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Launch Vehicle Historical Reliability

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Abstract

The cost associated with loss of vehicle, loss of crew, or loss of payload will have a significant impact on the economic viability of future launch vehicles. Therefore, future propulsion systems must address the economic reality of this situation and be designed and integrated into launch vehicle systems such that the probability of loss of vehicle and/or payload (including crew) is minimized. This paper addresses the reliability of U.S. space launch vehicles and the associated propulsion systems from an historical perspective. Historical data were obtained from open source information, including: TRW Space Log, AIAA Space Launch Systems, ANSER "Historical Look at U.S. Launch Vehicles," and COMSTAC Quarterly Reports. The historical launch vehicle reliability is determined from historical success rates of all U.S. launch vehicles and the associated failures allocated to the appropriate launch vehicle subsystems to gain insight into where future development efforts should be concentrated. Historical data shows that propulsion accounts for approximately 70 percent of all launch vehicle failures and that there is a factor of four difference between the historical failure rates of solid and liquid propulsion systems, (see Table 1). The catastrophic nature of propulsion failures is also evaluated and determined that there is no significant discriminator in the probability of catastrophic failures between solid and liquid propulsion systems.

Table 1 Launch Vehicle Reliability Summary

Component	Failure Count	Ratio	Attempts	Failure Rate	Success Rate
Propulsion	**55**	**66%**	**1,039**	**0.0529**	**0.9471**
Liquid Stages	36		1,841	0.0196	0.9804
Solid Boosters	19		3,382	0.0056	0.9944
Non-propulsion	**28**	**34%**	**1,039**	**0.0269**	**0.9731**
Guidance & Ctl	13		1,039	0.0125	0.9875
Lightning	1		1,039	0.0010	0.9990
Staging	7		1,039	0.0067	0.9933
Payload Fairing	5		1,039	0.0048	0.9952
Destruct System	2		1,039	0.0019	0.9981
Unknown	**7**	**		**	**
Total	**90**		**1,039**	**0.0866**	**0.9134**

**Assumed to be partitioned between propulsion and non-propulsion on 70:30 ratio.

Introduction

One of the key attributes that requires significant improvement in future launch vehicles is the overall launch vehicle system reliability. Improved reliability is critical to achieving significant reductions in overall launch vehicle costs. If the launch vehicle industry is to make significant advancements in improving reliability of the overall launch system, it is imperative that the major sources of unreliability be clearly understood.

This paper has been compiled in an attempt to gain a greater appreciation of the historical contributors to unreliability within the launch vehicle industry. Historical data also provides a point of departure for tests of reasonableness in assessing anticipated reliability improvements for future launch vehicle configurations and approaches.

Discussion

This paper attempts to capture the historical data available on U.S. launch vehicles and utilizes that data to quantitatively assess the overall launch vehicle reliability as well as understand the major contributors to the unreliability of launch vehicles. In the context of this paper reliability is synonymous with success rate because all of the calculations are based upon simple arithmetic calculations comparing successes to total attempts, thus eliminating any confusion associated with confidence levels or probabilities of occurrence. To put the results in perspective, the groundrules used in acquiring and analyzing the data is contained below.

- Only U.S. launch vehicles were considered.
- Launch vehicles included commercial, civil, and military.
- No ballistics missiles were included in the database.
- No sounding rockets were included in the database except for those instances when the exact configuration of the propulsion stages equated to those used on launch vehicles.
- Definition of propulsion includes only those elements required to achieve the basic insertion mission. (i.e., propulsion does not include any onboard station keeping).
- For both liquid and solid propulsion systems all elements necessary to make up a complete stage are included as part of the system(i.e., a boost stage includes structure, propellant, tankage, TVA, ignition, etc.).
- A mission was defined as successful if the spacecraft was placed in its correct final destination orbit no matter how it got there.
- Catastrophic failure is defined as explosion or immediate loss of control of the vehicle

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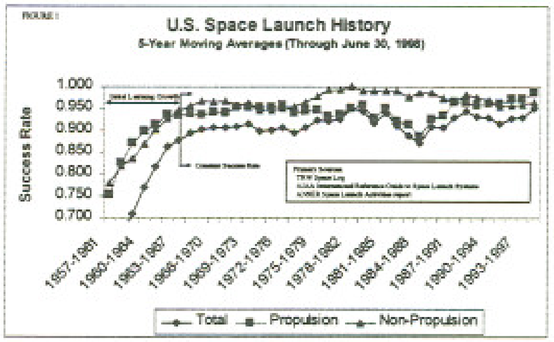
The data used in this report was limited to that available in open source literature. The primary sources of data for the database used include; the TRW space log, ANSER book titled "A Historical Look at United States Launch Vehicles," and the AIAA International Reference Guide to Space Launch Systems. Since it was difficult to clearly distinguish exact booster configurations for many sounding rocket and ballistic missiles systems (especially Atlas family), boosters for these applications were generally excluded from the launch vehicle database. Only when it was clear that the exact booster configuration used for these applications was also used as a lunch vehicle boost stage was it included in the database. Further research needs to be conducted to determine which of these sounding rocket and ballistic missile stages should appropriately be included in the databases. This becomes increasingly important as more and more ballistic missile assets are used directly as launch vehicle stages.

A summary of the historical launch vehicle success rate is shown in Figure 1. Notice that the points plotted are on a five-year moving average. This eliminates year to year variations in launch rate and number of failures. The historical success rate for launch vehicles follows a classic reliability learning curve where the initial years show significant learning effects during the development phases of the various launch vehicle programs and the later years show the more typical reliability capability of the systems. It is interesting the note that once the initial learning portion of the launch vehicle development history was overcome, the basic success rate for launch vehicles has remained constant at 0.91 from approximately 1964 until the present.



In reviewing the launch vehicle history data the failures can be segregated into a number of categories to gain increased insight into those areas that are the major contributors to unreliabities of launch vehicles. A summary of the segregated of failure categories is contained in Table 1. In reviewing the data in Table 1, it is interested to note that 70 percent of the total launch vehicle failures are attributable to propulsion in general and that 30 percent of the failures can be allocated to non-propulsion systems like avionics, staging, vehicle integration, etc.

Since propulsion is the major contributor to launch vehicle unreliability, this paper will concentrate on the attributes of propulsion that contribute to that large portion of the failure rate for launch vehicles. From a historical prospective it is interesting to note that the success rate for liquid propulsion stages is 0.980 while the historical success rate for solid boosters is 0.994. A summary of the specific failures attributable to liquid propulsion stages and solid boosters is contained in Appendix A, Tables A1 through A4.

The solid propulsion boosters can be segregated into three categories; upper stages, monolithic boosters, and segmented boosters. In this context upper stages consist of Apogee Kick motors (AKM, Perigee Kick motors (PKM), or escape motors. Monolithic boosters are stages used to achieve initial orbit that have a uniform monolithic propellant grain. Segmented boosters consist of all Titan strap-on boosters and Shuttle strap-on boosters. A summary of the success rates for each of these three solid propulsion categories is contained in Table 2. As expected, the monolithic boost stages have the highest reliability of all solid propulsion categories. Upper stages are essentially monolithic boosters, but their success rate is lower because of the inherent design and performance attributes necessary for an upper stage, which encourage high performance and high mass fraction. This drives solid propulsion upper stage systems to the limit of their capability for inert structural elements, as well as highly energetic propellant. The increased complexity associated with segmentation and size contributes to the reduced success rate of segmented boosters relative to monolithic boosters.

Table 2 Solid Propulsion History (1964-June 1998)

Booster Type	Failures	Attempts	Failure Rate	Success Rate
Upper Stage	10	621	0.0161	0.9839
Monolithic	6	2,371	0.0025	0.9975
Segmented	3	390	0.0077	0.9923
TOTAL	19	3,382	0.0056	0.9944

A similar segregation of propulsion types for liquid propulsion systems is summarized in Table 3. Like solid boosters, liquid upper stages have a significantly higher failure rate than boost stages (factor of 2). This is due to the necessity of high performance for upper stages as well as the required restart capability to satisfy both PKM and AKM requirements. There is a noticeable difference in success rate as a function of the propellant type being used. The cryogenic LOX/ hydrogen systems have a failure rate double that of other types of propellant systems (i.e., LOX/RP and hypergolic). This historical data also shows that 70 percent of the liquid propulsion failures occur in propulsion elements other than the engine itself.

Table 3 Liquid Propulsion History (1964-June 1998)

Booster Type	Failures	Attempts	Failure Rate	Success Rate
Upper Stage	13	351	0.0370	0.9630
Main Stage	23	1,490	0.0154	0.9846
TOTAL	36	1,841	0.0196	0.9804

	Stages			
Propellant	Failures	Attempts	Failure Rate	Success Rate
Cryogenic (LOX/LH2)	8	258	0.0310	0.9690
Other (LOX/RP, Hypergolic)	28	1,583	0.0177	0.9823
TOTAL	36	1,841	0.0196	0.9804

	Location of Failures *			
Propellant	Engines		Other	
Cryogenic (LOX/LH2)	2	25%	6	75%
Other (LOX/RP, Hypergolic)	8	29%	20	71%
TOTAL	10	28%	26	72%

* Classification from presentations to the National Research Council, Nov 14, 1991
Pete Leonard, L Systems, "Projected Launch Vehicle Failure Probabilities ..."
O. Glenn Smith, JSC NASA, "Reliability in Manned Transporation Systems"

Like many assessments, using historical success rates without taking into account other extenuating attributes may be misleading. Since the historical database contains a wide range of booster, direct comparisons between systems can potentially be somewhat misleading. An example would be comparing segmented solid boosters to monolithic solid boosters, where it takes a large number of monolithic boosters to satisfy the same mission requirements as a single segmented booster. An approach to consider in taking into account the significant difference in mission capability is summarized in Table 4. For this example historical data were normalized to a constant total impulse.

Table 4 Normalized Historical Reliability Comparison

Propulsion Element	Average Thrust (klbf)	Approximate Burn Time (sec)	Success Rate	Failure Rate	Failure Rate 100k lbf Thrust - 100 sec Burn Time
Monolithic Solids	115	60	0.9975	0.0025	0.00362
Segmented Solids	2000	120	0.9910	0.0077	0.00032

In capturing the various launch vehicle success rates we also included in the database the attributes of the various propulsion systems. In doing this we were able to determine the average thrust as well as average burn time for each of the major categories of propulsion systems. Using these data in conjunction with the success rates for the various propulsion elements. summarized in Table 2, we normalized the failure rate to an average thrust of 100,000 lbf over an 100 second burn time to get a comparison at equivalent total impulse basis. In the specific comparison alluded to earlier when you compare segmented solids to monolithic solids on a comparable total impulse basis the segmented solids have a significantly improved failure rate relative to the monolithic solids. However, in using this type of normalization one has to be careful because it would imply that a booster of identical design features that was twice as large would have twice the failure rate, which is not an accurate representation of what one would expect in reality. The main point of this example is to exhibit the necessity of taking care of in how one uses data in making comparison between various propulsion systems and that one should appropriately adjust design and historical data to truly reflect the mission application being evaluated.

In a qualitative sense many people advocate that increased complexity has a direct correlation to reduced reliability (i.e., an inverse relationship). In an attempt to quantify this hypothesis we extracted data from the Shuttle Failure Modes and Effects Analysis (FMEA) documentation generated by Marshall Space Flight Center for the Space Shuttle Maine Engine (SSME) and the Reusable Solid Rocket Motor (RSRM). A summary of the FMEA critical 1 failure modes is contained in Table 5. Crit 1 failure modes are those that result in loss of vehicle or crew. In Table 5 the failure modes for the RSRM and the SSME are summarized from a total failure count perspective. In this comparison only the RSRM elements are included and none of the booster elements (which include things like the skirt, thrust vector actuation recovery system, etc.) are addressed. But on a comparable basis none of the tankage or feed systems associated with the liquid SSME are included either. Therefore, the relative comparison is close to a one-to-one basis. From a FMEA comparison perspective the RSRM, with its inherent simplicity, has an order of magnitude fewer Crit 1 failure modes than the comparable SSME.

Table 5 Shuttle System FMEA Comparison

	Catastrophic Failure Modes		
	Total	Single Point	Redundant
RSRM *	141	91	50
SSME *	921		

* Excludes Booster Elements, Tank, and Related Systems

One area that tends to be grossly misunderstood and misstated from a reliability perspective, is the historical catastrophic failure probability of propulsion systems. In this particular context catastrophic failures are defined as those that are explosive or result in immediate loss of vehicle control. Using this definition Table 6-A summarizes the proportion of the total failures for solid boosters and liquid systems that would be categorized as catastrophic. A summary of the specific failures that were determined to be catastrophic for solid boosters and liquid systems are detailed in the appendix Table A-2 and A-4, respectively. As expected the ratio of catastrophic failures for solid propulsion systems is double the catastrophic ratio for liquid system. But the catastrophic failure ratio is not the real characteristic of interest in assessing the acceptability for launch vehicle systems. The real attribute of interest for launch vehicles is catastrophic failure probability, not failure ratio. Failure probability is the product of the catastrophic failure ratio and the failure rate. Table 6-B summarizes the catastrophic failure probability of solid boosters and liquid systems from a historical data perspective. From the perspective of historical catastrophic failure probability there is not a significant discriminator between solid boosters and liquid propulsion systems.

Table 6a Historical Catastrophic Failure Ratio

	Total Failures	Catastrophic Failures	Catastrophic Ratio
Solid	19	7	37%
Liquid	36	7	19%

Table 6b Historical Catastrophic Failure Probability

	Failure Rate	Catastrophic Ratio	Catastrophic Failure Rate
Solid	0.0056	37%	0.0021
Liquid	0.0196	19%	0.0037

Conclusion

From an historical perspective the data clearly shows that significant improvements in propulsion reliability are required of launch vehicles and to achieve the desired order at magnitude reduction in total launch costs. The historical data also substantiates the general rule of thumb that increased complexity results in reduced reliability. It is also imperative that if reduced probability of catastrophic failure is a system requirement, that both catastrophic failure ratio and propulsion system reliability be taken into account.

References

1. TRW Space Log
2. Isakowitz, Steven, "International Reference Guide to Space Launch Systems" Second Edition
3. Allred, A. G. "Quantitative Evaluation of Human Rating," AIAA-95-3701, September, 1995
4. ANSER, "An Historical Look at United States Launch Vehicles."

TABLE A1

olid Propulsion Non-Catastrophic Failures

Date	Vehicle	Failure	Comments	Payload
ower Stages				
05-Dec-75	SCOUT F-1	Propulsion	Third stage (X-259) nozzle failure	Dual Air Den
16-Aug-95	LLV-1	GN&C	Failed. Destroyed at 160 seconds because it was off course. First stage TVC control malfunction.	VitaSat, Gemstar
pper Stages				
19-Mar-64	DELTA B	Propulsion	Loss of stage 3 halfway through burn, probably a burnthrough. Payload and vehicle reentered.	IONOSPHERE BEACON
14-Jul-66	ATLAS D	Propulsion	Failed to orbit; AKM motor failure.	INTELSAT 2 F-1
26-Oct-66	DELTA E1		Failed to achieve GEO due to AKM malfunction	
27-Jul-67	ATLAS D	Propulsion	Injection motor failed	OV1-11
26-Jul-69	DELTA M	Propulsion	Stage 3 nozzle blown off. Normal operation through second stage cutoff. Coast phase normal through loss of data. Spin up, separation, ignition, and burnout occurred during blackout. Incorrect orbit resulted.	INTELSAT 3 F-5
23-Jul-70	DELTA M	Propulsion	AKM malfunction	INTELSAT 3 F-8
19-Aug-70	DELTA M	Propulsion	AKM malfunction	SKYNET 2
03-Feb-84	STS	Engines	Two payloads. Failure in both PAM-D rocket nozzles	WESTAR VI, PALAPA B-2
03-Feb-84	STS	Engines	Two payloads. Failure in both PAM-D rocket nozzles	WESTAR VI, PALAPA B-2
01-Dec-90	ATLAS E	Propulsion	Broken nozzle on DMSP booster motor caused incorrect orbit to be reached, satellite still became operational	DMSP 10

TABLE A2

Solid Propulsion Catastrophic Failures

Date	Vehicle	Failure	Comments	Payload
Lower Stages				
31-Jan-67	SCOUT B	Propulsion	Did not achieve orbit. Stage 4 motor graphite nozzle insert resulted in rupture of the motor case.	OV3-5
13-Sep-77	DELTA 3914	Engines	Castor IV burnthrough impinging on first stage caused vehicle to explode. Evaluation of material and samples from SRM as well as recovered SRM show that each of these motors had case mechanical properties well below drawing requirements.	OTS
14-Jul-80	THOR BURN	Propulsion	Catastrophic failure of second stage.	AMS 5
28-Jan-86	STS	Propulsion	Vehicle exploded 73 sec after launch - SRM field joint O-ring failure.	TDRS-B
18-Apr-86	TITAN 34D	Propulsion	SRM failure-due to insulation/case debonding, vehicle disintegrated . At SRM ignition the first explosive flash was noted. The flash appears on SRM 2 and is located appx. 120 deg from SRM TDC in SRM segment #1 just below joint segments 1 & 2.	BIG BIRD 20
02-Aug-93	TITAN IV	Engines/Huma	Burn-through in third segment of No. 1 SRM. Improper grain structure reworked 4 times, USAF signed off on it. Engineers said never reworked this much before, but didn't foresee a problem. Poor engineering judgment.	CLASS (KH-11)
17-Jan-97	DELTA-2 792	Propulsion	GEM case failure just after lift off. Some damage to pad and surrounding structures and vehicles	GPS II-R

TABLE A3

Liquid Lower Stage Propulsion Failures

Date	Vehicle	Failure	Comments	Payload
21-Jan-65	ATLAS D	Propulsion	Injection failure, no separation; Launch from side pod of ABRES vehicle failed.	OV1-1
12-Jul-65	ATLAS SLV-3	Propulsion	Destroyed by RSO. Premature sustainer engine cutoff. Component failure due to vibration environment. 22 components on 4 circuit boards isolated as most likely.	CLASS
03-May-66	THOR-TAT	?	Loss of sustainer engine pitch control due to fire in thrust section.	CLASS
17-May-66	ATLAS SLV-3	Propulsion	Vehicle went unstable when B2 pitch control was lost. Cause: Electrical short possibly due to cryogen leak.	GT-9 Target
26-Apr-67	TITAN IIIB	Propulsion	Stage 2 engine thrust dropped to appx. 1/2 nominal. Cause: Gross contamination on Martin side of interface.	CLPSS
27-Aug-69	DELTA L	Propulsion	Stage 1 hydraulic (gymbal) failure forced destruction. Flight normal until hydraulic supply pressure dropped. Simultaneously the hydraulic return pressure jumped. Both hydraulic pressures continued to oscillate and fluctuate erratically.	PIONEER E
21-Oct-71	DELTA N-6	Propulsion	2nd stage control gas-oxidizer vent valve failure. Gas leak caused a disturbing moment, coast phase not normal, and vehicle lost all altitude control. The tankage common dome appeared to be breached during coast phase.	NOAA-2
16-Jul-73	DELTA 300	Propulsion	2nd stage hydraulic pressure-pump motor failure. 2nd stage hydraulic system pressure and engine battery bus voltage started to decay in a manner indicating that the hydraulic motor pump had stopped prematurely. Fuel depletion caused shutdown.	ITOS-E
12-Apr-75	ATLAS F	Propulsion	Damaged thrust section allowed overheating and premature shutdown of the sustainer and vernier engines at 61 sec. Explosion in the flame deflector during the engine ignition sequence due to fuel bleeds over-boarded into flame deflector.	CLASS
18-Feb-76	THOR BURN	Propulsion	Main propulsion failure, under-performance	DMSP
15-Sep-76	TITAN IIIB	Propulsion	Stage 2 engine failed to shutdown on command, burned to completion. Thrust chamber valves received signal, failed to close. Cause: hard contaminate found in fuel valve.	CLASS
25-Mar-78	TITAN IIIC	Propulsion	Stage 2 turbine drive hydraulic pump failure after ignition. Hydraulic pressure increase until system burst, loss of vehicle control, destroyed by RSO. Stage 2 hydraulic pressure incurred a large overshoot but returned to normal for 20 sec.	DSCS II-C9/C10
29-May-80	ATLAS F	Propulsion	B-1 engine performance was 79% of nominal and so injection was 57 sec late, and so p/l separation was initiated by the p/l in its backup mode 7 sec prior to SECO. Unusable orbit..	NOAA-B
09-Dec-80	ATLAS E	Propulsion	Booster engine #2 shutdown prematurely, due to lube oil loses.	CLASS
18-Dec-81	ATLAS E	Propulsion	B-1 booster gas generator fuel cooling ports clogged.	NAVSTAR 7
03-May-86	DELTA 3914	Propulsion	Electrical short in 1st stage relay box caused premature main engine shutdown. Range safety vehicle destruction after aerodynamic forces caused tumbling.	GOES 7
25-Mar-93	ATLAS I	Propulsion	An inadequately torqued set screw on AC-74 allowed an internal stem screw to rotate out of adjustment. The stem screw was in the precision regulator of the Atlas' booster engine power control system.	UHF Follow-On

TABLE A3 (Cont)

Liquid Upper Stage Failures					
Date	**Vehicle**	**Failure**	**Comments**	**Payload**	**Upper Stage**
30-Jun-64	ATLAS LV-3	Propulsion	Premature 2nd stage shutdown; Centaur hydraulic failure C2 engine hydraulic system high pressure pump coupler failed during main engine start resulting in loss of control of vehicle.	Mass Model	CENTAUR
01-Sep-64	TITAN IIIA	Propulsion	Premature Transtage cutoff. Pressure system failure. Stage 3 (Transtage) helium pressurization system malfunction resulted in significantly reduced oxidizer consumption rate that caused a lower than predicted thrust.	TRANSTAGE	TRANSTG
15-Oct-65	TITAN IIIC	Propulsion	Propellant freezing in stage 3 engine bi-propellant valve. Stage 3 engine failed to shutdown resulting in vehicle tumbling. A fuel system leak was indicated.	OV2 1, LCS 2	TRANSTG
07-Apr-66	ATLAS LV-3	Propulsion	Centaur restart sequence failure. Engine ignition occurred but not sustained due to fuel depletion. Leak in RCS.	Mass Model	CENTAUR
06-Apr-67	ATLAS SLV-3	Other(Unknow	Agena D failed to restart.	ATS-2	AGENA
04-Apr-68	SATURN V	Propulsion	Stage 3 failure to restart, Stage 3 fuel leak	Apollo 6	S-IVB
10-Aug-68	ATLAS SLV-3	Propulsion	H_2O_2 booster pump supply system failure preventing boost pump operation. Centaur second main engine start was not achieved.	ATS-4	CENTAUR
11-Feb-74	TITAN IIIE	Propulsion	Centaur stage failed to start after separation. Vehicle failure due to failure of LO_2 boost pump.	VIKING TEST	Centaur D1T
09-Jun-84	ATLAS G	Propulsion	Failure occurred at Atlas/Centaur separation and vehicle subsequently tumbled during coast phase. Mode of failure was a LO_2 tank crack.	INTELSAT VA 9	Centaur D1A
02-Sep-88	TITAN 34D	Propulsion	Transtage pressurization system failure.	VORTEX (USA 31)	TRANSTG
18-Apr-91	ATLAS I	Propulsion	RL10 Engine failed to start; a valve failure allowed N_2 ice to form inside fuel TP.	BS-3H	Centaur D1A
22-Aug-92	ATLAS I	Propulsion	Pre-launch chilldown procedures resulted in ambient air freezing and jamming the RL-10 engine's oxidizer turbopump	GALAXY 1R	Centaur D1A

TABLE A4

Catastrophic Liquid Propulsion Failures

Date	Vehicle	Failure	Comments	Payload
Lower Stages				
02-Mar-65	ATLAS LV-3	Propulsion	Exploded on pad-propellant feed. Thrust lost due to fuel starvation of booster engines stemming from closure of fuel prevalve at 74 sec. Stage failed due to loss of thrust.	Mass Model
27-May-65	ATLAS D	Propulsion	Booster gas generator power loop failure - LOX flex line leak/starvation & exploded.	OV1-3
17-Feb-71	THOR AGEN	Propulsion	Exploded after 40 seconds.	CLASS
04-Dec-71	ATLAS SLV-3	Propulsion	Sustainer engine turbine damaged during engine start resulting in hot gas leaks and eventual failure of thrust section hardware. Fuel starvation under tank-fed conditions during engine start.	BMEWS E
29-Sep-77	ATLAS SLV-3	Propulsion	Destroyed: hot gas leak in the booster gas generator. The resulting fire in the Atlas thrust section resulted in vehicle destruction. The source of the hot gas was traced to a crack in the upstream omega joint in the booster gas generator.	INTELSAT 4A
28-Aug-85	TITAN 34D	Propulsion	Stage 1 engine shutdown prematurely - massive oxidizer leak. Shortly after stage 1 ignition, a series of anomalous events were experienced with the booster propulsion system, which resulted in loss of control by the guidance system and destruction.	KH-11-7
Upper Stages				
25-Oct-65	ATLAS SLV-3	Propulsion	Agena exploded 6 minutes after launch.	GT-6 Target

TABLE A5

Non-propulsion Failures				
Date	**Vehicle**	**Failure**	**Comments**	**Payload**
24-Mar-64	THOR TAT	GN&C	Electrical short circuit around flight control and guidance boxes.	CLASS
21-Apr-64	THOR ABLE STAR	Human	Human error by flight controllers.	CLASS
08-Oct-64	ATLAS SLV-3A	Unknown	Destroyed by R.S.O. following Agena malfunction	CLASS
05-Nov-64	ATLAS LV-3A	Structure	Agena D shroud failed to separate	MARINER 3
25-Aug-65	DELTA C	Propulsion	Stage 3 AKM initiator ignited before separation - charge bypassed the delay train- did not achieve spin rate needed for pointing stability and was unbalanced by attached debris. Did not achieve orbit.	OSO C
02-Sep-65	THOR TAT	GN&C	Guidance failure.	CLASS
21-Dec-65	TITAN IIIC	ACS	Transtage ACS nozzle 3 oxidizer valve failed to open. Subsequent to injection into the transfer orbit, ACS fuel was depleted which resulted in the loss of attitude control capability.	OV2 3, LES 3/4, OSCAR 4
06-Jan-66	THOR ALTAIR	Unknown	Payload failed to orbit.	CLASS
01-Jun-66	ATLAS SLV-3A	Structure	Agena ATDA fairing separation failure	GT-9 Target
26-Aug-66	TITAN IIIC	Structure	Payload fairing failure during SRM flight. Vehicle experienced a catastrophic failure 79 sec after liftoff. Abort of the flight occurred following disintegration of the P/L and the P/L fairing. The P/L fairing apparently collapsed.	8 IDCSP's
29-May-67	SCOUT B	Destruct	Third stage motor case through-bonding crack, indavertant destruct activation	ESRO 2A
18-May-68	THORAD	Human	Guidance failure caused by misalignment of gyro rate package during installment.	NIMBUS B
16-Aug-68	ATLAS SLV-3	Structure	Protective shroud surrounding second stage, Burner II , failed to separate.	OV5-8
18-Sep-68	DELTA M	GN&C	First stage control system(rate gyro) malfunctioned, vehicle destroyed by RSO. Divergent oscillation in pitch attitude starting at 20 sec increased until vehicle was out of control at 60 sec.	INTELSAT 3 F-1
06-Nov-70	TITAN IIIC	GN&C	IGS-IMU failure- failed to achieve GEO.	IMEWS 1
30-Nov-70	ATLAS SLV-3C	Structures	Nose fairing failed to jettison properly after Centaur main engine start. Centaur continued to function properly but could not achieve proper orbital conditions due to the extra weight carried. This was a unique OAO nose fairing no longer used.	OAO-B
08-May-71	ATLAS SLV-3C	GN&C	Mode of failure was loss of Centaur pitch stabilization shortly after Centaur main engine start. A probable cause was an open in diode at input to IC allowing voltage transient to cause failure of IC in rate gyro preamp.	MARINER 8

TABLE A5 (Cont)

16-Feb-72	TITAN IIIB	Other(Unknown)	Failure. (Space Log)	CLASS
20-May-72	TITAN IIIB	Other(unknown)	Failure. (Space Log)	CLASS
26-Jun-73	TITAN IIIB	Other(Unknown)	Failed to orbit.	CLASS
18-Jan-74	DELTA 2313	ACS	2nd stage attitude control E pack failure-electronics	SKYNET 2A
30-Aug-74	SCOUT D-1	Unknown	Achieved data, but at lower than intended orbit.	ANS A
20-Feb-75	ATLAS SLV-3D	Avionics(separation)	Atlas electrical disconnect failure during boost separation. This caused loss of stabilization during sustainer phase of flight.	INTELSAT 4 F6
20-May-75	TITAN IIIC	GN&C	Transtage IMU failure terminated flight. Internally shorted transistor due to contamination. At the II/III separation command, the IMU 90 deg power supply went to zero volts. Platform lost stabilization after the gyro wheels ran down.	DSCS II-B5
20-Apr-77	DELTA 2914	Structure	Clamp band between second and third stages released early, consequent coning during third stage burn produced low orbit. A malfunction of clamp band assembly caused a premature release of the 3rd stage from the 2nd stage.	ESA-GOES
04-Apr-83	STS	ACS	Control Attitude in IUS	TDRS-A
26-Mar-87	ATLAS G	Other/Human	Lightning struck vehicle during first stage flight. Guidance affected, vehicle tumbled and RSO destroyed 60 sec after launch.	FLTSATCOM 6
14-Mar-90	TITAN III	Avionics	Second stage failed to separate from payload - miswired separation system.	INTELSAT 6F3
17-Jul-91	PEGASUS		first stage control malfunction resulted in lower than intended orbit	MICROSAT 1-7
05-Oct-93	TITAN II		Believed placed in correct orbit, but ground crews cannot locate spacecraft.	LANDSAT-6
27-Jun-94	PEGASUS XL	Structures	Source: JSR. Orbital Sciences' Pegasus winged launch vehicle suffered its first launch failure. The modified Lockheed L-1011 carrier plane took off from Vandenberg AFB, California and released the first Pegasus XL.	STEP-1
22-Jun-95	PEGASUS XL	Structures	Incomplete separation of interstage adapter confined 2nd stage motor; destroyed by RSO.	STEP-3
05-Aug-95	DELTA 7925	Integration	Low orbit: it appears one of the GEM solids strap-ons failed to separate, causing the 1st stage to deliver less velocity than planned. The 2nd stage compensated by burning 35 seconds longer than planned on its 1st burn.	KoreaSat 1
23-Oct-95	Conestoga	Structure	The first Conestoga 1620 launch vehicle suffered interstage structural failure. The vehicle was destroyed 45s into the first stage burn, at an altitude of 11 km. The Conestoga uses a Castor 4B first stage core with Castor 4A and Castor 4B strapons.	Meteor Microgravity
04-Nov-96	PEGASUS		2-3 Staging failure	HETE