Apollo to Artemis: Mining 50-Year Old Records to Inform Future Human Lunar Landing Systems

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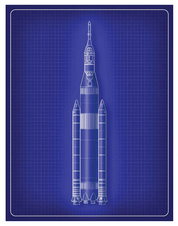
Background

Under the Artemis lunar exploration program, NASA is committed to landing American astronauts on the moon by 2024. While NASA's new Space Launch System rocket and Orion capsule will carry astronauts from Earth to the Gateway, the human lunar landing system has not yet been fully defined. As in the Apollo program, there are concerns for vehicle weight and internal volume such that seats may not be desirable, and standing during lunar descent and ascent may be a preferred engineering solution. With such a design, astronauts will experience $+G_Z$ (head-to-foot) accelerations during capsule accelerations, and it is unclear whether spaceflight deconditioned astronauts can tolerate these.

Apollo astronauts stood during lunar descent and ascent, and the data contained in the early program records for those missions represent a unique resource that may provide insights to the cardiovascular stress associated with this human landing system design.

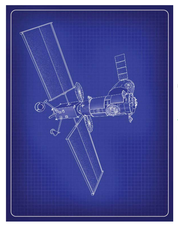


Space Launch System: ***Design Complete***

https://www.nasa.gov/specials/artemis

Orion Capsule: ***Design Complete***

https://www.nasa.gov/specials/artemis



The Gateway: ***Design Complete***

https://www.nasa.gov/specials/artemis

Lunar Landers: ***Seeking Proposals***

https://www.nasa.gov/specials/artemis

Objective

The objective of this work was to obtain cardiovascular data during the lunar descent and ascent phases of the five Apollo missions that landed on the moon.

Methods

Epidemiologists from the Lifetime Surveillance of Astronaut Health program reviewed more than 5,000 non-digitized pages of 50-year old medical and mission information from the Early Program Medical Records Inventory archived at the Lyndon B. Johnson Space Center. These data included:

- Astronauts' medical records
- Stand test results
- Lower body negative pressure test results
- Flight surgeon reports
- Biomedical engineer reports
- Medical debrief transcripts
- Mission-specific events

Placeholder for better picture of records

Results

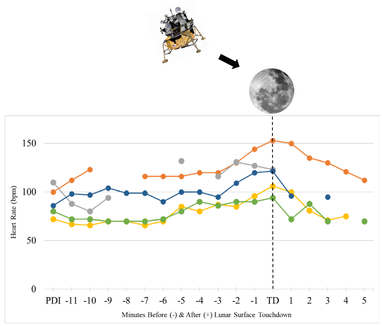


Figure 1: Heart rate response from Apollo Commanders from powered descent initiation (PDI) to touchdown (TD) on the lunar surface.

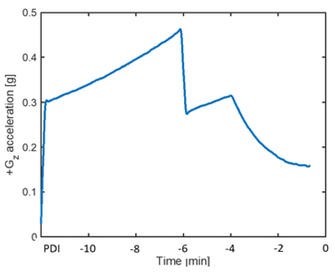


Figure 2: Model of G_Z loads, beginning at 0-G during lunar orbit, peaking above 0.4-G, and ending at 0.16-G on the lunar surface.

The only data systematically collected were Commanders' heart rates. Figure 1 shows the heart rates for each of the five Apollo astronauts during the lunar surface descent phase. The mean heart rate across these missions was about 96 beats per minute (bpm; range: 66 – 144).

Heart rates remained stable until the time of peak G-load when some Commanders appeared to experience a moderate increase of 10 – 20 bpm; however, heart rate did not decrease substantially when G-loads decreased (Figure 2). The mean heart rate increased, peaking at nearly 120 bpm close to touchdown (range: 94 – 153).

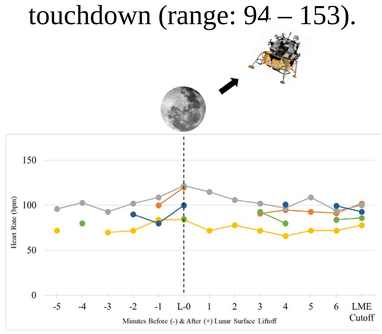


Figure 3: Heart rate response from Apollo Commanders before and during ascent from the lunar surface to lunar module engine (LME) cutoff.

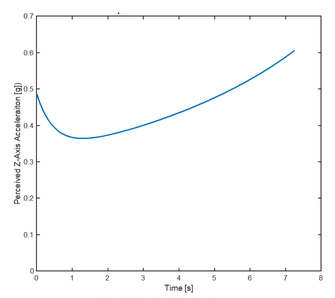


Figure 4: Model of the G_Z loads, beginning at engine ignition.

During the lunar ascent phase, the mean heart rate across the five Apollo astronauts was about 88 bpm (range: 70 – 109) (Figure 3). While there was an initial heart rate spike at liftoff, the average heart rate response did not increase over time.

The mean heart rate measured during the ascent phase was similar to that measured during the initial part of the descent phase (0.3 to 0.4-G), but it was about 20 bpm lower than during the latter portion of the descent phase – when G-loads were lower. That is, unlike descent, the heart rate response to ascent did not increase over time.

While the initial spike in heart rate (10-20 bpm) likely included orthostatic and psychological contributions, that the heart rate remained stable thereafter suggests that even though G-load increased, the effects of the stress of ascent did not increase further.

Almost all crewmembers reported experiencing symptoms of the cephalad fluid shift (e.g, full-headedness) during the adaptation to spaceflight, which was treated by using nasal "drops" to manage congestion symptoms until the symptoms subsided. However, the majority of astronauts reported no issues with nausea, vomiting, or disorientation during their mission.

Limitations

- Onboard the Apollo lunar module(s), one set of electrocardiogram sensors was available for biomedical data transmission.
  - Therefore, only the heart rates of the Commander were recorded.
- No blood pressure data or baseline information were recorded.
- Due to poor sensor quality and adhesives, there were periods of complete data loss.
- Very little biomedical data on the Lunar Module Pilot was available.
- No standardization of reporting from the biomedical engineers or flight surgeons across the Apollo missions.
  - This lack of consistency meant that the timing of the data from the biomedical engineer and flight surgeon logs was unlikely to be exact.
- The majority of these records were either handwritten or poorly copied, which impeded their interpretability.

Placeholder for example of the logs (no PII)

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Conclusions

Without blood pressure measurements, it has not been possible to differentiate orthostatic from psychological drivers of heart rate; yet, it is clear that the cardiovascular stress associated with landing on the moon is not small. However, unlike descent, the heart rate response to ascent did not increase over time.

The yield of data from this effort was not as complete as hoped; however, the data mined provided a unique source of information that otherwise would not have been available.

Continued efforts to extract data from historical sources may help the agency in assessing risks associated with future endeavors.

Acknowledgments

The authors would like to thank Tami Bradley and Marlana Jones for their assistance with pulling paper records from the Early Program Medical Records Inventory.

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