmbH a German-based company. Using the AM process, 60 µm layer thickness was formed within 80 h. In general, 80% of the total scope of a project in the aerospace industry, is implemented in comprehensive tests (**Figure 6**) [48]. The EOS's AlSi10Mg material is found to exhibit high strength and strong resistance to dynamic stress, making it the material of choice for printing high-stress components.

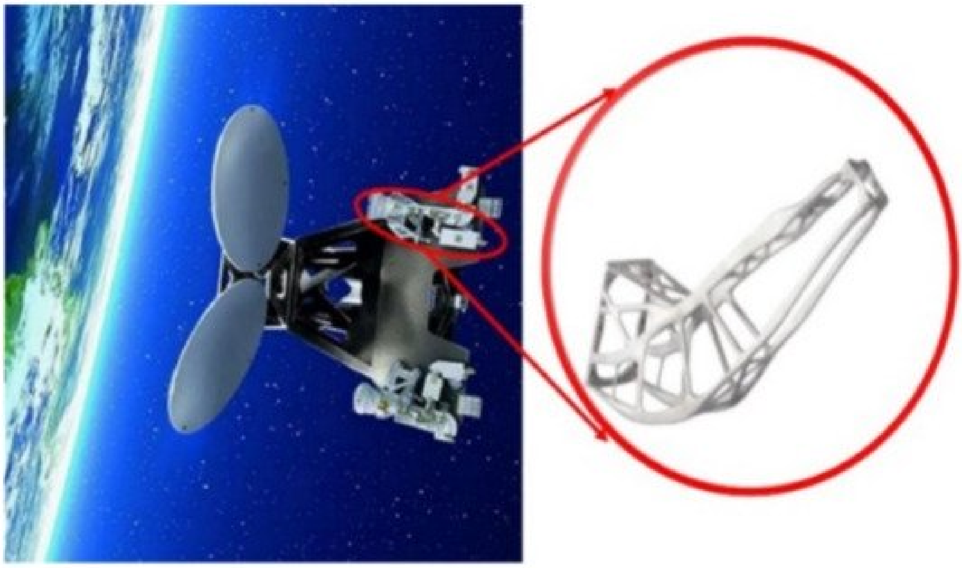

**Figure 6.** 3D printed Antenna bracket for reflector panel used on the Sentinel-1B satellite [48].

Several manufacturers have adopted AM for making brackets and have found positive results upon implementation. Surrey Satellite Technology, a British satellite company, says that AM has a significant role in changing the economics of space. The main reason behind that observation is the ability of AM for achieving optimization of the strength-to-weight ratio. In space flight, weight reduction indicates the savage of fuel, the crucial entity. The space antenna FusiA which is a 3D printed part possesses reduced weight. By the implementation of AM techniques, MDA Ltd., Brampton, Ontario, Canada, a Canadian space technology company, designed the space-bound part, a spacecraft interface antenna bracket optimized for a flight which has made it easy for the company to process the complex structures [49]. Nowadays, mesh structures are used, which doesn't add density to the structure but rather reduces weight. Similarly, Airbus also uses AM to fabricate brackets that hold reflectors. The company reports that the innovative design of the bracket as a result of DFAM reduces the weight of the satellite by 1 kg [48]. The 3D printed antenna bracket used in the Sentinel-1 B satellite is shown in **Figure 7**. A similar attempt by Juno wherein the aircraft is housed with AM-made support structures has been of great advantage in weight reduction in their mission to Jupiter.

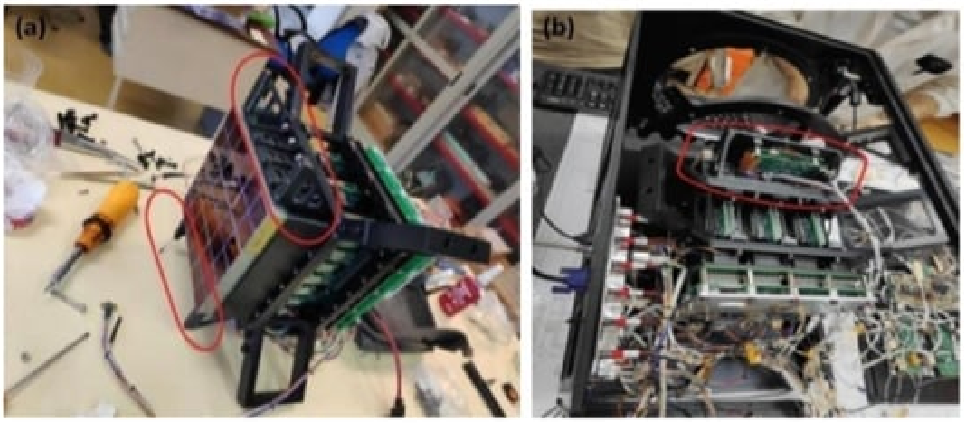


**Figure 7.** The Mini-EUSO used in the International Space Station: (**a**) 3D printed Ultem 9085 brackets (in red), and (**b**) The final unit with electronics included.

### 3.2. Reaction Wheel Brackets

The reaction wheel is a type of flywheel and is also a momentum wheel that is used primarily by space crafts and satellites. Brackets are used in the reaction wheel to hold a machine and they are also designed for the basic control of the spacecraft to rotate and to use the inertia time to adjust the satellite's position in place. Direct Manufacturing Research Center at Paderborn University carried out a study to determine the feasibility of AM to manufacture reaction brackets for satellites. The main focus of the work was to show the potential of AM for reducing waste, weight, cost, and time for producing reaction brackets [50]. A huge bracket that was used four times per satellite was chosen for analysis. The important aspect of AM is the provision for topology optimization. To achieve the biomimic shape on the bracket, a highly time-efficient semi-automatic voxel-based technique for topology optimization was applied. The developed model is shown in **Figure 8**. This allows the model to be built quickly and without stress. In addition, the value of the product shows the differences in the design of the product besides the products in the larger process, even in terms of cost. Wheel bracket made by AM process can reduce waste by 98% (from 56 kg to 0.8 kg), weight by 60% (from 1100 g to 450 g), time by 32% (from 59 h to 40 h), price by 53% (from 8000 € to 3800 €).

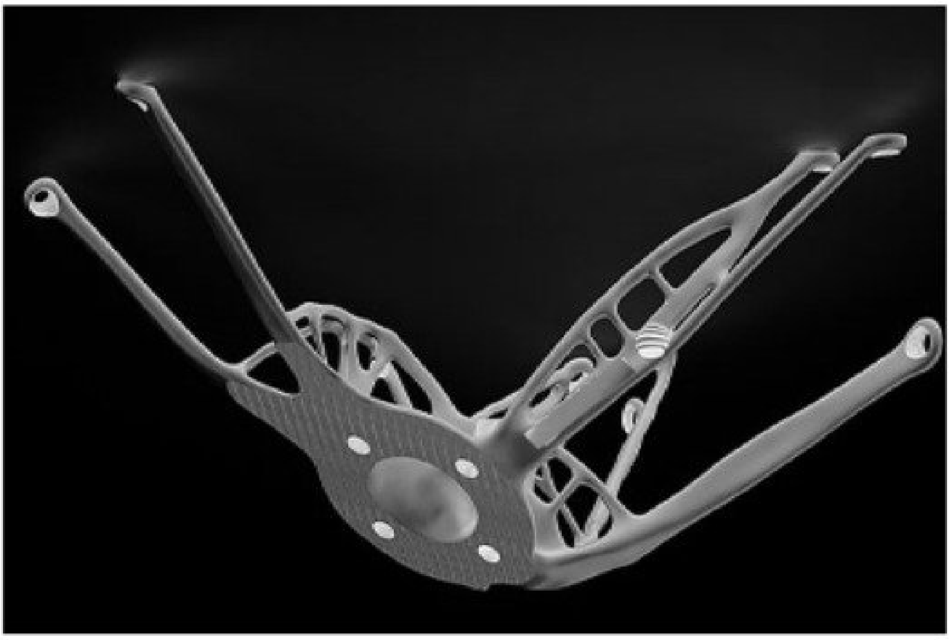

**Figure 8.** AM made reaction wheel bracket [50].

On the other hand, 3D printed reaction wheel brackets made of aluminum were housed in Space bus Neo [51]. The satellite also consists of sixteen antenna transmission brackets and ADPM (Antenna Deployment and Pointing Mechanism) of which, four are Al made and twelve are made of Ti, all of them were 3D printed. These 3D-printed wheel arches were designed to meet market demand for a low-cost antenna. As a result, the cost was reduced by 10% and the production time was also reduced by 1–2 months. Thales Alenia Space reports that. the biggest powder bed fusion-based printer was installed in Europe that has a build volume of (800 × 400 × 800 $mm^3$) to produce the large reaction wheel brackets, Similarly, Thales Alenia Space also includes plugs and cable connectors directly into the overall design, which is printed as a unit, avoiding additional installation requirements. To produce this large reaction wheel bracket (466 × 367 × 403 $mm^3$), the largest 3D powder printer-the Xline 2000R metal laser printer from the concept laser with (800 × 400 × 500 $mm^3$) building space-was installed [52].

## 3.3. Thruster Mount Bracket

A thruster is a propulsive device used by spacecraft for important activities like altitude control and station keeping in the reaction control system. Mounting of thrusters inside the spacecraft requires extensive care and the thrusters are mounted using brackets. The design of the mount bracket is an important aspect to be considered. Taking the advantage of design freedom in AM, the mount bracket has been modified on a larger scale. Kevin Chris Yakacki et al. [53] carried out work on Lockheed Martin GPS Satellite Bracket and developed an optimized model for manufacturing the thruster mount bracket using AM. The final generatively designed bracket included a thruster mount bracket that has been optimized for minimum possible support structure. Using DFAM for the topological optimization, the amount of support material required was reduced considerably. Before applying DFAM, the orientation of the part on the build plate from various surfaces of the part was chosen as the one with the least support needed [54]. The optimized thruster mount bracket built using AM is shown in **Figure 9**. The part was built using Aluminum material. Furthermore, the top left corner seen in **Figure 9** was an infill added to the design with those angles and geometry purely to eliminate the need for support materials on that corner of the bracket.

**Figure 9.** Optimized mount bracket using DFAM [53].

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