

# Legal Uncertainties Related to Additive Manufacturing in Space

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## Abstract

Additive manufacturing (AM), also referred to as three-dimensional printing, is a set of layer-by-layer processes for producing 3D objects directly from a digital model. Since its inception a few decades ago, the AM industry has grown to almost \$3 billion as of 2012, and is poised to grow to more than \$6.5 billion by 2019. While the field has great promise for terrestrial applications, its promise in space – reduced dependence on materials transported from earth and the ability to “live off the land” – has the potential to radically transform the space enterprise. There are a number of studies underway, both supported by the government and the private sector, that examine the technical feasibility and application of AM in outer space. Most recently, the U.S. National Academy of Science (NAS) published a report that explored the implications of space-based AM technologies for space operations and the manufacture of space hardware. The NAS report focused on technological and institutional issues not legal ones, even though legal questions such as those related to use of in situ resources (e.g., using lunar regolith to additively manufacture habitat or other facilities like launch pads on the surface of the moon) for manufacturing may arise when AM is used in outer space. This paper identifies and provides an assessment of select questions under public international space law involving AM in outer space on jurisdiction and control, ownership, registration, and liability.

## Article

In 2014, the U.S. National Academies of Science (NAS) released a report on additive manufacturing (AM) in space, often referred to as “3D printing.” According to the NAS report:

*“Additive manufacturing has the potential to positively affect human spaceflight operations by enabling the in-orbit manufacture of replacement parts and tools, which could reduce existing logistics requirements for the International Space Station (ISS) and future long-duration human space missions. The benefits of in-space additive manufacturing for robotic spacecraft are far less clear, although this rapidly advancing technology can also potentially enable space-based*

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*construction of large structures and, perhaps someday, substantially in the future, entire spacecraft. Additive manufacturing can also help to re-imagine a new space architecture that is not constrained by the design and manufacturing confines of gravity, current manufacturing processes, and launch-related structural stresses.”<sup>1</sup>*

While the NAS report provides an excellent exploration on the science, technology, and potential application of additive manufacturing in space, it does not identify legal questions associated with such activities.

This paper identifies and provides an assessment of select questions under public international space law involving AM in outer space on additively manufactured products as space objects, jurisdiction and control, determination of a launching state, ownership, registration, liability, harmful contamination, and government authorization and supervision.<sup>2</sup>

### **Section 1: Background on the Science & Technology of Space-Based Additive Manufacturing**

Additive manufacturing—commonly referred to as “3D printing”—is a general term encompassing various manufacturing methodologies, using different constructive materials and additive processes, each of which have specific advantages and constraints. More specifically, it is “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.”<sup>3</sup> Since its introduction of the first working 3D printer in 1984 by Charles Hall of 3D systems, additive manufacturing has become increasingly important for traditional, ground-based production of consumer and industrial products. To date, over a hundred companies world-wide have manufactured more than 30,000 additive manufacturing machines.<sup>4</sup> The sale of additive manufacturing machines for metal manufacturing in 2013 increased 76% over the previous year, and overall, the market for 3D printing products and services grew to over \$3 billion in 2013.<sup>5</sup> The primary buyers, in the medical

<sup>1</sup> [http://www.nap.edu/download.php?record\\_id=18871#](http://www.nap.edu/download.php?record_id=18871#) at 9 <July 27<sup>th</sup> 2014>

<sup>2</sup> In addition to public international space law, additive manufacturing also presents novel international and national legal questions on intellectual property, product liability, and export controls.

<sup>3</sup> ASTM F2792-12A

<sup>4</sup> T.T. Wohlers, “Wohlers Report 2013, Rapid Prototyping, Tooling and Manufacturing: State of the Industry,” Annual Worldwide Progress Report, 2013, Wohlers Associates Inc., Fort Collins, CO.

<sup>5</sup> Wohlers Associates Press Release, <http://wohlersassociates.com/press64.html>, Sales Of 3D Metal Printers Grew Over 75% In 2013, <http://www.forbes.com/sites/alexknapp/2014/05/21/sales-of-3d-metal-printers-grew-over-75-in-2013/>

(dental in particular) and aerospace industries, use AM for both prototyping and manufacturing; and applications in the aerospace sector are poised to skyrocket in the next few years).

Additive manufacturing is not just a different way to manufacture components and space-based devices, but rather offers a new way to re-conceptualize space architectures. On earth, additive manufacturing is already contributing to cost reductions for rocket components. In the future, it can lead to the construction of smaller, more reliable, less massive satellite systems or their key components (including support structure, power distribution system, solar arrays, instruments, outer protective shell, etc.), which could reduce launch requirements and costs. These savings could be multiplied when construction can occur on-orbit. In space, AM can enable the development of large structures made, for example of gossamer material, entirely unlike those needed in the high gravity environment of Earth, or to survive the rigors of space launch.

NASA is already investing in both terrestrial and space-based applications of AM. In Fall 2014, California-based private company Made in Space will be launching a 3D printer to the International Space Station. Grantees from NASA's Innovative Advanced Concepts (NIAC) program are exploring the use of lunar regolith to build launch pads and other infrastructure on the surface of the moon. Other efforts for space-based additive manufacturing are underway at several NASA centers. Other US agencies, such as NIST, DOD and others are examining other important issues related to certification and validation of AM-made components and devices.

## **Section 2: Identification of Legal Questions**

**Overview:** Space-based additive manufacturing is subject to general public international law, public international space law, private international law, and the laws of the national jurisdiction(s) applicable to the activity, products produced, and persons involved.

Within the field of public international space law (PISL), space-based additive manufacturing presents legal questions generally applicable to all space activities and questions unique to this particular type of activity.

The table below (Table 1) provides an overview of unique PISL questions identified in this article. Taxonomy of technical activity related to space-based AM is on the top line and consists of precursor materials for AM devices, AM devices, and products produced by AM devices. On the far left are categories of PISL legal areas. An "x" indicates a unique PISL question exists for a particular technical area in a particular legal area.

**Table 1. Taxonomy of PISL Legal Questions**

	Precursor Terrestrial	Precursor Celestial	Device In Facility	Device In Space	Product Retained	Product Transferred
Jurisdiction and Control			X			X
Registration			X		X	X
Liability	X	X	X	X	X	X
Launching State					X	X
Status as Space Object					X	X
Auth and Supervision			X	X		
Celestial Resources		X				
Property Rights						

**Space Objects:** Are products additively manufactured in outer space to be considered space objects for the purposes of the *Outer Space Treaty* regime? This author knows of no instance in which a product manufactured in outer space being was placed on a national registry as a space object. While objects released from the *International Space Station* have been registered as space object, none of these objects were manufactured in outer space.

What is the legal implication of this uncertainty? Under PISL, Jurisdiction and Control, Ownership, and Liability are anchored in the legal conception of a ‘space object.’ Uncertainty in whether products additively manufactured in outer space constitute ‘space objects,’ means that PISL is insufficient to provide States certainty as to their duties and rights. General principles of

international law will need to be relied upon to inform these legal questions and State practice will serve an important function in crystallizing a common understanding of the legal status of additively manufactured in outer space.

**Jurisdiction and Control:** Jurisdiction and control refers to the power of a state to affect persons, property, and circumstances.<sup>6</sup> Pursuant to Article VIII of the *Outer Space Treaty* (OST), if an additive manufacturing device is launched into outer space and registered, the State of registry retains jurisdiction and control of the object. “The legal consequence of jurisdiction and control is the applicability of the national law of the State of registry.”<sup>7</sup>

But what State retains jurisdiction and control on an additive manufacturing device located on another space object (e.g. space station or lunar facility)?

If an additive manufacturing device is located on the International Space Station (ISS), the *Inter-Governmental Agreement* (IGA)<sup>8</sup> governs. For example, NASA has a pending mission on the ISS to demonstrate that additive manufacturing devices work in outer space.<sup>9</sup> Jurisdiction, ownership, and control of the device are established pursuant to the IGA.

But what about when an additive manufacturing device is located in a space object but not be subject to an agreement such as the IGA? Pursuant Article VIII of the OST, the state of registry of a space object should retain jurisdiction and control over all personnel in their space object, including those operating an additive manufacturing device. But Article VIII is silent to jurisdiction over equipment. The treaties did not contemplate space objects or equipment to be located on a space object (i.e. space station or facility) that is of foreign registry. Indeed, Article II of the *Registration Convention* provides for an object to be registered by its launching State. Compliance with the treaty may result in instances in which additive manufacturing devices are launched as space objects, registered with a launching State, and thereafter placed on or in the registered space object of a another State.

Article VIII does articulate a common principle of jurisdiction found in public international maritime and aviation law. Specifically, that ships and aircraft are subject to the jurisdiction of the State in which they are registered. If one applies this principle, then the state of registry of the space object should have jurisdiction and control over all equipment and activities undertaken on-board, including additive manufacturing devices and their operation. Under this principle, a manufactured additive manufactured product whose

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<sup>6</sup> <http://www.britannica.com/EBchecked/topic/291011/international-law/233512/Jurisdiction>

<sup>7</sup> Pg. 163 Cologne Commentary Vol. 1

<sup>8</sup> Cite

<sup>9</sup> See *NASA Mission to ISS, 3D Printing in Zero-G* <  
[http://www.nasa.gov/mission\\_pages/station/research/experiments/1115.html](http://www.nasa.gov/mission_pages/station/research/experiments/1115.html)>

ownership is transferred to a 3<sup>rd</sup> party on-orbit would also be subject to the jurisdiction of the space object the manufactured product is located.

A legitimate rationale for applying this approach is that the State of registry of the space object is internationally responsible for authorization, continual supervision, and ensuring compliance with international law, as well as for the safety and operation of the space object. However, as is discussed in more detail below, providing jurisdiction to the space object over the additive manufacturing device registered to another State raises additional questions of jurisdiction, ownership, and liability for the additive manufactured products.

Today, when a space object is launched from the surface of the Earth, there have been and continue to be instances in which multiple governments could legitimately place a space object on their national registry (e.g. national of country 'a' procures a launch from country 'b'). This reality is recognized in Article II of the *Registration Convention*, which provides that in the case of two or more launching States in respect of a space object, they shall jointly determine which one of them shall register the object.

**Launching State:** A launching State is a State that launches or procures the launching of an object into outer space or from whose territory or facility an object is launch.<sup>10</sup> Launching States are internationally liable for damage by such an object and are required to place the space object on their national registry (or if there are two or more launching States of the same space object, jointly determine which State shall register).<sup>11</sup>

If a product is additively manufactured in outer space and thereafter released into outer space, does that action constitute a launch? Interestingly enough, there is State practice which supports this action being considered a launch. The United States has registered space objects that were released from the International Space Station. A legitimate reading of the law, in light of this practice, is that the ISS is a facility for the purposes of Article VII of the *Outer Space Treaty*. The implication is that additively manufactured products that are released into outer space could legitimately be deemed space objects launched and registered accordingly. Note that under PISL a space object can be launched from a facility and U.S. Government practice indicates that space objects (such as the ISS) can be considered facilities.

**Ownership:** "Ownership in outer space of space objects refers either to ownership established on the ground according to the relevant legal regime on earth or ownership established or transferred in outer space."<sup>12</sup> In principle, the owner of an additive manufacturing device may sell, lease, mortgage and otherwise dispose of the device and any products

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<sup>10</sup> See Article VII *Outer Space Treaty* (1967)

<sup>11</sup> See Article II *Registration Convention* (1974)

<sup>12</sup> Pg. 164 Cologne Commentary Vol. 1

manufactured by the device.<sup>13</sup> The State of registry determines the status and transferability of ownerships through its national laws.<sup>14</sup>

There is a question of overlapping (e.g. concurrent) jurisdiction, instances in which an additive manufacturing device registered by one State is located in a space object of a different State. In such instances, whose national laws apply for the question of ownership?

As discussed above, there is a legitimate rationale for the jurisdiction of a space object of foreign registry, and its national laws, should govern the sale of the additive manufacturing device or products produced on it, even if the additive manufacturing device is registered to a different State.

**Registration:** There is no precedent of a State registering an object manufactured in outer space. The OST regime is designed to register space objects<sup>15</sup> *launched* into outer space, not *manufactured* in outer space.<sup>16</sup>

The main purpose of the OST registration rules is to enable the identification of a space objects, thus allowing the identification of the State that has jurisdiction and control and is responsible for the particular space object.<sup>17</sup>

Should States register products manufactured on-orbit? And if so, should this registration have the legal effect as space objects registered that were launched into space? If a manufactured object is not registered, what State retains jurisdiction and control and responsibility for that object? Should it be the State under whose jurisdiction the object was manufactured?

**Liability:** Liability applies to the launching State of a space object, including its component parts, that causes damage to another State party or its national or juridical persons. While Article VII of the OST is the legal norm imposing liability for the act of launching a space object, the *Liability Convention* makes a further distinction between types of liability subject to the location of harm.<sup>18</sup>

It is unclear is how liability under the OST regime will be interpreted as applying to the launching States of additive manufacturing devices for claims of liability associated with a product manufactured on-orbit. Should the transfer of a manufactured product to a third-party terminate liability for the launching State and transfer liability to the State of the 3<sup>rd</sup> party? Should it matter if the additive materials were extracted in outer space or provided by a 3<sup>rd</sup> party? If provided by a 3<sup>rd</sup> party, is the launching State of the 3<sup>rd</sup> party also subject to liability for the product manufactured by the additive manufacturing device? And if so, on what basis and to what extent? If an

<sup>13</sup> See Pg. 164 Cologne Commentary

<sup>14</sup> Id. at 164

<sup>15</sup> Article 1 Registration Convention defines space object as “component parts of a space object as well as its launch vehicle and parts thereof.”

<sup>16</sup> See pg. 154 Cologne. “A criterion for space objects to be carried on the national registry is that such objects must be launched in earth orbit or beyond.”

<sup>17</sup> Pg. 154 Cologne

<sup>18</sup> Cologne at 136

additive manufacturing device is located on a space object of foreign registry, and hence not subject to the jurisdiction and control of the launching State of the additive manufacturing device, should the State exercising jurisdiction and control be liable, even if not a launching State?

**Harmful Interference:** Under Article IX of the *Outer Space Treaty*, States are required to conduct their activities in outer space and on celestial bodies so as to avoid their harmful contamination. Additive manufacturing activities must be conducted in accordance with this principle. For example, in-situ lunar additive manufacturing activities would be subject to this rule.

**Government Authorization and Supervision:** Under Article VI of the *Outer Space Treaty*, States are required to authorize and supervise national space activities. States should assess their national legislative and regulatory systems to determine if proper mechanisms are in place to fulfill their Article VI obligation for space-based additive manufacturing.

### Section 5: Conclusion

Additive manufacturing holds much potential for reducing human dependence on earth in space and on our ability to “live off the land” on other planetary bodies. There are many technical challenges before such a vision will come to fruition. However, the legal challenges to accomplishing this vision should not be underestimated. A PISL legal analysis of AM in outer space should distinguish between the following:

- Legal status of AM devices and precursor materials located on a space facility or in a spacecraft
- Legal status of AM device as a standalone space object independent of a space facility or spacecraft
- Legal status of AM products released into outer space from a space facility or spacecraft
- Legal status of AM produced products that are sold/transferred to foreign parties
- Legal status of AM precursor materials derived from in-situ celestial resources

An examination of these activities reveals that:

1. PISL does not seem to raise novel questions as to the legal status of AM devices, precursor materials, and AM products located on a space facility or in a spacecraft unless they are located on foreign registered facility of spacecraft in which case questions of jurisdiction and control arise. There seems to be no compelling reason to treat the AM equipment, raw materials and resulting tangible products any differently than other equipment functioning on-board a registered space object
2. The PISL status of AM devices that are standalone space objects independent of a space facility or spacecraft should be the same as any



other space object. There seems to be no compelling reason to treat AM devices that are standalone space objects independent of a space facility or spacecraft does to be treated differently than other space object.

3. The legal status of AM products released into outer space from a space facility or spacecraft does raise novel questions. This activity of releasing an object into space seems to cross a legal threshold. Unlike equipment and tangible items remaining on-board a registered space object, tangible matter released into outer space by design and purpose would appear to implicate the core purposes underlying the related space law concepts of jurisdiction and control, registration, liability and launching state -- namely, ensuring and attributing responsibility for objects that could (independently) damage other objects and/or otherwise interfere with the rights of others to use and benefit from outer space. In this scenario, there would seem to be strong legal policy arguments for applying the PISL concept and criteria of "launching state" (e.g., release from the "facility" as you identify, and the party "procuring the launch") and expecting the relevant launching states to identify a state of registry (RC, Art. II.2).
4. The sale or transfer of AM produced products will raise PISL questions related to the transfer of jurisdiction and control, ownership, and registration. The legal aspects of transferring space objects, particularly to a State which is not a launching State of the space object, is an issue area that is being examined by the UNCOPUOS legal subcommittee.
5. The use of in-situ celestial resources for AM activities raises questions as to the distinction between use and exploitation under PISL. State practice generally indicates that the use of in-situ resources is legitimate, so long as the use does not constitute national appropriation in violation of Article II of the OST. However, there is no definitive consensus as to what will or will not constitute national appropriation.

