A High-Tech "Near Miss" --
Organizational Decision Making Up Close
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Abstract

This near miss, a possible disaster, has so far been ignored by the organization in which it occurred, NASA, and by scholars of organizational disasters. This is a study of decision making based on participants' sworn testimony and on tape recorded conversations about ice danger to the space shuttle *Challenger* (often referred to by its flight number, "51L"). Unusually cold Florida weather the night before space shuttle *Challenger's* launch (January 27-28, 1986) caused NASA officials at the launch site to allow water hoses running to the top of the service structure next to the shuttle to continue dripping. That would prevent the hoses from freezing shut. But their dripping all night created a coating of icicles over the entire structure. All that ice became worrisome. It could dislodge from the rumbling acoustics created when the *Challenger's* motors were ignited. Swirling icicles could cause dangerous damage to the Orbiter's protective undersurface, which guarded it against the extreme heat generated when the Orbiter re-entered the earth's atmosphere toward landing. Post-accident testimony from all participants shows disparities among participants in visual access to ice conditions, in estimates of ice trajectories, in views of who had to prove what in order to proceed, and in organizational commitments to on-time versus safe launch. The pattern of disparities lines up a NASA engineer, Charles Stevenson and the Rockwell officials on the side of postponing *Challenger's* launch for safer conditions, and NASA's launch engineers and managers, particularly Aldrich, on the side of launching. Post-accident analyses of ice trajectories showed ice chunks coming closer than NASA engineers had projected.

Introduction

In many ways this "ice story" is a mini-version of the "O-ring" and "field joint" story played out the previous evening (see Lighthall, 2015). Both stories are about conflict, deliberations, and decision regarding possible danger to a shuttle component that had no back up and whose failure would result in loss of vehicle, mission, and astronaut crew. The vulnerable part of the *Challenger* in this near miss was its Orbiter's Thermal Protection System (TPS) which protected the Orbiter from heat as it re-entered the earth's atmosphere, with friction that generated 3,000°F that could destroy the Orbiter if a tile had been damaged. Like the boosters' sensitive joints, the protective ceramic tiles had a history of gouging and divots in flight.

The near-miss story unfolds in four parts, following recorded conversations between and among engineers and managers as they assessed the probability of ice damage to the Orbiter's undersurface. Damage could result from ice dislodged when the main engines and boosters fired up. We hear first-hand assessments by Charles Stevenson, a NASA engineer reporting severe, threatening ice conditions as he walks down the service structure. His reports of what he sees are heard by launch managers who observe ice conditions captured only by a fixed camera that sends its image to a television monitor. The fixed image they see leads them to question and challenge his assessments of ice conditions. We hear conversations among officials of Rockwell International as they make their assessments and agree with the engineer's warnings. We watch engineers, managers, and executives as they think through an unusual facet of cold weather—ice covering the Fixed Service Structure (FSS) alongside the shuttle.

Participants in this story, entirely different from those involved in the fateful deliberations the previous evening about launching the *Challenger*, are identified in

Figure 1.2
Participants Assessing Ice Danger to the Orbiter
The Morning of January 28, 1986

NASA

Name	**Position/Office Location**	**Location At Launch**
Jesse Moore	Associate Administrator Office of Space Flight (NASA Headquarters, Washington, D. C.)	Kennedy Space Center (**KSC**, in FL)
Arnold Aldrich	Manager, National Space Transportation System Program Office, Johnson Space Center (**JSC**) in Texas	Kennedy
Richard H. Kohrs	Deputy Manager, National Space Transportation System Program Office (JSC)	Kennedy
Thomas L. Moser	Director of Engineering (JSC)	Johnson
Richard Colonna	Orbiter Project Manager (JSC)	Kennedy
Horace Lamberth	Director, Shuttle Engineering (KSC)	Kennedy
J. A. "Gene" Thomas	Director, Launch and Landing Operations (KSC)	Kennedy
Charles Stevenson	Ice/Frost Team Supervisor (KSC)	Kennedy
B. K. Davis	Ice/Frost Team Member (KSC)	Kennedy

Rockwell International

Name	**Position/Office Location**	**Location At Launch**
Rocco Petrone	President, Space Transportation System Division (Downey, California)	Downey Plant, CA
Robert M. Glaysher	Vice President and Program Manager, Orbiter Operations Support (Downey, CA)	Kennedy
Martin Cioffoletti	Vice President, Systems Integration and Cargo Integration (JSC)	Kennedy
Al Martin	Site Director, Launch Support Operations (KSC)	Kennedy
John Peller *	Vice President for Engineering (Downey, CA)	Downey Plant, CA
Robert Weaver *	Director, Technical Integration (Downey, CA)	Downey Plant, CA
John Tribe *	Systems Engineering Director (Downey, CA)	Kennedy

* These name identifications taken from Hamburg (1987); all others are indicated in House of Representatives (1986), pp. 232-242.

Figure 1.2. Their question was, again, “Do we have a problem here?” Their answer too, in the end, was no. Yet film evidence showed they came closer to danger than they had predicted.[1] The narrative then reveals previous actions and experiences of the Houston manager, Arnold Aldrich, empowered to decide whether to proceed with launch or to delay. Just weeks earlier he had sent a highly critical memo to a long list of NASA subordinates criticizing deficiencies for the many delays of the immediately preceding launch. His memo revealed his intense commitment to completing each launch on schedule (Lighthall, 2015, Chapter 3).

Ice Conditions

Icicles hung from virtually every crossbar and surface of the fixed service structure (FSS) standing alongside the sky-pointed shuttle (Fig. 2.2). This giant tower rose some 220 feet from the floor of *Challenger*’s mobile launch platform (MLP), reaching 20 feet above the tip of *Challenger’s* external tank. The FSS was the ladder, so to speak, by which the work crews, astronauts, and fuel lines had access to the shuttle in its vertical position. Some hoses ascended the FSS to deliver liquid oxygen to the external tank; others traveled upward to deliver water for firefighting and for emergency showers and eyewash. Near each flight time the FSS’s elevator delivered the astronauts to the 195-foot level accessing the Orbiter.[2] Ice covered every inch of the FSS from 120 feet above the mobile launch platform deck (about even with the Orbiter crew cockpit) down to the mobile launch platform. Icicles “averaged approximately five-eighths inch in diameter and ranged from six to twelve inches long.”[3]

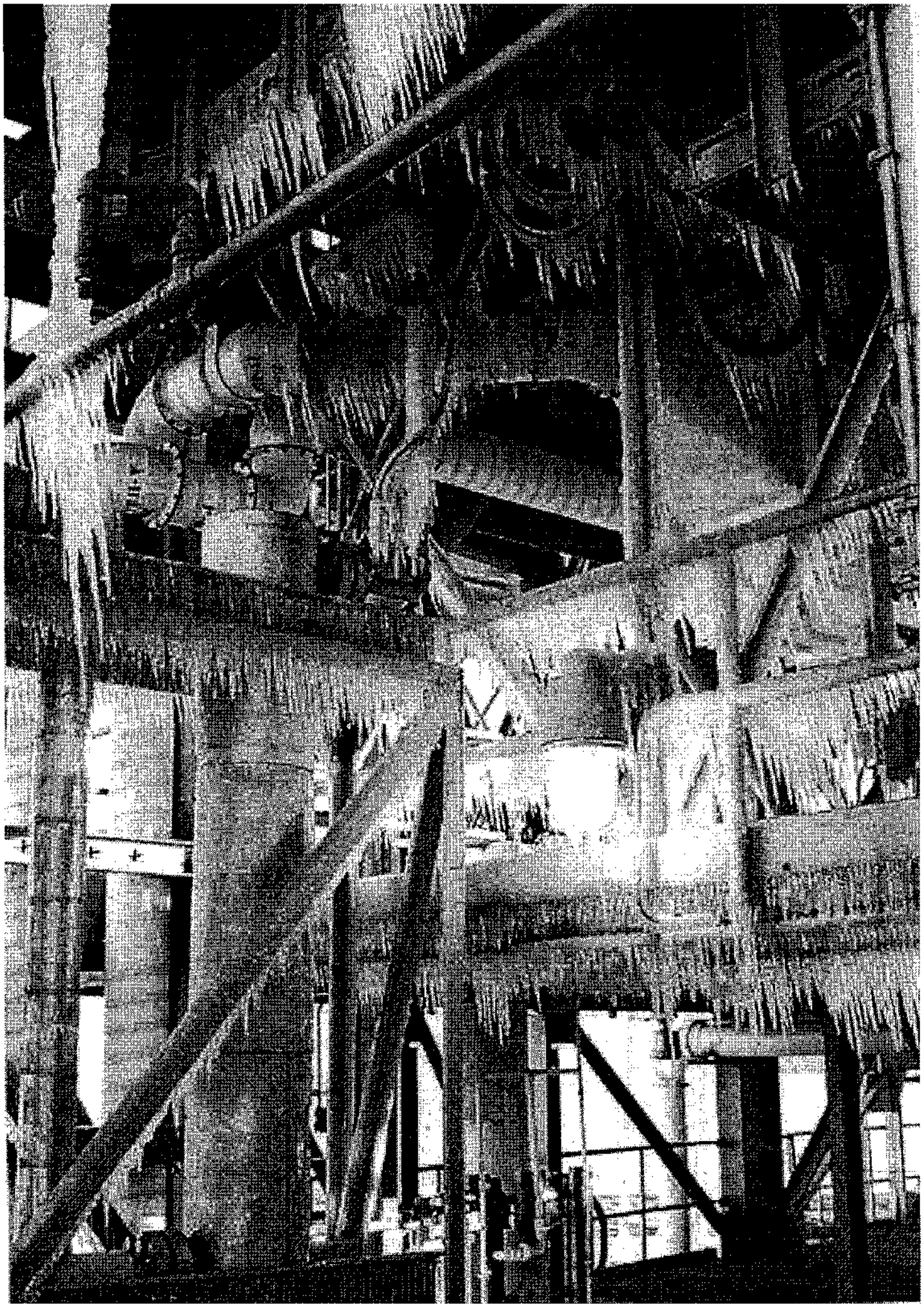

Figure 2.2. Icicles covering the upper levels of the Fixed Service Structure on the morning of the *Challenger* launch, ice conditions prompting Stevenson's warning to his managers. He could take in the full sweep of ice as he walked down the FSS, but his managers viewed merely a fixed, narrow view from a TV monitor.

Managers from NASA and managers and executives from Rockwell International, which manufactured the Orbiter, struggled to answer the question, “What would happen to falling ice once the main engines and the boosters were ignited?” Wind forces caused by the millions of pounds of thrust from the engines produced air currents swirling in ways no one could predict.

In the shuttle’s launch and ascent, any small piece of ice debris striking the tiles or panels protecting the wings’ leading edge or undersurface could dangerously degrade that protection. Falling and swirling icicles, therefore, qualified as a real danger. For eleven hours temperatures reaching 16 ºF had been cold enough to freeze water in the emergency shower and eyewash hoses reaching high up on the FSS. Drains that ordinarily would have carried the water off had become frozen shut. Spilling over the drains, wind-blown water sprayed down and across a wide expanse of the structure, freezing as it made contact with the cold steel crossbeams.

In Parts I and II we follow conversations leading up to a critical 9:00 AM Mission Management Team meeting. Part III considers experiences of Arnold Aldrich, the MMT leader, which shaped how he construed a situation to be avoided and the situation he faced as he initiated the 9:00 AM meeting. Part IV concludes the ice story by narrating the interchanges of the 9:00 AM meeting itself, ending in Aldrich’s decision.

I. Conversations: The engineer and managers

Events begin about 1AM on January 28, 1986, before the *Challenger’s* scheduled launch at 9:38 EST. Engineers and managers at NASA and Rockwell grapple with ice conditions that pose a threat to the undersurfaces of the Orbiter and its wings. Their unfolding perceptions, thoughts, and communications reveal some distinctive processes and deficiencies, but reveal as well processes and situations similar to those shaping the previous evening's deliberations about O-ring temperature and sealing dynamics of the boosters' joints. [4] By tracking how they thought their way to their conclusions we learn much about the pitfalls of thought and communication by which they reduced complex uncertainties to a confident decision.

Ice Reports

From 1:30 to 3:00 AM (EST) and again from just before 7:00 until almost 8:45 AM the day of the launch, Charles Stevenson, NASA's leader of the ice/frost team, and his associate and expert on external tank insulation, Billy K. Davis, inspected the ice conditions. As Stevenson makes his way down the icy FSS tower he converses by intercom with NASA launch managers seated in Kennedy's firing room. They talk about the extent of the ice and the possible threat that falling or swirling ice might pose to the Orbiter's thermal protection tiles. We then hear conversations among the NASA managers assessing the ice threat, followed by other interchanges with Stevenson where they question and test Stevenson about his assessment of the ice's extent and its danger. Other personnel remove ice from the water troughs below the boosters on the mobile launch platform. Despite a heavy concentration of anti-freeze, a layer of ice covers the troughs.[5]

In a first inspection, Stevenson reported ice at the 195-foot platform of the FSS, the platform where the astronauts would enter the Orbiter. Also, from this same platform in a pre-launch emergency, the astronauts would scramble for “baskets” that would carry them to safety on a cable (“slidewire”). Stevenson’s managers queried him from their positions in the Firing Room at Kennedy:

> **BL:**[6] (Chief, Mechanical Systems Division, Engineering Directorate at Kennedy): If they [the astronauts] had to go to the baskets for any reason, do they have a clear path through that ice?
>
> **Stevenson**: Oh, no. When you get over that way, we got ice . . . on the north side, that’s all one hard sheet of ice. Now, they could get to two baskets on the south side. . . . I’ll go take a look.
>
> **BL**: Okay. What’s it look like over there?
>
> **Stevenson**: Okay—some right at the elevator . . . going back toward the baskets, we got ice on the floor . . . to get between the elevator and the camera where you’re looking at, there’s some ice on the floor . . . and including the handrails that they would be holding on to . . .
>
> **BL**: What’s your Safety guy there think about that? You got a Safety guy with you, don’t you?
>
> **Stevenson**: Yes, he’s concerned. Matter of fact, there’s some ice right under my feet now that I look. . . . So the crew would have to walk across one slick spot. Around the baskets themselves it’s fairly clean. But to the northwest corner of the FSS where the baskets are, there’s heavy concentration of ice on the floor.
>
> **Lamberth** (Director of Engineering at Kennedy): Do you see anything out

there that makes it unsafe for the crew? [7]

Stevenson: At this time, I'd say from the elevator to the Orbiter Access Arm would be fairly good; the floor's in good shape. The elevator . . . doors are real hard to work but everything seems to work in that neighborhood. If they had to go to the slidewire, it'd be very slippery from the camera that you're looking at to the slidewire itself. There's an area about ten feet long where the handrails have ice on them, as well as the floor.[8]

These exchanges prompted discussion among Lamberth, launch director Gene Thomas, and "BL" as they watched their monitors in the Firing Room:

BL: If Charlie [Stevenson] thinks we have a concern with debris, and I guess I would find it hard to believe that we'd be concerned about it from the FSS, but if we do have a concern, can we go out there and try to clean it up a little bit?

Lamberth: Yeah, I think we could. . . . If we think there's some areas that we need to clean up a little bit, we probably could. . . .

Thomas: Hey, what kind of debris are you guys talking about?

BL: The icicles on the FSS.

Thomas: Yeah, and how is that going to hurt you?

BL: Well, that's what I'm saying. I don't think it—personally, I don't think it would, but I just wanted to . . .

Lamberth: [garbled] by there, you're not gonna hit the Orbiter, but Charlie's worried about it, Gene – [worried about] the acoustics releasing it and it being free when the Orbiter comes by.

Thomas: Boy, he's really stretching it.

Lamberth: Oh, no, I don't know whether that's stretching it too much or not.

Thomas: Well, I mean, if we can't ignore it, we need to feel comfortable about it.

Unidentified Voice: All right, Gene, remember the wind is coming from the northwest.

Thomas: We need to all know if we don't get back into tanking as soon as possible, we could possibly blow it [i.e., delay the launch] just for that.[9]

Sometime later Stevenson reported further about ice conditions on the FSS:

Lamberth: You feel comfortable with what you see out there, Charlie, now?[10]

Stevenson: We have a lot of ice, if that's what you mean. I don't feel comfortable with what's on the FSS.

Lamberth: Then what choices we got?

Stevenson: Well, I'd say that the only choice you got today is not to go [i.e., delay launch]. We're just taking a chance of [ice] hitting the vehicle.

Thomas: You see that much ice?

Stevenson: Well, the problem we have is we have a lot of icicles hanging, you know, even on the west side of the FSS . . . and I'm sure that stuff is going to fall off as soon as the acoustics [from ignited booster rockets] get to it. And you got a northwest wind . . . somebody will have to make that assessment.

If we're worried about that little bit of ice that comes off the hydrogen vent arm, and the GOX [gaseous oxygen] vent arm, what we have over here is considerably more than that, you know—it's a hundredfold.

Lamberth: You got enough ice that's over there that's big enough and got enough density to it that if it hits the Orbiter it could do some significant damage?

Stevenson: Yes, we do. . . . It's on the east side of the FSS, on the northeast corner of the FSS, which puts you about 65 feet or so from the vehicle. But it comes right to about where this camera is . . . it comes that far over.

BL: Charlie, I would doubt the wind could blow that over. Are you concerned about during—after engines start that things should kinda blow around?

Stevenson: Uh, yes. And the problem is it's [the ice is] so high, too . . . way up to the top.[11]

Stevenson's further descriptions of ice, along with readings of wind speed and wind direction were used by NASA engineers to calculate the likely "footprint" of ice coming off the FSS and falling onto the mobile launch platform. Figures 3.2 and 4.2 convey the engineers' predictions of falling ice, ice trajectories before the shuttle's engines became ignited. The predicted path of the falling ice indicated in Figure 3.2 shows that ice that happened to extend beyond the calculated footprint of the ice (hatched area in Fig. 3.2) would fly directly toward the leading edge of the Orbiter's wing. However, NASA engineers at Kennedy and Johnson who were studying the ice trajectories estimated that ice would fall no farther from the FSS than 16 feet, well short of the Orbiter. They advised that this *falling* ice posed no threat to the shuttle. As noted on the figures themselves, however, the predictions did not consider the *swirling* ice caught up in "aspiration," the exhaust-blown wind currents caused by the shuttle's ignited motors, blowing first downward, and then outward, upward, and back *inward* toward the ascending shuttle.[12]

NASA's Early Assessments of Ice Threat

As Stevenson reports his observations of ice, his managers question him with tests of increasing severity. After a number of doubts and questions, Stevenson observes that the danger posed by the ice he is seeing is "a hundredfold" more than the ice they regularly monitor that comes from the hydrogen and GOX vent arms. Immediately on the heels of that comment Lamberth asks if the ice risk is severe enough to meet four criteria of danger: amount of ice, size of ice, density of ice, and extent of damage.

Two features of the exchanges between Stevenson and his managers stand out. By their questions and doubts—"see anything out there that makes it unsafe?"; "hard to believe that we'd be concerned about it"; and "I would doubt the wind could blow that over"—Stevenson's managers are placing the burden on Stevenson to convince them of danger. While some initial questions call for Stevenson to offer proof of *safety* ("do they

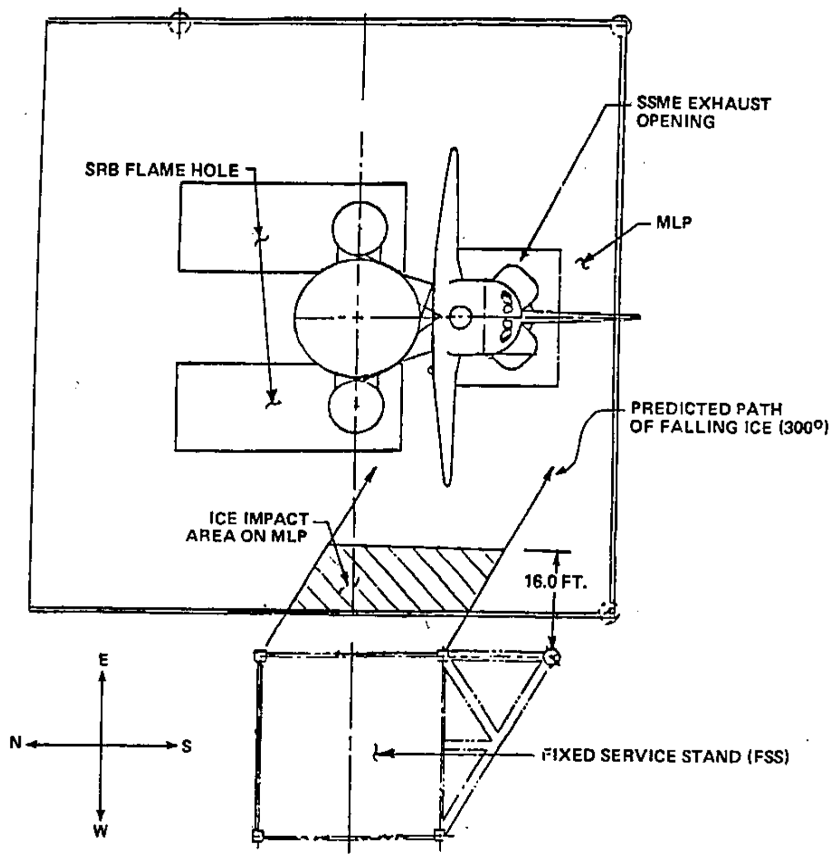

FIGURE 1 FSS ICE TRAJECTORY – DURING 51–L LAUNCH – PLAN VIEW

Effects Of Aspiration Not Considered
Particle Size : 6"x1"x1"
Wind Speed: 10 Kts.

Figure 3.2. NASA engineers' (post-accident) image of the calculated footprint and trajectory of falling ice from the Fixed Service Stand (hatched area), showing the estimated distance and spread of ice debris path from the FSS and from *Challenger's* wing – but erroneously indicating that this was the trajectory "*During* 51-L Launch." These calculations referred to conditions only prior to ignition, without the unpredictable directions of exhaust flow once the boosters were ignited – and without the resulting "aspiration," as noted: "Effects of Aspiration Not Considered."

have a clear path through that ice?"; "you feel comfortable with what you see out there?"), the cumulative and increasing force of their questions is to place Stevenson in the position of proving ice danger. The managers' testing of Stevenson ends with Lamberth's question about the sufficiency of ice size and density to cause "significant damage." Stevenson holds his ground: yes, ice could "kinda blow around."

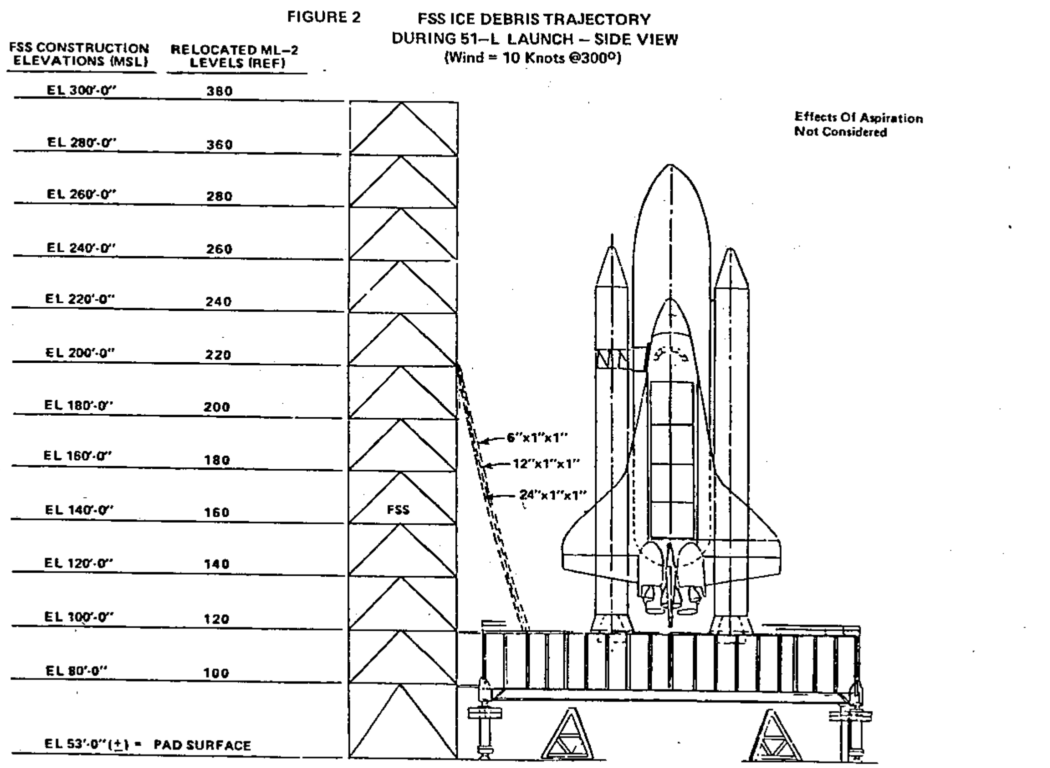

Figure 4.2. NASA engineers' (post-accident) rendering of calculated ice trajectories (of three sizes of icicle) falling from the FSS, assuming constant wind speed (no gusts) and constant wind direction. The title indicating "Debris Trajectory *During* 51-L Launch" was incorrect. These were pre-launch falling ice estimates, with "Effects of Aspiration Not Considered" as noted at upper right of the diagram.[13]

The managers are clearly assuming that launching the shuttle is safe from dangerous ice damage unless Stevenson can convince them it is not.

Second, we see an important social grouping here with respect to assessing ice. Stevenson, on one side, is the only participant who can observe the ice firsthand, and over the entire span of the FSS. His managers, on the other side, observe ice only through television monitors with limited scope. Those with limited access to the reality in question are more numerous and doubtful, questioning the assessments of the person with fuller observational access to that reality. This grouping also divides on the basis of positional power: Stevenson is subordinate in decision-making power to his managers.

Altogether, the content, sequence, and power differential of managerial questioning, placing Stevenson the subordinate on the defensive, constitute a collective force of intimidation, of shaping a view of reality according to the prevailing assumptions and limited views of the managers. In his immediate response, Stevenson resists the shaping force of his managers' discourse. As we shall see, he will later shorten his descriptions when he reports

II. Rockwell Managers: What Can We Be Sure Of?

At the same time that conversations were going on between Stevenson and his managers, exchanges were taking place among executives and managers of Rockwell International, maker of the shuttle's Orbiter. Would the Orbiter be free from flying ice once the shuttle's motors fire up? They try to settle on the "position" Rockwell will present in the 9:00 AM meeting. Their view contrasts with that of Stevenson's managers.[14]

John Tribe (Rockwell's director of Systems Engineering, at Kennedy Space Center in Florida, speaking to his colleagues at the plant in California): …There's a crew out there working on those [locations with ice and slush] right now. . . . The big concern is gonna be the mass of ice that is on the FSS, from the 235-foot level all the way down to the MLP [mobile launch platform]. Every platform had had water running on it all night and they're just—some of the close-ups of the stairwells look like, uh, something out of *Dr. Zhivago*. There's sheets of icicles hanging everywhere . . . the initial walkdown said icicles up to two feet long by an inch in diameter. . . . On the northwest corner, kind of graduating down to about three inches by one-quarter-inch diameter on the east side, with periodic one-foot icicles on the east side on some of the cross beams.

Bob Weaver (Rockwell's director of Technical Integration, speaking from Downey, California): Sounds grim.

Tribe: The big concern is that nobody knows what the hell is going to happen when that thing lights off and all that ice gets shook loose and come tumbling down and—what does it do then? Does it ricochet, does it get into some turbulent condition that throws it against the vehicle? Our general input to date has been basically that there's vehicle jeopardy that we've not prepared to sign up to . . .

Weaver: Okay. We didn't see this when we had icing conditions before?

Tribe: No, and they didn't run the showers all damn night before. They ran the showers this time and ran 'em, pretty heavily by the look of it, the drains froze up and they all overflowed… Is John [Peller, Rockwell's VP for engineering] in yet?

Weaver: No.

Tribe: Okay . . . somebody at his [level] needs to get in and try to get up to speed as fast as they can. They're going to be looking for a final position from Rockwell here very shortly [the 9:00 AM meeting of Aldrich's Mission Management Team]. . . . I've got Colonna and Bobola sitting here with Al Martin and myself, and we're probably going to be the forcing factor on this decision.

Until somebody can come up and tell us [what] the potential flow path is to the objects on the FSS at liftoff—you know, we're going to have to assume the worst case—but I don't think anybody is going to have that sort of data.

Weaver: This is going to be a tough one.[15]

At this point Stevenson reports that efforts to remove ice from the water troughs under the SRBs seemed to be effective. At the same time, Al Martin, Rockwell's site director for Launch Support Operations was talking over the network to his engineering group at Downey:

Martin: [T]he situation here is that—very quickly—when Charlie [Stevenson] gives his report, then they are gonna want to reconvene a top-level management meeting here. So whatever we want to say in that meeting we're gonna have to come up with it here and now, and I guess the situation is that there are icicles all over the stand [the fixed service structure (FSS)] . . . all up and down it, various levels—some of the icicles are two feet long, an inch or two at the base. . . . What they say is that when they touch them gently that they break off and for that reason I don't think there is any doubt about the fact in my mind that when we start the SSMEs [space shuttle main engines] a lot of these icicles are going to break off . . . and when they do break off . . . they're gonna come tumbling down, they can ricochet off of the service structure and then some of them wind up on top of the mobile launch platform (MLP). [16]

Stevenson then reports over the net, indicating the extent of ice at lower levels of the FSS and the ice higher, and says that he will return to the launch center to report to managers who would decide "whether the threat was sufficient to stop the launch."[17] The discussion with Rockwell resumed:

Martin: Okay. He [Charlie Stevenson] was just reporting on one of the levels . . . it just appears to me that when these icicles break off when they start the SSMEs some of them are very likely—in fact, I'll tell you, almost for sure—are gonna wind up on top of the MLP and then when we launch it seems to me it would be very difficult for anybody to predict where that debris would go . . . there would be a possibility of some of that debris impacting the Orbiter tiles, and I don't know how our aerodynamists or analysts could really say that that wouldn't happen. They can predict what happens when you drop a piece of ice in the wind. They can also predict what happens due to aspiration when you start the Solid Rocket Motors and SSMEs.[18] The real question is how do you predict what happens to ice chunks that are on top of the MLP at launch and where they go . . . there is ice on top of the MLP right now.

Weaver: That's unacceptable. Anything in the trough is unacceptable and any ice that would impact the vehicle during ascent is unacceptable and we can't predict what's going to happen to all that massive ice on the towers, so I think we're in a critical situation. . . . What we're worried about is the aspiration effects of the motion of the ice into the vehicle. . . .

We really don't have a data base to know what's going to happen to the ice. We do have some information that we can get horizontal movement of the ice into the vehicle ['aspiration'] . . . it's going to be bouncing all over the place. . .So you're going to have some horizontal velocity of ice.. . Our data base does not allow us to scientifically tell you what's going to happen to the ice.[19] Therefore, we feel we're in a no-go situation right now.

Martin: Okay. That, Bob, is a consensus down here, too . . . that there's . . . no way to predict what's going to happen, and I think that when we get into this next meeting, we need to state that as Rockwell's position and I think that's going to come up fairly soon, here.

Now, I have told Dick Colonna [NASA's Orbiter Project manager from Johnson Space Center, Houston, TX] that I suspect that's going to be the Rockwell position. I haven't told them officially. I've also told Horace [Lamberth] that, but I haven't told him that officially. And I guess, or, uh, do you think we're ready now to, uh, for Rockwell to state that position and do you want to go back to the MER [Mission Evaluation Room, at the Johnson Center] with that, or how do you want to handle it?

Weaver: Well, what I would like to do is get ahold of Glaysher [vice president and manager of Rockwell's Orbiter Operations Support]—we're not supposed to overrule him—and talk to him about it. Is he there?

Just before the 9:00 AM MMT meeting, Glaysher had a separate teleconference with the vice president of engineering at Downey, John Peller.

Peller: Hey, we've gone over this again. Colonna called me and wanted to see if there is a way we could give it a go. But when all the experts have looked at it, we still have concerns with three mechanisms. One, direct transport of falling ice into the vehicle at SSME ignition, and the wind is adequate to make that happen. . . . Secondly, you've got a rebound mechanism . . . that's clearly enough to cause significant tile damage. And, finally, the ice that ends up on the MLP and in the trough is all potential debris sources at SRB ignition and liftoff, and the trajectory those things take are [*sic*] highly unpredictable, and we just note in films tended to go in different directions. . . . So we've been through the three mechanisms, none of which we can completely clear.

Dr. Petrone's here, we've discussed it with him. We still are of the position that it's still a bit of Russian roulette; you'll probably make it. Five out of six times you do, playing Russian roulette. But there's a lot of debris. They could hit direct, they could be kicked up later by the SRBs [solid rocket boosters], and we just don't know how to clear that.

Glaysher: Okay. Our position fundamentally hasn't changed. We'll just go in now, we got a 9:00 o'clock, we'll go in and express it. I'll let you know what happens.

Peller: And obviously, uh, you know, it's their vehicle and they can take the risk, but our position is as stated.[20]

In sum, prior to the 9:00 AM Mission Management Team meeting the morning of the launch, the Rockwell managers' assessment was that the trajectory of swirling ice was unknowable, and the likelihood of ice hitting the Orbiter's tiles after ignition was therefore unknown:

- "The big concern is that nobody knows what the hell is going to happen" (Tribe)
- "very difficult for anybody to predict where that debris would go" (Martin)
- "no way to predict what's going to happen" (Martin)
- "We really don't have a data base to know what's going to happen to the ice" (Weaver)
- "the trajectory those things take are highly unpredictable" (Peller)
- "it's still a bit of Russian roulette" (Peller)

No uncertainty was felt, however, regarding the danger to the shuttle should ice actually strike the protecting tiles. The only reason to be concerned about uncertainty of ice hitting the tiles was that dangerous damage could well result if ice did hit them.

The decision to launch or to delay would be made at the end of the 9:00 AM MMT meeting by Aldrich, the team leader. Before that meeting, however, Rockwell's president of its Space Transportation System Division, Rocco Petrone, would have to put his stamp of approval on the position Rockwell would take in the meeting. Petrone had arrived at the Mission Support Room at Downey about 4:40 AM California time—7:40 AM (EST) at Kennedy Space Center—where discussions were already in progress about ice conditions at the Kennedy launch site in Florida. Petrone viewed scenes of ice at the launch pad on Downey's television monitors. He conferred by phone with his two senior managers at Kennedy, Glaysher and Cioffoletti, who were monitoring the Orbiter during the countdown. Petrone then met with groups of engineers and managers at Downey, ending up, as he later reported to the Presidential Commission, in "a top-level discussion at approximately 5:30 AM [PST—8:30 AM at Kennedy], from which we [Petrone, Glaysher, and Cioffoletti] drew the following conclusions":[21]

> Ice on the mobile launcher itself, it could be debris. We were very concerned with debris of any kind at the time of launch. With this particular ice, one, could it hit the Orbiter? There was wind blowing from the west; that appeared not to be so fast, that ice wouldn't hit the Orbiter but it would land on the mobile launcher. The second concern was what happens to that ice at the time you light your liquid fuel engines, the SSMEs, and would it throw it around and ricochet and potentially hit the Orbiter?
>
> The third aspect is one that has been discussed here of aspiration, what would happen when the large SRM motors ignite and in effect suck in air, referred to as "aspiration," and ice additionally would come down, how much unknown.

> The prime thing we were concerned about was the unknown base line. We had not launched in conditions of that nature, and we just felt we had an unknown.
>
> I then called my program managers in Florida at 5:45 AM (just before the MMT meeting at 9:00 AM at Kennedy) and said we could not recommend launching from here, from what we see. We think the tiles would be endangered, and we had a very short conversation. They had a meeting to go to, and I said, "Let's make sure that NASA understands that Rockwell feels it is not safe to launch." And that was the end of my conversation.[22]

Rockwell's Shaping of a Response to its Situation

In contrast to the conflict between Stevenson and his NASA managers, the Rockwell group was of a single mind. They were all working with the same criteria for deciding to launch—the same burden of having to prove that launch would be safe, and all shared the same standards of proof. They were together, also, in focusing on not simply falling ice, but three sources of ice danger. The most critical source of the three, because the least predictable, was ice caught in post-ignition swirling currents of aspirating exhaust from the boosters. "Aspiration," the Rockwell group understood, referred to the boosters' exhaust blowing downward, then outward, upward, and then back inward toward the shuttle.

Rockwell managers all framed their group's decision task as one of testing whether they could assure that the Orbiter's Thermal Protection System (TPS) was safe from ice. Since they could find no way to predict the trajectories of aspirating ice, they could not assure NASA the Orbiter's TPS would be safe. In this outlook, they presumed, in contrast to NASA managers, that the ice constituted a threat to the TPS. Further, they believed that not being able to predict the trajectories of the blizzard of ice shaken loose from the ignited engines was a lack of knowledge *sufficient by itself* to justify halting the launch. The Rockwell group was simply following NASA's usual Flight Readiness Review (FRR) norm of requiring proof of safety. Lacking proof of safety, according to this well-established norm, no approval of launch was possible or, to put the matter differently, to approve a launch while lacking positive proof that one's element (booster, orbiter, external tank) was ready for safe flight was to violate that strong norm.[23] Why the Rockwell group so uniformly conformed to the FRR safety norm while the NASA managers reversed it, seeking instead proof of risk, is a question addressed extensively in *Disastrous High-Tech Decision Making: From Dangers to Safety* (Lighthall, 2015, 131-133 and chapter 8).

Rockwell managers did reveal, however, that their situation of not being able to predict safe ice trajectories was a difficult one—"a tough one"; "we're in a critical situation"; "we're probably going to be the forcing factor in this decision." The difficulty lay in the fact that to oppose launch at that late hour in the launch countdown would clearly go against what they felt to be strong general commitment by NASA that the shuttle now poised for launch would be launched. The Rockwell managers began the 9:00 AM meeting in the posture, then, of feeling the pressure of launch expectation but had settled their "position" on what they would recommend to NASA. It would be NASA's Aldrich who would ask for their assessment of ice conditions and their go or no-go recommendation. For his part, Aldrich approached the meeting with his own expectations, and his own experiences.

III. Aldrich's Situations in the Countdown

Aldrich contemplates the unusual accumulation of ice on the FSS from his corner of the Kennedy control center. He views what appears on his monitors, and he hears what is reported to him. He hears, like all of us, through his assumptions, attitudes, and other tacit orientations that shape content and direction of his thoughts. He knows without thinking about it that as head of the Mission Management Team (MMT) he is the one responsible for deciding whether the team is "go" or "no-go" for this launch. He is the one who polls MMT members and contractors for their assessments and their go or no-go positions. He is the one who now must figure out safety or danger. But none of these responsibilities tells him how safe or how dangerous it will be to launch. To know, he must interpret and evaluate the realities being conveyed to him or elicited by him in his corner of the firing room.

Aldrich possesses certain technical concepts, mental "lenses" with which he brings into focus the information coming to him, tools by which he evaluates the safety or danger implied in what comes to him. As he polls his NASA managers for their assessments and reasoning, for example, he and they both know that whatever else they tell him he expects them to finish by saying they are either go or no-go. His interpretive set is (+) or (–). Much more complicated in origin, but not in its effect on his thinking, is a tacit attitude toward launch delays, an attitude triggered by his experience with the many delays in launching the immediately preceding shuttle flight (61C). Aldrich's frustrations with the delays of flight 61C had been expressed in a memorandum in which he criticized managers at Marshall for the "unnecessary" delay of 61C due to a lapse in attention to an important earlier memo. [24]

Much less specific, but far more pervasive and deeper was Aldrich's engineering commitment to rendering engineering realities and arguments in quantitative terms. If two conflicting versions of an engineering assessment were presented to him, he would find most persuasive the one substantiated with the most complete and rigorous quantitative analysis. Against that, reasoning alone would be only second best.

No NASA manager could afford to look kindly on launch delays. But Aldrich had recently developed a stronger, more pointed aversion. It was Aldrich who had just two weeks earlier composed an extensive memo calling all of NASA's centers to account for the launch aborts and many delays in flight 61C. It had been Aldrich's onerous task to delve into each of the delays, not just the one due to 61C's booster problem, and to carry out a detailed inquiry in order to draw out lessons for everyone at NASA. It was Aldrich who had to discover that the same malfunctioning substitute part that had caused the delay had been identified as defective two years earlier, and to discover that the identity of the defective part had not been communicated across NASA centers to prevent its use in 61C's booster.[25] For Aldrich, the many delays of 61C had once again underscored the idea not merely that delays were bad NASA business, but that delays could result from flaws that were unnecessary, stemming from carelessness.

Aldrich had ended his six-page, lesson-teaching memorandum with words that expressed his commitment to meeting NASA's launch schedule *consistently*:

[T]he NSTS program is proud of calling itself "operational." In my view

> one of the key attributes of an operational program is to be able to safely and consistently launch on time and land on time at the intended landing site. The STS 61C experience demonstrates that there are avenues for extra margin in this regard throughout the STS system.[26]

Aldrich, like Mulloy at Marshall, had developed a rule: no unnecessary delay. A crucial part of what would convince him that a delay was necessary was quantitative data and analysis. Unless some engineering data called for a delay of the *Challenger*, Aldrich would realize his hopes for another launch, this one almost on schedule.

With these outlooks, then, Aldrich began the 9:00 AM meeting, polling first Stevenson and his NASA managers, then the Rockwell officials, regarding their assessments and launch recommendation.

IV. The 9 A.M. Mission Management Team Meeting

Aldrich had arrived at the firing room at Kennedy about 4:30 AM, where the "countdown was proceeding normally, satisfactorily at least, with no new problems."[27] Stevenson and B. K. Davis had been diverted away from their normal prelaunch assessment of frost and ice on the external tank, and instead, had been examining the ice on the FSS, reporting the ice conditions over the hook-up with their managers in the firing room. "That was a unique inspection," Aldrich reported to the Commission, "and a unique report and a unique set of considerations."[28] Already the day before, as Aldrich explained, "I was clearly concerned about the ice on the facility as a constraint to launch, because I knew that we would be dealing with that as a problem on the following day [launch day, January 28].”[29]

The morning before launch, Aldrich reported, “The ice issue that we were concerned about . . . is damage from this ice to the thermal protection system [TPS] of the Orbiter, such as it will cause it to have a problem later in flight during the reentry phase if there is significant damage to the thermal protection system.” [30]

Aldrich explained to the Commission how the information was processed that came over the communication loop from the ice team:

> There is an engineering team in place in Florida in an alternate firing room. It’s adjacent to the one that is controlling the launch, and in it are [NASA] engineering managers for each of the projects: external tank, Orbiter, main engines, solid rocket boosters. And they have with them key technical people who are there specifically for analyzing unique problems or possible failure modes that come up while we’re going through a countdown that weren’t anticipated as being part of a normal count sequence.[31]
>
> I sit in the firing room for launches with a number of other key managers. . . I sit in a place that is called the operations support room. It is a little corner of the primary firing room that looks down on the firing room. . . . In there is Mr. Moore [“Level I” Administrator of NASA], Mr. Mulloy, Mr. Reinartz, Dr. Lucas [all from Marshall, in Huntsville, AL] . . . Richard Colonna, who is the Orbiter project manager from JSC . . . he sits right beside me . . . and a number of other people. . . .
>
> About 8:30 in the morning . . . Mr. Colonna, Orbiter project manager,

reported to me the assessment of the engineering team was that the icing condition . . . was looking very favorable to proceed with the launch. . . . However, they also reported that Rockwell might have some concern with that recommendation [Colonna's, to proceed with the launch]. . . .[32]

[T]he normal channel is for the Orbiter contractor, Rockwell, to report to Mr. Colonna, it is what we call Level III. . . . Mr. Colonna reports to me for the Orbiter at the Level II. . . .

And so I called what I would refer to as a partial Mission Management Team meeting, told Mr. Colonna that I wanted to review the ice team report and the engineering assessments with respect to it . . . and scheduled that meeting for 9:00 o'clock . . . specifically to deal with the ice that had formed on the fixed service structure and on the mobile launch platform itself. . . .[33]

It was quite a large group of people . . . twenty or thirty people. . . . We started the meeting by having a discussion, a report by the ice team, and Mr. Stevenson . . . made that report. And he was reporting about specific concerns in three different areas.

Aldrich then related in some detail Stevenson's report of how ice was distributed at various levels of the FSS, indicating that while the north and west sides of the FSS "had very large amounts of ice and icicles," "the east side, toward the Orbiter, had significantly less ice." [34] Stevenson ended his presentation to the 9 AM meeting, as he later reported, by indicating that the expected trajectory of falling ice:

> would stay within the 16 feet or so of the FSS. We expressed concern for the effects of aspiration, which was an unknown, and we left it at that. . . . The management system [i.e., Aldrich's MMT] again wrestled with that for quite a while and made phone calls and finally decided that it would not be a safety of flight issue to launch.[35]

Each of the Rockwell executives gave the Commission specific descriptions of their communication to Aldrich in the 9 AM meeting.

Robert Glaysher, Rockwell's senior executive at Kennedy, had been notified of the ice conditions about 4:00 AM (EST) where he was staying nearby. After arriving at Kennedy shortly before 8:00 AM, Glaysher conferred by phone with John Peller, head of engineering at Downey "and developed a position that Rockwell would take at the 9:00 o'clock meeting that was scheduled." Glaysher described Rockwell's assessment to the Commission:

> When I was asked Rockwell's position, I reiterated that there were three major unknowns . . . the first event was aspiration effects. The second was ice that would ricochet from the fixed service structure and head toward the vehicle. And the third category of unknown ice was ice that was resting on the mobile launcher platform at engine ignition. . . . [I]ce in the trough had already been discussed and resolved once the debris team had removed that ice. Those three categories of ice that I mentioned, however, we have no data base on which to base judgments of that. . . .

> We therefore felt that since we were in an unknown condition and were unable to predict where the ice would go or the degree of damage that would result . . . I then gave the following recommendation to NASA in which I said that Rockwell could not assure the safety of flight, or let me give you a better quote. . . . My exact quote was—and it comes in two parts. The first one was, Rockwell could not 100 percent assure that it is safe to fly which I quickly changed to Rockwell cannot assure that it is safe to fly.
>
> We then had a discussion about what that meant and the data base that we didn't have in effect. They then moved on to Mr. Al Martin and asked for a position or an opinion from him.[36]

Martin supported Glaysher but then commented on the unpredictability of ice "at lift-off," and pointed out to the Commission the importance of "debris":

> In the 9:00 o'clock meeting, Bob Glaysher was our spokesman, but I was asked if I had anything to add. . . . I made a statement like, "It has already been said." I also added that we do not have the data base from which to draw any conclusions for this particular situation with the icicles on the tower, and also, we had no real analytical techniques to predict where the icicles might go at lift-off.
>
> The other thing that I did was review the fact that prior to each launch there is great care taken to make sure that there is no debris out on the launch pad. A day or two before launch a crew goes out and they walk down the entire tower and walk down the mobile launch surface, and also the concrete apron around the

launch pad for the purpose of removing any debris. . . .

And I drew the corollary that the icicles in this case could very well become debris, that they might become dislodged from the tower when the SSMEs ignite a few seconds before liftoff, and they could impact on the mobile launcher surface and then become debris . . . and we had no way of predicting that.

So I was drawing a corollary between the care that is normally taken for debris and painting a picture that the icicles appeared to me to be in that same category. And so those were my only comments in that meeting.[37]

Martin Cioffoletti, Rockwell's VP for Systems Integration, recalled that prior to Aldrich's 9:00 AM meeting, he had conferred with "the John Peller folks" who had concluded that the ice would reach "only about halfway to the vehicle, free falling ice carried by the winds."

So we felt that ice was not a problem. However, it would land on the mobile launch platform. That, we considered a problem. We also investigated the aspiration data base we had, and we had seen the aspiration effect on previous launches . . . but we had never seen anything out as far as the fixed [service] tower. So we felt in fact it was an unknown. We did not have the data base to operate from on aspiration effects.[38]

At the 9:00 o'clock meeting I was asked by Arnie Aldrich, the program manager, to give him the results of our analysis, and I essentially told him what I just told you and felt that we did not have a sufficient data base to absolutely assure that nothing would strike the vehicle, and so we could not lend our 100 percent credence, if you will, to the fact that it was safe to fly. . . . I didn't use those words either. I just paraphrased that.

Commission Chairman Rogers later asked him, "Why don't you testify what you said, please?"

Cioffoletti: I said I could not predict the trajectory that the ice on the mobile launch platform would take at SRB ignition.

Rogers: And?

Cioffoletti: And that was the end of it.

Rogers: But I think NASA's position probably would be that they thought that you were satisfied with the launch. Did you convey to them in a way that they were able to understand that you were not approving the launch from your standpoint?

Cioffoletti: I felt that by telling them we did not have a sufficient data base and could not analyze the trajectory of the ice, I felt he understood that Rockwell was not giving a positive indication that we were for the launch.[39]

Rogers: [*turns to Glaysher*] Mr. Glaysher, did you make it clear that you felt there was a safety aspect and that you were not approving the launch?[40]

Glaysher: Yes, we actually discussed our position, and I stated more than once during the meeting Rockwell's position that we could not assure that it was safe to fly . . . when I first was asked to give our position, and it was also my last statement at the meeting, as the meeting wound up.

Dr. Sally Ride: Had Rockwell ever taken that position before on previous launches when the launch had occurred?

Glaysher: No, this was the first time where we had been in a position where we really had no data base from which to make a judgment, and this was the first time that Rockwell has taken an unsafe-to-fly position.[41]

Rogers regarded Cioffoletti's answer to Aldrich as incomplete. When Cioffoletti says he told Aldrich that they "could not predict the trajectory that the ice on the mobile launch platform would take at SRB ignition," Rogers asks, "And?" It seems to Rogers that NASA, that is, Aldrich, would not interpret Cioffoletti's answer as indicating lack of readiness to launch, and that Aldrich was asking for a definitive "go" or "no-go" response. In Rogers's view, anything other than a definite "no-go" would be interpreted by Aldrich as a "go." It might be a reluctant go or a qualified go, but it would be a go. In that interpretive frame, any statement that a contractor made about the *absence* of data or the *inability* to predict would count as very little in face of any evidence in favor of launching.

Cioffoletti's interpretation here, and the Rockwell executives' interpretation generally—that lacking evidence of safety was sufficient cause to deny readiness to launch—is consistent with the usual Flight Readiness Review position on hardware readiness, that unless one could prove one's element was ready, it was not ready for flight. [42]

Just prior to the 9:00 AM meeting, Thomas Moser, director of engineering at

Johnson, telephoned Rockwell's vice president of engineering at Downey, John Peller, to find out what Peller was concerned about. After Peller repeated the ice concerns that he had already worked out with Glaysher, Moser asked Peller not about trajectories of ice and the likelihood of ice hitting the Orbiter, but about the seriousness of damage that might be caused if ice struck the TPS. Moser asked Peller if he thought the Orbiter "would take safety critical damage." As Peller recalled,

> I said, "There's a probability in a sense that it was probably an unlikely event," but I could not prove that it wouldn't happen. . . .
>
> I never used the words "no-go" for launch. I did use the words that we cannot prove it is safe. And *normally that's what we were asked to do.* We were unable to do that in this particular case.[43]

In the minds of the Rockwell group, then, their uncertainty about what would happen to the ice after motor ignition constituted sufficient and "normal" grounds for halting a launch countdown. Not being able to give a clear "go" in the face of possible but unknown damage to a Crit-1 system like the thermal tiles was normally (in Marshall FRRs) the basis for withholding a certification of flight readiness.

Aldrich: Context and Understandings in the 9:00 AM Meeting

Aldrich had to integrate all the recommendations and opinions and, effectively, make the Level I decision to launch.[44] He asked each of the Rockwell officials in that 9:00 AM meeting for their assessments and asked Glaysher and Cioffoletti also for Rockwell's position on go or no-go for launch. In his later testimony before the Commission Aldrich gave useful detail about NASA's procedures for coping with conditions arising after the final Level I FRR, two weeks before the scheduled launch. The narrative Aldrich provided to the Commission reveals the questions he asked, whose answers he selected for attention, and what he remembered hearing:

> I asked the NASA managers involved for their position on what they felt about the threat of that to the Orbiter. Mr. Lamberth reported that KSC engineering had calculated the trajectories, as you've heard, of the falling ice from the fixed service structure east side, with current 10-knot winds at 300 degrees, and predicted that none of this ice would contact the Orbiter during its ignition or launch sequence; and that their calculations even showed that if the winds would increase to 15 knots, we still would not have contact with the Orbiter.[45]

Aldrich's assertion that KSC's calculated trajectories predicted that no ice would "contact the Orbiter *during its ignition or launch sequence*" is inaccurate (emphasis added). The data Aldrich referred to were those used as the basis for the sketches in figures 3.2 and 4.2, data and calculations that excluded effects of aspiration and therefore described *pre-ignition* trajectories only.[46] Stevenson had reported in his opening summary of ice conditions in the 9:00 AM MMT meeting that aspiration effects were not known.[47]

Aldrich continued describing the information he had received, indicating that Colonna had reported that similar calculations had been made in Houston by the mission evaluation team and that they had concurred—ice would not contact the Orbiter.

> At this point I placed a phone call to Mr. Moser . . . director of engineering at Johnson . . . and he confirmed the detailed agreement with Mr. Lamberth and Mr. Colonna's position . . . in addition to the discussion—I don't have it in my notes, but I remember it in more detail. We had some discussion of the falling ice, if it would hit the Orbiter after it was on the launch pad; was there in fact an issue from that ice coming back up and hitting the Orbiter.
>
> And both Mr. Lamberth and Mr. Colonna reported that their assessment was that the time it took for the ice to fall, to hit the Orbiter [*sic*: the launch pad] and to rebound, and the location of the fixed service structure on the MLP would not cause that ice in their view to be a concern to rebound and come up and impact the rear end of the Orbiter.[48]
>
> Following these discussions, I asked for a position regarding proceeding with the launch.[49] Mr. Colonna, Mr. Lamberth, and Mr. Moser all recommended that we proceed.
>
> At that time, I also polled Mr. Robert Glaysher, the vice president, Orbiter project manager . . . and Mr. Marty Cioffoletti, shuttle integration project manager. . . . Mr. Glaysher stated—and he had been listening to this entire discussion and had not been directly involved with it, but had been party to this the whole time.
>
> His statement to me as best I can reconstruct it to report to you at this time [50] was that, while he did not disagree with the analysis that JSC and KSC had

> reported, that they would not give an unqualified go for launch as ice on the launch complex was a condition which had not previously been experienced, and thus this posed a small additional, but unquantifiable, risk. Mr. Glaysher did not ask or insist that we not launch, however.[51]
>
> No other comments or recommendations were offered by the large group assembled with respect to the concern for proceeding with the launch.[52]

Despite having asked for Martin's and Cioffoletti's assessments of ice risks in the 9:00 AM meeting, assessments quoted earlier in this chapter, Aldrich not only made no mention of them to the Commission, but claimed that no other comments were made in the MMT meeting. This claim and his omission bear comment.

Having called on all three of the Rockwell officials for their assessments, and hearing their variations on the theme of lack of data and their uncertainty, Aldrich had heard more weighty doubt about safe flight to discount from Rockwell officials than he would have from hearing only from Glaysher. Instead of remembering three voices of caution, he remembers only one.[53]

After polling NASA and Rockwell managers, Aldrich felt "reasonably confident that the launch should proceed," but also was still sensitive to possible changes in ice conditions between this 9:00 AM meeting and the time of launch. He therefore asked for another ice inspection "to be performed as close to launch as possible . . . for the removal of any additional ice from the MLP deck that might have fallen."[54] Aldrich was focused on ice conditions prior to ignition.

Aldrich's Reasoning

Aldrich explained to the Commission that it had been NASA's practice, during "the first four to six flights," to continue flying the shuttle with post-flight evidence of some damage to the Orbiter's tiles, with frequent repairs of tiles after flights. Implied in his explanation is that some expected damage to the tiles—damage not considered severe enough to be a safety of flight issue—was both earlier and currently considered acceptable. Therefore, he implied, a report like Rockwell's—claiming an absence of data about ice trajectories and expressing a concern about some possible damage—simply pointed out a condition NASA had already recognized as possible but as not a safety of flight issue.

Rogers asked Aldrich if there had "ever been a time when a prime contractor or any other contractor voiced objections to the launch when you went ahead . . . ? Aldrich described his interpretation of Rockwell's position:

> My interpretation of the input that was made to me in the Mission Management Team meeting that I described is that a concern was voiced, and it was not an objection to launch. And I think the people that were in that meeting from Rockwell intended to offer me that concern, but they did not intend to ask me not to launch.[55]

Rogers then expressed a problem concerning the communication between Rockwell and Aldrich:

> If the decision making process is such that the prime contractor thinks he objected and says, testified under oath, that they took a position that it was unsafe to launch, and you say, that was not our understanding, that shows us serious deficiencies in the process.[56]

This prompted an extended explanation from Aldrich of why he should not have interpreted Rockwell's "concern" as an objection to launch. He explained that Rockwell had "taken positions very similar to the ones . . . they reported this morning," referring to the testimony reported above, from Glaysher, Cioffoletti, and Martin. That was testimony, Aldrich explained, "with respect to whether we should proceed with a known potential for debris on past flights." Referring to Rockwell's past "positions," Aldrich elaborated:

> None of those have been that close to launch as the one [for the *Challenger*'s ice conditions], but I feel both the nature of the threat and the risk—that is, is it safety [of flight] or turn-around damage[57]—and the kind of input that Rockwell made in that meeting, that is, we have a concern, we can't be completely sure that it's going to be satisfactory, but it is your decision, is consistent with the way that they reported to me in the past.[58]

Aldrich was referring to other instances of continuing to fly with post-flight evidence of minor damage to tiles, but he also added: "[F]or those earlier launches Rockwell definitely gave a go for launch at the . . . L minus one review [review of conditions the day before launch], following more lengthy deliberations than . . . during the morning of the 51L launch."[59]

Aldrich's attempts to explain his judgment as consistent with past occasions seems on the whole, although understandably, defensive—portraying his conduct as nothing out of the ordinary and considering the words of Glaysher as entirely consistent with earlier Rockwell positions about continuing to fly knowing the tiles had, and would again, experience damage that was not "safety critical." His portrayal of his response to Rockwell's position of uncertainty as a continuation of earlier similar situations reveals selective attention that omits other aspects of Aldrich's experience with Rockwell's statements about its Orbiter's flight readiness.[60]

If during the countdown Aldrich did take comfort from Rockwell's earlier acceptance of minor tile damage while continuing to fly, he did so despite the fact that Rockwell, on this occasion as never before, withheld its "go" for launch. It is clear from the whole of his testimony, however, that Aldrich had found his final comfort for deciding to launch in a different conclusion -- that even if some ice did reach the Orbiter, any damage it would cause would fall in the category of "turn-around damage," not "safety critical" damage—comfort found in a qualitative, categorical judgment about ice effects.[61]

Aldrich's Construal of Rockwell's Position

Rogers, Chairman of the Presidential Commission, pressed Aldrich: "Try to state what you thought their position was." Aldrich referred to Glaysher's own testimony about Glaysher's "first statement"— viz, "Rockwell could not 100 percent assure that it is safe to fly"—as representing "a key input" to Aldrich.

> **Rogers**: Did you think that meant that he agreed with the go position?
>
> **Aldrich**: No sir. I thought that meant that they did not have any additional factual material or hard analysis that could contribute to a better understanding of the situation.[62]

Aldrich's focus on Glaysher's statement about 100 percent assurance not only reduces Martin's and Cioffoletti's additional assessments to Glaysher's statement alone, but also selects the first and most extreme of Glaysher's two statements of Rockwell's position. By focusing on that statement alone, that Glaysher could not give 100 percent assurance of safe flight, it would be easy for Aldrich to dismiss it as a warning, since no one expects risk-free space flight. But Aldrich's further explanation reveals a criterion he used for judging as persuasive *any* assessment from Glaysher.

Aldrich was looking for "additional factual material or hard analysis to contribute to a better understanding of the situation." If Glaysher could not provide factual material or hard analysis showing actual ice threat, his assessment did not, in Aldrich's view, contribute to assessments already in hand. The quantitative (but seriously incomplete) assessments already in hand from NASA's own engineers, in contrast, did count as factual material and hard analysis. So all three of Rockwell's assessments—Glaysher's, Martin's, and Cioffoletti's—neither clarified nor contradicted assessments Aldrich already had in hand, assessments that did fit his criteria. The factual and hard analytical assessments indicated to Aldrich a "turn-around issue" only, and therefore a safe flight.

Vice Chairman Armstrong asked Aldrich to clarify his thinking about the Rockwell executives' concerns "about unknowns of aspiration . . . with airs or flows that are induced because of the engine exhaust." Given the repeated reference to "aspiration" in the preceding Commission testimony and in Stevenson's ice reports the morning of the launch, Aldrich's reply seems, not to put too fine a point on it, shocking:

> **Aldrich**: I may have missed the discussion of aspiration in that meeting. To my knowledge, the discussion on drawing ice into the Orbiter and SRB plume at ignition was discussed in the context of drawing ice from the MLP deck into the Orbiter, and that led very clearly to the situation of how much ice there would be on deck and where it would be located, and the conclusion of the ice assessment teams that the ice had been removed and my reaction that we should go back to check to see if no more ice had fallen or was in a threatening location to the Orbiter.[63]

That Aldrich missed both the Rockwell managers' references to "aspiration" and Martin's and Cioffoletti's explicit worries about swirling ice *after* motor ignition indicates a serious lapse in communication. Aldrich focused on the presence of ice on the launch platform, and once that was taken care of no threat existed, in his view. This focus, however, is entirely on pre-ignition ice on the platform. Once the main engines and then the boosters ignited, powerful acoustical forces would shake ice from the service tower down onto the launch platform and inward toward the Orbiter in trajectories that the Rockwell managers all said no one could predict. It is precisely these post-ignition forces that were referred to repeatedly by the Rockwell group (and by NASA's Stevenson) as "aspiration," and that the NASA models of trajectories and ice footprint excluded from their calculations. By focusing on ice trajectories that *could* be predicted *before* the acoustic effects of ignited motors, Aldrich missed the central concern being expressed by the Rockwell managers about ice patterns *after* ignition that *could not* be predicted.

Final Shaping of the Ice Decision

The MMT meeting itself had essentially two functions. One was to assemble assessments of the ice situation from all relevant participants. The other was to synthesize those assessments into a single picture of the real situation of ice as safe or dangerous, a picture that would indicate clearly either go or no-go. Before such a meeting, however, another process must take place, one in which individuals undertake dispassionate observation and analysis of the situation of interest, in this case, the ice and its margin of safety. Three processes, then, are crucial in any decision: initial assessments by relevant parties, assembly of those assessments, and synthesis of them into a coherent version of reality that becomes the basis for the decision.

That first process was flawed. Assessments by the NASA managers omitted an important variable: the effect of aspirating gases on the trajectories of icicles. In addition, Stevenson, whose reports of ice in the hours before the 9:00 AM meeting were full of detail, both descriptively and in evaluation ("hundredfold"), truncated his report in the meeting itself to description alone, omitting any evaluation. He mentioned "aspiration," but not in the language of earlier interchanges with his managers. Yet that omission of aspiration could still have been corrected. For Rockwell managers aspiration was *the* danger.

With that hanging flaw in NASA's assessment of the safety of the Orbiter from ice, the 9:00 AM meeting began. Assembling the assessments of any situation is a social process; it brings together the people who have observed, interpreted, and evaluated the situation of interest. The group's leader brings the relevant people together and solicits members' assessments, which then are synthesized into a coherent picture of the situation's safety and danger. Aldrich did bring all the relevant people together. Thus the available intelligence about the potential ice threat, with all of its strengths and weaknesses, was potentially available.

For that potential to be realized, however, the team leader would have to not only solicit members' assessments but would do so in a way that *clarified and corrected any limitations in the assessments.* That process would have to include questions and answers about the observations and analyses themselves—about variables included and excluded, analytical methods employed—in short, questions and answers about the *basis* of any conclusions drawn. Ordinarily such a process takes the form of *interchanges among* those who have made the observations and carried out the analyses. They are the ones who know firsthand how they gathered and analyzed their evidence.

This second crucial process was flawed. Aldrich did not suggest to the NASA managers and the Rockwell group that they should work out how they had arrived at different recommendations. If Rockwell engineers were unable to know ice trajectories and his NASA managers did know them, why? Any discussion between the two parties themselves would certainly have brought to light both Rockwell's concern about aspiration and the NASA group's omission of aspiration from their analysis.

Group deliberation was not on Aldrich's mind, however. Once he had heard the members' assessments, their participation was over and in his view the rest was up to him. The rest, in his mind, did not include probing members' assessments for possible omissions or flaws. As he defined his responsibility, it was to synthesize what he had heard into one best assessment of the safety and danger of ice and then decide to launch or delay. This construal of his role reduced the *testing and synthesizing capacity* of the Rockwell and NASA group to Aldrich's own knowledge and intellectual capacity alone.

By restricting his members' participation solely to reporting, Aldrich was forced either to resolve the contradiction, which his level of knowledge did not allow, or to simply choose between his managers' view and Rockwell's. Guided by his preference for quantitative analysis, he solved the contradiction by choosing. By simply choosing his managers' assurances of safety, he missed his chance to discover the key danger Rockwell managers were worried about, the boosters' wild ice-carrying currents of aspirating gas. [64]

Yet the flaw that lay hidden in NASA's first assessments could still have been discovered. A person in Aldrich's position could suddenly realize, even while favoring his own managers' quantitative analysis that something wasn't quite right, that there was a stark contrast between the precision of his managers' assessments, with their modeling of trajectories, and Rockwell's inability to make any quantitative assessment at all.

Or, a leader in Aldrich's position could challenge those reporting to him, both the Rockwell group, to determine what their reservations about launching were, and his own engineering managers, to determine the basis for their assurances of safety. But Aldrich possessed nothing like the technical competence required to do so. In particular, Aldrich's ignorance of the basic eddied flow of the boosters' ignited gases—thrusting downward, then outward, upward, and back inward toward the Orbiter, the flow pattern referred to as " aspiration"—revealed a deficiency in knowledge that at Marshall would have triggered ridicule from its director.

Lacking both substantive knowledge and a conception of his role as promoter of deliberation, Aldrich could detect no reason to interrupt the ongoing countdown. The obligation was on anyone who would interrupt the countdown to demonstrate sufficient cause to do so. Aldrich's mental set, together with the go-or-no-go form in which all assessment reports must finally take, allowed for only one of two conclusions—go or no-go. His outlook regarding a halt in the countdown was that unless a NASA manager or a contractor explicitly recommended no-go, their recommendation was a go, even if, like Rockwell, they indicated that they could not give a clear go. Go, therefore, was the default position, the one that had to be explicitly overturned for him to recommend a launch delay.

Yet even with that predisposition to continue the countdown, someone in Aldrich's position might catch himself, might come suddenly to the realization that what had to be proved was not danger, but safety. People do, after all, often catch themselves in false lines of thinking and prevent themselves from what later they realize could have been disastrous. They are able to do so, however, only with the thought tools and thinking habits that offer a contrasting perspective. Without conscious, explicit understanding of the crucial roles played in shaping reality assessments by evidence based argument -- by presumption, burden of proof, standard of proof, and testing of evidence and reasoning --

Aldrich had no mental apparatus, no words or ideas, with which to question his own privileging of go. [65]

Without those tools, Aldrich was left with the engineer's single tool of argument, a standard that demanded quantification. That tool rendered him blind to the signal that normally, in FRRs, means flight **Un**readiness -- the lack of clear evidence of safety.

The MMT's deliberative flaws did not turn out to be fatal, but only because the vicissitudes of aspirating ice on this occasion did not happen to include contact with the Orbiter's protective tiles. If fatal ice damage had occurred, its disastrous effects upon the Orbiter's reentry into the earth's atmosphere would have been preempted by the destruction of the *Challenger* less than two minutes after its launch.

Six Flaws in the Ice Deliberations

The ice deliberations were flawed in six ways. First, they were distorted by the weakening of an observer's voicing of his immediate, wide-angle, 3-D assessments of ice conditions by more powerful, intimidating managers, managers who had only indirect, narrow-angle observation of the conditions but who questioned, discounted, doubted, and imposed severe criteria to be met before his observations could be believed as signaling any danger. Second, NASA managers, in contrast to Rockwell managers, took the path of dangerous thinking by presuming a safe launch and assuming that danger, not safety, needed to be established by engineering analysis.

Third, the key manager, Aldrich, along with all other NASA participants, lacked knowledge of the safety-protecting potential of evidence-based argument Lighthall (2015, chapter 8) Specifically, he was oblivious to how presumption and burden of proof can alone determine the outcome of a dispute when the evidence is mixed. Fourth, Aldrich lacked crucial technical knowledge of launch conditions that would include understanding of aspirating currents. A fifth flaw was a failure of Aldrich's managers to inform him that they had omitted aspiration from their analysis—or a failure by Aldrich to hear that they had omitted it. Finally the proponents of contradictory assessments were prevented from probing and resolving their contradiction, a failure caused, in turn, by a deliberative process by which the team leader defined his role as the sole source of resolving contradictory assessments.

End Notes

1. Post-accident review of how the uncertainties of ice were dealt with concluded, in fact, that launching under those ice conditions might present a "high risk to flight safety." While no ice apparently struck the Orbiter, a number of pieces of sheet ice approximately 6 in. x 6 in. did strike the left hand booster. NASA's January 30, 1986 report on ice hazards to 51L (*Challenger*) commented on the failure of actual ice trajectories to "conform to predictions" that "the ice translated several times farther toward the vehicle than predicted" and "to do meaningful predictions of ice movement, the effects of aspiration must be considered" House of Representatives (1986, 242–43).

2. To see the position of the FSS in relation to the shuttle in launch-ready position, diagramed with vertical height indicators, see Presidential Commission on the Space Shuttle Challenger Accident. 1986. *Report*. Vol. V, 991–92, and Vol. III, N72 (hereafter, PC *Report*).

3. Charles Stevenson, responsible for monitoring launch conditions related to the Orbiter's tiles (its thermal protection system, or TPS), ice, frost, and debris, reported the ice team's observations from 1:30 to 3:00 AM the morning of the

launch. See PC *Report*, vol. V, 955–89.

4. See my account of that disaster, *Disastrous High-Tech Decision Making* (Lighthall, 2015).

5. See Stevenson's account before the Commission, PC *Report*, vol. V, 955–989.

6. Only initials and acronyms, not names, were provided by the House of Representatives (1986, 232-42). I have identified persons by name from the text itself, from titles, and from Hamburg (1987). BL remains unidentified except by first name, Bob, and by title provided by the House document, "chief, Mechanical Systems Division, Shuttle Engineering Directorate."

7. Apparently Lamberth did not consider impeded access to the safety baskets and slidewire an "unsafe" condition. The House Committee on Science and Technology did consider it a safety hazard for the astronauts, that "crew safety concerns should dictate that the ice situation described by the Ice Team leader [Stevenson] is unacceptable . . ." See House of Representatives (1986, 235).

    Note also Lamberth's question, asking whether Stevenson can see anything "unsafe for the crew." He does not ask, "Do you see that it's safe for the crew?" Implicitly, Lamberth is assuming that launching would be safe and is asking Stevenson if he sees evidence against that presumption. Lamberth places the burden of proving danger on Stevenson.

8. House of Representatives (1986, 234–35).

9. Ibid., 235.

10. Here Lamberth focuses on safety, asking if Stevenson, in effect, can attest to conditions being safe. Stevenson's reply that he is not comfortable creates uncertainty in Lamberth: "Then what choices we got?"

11. The significance of Stevenson's observation of ice "way up to the top" of the FSS is that the higher the ice, the more opportunity it has to strike the rising Orbiter,

once the ice is dislodged by the acoustics from the shuttle's ignited motors. See House of Representatives (1986, 236).

12. PC *Report*, vol. V, 992 and 1003, respectively. Note that no indication is given in these two diagrams of possible variation from the trajectory paths given for falling ice. The two graphed estimates, therefore, represent theoretical models without variation due to wind gusts greater than the assumed 10 knots or different in direction than the single direction calculated, 300 degrees azimuth—an unvarying northwest wind.

13. Note the absence of any estimate of variation from the engineers' linear trajectories. The absence of predictions as *probability* estimates entailing statistical concepts (e.g., mean, variance, standard deviation) characterizes virtually all of the quantitative analysis revealed in the six volumes of data and diagrams in the PC *Report*. The engineering estimates, like these linear trajectories, presented absolutes, pure models. This general practice reflected a kind of certainty rather sharply at odds with the exploratory, experimental nature of the space shuttle enterprise.

14. The Kennedy Center's Operational Intercommunication System enabled personnel physically in the Orbiter or working on the shuttle from stations on the FSS to communicate with each other and with managers in the Engineering Support Room and the Firing Room at Kennedy. OIS channel 245 linked personnel at Johnson, Kennedy, and Marshall, and channel 216 linked those centers with Rockwell engineers and managers in Downey, California. Quotations are from House of Representatives (1986, 233–42).

15. Ibid, 238-239.

16. Ibid, 239.

17. The language used by the House Committee, attributing to the Rockwell officials an understanding that they had the burden of proving the seriousness of the threat, was in error. All Rockwell officials assumed, in accord with all Flight Readiness

Reviews at Marshall, that the burden was on him who would claim *safe* flight. House of Representatives (1986, 239).

18. Martin here refers to the known fact, understood by participants in Lucas's Marshall FRRs, that once the boosters are ignited, the currents of air and gas take the form called "aspiration," that is, move downward, then outward, and then inward again, back toward the shuttle. He is clear, as the next sentence shows, that while the *fact* of aspiration is predictable, what will happen to ice debris caught up in the aspiration turbulence is not predictable.

19. "Scientific" proof was the standard established by William Lucas in his Flight Readiness Reviews at Marshall Space Center, a norm fiercely enforced (see Lighthall, 2015, Chapter 3).

20. House of Representatives (1986, 240-41). Peller's disavowal, here, of his personal connection to the Orbiter and of his company's identification with the Orbiter as a salient space-technology achievement seems astonishing—unless we understand the circumscribed framing of risk he gave in this icy conversation to the impending launch decision. His narrow focus on what was known and not known about swirling ice, and on how to word a response to Aldrich's request for go or no-go, apparently blocked out not only his company's ownership of its proudly designed and manufactured Orbiter, but also any awareness that if the Orbiter perished in the heat of re-entry after its mission, the astronauts, too, would perish. Rushed, high-pressure decisions mixed with fatigue can narrow one's mental focus in surprising ways.

21. Testimony by Petrone, Glaysher, Cioffoletti, and Martin, and from Aldrich himself, is drawn from Presidential Commission hearings, in which the Rockwell officials and Aldrich responded to Chairman Rogers's statement to them that the commission "would like to know exactly what was said and how that concern was expressed, and to whom." PC *Report*, vol. V, 1011.

22. Ibid. 1011–12.

23. See chapter 3 of *Disastrous High-Tech Decision Making* (Lighthall, 2015) for a discussion of FRR norms.
24. See Lighthall (2015, Chapter 3) for a discussion of the events and sentiments surrounding launch delays in general and the delay of 61C in particular.
25. Ibid.
26. Aldrich, Arnold. D. January 14, 1986. *Subject: STS 61-C Launch.* Memorandum from: GA/Manager, National Space Transportation System [Aldrich], to: "Distribution": Reinartz, Mulloy, and 23 others at headquarters, KSC, MSFC, and JSC. History archives, Marshall Space Flight Center, Huntsville, Alabama, D (drawer) 25, folder "61C 1986," 6 pages. -- FFL document M3.
27. PC *Report*, vol. V, 1020.
28. Ibid.
29. Ibid., 1019. Aldrich's statement about "a constraint to launch" suggests that foremost in his mind was the countdown toward launch, that the countdown was the normal process and any problem interrupting it was abnormal—an outlook tilted toward launch completion. His conception of the countdown as a smooth, unproblematic process is reflected in his assessment as he had entered the firing room: "the countdown was proceeding normally, satisfactorily at least, with no new problems."
30. Ibid., 1020.
31. Ibid., 1021.
32. Ibid., 1022.
33. Ibid.
34. Ibid. Present at the meeting, according to Aldrich, were Horace Lamberth, Kennedy's director of engineering; Richard Colonna; Charles Stevenson and his colleague, B.K. Davis; and Rockwell's Robert Glaysher, Martin Cioffoletti, and

Albert Martin.

35. Ibid., 987.

36. Ibid., 1012–13.

37. Ibid., 1013.

38. Ibid.

39. Cioffoletti expresses clearly here the view held by the Rockwell group, that to approve the Orbiter for launch one had to prove that it was flight ready. They were simply following the FRRs' normal requirement of proving safety of flight. Not knowing where ice would travel on aspirating currents was, in that view, tantamount to withholding approval necessary for launch.

40. Each of these commission queries assumes that unless someone objects to launch the launch will go forward, with at least the suggestion that the Rockwell officials were weak if not derelict in their communication responsibility. Yet to assume the launch will proceed unless objection is made is to place the burden of stopping a launch on the objector, a reversal of the normal FRR burden of proving that one's element is flight ready. The commission queries showed that many of them, Rogers in particular, did not understand the normal FRR presumption and burden of proof and did not understand the safety-protecting role of a presumption of danger until and unless safety could be proven.

41. PC *Report*, vol. V, pp. 1013–14.

42. See Lighthall (2015, 131-133, and Chapter 8) for discussion of NASA's organizational norms regulating safe preparation of shuttles for launch.

43. P.C. Interview with John Peller, April 10, 1986, pp. 13–14, quoted in P.C. *Report*, vol. I, p. 116, emphasis added.

44. Officially, Aldrich recommended a go or no-go decision to the final authority at Level I, in the person of Jesse Moore, NASA's Associate Administrator for Space

Flight. Since Moore depended on Aldrich for all technical knowledge that would serve as a basis for a final decision, and for Aldrich's evaluation of all of that knowledge, Aldrich effectively made the decision.

45. PC *Report*, Vol. V, 1024. For the diagrams of *pre-ignition* trajectories of falling ice and "footprint" of ice, presented above as figures 3.2 and 4.2, see PC *Report*, vol. V, p. 992 and p. 1003. Both include the disclaimer, "Effects of aspiration not considered."

46. While Aldrich had received the information on which figures 3.2 and 4.2 were based, the diagrams themselves were prepared later for the Presidential Commission.

47. Whether Aldrich's erroneous interpretation of the data reported to him was due to a gloss by Lamberth in reporting KSC's calculations or by Aldrich himself in misunderstanding Lambert's report is not known, but it resulted in a sense of certainty of safety on Aldrich's part in ignorance of aspiration effects, precisely the effects the Rockwell group had claimed could not be predicted.

48. Lamberth's and Colonna's assessments about the time taken for ice to fall and rebound were simply guesses, not based on data-based analysis, a matter commented on by NASA's January 30, 1986, report, "Hazard to Orbiter Tiles Posed by the Vertical Structure Ice: Mission 51L." See House of Representatives (1986, 243).

49. Aldrich's framing of his inquiries, focusing on "proceeding with the launch," again suggests that his foremost thoughts and expectations were anchored in the successful progress of the countdown toward a completed launch.

50. Aldrich's testimony was given February 27, 1986, just a month after the disaster.

51. PC *Report*, vol. V, 1024–25. During the countdown it was evidently easy for Aldrich to assume that the only way the launch would not go forward when the issue was one of engineering *judgment*, rather than engineering *data*, was if

someone "insisted" on a launch delay.

52. Ibid., 1025.

53. Including only Glaysher's words in his account to the commission, perhaps Aldrich discounted the significance of having asked Martin's and Cioffoletti's assessments because Glaysher was the senior representative of Rockwell and his comments alone voiced Rockwell's official position. However, since in the 9:00 AM meeting itself he asked for Martin's and Cioffoletti's assessments *after* hearing Glaysher's, it is apparent that he wanted more than Glaysher's official view. Was he looking at the time for differences in view among the Rockwell group? Was he simply honoring their presence as a matter of polite protocol? Had his post-accident memory sought a simplified order by deleting the other two assessments? Many interpretations are possible, but the record leaves us with little basis for choosing among them.

54. PC *Report*, vol. V, 1025.

55. Ibid., 1027.

56. Ibid.

57. "Safety of flight" and "turn-around damage" were two official categories of danger that structured all managers' thinking. Any issue that was categorized as a safety of flight issue required resolution before the shuttle could proceed to launch. "Turn-around damage" referred to damage not considered threatening to launch or flight or mission but would have to be repaired before the shuttle, once returned from orbit, could be "turned around" and readied for another flight. The point is that judgment as to whether an "issue" was to be considered in the one category or the other was often just that, a subjective judgment, not based on data or engineering analysis.

58. PC *Report*, vol. V, 1028.

59. Ibid., 1029.

60. The Rockwell positions he referred to, expressing caution while continuing to fly with tile damage, occurred during the first four or six shuttle flights only, three to five years earlier, during the testing and developmental phase of flight. Also, on those earlier occasions Rockwell had been explicit and definite in recommending launch—in Aldrich's own words, "definitely gave a go for launch." So, on the crucial matter of go or no-go, the earlier cautions were starkly different from Rockwell's assessments and launch position for 51L. Finally, Glaysher stated flatly, in response to Rogers's direct query, that Rockwell's response to Aldrich about the ice threat to 51L was the only time Rockwell had found itself without "a data base from which to make a judgment," and the only time before a launch Rockwell had failed to give a straight "go" recommendation.

61. This was precisely the judgment about damage to TPS tiles that Aldrich had interpreted Glaysher as making, similar to Aldrich's recall of Rockwell's early approval of continuing flights despite "turn-around damage": It was safe to fly then, and it is safe to fly for the same reason now.

62. PC *Report*, vol. V, 1030.

63. Ibid.

64. The problem of synthesizing the known realities distributed among different participants is central to any effective problem-solving process. The evening before, during Thiokol's caucus from the teleconference with NASA (see chapters 3-5 in Lighthall, 2015), Thiokol's senior Vice President, Jerold Mason, took dominating control of the caucus deliberations and turned a stone face to his engineers' presentations, reducing the available intelligence around the table to his alone, which was both biased and flawed. Aldrich did essentially the same, under different but still powerful production pressures. Deliberations among

engineers and managers in the *Columbia* accident (see this website) suffered repeatedly from the failure to synthesize participants' distributed intelligence regarding the dangers of foam debris. Elsewhere (Lighthall, 1989) I have suggested three complementary ways to conceptualize effective member participation, and explored cases from the automotive industry.

65. See chapter 8 of *Disastrous high-tech decision making*: *From disasters to safety* (Lighthall, 2015) for the power of formal argument to protect the highest of the competing values at issue in a disagreement – protection offered if and only if the participants understand the pitfalls as well as the protective power of formal, evidence-based argument.

References

Aldrich, A. D. January 14, 1986. *Subject: STS 61-C Launch.* Memorandum from: GA/Manager, National Space Transportation System [Aldrich], to: "Distribution."

Hamburg, J. (1987) Etched Forever: An account of the final hours of the Challenger. www.datamanos2.com/challenger/etched_forever.html *The Orlando Sentinel*.

House of Representatives. 1986. *Investigation of the Challenger Accident.* Report of the Committee on Science and Technology. Ninety-Ninth Congress, 2nd Session, House Report 99-1016, October 29, 1986.

Lighthall, F. F. 2015. *Disastrous high-tech decision making: From disasters to safety.* Indianapolis, IN: Kilburn Sackett Press. See www.high-techdangers.com .

Lighthall, F. F. 1989. Making and transcending local adaptations: A pragmatic constructivist perspective on "participation." In Magjuka, R. J. & Bacharach, S. B. (Eds) 1989. Structuring participation in organizations. *Research in the sociology of organizations. 7,* 1-26.

Presidential Commission on the Space Shuttle Challenger Accident, 1986. *Report*. Volumes I-V. Washington, DC: U. S. Government Printing Office, July 6, 1986.

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