A Slide Oddity: The Aristo Martin Space Rule

Robert A. James

Any slide rule aficionado who has clicked through a gallery of famous models has likely stopped to gawk at a curious device produced in 1962, close to the end of the Era.[1] Strange scales appear, like "$\%W_{pr}$," "K_4," "γ_{Bo}," "time of travel (years)," and "V_3 (soft landing)"—along with ordinary "C" and "D" scales to remind you that you are in fact looking at a slide rule. No, this "K" is not a cube scale. In the gutter beneath the slide, instead of typical physical constants there is a table of planets with symbols and their reported radii and escape velocity. This, then, is the Space Rule developed by engineers at the space systems division of The Martin Company and manufactured in West Germany by Aristo as model number 80123.

Few of us have seen this rule in captivity. It is "one of the rarest of the rare 20th century rules," in the words of Bob De Cesaris. The most widely available evidence is the crisp reproduction on Rod Lovett's collection photo site,[2] shown here as Figure 1.

Rarely has a scientific instrument met its moment so well. 1962 was a time of heightened interest in the space program and the quest to launch payloads into orbits towards interplanetary travel, in the interest of expanding human knowledge. Sadly, it was also a time of heightened awareness of the reach of intercontinental ballistic missiles (ICBMs) and their terrestrial targets, in the interest of exterminating fellow humans. Before the advent of distributed electronic computers (and this was a time when a "computer" was a person, generally a woman[3]), a slide rule might have been the conventional first approach to solving the relevant equations.

It seems remarkable today that in order to explore the vast reaches of the solar system, anyone would even think of relying on a piece of molded plastic with scales no more than 14 centimeters (five and a half inches) long—not even a full-size rule. We have no evidence that the rule was ever used by others. Like another famous rectangular prism of the 1960s, this device is "still a total mystery".[4]

I found three references in the literature on this subject. Rod Lovett provided an excellent illustrated overview[5] of the rule and accompanying manual and exercises. Will Marchant made a colorful presentation[6] illustrating some applications and furnishing anecdotes about the rule's creators, Michael Stoiko and Werner Furth. (Neither Marchant nor I owned this rule at the time of writing; each of us worked from the photos.) Marchant secured approvals for the manual to be posted online,[7] and the manual is also reproduced in print by Mike Konshak.[8] Also, Stoiko's daughter donated a 1960 prototype and provided other interesting materials to Mike Konshak at the International Slide Rule Museum (ISRM), who has posted them.[9]

This article supplements these materials by providing additional detail on the mysterious scales themselves and incremental comments on their operation. It then calls attention to what may be the greatest error in slide rule history—the reported size of Pluto.

Origins

Slide rules were used for trajectory calculations in ballistics almost from the beginning of the Era—they transited from Minister Oughtred to the war ministries of Europe. Rocket propulsion progressed from the fireworks of ancient China to the weapons of William Congreve. The dawn of the twentieth century saw the great rocketry triumvirate of Tsiolkovsky, Goddard and Oberth. Oberth's protégé Wernher von Braun worked at Peenemünde on the V-1 and V-2 before being retrieved in Operation Paperclip. The American ICBM and space programs then began to take shape.[10,11]

The Martin Company was a military and civilian contractor engaged in design and engineering of rocket boosters. In the nomenclature of the rocket business, an overall "vehicle" consists of the "payload" and the "booster." The booster is usually composed of multiple stages. Each of the payload and the stages has a mass and thus a weight, with each stage in turn containing propellant, structure, and equipment.

Marchant unearthed several interesting personal facts about Stoiko (1919-2010) and Furth (1930-2012). Stoiko worked on the Gemini program, underway by 1962, and authored a dozen books about space travel. Marchant reported that the successor company, Lockheed Martin Corporation, does not appear to have maintained records about the slide rule or its conception.

FIGURE 1. The Aristo 80123 Martin Space Rule (Photos by Rod Lovett[2])

Stoiko's daughter confirmed to ISRM that he worked on Operation Paperclip with captured V-2s, and contributed to development of the Viking, Vanguard, and Titan missiles. She provided a 1960 prototype of the Martin rule, larger in size than the final version (12"L x 2.25"W x 0.375"D, or 30.5cm x 5.7cm x 0.95cm), bearing some additional gauge marks and strange differences in planetary data (covered below). In a 1960 letter, The Martin Company released to Stoiko any patent or copyright claims in the rule and manual, but the 1962 rule and manual bear the Martin trade name and copyright; perhaps Aristo thought the device might sell better with the corporate connection.[9]

The exterior of the packaging for the slide rule and manual (see Figure 2) features a beautiful and dramatic illustration of two voyages around the solar system, requiring calculations far beyond what this slide rule could perform. The instrument must have had miniscule demand, some of which had to have been stoked by mere curiosity. Only a few examples are known to reside in collectors' hands today.

Design

The dimensions of the rule are reported by Lovett[12] as 18 cm (7") long by 3.8 cm (1.5") wide by 0.5 cm (0.2") deep. The scales vary in length but the longest are around 14 cm (5.5"). There are 30 of them, arranged as follows with those on the sliding panel in brackets:

Front: 5 Specialized [3 Specialized, C] D, 2 Specialized
Rear (solid): 12 Specialized
Back of Slide: [6 Specialized]
Gutter: Planetary data

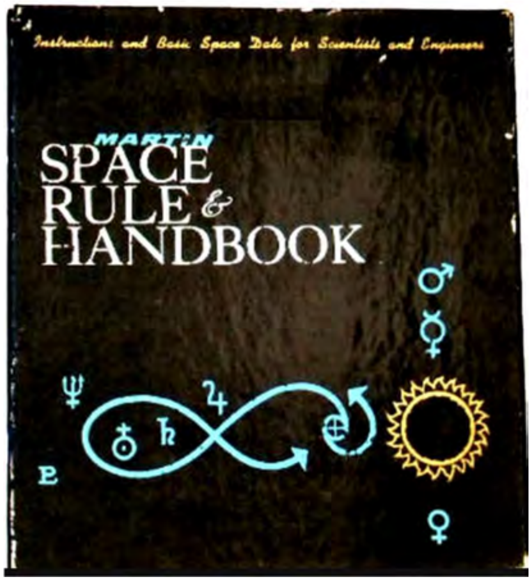

FIGURE 2. One Journey to Jupiter, Saturn, Uranus, Neptune and Pluto and Home; A Second Journey to the Nearby Planets and the Sun

The scales are detailed in Table 1. To call them "specialized" is an understatement; I am confident most are unique. Many consist of ratios or percentages, so one would have to do some simple mathematics simply to develop the numbers to input; I suppose that is what the "C" and "D" scales are for. Several of the exercises require data to be entered from the Appendices in the manual itself, so the rule is not self-contained.

Operation

My observation, preliminary to examining this device, is that ***the "Space Rule" is really a "Velocity Rule."*** To my disappointment, it is not an instrument useful for navigation calculations, such as for determining three-dimensional angles and burn rates as are needed to cross from one planet to another at exactly the right times in their orbits around the Sun. For that, one needs to turn to textbooks. At the Air Force Academy, Bate, Mueller & White published *Fundamentals of Astrodynamics*[13] (affectionately referred to by cadets as "BMW") in 1970 with traditional American units of measure and a second edition[14] in 2000 with measurements in metric units (*Système International*, SI).

Instead, the task of these Martin engineers was to produce enough thrust and manage the overall weight so as to achieve the velocity necessary either (in ballistics) to hit your target downrange or (in astrodynamics) to reach your target level of orbit or impact. The key measure is the basic Tsiolkovsky rocketry equation, relating velocity to engine performance and mass. Every space cadet should commit this to memory:

$$\Delta V = g_0 I_{sp} \ln (m_{initial}/m_{final}), \qquad \text{where}$$

- g_0 is the acceleration due to gravity on Earth at sea level (9.8 m/s^2);
- I_{sp} is the average specific impulse of the vehicle's engine ("specific" means relative to weight, so the total impulse in newton-seconds divided by weight in newtons yields a specific impulse denominated in seconds of time, strange as that sounds);
- $m_{initial}$ is the mass of the entire vehicle at launch—the sum of the masses of the payload, propellant, structures, and equipment; and
- m_{final} is the mass of the vehicle at the end of powered flight, comprising the payload plus structures and equipment, the propellant having been exhausted; the ratio is the vehicle's "mass ratio."

The specific impulse is constrained by a civilization's technology. For a solid chemical propellant, it might have been 140. For a modern liquid hydrogen/oxygen propellant, according to Woodward[15], the impulse can range from 200 to 450. That was about the technology level when this instrument was produced.

It is interesting that the Martin rule scale stretches a long way past the 1962 state of the art, to 1440. That would be sufficient to encompass nuclear reaction propellants in the 800 to 1200 range. Nuclear propulsion was contemplated at the time and seriously pursued as Project Orion[16] in the 1950s and 1960s. Greater impulses cited by Marchant[6], including ion thrusters at 3000 and VASIMR electrothermal thrusters at 12,000, lay and still lie in the future.

On the other hand, a given civilization *can* do something about m_{final}—namely, separating the booster into stages so that with the jettisoning of each stage, more and more of the mass of propellant, structure, and equipment is shed. The resulting stage-version of the Tsiolkovsky equation (see Woodward[15] at Equation 2.4) is a summation of velocities at different stages with less and less mass at each stage burn, resulting in greater and greater total velocity.

Table 1. The Scales of the Aristo Martin Space Rule, or, What in Blazes am I Looking at Here?

Scale and units	Range of values	Quantity
FRONT UPPER STATOR		
λ	1.25 to 9.2	(Initial weight of stage or object at launch) to (final weight at burnout)
K_4	∞ 100,000 to 1.5	[(n-3rd) stage weight] to (payload weight)
K_3	∞ 10,000 to 1.0	[(n-2nd) stage weight] to (payload weight)
K_2	∞ 1,000 to 1.0	[(n-1st) stage weight] to (payload weight)
K_1	∞ 50 to 1.0	[nth stage weight] to (payload weight)
FRONT SLIDE PANEL		
I_{sp} sec. (seconds of time)	140 to 1440	Overall specific impulse of engine (total impulse/weight) (in atmosphere, average; in deep space, instantaneous)
K_0	1-3.16	"Numerically equal to K'"
%Wpr	0 to 30 (short scale)	[(Propellant loaded remaining at burnout) to (total propellant)] x 100
↓MF	[Gauge mark]	Mass fraction: (mass of payload) to (mass of total vehicle at launch)
C	1 to 10	Ordinary base-10 logarithmic scale
FRONT LOWER STATOR		
D	1 to 10	Ordinary base-10 logarithmic scale
K'	5 to 1.25	λ/(λ-1); ratio of the ratios of gross to tare weight at the surface of the Earth
%Wd	30 to 0 (short scale)	[(stage dry weight) to (total stage weight)] x 100
MF	0.7 to 1.0 (short scale)	Mass fraction, (stage propellant consumed) to (gross weight of stage); 0<MF<1
REAR SLIDE PANEL		
V_3 (impact landing) 10^3 fps	35 to 54 (short scale; target gauge marks)	Burnout velocity required to leave earth orbit and coast to target aphelion, at which point the target gravity takes over and crashes the payload, i.e., a positive speed at impact on the target
V_3 (soft landing) 10^3 fps	30 to 260 (short scale; target gauge marks)	Sum of V_3 (impact landing velocity) plus additional counteracting velocity to achieve zero speed at impact on the target
Time of travel (years)	0.7 to 100+ (short scale)	Coast time for travel to interplanetary aphelion, outer planets only (Mars, Jupiter, Saturn, Uranus, Neptune, Pluto)
Vcirc 10^3 fps	200 to 14 (short scale)	Velocity of circular orbit around Sun
(Ra/Re)	1.2 to 100+ (short scale)	(aphelion distance) to 1 Astronomical Unit (AU)
(R/Re)	0.25 to 45 (short scale)	(Radius of orbit around Sun) to 1 AU
REAR STATOR		
(ε)ecc	0 to 1.25	Eccentricity of conic section orbit (0 (circle) < (ellipse) < 1 (parabola) < +1 (hyperbola))
Va 10^3 fps	26 to 0	Velocity at apogee
Ha 10^3 st.mi.	0.2 to 500 ∞	Altitude at apogee
Hm 10^3 st.mi.	0.2 to 100 ∞	Mean altitude of orbit
τ hr	1.5 to 500 ∞	Orbital period (hours)
V1 10^3 fps	25 to 38	Velocity at perigee
V2 10^3 fps	0 to 26	Velocity at burnout of booster, orbital velocity
R1 10^3 st.mi.	0 to 12	Range from burnout at low altitude to impact the Earth downrange
γ_{Bo} degrees (of angle)	45 to 10 [0]	Flight path angle at burnout (degrees from horizontal)
T_F minutes (of time)	0 to 41.5	Time of flight from burnout to impact
Ha st.mi.	0 to 800 to 0	Maximum altitude
Hc 10^3 st.mi.	∞ 1000 to 0	Altitude of circular orbit

So how much velocity is needed? It depends on your mission. Various orbit levels will determine your needs as illustrated in Table 2, adapted from Woodward.[15]

TABLE 2. Required Velocities for Orbital Mission Phases

Orbit Type	Total ΔV Required from Earth's Surface (km/s)
Low Earth Orbit (LEO)	9.7
Geosynchronous Transfer Orbit (GTO)	12.2
Geosynchronous Earth Orbit (GEO)	13.8
Low Lunar Orbit	13.6

The instruction manual[17] is divided into seven parts, I through VII. Everything is expressed in good old American foot-pound units; in this article I provide the SI equivalents. Lovett[5] covers the exercises in detail and I will not repeat his fine explication.

I. Your Slide Rule

The Martin engineers first declare that a mission is defined by its requisite velocity. Their objective is first, perhaps by using this rule, to calculate the velocity needed to put the payload into a particular orbit or on a target, and then, by other means, to design boosters, stages and propellants to achieve or exceed that figure.

The initial step is to calculate the "burnout velocity" with respect to the mass of the vehicle. To that bare minimum must be added sufficient "loss velocity" to overcome forces, notably, including gravity and aerodynamic drag. Other losses, such as for steering (yaw), maneuvering, reserve, safety, stabilization, and course correction, must also be overcome. Woodward[15] reports that modern texts suggest 1524 m/s to 1676 m/s of loss velocity are typical. Appendix A to the Martin manual suggests loss velocities for various missions range from 1000 to 6000 feet per second (fps), which convert into SI as 305 to 1830 m/s. The upper range of those figures is close to the current figures.

The launch can and should take advantage of the eastward rotation of Earth. The Martin manual reports that velocity as 1520 fps at the equator and 1520 fps cos λ for other latitudes should be used. That yields 464 m/s in SI terms at the equator, and is close to the current figure of 465.1 m/s. At the latitude of Cape Canaveral, this helpful velocity component is reported as 1340 fps (about 409 m/s), close to the 408 m/s current figure.

Finally, space launches must take into account the orbit of the Earth around the Sun, to fly either *with* the orbit for travel to the outer planets, or *against* the orbit for slowing down to visit Mercury or Venus. The Martin manual reports that orbital velocity as 97,760 fps, or 29,797 m/s in SI terms; that closely correlates with the current figure of 29,722 m/s (107,000 km/hr).

Taken together, these values produce a "characteristic mission velocity." With that information, the Martin engineers presumably began to design the necessary boosters.

II. Propellant Mass Fraction

These calculations relate the percentages of propellant remaining at stage burnout (%Wpr), the percentage of dry weight compared to loaded weight of a stage (%Wd), and the ratio of stage propellant consumed to gross stage weight (MF). If one knows two of these values, the Martin rule will enable calculation of the third.

For example, if one moves the hairline over the bottom front %Wd scale at 12.5 and moves the slide so that the %Wpr scale is at 7.5 under the hairline, one can read the gauge mark ↓MF on the slide and see that the propellant mass fraction on the MF scale on the bottom front is 0.809. The manual's Appendix B provides a set of curves that can supply any missing data.

III. Exterior Ballistics

This part ominously addresses the terrestrial targets of ICBMs. The lower reverse side of the rule is used—the V2, R1, γ_{Bo}, T_F, and Ha scales, in particular. One of the unsettling exercises involves "landing" a payload 5000 miles away, and deriving the associated burnout velocity, angle at burnout, time of flight from burnout to impact, and maximum altitude.

IV. Earth Orbital Mechanics

The scales on the upper reverse side of the rule, the ε, Va, ha, hm, τ, V_t and hc scales, are used to calculate the necessary velocity, orbital period, and altitude of various Earth orbits where some, but not all, of these values are known.

V. Booster Design

How large should each of the stages of the booster be? Several scales on the front of the rule are used to derive the missing value. A sample exercise: "Find the range of a single-stage IRBM [intermediate-range ballistic missile] with a launch weight of 46,500 pounds carrying a 3000-pound payload. The stage has a propellant mass fraction of 0.91 and an average specific impulse of 270 seconds."

VI. Stage Optimization

This part considers the additional steps to be taken if the specific impulse or mass fraction is different from stage to stage.

VII. Interplanetary Missions

This part, of course, is why most of us care about this rule.

The reverse side of the slide is the star of this show—the V3 (impact landing), V3 (soft landing), Time of travel, Ra/Re, V_{circ}, and R/Re scales, in particular. An "impact landing" velocity only requires the payload to reach the aphelion of the orbit of the target planet. At that point, the target's gravity takes over and the payload unceremoniously crashes onto the surface.

A "soft landing" velocity, on the other hand, takes the payload to the surface with enough thrust to counteract the target's gravitational attraction. A zero speed at the time and place of landing may technically be referred to as "not dying," and is hence preferred at least for manned expeditions. I do not know what they mean by a "soft landing" on a gaseous planet.

In introducing the two V3 scales, the manual assumes a principle from astrodynamics, the *Hohmann transfer*—whereby an object in one orbit takes an elliptical course to transfer to a higher orbit around the same or a different planet. This typically requires two incremental burns of propellant, one to reach and the other to establish the final trajectory. Hohmann conceived of the maneuver in 1925 after reading a science fiction novel; the mathematical steps are detailed in the BMW texts. The Martin manual's Appendix C contains elliptical equations, but does not explain how they might be used in the context of this rule.

Other simplifying assumptions are made. For example, the orbits of the planets are assumed to be coplanar and circular. That is probably close enough for the accuracy of a compact slide rule.

There are so few operations with which one can appreciate the intent simply by looking at the scales in Figure 1. One can imagine Katherine Johnson, the heroine of *Hidden Figures,* performing calculations like the following exercise, probably to more decimal places, working by hand, or with the available machinery.

EXERCISE ONE: Soft land a spacecraft on Mars. Determine the flight parameters.

> Move the hairline over the Martian symbol ♂ on the V3 (soft landing) scale. Directly read the velocity required to reach the planet's surface at zero speed of 55.9, hence 55,900 fps (17,038 m/s).
>
> Then move the hairline over ♂ on the V3 (impact landing) scale to find the velocity needed to get from the Earth to the Martian aphelion of 37.04, hence 37,040 fps (11,290 m/s). (As an aside, it is purest fantasy to read four or even three significant digits off of this tiny scale.) The other data may be immediately read: time of travel from Earth to the Martian aphelion, 0.71 years, and maximum distance of the payload from the Sun (Ra/Re), 1.52 Astronomical Units (AU).
>
> The difference between the soft landing and impact landing velocities, 55.9 minus 37.04 or 18.86, hence 18,860 fps (5749 m/s), is the reverse velocity needed to counteract Martian gravity and land smartly and smoothly on the surface of the red planet.

Concluding Operational Remarks

Most of the calculations on this rule involve single movements of the hairline or slide, followed by reading multiple results off of the scales. The device is thus more of a nomograph than a rule one would use to make a series of calculations by introducing additional variables.

I had the impression from the planetary symbols that it would be a general-purpose rule for space navigation. Instead, it is focused on determining the velocity, and thus the quantity of thrust, given vehicle stages and masses required for the boosters for a particular mission. Neither the rule nor the manual overpromised in this respect, though the packaging cover is a bit misleading.

The device remains to this day a fascinating window into rocket design in the early 1960s. It was a time when our highest ambitions for space travel were untested, and hence, limitless.

The Size of Pluto

I come now to a matter of some delicacy. The gutter of the rule, shown in Figure 1 above, contains data about each planet—its symbol, its escape velocity in feet per second, and its radius in statute miles. In Table 3, I converted all velocities and radii to SI units (meters per second and kilometers respectively) and compared them with current data as reported in Wikipedia. I confirmed that almost all of them measure up well with today's best estimates.

Almost all of them, I said. There is a singular exception—the data associated with Pluto. The escape velocity is off by a factor of 8.7x and the radius is off by a factor of 5.8x. I find no evidence that anyone has called attention to this discrepancy in the last 62 years.

TABLE 3. Erroneous Pluto Data

Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Rule escape velocity, fps [=0.305 m/s]	13,650 [4163]	33,850 [10,324]	36,700 [11,193]	16,730 [5103]	200,000 [61,000]	119,100 [36,326]	69,900 [21,320]	76,800 [23,424]	**34,500 [10,523]**
Current estimated escape velocity, m/s (Wikipedia)	4250	10,360	11,186	5030	60,200	36,090	21,380	23,560	**1212**
Rule radius, st.mi. [=1.609 km]	1,550 [2494]	3,846 [6188]	3,963 [6377]	2,060 [3315]	43,480 [69,959]	35,800 [57,602]	15,730 [25,310]	15,545 [25,012]	**4,300 [6919]**
Current estimated radius, km (Wikipedia)	2440	6052	6378	3396	71,492	60,268	25,559	24,764	**1188**

What could account for this error? I found that the size of Pluto has been on a long downhill toboggan ride ever since it was conceived, even before it was spotted or closely examined.

Neptune was discovered in the 1840s after astronomers found perturbations in the orbit of Uranus. Flush with that discovery, and noting perturbations in the orbit of Neptune itself, the stargazers searched for yet another planet, one they calculated might be about *seven times the mass of Earth*. Percival Lowell, the Bostonian who brought us tales of canals on Mars and spokes on a visible surface of Venus, joined the hunt for this "Planet X."

By the time Lowell's colleague Clyde W. Tombaugh spotted Pluto through close comparison of Arizona photographs in early 1930, the estimated mass had shrunk to between 0.5 and 1.5 Earths.[18] The disk was found to be bright not because Pluto is large, but because of an unusually high albedo due to being covered in ice. By 1948, the estimated mass was reduced to 0.1 Earths.[19] After 1978 the estimates further collapsed to the present 0.00218 Earths by mass, and 0.1868 Earths by radius.[20]

Pluto has absorbed two more body blows. The 1989 Voyager 2 flyby corrected the data on Neptune's orbit, and the need for a large Planet X completely vanished. Then the International Astronomical Union (IAU) in 2002 notoriously demoted Pluto to the status of a "dwarf" planet, eventually a "plutoid." Many individual astronomers and lay people, and the legislatures of Arizona, California, Illinois and New Mexico, have rejected the IAU demotion. We all feel like Pluto some days.

A further curiosity is that the gutter of the prototype states different data than the finished product for many of the planets (Figure 3). The Pluto escape velocity is sliced in half, 17,300 fps—still way off, but less in error than the manufactured rule. The radius is less different but still incorrect—it still states that Pluto is about the size of Earth. How an error *increased* from prototype to manufacture is certainly a puzzle.

It is possible that the Martin engineers who designed the Space Rule consulted not one but two pre-1948 reference works (musty encyclopedias in the employee lounge, perhaps?). Somehow they wound up with a 580% to 870% oversizing of the elusive outer planetoid. If there is a greater error in all of slide rule history, I would like to know about it.

FIGURE 3. 1960 Prototype with Different, But Still Incorrect, Pluto Data

The variance confirms my belief that I would not trust a 14-centimeter-scale slide rule with which to cross the cosmos. But I am also heartened by the human, all-too-human enterprise, that led to the creation of this extraordinary device.

Notes

1. Robert A. James, *The Deaths of the Slide Rule*, Journal of the Oughtred Society, 23:2, Fall 2014 https://sliderules.lovett.com/cookiedev/extendeddisplayarticle.cgi?match=roberta.jamesxxxjournaloftheoughtredsocietyvol.23,no.2,2014pg6.1.jpg (visited August 2024).
2. Rod Lovett, photographs of the Martin Space Rule, https://sliderules.lovett.com/aristo80123/aristo80123pics.htm (visited August 2024).
3. Margot Lee Shetterly, *Hidden Figures* (2016).
4. Stanley Kubrick & Arthur C. Clarke, *2001: A Space Odyssey* screenplay (1968).
5. Rod Lovett, *The Martin Space Rule,* Slide Rule Gazette Issue 8 (Autumn 2007) 71, https://sliderules.lovett.com/cookiedev/extendeddisplayarticle.cgi?match=rodlovettxxxsliderulegazette.issue8autumn2007pg71..1.jpg (visited August 2024).
6. Will Marchant, *The Rocket Science Behind the Martin Space Rule and Handbook,* Oughtred Society International Meeting 2020 (IM2020), presentation material: https://www.oughtred.org/meetings/Virtual%20IM2020/Will%20Marchant/The%20Rocket%20Science%20Behind%20the%20Martin%20Space%20Rule%20and%20Handbook.pdf
and video: https://youtu.be/Ysd7oG7_sXM
7. Computer History Museum, *Aristo 80123 Martin Space Rule,* https://www.computerhistory.org/collections/catalog/102746940 (visited August 2024).
8. Michael V. Konshak, *Military and Aerospace Slide Rule Instructions* chapter 12 (2021).
9. International Slide Rule Museum, *Aristo 80123 Martin Space Rule* (photos of 1960 prototype and other materials), https://www.sliderulemuseum.com/Aerospace.shtml (visited August 2024).
10. Chris Gainor, *To A Distant Day: The Rocket Pioneers* (2008).
11. Peter Macinnis, *Rockets: Sulfur, Sputnik and Scramjets* (2004).
12. Rod Lovett, Further Details about the Martin Space Rule Aristo 80123 https://sliderules.lovett.com/aristo80123/details.htm
13. Roger R. Bate, Donald D. Mueller & Jerry E. White, *Fundamentals of Astrodynamics* (1970).
14. Roger R. Bate, Donald D. Mueller, Jerry E. White & William W. Saylor, *Fundamentals of Astrodynamics* (second edition, 2000).
15. David Woodward, *Space Launch Vehicle Design,* University of Texas at Arlington MS thesis (2017), https://rc.library.uta.edu/uta-ir/handle/10106/27215 (visited August 2024).
16. George Dyson, *Project Orion,* Henry Holt & Co., 2002.
17. The Martin Company, *The Space Rule Handbook* (1962).
18. S.B. Nicholson & N.U. Mayall, *The Probable Value of the Mass of Pluto,* 7 Pubs. Astronomical Society of the Pacific 11 (1931) 350.
19. Gerard P. Kuiper, *The Diameter of Pluto,* 62 Pubs. Astronomical Society of the Pacific 62 (August 1950) 133.
20. S.A. Stern & D. J. Thorden, *Pluto and Charon* (1997).

Volume 33, Number 1 Spring 2024

JOURNAL OF THE OUGHTRED SOCIETY

The Aristo 80123 Martin Space Rule