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Cost Benefit Analysis for Incorporation of Prognostics

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Using Prognostics In a System

- Definition
  - The sensing, recording or interpreting or a systems operational parameters to monitor the operational health of that system.
    - Example: Engine Temperature gauge
- Potential Benefits
  - Prognostics must defer or prevent maintenance
    - Maintenance is either postponed until regularly scheduled service or not performed because the system is still operational.
    - Deferred or prevented maintenance can save support costs and\or increase system availability.
- Are Prognostics Beneficial?
  - Perform a Cost Benefit Analysis to document the cost and availability impact of prognostics

Prognostics Can Potentially Save Maintenance Costs

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Prognostics Example

- The Ace Missile Company Markets the Mighty Missile
  - Superior speed, range and payload
    - Acme Rocketmotors LLC produces a solid rocketmotor that provides the performance the Mighty Missile requires.
- Solid Rocketmotors Are Susceptible To Damage
  - Delamination (layers coming apart), twisting, cracking
    - Damage is caused by humidity, vibration and age
- Optic Fiber Prognostics Device
  - An optic fiber is mounted on the outer surface of the rocketmotor propellant
  - Delamination, twisting or cracking of the rocketmotor propellant strains the optic fiber which can be detected by testing

Prognostics Can be Incorporated into Rocketmotors

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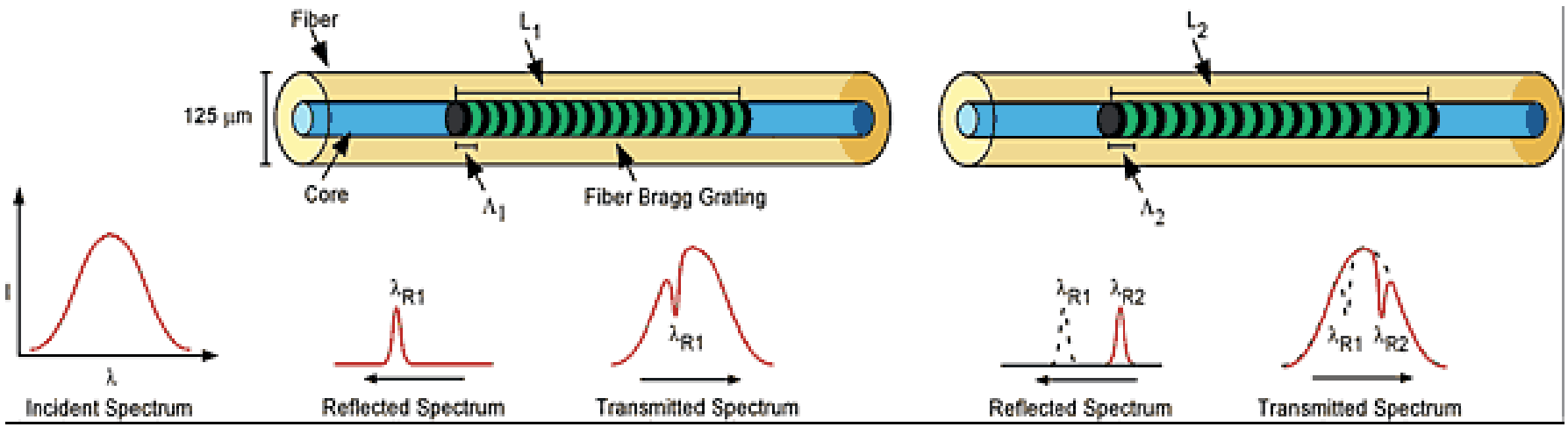
Optic Fiber Function

- The fiber is interrogated by sending light through it and reading the wavelength of the reflected light.
  - Light reflected by an unstrained fiber has a known wavelength.
  - Light reflected by a strained fiber will have a different wavelength.



UNSTRAINED FIBER **STRAINED FIBER**

Damaged Rocketmotors can be Identified

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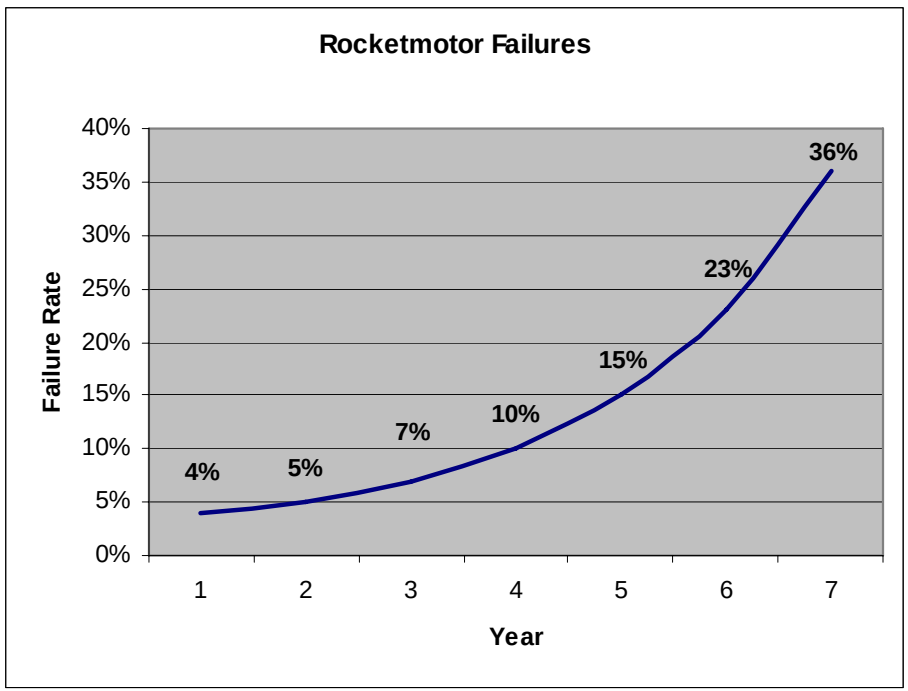
Rocketmotor Failure Rates

- The Mighty Missile rocketmotor has a guaranteed useful life of 10 years.
  - The rocketmotors fail at increasing rates over the next seven years



Year	Failure %	Storage 118	Fielded 125
1	4%	5	5
2	5%	6	6
3	7%	8	9
4	10%	12	12
5	15%	17	19
6	23%	27	29
7	36%	43	45
Totals	100%	118	125

Population Failures Over 7 Years

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Mighty Missile Operations

- Production
  - 250 missiles are produced each year
    - 125 go into storage (seven are used for test and training each year)
    - 125 are fielded
- Rocketmotors will be replaced once
  - Replace rocketmotors lot by lot each year as the ten year service life expires
  - Equip the rocketmotors with an Optic Fiber - test the missiles each year and replace failed rocketmotors
- Does using the Optic fiber provide a cost savings or increase in missile availability?

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Prognostics Cost Benefit Analysis

- Defining Cost Elements

Cost Element	Cost ('09 $s)
Rocketmotor	$20,500
Optic Fiber installation (per rocketmotor)	$250
Fiber Optic Test Set	$100,000
Depot Labor (touch) per hour	$68
Depot Labor (engineering support) per hour	$118
Customer Storage Facility labor per hour	$92
Ground Transportation; dollars per pound per mile	.000418792
Inflation (annual)	2.4%

- Cost Definition – Projection of Actuals
  - Costs are actual quotes provided by vendors and contractors
- Risks
  - Uncertainty about availability of parts
    - Rocketmotors and test set (bought in Program year 11)

Actual Costs Produce the Most Accurate Cost Estimate

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Program Year 11

A	B	C
1	Program Year	11
2	Assets used for testing (cumulative)	77
3	Prognostics cost	$712,218
4	Test set	$126,765
5	Depot Rocketmotor replacement cost	$29,425
6	Storage test labor cost	$9,554
7	Fielded test labor cost	$13,899
8		
9	**Rocketmotors with Optic Fiber replacement**	
10	Failed rocketmotors - storage	48
11	Failed rocketmotors - fielded (tested)	5
12	Rocketmotors replaced	53
13	Rocketmotor test\replacement (in storage) cost	$1,768,522
14	Rocketmotor test\replacement (fielded) cost	$643,899
15	Total Yearly Cost	$2,412,420
16	Available missiles	2,423
17		
18	**Lot by Lot rocketmotor replacement**	
19	Rocketmotors replaced	173
20	Rocketmotor replacement (in storage) cost	$1,412,413
21	Rocketmotor replacement (fielded) cost	$3,678,158
22	Total Yearly Cost	$5,090,571
23	Available missiles	2,423

First Year of Rocketmotor Replacements

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Program Years 20 and 21

A	B	C	D
24	Program Year	20	21
25	Assets used for testing (cumulative)	140	147
26	Depot Rocketmotor replacement cost	$36,427	$37,301
27	Storage test labor cost	$11,827	$12,111
28	Fielded test labor cost	$17,930	$18,444
29			
30	**Rocketmotor with Fiber Optic Cable replacement**		
31	Failed rocketmotors - storage	118	113
32	Failed rocketmotors - fielded (tested)	125	120
33	Rocketmotors replaced	243	233
34	Rocketmotor test\replacement (in storage) cost	$4,310,179	$4,227,119
35	Rocketmotor test\replacement (fielded) cost	$4,571,269	$4,494,559
36	Total Yearly Cost	$8,881,448	$8,721,678
37	Cumulative Cost	$45,320,010	$54,041,688
38	Available missiles	2,360	2,307
39			
40	**Lot by Lot rocketmotor replacement**		
41	Rocketmotors replaced (in storage)	118	0
42	Rocketmotors replaced (fielded)	125	0
43	Rocketmotors replaced	243	0
44	Rocketmotor replacement (in storage) cost	$4,298,352	$0
45	Rocketmotor replacement (fielded) cost	$4,553,339	$0
46	Total Yearly Cost	$8,851,692	$0
47	Cumulative Cost	$77,681,592	$77,681,592
48	Available missiles	2,360	2,187

Final Year of Lot by Lot Rocketmotor Replacements

Program Years 22 – 30 Missile Inventory Comparison

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A	B	C	D	E	F	G	H	I	J	K
49	Program Year	22	23	24	25	26	27	28	29	30
50	Depot Rocketmotor replacement cost	$38,196	$39,113	$40,052	$41,013	$41,997	$0	$0	$0	$0
51	Storage test labor cost	$12,402	$12,699	$13,004	$13,316	$0	$0	$0	$0	$0
52	Fielded test labor cost	$18,974	$19,518	$20,078	$20,655	$0	$0	$0	$0	$0
53	**Rocketmotors with Optic Fiber replacement**									
54	Rocketmotors replaced	221	204	180	144	88	0	0	0	1
55	Total Yearly Cost	$8,472,731	$8,011,246	$7,242,370	$5,939,819	$3,695,749	$0	$0	$0	$0
56	Cumulative Cost	$62,514,419	$70,525,665	$77,768,035	$83,707,853	$87,403,602	$87,403,602	$87,403,602	$87,403,602	$87,403,602
57	Available missiles	2,291	2,260	2,209	2,127	1,999	1,799	1,556	1,313	1,070
58										
59	**Lot by Lot rocketmotor replacement**									
60	Rocketmotors replaced	0	0	0	0	0	0	0	0	0
61	Total Yearly Cost	$0	$0	$0	$0	$0	$0	$0	$0	$0
62	Cumulative Cost	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592
63	Available missiles	1,944	1,701	1,458	1,215	972	729	486	243	0

Final Years of Optic Fiber Rocketmotor Replacements

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Program Year 36

A	B	C
64	**Rocketmotors with Optic Fiber replacement**	
65	Rocketmotor test\replacement (in storage)	$41,087,608
66	Rocketmotor test\replacement (fielded)	$46,315,994
67	Cumulative Cost	$87,403,602
68	Available missiles (years)	45,031
69	Rocketmotor Maintenance (per missile)	$37,035
70	Rocketmotor Maintenance (per year)	$1,941
71		
72	**Lot by Lot rocketmotor replacement**	
73	Rocketmotor replacement (in storage)	$36,662,374
74	Rocketmotor replacement (fielded)	$41,019,219
75	Cumulative Cost	$77,681,592
76	Available missiles (years)	34,850
77	Rocketmotor Maintenance (per missile)	$32,916
78	Rocketmotor Maintenance (per year)	$2,229

Final Maintenance and Operational Data

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Conclusions

- Additional Missile Availability at Additional Cost
  - Rocketmotors can be replaced at a lower per unit cost, or
  - More missiles can be available for longer time
- Rocketmotor Replacement is One Logistics Issue
  - All Logistics issues need to be considered together to determine the overall support cost for a program

The Cost Benefit Analysis Shows Maintenance Options