Applying Reliability Growth Analysis Methods to Assess In-service Reliability

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Applying Crow-AMSAA to Assess In-service Reliability

Statistical Methods

Reliability definitions:

"The ability of an item to perform a stated function under stated conditions, for a stated period of time." (JA1000, ISO 8402)

"The ability of an item to perform a required function under stated environmental/physical conditions for a stated period of time." (ARP5638)

- Quantifying reliability is based on failure events in periods of time using statistical analysis methods
- Statistical methods include:
  - Life Data Analysis (i.e. Weibull) based on measures of service life from beginning (install 'new') to end (remove for specific failure mode or cause)
  - Other methods based on observations in service/use periods such as Reliability Growth Analysis – RGA to include the Crow-AMSAA* model
- Systems in DoD service are repairable systems at some level with repairs documented over service period

*AMSAA – Army Materiel Systems Analysis Activity, now Combat Capabilities Development Command (CCDC) DEVCOM Analysis Center (DAC)

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Statistical Methods

- Reliability Growth Analysis (RGA) is a statistical method that enables measuring in-service reliability with the following benefits:
  - Reasonably accurate results with deficient/dirty data
  - Applicable to mixtures of failure modes (Unlike Weibull, which is single failure mode)
  - Applicable to multiple levels of indenture (system, subsystem, component)
  - Facilitates visibility through ease of trending
  - Pro-active through enabling predictions
    - Short- and long-range (months, quarters, years)
    - Existing and new (first time) occurrences
- RGA allows assessment, tracking, and prediction using typical maintenance data

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Statistical Methods

- Key advantages of Crow-AMSAA for monitoring In-service reliability:
  - Quantify removals statistically, regardless of failure mode
  - Get an indicator of direction (improving or declining) and impact (how many to expect and when) at any level
  - The process and the physical system are represented
    - Occurrences can be defined not just as removals but also events such as in-flight aborts, scheduled or unscheduled, etc.
    - Results for changes in process, including RCM failure management strategy, can be tracked and quantified
  - Tracking physical system and process changes shows patterns that aid in solving problems and making improvements
- Crow-AMSAA gives the basic data we almost always have, number of events over time, a factual voice for forecasting what comes next

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- Why can't we just count number of failures and hours without the Crow-AMSAA model?
  - Crow-AMSAA Beta parameter trends change over time
    - Beta < 1, number of events (i.e. failures) is decreasing
    - Beta = 1, number of events is constant (stable)
    - Beta > 1, number of events (i.e. failures) is increasing
  - Crow-AMSAA is also a prediction model, made possible by the linear regression of the log-log line
  - Just like Weibull, can use the graph to find out information
- Crow-AMSAA is a tracking model with prediction
- Why do we want to track and predict?

Important! Beta slope parameter interpretation

Planning and management of In-service reliability

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Assessing Reliability

- Crow-AMSAA model parameters
  - Lambda, which is the vertical intercept for the log-log line at a unit of time (t=1). Not to be confused with Failure Rate.
  - Beta is the slope of the log-log line that fits the data points.
  - Same term for Weibull and Crow-AMSAA, interpretation is different
    - Weibull is slope of Unreliability vs Time, a conditional probability of failure over time relationship
    - Crow-AMSAA is Number of Events vs Time, an occurrence over time relationship
- Over continuous operating periods failure events will occur, enabling application of Crow-AMSAA tracking and prediction

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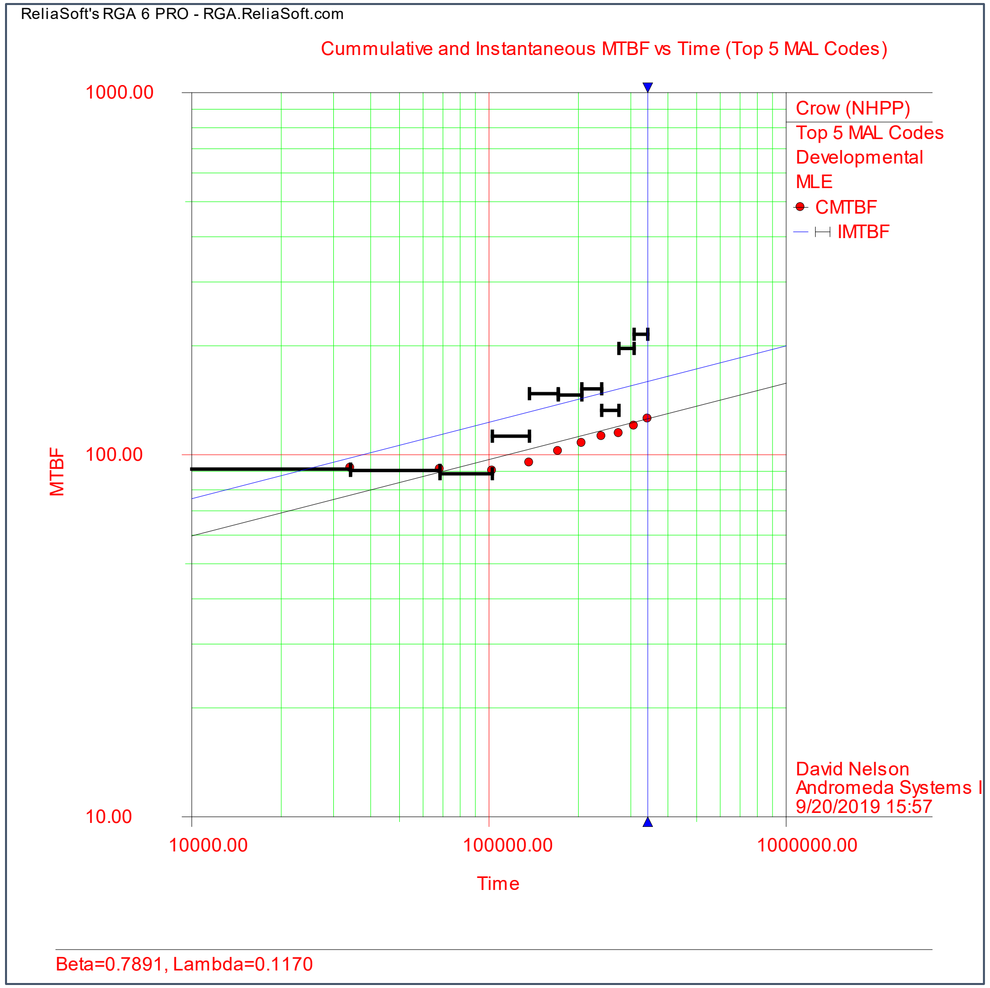
Cumulative and Instantaneous MTBF

- Like Weibull, Crow-AMSAA has different graphs
- MTBF changes over time
- As population ages, MTBF may change showing declining reliability
- Process or design improvement implementation should show increasing MTBF
- Is this improving or declining?

Improving, B < 1



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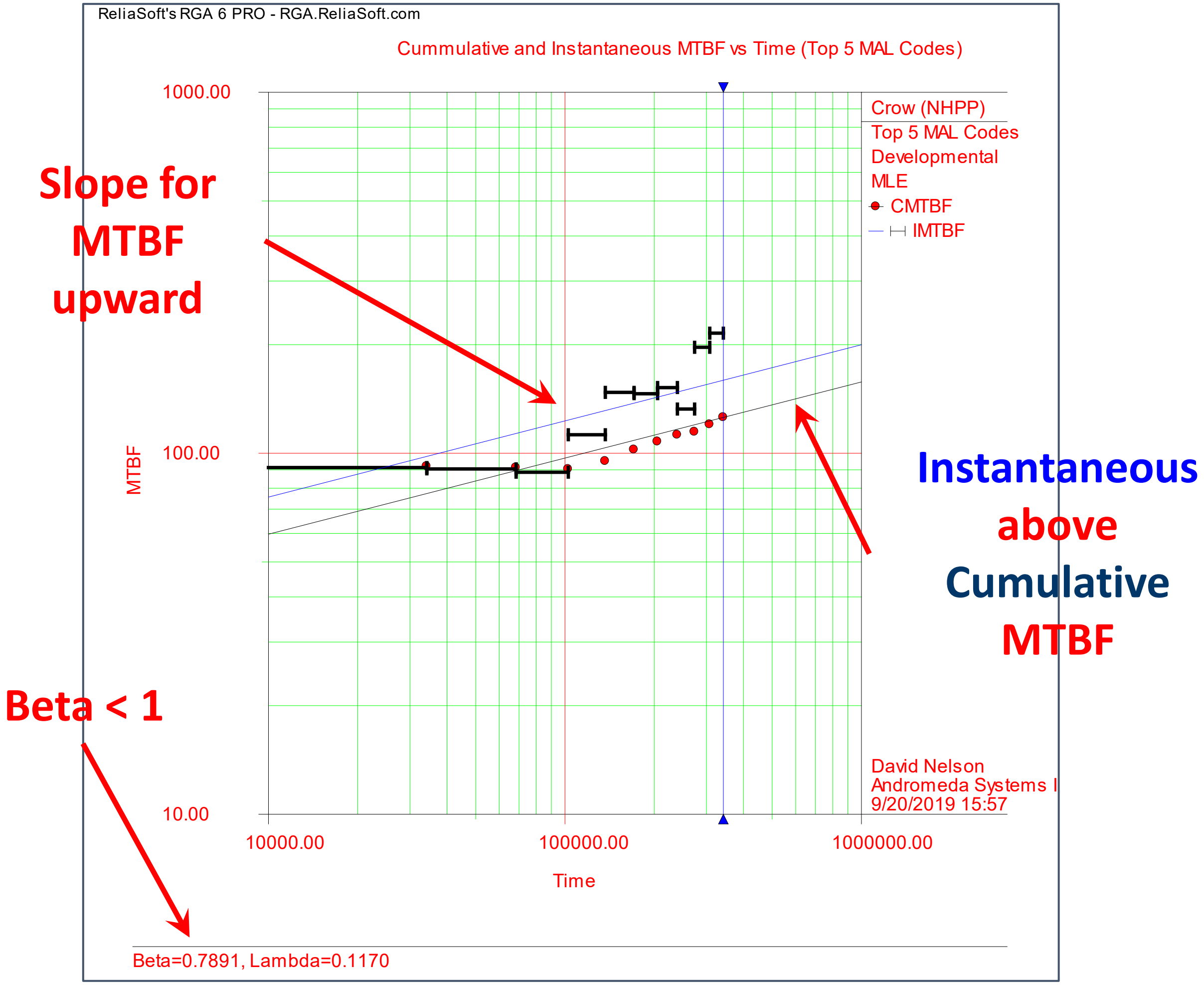
Cumulative and Instantaneous MTBF



- Blue line is Instantaneous
- Black line is Cumulative
- The way the offset goes, above or below the line, is an indicator for improving or declining
- For MTBF plot, Instantaneous above cumulative, B < 1 means improving

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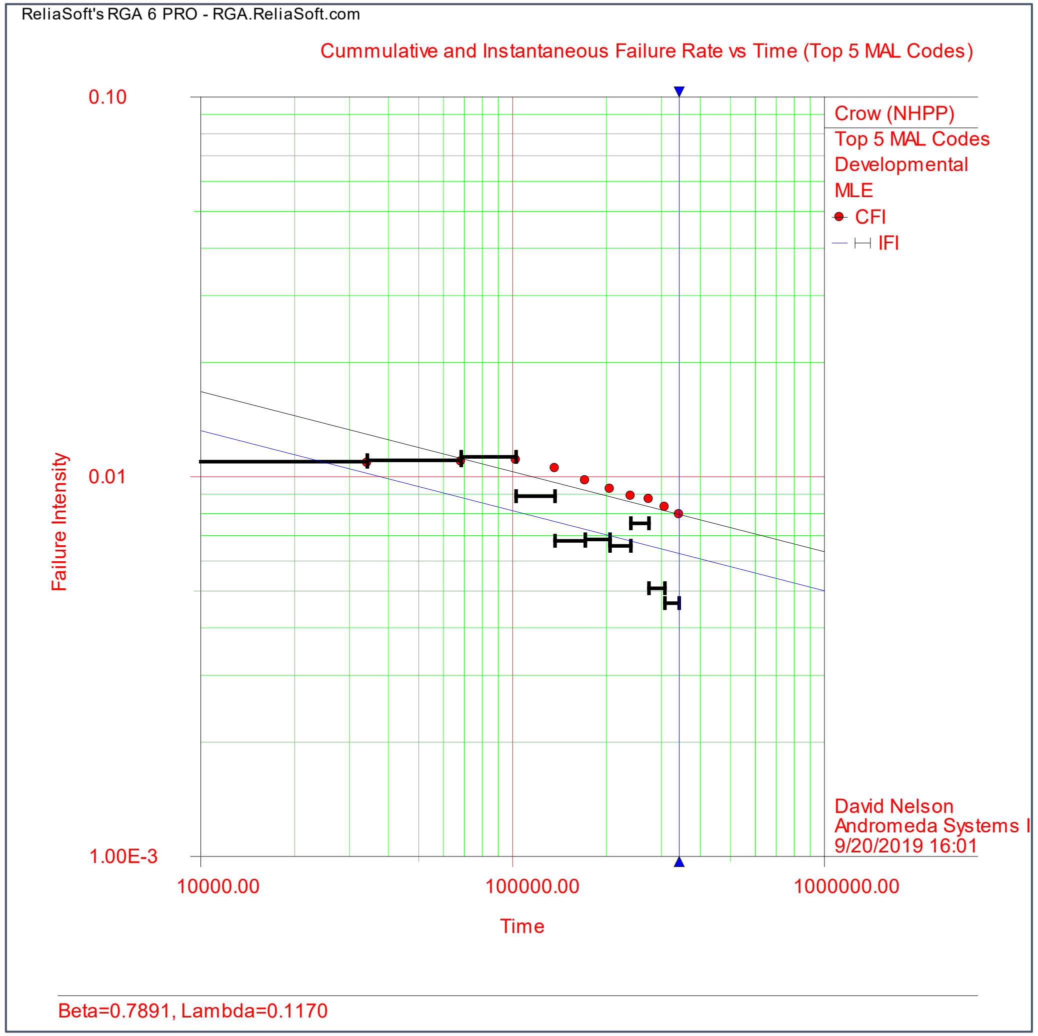
Cumulative and Instantaneous Failure Rate

- Failure rate (FR) and MTBF are still reciprocals of each other (i.e. 1/XXX) for Crow-AMSAA
- Improving FR decreases while improving MTBF increases
- The FR and MTBF relationship between cumulative and instantaneous is also reciprocal
- Is this improving or declining?

Improving

Instantaneous FR is below Cumulative FR



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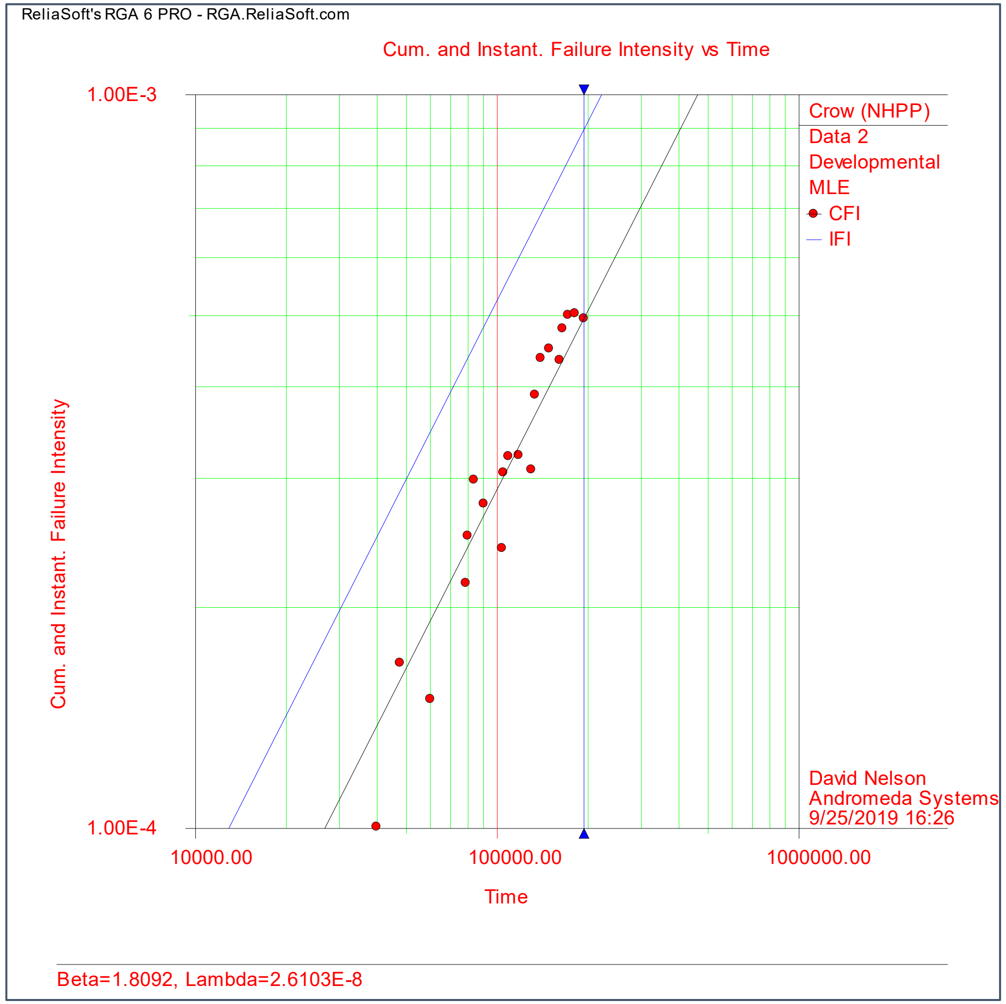
Cumulative and Instantaneous Failure Rate

- Here is another example

- What can you tell me about this one?
  - FR shown
  - B > 1
  - Instantaneous above cumulative
- Is this improving or declining?

Declining, B > 1



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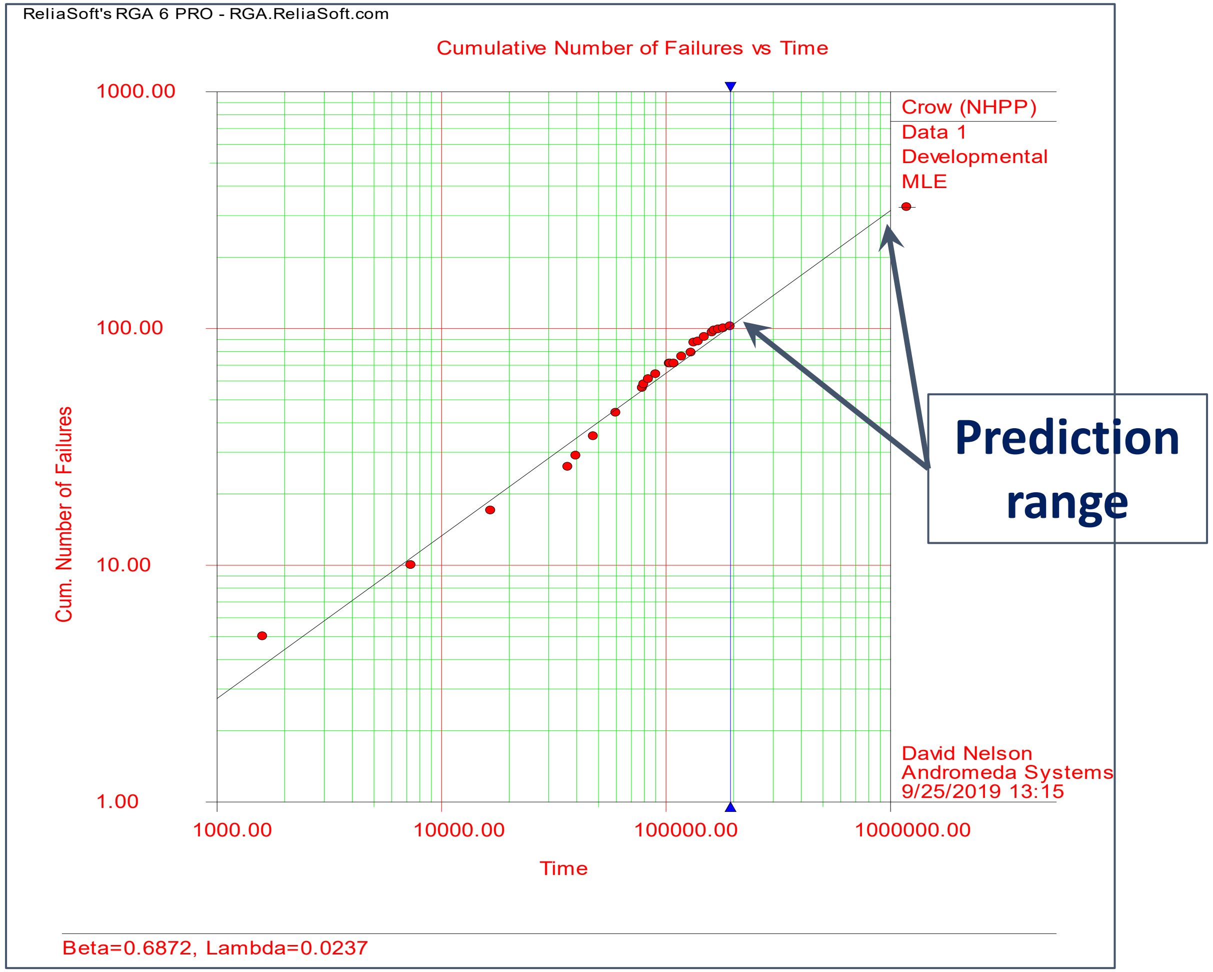
Cumulative Number of Failures vs Time



- Prediction is based on the projection of the line
- Vertical blue line shown through the last point, anything beyond that is prediction
- Prediction can be calculated for what period to expect next failure or at what time

Applying Crow-AMSAA to Assess In-service Reliability

- Crow-AMSAA visibility over occurrences enables trending changes in processes as well as physical system
- A change in process may produce a “cusp” in the Crow-AMSAA model, a clear indication where a change outside the as designed physical system
- A “cusp” is a point of transition, a place where a change clearly occurred and the new is no longer behaving like the old
  - Can be an improvement, point where new design or improved failure management strategy becomes dominant
  - Can also be a degradation, point where change in vendor, operating environment, or deficiency in repair process is negatively impacting occurrence

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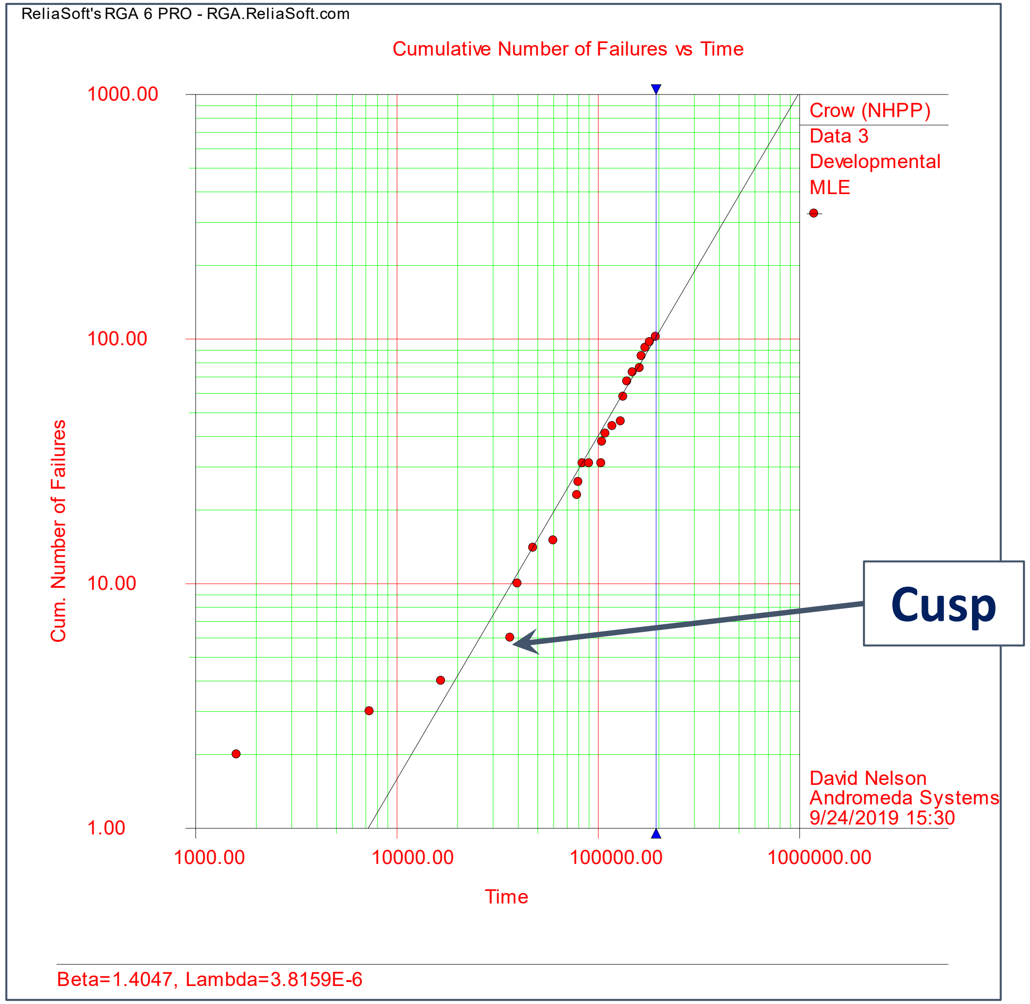
Data Visualization and Display



- Data points do not fit to a single line, two different slopes are indicated
- Time period where cusp is indicated tells when change took effect
- What does this cusp indicate?

Slope increased (B>1), cusp indicates a degradation or change for the worse

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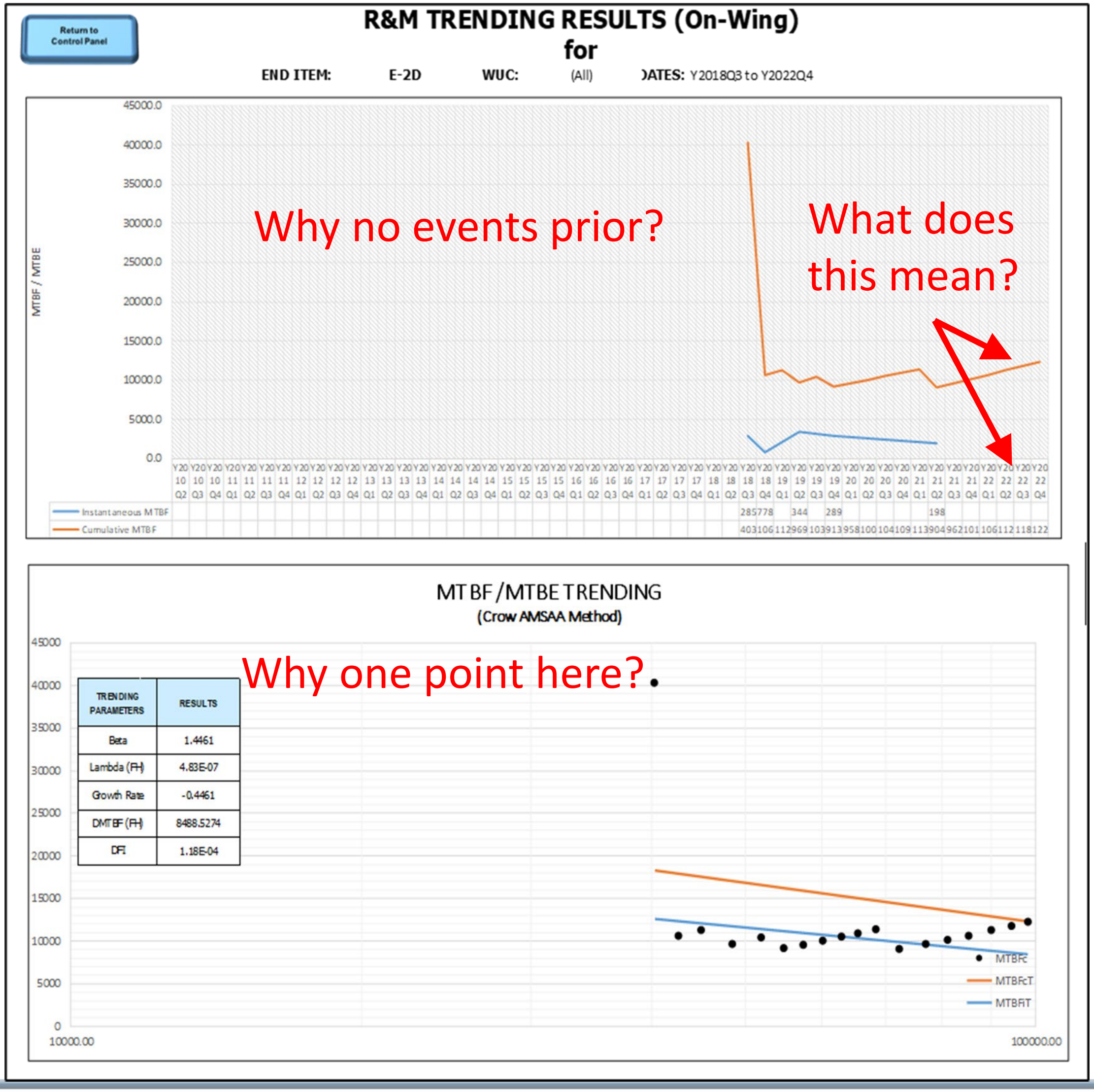
Data Visualization and Display



- Parameters tell part of the story
- Visualization in plots and graphs improves insight
- The top graph is the cumulative MTBFc (orange line) and instantaneous MTBFi (blue line)
- The bottom plot is a Crow-AMSAA plot, data is calculated in quarters
- What do you see?
  - Cusps? How many?
  - Three!
  - What about those cusps? Start? Stop?

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Case Study

RM Trend Tool analysis evaluated five factors over a five-year history using a weighted model:

1. Total occurrences (number of events in period) – by WUC for air vehicle and by event description from narrative for J85 represents frequency
2. MTBF trend (Crow AMSAA Beta and multiple averages over period) –provides insight whether occurrences decrease, are stable, or increase
3. Total Aircrew When Discovered Code events (A, B, C, and D) –provides representation of events with operational impact
4. Total Aircrew When Discovered Code Aborts (A and C) – representation of lost mission operational impact
5. Total EMT (Average EMT X Total Occurrences) – representation of downtime contribution over the period as total time spent correcting the failure derived by multiplying total occurrences by average EMT

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Case Study

Assessed Degrader Rank	WUC	WUC Description	Total Occurrences	Number of Maintenance Events Weighted Score at 0.1	MTBF Trend (change in Reliability) over time increase, stable, or decrease)	MTBF Trend (1 = stable or increase, 1.5 = decrease)	Total Aircrew When Discovered	Aircrew When Discovered Events Weighted at 0.2	Aircrew Aborts	Aircrew Aborts Weighted Score at 0.3	Total EMT hours	Total EMT Weighted Score at 0.3	Raw Overall Score	Overall Score Corrected for MTBF Trend (Increased Reliability)
1	42AAN	976J902 CONTROL UNIT GENERATOR	113.00	0.41	Stable	1.00	68.00	0.91	48.00	4.80	542.40	1.99	0.81	0.81
2	41AEJ	751872 REFRIGERATION PACKAGE	58.00	0.21	Decrease	1.50	31.00	0.41	14.00	1.40	632.20	2.32	0.65	0.65
3	63HDA	SE-052/FA RECEIVER-TRANSMITTER, RADIO	91.00	0.33	Decrease	1.50	79.00	1.05	16.00	1.60	136.50	0.50	0.52	0.52
4	52AG0	836525 COMPONENTS ASSY, STABILITY AUGMENTER	50.00	0.18	Decrease	1.50	23.00	0.31	11.00	1.10	230.00	0.84	0.36	0.36
5	42AAA	976J898 GENERATOR, ALTERNATING CURRENT	71.00	0.26	Stable	1.00	25.00	0.33	16.00	1.60	390.50	1.43	0.36	0.36
6	739K1	LN-260 COCKPIT DISPLAY UNIT	72.00	0.26	Decrease	1.50	39.00	0.52	10.00	1.00	100.80	0.37	0.32	0.32
7	14CA250	AL1020M4 ACTUATOR, ELECTROMECHANICAL, LINEAR	27.00	0.10	Decrease	1.50	18.00	0.24	13.00	1.30	118.80	0.44	0.31	0.31
8	51AAG	ARU-20A INDICATOR ATTITUDE	41.00	0.15	Decrease	1.50	38.00	0.51	12.00	1.20	53.30	0.20	0.31	0.31
9	17351	F5169211-13 LEADS UPPER (GOX) DISCONNECT, EJECTION SEAT	30.00	0.11	Decrease	1.50	17.00	0.23	13.00	1.30	30.00	0.11	0.26	0.26
10	11JET	1608T100 ACTUATOR, AUXILIARY AIR INLET DOOR	41.00	0.15	Decrease	1.50	18.00	0.24	9.00	0.90	118.90	0.44	0.26	0.26

- 42AAN Generator control unit scores high in all 4 numerical factors and top degrader overall. MTBFc is stable but occurrence is frequent.
- 8 of top 10 items show a decrease in reliability over the observation period.

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Case Study

Assessed Degrader Rank	WUC	WUC Description	Total Occurrences	Number of Maintenance Events Weighted Score at 0.1	MTBF Trend (change in Reliability) over time increase, stable, or decrease)	MTBF Trend (1 = stable or increase, 1.5 = decrease)	Total Aircrew When Discovered	Aircrew When Discovered Events Weighted at 0.2	Aircrew Aborts	Aircrew Aborts Weighted Score at 0.3	Total EMT hours	Total EMT Weighted Score at 0.3	Raw Overall Score	Overall Score Corrected for MTBF Trend (Increased Reliability)
11	13LG0	6002064 ANTI-SKID CONTROL BOX	26.00	0.09	Stable	1.00	22.00	0.29	17.00	1.70	83.20	0.31	0.24	0.24
12	63HAA	CA230F CONTROL, VHF/UHF RADIO	69.00	0.25	Decrease	1.50	53.00	0.71	2.00	0.20	96.60	0.35	0.23	0.23
13	52AAB	20100 GYRO RATE	77.00	0.28	Stable	1.00	19.00	0.25	5.00	0.50	300.30	1.10	0.21	0.21
14	41AC4	131100 VALVE, REGULATING	28.00	0.10	Stable	1.00	17.00	0.23	11.00	1.10	190.40	0.70	0.21	0.21
15	46LAA	203-003 GAUGE, LIQUID QUANTITY (FUEL	65.00	0.24	Stable	1.00	34.00	0.45	11.00	1.10	84.50	0.31	0.21	0.21
16	14AC120	14-73903 GRIP, CONTROL STICK	35.00	0.13	Stable	1.00	33.00	0.44	13.00	1.30	59.50	0.22	0.21	0.21
17	51X11	AAU19( )/A SERVO ALTIMETER	24.00	0.09	Decrease	1.50	16.00	0.21	5.00	0.50	64.80	0.24	0.16	0.16
18	46ACE40	106788S102 MOTOR WITH TRANSMISSION	28.00	0.10	Stable	1.00	9.00	0.12	7.00	0.70	170.80	0.63	0.15	0.15
19	14EJB	2-43330 ACTUATOR, RUDDER RH	19.00	0.07	Decrease	1.50	0.00	0.00	0.00	0.00	210.90	0.77	0.13	0.13
20	51X1S	ABU4( )/A ACCELEROMETER	29.00	0.11	Decrease	1.50	18.00	0.24	3.00	0.30	40.60	0.15	0.12	0.12

- Items ranked 11 through 20 have fewer high scores for the numerical factors but still significant effect on operations (aircrew discovered and aircrew aborts) and downtime contributions (total EMT)
- 3 of the 11 thru 20 items show a decrease in reliability for the period

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Summary

- Crow-AMSAA is another method that compliments Weibull
- Crow-AMSAA enables assessment, tracking, and prediction with typical maintenance data
- Indicates Direction and Impact
- Data quality NOT important
  - Any level, any event occurring during operating period
  - Basically, counting something in the operating period (removal, abort, one failure mode, all failure modes, LRU, Subsystem, System, End Item, ANYTHING you can count)
- Software or spreadsheet tool applies
- Specialized training not overly important, simple to use
- Can be applied as a weighted factor in evaluating top degraders

References

- MIL-HDBK 189C “Department of Defense Handbook Reliability Growth Management”
- Abernethy, Robert B., “The New Weibull Handbook,” Fifth Edition, Chapter 6
- NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook