IBM Tape History – Session 5:
Recovery of tapes damaged in Challenger disaster
Ric Bradshaw

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Also present:
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Introduction

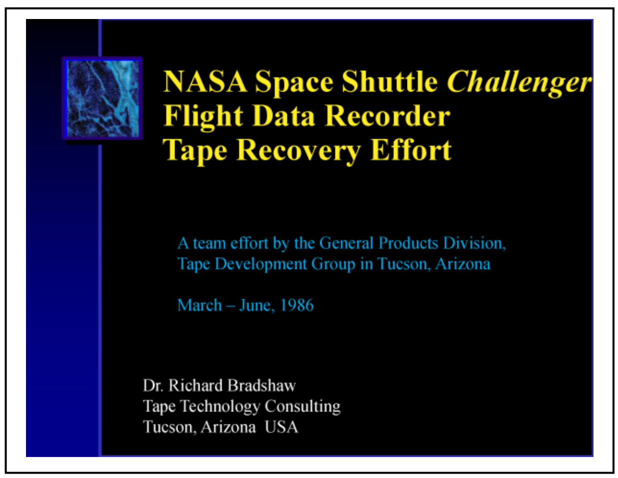
This is session one of five sessions held in Tucson, AZ, regarding IBM's tape storage history. The five sessions are:

1. Tape Media (CHM catalog number: 102737992)
2. Overview of tape products and product management (CHM catalog number: 102737994)
3. 3480 tape drive (CHM catalog number: 102738021)
4. Linear Tape Open (LTO) Consortium (CHM catalog number: 102738023)
5. Recovery of tapes damaged in Challenger disaster (CHM catalog number: 102738025).

See IBM Tape History Session 1: Media for an overview of IBM Tucson,

Dr. Ric Bradshaw was part of the IBM team that recovered the data from the severely damaged tapes recovered after the 1996 Challenger disaster. His observations, findings and conclusions are memorialized in a set of images that he has presented in a number of venues over the years; In October 2016 in Tucson for the Computer History Museum he recorded two sessions with his images. This is the edited transcript of the second session.

Interview



Bradshaw: Oh, I'm going to walk you through the recovery effort that IBM Tucson carried out in the spring of 1986 to recover the data flight recorder from the NASA space shuttle Challenger disaster. This was a joint effort in IBM, and one interesting part is how we actually wound up with it - it was totally accidental.

The disaster happened on the 28th of January, in 1986, when the Challenger blew up shortly after liftoff. It was an attempt by NASA to show that the space program, using the shuttle, had become safe and routine enough to allow civilians to now participate rather than trained astronauts. This was the first flight with a true civilian passenger on board, a schoolteacher, who had won a national competition to be the first woman to go in space, in a space shuttle. It was exciting. A lot of people watching it, and it blew up shortly after liftoff.

In hindsight, they knew at the time that there had been many incidents of O-ring problems for launches in cold weather. Here is a picture showing a snap from the video stream from the ground where they could see the plume. Now, instantly there was, when they started looking through all the information they had, right at they fired the engines, the liquid fuel and the solid fuel boosters, the first puffs of leakage from the O-rings were noted. So it was there from the beginning, in hindsight. The problem this time was that it

was the wrong direction. The plume leak was actually going to sever one of the attachment points for the solid fuel booster that now would eventually no longer be aligned to the main structure and would go off angle. And now the thing really didn't blow up from the internal fire. It actually disintegrated and then caught fire.[1]

What I wanted to walk you through is how we actually pulled this off. The flight recorders were found, it was quite an extensive search. It came apart at a very high speed, a very high altitude, and then scattered. So it's like needle in a haystack literally[2]. But these things had transponders on them so you could find them. I believe, from what we were told at the time, that the Ops-2 flight recorder, the one that was actually had the crew data being recorded, was in the capsule portion of the Challenger where the crew resided. And that hit the ocean, after being broken up, that recorder was actually in the worst shape of all of them -- you'll see some pictures of that. And that one didn't have a transponder that was giving, so it was hard for them to find. The Navy divers found it. I believe it was also at 100 or so feet of whatever, been six to seven weeks under, so it was badly corroded when it was recovered. They came to Tucson with the tapes, and what we knew when they told us is that they're reel-to-reel recorders. We did not see the recorder when they came to Tucson. They showed us a picture what it looked like. They were magnesium alloy reels, which to me surprised me. They did it for weight, but flying it and capturing it over the ocean, I thought, as a chemist, that was kind of silly, because those things are not stable. They will corrode, and they, indeed, they did, when they were in the ocean. Now, of course, none of them use magnesium. They use polymers, plastic, carbon fiber, which are much more stable and lighter and so greatly improved over what they used for the early shuttle missions. But a lot of the things that happened that were wrong with this led to improvement. So they improved the seals of the Challenger, they improved the flight recorders. So that's not the purpose of this discussion. What we're really here to talk about is what we did and how we got around it. So this is what we knew. And they came to Tucson, they being the NASA team. They had gone to their internal experts. They had gone to Ampex who made the media, and had gone to Jet Propulsion Laboratory. This is all in standing. We were not there. And they flew into Tucson totally by accident on the way back from California, on the way back to Texas, to the Johnson Space Flight Center in Houston. We had another interaction with them through a tribology project with Bharat Bhushan, an IBM tribologist, a very well-respected tribologist, who was working with NASA. It was a partnership, and they were doing some work on tribology in space and high vacuum systems and things. So it was a really fortuitous, that Bharat said, "Well, we have people here."

I'd collaborated with Bharat on a paper for IEEE, and the transactions of lubrication engineers, we had given a paper, again, in Houston, I think that was in '83 or '84. So he was aware of the work I was doing on Dynamic Mechanical Analysis (DMA) characterization of tape, which we were pioneering at the time.

[1] "Structural breakup of the vehicle began at approximately 73 seconds." Report of the PRESIDENTIAL COMMISSION on the Space Shuttle Challenger Accident, June 6, 1986, Chapter III – The Accident
[2] Initially 10 by 25 nautical miles it expanded to at least 370 square nautical miles. See: US Navy Naval Sea Systems Command Report on the Salvage of the Space Shuttle Challenger Wreckage, Chapter 4.1 Search Area

We'd published some of this, but limited, because IBM did a lot of material to support our customers that we felt as IBM and a corporation, was nobody else's business. So we never put information about what we were doing for other people's business out anywhere. So it was all considered fairly hush-hush.

Tucson, Arizona, was the IBM center of competence for magnetic recording. IBMers were everywhere; we had our people and fingers in almost every industry. My boss at the time had a contact in Owego, New York, who worked for Odetics who built the drives that were on the space flight Challenger. They were having trouble qualifying these drives for flight, pre-flight, with the Ampex media, which had been built in '69 and '70. That I'm aware of '71 was the last manufacturing run. They were having trouble building the drives from this archived media. They sent samples to us in I believe it was May of '85, and I completed the analysis and the report, both chemical, mechanical, electrical, everything. We did a full what we would consider inspection of the media. So I knew a lot about it. And turns out I probably knew more about it than the people who made it. Because nobody did DMA except us. Dynamic mechanical analysis is what I'm talking about. DMA, there's different ways. The one we did for coatings was using the actual coating, but the real trick was doing a finished tape and doing it by rule of mixtures, which now it's easily done. Other people are doing the work. Brian Weick at the University of California, University Pacific in Stockton, California, is continuing that work, really doing very thorough work. But at that time, there weren't a lot of instruments doing this, and nobody was doing it for tape. We had a polymer labs kludged together with pieces on the tabletop. We would tape a tape sample, clamp it, and under controlled pressure you'd stretch it back and forth, but you'd never stretch too long. You'd oscillate it up and down with a concentration as a function of temperature and frequency. In other words, we could do it at fixed frequency, or we could move the frequency. In other words, how fast, right. The reason is plastics change the response based on time. If you think about it, like Silly Putty, you pull it real slow, it stretches. And it just stays there, okay? If you hit it real hard, with a hammer, it shatters because it doesn't have time to flow out of the way. So the polymer reacts as a solid at one frequency. You hit quickly. You hit it long enough it creeps. This is true of called viscoelastic behavior. There's other types of polymers which are thermo plastic. In other words, you heat them to a certain temperature, they melt. That's what's called molding. Where you mold something, put it in a mold, heat it up, flows, cool it off, out comes a part. Polyethylene's like that. And other materials. Some are curable, where you start off with liquids like epoxy, you mix them together, they set up and they make a hard material, and that's how you cast them. There's different problems that come with it. Well, characterization of the properties is what you want to know about a tape. A substrate has certain properties of blending, flexure, and tensilization. How much it shrinks when you pull it is call Poisson's ratio, where you pull something along, it gets narrow in the middle. Well, you need to know that to a reasonable approximation, because if it's a tape and you squeeze the tracks it may get longer this way and narrow in the other. So you need to know that.

The other thing is the coating. The coating is under very unique properties in a tape relative to pieces of paper or anything else. It is wound on a reel and it's pulled in tension to make it go over a tape drive. Well, the inside, as the diameter changes, has vectors on the compression onto the hub. The hub then resists it out and presses back, so there's compression stretch between it. As you go further and further out, that gets less and less. On a big enough hub, the thing tangentially at the head, looks like it's being pulled this way [tangent to the reel]. There is no [radial] force. So those are the things we call loose wraps in tape where they just fall off the reel. So these are all problems that are all related to the mechanical problems of tape. And if that wasn't bad enough, a lot of tapes have a back coat, which is one thing, a substrate, and a mag coat. The mag coat is where all the business end is. This is the stuff that stores the data. This is the important stuff. All the rest is just transport. On the reel the back coat then contacts the mag coat, the magnetic recording material. Well, if it transfers or embosses, you wind up debris, you have things. So these are all critical pieces of the puzzle making a tape work. Well we were investigating this in the process of developing tape drives. I was doing work on this Ampex tape, wrote the report, so I knew what their tapes looked like. By the way, I could tell they were degrading. I had two vintages. I didn't know what they were. They sent us two samples. By the way, -- there is no paper trail. I gave the report to my boss. He sent on the report as IBM Internal Use Only to the IBM Federal Systems division in Owego, who then transferred to Odetics for information. I don't know if it got to Ampex or anything. I don't know.

Canister at first meeting

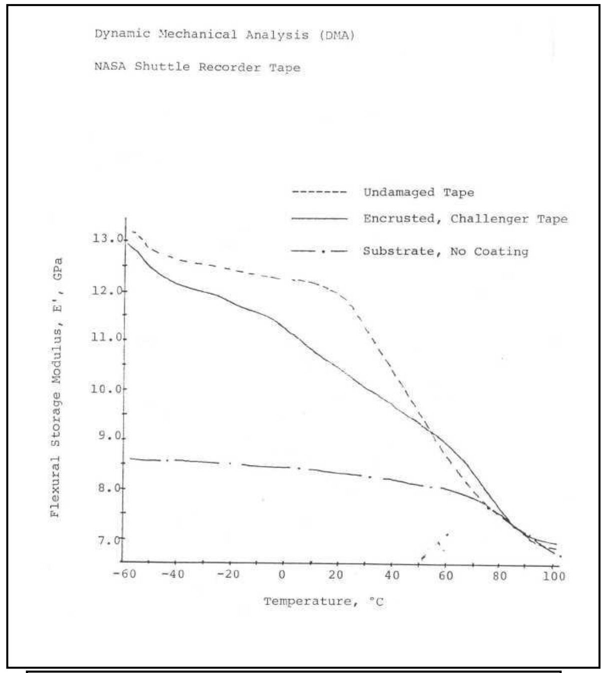

Actual unrecovered reel

I do know that NASA knew that there was an investigation, the media, into some recommendation that they needed to make new ones. And they were in the process of basically re-designed the whole thing and, starting over. And I think some of it had to do with the 3480. I really believe that they were starting to say, "Maybe it's time to get off this old formula and go to something else." And I think they actually went to disk drives, tell you the truth. But the net of it is that I had this data and we never heard anything. Then the Challenger disaster happens. We obviously, being Americans, were shocked and hurt. I mean, essentially innocent people died because of negligence in political decisions that were inappropriate.

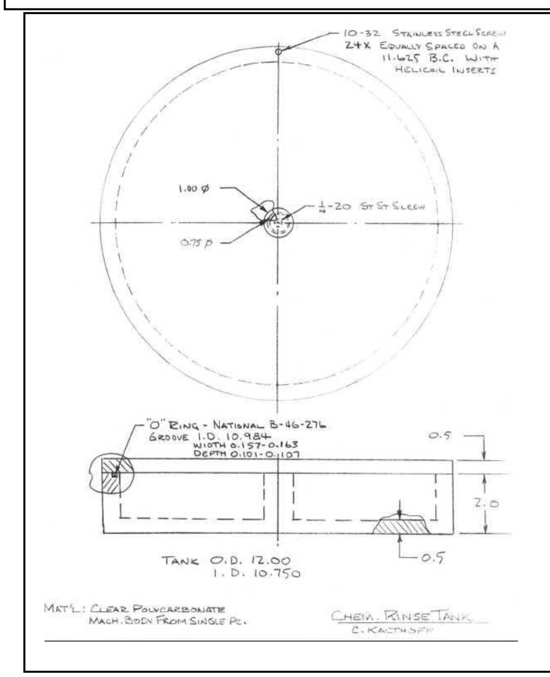
Also at the time, I was working with Morton on binders for advanced tape formulations using iron metal or barium ferrite particles rather than chromium dioxide. And I knew some of the people that were working on the O-rings for the engines. And these guys were hung out to dry by their managers as sacrificial lambs. It was wrong. But that's neither here or there.

Anyway, so what I want to talk about though is what we did. And at the meeting, when they showed up in Tucson, and I will show you a picture of it. Fact, let me do that right now. Show you what that tape looked like. This is what they arrived with in Tucson. They came with a movie canister with a loose spool of tape in it that looked like a piece of brie. It was completely white. Okay. Crusty white. There was magnesium flange and stuff, but it was inside this, and in this picture, not one of that reel, -- but this is what they showed us. At this first meeting where they showed us what they were doing and what they were up against and what they looked like, and everybody in the room except me just went, "Oh." And they were done. I went up, I asked gentleman who was from NASA, and it was a, I believe, was an Air Force colonel, or he may have been a one star general, and some civilians that were along with this that had just come from JPL, that were giving us the update. And they showed us a video of them recovering the stuff on the aircraft carrier from a-- and hosing it off, because it's just big, white clump. Looked like a brick. And there's this tape flange. And I said, "Oh, my God." Material that had no date on it because of the way the things were configured. And this is what they recovered and they were showing it. There was no data on this. They were not traveling. The real stuff was, they said, was in worse shape. They didn't tell us much more. I said, "Can I get a piece of it?" And they gave me six inches of the tape from the outside, and it was literally you could see places where there were holes in the substrate and there was coating missing. There was white deposits -- it really did look like a cake of brie, you know, the white chalky covering that you'd see on brie -- I don't know what else could call it. I went downstairs and I handed a small chip, had most white stuff on it, to Dr. Ed Bartkus, and Ed ran the SEM in our group. He came back while I was running the DMA. I went downstairs and because I needed to know what the substrate looked like too, I wiped the coating off. Unfortunately, given the fact that I'd worked on the good tape, I was using what I used to get the coating off the good tape. It was dimethyl formamide. I didn't need to. You could literally wipe this stuff off with acetone a very limited solvent. It was that poor adhesion. Just wipe the coatings off. Reason I did that, I needed to know what the substrate looked like. How bad was it degraded? I also noted that when I wiped it, it was originally kind of a milky color, and when I wiped it, it turned more clear. So in other words, there was a lot of stuff that'd been degraded pulled out of the Mylar in the oligomers. I analyzed that by IR later. Anyway, what Ed told me the white stuff was magnesium hydroxide.

There were actually little one-celled organisms on the tape. It's food. It's in the ocean. Things are going to find stuff that's edible … It didn't come from the ocean, it came from the surface. It's edible. Fatty acids. You know, "Ooh, good, food." So little bugs and things were all over it. It was really, quite honestly, covered with biological debris as well as magnesium hydroxide, which is a very caustic alkali. So now I knew what the white stuff was I had to get rid of. So I had a plan. I knew how to get that. The most soluble salt, but magnesium is a nitrate, so obviously convert it to nitrate and get rid of it. That was not the problem. Now, is there any mechanical integrity in the coating? That's where the DMA came in. And what I did is I ran this thing while Ed was doing this. And I ran the DMA. And I'll show you the chart in a minute. And what it said was very poor adhesion and poor coating integrity as well. Even in the process of mounting the clamps, I could see that the clamps would actually break the coating off. So I had to do it twice. But I clamped it, cooled it down with liquid nitrogen under very low tension, because I didn't want to stretch, have the coating come off. So the intent was to do it a little lower frequency than I did on original sample. So I wasn't going like this real quick. It was like 10 hertz, I believe, 10 cycles per second. So it was oscillating back and forth with a very low tension. Enough to keep it flat in the clamps. I ran it from sub-ambient to about 100 degrees C, I believe. These are the days before you could actually overlay them and stuff like that. I then went upstairs into the conference room, which was still going on, and I stood up in front of them, showed them this plot, which shows the original samples that I had run previously and the degraded tape. And what they are is plotted on the same scale, amplitude. This is the storage modules over temperature, at one frequency. And what you're seeing is as you go through this, and when this changes it's going from stiff to rubbery. That's called the glass transition. This is just a storage component. There's also a loss component, which is more complicated. That's why I didn't plot this for them, because you could see the degradation. You could see different little peaks in there. They were showing that this thing wasn't one contiguous-- and you could actually see traces of it in the way these things got multiple transitions. It is-- but what it tells me is that's what was in this chart that I wanted to show you. The bottom of this. It's really degraded some, but we should be able to recover the tape. So at this point, everybody in the room thought I was nuts. And now I'm not overdramatizing this scene, because quite honestly, -- this was it. We wound up going offsite. But the management of IBM who was present in the room did not want to commit to this because this was not our job, this thing. So there was a little bit of discussion that I had nothing to do with about what we were going to do and who we were going to tell about it. First of all, right off the bat there was going to be no press on this at all. "We're not involved. You didn't talk to us. It didn't happen, okay? Let's see what we can do first." Also, understand, again, there is no data on this sample they're giving us. So what we're going to do is we're going to see if we can get it apart, unspool it, and then write to it. Can we actually use it as tape? If we can write and read it back, then there's a chance we could read another tape and we could recover it. That was the plan.



We then left this meeting. I think it was, like, two or three in the afternoon, went around the corner down to Clem Kalthoff's office in the second floor of Building 61 on the old IBM Rita Ranch site. We being Ed Bartkus, myself, Dennis Byrne. Blair Finkelstein didn't show up. That's because right now we're just planning on how we're going to get the tapes apart. Then we have to get somebody to do the reading, okay? And that's a whole 'nother story. Blair Finkelstein that ran that effort.



We discussed what we needed to do and we needed something, because we'll show you in this reel, that the flanges are made of magnesium. We have to get rid of them. So we have to get rid of the magnesium hubs, otherwise in order to treat this thing I'd be chewing up this magnesium and eating the tape up. So we had to get rid of those. So we had a plan to have the model shop machine off everything. Then when we get done, we just have this loose tape. Well, we have to support it while we treat it. So we needed to make a hub that we could snap inside, this very unusual hub that was designed for their particular use of their drive, and that had to be insoluble or resistant to the solvents and the toxic nitric acid and things we were going to be putting in those. So it was obviously, the choice was, Delrin. Well, you don't just go to a thing and pick up a strip of Delrin. We literally machined it. We, the IBM model shop made it out of a big block of Delrin. They cut it out, cut a section out, and you'll see a picture of it. And a stainless steel spring to tension it against it. And we, it's interesting, we did some armchair engineering on a blackboard and we were dead right. I mean, that doesn't happen very often. But it shows if you have people with a lot of experience, you can pull stuff like this off.

Ed Bartkus went down the SEM and started getting ready to do that. And then what happened was Clem, who was amazing, great penmanship, this was all free-hand with a ruler and a compass. He did it on his desk on a piece of 8 1/2 X 11 printer paper, okay, and drew this up. This is the exact copy. It's a photocopy of his drawing that we then gave to the model shop to build a polycarbonate vessel that we could see through that we could also screw a top in for pressurization and vacuum so we could flush in and out between the wraps and get all the solvents we needed and the reagents. We needed to get magnesium out of it. By the way, we didn't know what we needed, but we wanted to make sure we had a vessel we could pressurize to the depth that it'd been at or/and evacuate. That was the plan. He sent us down and they worked all night on it and was there the next day. And my recollection is we got it. I came in the next morning early and the Delrin ring and that was there, and this was coming up in the afternoon. It's absolutely impressive piece of work. And meanwhile, I was setting up my lab -- it was all kludged. With didn't have a procedure for this. I had two hoods next to each other. One I was going to use for the treatment, the other one I was going to use to distill the stuff so I could constantly monitor. I had an IR. I had access to other things, GPC, gel permeation chromatography, infrared spectrometers, IR. I had pH meters. Everything I needed in there that I could follow this thing, because I also needed to weigh what I was pulling off, because I didn't want to keep pulling stuff out of this. I need to know, "What am I taking out, how much, and when to quit." This was okay because this one we didn't have data on.

NASA Shuttle Tape REcovery - Initial Attempt

	Supply Reel	Data Reel
	flanges, hub removed on Delrin Ring	hub cut,flanges intact
0.5M HNO_3	2 liters (pH 0.8-1.2)	2 liters (pH 0.6-1.8)
Distilled Water	10 liters (pH 1.3-2.2)	10 liters (pH 0.9-3.1)
	leaks fixed	hub, flanges removed
0.5M HNO_3	2 liters (pH 0.7-1.0)	2 liters (pH 0.6-0.8)
Distilled Water	78 liters (pH 1.2-5.9) two days	26 liters (pH 1.1-5.4) one day
Methanol, Anhydrous	8 liters one day	2.5 liters half day
Methanol + Lube (Butyl Stearate)	2 liters	2 liters
Methanol Rinse	None	2 liters
Methanol + Lube (Methyl Silicone)	1.5 liters	2 liters
Methanol Rinse	none	2 liters
Unwind, test		

We came up with a treatment process we had designed and this is the first chart. Now, this is a summary. It was all written on a blackboard. I kept tabs on everything by going over and checking off how many liters of this and that. This is the first one. And what's interesting about this chart on the very bottom is when we got through the treatment, what I'm looking at is how much nitric acid I used, 0.5

normal. That means the amount of acid that I was adding. And I couldn't go, you don't want to do, to weak or just it's too dilute. I need to get this thing going, but I can't get too strong. So I needed to watch it. When the pH started drifting from acid back up, it was fine. That's taking up the alkaline. But when it stays acid, it's done. There's no more. When I got there I stopped. Now I got to get rid of the water and the rest of the acid. I didn't neutralize it <inaudible>. Just let it sit for a bit. Started running it with dry methanol. Methanol is an alcohol. It's very, it's smallest alcohol. It's CH3. It's got one OH group, one meth. It's very low boiling. But it's very miscible in water, because it's polar. So it sucks up water. It's very hard to get purely dry methanol. But you can do it with a trick called molecular sieves. And I would distill it with molecular sieves to keep the water out, get it dry, put it back in, until I got no water out the other side. Now I knew I had it dry and I could just vent it with air and the methanol's gone. Okay. So there's nothing holding these thing together. Now, unfortunately, I've also pulled lubes out. Everything that was soluble in methanol is now gone from that tape. The water was the primary thing I was getting, but I'm also taking the lubes out and some of the degradation products. I need to get, re-lube, this tape. That was our plan from the very beginning. So what we did in this series was I try-- once I got the methanol washes done, I had a tape essentially with no magnesium hydroxide. It's no longer white; it's black. Now I need to get them apart, wraps. First thing I tried was the lubricant that was present in the tape when it was manufactured, it's butyl stearate. It's a fatty acid ester. It's a liquid. Anyway, at room temperature, this particular thing is a liquid, a viscous liquid. Almost like a baby oil. Okay. Which is not quite the same. But butyl stearate is, stearic acid, is a fatty acid. Okay. And it's butyl, butyl alcohol ester. That really didn't work. It wouldn't-- it would go in the thing, but it wouldn't-- it'd sit on the surface but it didn't go between the wraps. Even with pressurization. And in fact, there's a video I think I gave you, it was a little short one, but Clem Kalthoff was videotaping when it did and the thing blew up, I mean we were trying to pressurize the force and it just blew the hoses off, and I wound up with this stuff all over me, so he got a big laugh out of that, it's a three minute little clip. But, so that taught us that isn't going to work, so then we tried methyl siloxane, silicone, which is well known as a grease, oil, it likes, but it didn't work either. So then we tried a couple of things that I had been making in my lab that were fluorocarbons, and the one I finally tried almost dead last because I thought it would work for what we wanted but it was a disaster as a tape lubricant because, once it wetted the iron oxide surface of the tape, it stuck, and it made the surface like Teflon, nothing would stick to it, so tapes were just damp, you shut the power off and the thing would just fall off the tape drive. So it was a total disaster and when the guys tested it on the test stand when I was evaluating these lubes for lubricity and headwear, they were really upset with me because I contaminated their Bell and Howell and the capstans and everything in the tape path, so they said you clean it. Because this wouldn't clean up with just regular solvents and it was, I made a mess of that drive, it was all over the vacuum columns, it was all over the capstan, so I had to go in there and aggressively clean it and replace the capstan for them. So, it was in my notebook, and it got dubbed RSS [Ric's Secret Stuff], and hopefully this'll be on it, it was Ric's Secret Shit is what they called it okay? And my notebook number then was 237. It turns out I made 15, 16 grams and it worked. You put it in this thing and it would go in, wet the surface and then repel itself once it formed aligned monolayers on the opposing surfaces. It's a carbocyclic acid group on one end, a short hydrocarbon chain, and triflouoromethane on the end, three of them, so it was a tertiary fluorocarbon ether, on the end. So these little balls of fluorine didn't like each other and they'd go like this [move apart] , but they wetted the surfaces of any oxide, remember I'd just got done rinsing the tape coatings so that a lot of the binder was removed and I had a lot of pigment, so there was a lot of exposed iron oxide. So this stuff loved those oxides and sat on the surface, and it prevented the oxide from coming off the binder and sticking to the side, it worked. So, now we knew we had a method, it's not on this chart, this shows you the stuff we got to, because the dead last thing I did was this last one, and we didn't publish it because it was not commercially available, I made it, and we didn't want a commitment that I'm going to have to make this stuff okay? Point was, after we did that, we knew we had a process. So we had done that, and we got,

this is a summary of where we're at, we had a rinse tank, a methodology, a process, and we had worked out with the model shop a way of machining out the hubs.

But they can't get enough credit for this, I mean those guys were just amazing, I mean they did it, and they cared, they knew what they were doing, this is what happens when you get really good people, and they worked their butts off. And this is not their job, these guys, this is something they obviously had a passion for, they were world-class machinists, they could make anything. So, let me show you what happened when we actually got the data, now this is a different animal, when we sent these tapes off they had no data on it. We treated, left everything unchanged but set up a way of writing this thing and running it back and forth on a Bell and Howell which is an instrumentation reel to reel drive. Not anything like the recorders that were used to write the data in Odetics drives. Blair Finkelstein and Ray Kamens had constructed an experimental media evaluation tester which they now adopted to try to read and write the shuttle recorder tapes. It had some very unique features on it that allowed them to capture signals from experimental tapes so he could look at almost anything, and experimental Spin Physics had a very narrow gap, MR, magnetoresistance reader, and it had a write element which was a thin film write element, so this was all well out of the public domain, it was very much a standalone device, which you needed for this. Well, we had worked out this process so now we had that, now we had this tape that we thought could be written. Well he wrote it, read it back five or six times and sent it to NASA, never heard a thing.

Next thing we know, we seriously never got any response back, did it work? Next thing we know I get this call, come down to the Lab Director's room in building 40; there was this bunch of people there with this briefcase and they, I'm not making this up, with the handcuff and the chain, and inside that was these two tapes.

Operations-1 tape on left, partial Operations-2 tape on right

And what you're seeing, again, they're not in the drive as, these were removed from the hardware and put into 16 millimeter movie canisters for protection, and what you're looking at is the Operations-1 tape, Ops-1, you can see that this thing here is, the white thing inside is the actual media, it looks like white brie, it's crusted with magnesium hydroxide. Above you can see magnesium flange which is also degraded, it's mechanically broken, and below that is this grey area here, that's the actual hub, it is magnesium. Next to it is the one that they were most concerned, this is the Operations-2 tape. Ops-2 is the one with the voice data from the cockpit where the crew were. It had bio data, heartbeat, respiration, that kind of stuff, obviously very critical to knowing what was their condition. The other thing that people don't realize is, during that time we didn't have satellite linkages. A lot of the telemetry was stored, and because there's this big fireball behind it, you just couldn't send continuous stuff through because of the frequency involved, so what they did is they take snapshots, send it and get it through the ionization of the engine, and collect it from the ground, so that's where they got the data. Well, there were gaps, and as I understand it was like a couple of minutes that were crucial. When they went to go for power-up, there was audio communication, there was an uplink, but there was no transmission down, so the data they needed about the actual happenings after it blew up and started down was on these flight recorders, not in any transmissions coming from the Shuttle. So they wanted this data. This one was the most critical. This had operation for the engines which they wanted to know obviously, they wanted the information on the engines, the pumps, the pressures and things like that, for the liquid fuel, and the solid, I believe NASA would have all the details, they never told us everything, didn't need to. So our.

Gardner: So just to be really clear, because it gets confused, the reel canister to your right is.

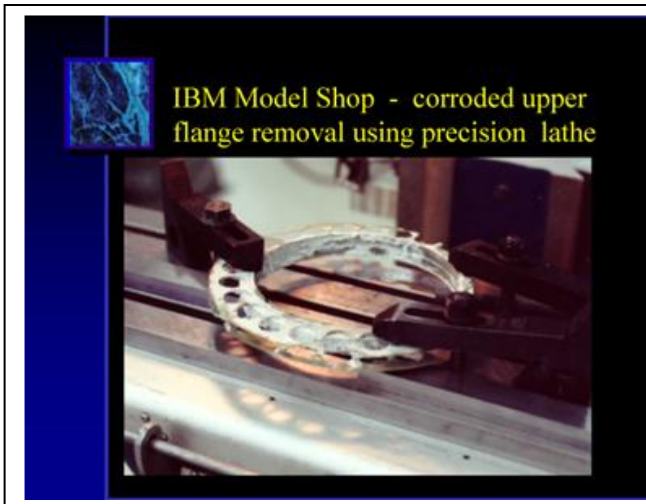
Bradshaw: Ops-1

Gardner: And the reel canister on the other side is Ops-2.

Bradshaw: That's correct.

Gardner: And again, Ops-1, recorded Shuttle information, Ops-2, recorded people information.

Bradshaw: People, and critical for the investigation. So, what I'm going to show you is a couple of pictures from the mechanical side, Ops-1 was mostly mechanically-intensive because of the flanges, we had a lot of machining to do. What the model shop would get was that spool, and now you can look at it before anything's been done, they're mounting it, and these guys were good at it, 'cause remember, this is a tape which is not in great shape, even before we started.



So we need to treat this, we don't want to do more damage to it in the process of trying to rescue it than was done by hitting the water, we don't want to do anything, we want to leave it alone. So these guys built these clamps, and these are all machining clamps, but they approached this with a lot of precision. This is when it's mounted, getting ready to drill out the, they take out a mill, and mill off the flange. Now literally you got to pay attention 'cause if you go too deep you're going to nick the tape. So they were going around the flange and knocking off this upper flange with a mill, and here is what it looks like as they're getting ready to mill it,

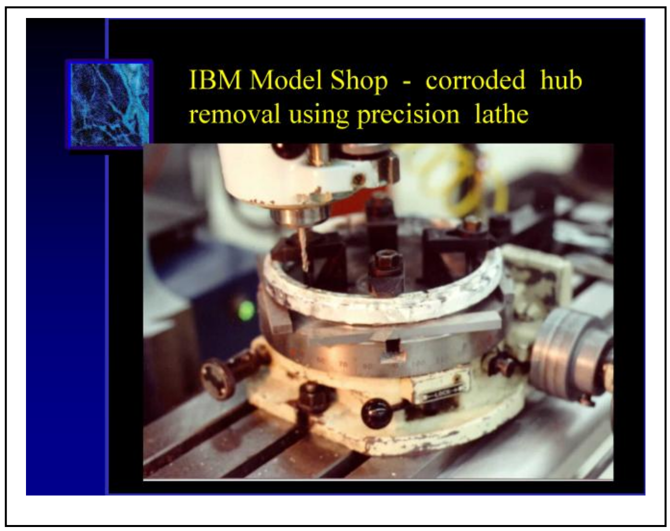
They're mounting it on a fixture that keeps it absolutely flat, a planer, we're talking within thousands of an inch, tens of thousands of an inch, extremely high precision, this is not your normal, even for that time, this was state-of-the-art equipment that we had at IBM.

Gardner: So the black things in the center are the clamps.

Bradshaw: The clamps are down but this base on the body, you see there's micrometers on the bottom of this, I don't know if you can see it, so that they can move this thing and keep it absolutely parallel 'cause they want that mill to go down and touch that but not nick the tape, within thousands of an inch, and you could see some of the flange, some of it's already milled off.

Gardner: Oh it's already been milled off at this point.

Bradshaw: Yes, Clem Kalthoff took these pictures. It was like two in the morning by the way okay, so it was an all-nighter with a lot of coffee. And then, what's happened now, is that once they get the flange off, they then go in with a drill, and drill out the hubs. These are these big blocks, and now, they drill down and then move the drill bit slowly toward the tape. Now before they did any of this, they wanted to verify how far could they go. Well we knew that there were at least ten to twenty wraps that the inside of this thing, they had no data, never did, never would, because this was used to wrap and insulate and attach the tape to the hub. So that was it, we knew we could get a couple of them, it turns out it was a good thing because these wraps were glued to the hub, chemically. Okay, they were absolutely corroded into it, so there was no way we could get those off. If we had to have recovered data we would have never gotten it. But, you can see them drilling this down, and what comes up next.



Gardner: Before you go on, I note you can see the camembert, or as you say, brie, the white corroded tape, which should be black.

Bradshaw: It's actually a dark brown but it looks black when it's wet. It's important to clarify for the machinist and the people that really want to be correct about it, really what these are, you do pilot drill holes, and then they're milled carefully until contact with the inner wrap, so this is actually a mill, this is not your normal drill press or anything like that, so this is really precision equipment and you can see the micrometers and things that are used to keep this thing absolutely parallel and flat, and this is not in the hands of anybody, this is a skill, and probably even a lost art now, most of this stuff is computerized.

Gardner: And actually what we see here is a drill bit which would be drilling a pilot hole, and then later a mill head would come in and mill from the drill hole towards the tape until it got to the tape.

Bradshaw: A lot of this was done with a microscopic examination so they knew exactly how deep they went into the tape, they did not want to go beyond a few wraps of the tape, that was, these guys were good. And this was Ops-1. This was one of the worst ones that we had as far as the amount of flange, whereas the, as you may recall, the Ops-2 tape had almost no flange, it was crushed pretty badly. So then we'll show you what they did next. Before we actually tried to start and move it.

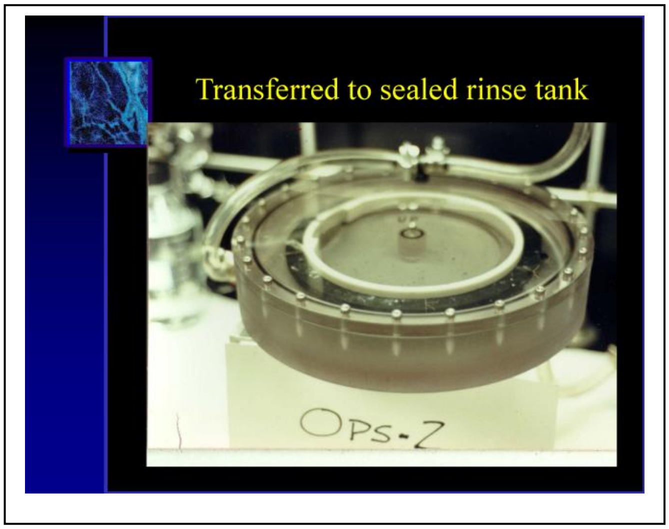
Now the hubs have been drilled out and milled to the tape kind of but we have not broken it off, and before we do that we don't want this tape, with no support, just falling off, so we would go through and, you see these arrows pointing to strings that were thread through these things where we milled it to, and we tied very loosely, to keep these tapes from falling apart when we tried to move them. So they were physically tied together before the hub was broken off, which is the next picture.

You see that what we've done is broken off the milled-out sections away, you see how much black material is still stuck to it? That's those inner wraps of tape which were sacrificial, luckily there's no data on them, in fact there was probably no data for 100 meters above that, but we didn't know that. So, what you're looking at now is the actual tape, without the flanges or the hub, and it's ready for treatment. Now the white stuff that you're seeing is where it was exposed and there's magnesium hydroxide, the places that were in contact with the magnesium hydroxide when we pulled it up, believe it or not, pulled some of that debris and stuff off with the flange. And there was magnesium and pieces of the tape edges on it, luckily there was no data near the edges of these tapes, these tapes were really wide margins thank God, because if they were modern tapes, we would have lost data.

Gardner: And the broken segments in the center?

Bradshaw: Are now removed, and now you'll see what we do with it, this is where that piece of wizardry in design of Clem Kalthoff paid off, what you see here is the Delrin flange, and a spring that we set inside, where we lifted the tape up. We actually did it the other way around, we let the tape inside about halfway down and then let this thing spring open very weakly, put the spring in it to keep some tension, it was very minimal tension, just enough to keep it open, and now we're ready to take it off this plastic. This is a ten-inch reel tape casing from a computer case that we use to move it into my lab. Now this is in my lab getting ready to put into the fixture. To treat it.

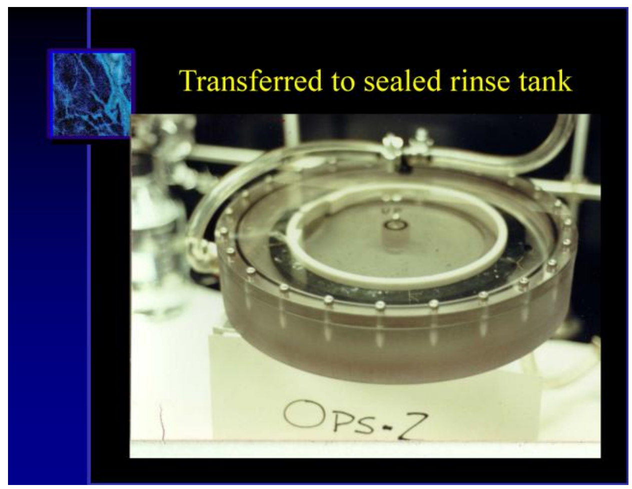
And what you're looking at now is the Delrin ring support of the tape inside the polycarbonate treating vessel, hooked up to the chemical rinsing apparatus and the sampling stuff, getting ready to do the treatment.



Again I want to show you, just to remind you what the tape looked like before we started.

This is what we got okay?

This is when it's getting ready to be treated, so we've already done quite a bit to get it ready. And now, what you're looking at in this particular picture.



Gardner: And so what we have here, the light circle is the Delrin ring?

Bradshaw: The Delrin, and the spring is the.

Gardner: The spring is there, and the black is now brown.

Bradshaw: Is the tape. Well it's actually brown when it dries out, you'll see another picture, it looks black when it's wet.

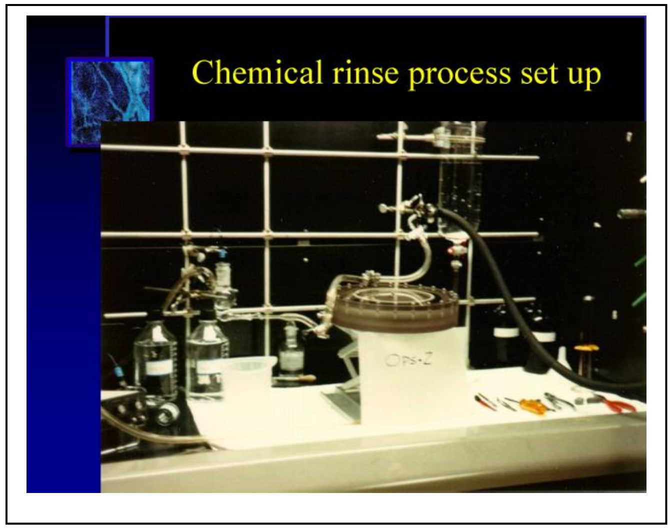
Gardner: And so this is the tape.

Bradshaw: The actual recorded data, correct.

Gardner: The process to clean up and lubricate.

Bradshaw: And right now it's in nitric acid, and that's why, you notice it doesn't look as white as it did as shown above when we first started, there was white material all over it. As soon as I hit it with nitric acid the stuff just sort of starts floating off. It doesn't all dissolve it just comes off. So this is the point where I'm watching it, and this particular tape by the way, because it had less mass than the Ops-1 or the payload tape, didn't take anywhere near as long to treat. Now I'm following all this stuff by ph, as soon as it starts to look like it's staying and sitting, it's not drifting, I'm done. Also, I'm taking this stuff off, drying it, weighing it, what am I getting off? How much is substrate, how much is coating? That's crucial.

Now I start hitting it with methanol to get the water off it. The methanol now is also taking out organics, so I flash-evaporate that, recover the methanol, dry it, also analyze everything I took off, what did I get off it? Well initially what I'm getting is a lot of lubricants, butyl stearates, and by the way, most of it's now hydrolyzed, it's no longer butyl stearate, it's butyl alcohol which is evaporated, and steric acid which is a wax. I also saw polyethylene crystals, phthalate crystals, polyethylene terephthalate. And I was seeing MDI and TDI, these are isocyanate components, a urethane binder that we use. I also saw pigment. So iron oxide pigment, the stuff that was being pulled out of the coating. So, this is what the apparatus looked like in my hood.

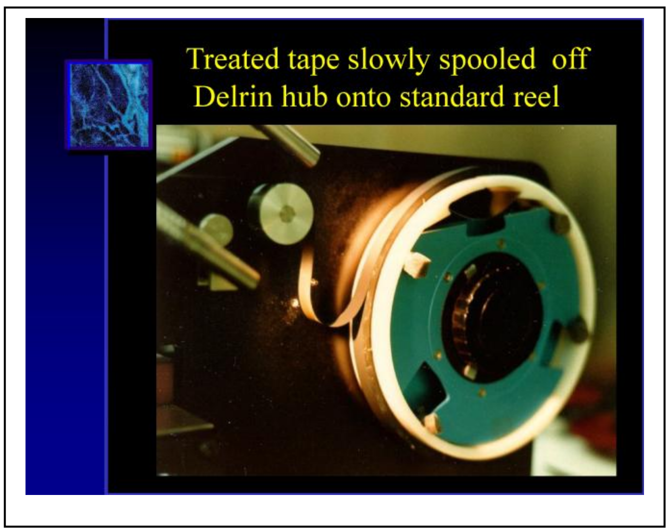


Now this is a photo op, not the actual thing we're working with, you'll notice nicely the tools are all laid out, this was a photo op. But, this is what my hood looked like, there was a ph tester, the treating solvents with the acid were added through the top, through a thing so I could monitor it. It's all run through, collected, and there was a place where I could collect all the rinses after I used it up, and there was another hood next door where I could evaporate, (distilling essentially) the solvents using an rotary evaporator and collect the residues and analyze it, and then back and forth, and you see bottles of acid, and there were brown bottles of methanol and brown bottles, the organics, you wanted to keep some of that. And the net of it was, we pulled it off.

This is what the tape looked like when it was removed from the vessel. Now one of the reasons, I'll just say this right now, or I didn't say, is the critical piece next was to reintroduce lubrication. In this case it's not just lubricant, I need to get the wraps so they can stick to each other. So I was telling you the story about the RSS. That particular fluorocarbon wetted, once it got any penetration, it would go in and push the layers apart, and you can see that we're successful, in fact we didn't even have to, they would literally fall off the hub, you can see that these things were starting to ripple. If we didn't have strings on it, it would have certainly just fallen right off the hub.

So now we take this, the tape is still very loose and can move around so the string's there, and we mount it into a homemade device that Dennis Byrne had built for another reason, an inspection fixture. In hindsight this reel is large because we had to do ten-inch reels, there's a microscope they had to look at the surface of the tape as it ran over a flat stage. This is what we did with that Delrin ring and the spring, we had it cut down, aluminum National Association of Broadcaster's standard half-inch reel, precision tape reel, that we cut down to allow us to mount the Delrin ring inside it, and we wedged it in with pieces of sponge from my lab that I just cut them in little wedges. So this is not tightly held, we can't, okay, and we're going to manually, and thank God Dennis built this thing so that we could turn the thing for the rheostat at any speed and tension we wanted, so we could do it very low tension, just enough to pull this across without, on rollers, and wind it onto another reel. And you see in here how it comes over, and we're letting a little loop come down. If that loop started to get tight we stopped, and we'd introduce a drop of the lubricant. Well it's not really a lubricant, let me put it this way, my contaminating fluorocarbon okay, and let it sit for a bit.

And what you can see this is actually a close-up, this is really instructive, first of all now you can see the true color, it's an oxide, it's brown. The sponges, the loose tolerances, and the fact that this was not perfect, there's white stuff still on this tape and the spots, and you can actually see, if you looked at it a little better picture, there are actually holes in some of the coating and some of the substrate, it pulled off. So there was magic that was done by Blair in getting things where there was no coating, where he would literally stop and go around it and reconstruct it, anyway. Very, a lot of wizardry and a lot of areas that made this work, but first thing you had to do it get the tape so we could unspool it, so that first, that was my part, was getting it apart, getting it cleaned up, re-lubing it so we could actually handle it. This is one of the things where it stuck and we put another drop of the RSS and let it sit in there, and the thing would just float off. So then we'd go on and get the next one. Now, once we got it on that, this spool was now wound onto another reel, and was re-tensioned and restacked, very slow speed but we're now restacking the whole thing, and in the process I also had a wipe station, that would wipe off this RSS, because we didn't need it anymore. So what we did is we wiped it with alcohol



to pull off as much as we could. Now admittedly the stuff that was stuck on the exposed oxide didn't come off, it just stayed, it was not, we didn't have to clean it, it wasn't worth it, we left it, but now it's little islands, it's not a continuous smear so we, and it wasn't going to transfer to the tape drive, so it worked. At least from what the guys doing the recording did, they told me it didn't contaminate their drive, I still had to go back and help them clean and make sure because, before you put any other tapes on.

Blair Finkelstein and Ray Kamens set up a Bell and Howell that was being used for experimental observation of development tapes, we were looking at all kinds of future products, metal, barium ferrites, all kinds of things, this is in the 80s before, you know, a lot of things had happened, but we were looking at everything. There was a Spin Physics head, a very narrow track MR reader, and a very narrow writer that we had. I believe the reader was like half the writer, it was like, the writer was somewhere around 100 microns, it's in the physics paper that we published at the Physics Society in Japan, Blair did the paper. And what it's doing here is you've got a drive where the raw tape, as we recovered it, is here, going up to a take-up reel, and the data's being copied to a virgin tape on the other side, an analogue tape, and I believe this particular tape was a Memorex tape okay? But, we then took all that stuff, digitized it, and put it on 3480, we put every tape that we recovered, all the data, on one cartridge. It took 50 feet, that's all. That's the difference in densities. And we did that so that they could reprocess it. If they needed to, and we got one pass and it gummed up and they got nothing, at least that original signal was captured digitally on something.

Gardner: I believe you said the reader was much narrower.

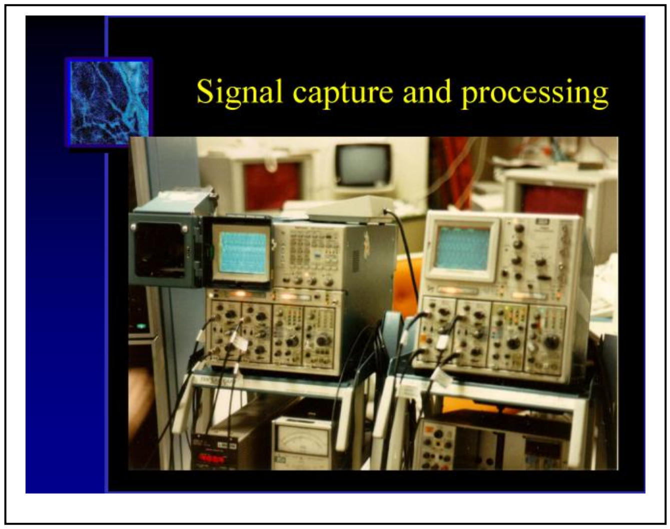
Bradshaw: Yes, it was an MR reader.

Gardner: And you needed multiple passes to span defects.

Bradshaw: Luckily, it turns out when we really got to, he flew, he said he couldn't believe it, he literally, for whatever reason he hit the track. Now admittedly, he was doing one track at a time, so this sounds a lot easier, think about it, one of them had five tracks, he had to do this five times. That's why we were worried, that, and by the way, we did clean this head. This thing was not perfect, we were getting debris collecting on the head and on the tape path. So this was labor-intensive, this was not something you'd want to sign up to do for the rest of your life and you'd have a career, but they did a great job.

Gardner: Did he search to find a continuous good track?

Bradshaw: What he would do is, when he got off it hit him. And by the way it's all digital, you're looking at this output, the analog from the pre-amp okay? And so he's got a pre-amp and let me show you, they have a picture and, Blair's still with IBM, he may have retired by now. Ph.D. in Optics, when I met him he had his Masters in Physics and he went on later with IBM. This is the two oscilloscopes, one is looking at the raw signal out of the pre-amp of the tape, and the other one is the one that's going to the writer, so it's been filtered, pre-amped, this is the raw data, you can see how noisy it is, this is the one that's cleaned up. Show you, there was a lot of wizardry going on and another component on this electronically, these guys had state-of-the-art things they were using. Admittedly the oscilloscopes were crude, but the stuff that's happening before it gets to there is really, the back of that Bell and Howell is nothing that Bell and Howell ever made okay? It was all custom-built stuff, pre-amps, cards and stuff. Really amazing job. And what they could do is, he didn't know where he was, so you can't rely on tachometers because this tape is useless, so he was literally writing a pattern on this thing so he could know where he was, and he was reading that while he redid, tried to, and then he would index the head to another track and do it all over again. So this was, there was a lot of labor, luckily it turns out it was a minute, so I think, this thing was not a high-speed transport, 'cause remember it was going to record days worth of data on this thing as the Challenger, the flight recorder, so it did not move very quickly. I believe it was 15 to 20 meters was actually the data we needed.



Gardner: So let me make sure I understand, he actually wrote a reference track in an unused area.

Bradshaw: That's correct.

Gardner: So that he could then use the reference track for position.

Bradshaw: And he had to write more than one. Some of the tapes were not that bad, so he was able to get away with this fairly easy, but this one, it was really in bad shape, and this is the one they needed so, we spent a lot of time, it took me less time to do the treatment, but it took him longer to look, but the thing is there wasn't that much signal on this tape, it was relatively short, the thing was turned on after launch.

Gardner: What was the density?

Bradshaw: I don't know, I really don't remember. But it was kilobits, it was very low, very low track and areal density. I'll bet you it was in the kilobits per square inch.

Gardner: Were there two types of channels being recorded, some digital and some analog?

Bradshaw: My understanding is most were analog. Blair is around and if you need to we can get him, he might be a guy you want to interview for their museum, to get a better detail on the signal recovery, 'cause my end of this was pretty much the chemistry and getting it apart.

Gardner: But based upon what you've told me and my understanding, weak as it is, is that in analog signal processing you just filtered it, cleaned it up and wrote the analog signal back to tape.

Bradshaw: That's correct. But then you also, because we were afraid, my understanding is all the analog stuff that he processed was also digitized, and written to a complete digital copy of everything, and that was on a 3480 cartridge.

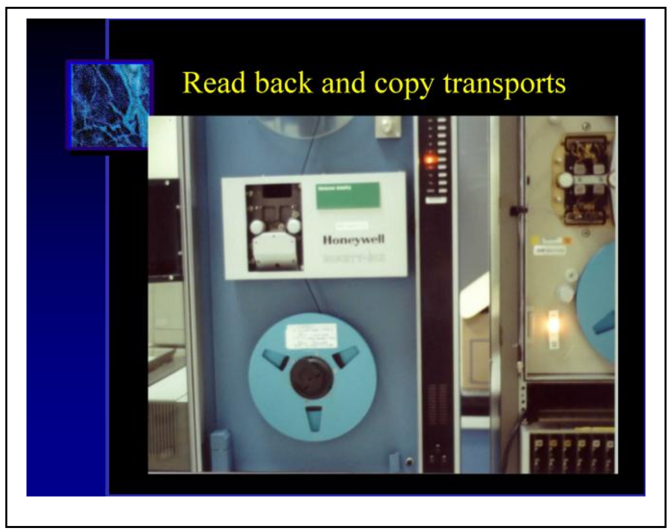
Gardner: Yeah and that's another question, so the digital stuff was digitally, since basically at the pre-amplifier level it's all analog anyhow.

Bradshaw: That's correct. Then it was converted to digital, it was encoded.

Gardner: Re-digitized, then rewritten as digital.

Bradshaw: In a 3480 format.

Gardner: So where did you record the analog signal?



Bradshaw: The analog, if you notice on the recorder that I showed you in the, here, on this picture, there were two instrumentation drives, two Bell and Howells okay? That was a Honeywell, there's a Bell and Howell and also there's a Bell and Howell, anyway. The reason for the Honeywell was the stage that was built so we could put very sensitive and laterally adjustable, moveable head, we could move it around, the other one was fixed okay? So in other words, Honeywell is the one we did the experimental stuff on, Bell and Howell is the one we copied to a standard format instrumentation drive okay? So it was a Bell and Howell format tape that the analog was filtered to the pre-amp, and written to that tape.

Gardner: In analog form on that.

Bradshaw: Exactly.

Gardner: So then it was also AD converted and what you have now is a digital file.

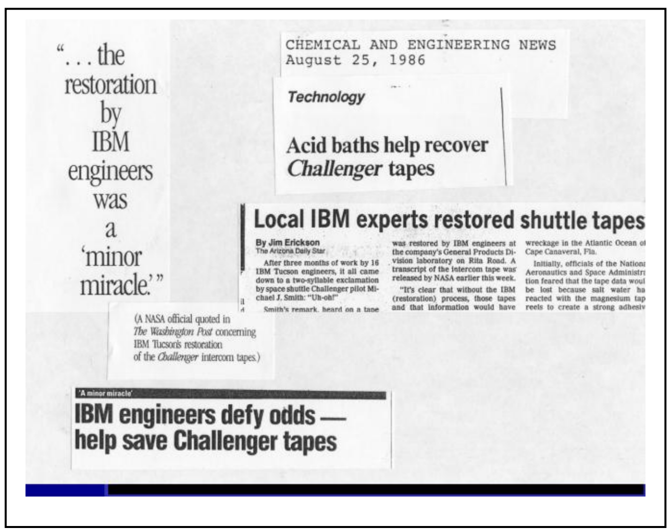
Bradshaw: That's correct.

Gardner: Or a digital audio file.

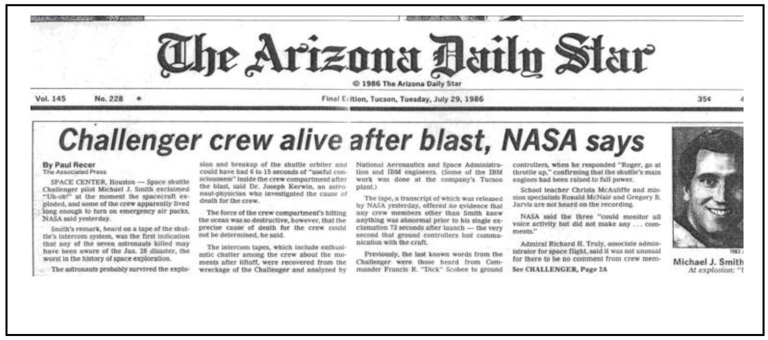
Bradshaw: That was because we were afraid, and Blair was correct, there was a couple of instances where literally it went to zero, we got no signal. So now he says, whoops. Now we either give up and say we lost it, and again, we still don't know whether this is vital data, whether it's noise before launch, all we knew is we're going to catch everything we can off of this tape, if we can't find it we're done you know, but. So what he would do is he would then scoot over, and see if he could find more of that same track somewhere else, and I think, and maybe he'll tell you that, it came out, and by the way we just took what we got, wrote these, and by the way the tape that was recovered, as well as the copy, as well, was all given to NASA, we don't have any of it, this was evidence, and there was a guy standing there watching us, so this stuff was never out of his sight, 'cause they wanted to make sure that this couldn't be substituted, fraud, and this guy had to swear to somebody at a court of law, that this was the tape that I gave him, this was, so, anyway, it was all legal. We didn't know, all we knew was the data, when he got done, Blair came out of his thing and said, whatever was on that tape I got it all. Now there was a couple of times that he and Ray, and by the way, these are long hours of processing, it took us six to eight days, but that's still 24 hours in a day essentially that we worked on this stuff.

Gardner: And as exempt employees you got no overtime.

Bradshaw: No, but believe me, we were so happy when we pulled it off that we went and paid our own coffee and stuff, and the techs that did it we paid for their stuff. We were not given any compensation by IBM although, I mean we didn't expect it okay? That wasn't the issue. We learned a lot and they got a lot of press for this, and it was a success, we were, and by the way, when we sent it back we didn't hear anything, then the next thing we know, we come in the morning one day, and a guy calls us from the press office of IBM, and says have you seen the papers? Ray said, yeah. There were all these things in Tucson and it hit the national media and it was in, 'cause obviously it was a success story, and this was about us, and then what came out



months later was the "Arizona Daily Star" headline that we've recovered it. And, at the time, we got very little information directly back from NASA, it was all filtered through the press releases and stuff, it wasn't until just a few years ago when I was at the Johnson Space Center, that I heard the rest of the story from the people there.



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Challenger crew alive after blast, NASA says

By Paul Recer
The Associated Press

SPACE CENTER, Houston — Space shuttle Challenger pilot Michael J. Smith exclaimed "Uh-oh!" at the moment the spacecraft exploded, and some of the crew apparently lived long enough to turn on emergency air packs, NASA said yesterday.

Smith's remark, heard on a tape of the shuttle's intercom system, was the first indication that any of the seven astronauts killed may have been aware of the Jan. 28 disaster, the worst in the history of space exploration.

The astronauts probably survived the explosion and breakup of the shuttle orbiter and could have had 6 to 15 seconds of "useful consciousness" inside the crew compartment after the blast, said Dr. Joseph Kerwin, an astronaut-physician who investigated the cause of death for the crew.

The force of the crew compartment's hitting the ocean was so destructive, however, that the precise cause of death for the crew could not be determined, he said.

The intercom tapes, which include enthusiastic chatter among the crew about the moments after liftoff, were recovered from the wreckage of the Challenger and analyzed by National Aeronautics and Space Administration and IBM engineers. (Some of the IBM work was done at the company's Tucson plant.)

The tape, a transcript of which was released by NASA yesterday, offered no evidence that any crew members other than Smith knew anything was abnormal prior to his single exclamation 73 seconds after launch — the very second that ground controllers lost communication with the craft.

Previously, the last known words from the Challenger were those heard from Commander Francis R. "Dick" Scobee to ground controllers, when he responded "Roger, go at throttle up," confirming that the shuttle's main engines had been raised to full power.

School teacher Christa McAuliffe and mission specialists Ronald McNair and Gregory B. Jarvis are not heard on the recording.

NASA said the three "could monitor all voice activity but did not make any . . . comments."

Admiral Richard H. Truly, associate administrator for space flight, said it was not unusual for there to be no comment from crew mem-

See CHALLENGER, Page 2A

Michael J. Smith
At explosion: "

And I have the full papers, they're in a file, I've got all the things, and interestingly, the interviews were never done with Clem, myself or Ed Bartkus. Ed did have his name in one of them where he's bent over holding on to the wrong end of the petcock. The people interviewed didn't do any of it. Which is fine. The only thing that irritated me really was how many people tried to take credit for the thing that didn't have anything to do with it and actually were an impediment so, which is unfortunately something that we live with. But, we're very proud of what the effort was.

Another detail that came out was that the professional astronauts were unconscious but alive when the thing hit, actually completely blew up, but the passengers, the non-professionals, because of their limited training never switched over to an internal air supply when the cabin started to vent. So they probably went out quickly, very, very quickly because of the loss of oxygen and pressure, whereas the others were unconscious probably from the explosion but were alive. So that's the sad part of it. Of course the whole thing's sad, that it happened at all.

The team that really did the work is, I'm proud to say that I was one of them, but without Ed Bartkus' SEM work and his obvious interest in unwinding, he spent hours unwinding this stuff, Clem Kalthoff, the design and the parts and the model shop that he helped, his interacts with the model shop was what drove this stuff, and these guys were obviously world-class machinists that did this work, I mean just turned it around and it was precision. They're the ones I bought dinner for by the way. And Clem, senior engineer too, he took them out a week later and gave them more dinner because, remember, we asked them to do this three times, so every time they did it and succeeded we went down and told them thank you, especially Ops-1 which was the one with all that machine work was done. Ops-2 really didn't do much, they didn't do anything actually.

Gardner: Well, they made the fixtures.

Bradshaw: Yeah but they didn't have to machine it and stuff. But the work they did on that Ops-1, because we did that before we did Ops-2, we learned a great deal about the handling of the final tape, that's what was really crucial, without them giving us extra, a lot of tape to work with, that would have been more trial and error. In the original files that are in our thing we're going to surrender to NASA, now that IBM has released the documents, they were all in IBM storage now for what, 30 years. IBM has all of the actual logs of how much I added and what was extracted and stuff, so it's quite interesting. And I was looking at it the other day, getting ready to do this, jogging the old memory bank of things that we did and how lucky we were in some ways, but the thing is, we thought about this in a quick meeting in Clem's office just after that first meet and nothing else changed after that, everything we planned worked, except for the lube thing which was trial and error. But when we finally gave up and put that RSS in it, that was a breakthrough, from the chemical standpoint. And then Blair's work on capturing the signal was not trivial at all. But like Blair would tell you, if you wouldn't have gotten the tape apart so I could run it, it wouldn't have mattered what we did. So the first thing was getting it so we could even read and write it, and saving it so we didn't tear it up in the process. The re-lubing step was blind-ass luck in a lot of ways, we just had the right material to do it. And we didn't have a lot of time to screw with it either, we tried four different compounds, and the one that I tried dead last was the thing that worked, and that's what we used. I did not make more of it, the little bit I had left was given to another recovery effort that was never published and will never be published. So there is none anymore, I mean I don't even think my notebook survived. You know how that goes, in IBM you turn them over to patent, especially if you can file a patent, and there were patentable things in there that were turned over, so the notebook is gone. I had another notebook that I used later and that's gone, I mean I don't have any of this, it's all IBM property and so it's all locked up someplace. And, but it was a great effort and I was very proud to be a member of the team that did it.

Gardner: I think it's an incredible example of serendipity to the benefit of the American public, that this small team was here in Tucson and got handed a task that everybody else said was impossible.

Bradshaw: Yeah, one thing about the management at IBM, don't tell them it can't be done. Quite honestly I think we had the best team of people, we occasionally went through some real jerks that we had to put up with, but luckily, at critical times, we had great managers. So, I mean at critical times in our careers, we had people with vision, and that trusted us. And by the way, they put us in line, don't lie to me, tell me what's happening. Joel did it to me many times. People would ask for the truth and you'd tell them, sometimes they'd get upset and they'd go after you, but you stuck to your guns.

Gardner: I think that is IBM's story. I've never worked there but I have worked with so many people who have a similar story.

Bradshaw: Power team. Unbelievable, it's a shame, it's a loss.

Gardner: And again, thank you from the Computer History Museum, this is Tom Gardner speaking for the Computer History Museum. Ric mentioned Joel, that's Joel Levine who's the gracious host at the West Press facility in Tucson, Arizona, and again, Ric to you and these three guys that you work with, my personal thanks for a great story, and if I can speak for the rest of the American community, thank you guys for what you did.

Bradshaw: Thank you.

END OF INTERVIEW

Editor's process notes:

1. Draft copy sent to Ric Bradshaw on August 25, 2016 as: 102738025-05-01_IBM_Tape5_Challenger_Ver2_TEG.docx.
2. Teleconferences on December 3 & 5, 2016 to review changes proposed by editor, resultant draft: 102738025-05-01_IBM_Tape5_Challenger_Final1.docx, dated 12/19/2016, sent to Bradshaw on 12/19/2016
3. Final edit on January 13, 2017 based upon feedback from Bradshaw in 102738025-05-01_IBM_Tape5_Challenger_Final1.rlbedit.doc, dated 1/7/2017.

4. Subsequent changes:
    a. Changed session name from “Recover of Data on Tapes Recovered from the Challenger Shuttle Disaster” to “”IBM Tape History – Session 5: Recovery of tapes damaged in Challenger disaster
    b. Changed associated session file name from “102738025-05-01_Challenger …” to “102738025-05-01_IBM_Tape5_Challenger …”
    c. Changed associated video file name from “Challenger_FINAL.mp4” to “IBM_Tape5_Challenger_FINAL_Part2.mp4”
    d. Moved Appendix 1 into session
    e. Revised introduction
5. Memorabilia offered by interviewees and accepted into the museum's permanent collection have CHM Lot Number's X7617.2016, X7620.2016, X7677.2016, X7678.2016 and X8091.2017.

6. All unknown or uncertain names, dates, places, products and other facts were verified to the extent possible. A collection of more than 100 pdf documents collected in conjunction with editing this transcript was provided to CHM as Incoming Receipt A2017.5820.