ngVLA Electronics Memo #7

EVLA Subsystem MTBF Analysis

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Abstract

This is a continuation of array element reliability studies that focuses on examining the MTBF and reliability of the EVLA antennas. In this memo we examine the MTBF of the F306 X-band reciever, cryogenics cold heads and compressors, L302 synthesizers, and D30x Digital Transmission System (DTS) modules. These modules were picked as representative of various electro-mechanical assemblies within an antenna. From this analysis, Model 22 cold heads and cryogenic compressors have the lowest MTBFs at 6,100 hours and 5,800 hours, respectively. We also found that the L302 is the most reliable of the subsystems examined with an MTBF of 20,400 hours. This memo captures the first use of a Weibull 3-parameter distribution to best model failures of a system in the EVLA.

Contents

1 Objectives

The purpose of this analysis is to:

- Further examine the Mean Time Between Failure (MTBF) of a selection of subsystems within the EVLA antenna following the MTBF analysis done of an entire EVLA antenna (ngVLA Electronics Memo #6)

- Provide a reference for MTBF failure hour allocation across all ngVLA Electonics subsystem designs based on representative eletco-mechnical assemblies in the EVLA

2 Methods

2.1 Failure Data Used

For the F306 X-band receiver, the failure data used to calculate its MTBF was a compilation of all open, long-term, and closed work-orders captured in JIRA with the component designation of F306 X-band receiver and Stress Test X-band from April 1, 2018 to April 30, 2020. Each work-order with either component designation was assumed to be a failure of the receiver itself. The total number of X-band receivers for the EVLA is 30.

Similarly for all D30x modules discussed in this memo, the failure data used to calculate its MTBF was a compilation of all open, long-term, and closed work-orders captured in JIRA with the component designation of the respective Digital Transmission System (DTS) module from May 1, 2018 to April 30, 2020. Each work-order with either component designation was assumed to be a failure of the module itself. There are 32 of each D30x module.

The L302 synthesizer failure data was comprised of all MainSaver work-orders from May 8, 2006 to May, 22 2018. Every work-order assigned to the L302 module was assumed to be a failure of the module itself. There are 112 L302 modules.

Table 1: Recorded Failures

Subsystem	F306	D301	D302	D303	D304	L302
Number of Failures	28	54	36	54	32	579

For each subsystem based on their respective time periods as described

Lastly, cryogenics system failure data has been split into each type of cold head and overall compressor failures and preventative maintenance recorded in the Cryogenics Lab and from MainSaver work-orders for CY 2015. There are a total of 28 Model 22 cold heads, 168 Model 350 cold heads, 28 Model 1050 cold heads, and 84 cryogenic compressors.

Table 2: Recorded Cryogenics Failures

Subsystem	Model 22 Cold Head	Model 350 Cold Head	Model 1050 Cold Head	Compressor
Number of Failures	40	81	23	127

It should also be noted that a cryogenics compressor failure does not indicate that the compressor hardware itself needed to be repaired or replaced. Cryogenics compressor failures also capture failures in the helium lines or when a helium charge is necessary as a result of low supply pressure or a temperature increase detected at the 15K or 50K stage of a receiver.

2.2 Calculations

2.2.1 F306 and D30x Calculations

The MTBF calculations and reliability discussed in this memo for the F306 receiver and D30x modules were calculated using Relyence FRACAS and Weibull software. Relyence FRACAS has the ability to incorporate the time between each failure individually, instead of just examining the total number of failures over a given period of time, making the MTBF calculations more accurate. The FRACAS entries are then used in Weibull to plot the failures and then calculates the best distribution curve fit for the reliability of the given subsystem. Relyence Weibull curve fitting has proven to be very accurate when modeling failures in a previous Electronics Division memo regarding the failure rates of WIDAR Baseline Boards.

A rough estimate of the calculations done via Relyence can be found by using the equations described in Section 2.2.2.

2.2.2 L302 and Cryogenics Calculations

The calculations and reliability discussed in this memo for the L302 synthesizer, cryogenic cold heads, and cryogenic compressor are much more simplistic than what was done with Relyence for the X-band receiver and DTS modules. This simpler approach should only be implemented when it can be determined that there is ample data censoring present in the sample. For the L302, cryogenic cold heads, and cryogenic compressor there are left censored data in the samples. The exact time each failure occurred is unknown but the total number of failures between each sample's respective start and end date is known. Therefore we have assumed a relatively constant failure rate for these subsystems' calculations.

To calculate the mean per-module failure for subsystem with a known total number of modules:

$$N_{\text{subsystem}} = \frac{N_{\text{fail}}}{\#of modules}$$

$N_{\text{subsystem}}$ can be used with the total number of hours of operation within the time-frame of reported failures to calculate the subsystem's failure rate parameter, λ.

$$\lambda_{\text{subsystem}} = \frac{N_{\text{subsystem}}}{hours}$$

From this, the MTBF of a subsystem can be calculated by:

$$MTBF_{\text{subsystem}} = \frac{1}{\lambda_{\text{subsystem}}}$$

The failure rate parameter can also be used to calculate the reliability, assuming and exponential model, by:

$$R_{\text{subsystem}}(t) = e^{-\lambda_{\text{subsystem}} t}$$

3 Cryogenics, Cold Heads and Compressors

3.1 Model 22 Cold Head

A Model 22 cold head has an MTBF of 6,100 hours. The reliability for a Model 22 cold head is

$$R_{\text{Model 22}}(t) = e^{-1.60\times10^{-4}t}$$

Plotting the Model 22 cold head reliability for 50,000 hours yields the curve shown in Figure 1. The Reliability Curve of the Model 22 cold head illustrates:

- 10% of Model 22 cold heads will have failed at approximately 650 hours
- 50% of Model 22 cold heads will have failed at approximately 4,250 hours
- 90% of Model 22 cold heads will have failed at approximately 14,100 hours

3.2 Model 350 Cold Head

A Model 350 cold head has an MTBF of 18,200 hours. The reliability for a Model 350 cold head is

$$R_{\text{Model 350}}(t) = e^{-5.50\times10^{-5}t}$$

Plotting the Model 350 cold head reliability for 100,000 hours yields the curve shown in Figure 2. The Reliability Curve of the Model 350 cold head shows:

- 10% of Model 350 cold heads will have failed at approximately 1,900 hours
- 50% of Model 350 cold heads will have failed at approximately 12,600 hours
- 90% of Model 350 cold heads will have failed at approximately 41,850 hours

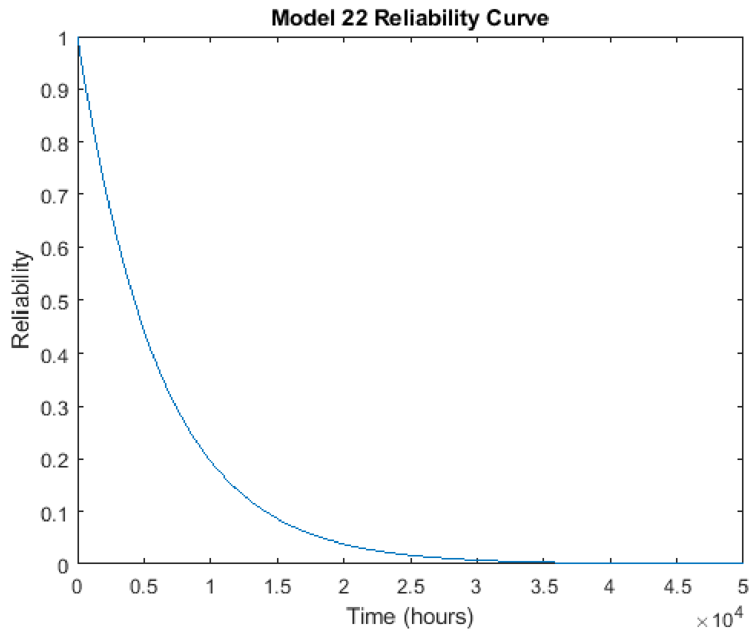

Figure 1: Model 22 cold head reliability curve

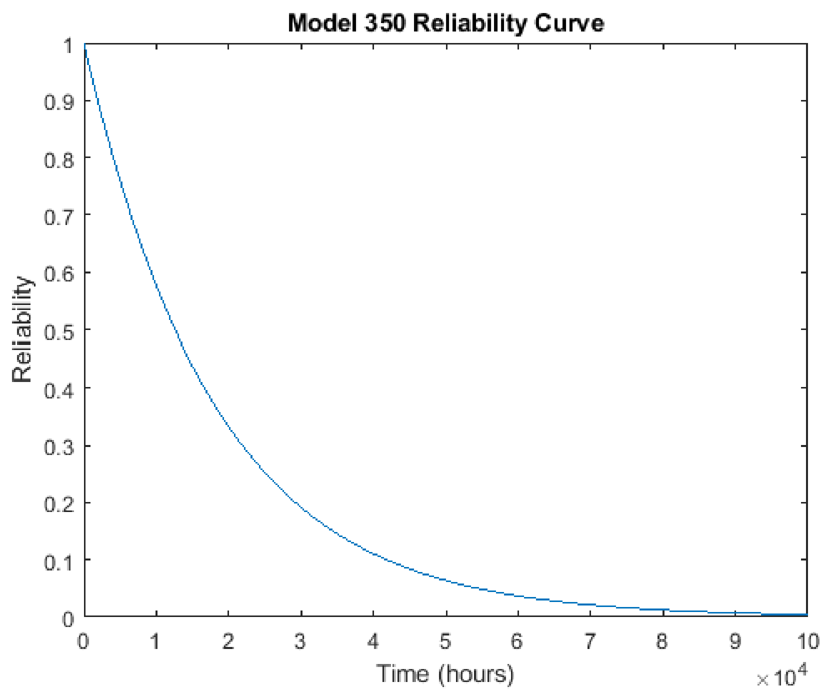

Figure 2: Model 350 cold head reliability curve

3.3 Model 1050 Cold Head

A Model 1050 cold head has an MTBF of 10,700 hours.The reliability for a Model 1050 cold head is

$$R_{\text{Model 1050}}(t) = e^{-9.40\times10^{-5}t}$$

Plotting the Model 1050 cold head reliability for 80,000 hours yields the curve shown in Figure 3. By

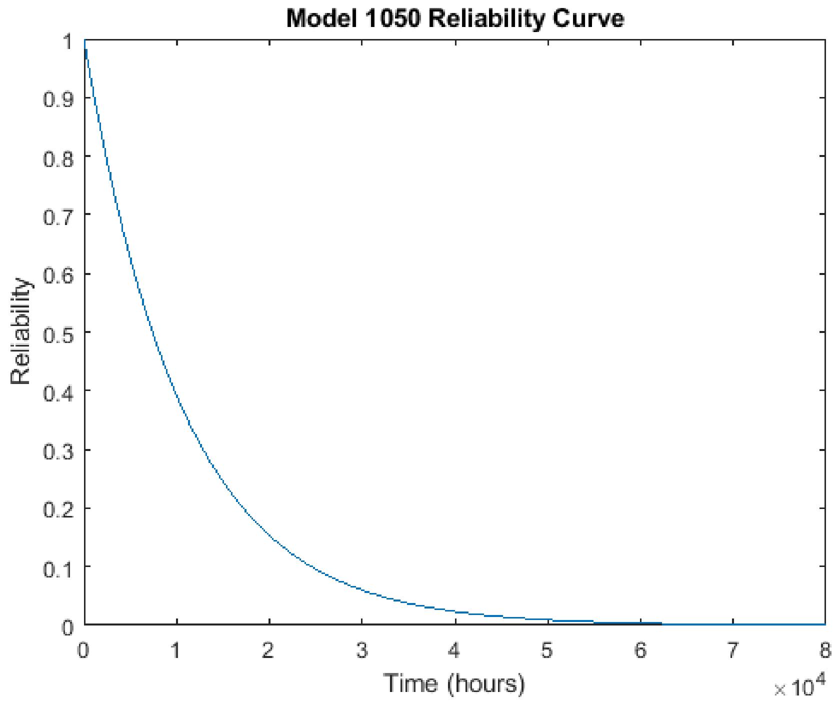

Figure 3: Model 1050 cold head reliability curve

examining the Reliability Curve of the Model 1050 cold head it can be seen that:

- 10% of Model 1050 cold heads will have failed at approximately 1,100 hours
- 50% of Model 1050 cold heads will have failed at approximately 7,400 hours
- 90% of Model 1050 cold heads will have failed at approximately 24,550 hours

3.4 Cryogenic Compressor

A cryogenic compressor has an MTBF of 5,800 hours.The reliability for a cryogenic compressor is

$$R_{\text{Compressor}}(t) = e^{-1.70\times10^{-4}t}$$

Plotting the cryogenic compressor reliability for 50,000 hours yields the curve shown in Figure 4. The Reliability Curve of cryogenic compressors shows:

- 10% of cryogenic compressors will have failed at approximately 600 hours
- 50% of cryogenic compressors will have failed at approximately 4,000 hours
- 90% of cryogenic compressors will have failed at approximately 13,300 hours

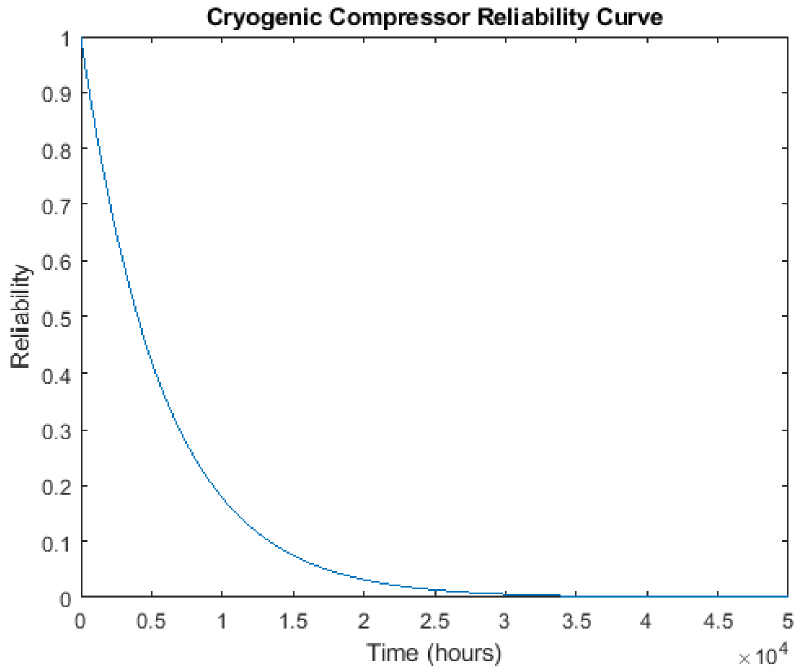

Figure 4: Cryogenic compressor reliability curve

4 F306, X-band Receiver

An F306 X-band receiver has an MTBF of 10,000 hours. The reliability for a F306 X-band receiver is

$$R_{\mathrm{F306}}(t) = e^{-9.90\times 10^{-5} t}$$

Plotting the F306 reliability in Relyence yields the curve shown in Figure 5.

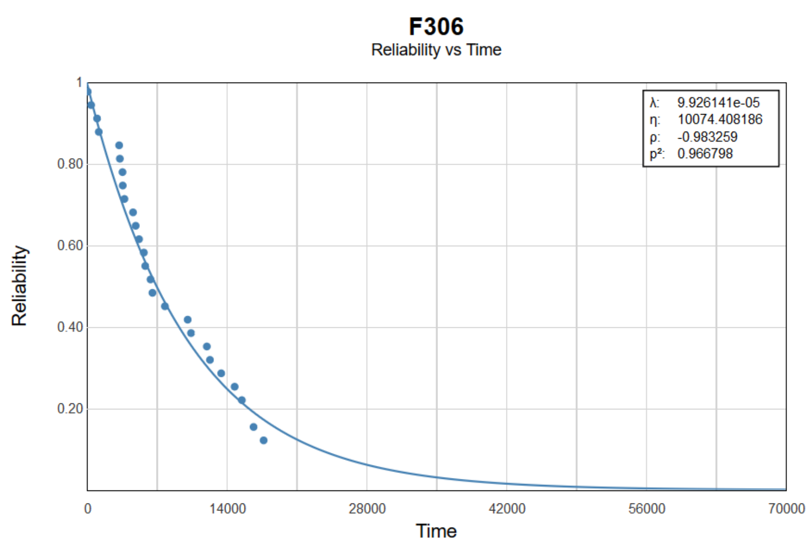

Figure 5: F306 Reliability Curve

The Reliability Curve of F306 receivers shows:

- 10% of F306 receivers will have failed at approximately 1,050 hours
- 50% of F306 receivers will have failed at approximately 7,000 hours
- 90% of F306 receivers will have failed at approximately 23,250 hours

5 L302, Synthesizer

The MTBF for an L302 module is 20,400 hours. The reliability for an L302 module is

$$R_{\text{L302}}(t) = e^{-4.90\times10^{-5}t}$$

Plotting the L302 Reliability for 100,000 hours yields the curve shown in Figure 6.

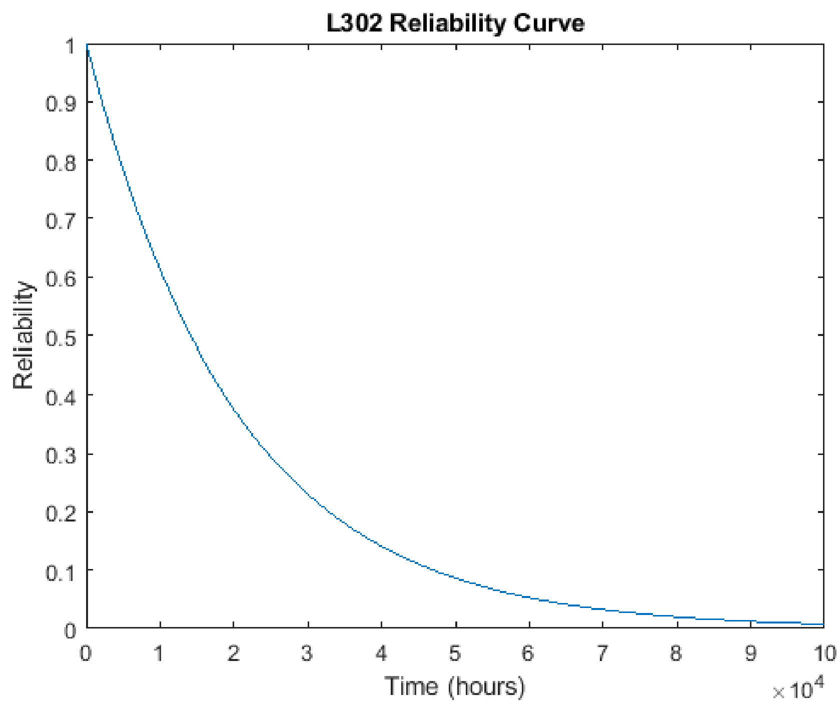

Figure 6: L302 Reliability Curve

Figure 6 shows:

- 10% of L302 modules will have failed at approximately 2,150 hours
- 50% of L302 modules will have failed at approximately 14,150 hours
- 90% of L302 modules will have failed at approximately 47,000 hours

6 D301, D302, D303, and D304, DTS Modules

During initial investigations of D30x module failure rates it became apparent that a decaying exponential would not model the failures accurately. When an exponential 1-parameter distribution was used to model each D30x module data in Relyence Weibull, the confidence residual varied from 0.91 to 0.81 whereas a Weibull 3-parameter distribution was higher than 0.98 for each DTS module.

A Weibull 3-parameter curve uses the variable β, the shape parameter or the Weibull slope, to describe the rate of failure. β determines the overall shape of the distribution and can be easily broken down into the three areas of the reliability bathtub curve.

- β is less than 1, it indicates that the failure rate decreases with time. This is the same concept as early-life failures.
- β is approximately equal to 1, failures occur at a fairly consistent rate. This indicates that the system is in the steady-state functionality part of its deployment cycle.
- β is greater than 1, the failure rate of the system is increasing with time. This is also known as end-of-life failure rate.

By focusing on the value of β calculated by Relyence Weibull, a Weibull 3-parameter distribution accurately models the failure rates and provides similar insights to our regularly used exponential 1-parameter distribution fitting to calculate reliability and MTBF. When examining the graphs below, please reference the solid line distribution. The dashed line distribution is the same, but shifted to based on the location parameter, γ, which provides an estimate of the earliest time a failure may be observed.

A D301 module has an MTBF of 11,000 hours and a β of 5.16. The D301 reliability curve is shown in Figure 7.

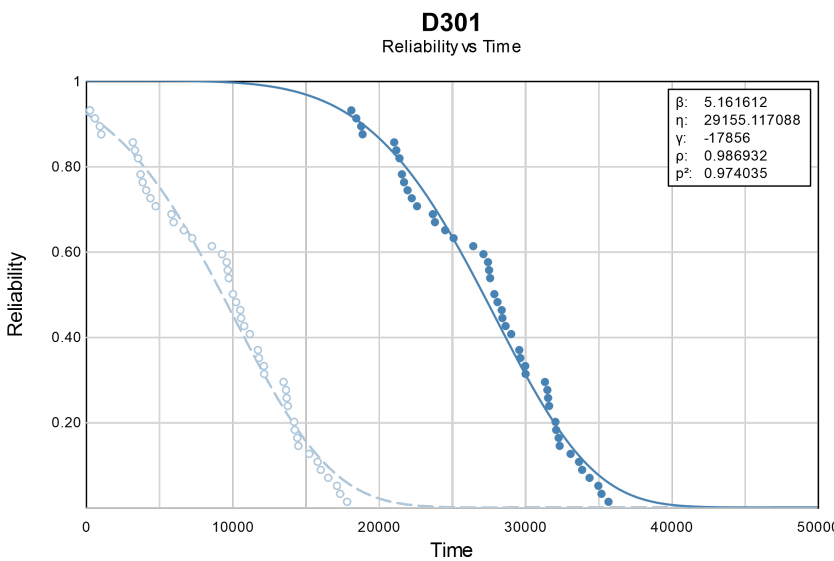

Figure 7: D301 Reliability Curve. The solid line distribution is the Weibull 3-parameter distribution. The dashed line is the same distribution as the solid line, but shifted based on the location parameter, γ, which provides an estimate of the earliest time a failure may be observed.

A D302 module has an MTBF of 16,700 hours and a β of 4.09. The D302 reliability curve is shown in Figure 8.

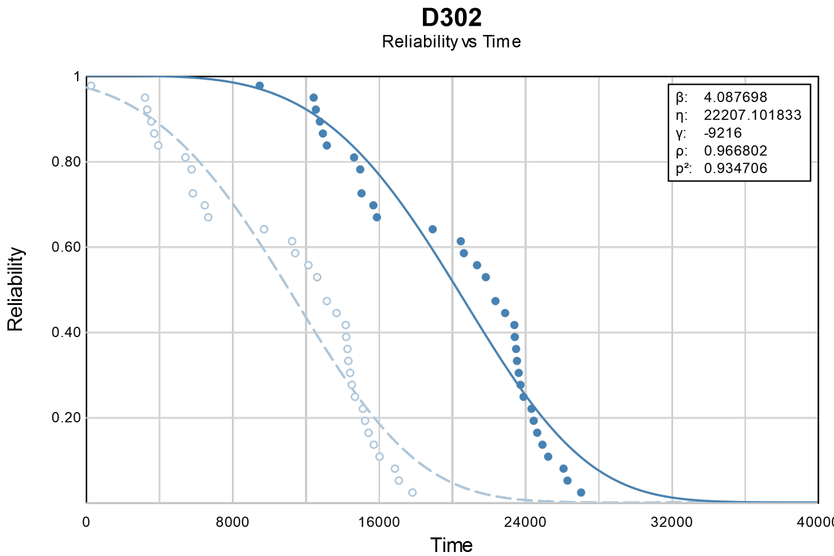

Figure 8: D302 Reliability Curve. The solid line distribution is the Weibull 3-parameter distribution. The dashed line is the same distribution as the solid line, but shifted based on the location parameter, γ, which provides an estimate of the earliest time a failure may be observed.

A D303 module has an MTBF of 11,000 hours and a β of 4.07. The D303 reliability curve is shown in Figure 9.

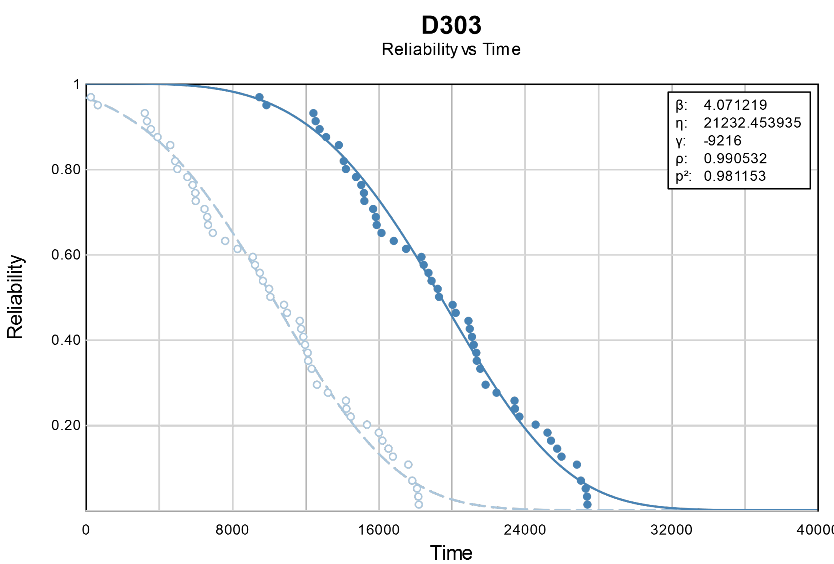

Figure 9: D303 Reliability Curve. The solid line distribution is the Weibull 3-parameter distribution. The dashed line is the same distribution as the solid line, but shifted based on the location parameter, γ, which provides an estimate of the earliest time a failure may be observed.

A D304 module has an MTBF of 18,800 hours and a β of 2.23. The D304 reliability curve is shown in Figure 10.

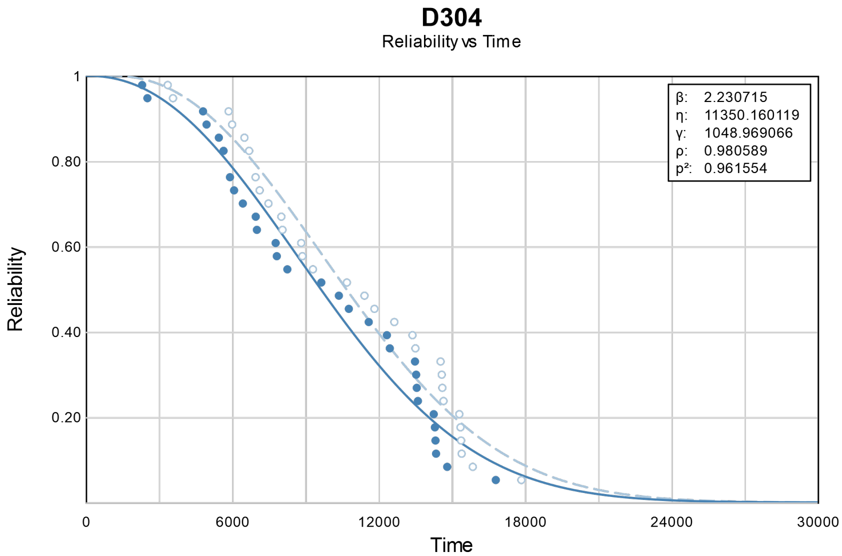

Figure 10: D304 Reliability Curve. The solid line distribution is the Weibull 3-parameter distribution. The dashed line is the same distribution as the solid line, but shifted based on the location parameter, γ, which provides an estimate of the earliest time a failure may be observed.

7 Conclusions and Future Works

In summary, the MTBFs for each subsystem assessed in this memo are displayed in the table below.

Table 3: Subsystem MTBFs in hours

Model 22	Model 350	Model 1050	Compressor	F306	L302	D301	D302	D303	D304
6,100	17,500	10,700	5,800	10,000	20,400	11,000	16,700	11,000	18,800

For each subsystem based on their respective time periods as described

From this analysis, Model 22 cold head and cryogenic compressor subsystems have the lowest MTBFs at 6,100 hours and 5,800 hours, respectively. We also found that the L302 is the most reliable of the subsystems examined with an MTBF of 20,400 hours. The MTBFs produced in this investigation provide an ample starting point for designing systems in ngVLA to meet more stringent reliability requirements than what was implemented during the design of EVLA.

Moreover, it can also be concluded that the Model 22 cold head has roughly half the MTBF of the Model 350 and Model 1050 cold heads, which mirrors the proportion of the different valve rotation rates between the models. The Model 22 cold head valve has twice the rate of revolution of the Model 350 and Model 1050 cold heads. This suggests that difference in design choice and the subsequent result of an increased rate in degradation Teflon seals in the system may be the source of the lower MTBF, providing a concrete example of the need to carefully predict subsystem reliability and simulate advanced life-cycle testing throughout the design of ngVLA.

As discussed in Section 6, all D30x modules have a β greater than 1. Further investigations are needed to assess whether all DTS modules are in fact reaching end-of-life failures or if there is another subsystem artificially causing increased failure rates across all of the DTS modules. Investigations to continue the examination of reliability at the component level of a subsystem would be valuable. Specifically, an investigation should be conducted to determine if the Relyence Reliability Prediction software that examines component reliability can predict a failure rate that matches what we are seeing in operation on the array.