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For NASA, Misjudgments Led to Latest Shuttle Woes

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"We are ready to fly."

It was June 24, and William W. Parsons, NASA's shuttle program manager, was speaking to reporters on a telephone conference call from the Kennedy Space Center at Cape Canaveral, Fla. Two and a half years of study and struggle, he told them, were over at long last. The shuttle Discovery could blast off in July.

At a closed-door meeting that afternoon, senior shuttle managers had ruled that the chances that debris from the giant external fuel tank would strike the Discovery at liftoff - in the kind of accident that doomed the Columbia and its seven astronauts in February 2003 - had been reduced to "acceptable levels."

The possibility that a large chunk of insulating foam might break away from a section of the tank called the protuberance air load ramp - PAL for short - never came up. It had been ruled out months earlier, checked off on a long list of items no longer worthy of urgent action.

Last Tuesday morning, NASA's contention that it had produced the safest fuel tank in shuttle history was shattered two minutes into the Discovery's mission to the International Space Station. Two spacewalking astronauts tested repair techniques at the station yesterday. [Page 17.]

The 0.9-pound piece of foam that fell from the PAL ramp on liftoff, which could have led to another catastrophe if it had ripped away a minute sooner, forced the immediate suspension of future shuttle flights until the problem could be resolved.

How did it happen? In hindsight, it is clear that the effort to resolve the PAL ramp problem was a chain of missed opportunities and questionable judgments, not just since the Columbia disaster but over the life of the shuttle program.

Potentially useful tests were not performed. Innovative solutions were not seriously pursued. Tantalizing clues were missed. In the end, the old engineering maxim "If it ain't broke, don't fix it" trumped vague misgivings about a part that had not shed any foam, as far as anyone knew, since 1983.

"After two and a half years, they should have been able to fix the foam," said Paul A. Czysz, a professor emeritus of aeronautical engineering at St. Louis University and a veteran consultant to NASA.

Now, with the future of the space station in the balance and the shuttle fleet just five years away from a mandatory retirement imposed by President Bush, NASA is still trying.

The space shuttle's external tank is used for just eight minutes, then ditched over the Indian Ocean. It holds more than half a million gallons of liquid hydrogen and liquid oxygen, the highly volatile gases the craft's main engines burn on the leap into orbit. The tank is covered with plastic foam; without that, it would ice over with moisture sucked from the Florida air.

At the dawn of the shuttle program, NASA rules said no foam at all should be allowed to hit the shuttle and possibly damage the fragile heat-resistant tiles that cover its aluminum skin.

But fidelity to those standards was relaxed over time; in fact, foam fell from a PAL ramp in two early missions, including the one in June 1983 on which Sally Ride became the first American woman in space. There may have been many more incidents, but dozens of shuttle missions have been launched in darkness, with no visual record of foam, and the tanks themselves cannot be retrieved from the ocean for analysis.

As the early tank was replaced with two lighter successors, the PAL ramps remained - one a 19-foot baffle along a channel for cables and pressurized lines along the forward end of the tank and the other the 37-foot strip along the flank of the cylindrical midsection of the fuel tank. And as experience showed NASA that shuttles returned safely despite well over 100 nicks and gouges requiring repair on many flights, the concerns abated over time.

Until Feb. 1, 2003, the day the Columbia disintegrated on its way home to Cape Canaveral.

It turned out that on liftoff, 16 days earlier, a 1.67-pound piece of foam had fallen from the tank and struck the leading edge of the shuttle's left wing. Despite years of assurance that such a strike could do no serious damage - a mind-set the Columbia Accident Investigation Board would call the "normalization of deviance" - the foam had cracked open a hole that admitted superheated gases when the shuttle re-entered the atmosphere, burning it up like a torch from within.

After the accident, NASA examined all possible sources of liftoff debris, eventually identifying more than 170. Engineers recognized that they could not eliminate all risk from debris, but they could do a much better job of reducing it.

The PAL ramp became a focus of attention: like the bipod arm ramp, the part of the tank implicated in the Columbia disaster, it is covered with foam by hand. NASA conducted extensive wind tunnel tests to see whether the ramp could be removed.

The wind tunnel tests of the ramp areas were all focused on aerodynamics - helping determine how air would flow around the craft and tank, or to improve understanding of where foam or ice or other debris might fly should it fall free of the tank. But there were no tests of the PAL foam itself at the speeds, pressures or vibrations of ascent.

So the only tests of how the ramp material might hold up under the rigor of launching were the launchings themselves, with astronauts aboard.

For many aeronautical engineers, a central rule in developing an aircraft is taking its components beyond the breaking point.

"If you don't break a wing, you just have assumptions about what might make it break," said Aldo J. Bordano, a retired NASA aerosciences chief who was on a panel that studied the agency's analysis of the external tank and foam.

He said that while it was premature to conclude whether mistakes were made, many panel members were frustrated with the lack of physical testing of the foam under liftoff conditions.

In any event, NASA decided that the tank without the ramp would expose the cables and hoses to destructive winds; agency engineers and managers considered alternatives but could not come up with any that inspired confidence.

"The community was very diligent about looking at this," Mr. Parsons said in announcing the PAL ramp problem last week. "We did realize that eventually one day we needed to put together a program to remove this PAL ramp if at all possible. But at the time, we didn't have enough data where we could technically do that and be safe."

There was no evidence that the ramp had shed foam since the early 1980's, he said, adding, "We had had very few problems with the PAL ramp and we decided it was safe to fly as is."

To Professor Czysz, of St. Louis, that decision shows limited imagination and NASA's tendency to look inward for answers.

"I think they tried to find the solution within their own ranks, using what they're already familiar with," he said. "They should have looked at more options," perhaps including different formulations of foam that might be more flexible.

But as Michael D. Griffin, NASA's new administrator and an engineer himself, said Friday, that would have violated the old tenet about fixing what is not broken.

"We debated and discussed whether the PAL ramp was broke" in the months that followed the Columbia disaster, he said. "The conclusion we came to was the wrong one, but the conclusion we came to after considerable study was that it was better to fly as is."

NASA engineers had already seen how fixes can break things. After they made a minor change in the foam application process in the late 1990's to comply with environmental rules, small divots of foam rained off of the tank during ascent. The phenomenon, called popcorning, was caused by trapped bubbles; NASA solved the problem by venting the foam with tiny holes, but it was a reminder, if any was needed, that seemingly small changes could have profound effects.

"Foam really is complicated," said Douglas D. Osheroff, a professor of physics at Stanford and a member of the board that investigated the Columbia accident. "Once you go supersonic, the top surface melts, the bottom surface is brittle as all hell because it's very cold, and you've got everything in between."

Although the material could be made less fragile by adding fibers to the foam, he noted, "that adds weight" to the shuttle, and any changes can take years.

Ultimately, the accident board recommended that NASA find ways to prevent any shedding of foam or other debris. And NASA gained confidence during the time between flights that it was making

progress.

Among other things, it improved the training processes for applying foam by hand. At the Michoud tank assembly plant in Louisiana, an observer monitors every worker spraying foam - "for every sprayer there's a watcher, a second pair of eyes," said June Malone, a NASA spokeswoman.

But the tank that flew with the Discovery last week was made before the new procedures went into effect, and NASA stopped short of requiring that the ramps be redone, said a spokesman, Martin J. Jensen.

After the Columbia accident board issued its scathing report on the causes of the Columbia disintegration - especially a "broken safety culture" at NASA that had grown complacent about all sorts of risks - another independent group was set up to monitor the agency's progress in fulfilling the accident board's safety recommendations.

That group, called the Stafford-Covey task force after the two former astronauts who led it, accepted NASA's argument that the PAL ramp did not urgently require alteration.

At its final meeting in June, however, it also found that NASA had failed to meet the goal of eliminating all debris. The group took issue with the way NASA determined that the foam chunks that might still fall off the tank were too small to cause critical damage. And it criticized the agency's tendency to depend on computer simulations when physical experiments might yield more valuable data.

Ultimately, however, the group accepted NASA's contention that it had raised the level of safety in general.

"You need to look at what the agency has done, not necessarily a scorecard," said Richard Covey, a co-chairman. Indeed, the tank modifications have reduced shedding, according to the array of cameras and sensors installed in the wake of the Columbia accident, to 25 nicks and dings counted after the Discovery's liftoff from the usual 145.

On Friday, Mr. Covey, who was pilot of the first shuttle mission after the 1986 Challenger accident, said that in light of the PAL ramp incident, his group, too, had erred - but added, "We certainly weren't any smarter, at that point, than the folks who were working it on the NASA side."

He agreed with the contention of NASA officials that the Discovery mission was a test flight that would provide data for further improvement. "You learn," he said, "and then you go fix and then you fly again."

A NASA engineer who works on tank safety issues said other areas of foam shedding from the Discovery's tank were even more troubling than the PAL ramp loss, especially a divot that popped from the vicinity of the left-hand bipod strut, the spot that shed the foam that brought down the Columbia.

"We worked the hell out of that," said the engineer, who was given anonymity because he said disclosure of his name would jeopardize his career. The loss of foam from that spot after so much work to correct the problem, he went on, proves that the problem is still far more complex than NASA understands.

So the space agency is back to the drawing board. Some of the options under consideration have come up before, including the elimination of the ramp, a "miniramp" that shrinks the size of the strip by two-thirds, and a small "fence" on the opposite side of the tray that would smooth airflow further. Another possibility, rotating the tank so the ramp faces away from the shuttle, would take years, engineers say.

Dr. Griffin, the NASA administrator, predicted Friday that the foam problem would be quickly repaired and said engineers would consider options that had not been tried before. But he added that the next generation of spacecraft would place cargo and crew members atop the tank and not on its side, where falling foam and ice invite disaster.

"As long as we put the crew and valuable cargo above the tank, we don't care what they shed," he said. "They can have dandruff all day long."

Dr. Jon Clark, widower of the Columbia astronaut Laurel Salton Clark, said the Discovery incident should be a warning to NASA. He is still a "big fan of the shuttle," he said. But "at some point you've got to say, 'Wow, maybe the critics who say this is a really flawed design are right.' "

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