

# MODELING DEFORMABLE HUMAN ARM FOR CONSTRAINED REACH ANALYSIS

H. Shin, N.I. Badler  
University of Pennsylvania

## INTRODUCTION

We are working on modeling a deformable human arm to improve the accuracy of constrained reach analysis. This work is a part of the project "Crew Task Simulation for Maintenance, Training, and Safety". Crewmembers are performing constrained reaches with arm and body for both intra- and extra-vehicular activity (IVA and EVA). They tolerate a certain level of tissue deformation when compressed against a solid object such as an obstacle or the joint in an extravehicular mobility unit (EMU). We have created a deformable arm segment by measuring skin indentation as a function of applied load. In order to populate the model with reasonable tissue properties we have built a simple but effective measuring device to acquire the non-linear force-depth relation from numerous sample points on an arm surface. Given an obstacle, our goal is to determine the reachable space under a certain level of tolerable contact force. We use a finite element method based on living tissue properties and the measured force-depth relations. This work will be applied to estimate the increase in reachable volume of a crewmember an EMU for EVA operation as well as for shirt-sleeved IVA operations.

## CURRENT STATUS OF RESEARCH

In order to acquire human skin properties we use a force-displacement measuring tool (Figure 1).

This gauge is constructed by modifying a standard force gauge and makes it possible to measure force and indentation simultaneously. We put a graduation in mm unit on the rod and attached a transparent thin, flat disk around the rod. Force can be measured up to 10 pounds and indentation can be measured from 3 mm to tens of millimeters. The contact shape is flat and circular and its area is  $1 \text{ cm}^2$ . We measured this relation at various locations on an arm. As we can see in Figure 2, the force-displacement relations differ from location to location and the relation is clearly non-linear. The graph shows that at the beginning of measurement, the deformation is very large with only a small load, but it hardly deforms at all after a certain point. This graph clearly shows the non-linear response offered by the internal structure (bones) within the arm segment. The human body is composed of various components such as bones, muscles, fat, and skin. Each component has its own biomechanical characteristics such as non-linear stress-strain relation and incompressibility (i.e., no volume change while deforming). It is very difficult to formulate each component precisely. Therefore, we need to simplify the model to some extent in order to make it computationally manageable without loss of realism. We expect that the empirical data obtained from human subjects will allow construction of a generalized geometric model of tolerable indentation levels.

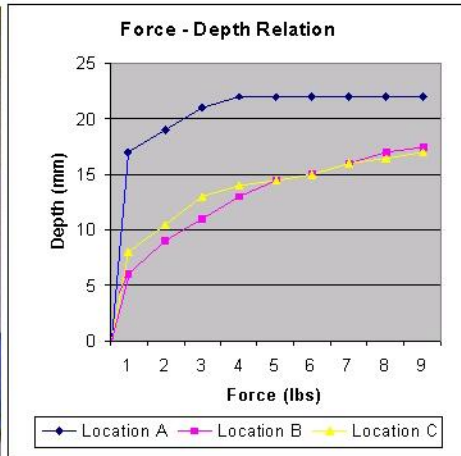


Figure 1. Force-depth gauge      Figure 2. Force-depth relation

This research is largely composed of two parts. The first part is modeling a deformable human arm based on these empirical biomechanical properties and calculating the deformation due to various contact areas. The second part is evaluating the reachable space (reachability) from the arm deformation in a given geometric (CAD) environment. Using the empirical force-displacement relation we have built a simple human arm model that deforms using a finite element method. We are now working on a human within an EMU model with more detailed geometry provided by Tietronix Software (Figure 3).



Figure 3. Astronaut & EMU geometry by Tietronix Software Inc.

**INDEX TERMS**

Skin deformation, Deformable arm, Human modeling, Finite element method, Reach analysis, EVA

