

Ethical Decisions - Morton Thiokol and the Space Shuttle Challenger Disaster - Index

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Abstract

A background summary of important events leading to the *Challenger* disaster will be presented starting with January, 1985, plus the specifics of the telecon meeting held the night prior to the launch at which the attempt was made to stop the launch by the Morton Thiokol engineers. A detailed account will show why the off-line telecon caucus by Morton Thiokol Management constituted the unethical decision-making forum which ultimately produced the management decision to launch *Challenger* without any restrictions.

The paper will continue with the post-disaster chronology of my working relationship with Morton Thiokol Management and conclude with a discussion on accountability, professional responsibility and ethical conduct which should be practiced in the work place, plus statements from the academic community about the plight of whistleblowers and my closing remarks.

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Nomenclature

- AIAA American Institute of Aeronautics & Astronautics
- FRR Flight Readiness Review
- IEEE Institute of Electrical and Electronics Engineers
- KSC Kennedy Space Center
- MEOP Maximum Expected Operating Pressure
- MSFC Marshall Space Flight Center
- ms milliseconds
- MTI Morton Thiokol, Incorporated
- NASA National Aeronautics and Space Administration
- SAE Society of Automotive Engineers
- SRM Solid Rocket Motor

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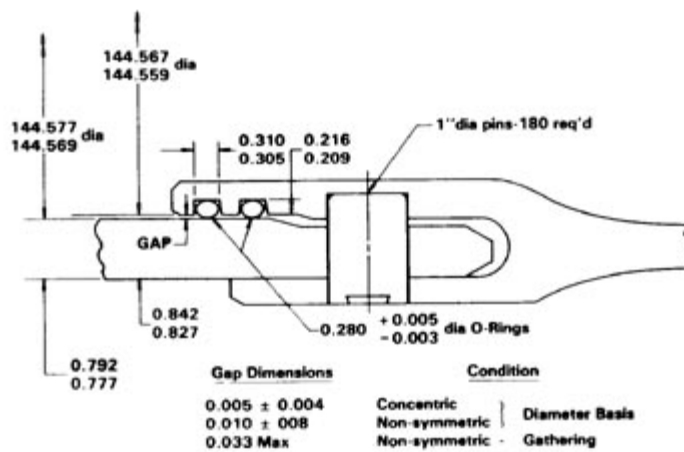
Introduction

You may have already concluded that the *Challenger* disaster was the result of only the decisions made during the evening prior to and the day of launch. As a senior engineer involved with the SRM's since July, 1980, and specifically with the joints since 1981, I can make the following statements from personal observations.

The SRM Program at MTI was suffering from the lack of proper original development work and some may argue that sufficient funds or schedule were not available and that may be so, but MTI contracted for that condition. The Shuttle program was declared operational by NASA after the fourth flight, but the technical problems in producing and maintaining the reusable boosters were escalating rapidly as the program matured, instead of decreasing as one would normally expect. Many opportunities were available to structure the work force for corrective action, but the MTI Management style would not let anything compete or interfere with the production and shipping of boosters. The result was a program which gave the appearance of being controlled while actually collapsing from within due to excessive technical and manufacturing problems as time increased.

This paper starts with January, 1985, which was the period of gross escalation of joint seal problems and continues with specific events that should have signaled either stopping the flights or as a minimum, changing the launch commit criteria to prevent launching below 53 °F (12 °C).

Figure 1 shows the SRM joint configuration for purposes of this discussion.



<u>Inches</u>	<u>Millimeters</u>	<u>Inches</u>	<u>Millimeters</u>
144.557		0.310	
144.569	3672.15	0.305	7.81
144.567			
144.559	3671.90	0.280	7.11
1.0	25.40	0.216	
0.842		0.209	5.40
0.827	21.20	0.033	0.84
0.792		0.010	0.25
.777	19.93	0.005	0.13

Figure 1 SRM FIELD JOINT

All dimensions are in inches with SI units for nominals given in the supplementary table. The first O-ring to seal internal hot gases is called the primary seal while the other is termed the secondary seal. There are 177 load carrying pins plus three locating pins for assembly clocking. Pressurization of the motor to 1004 psi (6.92×10^6 pascals) causes the gap dimension to increase 0.042 inches (1.07 mm).

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Pre-Disaster Background (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Background on the events, meetings, and SRM testing leading up to the Morton Thiokol Space Shuttle Challenger Disaster.

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Telecon Meeting (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

The evening telecon meeting between MTI, MSFC and KSC on January 27, 1986, was the final event preceding the Morton Thiokol Space Shuttle Challenger Disaster.

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Post-Disaster Treatment (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

This testimony outlines the post challenger disaster treatment, and the separation of engineers and management. Details the isolation and hostile work environment in the redesign effort at MTI"

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Professional Responsibility and Conduct (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Engineering and responsibility and ethics that must be followed in the work place, pertaining to lessons learned from the Morton Thiokol and the space shuttle Challenger disaster.

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Accountability (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Who is accountable and at what costs in the Morton Thiokol Space Shuttle Challenger Disaster.

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Closing Remarks (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Closing remarks regarding Robert Boisjoly's attempts to divert the Challenger disaster.

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Appendix (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

The Appendix providing references for regarding Robert Boisjoly's attempts to divert the Challenger disaster.

Pre-Disaster Background (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Author(s): Roger M. Boisjoly

The significance of starting with January, 1985, results from my observations made during the post flight inspection of hardware from Flight 51C which was launched on January 14, 1985. I found that hot combustion gases had blown by the primary seals on two field joints and had produced large arc lengths of blackened grease between the primary and secondary seals. Subsequent to reporting my findings, I was ordered to MSFC to present a preliminary report prior to formal FRR meetings.

I participated in the formal FRR's for flight 51E which was scheduled for an April launch. The presentations were given at MSFC in February at three successively higher level review boards with exclusions and refinements in content made at each board level. I spoke about my belief that the low ambient temperature prior to launch was responsible for such a large witness of hot gas (approximately 5500 °F [3040 °C]) blow-by but NASA Program Management insisted on that position being softened for higher and final review board presentations. The ambient temperature was 18 to 22 °F (-8 to -6 °C) several days prior to launch and in the 60 - 65 °F (16 to 18 °C) range at launch time and resulted in a seal temperature of 53 °F (12 °C) -which was calculated after the damage was found.

Accordingly, the final FRR assessment chart read as follows:

Evaluation Summary

- STS-51C primary O-ring erosion on two field joints
- STS-51C soot between primary and secondary O-rings on both field joints predicted after STS-11 observation, first time observed
- Evidence of heat affect on secondary O-ring of A68 (right hand) center field joint but no erosion --first time heat affect on secondary O-ring has been observed

Conclusion

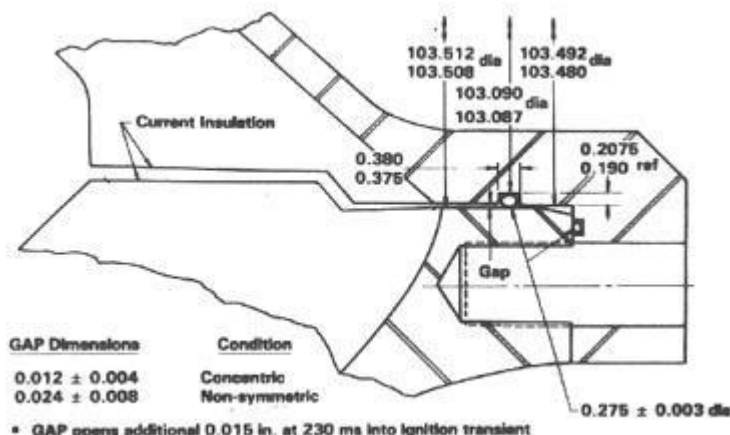
- STS-51C consistent with erosion data base
- Low temperature enhanced probability of blowby -- STS-51C experienced worst case temperature change in Florida history
- STS-51E could exhibit some behavior
- Condition is acceptable
- STS-51E field joints are acceptable for flight

These conclusions were accepted and the boosters were certified for launch.

I returned to MTI in Utah and met with Arnie Thompson, who was the Supervisor of Structural Design and Analysis for the SRM case segments, to discuss the hot gas blow-by scenario and the affects of cold temperature on O-ring resiliency, which we defined as the ability of the seal to restore itself to a round cross sectional shape after the squeeze on the seal is removed. The preliminary resiliency testing, which was requested by Arnie Thompson, was performed in March and showed that a low temperature of 50 °F (10 °C) was a problem, as the seal material could not follow the rate of gap opening and lost contact with its mating surface. The significance of this data was that the seal erosion and blow-by problem was known to occur within 0.60 seconds during the motor ignition transient. The data was discussed with MTI Engineering Management, but was thought to be too sensitive by them to release to anyone.

Another post flight inspection was performed in June, 1985, at MTI facilities in Utah on a nozzle joint from Flight 51B (SRM 16A) which was launched on April 29, 1985. The nozzle joint configuration is shown in Figure 2 with all dimensions in inches.

The bore (radial) seal is the primary seal and the face seal is the secondary seal in this joint.

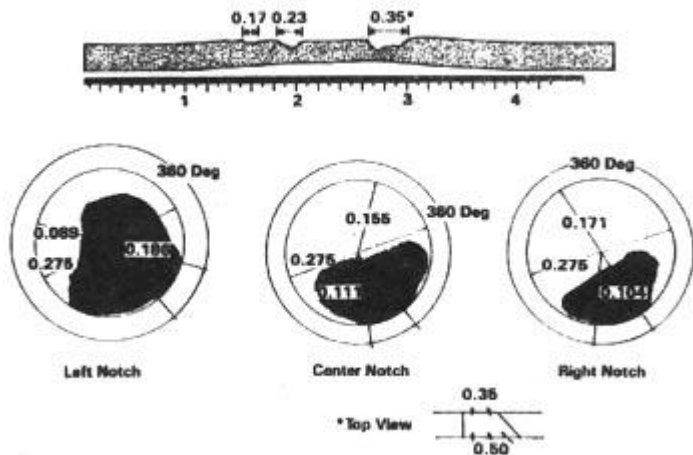


Inches Millimeters Inches Millimeters

103.512			
103.508	2629.15	0.275	6.99
103.492			0.2075
103.480	2628.54	0.190	5.05
103.090		0.024	0.61
103.067	2618.45	0.015	0.38
0.380			
0.375	9.59	0.012	0.30

Figure 2. SRM Nozzel Joint

This joint was found to have the primary seal eroded through in three places as shown in Figure 3.



Inches Millimeters Inches Millimeters

0.17	4.32	0.111	2.82
0.23	5.84	0.155	3.94
0.35	8.89	0.104	2.64
0.089	2.03	0.50	12.70
0.186	4.57	0.275	6.98

Figure 3. SRM-16A Nozzel Joint Primary O-Ring

The darkened areas represent the remaining seal material after the hot gas blow-by occurred. The secondary seal in the same joint was eroded to a depth of 0.032 inches (0.81 mm) but sealed as expected. It was postulated from the evidence that the primary seal had not sealed during the full two minutes of booster flight.

My former concerns about seal erosion and blow-by now escalated because if the same scenario should occur in a field joint, the secondary seal could also be compromised because it was a bore seal instead of the very safe face seal in the nozzle joint. This heightened concern was especially true for a low temperature launch because of the preliminary test results on seal resiliency at 50 °F (10 °C).

An FRR was held at MSFC on July 1, 1985 for flight 51F which was scheduled for launch on July 29, 1985, with an additional presentation given on July 2nd which covered the overall problem status with all the booster seals. The preliminary test results on O-ring resiliency that were obtained in March and kept secret were presented to NASA for the first time at this meeting.

The preliminary test configuration placed an O-ring seal into a flight size groove in a flat plate and compressed the seal 0.040 inches (1.02 mm) with another flat plate. After temperature conditioning of the assembly, the plates were separated 0.030 inches (0.76 mm) at a 2.0 inch (5.08 cm) per minute rate to simulate a flight rate of approximately 3.2 inches (8.13 cm) per minute (slightly unconservative).

The test results showed no loss of seal contact at 100 °F (38 °C); loss of seal contact for 2.4 seconds at 75 °F (24 °C) and loss of seal contact for in excess of 10 minutes at 50 °F (10 °C). The testing also showed that a larger diameter seal (0.295 in - 7.49 mm) lost contact for 2 to 3 seconds at 50 °F (10 °C). This showed that the larger diameter seal performed at 50 °F (10 °C) similar to the operational flight seal (0.280 in - 7.11 mm) at 75 °F (24 °C), which was why the larger seal was being considered for a short-term fix.

Everyone on the program, working with the joint seal problems, was now aware of the influence of low temperature on the field

joint seals.

Again, my concern about the joints increased due to the lack of attention being given to this problem by MTI. My notebook entry on August 15, 1985 reads as follows: "An attempt to form the team (I was referring to the SIRM Seal Erosion Task Team) was made on 19 July 1985. This attempt virtually failed and resulted in my writing memo 2870:FY86:073. This memo finally got some response and a team was formed officially. The first meeting was held on August 15, 1985 at 2:30 p.m." The memo I referred to is the one I wrote to the Vice President of Engineering at MTI on July 31, 1985. The memo was stamped COMPANY PRIVATE by my boss and had a very limited distribution until I read it to the Presidential Commission on February 25, 1986. The memo reads as follows:

"Subject: SRM O-Ring Erosion/Potential Failure Criticality. This letter is written to insure that management is fully aware of the seriousness of the current O-ring erosion problem in the SRM joints from an engineering standpoint. The mistakenly accepted position on the joint problem was to fly without fear of failure and to run a series of design evaluations which would ultimately lead to a solution or at least a significant reduction of the erosion problem. This position is now drastically changed as a result of the SRM 16A nozzle joint erosion which eroded a secondary O-ring with the primary O-ring never sealing."

"If the same scenario should occur in a field joint (and it could), then it is a jump ball as to the success or failure of the joint because the secondary O-ring cannot respond to the clevis opening rate and may not be capable of pressurization. The result would be a catastrophe of the highest order--loss of human life."

"An unofficial team (a memo defining the team and its purpose was never published) with leader was formed on 19 July 1985 and was tasked with solving the problem for both the short and long term. This unofficial team is essentially nonexistent at this time. In my opinion, the team must be officially given the responsibility and the authority to execute the work that needs to be done on a noninterference basis (full-time assignment until completed)."

"It is my honest and very real fear that if we do not take immediate action to dedicate a team to solve the problem, with the field joint having the number one priority, then we stand in jeopardy of losing a flight along with all the launch pad facilities."

The memo was signed by R. M. Boisjoly and concurred to by J. R. Kopp, Manager, Applied Mechanics, who was my boss.

During the July-August time period, NASA headquarters in Washington, D. C. asked MTI to prepare and present a summary of problems with all the booster seals on August 19, 1985. This was done and that is why I find it so incredible that top NASA management denies knowing anything about the problems with the joint seals, when questioned by the Presidential Commission.

MTI was then asked by NASA MSFC in September to send a representative to the SAE Conference in October to discuss the joint seal designs and solicit help from the technical experts in attendance. However, I was given strict instructions, which come from MSFC, not to express the critical urgency of fixing the joints but to only emphasize the joint improvement aspect during my presentation. I prepared and presented seven Viewgraphs to approximately 130 technical experts at the conference.

I then asked for help in the form of design improvement suggestions and stated that we were not asking for free advice but were willing to contract for work, but no one said a word. So Bob Ebeling and I spent the remainder of the convention time meeting with seal vendors whom we had previously contacted for help. In retrospect, I'm not surprised that no one responded to my pleas for help when I showed them the parameters of the joints. What they saw and heard were joint gap configurations (both static and dynamic) that were approximately an order of magnitude worse than anything they had previously encountered. I don't blame them for avoiding any comments and suggestions when asked.

The seal erosion task team was frustrated right from the start due to lack of management support to provide manpower and material resources necessary for us to accomplish the task of fixing the joints. Accordingly, I wrote a series of very damning activity reports in which I left no room for error about my feelings due to the lack of management support. The last such report written was on October 4, 1985 and reads as follows:

"SRM Seal Problem Task Team Status. The team generally has been experiencing trouble from the business-as-usual attitude from supporting organizations. Part of this is due to lack of understanding of how important this task team activity is and the rest is due to pure operating procedure inertia which prevents timely results to a specific request.

The team met with Joe Kilminster on October 3, 1985 to discuss this problem. He wanted specific examples which he was given and he simply concluded that it was every team member's responsibility to flog problems that occurred to organizational supervision and work to remove the road block by getting the required support to solve the problem. The problem was further explained to require almost full-time nursing of each task to insure it is taken to completion by a support group. Joe simply agreed and said we should then nurse every task we have.

He plain doesn't understand that there are not enough people to do that kind of nursing of each task, but he doesn't seem to mind directing that the task nevertheless gets done. For example, the team just found out that when we submit a request to purchase an item, that it goes through approximately six to eight people before a purchase order is written and the item actually ordered.

The vendors we are working with on seals and spacer rings have responded to our requests in a timely manner, yet, we (MTI) cannot get a purchase order to them in a timely manner. Our lab has been waiting for a function generator since September 15, 1985. The paperwork authorizing the purchase was finished by Engineering on September 24, 1985 and placed into the

system. We have yet to receive the requested item. This type of example is typical and results in lost resources that had been planned to do test work for us in a timely manner.

I for one resent working at full capacity all week long and then being required to support activity on the weekend that could have been accomplished during the week. I might add that even NASA perceives that the team is being blocked in its engineering efforts to accomplish its task. NASA is sending an engineering representative to stay with us starting October 14th. We feel that this is the direct result of their feelings that we (MTI) are not responding quickly enough on the seal problem. I should add that several of the team members requested that we be given a specific manufacturing engineer, quality engineer, safety engineer and four to six technicians to allow us to do our tests on a noninterference basis with the rest of the system. This request was deemed not necessary when Joe decided that the nursing of the task approach was directed.

Finally, the basic problem boils down to the fact that all MTI problems have #1 priority and that upper management apparently feels that the SRM program is ours for sure and the customer be damned."

The Activity Report was signed by Roger M. Boisjoly on October 4, 1985 and given to my boss's secretary. Unfortunately, I never received any comments back and I never knew if the contents of my activity reports were incorporated into the reports up through the management organization to the top.

Roger M. Boisjoly, Former Morton Thiokol Engineer, Willard, Utah

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Telecon Meeting (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

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Telecon Meeting (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Author(s): Roger M. Boisjoly

The evening telecon meeting between MTI, MSFC and KSC on January 27, 1986, was the final event preceding the *Challenger* disaster. The major activity that day focused upon the predicted 18 °F (-8 °C) overnight low and meetings with Engineering Management to persuade them not to launch below 53 °F (12 °C). My whole being was driven to action for this cause because of my memory of my January, 1985, participation in the inspection of the hardware from the previous coldest launch which had massive hot gas blow-by. The discussion activity concluded with the hurried preparation of fourteen Viewgraphs by various engineering groups which had less than an hour to respond for the scheduled evening telecon.

The following discussion is summarized to show the content of the engineering presentation. Figures labeled as Viewgraphs show the major thrust of the telecon and contain the actual content of the originals as presented, with SI units added, while others are summarized to give general content for brevity.

The first Viewgraph was a title page. The second Viewgraph showed a table of post history of O-ring damage on SRM field joints. The *third*, *fourth* and fifth Viewgraphs are shown as Figures 4., 5., and 6., respectively.

- field joint - highest concern
- erosion penetration of primary seal requires reliable secondary seal for pressure integrity
- ignition transient - (0-600 ms)
- (0-170 ms) high probability of reliable secondary seal
- (170-330ms) reduced probability of reliable secondary seal
- (330-600 ms) high probability of no secondary seal capability
- steady state - (600 ms - 2 minutes)
- if erosion penetrates primary o-ring seal - high probability of no secondary seal capability
- bench testing showed o-ring not capable of maintaining contact with metal parts gap opening rate to meop
- bench testing showed capability to maintain o-ring contact during initial phase (0- 170 ms) of transient

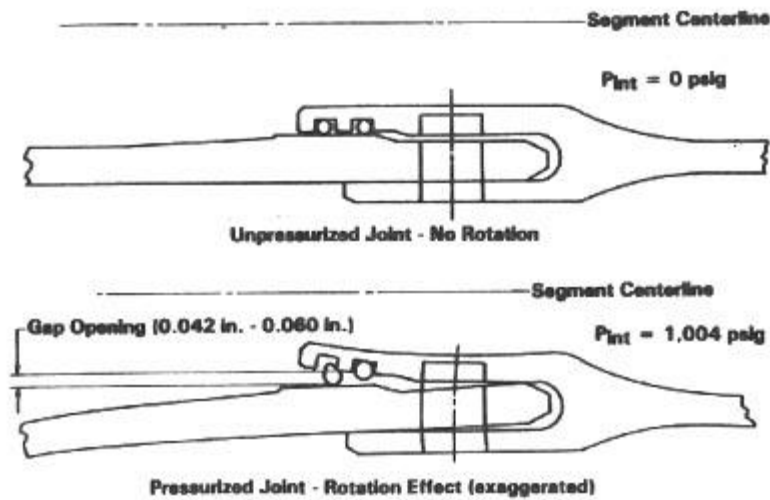
Figure 4. - primary concerns

Figure 4. was taken directly from the August 19, 1985 presentation to NASA headquarters. The last two statements show the reasons for both the high concern and for having a high probability of a secondary seal during the first portion of the transient time zone. The last statement was produced from testing at 50 °F (10 °C) which showed that a seal could maintain contact with its mating surfaces when compressed 0.040 inches (1.02 mm) and only 0.010 inch (0.25 mm) of compression was removed from the seal.

- a temperature lower than current data base results in changing primary o-ring sealing timing function
- srm 15a - 800 arc black grease between o-rings srm 15b - i 100 arc black grease between o-rings
- lower o-ring squeeze due to lower temp
- higher o-ring shore hardness
- thicker grease viscosity
- higher o-ring pressure actuation time
- if actuation time increases, threshold of secondary seal pressurization capability is approached
- if threshold is reached, then secondary seal may not be capable of being pressurized

Figure 5. - Field Joint Primary Concerns SRM 25

Figure 5. was the heart of the discussion at the telecon. The engineering issue was "Would the seals even actuate and seal due to changing their timing function?" This would place us in the category of having a high probability of no secondary seal capability while the primary seal would be experiencing massive blow-by erosion due to its inability to respond to the gap opening of the metal parts. The last two statements summarized the fear of loss of redundancy based upon my remembrance of the January, 1985 post-launch hardware inspection.



Inches Milli-meters

0.042 1.07
0.060 1.52

Figure 6. SRM Field Joint

Figure 6. shows the field joint in the "as assembled" configuration, plus the pressurized configuration which shows the gap opening parameter due to outboard radial deflection of the case membrane. The differential deflection between the membrane and the stiffer joint causes the inboard clevis leg to deflect inboard opposite the rotation of the tong, which causes the gap at the seals to open. This results in the secondary seal lifting off its seat at full pressurization without considering seal resiliency parameters.

The sixth Viewgraph showed a comparison of hot gas blow-by by comparing ARC lengths of blackened grease and some descriptive phases for various flights at different launch temperatures. The *seventh* Viewgraph was a table of O-ring shore hardness versus temperature. The *eighth* Viewgraph contained the preliminary O-ring resiliency data in a tabular form. Up to this point in the telecon, I was asked several times by NASA to quantify my concerns, but I said that I could not since the only data I had was already presented and that I had been trying to get more data since last October (1985). At this comment, the General Manager of MTI gave me a scolding look as if to say, "Why did you tell them that?" The presentation continued with Viewgraph nine which showed sub-scale test results of cold gas blow-by tests at 75 °F (24 °C) and 30 °F (-1 °C) which showed no leakage. This data was used as an argument by management to say that the joint sealed at 30 °F (-1 °C) but in fact, the tests were not seal tests at all, since the test ring was a solid block of metal which did not have the deflection characteristics of the full-scale joint and was never intended to test anything but incipient blow-by before any joint deflection occurred. Viewgraph *ten* contained a table of compression set data to aid in the visualization of seal permanent set characteristics. Viewgraph *eleven* is shown as Figure 7., It provided a comparison of O-ring squeeze for the *Challenger* joints (SRM 25) versus the previous coldest flight at 53 °F (12 °C) (SRM 15).

Motor	FWD		CTR		AFT	
	%	in mm	%	in mm	%	in mm
SRM-15A	16.1	0.045* 1.14	15.8	0.044 1.12	14.7	0.041 1.04
SRM-15B	11.1	0.031 0.79	14	0.039** 0.99	16.1	0.045 1.14
SRM-25A	10.16	0.028 0.71	13.22	0.037 0.094	13.39	0.037 0.094
SRM-25B	13.91	0.039 0.99	13.05	0.037 0.094	14.25	0.40 1.02

* 0.010 in. (0.25mm) erosion
** 0.038 in. (0.97mm) erosion

Figure 7. Field Joint O-Ring Squeeze (Primary Seal)

Viewgraph twelve is shown as Figure 8. The DM designates development motors, QM is qualification motors and SRM is flight motors. This chart showed the current data base versus the predicted *Challenger* seal temperature of 27 to 29 °F (-3 to -2 °C).

Motor	MBT**		Ambient		O-Ring*		Wind
	°F	°C	°F	°C	°F	°C	
DM-4	68	20.0	36	2.2	47	8.3	10 mph
DM-2	76	24.4	45	7.2	52	11.1	10 mph
QM-3	72.5	22.5	40	4.4	48	8.9	10 mph
QM-4	76	22.4	48	8.9	51	10.6	10 mph

SRM-15	52	11.1	64	17.8	53	11.7	10	mph
SRM-22	77	25.0	78	25.6	75	23.9	10	mph
SRM-25	55	12.8	26	-3.3	29	-1.7	10	mph
					27	-2.8	25	mph

* 1-D Thermal Analysis

** Propellant Mean Bulk Temperature

Figure 8. History of O-ring temperatures

Viewgraph thirteen is shown as Figure 9. The third and fourth statements under the first bullet are actually disclaimers for the development and qualification test data because the joint putty had been altered after assembly and prior to horizontal test firings. Observed holes in the joint putty were repaired since it was thought that the horizontal assembly was very severe on the joints and is what caused the holes in the putty and that vertical assembly would not cause such holes to occur. The reasoning was generally okay but that reasoning was never tested until sometime in 1985 when it was found that vertical assembly could indeed cause holes in the putty. The major faulty thinking lies in the fact that no specific vertical assembly testing was performed to verify the original assumption and that made the original horizontal test firings a series of successful tests without any sea] erosion.

- temperature of o-ring not only parameter controlling blow-by srm 15 with blow-by had an o-ring temp at 53 °F (11.7 °C) four development motors with no blow-by were tested at o-ring temp of 47 to 52 °F (8.3 to 11.1 °C) development motors had putty packing which resulted in better performance
- at about 50 °F (10 °C) blow-by could be experienced in case joints
- temp for srm 25 on 1-28-86 launch will be 29 °F (-1.7 °C) 9 a.m. 38 °F (3.3 °C) 2 p.m.
- have no data that would indicate SRM 25 is different than SRM 15 other than temp

Figure 9. - conclusions

Viewgraph fourteen is shown as [Figure 10](#).

- O-ring temp must be & mac179; 53 °F (11.7 °C) at launch development motors at 47 to 52 °F (8.3 to 11.1 °C) with putty packing had no blow-by SRM 15 (the best simulation) worked at 53 °F
- project ambient conditions (temp & wind) to determine launch time

Figure 10. - Recommendations

This concluded the engineering presentation. Then Joe Kilminster of MTI was asked by Larry Mulloy of NASA for his launch decision. Joe responded the he did *not* recommend launching based upon the engineering position just presented. Then Larry Mulloy asked George Hardy of NASA for his launch decision. George responded that he was appalled at Thiokol's recommendation but said he would not launch over the contractor's objection. Then Larry Mulloy spent some time giving his views and interpretation of the data that was presented with his conclusion that the data presented was inconclusive.

Now I must make a very important point. NASA'S very nature since early space flight was to force contractors and themselves to prove that it was safe to fly. The statement by Larry Mulloy about our data being inconclusive should have been enough all by itself to stop the launch according to NASA'S own rules, but we all know that was not the case. Just as Larry Mulloy gave his conclusion, Joe Kilminster asked for a five-minute, off-line caucus to re-evaluate the data and as soon as the mute button was pushed, our General Manager, Jerry Mason, said in a soft voice, "We have to make a management decision." I became furious when I heard this, because I sensed that an attempt would be made by executive-level management to reverse the no-launch decision.

Some discussion had started between only the managers when Arnie Thompson moved from his position down the table to a position in front of the managers and once again, tried to explain our position by sketching the joint and discussing the problem with the seals at low temperature. Arnie stopped when he saw the unfriendly look in Mason's eyes and also realized that no one was listening to him. I then grabbed the photographic evidence showing the hot gas blow-by comparisons from previous flights and placed it on the table in view of the managers and somewhat angered, admonished them to look at the photos and not ignore what they were telling us; namely, that low temperature indeed caused significantly more hot gas blow-by to occur in the joints. I, too, received the some cold stares as Arnie, with looks as if to say, "Go away and don't bother us with the facts." No one in management wanted to discuss the facts; they just would not respond verbally to either Arnie or me. I felt totally helpless at that moment and that further argument was fruitless, so I, too, stopped pressing my case.

What followed made me both sad and angry. The managers were struggling to make a list of data that would support a launch decision, but unfortunately for them, the data actually supported a no-launch decision. During the closed manager's discussion, Jerry Mason asked the other managers in a low voice if he was the only one who wanted to fly and no one answered him. At the end of the discussion, Mason turned to Bob Lund, Vice President of Engineering at MTI, and told him to take off his engineering hat and to put on his management hat. The vote poll was taken by only the four senior executives present since the engineers were excluded from both the final discussion with management and the vote poll. The telecon resumed and Joe Kilminster read the launch support rationale from a handwritten list and recommended that the launch proceed as scheduled.

NASA promptly accepted the launch recommendation without any discussion or any probing questions as they had done previously. NASA then asked for a signed copy of the launch rationale chart.

Once again, I must make a strong comment about the turn of events. I must emphasize that MTI Management fully supported the original decision to *not* launch below 53 °F (12 °C) prior to the caucus. The caucus constituted the unethical decision-making forum resulting from intense customer intimidation. NASA placed MTI in the position of proving that it was not safe to fly instead of proving that it was safe to fly. Also, note that NASA immediately accepted the new decision to launch because it was consistent with their desires and please note that *no* probing questions were asked.

The change in the launch decision upset me so much that I left the room immediately after the telecon was disconnected and felt badly defeated and angry when I wrote the following entry in my notebook. "I sincerely hope that this launch does not result in a catastrophe. I personally do not agree with some of the statements made in Joe Kilminster's summary stating that SRM- 25 (*Challenger*) is okay to fly."

After I had a chance to review a copy of Joe's chart, I realized that I didn't agree with any of his statements made to support a launch decision. I believe that anyone who has normal powers of reason will question the validity of Figure 11 as a document to support the *Challenger* launch.

1. calculations show that SRM-25 O-rings will be 20 °F colder than SRM-15 rings
2. temperature data not conclusive on predicting primary o-ring blow-by
3. engineering assessment is that: colder o-rings will have increased effective durometer ("harder')
4. "harder" O-rings will take longer to "seat"
5. more gas may pass primary O-ring before the primary seal seats (relative to SRM 15)
6. demonstrated sealing threshold is 3 times greater than 0.038" Erosion experienced on SRM-15.
7. if the primary seal does not seat, the secondary seal will seat
8. pressure will get to secondary seal before the metal parts rotate
9. O-ring pressure leak check places secondary seal in outboard position which minimizes sealing time
10. MTI recommends STS-51I launch proceed on 28 January 1986
11. SRM-25 will not be significantly different from srm-15.

Signed by Joe C. Kilminster, Vice President Space Booster Programs

Figure 11. MTI assessment of temperature concern on SRM-25 (51I) launch

The chart lists twelve separate statements. Statements 1, 2, 4, 5, 6, 8 and 9 actually support a no-launch decision. Statement 3 is actually a lie. There was no engineering assessment made during the caucus. Arnie and I continued to press for retaining the original decision of not launching below 53 °F (12 °C). Statement 7 addresses the erosion margin but erosion was not the primary topic of discussion that evening. We were all discussing whether the seals would even seal before hot gas blow-by would destroy them, this statement is the only one to support a launch but it was not part of the concern that night. Statement 10 neither supports nor is against a launch decision. It is simply a statement of engineering fact which states that when pressure is applied to an O-ring seal, it will move away from the pressure to the opposite side of the groove containing it. Statement 12 is a contradiction of statement 1 because everyone knew that 20 °F (-7 °C) colder seals were very significant as our preliminary test data had shown.

Therefore, MTI senior management reversed a sound technical recommendation without one shred of supporting data and without any re-evaluation of the data they had promised when they requested the caucus.

The next morning I paused outside Arnie Thompson's office and told him and my boss that I hoped the launch was safe, but I also hoped that when the booster joints were inspected that we would find all the seals burned almost all the way through the joint, and then maybe we could get someone with authority to take a stand and stop the flights until we fixed the joints.

Later, I was walking past the room normally used to watch the launches when Bob Ebeling stepped out to invite me to watch the launch. At first I refused because I didn't want to watch the launch, but he encouraged me to enter. The room was filled so I seated myself on the floor close to the screen and leaned against Bob's legs as he was seated in a chair. The boosters ignited and as the vehicle cleared the support tower, Bob whispered to me that we had just dodged a bullet. The reason Bob made this statement was that the propellant experts had told us that the boosters would explode at ignition if we developed a leak in the case. At approximately T+60 seconds, Bob again whispered to me that he had just completed a prayer of thanks to the Lord for a successful launch. Just 13 seconds later we both saw the horror of destruction as the vehicle exploded. We all sat in stunned silence for a short time; then I left the room and went directly to my office where I remained in shock for the remainder of the day. Two of my seal task team colleagues inquired about my condition at my office, but I was unable to speak to them and hold back my emotions, so I just nodded yes I was okay and they left after a short silent stay.

Within a day of the launch, one of my colleagues on the seal task force team told me that he was reviewing the video tape and thought he could see a plume of flame coming from a booster as it exited the explosion. My first thought was that one of the joints had failed, so I postulated several scenarios to fit the observations and one of them turned out to be what was found to cause the disaster. A failure investigation team was formed at MTI on January 31, 1986, which included Arnie Thompson and myself. The team was immediately sent to MSFC in Huntsville, Alabama.

Post-Disaster Treatment (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Author(s): Roger M. Boisjoly

The first hint that there would be separation between the engineers and management occurred during the preparation for the first closed-door testimony to the Presidential Commission. I was given very little notice that a hearing would be held on February 14, 1986. I had approximately two hours total by myself prior to the hearing and was struggling to organize a set of notes to aid me during my testimony, while management had their Publications Department prepare a formal set of professional Viewgraphs for their version of the events leading up to the launch decision. Meanwhile, at a pre-hearing meeting with management, the company attorneys advised us to answer all questions with only yes or no and not to volunteer anything freely. This advice was not followed by me nor Arnie Thompson and Al McDonald and there were obvious tense feelings between management and us after the testimony session.

Approximately five days later at MSFC, two Presidential Commission members requested a closed interview session on with Arnie Thompson, Joe Kilminster and me. During this meeting, I handed a packet of memos and activity reports to a commission member as a response to one of his questions and this action upset our company attorney. I sensed quite clearly from this time on that I had not endeared myself with MTI Management, since my memos would clarify the true circumstances leading to the disaster and would also counteract both NASA and MTI Management attempts to discredit our testimony up to that point. I thought it was unconscionable that MTI and NASA Management wouldn't tell the whole truth so that the program could go forward with proper corrective measures. Joe Kilminster then had a heated discussion with Arnie and me after the meeting. Joe strenuously objected to Arnie and me constantly correcting his technical version of what the data meant. Joe said that we were welcome to express our opinions but that he also was entitled to express his. We agreed but said we would continue to correct his version if his input was technically incorrect as it had been up to that time.

It was at this point that I realized that both NASA and MTI Management had been using me to supply them with the fine joint details. I had spent hours answering questions about how the joints worked, but I had thought it was pertinent to the failure investigation so I freely answered all questions and supplied all the information that made them appear to be very knowledgeable about the joints. I suspect that I fell into deeper disfavor with MTI Management after my public testimony to the Presidential Commission on February 25, 1986. Again, MTI Management had prepared beautiful color graphic Viewgraphs and printed books, while I struggled with my original notes. However, this time they were not allowed to speak from their Viewgraphs and were only allowed to submit the written material and answer questions. During my testimony, I directly rebutted MTI's General Manager's testimony concerning his statements about our supposedly non-unanimous engineering position at the telecon. My rebuttal was based on the fact that only Arnie Thompson and I were the principals involved during the continuing discussion at the telecon. Brian Russell and Bob Ebeling were the only other ones who spoke and they said only a few sentences. No one else said anything, either pro or con relative to launching, so I therefore consider all these people as non-entities and it matters not what they may say after the fact since they did not have either the conviction or the courage to speak out during the telecon. I know that Mason talked to some of those silent people after the disaster and interpreted what they said as support for the management decision to launch. I submit that his testimony is an example of management's deceit and half truth at its best by his attempt to discredit my previous testimony to the Commission.

We all gathered at MTI's resident office in Washington, D. C. after the testimony on February 25 and the intensity of bad feelings was so great that someone from management suggested that the company jet take us back to MSFC as soon as we gathered our personal belongings from the motel. Eventually cooler heads prevailed and we took a commercial flight the next morning. Later that some evening, management decided to send me back to Utah and keep Arnie Thompson at MSFC until the failure investigation was completed.

I was happy to return home because I wasn't pleased with the way MSFC Management was diligently attempting to find a condition other than low temperature which caused the disaster. For example, I witnessed NASA spend a two to three week side effort to prove that a *Challenger* joint close-out photo showed a twisted O-ring prior to mating. This was after I told them that the photo was only showing a track of smeared grease and not a twist because I had run a desk top test myself some time before to show that the O-ring could not twist as they were contending. I was proved right after their efforts failed to produce a twist in the O-ring and they finally admitted that the photo showed a smeared grease track.

In Utah I now began to sense the first signs of isolation from NASA, but I didn't fully recognize the situation and I continued to argue for full truthful disclosure while factions of MTI and MSFC Management were fully content to tell only half truths about the history of the development and production of the SRB's.

I realized for sure in mid-April that I was actually being isolated from NASA and the main redesign activity since mid-March while MTI Management was telling me of my great importance to the redesign effort. I was being asked to furnish technical design information for the new designs which was sometimes changed without my knowledge and was being presented to NASA by someone else with no copies of the final version of the presentation given to me for feedback. I was, in effect, actually isolated from the main redesign effort. Previous to my testimony, I always prepared and presented my own material and often my supervision gave me total freedom to do so because of their confidence in my ability. Unknown to me at the time, the President of Aerospace Operations at MTI had ordered that I should be kept isolated from NASA, and this was done with great subtlety to prevent detection by me and so I guess the company could say, if asked, "Yes, Roger Boisjoly still works here; in fact, he is the new seal redesign coordinator."

Working conditions kept deteriorating for some of us who had testified. Once again we were called to testify before the Presidential Commission in closed session on May 2, 1986. During the evening of May 1, we met with the President of Aerospace Operations at MTI, Mr. Ed Garrison, and he opened the meeting with a few general remarks about the upcoming session with the Commission. Then he addressed me and chastised me for airing the company's dirty laundry via my memos which I had given to the Presidential Commission. He also stated that MTI had suffered enough as a result of public disclosure but that we should continue to tell the truth, but we should consider the best way to state it before speaking. I quickly took exception to his remarks about me and said that I had simply tried to restore the truth in all testimony and I didn't consider my actions as airing dirty laundry. Bob Ebeling then spoke up with some support for me and he told Mr. Garrison that MTI should form a specific type of engineering development group. Garrison snapped at Bob and told him to stop and quit telling him how to run the company. We went into the Commission session the next day with conditions as tense as they had ever been and Chairman Rogers asked Al McDonald and me about our current job assignments. We answered him and he was visibly upset because we were being punished for honesty in our testimony. The Commission then decided to release the closed session testimony to the public and MTI received tremendous criticism from the Congress, the Presidential Commission and the news media.

A few days later, Al McDonald and I were invited back to Washington, D. C. by the Presidential Commission to review and comment on the final official accident analysis team report which was submitted to them by MSFC. The Commission had somehow found out that neither Al nor I had seen the final report. I submitted 12 pages of comments on the report and gave verbal testimony to four Commission members that the report findings were biased toward an attempt to downplay the effect of low temperature on the joint failure by trying first to focus blame on such things as assembly problems and other factors. The Commission members agreed with our comments and thanked Al and me for our willingness to review and comment on the report on such short notice.

Major morale problems now started to develop within MTI as some of our colleagues perceived that our testimony was causing damage to the company, but we didn't agree with that assessment and decided to try to correct it by requesting a meeting with three top executives at MTI who could do something about the internal strife. A private meeting was held on May 16, 1986 with the CEO, the President of Aerospace Operations, and the Vice President of the SRM Program. The meeting produced a very candid discussion of problems from our side but it was essentially one-sided with management telling us very little. The CEO even made it sound like we were on probation and if we worked hard and proved ourselves during the redesign activity, then everything would be forgiven. His attitude was certainly consistent with his criticism of Al and me in his previous statement to *THE WALL STREET JOURNAL*. I believe it was at this meeting that the CEO made the statement that the company was doing just fine until Al and I testified about our job reassignments on May 2. He said that those statements caused the company more harm than all the previous releases.

Al McDonald and I were supposedly restored to our former positions after MTI was scolded by some very angry U. S. Senators, but it was only a superficial restoration which the company skillfully reported by inference in a press release as a promotion for Al McDonald, who was to head the redesign activity, while my interface with NASA was restored. Actually, Al got only his old job back without a promotion and was not heading the redesign activity, while some people who had remained silent received promotions and the same people who wouldn't face up to the original bad joint design were now directing the joint redesign effort. Simply put, the joints have been redesigned by top management with direction down to the working level engineer who must engineer the details to make it work.

I had been chastised and criticized before my colleagues and ignored generally both personally and professionally, but I still tried to make my voice heard for the best joint redesign. I was the only one who reviewed the joint seal proposal submitted to MTI by Gray Tool Company of Houston, Texas and finally secured them a chance to present their seal design to MTI Engineering and Management. Many engineers were supportive of the design but, unfortunately for Gray Tool, the primary redesign configuration decision had already been made by MTI Management and they only have a poor political back-up position at this time.

Al McDonald, Arnie Thompson and I, along with MTI Management, were asked to testify at the House of Representatives Committee on Science and Technology hearings on June 17 and 18, 1986. The two days of preparations with attorneys and public relations people plus the testimony itself were almost more than I could withstand when combined with my treatment at MTI.

Approximately one month after my testimony to the House Committee, I could no longer endure the hostile environment at MTI, so I took some time off at the recommendation of a company executive. During this period of being absent from MTI, I realized that I could not subject myself again to the hostile environment, so I informed them that I would not return to work. I was then placed on extended sick leave from July 21, 1986 until January 18, 1987 at which time I qualified for long-term disability. I currently receive 60% of my former salary and for my disability case, my compensation will stop after two years, which is January 18, 1989.

Roger M. Boisjoly, Former Morton Thiokol Engineer, Willard, Utah

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Professional Responsibility and Conduct (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Author(s): Roger M. Boisjoly

What is everyone's professional responsibility and ethical conduct code which should be practiced in the work place? The following advice was given by Mr. Adolph J. Ackerman in June, 1967, in an article published by the IEEE. I firmly believe that his advice is timeless and applies to all generations in engineering. Mr. Ackerman said,

Engineers have a responsibility that goes far beyond the building of machines and systems. We cannot leave it to the technical illiterates, or even to literate and overloaded technical administrators to decide what is safe and for the public good. We must tell what we know, first through normal administrative channels, but when these fail, through whatever avenues we can find. Many claim that it is disloyal to protest. Sometimes the penalty disapproval, loss of status, even Vilification--can be severe. Today we need more critical pronouncements and published declarations by engineers in high professional responsibilities. In some instances, such criticism must be severe if we are properly to serve mankind and preserve our freedom. Hence it is of the utmost importance that we maintain our freedom of communication in the engineering profession and to the public. The decades ahead are bound to be a critical and difficult period and there will be occasions for sharp dissent and strong words if we are to meet our responsibilities." ¹

In a parallel vein, the AIAA has published a code of ethics for their members, known as Rule 2.4 which states,

"The member will indicate to this employer or client the adverse consequences to be expected if his judgment is overruled."²

More than 20 years ago I received some superb advice from a QA manager that I have applied throughout my career. He told me to ask myself the following question when faced with a tough question of whether a product was acceptable:

"Would you allow your wife or children to use this product without any reservations?" If I could not answer that question with an unqualified, "Yes," he said, I should not sign off on the product for others to use. That is what ethical analysis of acceptable risk should be.³

The academic community has studied many cases on whistle blowing and ethical conduct in our society and have some statements which apply directly to this discussion.

Professor William H. Starbuck, New York University's Graduate School of Business Administration said,

"The fact that people are in a hierarchy tends to amplify misperceptions. A low-level person has a fear that something might happen and reports it to a higher level. As it goes up the hierarchy, information gets distorted, usually to reflect the interests of the bosses."⁴

Professor of Communications at Boston University, Otto R. Lerbinger, states that corporate cultures try to ignore the unpleasant, and have to be counteracted by deliberately creating a culture that encourages people to bring up unpleasant information. He also states,

"in a group trying to move ahead with a decision, you find that those people that have anything negative to say are unpopular, so a manager deliberately has to encourage people taking the devil's advocate position. In a crisis situation, somebody has got to think about the possibility of something going wrong, and to use a worst case scenario approach."⁵

Professor of Sociology at Smith College, Myron P. Glazer, said that time and again there is the tendency to kill the messenger bringing the bad news rather than punish the wrongdoers. He also states that,

"People who hung tough with their organization managed to do very well. Hanging in there and not protesting is valued highly. They manage to survive because of their fundamental and correct belief that the organization will protect them."⁶

The research on the subject of whistleblowers leads to two conclusions. First, all whistleblowers attempt to achieve problem resolution through their organizational chain of command; and, second, they are all punished by the organization after whistle blowing outside the organization.

I testified to the Presidential Commission that I made my engineering position clear to MTI and NASA Managers about the consequences of launching in such cold weather, but then I felt helpless as they ignored my input and decided to launch anyway.

A NASA (MSFC) colleague of mine, Ben Powers, said, "You don't override your chain of command. My boss was there; I made my position known to him; he did not choose to pursue it " - "at that point, it's up to him; he doesn't have to give me any reasons; he doesn't work for me; it's his prerogative."⁷ I hope everyone can understand from these statements that all engineers who spoke out against the *Challenger* launch followed the same communications path that the researchers found; that is, their normal organizational chain of command. We also have been punished in varying degrees for our testimony to others.

Footnotes

- ¹Allan J. McDonald, "Engineering Ethics and the Challenger Accident," Address to Brigham Young University, December 4, 1986, page 10
- ²IBID
- ³Roger M. Boisjoly, "NASA, Morton Thiokol Must Rethink Risk", *The Scientist*, September 21, 1987, page 11
- ⁴Trudy E. Bell and Karl Esch, "The Fatal Flaw in Flight 51L," *IEEE Spectrum*, Volume 24, number 2, February, 1987, page 50
- ⁵IBID
- ⁶IBID, page 51
- ⁷IBID, page 49

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Accountability (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Author(s): Roger M. Boisjoly

I have filed a billion dollar law suit against MTI and a ten million dollar law suit against NASA plus a false claims suit against MTI on behalf of the U. S. Government. First, it is my intention to secure compensatory damages for my lost salary and ruined career and second, I hope the suits send a serious and significant message to MTI in particular and to executives of other companies and government agencies that they cannot make arbitrary irresponsible decisions that kill people and ruin the lives and careers of their employees without accountability. In my opinion, there has been zero accountability to date.

Everyone involved with the decision to launch *Challenger* at MTI and MSFC has been either transferred or taken normal or early retirement without any penalty for his actions. Further, MTI has not paid the \$10 million penalty in their contract for their hardware being responsible for the disaster and loss of seven lives and the destruction of over \$2 billion in hardware. An agreement between MTI and NASA has been reported in the media that MTI will take \$10 million less in profits when the production contract resumes. I would like to raise several very basic questions about these conditions. First, who receives the interest/investment benefit (millions of dollars) by not paying the contract penalty? Second, why did the cost of the boosters increase above the original contract price when it was common internal company knowledge that MTI was in the process of negotiating a lower price prior to the *Challenger* disaster to protect their single-source contract status? Also, why are NASA and MTI always making the point in the media that MTI is receiving no profit for the redesign when we all know that they will make it up when production resumes? Now, my colleagues, that is what I mean by zero accountability.

Roger M. Boisjoly, Former Morton Thiokol Engineer, Willard, Utah

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Closing Remarks (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Author(s): Roger M. Boisjoly

All of you must now evaluate your careers and emerge with the knowledge and conviction that you have a professional and moral responsibility to yourselves and to your fellow man to defend the truth and expose any questionable practices that will lead to an unsafe product. Don't just sit passively in meetings when you know in your heart that you can make a constructive contribution and also be prepared to share your ideas with others and to compliment others for their ideas, especially when their idea is better and may even replace yours. After all, you have a responsibility to promote the best product for a company and put personal pride aside. This is the best way to cultivate colleague respect and friendship, which in industry always results in a positive long-term benefit for you, the company and its product line.

I wish that the *Challenger* disaster had never happened and since I cannot turn the clock back, I hope that if anything good can result from this tragedy, then I desire that all academic institutions and professional societies will recognize the importance of teaching ethical behavior in decision-making situations by using actual case histories like this one to demonstrate what was wrong so everyone is aware and prepared for what to expect when confronting a similar situation requiring an ethical decision.

I have been asked by some if I would testify again if I knew in advance of the potential consequences to me, my family and my career. My answer is always an immediate yes. I couldn't live with any self-respect or expect any respect from others if I tailored my actions based upon potential personal consequences resulting from my honorable actions. As a result of this paper and other exposures to real case histories, I hope that your answer will also be yes.

I hope and expect a drastic improvement in ethical decision-making practices and employee treatment for promoting ethical conduct as a result of my law suits, talks and this paper. Maybe together as colleagues we can all accomplish the second goal in my law suits and eliminate or at least significantly reduce unethical decision-making practices within our industrial and government communities.

I will never forget and I hope this nation will never forget, especially the engineering community, the supreme sacrifice that the seven *Challenger* astronauts paid by forfeiting their lives for such an irresponsible launch decision. May we always remember astronauts Jarvis, McAuliffe, McNair, Onizuka, Resnik, Scobee and Smith for their courage and dedication to this nation's space program.

Roger M. Boisjoly, Former Morton Thiokol Engineer, Willard, Utah

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Appendix (Ethical Decisions - Morton Thiokol and the Challenger Disaster)

Author(s): Roger M. Boisjoly

The following material is presented after my talks to help those people who wish to read further on the subject of the *Challenger* disaster and related subjects.

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- *Report of the Presidential Commission on the Space Shuttle Challenger Accident*, U. S. Government Printing Office, 1986.
- Henry Petroski, *To Engineer is Human*, St. Martin's Press, New York, 1985.
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