NUMERICAL AND ANALYTICAL MODEL OF AN ELECTRODYNAMIC DUST SHIELD FOR SOLAR PANELS ON MARS. A. Chen[1], J. Meyer[2], C. I. Calle[3] , B. Linell[4], C. R. Buhler[4], S. Clements[5], and M. K. Mazumder[6]. [1]Department of Physics, Oklahoma Baptist University, Shawnee, OK 74804, [2]St. Gregory's University, Shawnee, OK 74804, [3]Electrostatics and Surface Physics Laboratory, NASA, Kennedy Space Center, FL 32899, [4]ASRC Aerospace, ASRC-15, Kennedy Space Center, FL 32899, [5]Department of Physics and Astronomy, Appalachian State University, Boone, NC 28608, [6]Department of Applied Science, University of Arkansas at Little Rock, Little Rock, AR 72204.

Introduction: Masuda and collaborators at the University of Tokyo developed a method to confine and transport particles called the *electric curtain* in which a series of parallel electrodes connected to an AC source generates a traveling wave that acts as a contactless conveyor. The curtain electrodes can be excited by a single-phase or a multi-phase AC voltage. A multi-phase curtain produces a non-uniform traveling wave that provides controlled transport of those particles [1-6]. Multi-phase electric curtains from two to six phases have been developed and studied by several research groups [7-9]. We have developed an Electrodynamic Dust Shield prototype using three-phase AC voltage electrodes to remove dust from surfaces. The purpose of the modeling work presented here is to research and to better understand the physics governing the electrodynamic shield, as well as to advance and to support the experimental dust shield research.

Analytical and Numerical Model: The govern equations for the electrodynamic shield can be classified into to parts: (a) charged particles interacting with the multi-phase electrodes induced *E*-field; (b) neutral particles' motion caused by dielectrophoretic forces. For the charged particles, the equations of motion can be derived from the forces involved:

$$\vec{F}_{\text{Total}} = \vec{F}_{\text{E}} + \vec{F}_{\text{Viscous}} + \vec{F}_{\text{G}} + \vec{F}_{mutual}$$

$$m\frac{d^2\vec{r}}{dt^2} = q\vec{E}(\vec{r},t) + 6\pi\eta a\frac{d\vec{r}}{dt} + m\vec{g} + \sum_{i=1}^{n} q\vec{E}_i(\vec{r},t)$$

where $q\vec{E}(\vec{r},t) = q\vec{E}(\frac{1}{r^2},\frac{1}{r^2})\cos(\omega t)$ (for a sinusoidal signal) provides a much larger force than the gravitational forces, $\vec{F}_{\text{G}}$. Here η is the viscosity and *a* is the particle diameter. $\vec{F}_{mutual}$ is the mutual interaction force among the charged dust particles, $\sum_{i=1}^{n} q\vec{E}_i(\vec{r},t)$ sums over all charged particles except itself. This is a highly nonlinear, coupled, many body-problem where exact solutions are unattainable analytically and must be achieved computationally.

For the neutral particles (uncharged particles), the force involved is a *dielectrophoretic force* [10] owing to an induced electric dipole interacting with the changing electric field of the electrodes. The time-averaged force of an electric dipole in a spatially (and time) dependent electric field is given by

$$\langle \vec{F} \rangle = \frac{1}{2}\text{Re}\left[(\vec{p}\cdot\vec{\nabla})\,\vec{E}^*\right]$$

where $\vec{E}^*$ is the complex conjugate of the electric field and $\vec{p}$ is the induced electric dipole moment. For spherical particles the dipole moment becomes

$$\vec{p} = 4\pi\varepsilon_m a^3 f_{\text{CM}}\vec{E}$$

where ε_m is the permittivity of the medium, a is the particle radius, and f_{CM} is the Clausius-Mossotti factor given by:

$$f_{\text{CM}} = \frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* + 2\varepsilon_m^*}.$$

Here ε_p^* and ε_m^* are the complex permittivities of the particle and the medium, respectively. Combining the above equations yields the following result for the time-averaged dielectrophoretic force experienced by polarizable spherical particles:

$$\langle \vec{F} \rangle = \pi\varepsilon_m a^3\left[\text{Re}(f_{\text{CM}})\nabla\vec{E}^2 + 2\text{Im}(f_{\text{CM}})\nabla\times(\vec{E}_{\text{I}}\times\vec{E}_{\text{R}})\right]$$

$\vec{E}_{\text{I}}$ and $\vec{E}_{\text{R}}$ are the negative gradients of the potentials ϕ_{I} and ϕ_{R}, while $\text{Re}(f_{\text{CM}})$ and $\text{Im}(f_{\text{CM}})$ are the real and imaginary parts of the Clausius-Mossotti factor respectively [11]. The analytical model is focused on finding a mathematical solution of $V(\vec{r},t)$ and $\vec{E}(\vec{r},t)$ in the 2-D plane above the electrodes for a time varing voltage imposed on the square shaped electrodes. This solution provides an important check for the numerical finite-element $\vec{E}(\vec{r},t)$ field calculation and for the DEP (dielectrophoretic force) numerical results.

The numerical modeling employed a finite-element method to calculate the $V(\vec{r},t)$ and $\vec{E}(\vec{r},t)$ over the entire plane with 12 electrodes embedded in a leyer of an insulating dielectric medium. These results are the bases for the charged and neutral dust particles trajectory calculation. The time integration is done by using the Huen-Verlet scheme over a fixed time domain.

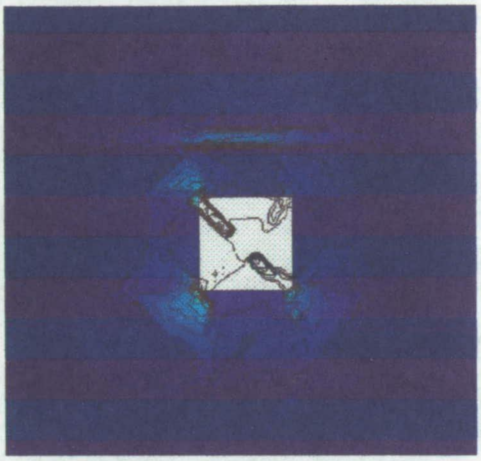

Figure 1. Contour plotting of the DEP field, sine wave, 900 volts, in one of the three-phase electrodes.

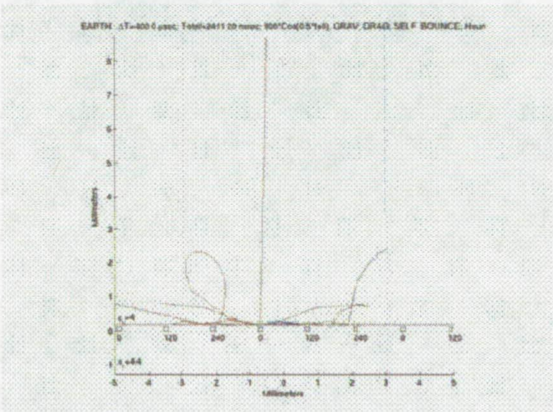

Figure 2. Trajectory calculation of 12 charged dust particles over 8 three-phase sine signals at 900 volts.

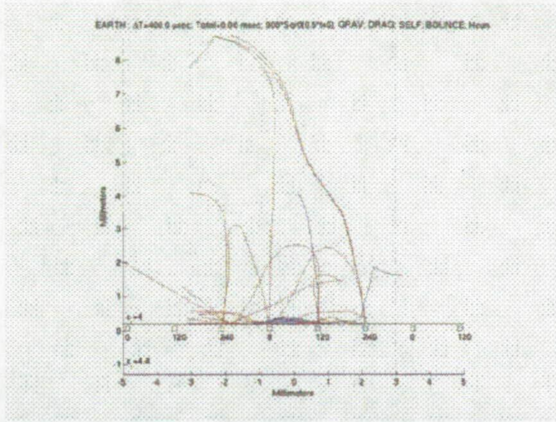

Figure 3. Trajectory calculation for 12 charged dust particles over 8 three-phase square signals, 900 volts.

Figure 1 shows the dense DEP force contour lines concentrating on top of an electrode at the boundary between the insulating medium and free space (Martian air/vacuum). The two lower conners have strong field lines due to the presence of a grounding plate at the bottom of the figure. The asemetrical results at the four corners were caused by the different phases of neighboring electrodes.

Figure 2 reveals that under a sine wave signal, dust particles trend to move along the dust shield surface. Comparing this result to the square wave signal in figure 3 shows that dust particles move in the vertical direction. These two different wave forms have about the same clearing factors but move the dust particles in quite different fashion.

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