

# United States

## Active Vertical Launch Success Rates

(for the purpose of discussing safety)

As of 9 Sept 2016

# Summary

- Today's US vertical launcher industry is significantly more reliable than historic fleets
  - Hovering close to 99% success rate
- Historic launch attempt success rates were lower (between 94-95%) in the 1970s and 1980s, but many of the rockets of those eras have been retired in favor of improved designs
- This analysis demonstrates the current industry launch attempt success rate, evaluated from a safety perspective, is ~99%.

# Sources of Data

- Numerous public sources of data available:
  - Launch company data
  - News coverage
  - Specialty media sources
- A commonly referenced online source:
  - Space Launch Report
    - <http://www.spacelaunchreport.com/log2016.html#rate>
  - Methodology for defining “success” and “fail” not focused on safety, but mission profile
    - Evaluation of specific “fail” records needed to determine if the uninvolved public was at risk

# Active US Launchers

- The following were identified as “active” US Vertical orbital launchers by the principle source (Space Launch Report) as of September 9<sup>th</sup>, 2016:
  - Delta II
  - Delta IV Medium (M)
  - Delta IV Heavy (H)
  - Atlas V
  - Antares
  - Falcon 9 v1.1\*
  - Falcon 9 v1.2
  - Minotaur 1<sup>†</sup>
  - Minotaur 4/5<sup>†</sup>
  - Minotaur C (Taurus XL)<sup>†</sup>

*\* As of approximately 15 Sept 2016, the principal source has moved Falcon 9 v1.1 to “recently retired” status; however, for the sake of this analysis, it remains as originally identified on 9 Sept 2016. Permutations of the analysis with and without the various F9 variants is contained in this presentation.*

*† The Minotaur launchers are principally solid fueled. The other rockets are principally liquid fueled.*

# Falcon 9 Variants

- There have been three significantly different variants of the Falcon 9 rocket
  - Signifies the rapid innovation occurring at SpaceX
  - Causes some confusion with quoted statistics for launch attempt success rates
    - What variants to include?
      - All versions -- v1.0, v1.1 and v1.2 (aka “Full Thrust” version)?
      - Only v1.1 & v1.2 (what was represented by the primary source as “active” of 9 Sept 16)?
      - Only the actual active version, v1.2?
- This analysis considers all three cases
  - Difference between cases is not considered material

# Analysis Considerations

- Active US orbital launchers evaluated
- All launch attempts evaluated
- Safety of uninvolved public in immediate vicinity of launch complex and down range
  - Evaluation of 1<sup>st</sup> stage and 2<sup>nd</sup> stage failures
  - Payload insertion into incorrect orbit or safely falling into the ocean downrange not considered a “fail” for safety purposes
  - 1<sup>st</sup> or 2<sup>nd</sup> stage engine cutoff within a few seconds of MECO or SECO not considered a “fail”

MECO = Main Engine Cut Off (1<sup>st</sup> stage propulsion termination prior to 1<sup>st</sup> and 2<sup>nd</sup> stage separation)

SECO = Second Engine Cut Off (2<sup>nd</sup> stage propulsion termination – note there may be multiple SECOs in some launches)

# Summary of Analysis

Analysis Case	Launch Attempt Success Rates <sup>1</sup> for US Active Vertical Orbital Launcher Fleet <i>(as of 9 Sept 16)</i>	
	All Launchers (solid & liquid)	Liquid Launchers
All Launch Attempts (incl. all F9 variants)	99.03%	98.84%
All Launch Attempts (incl. F9 v1.1 and v1.2 only)	99.01% <sup>2</sup>	98.92%
All Launch Attempts (incl. only F9 v1.2)	99.31%	99.24%

**NOTES:**

- (1) Does not include F9 v1.2 pad failure on 1 Sept 16 as it was not a launch attempt; however, this is calculated in the detailed analysis sheets following this table.
- (2) At the time of the analysis (9 Sept 2016), the primary source listed Falcon 9 v1.1 as an active launcher although SpaceX and other industry sources had listed it as “retired.” Therefore, to align with the primary source the 99.01% value was chosen as representative of the broad industry launch attempt success rate.

# **ANNEX – DETAILED SCENARIO CASE ANALYSIS**



# US – All Active Vertical Launchers

Source: <a href="http://www.spacelaunchreport.com/log2016.html#rate">http://www.spacelaunchreport.com/log2016.html#rate</a>						
<b>UNITED STATES -- ACTIVE VERTICAL LAUNCHERS / PRINCIPALLY LIQUID AND SOLID ENGINED / As per source table on 9 Sept 16</b>						
<b>as of 9 September 2016</b>						
LAUNCHER	"SUCCESSSES" AS DEFINED IN SOURCE TABLE	SUCCESSFUL 1ST STAGE AND/OR ORBITAL INSERTION	ATTEMPTS	LAST "FAIL"	FIRST LAUNCH	COMMENT
Delta II	151	152	153	1/17/1997	1989	First "fail" was orbital success in 1995 with KoreaSat1 when a solid strap-on failed but achieved useful orbit. The 1997 failure was a destruction event 13 seconds after lift off.
Atlas V	64	65	65	6/15/2007	2002	Only "fail" was an orbital success, 2nd stage shut down 4 seconds early but satellite achieved orbit.
Delta 4(M)	24	24	24	--	2002	
Minotaur 1	11	11	11	--	2000	
Falcon 9 v1.1	14	14	15	6/28/2015	2013	First stage failure 2 min 28 seconds (9 seconds before Main Engine Cut Off). Debris fell ~150 miles offshore.
Falcon 9 FT (v1.2)	8	8	8	--	2015	Does not include pre-flight pad-test failure on 1 Sept 16 as it was not a launch attempt. However, it is calculated in success rates separately below.
Minotaur 4/5	4	4	4	--	2010	
Taurus XL (renamed 'Minotaur-C')	6	9	9	3/4/2011	1994	First 'failure' in 2001 was caused by a temporarily stuck second stage steering vane but vehicle reached orbit but was unstable and re-entered safely downrange as designed. The second two failures occurred when late in the trajectory the satellite fairing would not separate, causing the rocket to fall down range. All three "failures" had successful first stage flights.
Delta IV (H)	8	9	9	12/21/2004	2004	"Fail" was on inaugural launch and was an orbital success when the main stage engine cores shut down 8-9 seconds early but the 2nd stage achieved orbit.
Antares	4	4	5	10/28/2014	2013	Failure above launch pad due to main engine failure.
Totals	294	300	303			
<b>1st Stage / Orbital Insertion Success Rate</b>	99.01%					
w/SpaceX pad failure included	98.68%					

Note: On or about 15 Sept 2016, the source moved Falcon 9 v1.1 flights to "Recently Retired" launchers. This table has not been updated to preserve its analysis state as of 9 Sept 2016.

# US – Active Liquid Launchers

Source:		<a href="http://www.spacelaunchreport.com/log2016.html#rate">http://www.spacelaunchreport.com/log2016.html#rate</a>					
<b>UNITED STATES -- ACTIVE VERTICAL LAUNCHERS / PRINCIPALLY LIQUID ENGINED / As per source table on 9 Sept 16</b>							
<i>as of 9 September 2016</i>							
LAUNCHER	"SUCCESSSES" AS DEFINED IN SOURCE TABLE	SUCCESSFUL 1ST STAGE AND/OR ORBITAL INSERTION	ATTEMPTS	LAST "FAIL"	FIRST LAUNCH	COMMENT	
Delta II	151	152	153	1/17/1997	1989	First "fail" was orbital success in 1995 with KoreaSat1 when a solid strap-on failed but achieved useful orbit. The 1997 failure was a destruction event 13 seconds after lift off.	
Atlas V	64	65	65	6/15/2007	2002	Only "fail" was an orbital success, 2nd stage shut down 4 seconds early but satellite achieved orbit.	
Delta 4(M)	24	24	24	--	2002		
Falcon 9 v1.1	14	14	15	6/28/2015	2013	First stage failure 2 min 28 seconds (9 seconds before Main Engine Cut Off). Debris fell ~150 miles offshore.	
Falcon 9 FT (v1.2)	8	8	8	--	2015	Does not include pre-flight pad-test failure on 1 Sept 16 as it was not a launch attempt. However, it is calculated in success rates separately below.	
Delta IV (H)	8	9	9	12/21/2004	2004	"Fail" was on inaugural launch and was an orbital success when the main stage engine cores shut down 8-9 seconds early but the 2nd stage achieved orbit.	
Antares	4	4	5	10/28/2014	2013	Failure above launch pad due to main engine failure.	
Totals		273	276	279			
<b>1st Stage / Orbital Insertion Success Rate</b>		98.92%					
w/SpaceX pad failure included		98.57%					

Note: On or about 15 Sept 2016, the source moved Falcon 9 v1.1 flights to "Recently Retired" launchers. This table has not been updated to preserve its analysis state as of 9 Sept 2016.

# US – All Active Launchers

## (includes all F9 variants)

Source:	<a href="http://www.spacelaunchreport.com/log2016.html#rate">http://www.spacelaunchreport.com/log2016.html#rate</a>					
<b>UNITED STATES -- ACTIVE VERTICAL LAUNCHERS / PRINCIPALLY LIQUID AND SOLID ENGINED / All F9 variants</b>						
<b>as of 9 September 2016</b>						
LAUNCHER	"SUCCESSSES" AS DEFINED IN SOURCE TABLE	SUCCESSFUL 1ST STAGE AND/OR ORBITAL INSERTION	ATTEMPTS	LAST "FAIL"	FIRST LAUNCH	COMMENT
Delta II	151	152	153	1/17/1997	1989	First "fail" was orbital success in 1995 with KoreaSat1 when a solid strap-on failed but achieved useful orbit. The 1997 failure was a destruction event 13 seconds after lift off.
Atlas V	64	65	65	6/15/2007	2002	Only "fail" was an orbital success, 2nd stage shut down 4 seconds early but satellite achieved orbit.
Delta 4(M)	24	24	24	--	2002	
Minotaur 1	11	11	11	--	2000	
Falcon 9 v1.0	4	5	5		10/8/2012	Only "fail" was successful launch of primary payload CRS-1 to ISS, but 2nd payload Orbcomm-OG2 placed in incorrect orbit.
Falcon 9 v1.1	14	14	15	6/28/2015	2013	First stage failure 2 min 28 seconds (9 seconds before Main Engine Cut Off). Debris fell ~150 miles offshore.
Falcon 9 FT (v1.2)	8	8	8	--	2015	Does not include pre-flight pad-test failure on 1 Sept 16 as it was not a launch attempt. However, it is calculated in success rates separately below.
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Taurus XL (renamed 'Minotaur-C')	6	9	9	3/4/2011	1994	First 'failure' in 2001 was caused by a temporarily stuck second stage steering vane but vehicle reached orbit but was unstable and re-entered safely downrange as designed. The second two failures occurred when late in the trajectory the satellite fairing would not separate, causing the rocket to fall down range. All three "failures" had successful first stage flights.
Delta IV (H)	8	9	9	12/21/2004	2004	"Fail" was on inaugural launch and was an orbital success when the main stage engine cores shut down 8-9 seconds early but the 2nd stage achieved orbit.
Antares	4	4	5	10/28/2014	2013	Failure above launch pad due to main engine failure.
Totals	298	305	308			
<b>1st Stage / Orbital Insertion Success Rate</b>	99.03%					
w/SpaceX pad failure included	98.71%					

# US – Active Liquid Launchers

## (includes all F9 variants)

Source:		<a href="http://www.spacelaunchreport.com/log2016.html#rate">http://www.spacelaunchreport.com/log2016.html#rate</a>					
<b>UNITED STATES -- ACTIVE VERTICAL LAUNCHERS / PRINCIPALLY LIQUID ENGINED / All F9 variants</b>							
<i>as of 9 September 2016</i>							
LAUNCHER	"SUCCESSSES" AS DEFINED IN SOURCE TABLE	SUCCESSFUL 1ST STAGE AND/OR ORBITAL INSERTION	ATTEMPTS	LAST "FAIL"	FIRST LAUNCH	COMMENT	
Delta II	151	152	153	1/17/1997	1989	First "fail" was orbital success in 1995 with KoreaSat1 when a solid strap-on failed but achieved useful orbit. The 1997 failure was a destruction event 13 seconds after lift off.	
Atlas V	64	65	65	6/15/2007	2002	Only "fail" was an orbital success, 2nd stage shut down 4 seconds early but satellite achieved orbit.	
Delta 4(M)	24	24	24	--	2002		
Falcon 9 v1.0	4	5	5		10/8/2012	Only "fail" was successful launch of primary payload CRS-1 to ISS, but 2nd payload Orbcomm-OG2 placed in incorrect orbit.	
Falcon 9 v1.1	14	14	15	6/28/2015	2013	First stage failure 2 min 28 seconds (9 seconds before Main Engine Cut Off). Debris fell ~150 miles offshore.	
Falcon 9 FT (v1.2)	8	8	8	--	2015	Does not include pre-flight pad-test failure on 1 Sept 16 as it was not a launch attempt. However, it is calculated in success rates separately below.	
Delta IV (H)	8	9	9	12/21/2004	2004	"Fail" was on inaugural launch and was an orbital success when the main stage engine cores shut down 8-9 seconds early but the 2nd stage achieved orbit.	
Antares	4	4	5	10/28/2014	2013	Failure above launch pad due to main engine failure.	
Totals	277	281	284				
<b>1st Stage / Orbital Insertion Success Rate</b>	98.94%						
w/SpaceX pad failure included	98.60%						

# US – All Active Launchers

## (only F9 version included is F9 v1.2)

Source:	<a href="http://www.spacelaunchreport.com/log2016.html#rate">http://www.spacelaunchreport.com/log2016.html#rate</a>						
<b>UNITED STATES -- ACTIVE VERTICAL LAUNCHERS / PRINCIPALLY LIQUID AND SOLID ENGINED / F9v1.2 only</b>							
<i>as of 9 September 2016</i>							
LAUNCHER	"SUCCESSSES" AS DEFINED IN SOURCE TABLE	SUCCESSFUL 1ST STAGE AND/OR ORBITAL INSERTION	ATTEMPTS	LAST "FAIL"	FIRST LAUNCH	COMMENT	
Delta II	151	152	153	1/17/1997	1989	First "fail" was orbital success in 1995 with KoreaSat1 when a solid strap-on failed but achieved useful orbit. The 1997 failure was a destruction event 13 seconds after lift off.	
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Delta IV (H)	8	9	9	12/21/2004	2004	"Fail" was on inaugural launch and was an orbital success when the main stage engine cores shut down 8-9 seconds early but the 2nd stage achieved orbit.	
Antares	4	4	5	10/28/2014	2013	Failure above launch pad due to main engine failure.	
Totals	280	286	288				
<b>1st Stage / Orbital Insertion Success Rate</b>	99.31%						
w/SpaceX pad failure included	98.96%						

# US – Active Liquid Launchers (only F9 version included is F9 v1.2)

Source:	<a href="http://www.spacelaunchreport.com/log2016.html#rate">http://www.spacelaunchreport.com/log2016.html#rate</a>					
<b>UNITED STATES -- ACTIVE VERTICAL LAUNCHERS / PRINCIPALLY LIQUID ENGINED / Only F9v1.2</b>						
<i>as of 9 September 2016</i>						
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Delta IV (H)	8	9	9	12/21/2004	2004	"Fail" was on inaugural launch and was an orbital success when the main stage engine cores shut down 8-9 seconds early but the 2nd stage achieved orbit.
Antares	4	4	5	10/28/2014	2013	Failure above launch pad due to main engine failure.
Totals	259	262	264			
<b>1st Stage / Orbital Insertion Success Rate</b>	99.24%					
w/SpaceX pad failure included	98.87%					