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Lifetimes and Reliabilities of Goddard Space Flight Center Spacecraft Launched since Calendar Year 2000, including Analyses by Mission Risk Class

Walter Thomas III
Goddard Space Flight Center
Greenbelt, Maryland

December 2024

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Reliability,Maintaiability, and Availability Branch

National Aeronautics and Space Adminstration

Goddard Space Flight Center
Greenbelt, Maryland

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Executive Summary

Lifetimes of 50 GSFC missions launched during and since 2000 were assessed using Weibayes and Weibull analyses.

Among the 50 missions, there was one launch failure, ten (10) missions are completed (no longer operating), four (4) were payloads only, and 36 spacecraft buses still are operating. All the missions have exceeded their mission required lifetimes or still are operating. This population of spacecraft has achieved 10-year reliabilities of 0.97–0.98, with a 90% confidence that spacecraft have reliabilities no less than 0.94. The GSFC 2000 and beyond population spacecraft lifetimes are characterised by a Weibull distribution having $\beta = 4.6$ and $\eta = 7{,}820$ days (20.6 years).

There are four (4) missions that are space instruments hosted on other spacecraft, for example, the International Space Station (ISS). One spacecraft, ST-5, had a short mission required life, 90 days. These five (5) missions were discounted (excluded) from subsequent spacecraft bus analyses.

For eight (8) completed spacecraft missions (GEDI and ST-5 were discounted), there were insufficient data to differentiate spacecraft bus lifetimes among Risk Classes **A**, **B**, and **C**.

For all spacecraft buses, including both completed and operating missions, there are significant differences in the numbers of spacecraft buses among Risk Classes **A**, **B**, and **C** for both *assigned* and *practiced* cases. These differences affected the Weibayes statistics.

Using Weibayes estimates for GSFC 2000 spacecraft bus operating times, current to 31 July 2024, one cannot conclude with statistical confidence there are differences between bus lifetimes for either the *assigned* or *practiced* cases, excepting there was a statistically significant difference between *assigned* Class **A** and Class **B** buses at 70% confidence. However, this difference was caused by the large numbers of *assigned* Class **B** buses ($n_B = 28$) compared to the few ($n_A = 4$) Class **A** *assigned* buses.

Though there are indications of differences in spacecraft bus lifetimes between risk classes, one cannot conclude there are differences between GSFC 2000 spacecraft bus Risk Classes **B** and **C** lifetimes with statistical confidence.

These data and conclusions are current to 31 July 2024. As missions continue to operate and accumulate operating times, the statistics and conclusions cited above may change and require updating. Note that this report considers only spacecraft buses, instruments and/or payloads were not analysed.

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Nomenclature and Acronyms:

ABI	Advanced Baseline Imager
EO-1	Earth Observing-1, a technology demonstration satellite
EOL	End-of-life
Fermi	A gamma-ray space observatory
GEDI	Global Ecosystem Dynamics Investigation
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
ISS	International Space Station
LCRD	Laser Communications Relay Demonstration
mle	maximum likelihood estimate
NASA	National Aeronautics and Space Agency
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Procedural Requirement
NICER	Neutron Star Interior Composition Explorer
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
SOARS	Spacecraft On-orbit Anomaly Reporting System
ST-5	Space Technology 5
Swift	Gamma-ray burst space observatory, now Neil Gehrels Swift Observatory
TDRS	Tracking and Data Relay Satellite
TSIS	Total and Spectral Solar Irradiance Sensor
β	shape parameter (slope) of a Weibull or Weibayes distribution
η	location parameter (characteristic life) of a Weibull or Weibayes distribution
n_i	number of itms in a population or or subgroup
t	time, in days (d) or years (y)

I. Introduction

The Center Chief Engineer requested a lifetime assessment of fifty (50) Goddard Space Flight Center (GSFC) missions launched during the year 2000 and beyond, and, more specifically, lifetimes of spacecraft buses for those missions and comparisons of spacecraft bus lifetimes for missions having Mission Risk Classes **A**, **B**, and **C**.

II. Approach

Weibayes[1] analyses [1] of spacecraft and bus accumulative operating times were employed to determine life distributions that included upper and lower life parameter confidence bounds. Deriving Weibayes estimates with a $\beta = 1.0$ shape parameter (that is, an exponential distribution) is accepted reliability engineering practice when no other available data or information are available for components and systems lifetimes. In other words, it assumes there were no infant mortal or wearout failures among the GSFC missions' population. Spacecraft bus lifetimes among the 44 buses were determined using Weibull[2] analyses of operating times, including four (4) mission end-of-life events that occurred after 2.4-8.3 times mission required lifetimes. Comparisons among spacecraft buses by their Mission Risk Classes used Weibayes distributions with their corresponding life parameter confidence intervals, and Weibull distribution bus operating time distributions to derive probability density (*pdf*) graphs for visual comparisons.

Mission Risk Classes included two separate categories: those *assigned* to a mission and those actually *practiced*. *Practiced* risk classes are those for which the spacecraft bus and payloads were developed, manufactured and launched to different, usually higher, assurance and other processes than their *assigned* risk classes. Two examples are the GOES and TDRS series satellites that originally were classified as Risk Class A missions and subsequently assigned Risk Class B. These changes occurred even though their strategic importance remained the same and mission lifetime requirements were either increased or unchanged and, in practice, most all the development and manufacturing processes also remained unchanged from before when the Risk Classes were altered.

III. Overview

Fifty (50) GSFC missions have launched since 2000. One mission (Glory) ended via a launch failure.

- Of the remaining forty-nine (49), ten (10) are completed (no longer operating) missions, having operated to 2.3 to 16.4 times their required mission lives. (One, ST-5 – a 90-day technology demonstration mission – is excluded from the above mission life statistic.)

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[1] Weibayes analyses are "one-parameter" Weibull distributions using an informed β (shape, or slope) parameter with lifetime data to construct a Weibull distribution. It is recommended best practice when there are few data, i.e., failures, in a population under investigation or study. It also includes capabilities for estimating confidence bounds about its distribution. See Ref. [1] for more details.

[2] The distribution bearing his name was invented by Dr. Woloddi Weibull (1987-1979) for materials strength and fatigue studies and subsequently has found wide applicability in life data analyses. The basic two-parameter Weibull distribution includes a shape (slope) parameter, β, and a location parameter, η; β characterises data variability and η locates the distribution along the abscissa. For time domain (i.e., reliability) data, β can change according to occurrence frequencies and characterises whether events are occurring less or more frequently or are random.

- Thirty-six (36) missions still are operating as of 31 July 2024, excluding the four payload-only missions. Of the operating missions, twenty-three (23) have operated longer than their mission required life – by 1.5-9.9 times their mission required lives.
- Thirteen (13) of the still operating missions have not yet reached their mission required lifetimes, having current operating times of 0.1 (GOES-19, launched 25 June 2024) to 10.5 years (TDRS-11, launched 21 January 2013).
- Four missions are hosted payloads (instruments): GEDI (Class-C, ISS), LCRD (Class-D, STPSat-6), NICER (Class-D, ISS), TSIS (Class-C, ISS); these are not included in spacecraft bus assessments.

For the 44 completed and operating missions having spacecraft buses, a Weibayes estimate for their accumulated operating lifetimes, using an exponential β = 1.0, provided a composite reliability shown in **Figure 1**. This is the reliability of 44 GSFC spacecraft launched since 2000 as of 31 July 2024, the solid (blue) line denoted as "Weibayes β = 1.0." A lower 90% confidence bound of the composite reliability is shown by the single dot-dashed (blue) line, denoted as "Weibayes Lower 90%."

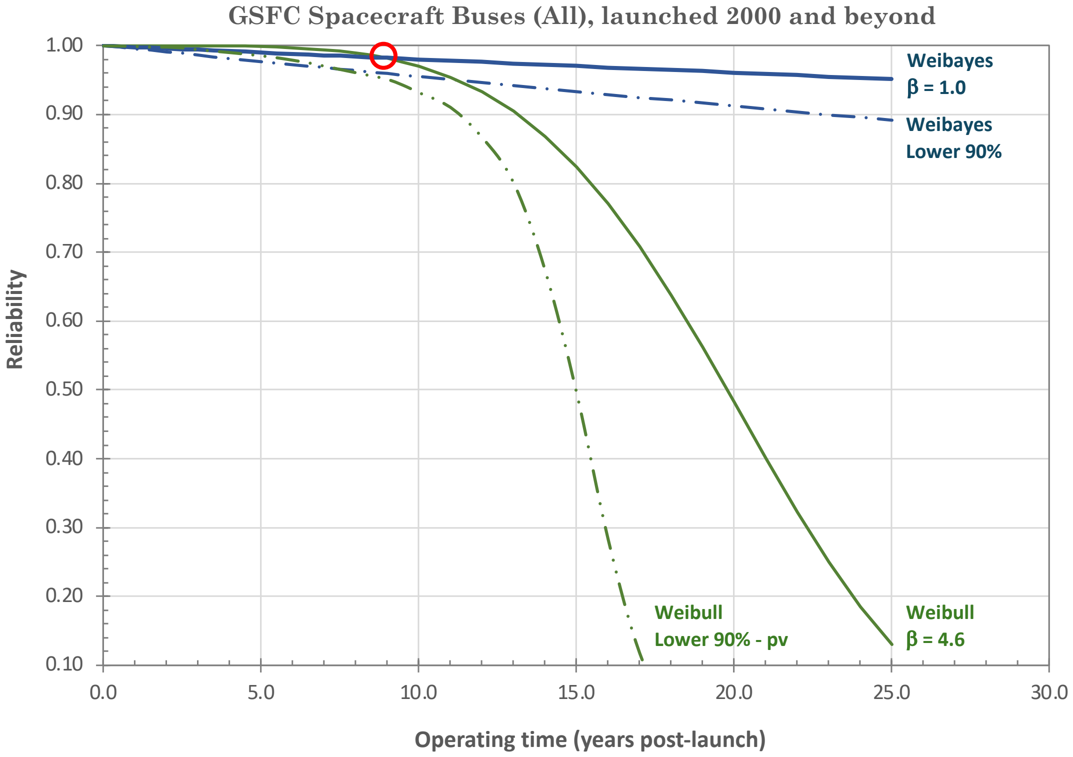

Figure 1. Lifetimes (reliabilities) of GSFC missions launched since 2000. The hosted missions (GEDI, LCRD, NICER, and TSIS) were discounted excluded) in these distributions. As of 31 July 2024, 36 of 46 missions still were operating.

Note that these data are time-terminated on 31 July 2024 for the still operating missions. As those missions continue to operate, that is, accumulate operating time, the reliabilities for all post-2000 GSFC missions will increase, assuming no premature failures.

Four spacecraft had end-of-life (EOL) events caused by bus degradation or failures long after they had accomplished their mission required life's. None of these operation ending events are deemed mission failures as they all had exceeded their mission required lifetimes. Nonetheless, in the context of assessing GSFC's spacecraft population lifetimes and reliability, it is appropriate to use these EOL events to derive a population lifetime (reliability) distribution.

RHESSI had an EOL terminating event [2] caused by degradation of its communications receivers[3]. NOAA-16 and -17 buses both had power system solar array shunt failures that ended their operations [3, 4, 5]. These two events were associated with known long-term power system design weaknesses for extended mission operations and known to not affect spacecraft operations during their mission required lifetimes (two years). GOES-12's bus had numerous thruster problems caused by valve leaks [6]; it eventually was replaced by GOES-13 assuming the GOES-East coverage.

Operating times for the 44 buses ranged from 0.1 to 24 years. Thirteen (13) spacecraft had operated less than their mission required lifetimes, and 23 others still are operating beyond their mission required lives, and eight (8) missions have been completed. The lifetime distribution for this population has Weibull parameters $\beta = 4.6$ and $\eta = 7{,}820$ days[4]. The corresponding reliability function along with its lower 90% confidence bound[5] is shown in **Figure 1**, above, (solid and double dot- dash dark green lines).

The Weibull distribution for this GSFC spacecraft population illustrates that actual spacecraft lifetimes are characterised by Weibull distributions, vs. exponential distributions typically used in prelaunch reliability predictions. For these GSFC lifetimes, prior to the approximate 8.5 year "cross-over" point, denoted by the red circle, the actual (Weibull) reliabilities are greater than the exponential reliabilities. This result is not inconsistent with numerous other prior GSFC spacecraft and space instrument lifetime and reliability analyses.

The above data and analyses used all 44 spacecraft buses, except the four (4) hosted instruments and the one short-lifetime spacecraft, and combined all four Risk Classes – **A**, **B**, **C**, and **D**.

As one requested comparison was assessments distinguishing among Risk Classes, statistics were accumulated by Risk Class and are summarised in **Table 1**, next page.

Assigned risk classes are those designated by the Mission Directorate early in a program. They are based on considerations provided in NASA Procedural Requirement NPR 8705.4 [7]. *Practiced* "risk classes" characterise those in which missions were developed, designed, manufactured, and tested to processes and assurance practices different, usually greater than, those commensurate with the assigned risk classes.

Information provided in Table I will become relevant in addressing some of the confusing results presented later in this report.

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[3] RHESSI communications receivers had degraded; its Principal Investigator and mission operations decided to end the mission vs. loosing capabilities to communicate with the spacecraft.

[4] η is the location parameter (called characteristic life) of a Weibull distribution, when 63.2% of the events have occurred.

[5] This lower confidence bound is a more conservative "pivotal" estimate, based on the few EOL events (4) and the censored still-operating times. A less conservative lower 90% bound based on a Fisher matrix estimate is shown in **Figure A-II-1** in the Appendices.

Table I. Summary of Spacecraft Cumulative Operating Times and Mission Required Lives by Mission Risk Class

Risk Class	ni Completed	ni Operating	Cum. Opr'g. *t* (d)	Mission req'd life (y)		
				Mean	Min	Max
Assigned:						
A	2	2	17,716	5.3	5	6
B	3	25	115,123	9.3	1	15
C	2	8	38,206	3.2	1	7
Practiced:						
A	3	15	81,356	10.3	5	15
B	3	12	54,253	5.3	2	15
C	2	9	44,930	3.3	1	7

IV. Completed Missions

Eleven (10) missions have completed (ended) their missions. These include one short required-life missions (ST-5, 0.15 y) and a hosted instrument (GEDI, 4.0 y operation)[6] [9]. Thus, there are only eight (8) spacecraft buses relevant for assessing lifetimes. Weibayes results are shown below, in **Table II**.

For these data, the confidence bounds "overlap," i.e., between adjacent risk class rows, a lower bound (left column) is within an adjacent row's upper bound. That is, confidence bounds about the lifetimes (η's) are not different between the risk classes. To be significantly different statistically, a lower bound must be greater than an adjacent upper bound at a specified confidence.

Thus, statistically, one cannot state that risk classes A, B, and C for completed missions have different lifetimes (for both η's or medians) for either the *assigned* or *practiced* cases. For completed missions launched since 2000, there are two few data to discern differences among risk classes.

Table II. Weibayes results for completed mission spacecraft buses.

Risk Class	n_i	η (days)	Median (d)	Confidence intervals (d)	
				L90%	U90%
Assigned:					
A	2	8,640	5,990	3,750	82,010
B	3	12,620	8,750	5,480	119,750
C	2	8,740	6,060	3,800	82,980
Practiced:					
A	3	16,250	11,260	7,060	184,220
B	3	11,720	8,120	5,090	111,260
C	2	12,100	11,850	5,220	113,980

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[6] The GEDI instrument was removed on the ISS on 17 March 2023 and stored. It was reinstalled onto its original ISS position on 22 April 2024 and is to begin operations again [8].

V. All Missions (both completed and operating)

Of the 44 launched spacecraft buses (hosted instruments and one intended short mission, ST-5 were discounted), 36 (82%) still are operating. Of those still operating, GOES-17(R) was placed into standby after eight (8) months operation because of the loop heat pipe problem in its primary Advanced Baseline Imager (ABI) instrument; this was *not* a spacecraft bus anomaly.

For all spacecraft buses, Weibayes estimates for lifetimes were derived along with associated upper and lower confidence bounds about the characteristic life (η). For these cases, both 90% and 70% [7] confidence bounds were derived. These data are shown in **Table III**, below, categorised by mission risk class and risk class type (*assigned* v. *practiced*).

Corresponding Weibayes reliabilities are shown in **Figures 2** and **3** on the following page.

Excepting one case, none of these bus lifetimes were different statistically; that one case was **B** buses had significantly longer lifetimes than **A** buses at 70% confidence for *assigned* risk classes.

Table III. Weibayes data for All spacecraft buses, by Mission Risk Class and type.

Risk Class	n_i	η (days)	Median (d)	Confidence intervals (d)			
				L90%	U90%	L70%	U70%
Assigned:							
A	4	17,700	12,300	7,690	167,960	14,700	49,610
B	28	115,100	79,800	50,000	1,092,720	100,450	338,050
C	9	36,400	25,230	15,810	345,430	30,230	202,040
Practiced:							
A	17	80,400	55,730	34,920	763,160	66,790	225,440
B	15	54,200	37,590	23,560	514,850	45,606	151,090
C	10	45,800	31,750	19,900	434,810	38,050	128,440

Figure 2 is a notional graphic illustrating differences among Weibayes lifetimes for the several subgroups.

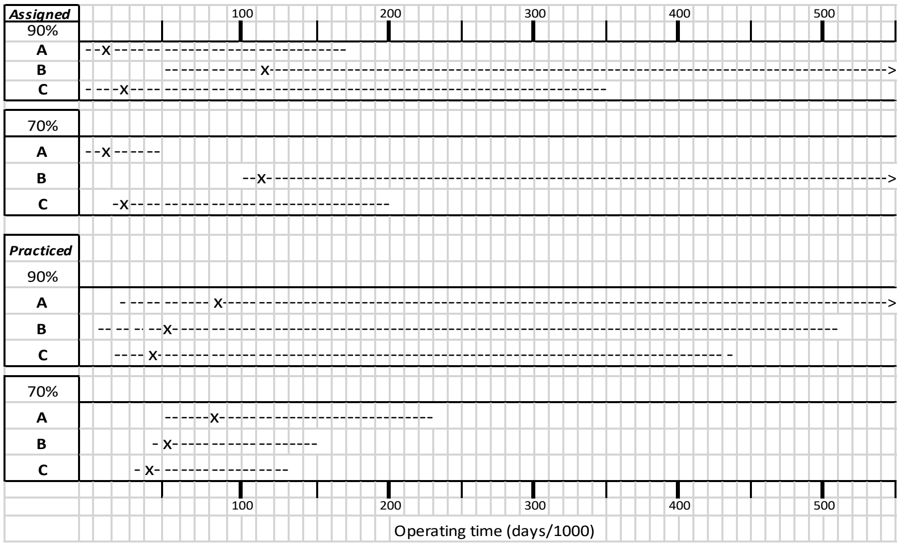

Figure 2. Line graphic depicting differences among Risk Class subgroups.
x's denote Weibayes η's; beginning and end dashes are lower and upper confidence bounds.

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[7] A 70% confidence bound is *conceptually* similar to one standard deviation of a normal distribution.

For the line graphic, the plotted dashes and x's are the **Table III** data plotted to the nearest approximate 1000 days; the denoted numbers are operating days divided by 1000. The x's indicate the approximate distribution η's. Ending " ->" notations indicate upper bounds greater than the righthand 550-day graphic end time.

One facet to note among all the line plots is that the Weibayes characteristic life parameters (η's) all are displaced far to the left within each subgroup's distribution representation. This is because buses with low operating times also will cause an η leftward shift. Of the 36 still operating spacecraft buses, 13 buses have not yet operated to their mission required lifetime. These ranged from 0.1 to 10.5 years operation[8]; the 0.1 is for the GOES-19 just launched in June 2024.

Another important contributor to the differences between the *assigned* and *practiced* cases is the disparate number of **B** Risk Class spacecraft compared to **A** and **C** Classes; there are 28 *assigned* risk class spacecraft for **B** and only four (4) and ten (10) for **A** and **C**, respectively. As the Weibayes computation accumulates individual operating times for each subgroup, this larger number of risk class **B** spacecraft, including six (6) that have operated for more than five times (5X) their mission required lifetimes, substantively increases both its η and upper bound.

Most all the differences between spacecraft numbers for Classes **A** and **B** for the *assigned* and *practiced* cases derive from the GOES and TDRS series that originally were classified Risk Class **A**. Thirteen (13) of those previously assigned as Class **B** were changed to **A** for the *practiced* case. The other change was the Aura spacecraft changing from **B** to **A** for the *practiced* case; its "sister," spacecraft, launched two years earlier, used the same bus and had been assigned Risk Class **A**.

Another means for understanding differences between the cases and risk classes is to plot operating times for each subgroup as probability density functions (*pdf*'s)[9]. This method uses operating times for each subgroup to provide a statistical distribution from which a first derivative is computed, the *pdf*'s. Weibull distributions provided the best fits[10]. The *pdf*'s for each case (*assigned* v. *practiced*) are shown as **Figures 3** and **4**, on the next page.

Comparing the *assigned* case, Classes **A** and **B** have peaks at about the same lifetimes – about 15 years. Those are greater than for **C** whose peak is about 11.5 to 12 years. For the *practiced* case, for which thirteen (13) former class **B** buses are now **A** buses, the difference between classes **A** and **B** is more distinct; **A**'s peak is at 17.5 years whereas **B**'s peak is now at 12 years. The later decreased peak (for **B**) resulted from both fewer number of buses (15 v. 28) and fewer long operating times. For Class **C** buses, the peak remained relatively unchanged. Its "extended" upper tail is driven primarily by the longevities of the EO-1 (16.4 y), Fermi (16.1 y), and Swift (19.7 y) spacecraft. These operating lifetime *pdf*'s were generated from median data. They provide a pictorial view of spacecraft bus lifetime differences viewed in a risk class perspective. They, however, do not prove any statistically significant differences in lifetimes between the several cases and risk classes.

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[8] This factor is what had been referred to as "penalising" the lifetime data computations mentioned in a prior discussion; the low operating times cause the lower tail of the lifetime distribution to extend leftward, which then decreases characteristic life (η) and "widens" the lower bound.

[9] *pdf*'s are first derivatives of the Weibull (cumulative) distributions.

[10] As these are distributions *not* related to failures, these are *not* Weibull failure distributions.

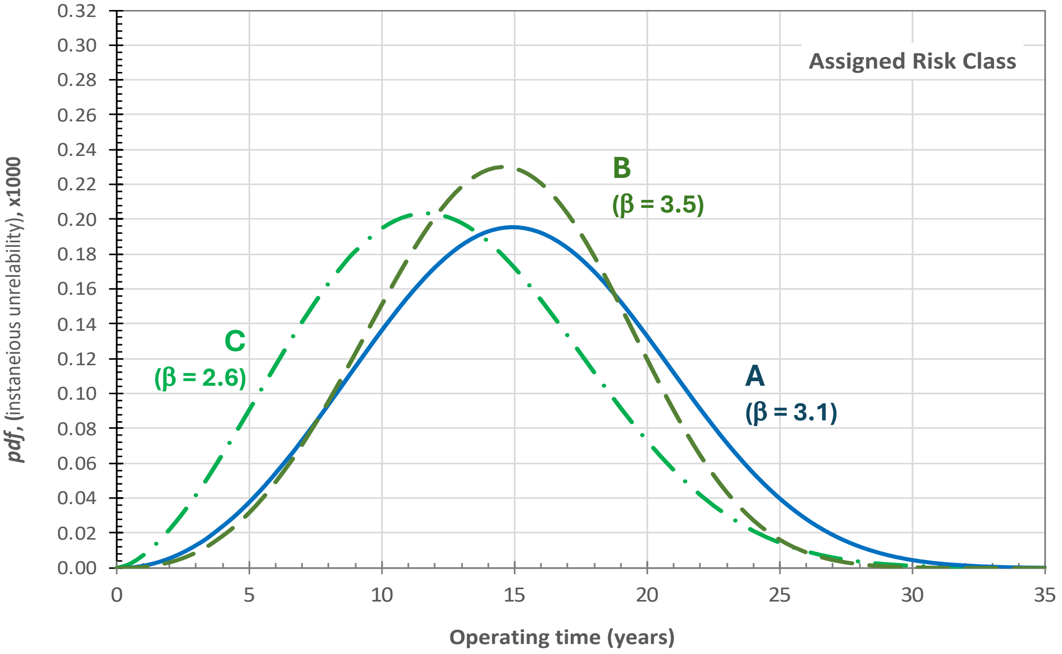

Figure 3. GSFC spacecraft buses launched 2000 and later, *Assigned* case – *pdf*'s by Risk Class.

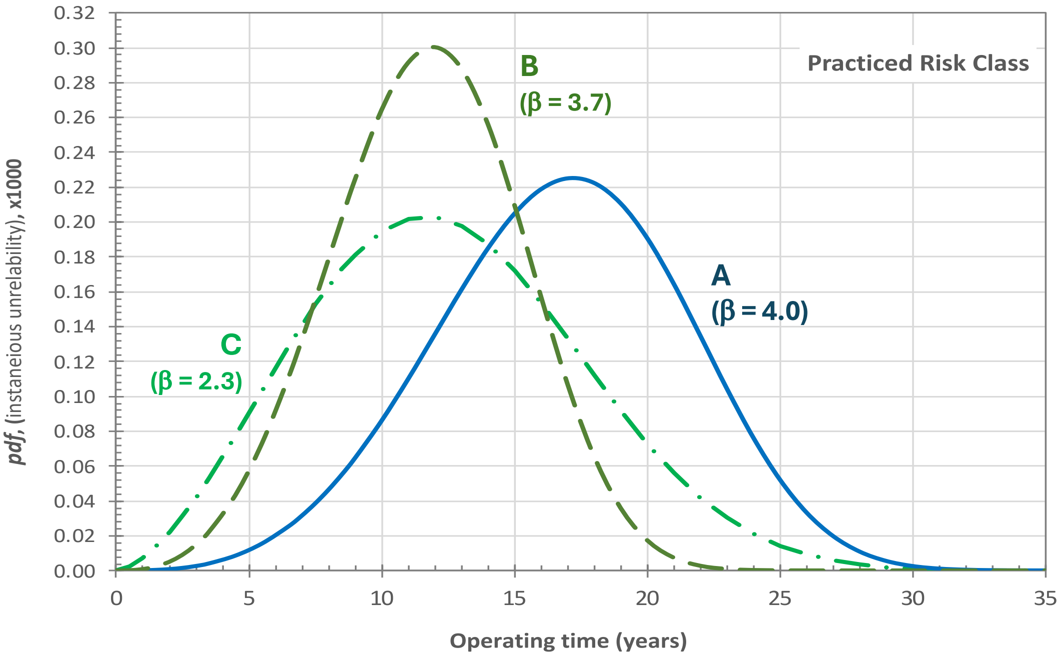

Figure 4. GSFC spacecraft buses launched 2000 and later, *Practiced* case – *pdf*'s by Risk Class.

Reliabilities derived from the Weibayes risk class and cases data are provided as **Figures 4** and **5**. The only two that are significantly different statistically are Risk Class **A** v. **B** for the *assigned* case. However, there are issues with those data, as described above, that preclude making a definitive conclusion regarding those data subgroups. The other subgroup comparisons are not significantly different statistically.

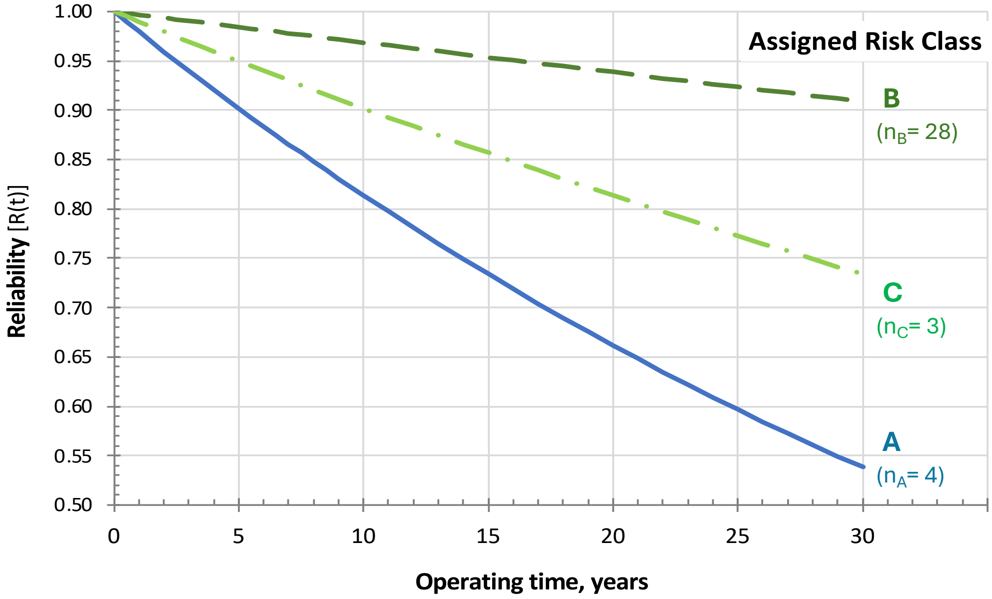

Figure 5. Weibayes reliabilities for All spacecraft buses for *Assigned* Risk Classes.

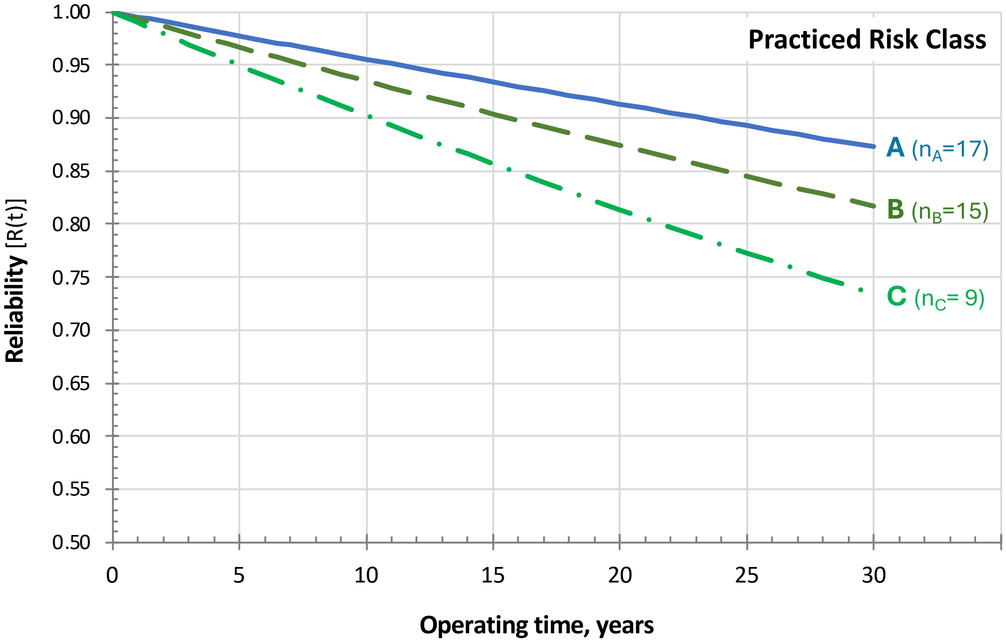

Figure 6. Weibayes reliabilities for All spacecraft buses for *Practiced* Risk Classes.

VI. Discussion

Data included in this report should be considered interim and subject to revisions. This is because of the large number (36 of 44) of spacecraft in this year 2000 and later population that still are operating. Only about 16-18% of the year 2000 and forward missions have been completed. Nonetheless, the longevity of GSFC space missions, particularly for those developed, manufactured, and launched under less restrictive risk classification criteria (Risk Class **C**), is a testament to their robust designs and the ingenuity of the design and operational teams providing "workarounds" to address on-orbit anomalies that sometimes occur. Perhaps less intuitive is that barring fundamentally life-limited items or fuel limitations, well-designed spacecraft buses using modern manufactured components do not exhibit wear-out over useful operational timespans.

These data will require revisions as the missions either complete or otherwise end.

As noted above and evidenced in these analyses, having missions at various stages in their operational lives make rigourous (i.e., statistically credible) comparisons between, for instance, risk classes difficult because of wide ranges between the newer operating times and those that are operating far beyond their required mission lifetimes. This results in subgroups having wide ranges between the "young" and "old" spacecraft that led to the "overlapping" confidence bounds that negated a statistically rigourous comparison.

The *pdf* methods presented herein provide one alternative to addressing the disparate sample sizes between compared subgroups. However, unless the realised distributions, that is, those underlying the subgroup lifetimes from which the *pdf*'s are derived, have accumulated operating times displaced widely from each other, those results likely will not yield statistically significant comparisons.

Another approach might be utilising Monte Carlo methods to generate surrogate distributions for subgroups having fewer numbers so that the "sample sizes" within each subgroup are similar. This approach would address the disparate differences in subgroup sizes, i.e., numbers of spacecraft in each subgroup, and would be applicable only for comparing subgroup differences. To date, this had not been tried.

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VII. Conclusions

1. Forty-four (44) GSFC spacecraft buses have launched and operated since 2000; this total excludes one short-term required life mission, ST-5. Of those 36 still operating, 23 of those have exceeded and 13 have not reached their mission required lifetimes.
2. Spacecraft bus reliabilities for this GSFC 2000 population are 0.97-0.98 after 10 years operating (median estimates) and 0.88-0.97 after 15 years operation. One can be confident (at 90%) that GSFC 2000 spacecraft buses' reliabilities are no less than 0.94 after 10 years operations.
3. For GSFC 2000 completed missions ($n_i = 8$), there are insufficient data to establish that there are different lifetimes among Risk Classes **A**, **B**, and **C**.
4. For GSFC 2000 spacecraft buses, there are significant differences in the numbers of spacecraft buses among Risk Classes **A**, **B**, and **C** for both *assigned* and *practiced* cases. These differences affected the Weibayes statistics.
5. Using Weibayes estimates for GSFC 2000 spacecraft bus operating times, current to 31 July 2024, one cannot conclude with statistical confidence there are differences between bus lifetimes for either the *assigned* or *practiced* cases, excepting there was a statistically significant difference between *assigned* Class **A** and Class **B** buses at 70% confidence. However, this difference was caused by the large numbers of assigned Class **B** buses (n_B= 28) compared to the few (n_A = 4) Class **A** buses.
6. Probability density function (*pdf*) distributions illustrated differences between GSFC 2000 spacecraft buses for Classes **A**, **B**, and **C** for both *assigned* and *practiced* cases. However, these differences were not statistically significant.
7. One cannot conclude there are differences between GSFC 2000 spacecraft bus Risk Class **B** and **C** lifetimes with statistical confidence.

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[2] Abbey Interrante, "NASA Retires Prolific Solar Observatory After 16 Years," NASA Press Release, available online from: https://www.nasa.gov/missions/rhessi/nasa-retires-prolific-solar-observatory-after-16-years/, posted 20 November 2018, accessed 09 August 2024.
Note that there were no GSFC C300 SOARS anomaly records indicating issues with the spacecraft's communication receivers among the 31 RHESSI records. Also, the RHESSI Telecomm Subsystem had two separate receivers: Fore and Aft.

[3] Wikipedia article, "NOAA-16;'Anomaly, Decommissioning and Breakup' ", Wikipedia, The Free Encyclopedia, last revision 16 May 2024, accessed 10 September 2024.

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[7] NASA Procedural Requirement, "Risk Classification for NASA Payloads," NPR 8705.4A, NASA Office of Safety and Mission Assurance, NASA Headquarters, Washington, D.C., 29 April 2021, 28 pp.
Note: Previous versions of this document would have been applicable for missions selected before 2021.

[8] GEDI Ecosystem Lidar, Mission Status, "Return of the GEDI," University of Maryland, College Park, Maryland, https://gedi.umd.edu/category/mission-status/, uploaded 22 April 2024, accessed 22 August 2024.

Appendix I. GSFC Spacecraft Missions Launched 2000 and Beyond

Mission	Risk Class	Launch Year	Mission Reqd Life (MRL, y)	Launch Date	EOL Date	Lifetime (days)	Life-time (y)	EOL Cause, Notes
EO-1	C	2000	1	2000-11-21	2017-03-30	5973	16.4	Decommissioned; fuel depletion
GOES-11(L)	A	2000	*5 (10)*	2000-05-03	2011-12-06	4234	11.6	Decommissioned; outdated [1]
TDRS-8(H)	*A(B)*	2000	11	2000-06-30	*2024-07-31*	*8797*	*24.1*	Active
NOAA-16(L)	B	2000	2	2000-09-21	2014-06-09	5009	13.7	APT inop 15Nov2000; lost contact 06Jun2014 via "critical anomaly;" Decommisioned 09Jun2014 2014, broke up 25Nov2015
GOES-12(M)	A	2001	5	2001-07-23	2013-08-16	4407	12.1	Decommissioned 2013; leaky thrusters starting 2007, retired 2013
RHESSI	*C(D)*	2002	2	2002-02-05	2018-08-16	6036	16.5	"COMM issues; S/C turned off by PI decision, citing "ageing" receiver (though no SOARS record of any COMM anoms). [2]
TDRS-9(I)	*A(B)*	2002	11	2002-03-08	*2023-01-05*	*7608*	*20.8*	Decommissioned 05Jan2023. 2023: low fuel, at launch, had a valve issue, took 6 months to get to GEO
Aqua	A	2002	6	2002-05-02	*2024-07-31*	*8126*	*22.2*	Active. AMSU-E: lubricant depletion beginning 2007, turned off 03Dec2015; AMSU-A1: 3 ch's lost as of Aug2017; AMSU-A2: power subsys f. 24Sep2016, ch's 1&2 inop; CERES: SW band module 4 ch f. 30Mar2005, other 2 ch's opnl; HSB: Scan motor f. 05Feb2003; MODIS: Some SW visible band ch's degraded 2017.
NOAA-17(M)	B	2002	2	2002-06-24	2013-04-10	3943	10.8	AMSU-A1 scan motors f. 28Oct2003; AAMSU-B LOsc f. 16Dec2009 (Chs18,19,20); AVHRR scan motor f. 15Oct2010. SC: STX3(COMM) f. 28Apr2003 (1:4); EPS Solar Array Shunts A&B dgrd'd 07Jan2012; Decommisioned in 10Apr2013, broke up10Mar2021
TDRS-10(J)	*A(B)*	2002	11	2002-12-02	*2024-07-31*	*7912*	*21.7*	Active
ICESat	*B(C)*	2003	3	2003-01-13	2010-08-14	2770	7.6	Sci. Deactivated 25Feb2010. Bus tuned off 14Aug2010. Laser TX#1 f. 29 Mar 2003. GLAS instr (Laser TX#2&##) opr'd intermittently (~15 mo.) for remainder of mission; Last Laser TX f. 11Oct2009.
Aura	*A(B)*	2004	6	2004-07-15	*2024-07-31*	*7321*	*20.0*	Active. Bus: Solar array (SA) conn. anom 12Jan2005; 1/2 of 1 SA (11 total) f. - MMOD; S&DH FMU/SSR anom 04Dec2007, rcrg Jan2017; SA ARE anom 12Mar2010 (MMOD) & 24Apr2013. INSTR: TES dgrd'd, decomm'd 31Jan2018; HIRDLS chopper motor f. 17Mar2008; MLS Ch13 dgrd'd (aging) Feb2005, dactv'd, Ch12 f. 06Aug2013; OMI 2007 dgrd'd ("row anom"). [3]
Swift	C	2004	2	2004-11-20	*2024-07-31*	*7193*	*19.7*	Active. Bus: Gyro issue, ops wkard to 2-gyro opns, no SOAR record. INSTR: XRT thermoelectric cooler (TEC) power supply f. 04Dec2004, ops workaround;
NOAA-18(N)	B	2005	2	2005-05-20	*2024-07-31*	*7012*	*19.2*	Active.
ST-5 (3 S/C)	C	2006	0.25	2006-03-22	2006-06-30	100	0.27	3 microsats; tech. demonstration completed
GOES-13(N)	*A(B)*	2006	10	2006-05-24	*2024-07-31*	*6643*	*18.2*	New bus BS-601; G-13E to Dec2017; EWS-G1 (USAF/USSF) active Sep2020-Oct2023. SXI damaged by solar flare Dec2006; MMOD hit 22May2013; Sounder anom. 20Nov2015, all 18 IR Chs affected.
Fermi (GLAST)	C	2008	5	2008-06-11	*2024-07-31*	*5894*	*16.1*	Active. Bus: Solar Array Drive f. 16Mar2018, cause undetermined.
NOAA-19(N')	B	2009	2	2009-02-06	*2024-07-31*	*5654*	*15.5*	Active.
LRO	C	2009	3	2009-06-18	*2024-07-31*	*5522*	*15.1*	Active. INSTR: LCROSS mission complt'd 09Oct 2009; MinRF TX f. 04Jan2011;LRO MIMU dgrd'd, turned off Spring2018 (no SOARS record), FSW developoed to use Star Tracker).
GOES-14(O)	*A(B)*	2009	10	2009-06-20	*2024-07-31*	*5520*	*15.1*	To storage 29Feb2020; replaced, is spare
SDO	B	2010	5	2010-02-10	*2024-07-31*	*5285*	*14.5*	Active.
GOES-15(P)	*A(B)*	2010	10	2010-03-04	*2024-07-31*	*5263*	*14.4*	Deactivated 02Mar2020, storage; moved W, to USSF EWS-G2 22Sep2023

A(B) , *B(C)* , and *C(D)* indicate *Practiced (Assigned)* Risk Classes for those that are different.

Itallicised Mission Required Lifetimes are corrected lifetimes.

Lifetime cells colour coding:

⬜	⬜	Completed
⬜	▨	Completed, discounted
🟩	▨	Operating, discounted
🟩	🟩	Operating, at > mission required lifetime
🟩	🟩	Operating, at < mission required lifetime

Appendix I. GSFC Spacecraft Missions Launched 2000 and Beyond, cont'd.

Mission	Risk Class	Launch Year	Mission Rqd Life (MRL, y)	Launch Date	EOL Date	Lifetime (days)	Life-time (y)	EOL Cause, Notes
Glory	C	2011	3	2011-03-04	-			launch failure
NPP-Suomi	B	2011	5	2011-10-28	*2024-07-31*	*4660*	*12.8*	Active.
TDRS-11(K)	*A(B)*	2013	15	2013-01-21	*2024-07-31*	*4209*	*11.5*	Active.
LandSat-8	B	2013	5	2013-02-11	*2024-07-31*	*4188*	*11.5*	Active. INSTR: TIRS SSM-A Encodeer anom 19Dec2014, SSM-B Encoder 03Nov2015m Apr2016: algorithm developed to resolve SSM anoms.
MAVEN	B	2013	2	2013-11-18	*2024-07-31*	*3908*	*10.7*	Active. Bus: IMU f's: #1 03Nov2017, #2 Feb2022 (no SOARS record)
TDRS-12(L)	*A(B)*	2014	15	2014-01-24	*2024-07-31*	*3841*	*10.5*	Active.
GPM	B	2014	3	2014-02-28	*2024-07-31*	*3806*	*10.4*	Active. BUS: Shorted SA cell 12Sep2017; Coarse Sun Senore CSS11B f.; RWA#2 bearing f. 30May2019;
SMAP	C	2015	3	2015-01-31	*2024-07-31*	*3469*	*9.5*	Active. INSTR: Power supply for radar transmitter f. 07Jul2015, SEGR in the SAA; radiometer continues to operate.
DSCOVR	*C(D)*	2015	*5*	2015-02-11	*2024-07-31*	*3458*	*9.5*	Active. BUS: MIMU f. 27Jun2019, FSW patch for Star Tracker only opns.
MMS (4 S/C)	C	2015	*2.4*	2015-03-13	*2024-07-31*	*3428*	*9.4*	Active. 1 DTU startracker on 1 SC died in 2019
OSIRIS-REx	B	2016	7	2016-09-08	*2024-07-31*	*2883*	*7.9*	Active.
GOES-16(R)	*A(B)*	2016	15	2016-11-19	*2024-07-31*	*2811*	*7.7*	New bus: LM A2100A; G-16E opnl 18Dec2017
NICER	D	2017	1.5	2017-06-03	*2024-07-31*	*2615*	*7.2*	Active. ISS hosted.
TDRS-13(M)	*A(B)*	2017	15	2017-08-18	*2024-07-31*	*2539*	*7.0*	Active.
JPSS-1/NOAA-20	B	2017	7	2017-11-16	*2024-07-31*	*2449*	*6.7*	Active.
GOES-17(S)	*A(B)*	2018	15	2018-03-01	*2018-11-13*	*257*	*0.7*	Now G-17W; INSTR: ABI LHP issue 23May2018; to Standby 13Nov2018
TSIS	C	2017	5	2018-03-14	*2024-07-31*	*2331*	*6.4*	Active. Beginning date is opnl start date on ISS, not LaunchDate.
ICESat-2	C	2018	3	2018-09-15	*2024-07-31*	*2146*	*5.9*	Active. BUS: 26Jun2019 & 04Apr2022, SADA potentiometer dgrdn caused anomalous SADA position, Signif Mission Imact
GEDI	C	2018	2	2019-03-25	2023-03-17	1453	4.0	Deactv'd, demounted for another instr, to ISS storage. Reinstalled 22 April 2024; no update on opnl status.
Solar Orbiter	C	2020	7	2020-02-10	*2024-07-31*	*1633*	*4.5*	Active. ESA S/C; SoloHI Instr/NASA/NRL; no SOARS records
LandSat-9	B	2021	*15*	2021-09-27	*2024-07-31*	*1038*	*2.8*	Active. INSTR: TIRS-2 upgraded to Class B, stray light and SSM problems fixed.
Lucy	B	2021	12	2021-10-16	*2024-07-31*	*1019*	*2.8*	Active. BUS: Solar array deployment problems 16Oct2021, 05Aug 2022 SA 353-357 degrees open, unlatched, 04Dec2022 no further SA work.
LCRD	D	2022	2	2022-06-28	*2024-07-31*	*764*	*2.1*	Active. Payload ONLY. Late deliveries and cost overruns suggest > Class D implementation.[4] Used on-orbit opnl initiation date [7].
JWST	A	2021	*5(7)*	2021-12-25	*2024-07-31*	*949*	*2.6*	Active. [5]
GOES-18(T)	*A(B)*	2022	15	2022-03-01	*2024-07-31*	*883*	*2.4*	Now G-18W
JPSS-2/NOAA-21	B	2022	7	2022-11-10	*2024-07-31*	*629*	*1.7*	Active. BUS: Primary Ka transmitter died in 2023, No SOARS record
PACE	C	2024	3	2024-02-04	*2024-07-31*	*178*	*0.5*	Active. [6]
GOES-19(U)	*A(B)*	2024	15	2024-06-25	*2024-07-31*	*36*	*0.1*	Commissioning, as of 31Jul2024

A(B) , *B(C)* , and *C(D)* indicate *Practiced (Assigned)* Risk Classes for those that are different.

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Appendix II. Weibull reliabilities for GSFC 2000 population showing differences between Fisher-matrix and pivotal (Monte Carlo) lower 90% confidence bounds.

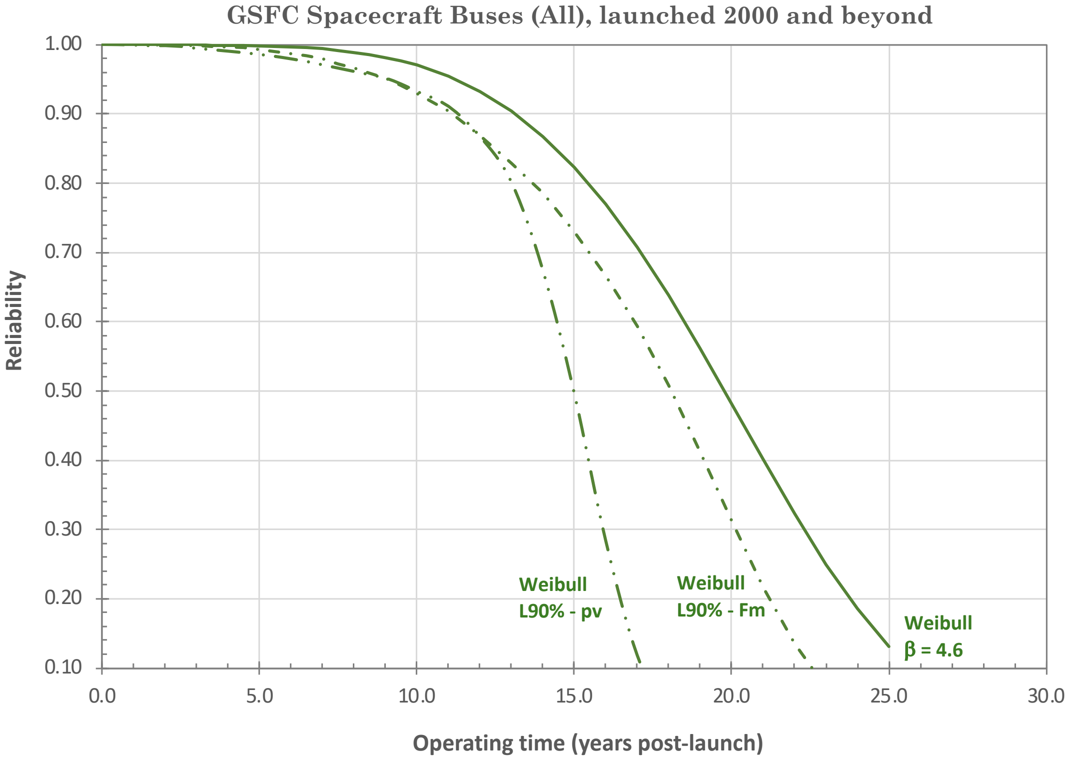

Figure A-II-1. Differences between Fisher matrix (Fm) and pivotal (Monte Carlo - pv) lower 90% Confidence bounds.