NASA, Space Portal and Daniel Rasky

Steve Taranovich - June 29, 2013

This article outlines a group discussion with Daniel Rasky, spurred on by the NASA Technology Exchange program aligned with the Speed2Design campaign sponsored by Littelfuse.

I am a space junkie. I knew that I wanted to be in electronics when I saw the first Mercury capsule launched and watched TV that whole day as Walter Cronkite covered the story from every scientific angle. I was hooked. That’s why I am excited to be invited to speak to NASA experts and bring their expertise to you as it relates to Power management and Analog design.

Who is Daniel Rasky?

Dan Rasky is the director and co-founder of the Space Portal, which has had a significant role in establishing several notable and successful NASA programs, including the Commercial Orbital Transportation Systems (COTS) program, the Innovative Lunar Demonstration Data (ILDD) program, and the Commercial Reusable Suborbital Research (CRuSR) program. He is recognized as an expert on advanced entry systems and thermal protection materials. In the 1990s, he and his research colleagues at NASA Ames invented a heat-shield material called Phenolic Impregnated Carbon Ablator (PICA).

In 2009, Rasky completed a one-year Interagency Personnel Assignment (IPA) with the Space Grant Education and Enterprise Institute, serving as a senior research Fellow supporting emerging space companies. One of these companies was Space Exploration Technologies Corp. (better known as SpaceX). In 2010, the Falcon-9 rocket carried the Dragon capsule with its SpaceX fabricated PICA-X heat shield into space. Rasky has made significant contributions to flight hardware for eight NASA missions, including the Stardust comet sample return mission. PICA will also be used for the primary heat-shield for the upcoming Mars Science Laboratory (MSL) lander mission.
Rasky has received the Senior Professional Meritorious Presidential Rank Award, the NASA Inventor of the Year Award, the NASA Exceptional Achievement Award, the NASA Exceptional Service Medal, 12 NASA Group Awards, and eight Space Act Awards. He has six patents, 64 publications, and is an associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA) and a senior member of the American Society of Mechanical Engineers (ASME).

**PICA heat shield**

Rasky had been a key part of the PICA-X carbon tile, without which there would have been no Mars Curiosity on Mars in 2013.

I was curious about the applications of such a material in electronics or semiconductor processes such as a heat shielding material that might be used in conjunction with a heat sink in high temperature areas. I asked Rasky if such an application has been found. Rasky replied that, yes, the one for electronics is a cousin to PICA called SIRCA, that is, Silicone Impregnated Resuable Ceramic Ablator. It’s a silica-based tile with silicone impregnation. It’s RF transparent and non-conductive, so unlike the carbon-fiber PICA material, it would not conduct electricity or block RF signals. The SIRCA material would be good around antennas in that it would not interfere with the RF transmission/reception.

Rasky continued, “So SIRCA is a sort of ‘sibling’ to PICA. They were developed as a family of what’s called a lightweight ceramic ablator that started with ceramic substrates. So you could use a silica substrate or a carbon substrate and then add in a polymer impregnant that you can add in. In effect, you add silicone into the silica substrate and get SIRCA; you add phenolic to the carbon substrate and get PICA.

The family was developed so that you could alter both the ceramic substrate material and the polymer impregnant. You could optimize the material for whatever application you had in mind.”

“It turns out that PICA had a higher heat ablative performance which was of interest to SpaceX, but they also use a variant of SIRCA on the back shell which they call XIRCA, a flexible silica blanket that has silicone impregnation”, Rasky told us. SpaceX developed PICA-X, a version of NASA’s PICA, to protect the Dragon spacecraft on its return to Earth.
A sample of PICA-X heat shield material subjected to temperatures of up to 1850 degrees Celsius (3360 degrees Fahrenheit), at the Arc Jet Complex at NASA Ames Research Center, Moffett Field, California. The NASA-originated PICA material holds the record for high-speed reentry into the Earth's atmosphere. The SpaceX-developed and manufactured PICA-X variants meet or exceed the performance of the original material, to protect the Dragon spacecraft on its return to Earth. (Image courtesy of SpaceX)

“The real innovation”, Rasky said, “was how to put in a polymer at low density into a largely air void material.” Both the substrates for SIRCA and PICA are 80% to 90% void with only 10% to 20% fiber volume making pretty much an open void. This is how the density is kept low and thus the weight is also low. The innovation came in when they found out how to impregnate uniformly into this type of void structure and not fill it up with the impregnating material which would make it quite heavy—not good for exiting the Earth’s atmosphere or for efficient space travel.

Chemists at work

Their chemists were able to work out an approach to essentially “paint” the fibers with a polymer. You could dial in the density of polymer desired to impregnate the ceramic substrate. Rasky said, “There are two big knobs, the substrate that you're using and to what density and the other big knob is what polymer that you would impregnate in and to what density.”

Rasky told us that this would give you a fair amount of range in the type of materials that you can produce depending upon the application you have in mind. He continued, “Actually, our chemist came up with it very quickly. We had a very good chemist working with the scientists. She is one of the co-inventors, Dr. Min Tae Soo, and when we explained to her what we wanted, that we wanted to
put polymer into the ceramic substrate...and essentially ‘paint’ the fibers, it was only about a week or two, she came up with the way to do it.” That’s when Dr. Soo came up with the idea of diluting the polymer into a solvent and do the impregnation into the substrate, then polymerize the impregnant before you remove the solvent. The remove the solvent and the polymer is now impregnated uniformly through the substrate but at the desired density you want.

I commented to Rasky asking if that once you remove the solvent, there would now be a fine coating of material left and he said, “Well, we’ve looked at the topology and the morphology in the material and it turns out you get some interesting structures depending on some of the other additives that are put in it. You can get kind of web structures or you get a variety of structures of the polymer with regard to the fibers. So it’s somewhat complex, but the bottom line is that you have a nice distribution of polymer through the material. And what that does, it turns out, it has a key aspect or a key feature that makes this work for thermal protection system (TPS) and that permeability drops dramatically from just the ceramic substrate. In other words, the ceramic substrate themselves, because they’re largely void space, 89% void space, they have quite a bit of permeability, air and other things can get in them. And once they go through the impregnation process, their permeability drops dramatically. And that’s important to not allow hot gases to come in when you use them for thermal protection systems.”

Protected by a PICA-X heat shield in this artist's rendition, the Dragon spacecraft re-enters the Earth's atmosphere at around 7 kilometers per second (15,660 mph), heating the exterior of the spacecraft as high as 2,000°C (3,620°F) (Image courtesy of SpaceX)

Apollo ablator

As compared to what NASA used on the Apollo program as a heat shield, APOLLO ablator AVCOAT 5026, PICA brings down the touch labor cost significantly, Rasky told us, “That one has a lot of hand work because you have a fine honeycomb that you first have to bond carefully to the TPS carrier structure and then you have to fill each cell. And that’s one of the things that I know our Orion project has hoped to automate, to do robotically. And that takes a lot of hand-work. Whereas, you’re right, the PICA and SIRCA are both billet fabrication approaches, so more similar to standard hand automated manufacturing where they use, what they call, foam blocks for interior spacing materials. And so you can make these things in big billets. The PICA, it's only limited by the size of the carbon
billet that you can get. We were buying carbon billets at SpaceX that were roughly 24 inches by 42 inches by about 15 inches and so we can impregnate entire billets. In fact, they have a capability there to do six billets in one batch, so they could develop lots of bulk material quickly and then you cut out the individual pieces that you want out of those billets, like you would out of a foam block and then attach that to the carrier structure. So, from that standpoint, yeah, it reduced the touch labor considerably compared to a hand filled AVCOAT 5026.”
XIRCA also has some cost-saving aspects. Rasky went on, “This is now a blanket that’s similar to what we actually flew on the Shuttle. There was a thing called AFRSI, Advanced Flexible Reusable Surface Insulation, and what SpaceX did is they took that basic AFRSI blanket, which you can get from Johns Mansville, they produce these thermal blankets—it’s a stitched blanket. But they worked out a way to do a silicone impregnation based off of our patent that we have for XIRCA.

What that allows them to do then is to have these flexible blankets on the aft heat shield of Dragon. It turns out on these space vehicles the aft heat shield, the one that’s downstream from the hottest heating, is usually where you have all your closeouts. You have, complex seals, you have thrusters for your reaction control system. You typically have doors and panels. And they were running into a lot of cost of what are called closeouts. And closeouts are, if you’re trying to put thermal protection systems on a complex panel that has a door or other things.”

Rasky continued, “Maybe you can have some rigid TPS over parts of the door but where the door connects with other doors or other pieces, you have a gap and that’s where you need to do what's called a closeout. It’s usually a flexible seal of one type or another that you fill in. Same way those things are expensive and what they’ve been able to do is go to XIRCA, which is a big flexible blanket that essentially functions as both the acreage cover for the panel and also the closeout. So again it's dropped down their touch labor cost considerably on the aft heat shield. So they’re apparently quite happy with both the PICA and the XIRCA.”

**Ames' contributions to SpaceX Dragon's heat shield with section on MSL**

I thought that XIRCA was a pretty clever modification of SIRCA by SpaceX to exactly fit their need on Dragon. They first were using a material called Acusil II, which came from a company for which Rasky had formerly worked, ITT-Aerotherm. Acusil II is called a syntactic, a foam silicone polymer, that has both silica micro-balloons and fibers stirred into it. It is applied as a kind of paste, Rasky told us, onto a carrier structure and then you vacuum-bag it, cure it and machine the odd mold lines on it. This was used on the first versions of Dragon. SpaceX found that it was quite expensive and also quite a schedule driver. They first looked into making some of their own rigid materials, syntactic foams. They do have that now as well, but on top of that they went to the impregnated blankets, XIRCA, and found that this has cut their cost considerably.

**NASA working with the private sector**

Cody Miller from eeweb asked about NASA working with private companies and similar trends like that of working with SpaceX.

Rasky told us, “Yeah, I think we are going to see it continue and expand. And I think you may have seen some recent announcements where NASA is working now with Bigelow. There is a Bigelow expandable habitat that is going to be going up on the international space station called Beam. Or was it Bigelow Expansion something Module (EDN Editor Steve Taranovich: It was the Bigelow Expandable Activity Module). Expansion auxiliary module something to that effect. You are going to see this partnership activity expanding for several reasons. One is that it allows NASA to leverage our resources with resources in the private sector. For example the capability that SpaceX has put together for essentially 300 million is really what the government put in on the NASA side to put the
Falcon 9 and now the Dragon Cargo Carrier in place.”

(Image courtesy of Bigelow Aerospace)

Rasky continued, “That's a fraction of what would have cost had this been a NASA-led activity. So what we're seeing some real cost advantages to getting the needed capabilities in place at a much more affordable price where the industry has the capability to do so. And that's not all areas where these partnerships will work. But where you have sufficient commercial expertise like SpaceX has shown and now Bigelow and the fact that also orbital scientists with their Antares, being able to partner with these companies to get needed capabilities and services in place, I think is going to be very, very compelling. Because you can do it quicker and at a lower price. And I'd just point out that this model in some ways is not new for NASA. Particularly if you look at the organization which was the precursor for NASA which was the National Advisory Committee for Aeronautics (NACA).

And this was the organization that was set up essentially a 100 years ago to help support the budding aviation industry at the time. And worked very, very successfully with our aviation industry to develop a very important business area. Both for national security and commercial purposes. And I think that you can look at the model and the success record that the NACA had from 1915 in its conception to 1958 when Eisenhower formed NASA, NACA had been very successful. And I think you can look up that President Eisenhower was hoping that same success would spin over to the space side. So that's someone looking at an old model, where you have the government working collaboratively with the commercial industry to pursue common goals. So that model which got kind of pushed to the side with the whole Apollo development because of the need to push out a government sponsored program to take on the Soviets and race to the moon that pushed the NACA model off to the side, but now that model, I think is coming back more in play.

Emerging space companies and aviation companies comparison

And, I think there are quite a few similarities between the emerging space companies now and the emerging aviation companies 100 years ago. So, I think it's not a surprise that we're seeing that model come back into play and seeing that, that'll be quite effective, and I think we'll see it being used more widely as we go forward.”

Miller wanted to know if Rasky saw the same level of engineering innovation happening in this private sector model. To which Rasky responded, “Oh yeah, absolutely, but at different levels. And, this is where, yeah, I think that NASA working collaboratively with private industry will both benefit. What I mean by that, private industry needs to take and harvest really near term developments and capabilities. They typically have a three to five-year horizon, where they could put private equity at risk. And so, things that are longer term than that, they can't really put any time into or any resources into. And the government, in contrast, we have the luxury of being able to pursue lower readiness technologies, and longer term objectives.
And I think that, again, in the government working collaboratively with private industry, they’re saying that they do better on near-term projects and applications, and they’re saying that the government does better with just longer term, and also what we call broad sweeps. And broad sweeps are where the government will do a whole range of variations on a particular design, so that you have a good base of information for point design. And this, had an impact on the NACA era...

There would be studies of propellers, of wing shapes, and various types of control configurations for airplanes. And then, NACA would do very detailed and broad sweeps of different variations and then publish reports that the private plane makers could come in and check specific propeller designs, wing designs for their particular application.

And we’re seeing that same need now with regard to a number of things that the emerging space industry is pursuing. They would love to see variations in injector designs for engines, different types of thrust chambers, metal compositions, variations of thermal protection systems, densities and their material compositions. And, they don’t have the luxury of doing these types of studies, because they need to get to a product quickly. And, I know that they would love to have the government doing these more foundational studies. And also, then taking on more advanced technologies that are not yet proven, that need more laboratory development than they can put resources into on their side.”

Miller followed up with the question, “Tell me, I don’t know what experience you might have, most of our audience are electronics engineers, and is there any insight maybe into what it’s like working at NASA?”

Rasky answered, “When we set up our TPS shop, our neighbor was the whole avionics group, and we’re working with carbon fibers and phenolics, and in fact we’re doing, heating the phenolics until you get phenolic burn smells, and we were freaking the electronic engineers out. [laughter] We’d run a batch of material and we have this terrible phenolic burn smell, that’s the same smell you get when you have a short circuit in an electronics board, it’s the same with carbon fibers, and then you wanna see terror in an electronics tech guy, just tell them that you work on carbon fibers that shorts
out other components. So they actually ended up complaining about it and they got it moved up to
the third floor, and TPS back on the first floor.

But again, back to what the work that electronics folks do, where there’s an application, it’s on the
heat transfer side, both to transfer heat effectively, as well as to insulate and protect components
that need thermal insulation of one type or another. Okay, then and I mean, again you’re looking at
standard heat transfer calculations, thermal stress calculations and the like. And so there’s... I
guess, what you call packaging engineers from your electronic readership, they’re the ones who’ve
been doing more of the mechanical engineering side of electronics design.”

How do you test a heat shield?

How do you test a heat shield?

Lou Frenzel from Penton asked this question and Rasky had a simple answer----a torch. An
oxygen/acetylene torch would work as a first step. The professional way would be using what’s
called an arc-jet, that’s an arc-heated wind tunnel. Unfortunately, you can’t get the air moving
quickly enough through a wind tunnel to simulate re-entry. It’s not possible to put that much energy
into the velocity of air in a wind tunnel. Instead, you strike a very long arc from one end of the tube
to the other. At NASA Ames they have these arc-jet facilities and they run in the tens of MW of
energy consumed. The tubes are typically four to six inches in diameter and they can run two or
three meters in length. Then you blow air through that tube and it get heated to very, very high
temperature. Next, you put it through a converging/diverging nozzle and then have that impinge
upon your model. That best simulates the energy and chemistry of an actual re-entry into Earth’s
atmosphere.
As for electronic instrumentation used in this process, NASA Ames uses thermocouples and then various types of calorimeters and also IR spectrometers. One of the tough issues is that this is an exceedingly noisy environment because of the large arc you have just struck. The arc is only a few feet away from your test model and the engineers are challenged to have adequate shielding to keep out this noisy RF from the instrumentation.

**Commercial and industrial applications for PICA**

Linda Bell, from NASA Tech Briefs asked this question, to which Rasky replied, “Well, actually, the substrate itself, PICA is made of a carbon tile substrate and has phenolic impregnation. The carbon tiles actually come from the vacuum furnace industry. They use it as insulation for vacuum furnaces. In fact, the people that we buy the substrates from, that’s their primary market, vacuum furnaces. So, now once you put the phenolic in it, okay that’s now less applicable for a vacuum furnace where you could have essentially vaporization that will occur if you pulled the full vacuum on the phenolics. So, it’s now less applicable for vacuum furnaces but, PICA itself, really, I think, heat shielding applications particularly for any type of abort systems or something has to have some protection in case it burns up... We already have used a variety of SIRCA in high performance applications like for race cars, for shielding of firewalls and exhaust systems and things of that sort. So, I think the industrial applications are probably more aligned to the SIRCA family of products. Well maybe that and a few things for a very high thermal shielding of very high temperature processes or devices, which may be able to make use of PICA.”

Deb Kirby wanted to know what industry vacuum furnaces were used in and Rasky told her that they are used for high temperature metal processing and component manufacturing. They use an inductive heater to heat a susceptor and melt very high temperature materials.

A follow up question from Kirby was whether they are used in the semiconductor industry for some kind of semiconductor fabrication, to which Rasky replied, “Yes I think for semiconductor is one application that usually uses vacuum furnaces. We have been doing depositions which you might have seen such as circuit board manufacturing and IC manufacturing.”

Linda Bell from NASA Tech Briefs then asked about Rasky’s work with SpaceX and the Space Portal. The question was regarding safety and how firms like Virgin Galactic, SpaceX and others are handling safety, especially with plans to transport people. Rasky told us, “Yes, well right now actually the organization that’s really in-charge of making sure that things are handled in a reasonable safe manner is the FAA which actually handles all the licensing, launches and also reentries and they actually have a long track record of working in the aviation industry, experimental aircraft and new aircraft. And what they have done, I have to say, they have done very good job at this point, they are using that whole database on how to make sure that uninvolved public is safe from mishaps and apply those same rules in their whole 100 year history of experience and now to this new space industry. And to this point, that has been going very well. And I think again these companies if they aren't safe they aren't gonna be able to get customers. So safety is important to them. Now they do handle things differently than NASA would under some of our systems that we have operated. Although they look a lot to what NASA has done, how do we handle the redundancy systems in terms of electrical and electronic components and mechanical systems and so on.
But then they make the judgment as to what level of design safety they need to get the licensing that they need from the FAA as well as have a safe enough system that they believe they have a commercially viable product. And so to this point I think it’s worked quite well. As I said we’re leveraging off a lot of experience from the aviation industry.”

Deb Kirby then asked, “Just that kind of raises an interesting question, can you talk about the relationship between NASA and the FAA to kind of coordinate that licensing process?” To which Rasky replied, “It's been very good and again we don't do any licensing at NASA and that was one of the reasons why the FAA stepped in—that is a role that they have historically held. So they understand that process. And we've actually had certain colleagues in the FAA who are formerly from NASA. So there has been very good transfer of expertise and information. And to this point it's gone very, very well. We have a number of joint conferences we have with the FAA then they will attend our conferences and we will attend theirs to make sure we have a good exchange of information. And as I said, NASA is more than happy to have some of that licensing duty because it is not a trivial piece of work and there are procedures and approaches for doing it correctly in the FAA and we are in a good position to do that. So at this point it's worked quite well.”

**Using PICA on Mars Curiosity**

I was very interested in what Mars Curiosity had as its heat shield and Rasky told me, “Yeah, Mars Curiosity in fact had a full body heat shield. And in fact it actually enabled the mission as it turns out because the standard heat shield for Mars entry is something that was developed in the 70's for the Viking lander called SLA 561. And it turns out that it wasn't going to work for Mars Curiosity. In fact when our group here was looking at certifying the heat shield for Mars Curiosity, that's a very big vehicle as you probably know. Now it turns out that the heating that it was going to be receiving on Mars entry was going to be quite extraordinary. And when they went to do the testing, they found that that heat shield wouldn't work. It was literally... there one minute and gone the next. It was well over the sort of mechanical loss limit of the material. And so it was a bit of a scramble to find a replacement in time to be able to make the mission and so we went from the standard Mars heat shield to PICA and PICA worked very, very well and all of that eventually saved the mission.
The Mars Science Laboratory Heat Shield was the first-ever tiled ablative heat shield
(Image courtesy of NASA Ames)

It would probably have been delayed considerably. So they would have had to do a significant redesign of the mission and we would have missed the launch window and so on. So they were able to do pretty much, it's a one for one swap from the Viking material to PICA and well, that worked on the mission.”

I'm ready now for my first trip to Mars! Anyone else want to go?