Large Satellite Bus Reliability

Overview

- NASA is proposing to build a small space station (i.e., a large satellite) in Cis-lunar orbit called the Lunar Orbital Platform-Gateway (LOP-G), formerly called Deep Space Gateway (DSG)
- A satellite bus is composed of the satellite spacecraft infrastructure (minus the payload) and generally includes power, propulsion, avionics, and guidance, navigation and control
- At the heart of the DSG is the Power and Propulsion Element (PPE) which is conceptually similar to previously designed and operated satellite buses
- In November of 2017, five companies were awarded contracts by NASA to research PPE designs
- In order to better understand the reliability of large satellite buses which may be the starting point of the PPE, NASA used Weibull analysis to evaluate spacecraft with similar masses and design life to the PPE
- Additionally, a subset of the large satellites that were manufactured by any one of the five companies was also evaluated
- The goal is to establish a ballpark estimate (i.e., a lower bound) for the Gateway PPE reliability

Seradata SpaceTrak Database

- Initially developed to support insurance of satellite launches
  - Data is gathered from public and private sources

- Some of the data SpaceTrak provides
  - Event histories and lifecycle for all spacecraft since Sputnik in 1957
  - All orbital launch attempts, successes, and failures
  - Satellite mission, sector, orbit, age, status, anomalies, and capacity lost

- Several papers on Satellite reliability have been published utilizing SpaceTrak Database
  - "Satellite Reliability: Statistical Data Analysis and Modeling" Jean-Francois Castet, Joseph H. Saleh September 2009
    - Overall Reliability: 1 year - 0.97 (1:33), 15 years – 0.899 (1:10)
  - "Spacecraft electrical power subsystem: Failure behavior, reliability, and multi-state failure analyses" So Young Kim, Jean-Francois Castet, Joseph H. Saleh, October 2011
  - "Spacecraft attitude control subsystem: Reliability, multi-state analyses, and comparative failure behavior in LEO and GEO" Jessica K. Wayer, Jean-Francois Castet, and Joseph H. Saleh, December 2012
  - "Electric propulsion reliability: Statistical analysis of on-orbit anomalies and comparative analysis of electric versus chemical propulsion failure rates" Joseph H. Saleh, Fan Geng, Michelle Ku, Mitchel L. R. Walker II, December 2016

Seradata SpaceTrak Database—Continued

To get data representative of Gateway, the following filters were used:

- Operational life: 15 years
- Mass: At least 2,500 kg

Seradata SpaceTrak Database—Continued

This table shows satellite bus operating times with an operational design life of 15 years and mass > 2,500 kg. Failures are BOLD.

Operational Time (in years)												
0.003	0.67	1.80	2.79	3.95	5.14	6.29	7.89	**9.21**	**10.79**	13.55	15.98	18.67
0.03	0.76	1.81	2.82	3.96	5.25	6.35	7.99	9.27	10.94	**13.59**	16.01	19.07
0.05	0.76	1.84	2.89	4.07	5.30	6.42	7.99	9.35	11.03	14.14	16.43	19.23
0.10	0.80	1.90	2.93	4.14	5.36	6.50	8.06	9.37	11.06	14.29	16.52	19.48
0.11	0.81	1.94	2.95	4.22	5.37	6.50	8.06	9.37	11.10	**14.30**	16.53	19.96
0.13	0.87	1.98	3.08	4.32	5.47	**6.57**	8.13	**9.41**	11.25	14.45	16.62	19.97
0.13	0.91	1.99	3.09	4.33	5.48	6.58	8.17	9.44	11.28	**14.51**	16.84	20.22
0.14	0.91	2.02	3.09	4.46	5.51	6.58	8.20	9.44	11.30	14.53	17.01	20.24
0.18	0.92	2.04	3.12	4.52	5.51	**6.65**	8.22	9.45	11.42	**14.57**	17.06	20.47
0.25	0.99	2.09	3.14	4.55	5.51	6.89	8.25	9.50	11.48	14.61	17.08	20.50
0.25	1.04	2.09	3.17	4.59	5.57	6.89	8.25	9.59	11.59	**14.69**	17.13	20.81
0.25	1.12	2.13	3.19	4.65	5.64	6.90	8.27	9.59	11.70	**14.94**	17.14	21.20
0.37	1.12	2.13	3.19	4.78	5.65	6.98	8.39	9.60	11.70	**14.97**	17.19	21.21
0.39	1.23	2.13	3.20	4.78	5.76	7.01	8.39	9.68	11.76	15.05	17.32	21.62
0.39	1.26	2.18	3.29	4.80	5.92	7.10	8.51	10.01	12.20	15.18	17.34	23.06
0.40	1.40	2.21	3.48	4.92	5.98	7.21	**8.58**	10.02	12.28	15.23	17.36	23.54
0.42	1.42	2.22	3.66	4.92	6.08	7.29	8.63	10.02	12.41	15.34	17.36	27.59
0.44	1.42	2.25	3.66	4.95	6.12	7.29	8.73	10.13	12.50	15.38	17.44	
0.46	1.44	2.35	3.76	4.96	6.12	7.36	8.77	10.37	12.72	15.44	17.92	
0.46	1.44	2.48	3.78	4.98	6.14	7.40	8.92	10.38	12.77	15.54	18.02	
0.51	1.48	2.48	3.78	4.99	6.15	7.46	8.92	**10.50**	**12.89**	15.59	**18.05**	
0.54	**1.50**	2.56	3.82	5.02	6.16	7.50	8.94	10.55	12.93	15.60	**18.15**	
0.54	1.53	2.56	3.87	5.02	6.16	7.57	9.04	10.55	13.10	15.73	18.16	
0.60	1.69	2.67	3.90	5.10	6.17	7.67	9.06	10.62	13.34	15.75	18.22	
0.64	1.71	**2.77**	3.91	5.14	6.27	**7.85**	9.17	10.70	**13.35**	15.83	18.43	

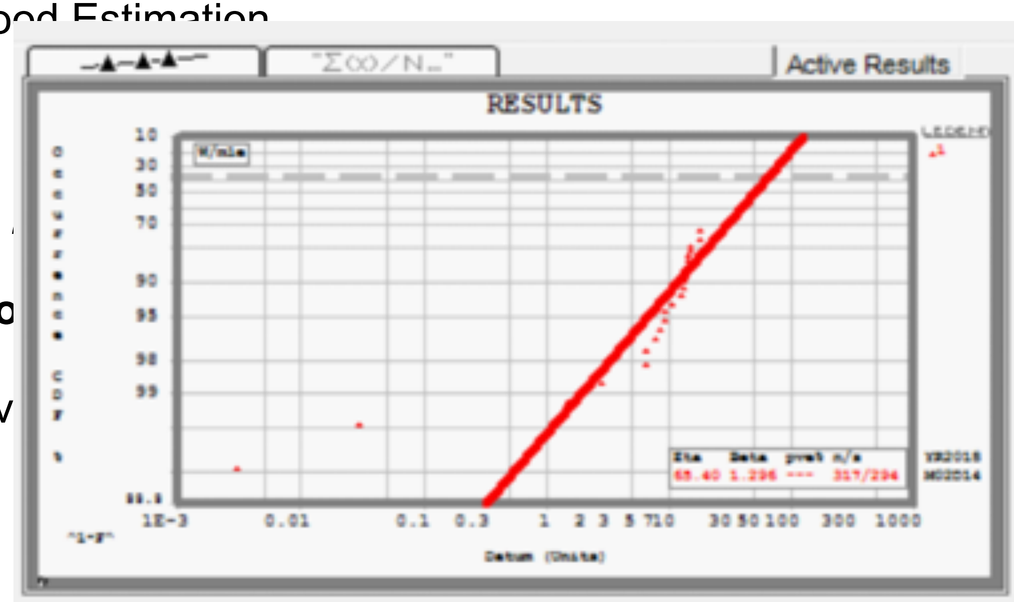
Large Satellite (>2,500kg) Reliability

The data was fed into SuperSmith Weibull and the parameters were calculated using Maximum Likeliho

Weibull Parameters:

***β* ≈ 1 indicates near co**

Predicted Reliability ov



Weibull analysis of 317 Spacecraft with operating times varying from 0.003 years to 28 years (~2500 total years on-orbit through November 17, 2017) and 23 failures with failure times varying from 0.003 years to 18 years

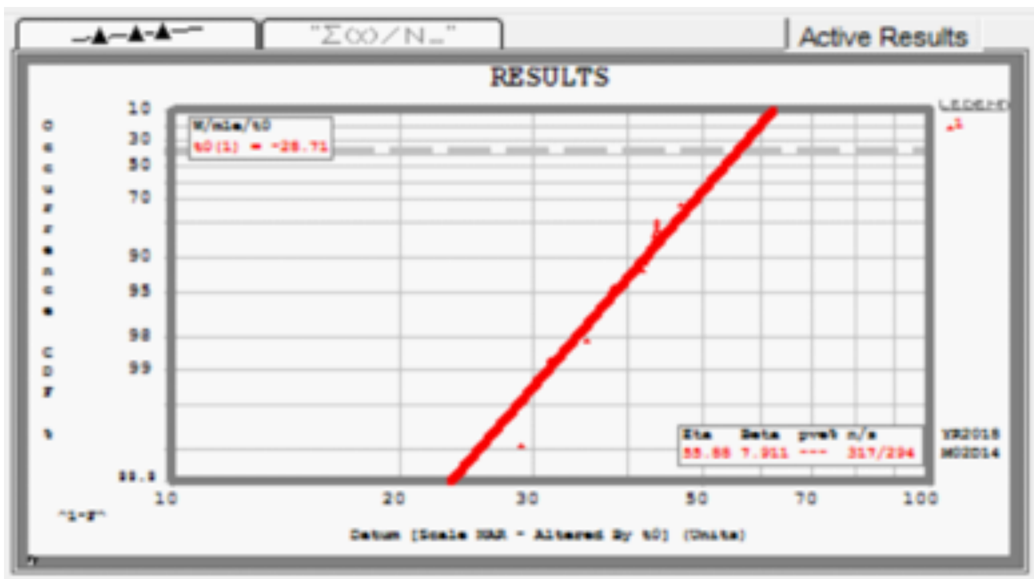
- Source: Seradata SpaceTrak as of November 17, 2017
- Spacecraft retirement prior to design life of 15 years were considered failures
- Spacecraft failures after retirement were considered if the spacecraft was retired due to the failure

Large Satellite Reliability
Three Parameter Weibull Analysis

The three parameter Weibull appears to give a better fit but does not significantly change the results.

Parameters: $\beta = 7.9$, $\eta = 56$, $t_0 = -29$

Predicted Reliability at 15 years = **0.87**



Specific Five Manufacturers

Specific Five Data Set

This is the same data set (15 years, mass > 2,500 kg) but only includes five selected manufacturers. Failures are BOLD.

Operational Time (in years)							
0.13	1.81	4.59	6.50	8.73	12.50	16.01	19.97
0.13	2.13	4.65	**6.57**	**9.21**	12.72	16.43	20.22
0.14	2.13	4.78	6.58	9.35	12.77	16.52	20.24
0.18	2.21	4.78	**6.65**	9.37	12.93	16.53	20.47
0.25	2.22	4.80	6.89	**9.41**	13.10	16.62	20.50
0.37	2.35	4.92	6.89	9.50	13.34	16.84	20.81
0.40	2.48	4.99	6.98	9.59	13.55	17.01	21.20
0.44	2.56	5.02	7.01	9.60	**13.59**	17.06	21.21
0.51	2.79	5.10	7.10	9.68	14.14	17.08	21.62
0.67	2.82	5.25	7.36	10.01	14.29	17.13	23.06
0.91	2.95	5.30	7.57	10.13	14.45	17.14	23.54
0.91	3.09	5.36	7.67	10.37	**14.51**	17.32	27.59
0.92	3.17	5.37	**7.85**	10.55	**14.57**	17.36	
0.99	3.19	5.47	7.89	**10.79**	14.61	17.44	
1.12	3.20	5.51	7.99	10.94	**14.69**	17.92	
1.23	3.29	5.51	8.06	11.06	**14.94**	18.02	
1.26	3.66	5.51	8.17	11.10	15.05	**18.05**	
1.40	3.78	5.65	8.20	11.28	15.34	**18.15**	
1.42	3.82	5.76	8.25	11.42	15.44	18.16	
1.42	3.87	5.98	8.25	11.48	15.54	18.22	
1.44	3.95	6.08	8.27	11.59	15.59	18.43	
1.48	3.96	6.12	8.39	11.70	15.60	18.67	
1.53	4.07	6.14	8.39	11.76	15.75	19.23	
1.69	4.22	6.16	8.51	12.28	15.83	19.48	
1.71	4.33	6.35	**8.58**	12.41	15.98	19.96	

Large Satellite (>2500kg) Reliability (Specific Bus Manufacturers)

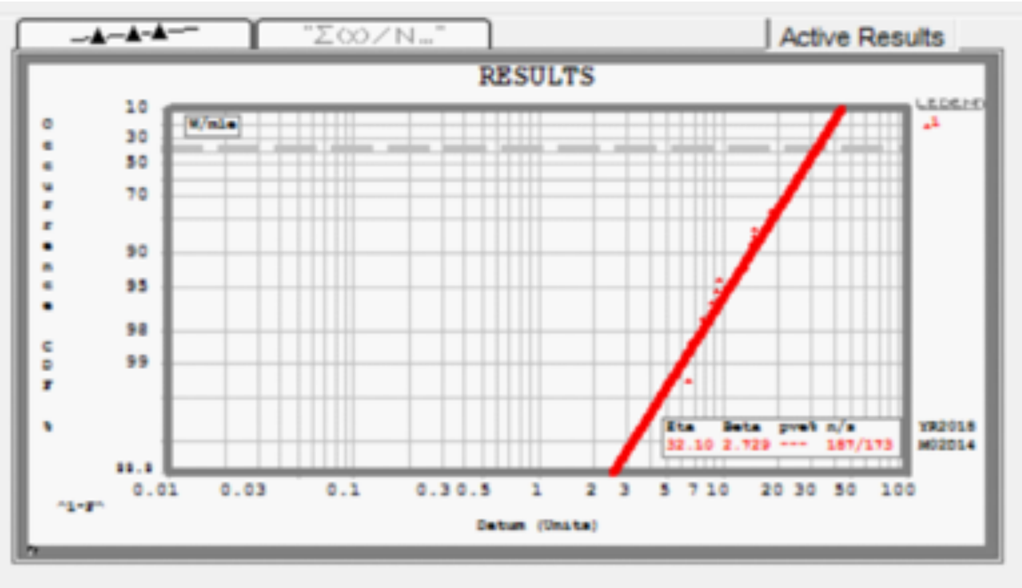
Specific Five Data Set

This is the same data set but only includes the five selected manufacturers.

Weibull Pa

Predicted Re

β > 1 indic



Weibull analysis of 187 Spacecraft with operating times varying from 0.1 years to 28 years (~1700 years on-orbit through November 17, 2017) and 14 failures with failure times varying from 6.6 years to 18 years

Source: Seradata SpaceTrak as of November 17, 2017

- Spacecraft retirement prior to design life of 15 years were considered failures
- Spacecraft failures after retirement were considered if the spacecraft was retired due to the failure

Summary

Analysis using SpaceTrak database as of November 17, 2017 indicates predicted reliability of large satellites (>2500kg) with design life of 15 years is about 0.86. Narrowing down to specific bus manufacturers increases predicted reliability to 0.88.

- Failure of solar arrays and ion propulsion systems were the cause of most of the failures used in the specific bus manufacturer reliability prediction

- Predicted reliability is consistent with expectation for a non-repairable complex system over 15 years