THE VALUE OF PERFORMANCE.
NORTHROP GRUMMAN

Comprehensive Update on Domestic and International Small Launchers

Corrections, additions, and comments are welcomed and encouraged!

16 January 2019

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Listing Criteria

NORTHROP GRUMMAN

- Have a **maximum capability** to LEO of 1,000 kg or less (definition of LEO left to the LV provider).
- The effort must be for the development of an **entire launch vehicle system** (with the exception of carrier aircraft for air launch vehicles).
- Mentioned through a web site update, social media, traditional media, conference paper, press release, etc. **in the past 2 years**.
- Have a stated goal of completing a **fully operational space launch (orbital) vehicle**. Funded concept or feasibility studies by government agencies, patents for new launch methods, etc., do not qualify.
- Expect to be **widely available** commercially or to the U.S. Government
- No specific indication that the effort has been cancelled, closed, or otherwise disbanded.

Corrections, additions, and comments are welcomed and encouraged!

We did not …

… Talk to the individual companies

… Rely on any proprietary/confidential information

… Verify accuracy of data found in public resources

  – Primarily relied on companies' web sites

- Funding sources, when listed, are not implied to be the vehicles sole or even majority funding source.

We do not make any value judgements on technical or financial credibility or viability

Six Operational Systems

Organization	Vehicle Name	Country	First Launch
Northrop Grumman	Pegasus XL	USA	5-Apr-90
Northrop Grumman	Minotaur I	USA	27-Jan-00
China Aerospace Science and Technology Corporation	Chang Zheng 11	China	25-Sep-15
ExPace	Kuaizhou-1A	China	9-Jan-17
China Aerospace Science and Technology Corporation	Kaituozhe-2	China	3-Mar-17
Rocket Lab	Electron	USA/New Zealand	21-Jan-18






Thirty-nine Under Development

NORTHROP GRUMMAN

Organization	Vehicle Name	Country	Latest Launch Date
Gloyer-Taylor Laboratories	ACE	USA	2021
PLD Space	Arion 2	Spain	3Q 2021
Astra Space	Astra	USA	
Bagaveev Corporation	Bagaveev	USA	2019
zero2infinity	Bloostar	Spain	2017
Stofiel Aerospace	Boreas-Hermes	USA	2019
CubeCab	Cab-3A	USA	2020
LEO Launcher	Chariot	USA	Q4 2018
Cloud IX	Cloud IX	USA	
Scorpius Space Launch Company	Demi-Sprite	USA	Early 2020
Gilmour Space Technologies	Eris	Australia/Singapore	Q4 2020
Firefly Aerospace	Firefly Alpha	USA	Q3 2019
Aphelion Orbitals	Helios	USA	2021
iSpace	Hyperbola-1	China	Q3 2019
Rocketcrafters	Intrepid-1	USA	Q1 2019
Virgin Orbit	LauncherOne	USA	H1 2018
Interorbital Systems	NEPTUNE N1	USA	
Linkspace Aerospace Technology Group	NewLine-1	China	2020
Orbital Access	Orbital 500R	United Kingdom	2020

Organization	Vehicle Name	Country	Latest Launch Date
One Space Technology	OS-M1	China	2018
Stratolaunch	Pegasus (Strato)	USA	
SpaceLS	Prometheus-1	United Kingdom	Q4 2017
Orbex	Proprietary	United Kingdom	
ISRO	PSLV Light	India	Q1 2019
Launcher	Rocket-1	USA	2025
Space Ops	Rocky 1	Australia	2019
ABL Space Systems	RS1	USA	Q3 2020
Celestia Aerospace	Sagittarius Space Arrow CM	Spain	2016
Skyrora	Skyrora XL	UK/Ukraine	
ESA	Space Rider	Europe	2020
RocketStar	Star-Lord	USA	2018
CONAE	Tronador II	Argentina	2020
SpinLaunch	Unknown	USA	
VALT Enterprises	VALT	USA	
Vector Space Systems	Vector-R	USA	H2 2018
Departamento de Ciencia e Tecnologia Aeroespacial	VLM-1	Brazil	2019
Equatorial Space Indistry	Volans Block I	Singapore	2021
bspace	Volant	USA	2018
LandSpace	Zhuque-1	China	Q4 2018

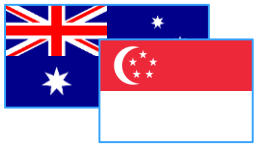
Country of Origin

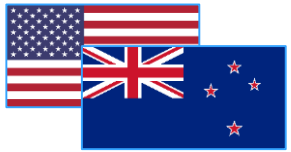




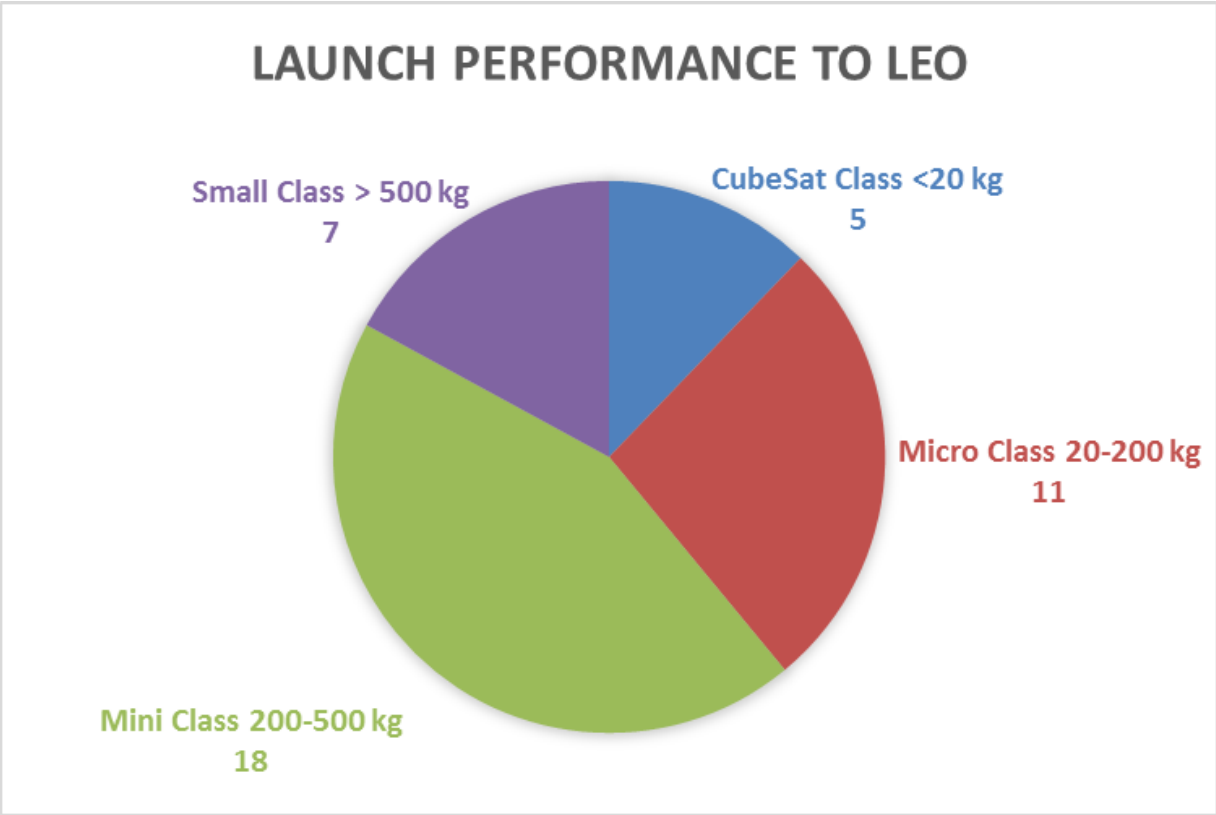


Country	Count
USA	23
China	7
United Kingdom	3
Spain	3
Argentina	1
Brazil	1
UK/Ukraine	1
Australia/Singapore	1
Australia	1
USA/New Zealand	1
Europe	1
India	1
Singapore	1

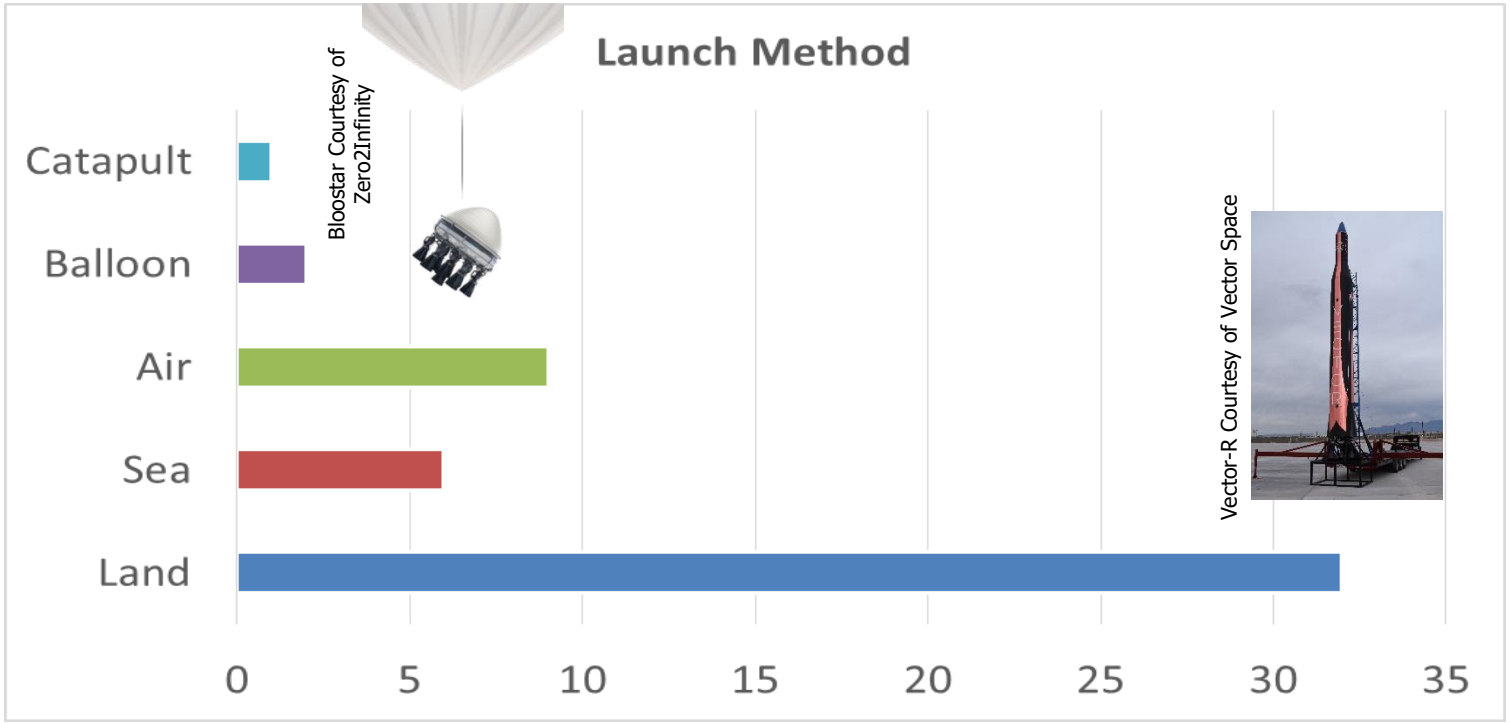





How Small is Small?

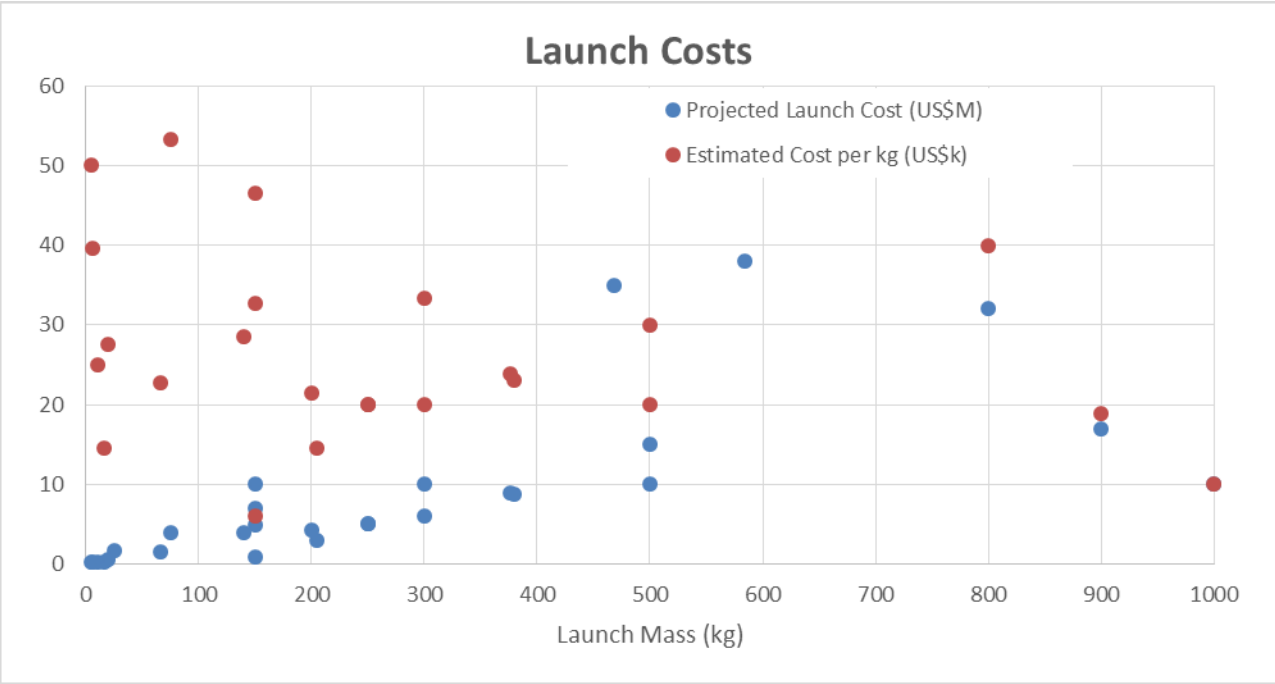


Varied Launch Methods



Note: A number of vehicles have multiple launch methods

Next Generation Launch Costs



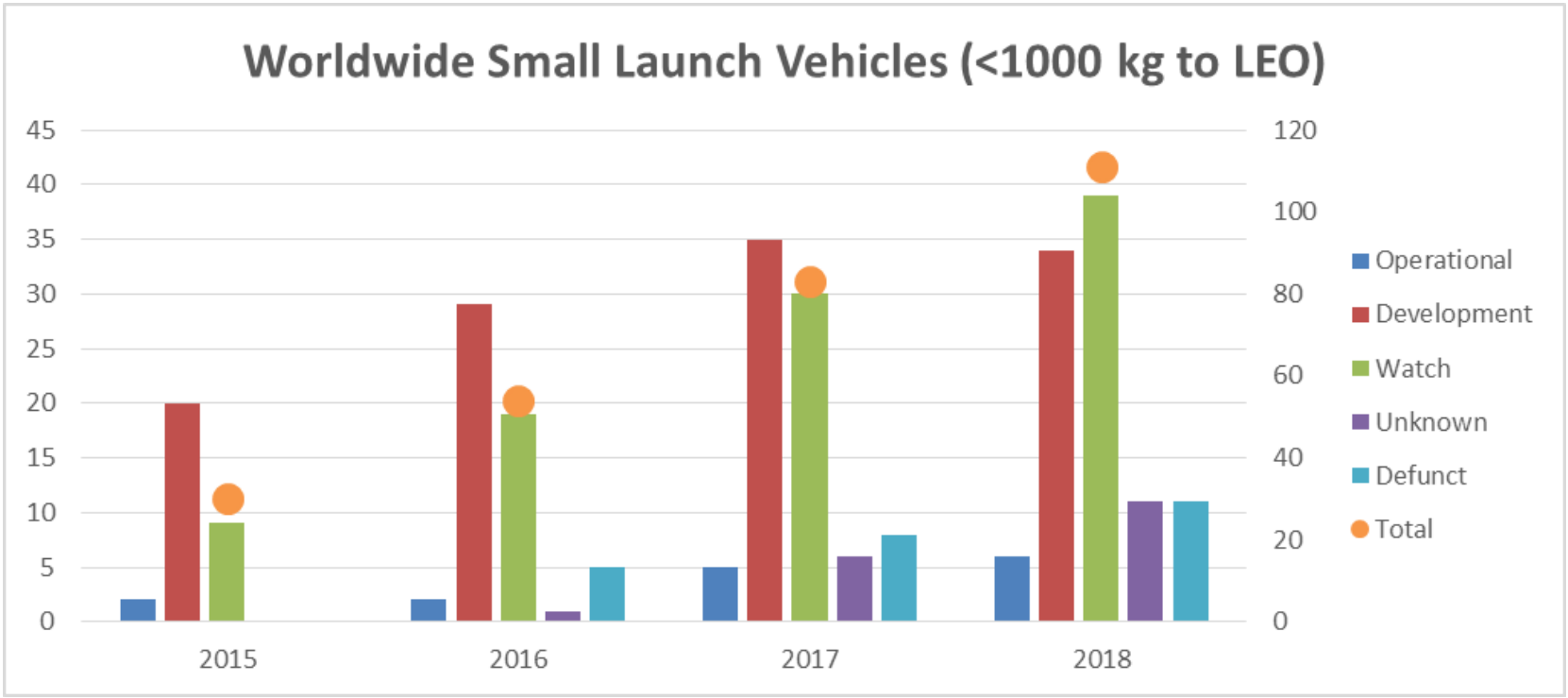
Assumptions:
Lowest cost in range given
Highest performance in range given
No attempt to normalize for differing definitions of LEO
No attempt to ensure services provided are equivalent

Comparison:
Falcon 9 (pre-flown): ~$2.8k / kg

Funding Sources

Governments (National and Local)	• NASA • ESA • Horizon 2020
Angel Investors	• Seed Angels • Space Angels • Sand Hill Angels
Venture Capital	• Kholsa • Shunwei Capital • New Gen Silicon Valley Partners
Other	• Crowdfunding • Presales

Trends Since 2015



Since TRB 2018 New Players and Progress …

New Players Include …

- Astra Space
- ABL Space Systems
- Equatorial Space Industry
- And many more on “watch list”

Orbital Launches

- Kaituozhe-2
- Electron

Suborbital Flight Tests

- Skyrora
- Astra Space
- InterStellar
- One Space
- And many more engine tests

Significant General Press Coverage

- Motley Fool
- The Economist
- Forbes
- Wall Street Journal
- Ars Technica

…And Plenty of Heartbreak as Well

Status Unknown

- Super Strypi
- SS-520-4
- Haas 2CA
- Exo
- Black Arrow-2
- Taimyr
- M-OV
- North Star
- Demi Sprite
- Unreasonable Rocket

Programs Canceled or Postponed

In 2015, 12 of our surveyed vehicles promised a launch by 2017
As of December 2018 only two have flown and attempted orbital launch
(plus two more that were not in 2015 survey)

Company folded

- Garvey Space Corporation (incorporated into Vector)
- Swiss Space Sytems
- Firefly (back as Firefly Aerospace)
- XCOR
- SOAR

Forty-Four Additional Vehicles On the Watch List

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Organization	Vehicle Name	Country
Aerojet Rocketdyne	Hera II	USA
Aevum	Ravn	USA
Airbus	Unknown	France
ArianeGroup	Q@ts	Europe
Avio SpA	VegaC Lite	Italy
B2Space	Colibri	UK
Blue Origin	New Shepard+	USA
bluShift Aerospace	Unknown	USA
Cloud Aerospace	CloudOne Plus	USA
Dawn Aerospace	Mk-3	Netherlands
Deimos	Unknown	Portugal
Eclipse Orbital	Corona	USA
FORE Dynamics	NFR-1	USA
Heliaq Advanced Engineering	Austral Launch Vehicle	Australia
HyImpulse	Unknown	Germany
Independence-X Aerospace	DNLV	Malaysia
InterStellar Technologies	Zero	Japan
JAXA	SS-520-4	Japan
JP Aerospace	Airship to Orbit (ATO)	USA
Isar Aerospace Technologies	Spectrum	Germany
KB Yuzhnoye	Unknown	Ukraine
Kiwi Orbitals	Unknown	New Zeland

Organization	Vehicle Name	Country
Leaf Space	Primo	Italy
LEO Aerospace	Rockoon	USA
MT Aerospace	Unknown	Germany
New Ascent	Unknown	USA
New Rocket Technologies	Light Satellite Launch Vehicle	Russia
Odyne Space	Unknown	USA
Onera	Altair	France
Pangea Aerospace	Meso	Spain
Pipeline2Space	Unknown	USA
Roketsan	Space Launch System	Turkey
Rose Galactic	Anthium Orbital Cannon	USA
SMILE	SMILE	Europe
Space Walker	Unit 2	Japan
StratoBooster	StratoBooster	United Kingdom
Thor Launch Systems	Thor	USA
TiSpace	Unknown	Taiwan
U. Hawaii, Aerojet Rocketdyne, Sandia	Super Strypi	USA
United Frontiers LLC	Oceanic Orbital Launch Vehicle	USA
UP Aerospace	Spyder	USA
Vanguard Advanced Systems	Athena	UK
Vogue Aerospace	Vogue RLV	USA/Italy
X-Arc Aerospace	PQXI-1	United Kingdom

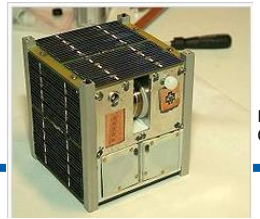
- Not enough information to qualify for the survey. Some are hearsay/rumors

Launch Vehicle Individual Summaries

- The new crowd of small launch vehicle incorporate a wide spectrum of propellants, launch methods, and other unique attributes that are designed to provide that winning edge over competitors. In the following summaries, we attempt to outline some of unique attributes various vehicles

Note: Not all vehicles are shown. No specific criteria were used for inclusion in the next few slides. Goal is to illustrate wide variety of new approaches.

CubeSat Launchers



Ncube-2
Courtesy of Wikipedia

Helios Courtesy of Aphelion Orbitals

Helios utilizes a combination of liquid and solid stages. An aerospike engine and proprietary high density propellant provide 20 kg to orbit in this vehicle from Aphelion Orbitals

Cab-3A is an F-104 Starfighter air-launched vehicle with 3U capabilities from CubeCab

Cab-3A Courtesy of CubeCab

NEPTUNE N1 is a multi-stage pressure fed turpentine ground launched vehicle with single common core using white fuming nitic acid oxidizer with 6 kg capabilities from Interorbital Systems

Neptune N1 Courtesy of Interorbital Systems

Cloud IX Courtesy of Cloud IX

Cloud IX is a two-stage solid fuled vehicle that's balloon lofted before ignition with 22 kg capabilities from Cloud IX

Bagaveev Test Vehicle Courtesy of Bagaveev Corp

Bagaveev is two-stage liquid fueled vehicle with pressure fed 3D printed engines and ground or sea launch platform with 10kg capabilities from Bagaveev Corporation

Micro Launchers

Orbcomm
Courtesy of Northrop Grumman

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Vector-R Courtesy of Vector Space

Vector-R is a two-stage all composite pressure fed propylene ground launched vehicle using LOX as an oxidizer with 30 kg capabilities from Vector Space.

Bloostar Courtesy of Zero2Infinity

Bloostar is a three-stage all composite pressure fed liquid cryogenically propelled balloon launched vehicle with toroidal tanks with 75 kg capabilities from Zero2Infinity.

OS-M1 is a three-stage solid fueled launch vehicle with 200 kg capabilities from One Space Technology in China.

Haas2Ca Courtesy of ARCA

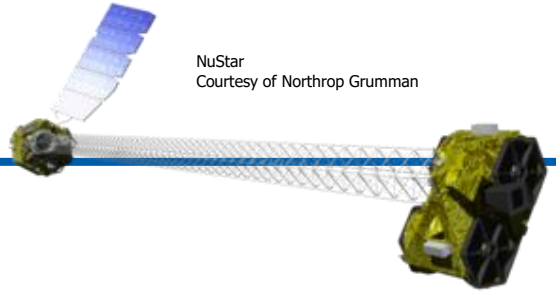
Arion 2 Courtesy of PLD Space

Arion 2 is a three-stage partially reusable liquid fueled launch launched from land with 150 kg capabilities from PLD Space.

Electron is a two-stage LOx/kerosene ground launched vehicle using 3D printed engines with electric fuel pumps with 150 kg capabilities from Rocket Lab.

Electron Courtesy of Rocket Lab

Mini Launchers



NuStar
Courtesy of Northrop Grumman

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LauncherOne Courtesy of Virgin Galactic

LauncherOne is a two stage RP-1 fueled 747 air launched vehicle with LOx as an oxidizer with 500 kg capabilities from Virgin Orbit.

Prometheus-1 Courtesy of SpaceLS

Prometheus-1 is a multi-stage kerosene ground launched vehicle with reusable first stage using H2O2 oxidizer with 250 kg capabilities from SpaceLS.

Orbital 500 Courtesy of Orbital Access

Orbital 500 is an air-launched rocket (likely a DC-10) with 500 kg capabilities from Orbital Access

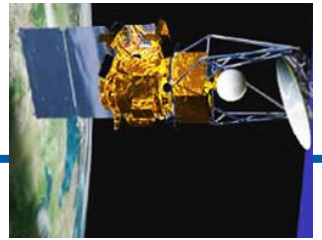
Volant is a three-stage solid ground launched vehicle with 215 kg capabilities from bSpace.

Volant Courtesy of Alaska Aerospace Corp

Tronador II is a ground launched 2.5 stage rocket LOx/RP-1 fueled first stage (sheds two engines) and hydrazine second stage with 250 kg capabilities from CONAE.

Tronador II Courtesy of Wikipedia

Small Launchers



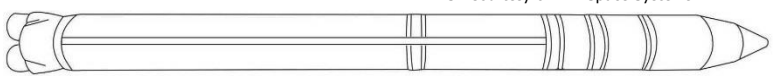
Coriolis
Courtesy of Northrop Grumman

SpaceRider Courtesy of ESA

SpaceRider is a reusable spaceplane lofted on a Vega-C rocket. Payload performance of the spaceplane is 800 kg. The vehicle is being fielded by ESA.

Alpha Courtesy of Firefly

Alpha is a two-stage liquid ground launched vehicle utilizing "well-established technology" with 1000 kg capabilities from Firefly.



RS1 Courtesy of ABL Space Systems

RS1 is a ground launched two-stage rocket LOx/RP-1 fueled vehicle with no fixed launch infrastructure requirements. It has with 900 kg capabilities under development by ABL Space Systems.

Summary

Summary

- SpaceX's success has created "launch fever"
- Small launch vehicles are attempting to capitalize on the expected explosion in small satellite launch requirements
- Few current medium/large launch vehicle suppliers are participating in perceived market demand explosion (yet!)

What will 2019 hold?

- Please provide corrections, additions, and comments to:
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  - Twitter: @rocketscient1st