**Some Thoughts on Stagecoach, Lessons from Apollo, and a Concept of Exploration Systems Optimization**

Dave Akin
dakin@ssl.umd.edu
301-405-1138

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With the completion of the meeting in DC and the nice artist's concept distributed by Anil, I think we're getting a good handle on Stagecoach (still hate the name) and its concept of operations. If I can try to synopsize the concept, it's to push the envelope for the lightest weight pressurized rover possible, and examine its use in place of the Apollo Lunar Roving Vehicle (LRV) for similar sorties. We've been talking about a single eight-hour EVA day, as a sortie from a lander or outpost, and exploiting a (hypothetical) quick-don/quick-doff suit in a suitlock/suitport to allow several surface EVAs during a single sortie. We did discuss extending the sortie beyond eight hours by using the pressurized cabin feature during the drive there/drive back, and we (at least implicitly) are using the rover to eliminate the walk-back safety requirement of Apollo.

Given our general adoption of the Apollo LRV paradigm, I thought it would be worthwhile to learn more about the use of LRV in the Apollo J-class missions. I spent some time digging out some references with operational metrics; the primary reference I used for timeline data is listed below.[1]

The LRV was used during nine EVAs, three each from Apollos 15, 16, and 17. I looked at LRV usage, concentrating on driving time and surface operations intervals between stops. I've excluded engineering test operations, such as post-deployment checkout and the "grand prix" tests of Apollo 16. The result is a record of 47 driving intervals, or slightly more than five per EVA. The shortest drive was half a minute; the longest was 72 minutes. There were 38 intermediate surface intervals (I'm not counting activities after the LRV returns to the LM), with a shortest surface excursion of four minutes and the longest slightly over two hours.

Some additional insight can be gained by looking at the probability density functions of this data. Figure 1 shows the trends in driving time. The chart suggests that there are two normally distributed trends in the population; short drives (red diamond-shaped data points; less than 20 minutes) and longer drives (blue squares). 80% of all Apollo LRV drive intervals fall into the "short drive" category. A study of Apollo traverse maps explains this trend, as each EVA had long traverses to one or two surface investigation sites, with a number of short repositioning drives at many sites.

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[1] E. C. Smith and W. C. Martin, "Lunar Roving Vehicle Navigation System Performance Review" NASA TN-D-7469, November, 1973.

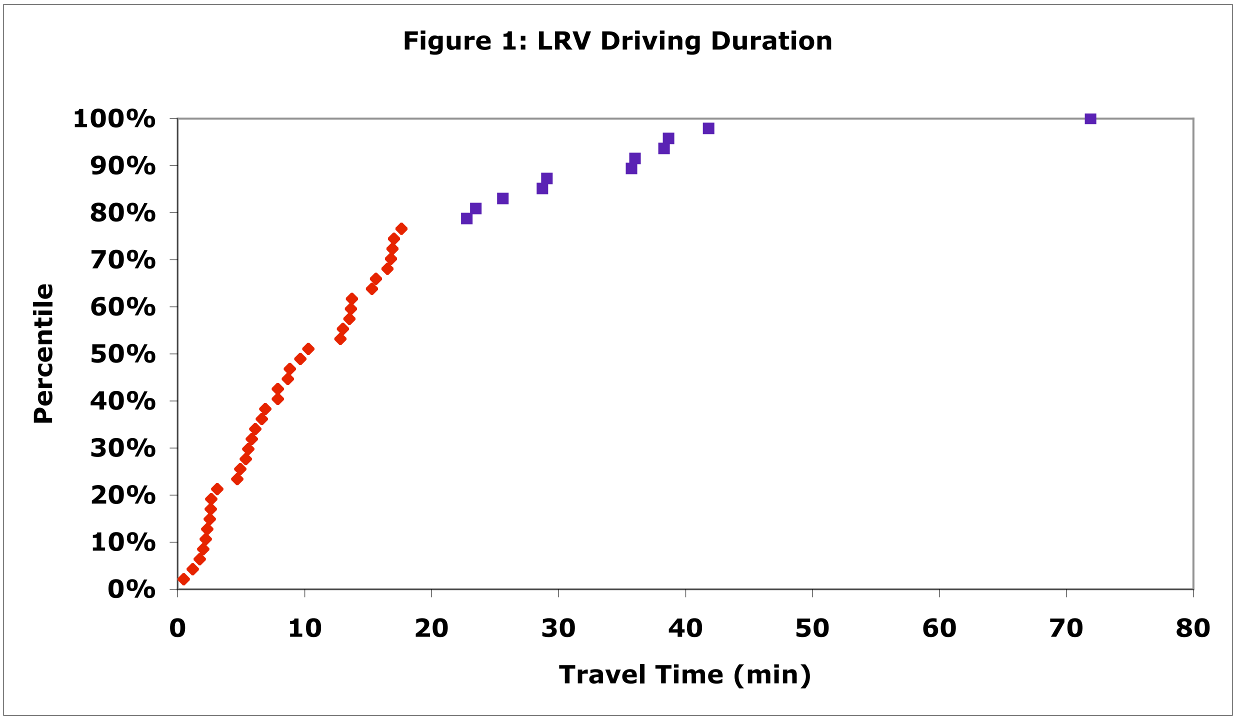
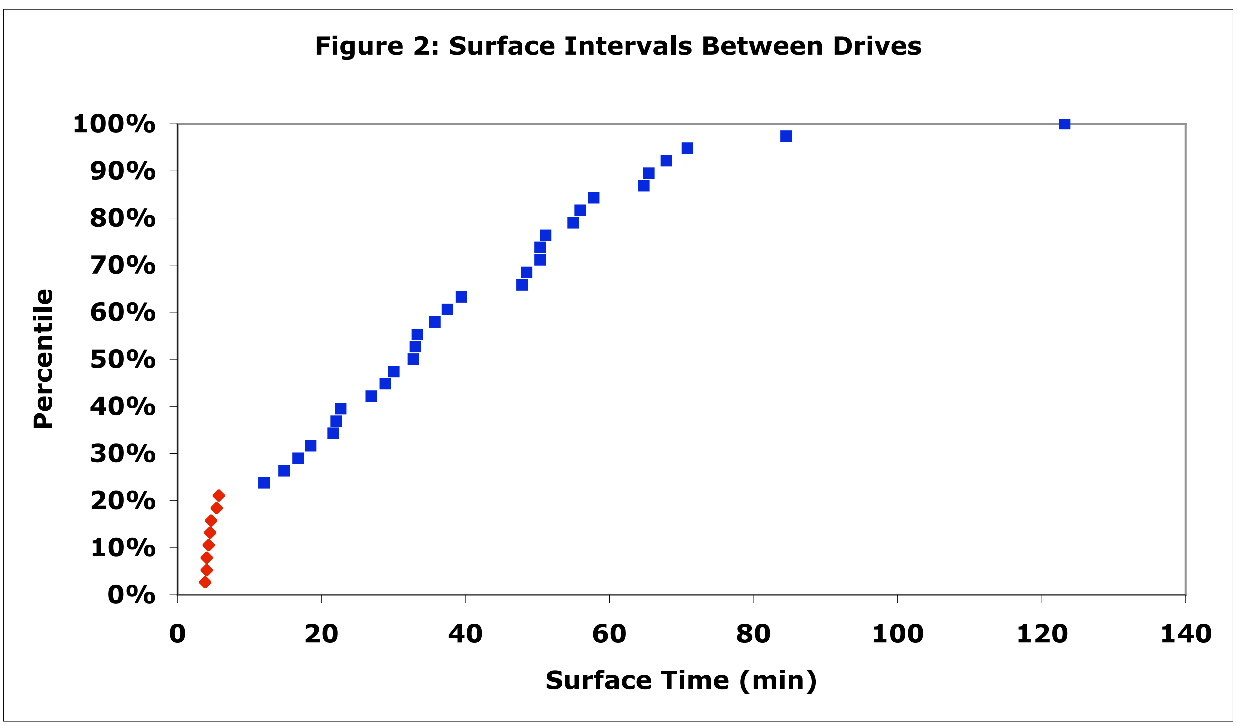
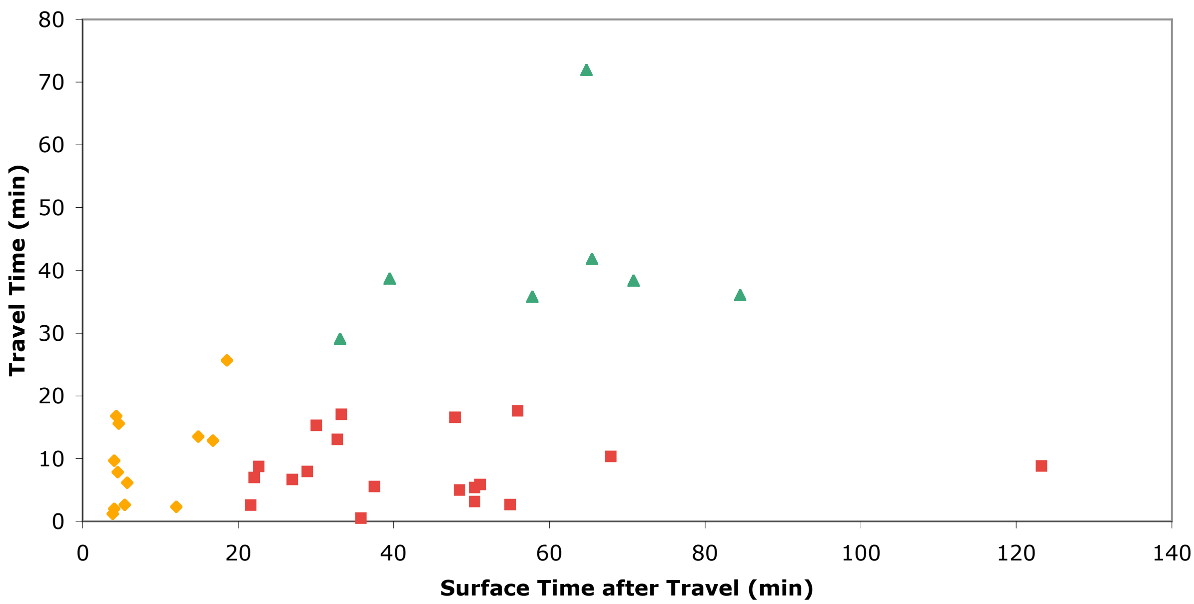



Figure 2 shows the similar data trends for surface intervals between LRV drives. There is a small, but significant population (20%, shown with red diamonds) of "quick stops" of 4-5 minutes at a site, and an almost perfect normal distribution of stop durations from 12 to 71 minutes, with two long-duration outliers at 84 and 123 minutes (blue squares). This does not include the "drive-by" sampling stops of the later Apollo missions, where quick "grab" samples were collected while seated in the LRV.



While this information is interesting in its own right, my objective was to glean information that would help understand the roles and limitations of Stagecoach. For convenience, Figure 3 plots surface interval times vs. travel times for EVA segments. (Each data point is the drive time to a location, followed by the surface EVA time at that location.) Other than demonstrating that the bulk of the total EVA time is spent in surface activities, there are no other direct correlations visible in this plot.

**Figure 3: Drive/Walk Correlation**




The big innovation of Stagecoach is the "quick don/quick doff" suit interface, allowing the crew to easily move back and forth from inside to outside. An interesting question is, what constitutes "quick"? Current EVA checkout and donning is probably an hour or more, even ignoring prebreathe requirements. At the other end, I would estimate that the time required for me to get ready for a routine dive in our neutral buoyancy tank (including setting up and checking out the equipment, collecting all the stuff I need for the dive, and last-minute bathroom break) to be about 5-10 minutes. So, let's say 10 minutes will be required to transition each way into and out of Stagecoach. As a rough order of magnitude estimate, let's take a page from Mike's workload efficiency index and assume that you want to get at least twice as much time in your new environment as it takes to get there. That means, of the 38 Apollo EVA stops shown above, 12 are not candidates for getting into the suit and going outside because the surface interval required is less than 20 minutes (orange diamonds), and the 19 red squares are not candidates for going back into the pressurized volume because the upcoming driving time is less than 20 minutes. (There are actually 30 data points that meet this criteria, since 11 of the 12 points where the surface time is less than 20 minutes also includes a transit time of less than 20 minutes.) Over nine Apollo EVAs, there are only seven instances (green triangles) where there is a drive of greater than 20 minutes, followed by a surface activity of more than 20 minutes.

I would be the first to caution everyone not rely too heavily on the specific numbers here. The Apollo data is extensive, but not sufficiently populated to spend a lot of time looking for statistical significance. My assumptions of ingress/egress time and minimum duration acceptable for going inside or outside were just that - assumptions - and you are encouraged to draw the lines wherever on the plot you think they best belong. Finally, while we talk about using Stagecoach like an LRV, there are a lot of options enabled by a lightweight pressurized rover that would encourage a different profile of driving and surface exploration than was adopted in Apollo. Indeed, that's really the point I would like to emphasize from this analysis: for a single day-long EVA, other than the long drive out to an exploration site and back from it (assuming you don't make a lot of intermediate stops along the way), the only time you are likely to spend even a minimal effort to go inside is during the initial and final traverses. You could elect to take a break at lunchtime and go in to enjoy your sandwich, but other than that you would probably spend the entire day in your suit. (I would like to encourage Mike Gernhardt and Dean Eppler to comment on this conclusion from the standpoint of their saturation diving and field geology experience.)

In my opinion, this quicky analysis puts to rest the idea of a pressurized rover as nothing more than a more "luxurious" LRV. If we're going to pay the marginal developmental and transport costs of building and flying Stagecoach (as compared to a pressurized rover), we need to fit it into a unique niche of its own. For example, it might be worthwhile as a way to avoid the impact of the Apollo walk-back requirement. (Which, of course, says that it better have a life support system independent of the on-suit backpacks.) Extending the on-site EVA time by providing life support on the way there and back and allowing a full 6-8 EVA hours at the exploration site (further augmented by a rest break inside at lunch) would be an augmentation to the LRV paradigm, and would allow a systems trade study to decide if the added capability justifies the additional costs. Similarly, greater augmentations could be provided by a routine overnight capability, which would drive towards a bigger and more expensive vehicle with more capabilities.

All in all, Stagecoach is shaping up into an excellent point design, but I worry that we haven't spent enough time thinking critically about its "niche" in the exploration scenario. While I hope we continue to delve deeper into its design, it would be more satisfying (in my humble opinion, at least) to use the brainpower and freedom of a "blue sky" activity to explore the entire spectrum of surface exploration, and (in a similar manner to our Stagecoach activity) examine concepts and operational modes that may not have been looked at before, or at least in any detail.

Between the moon and Mars, we have two whole planets to explore. The surface area of Mars is (surprisingly close to) nearly the same as the land area of Earth. Even the moon is 38 million square kilometers, about 1/4 the area of Mars or the same area as North and South America. How can we explore something more than the 10 km around our lunar outpost? How can we extend human presence 50 km away, or 500 km, or 5000 km?

[Self-plug warning:] These are issues I have posed to my senior design classes for many years now, and you might be interested in some of the concepts they have come up with. The overall index page for past studies is

http://spacecraft.ssl.umd.edu/academics/484.archives/484.archive_index.html

Below are links to PDF summaries of some of the most applicable studies:

Minimum size pressurized rover (100 km range; 7 day endurance; crew of 2)
http://spacecraft.ssl.umd.edu/academics/484.archives/2005.SPRITE.RASCAL_paper.pdf

EVA support rovers
http://spacecraft.ssl.umd.edu/academics/484.archives/2001.BURRO.HEDS-UP_paper.pdf

5000 km range Mars rover
http://spacecraft.ssl.umd.edu/academics/484.archives/1998.MERLIN.HEDS-UP_paper.pdf

Lunar human circumnavigation (in a single lunar day using solar power)
http://spacecraft.ssl.umd.edu/academics/484.archives/2000.Magellan.HEDS-UP_paper.pdf

Antipodal range Mars transport (actually a blimp, but includes trade studies of alternatives for 10,000 km-class range for Mars)
http://spacecraft.ssl.umd.edu/academics/484.archives/1999.MARV.HEDS-UP_paper.pdf

The point here (other than trying to generate hits on my web site) is that there are a lot of potential missions beyond Apollo EVA range, and I wouldn't want to artificially constrain our considerations to near-term short-range systems.

Along a similar vein, I was in a meeting with Jim Garvin last Friday, and he gave a great presentation about Apollo and Mars exploration with implications for human exploration. One of the things which struck me were the pictures of wonderful crater sites a few meters away from the Apollo astronauts, which they couldn't go into or even approach the rim walls of because of safety concerns. He also discussed the opportunities lost to the rigid walk-back criteria, which limited both total traverse distance and opportunities for extended operations. There are some desirable activities (deep coring, for example) that needs extensive equipment and (perhaps) larger EVA crew sizes, and some things that can be easily done by a single individual.

It seems to me that almost everything you need to categorize a particular approach to EVA operations can be localized in four dimensions: distance, duration, terrain, and payload (including both number of crew and size of cargo). What I would love to do (and what might make sense for a "blue sky" team looking for innovative EVA systems) would be to set ambitious upper limits to the four dimensions, and look for more innovative concepts like Stagecoach that occupy a region in this design space, and then do some trade studies. As you go from a 10 km range to a 1000 km range, and from a duration of hours to days or weeks, what is the optimum place to transition from unpressurized to pressurized rovers? Are pressurized rovers "one size fits all", or should you be thinking about a mixed fleet approach with large and small ones? If we want to safely travel down a 45° slope into a lunar rille or impact crater, should that vehicle be the pressurized rover that brought you there, a short-range unpressurized rover, or even a specialized legged climbing/rappelling machine? What's the lunar equivalent of a helicopter, and how would that fit into the mix?

[Brief aside: I think the best information we could get on a "mixed fleet surface transport system" for a lunar outpost or Mars base might be from the NSF Antarctic operations. They use C-130s, helicopters, a variety of snowmobiles (unpressurized rovers), and enclosed cabin tracked vehicles (pressurized rovers). I suspect the time to get into and out of thermal garments in the Antarctic might be comparable to advanced suit ingress/egress, and it would be interesting to find how how they've evolved their approach to when to go in and out, and what type of vehicle is used for what type of mission. Robert Trevino from JSC spent some time in the Antarctic a number of years ago looking at their solutions to operational issues like these, and might have some valuable insights.]

[Brief aside to the brief aside: We're "EVA Blue Sky", right? Why am I thinking "inside the box" and limiting this to rovers? How about flying vehicles? Self-repairing suits? Force-augmented suits? Flying suits? Maybe there's a fifth dimension of the design space for how directly the human is coupled to the technology? If we get back to fundamental principles of getting the human to remote locations on other planetary surfaces for science and exploration, what concepts could we shake out if we don't focus just on transportation?]

My bottom line (and I apologize for running on at the keyboard, but I really love this stuff) is that I hope we get a chance to make contributions at all of these levels - innovative concepts throughout the EVA design space, preliminary validation through point designs like our activities to date on Stagecoach, and systems trade-off analyses that start to identify the most beneficial regions of design space to populate with new technologies. I don't mean to step on your toes, Ken, and I've probably already outlined $20M or so in design activities, but this is the type of question I've been working toward in my lab for many years, and I'd love to see what the brainpower of this group could come up with. I'll happy to do whatever you want, though. (I'll reiterate the tradition of the USAF Thunderbirds, whom I understand end each briefing with everyone saying, "Damn glad to be here!")