Reusability in the New Space Revolution

Produced by Zachary Friedman

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01

Background

A brief history of the RLV market

Interviews Held

Scope of Analysis

Market Viability

- The goal of this presentation is to analyze reusability in the role of **market viability**
- Engineering elements will not be covered as in-depth

Industry Focus

- Companies profiled are NewSpace, referring to emerging entrepreneurial space endeavors
- Focus on **orbital** regime (rather than suborbital or deep space)

Payload Focus

- Focus only on **non-human** payloads (e.g., no SNC Dream Chaser)
- Payloads mainly focused on smallsats

Launch Vehicle Definitions

Small Lift Vehicle

- Up to 2,000 kg to LEO
- e.g., Electron, Alpha, LauncherOne

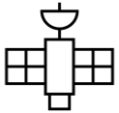
Medium Lift Vehicle

- Up to 20,000 kg to LEO
- e.g., Falcon 9, Soyuz, Atlas

Heavy Lift Vehicle

- 20,000 - 50,000+ kg to LEO
- e.g., Delta IV Heavy, Starship, New Glenn

Payload Definitions

Smallsat 	Satellite weighing less than 500 kg
Constellation 	A group of satellites working together as a system
LEO 	Low Earth Orbit refers to a period of 128 minutes or less and an eccentricity of less than 0.25
Rideshare 	Placing multiple payloads on the same mission to reduce launch costs for customers

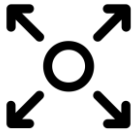
The core focus of developing reusable launch vehicles is to lower the financial barriers and environmental impacts of in-space activity

Lower Cost

Reusability serves as one of the main methods to lower the cost of access to space, as the most expensive components of a vehicle can be reused

Less Waste

Reusable vehicles greatly minimize waste, scaling with the number of times a vehicle can be reused



Increased Capacity

Minimizing downtime between flights through refurbishment rather than complete vehicle construction can allow for an increase in launch capacity

The Space Shuttle was the first successful RLV, but failed to deliver on cost promises. After decades without a promising replacement, a number of new firms are developing reusable vehicles

1981: Space Shuttle

- First successful RLV
- Desired cost $1,340/kg*
- Actual of $55K/kg
- LM VentureStar program cancelled in 2001

2015: Falcon 9

- First orbital class reusable rocket
- Most launches of all U.S. rockets in operation
- Brings launch costs down to $2,500/kg

2020s: NewSpace

- Reusability in SLV's and MLV's
- Fully reusable vehicle development
- $10-20/kg with Starship**

*Inflation adjusted to 2011 program completion

**Claimed cost, heavily debated by industry experts


SPACEX

The SpaceX Falcon 9 has driven down costs with a reusable first stage, and the Starship promises to further revolutionize the industry

SpaceX Vehicles

Falcon 9

- First flight 2010
- 70 m height
- 3.7 m fairing diameter
- 22,800 kg to LEO
- $2.5-3k cost/kg to LEO

Falcon 9 has enabled SpaceX to provide contracts at 1/10th the cost/kg of legacy companies, making it the most launched vehicle in 2021 (31 launches)

Starship

- First orbital flight 2022
- 120 m height
- 9 m fairing diameter
- 100 tons to LEO
- $10-20/kg to LEO*

The fully reusable Starship will carry crew and cargo to orbit, the Moon, and Mars at record high payload capacity and record low costs

*Claimed cost, heavily debated by industry experts

BLUE ORIGIN

Blue Origin places a heavy emphasis on reusability, although their orbital vehicles are less flight-proven than SpaceX's

Blue Origin Vehicles

New Shepard

- Manned suborbital flights in 2021
- Single stage
- 25 m height
- 2.8 m^3 capsule for 6 passengers

New Shepard offers suborbital space flights on a reusable platform and serves as a testbed for Blue Origin technologies

New Glenn

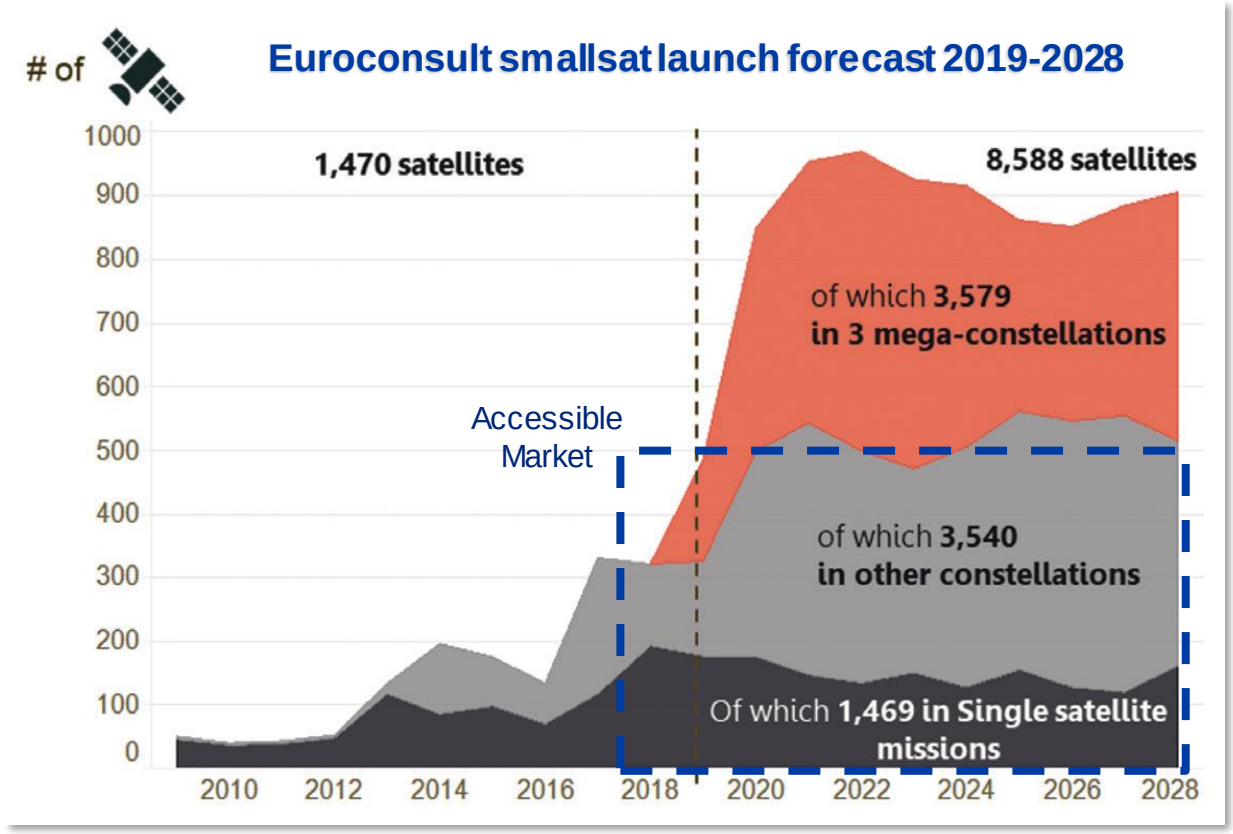
- First orbital flight 2022 (est.)
- 96 m height
- 7 m fairing diameter
- 45,000 kg to LEO
- Unknown cost/kg

New Glenn is designed to transport payloads to orbit and deep space, with a 25x reusable first stage

02 Customer Base

How customers are enabling the NewSpace revolution

The smallsat market has exploded in recent years, leading to new business opportunities in the launch market



Market Changes

- Technological advancements have led to a decrease in satellite size, increasing smallsat launch demand
- Starlink, Kuiper, and OneWeb account for a large percentage of satellites but have dedicated launch providers
- Older data underestimates size of Starlink

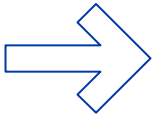
The majority of megaconstellations have dedicated launch providers, leaving little room for new market entrants

Constellation	Size	Launch Provider
Starlink	30k	SpaceX as sole launch provider
Kuiper	3,236	• Arianespace • ULA • Blue Origin
OneWeb	648	• $^{2}/_{3}$ Roscosmos • $^{1}/_{3}$ SpaceX

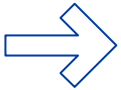
Despite a seemingly large smallsat market, the total share available to small launch providers in the US is much smaller

Smallsat Market Size

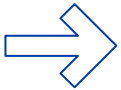
$3.3B
2020



$13.7B
2030



84% Of all smallsats built in the next decade will be in constellations



50% Of smallsat launch demand will be American

$1.1B Estimated available single smallsat mission market size in the US 2030

The total available U.S. smallsat launch market is likely too small to support the increased competition among small launch vehicles

Total market size provided by Valuates Reports, 2022

With an increasing number of small vehicles on the market, companies must establish unique value propositions to remain competitive

Cost

Providing the lowest cost per kg to smaller missions

Dedicated Launch

Providing dedicated launches to small payloads

Launch Location

Bringing launch accessibility to untapped regions

Launch Timeline

Providing launch services on short notice for urgent missions

03
Company Profiles

Promising new players in the launch industry

Company Profiles

Rocket Lab

Rocket Lab is a leading small launch provider with a high market presence and increased interest in reusability

Mission:
Remove the barriers to commercial space

Founded: 2006

Employees: 600

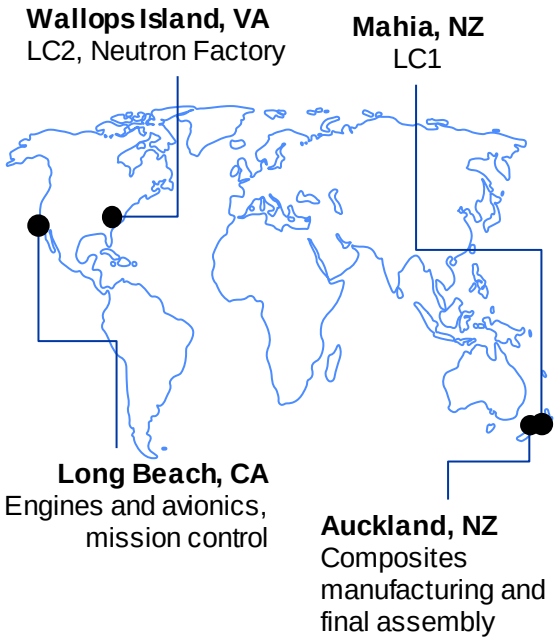
Funding: $750M

Ownership: Public

Product: Vehicles, Spacecraft, Components

Successful Launches: 22

Failed Launches: 3



2006
Company Founding

May 2017
First launch (Failed)

Jan. 2018
First orbital success

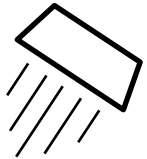
Oct. 2019
Photon satellite bus announced

Dec. 2021
Plans for Neutron MLV announced

Rocket Lab's offerings span both launch and space systems

Launch Vehicles

- Launch vehicles Electron and Neutron will be capable of serving a large majority of the commercial launch market
- Missions for commercial smallsat providers, mega-constellations, NASA, and the DOD



Space Systems

- The Photon serves both as the upper stage of Electron and a spacecraft for LEO to lunar satellite missions
- Photon will be used with Electron to launch NASA's CAPSTONE CubeSat to lunar orbit in 2022

Satellite Components

- With recent acquisitions, product offerings include star trackers, reaction wheels, software, and separation systems
- Allows for diversified revenue streams with high-margin products while vertically integrating their own operations

TAKEAWAYS

- Building space systems and satellite components allows for a **vertically integrated** company, both lowering operating expenses and increasing revenue
- Rocket Lab understands a **larger launch vehicle** will be required to serve the majority of the launch market

Rocket Lab has lowered costs through additive manufacturing, automation, and vertical integration, with plans for complete reusability

Additive Manufacturing	Rocket Lab uses metal 3D printing to produce its Rutherford engine and automated fiber placement for carbon composites
Automation	Carbon composite manufacturing is completed with a robot that can produce an airframe every 12 hours
Vertical Integration	Limited access to components for production forced vertical integration, leading to in-house capabilities and multiple large acquisitions
Reusability	The Electron SLV is moving towards reusability, and the planned Neutron MLV promises to be one of the most reusable vehicles ever

Rocket Lab has successfully launched its Electron SLV 22 times and announced details of the Neutron MLV in December 2021

Vehicle Comparison

Specs

- First flight 2017
- 18 m height
- 1.2 m fairing diameter
- 300 kg to LEO

Mission

- Smallsat & cubesat
- Dedicated & rideshare
- Lunar spacecraft
- $7.5m/launch

Specs

- First flight 2024 (EST.)
- 40 m height
- 5 m fairing diameter
- 15,000 kg to LEO*

Mission

- Smallsat constellations
- Human spaceflight
- Interplanetary

*8,000 kg for land-based booster landing

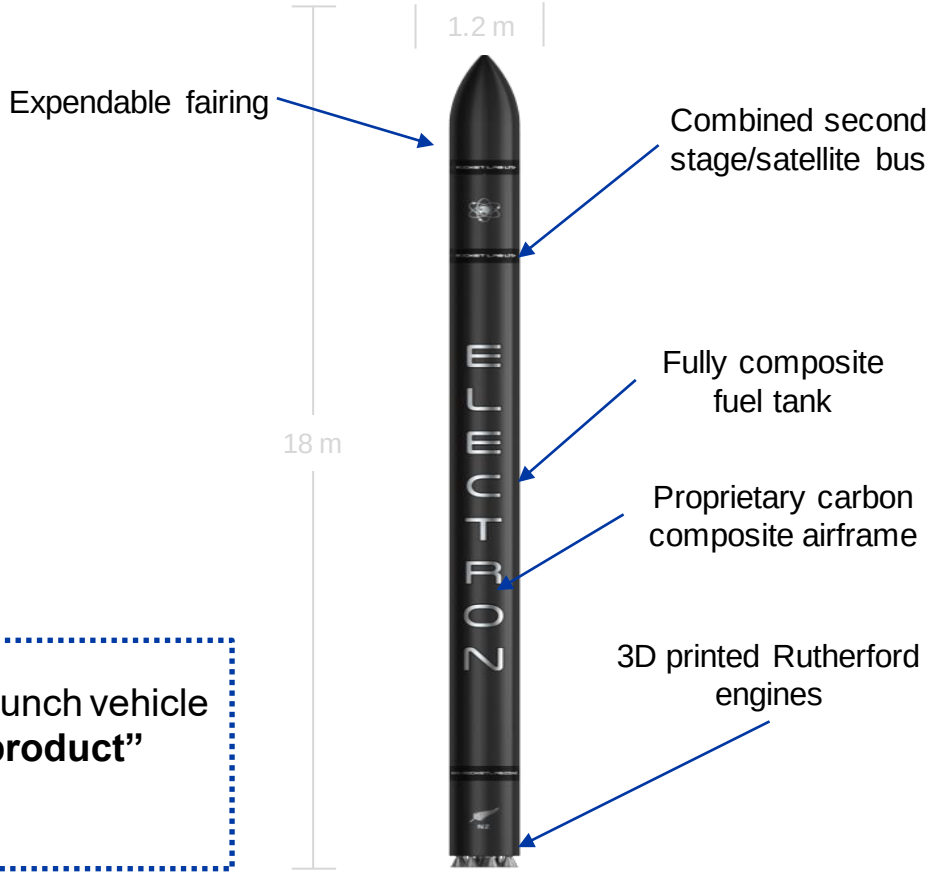
Electron was not originally designed to be reusable, but air-based recovery plans are in progress

OVERVIEW

- Electron was designed to be an expendable launch vehicle, but Rocket Lab has begun recovering the first stage
- Notable features include a fully composite airframe and fuel tanks
- Boosters are currently recovered from the ocean, but will be caught with helicopters
- First helicopter recovery scheduled for **2022**

"I think anybody who's not developing a reusable launch vehicle at this point in time is developing a **dead-end product**"

– Rocket Lab CEO Peter Beck



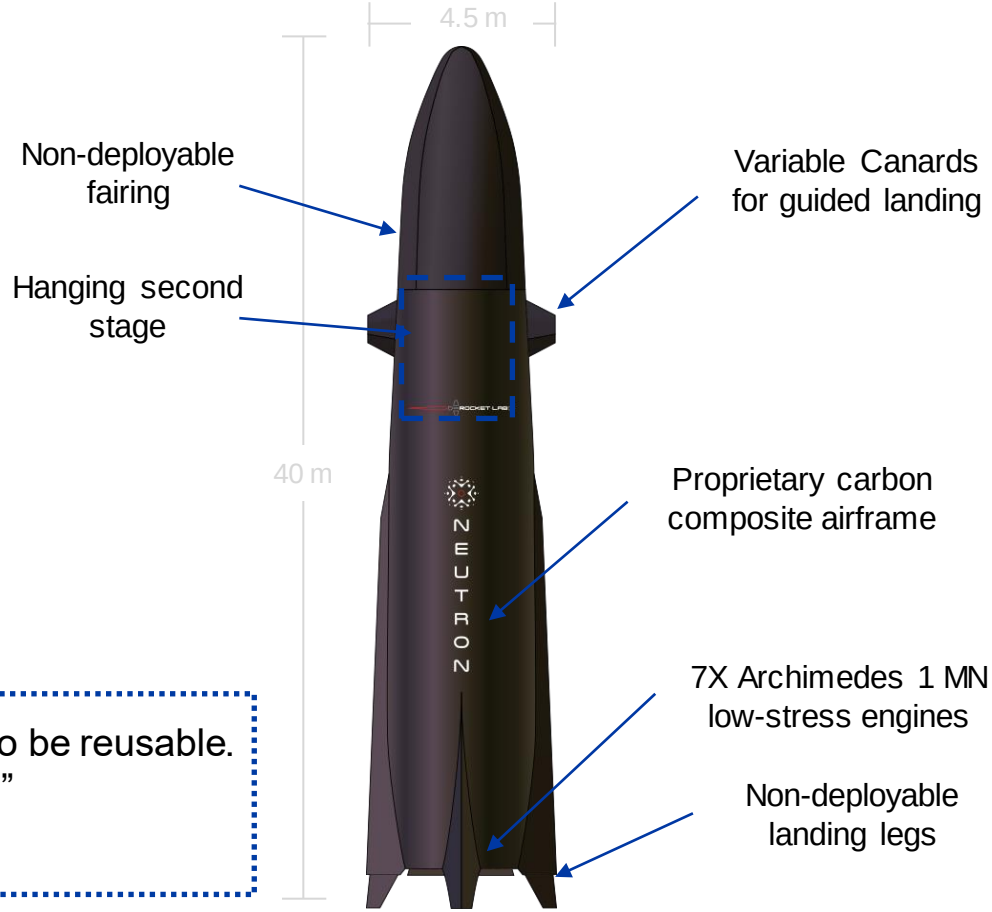
Every portion of Neutron is designed with reusability in mind

OVERVIEW

- Neutron's core focus is reusability, meant to **compete with Falcon 9** at a lower price
- Notable features include tapered airframe to limit shock heating, a hanging second stage, and a **non-deployable fairing**
- Neutron can place 8,000 kg into LEO if **landing at the launch site**, or 15,000 kg if expended
- First launch planned for **2024**

"We've really optimized the vehicle from day one to be reusable. Every decision is based around that."

- Peter Beck



Firefly Aerospace

Firefly is a private aerospace firm developing a family of launch vehicles and in-space platforms to allow for affordable small launch

FIREFLY AEROSPACE

Mission:
Improve life on Earth from space

Founded: 2014

Employees: 700

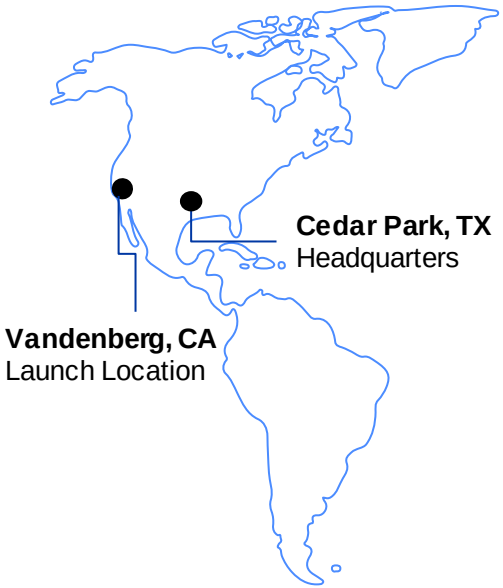
Funding: $272M*

Ownership: Private

Product: *Vehicles, Spacecraft, Components*

Successful Launches: 0

Failed Launches: 1



2014
Company founding

2017
Re-Creation after bankruptcy

May 2018
R&D site founded in Dnipro, Ukraine

Feb. 2021
NASA awards Blue Ghost Lunar Lander

Sep. 2021
First flight, unsuccessful

*Estimated

In addition to multiple launch vehicles, Firefly is focused on developing lunar landers and space utility vehicles.

Launch Vehicles

- Firefly Alpha will deliver 1 metric ton to LEO, serving the smallsat market
- Future vehicles will include Falcon 9 competitor Beta, and a reusable spaceplane known as Gamma

Space Vehicles

- Blue Ghost Lunar Lander won a $93M to take 10 payloads to the Moon for NASA Artemis program. It will fly on a SpaceX Falcon 9
- Space Utility Vehicle (SUV) being developed as the "swiss army knife of spacecraft"

Component Supplier

- Firefly will become a Tier 1 supplier of components to space launch companies
- Offerings will include the Reaver rocket engine and composite structures

Key Quotes

- "We are not a rocket company. Its 1/3rd of our space transportation architecture."
- "The rocket gives the keys to space. But the big revenue is doing **things in space**. Blue ghost gives $150m revenue, compared to our launch vehicle's $15m."

  - CEO Tom Markusic

Firefly Alpha has one failed launch as of 2021, and Beta will be Firefly's MLV; neither vehicle is planned to be reusable at this time

VEHICLE OVERVIEW

Alpha

Specs	Mission
• First flight 2021 • 29 m height • 2 m fairing diameter • 1,170 kg to LEO • $15M/launch • $13k/kg	• Designed to address the smallsat market • Desired twice/month launch cadence • Notable features include a composite airframe and purposefully simple engine design

Beta

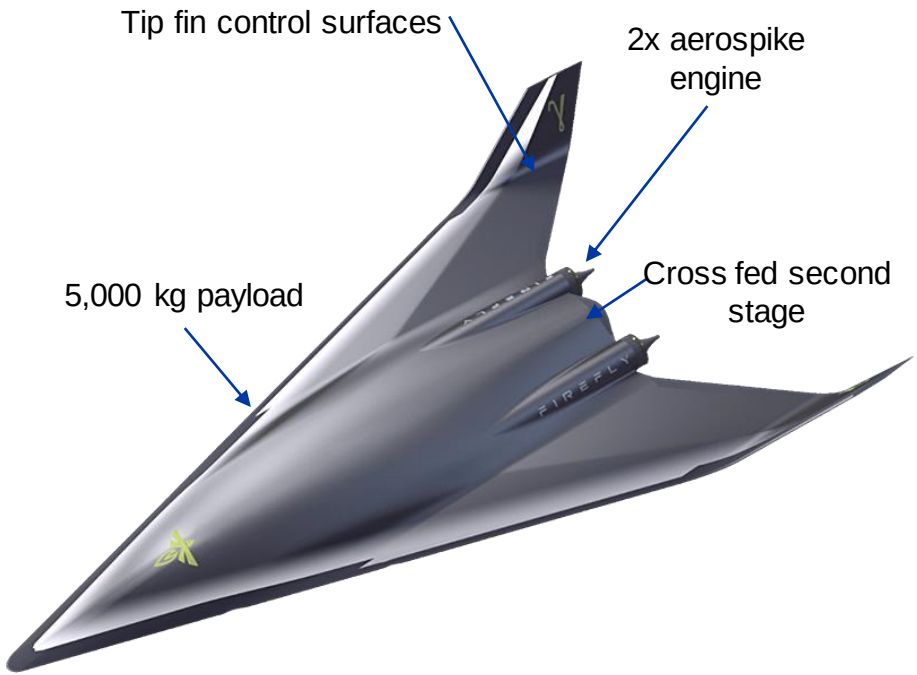
Specs	Mission
• First flight 2024 • 60.2 m height • 4.7 m fairing diameter • 11,000 kg to LEO	• Designed to compete with Falcon 9 • Goal of lowest cost/kg in its class • Similar in design to Alpha, but larger

Gamma is Firefly's future vision for a reusable spaceplane, with testing planned for the late 2020's

OVERVIEW

- Gamma is a concept for a reusable spaceplane designed to place satellite constellations into orbit
- Gamma will be **75% reusable** by cost
- Notable features include aerospike engines and potential for hypersonic Earth transport
- A formal design is planned for 2025

Gamma is Firefly's one glimpse at reusability, but remains as little more than a concept



Firefly is focused on high-margin operations using lightweight material, vertically integrated missions, and offshoring development

Automation	Similar to Rocket Lab, composite manufacturing is completed with automated fiber placement, bringing manufacturing time down to 14 days and producing the worlds largest all-carbon fiber rocket
Offshoring	With acquisition by Ukranian entrepreneur Max Polyakov in 2017, Firefly draws from Soviet-era technology and has a 200 person R&D facility in Dnipro, Ukraine
Complete Missions	Offering launch vehicles, space utility vehicles, and lunar landers will make Firefly an end-to-end space service provider

Rather than decrease costs through reusability, Firefly aims to increase revenues through a variety of in-space platforms

Virgin Orbit

Virgin Orbit is a smallsat launch provider using an air-based launch system to open space to markets lacking traditional launch infrastructure

Mission:
Space for everyone from everywhere

Founded:	2017	**Product:**	Launch Vehicles
Employees:	600	**Successful Launches:**	3
Funding:	$400M*		
Ownership:	Public	**Failed Launches:**	1

2017
Company founding

May 2020
First launch (failed)

Jan. 2021
First orbital success

Apr. 2021
Deal to launch from Brazil

Aug. 2021
Announcement to go public

*Estimated after SPAC merger

Virgin's two-part launch system involves a two-stage liquid fueled rocket that drops from the wing of a Boeing 747

LAUNCH SYSTEM

Specs

- First flight 2020
- 21 m height
- 1.5 m fairing diameter
- 500 kg to LEO
- $12M/launch
- $30k/kg

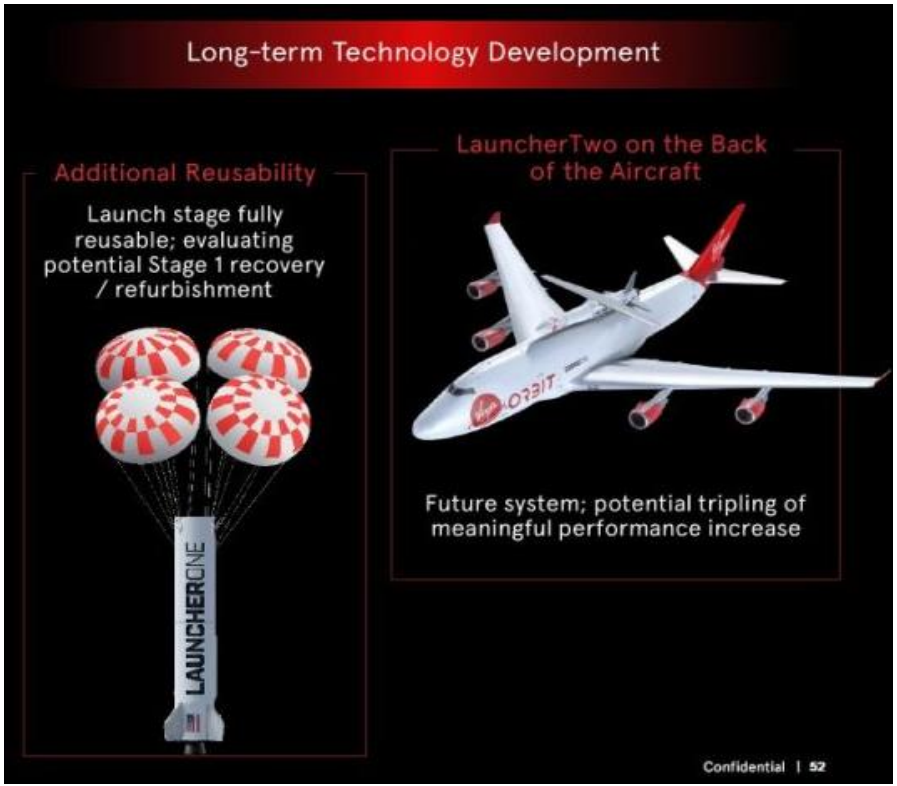
Mission

- Bringing launch services to areas without traditional launch infrastructure
- Main launch focus on smallsat market
- Provide dedicated launch services to desired inclinations at a premium

LauncherOne

Cosmic Girl

Virgin Orbit has given some hints at reusability for its vehicles, but is more likely to double down on their distinct competitive advantages



Virgin Orbit has presented possibilities for reusability in its investor presentation but is unlikely to pursue a reusable vehicle in the near-term

Credit: Virgin Orbit Investor Presentation

Virgin's launch system provides unique access to international clients, but comes with limitations to future scaling opportunities

Pros

- Access to allied nations (e.g., Brazil, UK, Poland)
- More orbital inclinations
- Potential for simplified land-based vehicle recovery
- More vacuum-optimized nozzle
- Readily available pilots and parts for carrier vehicle

Cons

- Large fixed costs for operating 747
- Major limiting factor on launch vehicle size
- Increasing carrier vehicle size will destroy main value proposition
- Smallsats alone may not be sufficient to support long-term profitability and growth

Virgin Orbit's success largely relies on the hypothesis that there is a large enough global smallsat market to support operations, and that customers will pay a premium for a more dedicated service

Astra

Astra is an emerging small launch provider with the main goal of reaching space as economically as possible

ASTRA

Mission:
Improve life on Earth from space

Founded: 2016

Employees: 100

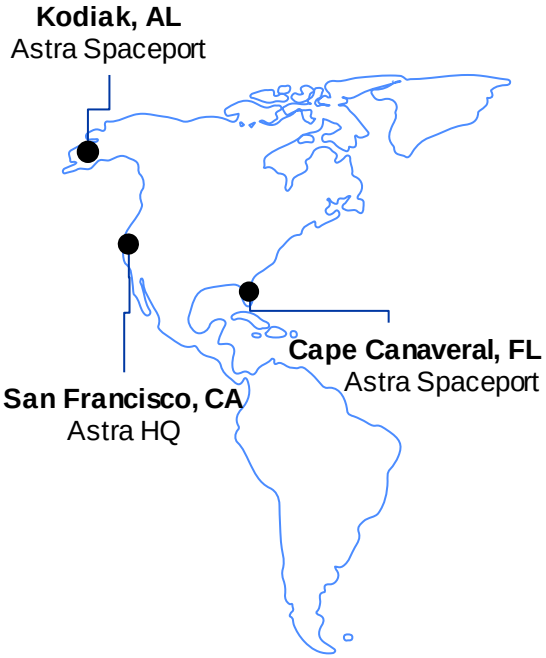
Funding: $500M

Ownership: Public

Product: Launch Vehicles

Successful Launches: 2

Failed Launches: 6*



2016
Company Founding

2018
Two Failed Suborbital Flights

2020
Two Failed Orbital Flights

June 2021
Astra Goes Public Via SPAC Merger

Nov. 2021
First Successful Orbital Launch

*Two failed suborbital launches and four failed orbital launches

Astra has taken an approach of minimizing launch costs, possibly at the expense of reliability

Cheap and lightweight	Astra abandoned carbon fiber fairings early on in favor of aluminum tubing to drop costs from $250k to $33k
Transportable	Both the vehicle and strongback are meant to be transported in standard shipping containers for a cheap, simple procedure
Low Overhead	Astra needs just ten people in mission control and six for vehicle setup
Avoiding Reusability	As the smallest of the smallsat launch vehicles, reusability does not make financial sense for Astra, so costs are cut elsewhere

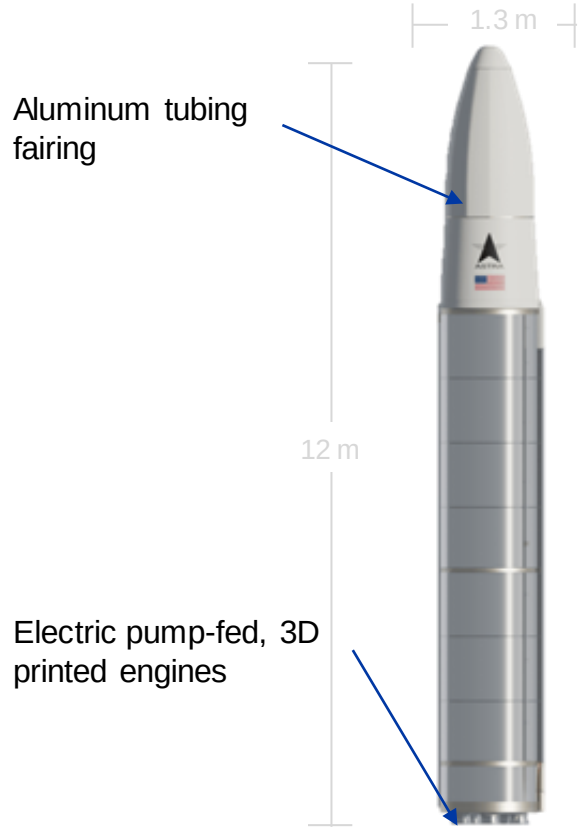
Unlike its competitors, Astra has no plans for a reusable vehicle, but instead focuses on minimizing fixed and variable costs

ROCKET 3

- Astra is focused on limiting costs per launch as much as possible, rather than investing in novel technologies
- Vehicle features include complete aluminum fairings and body and 3D printed engines
- No plans for reusability in any portion of the launch vehicle

"We can now take the entire spaceport… pack it into four shipping containers, unpack it, and launch the rocket with five people"

- Astra CEO Chris Kemp



Relativity Space

Relativity

Relativity is a rocket manufacturer focused on complete 3D printing of its launch vehicles

Relativity

Mission:
Building humanity's multiplanetary future

Founded: 2015

Employees: 700

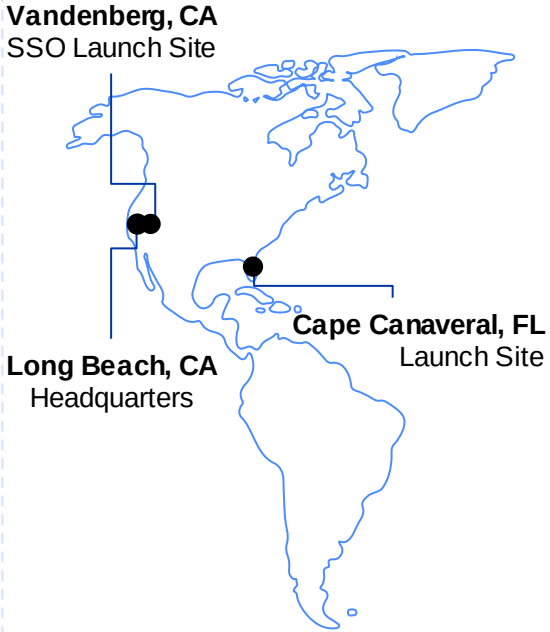
Funding: $1.3B

Ownership: Private

Product: Launch Vehicles

Successful Launches: 0

Failed Launches: 0



2015
Company founding

Jan. 2019
FL launch site acquired from USAF

Feb. 2020
120K sqft. HQ constructed

June 2021
$1.3B funding at $4.2B valuation

June 2022
First planned launch of Terran 1

Relativity operates like a modern software startup, including venture capital funding and autonomous manufacturing

Venture Capital	Relativity began in VC firm Y Combinator. It has now raised $1.3B and has no plans on going public
3D Printing	Relativity developed the worlds largest metal 3D printer (Stargate) to make its vehicles 95% 3D printed by weight
Software-Driven Ops.	Relativity is heavily focused on automating as much of their manufacturing process as possible to decrease costs

By treating its operations like a Silicon Valley software company, Relativity has been able to fund its operations while remaining private and develop a launch vehicle that is both low cost and easy to iterate

Terran 1 is Relativity's first launch vehicle, and is the largest vehicle amongst its competitors in the SLV market

Specs

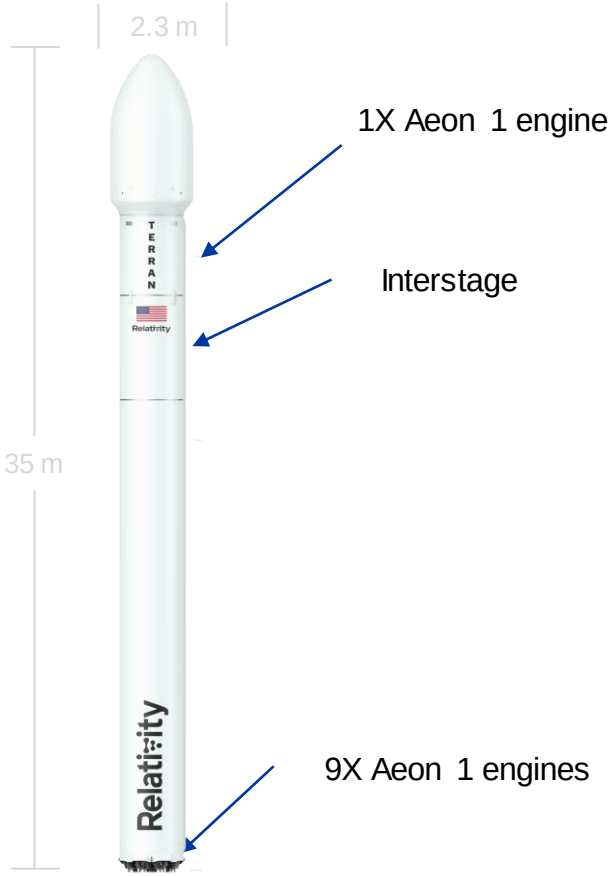
- First flight 2022
- 35 m height
- 3 m fairing diameter
- 1250 kg to LEO
- $12M/launch
- $9.6k/kg

Terran 1

- The largest of the small launch vehicles, design to serve constellation deployment and resupply
- Terran 1 can go from raw material to finished product in just 60 days
- There are no current plans for Terran 1 to be reusable

" [3D printing] is the most disruptive technology in our lifetime for aerospace and potentially for other manufacturing industries"

- Relativity Founder Tim Ellis



Terran R is Relativity's next generation, fully reusable and entirely 3D printed rocket

Specs

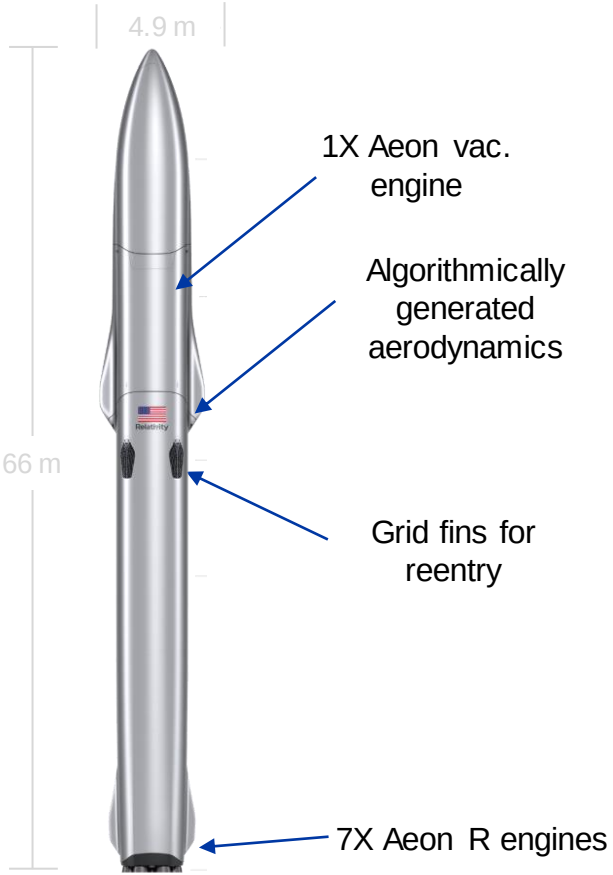
- First flight 2024
- 29 m height
- 2 m fairing diameter
- 20,000 kg to LEO

Terran R

- The first stage, second stage, engines, and fairing will all be reusable
- Algorithmically determined geometries are 3D printed to limit weight and enhance aerodynamics
- Terran R's long-term vision is to offer point-to-point space freight missions between Earth, Moon, and Mars

"Even with 3D printing, making it reusable has got to be part of that future"

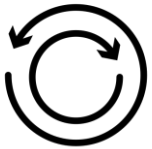
- Relativity Founder Tim Ellis



Rather than invest in near-term reusability, automation and 3D printing have become the primary goals for Relativity

Fewer Parts

- A standard vehicle has 100,000 parts, and Relativity believes their vehicle can have 100x fewer
- The Aeon 1 engine has less just 100 parts taking 9 days to print



Rapid Iteration

- Traditional manufacturing requires specialized tooling, limiting the ability for rapid iteration
- Additive manufacturing allows for cheap and fast iteration of parts

Less Labor

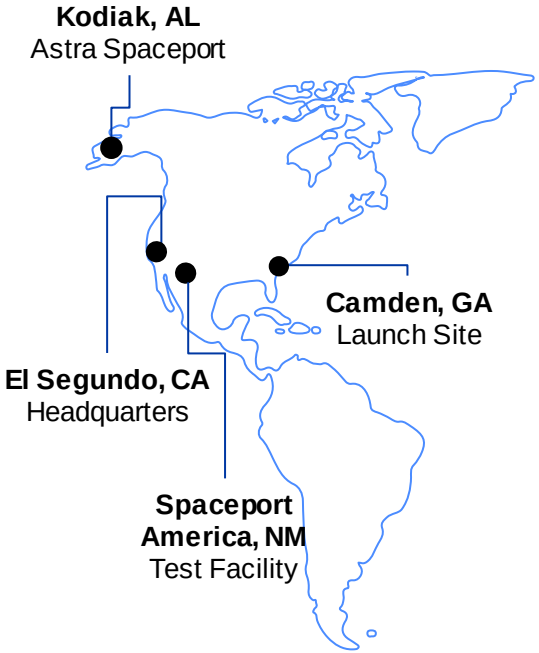
- 3D printing requires fewer machining processes, leading to less need for skilled labor
- Automating manufacturing processes will further decrease labor needs for vehicle manufacturing

ABL Space Systems

ABL Space Systems is focused on building a simple, rapidly deployable launch system with 100% American vehicle construction

Mission:
Launch Simply

Founded:	2017	**Product:**	Launch Vehicles
Employees:	160	**Successful Launches:**	0
Funding:	$420M		
Ownership:	Private	**Failed Launches:**	0



2017
Company founding

2018
Georgie launch site acquired

2019
Successful engine testing

Nov. 2021
Amazon Kuiper launch contract

Mid 2022
Planned first launch in Kodiak, AL

ABL is focused on producing the most simple and cost-effective rocket ever

Simple Design	The vehicle is produced with aluminum structures, 3D printed engines, and modular avionics
3D Printing	Similar to competitors, 9 3D printed engines will be used on its first stage and 1 3D printed engine on its second stage
Transportable	The GS0 launch system will utilize shipping containers for the vehicle, ground support, and even mission control
Launch from Anywhere(?)	ABL states they can launch anywhere with a 150’ x 50’ concrete pad, though the logistics of this system remain unproven

Similar to Astra, ABL is focused on a simple, cost-effective vehicle. Not much is known about the vehicle, but it will not be reusable

Specs

- First flight 2022
- 27 m height
- 1.8 m fairing diameter
- 1,350 kg to LEO
- $12M/ launch
- $8,900/kg to LEO

RS-1

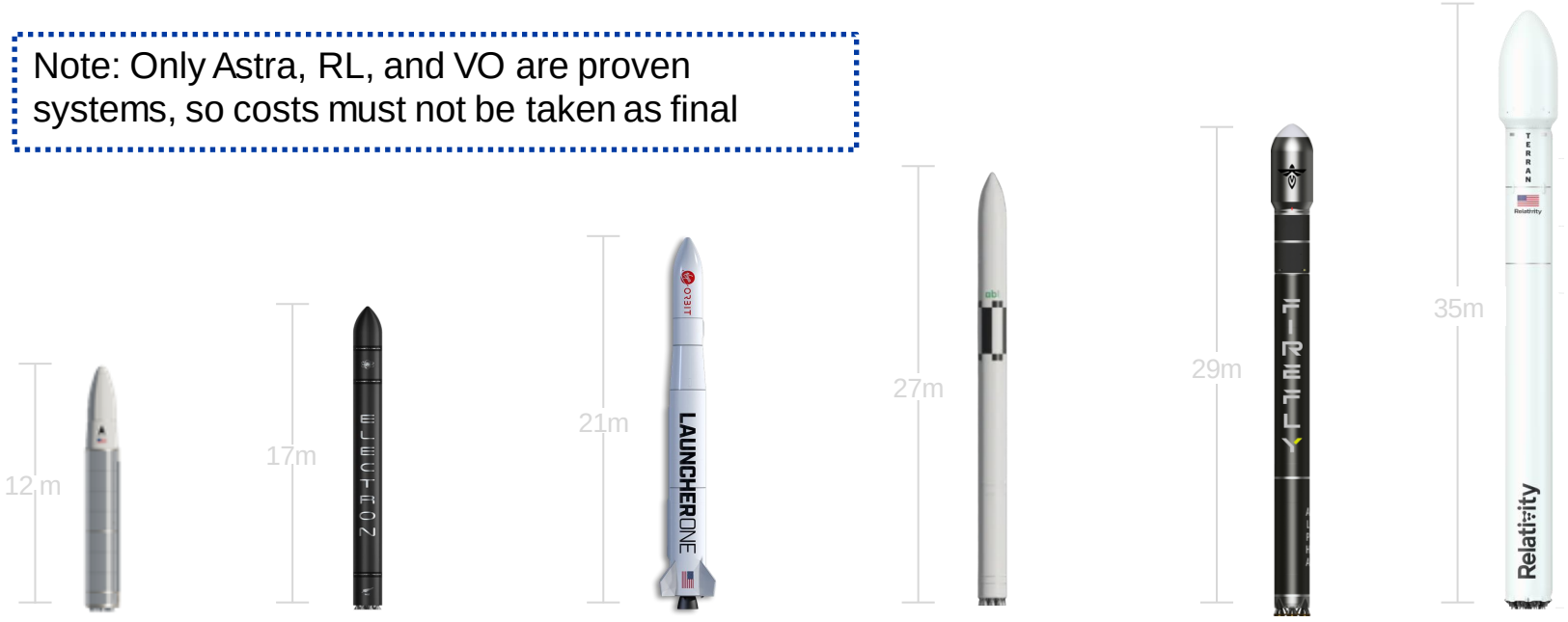
- ABL's vehicle is focused on simplicity, rather than reusability
- ABL has a launch manifest of 75 contracts
- RS-1 aims to launch from Kodiak, AL in 2022
- Contracted for Kuiper's first satellites
- Up to 58 launches for Lockheed Martin

04 Key Takeaways

Vehicle Comparison

	Astra Rocket 3	**Rocket Lab** Electron	**Virgin Orbit** LauncherOne	**ABL** RS-1	**Firefly** Alpha	**Relativity** Terran-1
Payload to SSO	150 kg	200 kg	300 kg	1000 kg (Est.)	630 kg	900 kg
Cost/kg	$16.7k	$37.5k	$40k	$12k	$42k	$13.3k

Note: Only Astra, RL, and VO are proven systems, so costs must not be taken as final



Key Benchmarks

Reusability

How reusable, if at all, are the vehicles?

Payload Cost/kg

Cost to send payloads into orbit

Program Maturity

Are the vehicles flight proven?

Reliability

How reliable is the launch vehicle?

Innovation

New technology and competitive advantage

Company Comparison

	ROCKET LAB	FIREFLY AEROSPACE	ASTRA	Virgin ORBIT	Relativity	abl
Current Reusability	Partial	No	No	No	No	No
Planned Reusability	Yes	Maybe	No	Maybe	Yes	No
Payload cost/kg (SSO)	$37.5k	$42k	$16.7k	$40k	$13.3k	$12k
Flight Proven?	Yes	No	Yes	Yes	No	No
Reliability	22/25	0/1	2/8	3/4	N/A	N/A
Innovation	Reusability	Complete Missions	Cost	Air Launch	3D Printing	Launch Location

Reusability will be one strategy incorporated by many companies as they look to decreases cost and compete for limited contracts

Key Findings

1

Anyone can make a launch vehicle
With the NewSpace revolution, dozens of companies are developing launch vehicles. Firms must establish unique value propositions to remain competitive.

2

Reusability is key
Many firms are actively developing or planning a reusable launch vehicle, and those that are not will need to find other ways to compete economically.

3

Reusability requires scale
Due to the fixed costs (recovery operations, etc.), reusability only makes financial sense once a vehicle reaches a certain size or utilizes innovative recovery methods.

4

Small vehicles as a proxy
A common strategy is developing a non-reusable small launch vehicle as a testing ground and proof of concept for a larger, often times reusable vehicle.

QUESTIONS?

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