

Lachesis: Optimization of a handheld line launcher of for microgravity utility and rescue tasks

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## Abstract

Line launchers are devices that have been used for centuries for maritime rescue operations. The typical implementation is the use of a gun, rocket, or mechanical launcher to hurl a grappling hook or flotation buoy for stranded ships and overboard sailors. Microgravity offers analogous use cases, ranging from microsatellite operations to space debris interception. As such, the Lachesis line launcher is a handheld device that is purpose-built for microgravity applications. After the user pulls the trigger, a laser ignites a smoothbore rocket-propelled projectile which carries a nylon line behind it. Angled threads in the barrel provide the spin and stability that is typically only achieved by conventional rifling. To reduce weight, most components are 3D-printed out of polylactic acid (PLA), a biodegradable and light plastic. With a total weight of 68 g and a projectile kinetic energy of 0.127 J, the Lachesis line launcher presents an effective, potential option, even with contemporary operational constraints. The design combines several proven principles to demonstrate the viability and use case for an updated line launcher in orbital operations.

*Keywords*: line launcher, microgravity, object capture

## 1 Introduction

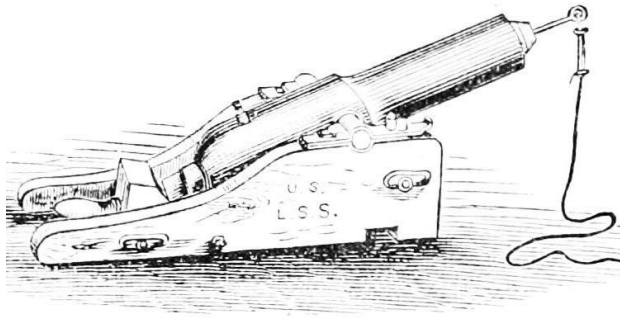
Line launchers are a maritime rescue device used in rescue operations for centuries (Spangler & Homer). The typical implementation is the use of a gun, rocket, or mechanical launcher to hurl a grappling hook or flotation buoy for stranded ships and overboard sailors. Microgravity offers analogous use cases, ranging from microsatellite operations to space debris interception. As such, the Lachesis line launcher is a handheld device purpose-built for microgravity. After the user pulls the trigger, a laser ignites a smoothbore rocket-propelled projectile carrying a nylon line behind it. Angled threads in the barrel provide spin and stability typically only achieved with conventional rifling. With improved materials and technologies, the launcher presents a safe potential option even with contemporary operational constraints. The Lachesis line launcher combines several proven principles to demonstrate the viability and use case for an updated line launcher in orbital operations.

### 1.1 General Concept

The Lachesis line launcher is named after one of the Greek Fates, the three goddesses that determined the lives of mortals. Clotho spun the thread of life, Lachesis measured it, and Atropos cut it (Graves, 2012). The line launcher required a thin, strong thread, which could be used in lifesaving applications (Skoog, 2019). As the device could lengthen human survival, the name of Lachesis was chosen. While the name is archaic, the technologies utilized are more contemporary. The objective was to design a handheld line launcher for outer space.

### 1.2 Background

Line launchers are rescue devices originally designed for maritime or sailing applications. At their most rudimentary, they consist of a launcher and a line attached to a profile, which is intended to be throw further than human strength allows. They have included specialized firearms, rockets, and mechanical launchers to discharge rescue buoys for overboard sailors or grappling hooks for towing vessels (Rundle, 1937; Niblack, 1927). Specialized line launching guns were developed in the Victorian era, such as the Lyle cannon used by the US Coast Guard's precursor organization, the US Life-Saving Service (Spangler & Homer). The Lyle cannon is shown in Fig. 1.



**Figure 1: A Lyle cannon used by the United States Coast Guard (Wikimedia Foundation, 2022).**

Handheld versions also existed, such as the British Schermuly pistol-rocket apparatus shown in Fig. 2 (Parade Antiques, 2023; Rundle, 1937).



**Figure 2: A preserved Schermuly pistol-rocket apparatus (Parade Antiques, 2023).**

Presently, International Convention for the Safety of Life at Sea (SOLAS) regulations mandate certain ships carry a line-launcher aboard (Snook, 1974; International Maritime Organization, 1974).

Outer space offers several potential use cases for a line launcher. The first is the same as its maritime counterpart: rescuing personnel and securing objects that are adrift. Current extravehicular activity is performed at the end of a robotic arm, but future spacecraft and space stations may not include such a feature. Handholds are often designed so that an astronaut always has a single hand in contact with the craft, thus tools should be designed for single-handed use where possible. Similarly, a line launcher could be used to deploy specialized sensors, intercept incoming objects, and secure components (Liu, Qiu, Li, & Yang, 2017; Zhao, Liu, & Wu, 2020; Sizov & Aslanov, 2020). Outside of the scope of handheld use, a space-based line launcher system could be mounted on a satellite as a capture or tether system (Sizov & Aslanov, 2020).

A line launcher requires range and accuracy. As the projectile is still attached to the launcher, recoil like that from a firearm or compressed gas gun could throw off the user's aim. A purely mechanical launcher, such as a crossbow or slingshot, would need to be resistant to the extreme temperatures present in space. Rocket-based line launchers can potentially allow for a longer range since they slowly burn fuel over a longer period of acceleration (Woodford, 1932; Ambur, Jaunky, Lawson, Knight, & Lyle, 2004). With an equivalent propellant weight and a similar projectile size, a rocket could cover a longer distance than a conventional firearm. A rocket launcher would lack the recoil of a firearm, eliminating the recoil force on a user or platform in microgravity.



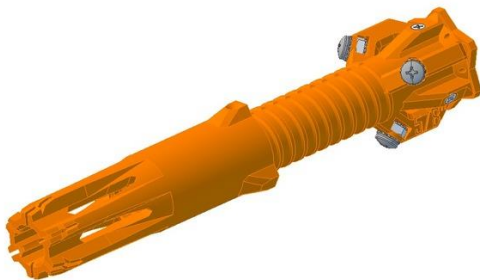
**Figure 3: An M. B. Associates "Rocketeer" gyrojet pistol in original packaging (Wikimedia Foundation, 2023).**

The M. B. Associates (MBA) Rocketeer pistol shown in Fig. 3 provides an example of a rocket launching pistol, allegedly inspired by the weapon of the science fiction character Buck Rogers (Carpenter, 2010). While it resembles a conventional firearm, there are periodic apertures in the barrel to allow the venting of exhaust. The Rocketeer pistol discharged a gyrojet, a rocket engine inside a metal slug. These projectiles accelerated down the barrel, reaching terminal velocity after meters away from the shooter. The cost and complexity of the system made the Rocketeer pistol expensive and unreliable (Dillon & Thornton, 1967).

While impractical as a weapon, the Rocketeer and its gyrojet were a pioneering pistol design (Dillon & Thornton, 1967). Many factors can complicate a rocket launch: impulse, energy, direction, friction, delivery time, and outgassing. Launching a rocket from a "gun" or rigid casing tube enables it to have a greater initial velocity, as the pressure from the heated exhaust behind it exerts additional force (Woodford, 1932). A short propellant burn time is optimal for ensuring a stable and accurate gyrojet trajectory. However, launching a rocket from inside a container or gun-barrel helps ensure consistent outcomes for each (Woodford, 1932).

Despite this potential advantage, the original gyrojet gun was plagued by the high cost of ammunition manufacture, questionable accuracy, and rapidly changing regulations (Carpenter, 2010). As with bullets, rockets can be spin-stabilized since a rotating projectile has a longer effective range. Conventional firearms include rifling, but rockets (including gyrojet rounds) typically require more than one angled nozzle to obtain the same result. The original gyrojet rounds required drilling angled nozzles in the rear of each cartridge, a more complex manufacturing task than simpler rockets with single nozzles (LaRocco, *Throwing a line to Tomorrow*, 2021; Carpenter, 2010). Without the angled rocket nozzles, gyrojets would be unable to spin-stabilize.

Developments in another type of launcher could potentially stabilize a smoothbore projectile, such as a shotgun slug or single-nozzle gyrojet round. Foam dart blasters are toys for which hobbyists have developed novel attachments, including analogs to conventional rifling to improve accuracy (Captainslug, 3; Phillips, 2022).



**Figure 4: Muzzle attached rifled 3D-printed barrel for foam dart blasters (Captainslug, 3).**

One such analog is the use of strings in a barrel attachment, pulled taut at slight angles relative to the projectile's direction of travel. While this applies a slight friction, the string is flexible enough to compress as the projectile passes by. As such, it serves an analogous function to rifling in a smoothbore projectile. Other variants of the concept use mechanical roller bearings in a similar manner. Shown in Fig. 4, such "soft rifling" resulted in more consistently clustered shots relative to its absence. The device from Fig. 4 is meant to friction fit onto common foam dart blasters via the muzzle. A potential benefit of using gyrojet rounds with such a system is that the rocket will burn more propellant while passing the rifling and accelerate to a higher velocity while leaving the barrel. The concept has not yet been applied broadly outside of the foam dart hobbyist community.

A line launcher requires a secure tether to perform its role. Historical line launchers used rope or buoyant cable, strong enough to secure ships in stormy seas. Current nautical lines, such as Spectra ® and Dyneema ®, would be bulkier and heavier than more novel materials. A smaller, handheld line-launcher would require different considerations in microgravity. The line would need to be light and strong, and able to withstand objects moving at far higher absolute and relative speeds than their terrestrial counterparts. Fullerenes have the highest documented tensile strength, although fabrication of single carbon nanotubes or graphene ribbons has proven costly. The light weight and high tensile strength of a fullerene line would potentially make them ideal, but commercial alternatives should not be overlooked. As the weight of objects is effectively reduced in the lack of terrestrial gravity, the force applied to a line may likely be reduced. In both maritime and microgravity environments, the material's Young's modulus and the longitudinal frequencies would need to be considered, as the stress on the line would be inconsistent. The line could periodically tighten and slacken. Commercial fishing line could be an effective substitute, in lieu of affordable fullerene lines.

A line requires a means to carry it. While rockets and guns were used previously, reliable ignition is integral to the device's function. The Schermuly pistol-rocket apparatus used a blank cartridge to ignite a black powder rocket, adding a second step to the process. The MBA gyrojets used a conventional firearm primer to ignite the rocket propellant, triggered by an unreliable mechanism. Model rockets use electric ignition, with an electric match triggered by a button press. Electronic ignition can bypass the problems and complexity of a mechanical system, but this requires a direct electronic connection with a power and launch circuit. In the event of a secondary line being needed, the entire circuit must be re-established with a specialized circuit in the launcher as the entire device would be useless if the circuit was broken. An alternative is optical ignition, i.e., the use of a laser to ignite the rocket. Shown in Fig. 5, optical ignition has already been used as a substitute for conventional primers in a line of Voere's hunting rifles (Voere, 2015).



**Figure 5: Voere laser ignition system for bolt-action rifle (Voere, 2015).**

Optical ignition does not require a direct physical or electrical connection between the device and launcher, making it suitable for ignition of the line-carrying rocket. Voere's prototype needed to incorporate a sufficiently powerful laser and be physically robust enough to withstand its intended purpose.



**Figure 6: Soviet TP-82 cosmonaut survival pistol (Wikimedia Foundation, 2023).**

Using a lighter material to fabricate the launcher would reduce its mass, which would also reduce payload-dependent launch fuel costs. A precedent for firearms in space is the Soviet-designed TP-82 cosmonaut survival pistol, to assist survival after landing in remote Central Asia by launching flares, defending against predators, and hunting small game, shown in Fig. 6 (Popenker, 2022). The pistol was later stored disassembled, due to internal space and safety considerations. Similarly, many line launchers are stored disassembled during transport on vessels where cargo space is at a premium. As such, the line launcher would be transported disassembled, and then stored assembled until needed, as with its maritime counterpart. Using 3D-printed plastics for both the launcher and the rocket such as polylactic acid (PLA) could enable rapid, low-cost fabrication. Other rocket-launching pistols, such as flare guns, do not require excessively strong barrels or containers. Even if the line launcher or rocket is “dropped” in orbit, PLA degrades in ultraviolet (UV) light. As such, the device would degrade in orbit under constant UV exposure, instead of becoming a persistent orbital hazard (Nogales, et al., 2018). These considerations drove the development of two sequential prototype line launchers.

## **2 Methods**

### *2.1 Prototype 1*

Two separate prototypes of Lachesis were constructed. The first prototype was a 3D-printed, modular pistol with laser ignition, textile rifling, a nylon line, and PLA composition. All plastic parts were 3D-printed with PLA with a 20% infill. The rear of the pistol contained an opened slot to fit a laser pointer. All parts were designed to reattach with a friction fit, shown separately in Fig. 7.



**Figure 7: Primary 3D printed prototype components including barrel, grip, magazine, and projectile.**

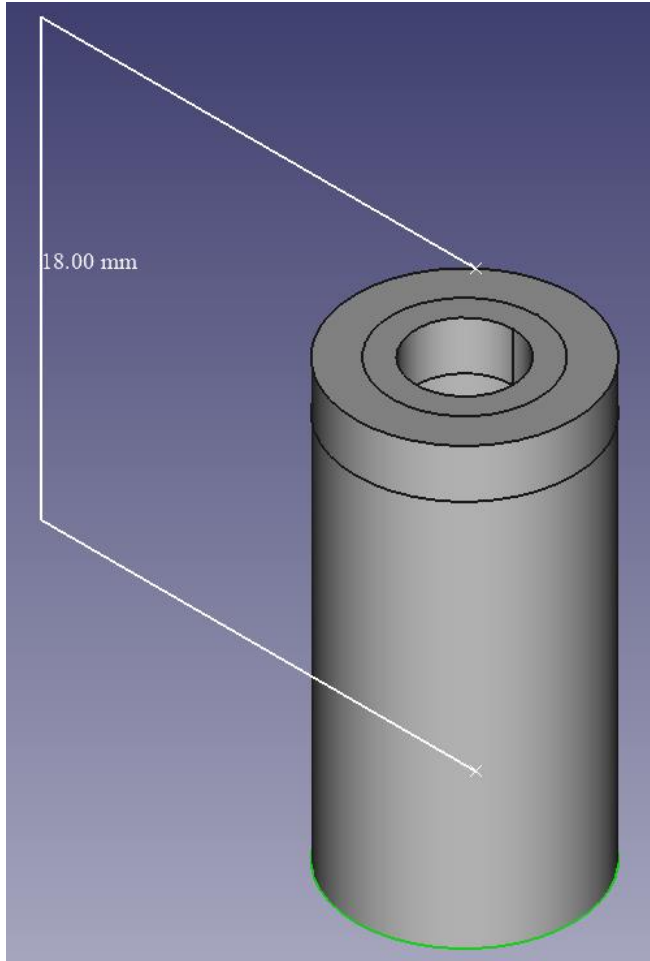
The external laser pointer was bulky, but it contained the essential components: batteries, circuitry, and an activation switch. A final iteration would have the components fully integrated, but basic testing commenced with the aperture-mounted laser. By aligning the laser in position, it would be pointed directly down the nozzle of the rocket. The continuous-wave 450 nm laser produced 50 mW of power. The laser system required  $\sim 3$  s to reach maximum intensity. With electronics positioned inside, the assembled system is shown in Fig. 8.



**Figure 8: Lachesis prototype 1 fully assembled.**

A thin sheet of acrylic was positioned between the laser collimating lens and the rocket. Based on models from the open-source Ronin Rocket Repository, two 3D-printed PLA rocket engines were tested: Phi (9 mm) and Tau (5.7 mm) (LaRocco, Ronin Rocket Repository, 2022). The mass of the standard dart was 0.2 g.





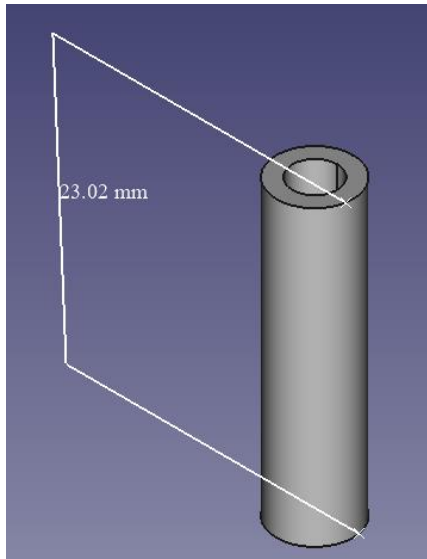
**Figure 9: Phi rocket engine (18mm in diameter, with a 4.5mm radius).**

The Phi rocket engine is shown in Fig. 9. Phi series rockets would be wrapped in electrical tape to increase friction and engage rifling, while Tau series rockets would be embedded within short foam darts (12.7 mm in diameter and 38 mm in length) to provide additional thrust. For the Phi series projectiles, the line was attached via looping the line through the rubber portion of the dart and tape.



**Figure 10: Phi rocket engine within dart.**

Shown in Fig. 10, the total mass of a Phi rocket dart was 0.35 g. As shown in Fig. 11, the Tau series rocket was inserted within the dart, allowing the line to be threaded through apertures in the dart's foam head. The total projectile mass for a Tau rocket dart was 0.25 g. Both were tried independently to determine which was more reliable. The velocity of each was measured via ballistic chronograph.



**Figure 11: Tau rocket engine (6mm in diameter, 23mm in total height).**

Prior line launchers had either an under-barrel or barrel-mounted spool of line. An external mounting position could potentially result in a tangled line if mishandled. The line would need to be spooled or coiled in such a way that it could be rapidly inserted or mounted onto the launcher. As the launcher was designed in the likeness of a pistol, placing the line in the “magazine” was attempted. A bracket at the bottom of a detachable “magazine” was used as a line tie-off point, as shown in Fig. 12.



**Figure 12: Magazine-based assembly containing line, spool, and rocket.**

Monofilament KastKing (NY, USA) fishing line with a 0.4 mm diameter was used as the test line. The line snaked from the nose of the projectile down into the “magazine” spool. The potential rapid ignition and burn rate was within 100 ms. Based on prior testing, the line would not be burnt behind the rocket.

### *2.1.1 Calculation*

Refinement of a handheld line launcher required complex calculations regarding force diagrams, propellant burn rates, and orbital kinematics. In microgravity, a handheld tethering system was especially a complex problem. However, the core function of a line launcher is delivering a line-carrying projectile with consistent velocity. As such, refining the first step was the most important part of early-phase prototyping. The design had to ensure that the projectile could be reliably launched with consistent velocity at a constant distance, with other factors being controlled.

The initial test methodology involved positioning a ballistic chronograph in front of the launcher. The rocket was secured at the muzzle with a friction fit. The laser was positioned behind the rocket nozzle at a distance of 5.1 cm, and was protected by a thin acrylic sheet. Fishing line atop the rocket ensured it would travel through the chronograph.



The tests were performed to confirm they could successfully ignite. Initial results were used to inform the design of a second prototype.

A D-class model rocket was used as the upper boundary for line-carrying rocket performance, with a total impulse of 10.01–20.00 Ns (National Association of Rocketry, 2023). As with traditional model rocket engines, black powder was used as the propellant in both rocket engines. For the Phi engine, 1.16 g of black powder was used. For the Tau engine, 0.33 g of black powder was used. Conventional firearm cartridge velocities were used to estimate the maximum kinetic energy of each rocket. Phi was approximated to a .38 Special cartridge, with a kinetic energy of 270 J while Tau was approximated to a .22 LR cartridge, with a kinetic energy of 180 J. These values were calculated for contemporary smokeless powder, rather than traditional black powder (SAAMI/ANZI, 1992). As such, the maximum effective kinetic energy could be reduced to less than half of the recorded values (LaRocco & Lehr, Jeju Archive of Mechanical Launchers, 2022). The burn time was assumed to be approximately 100 ms of ignition, based on the MBA gyrojet pistol (Carpenter, 2010). The Tsiolkovsky rocket equation is given below in Eq. 1 (Dvornychenko, 1990).

$$\Delta v = v_f - v_i = v_e \log \left( \frac{m_i}{m_f} \right), (1)$$

where  $\Delta v$  is the change in velocity,  $v_f$  is the final velocity,  $v_i$  is the initial velocity,  $v_e$  is the effective velocity,  $m_i$  is the initial mass, and  $m_f$  is the final mass.

The encasing of each rocket in a short foam dart and tape would add to the friction prior to departing the barrel, due to engaging the soft rifling. It was hypothesized that the rocket would reach its maximum velocity at the end of the barrel, analogous to the muzzle velocity of a firearm. A ballistic chronograph was positioned at the prototype's muzzle. The projectile consisted of the rocket, powder propellant, electrical tape, and a foam dart. Each projectile was weighed before and after launch to calculate its specific impulse and kinetic energy. Kinetic energy,  $E_k$ , was calculated using Eq. 2, where  $m$  is the object mass and  $v$  is the velocity (Tipler & Mosca, 2007).

$$E_k = \frac{1}{2}mv^2 (2)$$

Tests were performed with and without soft rifling to estimate the friction on the projectiles. The soft rifling consisted of a hollow cylinder 2.5 cm long with holes at a 15° angle to the horizontal plane, to impart rotational friction. Twine or fishing line was threaded through each of four pairs of holes.

The chronograph's distance from the end of the barrel was used to ensure the maximum velocity was reached. In the event the projectile failed to clear the barrel, the configuration was noted. In the event where the onboard propellant was insufficient to allow the projectile to clear the rifling or the dart contained no rocket, a pneumatic launcher was used instead. The secondary launcher was sufficient to accommodate the mass of the projectile. The pneumatic launcher could be positioned behind the launch unit, just as with the laser pointer. Otherwise, the configurations were identical.

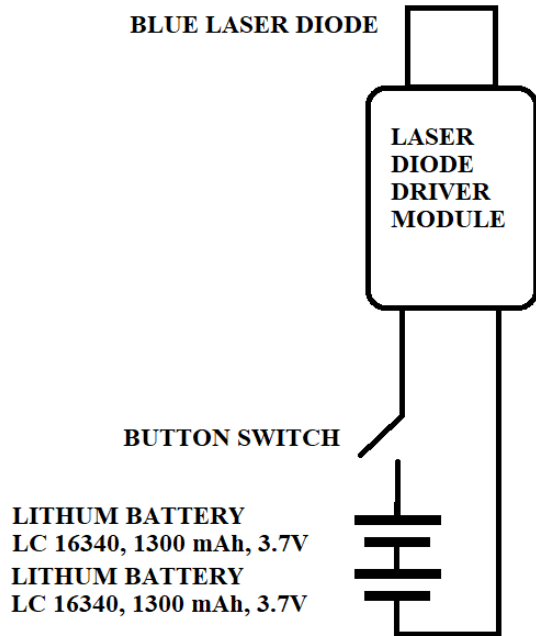
## 2.2 Prototype 2

The second prototype integrated the electronics and a different line launcher configuration. Positioning the line behind the projectile resulted in continuous failures during both rocket and pneumatic launches. In the case of rocket launches, the fishing line melted due to the heat of the exhaust. During malfunctions from pneumatic launches, the line snagged. A more conventional line storage configuration was used instead, where the line was coiled in a plastic ring around the muzzle. To secure the line to the barrel, 10 cm of soft rifling was attached to the coil to create a friction fit between the component and the barrel. Epoxy was used to additionally secure it. Two variants of soft rifling, one with thick twine and the other with fishing line, were employed. To reduce the chance of friction stopping the projectile entirely, a single soft rifling segment of 2.5 cm was used during testing.



**Figure 13: Lachesis prototype 2 with projectile, thicker wire, and muzzle-mounted line spool.**

The entire device is shown in Fig. 13. To improve the weight and balance of the device, the optics and the control circuitry were positioned at the rear of the launcher. To improve grip ergonomics and stability, the batteries were relocated in the handle, along with 55 g of metal screws. A heavier gauge wire was used to accommodate the higher electrical current in the electrical circuit, as shown in Fig. 14. A 3D-printed cone was used to create a friction fit for the collimator lens in front of the laser diode. A button switch connected the batteries and laser diode driver circuit, which was used as the trigger.



**Figure 14: Electrical schematic of optical ignition circuit, including 447nm blue laser diode (MDL-XS-447).**

The body of the prototype was held together with a friction fit, allowing it to be safely disassembled and stored as necessary. The length of the assembled prototype was approximately 310 mm. The total mass of the prototype was 13 g, for a total mass of 68 g, including the metal screws. The two prototypes are compared against each other in Fig. 15.



**Figure 15: Two prototype line launchers, with Prototype 1 on bottom and Prototype 2 on top.**

The tests were repeated with the second prototype at 1 m, comparing the effects of soft rifling and projectile configuration. The performance factors were the soft rifling and the projectile configuration. The primary analysis was conducted with the second prototype. The first tests conducted were to compare use of the thick twine soft rifling, fishing line soft rifling, and no soft rifling. Three shots with each projectile were attempted. If the first two attempts

at rocket ignition failed, they were launched pneumatically. In the event of a launcher failure or malfunction, the remainder of the tests would be conducted with the pneumatic launcher. A two-way analysis of variance (ANOVA) was conducted with post-hoc tests in Python.

### 3 Results

The two primary conditions included the rifling type (no rifling, nylon line-based rifling, and twine-based rifling) and projectile time (basic dart, dart with Tau rocket, and dart with Phi rocket). As shown in Table 1, the presence of rifling lowered the average velocity by over 20 ms<sup>-1</sup> for standard darts. The use of rocket and dart hybrid projectiles also indicated a drastic drop in velocity due to the friction increase. By the time the projectile left the barrel, the entire propellant had been expended. The average time from trigger pull to launch was 3.2±1 s.

**Table 1: Average Velocity (ms<sup>-1</sup>) and Standard Deviation of Rifling and Projectiles at 1 m**

<u>Rifling</u>	<u>Dart</u>	<u>Tau</u>	<u>Phi</u>
<i>None</i>	41.4±1.9	31.9±1.9	25.6±3.9
<i>Nylon</i>	21.2±2	6.4±1.1	6.9±0.5
<i>Twine</i>	22.5±1.9	7.9±0.5	6.9±1.5

The measurements include the average mean from three measurements and the standard deviation across observed measurements. Using Eq. 2, the highest projectile kinetic energy was 0.171 J for a standard dart. The highest kinetic energy was 0.127 J for a rocket projectile, substantially less than for the foam dart projectile’s maximum kinetic energy. The ANOVA revealed significant differences in the observed results. Each variable is a sub-heading in Table 2, listing the two variables (rifling and projectile type), and their interaction. The first column of Table 2 shows the Sum of Squares, corresponding to the total size of each effect. The next column includes the degrees of freedom. The second column in Table 2 shows the degrees of freedom (*df*), is based on group means and sets. The third column includes the F-score, a statistical measure used to test each hypothesis. The final column in Table 2 shows the probability, the *p* score. If the value is less than 0.05, the result is statistically significant.

**Table 2: ANOVA Results for Velocity Measurements**

	<u>Sum of Sq</u>	<u>df</u>	<u>F</u>	<u>PR(&gt;F)</u>
<i>C(rifling)</i>	2638.732	2	339.6861	5.08E-15
<i>C(projectile)</i>	1219.743	2	157.0185	4.04E-12
<i>C(rifling):C(projectile)</i>	45.14148	4	2.90555	5.12E-02
<i>Residual</i>	69.91333	18	NaN	NaN

As shown in Table 2, the interaction of the two primary effects (rifling and projectile type) was not statistically significant, albeit by a close margin. The added mass of even a small rocket (such as Tau) was enough to add a significant velocity. The implications of the dramatic drop in velocity warrant a closer investigation into optimization of projectile design and soft rifling.

### 4 Discussion

The re-invention of the line-launcher for microgravity extends well beyond a single, handheld device. The Lachesis system demonstrates a successful and novel integration of independently verified technologies. The concept of a line launcher validates a general-purpose projectile launcher with applications beyond rescue, including aerospace, industry, and defense. For defense and industry, the use of optically ignited single-nozzle gyrojets with “soft rifling” could greatly reduce gun barrel corrosion in small arms (Kumar, Kalra, & Jha, 2022). In aerospace, similar units could be mounted on the bodies of spacecraft for object capture or antennae deployment (Sizov & Aslanov, 2020; Zhao,

Liu, & Wu, 2020). The applications of the device are far too numerous to list, although certain limitations must be addressed.

The study had several primary limitations. The first limitation is the lack of more complex kinematic models and simulation. The second limitation with the soft rifling is that roller-bearing based “rifling” may have a consistently superior performance, even with smoothbore and soft projectiles. A third limitation is the potential reliability of the launcher under stress. A fourth limitation is the drag induced by the rifling, which may put into question the need for it. A fifth limitation is the nature of the line projectile itself, as prior line launchers used grappling hooks or flotation buoys to ensure a reliable attachment or consistent positioning. A sixth limitation is the short span of line included in the study. A final, seventh potential limitation is the relative weakness of the nylon fishing line compared to traditional rope on line launchers. However, these problems could be addressed in future work.

A future investigation could improve upon the points raised. More complex models and calculation can be used to refine the core device demonstrated here. The physical prior tests were performed with space constraints, precluding the use of longer lines. The comparison of soft rifling against roller bearing rifling, as well as variants of each, is perhaps the largest change (Phillips, 2022). The existing soft rifling dropped the velocity well below that reported using darts in pneumatic foam dart blasters (Phillips, 2022). This may be attributable to a single longer segment with too much friction, as opposed to several smaller ones, as used in comparable foam dart blasters (Captainslug, 3). The second major improvement is substantially improving the reliability of the rocket ignition mechanism and ~3 s warmup period with the laser. While a pneumatic system was included for preliminary tests, a conventional rocket engine offers far more advantages in line-carrying distance (Skoog, 2019). Protecting optical components could be accomplished by substituting a different type of acrylic or transparent material between the laser and rocket, potentially including a sacrificial one on the rear of each projectile.

The Voere laser-ignition system uses a translucent material where a primer would be in a conventional rifle cartridge, so a similar material could be positioned at the nozzle of each rocket, even if it was sacrificial (Voere, 2015). As with other optically-ignited rocket launch systems, a pulsed laser may be more immediate and reliable than a modified continuous-wave laser. Substituting the continuous-wave laser with another mechanism, such as photo-ignition, could greatly simplify the electronics and reduce the cost (Badakhshan, Danczyk, Wirth, & Pilon, 2011). An optimized fuel mix could similarly improve range and power, allowing a more consistent rocket acceleration (Woodford, 1932).

Similarly, the line itself could benefit from a stronger material composition and a novel adhesion mechanism. The nylon fishing line could be substituted with carbon nanotube and fullerene-based materials (Bai, et al., 2018). The mechanism of line attachment to the target was unexplored in the paper, as the launch system had to be demonstrated first. While prior line launchers used grappling hooks, new materials present novel possibilities. Synthetic setae, which use van der Waals forces to adhere to materials like a gecko’s foot, could greatly increase attachment reliability compared to chemical adhesives or mechanical protrusions (LaRocco, Evaluation of synthetic setae pads for dry attachment of an ultrasound transducer, 2019). Such materials can be cheaply and commercially procured. Lighter than both the Soviet TP-82 and British Schermuly pistol-rocket apparatus, the Lachesis line launcher can potentially serve as a lighter tool for space and airborne emergency response (Snook, 1974).

## **5 Conclusions**

The described device reinvents the classic line launcher for outer space. While the contemporary maritime economy still uses line launchers, the commercial spaceflight economy has not yet adopted them. As with the terrestrial counterpart, line launchers offer operational utility, including object capture, antennae deployment, and rescue. The rocket-based Lachesis system prototype possesses several unique advantages relative to prior launchers. It possesses a light mass (68 g with metallic components added for balance) a contactless optoelectronic launch system, a novel method of stabilizing the projectile, and the ability to be disassembled and reassembled. The use of 3D-printed PLA components also ensures the unit would be eroded by ultraviolet light in orbit, to ensure it does not linger as space debris. Improvements to the launch system, the line design, the soft rifling, and the materials would be iterative improvements upon a proven concept. Despite these relative shortcomings, the Lachesis line launcher reintegrated several proven principles together to demonstrate the viability and use case for an updated line launcher in orbital operations.

### *Data Availability*

Computer models and data used in this work are available at: <https://github.com/javeharron/lachesislinelauncher>

### *Declaration of Competing Interests*

The primary author has no conflicts of interest to declare.

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### *About the Author*

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