Parts Reliability and System Reliability

Yuan Chen[1], Amanda M. Gillespie[2], Mark W. Monaghan[2], Michael J. Sampson[3], Robert F. Hodson[1]

[1]NASA Langley Research Center, [2]SAIC-LX-2, NASA Kennedy Space Center, [3]NASA Goddard Space Flight Center

NEPP ETW 6-11-2012

Purpose

- **Parts reliability and system reliability**
  - Fundamental differences between basics
  - Relationship between parts reliability and system reliability
  - Impact of parts reliability on system reliability
- **Understanding the assumptions and limitations of each analysis**
  - Questions:
    - Using system reliability to direct parts selection
    - Interpreting system reliability in absolute values
  - Example: flight computing architectures for common launch vehicles
- **Misconceptions on parts selection strategy**

Outline

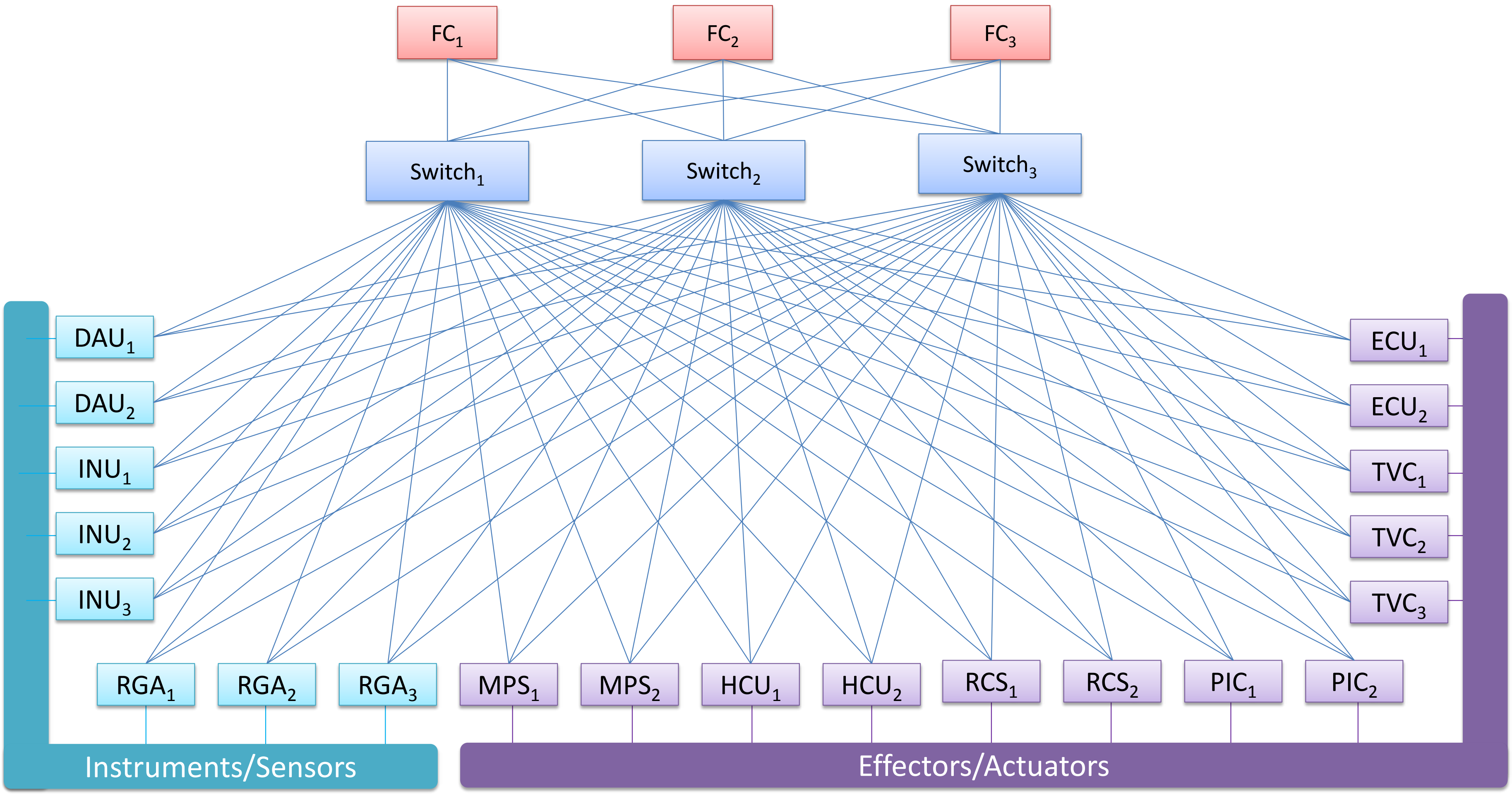
- Purpose
- Flight computing architectures
- System reliability analysis
- Parts reliability impact on architecture reliability
- Parts selection
- Conclusion

Flight Computing Architectures

- Fully Cross-Strapped Switched Triplex Voter (FCSSTV)
- Partially Cross-Strapped Switched Triplex Voter (PCSSTV)
- Channelized Bussed Triplex Voter (CBTV)
- Fully Cross-Strapped Switched Self-Checking (FCSSC)
- Fully Cross-Strapped Bussed Self-Checking (FCSBSC)
- Channelized Bussed Self-Checking (CBSC)

3 Voter, 3 Self-Checking
3 Switched, 3 Bussed
Highly Channelized, Partially & Fully Cross-Strapped Architectures

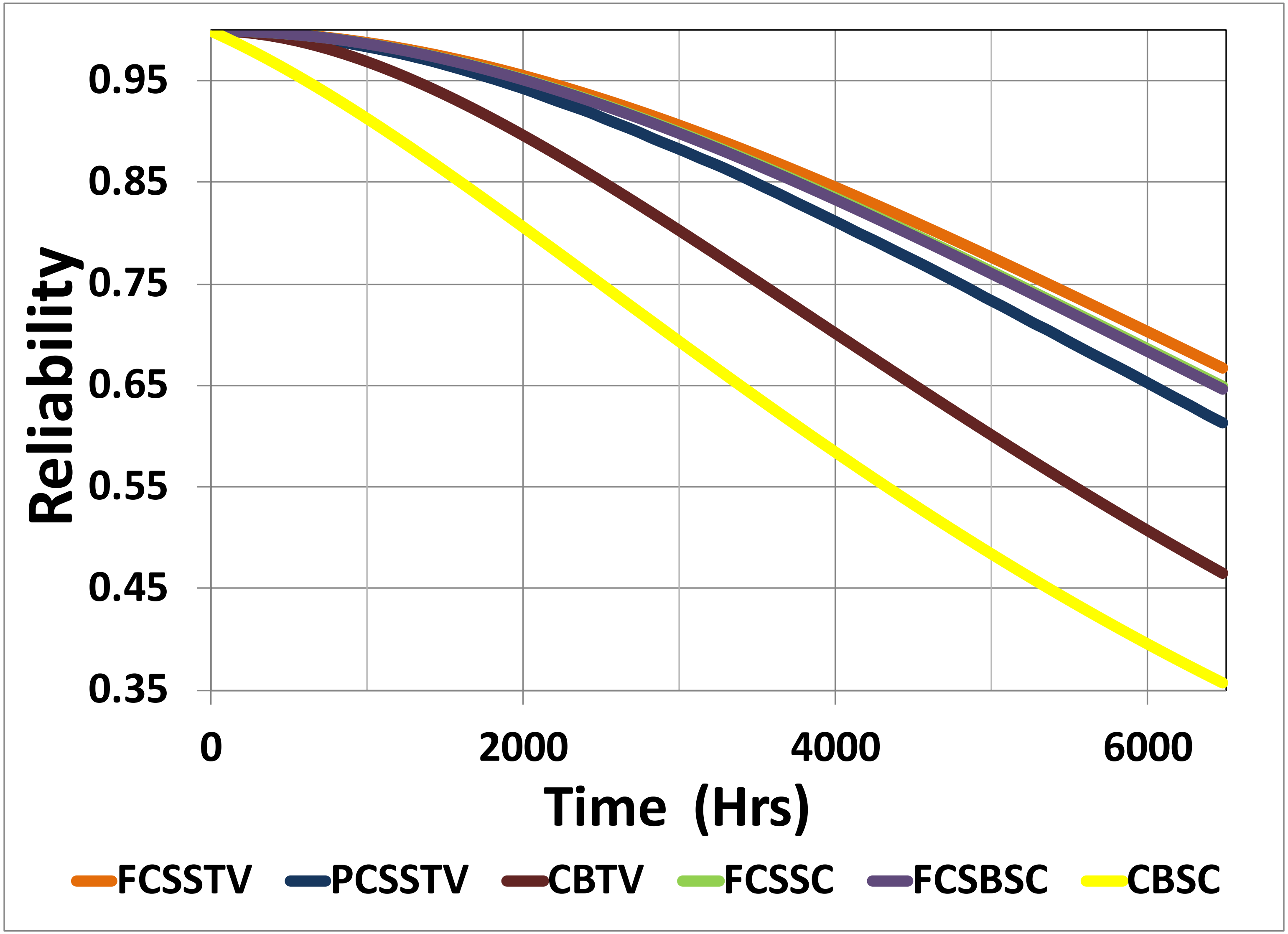
Example of Architectures



Assumptions

- **Fault tolerance**
  - **One fault tolerance by design for all function element groups**
- **Failure modes**
  - **Only hard or non-recoverable failures considered**
  - ***No common failure mode included***
- **Failure rate and failure criteria**
  - **Same for each type of sensors and effectors**

Architecture Reliability Plot



Architecture Reliability Table

Architecture	R (24 hrs)	R (9 months)
FCSSTV	0.999993	0.666999
PCSSTV	0.999991	0.613596
CBTV	0.999979	0.464581
FCSSC	0.999992	0.648547
FCSBSC	0.999992	0.646730
CBSC	0.999960	0.357675

Parts reliability does not matter for short missions??

This is system reliability; it is *<u>system</u>* reliability which does not show much difference, *<u>NOT parts</u>* !!

Exponential for System Reliability

- **Exponential** $MTTF_{\text{exponential}} = 1/\lambda$

⬇

Assumption: random defects; no infant mortality

⬇

- **Workmanship and proper build and assembly issues are not considered**
- **Results misleading if one or some of the parts not properly screened or used under certain bias condition when different failure modes may occur**

Weibull for System Reliability

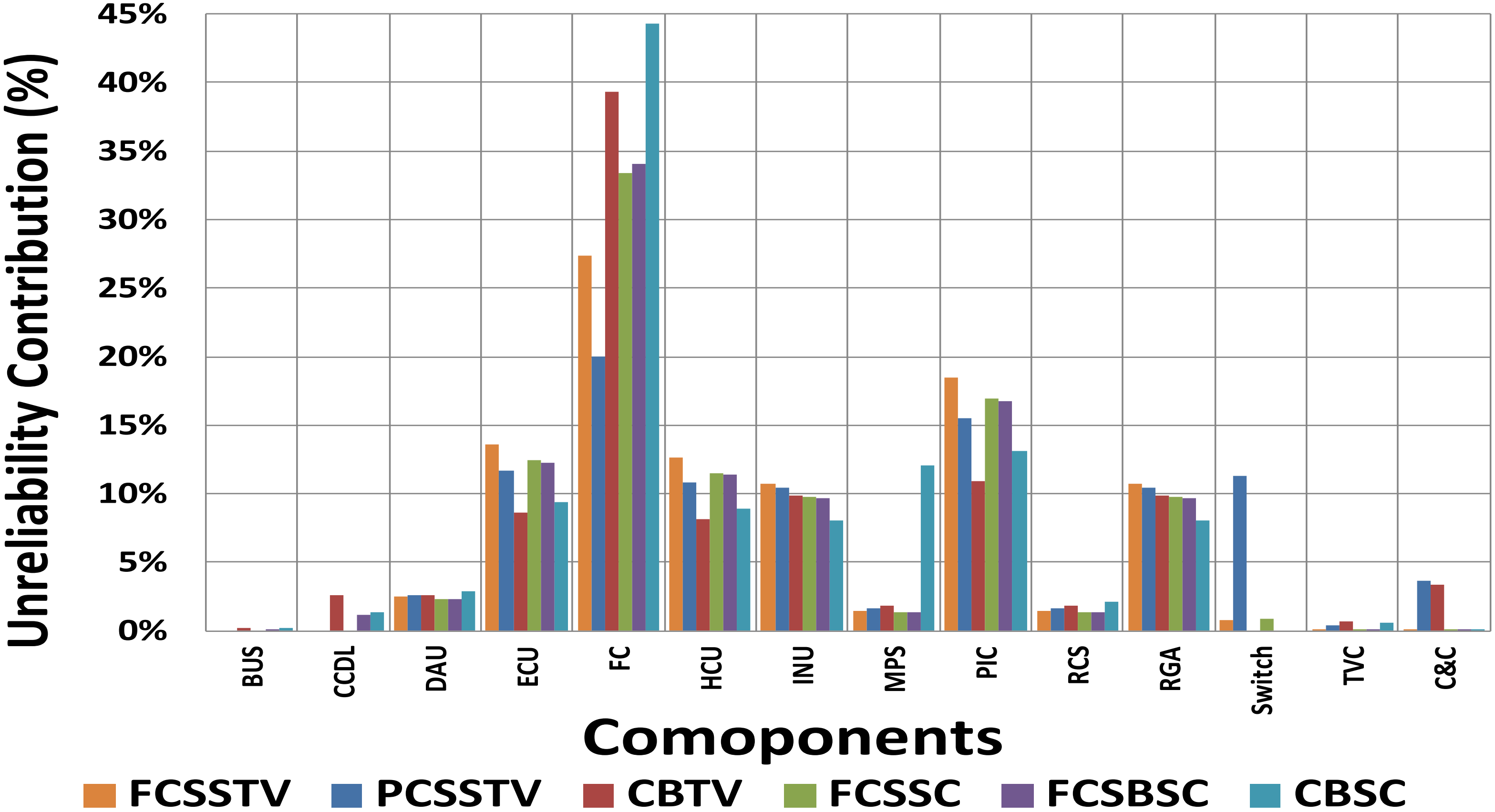
- **Weibull** $MTTF_{\text{Weibull}} = \alpha * \Gamma(\frac{1}{\beta} + 1)$
  - **Failure modes for β<1, =1, >1**
- **Weibull to replace Exponential in system reliability analysis *and*** $MTTF_{\text{Weibull}} = MTTF_{Exponential}$

Explore impact of parts operating in 3 regions by changing β

Assume the same parts lifetime

Impact of β only: impact of parts reliability in terms of operating regimes, not lifetime, on system reliability

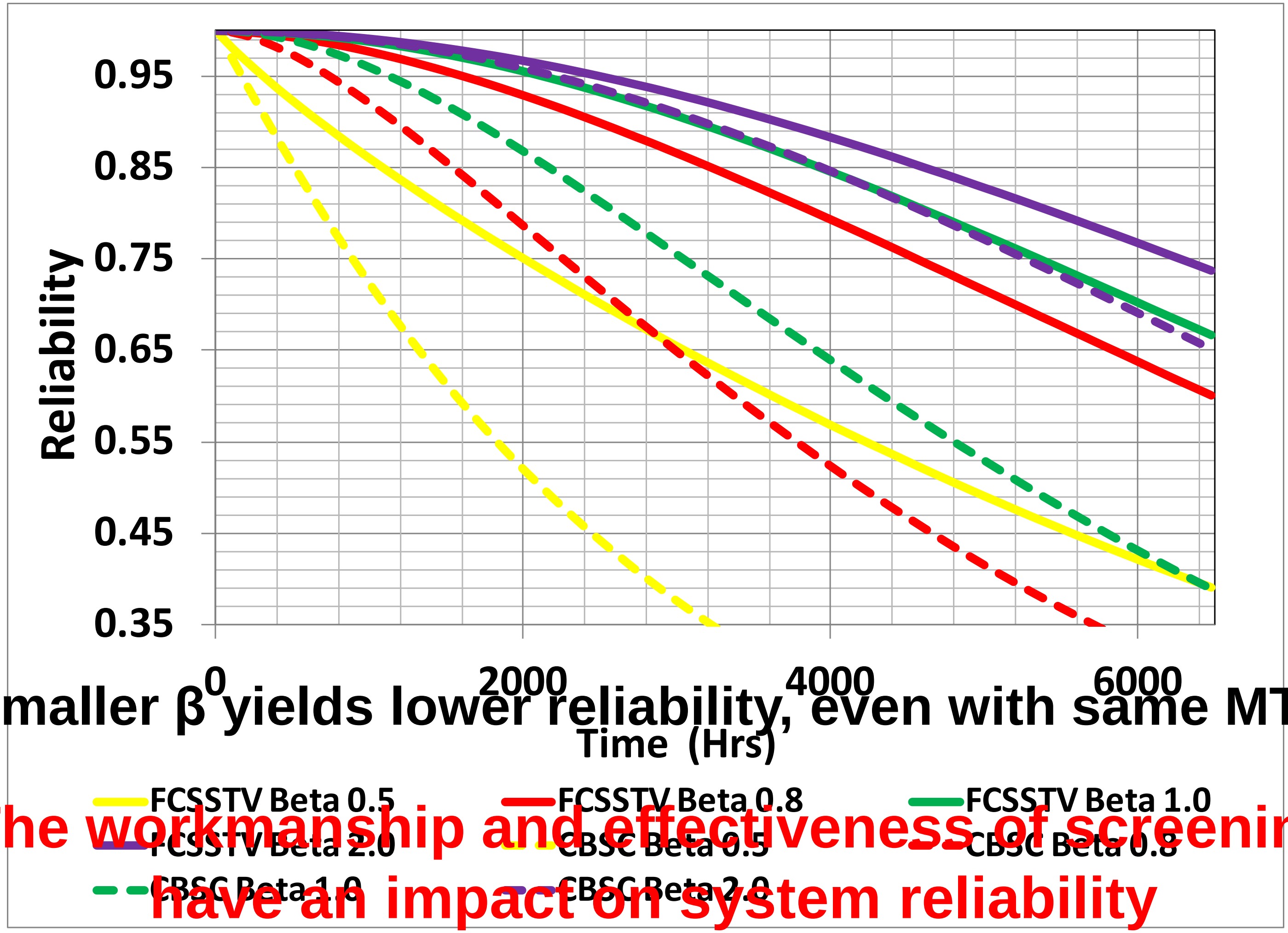
System Un-reliability Distribution



FC is the biggest contributor

Assume different β while keeping the same MTTF

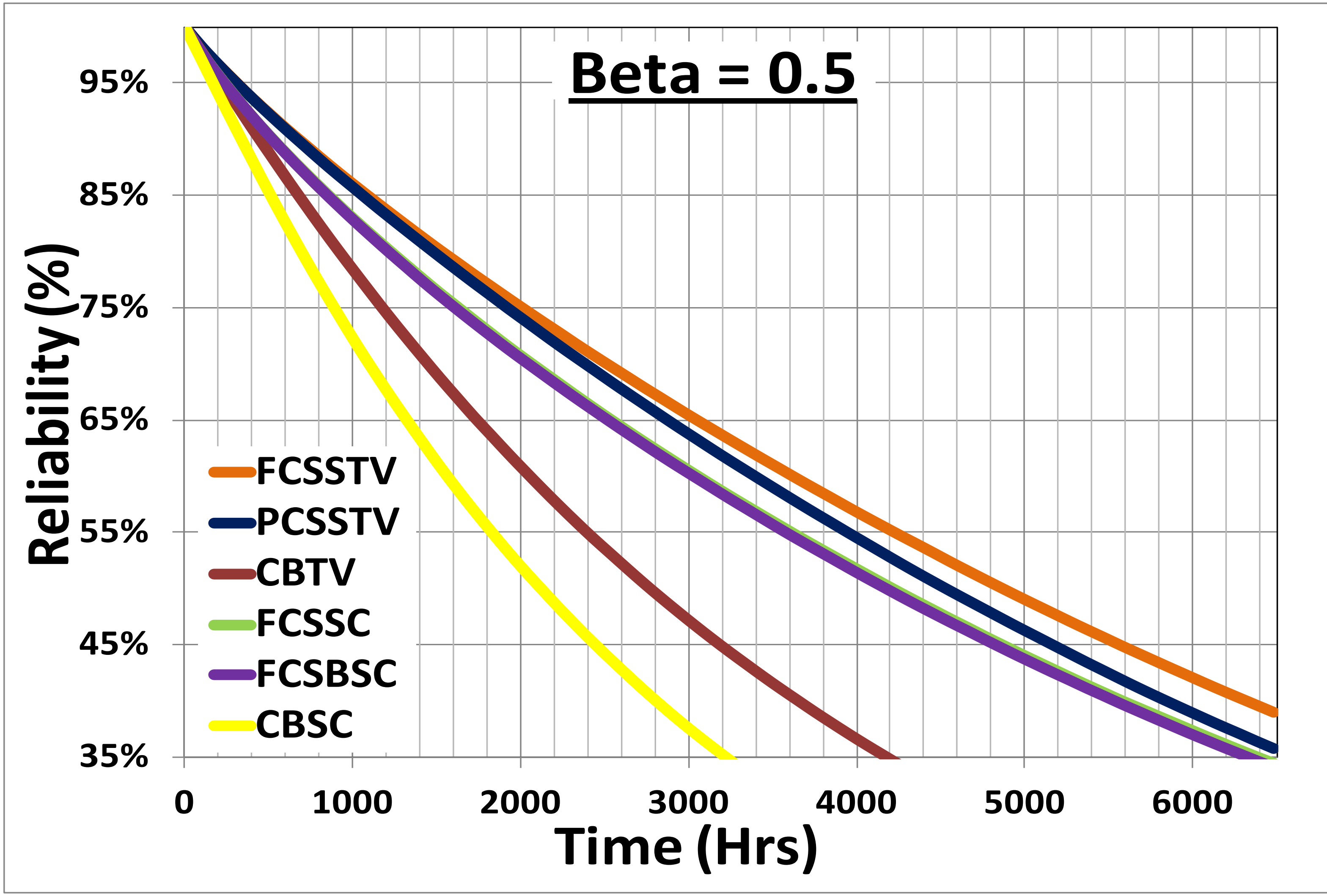
Impact of β



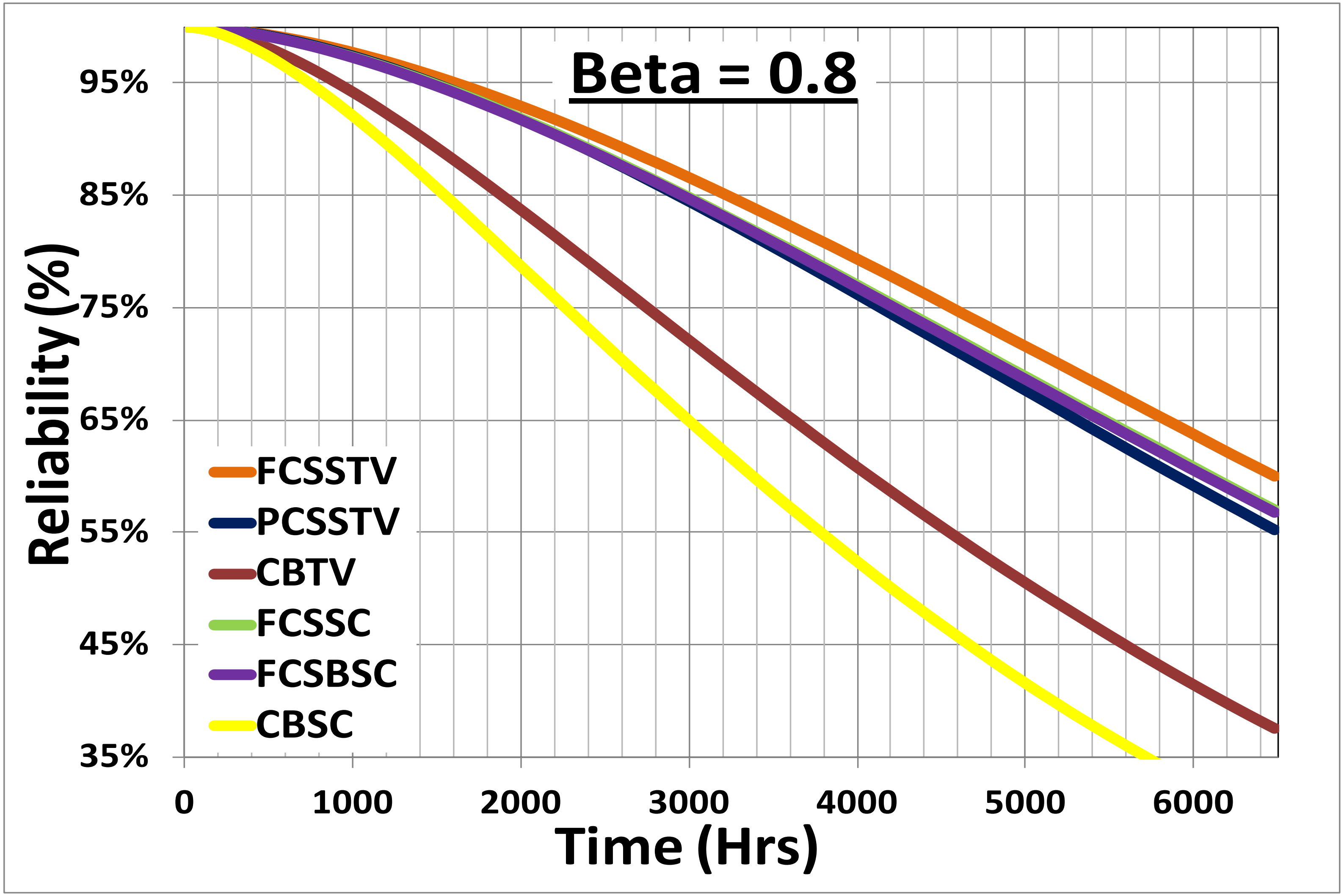
Smaller β yields lower reliability, even with same MTTF

The workmanship and effectiveness of screening have an impact on system reliability

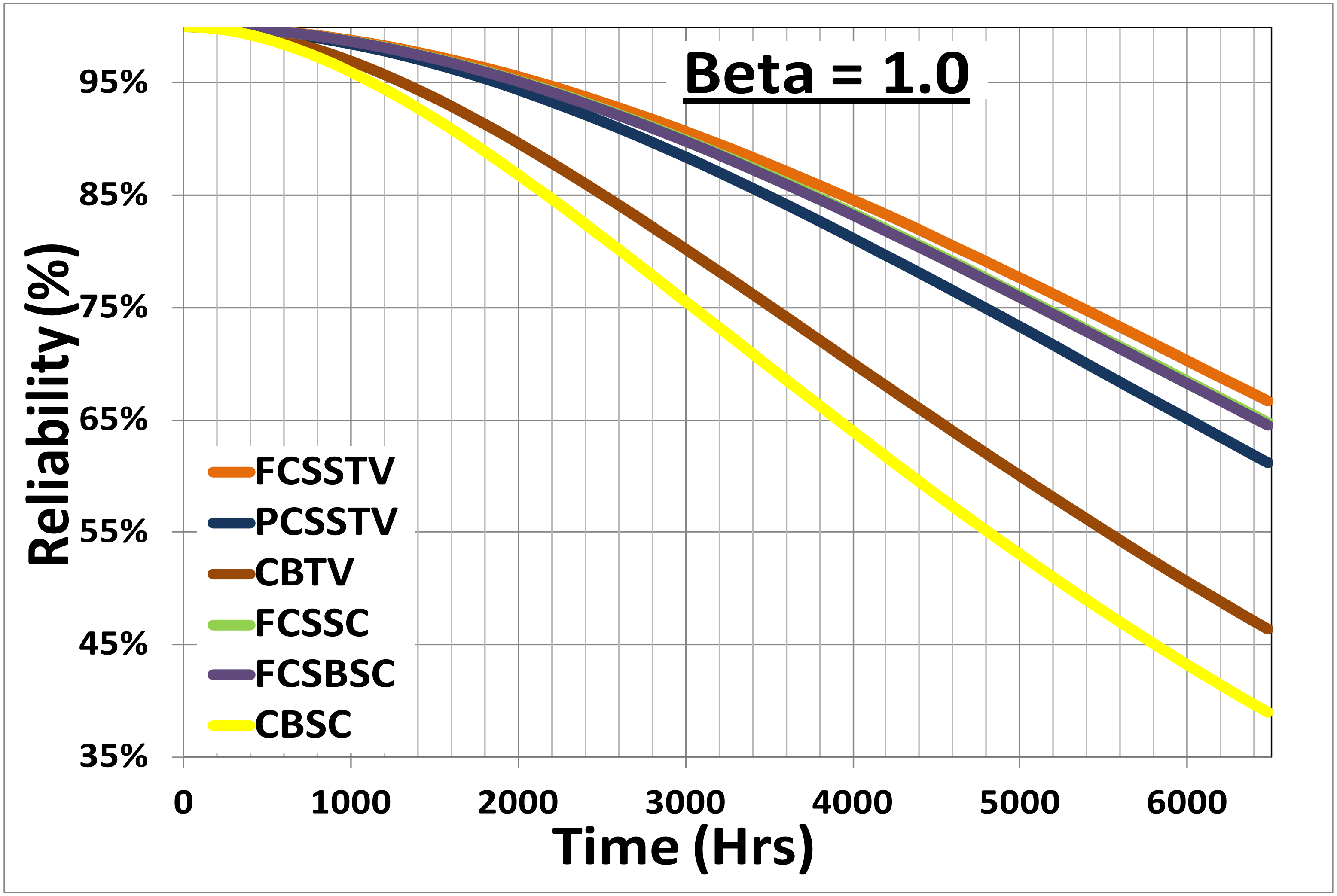
When Beta Changes



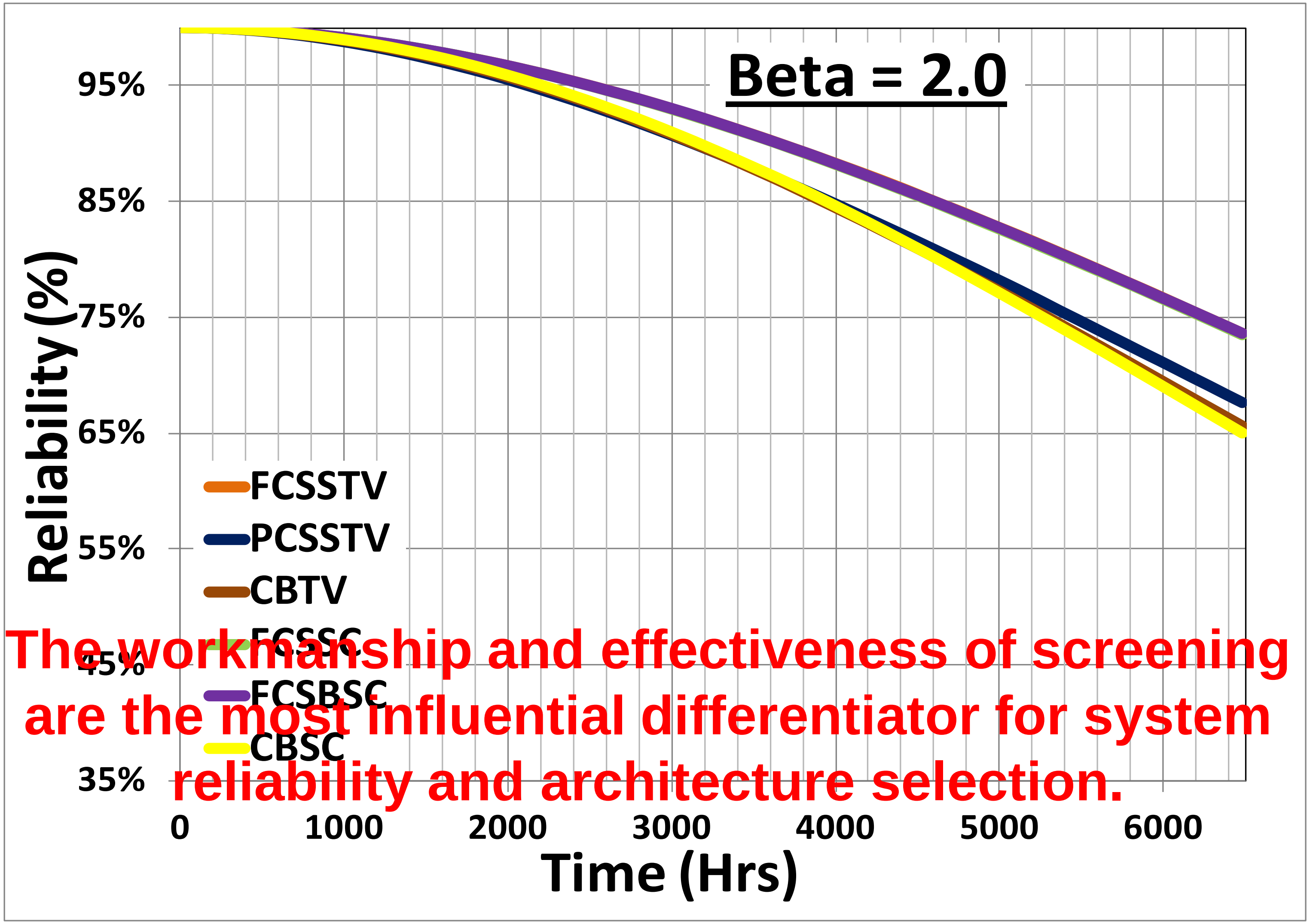
When Beta Changes



When Beta Changes



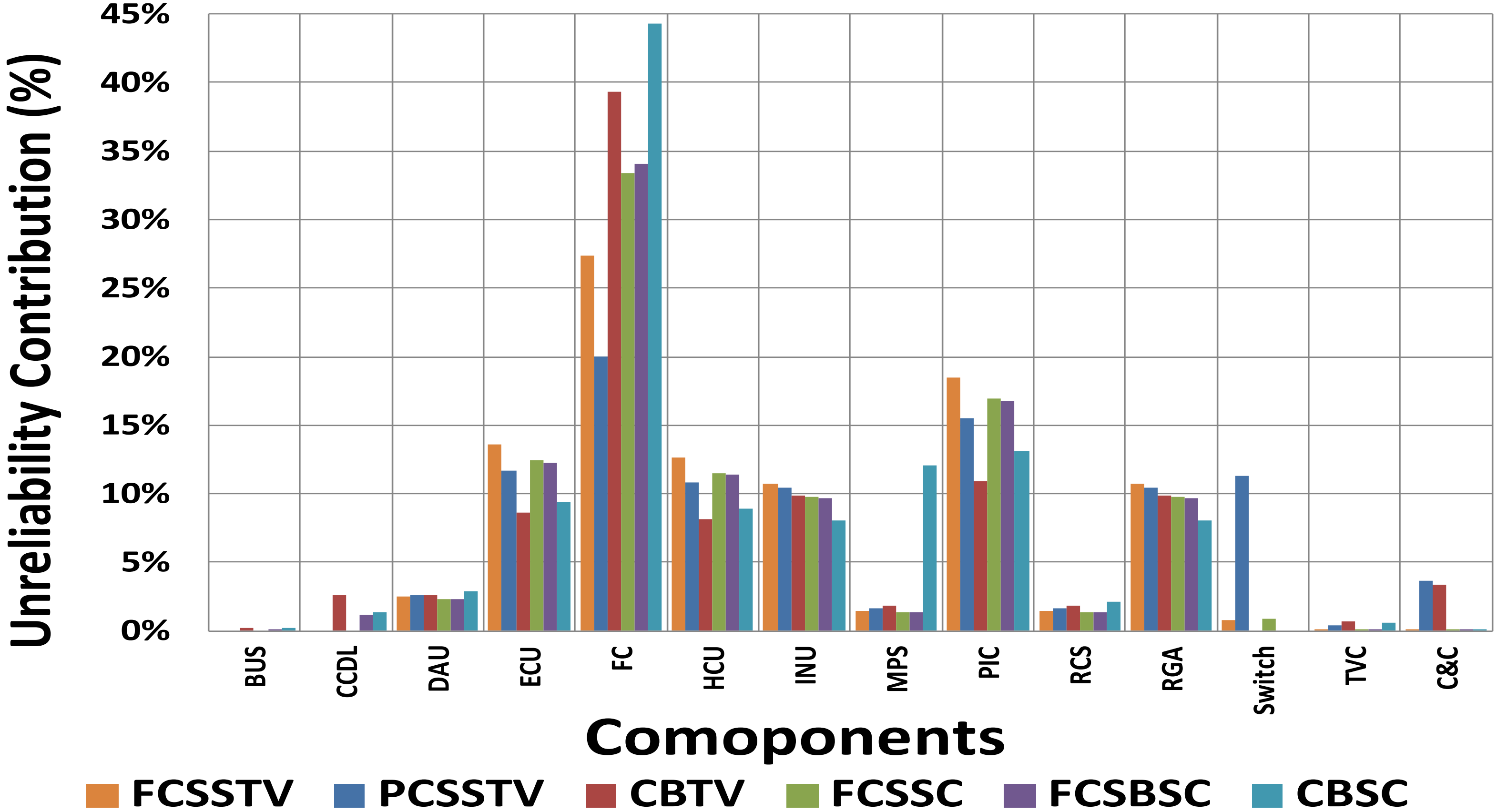
When Beta Changes



The workmanship and effectiveness of screening are the most influential differentiator for system reliability and architecture selection.

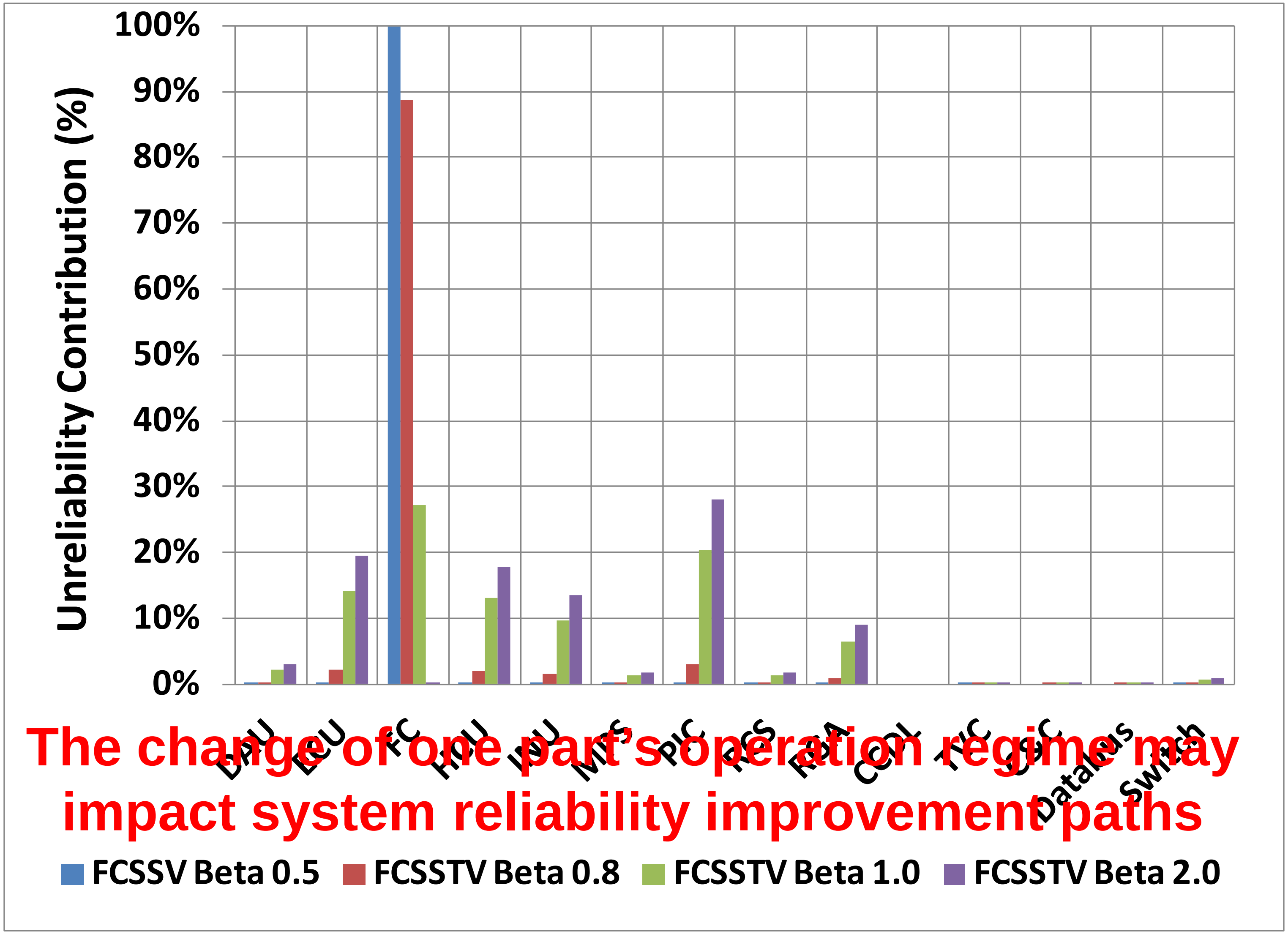
System Improvement Paths

System Un-reliability Distribution



System reliability: should not focus on the absolute numbers, but on how to improve overall reliability

When Beta Changes



The change of one part's operation regime may impact system reliability improvement paths

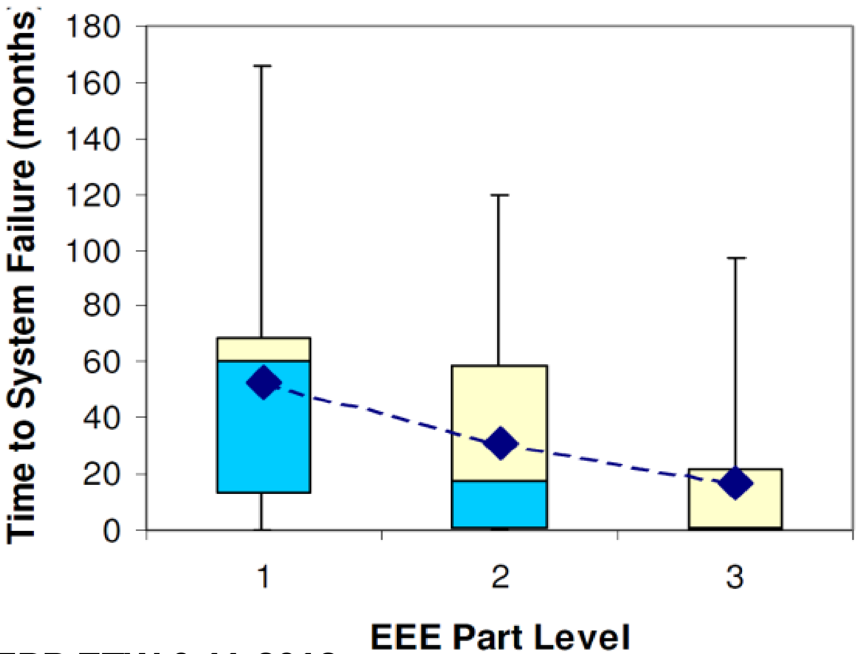
Misconception I

- **Misconception: Less Stringent Component Selection Plan for Shorter Missions**
  - **Depends on the actual architecture**
  - **May yield a less stringent up-screening procedure**
  - **May suggest "lower grade parts" and "upgrading"**
    - **NASA NEPP cost model indicates more costly.**

Beta	R (24 hrs)					
	FCSSTV	PCSSTV	CBTV	FCSSC	FCSBSC	CBSC
0.5	0.995388	0.995412	0.994807	0.993915	0.993867	0.992985
0.8	0.999935	0.999932	0.999878	0.999910	0.999923	0.999825
1.0	0.999993	0.999991	0.999979	0.999992	0.999992	0.999960
2.0	0.999986	0.999984	0.999985	0.999981	0.999994	0.999981

Misconception II

- **System Reliability Analysis and System Level Testing are Sufficient for Component Selection and Component Level Testing**
  - **Roles and limitations of system reliability – early failures**
  - **Testing at system does not give full access to parts characteristics – translation**
  - **Impact of parts reliability on system reliability – depends**



Conclusions

- **Parts reliability, not only lifetime, but also the operation regimes, has direct impact on system reliability.**
  - **Workmanship and effectiveness of screening has greater impact on system reliability.**
- **Critical for space missions to evaluate the risk, risk mitigations and impacts of the parts selection plan**
  - **Not technically justified:**
    - **a "less stringent" parts plan for shorter missions**
    - **an attempt to use system reliability analysis and testing for component selection or reliability**
  - **Both system reliability analysis and parts reliability analysis must be fully understood and fully implemented to ensure mission success.**
    - **<u>Screening is the key!!</u>**