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Journal of Space Ops & Communicator: Interview

Objective: Interview John A. Carr about exciting work with

Thin Film based Solar Arrays

Interview by Christopher R. Simpson **Email:** simpsonchristo@gmail.com

INTRODUCTION:
John A. Carr, Ph.D. currently works at Marshall Space Flight Center in the **Office of Chief Technology**. We interviewed John about his recent work on improving solar sails; adding packable solar panels to improve power generation and management for vehicles using solar sails.

1. **Could you give us a brief technical overview of what you're trying to do**?

The use of thin-film based solar arrays for spacecraft applications has long been recognized as an advantageous power generation option. Thinner materials yield a mass savings, equating to lighter launch loads and/or more payload allocation. Perhaps more interestingly, their mechanical flexibility lends itself well to stowage and deployment schemes. These benefits make thin-film arrays an exciting prospect for space community.

A particularly interesting application is for small spacecraft – where mass, volume, and surface area are extremely limited. This causes push and pull between the spacecraft subsystems and ultimately limits capability. That is, with state of the art hardware, there are very real limits as to what can fit in these small spacecraft. The power system is no stranger here – most small spacecraft find themselves limited in power. But what if we can change this? What if we can double or triple the amount of power available to small spacecraft, using the same volume and mass resources. This would help usher in a new generation of capability.

This is the very small. On the other end of the spectrum is the very large. Typically, Jupiter is stated as the demarcation for solar power. Deeper in space the array becomes so massive its mission use is not feasible. We typically turn to plutonium-238 and RTGs in this case. But what if we can extend the range solar power? Enable solar electric generation to reach out as far as Pluto? This could be an extremely important tool in our power generation tool box, enabling some missions to go further without dependence on nuclear sources.

We are solving these problems and enabling these capabilities by marrying solar sails – extremely thin aluminum coated polyimide which utilize photon reflection for propulsion – to thin-film solar cells – extremely thin semiconductor devices that convert solar energy into electricity.

2. **Can you imagine projects which take advantage of both properties – photon reflection for propulsion and powered generation?**

It's an interesting question that we have been pondering on our end. Back of the napkin calculations say that even with a 'power sail' fully populated by thin-film solar cells, we will get photon reflection propulsion along with the electrical generation. Of course, this is even truer for a 'part power sail', which is only partially populated with solar cells. I think for some missions this extra propulsion, for example in the case of the full power sail, may be a nuisance force that the primary propulsion system will have to negate. However, I do think there are missions which could harness this to their advantage and take some load from the primary thruster (use less fuel, etc.). A few design reference missions should be studied to determine the characteristics both 'classes' of missions.

3. **What are some of the challenges you're facing**?

Our current challenge is survivability in the space environment. We have developed these thin-film solar array systems and tested them in a host of simulated space environments. We even currently have some small samples on orbit. What we have found is that survivability is limited to perhaps a few years depending on the environment. This is great for small spacecraft which may need only a few months to a few years to complete their missions. However, as we try to extend the lifetime of these small spacecraft and grow these thin-films arrays to the very large, longer lifetimes will be needed. How do alter our material sets to survive for 10, 20, or more years?

4. **What are the main lifetime determining factors?**

Ultra violet radiation is biggest limiter. The flexible polyimide coating we are using yellow relatively quickly under UV, reducing the amount of light that ultimately reaches the solar cells. We are currently working with a materials company to improve (slow) this yellowing. UV reflective coatings are also a natural solution that have yet to be explored. We must also keep in mind that as we go deeper into space, the intensity of light (UV included) falls off at d^2 – where d is the distance from the sun. This means the arrays generate less power per unit area, but yellow more slowly. How are 1AU data extrapolates to deep space and what that means for survivability has yet to be studied Second to UV in these systems is particulate radiation. To keep the cell stack as thin and as low mass as possible, we currently work with relatively thin coatings (<1mil). Further, the polyimide is less dense than traditional solar cell glass coatings. Both equate to less radiation protection. For longer term missions thicker, and perhaps denser, flexible coatings will need to be explored give adequate radiation protection.

5. **What are some of the technical challenges you've overcome?**

Deployment was a major technical challenge. Though thin films are lightweight and, thereby, don't require a lot of force for deployment, designing a system which can be confidently testing in 1g without overdesigning (mass, volume, force, etc) for ~0g was difficult. This caused challenges with how to ground test – how to gravity offload without blinding ourselves to potential microgravity problems. For example, imagine a boom deployment. Because of our required design, we had to have this boom deploy from the ground upward in testing – fighting the full force of gravity. If we design such that this boom deploys readily in 1g, it may be too forceful for space, causing snapback, boom buckling, etc. So we designed a gravity offload rig with counter balances to help offset the gravity. However, by using this rig, we confined at least one degree of freedom – what if there is a torsion, etc. in that axis that we are not seeing? This was overcome by multiple test rigs, parabolic flight testing, and the like. Nonetheless, it was challenging.

6. **Are there other deployment methods possible?**

I think there are. I think one of the main advantages of the thin-films is their mechanical flexibility, which lends itself well to stowage and deployment schemes. We have explored a couple other deployment methods at a high level. I wont detail them, but one can imagine rolled arrays, accordion folded arrays, even origami folded arrays to really improve packing efficiency. In each of these cases different boom types – e.g. tape booms, telescoping booms, etc – or other deployment/structural mechanism – e.g. inflatables – could be used for the on orbit deployment. There is scope to explore here – especially for deploying extremely large arrays (say >300kW+ at 1AU). Others yet say let's not deploy, but actually fabricate there very large structure in space – a very interesting concept.

7. Are the technical challenges you're facing limited to spacecraft using thin film solar arrays?

For certain mission types, I think thin-film solar arrays are ready for in-space testing. The challenge then becomes programmatic. Very few want to risk their mission objectives to fly and prove out a new technology. This is where NASA steps in and runs technology demonstrators. This is something we are working towards, but there are a lot of potentially useful technologies out there and prioritizing need, infusion, and demonstration timing while balancing resources and manpower becomes the challenge.

8. How do you think this will improve future spacecraft missions?

In the near term, I envision this being used to create highly capable small spacecraft. I think there are a lot of applications in that realm, but most interesting to me is the concept of daughter ships. Imagine we have a flagship mission going to the heliopause (or any deep space target). Along the way, this *mother* ship could deploy secondary *daughter* ships (small spacecraft) to collect science of interest at strategic points. The deeper you go into space the less solar power there is available and the more power you need to close link margins. Our large, fhin-film array could help alleviate this issue, enabling multiple daughter ships to be dropped along the way – improve science per dollar.

9. Have you implemented any of the improvements on any current missions?

We have not. We are currently working towards a Technology Readiness Level 7 (TRL7) in space demonstration to help buy down risk for future mission infusion.

Dr. John Anthony Carr is a power subsystem engineer in Marshall Space Flight Center's (MSFC) Electrical Integration and Power Subsystem Branch. Dr. Carr's background is in microelectronics and semiconductor physics. Prior to NASA, Dr. Carr spent time at Micron Technology, working on memory devices. Dr. Carr then transitioned to academia to research microfluidics and organic photovoltaic cells. Since joining NASA, Dr. Carr has focused on the technology development of thin-film solar arrays – he is currently the Principal Investigator for the Lightweight Integrated Solar Array and anTenna (LISA-T) program.

Edited by Joachim J. Kehr Editor SpaceOps News, Journal of SpaceOperations & Communicator
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