Instructor's Manual

Implications and Ramifications of Engineering Design of Field Joint for Space Shuttle:STS 51-L

1. Educational Objectives

The objectives of this case are for students to:

1. Evaluate the consequences of choos ing an engineering design.
2. Critically evaluate several options by applying engineering design consid erations, statistical methods, and principles of ethics, to the informa tion provided.
3. Make a decision and defend it.

2. Definition of the Intended Field for the Case

This case study could be used at undergraduate and graduate courses in engineering design, operations management, and industrial design. It would also be useful in engineering and business ethics courses. It could be covered in either a 2-hour session or two 1-hour sessions.

3. Theoretical Basis of Research

The material in this case study has been written based on material available from secondary sources and has been checked with NASA engineers to verify the accuracy. The ethics material has been based upon principles from professional codes of ethics. The codes of ethics from the following professional societies were provided to students as supplementary material: AIAA, ASCE, ASME, IEEE, IIE, and NSPE. In addition, the students could be provided an introduction to the principles of ethics including Kantianism or Utilitarianism.

4. Possible Answers for Class Presentations

In the following discussion, we will list the engineering, ethical, and statistical reasons for launching and not launching STS 51-L. The students could use some of these points in answering their questions and playing the roles.

I. Defend the launching of STS 51-L

STS 51-L should be launched for the following reasons:

(A) Engineering Design Considerations

a) There were 24 successful launches in which O-ring erosion did not pose any serious threat to flight safety

b) Of the 24 launches, only 7 STS missions had O-ring distress.

c) The secondary seal was redundant in all but worst case scenarios.

d) There was a .005 inch "safety margin" of erosion on the primary O-ring. Lab test showed that the O-ring would seal at 3,000 psi with .095 inches of erosion far above the launch pressure and any previous after flight erosion.

e) There has been extensive testing be tween 1980-86 qualifying the abilities of the SRM.

f) Past erosions has always been within acceptable limits.

g) If the SRB had to be redesigned, it would set the space shuttle launch back two years. Some risks must be taken to pursue new innovations.

(B) Statistical Data Analysis:

a) Blow-by of O-rings cannot be linked to cold temperatures since two SRMs had severe blow-by at 75° F.

b) There is no test data that conclusively links cold temperatures to severe O-ring damage. A launch at 70° F had more O-ring erosion than a launch at 53° F.

c) There is no test data for 26° F which shows that this temperature would be unacceptable.

d) The probability of failure of both O-rings is estimated to be very low.

(C) Ethical Considerations:

Utilitarianism is based upon the principle of utility which states that the goal of every action is to provide the greatest good over bad. Let us now weigh the different options to decide which option will create a greater balance of happiness over unhappiness. Positive numbers will show happiness and negative numbers will show unhappiness.

1. Do Not Launch the Shuttle

Beneficial/ Not Beneficial	Amount of people
+ Benefits the astronauts	(+) 7
- Does not benefit NASA (costs money and will be behind schedule)	(-) 1000's
- Does not benefit MTI (image of being incompetent)	(-) 100's
- Does not benefit the citizens (wasted tax dollars)	(-) Millions
TOTAL	**(-) Millions**

2. Launch the Shuttle

Beneficial/ Not Beneficial	Amount of people
- Does not benefit the astronauts (they die)	(-) 7
+ Benefits NASA (on schedule, satisfies Congress and citizens)	(+) 1000's
+ Benefits MTI (good product)	(+) 100's
+ Benefits citizens (no wastage of tax dollars)	(+) Millions
TOTAL	**(+) Millions**

This indicates that launching STS 51-L is an ethical choice.

(D) Summary:

The launch of STS 51-L seems to be ethical and safe from an engineering standpoint. Since the secondary O-ring will be redundant in most cases and the probability of failure of both O-rings is very low, NASA should continue with the launch.

II. Defend not launching STS 51-L.

STS 51-L should not be launched for the following reasons.:

(A) Engineering Design Considerations:

a) Lower O-ring squeeze due to the lower temperature and higher O-ring shear hardness increases the time for the primary O-ring to seal. If the primary O-ring does not seal, blow-by could occur and the secondary O-ring may also not seal. (This is the argument given by engineers shown in Appendix 8).

b) Joint rotation increases the gap that the O-ring must seal. When the gap is bigger, the O-ring may not seal the entire gap and then gases might leak out of the gap.

c) Cold temperature increases joint grease viscosity (makes it thicker) which increases the O-ring sealing time.

d) If actuation time of the primary O-ring is increased, secondary O-ring sealing is less likely. Between 600 milliseconds and 2 minutes of the primary O-ring not sealing, there is a high probability that the secondary O-ring would not seal.

e) A warm O-ring that has been compressed will return to its original shape much more quickly than a cold O-ring. Thus, a warm O-ring will follow the opening of the tang-to-clevis gap while a cold O-ring may not. A compressed O-ring at 75°F is five times more responsive in returning to its uncompressed shape than a O-ring at 30°F.

f) SRM 15 on Flight 51-C, the coldest O-ring temperature launch, had severe erosion.

g) If an accident occurs, NASA could suffer severe setbacks such as schedule delays, legal costs, etc.

(B) Statistical Data Analysis[1]

Appendix 9 in the case study shows incidents of O-ring distress and temperature. A graphical representation of that material is shown in Figure 1. Based on this chart, Boisjoly and other MTI engineers were unable to correlate temperature and O-ring erosion because of the severe erosion at 75 degrees (STS 61A).

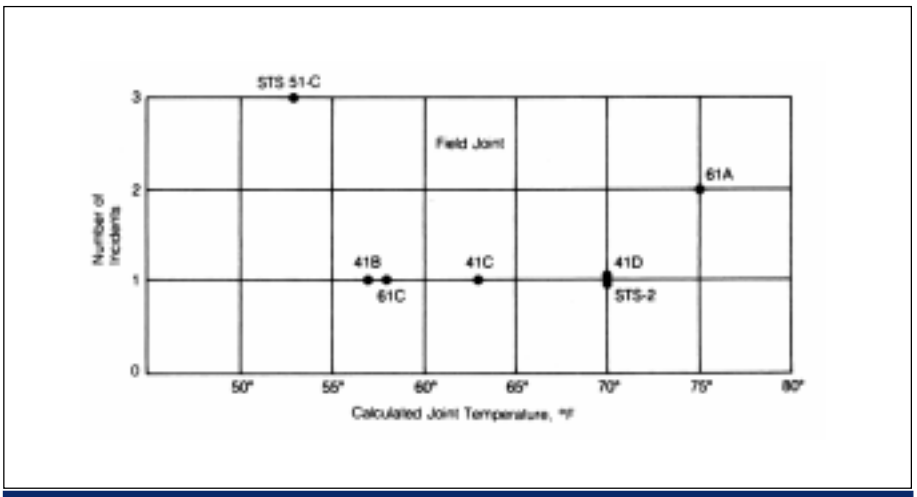

Figure 1: STS Missions with O-ring Distress (Erosion, Blow-by)

Figure 2 shows all of the STS missions, those that had incidents of O-ring erosion, as well as those that did not based on the information given in Table 1 of the case study.

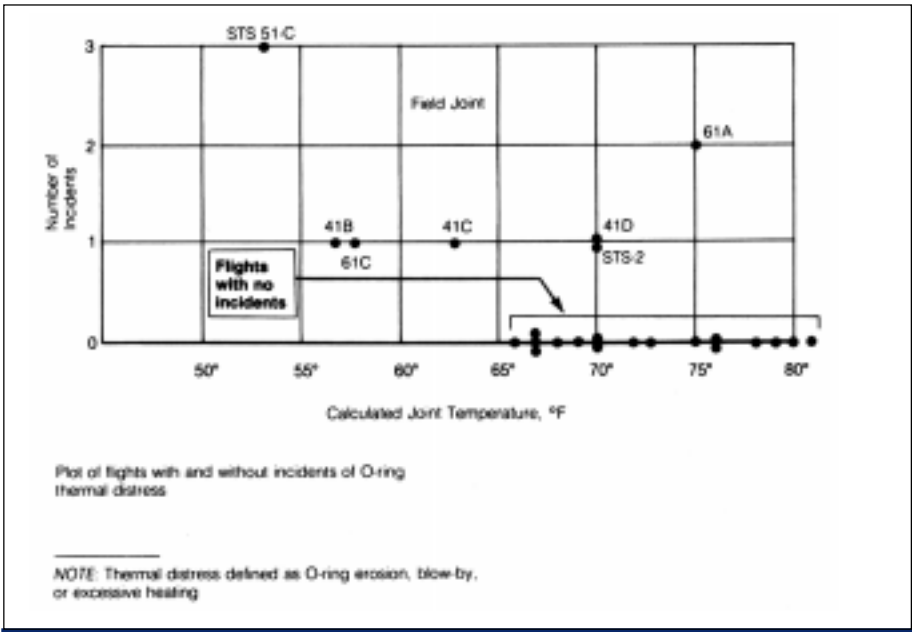

Figure 2: Complete Plot of STS Missions

As shown in Figure 3, by fitting a curve to the data points, it is possible to see the correlation between temperature and O-ring distress. A Median Polish curve is an empirically generated curve that connects medians of subgroups of data points. By performing this analysis, the data point of STS 61-A could be classified as a statistical outlier. In addition, a linear regression analysis was performed on the data in Table 1 showing the regression line in Figure 3. Both statistical analyses demonstrate that the 26°F launch of STS 51-L might cause 2 or more O-ring thermal distress incidents.

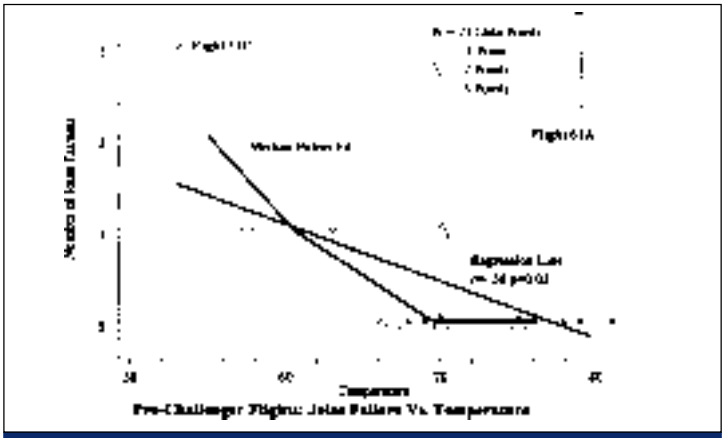

Figure 3: Regression analysis of data in Table 1 (THE Y-AXIS NEEDS TO BE NUMBER OF O-RING DISTRESS INCIDENTS)

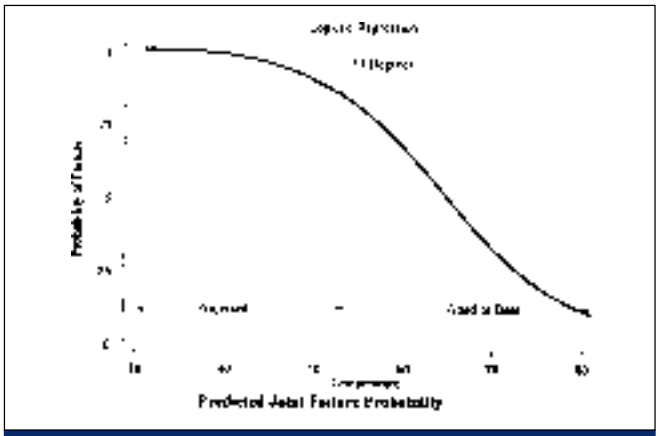

Figure 4: Logistic Regression Analysis of Data in Table 1

Figure 4 shows a logistic regression analysis of the data in Table 1. The probability of failure at 26° F (the Challenger launch temperature) is close to 100%. At 53 degrees, the probability is estimated to be approximately 80%. Therefore, from a statistical point of view, the launch should not proceed.

(C) Ethical Considerations:

Utilitarianism is based upon the principle of utility which states that the goal of every action is to provide the greatest good over bad. Let us now weigh the different options to decide which option will create a greater balance of happiness over unhappiness. Positive numbers will show happiness and negative numbers will show unhappiness.

1. Do Not Launch the Shuttle

Beneficial/ Not Beneficial		Amount of people
+ Benefits the astronauts	(+)	7
- Does benefit NASA (no law suits or bad reputation)	(+)	1000's
- Does not benefit MTI (image of being incompetent)	(-)	100's
Neutral to the citizens (wasted tax dollars versus lack of anguish)		0
TOTAL	**(+)**	**1000's**

2. Launch the Shuttle

Beneficial/ Not Beneficial		Amount of people
- Does not benefit the astronauts (they die)	(-)	7
Neutral to NASA (satisfies Congress and citizens versus intense scrutiny of operations)		0
+ Benefits MTI (good product)	(+)	100's
Neutral to citizens (wastage of tax dollars versus costly redesign)	(+)	0
TOTAL	**(+)**	**100's**

This indicates that not launching STS 51-L is an ethical choice from utilitarianism.

Kantianism states that all parties involved must be aware of every aspect of the problem and be able to make a rational decision based on the information presented. In the decision regarding STS 51-L, it is very clear that the astronauts who were very much a part of the team, had no idea of the problem at all. They were completely in the dark regarding the temperature of launch and so were their families to a large extent. Had the astronauts known about the problem and its related results, they would have surely not accepted to launch the shuttle on that fateful mission. Since the astronauts are the ones who are actually in the Shuttle at the time of launch, they should have been notified of the problem and their suggestion should have also been considered. If the astronauts had been informed about the problem and they had made a choice to launch after considering the pros and cons of the problem, then the principle of Kantianism would have been satisfied. It was a risk and it would have been a calculated risk had everyone involved been notified about it. The decision to launch or otherwise would have had to be unanimous and not of a few people in the higher rungs of the organizational structure. Therefore, deciding not to launch is ethically appropriate from both utilitarianism and Kantianism.

(D) Summary:

Not launching STS 51-L seems to be ethical and correct from an engineering standpoint. Since cold temperatures negatively impacted the sealing capability of the O-rings and joint rotation is a continuous problem, NASA should not launch and spend resources to redesign the field joint.

[1] The material in this section has been adapted from Rosa Lynn B. Pinkus, Larry J. Shuman, Norman P. Hummon, and Harvey Wolfe, *Engineering Ethics: Balancing Cost, Schedule, and Risk - Lessons Learned from the Space Shuttle*, Cambridge University Press, Cambridge, UK, 1997.