Flight Experiments of Planetary Gravitational effects on Thermosyphon Flooding Limits. M.A. Gibson[1], D.A. Jaworske[2], J.L. Sanzi[3], D. Ljubanovic[4], E.A. Sechkar[5], [1,2] NASA Glenn Research Center ([1]marc.a.gibson@nasa.gov, 21000 Brookpark Rd.; Cleveland, OH 44135), [3]SEST Inc (18151 Jefferson Park Rd. Ste. 101; Middleburg Heights, OH 44130), [4]Gilcrest Electric (570 Ternes Ln; Elyria, OH 44035), [5]ASRC Aerospace Corp. (21000 Brookpark Rd.; Cleveland, OH 44135)

Introduction: Fission Power Systems have long been recognized as potential multi-kilowatt power solutions for lunar, Martian, and extended planetary surface missions. One of the major components of the power plant's latest heat rejection system are titanium water thermosyphons. Multiple thermosyphons are typically used in fission power systems to assist in spreading the waste heat from the power converter over large areas of radiator surfaces. The thermosyphons near-isothermal heat conductance is achieved by a two phase process between evaporator and condenser which can be tailored to a wide range of operating temperatures by selection of the correct working fluid and thermal design. Thermosyphons, unlike heat pipes, rely solely on gravity to assist the fluid from the condenser back to the evaporator during the two-phase heat exchange process. Thermosyphons have multiple limits related to their maximum heat transfer capacity with the most common being condenser flooding. This limiting phenomenon occurs when the vapor velocity leaving the evaporator restricts the condenser fluid from returning to the evaporator. This restriction in the working fluid's mass flow rate from condenser to evaporator creates a stall condition in the heat transfer process. Once stalled, or flooded, the evaporator dries out and its temperature increases which leads to further worsening conditions. Condenser flooding is substantial to the power system in the fact that recovering from the event could require a cool down and possible restart.

Understanding the validity of thermosyphon flooding, it was essential to govern research that aimed at understanding the phenomenon in Reduced Gravity Environments (RGE), applicable to planetary surface power systems. Research investigations into reduced gravity flooding limits led only to analytical models that took into account gravity but failed to prove it through experimentation. This experiment was designed to set precedence on determining the flooding limitations of thermosyphons in RGE. The RGE would be obtained using parabolic flights on the Zero G Corporation's G-Force 1 aircraft.

Experimental Design: An array of 12 (24" long X 0.25 inch O.D.) titanium water thermosyphons were built using electrically heated evaporators and forced air cooled condensers (figure 1). The thermosyphons were scaled in a manner such that the required electrical power to cause flooding was reduced, allowing multiple units to be fed by the aircraft's limited power supply. The heaters as well as the forced air cooling were controllable, allowing the operator to adjust the thermosyphons total heat addition and subtraction.

The data acquisition and control system was built from a National Instruments PXI real-time platform and Labview software. The user interface screens and control algorithms were specifically designed to allow the test operator a comprehensive display of all twelve thermosyphons and their critical parameters. Careful attention was given to the overall system design to allow the test operator quick control action during the short periods of parabolic maneuvers.

Figure 1: Thermosyphon Array in RGE Flight Rack

Modeling: Flooding correlations relating to thermosyphons have been studied in detail by numerous experts. After spending multiple days in the lab studying the flooding phenomenon, it is evident that additional work is still needed to produce a moderately accurate predictive model that accounts for geometry, fluids, gravity,…etc. Shatto, Besly, and Peterson [2] provided a summary on experimental investigations of closed two-phase thermosyphons using multiple sources. All of the sources were studied and compared with data from both 1g and reduced g experiments with Faghri et al [1] and Tien and Chung[3] being selected as the two baseline models for this investigation.

1g Testing: A significant amount of 1g testing occurred at the heat pipe research lab at NASA's Glenn Research Center to fully understand the experiment operations, tailor the control system for parabolic flights, and compare the results with the correlation models. The 1g test results are shown in figure 2 with total heat transfer compared to the thermosyphon's adiabatic temperature. The adiabatic temperature of each thermosyphon was achieved by controlling the ratio of evaporator heating to condenser cooling, thus giving a large range of flooding data for expanded correlation. This data, when used correctly, provides a useful upper design limit for the maximum amount of heat a thermosyphon can transfer at its designed steady state temperature range.

The 1g results as a whole fell in between the correlation models from Faghri et al [1] and Tien and Chung[3]. During experimentation and data reduction it was evident that all twelve thermosyphons, although identical in design, produced different flooding results. Additionally, it was found through testing that each individual thermosyphon by itself could produce different flooding results based on the test procedures and rate of heat transfer.This was an important result because all of the data from the correlating models used single thermosyphon experiments and wouldn't have been able to see the effects of manufacturing procedures, fluid charge, and non-condensable gases that have become important variables in flooding limits and their correlating models.

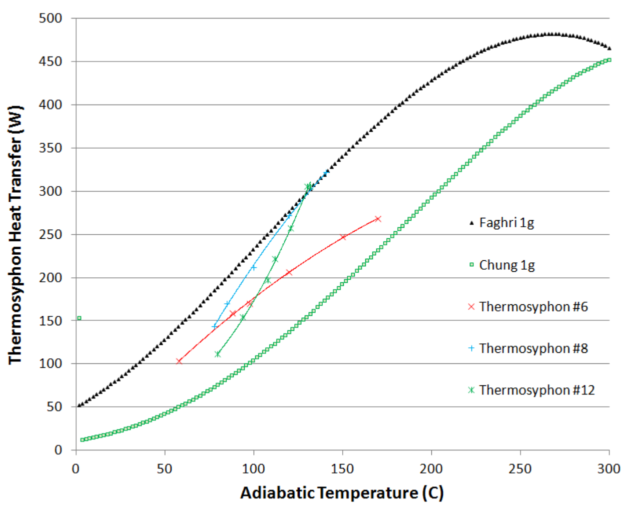

Figure 2: Thermosyphon Flooding and Correlations at 1g

It is hypothesized that the variability of thermosyphon fabrication on top of non-standardized test procedures has led to the same variability and confusion in correlation models. Tightening the data through improved test procedures and heat pipe manufacturing at 1g was going to be crucial before flying the experiment in RGE.

Parabolic Flight RGE: The first of two flight campaigns took place on Sept. 19-22, 2011 with the second to take place in March 2012. During the first flight campaign 160 parabolas were flown in 4 days of flights: 48 lunar, 12 Martian, and 100 zero. Experience from the first flight campaign was pivotal in gathering RGE flood data and improving the experiment for the second flight campaign. Data correlations and flight results will be shared during the presentation portion of this paper.

References:

[1] Faghri, A., Chen, M. M., & Morgan, M. (1998). 1988 National Heat Transfer Conference (pp. 291-303).
[2]Shatto, D. P., Besly, J. A., & Peterson, G. P. (1996).. 31st Thermophysics Conference. AIAA, 96-1832.
[3]Tien, C. L., & Chung, K. S. (1979). AIAA , 78-382