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Where is Space? And Why Does That Matter?

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Abstract

Despite decades of debate on the topic, there is no consensus on what, precisely, constitutes the boundary between airspace and outer space. The topic is mired in legal and political conundrums, and the easy solution to-date has been to not agree on a definition of space. Lack of a definition, some experts claim, has not limited space-based activities, and therefore is not a hurdle that must be overcome. There are increasing calls however in light of increasing (and expectations of increasing) space traffic, both orbital and sub-orbital. This paper summarizes the proposed delimitation of space, the current debate on whether or not the boundary should be defined and internationally accepted, and our assessment on the need to define it based on emerging space traffic management needs.

A. Introduction

The general notion of "air" and "space"[1] is relatively well understood in terms of how mobility is undertaken in each. Air involves flight by either aerostatics (balloons and airships) or aerodynamic lifting surfaces such as wings and rotors (airplanes, sailplanes, and helicopters). Space involves flight by rocket-boosted vehicles whose flight paths are governed by ballistics

[1] This paper focuses on definitions of space, generally speaking, without any particular focus on a region of space. These regions could comprise Geospace (region of outer space near the Earth), Cislunar space (region between Earth's atmosphere and the Moon), Interplanetary space (the space around the Sun and planets of the Solar System), Intersteller space (physical space within a galaxy not occupied by stars or their planetary systems), or Intergalactic space (physical space between galaxies).

and orbital mechanics. However, there is no consensus on what, precisely, constitutes the boundary between airspace and outer space. In this paper, we summarize the literature in three areas: available definitions of the lower accepted boundary of space, the need for a standardized internationally-accepted definition, and the need for not doing so. We conclude with our recommendation on the topic.

B. Known Demarcations between Air and Space

To ascertain where space began, we started by looking for clarity in the definitions of space, and found that most of them stem from the perception that space is what is beyond the Earth's atmosphere. However, there is no consensus over what constitutes the delineation between "Earth's atmosphere" and "beyond." Section 103 of the NASA Authorization Act of 1958 defined the term aeronautical and space activities as "research into, and the solution of, problems of flight within and *outside the Earth's atmosphere*" [emphasis added] (National Aeronautics and Space Act of 1958). In the same vein, NASA's definition of space in the Dictionary of Technical Terms for Aerospace Use did not specify a point of delimitation (National Aeronautics and Space Administration 2008) but called it:

- Specifically, the part of the universe lying outside the limits of the Earth's atmosphere
- More generally, the volume in which all celestial bodies, including the Earth, move

The NASA definition was incorporated by the Organisation for Economic Co-operation and Development (OECD) in its own definition in the 2012 *Handbook on Measuring the Space Economy*:

> The space sector includes all actors involved in the systematic application of engineering and scientific disciplines to the exploration and utilisation of outer space, *an area which extends beyond the earth's atmosphere* [emphasis added] (Organisation for Economic Co-operation and Development 2010).

In a footnote, the handbook alludes to the ambiguity mentioned above:

> Where does airspace end and where does space begin? This is not only a statistical issue as of mid-2011, [but] there is no formally accepted legal delimitation of 'outer space' internationally, although there is a growing corpus of norms and treaties dealing with space activities.

The United States Air Force (USAF) official space documents do not define space either but reference key characteristics (e.g., overflight, persistence, speed). Implied across official doctrine is that space is the region governed by the fundamentals of orbital mechanics (Kepler's Laws) where objects possess the energy to remain in orbit instead of returning to Earth. Air Force documents also characterize space as a medium—like the land, sea, and air—within which military activities shall be conducted to achieve U.S. national security objectives (United States Air Force 2004; Joint Chiefs of Staff 2009; Air Command and Staff College 2009). Space is a domain enabling many joint-force-essential capabilities that derive from exploitation of the

unique characteristics of space, among which include a global perspective and lack of overflight restrictions and the speed and persistence afforded by satellites.

There have been attempts to formally delimit space. Definitions on the delimitation of air from outer space are sometimes based on spatial characteristics (e.g., use of specific altitudes from sea level to demarcate where the Earth's atmosphere stops) and sometimes arbitrarily. In our research, we found five altitudes, ranging from 50-110 miles, which delimits space. Table 1 below discusses each, by height, and shows which are set using a scientific basis, and which are more arbitrary, based on convenience or norm. Figure 1 shows the altitutudes visually.

Some experts have noted that function and purpose might lead to more appropriate distinctions between aircraft and spacecraft than altitude (Federal Aviation Administration 2010). For example, space begins where we begin space-based work (like place satellites). This definition has not been explored in this paper because the distinction between what can be done from outer space and what from airspace is increasingly getting blurred. For example, high-altitude balloons of today and the future can collect earth observation data that previously only space based assets could.

Table 1: Known Delimitations between Air and Space

Proposed Boundary	Reasoning	Further Background	Used By
50 mi (80 km)	"Roughly the point at which aerodynamic control surfaces are no longer useful" (Stone 2012)	This line was set through testing of the X-15. The X-15 is designed for control in both the atmosphere and out space. It was at the 50 mile line where the X-15 switched from aerodynamic controls to the atmospheric propulsion system	National Advisory Committee on Aeronautics (NACA), NASA, U.S. Military
62.5 mi (100 km)	Karman line- A vehicle at this point (which can be between 53-60 mi depending on air density) would have to fly faster than orbital velocity to derive sufficient aerodynamic lift from the atmosphere to support itself. At this point, air density is about 1/2,200,000 the density on the surface of the Earth (Marciacq et al. 2008)	As certain parameters, such as solar flux, magnetic index, and others are varied, the calculated altitude varies. However, the boundary to space is set at 100 km for ease of use. This is the most common and internationally used boundary [2], and was also the target altitude used by the Ansari X-Prize to build and launch a "spacecraft"	Fédération Aéronautique Internationale (FAI), International Air Sports Federation, US Aeronautic Association
73 mi (118 km ± 0.3km)	The midpoint of gradual transition over tens of kilometers from relatively gentle winds of the Earth's atmosphere to more violent flows of charged particles in space. As	This study examined space between 100km and 150 km. There is a gradual transition from magnetospheric to thermospheric control. This area is important	Found by Sangelli et Al., but not functionally used by an organization

	found with the Supra-Thermal Ion Imager measuring ion collision frequency and ion cyclotron frequency (Sangalli et al. 2009).	because it affects the transition of an object from aeronautic to astronautic flight control.	
76 mi (122 km)	Boundary used by NASA Mission Control as the point of reentry and at which atmospheric drag becomes noticeable.	There is a strong inverse relationship between altitude and atmospheric drag; growing exponentially with decreasing altitude. "Lowering a circular orbit altitude from 300 to 220 km implies a drag-induced orbit energy loss more than 4 times greater, resulting in altitude loss increase from 1.1 km to 4.5 km per day in the selected case" (Ceccanti). There is not one single point at which atmospheric drag because noticeable because it depends on the object and the reason for NASA using this demarcation is that it is the altitude at which the shuttle changes from astronautical control with thrusters to aeronautical control via air surfaces.	NASA Mission Control
80-93 mi (129-150 km)	The US Army training documents refer to the 80-93 miles zones as the lowest perigee attainable by an orbiting space vehicle. 80 miles is the	The lowest recorded orbit for a satellite was the Compton Gamma Ray Observatory that orbited the Earth one last time before reentry at a perigee	US Army training reference text

	lowest altitude at which an object in an elliptical orbit can complete at least one full revolution without propulsion and 93 miles is the lowest orbit an object in circular orbit can complete one full revolution.	of 93 miles in 1999. However this perigee is not sustainable for more than one full orbit around Earth (Harwood 2000). This orbit is unsustainable. In fact, it is not until 200 miles that an object can orbit without propulsion and not reenter Earth's atmosphere (Army Space Reference Text). Therefore the delimitating space at 80-93 miles is not significantly more accurate than any other definition give.

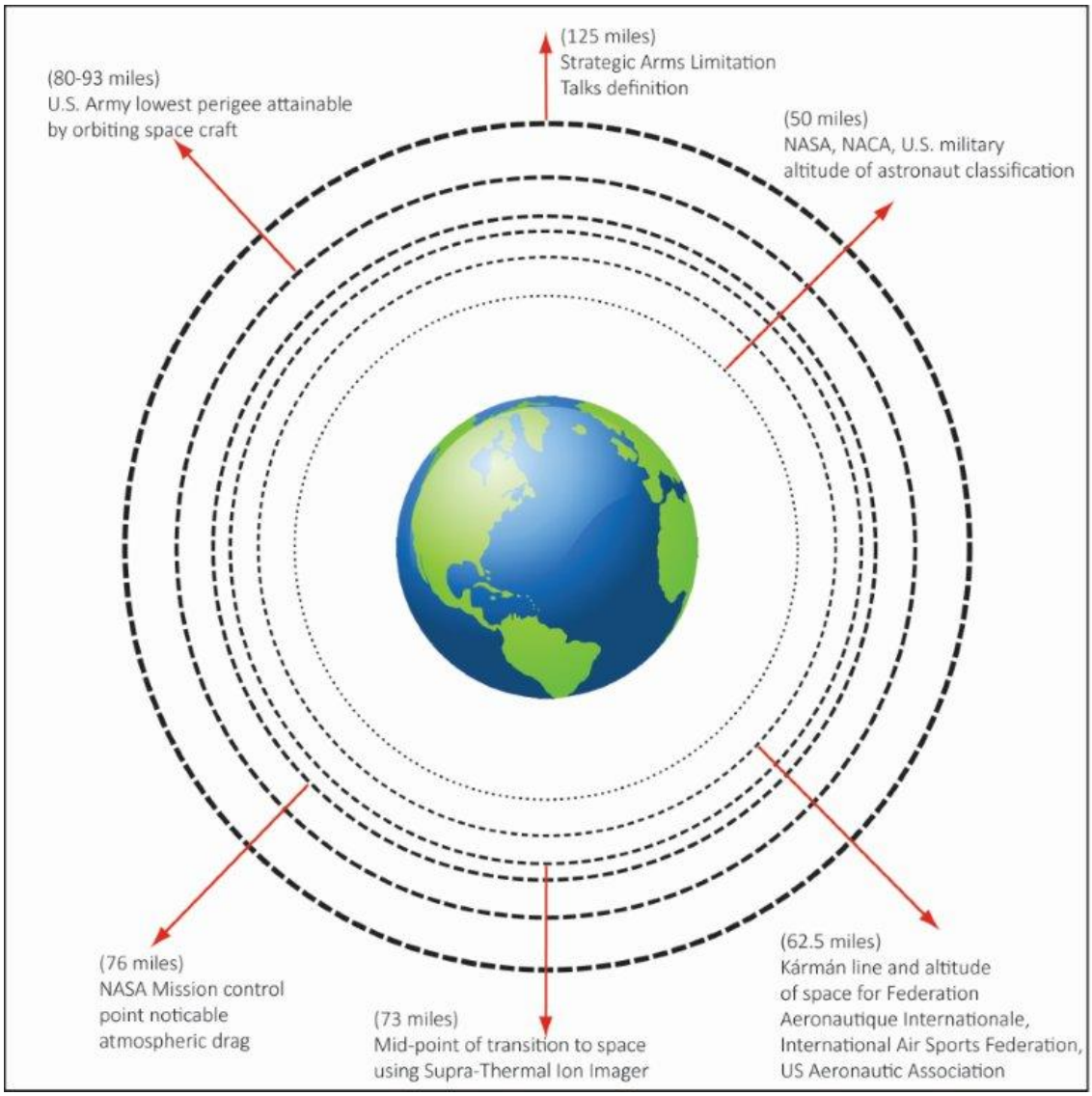

Figure 3: Pictorial Representation of the Range of Boundaries

C. Typical Arguments A*gainst* Having a Delimitation

Having discussed some of the boundaries proposed either scientifically or arbitrarily, it is worth discussing whether to promulgate one. There are arguments on both sides. We begin with the status quo – arguments against having one. The United Nations (UN) General Assembly, in the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (hereafter referred to as the Outer Space Treaty), does not specify a starting point for space. The definition of space in these treaties refers to "the exploration and use of outer space, including the Moon and other celestial bodies …" (United Nations 1966) without any further clarification of a boundary between airspace and outer space.

Some experts believe a definition of the boundary of space is impossible to create. Hans Haubold, senior program office at the UN Office for Outer Space Affairs (OOSA), noted that the atmosphere is too "fuzzy for a physics-based definition to ever be established" (Kois 2004). The atmosphere is indeed dynamic and fluctuates in density which makes any delimitation imprecise. For example, as discussed in Section B above, for reasons related to changes in air density, the Karman line fluctuates between 84-100 km.

It was also noted that the lack of a definition of space had not yet led to any adverse effects and that the definition, if implemented, could impede on development and growth of potential space technologies. This is the main concern of the United States and others as voiced for years in the Legal Subcommittee (LSC) of the UN Committee on the Peaceful Uses of Outer Space (United Nations General Assembly 2010). The U.S. position on the desirability of a lack of definition was clear:

> With respect to the question of the definition and delimitation of outer space … our position continues to be that defining or delimiting outer space is not necessary. No legal or practical problems have arisen in the absence of such a definition. On the contrary, the differing legal regimes applicable in respect of airspace and outer space have operated well in their respective spheres. The lack of a definition or delimitation of outer space has not impeded the development of activities in either sphere.
>
> We have not been persuaded by the reasons put forth for undertaking such a definition or delimitation. For example, some delegations support the notion of such a definition for its own sake. But without a practical problem to address, undertaking such a definition would be a risky exercise, as explained more fully below. Other delegations suggest that a definition or delimitation is somehow necessary to safeguard the sovereignty of states. However, we are aware of no issue of state sovereignty that would be solved by defining outer space (U.S. Department of State 2001).

This position has been restated as recently as 2014 (personal communication, September 11, 2014)

> The U.S. Delegation will continue to oppose any proposals to define or delimit outer space…. The U.S. Delegation may point out that many years of debate have not furthered LSC [Legal Subcommittee] understanding of delimitation issues and that no real-world problems have arisen during the more than 50 years of space use and exploration as a result of the absence of any definition/delimitation of outer space. To the contrary, attempts to establish an arbitrary line between airspace and outer space may create confusion or otherwise hinder the peaceful use and exploration of space. To date, the Federal Aviation Administration (FAA) licensing and regulation of reusable launch vehicles, including suborbital vehicles, have not been hampered by the absence of any delimitation of outer space.

The United Nations Scientific and Technical Subcommittee in 1968 had advised the Legal Subcommittee that it was currently impossible to identify a precise definition of outer space (United Nations 2002). Their findings were consistent with the United States stance; a lasting definition could not be made with current technologies, but a definition should be created in the future when relevant. It appears that based on the literature in the field, the desire to leave space undefined has not yet been an issue for most space-faring countries.

D. Typical Arguments *For* a Delimitation

In some ways, it is obvious why delimitation is needed – as per the 1919 Paris Convention, in airspace, states possess exclusive jurisdiction, and in space, there can be no exercise of sovereignty and territorial jurisdiction (Oduntan 2003). Knowing how high the sovereignty goes may be critical. In a recent session of the Legal Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (COPUOS), for example, the Netherlands, while it does not support delimitation, stated that, "Such [referring to a need to define a boundary] a need may arise in the future as a result of technological developments in space and aviation technologies, in particular the development of private commercial space flight and space tourism" (United Nations 2010).

The issue of the altitude to which sovereignty extends first became an issue in 1976 when through the *Bogota Declaration,* eight nations claimed Geosynchronous Earth Orbit (GEO) above their nation to be part of their national resources and therefore under their sovereign control (Journal of Space Law 1978). The declaration was not upheld internationally partially due to the extreme importance of geosynchronous orbit for communication and navigation, but also the equatorial nation's inability to protect their claimed "natural resource." In any case, Sputnik had previously set the precedent that space was international and not within sovereign air space, and the Bogota declaration was considered spurious. However, this incidence could have potentially been avoided had space been delimited prior to the declaration, and proponents of delimitation believe that a standard international definition will reduce such conflicts and tension in the future when pertinent issues arrive (Benko et al. 2013).

The arguments for delimitation have changed since the *Bogota Declaration*. Currently, nations do not doubt the placement of orbital air craft as international versus national territory, instead the issue today stems from increased traffic from spacecraft take-off and landing. Space craft launching or returning from orbit often travel through potential foreign air space to land at their desired location. For example, both the BRAUN satellite in 1988 and the U.S. Space Shuttle flew under 110 km altitude during landing (Benko 2013). A more recent example is the 2012 launch of a North Korean satellite. South Korea threatened to shoot down a North Korean satellite launch if it entered South Korean airspace (Strauss 2013). Fortunately for both parties, neither understood where exactly South Korea's air space ended.

A final argument for delimitation refers to the concept of "innocent passage"[3]. Innocent passage is a term that refers to maritime concept that grants a foreign nation access to territorial waters when the vessel is peaceful. The United Nations defines innocent passage as travel that is "not prejudicial to the peace, good order or security of the coastal State" (United Nations, Oceans and Law of the Sea. 1982). Currently, passage over nations for space travel is treated in a similar way to innocent passage. Nations are currently not required to notify neighboring nations of a launch or landing of space craft, regardless of the altitude at which the space craft will travel through (Benko 2013). However, a nation can make a claim to non-innocent passage through air space and claim that the spacecraft passage is not peaceful, which would allow that nation the sovereign right to deny passage with potential force (Ito 2011). If space is delimited, it would be clear at which point a nation would need to notify surrounding nations of launch or reentry. Potential situations of airspace passage denial would be avoided if space is delimited now.

E. Emerging Arguments for Considering Delimitation

As the previous section described, arguments for delimitation typically relate to potential disagreement about how to know when a spacecraft has entered a nation's airspace. In the early years of space flight, this was not an issue since there was only a small number of spacefaring nations, but in recent years, this issue may come to a head for two reasons. First, there is increasing participation from nations around the world, which has international implications. Second, there is increasing volume of sub-orbital traffic, which has both domestic and international implications. Each is discussed in turn below.

1. Increasing International Participation

Since 2003, 28 countries have increased their spending on space programs from a little as zero dollars to as much as $190 million as shown in the figure below. This increase in participation brings concern over the lack of current definition and regulation over upcoming space and suborbital technologies. As there is increasing participation in space related activities, the need to have firmer controls on space terms, including those related to boundaries, may need to be addressed.

[3] The concept of "innocent passage" is borrowed from the *1982 Law of the Seas* that stipulates that an innocent ship under certain circumstances can pass through sovereign waters freely.

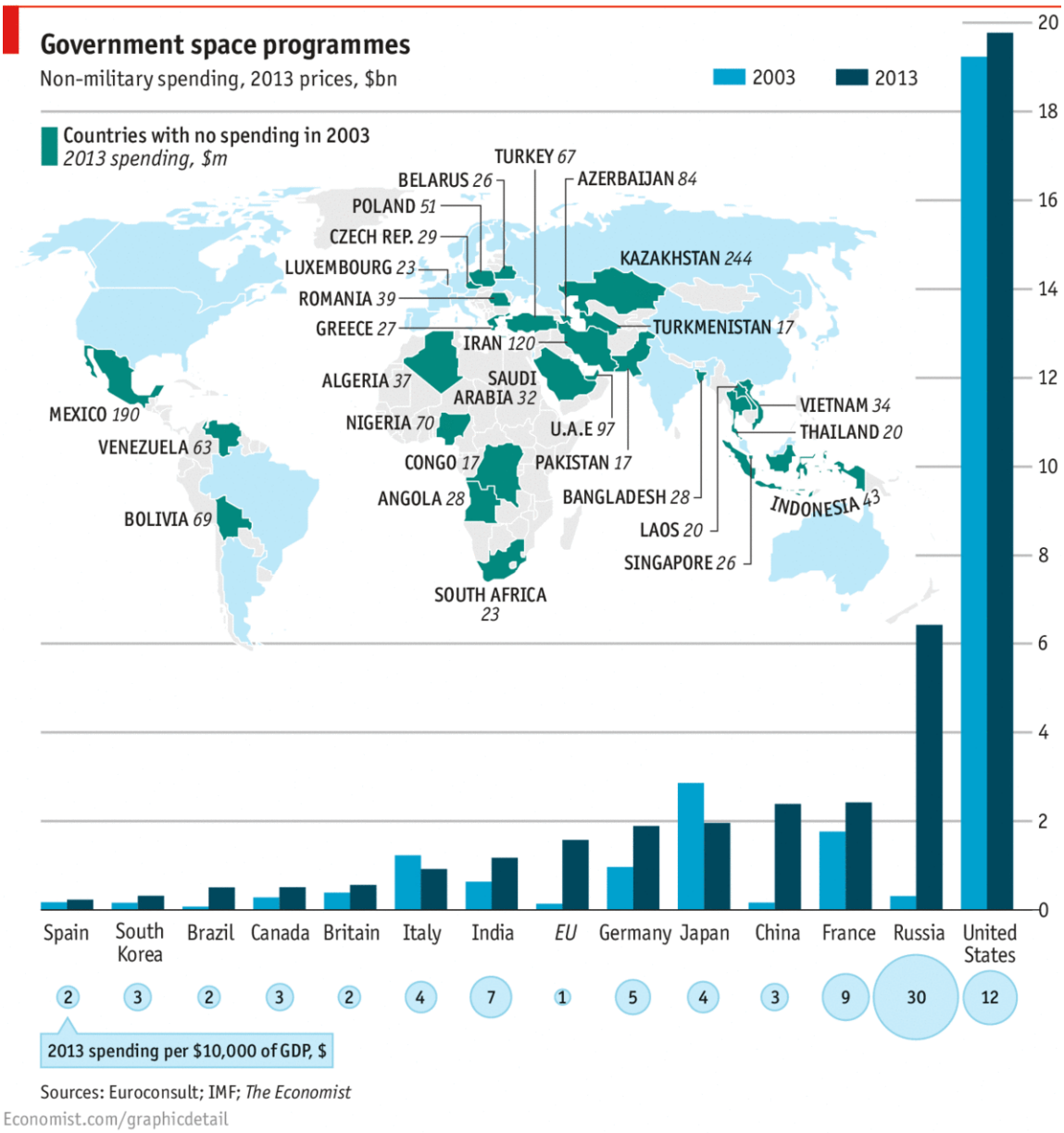

Figure 4: Increasing participation in space related activities

2. Increasing Sub-Orbital[4] Traffic

In recent years, suborbital activity has increased, both in the United States and in other countries. A recent study of suborbital reusable vehicles (SVRs) expect the frequency of SVR flights to increase from 1,100 at first year of operation to 1,500 seats over a 10 year period in an environment supporting growth (The Tauri Group 2012).

Is increasing suborbital traffic a reason to reconsider the issue of delimitation of space? As the Table below shows, several of the suborbital vehicles reach and exceed the delimitation lines discussed in Section B. Should they be regulated as air vehicles or space vehicles?

Table 2: Sampling of Suborbital Vehicles

Vehicle Type	Company	Vehicle	Year of Test Flights	Country of Origin	Altitude	Relevance to air-space boundary
Suborbital Launch Vehicle	Armadillo Aerospace	Hyperion	2014	United States	62.5 mi	Med
Suborbital Launch Vehicle	Blue Origin	New Shepard	TBD	United States	62.5 mi	Med
Suborbital Launch Vehicle	Masten Space Systems	Xaero	2011	United States	62.5 mi	Med
Suborbital Launch Vehicle	**UP Aerospace**	**SpaceLoft**	**2006**	**United States**	**99.5 mi**	**Hi**
Suborbital Launch Vehicle	Virgin Galactic	SpaceShipTwo	2010	United States	62.5 mi	Med
Suborbital Launch Vehicle	XCOR Aerospace	Lynx	2012	United States	62.5 mi	Med
Suborbital Launch Vehicle	German Aerospace Center	SpaceLiner	TBD	Germany	62.5 mi	Med
Suborbital Launch Vehicle	**ARCA**	**ARCASPACE**	**2016**	**Romania**	**112 mi**	**Hi**
Suborbital Launch Vehicle	Copenhagen Suborbitals	Multiple		Denmark		
Suborbital Launch Vehicle	Swiss Space Systems		2017	Switzerland	62.5 mi	Med
Suborbital Launch Vehicle	World View Enterprises	World View (Balloon)		United States	18.6 mi	Low
Suborbital-hypersonic	DARPA	XS-1 Program	2010	United States	Unknown	
Rocket powered aircraft	USAF	X-15	1960	United States	50 mi	Med
Suborbital Launch Vehicle	Orbital	Pegasus	1990	United States	BL	

[4] The Federal Aviation Administration in the United States defines a suborbital trajectory in legislation as "the intentional flight path of a launch vehicle, re-entry vehicle, or any portion thereof, whose vacuum instantaneous impact point does not leave the surface of the Earth" (Commercial Space Launch Activities of 2009).

The table above shows that there is suborbital activity not just in the United States but also abroad. As a result the international issues discussed in the previous subsection apply to suborbital traffic as well. For example, landing of suborbital launches will often require pass overs of foreign airspace during landing and launch, especially in Europe where nations share many borders. A lack of forethought and standards could lead to an inability of nations of complete suborbital operations over foreign regions.

F. Summary

In this paper, we have summarized a sampling of scientific and other definitions of the boundary of outerspace, and summarized the arguments for and against setting an internationally recognized boundary. The arguments against delimitation follow the line of reasoning that a lack of definition has not hurt space developments, and therefore no standardized definition is necessary. This is similar to the argument that lack of a definition of the term terrorism has not prevented nations from acting on terrorism related activities. Arguments for delimitation are related to international disputes regarding crossing perceived airspace. No arguments, however, have been made re the impact on the topic related to increasing suborbital traffic.

G. Acknowledgement

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