COMPARISON OF LANCE BLADE DATA AND ANALYTICAL FORCE MODELS. R. H. King[1], P. J. van Susante[2], and R. P. Mueller[3], [1]EG Division, CSM, 279 Brown Hall, Golden, CO 80401, rking@mines.edu, [2]EG Division, CSM, Golden, CO 80401, [3]National Aeronautics & Space Administration (NASA) Kennedy Space Center, KSC, Florida 32899.

A lightweight bulldozer blade prototype has been designed and built to be used as an excavation implement in conjunction with the NASA Chariot lunar mobility platform prototype. The combined system was then used in a variety of field tests in order to characterize structural loads, excavation performance and learn about the operational behavior of lunar excavation in geotechnical lunar stimulants. The purpose of this effort was to evaluate the feasibility of lunar excavation for site preparation at a planned NASA lunar outpost.

The LANCE blade was outfitted with instrumentation in soil tests at Johnson Space Center. During these tests the LANCE blade was attached to the Chariot vehicle (Figure 1) and driven through a prepared simulant bed at various depths and velocities. To record the load on the system from the excavation forces the blade was equipped with five load button style load cells. The load cells were sandwiched between the LANCE interface plate and its five attachment points. Note that the cross section in Figure 1 occurs at the location of two of the five load cells. Laser distance meters were used to record the depth of the blade and were attached to outrigger mounts on each end of the LANCE blade pointing downward toward the simulant bed. Another laser distance meter was positioned above the blade and pointing outward toward a stationary target. This meter was used to record the velocity of the blade. The load cells were recorded using a National Instruments field point data acquisition (DAQ) system.The DAQ acquired and scaled the resistive measurement from the load cells and passed it over an ethernet connection on-board Chariot to a laptop running a Lab View VI for data logging. The VI on the laptop was also connected to the laser distance meters via a Bluetooth connection. All of the measurements; depth, velocity, and force were recorded versus elapsed time. Also, in an effort to record the surcharge in front of the blade, horizontal stripes were placed at regular intervals on the surface of the LANCE moldboard. Video cameras were synchronized with the VI and provided views of the surcharge during the test from a head-on and side view.

This experimental data is compared to results from analytical models that can possibly be used to calculate blade-soil interaction forces. The analytical models are evaluated and a sensitivity analysis is done to discover the most important soil properties that need to be determined experimentally with the most accuracy. Values for soil mechanical properties of lunar simulants and some control soils are determined and used as input parameters for the models.

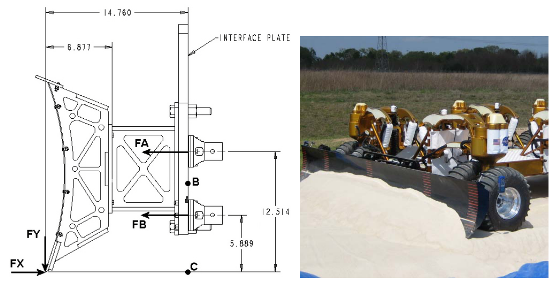

Figure 1: Side View (inches) with Load Cells at FA and FB (left) and the Blade pushing GRC-1 Lunar Regolith Simulant During a Test (right)

Because published and measured soil properties vary considerably, it was chosen to study the effect of this variation on the excavation forces. The large range of properties creates a substantial range of excavation force values making design optimization difficult. A computer program was developed that would accept a range of soil property values based on the literature and professional judgment. Soil property values represented five different soil types: Ottawa Sand, Quarry sand, GRC-1 and JSC-1A lunar simulant, and lunar regolith. The software used models from: Osman, Gill & Vanden Berg / Blouin, Swick and Perumpral, Mckyes, Luth and Wismer sand, Balovnev bulldozer blade, Zeng and Qinsen and Shuren. The Swick and Perumpral model is essentially the same as the McKyes model. The sensitivity of the forces, predicted by the models, to soil properties was analyzed by varying one soil property at a time while holding the other properties constant.

The results are presented in Table 1.

Table 1: Ranking of Analytical Models Based on Comparison with LANCE field test data.

Models/criteria	Surcharge included in model	Model behavior over range of soil properties	Other observations	Ranking for bulldozer model consideration
Qinsen & Shuren	Yes	Best fit with chariot data	Reasonable values	High
Balovnev	Yes	Good fit, including surcharge	Reasonable values	High
Zeng	Yes	Asymptotic behavior occurs, but good fit otherwise	Reasonable values	High
Osman	Yes	No good automatic iteration algorithm for complex geometric math problem	Unstable behavior, but good values when stable	Medium
Swick & P	Yes	Asymptotic behavior occurs		Medium
McKyes	Yes	Asymptotic behavior occurs		Medium
L&W sand	No	Not dependent on important parameters		low
Gill & vdB / Blouin	No	No surcharge		Low

The results showed that surcharge plays a very significant role in the horizontal forces needed for bulldozing. The following models take surcharge into account with a separate surcharge parameter: Qinsen & Shuren, Zeng, McKyes and Osman. The Osman model gives results that are the opposite from what would be expected and is considered to require a more complex iteration routine than the one used in this study. Balovnev consideres surcharge in the form of geometry parameters, not in a separate surcharge parameter; nevertheless, the Balovnev horizontal force increase with increasing surcharge.

The study concluded that the current analytical models do not allow for a time varying accumulation of soil in front of the blade, nor can they calculate the force distribution over the surface of the blade. Consequently finite element analysis (FEA) methods can help analyze the horizontal force increase with forward motion over time while varying the surcharge from zero to the maximum steady state surcharge. 3D Finite element analysis will also allow for a stress/force distribution to be calculated on the blade at any time during the simulation. The total horizontal force on the blade, calculated with FEA, could then be compared to the analytical models and the experimental data. FEA also allows for a more accurate constitutive soil model which describes the soil behavior in much more accurate detail than assumed in the analytical models. FEA will thus allow a more accurate prediction of the expected excavation forces which will result in the lightest weight, most reliable blade design.