National Aeronautics and Space Administration

Spaceflight Over the Last Ten Years: Failures and Fix-ups 2013 – 2022 RAMS XV Conference

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ARTEMIS

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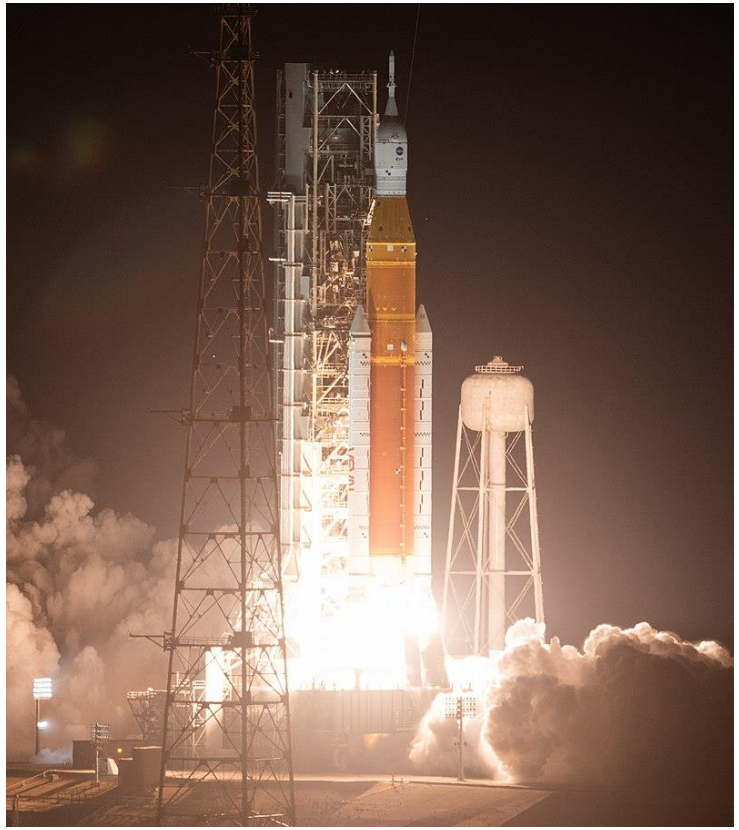
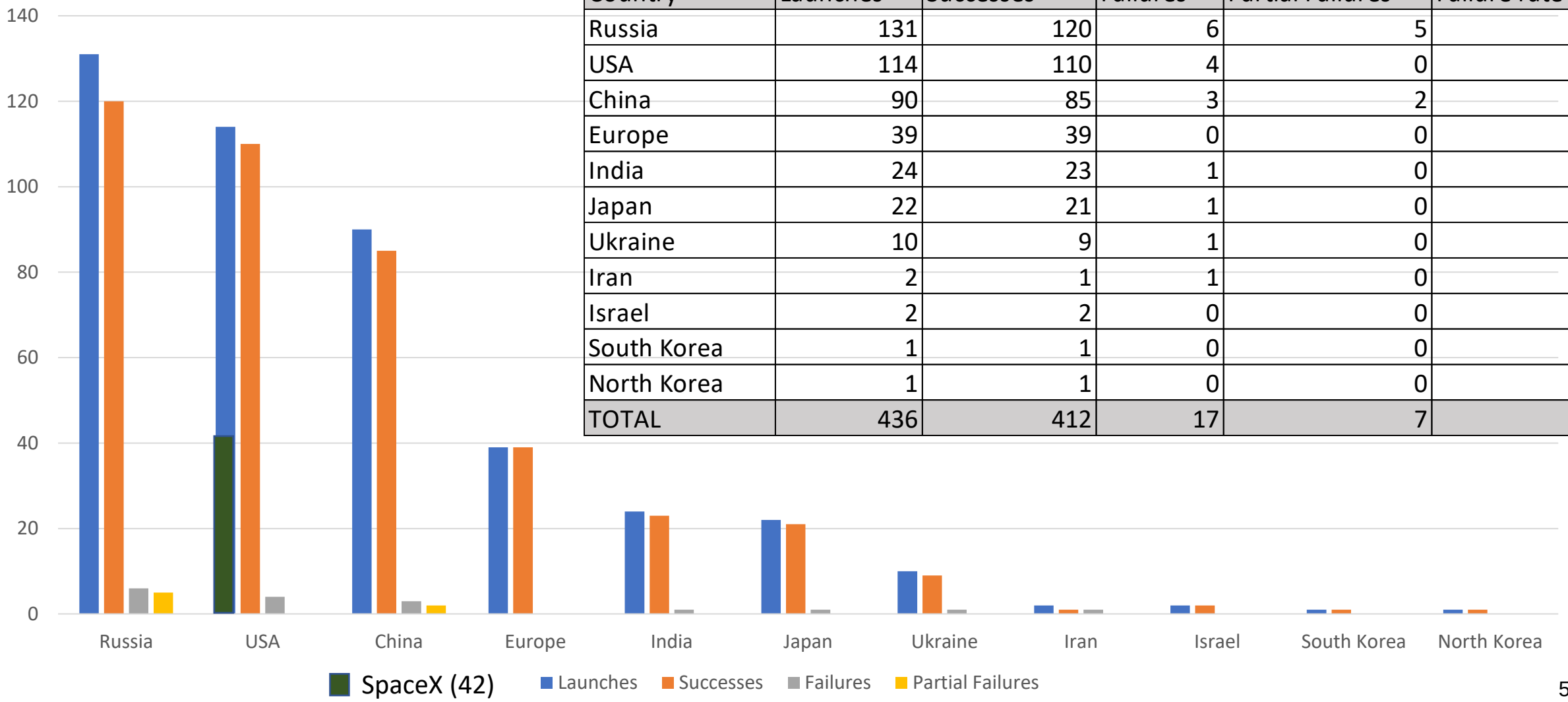
Introduction



- As of 7/13/23
- Mars on the radar
- Innovations, SpaceX
- 1201 Launches, 1134 successes
- Launch Leaders

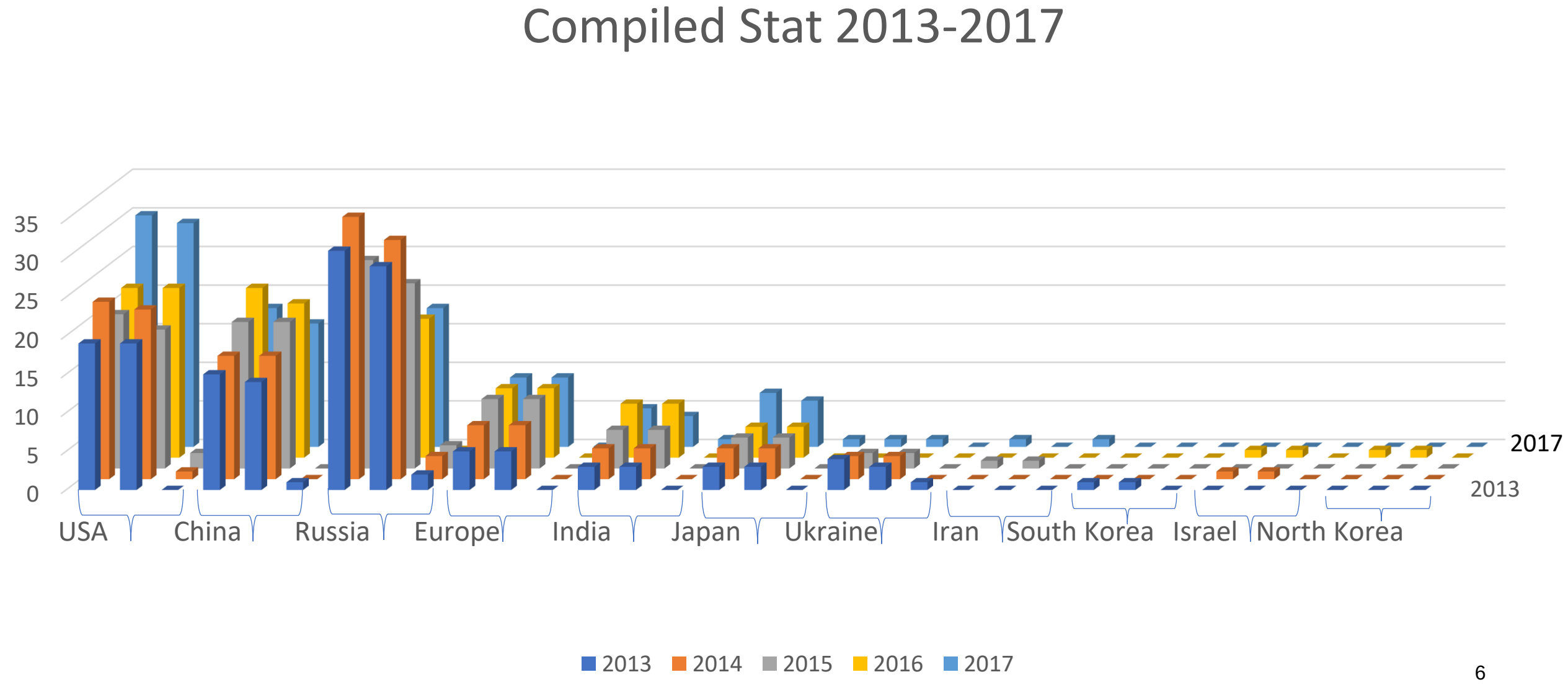
Launch Statistics

Orbital Launches 2013 - 2017

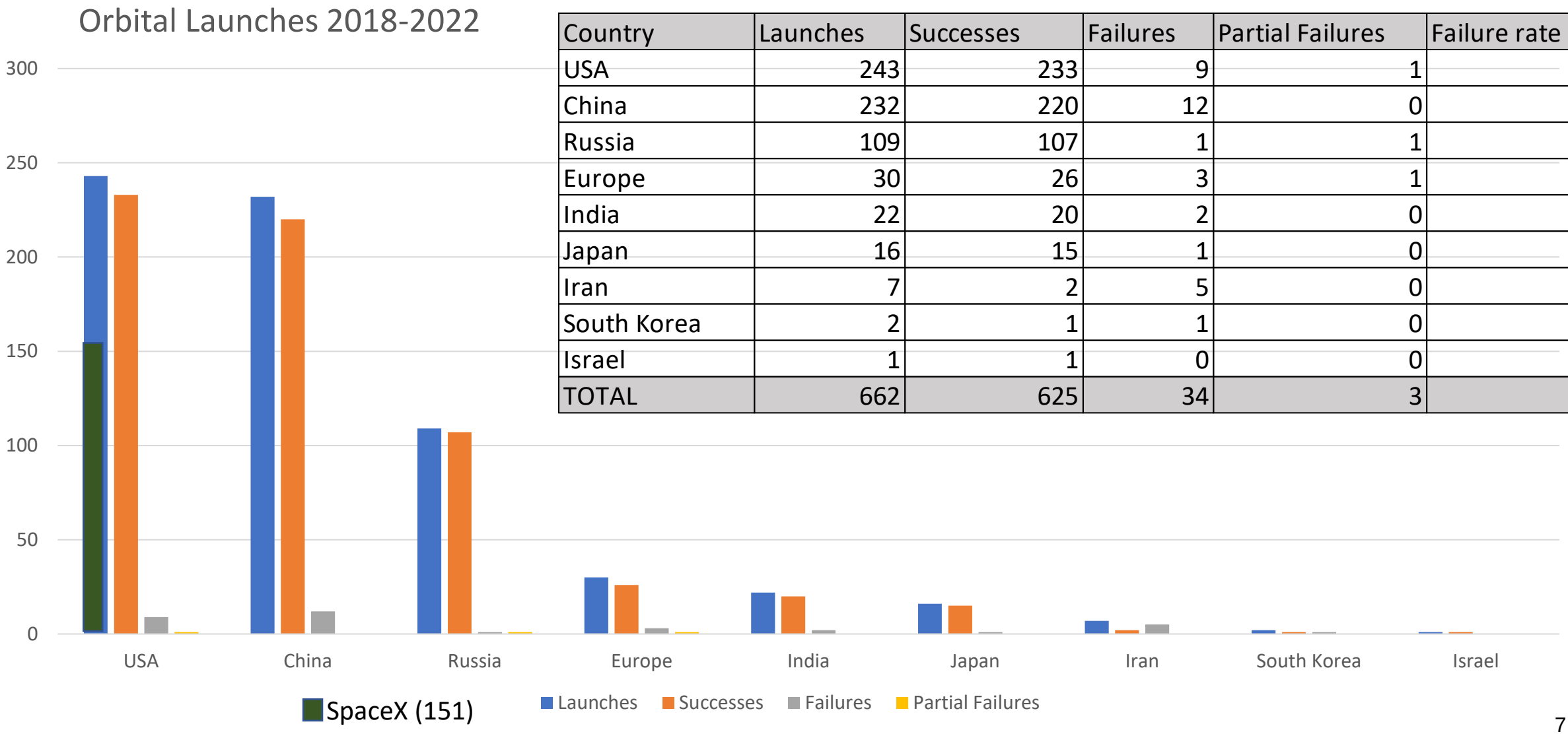


Country	Launches	Successes	Failures	Partial Failures	Failure rate (%)
Russia	131	120	6	5	8.40
USA	114	110	4	0	3.51
China	90	85	3	2	5.56
Europe	39	39	0	0	0.00
India	24	23	1	0	4.17
Japan	22	21	1	0	4.55
Ukraine	10	9	1	0	10.00
Iran	2	1	1	0	50.00
Israel	2	2	0	0	0.00
South Korea	1	1	0	0	0.00
North Korea	1	1	0	0	0.00
TOTAL	436	412	17	7	5.50

2013-2017

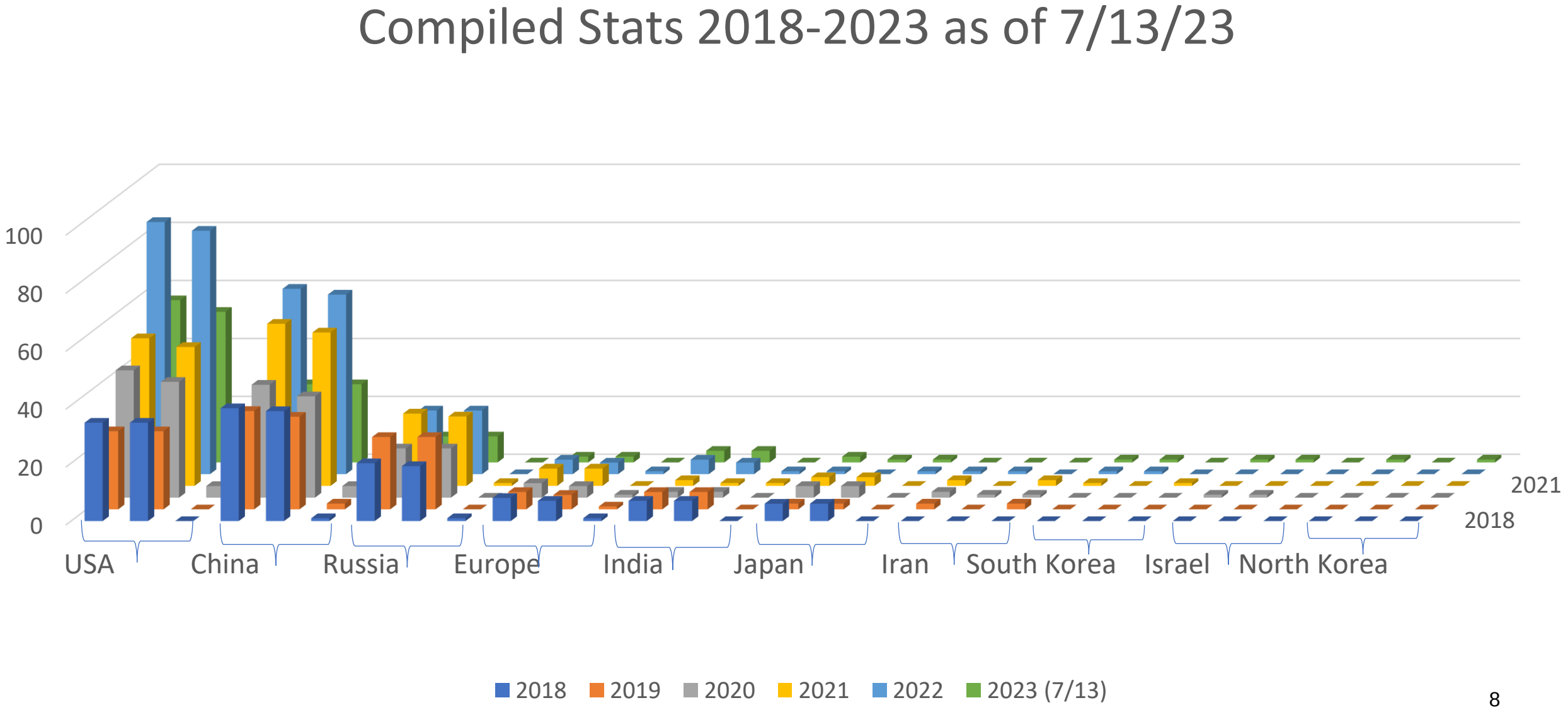

Compiled Stat 2013-2017
35
30
25
20
15
10
5
0
2017
2013
USA
China
Russia
Europe
India
Japan
Ukraine
Iran
South Korea
Israel
North Korea
2013
2014
2015
2016
2017

Orbital Launches 2018 - 2022

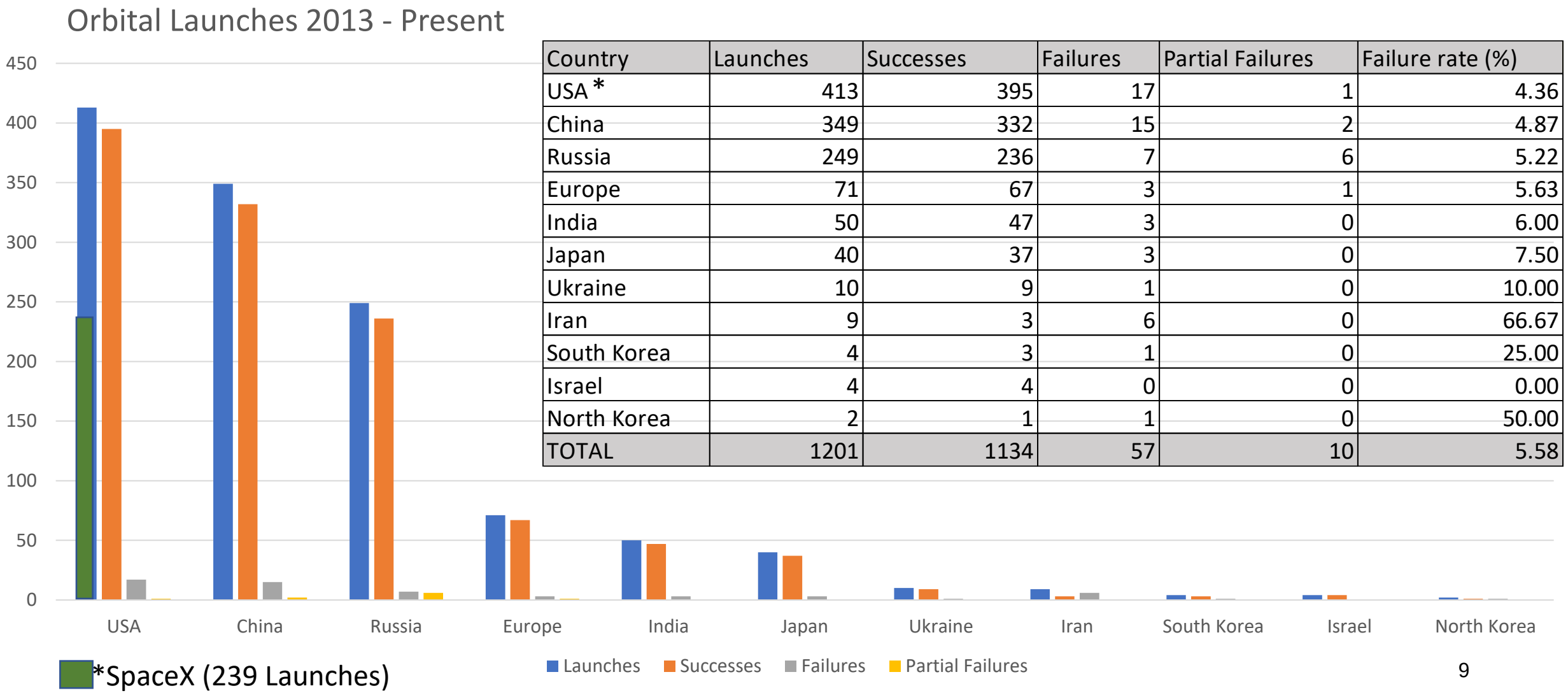


Country	Launches	Successes	Failures	Partial Failures	Failure rate (%)
USA	243	233	9	1	3.70
China	232	220	12	0	5.17
Russia	109	107	1	1	0.92
Europe	30	26	3	1	10.00
India	22	20	2	0	9.09
Japan	16	15	1	0	6.25
Iran	7	2	5	0	71.43
South Korea	2	1	1	0	50.00
Israel	1	1	0	0	0.00
TOTAL	662	625	34	3	

2018-2023 as of 7/13/23

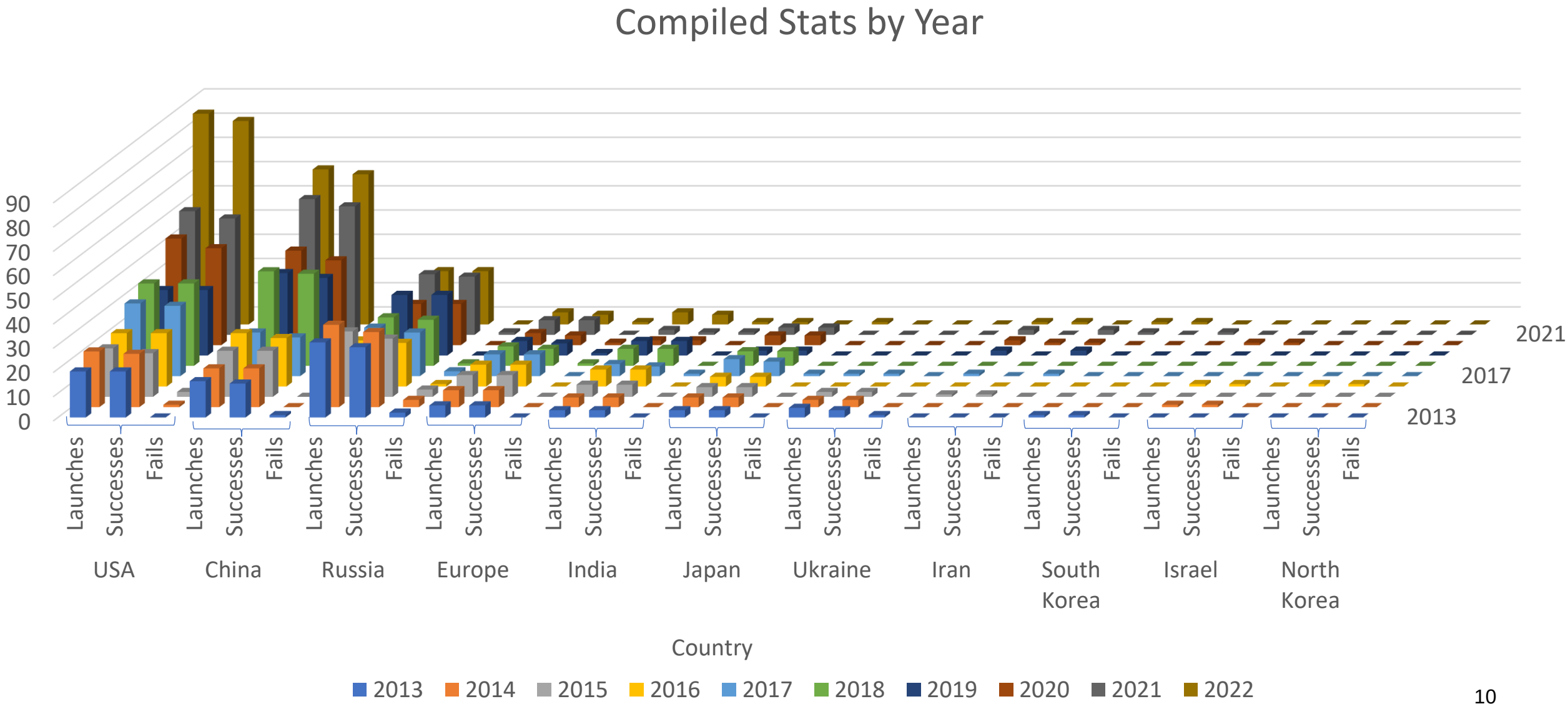


2013-Present Orbital Launches by Country



Country	Launches	Successes	Failures	Partial Failures	Failure rate (%)
USA *	413	395	17	1	4.36
China	349	332	15	2	4.87
Russia	249	236	7	6	5.22
Europe	71	67	3	1	5.63
India	50	47	3	0	6.00
Japan	40	37	3	0	7.50
Ukraine	10	9	1	0	10.00
Iran	9	3	6	0	66.67
South Korea	4	3	1	0	25.00
Israel	4	4	0	0	0.00
North Korea	2	1	1	0	50.00
TOTAL	1201	1134	57	10	5.58

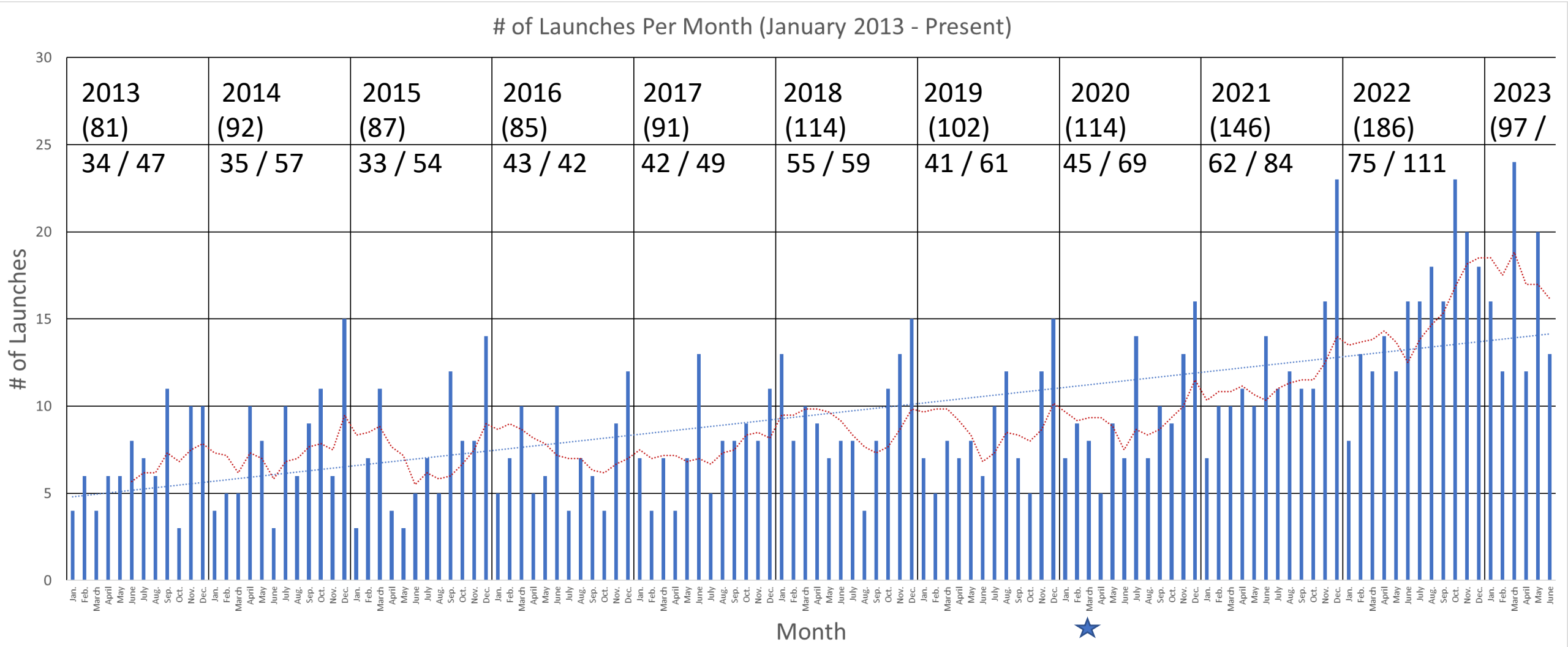
Overall (2013 – 2022)



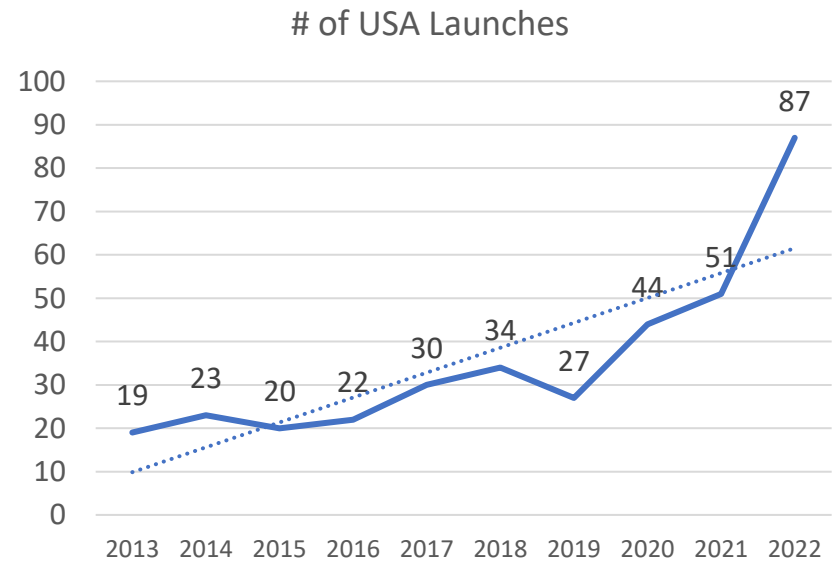
Failure Rates Over Last 10 Years by Country

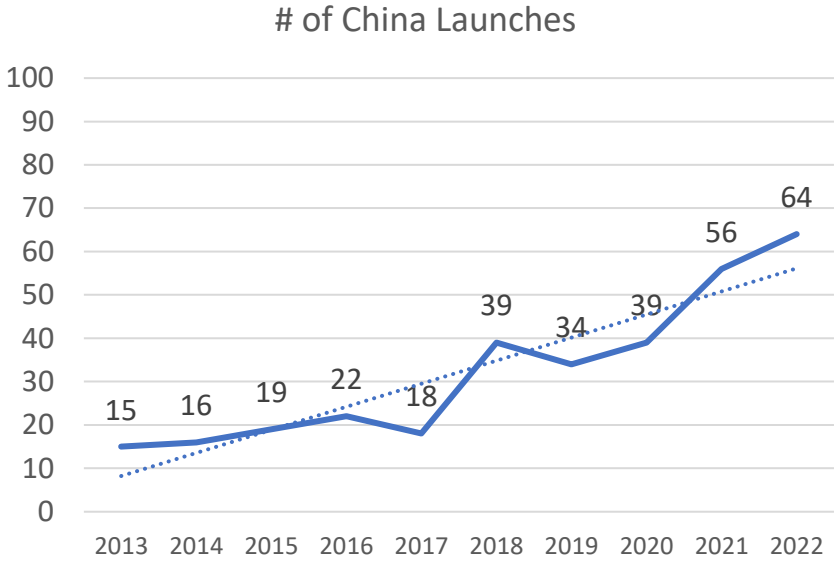
	Failure Rates (%) Over Last 10 Years by Country																					
	2013		2014		2015		2016		2017		2018		2019		2020		2021		2022		2023 (so far)		TOTAL	
Country	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%	Fail/Launch	%
USA	0/19	0	1/23	4.35	2/20	10	0/22	0	1/30	3.33	0/34	0	0/27	0	4/44	9.09	3/51	5.88	3/87	3.45	4/56	7.14	18/413	4.36
China	1/15	6.67	0/16	0	0/19	0	2/22	9.09	2/18	11.11	1/39	2.56	2/34	5.88	4/39	10.26	3/56	5.36	2/64	3.13	0/27	0	17/349	4.87
Russia	2/31	6.45	3/34	8.82	3/27	11.11	1/19	5.26	2/20	10	1/20	5	0/25	0	0/17	0	1/25	4	0/22	0	0/9	0	13/249	5.22
Europe	0/5	0	0/7	0	0/9	0	0/9	0	0/9	0	1/8	12.5	1/6	16.7	1/5	20	0/6	0	1/5	20	0/2	0	4/71	5.63
India	0/3	0	0/4	0	0/5	0	0/7	0	1/5	20	0/7	0	0/6	0	0/2	0	1/2	50	1/5	20	0/4	0	3/50	6.0
Japan	0/3	0	0/4	0	0/4	0	0/4	0	1/7	14.29	0/6	0	0/2	0	0/4	0	0/3	0	1/1	100	1/2	50	3/40	7.5
Ukraine	1/4	25	0/3	0	0/2	0	N/A	N/A	0/1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1/10	10
Iran	N/A	N/A	N/A	N/A	0/1	0	N/A	N/A	1/1	100	N/A	N/A	2/2	100	1/2	50	2/2	100	0/1	0	N/A	N/A	6/9	66.67
South Korea	0/1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1/1	100	0/1	0	0/1	0	1/4	25
Israel	N/A	N/A	0/1	0	N/A	N/A	0/1	0	N/A	N/A	N/A	N/A	N/A	N/A	0/1	0	N/A	N/A	N/A	N/A	0/1	0	0/4	0
North Korea	N/A	N/A	N/A	N/A	N/A	N/A	0/1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1/1	100	1/2	50
Year Overall	4/81	4.94	4/92	4.35	5/87	5.75	3/85	3.53	8/91	8.79	3/114	2.63	5/102	4.9	10/114	8.77	11/146	7.53	8/186	4.3	6/103	5.83	67/1201	5.58

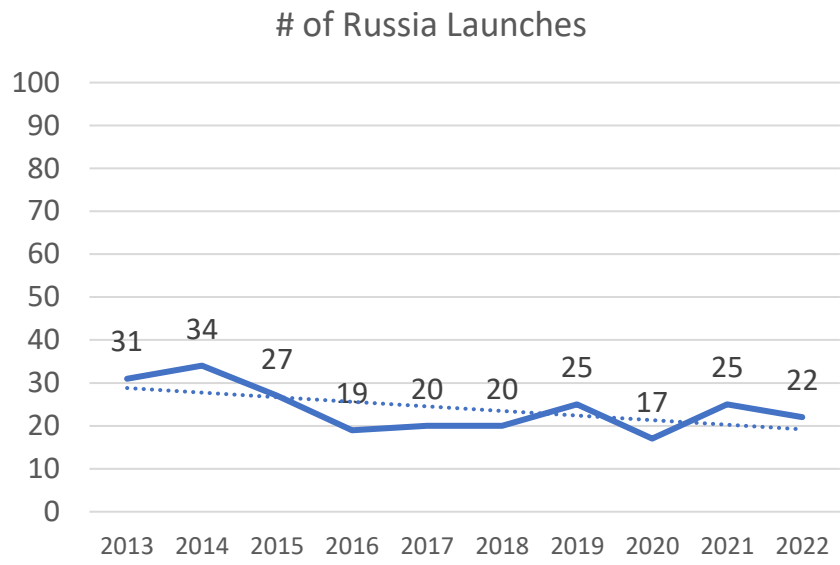
Launches by Month Over 10 Years

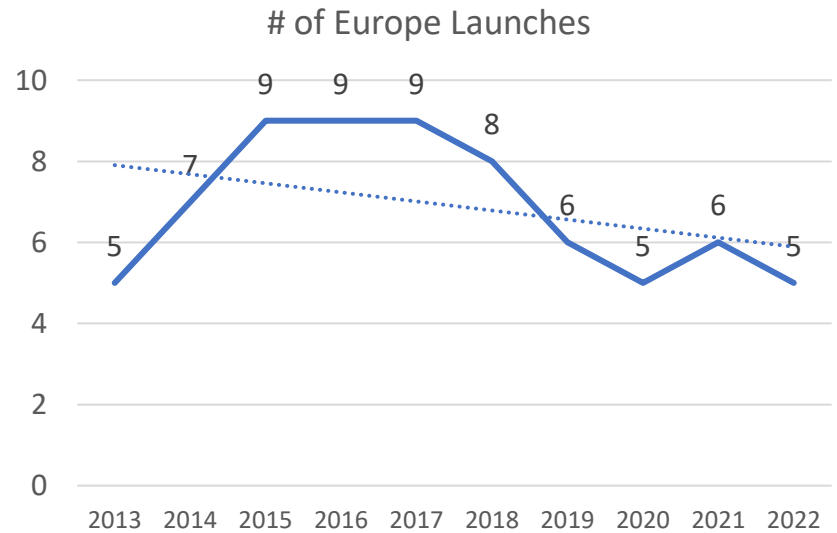


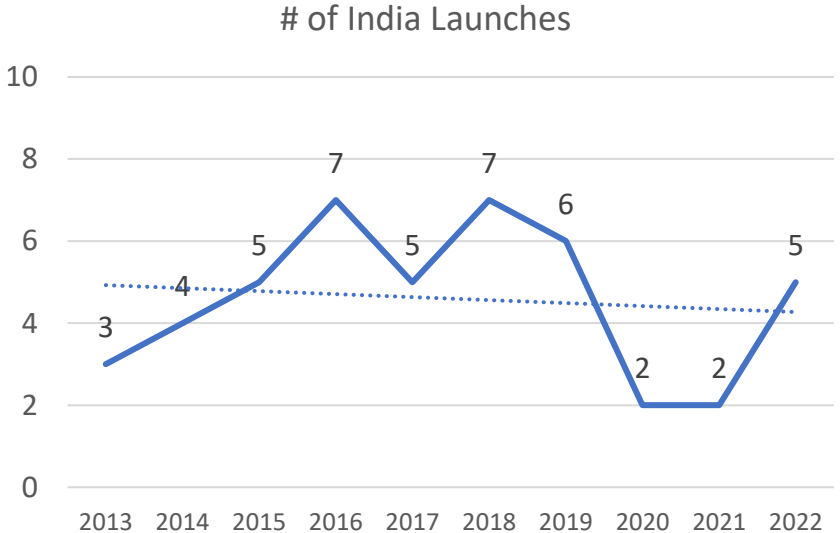
Ten-Year Trend Charts

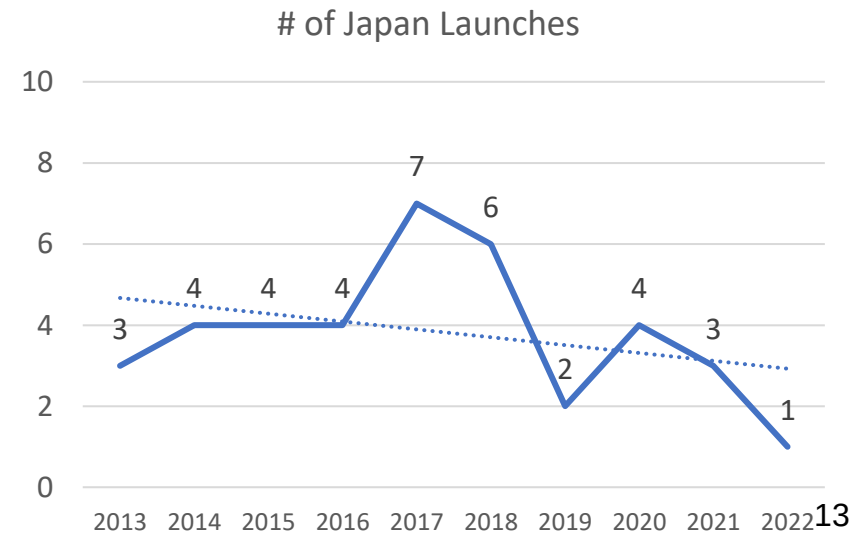




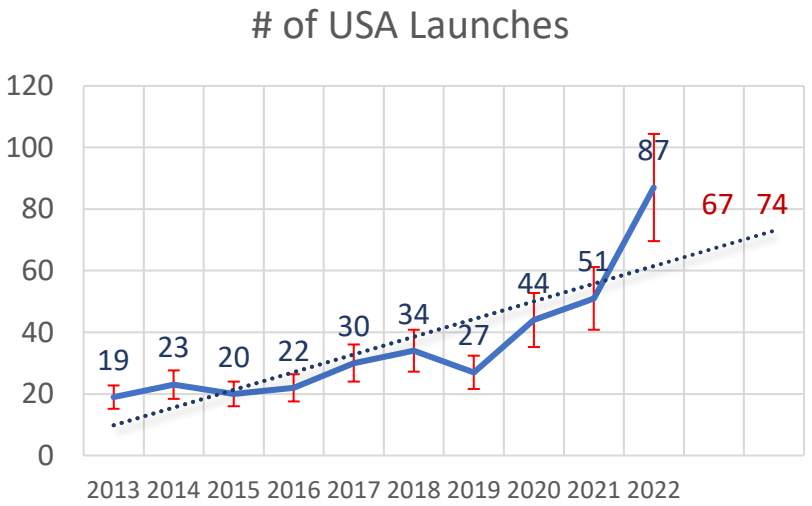


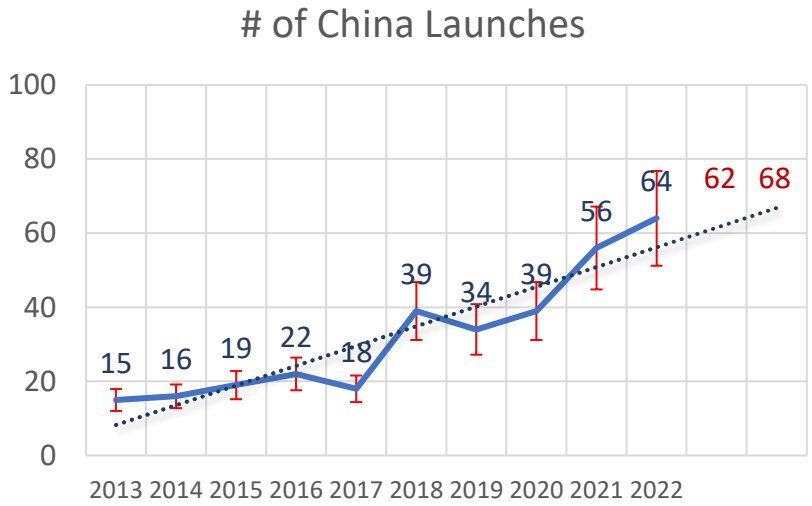


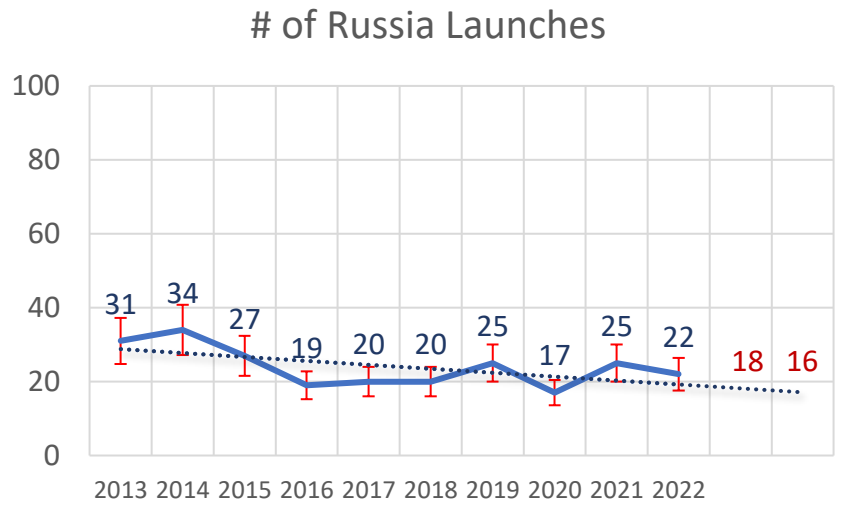


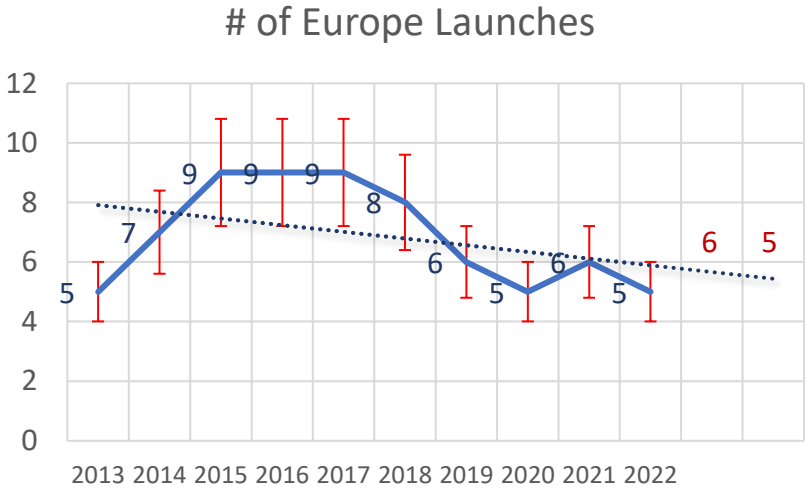


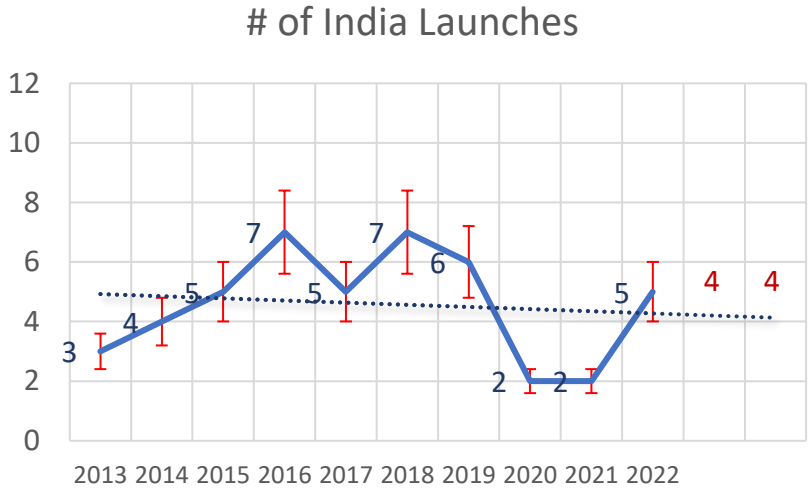
10-Year Linear Forecasting (2023-2024)

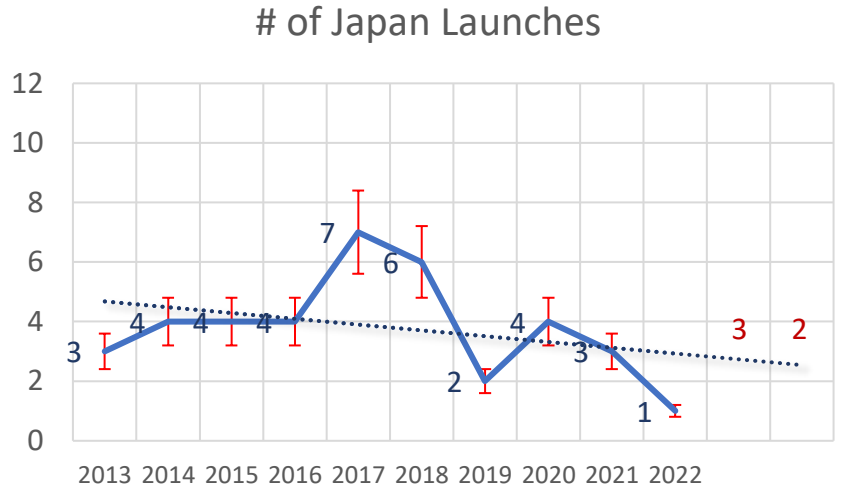












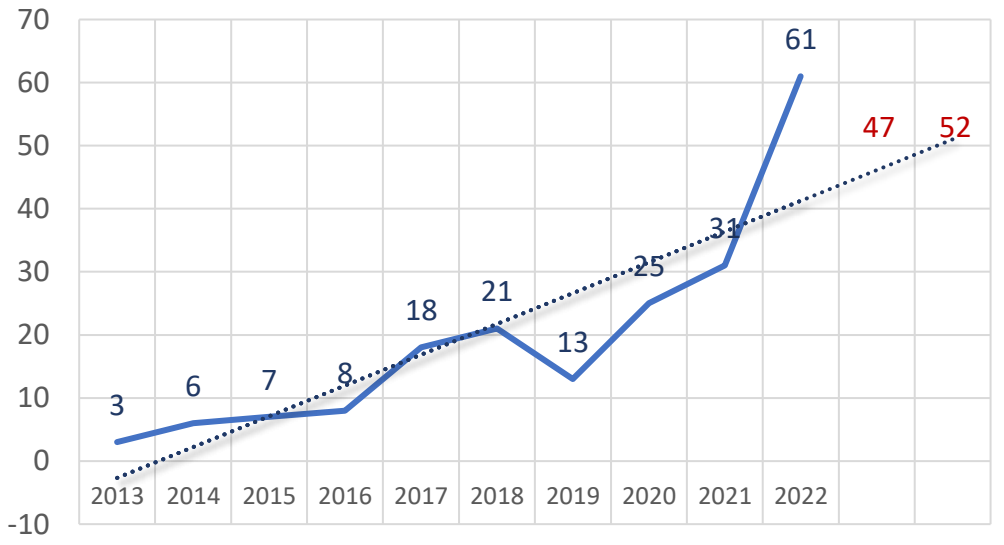
Linear Forecast Data

Country	Launches ('23)	Launches ('24)
USA	67	74
China	62	68
Russia	18	16
Europe	6	5
India	4	4
Japan	3	2
Total	160	169

- Likely, SpaceX and other industry providers will contribute more than this due to coming Starship and commercial goals
- USA will also have more industries up and coming contributing to their launch numbers

SpaceX

Year	# of Launches
2013	3
2014	6
2015	7
2016	8
2017	18
2018	21
2019	13
2020	25
2021	31
2022	61
2023	47
2024	52



Failure Breakdown/Analysis

Failures from 2013 to Present (7/13/23)

- 1201 Launches, 1134 successes, 67 failures, ~5.58% failure rate, 1-in-18.
- Most failures were maiden voyages or older spacecrafts.
- Each overall failure and partial failure stem from failures of specific systems, including Liquid Engines or Solid Rocket Motors, Software, GNC, Separation, TVC, TPS, Human Error, MPS, Avionics, Structural, and Unknown.
- Note: All failure system labels are applied by an engineering best guess and the publicly available data online.

System Failures 2013-2017 and Causes

Ukraine – Zenit-3SL 2/1/13	Russia – Proton-M 5/15/14	USA – Falcon 9 6/28/15	Russia – Soyuz-U 12/1/16	India – PSLV-XL 8/31/17
First stage failure. Accident caused by failure of the first stage hydraulic power supply unit pump, which lead to loss of engine gimbal control.	A third stage vernier thruster failed after the failure of the turbopump structural support caused damage to the oxidizer inlet line.	Vehicle disintegrated after second stage helium tank support strut failure caused helium tank to break through second stage tanks.	Telemetry was lost. At this time, it separated from the third stage, almost six minutes earlier than nominal. A high-altitude explosion occurred.	Payload fairing failed to separate
Liquid Engine System Failure	Liquid Engine System Failure	Structural Failure	Avionics Failure	Separation Failure

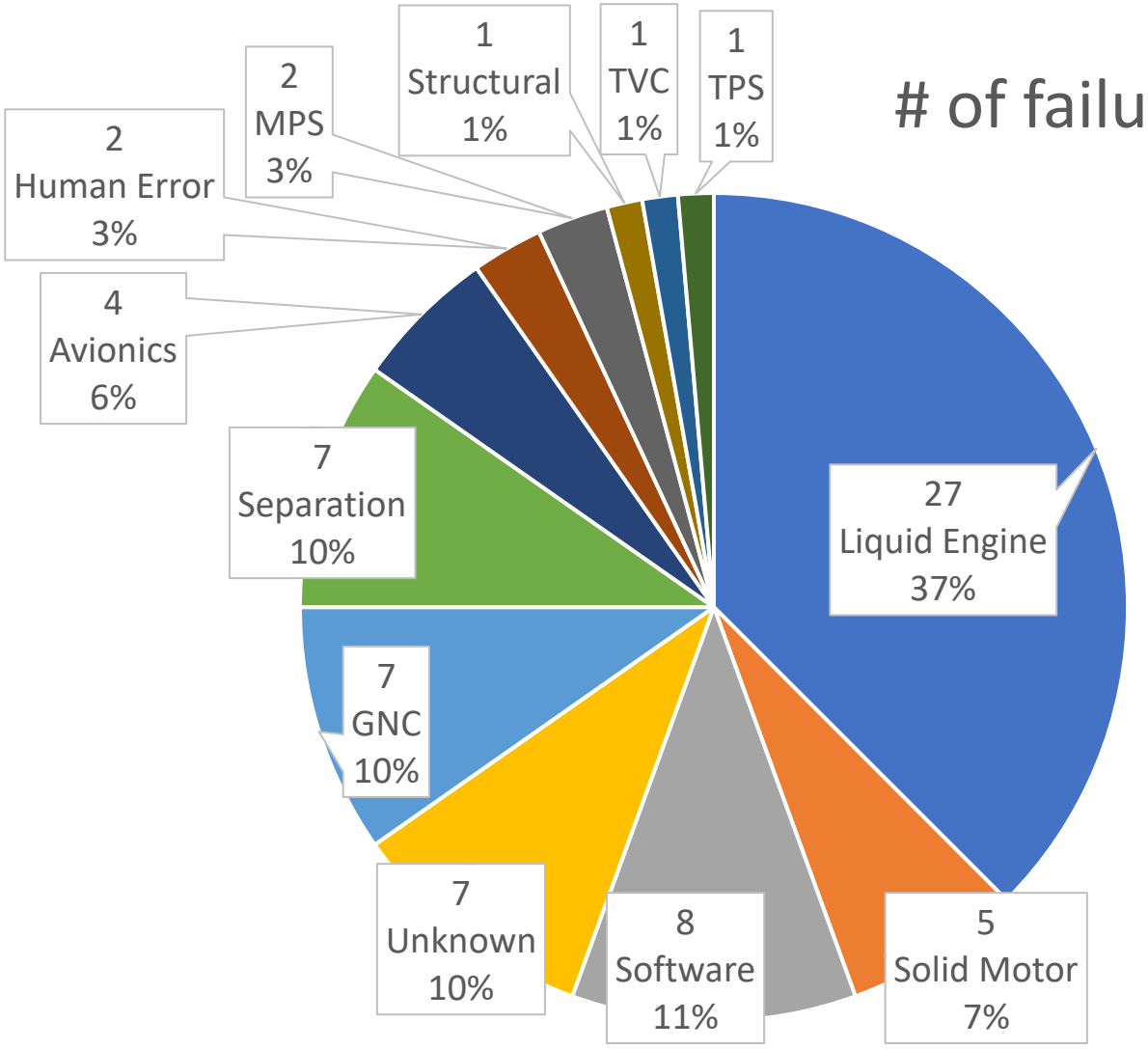
- 24 total failures across the five years, 412 Successes

System Failures 2018-Present and Causes

Europe – Ariane 5 1/25/2018	Europe – Vega 7/11/2019	Iran– Simorgh 12/30/2021	USA – Rocket 3.3 2/10/2022	USA – Starship 4/20/23
Error in programming of the Guidance, Navigation, and Control (GNC). Satellites were placed on an off-nominal orbit.	Thermo-structural failure in the forward dome area of the Z23 motor.	Failed to reach orbit.	Wiring error in the separation mechanism and a software flaw in the thrust vector system.	Resulted in a failure, with the flight termination system being triggered after a failed stage separation.
GNC System/Software failure	TPS failure	Unknown System failure	Separation System, TVC System and Software failure	Separation System failure

- 43 total failures, 722 Successes

System Failures



- The multi-faceted failures were counted in more than a single category. (67 failures +)
- Nearly half of the failures occurred within the propulsion system or closely related phenomena.
- There is a lot of unknowns remaining due to some lack of analysis or withholding of information.

Specific Failure Cases

Russia – Proton-M (July 2, 2013)

- The rocket started veering off course right after leaving the pad, deviating from the vertical path in various directions and then plunged to the ground seconds later nose first. The payload section and the upper stage were sheered off the vehicle moments before it impacted the ground and exploded.
- Investigators found critical angular velocity sensors installed upside down. Each of those sensors had an arrow that was supposed to point toward the top of the vehicle, however multiple sensors on the failed rocket were pointing downward instead.
- The flight lasted no more than 30 seconds.

USA – SPARK (November 4, 2015)

- Maiden Flight

- Live coverage of the launch showed the telemetry provide a view of the rocket spinning out of control. The feed then went blank. Spectator video show what appeared to be a breakup event at the same time the telemetry portrayed an issue.
- Vehicle lost attitude control at T+1 minute.

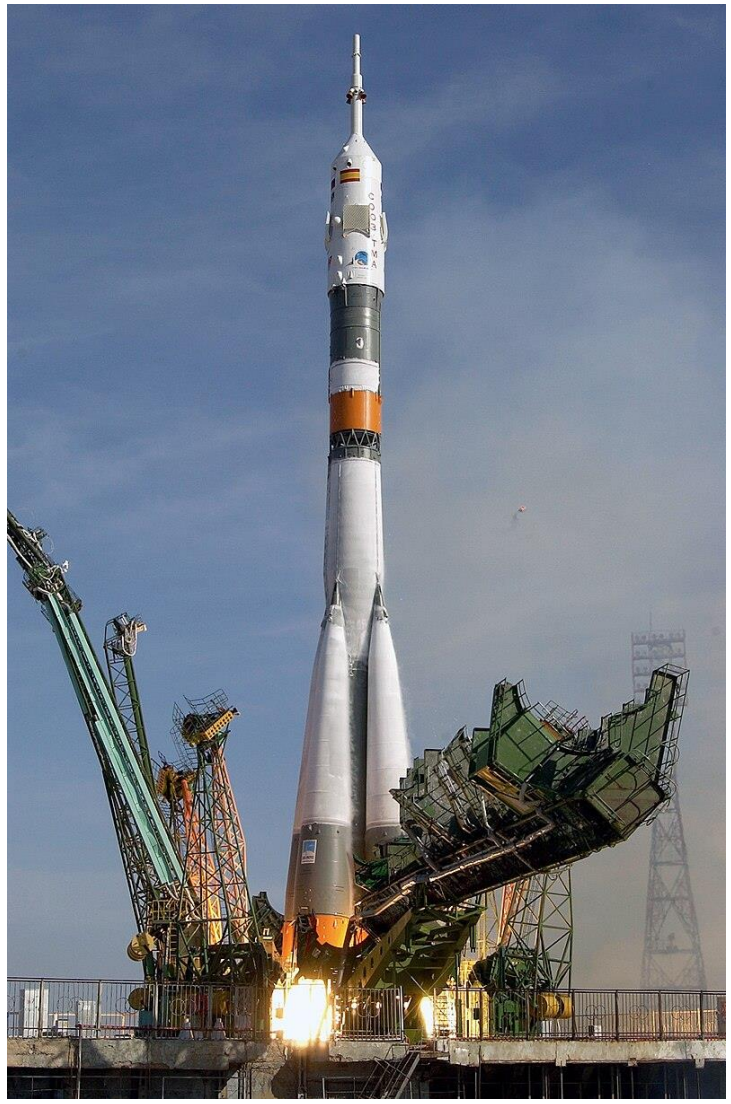
USA – Electron (May 25, 2017)

- Name: “It’s a Test”
- First launch / Maiden Flight
- After reaching an altitude of about 224km (139mi), the telemetry feed to the range safety officer was lost and the rocket was destroyed by range safety officer.
- Post-flight analysis determined the issue to be a simple ground software failure rather than a problem with the rocket.

Russia Soyuz-FG (October 11, 2018)

Overall failure resulted from a first stage booster failing to jettison at about 119sec from launch. This booster then collided and damaged the second stage, triggering the Flight Termination System (FTS).

The **escape system designed for the mission worked perfectly**, and the astronauts were retrieved about 400km from the launch site after parachuting back to the ground.



Europe Vega (July 11, 2019)

- The launch failed due to a thermo-structural failure on the second stage's forward dome, resulting in higher temperatures.
- Crashed down in the Atlantic Ocean.
- Failure came after 14 successful missions
- TPS System failure

USA LauncherOne (May 25, 2020)

The LauncherOne rocket is the first air-launched orbital-class vehicle with liquid-fueled engines (Clark, 2020).

- Initial flight test
- Faulty propellant feed line.
- LOX could not flow to the engines.
- MPS failure

South Korea Nuri (KSLV-II) (October 21, 2021)

- The Nuri's stage three engine fired 45 seconds shorter than intended, preventing it from reaching orbit (Inocencio, 2021).
- This failure was likely due to something such as a leak in the propellant feedlines or closely related phenomena.
- Liquid Engine System failure

USA Firefly Alpha (October 1, 2022)

- Tweeted “100% mission success” too early. (Partial Failure)
- The rocket reached orbit as intended, but it dropped its payloads at a lower orbit than necessary for success (Rabie, 2022).
- Unknown System failure, but it is likely a sensor, software, or GNC failure.

Japan Epsilon (October 12, 2022)

- After launch, it was deemed “not in the right position to orbit the Earth” and was self-destructed less than 7 minutes into flight (Al Jazeera, 2022).
- The rocket’s trajectory deviation could have been a result of several things.
- Ultimately a GNC failure

Summary

- 1201 Launches, 1134 successes, 67 failures, ~5.58% failure rate

- Many more successes than failures, and the failure rate is decreasing

- The number of launches, as well as general interest in the spaceflight industry is increasing relatively quickly

- Failures still occur and are a prevalent concern for the future

- Looking at specific failures and their underlying causes

Failure Consideration

- The trend is increasing orbital launches and decreasing failures.
- How do we continue this?

- What were the biggest causes of failure? Risks?

- Think CAIB Report and Rogers Commission Report.
- -> Lessons Learned! Safety Culture is key!

RISK MANAGEMENT

Thank you

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