

Design Description and Initial Characterization Testing of an Active Heat Rejection Radiator with Digital Turn-Down Capability

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ABSTRACT

NASA's proposed lunar lander, Altair, will be exposed to vastly different external temperatures following launch till its final destination on the moon. In addition, the heat rejection is lowest at the lowest environmental temperatures (0.5 kW @ 4K) and highest at the highest environmental temperature (4.5 kW @ 215K). This places a severe demand on the radiator design to handle these extreme turn-down requirements. A radiator with digital turn-down capability is currently under study at JPL as a robust means to meet the heat rejection demands and provide freeze protection while minimizing mass and power consumption. Turn-down is achieved by independent control of flow branches with isolating latch valves and a gear pump to evacuate the isolated branches.

A bench-top test was conducted to characterize the digital radiator concept. Testing focused on the demonstration of proper valve sequencing to achieve turn-down and recharge of flow legs. Test results indicate the digital radiator concept to be feasible based on extrapolation to flight-like conditions. A thermal/fluid model was developed to determine the required flow rates, number of operational flow branches, etc. Future work is necessary to test at environmental conditions where an empirical freeze assessment can be conducted.

INTRODUCTION

National Aerospace and Space Administration (NASA) is planning to send astronauts back to the moon as part of its Exploration Program. One of the lunar missions in this program is Altair Lunar Lander which will be launched on an Ares launch vehicle and land in the polar region of lunar surface. Altair will carry three astronauts and will travel for four days before it lands on the lunar surface. The total duration of stay on Moon is about six months.

One of the thermal control challenges of the Altair Lander is varying waste heat rejection capability that is required during its mission. The heat rejection capability varies from 0.5 kW to 5 kW, further the lower heat rejection is needed during its coldest environment of 4 K while the highest heat rejection is needed during its operation in the warmest environment of 215 K. The heat rejection requirements for the Altair Lander is given in Table 1.

As part of the selection process for a variable heat rejection radiator, a detailed trade study was conducted in 2007. Several radiator technologies were traded off to see which ones met the Altair requirements shown in Table 1 for the different phases of the mission. The goal of the trade-off studies was to select a candidate radiator technology that required minimum amount of electrical power, had the lowest mass, and could have a robust design yet flexible in operation.

Table 1. Altair Mission Power Rejection Requirements

Mission State	Power Available [W]	Power Used [W]	Power Rejected [W]	Equivalent Sink Temp [K]
LEO w/ Earth Departure Stage – 4 days	1500	200	1300	188 K (TBC)
Cruise w/ Orion – 4 days	1500	1000	500	4
Pre-LLOI – 4 hours	1500 to 5000	1000 to 500	500 to 4500	4K - To be calculated
LLO – 1 day	5000	500 min	4500 max	To be calculated
Surface – 7 days	5000	500 min	4500 max	215/188K

The two driving power rejection requirements are highlighted in bold – during cruise when the heat rejected is 500W to a 4K environment and on the surface when the maximum heat rejected is 4500W to an equivalent surface temperature of 215K. Additionally, the temperature drop across the radiator is not to exceed 20K.

The radiator technologies considered for trades were 1) mechanical louvers, 2) electrochromics surface coating, 3) heat switches, 4) vapor compression heat pumps, and 5) digital radiators.

The trade study results indicated that the digital radiator technology offered several advantages over the other choices. These advantages are: 1) lower mass and power, 2) flight-proven technology with isolation latch valves, 3) ability to fine-tune the heat rejection over a range of desired values, which allows incorporation of late changes in the power budgets. This is a very important feature as the reality of spacecraft power budgets always indicate changes till very late. 4) ability to isolate a branch in the event of micrometeoroid impact which could potentially lead to loss of mission if not isolated. The mission could survive at the cost of degraded performance.

The main features of the digital radiator are described in the following section.

DIGITAL RADIATOR (DR)

The Apollo mission had used a Stagnation Radiator design which caused the radiators to gracefully reduce the heat rejected by allowing the fluid in the outer lines to become more viscous as it got colder and effectively reducing the flow rates. This feature was simple to implement, but the design phase was more complex. The Apollo mission had much more benign environments, having to deal with only a 1:1.6 turn-down

requirement vs the Altair's 1:10^[3]; in addition there was no requirement to reject heat at the higher temperatures as for Altair. JSC is currently evaluating a stall-resistant radiator with low temperature stalling characteristics and low susceptibility to premature stalling^[1]. However, it has proven to be very difficult to analyze; testing of the radiators have shown that the destalling takes much longer (around 4-5 hr) versus predicted values of 17 to 37 minutes made by JSC and a contractor (verbal discussions with Ryan Stephan). Given this level of uncertainty, there might not be sufficient time for the radiator to transition to the higher heat rejection rates without active heating control as required while transitioning from cruise to Pre-LLOI which is scheduled to be within 4 hr. This uncertainty in combination with uncertainties in the actual power levels suggests an alternate more predictable variable radiator is desirable.

The JPL Digital Radiator builds on the Stagnation Radiator concept with the existence of multiple parallel legs. However, the concept deviates from that point. The key idea behind the Digital Radiator is to provide variable heat rejection capabilities by allowing the isolation of the flow segments not needed when the heat rejection is low, and allowing flow in all segments when the heat rejection is high. This is achieved with a combination of isolating latch valves on either side of the flow branches and a gear pump to evacuate the fluid from legs which are not needed for heat rejection.

The DR system utilizes a single phase centrifugal pump to circulate the fluid over the electronics and the radiator legs. An accumulator is sized to accommodate all the fluid drained from the legs as well as to accommodate volume changes due to temperature variations. The concept is shown in Fig 1.

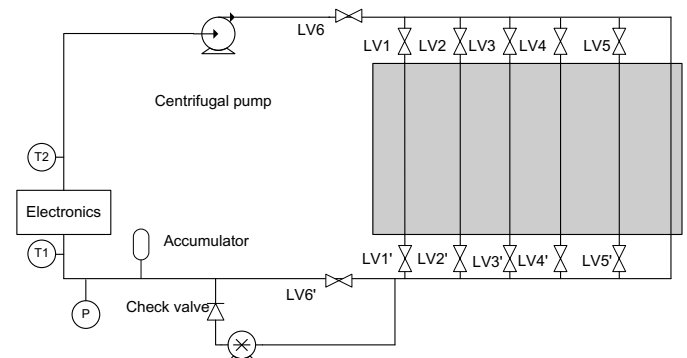


Figure 1. Schematic of Digital Radiator system

In addition to the centrifugal pump, a gear pump is provided to drain the fluid from the branches not needed. The gear pump is activated only when the fluid is to be drained from a/multiple leg(s). In addition to the variable legs (only 5 shown for simplicity) an additional fluid leg which is always "on" is provided to ensure no freezing occurs in the last leg. This will be illustrated below.

The actual operation of the system to accommodate a transition from a high heat rejection state, when all the branches are open for rejection, to a lower heat rejection state is as follows:

1. Turn off centrifugal pump
2. Isolate radiator from remaining system with LV6 and LV6' and close all branch valves LV1, LV1' to LV5, LV5'
3. Open lower latch valve LV5'
4. Turn on gear pump to evacuate last branch. In this process all the fluid upstream (manifold) and downstream of LV5 as well as the fluid in the "always on" branch will be evacuated.
5. Close LV5' and open all other latch valves, except LV5 (which isolates the unwanted branch only).
6. Turn on centrifugal pump to start system up again.

The check valve downstream of the gear pump ensures that the fluid flow from the gear pump is only permitted when evacuating the lines.

The variable heat rejection state changes will be controlled by the flight software which can be programmed to include fault protection as well.

DIGITAL RADIATOR DESIGN TRADES

Besides the waste rejection requirement of the radiator, a few assumptions are made for the Altair radiator. A cartoon of the radiator mounted on Altair is shown in Figure 2. Some of the key assumptions made for the Altair radiator are the following:

- The radiator is in two halves and each half mounted on opposite sides of the Altair Lander
- The baseline working fluid is HFC-245fa (or R-245fa) and the backup fluid is HFE-7000
- The approximate dimensions of each radiator is 2.5 m X 4.5 m
- The radiators are body mounted and only one side of each is exposed to the cold sink
- The radiator is single-fault tolerant for a puncture of any one tube

A thermal/fluid model was developed with Thermal Desktop for conducting the trades as well as to determine the radiator performance under the different environments. This also allowed the capability of studying different trades for optimizing the mass and power requirements.

The various radiator configuration parameters currently being traded off are the following:

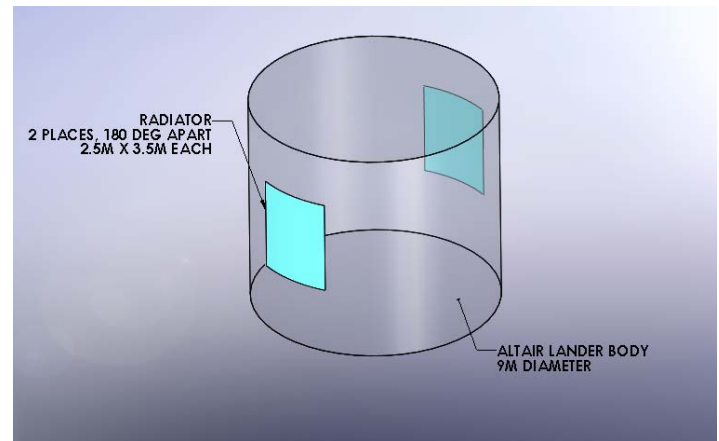


Figure 2. Digital Radiator Layout on Altair Body

- Number of parallel tubes in the radiator and orientation of radiator
- Number of branches of tubes (each branch with two valves) and number of tubes in each branch
- Radiator wall thickness
- Tube outer diameter: 1/4", 3/8", 1/2", 3/4", and 1"
- Radiator aspect ratio
- Working fluids and mass flow: HFC-245fa and HFE-7000
- Fault tolerance

In order to reduce the number of latch valves, the flow legs can be bunched together to reflect the heat rejection requirements for the different phases. As an example, the Digital Radiator might look something like in Fig 3.

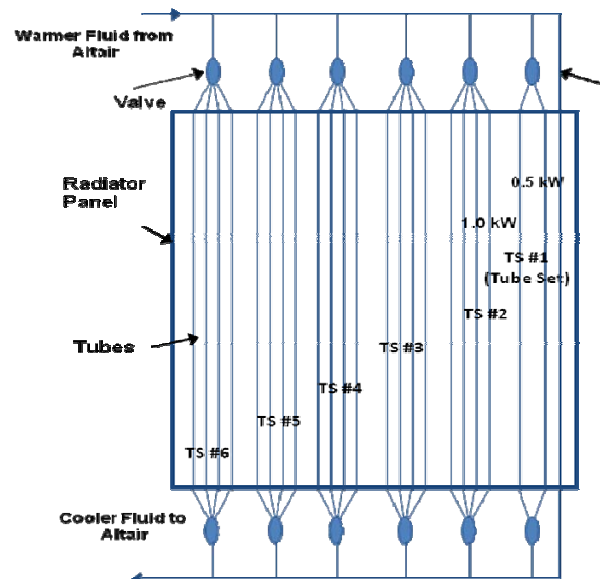


Figure 3. Digital Radiator with legs manifolded for mission phases