The Costs of Unsuitability and Benefits of Building in Reliability, Availability and Maintainability

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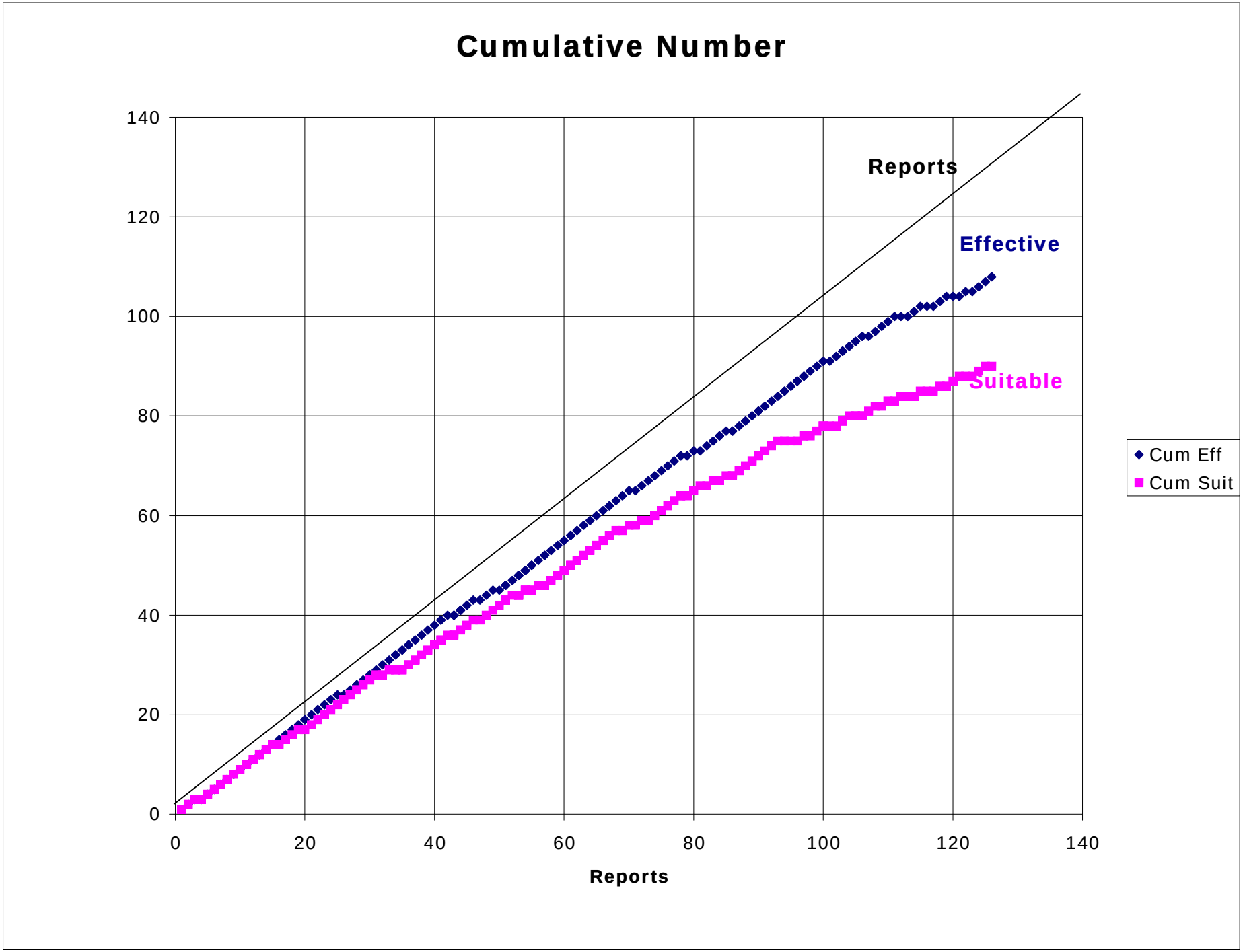
Cumulative Number
140
120
100
80
60
40
20
0
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20
40
60
80
100
120
140
Reports
Reports
Effective
Suitable
Cum Eff
Cum Suit

DoD IOT&E Results FY 2001 - 2003

Program	Service	ACAT	IOT&E Result		Reason
FY 2001					
F-15 TEWS	USAF	II	Effective	Not Suitable	Reliability, Maintainability, Availability
V-22 Osprey	Navy	1D	Effective	Not Suitable	Reliability, Availability, Maintainability (RAM), Human Factors, BIT
Joint Direct Attack Munitions (JDAM)	USAF	1C	Effective only with legacy fuses	Not Suitable	Integration with delivery platforms
M2A3 Bradley Fighting Vehicle	Army	1D	Effective	Suitable	
FY 2002					
Joint Primary Aircraft Training System (JPATS)	USAF	1C	Effective with deficiencies	Not Suitable	RAM, Safety, Human Factors
Cooperative Engagement Capability (CEC)	Navy	1D	Effective	Suitable	
Multiple Rocket Launcher System (MLRS)	Army	1C	Effective	Suitable	
MH-60S	Navy	1C	Effective	Not Suitable	RAM, excessive administrative and logistic repair time impacted RAM
FY 2003					
B-1B Block E Mission Upgrade Program	USAF	1D	Effective	Not Suitable	16% decrease in weapons release rate, reduction in accuracy of Mark 82 low drag weapons, 14% hit rate on moving targets
Sea wolf Nuclear Attack Submarine	Navy	1D	Effective	Suitable	Several requirement thresholds were not met but overall system effective and

DoD IOT&E Results FY 2004, 2005

Program	Service	ACAT	IOT&E Result		Reason
FY 2004					
Evolved Sea sparrow Missile	Navy	II	Effectiveness unresolved	Suitable	Testing was not adequate to determine effectiveness.
Stryker	Army	1D	Effective	Suitable	
Advanced SEAL Delivery System (ASDS)	Navy	1D	Effective with restrictions	Not suitable	Effective for short duration missions; not effective for all missions and profiles. Not suitable due to RAM.
Tactical Tomahawk	Navy	1C	Effective	Suitable	
Stryker Mortar Carrier-B (MC-B)	Army	1D	Effective	Not Suitable	RAM and safety concerns.
FY 2005					
CH-47F Block I	Army	1C	Effective	Not Suitable	RAM; communications system less suitable than CH-47D; did not meet Information Exchange Requirements for Block I.
F/A-22	USAF	1D	Effective	Not Suitable	RAM; needed more maintenance resources and spare parts; BIT
Joint Stand-Off Weapon-C	Navy	1C	Not Effective		Not effective against moderately hardened targets; mission planning time was excessive.
Guided-MLRS	Army	1C	Effective	Suitable	
High Mobility Attack Rocket System (HMARS)	Army	1C	Effective	Suitable	
V-22 Osprey	Navy	1D	Effective	Suitable	
EA-6B (ICAP III)	Navy	II	Effective	Suitable	

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result		Technical Reason
FY 2002					
F-15 TEWS	USAF	II	Effective	Not Suitable	RAM

SE Issues		
Issue	**SE Area**	**Rationale**
Requirements	Reasonableness Verification	RAM requirements not fully defined. BIT architecture and subsystem reliability not designed into system. BIT system was a major requirement for the system.
Program Planning	Allocation Sufficiency	Program focused mainly on Band 1.5 and did not address newer SAM systems; inadequate processing capability. Systemic analysis was not performed; might have captured systems integration problems and identified root causes for inadequate processing.
Acquisition Strategy	Acceptability	Program integrated Electronic Warfare (EW) systems with known reliability issues without performing a systemic analysis prior to design and integration.
Technical Process	Requirements Development System Integration, Test, and Verification	Program did not establish sound independent technical review processes. Software assurance and metrics not sufficiently established. Technical entrance and exit criteria not established for Developmental Test (DT) reviews and decisions.

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result		Technical Reason
FY 2002					
Joint Primary Aircraft Training System (JPATS)	USAF	1C	Effective with deficiencies	Not Suitable	RAM; safety; human factors.

SE Issues		
Issue	**SE Area**	**Rationale**
Requirements	Reasonableness Verification	No ORD Thresholds for R&M; program measured against objectives.
Program Planning	Allocation Sufficiency	Acquisition Reform – pilot program. Designed as COTS program. Multiple slips: evidence of a schedule-driven nature. Requirements not fully defined and understood.
Acquisition Strategy	Acceptability	Simple COTS approach. “Militarization” not fully defined or understood. Multiple slips: evidence of schedule-driven nature.
Technical Process	Requirements Development System Integration, Test, and Verification	COTS mentality led to simplistic test approach (e.g., FAA cert, Contractor Qual Test approach led to insufficient DT). Multiple slips. Requirements not tracked/traced to a verification and test plan.

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result		Reason
FY 2001					
Joint Direct Attack Munitions (JDAM)	USAF	1C	Effective only with legacy fuses	Not Suitable	Excessive mission planning times (Navy); system reliability; B-52 load times; container deficiencies (stacking, carrier ops).

SE Issues		
Issue	**SE Area**	**Rationale**
Requirements	Reasonableness; Design Synthesis Verification	B-52 load times not reflective of new complexity. Navy carrier operability (ruggedness) not adequately captured/defined. Significant focus on capability (accuracy). Reliability relied heavily on “warranty.”
Acquisition Strategy	Acceptability	Acquisition Reform – pilot program. Small program office. Capability-based contracting strategy; significant SE contracted as result. Significant focus on capability (accuracy). Reliability relied heavily on “warranty.”
Technical Process	System Integration, Test, and Verification	Unrealistic load times; test team load crew experience, training; test team mission planning experience/training.
Reducibility and Production Planning	Quality Control (Plant Layout)	Storage reliability. Significant failures related to minor quality control errors (i.e., missing sealant, kit packed with wrong covers, etc.).

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result		Reason
FY 2003					
B-1B Block E Msn Upgrade Program	USAF	1D	Not Effective	Suitable	16% decrease in weapons release rate; reduction in accuracy of Mark 82 low drag weapons; 14% hit rate on moving targets.

SE Issues		
Issue	**SE Area**	**Rationale**
Requirements	Reasonableness Verification	Validity of effectiveness measures, based on comparison with prior block (not as complex; different release mechanism; different weapons mix; key requirement met: weapons flexibility).
Acquisition Strategy	Acceptability; Sufficiency	Software conversion oversimplified. Significant program growth. “Program clarity” - funded program did not address numerous “known issues”; resulted in re-identification of numerous issues (situational awareness, controls and displays, reliability).
Technical Process	System Integration, Test, and Verification	T&E measures not well founded in ORD/CDD.

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result		Reason
FY 2003					
F-22	USAF	1D	Effective	Not Suitable	RAM; needed more maintenance resources and spare parts; BIT.

SE Issues		
Issue	**SE Area**	**Rationale**
Requirements	Reasonableness Verification	RAM requirements not fully defined for IOT&E but for a mature aircraft at 100K flight hours. RAM and BIT requirements not tracked/traced to a verification or test plan.
Acquisition Strategy	Acceptability; Sufficiency	Program did not recognize or fully fund RAM requirements and software development, especially the maintenance software portion. Labs were insufficiently supported with hardware-in-the-loop.
Technical Process	System Integration, Test, and Verification	Program did not establish entrance/exit criteria for software development, verification, validation, and test. Software not adequately tested and fixed in the lab prior to flight test. Mission technical issues overshadow RAM issues and RAM resources diverted to technical mission issues. Program did not have a sound risk assessment program.

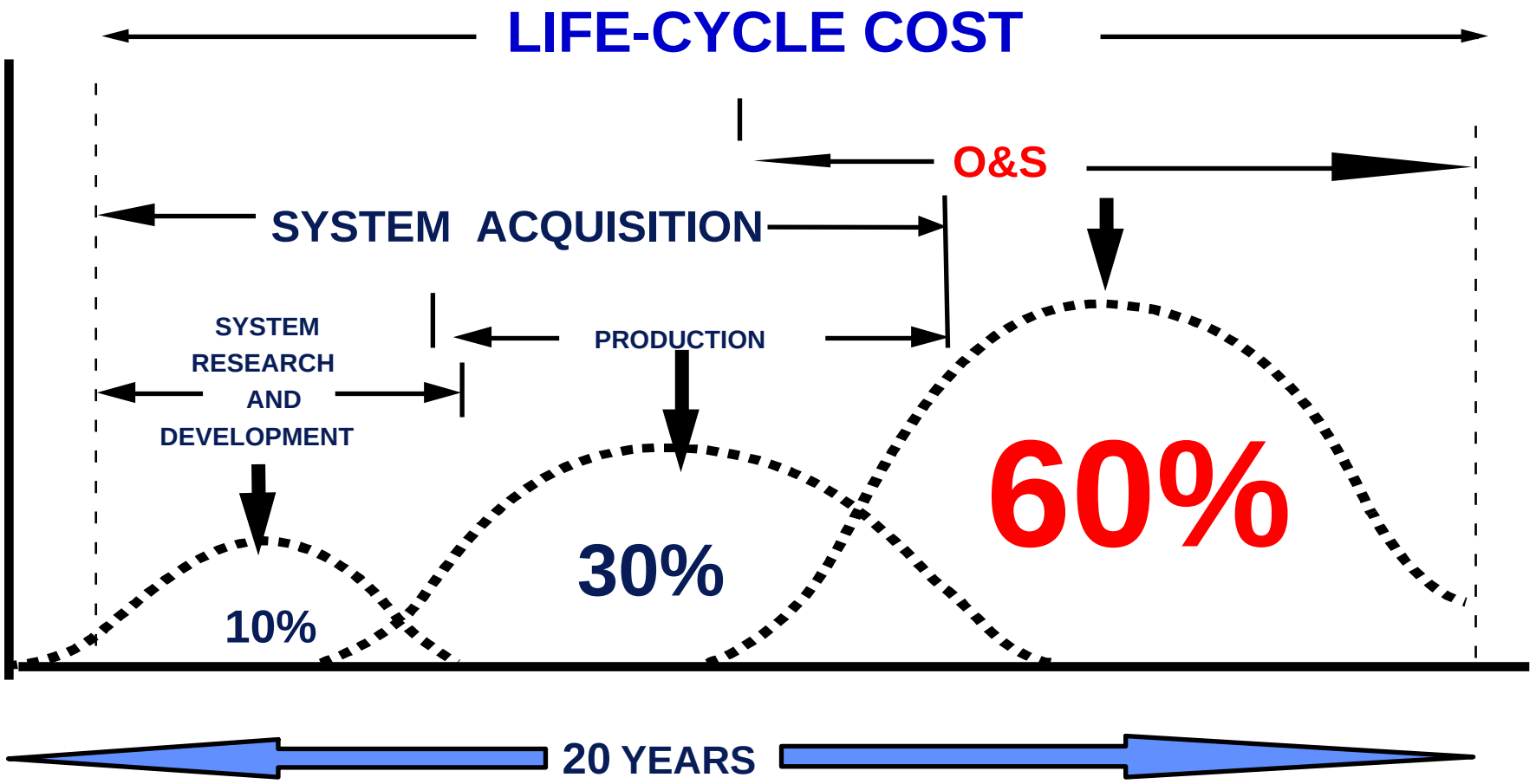
Additional Costs When a System is Judged Unsuitable (1)

- Some programs extended their SDD and added resources to redesign, reengineer and to retest till they became suitable
  - V-22 extended its SDD by five years and spent ~$1B to resolve its suitability issues. (It had a catastrophic failure in 2000)
  - C-17 is likely to be another interesting case.
- When failure in OT&E delays the full production and the fielding of a new system, it may require extra cost to operate and support, and in some cases, even Service Life Extension Program (SLEP) on legacy systems.

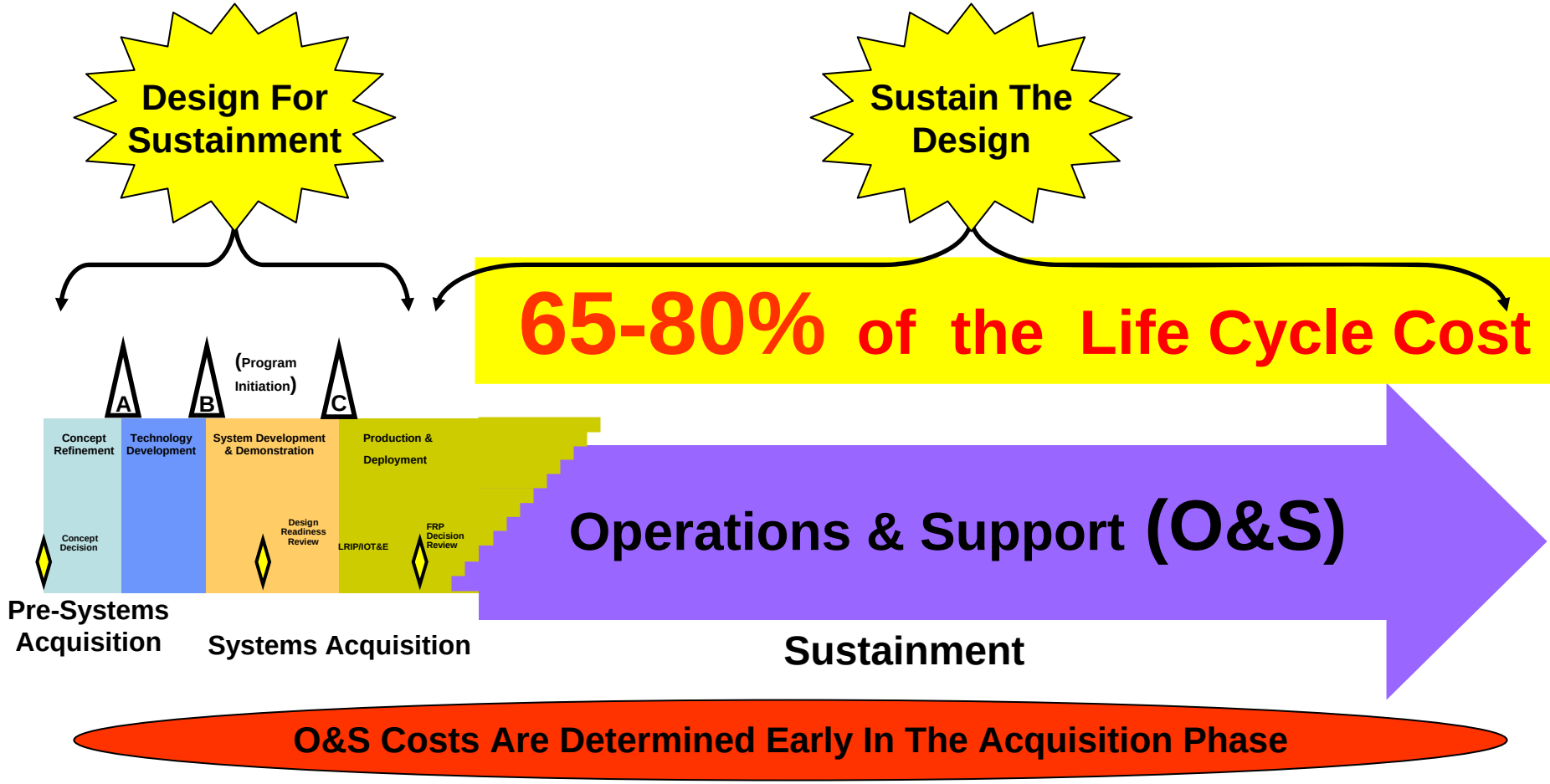
Additional Costs When a System is Judged Unsuitable (2)

- Some programs were granted FRP and delayed RAM remedial actions as Block Upgrades
  - Approach requires additional cost for RDT&E and retrofit. It is also more expensive to maintain and support several different configurations than one.
  - It turns to a spiral development approach.
  - Identify related RAM development and retrofit costs
  - Estimate additional operating and support costs for extra configurations
- Some programs are fielded with known RAM shortcomings
  - Extra costs for repair and maintenance or contractor logistic support when fielded at insufficient RAM level
  - Possible cost to procure and operate additional units to compensate for low availability to meet desired sortie rates or ton-mile capacity

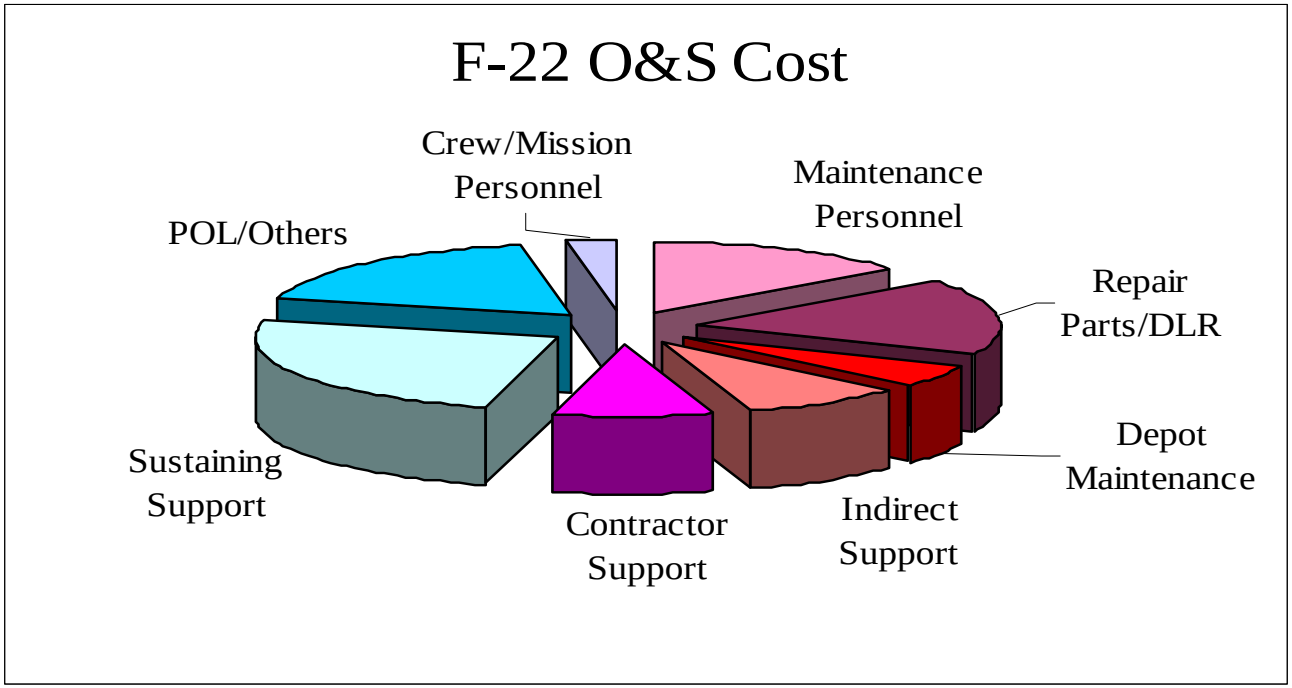
LCC Distribution



Life Cycle Management



R&M drives O&S Costs



R&M affects about half of F-22 O&S cost:

Maintenance personnel, repair parts/depot level repairables, depot maintenance, indirect support and contractor support

Four Causes

- No requirements
- Lack of incentives
- Attention elsewhere
- Poor Systems Engineering

JROC Memo: 17 Aug 2006

"MATERIEL AVAILABILITY" KPP for all MDAPs and Select ACAT II and III

(KSAs):

A. Materiel Reliability KSA

B. Ownership Costs KSA

JROC Approved* Mandatory Sustainment KPP and KSAs

- Single KPP:
  - **Materiel Availability** $\left(= \frac{\text{Number of End Items Operational}}{\text{Total Population of End Items}}\right)$
- Mandatory KSAs:
  - **Materiel Reliability** (MTBF)$\left(= \frac{\text{Total Operating Hours}}{\text{Total Number of Failures}}\right)$
  - **Ownership Cost** (O&S costs associated w/materiel readiness)
- Ownership Cost provides balance; solutions cannot be availability and reliability “at any cost.”

***JROC Approval Letter JROCM 161-06 Signed 17 Aug 06; Revised CJCS 3170 will put into Policy**

Return on Investment

Estimate O&S and Initial Spares of Different F-22 MTBMs (Constant 2006 $B)

Reliability Level at Maturity		MTBM in Hours (1)	O&S & Initial Spares (2)	Life Cycle Cost Difference (3)
FOT&E Actual	(1a)	**0.65**	**$ 42B**	**$ 7B**
IOT&E Actual with Historical Growth	(1b)	**0.83**	**$ 40B**	**$ 5B**
Air Force Program Reliability Projection	(1c)	**1.50**	**$ 35B**	

(1) Mean Time between Maintenance. F-22 ORD established MTBM threshold at 3 hours.
- (1a) MTBM of 0.65 hours achieved in Follow-on Operational Test and Evaluation (FOT&E).
- (1b) IOT&E MTBM score 0.45 hours. F-22 will achieve MTBM of 0.825 hours at maturity (100,000 FH), if its reliability growth rate is similar to the historical rates of existing fighter aircraft programs.
- (1c) Air Force Program Office projects F-22 to achieve 1.5 hours MTBM at maturity.

(2) O&S cost for 148 Primary Aerospace vehicle Authorization (PAA), 336 flying hours per aircraft per year for 24 years. Initial spares requirement for 182 Total Active Inventory (TAI), computed at $120M recurring flyaway cost each.

(3) Baseline assumes the Air Force projected 1.5 hours MTBM at maturity. At the F-22 ORD MTBM threshold of 3 hours, the estimated life cycle cost would be $4B lower than the baseline in constant 2006 dollars.

F-22 life cycle cost could be $5B – $7B (constant 2006) more if projected program reliability is not realized.

Return of R&M Investment
(Present Value 2006 $B)

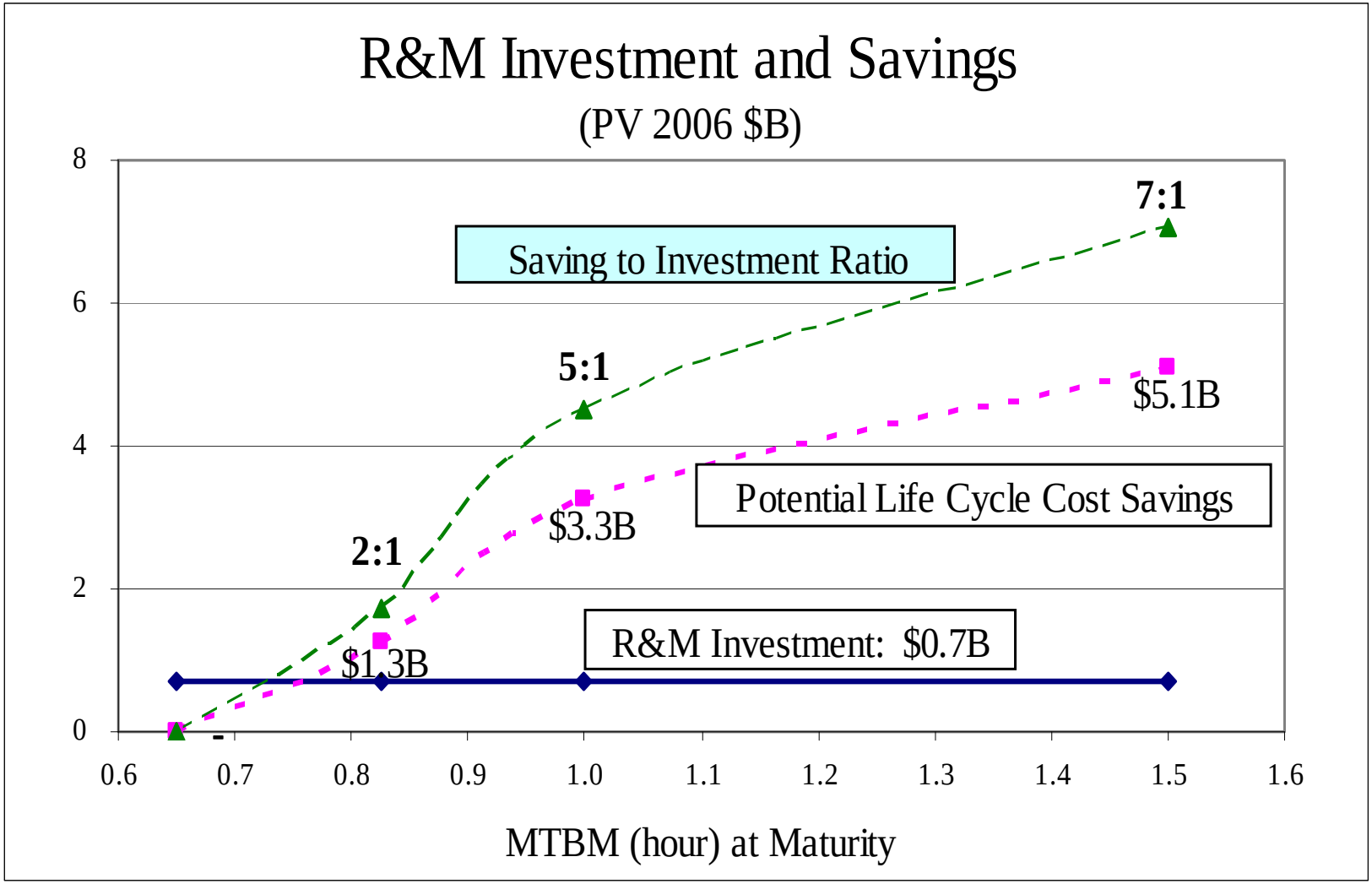
Reliability Level at Maturity	MTBM in Hours (1)	O&S & Initial Spares (2)	RDT&E & Retrofit (3)	Savings to Investment Ratio
FOT&E Actual	0.65	$ 30B		
Air Force Program Reliability Projection	1.50	$ 25B		
Potential Savings (4)		**$ 5B**		
Budgeted Investment			**$ 0.7B**	
Potential Return of Investment				**7 : 1**

(1) Mean Time between Maintenance. F-22 ORD established MTBM threshold at 3 hours.
F-22 Follow-on Operational Test and Evaluation (FOT&E) MTBM score 0.65 hours.
Air Force Program Office projects F-22 to achieve 1.5 hours MTBM at maturity.

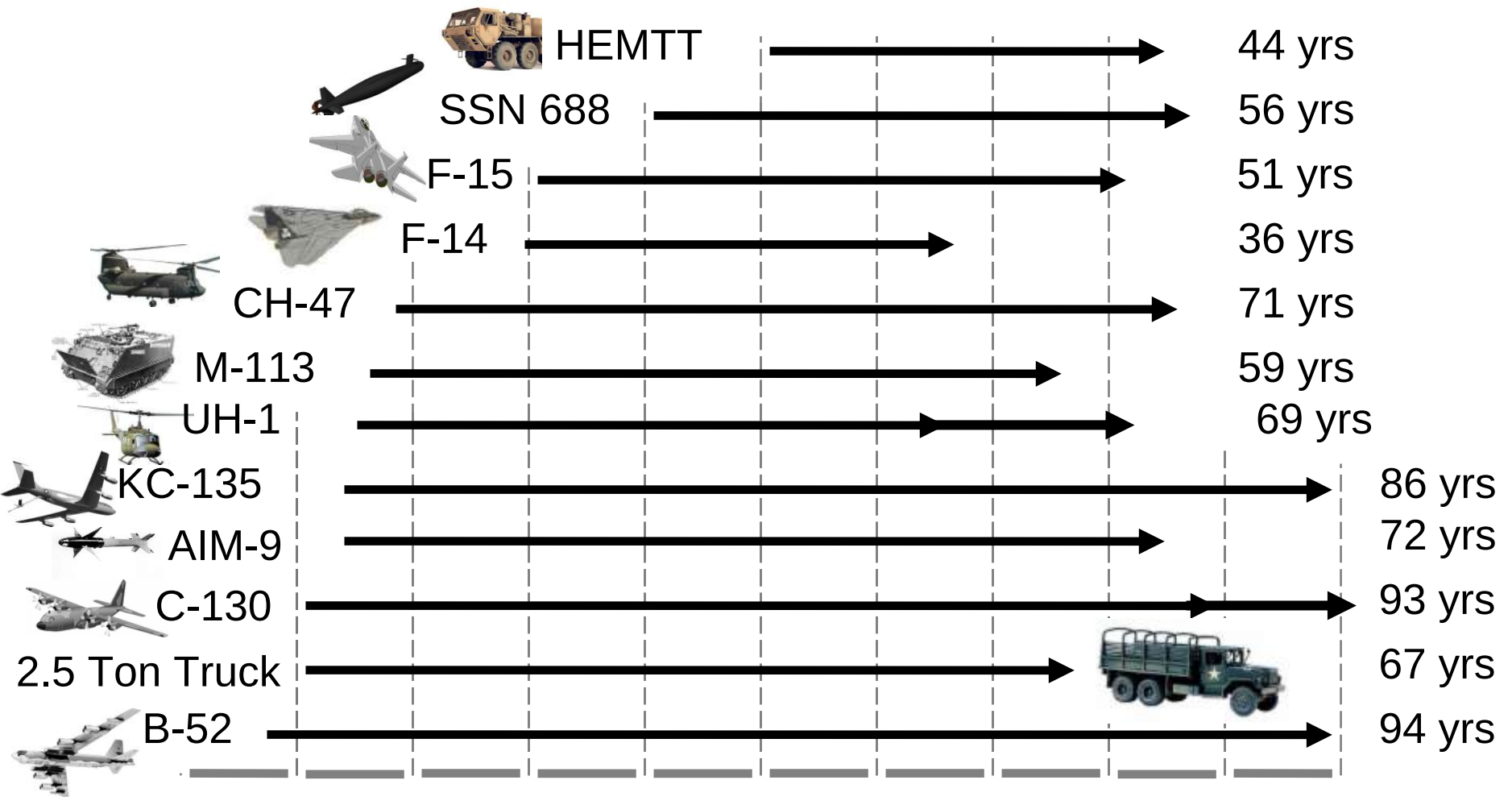
(2) O&S cost for 148 Primary Aerospace vehicle Authorization (PAA), 336 flying hours per aircraft per years for 24 years.
Initial spares requirement for 182 Total Active Inventory (TAI), costed at $120M recurring flyaway cost per aircraft.

(3) President Budget Submission (February 2005 and February 2006):
F-22 Reliability and Maintainability Maturation Program (RAMMP).
F119 engine Component Improvement Program (CIP).
R&M retrofits: air vehicle RAMMP modification and F119 engine CIP modification

(4) Saving will be substantially lower if F-22 does not achieve MTBM of 1.5 hours at maturity.


R&M Investment and Savings
(PV 2006 $B)
8
6
4
2
0
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
7:1
Saving to Investment Ratio
5:1
$5.1B
Potential Life Cycle Cost Savings
$3.3B
2:1
$1.3B
R&M Investment: $0.7B
-
MTBM (hour) at Maturity

Defense System Life Cycles



SOURCE: John F. Phillips DUSD (L)

Myths about Building-in Reliability, Availability and Maintainability

Myth 1: Building-in Reliability costs money.

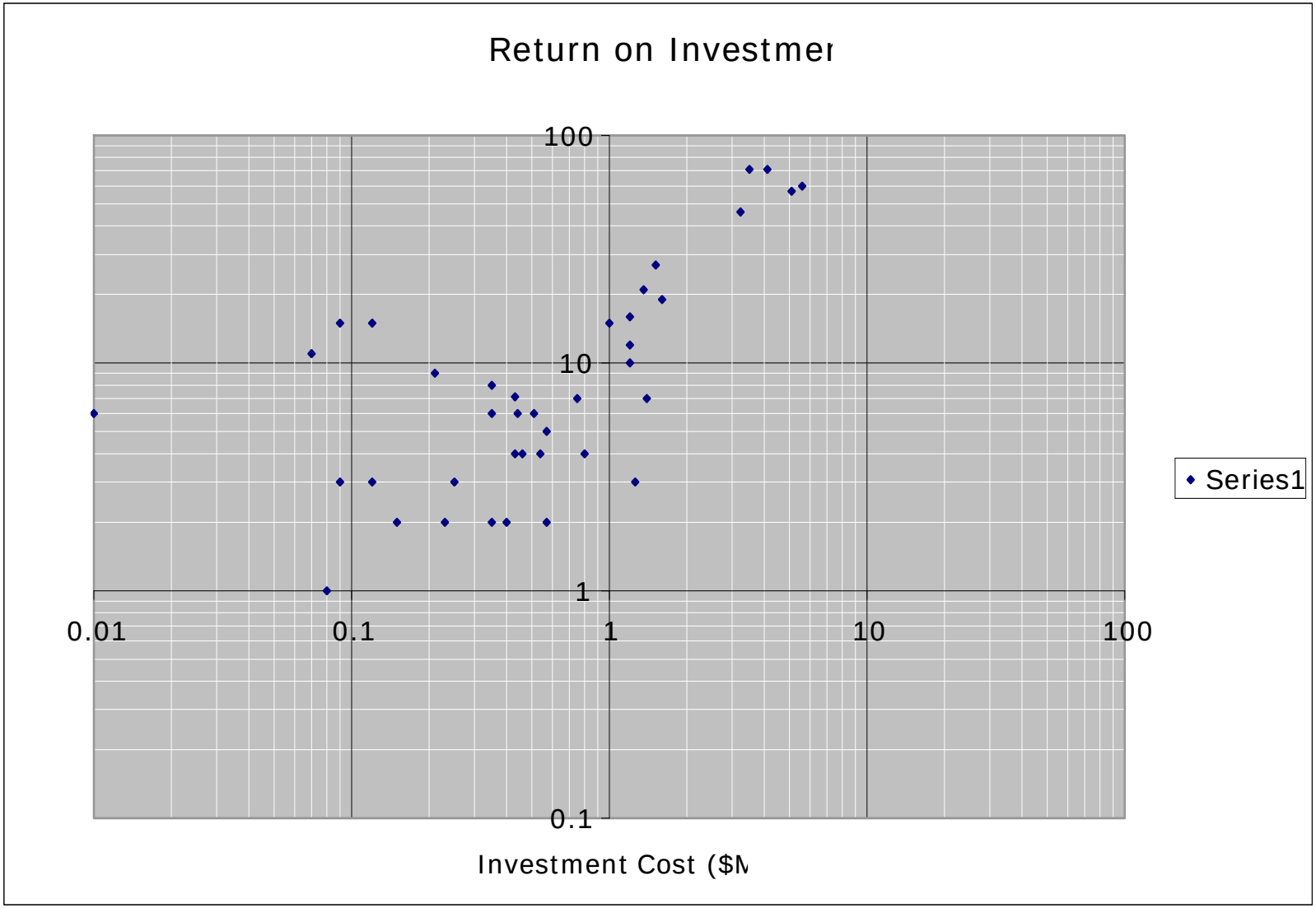
HH-60H and MH-60S Reliability and Cost Comparison

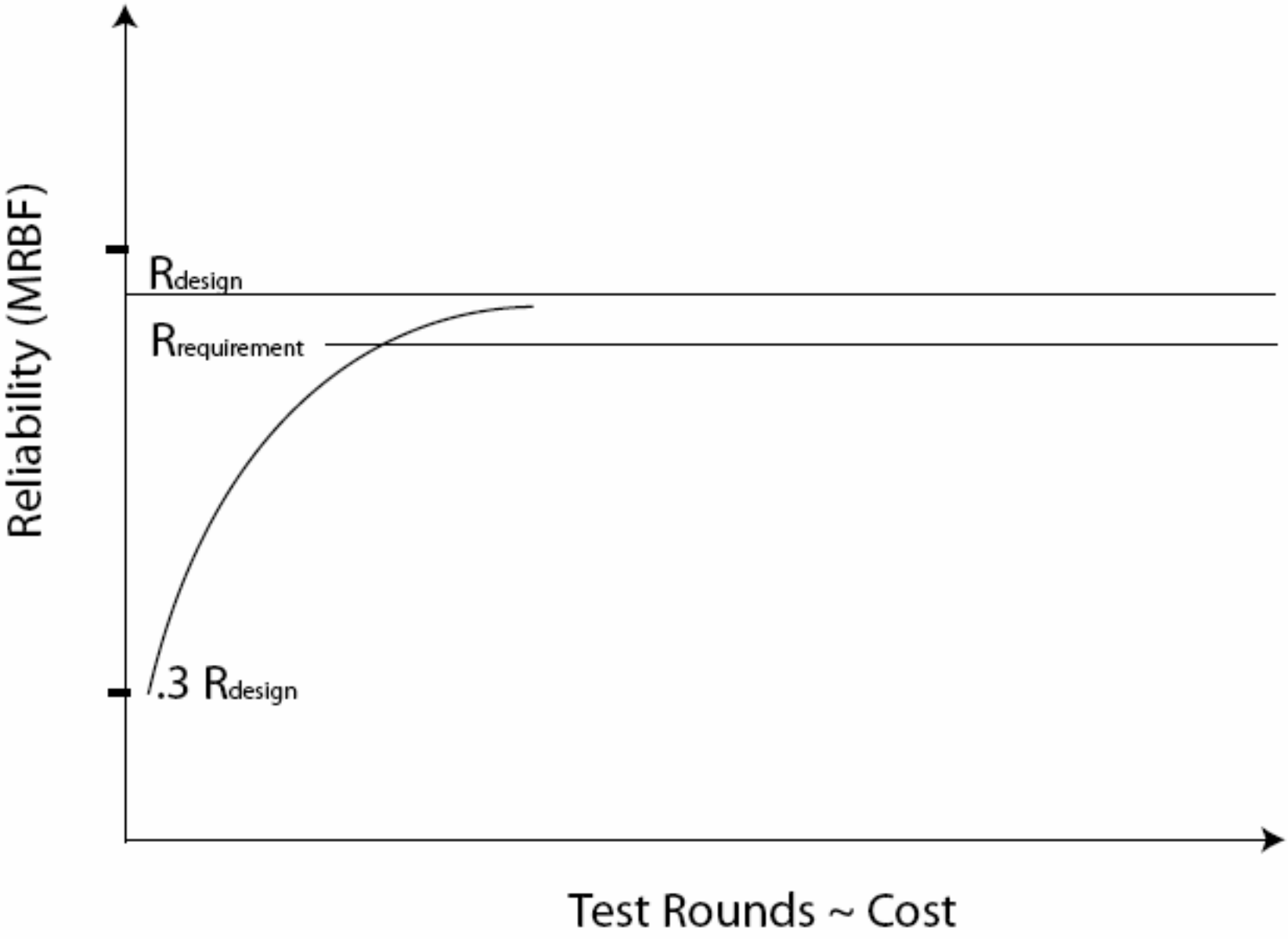
HH-60H		
Component	**MFHBR**	**PUC (FY07$K)**
CPU159/A AFCS COMPUTER	582	$180
AUXILIARY POWER SYSTEMS	2,160	$86
SECT'S 2/3/4 DRIVE SHAFT ASSY	6,480	$4
CP1820/ASN150 NAV COMPUTER	434	$99
STABILATOR AMPLIFIER INSTALL	549	$34
MLG DRAG BEAM/AXLE ASSY	*>10,000	$24
FLOOR ASSEMBLY	*>10,000	$10
T1360( )/ALQ144(V) TRANSMITTER	582	$52

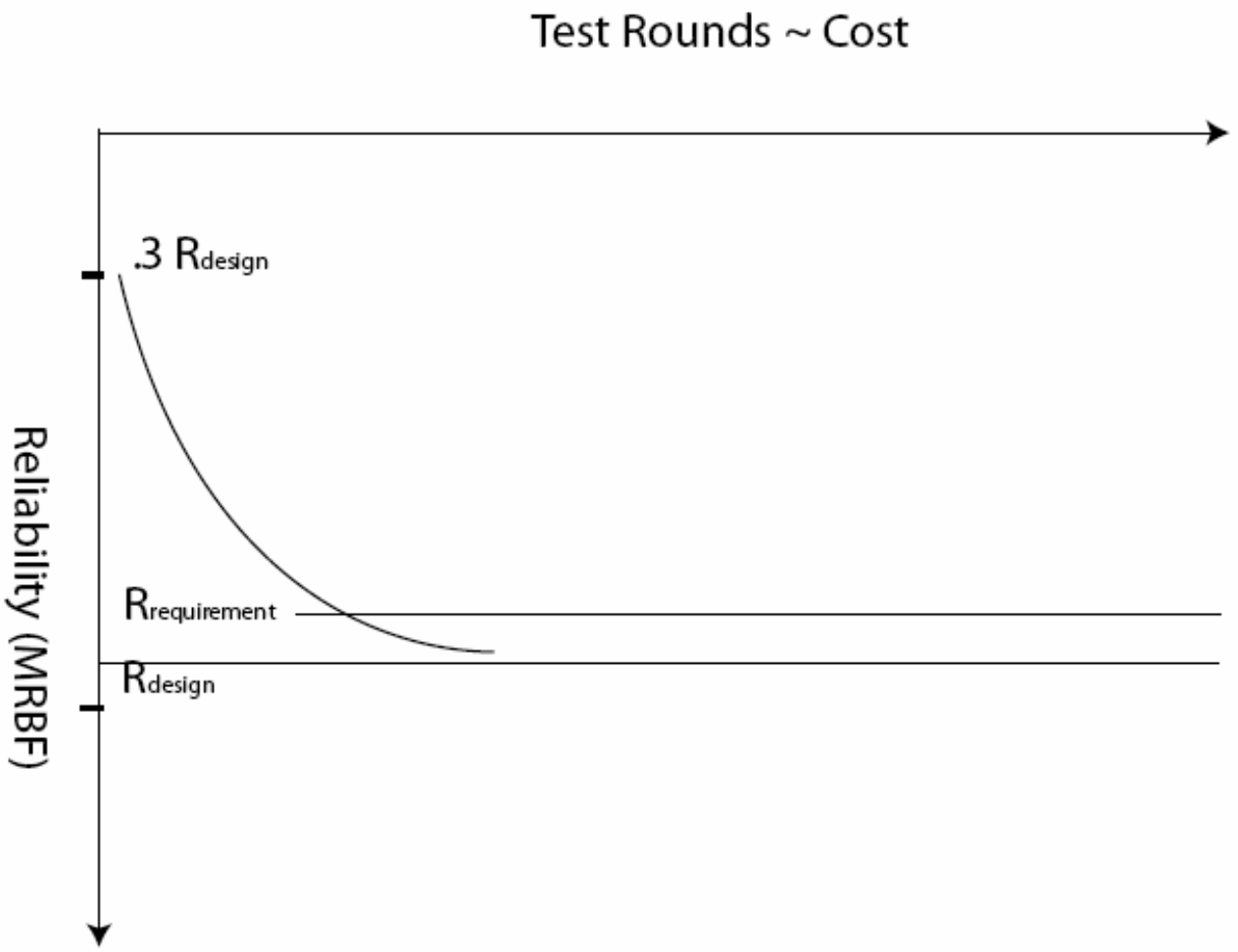
MH-60S		
Component	**MFHBR**	**PUC (FY07$K)**
CPU133/A DIGITAL COMPUTER	1,944	$86
ACFT POWER UNIT	*>10,000	$80
SECTIONS 2/3/4 DRIVE SHAFT ASSY	*>10,000	$4
CP-2428/A DIGITAL DATA COMPUTER	2,236	$84
AMPLIFIER INSTALLATION	1,351	$43
BEAM-AXLE ASSEMBLY	*>10,000	$26
AIRCRAFT FLOOR	*>10,000	$20
LIGHT,INFRARED TRANSMITTER	*>10,000	$5

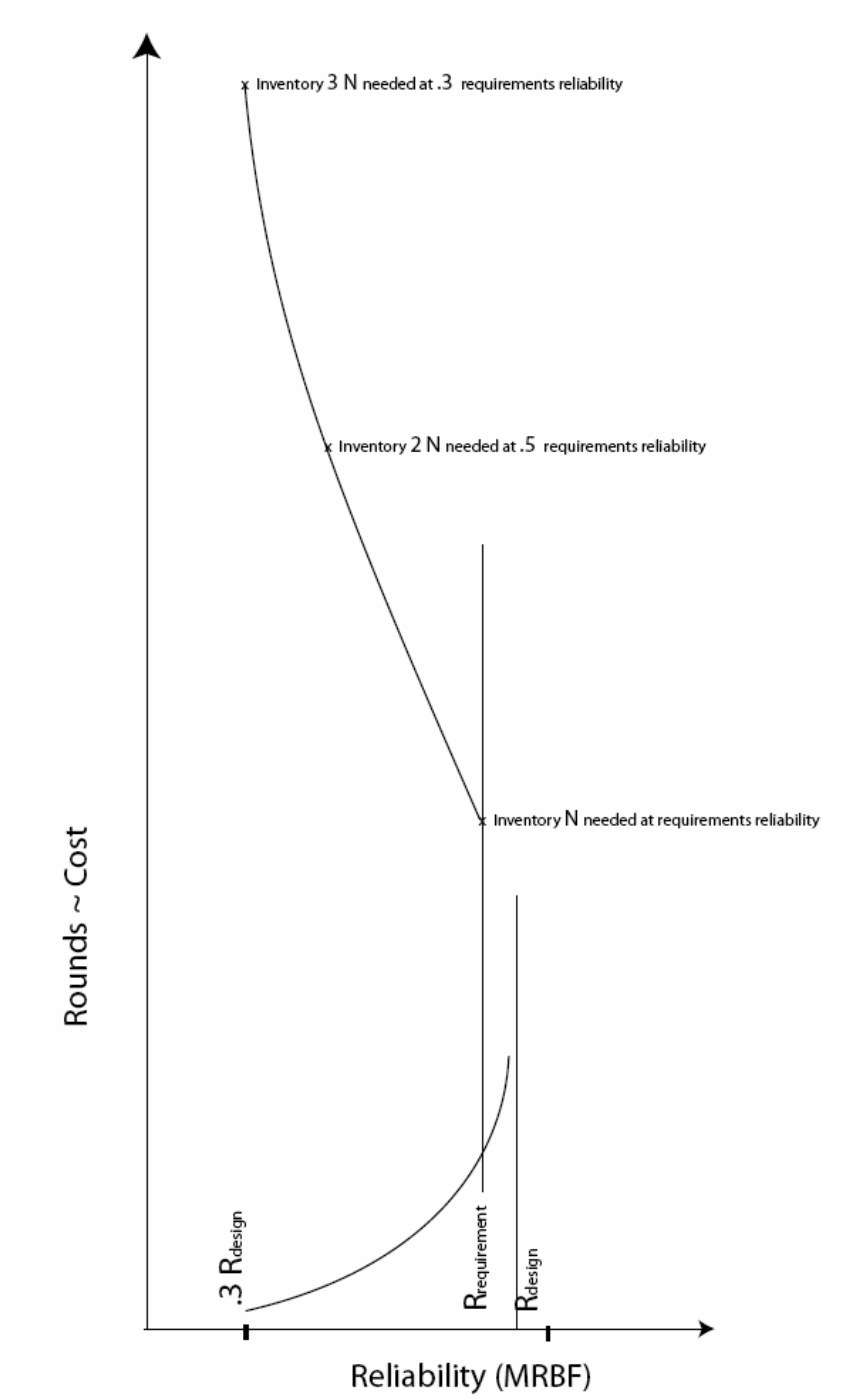
* 0 failures observed in one year

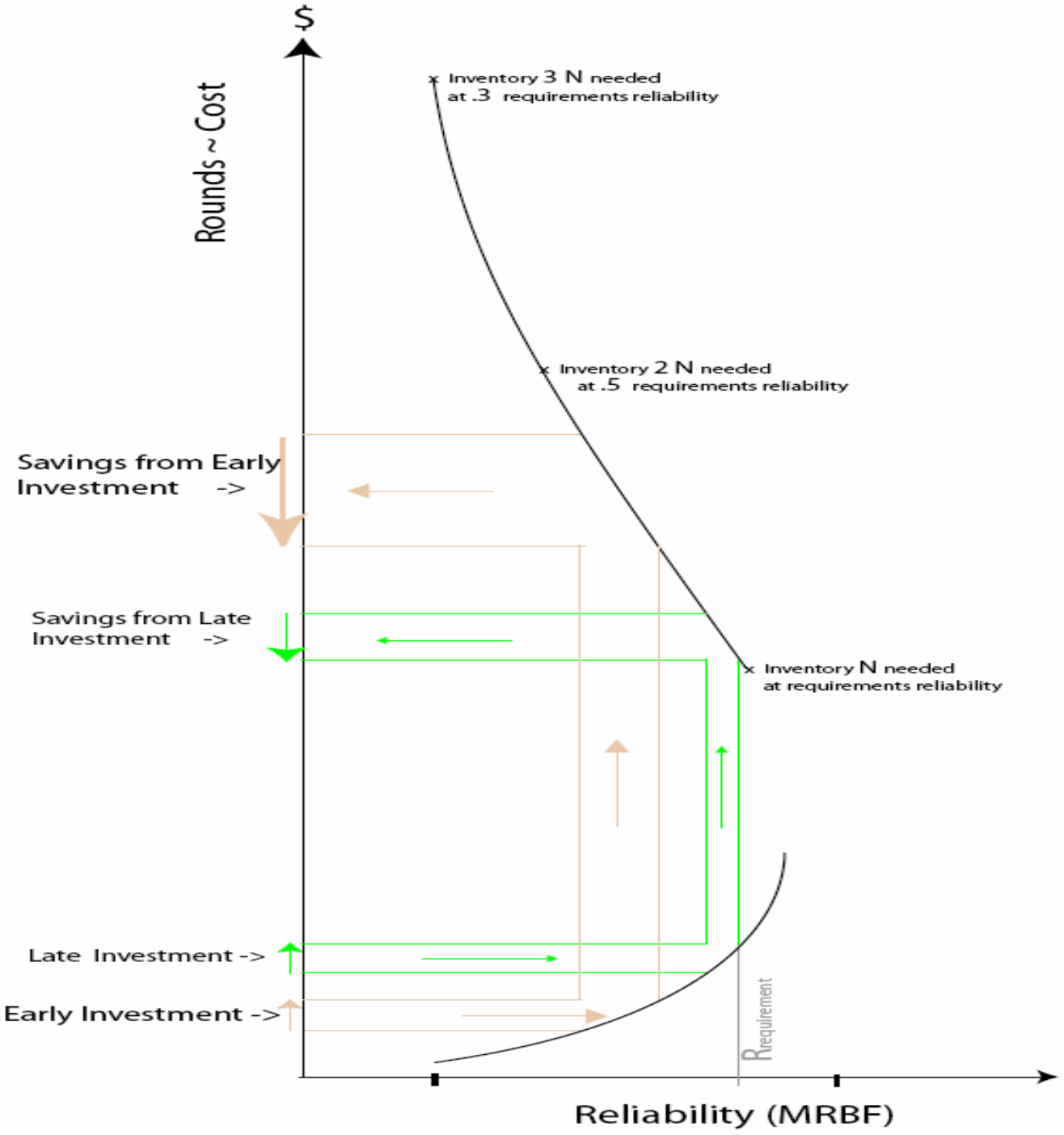
When to Invest?


Return on Investmer
100
10
1
0.1
0.01
0.1
1
10
100
Series1
Investment Cost ($M

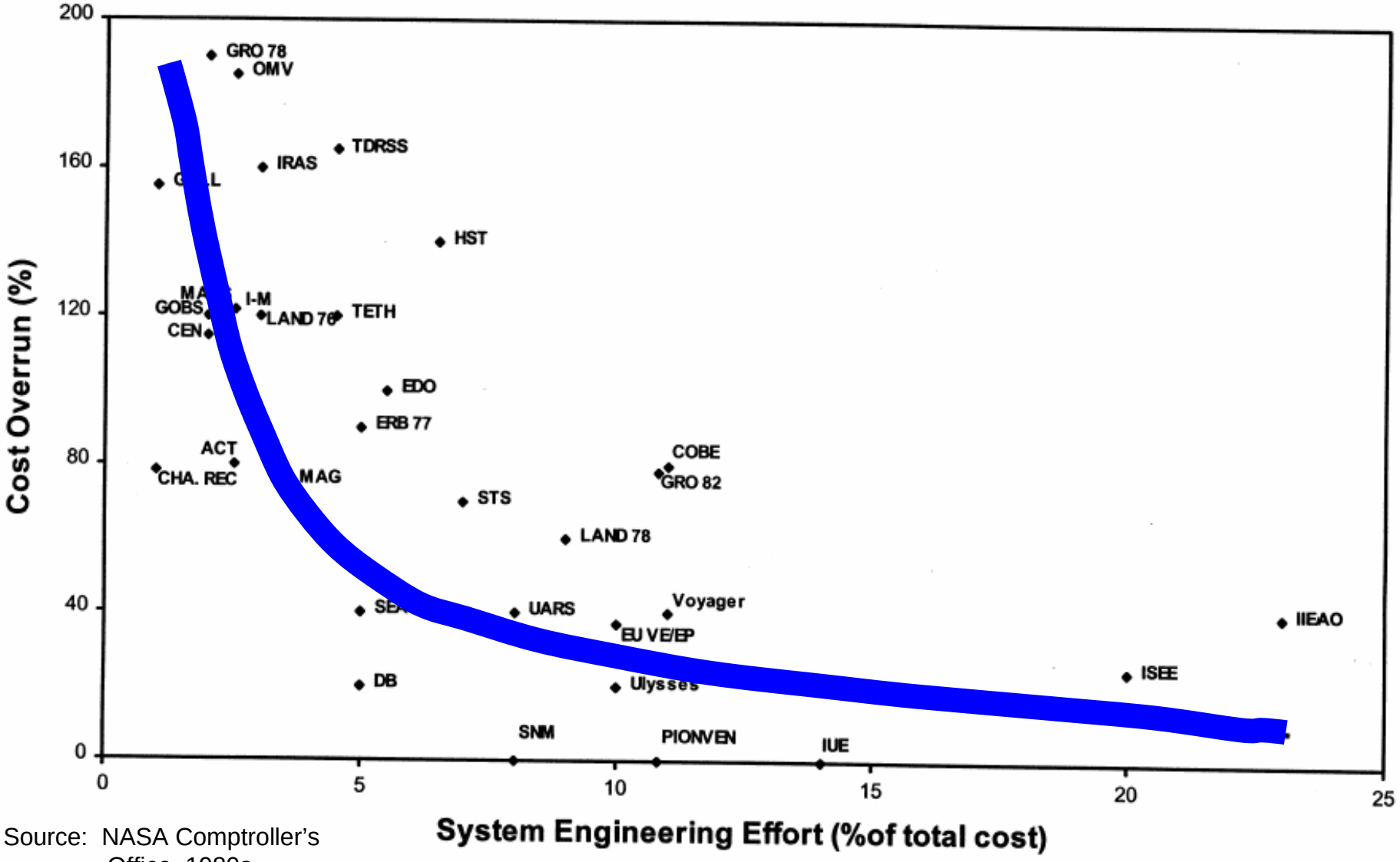

Reliability (MRBF)
Rdesign
Rrequirement
.3 Rdesign
Test Rounds ~ Cost


Test Rounds ~ Cost
.3 Rdesign
Reliability (MRBF)
Rrequirement
Rdesign


Inventory 3 N needed at .3 requirements reliability
Inventory 2 N needed at .5 requirements reliability
Inventory N needed at requirements reliability
Rounds ~ Cost
.3 Rdesign
Rrequirement
Rdesign
Reliability (MRBF)


$
Rounds ~ Cost
Inventory 3 N needed
at .3 requirements reliability
Inventory 2 N needed
at .5 requirements reliability
Inventory N needed
at requirements reliability
Savings from Early
Investment ->
Savings from Late
Investment ->
Late Investment ->
Early Investment ->
Rrequirement
Reliability (MRBF)

The Value of SE



– Source: NASA Comptroller's Office, 1980s

The Value of SE (cont.)

LTV Aerospace and Defense Company study on the benefits of the SE process – 1992

- Product development time reduced by as much as 60%
- Engineering change orders reduced by 50%
- Redesign and rework effort reduced by as much as 75%
- Manufacturing costs reduced by as much as 40%

Source: James Martin, Systems Engineering Guidebook, 1997

Benefits of Systems

Launch (Project)	# of Points	Cost ($K)	$ / Point	Use SE?
System 1	12,934	30,000	2,319	No
System 2	10,209	14,904	1,460	Yes
System 3	4,678	6,614	1,414	Yes
System 4	8,707	18,075	2,076	No
System 5	1,223	2,400	1,962	No
System 5	4,600	10,309	2,241	Yes
Total/Average	**42,351**	**82,302**	**1943**	**N/A**
Total/Average with SE	**19,487**	**31,827**	**1,633**	**Yes**
Total/Average without SE	**22,864**	**50,475**	**2,208**	**No**
Percent improvement			**35.17%**	

Over a two year span, IBM has seen a 35% cost saving (productivity improvement) in large-scale integration projects that use the Systems Engineering process.

Source: “Application of Templates and Metrics to Enhance and Assess Systems Engineering Effectiveness in the IT Sector”, D. Verma and P. Popick, Jan. 8, 2003.

Summary

- How to Address Problems
- Size of ROIs
- When to invest

THE END

Weapon Systems

CH-47
Multiple
UH-60
AH-64
CH-47 & AH-64
H-47/H-64
Ground Support
Patriot Missle
B-1B
A-10
F-16
C-130
B-52
C-5A/F-15
F-15
F-15/Multiple
F-15 & F-16
KC-135
F100/F-119
Minuteman
Multiple (Fuel)
F/A-18
Multiple (Navy)
EA-6B
H-60
AV-8B
T-64
F404
AH-1/H-46
C-130/P-3
CH-46
E2-C-2
EA-6B, E-2/C-2
F/A-18 & E2/C2
H-1
HMMWV
T-58
T700
UH-1

Assessing Cost and R&M

- Models to link Mean Time Between Maintenance and other R&M metrics to requirements for
  - Maintenance manpower
  - Sustaining spares
  - Initial spares
- F-22 example
  - Compare the O&S cost and initial spares requirement for a range of reliability assumptions, following established analytical approaches for other F-22 Studies.
  - Tabulate the trade-off between budgeted F-22 R&M investment (RDT&E and retrofit) and potential O&S and initial spares savings.