VENUS ANALOG TESTBED FOR RASP AND SAMPLE ACQUISITION TESTING G.H. Peters[1], G.S. Mungas[1], S.D. Murray[1], J. Polk[1], R. Lindemann[1], L. Beegle[1], [1]Jet Propulsion Laboratory, California Institute of Technology, M/S 306-336, 4800 Oak Grove Dr., Pasadena CA, 91109; ghpeters@jpl.nasa.gov)

Introduction: Similar in size Venus has been called Earth's sister planet. However with an atmospheric pressure of 90bar and surface temperatures exceeding 460ºC, the conditions on the surface of Venus are some of the most extreme in the solar system. Our desire to go to learn more about our neighboring planet is pushing the envelope for sample handling technologies. The Venusian environment is extremely hazardous to hardware. For in situ missions to Venus one of the main challenges will be acquiring samples, delivering and analyzing them before the spacecraft succumbs to the environment.

During a RASP interaction with a solid sample, the high speed (1000+ rpm) RASP cutting bit imparts a large velocity component to RASPed particles that is approximately the tangential tool velocity at the RASP cutting interface. While RASPing in a vacuum or low pressure gas (i.e. Mars Phoenix ISAD RASP as shown in Fig. 1), the resultant cutting particle trajectories are very close to ballistic. In denser atmospheres, the atmospheric fluid can significantly alter particle flow characteristics. In fact, in preliminary RASP tests in water, the viscous fluid interactions with the RASP bit generated very strong fluid vortices in the vicinity of the RASP bit that dominated the transport of RASPed particles. Based on these preliminary results, we anticipate that in the viscous (high temperature CO_2 near critical point) dense Venus atmosphere, the fluid interactions with the RASP bit will play a significant role in the collection and delivery of RASPed cuttings. In fact, RASP bit and sample collection housing designs that incorporate Venus atmospheric fluid dynamics considerations may likely augment the ability to collect sample including unconsolidated soils where the RASP is not actually performing significant cutting. In the absence of these considerations, there is a strong possibility that residual vorticity in the Venus atmosphere local to the RASP bit will complicate particle settling and collection in a desired collection region.

Based on these observations, we are in the process of assembling a test facility for aiding in the design and testing of a RASP system under simulated Venus conditions. To support RASP sample handling testing in parallel with high temperature actuator development, we have identified a lower temperature fluid analog solution for simulating the RASP cutting particle trajectories and behavior in the Venusian environment.

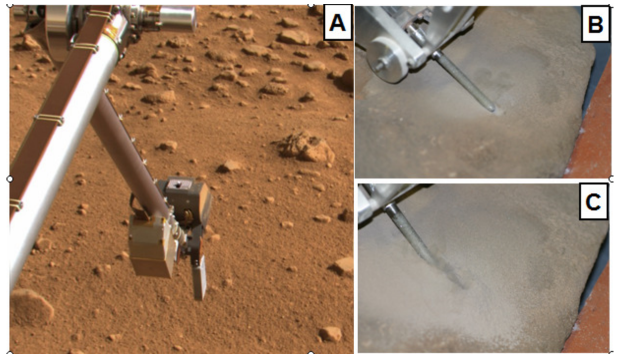

Figure 1 – RASP deployed on Mars Phoenix mission (Photo credit of NASA/JPL). Pneumatically actuated prototype RAPS system cutting into Basalt rock under earth atmospheric conditions. *Left*: Beginning the RASP cut. *Right*: After ~1 minute the RASP bit has plunged beyond 2cm depth.

Analog Environment Design: The fluid acceleration on a spherical particle (analytical approximation to RASP cutting) can be derived [1]:

$$\vec{a}_{particle} = \frac{C_d\, A_{particle}}{2\, m_{particle}} \rho_{fluid} \left|\vec{v}_{fluid} - \vec{v}_{particle}\right| \left(\vec{v}_{fluid} - \vec{v}_{particle}\right) + \vec{g}$$

$$For \quad \mathrm{Re} \equiv \frac{\rho_{fluid}\left|\vec{v}_{fluid} - \vec{v}_{particle}\right| d_{particle}}{\mu_{fluid}} < 0.5 \quad \Rightarrow C_d = \frac{24}{\mathrm{Re}}$$
$$else \quad C_d \approx 22.1\,\mathrm{Re}^{-0.592} \tag{1}$$

where the empirical curve fit for Re>0.5 has been initially curve-fit from with a correlation coefficient of 0.979. To provide an adequate testbed for ultimately conducting simulated RASP testing in a Venusian atmosphere, an analog test fluid whose density, ρ_{fluid}, and dynamic viscosity, μ_{fluid}, closely matches the Venusian atmosphere should be chosen. Note that for Re>0.5, $\left|\vec{a}_{particle}\right| \propto \rho_{fluid}^{\;0.408} \mu_{fluid}^{\;0.592}$ whereas for Re<0.5, $\left|\vec{a}_{particle}\right| \propto \mu_{fluid}$. Most of the initial RASP bit interactions with a medium will result in Reynolds numbers of the initially accelerated particles that are >>0.5. After deceleration through fluid drag with the local atmosphere, residual particles entrained in the vortical boundary layer flow of the RASP bit will tend to have Reynolds numbers <0.5.

Table 1. Argon Simulant Comparison to Venus Atmosphere Conditions

	Pressure		Temp	Viscosity	Density	Argon to Venus Particle Deceleration Ratio Error	
	MPa	*psia*	*C*	*μPa·s*	*kg/m^3*	*Re<0.5*	*Re>0.5*
Venus Atmosphere	9.1	1318	470	?	?		
CO_2	7.5	1088	427	32.13 [2]	56.7 [3]		
CO_2	7.5	1450	527	35.46 [2]	49.2 [3]		
CO_2	10.0	1088	427	32.39 [2]	75.5 [3]		
CO_2	10.0	1450	527	35.66 [2]	63.3 [3]		
Assumed Analog Venus Atmospheric Properties	9.1	1318	470	33.71	64.2		
Argon 1	9.1	1318	20	20.96 [4]	161.0	0.62	1.10
Argon 2	**9.1**	**1318**	**200**	**32.23 [4]**	**92.3**	**0.96**	**1.13**
Argon 3	9.1	1318	400	41.15 [4]	64.8	0.89	0.94

Table 1 compares the fluid properties and the error ratio in particle acceleration of high pressure/high temperature CO_2 [2] at Venus conditions as compared to an Argon analog fluid as a function of Argon temperature and pressure.

Status and Future Work: In our proposed work, we'll experimentally evaluate RASP cutting bit and sample handling interactions in the argon and eventually full Venus simulation chamber. We'll also investigate the development of a 2D Fluid Dynamics simulation tool that we can correlate with our experimental results and use for extrapolation of sample handling processes to sampling system geometries that may eventually be needed for flight. A large part of our effort went towards design and assembly of the Venus Analog Testbed (VAT). Constructed by a boiler manufacturer, the VAT is capable of 1500psi and can be operated at elevated temperatures of up to 200ºC. Pressure is provided by pressurized gas supply and the heating is provided from a separate oil heater unit that circulates hot fluid through the outer jacket of the VAT.

The RASPbit and sawing action motors are poweded by pneumatic motors to avoid the proplems associated with the thermal environment inside the chamber. In the future we'll incorporate high temperature flight-like actuators for powering the RASP.

Acknowledgements: The research described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was supported under internal RT&D funding.

References: [1] J. A. Roberson and C. T. Crowe. (1993) Engineering Fluid Mechanics. [2] A. Fenghour, W. A. Wakeham, V. Vesovic. (1998) *J. of Phys. and Chem. Ref. Data, 27*, 31-44. [3] R. Span and W. Wagner. (1996) *J. Phys. Chem. Ref. Data*, *25*. [4] R.C. Weast et. al. (1974) CRC Handbook of Chemistry and Physics.

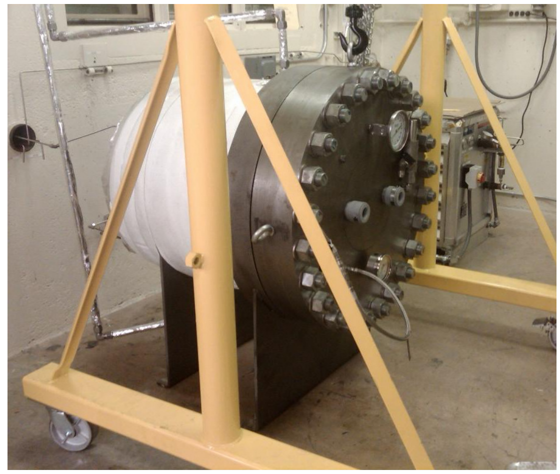

Figure 5. Venus Analog Testbed for supporting RASP and Sample Acquisition Testing in Venus Conditions

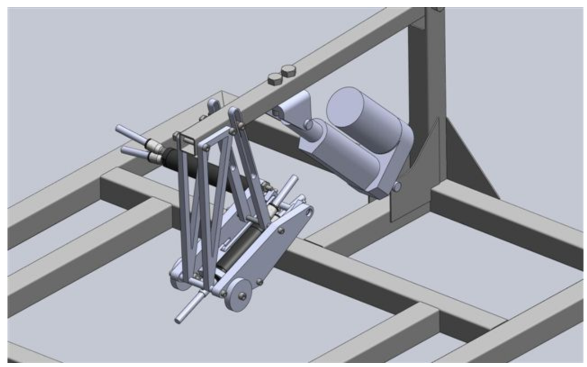

Figure 6. Venus Research RASP system model

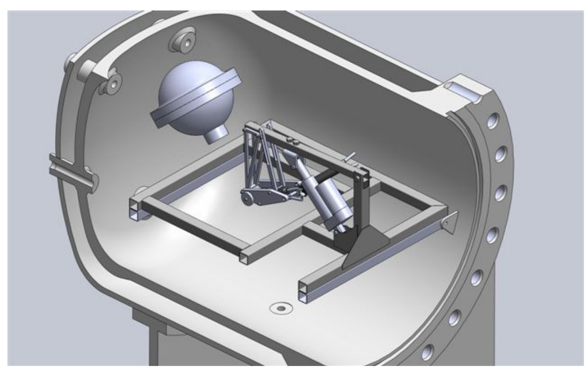

Figure 7. Venus Analog Testbed Annotated Model showing the RASP system placement inside the VAT