A Clash of Engineering Cultures? NASA Engineers, R&D Culture, and the Space Shuttle as an Operational System

(The Maintainers Workshop Concept Paper)

Premise:

The topic that I proposed for this meeting relates to an exploration of how an R&D organization, one well-known for its innovative activities such as landing people on the Moon in the 1960s, came to grips with a much more mundane activity, operating a fleet of Space Shuttles for thirty years.

No question, the aerospace engineering culture of NASA emphasizes innovation and the development of new technologies, and those who go to work for the space agency have long been attracted by the thrill of tackling new and unresolved problems. In its first twenty-five years, seemingly, NASA had a new R&D project constantly underway and design engineers happily moved from one to another of these efforts. This was largely the norm until the first orbital flight of the Space Shuttle in 1981. At that point, the program was intended to become operational, providing relatively airline-like space access. This meant that the bulk of the research, development, and testing for the Space Shuttle would be halted—NASA officials intended to pursue only modest upgrades thereafter—as the vehicle would open orbital space to "routine" operations. The Space Shuttle, of course, never delivered "routine" spaceflight and its flights were never airline-like. Most of the explanations for the shuttle's failure to deliver on this promise emphasize its experimental status, its different flight requirements, and its advanced technology.

Those explanations are fine as far as they go, but in addition the NASA engineering culture emphasizing innovation and R&D ensured that those who were a part of the shuttle program constantly sought to upgrade the system rather than maintaining and flying it as is common among airlines. The result was that none of the orbiters were identical, and that constant efforts to alter shuttle technology meant that no two flights were even similar. The "maintainers" were not dominant at NASA and the constant modification of the technology ensured that there was never an opportunity to operate it efficiently. This paper will explore this theme in the 35-year history of the Space Shuttle program and offer some thoughts on the clash between the divergent ideology of R&D versus maintenance in the context of NASA and the Space Shuttle. As such it addresses one of the central questions asked in the conference's Call for Papers: "How does labor focused on novelty and innovation differ from labor focused on maintenance and conservation?" To this I would ask another: "How do these divergent engineering cultures interact and achieve useful synergy?"

I posted this on my blog and asked for feedback. Here is what I got. In my oral presentation I will reconsider both the premise of my original research project and some of the comments from

readers of the blog post. I specifically asked if I was off base in my assertions. Apparently not, if the responses are any indication.

Responses:

February 8, 2016 at 6:50 am (Edit)

Hi Roger
Very interesting.
Some thoughts on building a case.
You would need to establish a pattern in the rationales for the upgrades. Some/many may have been conservative changes for safety/operational requirement driven needs.
Also Roger you can't assume the shuttles came off the production line in the same identical configuration and those configurations subsequently diverged through upgrades. We would need to dig deeper here.

Problem with writing about culture is that it is hard to get evidence
All the best,
Kevin

Liked by 1 person

Reply

 **Steven Fawkes** *says:*

February 8, 2016 at 6:57 am (Edit)

This is a really interesting area for a paper and further research. One aspect in NASA was (is) probably sheer numbers of innovators vs. maintainers with innovators greatly out-numbering maintainers. As you say NASA tends to be a self-selected group of innovation focused engineers. Another aspect, which comes out in other non-aerospace areas as well, is how you integrate the maintainers into the design and innovation phase. In many cases, e.g. high profile buildings, there is little integration so the end product ends up being bespoke and having high maintenance costs caused by a combination of equipment choice and bad design (for example making access difficult). When maintainers are integrated into the design phase maintenance costs are reduced.

Liked by 1 person

Reply

 **Andy Prince** *says:*

February 8, 2016 at 3:20 pm (Edit)

Roger,
Very interesting theory. I do have some things you might want to consider. First, the Shuttle Program faced significant obsolescence issue over the last two thirds of its life. Some of these issues were driven by EPA rules, etc. but others were more economic in nature. For many secondary and tertiary suppliers (often niche industries most of us are not familiar with) providing materials to support the shuttle program was at best a break even business. Some only did it out of national pride. Significant resources were expended to maintain existing vendors and qualify new ones.
Second, in my opinion neither the technology nor experience base was ready to develop a true operational system. In many ways human spaceflight is still in its infancy when compared to other modes of transportation. I am sure that having just gone to the moon we felt like we could do anything. And while reusability did pay economic benefits, the dream of airline type operations was not realistic. A large bureaucracy, both government and contractor) grew up around the need to grow and maintain the knowledge base needed to keep the shuttles flying.
Third, the Shuttle Program I observed was a strange mix of conservatism and innovation. Many improvements were made to the hardware over the life of the system – which is much to your point about the R&D culture. However, at the same time, other elements of the program remained stuck using 1970's technologies and processes right up until the end. Generally speaking, unless a change was needed for performance or safety, it did not happen.

Liked by 1 person

Reply

1.  **Erik** *says:*

February 8, 2016 at 3:24 pm (Edit)

The innovation problem goes deeper still. Airliners are designed to be maintained–Shuttle wasn't. A culture that understood maintainability would never have designed a vehicle whose engines have to be yanked after each flight.

Erik

Liked by 1 person

Reply

2.  **mike shupp** *says:*

February 8, 2016 at 8:04 pm (Edit)

You might indeed be off base, but I'd love to see your thoughts anyhow.

Kevin makes a nice point. The orbiters were built over several years. Rockwell had an aeroheating group which estimated how hot portions of the vehicle got during ascent and re-entry, using wind tunnel data and theoretical models. Roughly speaking, it took about a year to figure out aeroheating profiles for a particular vehicle for a variety of trajectories. This data then went to a second group which calculated how much of that exterior heating actually penetrated the skin and thermal shielding of the vehicle, and how that heat would spread through the structural framework.
This took about a year, and meanwhile the aeroheat group was preparing improved estimates.

The numbers from the structural heating group went off to a weights group, which looked at the heating on the structure, determined if the structure was sturdy enough to withstand operation with those heating loads or should be beefed up in places or could be trimmed down to reduce weight. This took about a year. Their data got transferred to the people who created the blueprints that eventually went to the people who built the vehicle. Their data was also fed back to the aeroheating and other groups who could repeat their analysis with better notions of vehicle geometry, etc. And the cycle would begin again.

So yes, there were differences in the individual orbiters, and arguably the design was refined as it moved from Enterprise to Endeavor. GOLD STAR FOR KEVIN.

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Another point I'd make, taking off from Andy Prince's observations:

What struck me when I was in aerospace in the 1970s and 1980s was that no one wanted or expected space flight to ossify as it did about the shuttle. The common notion among engineers

at Rockwell, for example, while shuttle was being developed, was that once the first four orbiters were operational, some other manned space project would come along, perhaps a second generation shuttle, perhaps a moon program of some kind, because that was the way things went in the aerospace business. I don't recall something like ISS being viewed as a goal, largely I suspect since ISS has more the aura of an "intermediate" nature rather than that of a true Program. These guys were NOT "maintainers" in your terms.

Other hand, once you accepted that manned space had settled down on shuttle (and Soyuz), you had another problem to face: where would the next generation of flight vehicles come from? Traditionally, in a long production run of aircraft or automobiles or consumer products, small changes are made along the way — seat belts get added, better alloys go into engines, welds replace rivets, better fabrics are used as seat covers, avionics get upgraded, etc. The 20,000th Boeing 707 was a better bird than the 1st, even if the silhouettes looked similar. When your production run is four or five orbiters, and nobody plans any follow-up for a decade or more, you've got a Major Issue to deal with: do you try to make those vehicles as similar as possible and as close to their original condition as humanly possible? Or do you make changes over time so those vehicles somehow "evolve" to improve their capability despite the lack of 2nd or 3rd generation follow ups?

I think you can make a case that "maintenance" wasn't a likely option for those working on the "operational" space shuttle, that the very constraints that surrounded those engineers pushed them into "innovation", even if the politicians and program managers or the era never foresaw this happening.

Liked by 1 person

Reply

3. **dphuntsman** *says:*

February 8, 2016 at 9:59 pm (Edit)

Roger, as someone who was a proud shuttle participant at NASA for my first 15 years in the agency, I understand what you're trying to get at. But, I think you may be missing the larger picture entirely; and taking the wrong lessons-learned from the shuttle experience.

The primary lesson learned is not in the engineering and operational details per se; the prime lesson learned was that we NASA/government engineers, and government in general, are not

good at: designing, building, owning, operating large space systems that are intended to be 'operational', except for maybe the purely scientific instances (e.g., telescopes, probes, et al). All of the 'incentives' in our NASA/governmental system work against it. I could give you another list of those negative incentives!

Even Apollo proves the point. For while Apollo could work at its primary (political) goal of flags and footprints on the ground by a set date – it was NOT good at being the first step in a sustainable program to KEEP us in space. It was unaffordable to own and operate (the incentives weren't in that direction, neither by politics or schedule).

SLS/Orion fall in the same category. Do you really think, over 50 years past Apollo, that having us NASA guys design/build/operate a large, throwaway rocket that may only fly once every two years, is going to be "operational" in any economic sense of the word? It won't be. And like Apollo, it won't be part of any sustainable space future. i.e., like Apollo, it really doesn't pave the way for cheaper or more economic or much more frequent use that yet even more people/corporations/countries can then build on to produce even more economies of scale.

For a space system to have strategic and economic "legs", one must think in terms of each part being a cog in the process of space *economic* development. And having us government types do the design/building/operating, etc., under government controls, and not having the proper economic outlook and practices (by definition), you'll get the same results.
Yet one of the reasons, as one comment or above notes, we have stagnated since shuttle, is that over time we in NASA – with help from our myopic Congress – have been on an almost continuous decline in sponsoring, doing, and demonstrating real cutting edge R&D that the rest of America – i.e., the private sector – can then use to make economic space systems. And it's the private sectors that have the incentives to do that.

To give a brutally brief summary:
1. Without re-energizing NASA's space tech R&D to create new seed corn to grow things, we're not going to have the breakthroughs that "we" – especially the private sector, who will need to implement and expand things – that are absolutely required. The reduction in real space tech R&D over many years now is roughly coincident with the shuttle, and ISS, "operational" programs absorbing so much of NASA's energies and monies. We've got to fix that indirect, understated problem that started with the shuttle program's shift of focus to operations.
2. Final development of *real* operational systems can be spurred on/jump-started by NASA – evidence, the COTS, then CRS (where NASA served as an anchor tenant for the systems

developed under COTS), and now commercial crew. A key point of these successful/succeeding programs: the government was not the designer/builder/owner/operator. (though it clearly serves as an inspector, guide, help mate, etc.). In both cargo and crew cases, the systems are ultimately those of the companies, which are incentivized to keep on going with them, and not just to feed solely off of the government trough completely. And we are getting competitive, non-single point systems to boot, unlike a single big massive unaffordable government system.
So I guess I'm saying that, instead of looking at the details of what NASA was doing with its government designed/owned/operated vehicle and trying to directly extrapolate; don't let the trees obscure the bigger forest, the bigger picture. The lesson is: For Christ sake, having a government agency turn into an operational thing is not only not what it does well, it also means that necessary R&D for the future is increasingly not done. AND, final development of products intended to be 'operational' can be partnered with government; but must in the end be in (multiple!) private hands, with the right incentives to build increasingly cheaper, more reliable systems, that all can then use to bootstrap even more human (not just NASA) expansion into space.

Dave Huntsman

Liked by 1 person

Reply

4. **chrisbpetty** *says:*

February 9, 2016 at 1:18 pm (Edit)

Roger,
I think this sounds like a really interesting approach and obviously has major implications as we move more towards re-usable commercial systems that NASA may purchase flights on while still creating their own space access systems.

I think at the heart of this there's a question whether NASA is really the appropriate organization to be running an 'airline-like' space access system (if such a thing is even possible!) – maybe that's just not the best use of their time, budget and effort. In the same sort of way, the NACA never tried to manufacture aircraft or run an airline – they were able to concentrate on R&D and passing those benefits down to industry who could then apply them commercially.

I'd be interested to know if any conclusions on this subject were reached within NASA and how much this influenced decisions and attitudes towards the ill-fated VentureStar in the 1990s. Clearly lack of budget to build and maintain a fleet of SSTOs was a big factor here, but was there also a recognition that NASA really wasn't suited to the role of owner/operator?

chris
thehighfrontier.worpress.com

Liked by 1 person

Reply

- **dphuntsman** *says:*

February 9, 2016 at 7:36 pm (Edit)

how much this influenced decisions and attitudes towards the ill-fated VentureStar in the 1990s. …… but was there also a recognition that NASA really wasn't suited to the role of owner/operator?
Chris, the simple answer is, not only has the agency – which I'm still in, after 41 years – *not* recognized that it isn't suited to the role of developer/owner/operator (.e.g., it's doing so for SLS/Orion), it took exactly the wrong "lessons" from Shuttle and VentureStar et al. Before he retired from NASA, I brought this up to the head of Exploration Systems Development at NASA, Dan Dumbacher, and he essentially said the same (wrong) thing that the rest of NASA senior management is going by: Shuttle, Venturestar, etc. proved reusable launch vehicles won't work (!); we know what will work (i.e., the Apollo paradigm); end of story. I got that from the NASA chief engineer, also.
And those are the absolutely wrong lessons.

We, as a government agency, are never going to be good at designing/owning/operating *any* truly economically operational launch system. But we *can* help be the jump-starter, partial investor, advisor, etc. etc. to help jump start new competitive industries that *will* do those things. The examples of the types of ways forward are clear: COTS-style then CRS-style, commercial crew likewise, jumpstarting whole new cost-effective rocket systems and spacecraft capabilities with more than one competitor and design/operational solution.
While the agency is at least continuing on with commercial cargo and crew, since 2010 (when commercial crew started), NASA has essentially 100% gone back to the old way of doing business. The way that led to ever-increasing costs, decreasing capabilities, loss of economic

competitiveness, and loss of any confidence that we can lead to a true sustainable, growing, space-faring civilization, led by a free people.

We know what works: Making sure NASA becomes once again a technology generation engine, not just for the agency's internal missions, but for the country, in a way similar to what NACA was for aeronautics; *and* that NASA then partners, in the right way, with the nascent commercial space industry to invest in them, advise them, and expand their capabilities in a way that helps us all. And come the next new Administrator, we need him/her to understand that, and to lead that absolutely necessary change, if we are to have a real space future.
Dave Huntsman

Liked by 2 people

Reply

5.  **Damara Arrowood** *says:*

February 9, 2016 at 2:43 pm (Edit)

You are absolutely not off base. On the bright side, I'm told the culture has changed considerably for the best. Having a former shuttle pilot as an Administrator most likely sped that process, which is what any org or company is required to do in order to survive. I will refrain from using any of the standard-issue Silicon Valley buzzwords...

I would like to comment (possibly advise) directly on the subjects of the abstract offline if possible. Is there an email address for anyone who may choose to comment offline? In other words, may we have permission to speak freely?

Liked by 1 person

Reply

6.  **tony galeano** *says:*

February 10, 2016 at 2:06 am (Edit)

From my own experience, NASA is certainly not unique in showing the wide cultural gap between "dreamers and doers". The U.S. Army and the airlines were replete with "who the hell designed this?" frustrations. The M-16 rifle seemed to be designed by someone who never imagined cleaning it. The Embraer 135/145 regional jet cargo bin has a sloping floor, so all the

bags are constantly sliding downhill into you. On my first car, you had to remove the right front wheel to change the oil filter. These are exceptions, for the most part.

I believe that NASA and its contractors lost touch with their military aviation roots, and the designer/maintainer working relationship that went with it. The progression from blueprint, to mock-up, to prototype, to initial production, and then into service gave both groups multiple opportunities to discuss and hash out issues. Even after something goes into service, this process continues- as many pilots have said, "Don't fly the A model of anything!" Once in regular service, emergency safety issues aside, there is an established procedure for grouping improvements together to avoid addressing them piecemeal. The A model is followed by the B, and within models, upgrades are still made en mass; witness the F-16C, Block 40, Block 50, Block 52 etc.

Obviously NASA didn't have the luxury of a large fleet to directly translate this idea over, but it feels like the spirit of the process was forgotten in the quest for the next improvement.

I also wonder if NASA is a perfect storm of the prototypical American desire for the latest and shiniest toys, vs. sticking with 'old reliable'. We would never be content to fly the same booster for almost 50 years like the Russians' Soyuz, but we also shouldn't be the space equivalent of always standing in line for the newest iPhone. "Faster, Better, Cheaper" was just a rephrasing of "2nd best tomorrow" or, "perfect is the enemy of good enough". Militaries, airlines, and auto makers all seem to have settled into a more realistic and practical mindset (for the most part), but NASA definitely swung in the other direction.

Liked by 2 people

Reply

7.  **spacegary** *says:*

February 12, 2016 at 1:55 pm (Edit)

You are not off base. It sounds like a fascinating analysis. The comments seem to indicate a wealth of people with experience/material for you. I look forward to reading the results. Thank you.