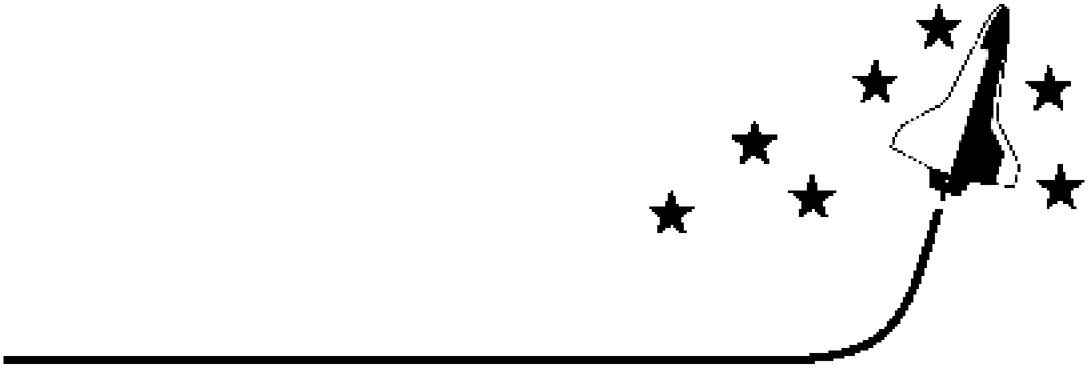
FACULTY NOTES

The LTAs and Spinoffs are designed so that each professor can implement them in a way that is consistent with his/her teaching style and course objectives. This may range from using the materials as out-of-class projects with minimal in-class guidance to doing most of the work in class. The LTAs and Spinoffs are amenable to small group cooperative work and typically benefit from the use of some learning technology. Since the objective of the LTAs and Spinoffs is to support the specific academic goals you have set for your students, the Faculty Notes are not intended to be prescriptive. The purpose of the Faculty Notes is to provide information that assists you to take full advantage of the LTAs and Spinoffs. This includes suggestions for instruction as well as answers for the exercises.



FACULTY NOTES

LTA 1

Spare Parts for the Space Shuttle

The purpose of the guide is to give suggestions to the instructor as to various ways to implement this project. This Laboratory Technical Activity (LTA) contains two separate Sections which can be done independently. The first Section, Line Replaceable Units, has a suggested level of College Algebra; however, with some modifications it may be suitable for Intermediate Algebra as well. The second Section, Non-repairable Parts, could be used in an Elementary or Intermediate Algebra class, although to complete Parts C, D, and E students must be familiar with constructing functions. Each Section begins with an introduction written by Logistics Engineers at Kennedy Space Center. The information about the fuel cells, the mass memory units, the primary thrusters, and the main landing gear tires was also provided by the engineers at the KSC.

When completing the activities, it is important to remember that the type of technology used will have an effect on the accuracy of the answers, particularly in the use of the POS equation. As a result, the answers you generate with your technology may be slightly different than those given in the solutions that follow.

Many libraries have videos showing a Shuttle launch and landing. Students may find it helpful to watch one of these videos before beginning the project. In a video the student can see the size of the Shuttle itself, and it helps them to visualize just how little room there is for the 250,000 parts.

Section 1

Line Replaceable Units

Fuel Cells

The LTA is designed to be used in a cooperative setting. Encourage students to fill in the worksheet as they read through the material. The Fuel Cell Unit may be worked as a large group (the entire class), and then using this model the class may be divided into groups to do Optional Example 1 (Mass Memory Units) and Optional Example 2 (Aft Yaw Primary Thrusters). These optional examples are located in the Faculty Notes at the end of this Section. Another suggestion is to have the Mass Memory Units and Aft Yaw Primary Thruster modules assigned to groups to be done outside the classroom. The groups would be expected to report their results at a later date to the entire class.

Before doing Optional Examples 1 and 2, the groups could do research papers on Mass Memory Units and Primary Thrusters by exploring some of the NASA sites on the Internet. One such site is www.nasa.gov/shuttle.

The instructor may choose to do the Fuel Cell Section as a classroom activity and use the Probability of Sufficiency equation strictly as a formula that students enter into the calculator and evaluate using lists.

If there is not enough time to complete the whole activity, or appropriate technology is not available, the class could compute P(n) for one or two values to see how the POS equation works, and then students could be given the completed table and/or graphs to analyze. If the students are assigned Part D – Calculating the POS using the TI 83™ Graphing Calculator, you may want to review the calculator instructions with the class. The calculator keystrokes are written for a student who is already familiar with the technology.

Class Tested Suggestions for Implementation

1) Assign the introductory material to be read for homework prior to the class in which the work is actually done. Also have the students work through, on their own, the MDR and the TPOT calculation pages.
2) Make an overhead of the MDR and TPOT pages, and fill these in with the entire class to review what they read and also to insure that they all have the same results.
3) Duplicate the acronym page and the formula sheet (both located later in this section of the Faculty Notes) for referral by the group as they do their work.
4) Form groups of three to enter the calculations into the chart titled, POS Calculations for Fuel Cells, and to enter the data into the calculator. Assign the following roles:
    Quality Control Person: fills in the charts after all members of the group agree on the calculations.
    Logistics Engineer: responsible for correct calculator entry; checks work by comparing to other group members' calculations.
    Reference Person: finds all the information needed in the handout--formulas, acronyms, calculator entry sheet, etc.
5) Have students calculate the P(n) and POS by following the handout for one case and then doing it for 0 - 10 spares using lists and the sheet provided.
6) Check entries on an overhead transparency of POS Calculations for Fuel Cells.
7) Discuss having a POS of 90% and the current turnaround time of 316 days.
8) Have students recalculate the POS if the number of flights is changed to 12 and then to 15 per year (Spinoff 1A). Fill in corresponding sheets and charts.
9) Discuss what effect this change would have on the number of spare fuel cells needed.
10) For homework or extra credit have students complete Optional Example 1, Mass Memory Units and/or Optional Example 2, Aft Yaw Primary Thrusters.

Group Activity

Divide the class into groups of 2 students. One student is the reader and the other student is the listener. The reader reads the first page and the listener listens to what is read and then paraphrases the material back to the reader. The two students switch roles to read and paraphrase the second page.

Suggested Activity: The acronym page is given without the explanation of the acronym, and the students go back through the material and fill in as many acronym explanations as possible at this time.

Each pair of students is now joined by another pair, and the four discuss what they have read to see if either pair did not understand something, or if the other pair interpreted some of the material differently. Discuss as a class.

Group Project: Construction of a Box the Size of a Fuel Cell

Construction of a box with no lid that is the size of a fuel cell may help students to visualize the size of each fuel cell and how much space the three fuel cells require inside the Shuttle. These fuel cells generate electricity, the drinking water for the crew, and the vehicle coolant. By actually constructing three boxes students can visualize the importance of what is happening in such a small area.

Group Size: Group of 4 (can be the two pairs originally grouped together to discuss what they read)

Supplies: 1- 3 sheets of cardboard each of which measures at least 73"x43" depending on whether the groups make one or three fuel cells.

Roles: Construction Engineer: Person who actually cuts out the cardboard and assembles it into a box

Logistics Engineer: Does the measuring and figures out the size of the square to take out of each corner in order to have a box that measures 45" long x 15" wide x 14" high

Assembler: Tapes the sides in order to provide strength to the box

Quality Control Person: Checks each person’s job to see that the measuring and construction is correct.

Individual Accountability: When the team is satisfied with its performance, each member puts his or her initials inside each box.

Suggestion: The following sheet can be duplicated with or without the explanations. If the meanings are not included, the sheet can be given to the students with the assignment to complete it. This may be given out as an advance assignment prior to working as a group in class if the instructor wants the students to read through the LTA for homework. By assigning the acronym sheet for homework the instructor knows if students did the reading. Note that this acronym sheet includes information from all parts of this LTA, including Spinoffs and optional examples, so instructors may choose to use only those terms related to the material they cover for class.

What Do All Of These Letters Stand For?

Acronym	**What It Stands For**
CRT	Cathode Ray Tube
GPC	General Processing Computer
LE	Logistics Engineer
LRU	Line Replaceable Units a. repairable LRU b. non-repairable LRU
LTA	Laboratory Technical Activity
MDR	Maintenance Demand Rate --- the total number of failures of a part per 1000 operating hrs
MMU	Mass Memory Unit
MSL	Minimum Stock Level
OQ	Order Quantity
POS	Probability of Sufficiency --- Determines the chances of having a part available when needed
RCS	Reaction Control System
TPOT	Total Projected Operating Time depends on: QPV Quantity per vehicle FPOT Flight Power-on time/flight GPOT Ground Power-on time/flight Number of flights / yr

Suggestion: Since there are numerous formulas for the students to apply, the instructor may also want to have students keep a separate sheet listing all of the formulas used. In this way they can easily go back and grab the formula instead of searching through the text. Again, the instructor can blank out the formulas before duplicating if desired. The instructor may want to design a similar sheet if Section 2 (Non-repairable Parts) is also be covered by the class.

Formula Sheet

Maintenance Demand Rate (MDR)

$$\text{MDR} = \frac{\text{Total Failures}}{\text{Total Hours Experienced In The Past}} * 1000$$

Total Projected Operating Time (TPOT)

TPOT = QPV*(FPOT+GPOT)*Flight Rate Per Year

Probability of n Removals P(n)

$$P(n) = \frac{(lT)^n * e^{-lT}}{n!}$$

where

n = the number of removals
T = repair turnaround time of the item in days
λ = removal or failure rate per day

Lambda λ

$$l = \frac{MDR}{1000} * \frac{TPOT}{365}$$

Probability of Sufficiency

$$POS = \sum_{n=0}^{S} \frac{(lT)^n * e^{-lT}}{n!}$$

Suggestion: The instructor may choose to have students write programs for all of these formulas if using graphing calculators or computers. A program is given for calculating lambda. Using this as a model, programs can be written to evaluate all of the formulas.

A Program to Calculate LAMBDA

```
PROGRAM:LAMBDA

Disp "QPV=?"
Prompt Q
Disp "FPOT=?"
Prompt F
Disp "GPOT=?"
Prompt G
Disp "TOTAL FLIGHTS="
Prompt S
Q(F+G)*S→H
Disp "TOTAL FAILURES="
Prompt T
T/H*1000→M
Disp "MDR="
Disp M
Disp "FLIGHT RATE"
Prompt R
Q(F+G)*R→P
Disp "TPOT="
Disp P
Disp "LAMBDA="
M/1000*P/365→L
Disp L
```

Following is a copy of the POS Calculation for Fuel Cells Worksheet and two additional examples of POS calculations for Line Replaceable Units – Mass Memory Units (MMUs) and Aft Yaw Primary Thrusters.

Worksheet: POS Calculation for Fuel Cells

Total Hours Experienced in the Past = QPV * (FPOT + GPOT) * Total Flights

QPV =
FPOT =
GPOT =
Total Flights =
Total Hours =

MDR = (Total Failures/Total Hours) * 1000

Total Failures =
Total Hours=
MDR =

Total Projected Operating Time = QPV * (FPOT + GPOT) * Flight Rate

QPV =
FPOT =
GPOT =
Flight Rate =
TPOT =

Lambda = (MDR/1000)*(TPOT/365)

Lambda =

T (Repair turnaround time) = 250 300 316 350

S (Total Spares)	0	1	2	3	4	5	6	7	8	9	10
POS(T=250)											
POS(T=300)											
POS(T=316)											
POS(T=350)											

Optional Example 1 - Mass Memory Units

In Section 1 (Fuel Cells) of the LTA we calculated POS values for fuel cells. We will now apply the same technique to determine the POS for mass memory units.

Mass memory units (MMUs) are reel-to-reel digital magnetic storage devices for basic flight software. There are two MMUs on each shuttle. An MMU is box-shaped, weighs 22 pounds, and has a tape that is 602 feet long and one-half inch wide. The MMUs store background formats for certain cathode ray tube (CRT) displays and the checkpoints that save system data in case the systems management general processing computer (GPC) fails. Thirty-four million bytes of information can be stored on each MMU.

QPV stands for the Quantity Per Vehicle, the number of mass memory units on each shuttle. Each vehicle has two mass memory units. The total number of mass memory unit failures as of May 1997 was 23.

The number of hours that the mass memory units are used on each flight is dependent upon the number of hours used in flight, or the Flight Power-On Time (FPOT) per flight, and the number of hours used while the Shuttle is still on the ground, called Ground Power-On Time (GPOT) per flight. For these mass memory units the Flight Power-On Time (FPOT) is 119.5 hours and the Ground Power-On Time (GPOT) is 1810 hours. The flight rate is 8 flights per year.

The number of hours that the mass memory units have already been used also depends on the number of Shuttle flights. As of May 1997, NASA calculates this number by using the total number of flights since Shuttle missions resumed after the Challenger accident. As of July 1997 the total number of flights was 53.

Use this information to complete the following worksheet and to graph the four POS functions corresponding to the turnaround times 150 days, 200 days, 240 days, and 300 days.

Worksheet: POS Calculation for MMUs

Total Hours Experienced in the Past = QPV * (FPOT + GPOT) * Total Flights

QPV =
FPOT =
GPOT =
Total Flights =
Total Hours =

MDR = (Total Failures/Total Hours) * 1000

Total Failures =
Total Hours=
MDR =

Total Projected Operating Time = QPV * (FPOT + GPOT) * Flight Rate

QPV =
FPOT =
GPOT =
Flight Rate =
TPOT =

Lambda = (MDR/1000) * (TPOT/365)

Lambda =

T (Repair turnaround time) = 150 200 240 300

S (Total Spares)	0	1	2	3	4	5	6	7	8	9	10
POS(T=150)											
POS(T=200)											
POS(T=240)											
POS(T=300)											

Optional Example 2 - Aft Yaw Primary Thrusters

In Section 1 (Fuel Cells) of the LTA we calculated POS values for fuel cells. We will now apply the same technique to determine the POS for aft yaw primary thrusters.

The primary thrusters are small engines providing 850 pounds of thrust for attitude maneuvers and small velocity changes. The Orbiter has 38 primary thrusters. Fourteen are located in the forward reaction control system (RCS) and 24 are located in the two aft reaction control systems. The aft thrusters consist of 3 unique configurations (12 pitch, 8 yaw, 4 +x).

The number of hours that the aft primary thrusters are used on each flight is dependent upon the number of hours used in flight, or the Flight Power-On Time (FPOT) per flight, and the number of hours used while the Shuttle is still on the ground, called Ground Power-On Time (GPOT) per flight. For these aft primary thrusters the Flight Power-On Time (FPOT) is 230 hours and the Ground Power-On Time (GPOT) is 13 hours.

The number of hours that the aft primary thrusters have already been used also depends on the number of Shuttle flights. NASA determines this number by using the total number of flights since Shuttle missions resumed after the Challenger accident. As of May 1997, the total number of flights is 53. During that same time interval there have been 88 aft primary thruster failures. The flight rate is 8 flights per year.

QPV stands for the Quantity Per Vehicle. Observe that the MDR is calculated using a QPV of all 24 aft primary thrusters, but the TPOT is based on a QPV of only the 8 aft yaw primary thrusters. Here is the logistics engineers' explanation for this difference:

> "QPV=24 is the total number of aft primary thrusters on a shuttle, there are three configurations of aft thrusters on a vehicle, there are 12 pitch type, 8 yaw type, and 4 +x type (12+8+4=24). All the aft primary thrusters fail at the same rate; the pitch do not fail faster or slower than the yaw. When QPV of 24 was used, we were calculating the maintenance demand rate (removal rate, failure rate). Since all three types fail at the same rate, we "lumped" all the failure data together to hopefully get a more accurate number-theoretically, if we took only the pitch failures, the pitch QPV (12), the pitch hours and calculated the MDR we should get the same if we took only the yaw failures, yaw QPV, the yaw hours and calculated the MDR. Lumping them all together gave us a larger statistically data base and hopefully a more accurate number. That was to find the failure rate. However, to find how many spares we need of a particular type since the pitch, yaw, and +x are all unique, not interchangeable, a composite could not be used. The required spares had to be determined separately."

Use this information to complete the following worksheet and to graph the four POS functions corresponding to the turnaround times 180 days, 250 days, 300 days, and 350 days.

Worksheet: POS Calculation for Aft Yaw Primary Thrusters

Total Hours Experienced in the Past = QPV * (FPOT + GPOT) * Total Flights

QPV =
FPOT =
GPOT =
Total Flights =
Total Hours =

MDR = (Total Failures/Total Hours) * 1000

Total Failures =
Total Hours=
MDR =

Total Projected Operating Time = QPV * (FPOT + GPOT) * Flight Rate

QPV =
FPOT =
GPOT =
Flight Rate =
TPOT =

Lambda = (MDR/1000) * (TPOT/365)

Lambda =

T (Repair turnaround time) = 180 250 300 350

S (Total Spares)	0	1	2	3	4	5	6	7	8	9	10
POS(T=180)											
POS(T=250)											
POS(T=300)											
POS(T=350)											

Section 2

Non-repairable Parts

Main Landing Gear Tires

Section 2 involves calculating the Minimum Stock Level (MSL) and the Order Quantity (OQ). In this section students are given formulas and asked to evaluate them using values supplied by the logistics engineers at Kennedy Space Center. Parts A and B can be done by beginning algebra level students.

After Parts A and B are completed, any or all of Parts C, D, and E can be done. These parts concern what happens if some of the quantities in the formulas are changed. These have been written to allow students to construct their own functions using the original MSL and OQ formulas. Thus, Parts C, D, and E are designed more for a College Algebra class and are more time-consuming than the first MSL and OQ calculations. However, Parts C, D, and E could be used in Introductory or Intermediate Algebra classes by omitting the construction of formulas and simply allowing students to fill in the charts. They will still be able to see the effect of the changes in number of flights, number of tires on hand, etc., on the MSL and the OQ.

Suggestion: The Minimum Stock Level and Order Quantity calculations can be done in class, along with one of the Parts C, D, and E. Students often have trouble constructing the functions in Parts C, D, and E and seeing what the variables represent, so working through one of Parts C, D, and E in class can be helpful. The class can then be assigned the other Parts to do in groups or as an outside assignment. It is also helpful to remind the students that all these functions are linear or piecewise linear, since they are already familiar with equations of lines.

Alternate Suggestion: Before class have the students read the introductory material and complete the calculations for the Minimum Stock Level and the Order Quantity using the given values. This will help students to become familiar with the project. In class, students complete one or more of the Parts C, D, and E either together as a class or in groups. One possibility, depending on class size, is for the students to divide into three groups, with each group assigned one of the Parts C, D, and E. Each group is then responsible for presenting its findings to the rest of the class.

LTA and Spinoff Solutions

Section 1

Line Replaceable Units

Fuel Cells

Part A Calculating the Maintenance Demand Rate (MDR)

1) 3 fuel cells

2. a) 3 fuel cells
   b) 230 hours
   c) 36 hours
   d) 53 flights
   e) $3 \cdot (230+36) \cdot (53) = 42{,}294$ hours

3. a) 46 failures
   b) 42,294 hours
   c) $\text{MDR} = \frac{46 \text{ failures}}{42{,}294 \text{ hours}} \cdot 1000 \text{ hours} = 1.0876$
   d) 1.0876 failures in 1000 hours

Part B Calculating the Total Projected Operating Time (TPOT)

1. a) 3 fuel cells
   b) 230 hours
   c) 36 hours
   d) 8 flights/year
   e) $\text{TPOT} = 3 \cdot (230 + 36) \cdot (8) = 6384$ hours
   f) NASA predicts that the total number of operating hours for all the fuel cells in one year will be 6384 hours. This assumes there are 8 flights per year.

Part C Calculating the Probability of Sufficiency (POS)

1. a) The formula for the MDR finds the number of failures in 1000 hours. Dividing the MDR by 1000 gives the number of failures in 1 hour.
   b) TPOT is the number of hours that the part is in use in one year. (Note: The word "part" here refers to all parts of one kind.) Dividing the TPOT by 365 gives the average number of hours that the part is in use each day.

2. a) 1.0876
   b) 6384 hours
   c) $l = \frac{1.088}{1000} \cdot \frac{6384}{365} = 0.01902 \text{ failures / day}$

3. a) n = 0 failures, T = 250 days, and $\lambda = 0.01902$ fuel cell failures per day
   b) P(0) ˜ 1%

4. a) n = 1, T = 250, and $\lambda = 0.01902$
   b) P(1) ˜ 4%

5) P(2) ˜ 10%

6. a) POS ˜ 1% + 4% + 10% = 15%
   b) There is a 15% chance that there will be 2 or fewer fuel cell failures in a 250 day period.

Part D Calculating the Probability of Sufficiency (POS) Using a TI-83™ Graphing Calculator

Exercises 1 through 5 are TI-83™ hands-on activities with accompanying guidance and answers in the text.

6)

Table 1

S (Total spares)	0	1	2	3	4	5	6	7	8	9	10
POS (T = 250)	1%	5%	15%	30%	48%	66%	80%	89%	95%	98%	99%
POS (T = 300)	0%	2%	8%	18%	33%	49%	65%	78%	88%	93%	97%
POS (T = 316)	0%	2%	6%	15%	28%	44%	60%	74%	85%	92%	96%
POS (T = 350)	0%	1%	4%	10%	21%	35%	50%	65%	77%	86%	92%

7. a) 250 days: 8 spares
   300 days: 9 spares
   316 days: 9 spares
   350 days: 10 spares
   b) The greater the turnaround time, the greater is the number of spares required to attain a Probability of Sufficiency of 90%.
   c) decrease
   d) 250 days. NASA would choose a lower turnaround time because items out for repair would return more quickly, reducing the number of spares needed.

8) Increasing the turnaround time decreases the Probability of Sufficiency for 5 spares.
The probability of having a spare available decreases as the turnaround times become longer.

9) As you increase the number of spares, the Probability of Sufficiency increases. In practical terms, this means that if more spares are kept in inventory, then a spare is more likely to be on hand when it is needed.

The foregoing work with fuel cells is organized and summarized in the following Probability of Sufficiency Worksheet.

Completed Worksheet

POS Calculation for Fuel Cells

Total Hours Experienced in the Past = QPV * (FPOT + GPOT) * Total Flights

QPV = 3 fuel cells
FPOT = 230 hours
GPOT = 36 hours
Total Flights = 53 flights
Total Hours = 42,294 hours

MDR = (Total Failures/Total Hours) * 1000

Total Failures = 46
Total Hours = 42,294
MDR = 1.0876 failures per 1000 hours

Total Projected Operating Time = QPV * (FPOT + GPOT) * Flight Rate

QPV = 3 fuel cells
FPOT = 230 hours
GPOT = 36 hours
Flight Rate = 8 flights per year
TPOT = 6384 hours

Lambda = (MDR/1000) * (TPOT/365)

Lambda = 0.01902 failures/day

T (Repair turnaround time) = 250 300 316 350

S (Total Spares)	0	1	2	3	4	5	6	7	8	9	10
POS(T=250)	1%	5%	15%	30%	48%	66%	80%	89%	95%	98%	99%
POS(T=300)	0%	2%	8%	18%	33%	49%	65%	78%	88%	93%	97%
POS(T=316)	0%	2%	6%	15%	28%	44%	60%	74%	85%	92%	96%
POS(T=350)	0%	1%	4%	10%	21%	35%	50%	65%	77%	86%	92%

Optional Example 1 - Mass Memory Units

Completed Worksheet

POS Calculation for MMUs

QPV = 2 MMUs
FPOT = 119.5 hours
GPOT = 1810 hours
Total Flights = 53 flights
Total Hours = 2·(119.5+1810)·(53) = 204,527 hours

$$\text{MDR} = \frac{\text{Total Failures}}{\text{Total Hours}} \cdot 1000$$

Total Failures = 23
Total Hours = 204,527
MDR = 0.11245 failures per 1000 hours

Total Projected Operating Time (TPOT)

QPV = 2 MMUs
FPOT = 119.5 hours
GPOT = 1810 hours
Flight Rate = 8 flights per year
TPOT = 2·(119.5 + 1810)·(8) = 30,872 hours

$$\text{Lambda} = \frac{0.11245}{1000} \cdot \frac{30{,}872}{365}$$

Lambda = 0.00951 failures/day

S (Total spares)	0	1	2	3	4	5	6	7	8	9	10
POS (T = 150)	24%	58%	83%	94%	98%	100%	100%	100%	100%	100%	100%
POS (T = 200)	15%	43%	70%	87%	96%	99%	100%	100%	100%	100%	100%
POS (T = 240)	10%	33%	60%	80%	92%	97%	99%	100%	100%	100%	100%
POS (T = 300)	6%	22%	46%	68%	84%	93%	97%	99%	100%	100%	100%

Optional Example 2 - Aft Yaw Primary Thrusters

Completed Worksheet

POS Calculation for Aft Yaw Primary Thrusters

QPV = 24 Aft Primary Thrusters
FPOT = 230 hours
GPOT = 13 hours
Total Flights = 53 flights
Total Hours = 24·(230+13)·(53) = 309,096 hours

$$\text{MDR} = \frac{\text{Total Failures}}{\text{Total Hours}} \cdot 1000$$

Total Failures = 88
Total Hours = 309,096
MDR = 0.2847 failures per 1000 hours

Total Projected Operating Time (TPOT)

QPV = 8 Aft Primary Thrusters
FPOT = 230 hours
GPOT = 13 hours
Flight Rate = 8 flights per year
TPOT = 8·(230 +13)·(8) = 15,552 hours

$$\text{Lambda} = \frac{0.2847}{1000} \cdot \frac{15{,}552}{365}$$

Lambda = 0.01213 failures/day

S (Total spares)	0	1	2	3	4	5	6	7	8	9	10
POS (T = 180)	11%	36%	63%	82%	93%	98%	99%	100%	100%	100%	100%
POS (T = 250)	5%	19%	42%	64%	81%	91%	96%	99%	100%	100%	100%
POS (T = 300)	3%	12%	30%	51%	70%	84%	92%	97%	99%	100%	100%
POS (T = 350)	1%	8%	20%	39%	58%	75%	86%	93%	97%	99%	100%

Section 2

Non-repairable Parts

Main Landing Gear Tires

Part A Calculating the Minimum Stock Level (MSL)

1)

$$\text{MSL} = \left(\frac{\text{average issue rate}}{\text{flight}} \cdot \frac{\text{flights}}{\text{year}} \cdot \frac{1\text{ year}}{12\text{ months}}\right)\left(\text{lead time} + \text{safety pad of 12 months}\right)$$

The effect of " 1 year / 12 months" is to express the issue rate in terms of months rather than years. This is needed for consistency in units since the lead time and safety pad are given in months.

2) Issue rate = 4 tires

3) $$\text{MSL} = \left(\frac{4\text{ tires}}{\text{flight}} \cdot \frac{8\text{ flights}}{\text{year}} \cdot \frac{1\text{ year}}{12\text{ months}}\right)\left(9\text{ months} + 12\text{ months}\right) = 56\text{ tires}$$

4) When the inventory level declines to 56, you should place a new order for tires.

Part B Calculating the Order Quantity (OQ)

1)

$$\text{OQ} = \left(\frac{\text{average issue rate}}{\text{flight}} \cdot \frac{\text{flights}}{\text{year}} \cdot \frac{1\text{ year}}{12\text{ months}}\right)\left(\text{support period required}\right)$$
$$+ \text{ MSL} - \text{Due - In Qty.} - \text{Ser.}$$

a) Average issue rate / flight = 4 tires
b) Flights / year = 8
c) Support period required = 12 months
d) Minimum Stock Level (MSL) = 56 tires
e) Due-In Qty. = 0 tires
f) Ser. = 54 tires
g)

$$\text{OQ} = \left(\frac{4\text{ tires}}{\text{flight}} \cdot \frac{8\text{ flights}}{\text{year}} \cdot \frac{1\text{ year}}{12\text{ months}}\right)\left(12\text{ months}\right) + 56\text{ tires} - 0\text{ tires} - 54\text{ tires}$$
$$= 34\text{ tires}$$

2) Under the given conditions NASA needs to order 34 more tires.

Part C How a Change in the Number of Flights per Year Affects the Minimum Stock Level (MSL) and the Order Quantity (OQ)

1)

Table 1

Number of Tires per Flight	Number of Flights per Year	Lead Time	Safety Pad	Minimum Stock Level (MSL)
4	6	9 months	12 months	42 tires
4	8	9 months	12 months	56 tires
4	12	9 months	12 months	84 tires
4	15	9 months	12 months	105 tires

2) $$\text{MSL} = \left(\frac{4\text{ tires}}{\text{flight}}\cdot\frac{\text{X flights}}{\text{year}}\cdot\frac{1\text{ year}}{12\text{ months}}\right)\left(9\text{ months}+12\text{ months}\right) = 7\text{X}$$

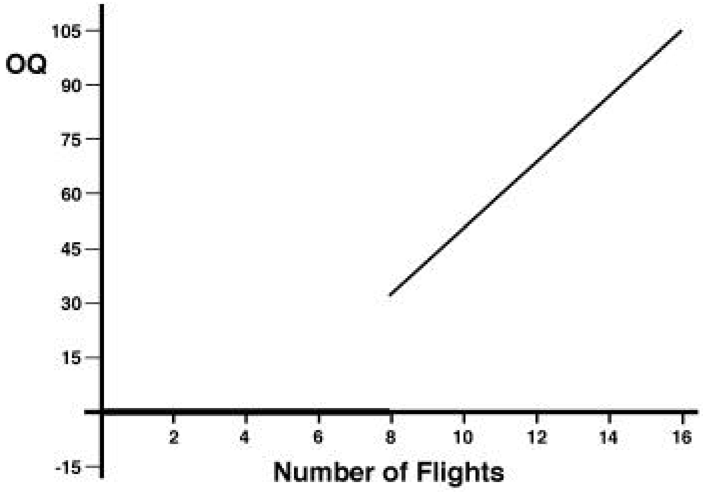
3) Since the number of serviceable parts on hand = 54, the Order Quantity is 0 when the MSL is less than 54. From exercise 2, we see that this occurs when 7X<54. This implies that X<8. As a result, the Order Quantity is the following piecewise function.

$$\text{OQ} = \left[\left(\frac{4\text{ tires}}{\text{flight}}\cdot\frac{\text{X flights}}{\text{year}}\cdot\frac{1\text{ year}}{12\text{ months}}\right)\left(12\text{ months}\right)\right] + 7\text{X} - 0\text{ tires} - 54\text{ tires}$$

$$= \left[\left(4\text{X}\cdot\frac{1}{12}\right)\cdot 12\right] + 7\text{X} - 0 - 54 = 11\text{X} - 54 \quad \text{if X} \geq 8$$

$$\text{OQ} = 0 \quad \text{if X} < 8$$

4. a)



Note: The above graph of OQ versus the number of flights is drawn in two continuous pieces to "guide the eye". It is important to remember that in reality the domain and range consist of only whole numbers.

b) When there are fewer than 8 flights, the slope of the graph is zero. In this case, the MSL is less than the Ser. , so no tires need to be ordered. When there are 8 or more flights, the slope of the graph is 11 = 11/1. This means that 11 more tires must be ordered for each additional flight.

5)

Table 2

Number of Tires per Flight	Number of Flights per Year	Safety Pad (in Months)	MSL	Due-In Quantity	Ser.	Order Quantity (OQ)	Cost per Tire	Total Cost
4	6	12	42	0	54	0 *	$5560	$0
4	8	12	56	0	54	34	5560	189040
4	12	12	84	0	54	78	5560	433680
4	15	12	105	0	54	111	5560	617160

* Tires are not ordered when the Serviceable Quantity is greater than the MSL

Part D How a Change in the Number of Tires on Hand Affects the Order Quantity (OQ)

The MSL at 8 flights per year is 56. If the Serviceable Quantity (Ser.) is greater than the MSL, you would not order any tires (OQ = 0). Thus, the Order Quantity function is piecewise.

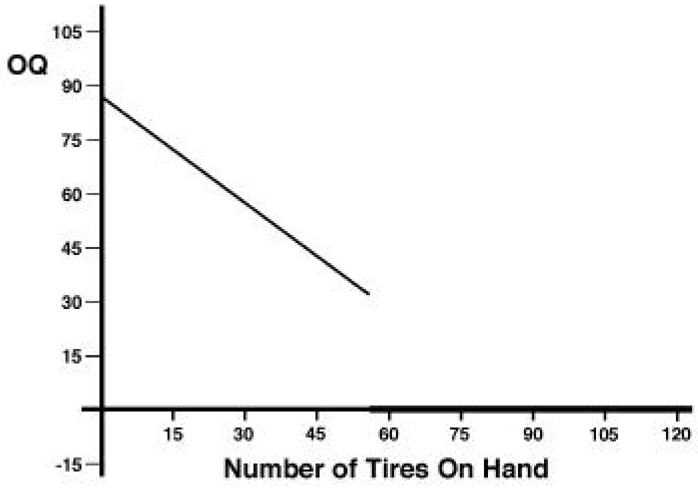
1) $$\mathrm{OQ} = \left[\left(\frac{4\text{ tires}}{\text{flight}}\cdot\frac{8\text{ flights}}{\text{year}}\cdot\frac{1\text{ year}}{12\text{ months}}\right)(12\text{ months})\right] + 56\text{ tires} - 0\text{ tires} - \mathrm{X}$$

$$= 32 + 56 - \mathrm{X}$$

$$= 88 - \mathrm{X} \quad \text{if } \mathrm{X} \le 56$$

$$\mathrm{OQ} = 0 \quad \text{if } \mathrm{X} > 56$$

2. a)



This graph is drawn in two continuous pieces. It is important to remember that in reality the domain and range consist of only whole numbers.

b) When the Serviceable Quantity is less than or equal to 56, the slope of the graph is equal to –1. Thus, as the number of tires on hand increases by 1, the number of tires to be ordered decreases by 1. When the Serviceable Quantity is greater than 56, the slope of the graph is zero. Since the Serviceable Quantity is greater than the MSL, no tires need to be ordered.

c) The y-intercept is 88. If there are no tires on hand, 88 need to be ordered.

3)

Table 3

Number of Tires On Hand (Ser.)	Order Quantity (OQ)
0	88
27	61
54	34
81	0 *

* The Serviceable Quantity of 81 tires is greater than the MSL. Therefore, no tires are ordered (OQ = 0).

4) Answers will vary.

Part E How a Change in the Safety Pad Affects the Minimum Stock Level (MSL) and the Order Quantity (OQ)

1) $$\text{MSL} = \left(\frac{4\text{ tires}}{\text{flight}} \cdot \frac{8\text{ flights}}{\text{year}} \cdot \frac{1\text{ year}}{12\text{ months}}\right)\left(9\text{ months} + \text{X months}\right) = \frac{32}{12}\cdot(9+\text{X})$$

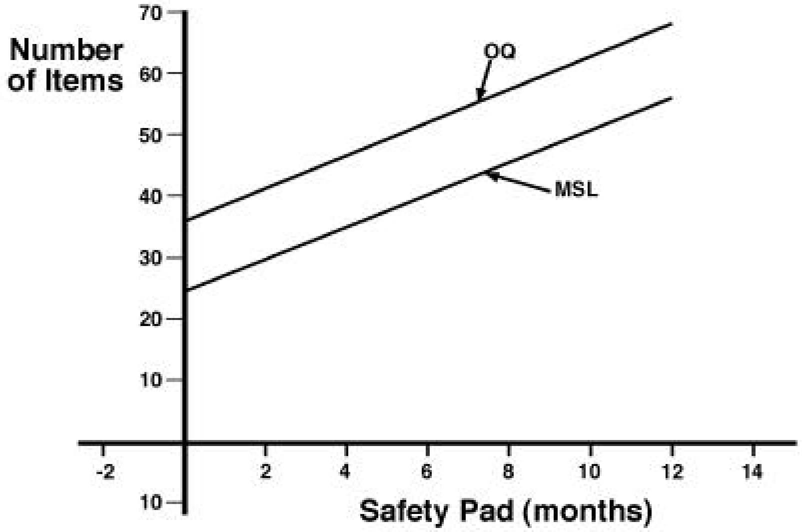
$$= \frac{8}{3}\cdot(9 + \text{X})$$

$$= \frac{8}{3}\cdot\text{X} + 24$$

2) $$\text{OQ} = \left(\frac{4\text{ tires}}{\text{flight}} \cdot \frac{8\text{ flights}}{\text{year}} \cdot \frac{1\text{ year}}{12\text{ months}}\right)\left(12\text{ months}\right) + \left(\frac{8}{3}\cdot\text{X} + 24\right) - 0\text{ tires} - 20\text{ tires}$$

$$= \frac{8}{3}\cdot\text{X} + 36$$

3)



4. a) The lines are parallel and increasing. Both have the same slope but the y-intercepts are different.

   b)

Table 4

Safety Pad (months)	Minimum Stock Level (MSL)	Order Quantity (OQ)
0	24	36
3	32	44
6	40	52
9	48	60
12	56	68

5) The value of the Order Quantity function for a safety pad of 10 months is approximately 62.7 which must be rounded up to 63 tires.

6) For all values of the safety pad the Minimum Stock Level exceeds the Serviceable Quantity (20 tires). Tires must be ordered, i.e. the Order Quantity is greater than zero, regardless of the value of the Safety Pad.

SPINOFF 1A

How a Change in the Number of Flights per Year Affects the Probability of Sufficiency

1)

Table 1

Flights per Year	Total Projected Operating Time (TPOT)	Lambda (λ)
8	6384	0.01902
12	9576	0.02853
15	11970	0.03567

2. a)

Table 2 (answers are percents)

S (Total Spares)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
POS (8 flights per year)	0	2	6	15	28	44	60	74	85	92	96	98	99	100	100	100	100
POS (12 flights per year)	0	0	1	2	5	11	21	32	45	59	70	80	87	93	96	98	99
POS (15 flights per year)	0	0	0	0	1	3	7	13	21	31	43	55	66	76	83	89	93

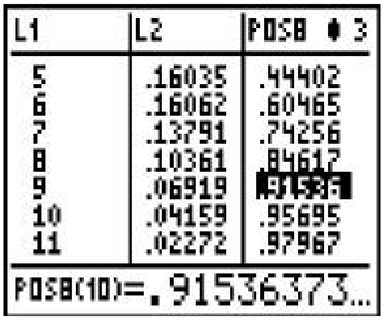
b) 9 spares for 8 flights
13 spares for 12 flights
16 spares for 15 flights

c) 75 times out of 100 (or 3 out of 4 times) a spare will be available

d) 8 spares for 8 flights
11 spares for 12 flights
13 spares for 15 flights

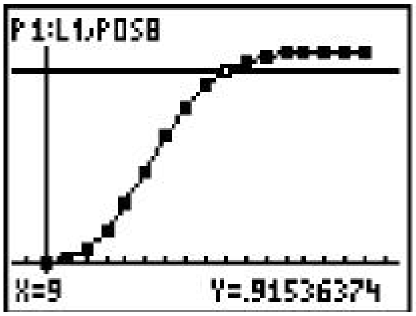
e) Answers will vary.

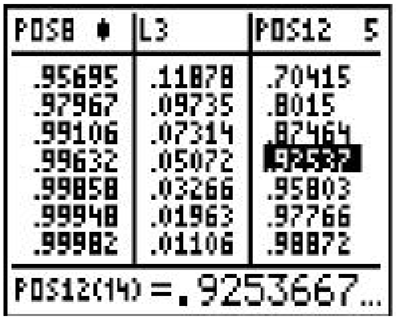
3) TI-83™ graphs



L1	L2	POS8 ◆ 3
5	.16035	.44402
6	.16062	.60465
7	.13791	.74256
8	.10361	.84617
9	.06919	.91536
10	.04159	.95695
11	.02272	.97967

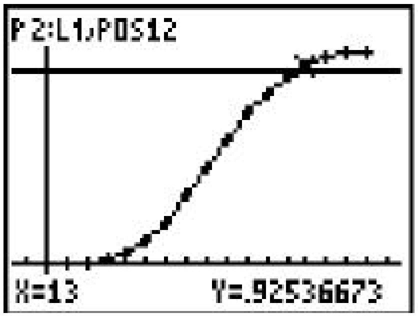
POS8(10)=.91536373...

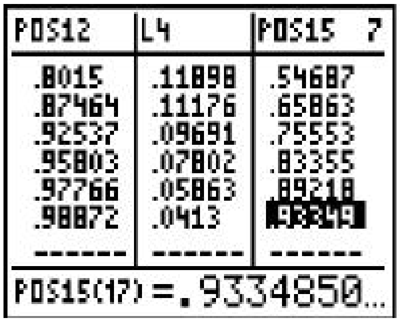




POS8 ◆	L3	POS12 5
.95695	.11878	.70415
.97967	.09735	.8015
.99106	.07314	.87464
.99632	.05072	.92537
.99858	.03266	.95803
.99948	.01963	.97766
.99982	.01106	.98872

POS12(14) =.9253667...





POS12	L4	POS15 7
.8015	.11898	.54687
.87464	.11176	.65863
.92537	.09691	.75553
.95803	.07802	.83355
.97766	.05863	.89218
.98872	.0413	.93349
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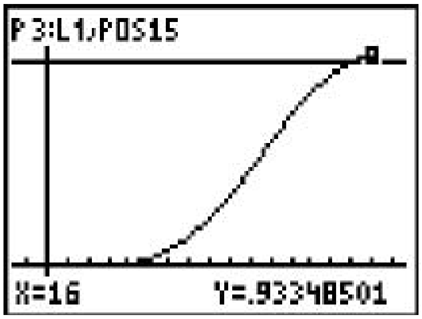
POS15(17) =.9334850...



To determine how many spares are necessary to reach a POS of 90% it may be helpful to also graph the line y = 0.9 (or y = 0.75 to see how many spares are necessary for a POS of 75%). That way it is easy to see where the POS reaches the 90% or 75% level.

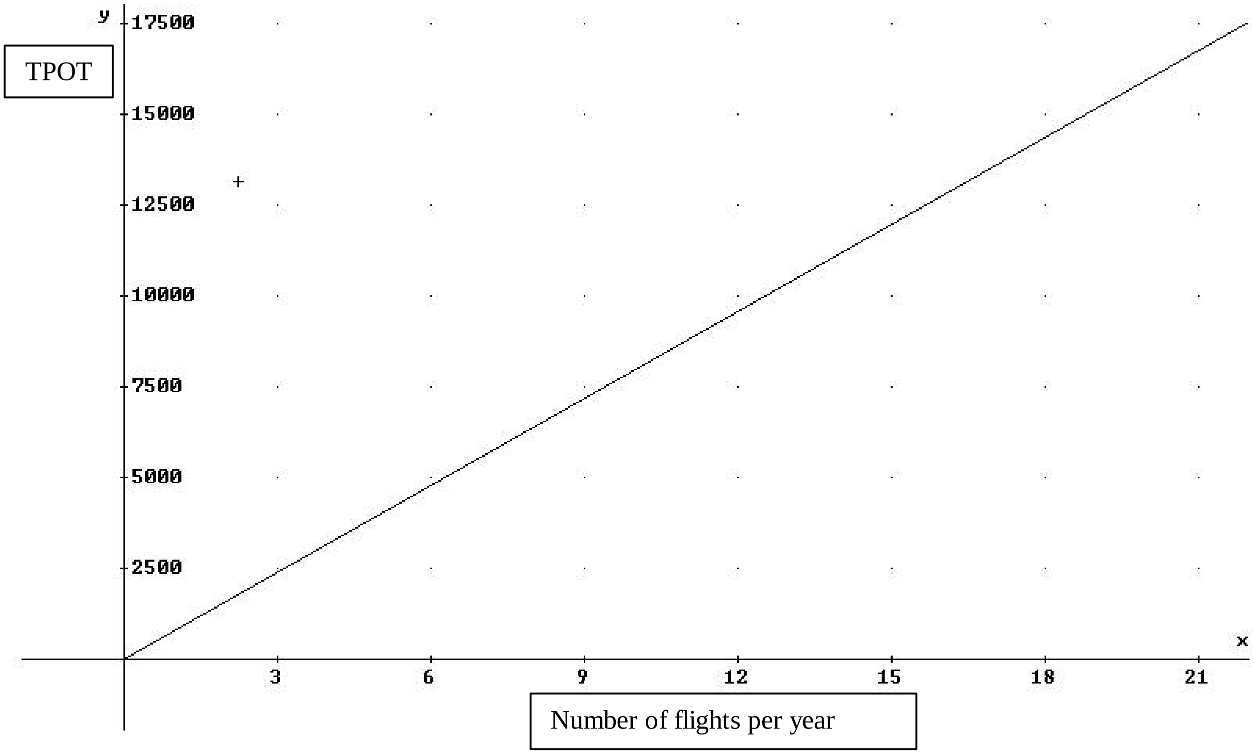
4) The answers should be the same.

SPINOFF 1B

How the Number of Flights Per Year Changes the Total Projected Operating Time for Fuel Cells

1) TPOT = QPV*(FPOT+GPOT)*flight rate per year
= 3(230+36)X
= 798X

2. a)



b)

Flights per Year	Total Projected Operating Time (TPOT)
5	3990 hours
8	6384 hours
12	9576 hours
15	11970 hours
20	15960 hours

3) The slope represents the total hours that the fuel cells will be in use for one flight.

4) The slope would change if the number of hours that the fuel cells are in use for each flight changes.

5) No. The function only makes sense for integer values of X since X stands for the number of flights per year.

6) Answers will vary.

7) 18 flights would be possible since the TPOT for 18 flights is 14364 hours, but the TPOT for 19 flights is 15,162 hours.