WIND-FLOW OVER SEIF DUNE MODELS: IMPLICATIONS FOR MARS. H. Tsoar[1], G. R. Wilson[2], R. V. Coquilla[2], B. R. White[3], and R. Greeley[4] [1]Ben Gurion University of the Negev, Department of Geography and Environmental Development, Beer Sheva, 84105, Israel (tsoar@bgumail.bgu.ac.il), [2]Arizona State University, Department of Geology at NASA Ames Research Center, MS 242-6, Moffett Field, CA 94035 (gwilson@humbabe.arc.nasa.gov), [3]University of California, Davis, Department of Mechanical, Aeronautical and Materials Engineering, Davis, CA 95616 (brwhite@usdavis.edu), and [4]Arizona State University, Department of Geology, Box 871404, Tempe, AZ 85287 (greeley@asu.edu).

Introduction: In 1971 Mariner 9 revealed the presence of sand dunes on Mars mainly in the Hellespontus region [1]. Viking Orbiters 1 and 2 have revealed, through their high resolution images, a huge dune field that covers much of the north polar region [2] and many isolated sand patches over the planet, especially within old degraded craters west of Hellas Planitia.

According to the GCM predictions the winds on Mars are probably bi-directional [3], this is also indicated by the orientation of dune slip faces and wind streaks [2]. Similar wind directions on Earth have produced more complicated dune morphologies of seif and star dunes which are widespread over the world deserts [4]. Recent works indicate some rare occurrence of linear (seif) and star dunes on several locations on Mars from images that show indistinct shapes after magnification [5,6]. It is important to determine whether the rareness or apparent absence of seif and star dunes on Mars is related to age, image resolution, different mechanisms of formation and movement, or to some other reasons.

Objective: It is the objective of this study to look at wind flow-fields around seif dune models in the wind tunnel. Detailed work on a seif dune in the Sinai desert has demonstrated the importance of the lee side separation vortex in the form and development of seif dunes [7,8]. Wind that encounters the dune obliquely, at acute angle of incidence (25^{o}-45^{o}), is deflected on the lee side of the dune and flows along that side parallel to the crest line.

There are many types of dunes on Earth, with longitudinal (seif) and star dunes as the dominant types [4]. On Mars the crescent barchans and their varieties seems to be the only types found [2]. One possible explanation that can be tested both theoretically and empirically is the lee side effect of the separation eddies downwind of dunes. It is the objective of this study to measure surface shear stress and wind direction on the wind-ward and lee side of a seif dune model as a function of Reynolds number and angle of attack (Figure 1).

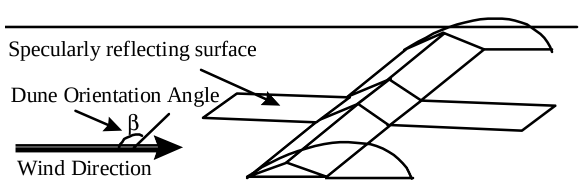

Figure 1. Wind tunnel configuration.

Experiment: This study utilizes a new and innovative testing technique to measure mean skin-friction on wind-tunnel models that was previously not easily possible [9]. Termed the fringe-imaging skin-friction (FISF) method, it utilizes lubrication theory to relate the local skin friction to the thinning of an oil film placed on the test surface. The oil thickness is determined by measuring the fringe spacing from photographs. Mean skin-friction and wind direction distributions can be obtained simultaneously in a single run by using multiple oil drops.

The basis of the FISF method is in the principles of lubrication theory that related the slope of the surface of a very thin layer of oil to the shear stress acting on it. The procedure, summarized in Figure 2, consists of placing drops of oil on a specularly reflecting surface and subjecting it to an airflow. The oil will be blown downstream, forming a inclined surface whose profile can be determined using interferometry.

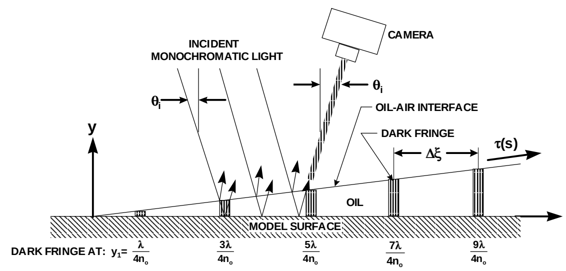

Figure 2. Interference pattern produced by oil film.

By illuminating the oil with monochromatic light, interference fringes are produced due to the reflected light from the model surface interfering with that reflected from the oil surface. The inclination of the oil film can be determined by measuring the spacing between the fringes. The relationship between skin-friction coefficient and fringe spacing is expressed as [9]

$$c_f = \left[\frac{2(n_0 \rho_0 \nu_0)(\cos\theta_r)/(\cos\theta_i)}{q_\infty \lambda t_{run}} \right] \Delta\xi_f \qquad [1]$$

where c_f is skin-friction coefficient, n_0 is index of oil refraction, is ρ_0 is density of oil, υ_0 is viscosity of oil, θ_i is incidence angle, θ_r is refraction angle, q_∞ is free stream dynamic pressure, λ is light wavelength, t is run time, and $\Delta\xi_f$ is fringe spacing along model surface from oil leading edge.

Average surface shear stress, $\bar{\tau}$, can be related to the skin-friction coefficient through the following relationship

$$\bar{\tau} = c_f \frac{1}{2} \rho U^2 \qquad [2]$$

This technique has allowed simulation of flow over sands dunes that were previously not reasonably possible. The results from this study and subsequent experiments has broad implications for dune forming processes on Mars and Venus.

Analysis: The laboratory measurements are similar to field results that show a drop in the shear stress near the windward plinth of the model and from there it increases sharply to a maximum at the crest. There is another drop is shear stress at the less slope near the crest line and increases down-wind (Figure 3).

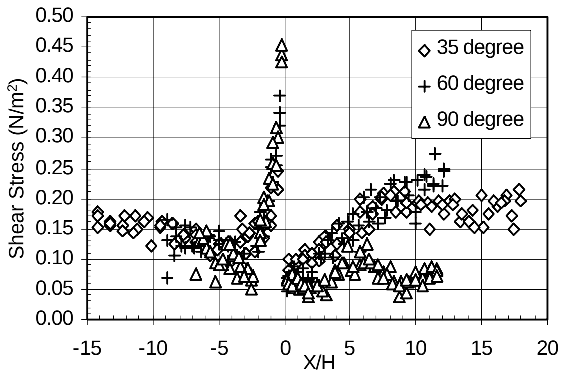

Figure 3. Shear stress distribution for β *= 35, 60, and 90 degree dune orientation (Re = 29,000)* .

The wind directions on the lee slope diverts from it free stream coarse and turns quasi-parallel to the crest line. In all cases, the flow is separated, the crest line being the line of separation. The line of reattachment is down-wind of the crest, around X/H = 10 (Figure 4).

The Reynolds number dependence of flow over a simulated 0.5-2 meter seif dune on Mars is shown in Figure 5. Note that Reynolds number independence on the lee side of the dune appears to occur above 15,000.

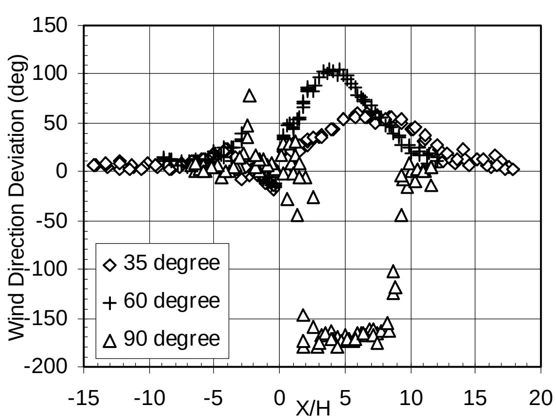

Figure 4. Wind Direction Deviation for β *= 35, 60, and 90 degree dune orientation (Re = 29,000).*

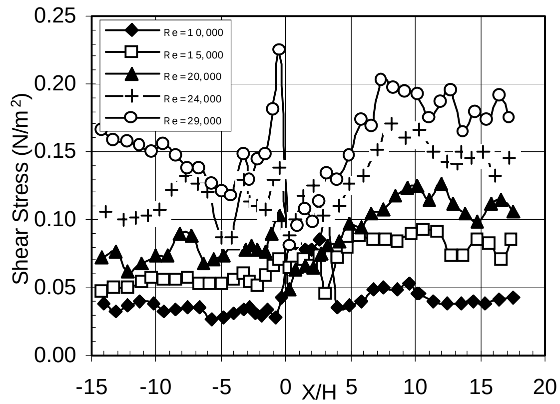

*Figure 5. Reynolds number dependence of over seif dune (*β *= 35 degree dune orientation).*

Summary: A new technique has made measurement of surface stress on simulated Martian seif dunes possible. If seif dune on Mars exist, flow creating them would be at a low Reynolds number compared to terrestrial seif dunes. The preliminary results presented are for simulated Martian dunes on the order of 1 m high. Lee side reattachment is Reynolds number dependent (see Figure 5). These results indicate that for low Reynolds number flows (i.e. Mars conditions), that the mechanisms required for seif dune formation are present on Mars, but the scale of Martian seif dunes are would have to be on the order of 12 times smaller. If the scale or Reynolds number were any greater, the mechanisms for dune formation and sand particle flux would only allow for simple dune types.

References: [1] Cutts, J.A. and Smith, R.S.U., 1973. Aeolian deposits and dunes on Mars. *J. Geophys*. Res., 78: 4139-4154. [2] Tsoar, H., Greeley, R. and Peterfreund, A.R., 1979. Mars: The north polar sand sea and related wind patterns. *J. Geophys. Res*., 84: 8167-6180. [3] Greeley, R., Skypeck, A. and Pollack, J.B., 1993. Martian Aeolian Features and deposits: Comparisons with General Circulation Model Results. *J. Geophys. Res*., 98: 3183-3196. [4] Pye, K. and Tsoar, H., 1990. *Aeolian Sand and Sand Dunes*. Unwin Hyman, London. [5] Lee, P., Thomas, P.C., Veverka, J. and Cavlo, S., 1993. Discovery of Longitudinal Dunes on Mars (abstract). *Bull. Am. Astron*. Soc., 25: 1038. [6] Edgett, K.S. and D.G. Blumberg. 1994. Star and linear dunes on Mars. *Icarus* 112,448-464. [7} Tsoar, H., 1983. Dynamic processes acting on a longitudinal (seif) sand dune. *Sedimentology*, 30: 567-578. [8] Tsoar, H. and Yaalon, D.H., 1983. Deflection of sand movement on a sinuous longitudinal (seif) dune: Use of fluorescent dye as a tracer. *Sed. Geol*., 36: 25-39. [9] Monson, D. J., G. G. Mateer, and F.R. Menter. 1993. Boundary-layer transition and global skin friction measurement with an oil-fringe imaging technique. SAE Technical Paper #932550.