Name ______________________________

ASE 379L Final Exam - May 9, 2008

100-point total

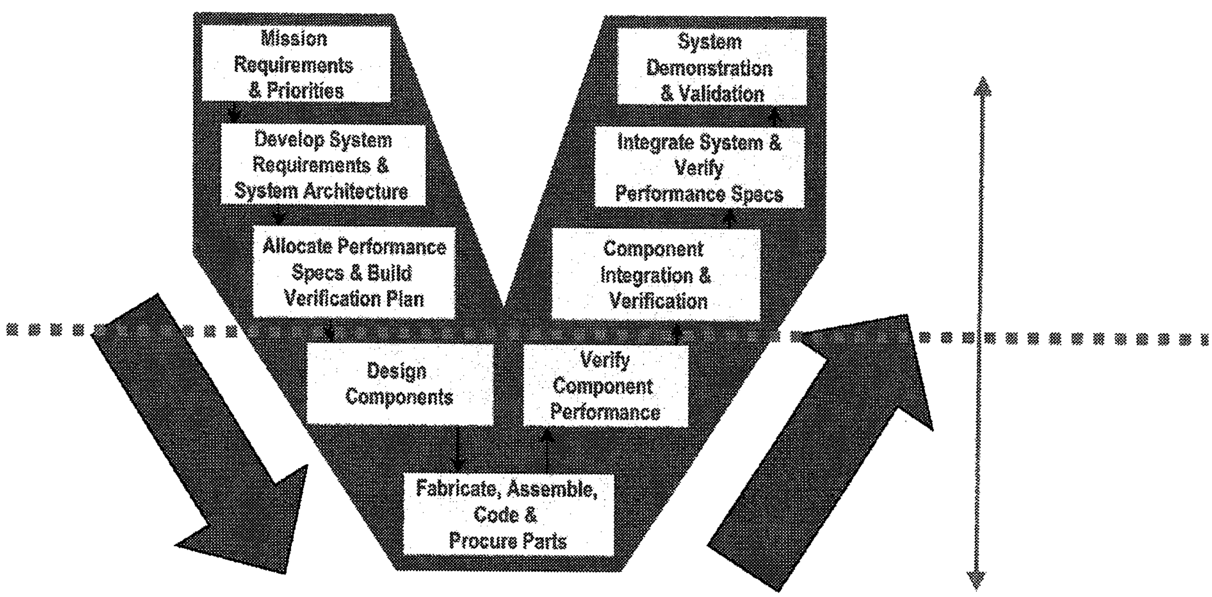
Problem 1 (5 points)

For the systems engineering Vee Diagram below:

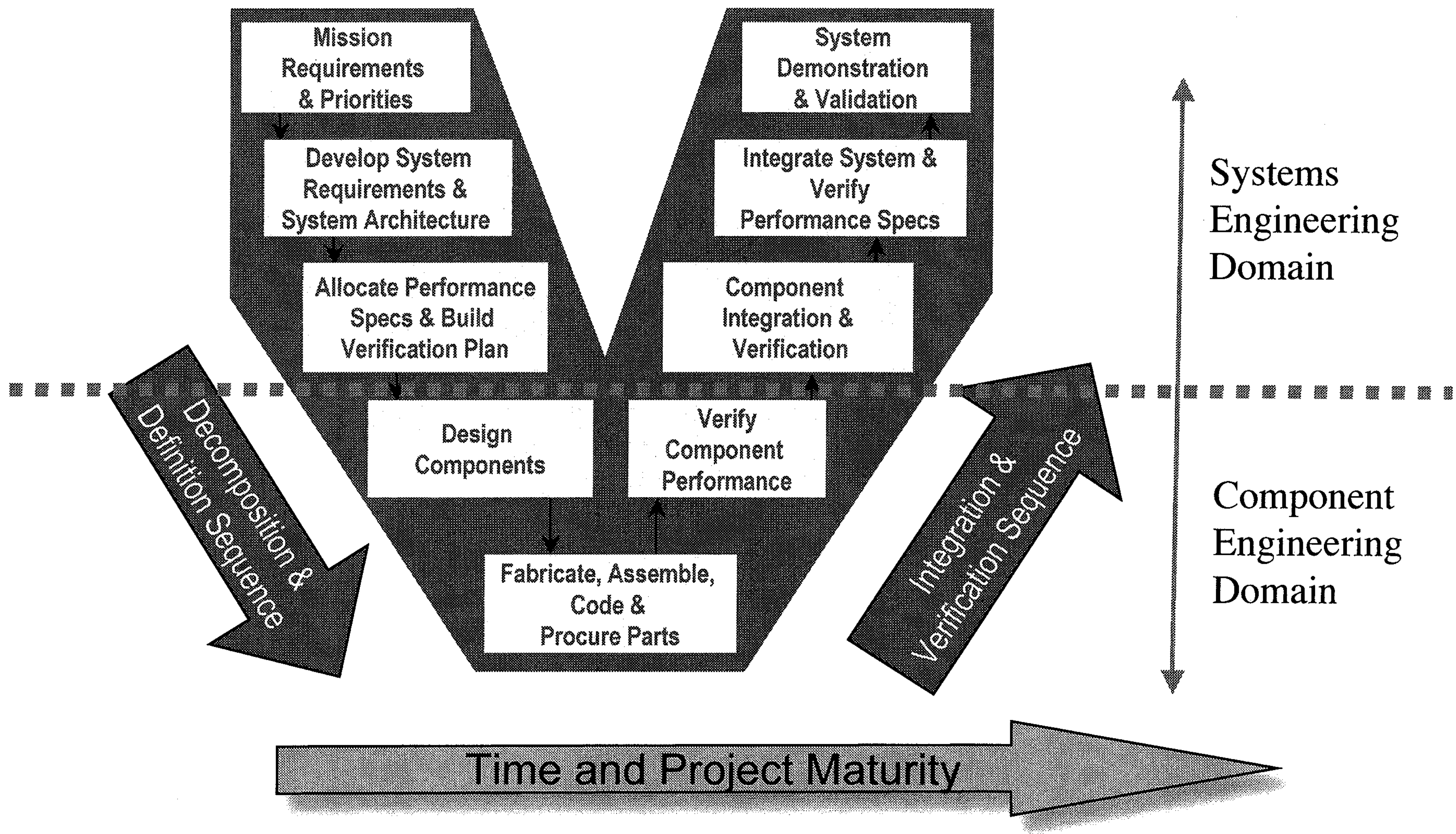
2 pt (a) Describe the intent of the arrow on the left (1 pt) and the arrow on the right (1 pt).

2 pt (b) How does the Vee relate to the system life cycle?

1 pt (c) What aspects of the Vee are the responsibility of the systems engineer?



Systems Engineering Guides *the Highest Levels of Analysis and Integration*

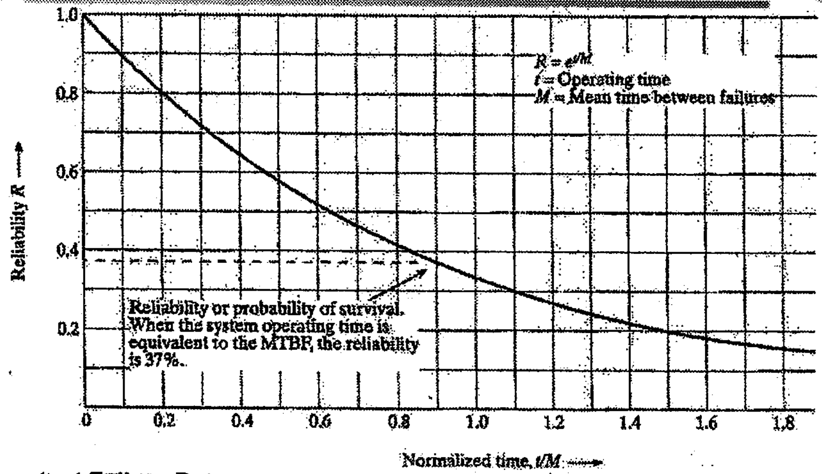


Problem 2 (6 points)

2pt (a) Draw and label the "Bathtub" Failure Rate Curve.
2pt (b) Explain the meaning of the curve.
2pt (c) Explain the application of the exponential function that models the probability distribution of reliability as it relates to the curve.

Constant Failure Rate

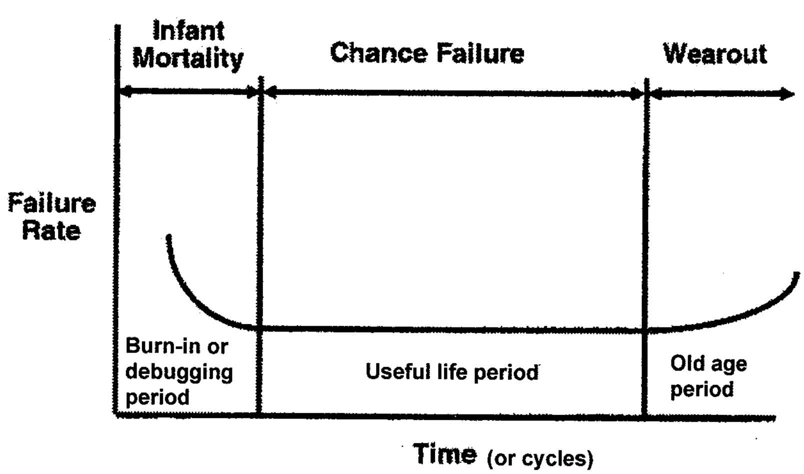
Source: Blanchard and Fabrycky, Systems Engineering and Analysis, Prentice Hall, 1998



Constant Failure Rate:

- Probability Distribution of reliability is an exponential function
- Although an individual component may not have an exp reliability distribution, in a complex system with many components the overall reliability may appear as a series of random events and the system will follow an exponential reliability distribution.

The "Bathtub" Failure Rate Curve



Because of burn-in failures and/or inadequate quality assurance practices, the failure rate is initially high, but gradually decreases during the infant period. During the useful life period, the failure rate remains constant, reflecting randomly occurring failures. Later, the failure rate begins to increase because of wear-out failures.

Problem 3 (**6** points)
For space system verification, testing is the preferred means for evaluating a system's performance and compliance with requirements. For each of the 3 types of environmental test, describe at least 2 purposes for the test.

(a) Structural dynamics test < 1 pt / purpose, 1 pt
(b) Space simulations test
(c) Electromagnetic test

Key Space Environmental Tests

Test	Purpose	Equipment/Facilities Required	Process
Vibration & Shock Testing Structural Dynamics Test	Ensure product will survive launch Comply with launch authority's requirements Validate structural models	Vibration table and fixture enabling 3-axis testing, and/or Acoustic chamber	Do low-level vibration survey (a.k.a. modal survey) to determine vibration modes and establish baseline Do high-level random vibration following profile provided by launch vehicle to prescribed levels Repeat low-level survey to look for changes Compare results to model
Thermal & Vacuum Testing Space Simulations Test	Induce and measure outgassing to ensure compliance with mission requirements Ensure product will perform in a vacuum under extreme flight temperatures Validate thermal models	Thermal/vacuum chamber Equipment to detect outgassing (e.g. coldfinger or gas analyzer) as needed Instrumentation to measure temperatures at key points on product (e.g. batteries)	Operate and characterize performance at room temperature and pressure Operate in thermal and/or thermal vacuum chamber during hot and cold-soak conditions Oscillate between hot and cold conditions and monitor performance Compare results to model
Electromagnetic Interference/ Compatibility (EMI/EMC) El. test	Ensure product does not generate EM energy that may interfere with other spacecraft components or with launch vehicle or range safety signals Verify that the product is not susceptible to the range and/or launch EM environment	Radiated test: Sensitive receiver, anechoic chamber, antenna with known gain Conduction susceptibility matched "box"	Detect emitted signals, especially at the harmonics of the clock frequencies Check for normal operation while injecting signals or power losses

Problem 4 (8 points)
A program has a set of activities (A through G) to accomplish before completion. The diagram below shows the network of these activities and their estimated duration. Answer the following questions:

(a) Designate, by activity letters, the critical path for the program, from program start to program completion. How long is the critical path in days?

A - B - E - G

8 + 8 + 2 + 10 = 28 days

4pts

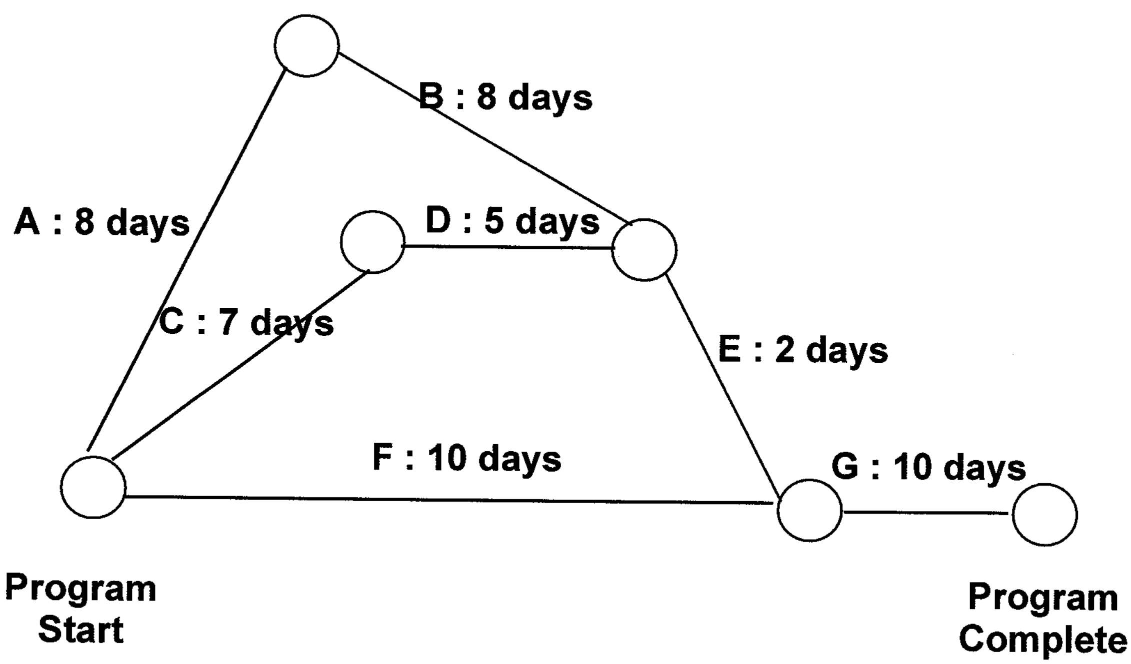
(b) How much float exists for each of the remaining paths? Designate each path by the activity letters, and express the float in days.

2 pts

C - D - E - G
7 + 5 + 2 + 10 = 24 => 4 days float

F - G
10 + 10 = 20 => 8 days float

2 pts



Problem 5 (2 points each; 20 points total)

Match definitions with key systems engineering terms, using the word bank below.
WORD BANK:

a) Gantt chart	~~b)~~ Monte Carlo	~~c)~~ technology readiness level
d) trade study	~~e)~~ demonstration	~~f)~~ analog model
~~g)~~ bottoms-up estimating	~~h)~~ fault tree	~~i)~~ beta distribution
~~j)~~ SEMP	k) normal distribution	l) iconic model
~~m)~~ peer review	n) inspection	o) simulation
p) project plan	q) Taguchi method	r) parametric estimating
s) event tree	~~t)~~ milestone chart	u) mission concept review

__c__ A measure used to assess the maturity of evolving materials, devices, components, etc. prior to incorporating into a system.

__h__ A graphical representation where successive subordinate failure events are identified and logically linked to the top event.

__g__ Estimate is based on the cost of materials and labor to develop and produce each element, at the lowest level of the WBS possible.

__b__ A computational algorithm where input parameters are randomly selected.

__t__ A graphic portrayal of a project that shows the events to be completed on a timeline.

__e__ Determines conformance to system/item requirements through the operation, adjustment, or reconfiguration of a test article.

__j__ Document that ^ Defines for all project participants how the project will be technically managed within the constraints established by the project.

__m__ A review by individuals selected from outside the project according to their expertise in the applicable disciplines. These reviews help you take advantage of other engineering experience from colleagues who have worked on different missions.

__i__ The probability distribution function often used in schedule analysis, where a most likely estimate, an optimistic estimate, and a pessimistic estimate are required.

__f__ A model that behaves like the real system; often used to compare something unfamiliar with something that is familiar.

Problem 6

Design margins calculation (10 points)

The end-of-mission life capability of a spacecraft power system is 200 watts. Your instrument is expected to use 50 watts, including 25% contingency. You are allotted 75 watts by the satellite provider.

5 pts

- What is the instrument's power contingency in watts?

$$\% C = \frac{C}{\text{Max exp} - C} \times 100$$

$$.25 = \frac{C}{50 - C}$$

$$.25(50 - C) = C$$

$$12.5 - .25C = C$$

$$12.5 = 1.25C$$

$$10 = C$$

contingency = 10 watts

5 pts

- What is the instrument's power margin in watts and as a percentage (%)?

$$\% M = \frac{M}{\text{Max allotted} - M} \times 100$$

$$\frac{75-50}{75-(75-50)} = \frac{25}{50} = 50\%$$

margin = 25 watts

Problem 7

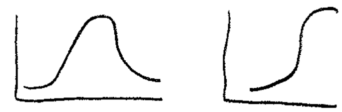
General questions (4 points each):

2 pt 2 pt

(a) What's the difference between PDF and CDF; how are they related?

Monte Carlo lecture under cost folder (slide 10)

CDF is the integral of the PDF



4pt (b) What's the difference between Preliminary Design Review (PDR) and Critical Design Review (CDR)?

1pt 1 pt

(c) What is the difference between measures of effectiveness and measures of performance? Give one example of each.

1pt 1pt

Preliminary Design Review (PDR)

- The PDR is not a single review but a number of reviews starting with the specific component PDRs, followed by the system-level review.
- The PDR establishes the "design-to" baseline and ensures that it meets the program, project , system, subsystem, or specific component baseline requirements.
- The PDR process should:
  - Establish the ability of the selected design approach to meet the technical requirements (i.e., Verifiability/ Traceability);
  - Establish the compatibility of the interface relationships of the specific end item with other interfacing items;
  - Establish producibility of the selected design;
  - Establish the operability of the selected design;
  - Assess compliance with reliability and system safety requirements;
  - Establish the feasibility of the approach;
  - Address status, schedule and cost relationships.

- ***See NASA NPR 7123.1 (2006) Appendix G for Technical Review Entrance and Success Criteria.***

<u>CDR:</u> Is the system design mature enough to proceed with full-scale fab, assembly, I & T?
(p6) of Tech Rvs Mod

Evaluation Criteria

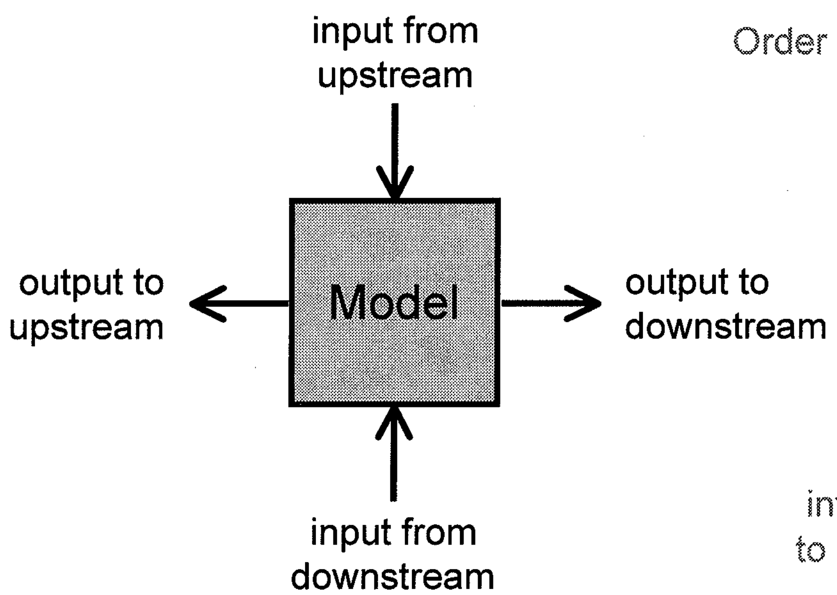
- Trade studies depend upon having criteria for making decisions based on measure of effectiveness (voice of the customer) and measures of performance (voice of the engineer).
- Example measures of effectiveness
  - Life cycle cost
  - Schedule, e.g., development time, mission duration
  - Technology readiness level (maturity of concept/hardware)
  - Crew capacity
  - Payload Mass
- Example measures of performance
  - Mass
  - Power consumption
  - Specific impulse
  - Consumables required
  - Propellant type

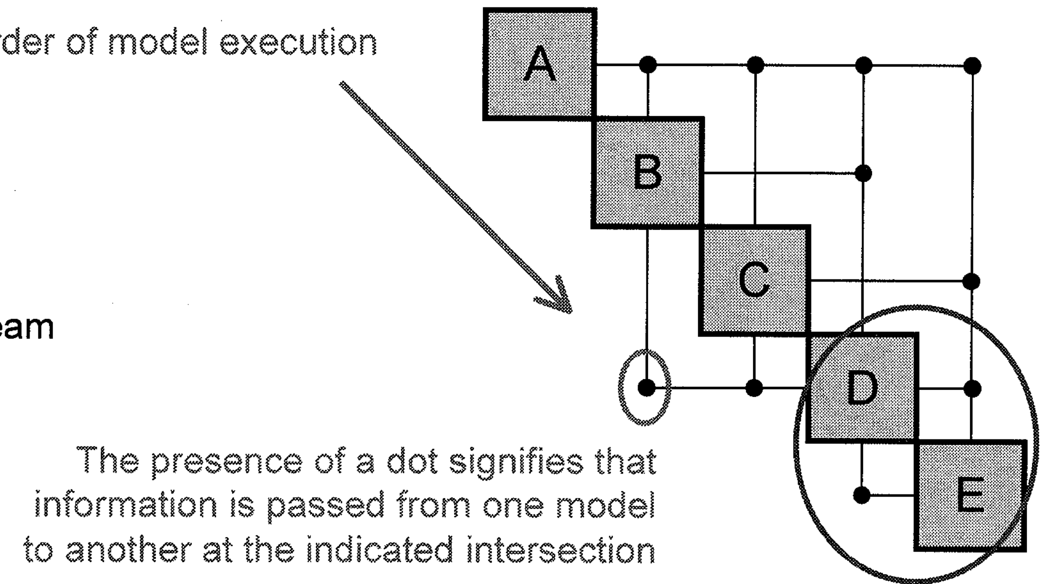
Problem 7 (continued)
General questions (4 points each):

(d) What does it mean to have a closed design?

(e) What is the relationship between the TRL scale and risk?

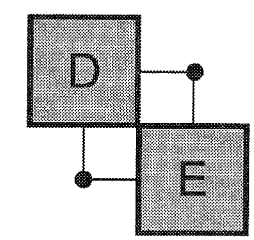
N^2 Diagrams





The design is said to be "**closed**" when all iterations have converged and all the inputs/outputs to all the model are consistent with each other.

Feedback requires iteration. The two relevant models must iterate until the outputs and inputs match.



In this case, for example, on the first pass through the N^2 diagram you must guess the inputs from E to D (because you have not yet run model E). After you run D, you use the outputs to run E. You will see that the outputs of E probably do not match your guess. Therefore you rerun D using the updated values of the outputs from E. The new outputs of D will require you to rerun E, and so on. You must continue to iterate until the process converges.

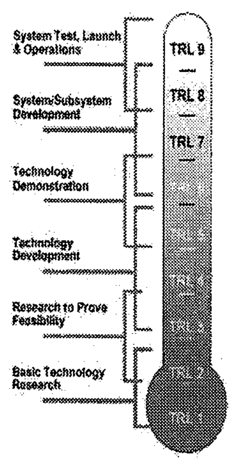
Intro: Technology Readiness Levels

- The Technology Readiness Level (TRL) is a NASA-established classification scale against which to measure the maturity of a technology.
  - Describes the state-of-the-art of a given technology
  - Provides a “baseline” from which to advance (ultimately to flight)
- TRLs range from 1 - basic technology research to 9 - full operational capability in space.
- Typically, a TRL of 6 - technology demonstrated in a relevant environment - is required for a flight project development to be approved for implementation.
- TRLs indicate the inherent development risk.
  - A TRL of 1 or 2 represents a situation of relatively **high risk**
  - TRLs of 3-5 represent moderate risks
  - TRLs of 6-8 represent low risks

2

Technology Readiness Level is a Measure of Risk

Technology Readiness Level (TRL) is a measure used to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem.



Low Risk ∅
< 5
< 10
< 10%
10 - 15%
15 - 20%
20 - 25%
High Risk
> 25%

3

Risk can also be translated into cost impact

Problem 8 (15 points)

You are an engineer tasked with estimating the reliability of the communications subsystem for the NEAR spacecraft (schematic shown in Figure 1). Specifically, you are asked to report the probability that the communication subsystem will be capable of successfully *transmitting* data through the high gain antenna. Recalling all the useful things you learned in your systems engineering class, you use the communication system schematic from in Figure 1 to draw the block diagram shown in Figure 2. **Use the block diagram and reliability data shown in Figure 2 to estimate the reliability of the NEAR communications subsystem.**

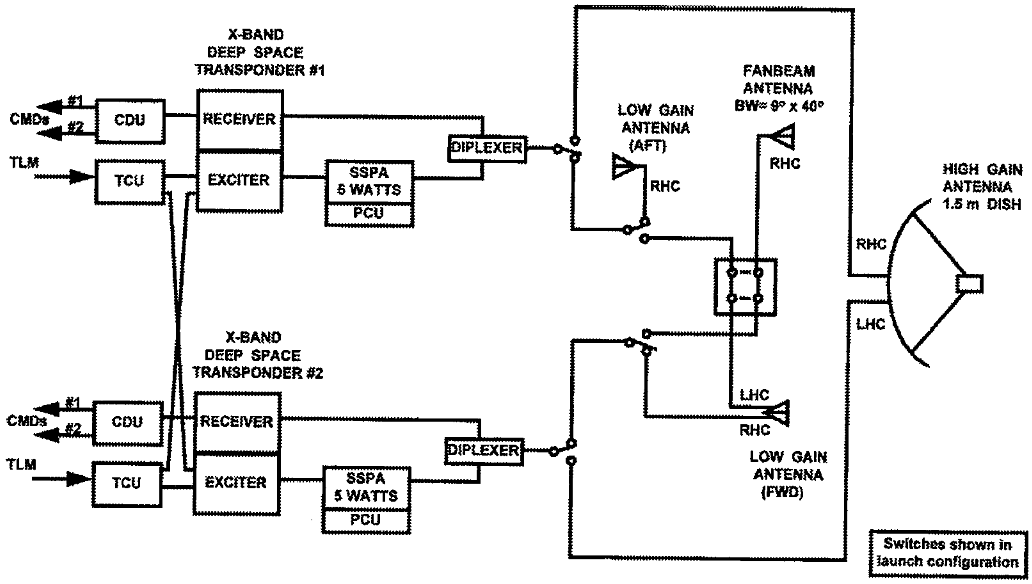


Figure 1. Schematic of communications subsystem for NEAR spacecraft.

[Ref: Santo, A.G., Lee, S.C., and Gold, R.E., "NEAR Spacecraft and Instrumentation," The Johns Hopkins University Applied Physics Laboratory.]

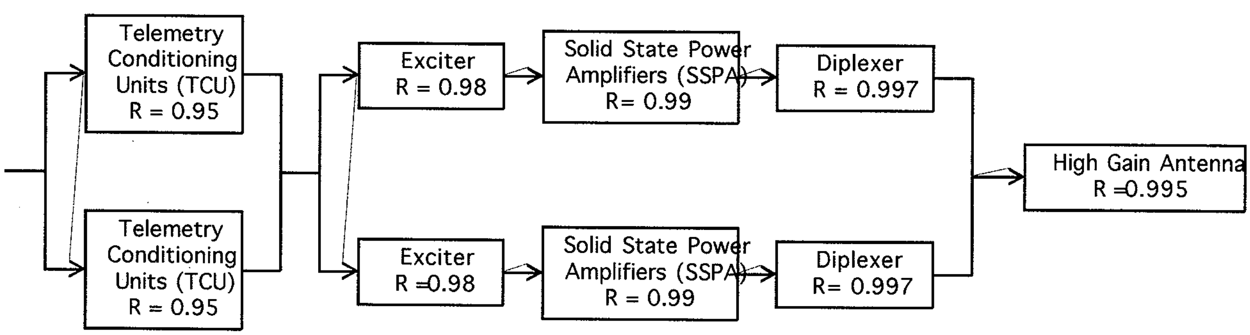
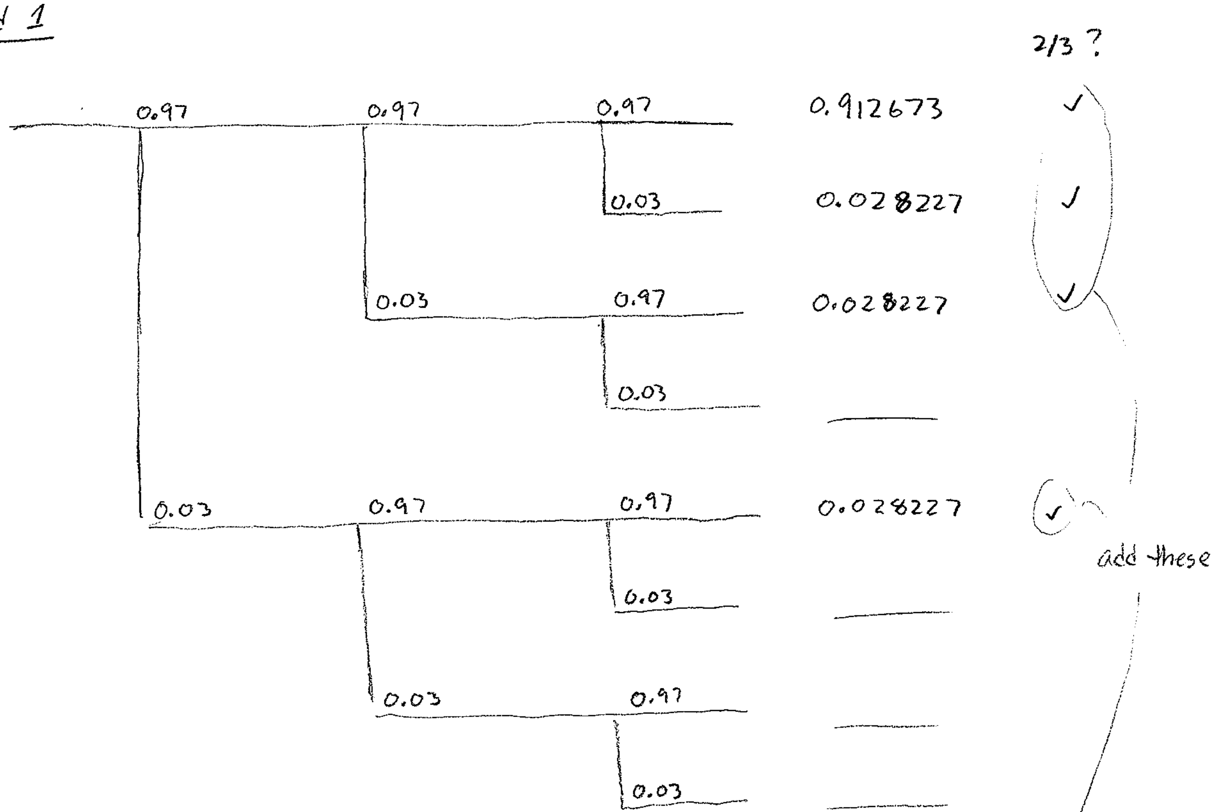


Figure 2. Block diagram for reliability calculations.

Problem 9 (10 points)

You are helping design the descent stage for a lunar lander. Although your team's design uses three identical engines, only two must function for a safe landing. Each engine has a reliability of 0.97. What is the probability that at least 2 of the 3 engines will function properly?

Method 1



0.912673 + 3 * 0.028227 = 0.997354

Method 2

k-of-n

$$R_{k,n} = \sum_{i=k}^{n} C\binom{n}{i} R^{i}(1-R)^{n-i} \quad , \quad C\binom{n}{i} = \frac{n!}{i!(n-i)!}$$

$$R_{2,3} = C\binom{3}{2}R^{2}(1-R)^{3-2} + C\binom{3}{3}R^{3}(1-R)^{3-3}$$

$$C\binom{3}{2} = \frac{3!}{2!(3-2)!} = \frac{6}{2\cdot 1} = 3$$

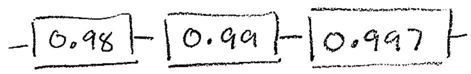
$$C\binom{3}{3} = \frac{3!}{3!(3-3)!} = \frac{6}{6\cdot 1} = 1$$

$$= 3R^{2}(1-R) + R^{3}$$

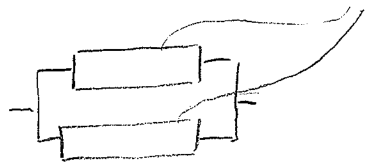
$$= 3(0.97)^{2}(0.03) + (0.97)^{3} = 0.084681 + 0.912673 = 0.997354$$

Same

Workspace for Problem 8

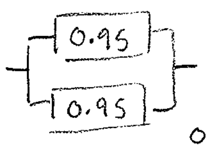


$0.98 * 0.99 * 0.997 = 0.9672894$



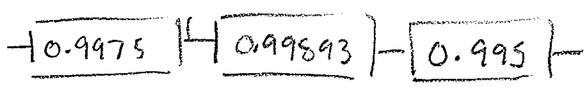
$0.9672894 + 0.9672894 - (\ \ )(\ \ ) = 0.99893$ ✓

.93564878



$0.95 + 0.95 - 0.95 * 0.95 = 0.9975$ ✓

0.9025



$0.9975 * 0.99893 * 0.995 = \underline{0.99145}$ ✓