MISSION SENSOR RELIABILITY REQUIREMENTS
FOR
ADVANCED GOES SPACECRAFT

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1.0 INTRODUCTION

NOAA/NESDIS has specified 7-year operational lifetimes for follow-on GOES spacecraft (GOES Q and beyond). The primary sensors for these spacecraft are the Advanced Baseline Imager (ABI) and Advanced Baseline Sounder (ABS). Both sensors are mission critical: the spacecraft will be replaced if either fail. This report explains how reliability budgets for the ABI and ABS can be defined to meet the 7-year lifetime requirements for the satellite.

2.0 RELIABILITY MODELS

Reliability is the product of: 1) Random reliability and 2) wearout reliability.

The development of the random reliability model is based on detailed drawings of the satellite subsystems. The model accounts for the possibility of system breakdown due to piece-part failures which are characterized by constant failure rates (Ref. 1). A Weibull function is used to model random reliability for military and government satellites (Ref. 2). The two-parameter Weibull reliability function is defined as

$$R(t) = exp\text{-}(t/\alpha)^{\beta},\ t \geq 0$$

Two parameters, α and β, define the Weibull reliability function. α is a scale parameter with units of months or years, and is proportional to the MMD. Figure 1 shows Weibull distributions for different values of α. Larger α values indicate higher piece-part reliabilities.

β is a unitless parameter related to design robustness. A value of β equal to 1.0 is characteristic of single-string designs. β between 1.4 and 1.7 is typical for satellites (Figure 2).

The wearout reliability model accounts for depletion of expendables, wearout of mechanical parts, etc. Calibrating the wearout reliability model requires detailed knowledge of the possible wearout mechanisms-knowledge difficult to obtain in the early stages. The mean wearout time for military and government satellites is assumed to exceed the specified Design Life. Mechanical components are usually designed to wear out well beyond the Design Life.

Figure 3 shows how the product of a Weibull random reliability function and a Rayleigh wearout distribution results in the overall reliability function.

Bottom-up reliability calculations assume statistical independence, i.e., the likelihood of failure of one subsystem is not influenced by the likelihood of failure of other subsystems. Assuming statistical independence makes bottom-up reliability calculations tractable, but is not strictly valid. Many factors that cause failures such as stress due to launch loads, piece parts from the same manufacturing batch, thermal environments, and handling during integration introduce dependence among the subsystem failure likelihoods.

3.0 RELIABILITY SPECIFICATIONS

Mean Mission Duration (MMD) is the average life of the satellite (Figure 4), and is quantified by the area under the reliability function. Different reliability functions can result in the same MMD (Figure 5).

The Design Life (DL) specification should include the operational lifetime plus projected ground and on-orbit storage periods. Designers will select components that meet or exceed the DL, and so the DL specification is an important cost driver. The probability of achieving the DL also depends on shape of the applicable reliability function.

4.0 GOES Q BUS AND SENSOR RELIABILITY REQUIREMENTS

The bus should outlive the sensors in order to provide diagnostic information and perform post-mission maneuvers. Today's GEO buses have MMDs in the range of 10 to 15 years, so achieving high bus reliability is no problem.

Preliminary reliability budgets for the GOES Q bus and ABI and ABS sensors were determined using the following procedure.

First, the Design Life was specified as 10 years, a round number that is within 140-150% of the satellite's MMD and is typical of similar types of satellites (Ref. 3).

Next, the α and β values were adjusted to achieve an overall MMD of 7 years, assuming the spacecraft bus is the stronger link in the reliability chain and keeping the ratio of α and β "in family" compared to today's satellites. It was also assumed that the wearout reliabilities exactly coincide with the specified Design Life of 10 years, i.e., the random reliability model is sharply truncated at 10 years. A less conservative assumption would put the mean wearout reliability a year or two beyond the Design Life, and would count the additional expected life beyond the Design Life of 10 years. But since the characteristics of wearout reliability for the GOES sensors are unknown, and given the other approximations such as the unspecified shape of the random reliability curve (the α and β values) and the statistical independent assumption, truncating the reliability curve at the specified Design Life is a reasonable conservative approximation. *

Table 1 lists preliminary reliability budgets proposed for GOES. Figure 6 illustrates the corresponding reliability functions.

TABLE 1

	α	β	**Design Life**	**MMD**	**R (DL)**
Bus	451 mo	1.7	10 yr	9.6 yr	0.9
Sensors	178	1.7	10 yr	8.4	0.6
Platform	111	1.6	10	7.0	0.3**

5.0 SUMMARY

This report discusses how the 7-year MMD system reliability requirement for GOES Q and follow-on satellites can be flowed down to the bus and critical payloads. Judgment and experience are required to define GOES Q reliability budgets because the 7-year MMD requirement is not a complete reliability specification. The parameter set presented in Table I is not unique. Other combinations of values for Design Life and reliability at Design Life can result in the same satellite MMD. However, the values cannot vary drastically from the values chosen in this report and still meet NOAA's satellite MMD requirements. The selected parameters are a representative set that falls within the relatively narrow range of observation for today's satellite systems.

*The argument can also be made that operation beyond the Design Life of 10 years, while probable, should not be counted in the calculation of the average lifetime because the satellite will likely be replaced after 10 years of operation regardless of its operational status.

**Assumes the series combination of the reliabilities of the bus and two sensors:

$R (DL) = (0.9) (0.6) (0.6) = 0.32$.

6.0 REFERENCES

1. MIL-HDBK-2 1 7F (USAF), "Reliability Prediction of Electronic Equipment," December 1991.

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3. MIL-STD- 1 534B (USAF), "Reliability Program Requirements for Space and Launch Vehicles," 25 October 1988.

4. Dezelan, R. W., "NOAA's Current and Future GOES Systems: Availability Analysis," ATR-99(2331)-2, The Aerospace Corporation, April 1999.

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Figure 1. Weibull Reliability Functions – Variation of α.

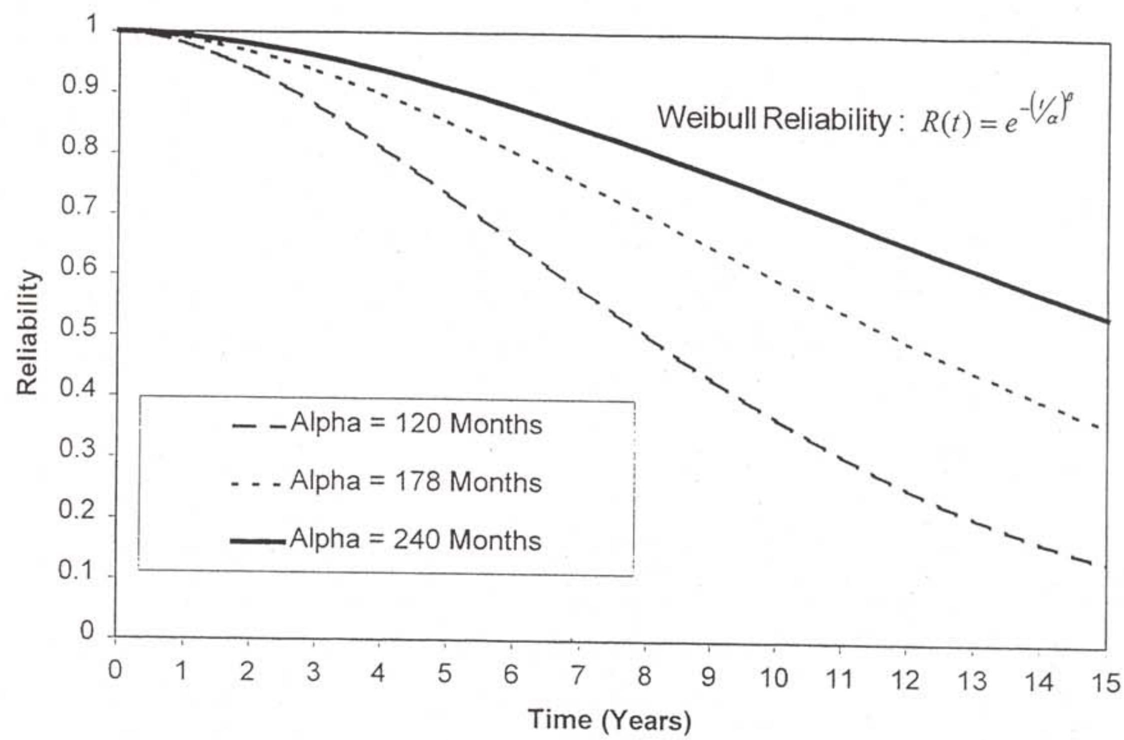

Figure 2. Weibull Reliability Functions – Variation of β.

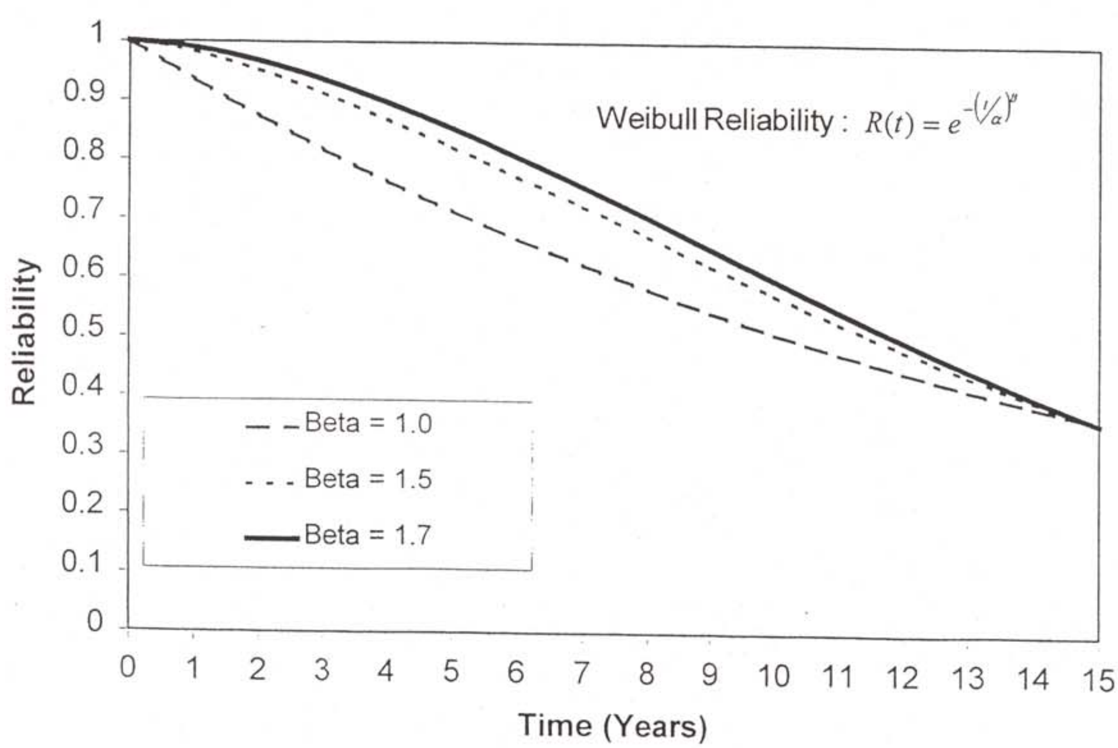

Figure 3. Rayleigh Wearout Distribution

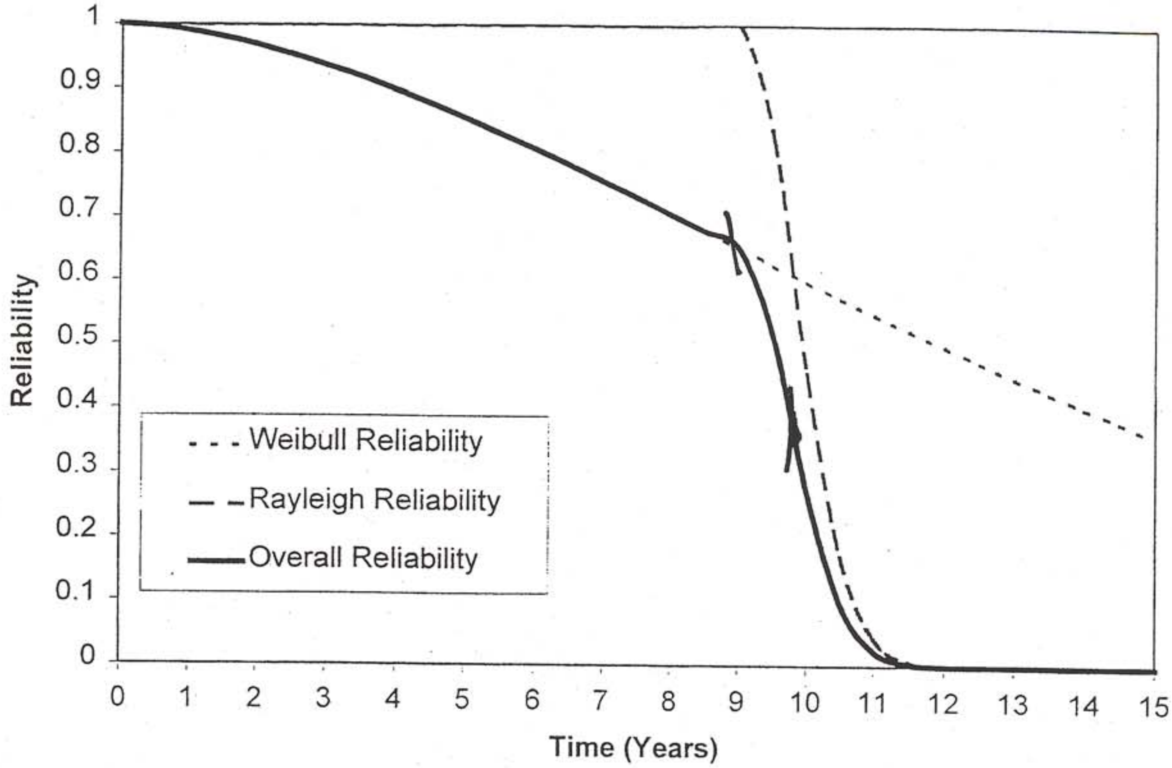

Figure 4: Mean Mission Duration

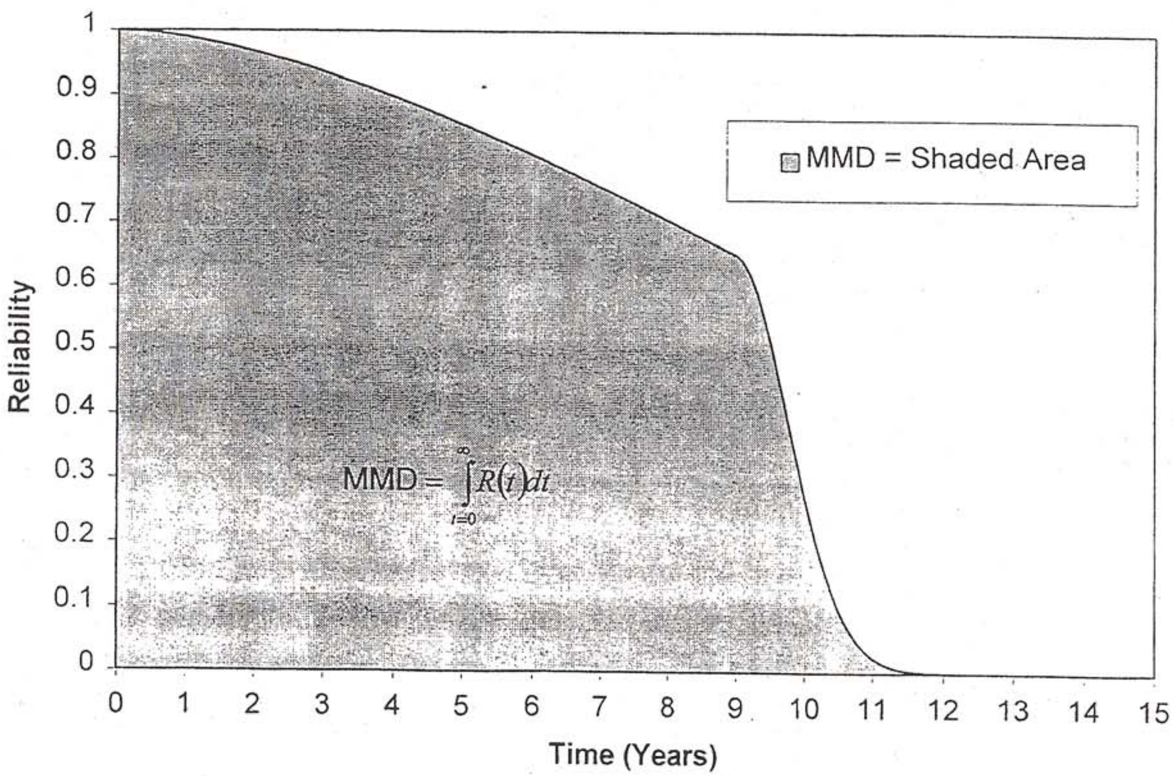

Figure 5. Different Reliability Functions With Same MMD

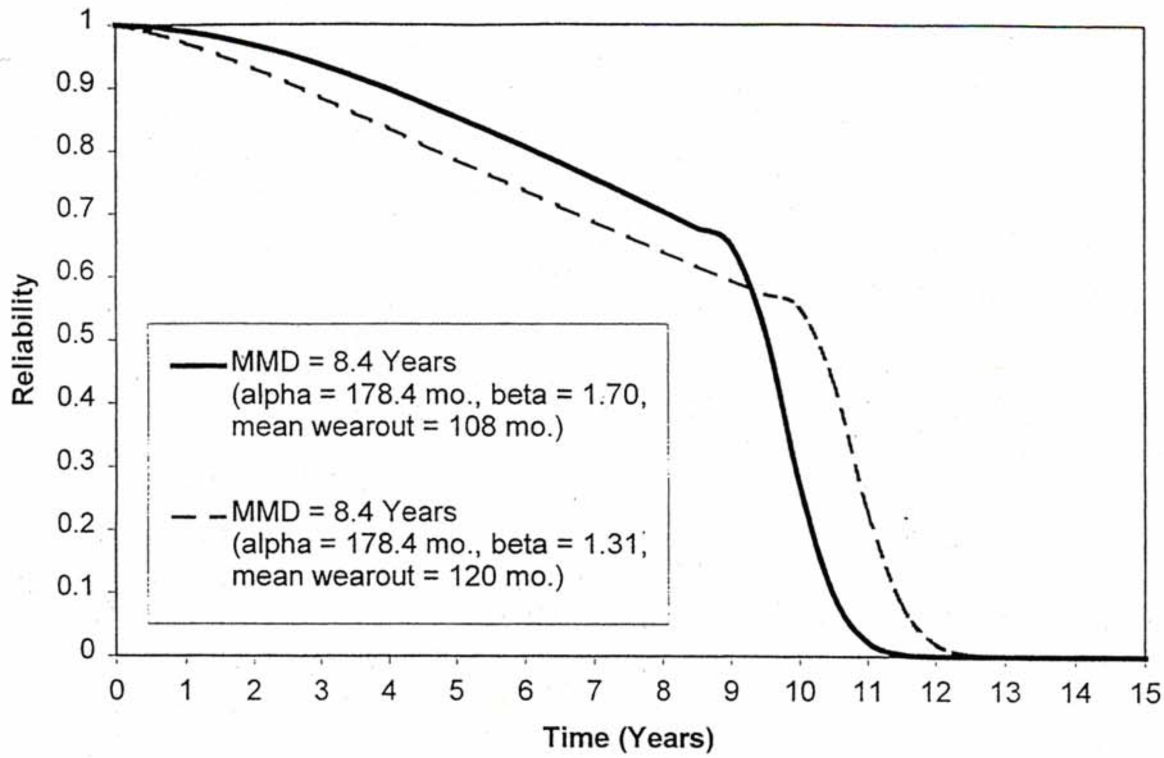

Figure 6. Recommended Weibull Reliability Function for GOES Q