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AMSAA
Excellence in Analysis

A Successfully Implemented Coordinated Subsystem Reliability Growth Planning Approach

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Topics

- *Reliability Growth Planning Model SSPLAN*
  - Overview
  - Principal Benefits and Features
  - Model Inputs and Outputs
  - Procedure used to Generate Model Outputs
- *Bombardier Applications*
  - Bombardier Overview
  - Problem Statement / Opportunity
  - Reliability Maturation Model
  - New Reliability Growth (NRG II) Model Objectives
  - Railway example of implementation process
  - Interactions between basic elements of reliability process
  - Summary of NRG II Benefits

SSPLAN Overview

- Reliability Growth Planning Model based on system level reliability objective (mean test duration between failure, MTBF) and coordinated subsystem growth program inputs.

- Applies to systems composed of a series of subsystems that independently generate failures.

- Can accommodate a mixture of growth and non-growth subsystems.

- Measure of test duration, t , is continuous (e.g., time, distance).

- Assumes for each growth subsystem i, the number of failures that occur in test interval [0,t], $N_i(t)$, is governed by a nonhomogeneous Poisson process (NHPP) with a power law mean value function $\lambda_i t^{\beta_i}$ assumed at system level in U.S. MIL-HDBK-189.

- Developed by AMSAA and documented in AMSAA Reliability Growth Guide (Technical Report No. TR-652, Sept. 2000)

Principal Benefits and Features

- **Helps construct a set of subsystem planning curves with associated subsystem test durations and target MTBFs**
  - that are consistent with system reliability objective and growth subsystem reliability allocations
  - whose achievability can be gauged by past experience

- **Subsystem planning curves and test durations have property that if realized during developmental test program, with a *specified probability*, subsystem test data would provide a *specified level of assurance* that system reliability objective is met.**

- **Subsystem planning curves support decision process with respect to allocation of test resources**
  - prior to test program
  - during testing with regard to reallocation to address subsystem reliability deficiencies
    - ✓ can provide objective basis for prioritizing subsystem corrective action efforts

- **System and associated subsystem planning curves serve as benchmarks against which reliability improvement can be measured**
  - highlights to program management and customers assessed reliability versus reliability goals at program milestones
    - ✓ at system and subsystem levels

Model Inputs & Outputs

- ## *System Level Inputs*

  - System MTBF objective, $M_{obj,Sys}$

  - Statistical confidence level γ for lower confidence bound LCB_{γ} on achieved system MTBF

  - Specified probability p_0 that subsystem test data would yield a value of LCB_{γ} that meets or exceeds $M_{obj,Sys}$ if subsystems grow in accordance to planning curves for planned test durations

    - ✓ γ is the *specified level of assurance*

    - ✓ p_0 is the *specified probability* that assurance level would be realized under growth assumption

- ## *System Level Output*

  - System MTBF target , $M_{targ,Sys}$

    - ✓ Reciprocal of sum of subsystem target failure intensities

    - ✓ $M_{targ,Sys} > M_{obj,Sys}$ for practical values of γ and p_0

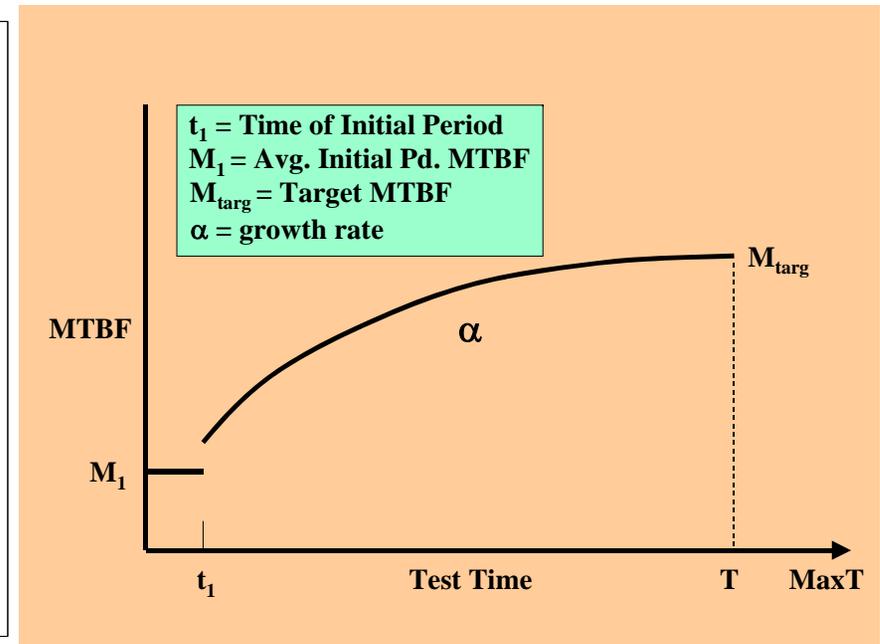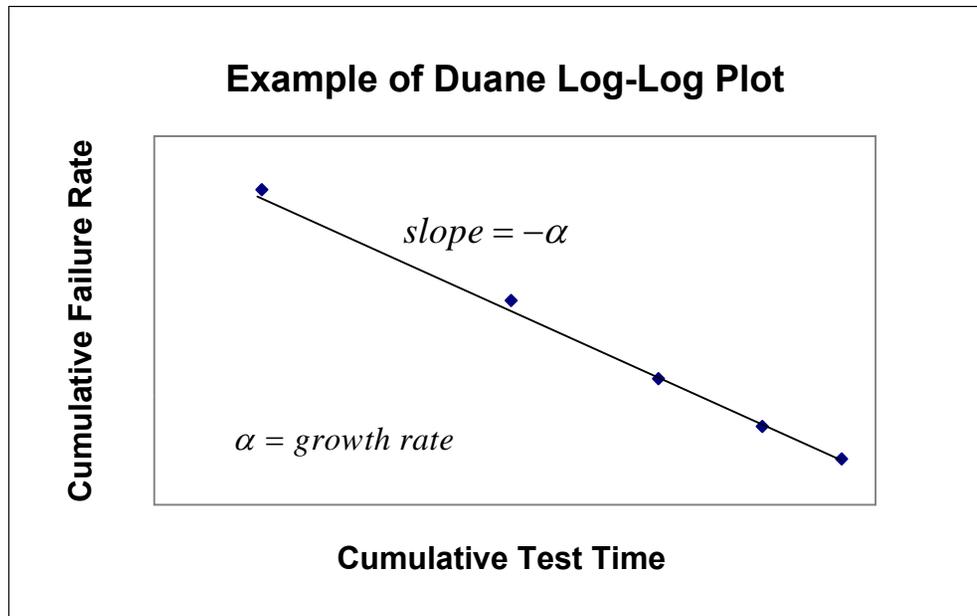# Model Inputs & Outputs

- *Growth Subsystem Inputs*
  - Growth rate α_i
    - ✓ Negative of slope on log-log plot of expected cumulative failure intensity versus cumulative test duration
  - Initial test period $t_{1,i}$
    - ✓ Growth is planned to commence by the end of initial test period
  - Average MTBF expected over initial test period, $M_{1,i}$
  - Allocation fraction, a_i, of growth subsystem portion of target system failure intensity to growth subsystem i
    - ✓ If all subsystems have growth programs, target failure intensity for subsystem satisfies $\lambda_{targ,i} = a_i \cdot \lambda_{targ,Sys}$
  - Maximum subsystem test duration

- *Growth Subsystem Outputs*
  - Test duration for subsystem i, T_i
  - Target MTBF for subsystem i, $M_{targ,i}$
  - Expected number of subsystem failures in test, $E(N_i) = T_i / \{(1-\alpha_i) \cdot M_{targ,i}\}$

Duane Plot and Subsystem Idealized Reliability Growth Curve

Example of Duane Log-Log Plot

Cumulative Failure Rate

$slope = -\alpha$

$\alpha = growth\ rate$

Cumulative Test Time

t_1 = Time of Initial Period
M_1 = Avg. Initial Pd. MTBF
M_{targ} = Target MTBF
α = growth rate

M_{targ}

MTBF

α

M_1

t_1 Test Time   T   MaxT

Duane Postulate: If changes to improve reliability are incorporated into the design of a system under development, then on a log-log plot, the graph of cumulative failure rate versus cumulative test time tends to exhibit a linear relationship (Duane, 1964).

Outline of Procedure to Obtain Subsystem Test Durations
(case where all subsystems are growth subsystems)

- **$N_i(t)$ is a NHPP with rate of occurrence function $\rho_i(t)$**
  - $\rho_i(t) = \lambda_i \beta_i t^{\beta_i - 1}$ where $\beta_i = 1 - \alpha_i$ and $\lambda_i = t_{1,i}^{\alpha_i} / M_{1,i}$ for growth subsystem i
- **Steps**
  - **Use trial value $M_{targ,Sys}$ to calculate $\lambda_{targ,i} = a_i \cdot \lambda_{targ,Sys}$**
  - **Obtain trial value T_i by inverting eq. $\lambda_{targ,i} = \rho_i(T_i)$**

  - **For each growth subsystem i simulate NHPP from 0 to T_i**

  - **Calculate pseudo demo. test no. of failures $n_{D,i} = n_i /2$ & time $T_{D,i} = T_i / (2\beta_{est,i})$**
    - ✓ $\beta_{est,i}$ is max. likelihood estimate of β_i from simulated growth test data.
    - ✓ Equate point estimate and LCB on $M_{targ,i}$ from pseudo demo. data to estimates from growth data to obtain pseudo demo. test data.

  - **Combine subsystem pseudo demo. data to obtain approximate LCB_γ on $M_{targ,Sys}$**
    - ✓ Applied Lindström – Madden method adapted for continuous test duration.
    - ✓ Could use other methods for combining pseudo demonstration test data.

  - **Repeat last 3 steps prescribed no. of times to estimate Prob ($LCB_\gamma \geq M_{obj,Sys}$)**
  - **If estimated probability is close to p_0 stop - the current trial T_i are chosen as the subsystem test durations ; otherwise adjust $M_{targ,Sys}$ and repeat above steps.**

AEROSPACE & RAILWAY INDUSTRIES APPLICATION

A Successfully Implemented Coordinated Subsystem

Reliability Growth Planning Approach

Bombardier's Implementation/Customization of the SSPLAN –

New Reliability Growth (NRG II)

Company Overview

- Corporate office based in Montréal, Canada
- Workforce of some 55,800 people worldwide as at January 31, 2006
- Revenues of $14.7 billion for fiscal year ended January 31, 2006
- More than 94% of revenues coming from foreign markets
- Listed on the Toronto Stock Exchange (BBD)

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The focus of Bombardier Inc. is based on two pillars

Transportation

45% of total Revenues

Annual Revenues in (2005/2006):
US$6.6bn

Aerospace

55% of total Revenues

Annual Revenues in (2005/2006):
US$8.1bn

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*Figures for the year ending January 31, 2006

Problem Statement / Opportunity

- **Problem Statement**
  - Warranty costs and customer dissatisfaction
  - Weakness in the process to predict, optimize and govern the product reliability in order to meet Entry into Service and in-service performance.

- **Opportunity to raise reliability performance**
  - Insure reliability performance meet commitments as per schedule
  - Reduce Warranty cost
  - Model Life Cycle Cost
  - Improve Maintenance Program
  - Highlight to senior management reliability progress of all subsystems
  - Prioritization of corrective actions

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Reliability Maturation Model
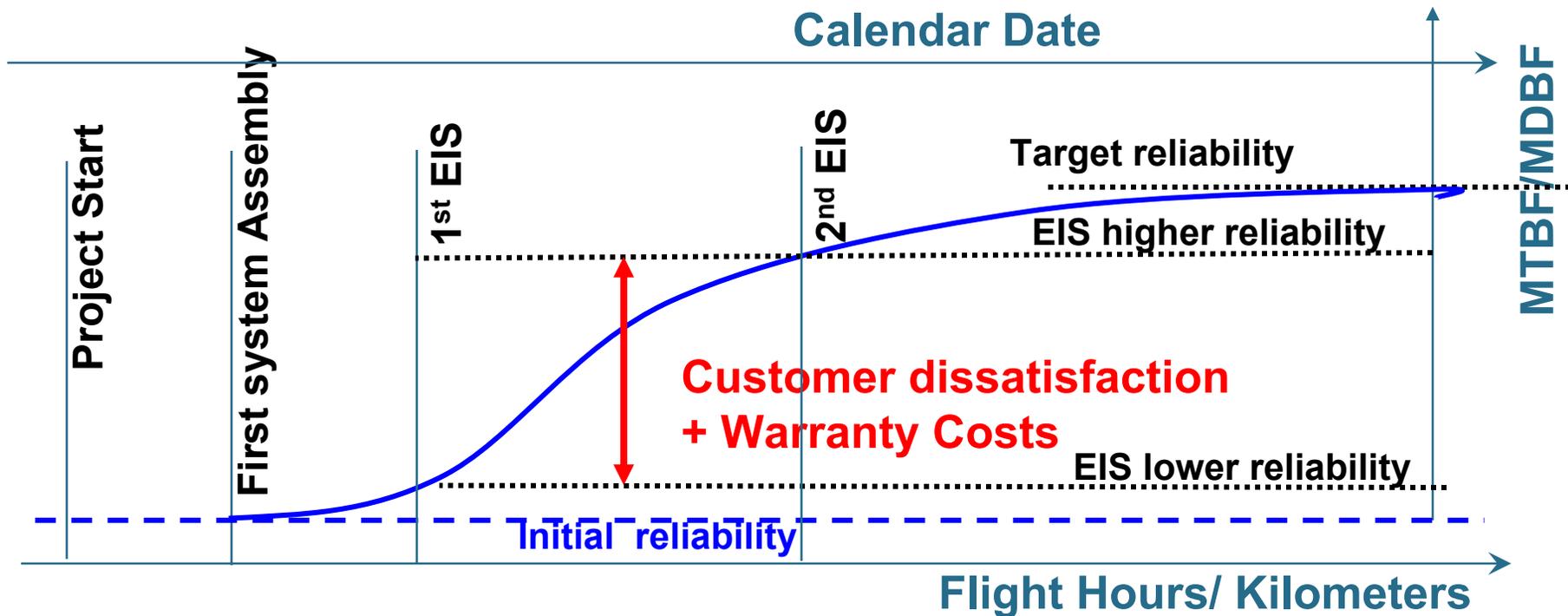
- **Potential shortfalls in managing reliability**
  - System Reliability measurements start too Late.
  - No Prediction of reliability at Entry Into Service(EIS).
  - No Proactive action to ensure that EIS reliability will be met.

  Address in growth plan

- **Need reliability growth program plan to conduct trade-off analysis between EIS calendar date and EIS expected reliability.**

- **Need to measure against program plan.**

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New Reliability Growth (NRG II) Model Objectives

- **Predict Reliability Maturation**
  - Based on past performance by system and supplier
  - Include reliability growth from the start of testing
  - Supports spares contingency requirements
- **Optimize lifecycle costs linked to reliability**
  - Perform trade studies between increasing testing and fixing issues in the field
  - Allow analysis between EIS calendar date and EIS expected reliability
  - Optimize maintenance program
- **Govern Reliability Growth and issues from day one**
  - Set up a framework to compare actual reliability to planned reliability
  - Comparison provides basis for efficient proactive management with regard to failure mode mitigation
- **Utilize coordinated subsystem reliability growth strategy**

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Classic growth – Planning and monitoring at system level only

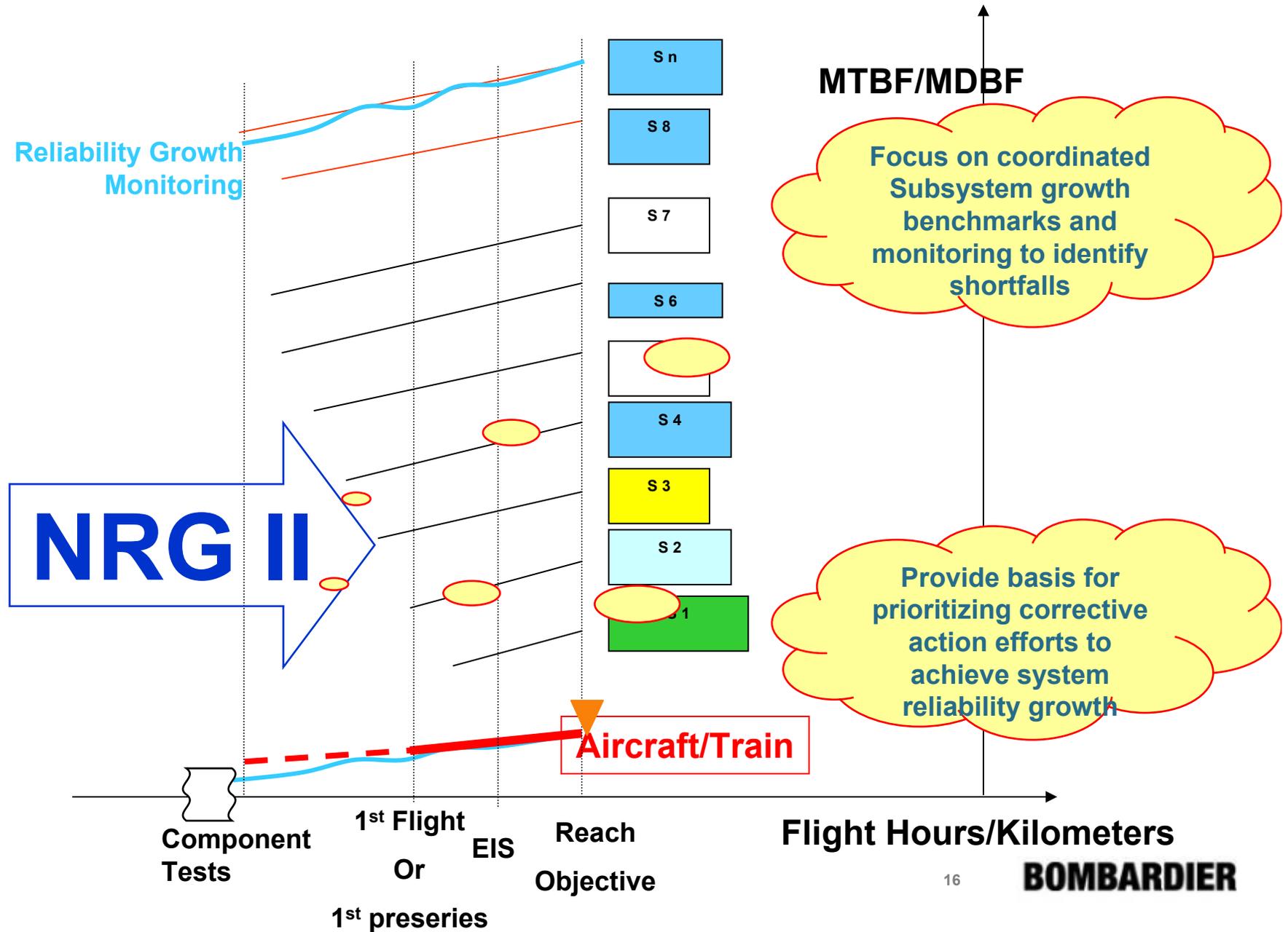Can result in difficulty establishing subsystem maturity risk and viable EIS date

S n

S 8

S 7

S 6

S 5

S 4

S 3

S 2

S 1

MTBF/MDBF

Aircraft/Train
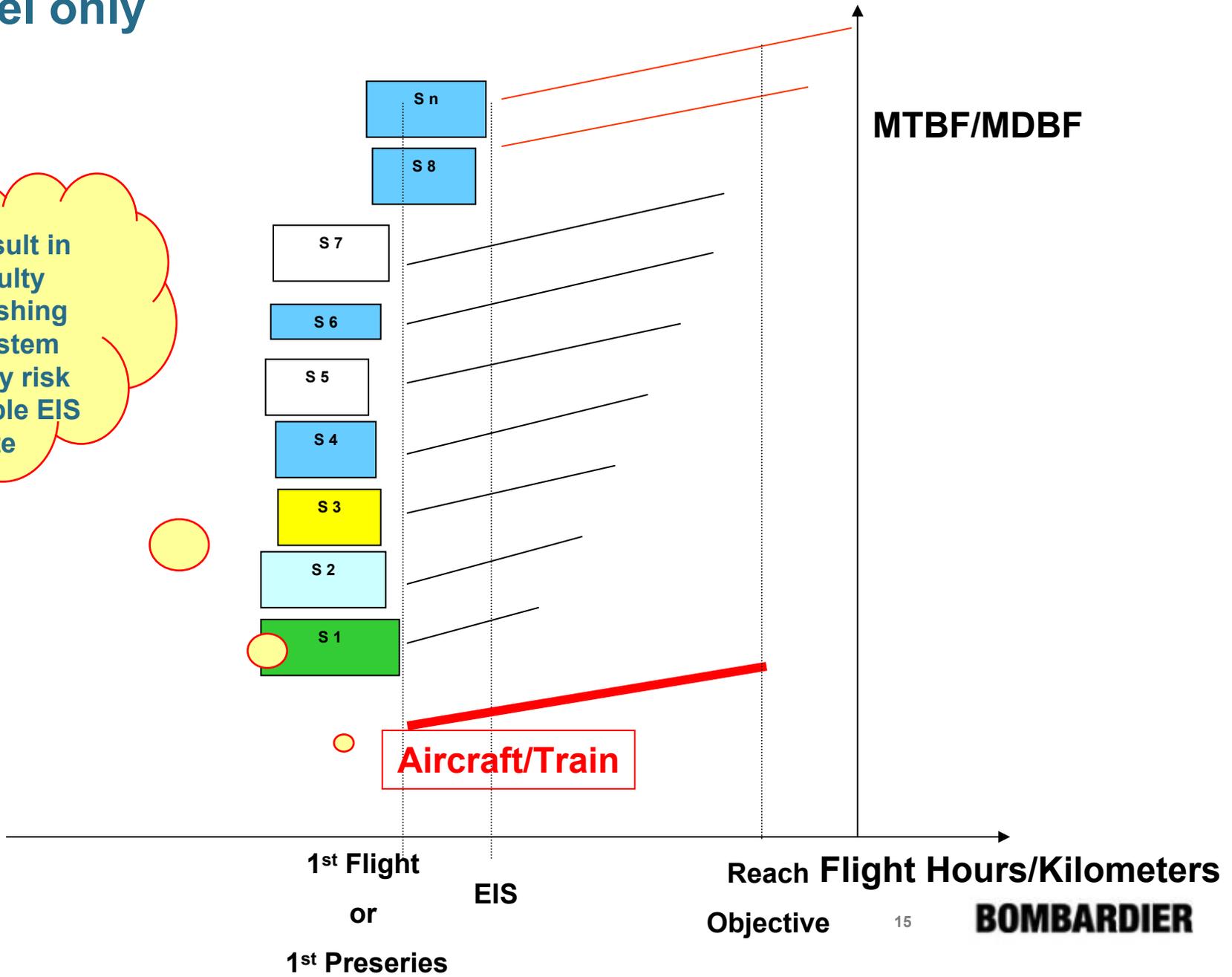
1st Flight
or
1st Preseries

EIS

Reach Objective

Flight Hours/Kilometers

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NRG II Approach

Reliability Growth Monitoring

NRG II

S n

S 8

S 7

S 6

S 4

S 3

S 2

S 1

Aircraft/Train

MTBF/MDBF

Focus on coordinated Subsystem growth benchmarks and monitoring to identify shortfalls

Provide basis for prioritizing corrective action efforts to achieve system reliability growth

Component Tests

1st Flight Or

EIS

1st preseries

Reach Objective

Flight Hours/Kilometers

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Reliability Growth : method NRG II

- Name of the Product
- MDBF or MTBF Objective (Contractual)
- Confidence Level
- Acceptance Probability
- List of all Main Subsystems

NRGII

NRG II

Project   ?

Project properties

Name: European Train

Objective → Goal MDBF (Km) 3816

Confidence level 0,8

Acceptance Probability 0,8

Description For Demonstration

Project failure allocation % : 100

Cancel   Apply

Run   Options

European Train
- Serie 1
- Serie 2
- Serie 3
- Serie 4
- Serie 5
- Serie 6
- Serie 7
- Serie 8
- Serie 9
- Serie 10
- Serie 11
- Serie 12
- Serie 13
- Serie 14

Reliability Growth : method NRG II

- Growth rate alpha
- Failure intensity allocation
- Initial MDBF
- Initial Test Distance
- Maximum Test

NRGII

NRG II

Project ?

Sub System requirements

Name: S 8

WBS (optional) :

Reliability Growth Specifications

(•) Growth   (○) Non-Growth

Growth Rate   0,22

Failure Intentisity Allocation   0,1434

Initial conditions (need both)

Initial MDBF (Km)   5938

Initial Distance (Km)   17814

Simulations Specifications

Maximum Test   3000000000

Cost per test hours   0

Cost per failure   0

Optional data
Comments and/or Assumptions

Cancel   Apply

Run   Options

European Train
- S 1
- S 2
- S 3
- S 4
- S-5
- S 6
- S 7
- S 8
- S 9
- S 10
- S 11
- S 12
- S 13
- S 14

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Reliability Growth : method NRG II

NRGII

Per Subsystem:
- Number of Failures
- Total test Distance
- Final MDBF

For the Product:
- Computed Target MDBF

Project	File Name : 2007_02_13_European Train #3				
Name	Comments and/or Assumption	Objective MDBF (Km)	Confidence level	Probability of acceptance	Number of subsystems
European Train	For Demonstration	3816	0.8	0.8	14

Sub-systems			Initial conditions							
Name	G/N	Alpha	Initial MDBF (Km)	Initial Distance	Maximum Distance	MDBF (Km) at system objective	Failure Allocation	Expected failures	Total test Distance	Final MDBF (Km)
S 1	Growth	0,39	311,509	934,528	3000000000	1,413,333	0.0027	17.64	17,055,812	1,585,039
S 2	Growth	0,19	21,000	65,000	3000000000	50,543	0.0755	86.89	3,989,576	56,684
S 3	Growth	0,2	22,035	66,105	3000000000	85,369	0.0447	437.94	33,542,866	95,741
S 4	Growth	0,22	6,113	18,338	3000000000	27,394	0.1393	380.71	9,123,000	30,722
S-5	Growth	0,19	25,435	76,500	3000000000	47,522	0.0803	28.68	1,238,304	53,295
S 6	Growth	0,21	33,677	101,030	3000000000	150,830	0.0253	535.68	71,584,125	169,154
S 7	Growth	0,2	33,456	111,457	3000000000	70,667	0.054	42.97	2,724,189	79,252
S 8	Growth	0,22	5,938	17,814	3000000000	26,611	0.1434	380.78	8,863,814	29,844
S 9	Growth	0,23	3,787	11,362	3000000000	16,975	0.2248	278.63	4,084,317	19,037
S 10	Growth	0,19	35,000	105,000	3000000000	63,920	0.0597	25.96	1,507,564	71,685
S 11	Growth	0,4	578,518	1,735,553	3000000000	2,544,000	0.0015	15.27	26,139,970	2,853,071
S 12	Growth	0,24	7,454	22,363	3000000000	33,415	0.1142	209.24	5,959,427	37,475
S 13	Growth	0,2	26,997	80,922	3000000000	120,759	0.0316	777.53	84,240,787	135,431
S 14	Growth	0,37	279,284	837,853	3000000000	1,272,000	0.003	21.95	19,724,117	1,426,535

System			
Epsilon	Number of iterations	Computed probability of acceptance	Computed target MDBF (Km)
	500	0.8	4280

Output

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Example of Reliability Growth monitoring of initial subsystem MDBF's for a Product composed of 14 subsystems
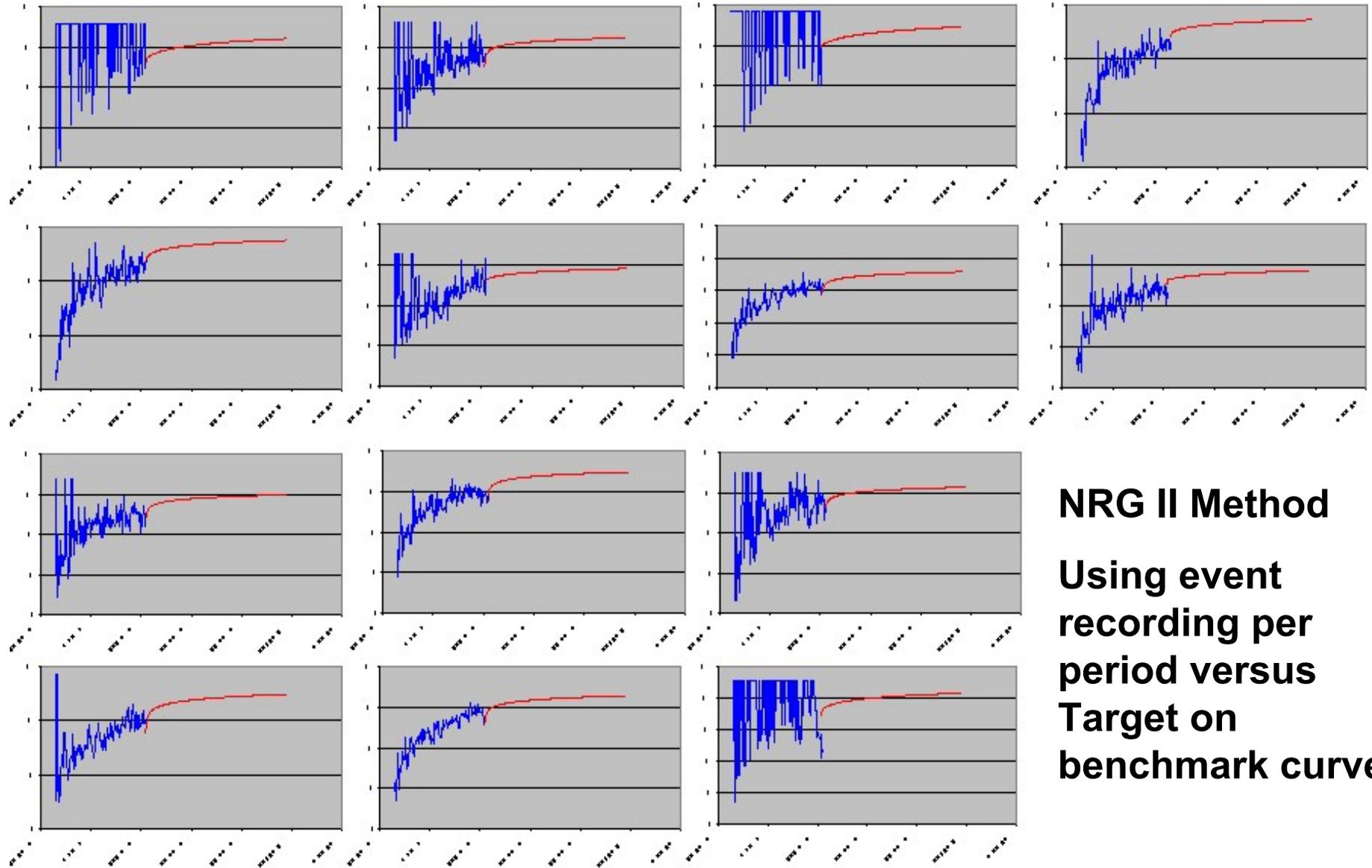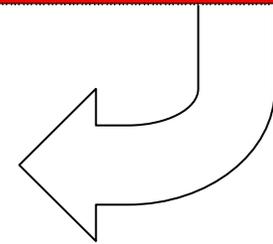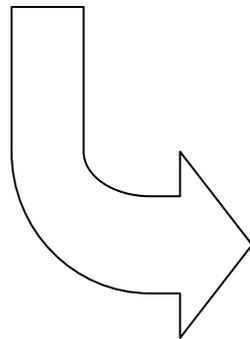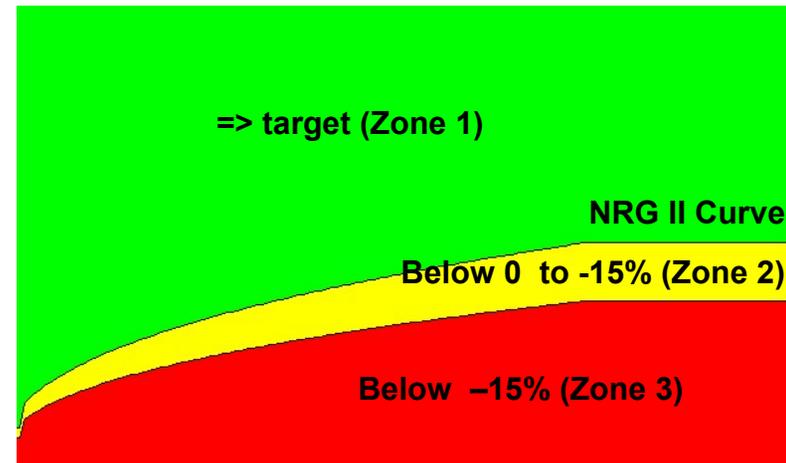

NRG II Method

Using event recording per period versus Target on benchmark curve

Establishing priority of corrective actions

Life Cycle Cost

Zone	% measured LCC exceeds target LCC
1	Less 5%
2	5 to 15%
3	15% and up

Reliability performance

=> target (Zone 1)

NRG II Curve

Below 0 to -15% (Zone 2)

Below −15% (Zone 3)

		Reliability performance		
		>= target	below 0 to -15%	below -15%
	Zone	1	2	3
LCC — Less 5%	1	1	2	3
LCC — 5 to 15%	2	2	4	6
LCC — Above 15%	3	3	6	9

Priority weight

Safety failures have the highest priority

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Interactions between basic elements of reliability process

FRACAS

Failure Reporting Analysis and Corrective

Actions System

NRG II

New Reliability Growth Tool

RCM

Reliability Centered Maintenance

LCC

Life Cycle Cost

Engineering Mod

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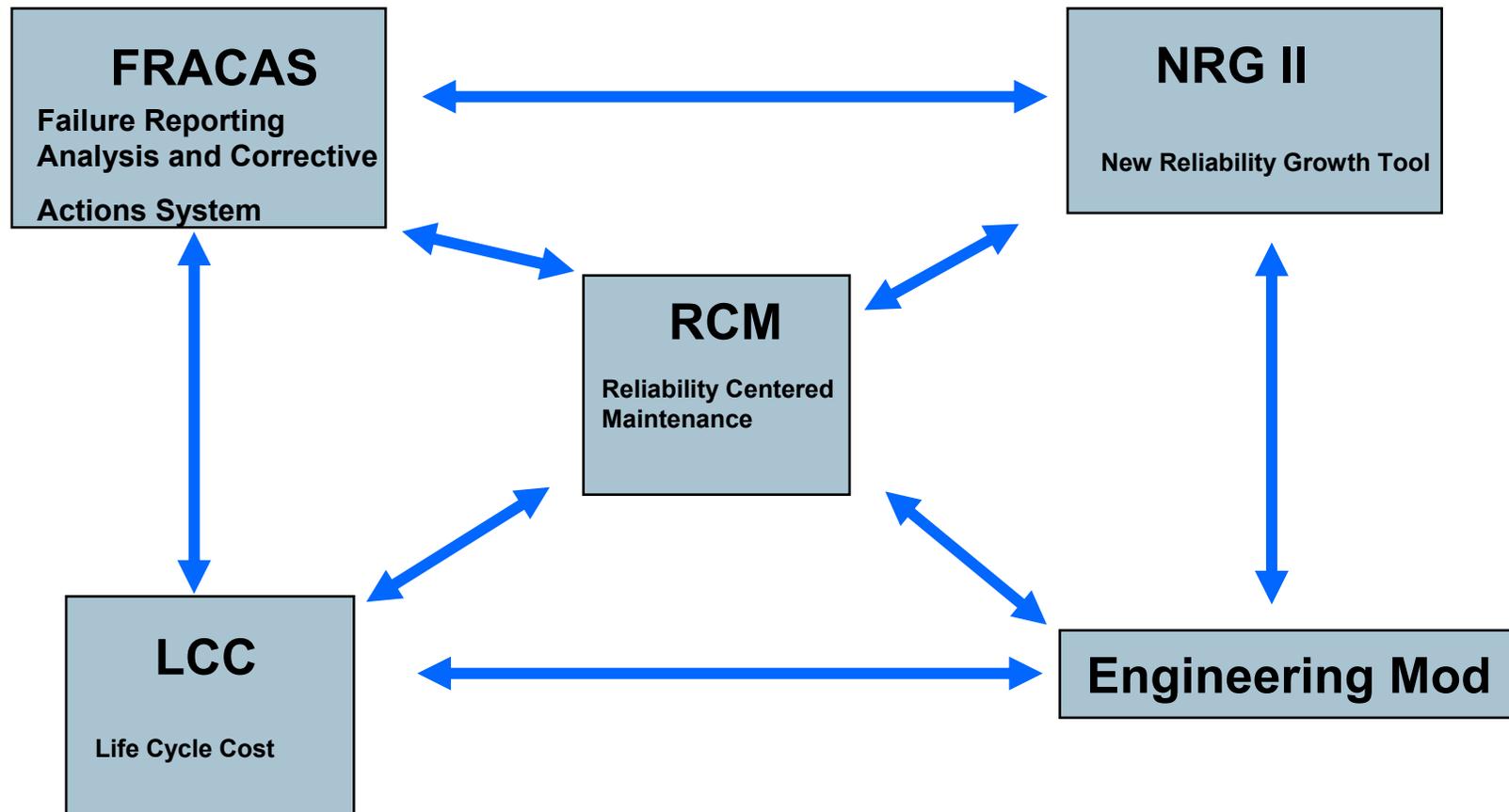
Summary of NRG II Benefits

- **Promotes a proactive approach to maturing product reliability**

- **Establishes corrective action priority based on comparisons of measured LCC and reliability values to target values**

- **Highlights to senior management reliability progress of all subsystems**

- **Reduces cost of Product Introduction**

- **Assists in modeling LCC**

- **Assists in performing trade-off analysis between EIS calendar date and expected EIS reliability**

- **Helps in optimizing maintenance program**

- **Applies to new product development or in-service improvements**

Fosters idea that reliability growth is a responsibility we all share to achieve customer satisfaction

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