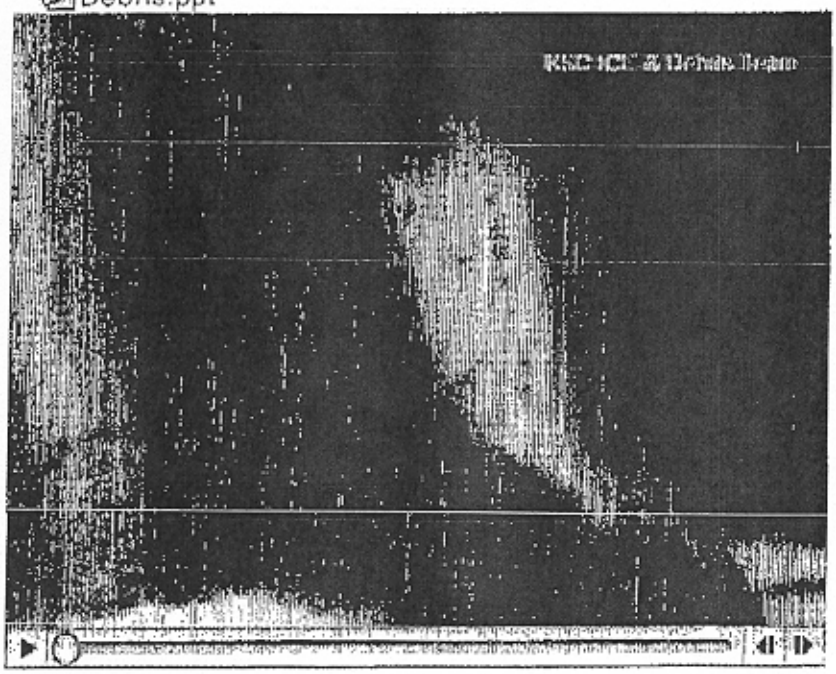
X-Sender: r.h.daugherty@pop.larc.nasa.gov
Date: Tue, 28 Jan 2003 14:15:27 -0500
To: "SHUART, MARK J" <M.J.SHUART@larc.nasa.gov>
From: "Robert H. Daugherty" <r.h.daugherty@larc.nasa.gov>
Subject: Foam and Tile
Cc: H.M.ADELMAN@larc.nasa.gov

Mark...attached are two files that I've received regarding the concern about ET foam around the orbiter bipod support coming off and possibly damaging tiles ... perhaps around the main gear doors. So far, our involvement has been one of providing the current model of drag associated with landing with two tires flat prior to touchdown and some thought exercises of what might happen if the wheel well were burned into....something that is arguably very unlikely. Interestingly, in the powerpoint pitch, they talk about a test in which the "crater" caused by an impact test dug out 3 cubic inches of tile. They say their estimated "flight condition" is 1920 cubic inches of "crater". Hopefully I'm reading that wrong, but as they say...that is way outside their test database. No official request has been made upon us at this time. And there is no formal simulation going on as far as I know regarding landing with two tires flat prior to touchdown...its just a coincidence that landing with ONE tire flat is being simulated right now at the Ames VMS in astronaut training where they are using our newest load-persistence model so it is a very convenient time to look at two tires flat if they can squeeze it in. Will keep you informed as I hear more...if I do.
Bob

Debris.ppt



E212.mpg

To: r.m.martin-larc.nasa.gov, d.l.dwoyer
From: "Mark J. Shuart" <m.j.shuart@pop.larc.nasa.gov>
Subject: Fwd: Foam and Tile
Cc:
Bcc:
X-Attachments: Debris.ppt E212.mpg

Ruth, Doug,

I am sending this to both of you since Doug is off-site and I thought the OD ought to know. Also, I am advised that the fact that this incident occurred is not being widely discussed. I'll keep you informed if we get more calls.....Mark

Date: Tue, 28 Jan 2003 14:15:27 -0500
To: "SHUART, MARK J" <M.J.SHUART@larc.nasa.gov>
From: "Robert H. Daugherty" <r.h.daugherty@larc.nasa.gov>
Subject: Foam and Tile
Cc: H.M.ADELMAN@larc.nasa.gov

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Bob

To: d.l.dwoyer, r.m.martin
From: "Mark J. Shuart" <m.j.shuart@pop.larc.nasa.gov>
Subject: Fwd: Tile Damage Update
Cc:
Bcc:
X-Attachments:

Doug, Ruth,

The latest info on the Shuttle is below. It will be interesting to see the extent of the damage after landing on Saturday.....Mark

> Date: Wed, 29 Jan 2003 15:51:28 -0500
> To: "SHUART, MARK J" <M.J.SHUART@larc.nasa.gov>
> From: "Robert H. Daugherty" <r.h.daugherty@larc.nasa.gov>
> Subject: Tile Damage Update
> Cc: H.M.ADELMAN@larc.nasa.gov
>
> Hi Mark,
> Nothing terribly new but a few things talked about today with some folks at the Ames VMS. Apparently the current "official" estimate of damage is 7 inches by 30 inches by half the depth of the tiles down to the densified level. One of the bigger concerns is that the "gouge" may cross the main gear door thermal barrier and permit a breach there. No way to know of course. A JSC colleague and I talked to the sim guys and are urging them to simulate a landing with two tires flat prior to touchdown...it is as simple as hitting a software button and simply doing it...but since no Orbiter Program Management is "directing" the sim community to do this it might need to get done "at night". An anecdote they told us is that this was already done by mistake this week and the commander lost control of the vehicle during our load-persistence simulations. It seems that if Mission Operations were to see both tire pressure indicators go to zero during entry, they would sure as hell want to know whether they should land gear up, try to deploy the gear, or go bailout...we can't imagine why getting information is being treated like the plague. Apparently the thermal folks have used words like they think things are "survivable", but "marginal".
> I imagine this is the last we will hear of this.
> Take care,
> Bob

To: d.l.dwoyer
From: "Mark J. Shuart" <m.j.shuart@pop.larc.nasa.gov>
Subject: Fwd: RE: Main Gear Breach Concerns
Cc:
Bcc:
X-Attachments:

Doug,

Here's the latest from JSC on the damage to the orbiter tiles. Looks like they believe all has been addressed.....Mark

From: "LECHNER, DAVID F. (JSC-DF52) (USA)" <david.f.lechner1@jsc.nasa.gov>
To: "'Robert H. Daugherty'" <r.h.daugherty@larc.nasa.gov>
Cc: M.J.SHUART@larc.nasa.gov, H.M.ADELMAN@larc.nasa.gov,
"CAMPBELL, CARLISLE C., JR (JSC-ES2) (NASA)"
<carlisle.c.campbell@nasa.gov>
Subject: RE: Main Gear Breach Concerns
Date: Fri, 31 Jan 2003 12:17:34 -0600

Bob,

I really appreciate the candid remarks. As always your points have generated extremely valuable discussion in our group. Thank you. We have been discussing and continue to discuss the all possible scenarios, signatures and decisions. Your input is beneficial. Like everyone, we hope that the debris impact analysis is correct and all this discussion is mute.

David F-M Lechner
Space Shuttle Mechanical Systems
Mechanical, Maintenance, Arm & Crew Systems (MMACS)
United Space Alliance, Johnson Space Center
(281) 483-1685

-----Original Message-----
From: Robert H. Daugherty [mailto:r.h.daugherty@larc.nasa.gov]
Sent: Thursday, January 30, 2003 5:23 PM
To: LECHNER, DAVID F. (JSC-DF52) (USA)
Cc: M.J.SHUART@larc.nasa.gov; H.M.ADELMAN@larc.nasa.gov; CAMPBELL, CARLISLE C., JR (JSC-ES2) (NASA)
Subject: Main Gear Breach Concerns

Hi David,
I talked to Carlisle a bit ago and he let me know you guys at MOD were getting into the loop on the tile damage issue. I'm writing this email not really in an official capacity but since we've worked together so many times I feel like I can say pretty much anything to you. And before I begin I would offer that I am admittedly erring way on the side of absolute worst-case scenarios and I don't really believe things are as bad as I'm getting ready to make them out. But I certainly believe that to not be ready for a gut-wrenching decision after seeing instrumentation in the wheel well not be there after entry is irresponsible. One of my personal theories is that you should seriously consider the possibility of the gear

not deploying at all if there is a substantial breach of the wheel well. The reason might be that as the temps increase, the wheel (aluminum) will lose material properties as it heats up and the tire pressure will increase. At some point the wheel could fail and send debris everywhere. While it is true there are thermal fuses in the wheel, if the rate of heating is high enough, since the tire is such a good insulator, the wheel may degrade in strength enough to let go far below the 1100 psi or so that the tire normally bursts at. It seems to me that with that much carnage in the wheel well, something could get screwed up enough to prevent deployment and then you are in a world of hurt. The following are scenarios that might be possible...and since there are so many of them, these are offered just to make sure that some things don't slip thru the cracks...I suspect many or all of these have been gone over by you guys already:

1. People talk about landing with two flat tires...I did too until this came up. If both tires blew up in the wheel well (not talking thermal fuse and venting but explosive decomp due to tire and/or wheel failure) the overpressure in the wheel well will be in the 40 + psi range. The resulting loads on the gear door (a quarter million lbs) would almost certainly blow the door off the hinges or at least send it out into the slip stream...catastrophic. Even if you could survive the heating, would the gear now deploy? And/or also, could you even reach the runway with this kind of drag?
2. The explosive bungies...what might be the possibility of these firing due to excessive heating? If they fired, would they send the gear door and/or the gear into the slipstream?
3. What might excessive heating do to all kinds of other hardware in the wheel well...the hydraulic fluid, uplocks, etc? Are there vulnerable hardware items that might prevent deployment?
4. If the gear didn't deploy (and you would have to consider this before making the commitment to gear deploy on final) what would happen control-wise if the other gear is down and one is up? (I think Howard Law and his community will tell you you're finished)
5. Do you belly land? Without any other planning you will have already committed to KSC. And what will happen during derotation in a gear up landing (trying to stay away from an asymmetric gear situation for example) since you will be hitting the aft end body flap and wings and pitching down extremely fast a la the old X-15 landings? My guess is you would have an extremely large vertical decel situation up in the nose for the crew. While directional control would be afforded in some part by the drag chute...do you want to count on that to keep you out of the moat?
6. If a belly landing is unacceptable, ditching/bailout might be next on the list. Not a good day.
7. Assuming you can get to the runway with the gear deployed but with two flat tires, can the commander control the vehicle both in pitch and lateral directions? One concern is excessive drag (0.2 g's) during TD throughout the entire saddle region making the derotation uncontrollable due to saturated elevons...resulting in nose gear failure? The addition of crosswinds would make lateral control a tough thing too. Simulating this, because it is so ridiculously easy to do (sims going on this very minute at AMES with load-persistence) seems like a real no-brainer.

Admittedly this is over the top in many ways but this is a pretty bad time to get surprised and have to make decisions in the last 20 minutes. You can count on us to provide any support you think you need.

Best Regards,
Bob

X-Sender: d.m.bushnell@express.larc.nasa.gov
Date: Wed, 5 Feb 2003 09:03:38 -0500
To: d.l.dwoyer@larc.nasa.gov, d.c.freeman@larc.nasa.gov,
c.m.darden@larc.nasa.gov, c.e.harris@larc.nasa.gov,
r.m.martin@larc.nasa.gov, a.kumar@larc.nasa.gov,
m.p.saunders@larc.nasa.gov, j.m.mckenzie@larc.nasa.gov,
m.j.shuart@larc.nasa.gov, g.r.taylor@larc.nasa.gov
From: "Dennis m. Bushnell" <d.m.bushnell@larc.nasa.gov>
Subject: Shuttle Heating/TPS

Was on Travel - Just returned,reason this was not sent earlier...[called Doug on this Sunday around noon].Maybe "you'all" already know this...

1.Undersigned was on the Walt Williams/NASA Chief Engineer Shuttle First Flight Certification team in 1980/81 Responsible for Boundary Layer Transition/TPS/Re-entry Heating.The report we [John Bertin and I] sent in indicated the Following:

- Peak Heating is at some 218 Kft.IF the flow is turbulent at Peak heating the heat shield would/could burn through the wheel well doors [even with undamaged tiles].

- Transition data from previous flights [Prime,Asset,etc.] indicated Transition Reynolds Numbers at Shuttle Hypersonic Conditions on admittedly rough surfaces well below a Million Reynolds Number but the data were all over the map.Taking the lower bound [with a rough surface] Turbulent flow at peak heating appeared possible....We therefore specified tile-to-tile and tile gap smoothness criteria which were pretty severe.

- As I recall the observed shuttle transition is usually around 180Kft.

2.On the first flight there were thousands of dings/gouges in the tiles post

flight which were almost all on the left wing and traced to ice impingement from launch vibrations dislodgment of the ice which builds up on the external tank dump line - WHICH IS LOCATED IN PROXIMITY TO THE LEFT WING ON THE STACK [Dump line is attached to the tank but runs down the side of the tank near where the windward side of the left wing is positioned when mated to the tank in the launch stack].Why this dump line was not repositioned to the other side of the tank away from the orbiter I do not understand....Over the years each flight has experienced a unique set of heat shield damage from this ice impingement and as a consequence shuttle transition varies mightily flight-to-flight.Several times this damage was quite severe.

3.All of this [1 above] is for undamaged [in the sense of thermal protection, not transition/roughness] tiles.More extensive tile damage,whether from external tank insulation or ice impingement,would obviously add insult to injury and compromise TPS integrity AS WELL AS ACT AS A BOUNDARY LAYER TRIP.IF the gouges were extensive enough then free shear layers form which have VERY LOW TRANSITION REYNOLDS NUMBERS [below a hundred thousand] AND large Impingement HEATING PEAKS.

We [the agency] should have done more analysis of this whole situation/taken it more seriously as well as repositioned that tank dump line to minimize ice impingement....The ice buildup/fracture patterns/subsequent impact patterns/effects due to launch vibration/loads is not deterministic.Just the ice,sans tank insulation,could conceivably have caused "Grievous Harm"...

Dennis Bushnell

From: [redacted]
Subject: Columbia Video - Launch Debris Observations
To: Cindy Lee <C.C.LEE@larc.nasa.gov>

Hi Cindy,

I would like to offer several observations regarding the theory that debris damaged Columbia's left wing during launch on January 16, 2003. I would like to be able to discuss these ideas during an appropriate Columbia accident investigation meeting here at LaRC.

1. The video footage (apparently provided by the KSC Ice & Debris Team) appears to show that the debris, assumed to be polyisocyanurate foam from the external tank (ET), may not have originated from the ET. In the first few frames of the video sequence, the debris appears to come from a location obscured by the orbiter and ricochets off the ET. The origin of debris still could be from the ET, or possibly the underside of the orbiter. After contacting the ET, the debris fragments into two visible pieces. The first, apparently smaller, debris fragment produces a small shower of particles that can be seen at the trailing edge of the left wing. The second, larger piece of debris appears to result in a much larger impact on the trailing edge of the left wing. The debris may have been made of ice or some other material(s) and could be much more massive than the calculated 1.211 kg (2.67 lb.). If the photogrammetric measurements accurately measured the debris to be 0.508 x 0.406 x 0.452 meters (20 x 16 x 6 inches), and it was made of solid ice, the mass could be approximately 28.7 kg (63.4 lb). The energy released from this impact could be almost 25 times greater than estimated. Other dense materials, such as aluminum, would make this impact even more damaging. I would like to suggest a re-examination of the debris impact video footage to determine if the fragment(s) could have originated from another location, possibly an ice buildup somewhere under the orbiter. As a reference, if the debris was 1.211 kg. and assuming a conservative relative impact velocity of 457.2 m/s (2 x 750 fps used in the JSC analysis), the kinetic energy would have equivalent to a 500 lb safe impacting at 75 mph. If the debris was 28.7 kg, that would be the equivalent of a 500 lb safe hitting the wing at 365 mph.

2. If the observation in #1 above can proven to be incorrect, and it can be definitively determined that the debris was foam insulation from the ET, there still appears to be an issue regarding its thickness. It has been estimated that the debris was 0.152 meters (6 inches) thick. Several sources that I have found indicate that the insulation is sprayed on the ET to a thickness of 1-2 inches. It is certainly possible that certain locations on the ET may have insulation that is 6 inches in depth, but how thick was the insulation at the point where it is believed to have separated? How accurately is this location known? I assumed that the volume of ET insulation can be approximated by a thin walled cylindrical body with flat, circular plates on each end. I assumed that the ET was 46.8 meters (153.8 ft) in length, 8.412 meter (27.6 ft) in diameter. I used a density of 38.63 kg/m^3 (calculated from the mass and size of the foam debris assumed in #1 above).

Using a uniform thickness of 0.152 meters (6 inches), I estimate the total mass of the insulation to be 8080 kg (17,813 lb). This is 3.7 times greater than the 2187 kg (4823 lb) that is stated on the NASA Human Space Flight Shuttle Reference web page. A 0.0254 meter (1 inch) thickness results in a total mass of 1328 kg (2928 lb), and a 0.0508 meter (2 inch) thickness results in a total mass of 2664 kg (5873 lb). These totals are consistent with a thickness of 1-2 inches. It is possible that the numbers stated on the Space Flight web page are not very accurate, but I would not expect them to be that much off. I have not heard any discussion about variations in the insulation thickness, and I would like to understand how certain we can be that the debris was entirely made of foam.

3. Even if the damage to the tiles was not obviously visible, could this type of impact carve out a significant channel in the protective tiles? This channel

would then allow extreme heating to occur down the length of the wing. How many re-entries had the tiles in the area of the suspected damage been through? Is it possible that this area could have had "older" tiles that could be more easily loosened from the wing during impact, but only separated during re-entry or later during ascent? Could the impact result in a significant increase in the surface roughness of the tiles around the impact area, and could this result in a high turbulent heating that caused tiles to be shed during re-entry? Finally, it is reasonable that the impact could have multiple effects on the orbiter, such as damage to control surfaces.

Thanks very much for your attention to these observations. I hope that they are helpful in the investigation of this terrible loss for the astronauts and their families, NASA, and our country.

Dan

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Daniel D. Mazanek

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