ARTICLES

THE NON KÁRMÁN LINE: AN URBAN LEGEND OF THE SPACE AGE

Thomas Gangale[*]

I. INTRODUCTION

The von Kármán line, named for the Hungarian-American aerodynamicist Theodore von Kármán, is commonly represented as lying at an altitude of 100 kilometers (62.1 statute miles) above the Earth's mean sea level. It is commonly represented by the *Fédération Aéronautique Internationale* (FAI), an international standard setting and record-keeping body for aeronautics and astronautics, as the boundary between the Earth's atmosphere and outer space. The von Kármán line has long been proposed as the basis for the legal delimitation between airspace and outer space; however, the available evidence suggests that von Kármán himself never proposed a boundary at 100 kilometers, and that his engineering work was misinterpreted by lawyers who were seeking an altitude of physical significance as the basis for delimitation. It is doubtful that a line of lasting significance based on aerodynamic theory alone, independent of technological assumptions, can be drawn.

For several reasons, the discussion on the legal delimitation of outer space is becoming more topical and important. Since the 1950s, a major role in that discussion has been played by references to the von Kármán line as a feasible boundary of lasting significance based on immutable physical principles; however, those references are inconsistent as to both the altitude of the line and the

[*] J.S.D. in space, cyber and telecommunications law, University of Nebraska-Lincoln College of Law, 2017; M.A. in international relations, San Francisco State University, 2006; B.S. in aerospace engineering, University of Southern California, 1978.

scientific reasoning supporting it. As interest in solving the delimitation issue rises within the legal community, it becomes increasingly important to investigate the origin of the von Kármán line, what it means, and how it came to be used. This article is in part a guided tour through legal history, and in part a discussion of the technical insignificance of the von Kármán line and why it should not be used as the basis for the legal delimitation between airspace and outer space.

II. THE 50-MILE LINE – U.S. EXPERIENCES

The issue underlying the discussion regarding the von Kármán line had drawn early attention in the United States in particular. Already in 1963, a footnote in McDougal *et al.*[1] discussed a Col. Schofield of the US Air War College, who in 1958 referred to a line at 50 nautical miles (303,800 feet, 57.54 statute miles, 92.59 kilometers). The altitudes and downrange distances reached by ballistic missiles were traditionally expressed in nautical miles, and this practice carried over into National Aeronautics and Space Administration (NASA) mission operations to also include the expression of apogees and perigees in such terms. Given that the United States established the use of nautical miles at the beginning of human spaceflight,[2] it is unfortunate that the literature on the legal delimitation of outer space has been extraordinarily imprecise, in that authors who express altitudes in terms of miles typically have neglected to specify whether they mean statute miles (5,280 feet) or nautical miles (6,076 feet).[3] Of course, authors who express altitudes in terms of kilometers did so without such ambiguity. Aviators only use statute miles to the extent that they also happen to have driver's licenses; statute miles are used on land, but nautical miles rule the sea and the air. As a former United States Air Force (USAF) aviator, this author's initial bias was to assume that other authors, despite mostly being non-aviators, meant nautical miles

---

[1] Myres S. McDougal et al., LAW AND PUBLIC ORDER IN SPACE, 334 n.450 (1963).

[2] NASA Public Affairs Office voice over commentary of Space Shuttle mission events switched from nautical miles to statute miles in 2000.

[3] The nautical mile is a "natural" unit of distance for navigation on Earth, since it is equal to a minute of latitude; since there are 60 minutes in a degree, it is $90 \times 60 = 5{,}400$ nautical miles from the equator to either pole. The Système Internationale's unit of distance is also based on the dimensions of Earth; it is 10 million meters from equator to pole.

implicitly; however, there are enough instances in the literature on the legal delimitation of outer space in which such an assumption is certainly incorrect. Thus, this author has concluded the opposite: that most jurists have used statute miles.

In fact, such authors are not the only imprecise ones. Air Force Instruction (AFI) 11-402, dated 13 December 2010, defines the criterion for being eligible to wear an astronaut badge on one's uniform:

> 2.3.2. A USAF rated officer qualified to perform duties in space (50 miles above the earth's surface) who completes a minimum of one operational mission is eligible for the astronaut qualifier (pilot astronaut, CSO [Combat Systems Officer] astronaut, observer astronaut, ABM [Air Battle Manager] astronaut, and flight surgeon astronaut). [4]

> 7.4.1.4. Member was assigned to perform aircrew member duties and completed a minimum of one operational mission in space (50 miles above the earth). In addition to eligibility for permanent award of the aircrew member badge, the individual is eligible for the astronaut qualifier.[5]

At first blush, this does not settle the issue; the instruction could mean either statute miles or nautical miles.[6] Indeed, it is strange that the instruction uses the word "miles," whatever the type of mile that is intended, as cockpit altimeters are calibrated in feet and that is what aviators use; as noted *supra,* the expression of altitude in nautical miles originated in the development of ballistic missiles. This instruction replaced Air Force Regulation (AFR) 60-13, "Aviation Service, Aeronautical Ratings and Badges," which in turn replaced AFR 35-13, which dated from 1962. On 17 July of that year, Robert M. White piloted North American X-15A No. 3[7] to an altitude of 95.9 kilometers. Since this was above 50 miles (nautical

---

[4] AFI 11-402, *Aviation and Parachutist Service, Aeronautical Ratings and Aviation Badges,* 19 (13 December 2010), http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi11-402/afi11-402.pdf.

[5] *Id.* at 103.

[6] A brother retired USAF officer related to this author that when he inquired on this author's behalf whether the AFI meant statute miles or nautical miles, the cognizant Pentagon office responded, "That's a good question. What do you think it should be?"

[7] Mark Wade, *X-15,* Encyclopedia Astronautica, http://www.astronautix.com/project/x15.htm.

as well as statute), the USAF awarded White an astronaut badge. Altogether, there were thirteen X-15A flights that exceeded fifty statute miles (80.45 kilometers, 264,000 feet) altitude, only four of which also exceeded fifty nautical miles (92.59 kilometers, 303,800 feet). Thus, the nine flights which were above fifty statute miles, but below fifty nautical miles, are of interest. Did the USAF award the pilots astronaut badges? It *did* award them to the USAF pilots, but not to the four civilian NASA pilots who participated in the program and who also flew above fifty statute miles.

> That inequity was rectified [on 23 August 2005] when retired NASA pilot Bill Dana, and family members representing deceased pilots John B. McKay and Joseph A. Walker, received civilian astronaut wings acknowledging their flights above 264,000 feet altitude - 50 miles high.[8]

Indeed, 264,000 feet is fifty statute miles.[9] So ultimately, the regulation was interpreted as meaning fifty statute miles, whatever its original intent.

The Federal Aviation Administration (FAA) followed the USAF's suit, getting its hand into the game not quite a year ahead of NASA.

> After SpaceShipOne won the $10 million Ansari X Prize competition last week, the man who took it into space, Brian Binnie, became the second person ever to receive a new kind of honor: commercial astronaut wings awarded by the Federal Aviation Administration for those who fly more than 50 miles above Earth.
>
> Michael W. Melvill, who flew the plane on its first two successful missions, in June and in September, is the only other person to receive the pin, which resembles those worn by spacefarers in NASA and the military.[10]

---

[8] Frederick A. Johnsen, *X-15 Space pioneers Now Honored as Astronauts,* Dryden Flight Research Center (23 August 2005), http://www.nasa.gov/centers/dryden/news/NewsReleases/2005/05-57.html#.UhVOO5h33dm.

[9] A number of Internet sources misreport the criterion for U.S military astronaut badges as 100 kilometers. *See e.g.,* Wikipedia, *Astronaut Badge,* https://en.wikipedia.org/wiki/Astronaut_badge.

[10] John Schwartz, *Now Earning Wings, a New Kind of Astronaut,* THE NEW YORK TIMES (12 October 2004), http://www.nytimes.com/2004/10/12/science/space/12astr.html.

Currently, the FAA has not issued formal regulatory guidance for the issuance of a Commercial Astronaut Certificate, but as an interim measure, it has established the practice of awarding 'Commercial Astronaut Wings' to commercial pilots who have demonstrated the requisite proficiency.[11] Thus, there is as of yet no FAA commercial astronaut rating, much less an FAA-certified training course, for such a rating; meanwhile, flying above fifty statute miles demonstrates the requisite proficiency.[12]

The question remains: what was the origin of the 50-mile number, whether statute or nautical? And, did it have a rational basis in aeronautics?

III. THE 275,000-FOOT LINE

According to lore, the Hungarian-American aerodynamicist Theodore von Kármán initially calculated circa 1957 an altitude of 275,000 feet (83.81 kilometers, 52.08 statute miles, 45.3 nautical miles), and he did so specifically for the purpose of indicating where airspace gave way to outer space. This is incorrect. Furthermore, from this point, like a multiple independently-targetable reentry vehicle (MIRV), this original idea appears to have fissioned off onto several independent trajectories.

Andrew G. Haley coined the term "Kármán line" in 1957, referring to 275,000 feet as:

> a critical jurisdictional line, marking the theoretical limit of air flight, which I term the Kármán Line. It must be noted with care that the exact location of this line of primary jurisdiction

---

[11] United States Government Accountability Office, *Commercial Space: FAA Should Examine How to Appropriately Regulate Space Support Vehicles*, *www.gao.gov/assets/690/681227.pdf*.

[12] *Remarks by Patricia Grace Smith, Associate Administrator for Commercial Space Transportation, Federal Aviation Administration,* Presentation of FAA commercial astronaut wings to SpaceShipOne pilot Mike Melvill, 21 June 2004, https://www.faa.gov/about/office_org/headquarters_offices/ast/media/PGS_Melvill_wings_2004-06-21.pdf. "Like U.S. military and NASA astronauts, the FAA now has its own way to recognize those who reach space in the United States through private endeavors. DOT/FAA Commercial Astronaut Wings are awarded to pilots and flight crew on board an AST-licensed launch vehicle on a flight that exceeds 50 miles." The inference of statute miles is by reference to U.S. military and NASA practices. *See also* Erik Seedhouse, ASTRONAUTS FOR HIRE: THE EMERGENCE OF A COMMERCIAL ASTRONAUT CORPS, 44 (2012): "…[T]he United States Air Force and the Federal Aviation Administration (FAA) consider an altitude of 80 km (50 miles, 264,000 feet) as the altitude to qualify as space flight."

> is not presented as an apodictic solution of the problem. The Kármán primary jurisdictional line may eventually remain, or, after due consideration of such developments as improved techniques of cooling and the discovery of more heat resistant materials, this line may be changed significantly. But, while these changes will be in the exact location of the Kármán Line, the existence of the line is certain and wherever the line is finally drawn will be the place where "airspace" terminates."[13]

From this passage, it is to be understood that the scientific rationale for the von Kármán line was aerothermal, that atmospheric friction was the principal barrier to aircraft attaining high altitudes. It can also be noted that Haley considered 275,000 feet to be a soft number which "may be changed significantly."[14] Despite this, he accepted as an article of faith that "the existence of the line is certain."[15] It is possible, although by no means certain, that the USAF's criterion of fifty miles for awarding astronaut wings derived from a rounding downward from 52.08 statute miles.

Elsewhere Haley stated:

> The basic advantage of a criterion such as the Karman Line lies in its practical application—it effectively separates the territory of air-breathing vehicles from that of rocket vehicles.[16]

Here, Haley invoked a different basis for the von Kármán line: a distinction in the methods of propulsion; however, in terms of aerodynamics, thrust is thrust. Although it is true that jet engines can operate at higher altitudes than piston-driven propeller engines, there is considerable overlap in the operational altitude regimes of jets and propeller aircraft; in turn, this is also true of jet-propelled "air-breathing vehicles" *versus* rocket-propelled "non-air-breathing

---

[13] Andrew G. Haley, *Space Exploration: The Problems of Today, Tomorrow and in the Future,*2 PROC. ON THE L. OF OUTER SPACE OF OUTER SPACE, 49, 50 (1959).

[14] *Id.*

[15] *Id.*

[16] Andrew G. Haley, *Survey of Legal Opinion on Extraterrestrial Jurisdiction,* paper given at the 11th Congress, International Astronautical Federation, Sweden, reprinted in Legislative Reference Service, Library of Congress, LEGAL PROBLEMS OF SPACE EXPLORATION, S. Doc. No. 26, 87th Cong., 1st Sess., 723 (1961).

vehicles."[17] Nor is the altitude limit of "air-breathing vehicles" set in stone; the advancement of supersonic combustion ramjet (scramjet) technology has long been considered the key to the development of single-stage-to-orbit vehicles, such as NASA's abandoned Rockwell X-30 National Aero-Space Plane.[18] Further blurring the dichotomy of aeronautics/air-breathing engines *versus* ballistic missile technology, sources in the Russian military have stated that a scramjet test on 12 February 1998 related to the development of a maneuverable ICBM warhead. In the United States, scramjet development achieved a milestone with the 1 May 2013 flight of the Boeing X-51 at Mach 5.1 (2,900 knots, 3,400 statute miles per hour; 5,400 kilometers per hour).[19] If there is a separation, either in speed or altitude, of the "territory of air-breathing vehicles from that of rocket vehicles," it has yet to be determined, and therefore no proposed line can have a "practical application."

The literature citing the von Kármán line as 275,000 feet, 52.08 statute miles, or 83.81 kilometers is extensive and fairly continuous: Gorove 1958,[20] Haley 1958,[21] Quigg 1958,[22] Cooper 1959,[23] Bookout 1960,[24] Seara Vázquez 1960,[25] Lipson and Katzenbach 1961,[26] Schrader 1962,[27] Haley 1963,[28] McDougal *et al.* 1963,[29]

---

[17] For example, the Messerschmitt Me-163 Komet, a rocket propelled fighter aircraft, entered service in 1944. *See* Mano Ziegler, ROCKET FIGHTER: THE STORY OF THE MESSERSCHMITT ME 163 (1976).

[18] Mark Wade, *X-30,* Encyclopedia Astronautica, http://astronautix.com/lvs/x30.htm.

[19] United States Air Force. *Factsheets: X-51A Waverider,* http://www.af.mil/About-Us/Fact-Sheets/Display/Article/104467/x-51a-waverider/.

[20] Stephen Gorove, *On the Threshold of Space: Toward a Cosmic Law Problems of the Upward Extent of Sovereignty*. 1 PROC. ON L. OUTER SPACE 69, 72 (1958).

[21] A. G. Haley, *Space Law—The Development of Jurisdictional Concepts,* 7 PROC. INT'L ASTRONAUTICAL CONG. 170 (1958).

[22] Philip Quigg, *Open Skies and Open Space,* 37 FOREIGN AFFAIRS 95 (October 1958).

[23] John Cobb Cooper, *The Problem of a Definition of "Air Space,"* 1 PROC. ON THE L. OF OUTER SPACE 38, 40 (1958).

[24] Hal H. Bookout, *Conflicting Sovereignty Interests in Outer Space: Proposed Solutions Remain in Orbit!, 7* MIL. L. REV. 23-49 (January 1960).

[25] Modesto Seara Vázquez, *The Functional Regulation of the Extra-Atmospheric Space,* 2 PROC. ON THE L. OF OUTER SPACE 143 (1960).

[26] Leon Lipson & Nicholas deB. Katzenbach, REPORT TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION ON THE LAW OF OUTER SPACE §636, §643 (1961).

[27] George D. Schrader, *National Sovereignty in Space,* 17 MIL. L. REV. 41, 52 (July 1962).

[28] Andrew G. Haley, SPACE LAW AND GOVERNMENT, 78-79, 98 (1963).

[29] McDougal et al., *supra* note 1, at 220, 264-265, 333.

Christol 1966,[30] Hyman 1966,[31] Johnson 1966,[32] Lachs 1966,[33] Smith 1969,[34] Taubenfeld 1969,[35] Lay and Taubenfeld 1970,[36] Mushkat 1970,[37] UNCOPUOS 1970,[38] Lachs 1972,[39] Haanappel 1977,[40] Perek 1977,[41] Rosenfield 1979,[42] Bridge 1980,[43] Gallagher 1986,[44] Orr 1997,[45] Dolman 2002,[46] Hobe 2007,[47] Dodge 2009,[48] and Gerhard 2011.[49]

---

[30] Carl Q. Christol, THE INTERNATIONAL LAW OF OUTER SPACE, 248 (1966).

[31] William A. Hyman, MAGNA CARTA OF OUTER SPACE, 188 (1966).

[32] Rodney W. *Johnson, Problems of Law and Public Order in Space,* 52 AM. BAR ASSOC. J. 6: 555, 556-557 (June 1966), http://www.jstor.org/stable/25723642.

[33] Manfred Lachs, *The International Law of Outer Space,* III RECUEIL DES COURS, 35 (1966).

[34] Delbert D. Smith, *The Legal Ordering of Satellite Telecommunication: Problems and Alternatives,* 44 IND. L. J. 3, 379 (1969), http://www.repository.law.indiana.edu/ilj/vol44/iss3/1.

[35] Howard J. Taubenfeld, *Outer Space: The "Territorial" Limits of Nations,* 38 FORDHAM L. REV. 1, 5 (1969), http://ir.lawnet.fordham.edu/flr/vol38/iss1/9.

[36] S. Houston Lay & Howard J. Taubenfeld, *The Law Relating to Activities of Man in Space,* 43 (1970).

[37] Marion Mushkat, *New Developments in Outer Space Law and Their Role in Increasing International Security,* ZAÖRV 123 (1970).

[38] U.N. Doc. A/AC.105/C.2/7, *The Question of the Definition and/or the Delimitation of Outer Space,* 44 (7 May 1970).

[39] Manfred Lachs, THE LAW OF OUTER SPACE: AN EXPERIENCE IN CONTEMPORARY LAW-MAKING, 83 (1972).

[40] Peter P.C. Haanappel, *Definition of Outer Space and Outer Space Activities,* 20 PROC. ON L. OUTER SPACE 53, 54 (1977).

[41] Lubos Perek, *Scientific Criteria for the Delimitation of Outer Space,* 5 J. SPACE L. 1:111, 114 (1977), http://www.spacelaw.olemiss.edu/jsl/pdfs/back-issues/jsl-5-1.pdf.

[42] Stanley B. Rosenfield, *Where Air Space Ends and Outer Space Begins,* 7 J. SPACE L. 2: 137, 139 (Fall 1979), http://www.spacelaw.olemiss.edu/jsl/pdfs/back-issues/jsl-7-2.pdf.

[43] Robert L. Bridge, *International Law and Military Activities in Outer Space,* 13 AKRON L. REV. 649, 651 (1980).

[44] Michael G. Gallagher, *Legal Aspects of the Strategic Defense Initiative,* 111 MIL. L. REV. 11, 20 (Jan. 1986).

[45] Shannon H. Orr, NATIONAL SELF-INTEREST IN THE COSMOS: A REGIME ANALYSIS OF OUTER SPACE, 59 (1997). M.A. thesis, University of Guelph.

[46] Everett Dolman, ASTROPOLITIK: CLASSICAL GEOPOLITICS IN THE SPACE AGE, 115 (2002).

[47] Stephan Hobe, *Legal Aspects of Space Tourism,* 86 NEB. L. REV. 439, 442 (2007).

[48] Michael S. Dodge, *Sovereignty and the Delimitation of Airspace: A Philosophical and Historical Survey Supported by the Resources of the Andrew G. Haley Archive,* 35 J. SPACE L. 1: 5, 27 (2009).

[49] M. Gerhard, *Space Tourism: The Authorisation of Suborbital Space Transportation,* in NATIONAL SPACE LEGISLATION IN EUROPE: ISSUES OF AUTHORISATION OF PRIVATE SPACE ACTIVITIES IN THE LIGHT OF DEVELOPMENTS IN EUROPEAN SPACE COOPERATION, 280 (Frans G. von der Dunk ed. 2011).

US Army Lieutenant Colonel Hal H. Bookout related a concise explanation of the von Kármán line in 1960:

> The X-2 rocket plane flight whereby Captain Ivan *[sic]* C. Kincheloe attained the altitude of 126,000 feet is cited by its proponent to illustrate the separate parts played by aerodynamic lift and centrifugal force. The flight is characterized as strictly an aeronautical adventure and not partaking of space flight. It is contended that at the altitude indicated, aerodynamic lift carries ninety-eight percent of the weight while only two percent is attributed to centrifugal force. In carrying forward this concept of measuring the separate contributions made to aerial flight by aerodynamic lift and centrifugal force, the Karman line is drawn at approximately 275,000 feet or 52 miles—where an object traveling in a so-called corridor of continuous flight at 26,000 feet per second is completely taken over by centrifugal force. At this point where "all" aerodynamic lift is said to be gone, the sovereignty of the underlying state would find a boundary "capable of physical and mathematical demonstration at a reasonably stable height."[50]

Arguably, the best recent assessment of Haley's original work on this subject, including his personal letters, was by Michael S. Dodge in 2009, who stated that the "von Kármán Primary Jurisdictional Line" is 275,000 feet.[51]

IV. THE 100-KILOMETER LINE

Haley himself was inconsistent in his references to the von Kármán line. From his initial citing of 275,000 feet,[52] a year later he referred to an agreement between delegates to the *Fédération Aéronautique Internationale* (FAI)[53] from the United States and the Soviet Union regarding a 100-kilometer line as a determination of space flight records as "this coincides with the Karman line theory."[54] Obviously, 275,000 feet (83.8 kilometers, 52.08 statute

---

[50] Bookout, *supra* note 24.

[51] Dodge, *supra* note 48.

[52] Haley, *supra* note 13, at 50.

[53] A nongovernmental organization, which therefore does not represent the official positions of governments.

[54] Andrew G. Haley, *Survey of Legal Opinion on Extraterrestrial Jurisdiction,* 3 PROC. ON THE L. OF OUTER SPACE 41 (1961).

miles) does not "coincide" with 100 kilometers (328,100 feet, 62.14 statute miles) in an exact sense. Similarly, McDougal *et al.* viewed the FAI line as "supporting" the von Kármán line without realizing the two were miles apart:

> In support of this altitude [of 275,000 feet/52 statute miles] it is also emphasized that agreement has been reached within the Federation Astronautique Internationale to the effect that for the purposes of keeping records the flight exceeding 62 miles (100 km) altitude will be considered as "space flight." [55]

It is not clear that the von Kármán calculation and the IAF number ever had anything to do with each other.[56] Antonio Ambrosini, the first chairman of the Legal Subcommittee of the Ad Hoc Committee on the Peaceful Uses of Outer Space, had urged a delimitation of outer space at 100 kilometers (62.14 statute miles) in 1958;[57] thus, this altitude might be more properly called the Ambrosini line. Alternatively, the genealogy of any proposed delimitation of outer space at approximately 100 kilometers altitude may be traced to John Cobb Cooper, who in 1951 suggested 60 statute miles (96.55 kilometers) as the upper limit of airspace; thus this altitude might be more properly called the Cooper line.[58] It may be that by 1960, there was more support in the FAI for the Cooper-Ambrosini line than for the von Kármán line. One may speculate that they were viewed as representing more or less the same idea, and thus misappropriating the famed aerodynamicist's name to grace the 100-kilometer line may have been either an innocent error of inclusion or a generous gesture to von Kármán. The effect, however, was

---

[55] McDougal *et al., supra* note 1, at 334. Imagine being able to persuade a traffic policeman that one had been "supporting" the 55 MPH speed limit while driving one's automobile at 62 MPH.

[56] This was not the first time that von Kármán's name was taken in vain. A 1940 report of the National Academy of Science stated that the gas turbine engine would never fly; this was a year after the Germans began flight-testing a prototype jet aircraft. Von Kármán wrote in his autobiography that he was very embarrassed about this because he was the chairman of the committee that was responsible for the report; he claimed that he was on travel on the day they wrote up the final draft. *See* Peter J. Mantle, *Introducing New Technology into the Navy,* in LECTURES ON ADVANCED TECHNOLOGIES AT U.S. NAVAL ACADEMY, 1985-1987, 41-62, 53 (A. E. Bock ed., 1989).

[57] U.N. Doc. A/C.1/PV.982, 56 (12 November 1958).

[58] John Cobb Cooper, *High Altitude Flight and National Sovereignty,* 4 INT'L L. Q. 41: 411 (1951).

to imply a technical basis for the 100-kilometer line which did not exist.

V. THE 90-KILOMETER LINE

Elsewhere, Haley referred to "the occurrence of free molecular oxygen in the atmosphere up to 90 km (295,000 ft). It is only above this level (called the von Kármán Line) . . . ."[59] Here, he not only introduced a third altitude, but also a fourth technical rationale.[60] The "occurrence of free molecular oxygen" had nothing at all to do with an alleged aerothermal barrier, nor to the air-breathing/non-air-breathing propulsion dichotomy, nor to the calculation of aerodynamic lift *versus* centrifugal force.

VI. THE 60-KILOMETER LINE

That Haley had no strong feeling either way is further suggested by the following passage based on information provided by Austrian aerospace engineer Eugen Sänger, who placed the limits "of aeronautics proper at about sixty kilometers, or 37.3 miles:"[61]

> [I]n scientific terms there are three distinct regimes of flight, each possible within certain ascertainable, but by no means ascertained, limits: the aeronautical regime; the corridor of atmospheric escape and the astronautic regime.[62]

McDougal *et al.* wrote in 1963:

> The "escape corridor" of Haley extends from the altitude of 37.3 miles above the earth's surface to "about 3,725 miles." In this corridor operate ballistic missiles and "rocket vehicles" which represent "the transition from aeronautics to astronautics," whereas satellites are in the "domain of pure astronautics upon reaching orbital velocity."[63]

---

[59] Andrew G. Haley, *Space Exploration: The Problems of Today, Tomorrow and in the Future,* 2 PROC. ON THE L. OF OUTER SPACE 49 (1959).

[60] As well as a second name for it: the "von Kármán line" *vs.* the "Kármán line."

[61] Andrew G. Haley, *The Law of Space and Outer Space,* 33 SO. CAL. L. REV. 370, 373-374 (1960).

[62] *Id.*

[63] McDougal *et al., supra* note 1, at 333-334. It may be observed that here Haley appears to have espoused a mixture of the functional and spatial approaches.

Thus, a fourth altitude was introduced that was attributed to Haley (perhaps erroneously) and to von Kármán by implication.

VII. BLURRED LINES

In sum, the evidence suggests that the von Kármán line of 275,000 feet was just one of several ideas that Haley considered, so it is doubly ironic that it has since taken such significance and at the wrong altitude (100 kilometers). In 1963, McDougal *et al.* referred to the von Kármán line as 275,000 feet,[64] while also citing separately the FAI line of 100 kilometers. Nevertheless, from the 1960s to date, numerous sources have cited 100 kilometers as being the von Kármán line. It may be suggested that later references to 100 kilometers are explainable as someone having revised von Kármán's figure upward to the value that has since come to be widely reported. If this were so, the question would be whether this upward revision was arrived at via valid aerodynamic data and/or credible physical assumptions, or whether it merely reflected some desire for a rounder and higher number without a scientific basis. What appears to have happened is that the FAI's 100-kilometer line came to be associated with von Kármán; however, this author has found no evidence of any connection between von Kármán himself and the FAI line; rather, Haley declared that the FAI line "coincides with the Kármán line theory."[65] This suggests that reference to the 100-kilometer line as the von Kármán line is a misnomer, an urban legend that has developed in the course of the past half century and which has now become a "just so" story. The inaccuracies in the reminiscences of S. Sanz Fernández de Córdoba, president of the FAI, bolster this conclusion:

> A lot of calculations were made, and finally it was reached the conclusion, accepted by all scientist involved, that around an altitude of 100 km, the boundary could be set. By the way, most calculations, which I could see at the time, were using nautical miles for altitude. That was probably because it was the only unit of length more or less common at the time . . . So the altitude decided upon had a very uneasy number to remember. It

---

[64] *Id.* at 264-265.

[65] Haley, *supra* note 16.

> was apparently Von Karman himself who realised, and proposed to the rest, the very round number of 100 Km (very close to the calculated number). The rest of the people eagerly accepted it.
>
> The 100-Km altitude, ever since named the "Karman Line", came thus into existence as the boundary separating Aeronautics and Astronautics.[66]

Meanwhile, in 1958, Haley, in his position in the International Astronautical Federation (IAF, not to be confused with the FAI; Haley was president 1957-1958 and general counsel 1959-1963) was campaigning for a "definition of airspace:"[67]

> I urge that at a plenary session of the Congress, the President of the International Astronautical Federation be authorised to appoint a Committee of seven persons, consisting of four physicists and three lawyers, who will draft a definition of "airspace" and recommend a rule delimiting airspace jurisdiction, such definition and rule to be supported by a statement of Findings of Fact and Conclusions of Law. The resolution should be transmitted to the attention of the Secretary-General of the United Nations and to the Secretary-General of the International Civil Aviation Organization (ICAO), with the statement that the Committee will cooperate with the appropriate officials of said organizations. [68]

In 1960, Haley reported an agreement on 100 kilometers in the FAI. However, if von Kármán had any involvement in this, why would Haley and McDougal *et al.* have referred to the von Kármán line as 275,000 feet in 1963, the year in which von Kármán died? No evidence has been found that von Kármán repudiated the

---

[66] S. Sanz Fernández de Córdoba, *100km Altitude Boundary for Astronautics,* Fédération Aéronautique Internationale (2004), http://webcache.googleusercontent.com/search q=cache:L8F2R7qfsnsJ:www.fai.org/sig-slider-news/111-icare/35876-100km-altitude-boundary-for-astronautics+&cd=1&hl=en&ct=clnk&gl=us.

[67] National Center for Remote Sensing, Air, and Space Law, ANDREW G. HALEY (1904-1966) (2012), http://www.spacelaw.olemiss.edu/archives/haley/bio.html. It is noted in passing with some irony that, as opposed to a "definition of outer space," as one might expect of the IAF, an astronautics organization, Haley instead requested "definition of airspace," which more properly would have been in the purview of the FAI as an aeronautics organization. Of course, what is not below a line is above the line, *et vice versa.*

[68] Haley, *supra* note 21, at 174.

275,000-foot line, just as no evidence has been found that he proposed a line in any publication during his lifetime. Also, why in 1963 did McDougal *et al.* cite the FAI line of 100 kilometers as a number which was distinct from the von Kármán line of 275,000 feet? The evidence suggests that the von Kármán line of 275,000 feet (83.81 kilometers) and the IAF line of 100 kilometers are two distinct items that have been conflated. Francis Lyall and Paul Larsen[69] provided the ultimate expression of this conflation, referring twice to the von Ka□rma□n line as "100 km/62 miles (275,000 ft)," thereby having it both ways.

Aside from Haley's own four technical descriptions of the rationale for the von Ka□rma□n line, other authors have described it inaccurately. Perek expressed it as the "theoretical limit of air flight at an altitude where aerodynamic lift is exceeded by the centrifugal force. This happens at about 84 km."[70] Centrifugal force exceeds aerodynamic lift when it accounts for more than half of the total lifting force on the vehicle, this could occur as low as 64 kilometers, depending on the assumed lift coefficient. Halstead even mischaracterized the 100-kilometer limit as "the lowest altitude at which Earth orbit can be maintained by a satellite, a somewhat randomly selected altitude of 100 kilometers."[71] Actually, Halstead's misrepresentation of the von Ka□rma□n line was a description of a competing theory for the delimitation of outer space: the lowest perigee of a satellite.

The Hungarian jurist Gyula Gál wrote in 1961:

> According to a theory of Haley, the legally relevant line starts where, in aviation, the aerodynamic factor is replaced by the Kepler force. If, for instance, a body proceeds at an altitude of 80 kilometers with a speed of 10,000 meters per second, the former decreases to 0, and the range of the effect of the latter begins. This limit creates a new physiological-psychological situation which requires a new legal regulation. The Haley line,

---

[69] Francis Lyall and Paul B. Larsen, SPACE LAW: A TREATISE, 167 (2009).

[70] Perek, *supra* note 41, at 122.

[71] C. Brandon Halstead, *Prometheus Unbound? Proposal for a New Legal Paradigm for Air Law and Space Law: Orbit Law,* 36 J. SPACE L. 1: 143, 153 (2010).

> however, is a mathematical function of altitude and speed, and changes together with these.[72]

Johannes Kepler's laws were a purely mathematical description of planetary motion without ascribing any "force" as the cause of the planets' behavior,[73] thus the so-called "Kepler force" is a misnomer. It was Isaac Newton's laws of motion which stated that mass *(any* mass, not solely planets) had the property of inertia, which in circular motion manifests as centrifugal force. His law of universal gravitation stated that any mass also generated gravitational force.[74] Although the cited altitude of 80 kilometers can be seen as a rounding down from 275,000 feet (83.81 kilometers), the reference to the speed of 10,000 meters per second requires some explanation. If one accepts the definition of the von Ka□rma□n line as being a combination of altitude and speed where aerodynamic lift becomes zero and a vehicle is supported entirely by centrifugal force, a vehicle at 80 kilometers altitude would require a speed of 7,910 meters per second to orbit Earth by inertia alone (neglecting atmosphere entirely). The speed cited by Gál is closer to escape speed, about 11,000 meters per second (depending on altitude) - the speed at which an object leaves Earth orbit and is captured by the Sun's gravity. This speed is not at all relevant to the von Ka□rma□n line.

Inaccuracies abound in Nicolas Mateesco Matte's 1969 account:

> Dr. von Karman reached the conclusion that the altitude of about 85 kilometers... is the limit at which the aerodynamic displacement ceases and the force of the Kepler laws begins. The Karman line is the foundation of the criterion of the ascensional pressure. However, this "Karman primary jurisdictional line" is now placed at a height of about 100 kilometers, according to new scientific research. Bloomfield considers that the

---

[72] Gyula Gál, *Air Space and Outer Space,* UNITED STATES SENATE SYMPOSIUM ON LEGAL PROBLEMS OF SPACE EXPLORATION, 87th Cong., 1st session, Senate Doc. 26, 1141, 1148 (1961).

[73] Curtis Wilson, *Kepler's Laws, So-Called* (May 1994). 31 HAD NEWS, Historical Astronomy Division, American Astronomical Society.

[74] Millard F. Beatty, PRINCIPLES OF ENGINEERING MECHANICS: VOLUME 2 DYNAMICS—THE ANALYSIS OF MOTION, Volume 33 of Mathematical Concepts and Methods in Science and Engineering (2005).

> Karman line of 55 miles is already obsolete since the X-15 has extended this limit. The Dyna-Soar will travel at speeds of 16,000 miles an hour at an altitude of about 60,000 miles, circling the world in 90 minutes, and will pass from the region of air to that of space.[75]

Again, there is no "force of the Kepler laws." Moreover, the term "ascensional pressure" is unknown to this aerospace engineer, but it may have been an attempt to refer collectively to the upward forces that act on a hypersonic airplane: aerodynamic lift and centrifugal force (a manifestation of Newtonian inertia). It may be noted that Mateesco Matte alluded to an earlier version of the von Ka□rma□n line as 85 kilometers (52.82 statute miles) and as 55 statute miles (88.51 kilometers), both numbers being somewhat above 275,000 feet (52.08 statute miles, 83.81 kilometers). Mateesco Matte did not indicate who subsequently placed the von Kármán line at 100 kilometers. The flight of the X-15A[76] above the von Kármán line of 275,000 feet did not render the line obsolete, since it flew above 275,000 feet due to the thrust of its rocket engine, not due to aerodynamic lift alone. The Boeing X-20 Dyna-Soar[77] was to have been launched on a Martin Marietta Titan IIIC rocket,[78] so its ascent into orbit would have been irrelevant to the von Kármán line. Without going into the mathematics, for the X-20 to have traveled "at speeds of 16,000 miles an hour at an altitude of about 60,000 miles, circling the world in 90 minutes" would have violated Kepler's third law of motion, but in fact, the X-20 never traveled at any speed, since the US Department of Defense canceled the program in 1963, six years before the publication of Mateesco Matte's book.

---

[75] Nicolas Mateesco Matte, AEROSPACE LAW, 30-31 (1969).

[76] Mark Wade, *X-15,* Encyclopedia Astronautica, http://www.astronautix.com/x/x-15a.html.

[77] Mark Wade, *Dynasoar,* Encyclopedia Astronautica, http://www.astronautix.com/d/dynasoar.html.

[78] Mark Wade, *Titan 3C,* Encyclopedia Astronautica, http://www.astronautix.com/t/titaniiic.html.

VIII. THE SEARCH FOR THE SOURCE

So, what of von Kármán's own publications, and his mention of an altitudinal line? Hugh L. Dryden, who was Director of the National Advisory Committee on Aeronautics from 1947 to 1958 and Deputy Administrator of NASA from 1958 to 1965, did not mention the von Kármán line in his extensive biographical memoir of von Kármán.[79] Dryden would certainly have been aware of the von Kármán line had it been among von Kármán's own publications; neither has this author found a publication authored by von Kármán himself that documents any calculation regarding this.

At a 1957 conference (proceeding published in 1958), Haley cited a 1956 paper by von Kármán:

> As I have pointed out in earlier papers, Dr. von Kármán has suggested methods of formulating the jurisdiction of space law. Last spring he told me that he had delivered a paper at a luncheon at the University of California, Berkeley, entitled "Aerodynamic Heating—the Temperature Barrier in Aeronautics," and in that paper he had occasion to use a diagram made by Masson and Gazley of the Rand Corporation showing the possible ranges for continuous flight in the velocity-altitude coordinate system. Later on, he sent me a copy of his paper which contains the Masson and Gazley diagram. He said that this diagram, although designed to show the variation of velocity versus altitude for various values of dynamic pressure and equilibrium pressure, in the hands of a skilled person could readily be used to show the regimes of atmospheric and extra atmospheric flight and to depict the jurisdictional boundary lines thereof.
>
> I have unskillfully redone the Masson and Gazley diagram (see Fig. 1) to indicate curves showing the high altitude sounding rocket regime, the earth orbital satellite regime and the Kepler regime (earth escape velocity), and some supernumerary information, but most importantly, I have shown what I now call the Kármán primary jurisdiction line.
>
> I have reproduced the Masson and Gazley right side curve—the so-called temperature barrier, or heat barrier—simply to

---

[79] Hugh L. Dryden, THEODORE VON KÁRMÁN: 1881-1963 (1965). Washington: National Academy of Sciences, http://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/von-karman-theodore.pdf.

show the present state of the art, and thus arbitrarily to delimit the corridor of continuous flight. This line has nothing to do with the jurisdictional question as improved techniques in cooling and discovery of heat resisting materials will undoubtedly change this curve.

Fig. 1 is intended to be illustrative, and it is not presented as an apodeictic solution of jurisdictional boundary lines. The Kármán primary jurisdictional line may eventually actually remain as shown on Fig. 1 or, after due consideration, the line may be significantly changed. In any event, this is the line at which "airspace" terminates.[80]

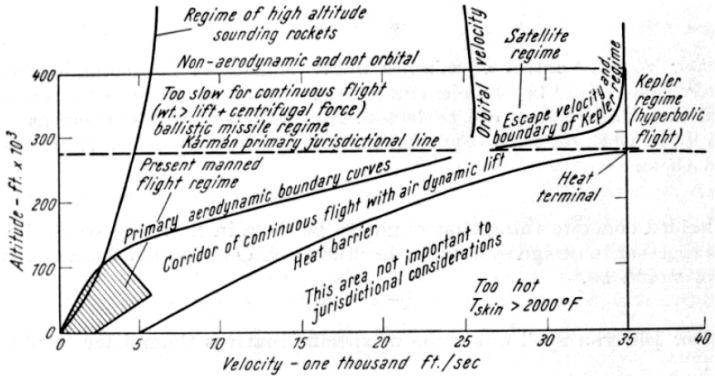

Figure 1: Diagram Showing Regimes of Atmospheric and Extra-Atmospheric Flight and Depicting the Jurisdictional Boundary Lines. *Source:* Haley 1958, at 274

Haley's diagram depicts the "corridor of continuous flight" to which Bookout referred.[81] Haley referred to the "high altitude sounding rocket regime, the earth orbital satellite regime and the Kepler regime (earth escape velocity)" in relation to the "Kármán primary jurisdiction line."[82] This is far from being an unambiguous statement that the line is where aerodynamic lift is completely taken over by centrifugal force. Simultaneously, Haley dismissed

---

[80] Haley, *supra* note 21, at 174-175.

[81] Bookout, *supra* note 24.

[82] Haley, *supra* note 21 at 174-175.

the "so-called temperature barrier, or heat barrier" as having "nothing to do with the jurisdictional question as improved techniques in cooling and discovery of heat resisting materials will undoubtedly change this curve;" yet the 1956 von Kármán paper, which Haley cited, dwelt on exactly this: the problems of aerodynamic heating on vehicles traveling at hypersonic velocities.[83] Von Kármán's paper contained a simpler version of the Masson and Gazley diagram. Figure 2 shows no horizontal altitude line of any kind, much less one which is either a barrier to aerodynamic flight or is "jurisdictional," nor does it depict "escape velocity and boundary of Kepler regime," as did Haley's version. The text of von Kármán's paper contained no reference to any specified altitude, and the one barrier he mentioned was "the temperature barrier" as it related to materials which were then known:

> The upper limit for the velocity is computed in this diagram somewhat arbitrarily. The main engineering problem consists of finding methods that allow an extension of the temperature barrier toward higher velocities. The heat emission in continuous flight by radiation varies at a rapid rate as the surface temperature increases and also varies with the altitude. Unfortunately, at surface temperatures permissible for current materials, the radiation represents a small amount in comparison with the heat input to be expected. Therefore, artificial means are necessary to reduce the heat input or to transfer heat from the airplane or missile to the surrounding space.[84]

---

[83] Theodore von Kármán, *Aerodynamic Heating—The Temperature Barrier in Aeronautics,* PROC. HIGH-TEMPERATURE SYMPOSIUM, BERKELEY, CALIFORNIA (1956).

[84] *Id.* at 141-142.

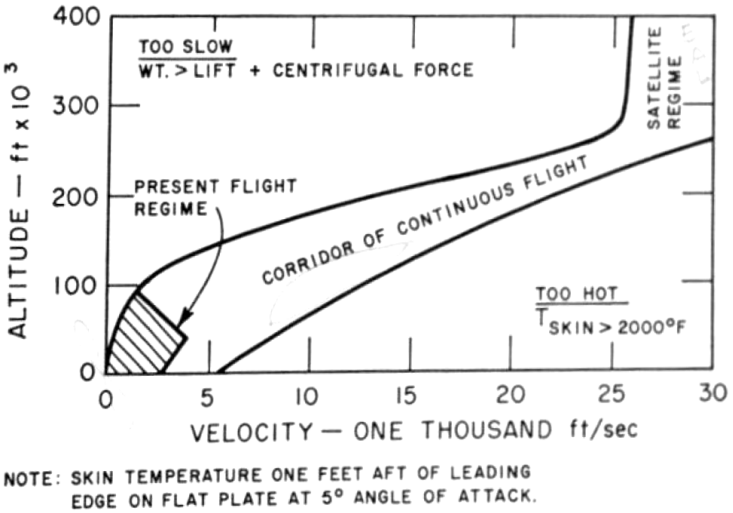

Figure 2: Variation Versus Altitude for Various Values of Dynamic Pressure and Equilibrium Temperature. *Source:* Von Kármán 1956, at 141

What is certain is that von Kármán's 1956 paper included a diagram which contained no horizontal line whatsoever; it would not have made sense to, since he indicated in his article that the curves in the diagram, although based on his long experience, were "somewhat arbitrary." A year later, Haley presented a redrawn diagram at a conference, in which he had "penciled" his proposed "Kármán primary jurisdiction line" at 275,000 feet. This is the proverbial "smoking gun;" von Kármán's 1956 paper depicted the "weapon" as it existed just before it was fired, and Haley's 1957 conference presentation depicted the "smoke" wafting from the end of the barrel.

It may be that Haley interpreted the point of inflection in Figure 1 (around 250,000-280,000 feet) at which the upper line delimiting the "corridor of continuous flight" bends straight upward from a previously rather gradual slope, coupled with the area designated as the "satellite regime," as a kind of "turning point" legitimizing a transition from legal airspace to legal outer space. However, this is pure speculation, as Haley did not explain any rationale for his 275,000-foot line in relation to this. In any case, both boundaries of

the "corridor of continuous flight" depended on the state of the art of materials science in 1956. The lower boundary, labeled the "heat barrier," depended on the ability of a vehicle to withstand heat loading, and the upper boundary, labeled "primary aerodynamic boundary curves," depended on a vehicle's weight *versus* its forward velocity. Assumptions inherent in these curves, which may have been valid in 1956, ceased to be valid as aerospace technology progressed, as will be explained in more detail *infra*. It may be that the von Kármán line had its genesis in an "Ask Yurij" scenario.[85] Haley asked von Kármán a question for which there was no documented answer,[86] so von Kármán jotted down a "back of the envelope" answer (Figure 2) which satisfied Haley, but which he may have misunderstood. Von Kármán returned to his real work, and a legend was born.

The closest thing to a statement by von Kármán regarding the line bearing his name is the following passage:

> Where space begins . . . can actually be determined by the speed of the space vehicle and its altitude above the earth. Consider, for instance, the record flight of Captain Ivan *[sic]* Kincheloe in an X-2 rocket plane. Kincheloe flew 2000 mile per hour at 126,000 feet, or 24 miles up. At this altitude and speed aerodynamic lift still carries 98 per cent of the weight of the plane, and only two per cent is carried by centrifugal force, or Kepler Force, as the space scientists call it. But at 300,000 feet or 57 miles up this relationship is reversed because there is no longer any air to contribute lift. Only centrifugal force prevails. This is certainly a physical boundary, where aerodynamics stops and astronautics begins, and so I thought why should it not also be a jurisdictional boundary? Haley has kindly called it the Kármán Jurisdictional Line. Below this line space belongs to each country. Above this level there would be free space.[87]

---

[85] As described by Sheryl L. Bishop and Marilyn Dudley-Flores in a personal communication, "Ask Yurij" refers to an apocryphal situation in the Russian space program in which the answer to a technical question cannot be found in documentation, thus the inquirer is handed off to a reputed expert on the subject, the proverbial Yurij.

[86] Haley and von Kármán had known each other at least since 1942, when Haley drew up the articles of incorporation for Aerojet Corporation, of which von Kármán was one of its founding engineers and briefly its first president; Haley succeeded von Kármán as president of Aerojet later that same year.

[87] Theodore von Kármán, with Lee Edson, THE WIND AND BEYOND, 343 (1967).

This passage is notable for several reasons. For one thing, this autobiography was published four years posthumously, which raises the question as to how much the ghost writer rewrote material based on von Kármán's notes without his being able to validate the book's technical content. Also, it perpetuates the controversy as to whether the von Kármán line had its origins in aerothermal concerns or in Newtonian inertia (so-called "Kepler Force"). Another point is that Iven Kincheloe's flight in a Bell X-2[88] occurred on 7 September 1956 (Bookout[89] referred to the same flight in 1960). It can be inferred that von Kármán's notes date from no later than 7 March 1961, when X-15A pilot Robert White broke both Kincheloe's speed and altitude records (White had broken the individual records on separate flights the year before; 3,397 kilometers per hour 1,834 knots, 2,111 statute miles per hour) on 12 May 1960 (41.605 kilometers or 25.854 statute miles on 12 August 1960). Then, of course, there is the fact that the passage *supra* references 300,000 feet (91.43 kilometers, 56.82 statute miles) and neither 275,000 feet, 90 kilometers, nor 100 kilometers, three altitudes which Haley cited. This creates additional doubt, rising to the level of reasonable doubt, as to where the von Kármán line was actually supposed to be. Did von Kármán come up with one number (300,000 feet) circa 1956, but suggest another (275,000 feet) to Haley in 1957, or did von Kármán come up with one number (275,000 feet) circa 1956, and relay it to Haley, but calculated another (300,000 feet) at some later date, or did Haley interpret von Kármán's 1956 diagram as implying a line at 275,000 feet without von Kármán's having specified this altitude? Added to the muddle is the true origin of the 100-kilometer line, in which Haley may have had some involvement, although there is no evidence that von Kármán did.

IX. A CONCEPTUAL-LEVEL ANALYSIS

Most remarkable is that von Kármán's calculations, whether based in aerothermal issues or in Newtonian mechanics, have yet to see the light of day, despite the enormous importance that has been imputed to the line that bears his name. All that is extant is

---

[88] Henry Matthews, THE SAGA OF THE BELL X-2, FIRST OF THE SPACESHIPS (1999).

[89] Bookout, *supra* note 24.

Figure 2, in which the curves depicted therein were drawn somewhat arbitrarily by von Kármán's own admission. An exhaustive technical analysis of the von Kármán line, based in Newtonian mechanics and aerodynamics, is beyond the scope of the present article; however, the relevant technical issues can be discussed on a conceptual level without mathematical rigor.

Stipulating for the moment that the altitude of the von Kármán line was based on aerothermal problems, the advance of materials science has certainly overtaken any such calculation. The thermal protection blankets and tiles used on the Space Shuttle did not exist in 1956, although carbon phenolic ablative materials were being developed for ballistic missile reentry vehicles and for recoverable spacecraft, this technology was in its infancy. An aeronautical application of the latter technology, in the form of an X-15A with a complete heat-resistant ablative coating, did not take to the air until 28 June 1964.[90]

More credible, and certainly most often cited, is that the altitude of the von Kármán line was based on the dominance of Newtonian inertia over aerodynamic lift in a specified speed regime, resting on the idea that at a certain altitude, an airfoil[91] must have so much speed in order to produce lift that centrifugal force takes over.

If an aerodynamic vehicle were to exceed the von Kármán line, could it be said to have reached the lower limit of outer space? If it were to shut down its engine, drag would decelerate it, lift would decrease, and the vehicle would descend. No vehicle could maintain its speed and height at this altitude by inertia alone. This would also be true of an aerospace vehicle which achieved an altitude and speed one kilometer above the von Kármán line by using its engine to counter not only drag but weight as well; once its engine were shut off, drag would decelerate it and the vehicle would descend. So, there is no justification here for concluding that there is a definite theoretical limit.

Well, but wait a minute, would not such a vehicle have centrifugal force "take over?" Take over what? Centrifugal force can be

---

[90] *Richard Tregaskis, X-15 DIARY: THE STORY OF AMERICA'S FIRST SPACE SHIP (2000).*

[91] An airfoil is the cross-sectional shape of a wing, blade (of a propeller, rotor, or turbine), or sail. The motion of this shape through air produces aerodynamic force.

thought of as an upward force (actually the story is more complicated, an interaction of the vehicle's inertia and Earth's gravity), as is aerodynamic lift, but drag is a backward force, acting to decelerate the vehicle's forward motion, against which forward thrust must be continuously applied in order to maintain speed. The slower the forward motion, the less centrifugal force, and the vehicle descends. Anything that is incapable of maintaining straight and level flight at a specified altitude if not under continuous thrust is obviously in the atmosphere and can scarcely be regarded as being in outer space.

Finally, it is untrue that aerodynamic lift is impossible above the von Kármán line, as is sometimes reported.[92] This is demonstrated in Figure 3. The dashed line curve is the reentry profile for a spherical reentry vehicle, such as Vostok. Being a sphere, it develops no lift but is subject to drag, and of course, having mass, it is subject to acceleration in a gravity field. Thus, the shape of the dashed line curve is due to drag decelerating the forward motion of the vehicle and due to gravity accelerating the vertical motion of the vehicle. The solid line curve is the reentry profile for a Space Shuttle Orbiter. This curve would also become steeper due to drag and gravity were it not for aerodynamic lift. Instead, the curve becomes noticeably shallower at an altitude of about 88 kilometers (55 statute miles), as lift becomes dominant over drag and gravity. Obviously, weaker lift is generated at even higher altitudes during reentry, well before it becomes the dominant force.

---

[92] *See e.g.,* Wikipedia, *Kármán line,* https://en.wikipedia.org/wiki/K%C3%A1rm%C3%A1n_line (accessed 27 February 2016).

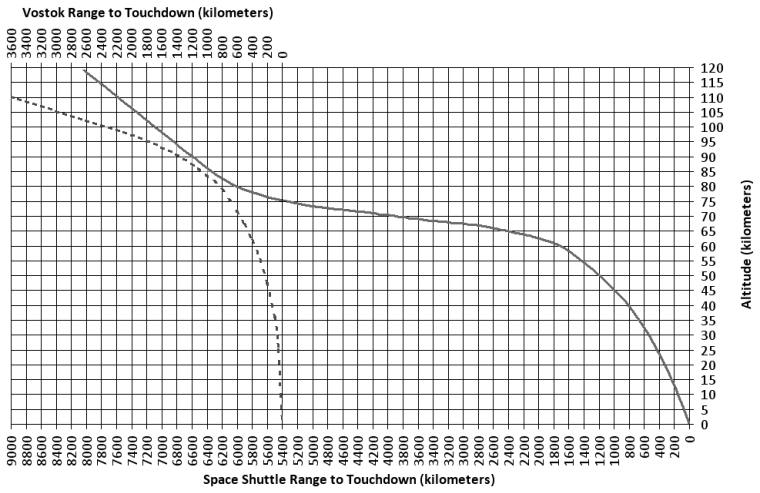

Figure 3: Reentry Profiles of Vostok and Space Shuttle Orbiter

A basic understanding of the technical issues can be obtained by considering the classical lift equation:

$$L = \tfrac{1}{2}\rho v^2 C_L S \qquad (1)$$

where L is the force of lift, ρ is air density, v is velocity, C_L is the airfoil's lift coefficient (for a given angle of attack), and S is the planform area of the lifting surfaces. The higher the altitude, the lower the air density, and therefore the higher the velocity must be to maintain the same lift (and the more frictional heating to which the vehicle is subjected). However, for an aircraft in straight and level flight,[93] lift equals weight. If an aircraft could be built lighter, then it would require less lift. Since lift is proportional to the square

[93] "Straight and level" flight, synonymous with maintaining constant heading and altitude over a prescribed distance, is in reference to the surface of Earth, which is curved; it is not in reference to an inertial reference system such as orbits and trajectories in outer space. If an airliner flew a constant altitude from Auckland to San Francisco, roughly one quarter of the way around the world, it would of course fly a curved path in the three-axis inertial sense, yet it would be considered to be flying "straight and level" in the aeronautical sense.

of the velocity, a lighter aircraft (requiring less lift) could fly considerably slower while maintaining the same altitude, or alternatively, the aircraft could maintain a higher altitude for the same velocity, a velocity which might be slower than where centrifugal force "takes over." Gyula Gál understood this in 1961:

> The Haley line . . . is a mathematical function of altitude and speed, and changes together with these.[94]

Thus, the upper curve portrayed in Figure 2 can shift depending upon weight, wing area, parasitic drag (as a function of the form and shape of the object), angle of attack, and thrust. If there were such a thing as a von Kármán line, it would depend on the structures technology of the time. In the 21st century, aircraft are constructed with lightweight composite materials that did not exist in von Kármán's time. Furthermore, the increased heat resistance of advanced materials can shift the lower curve of Figure 2. Whatever calculation one makes involves certain assumptions regarding technology. Absent having in hand the exact set of assumptions with which von Kármán began, one cannot arrive unambiguously at the line he calculated.[95] As Perek observed in 1977:

> The definition is to some degree connected with a particular degree of technological development . . .[96]

Also, a 1977 UNCOPUOS report noted:

> [T]he criticism based on the observation that the von Karman line is unstable since it is linked to technological development continues to be maintained.[97]

---

[94] Gál, *supra* note 72.

[95] In his doctoral dissertation, the author examines, in addition to the von Kármán line, many other proposals for the legal definition and delimitation of outer space, as well as arguments against any definition or delimitation, and proposes a solution. *See* Thomas Gangale, *The Definition and Delimitation of Outer Space and Territorial Airspace in International Law* (2017), J.S.D. dissertation, University of Nebraska).

[96] Perek, *supra* note 41, at 123.

[97] U.N. Doc A/AC.105/C.2/7/Add.1, *The Question of the Definition and/or the Delimitation of Outer Space,* 21 (1977).

X. SORRY, WRONG NUMBER

With respect to aerodynamics, there is nothing inherently remarkable about a line drawn at 60 kilometers, at 50 statute miles, 275,000 feet, at 300,000 feet, at 90 kilometers, at 50 nautical miles, at 100 kilometers, or at any other altitude. The von Kármán line, wherever it was drawn and by whomever it was drawn, had its origin in a theoretical calculation based on the aerospace technology of the 1950s, has never found a practical use in engineering, and has been misinterpreted by lawyers as having some physical significance, which in fact it does not have.