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Deformable Human Body Model Development

William O. Wray* and Toru Aida

Abstract

This is the final report of a three-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). A Deformable Human Body Model (DHBM) capable of simulating a wide variety of deformation interactions between man and his environment has been developed. The model was intended to have applications in automobile safety analysis, soldier survivability studies and assistive technology development for the disabled. To date, we have demonstrated the utility of the DHBM in automobile safety analysis and are currently engaged in discussions with the U. S. military involving two additional applications. More specifically, the DHBM has been incorporated into a Virtual Safety Lab (VSL) for automobile design under contract to General Motors Corporation. Furthermore, we have won $1.8M in funding from the U.S. Army Medical Research and Material Command for development of a noninvasive intracranial pressure measurement system. The proposed research makes use of the detailed head model that is a component of the DHBM; the project duration is three years. In addition, we have been contacted by the Air Force Armstrong Aerospace Medical Research Laboratory concerning possible use of the DHBM in analyzing the loads and injury potential to pilots upon ejection from military aircraft. Current discussions with Armstrong involve possible LANL participation in a comparison between the DHBM and the Air Force Articulated Total Body (ATB) model that is the current military standard.

Background and Research Objectives

The objective of this research was to develop a Deformable Human Body Model (DHBM) that is capable of simulating a wide variety of deformation interactions between man and his environment. The amount of computing power available for such simulations is growing rapidly through the advent of massively parallel processing. The DOE sponsored Accelerated Strategic Computing Initiative (ASCI) and Delphi Project are expected to provide a 100 teraflop capability (and beyond) during the next decade. These enormous gains in computing power will revolutionize the conduct of science and

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engineering in many fields. In particular, it is now reasonable to consider using finite-element simulations to study the complex deformation mechanics of the human body at levels of detail that were unthinkable a short time ago. The potential applications of such a capability are quite numerous and include problems of interest to the civilian and military sectors alike. We shall describe herein the DHBM that was developed under LDRD support and the Virtual Safety Lab (VSL), a DHBM application to vehicle safety analysis, that was developed with a combination of LDRD funds and contract support from the General Motors Corporation. LDRD funds were used for those parts of the joint project that specifically enhanced user access to the DHBM. Los Alamos National Laboratory has retained rights to all non-automotive applications of DHBM/VSL technology. Some of the capabilities embodied in the VSL are readily transferable to military applications of the DHBM that are under current consideration. These applications include: 1) development of a noninvasive intracranial pressure measurement system (to be based on analysis conducted with the detailed head model component of the DHBM); and 2) use of the DHBM to simulate the effect of acceleration and wind blast forces on pilots when ejecting from military aircraft.

The U.S. automobile industry relies primarily on full-scale crash tests using anthropomorphic dummies to benchmark the safety of new designs. But these full scale tests can cost up to $700,000 each, and the high cost limits the number of configurations (combinations of vehicle type, occupant anthropometry and collision parameters) that can actually be investigated. This limitation can lead to design flaws that may be dangerous to occupants who, for example, are significantly larger or smaller than the norm. The air bag design that caused several hundred fatalities among children and small statured women in the United States during the mid 1990s provides an excellent case in point. These fatalities were the direct result of the impact of the inflating air bag on the occupants' heads, frequently during collisions that would have otherwise been survivable.

To provide a less expensive method for evaluating the safety of new designs, a method that complements the full-scale crash tests that will always be a necessary adjunct, General Motor Corporation awarded a contract to Los Alamos National Laboratory (LANL) for development of a Virtual Safety Lab (VSL). The VSL, when fully implemented at General Motors, will enable automobile designers to simulate a full scale crash test using detailed finite-element models of both the vehicle and its occupant.

The VSL provides a "point and click" graphical user interface that enables a designer to select a particular vehicle configuration, specify occupant anthropometry, import detailed biomechanical models for specific body components, set collision parameters, execute a test calculation, view animated results and assess the potential for occupant injury, all without requiring that the designer have expertise in computational mechanics and finite element analysis.

Importance to LANL's Science and Technology Base and National R&D Needs

This research relates to two core competencies at Los Alamos National Laboratory. First, the DHBM/VSL contributes to the *Theory, Modeling and High Performance Computing* competency area through development and demonstration of a practical software system for "virtual testing." Due to the current ban on underground testing, the nuclear weapons program must rely increasingly on computer simulations; in effect, aging weapons must be tested by simulation rather than by actual critical detonation. The concepts and methods developed for the DHBM/VSL may actually be of direct use to the nuclear weapons community.

Second, the DHBM/VSL contributes directly to the *Bioscience and Biotechnology* competency area. The DHBM, with its detailed head model, provides a realistic continuum representation of the human body that has applications in vehicle safety analysis, soldier survivability analysis, combat casualty care and assistive technology. The continuum description of the human body complements the molecular and cellular description that is more typical of the Los Alamos bioscience program.

Scientific Approach and Accomplishments

The human occupant model developed at Los Alamos is based on a finite-element model of the Hybrid III Anthropomorphic Test Dummy (50th percentile group, male) developed by the National Crash Analysis Center (NCAC) at Georgetown University under contract to the National Highway Traffic Safety Administration. Version 1 of the NCAC dummy model has 16,000 nodes (computational points) and is available on the Internet at http://gwuva.gwu.edu/ncac/public.html. Los Alamos has adopted this model and added two critical enhancements that greatly increase its utility for a variety of applications. First, we added the capability to scale the model based on international anthropometry[1] (20 regions worldwide, 5th, 50th and 95th percentile groups, male and female, all projected to the year 2000) or on the basis of ten individually specified anthropometric measurements. The regions included in the international anthropometry database are listed in Table 1 and the ten anthropometric measurements used in the scaling procedure are listed in Table 2.

Table 1. International Anthropometry Regions in the VSL

1. North America	11. West Africa
2. Latin America	12. Southeastern Africa
3. L. America (Europ.-negroid pop.)	13. Near East
4. Northern Europe	14. North India
5. Central Europe	15. South India
6. Eastern Europe	16. North Asia
7. Southeastern Europe	17. South China
8. France	18. Southeast Asia
9. Iberian Peninsula	19. Australia (European pop.)
10. North Africa	20. Japan

Table 2. Anthropometric Measurements Used in VSL Scaling

1. Head Circumference	6. Forward Reach
2. Head Length	7. Sitting Hip Breadth
3. Head Breadth	8. Erect Sitting Height
4. Bideltoid Shoulder Breadth	9. Buttock-Knee Length
5. Biacromial Shoulder Breadth	10. Knee Height

Secondly, we have provided the capability to substitute detailed biomechanical component models for the corresponding dummy components. Appropriate detailed component models for the thorax and lower body are under development at Wayne State University and NCAC, respectively. To demonstrate the substitution capability of the VSL and provide a research tool for studying blunt body trauma to the head, we have also developed a 60,000-node finite-element model of the human head.

The LANL head model is based on the Visible Human Dataset provided by the National Library of Medicine[2]. The first step in the development process was to convert the cross-sectional information provided by the dataset to three-dimensional objects representing the three primary physiological layers. This task was accomplished by: 1) displaying the cross sections one at a time and marking the boundaries between the outer soft tissue, the skull and the brain; and 2) assembling the partitioned cross sections into three separate three-dimensional objects. The outer soft tissue, skull and brain objects generated by this method are presented in Figures. 1, 2 and 3, respectively. These three-dimensional objects have a resolution of 2 millimeters, which is sufficient to make the Visible Human subject easily recognizable.

The next step was to construct finite-element meshes on the three objects representing the head. This process has been completed for the outer soft tissue and for the brain, but is only partially complete for the skull. The finite-element model of the outer soft tissue layer is presented in Figure 4. This model has a resolution of about 4 millimeters, which is fine enough that the subject is still easily recognizable.

The VSL has been incorporated into the Khoros[3] program as an application toolbox. Khoros is a software integration environment developed by Khoral Research, Inc., in Albuquerque, New Mexico. The VSL toolbox, which is accessed by a cascading pulldown menu called *Glyphs* (see Figure 5), consists of five component tool drawers. (The word "Glyphs" is simply another name for "Icons.") The five tool drawers available in the VSL are:

- *Visualization*
- *Occupant Models*
- *Occupant Operations*
- *Vehicle Models*
- *Crash Test*

Each tool drawer contains a set of tools. When a tool is selected from a tool drawer, the outline of a glyph appears on the work space. The glyph may be moved to the desired location with the mouse and positioned there by clicking the mouse button. Procedures are created by stringing together a series of tools in an appropriate sequence. The contents of the five tool drawers and their use in developing procedures for vehicle crash analysis are described in the following sub-sections.

Visualization:

The *Visualization* tool drawer (see Figure 6) contains two tools. The first tool, *Display Current Model*, is used to provide a three-dimensional image of the finite element model being constructed for a specific crash simulation; it can be inserted at any point in a sequence of operations and will, as the name implies, display the current state of the finite-element model being developed.

The second tool, *View Collision Results*, provides access to animated results and other graphical information at the conclusion of a crash simulation . This glyph can only be used at the end of a sequence of operations that defines and executes a crash calculation.

Occupant Models

The *Occupant Models* tool drawer (see Figure 7) provides direct access to the Hybrid III 50th percentile male Anthropomorphic Test Dummy model or to any other derivative model that the user may have previously constructed using tools from the *Occupant Operations* tool drawer. One such derivative model is the *South China Woman (5th percentile)*, which is included as an example in the *Occupant Models* tool drawer.

Alternatively, the user can choose the *Select Occupant Model* glyph, which can then be used to select an occupant model dynamically from the glyph itself at any point during the construction of a crash simulation procedure.

An example of a simple VSL procedure, involving selection of the *Hybrid III ATD (50%M)* glyph from the *Occupant Models* drawer and display of that model using the *Display Current Model* glyph from the *Visualization* tool drawer, is depicted in Figure 8. The control connection between the two glyphs is generated by clicking on the small square control ports on each glyph in the proper sequence. The procedure is executed by clicking on the running man icon in the upper left corner of the workspace. The result of executing this simple procedure is presented in Figure 9, where the unmodified Hybrid III dummy model has been displayed using the I-DEAS [+] mesh generation software package.

<u>*Occupant Operations*</u>

The *Occupant Operations* drawer contains three tools, as depicted in Figure 10. These tools are capable of modifying the originally selected occupant model in several ways. The *Substitute Bio Component* glyph enables the user to substitute a detailed biomechanical component model for the corresponding dummy component; specification of which component is to be substituted is made from a special glyph menu called a "pane," which is accessed by clicking on the small black triangle in the upper left corner of the glyph.

The user may also scale the occupant model by using the *Select International Anthropometry* glyph. In this case, the anthropometric region, percentile group and sex are selected from the pane menu associated with the glyph. An example is presented in Figure 11, where the Hybrid III model is first modified by substituting the LANL Head Model and subsequently scaled to represent a 5th percentile group woman from the South China region. After making the appropriate selections in the pane menus, the panes are closed by clicking on the *Close* buttons.

As an alternative to selecting an international anthropometric group, the user can choose the *Specify Occupant Dimensions* glyph, which allows characterization of the occupant by specifying each of ten anthropometric measures. Again, the dimensions are entered on the pane menu of the glyph, as illustrated in Figure 12. The dimensions appearing on the menu in Figure 12 are default values which represent the Hybrid III 50th percentile group male. These values must be changed by the user in order to affect an alteration of the original dummy model.

<u>*Vehicle Models*</u>

Two highly simplified vehicle models (*Rigid Test Vehicle* and *Deformable Test Vehicle*) were developed by LANL and included in the *Vehicle Models* tool drawer to provide a test and demonstration capability for the VSL (see Figure 13). Ordinarily, detailed vehicle models would be provided by the user; the *Vehicle Models* tool drawer contains a *User Defined Vehicle* glyph for that purpose. The *Vehicle Models* tool drawer also contains a *Select Vehicle* glyph that allows the user to pick a vehicle for analysis from the pane menu associated with the glyph.

Crash Test

The *Crash Test* tool drawer contains four glyphs that are used to set up and execute a simulated crash test (see Figure 14). The first glyph, *Combine Veh. & Occ.*, takes a selected occupant model and places it in a selected vehicle model. The "combine" operation rotates the occupant model to the correct orientation, translates the model so that the buttocks are 0.5 millimeter above the vehicle seat bottom and then translates the model a second time to provide a 0.5 millimeter standoff distance between the occupant back and vehicle seat back.

Figure 15 illustrates a procedure for defining the occupant, selecting a test vehicle, combining the occupant and vehicle models and displaying the resulting combined model. The pane menu for the *Select Vehicle* glyph has been opened and the *Rigid Test Vehicle* has been selected.

The result of executing this procedure is presented in Figure 16; here the LANL head model has been substituted for the dummy head and the combination has been scaled to represent a 5th percentile group South China woman. Some of the outer layer of soft tissue on the head model has been cropped along the back and bottom of the skull to make it compatible with the dummy neck to which it is attached. The occupant model is seated in the *Rigid Test Vehicle*.

After placing the occupant in the test vehicle, the user can select the *Set Collision Parameters* glyph to provide a mechanism for specifying the vehicle speed and direction relative to a rigid test barrier. The collision parameters are entered in the pane menu that is associated with the "collision parameter" glyph, as illustrated in Figure 17.

The *DYNA3D* glyph is used to execute the finite-element calculations that are set up by defining the occupant, vehicle and collision parameters. This glyph, which is not yet operational in the VSL, will use the DYNA3D [5] explicit finite-element code developed at Lawrence Livermore National Laboratory to perform the computations.

The *Encapsulated Procedure* glyph in the *Crash Test* tool drawer contains a complete crash test procedure that can by modified by introducing new data through menus in the glyph panes. This glyph differs in appearance (see Figure 18) and function from the other glyphs in the VSL. By clicking on the white triangle in the upper right corner of the glyph, the user can display the encapsulated procedure on the worksheet, as illustrated in

Figure 19. Note that all glyphs that require user input through pane menus have been located on the left side of the workspace. This arrangement makes it easy for the user to step through the glyphs, opening the panes in sequence, selecting the desired options and entering the necessary data as he/she sets up a crash test simulation.

It should be noted that the process of encapsulating procedures is an option provided by the Khoros software through the *Control* menu, as indicated in Figure 20. Note that the last item in the menu is *Encapsulate Workspace*. The user simply sets up the desired procedure by selecting the needed glyphs and joining them with control connections in the proper sequence. Then the procedure is encapsulated by selecting the *Encapsulate Workspace* option from the *Control* menu; at that point the user will be asked what to name the new procedure and where (toolbox and tool drawer) to store it. In addition, note that the *Control* menu provides the capability to set up loops and conditional branches within a procedure. Although we have not used these options to date, they would clearly be very useful for setting up a series of crash test simulations to explore the effect of variations in selected parameters on occupant safety.

References

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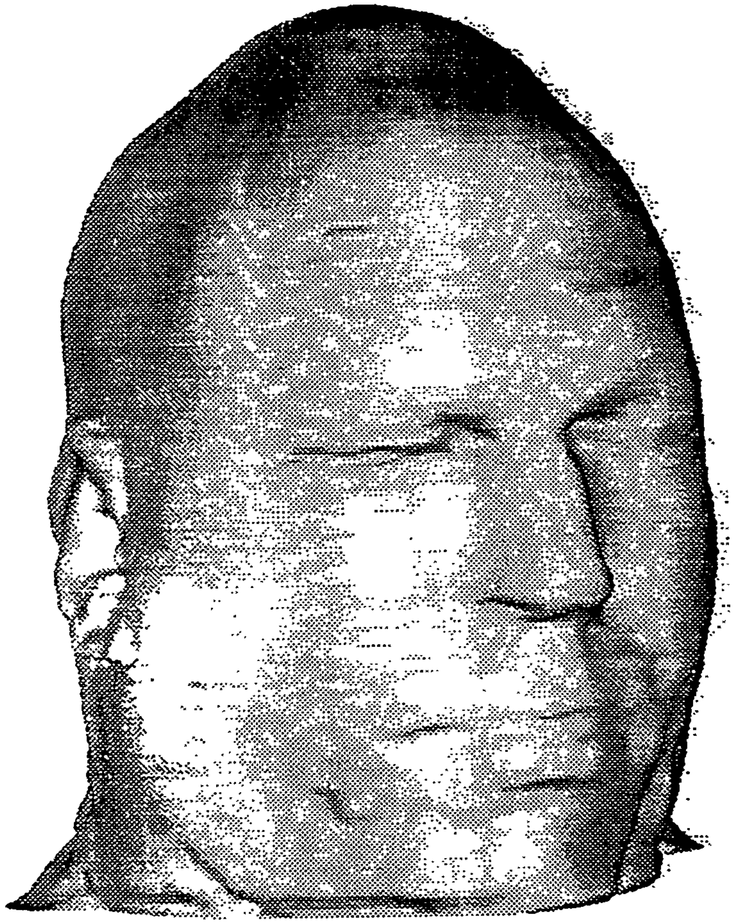
[2] Spitzer, V., Ackerman, M. J., Scherzinger, A. L., and Whitlock, D., "The Visible Human Male: A Technical Report," Journal of American Medical Informatics Association, Vol. 3, No. 2, pp. 118-130 (1996).

[3] *Khoros Pro User's Guide*, Khoral Research, Inc., Albuquerque, NM (1996). Khoros is a trademark of Khoral Research, Inc.

[4] *I-DEAS Master Series 2.0/Exploring I-DEAS Simulation* : Structural Dynamics Research Corporation, Milford, OH (1994).

[5] Whirly, R. G., Engelmann, B. E., Hallquist, J. O. *DYNA3D: A Nonlinear, Explicit, Three-Dimensional Finite Element Code For Solid and Structural Mechanics—User Manual*, Lawrence Livemore National Laboratory (1993).



[illegible] for LANL head model.

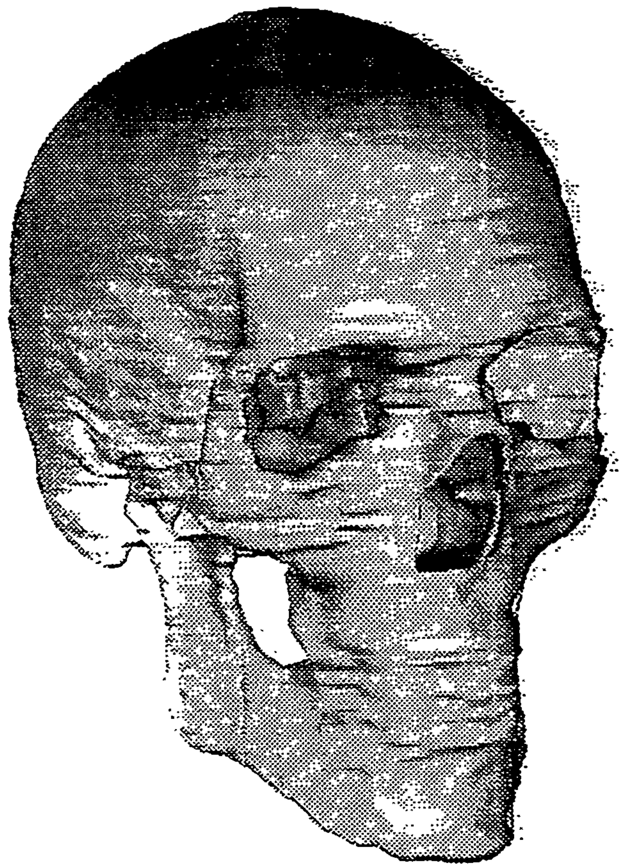


Figure 2: Three-dimensional skull object for LANL head model.

Figure 3: Three-dimensional brain object for LANL head model.

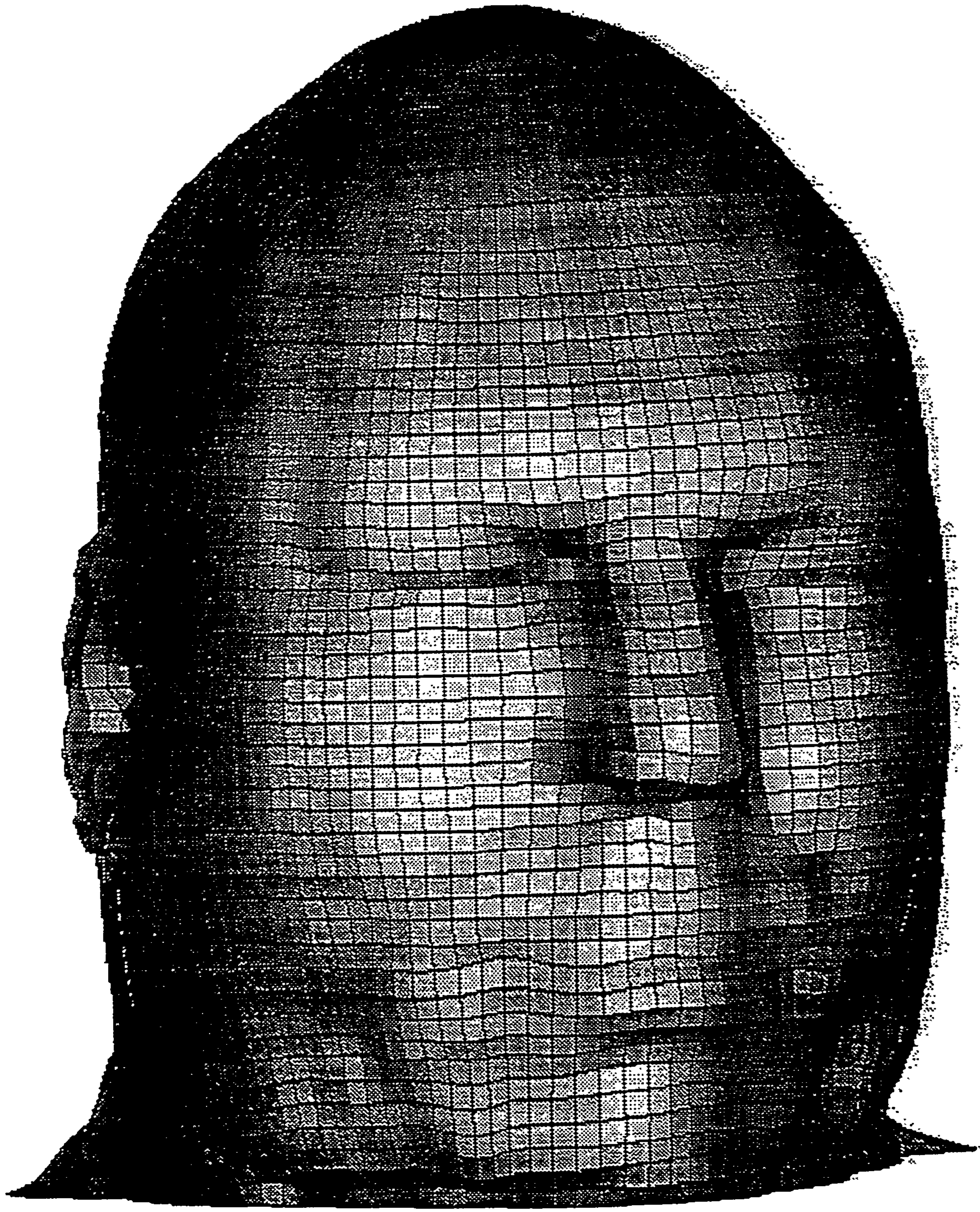


Figure 4: The LANL head model (external soft tissue).

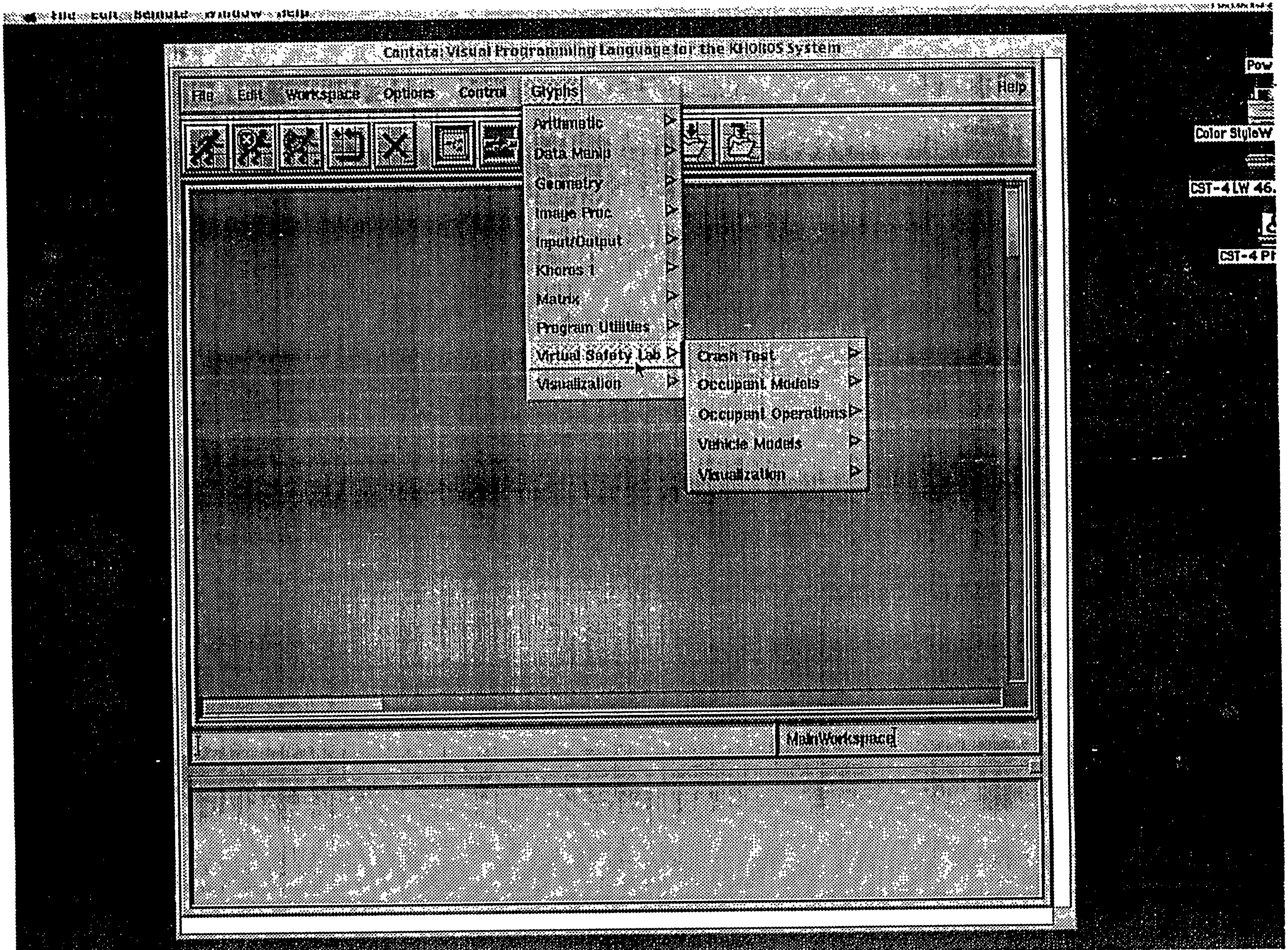


Figure 5: The *Virtual Safety Lab* Toolbox in Khoros.

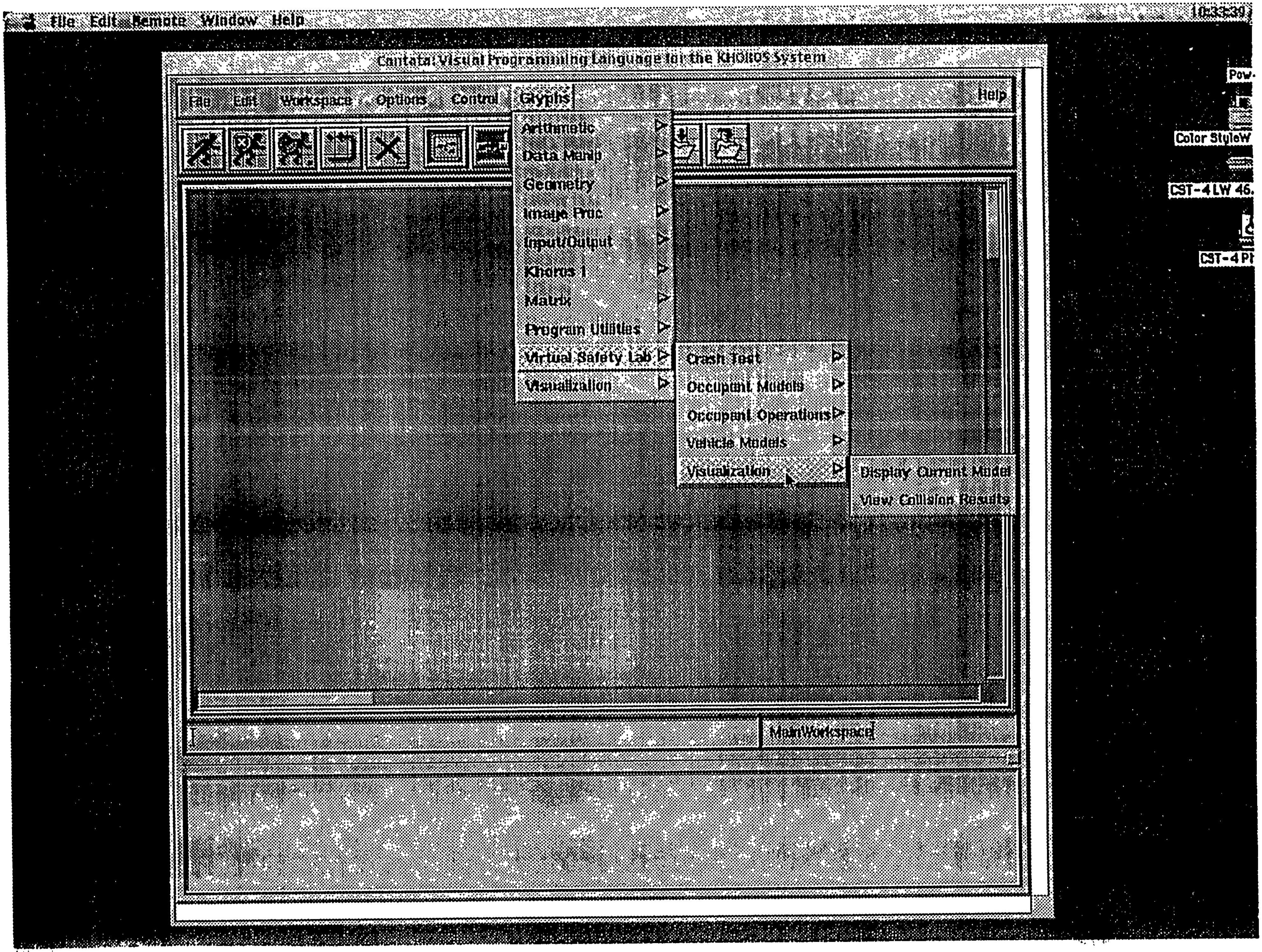


Figure 6: The *Visualization* Tool Drawer.

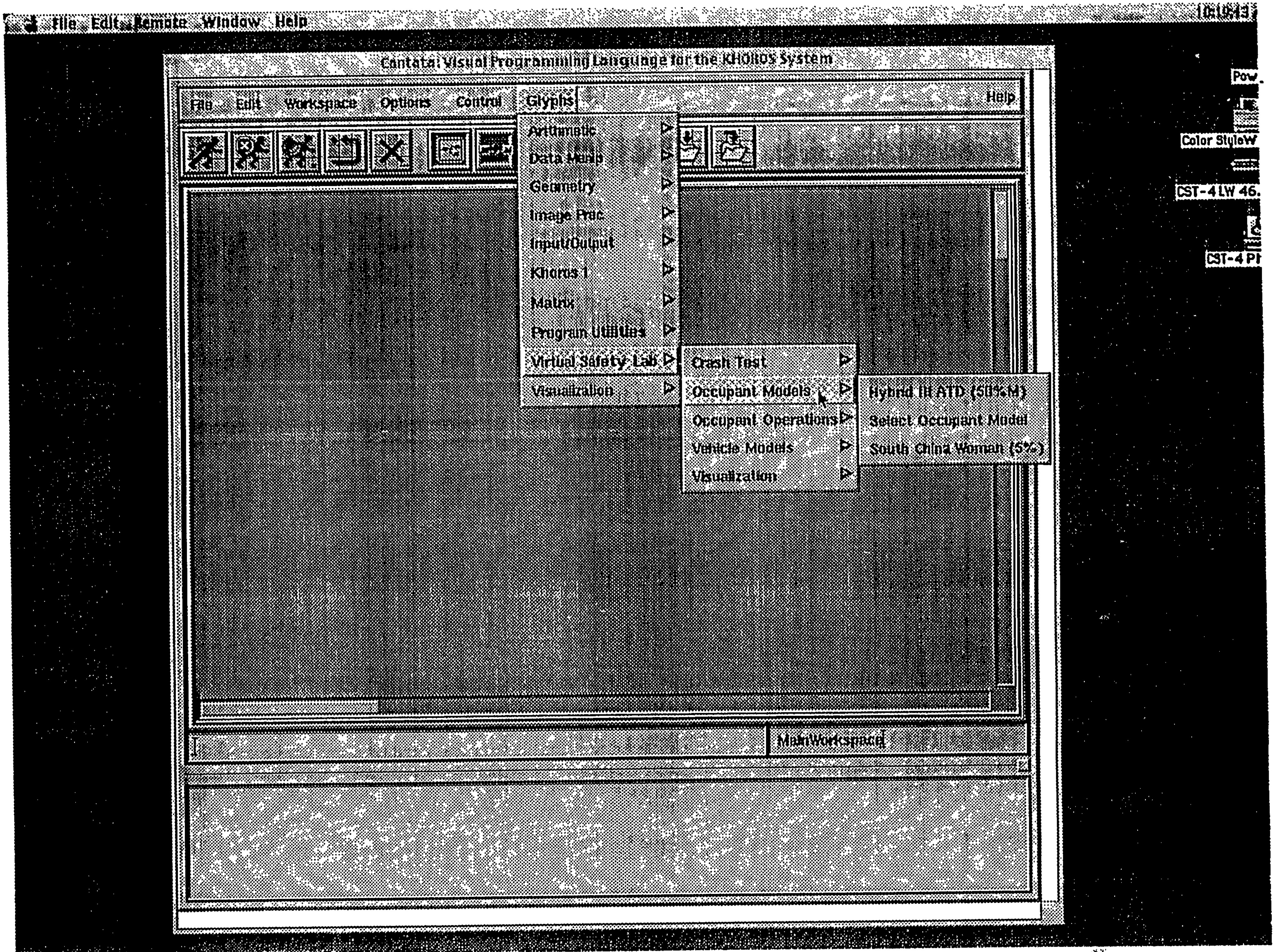


Figure 7: The *Occupant Models* Tool Drawer.

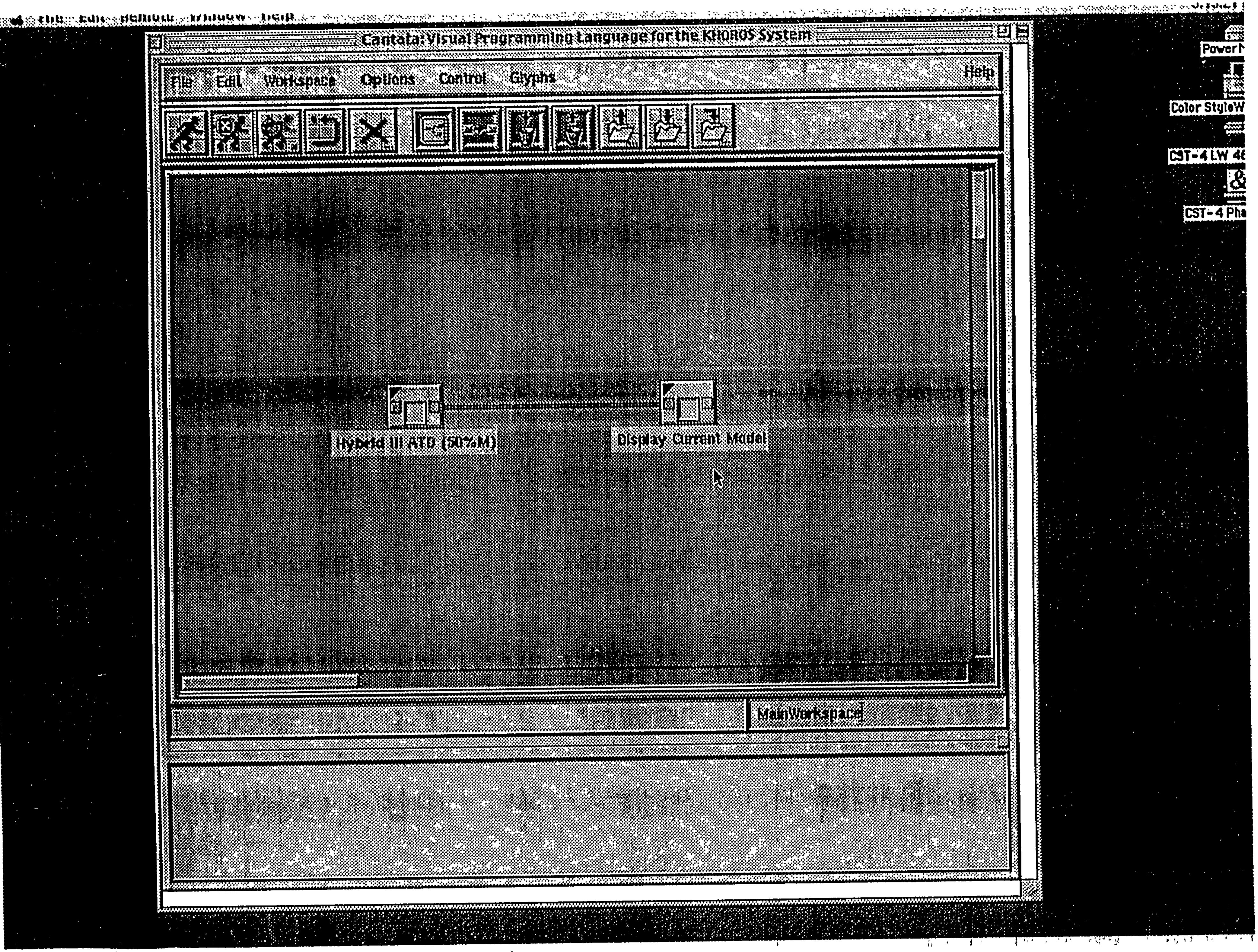


Figure 8: A Simple Virtual Safety Lab Procedure

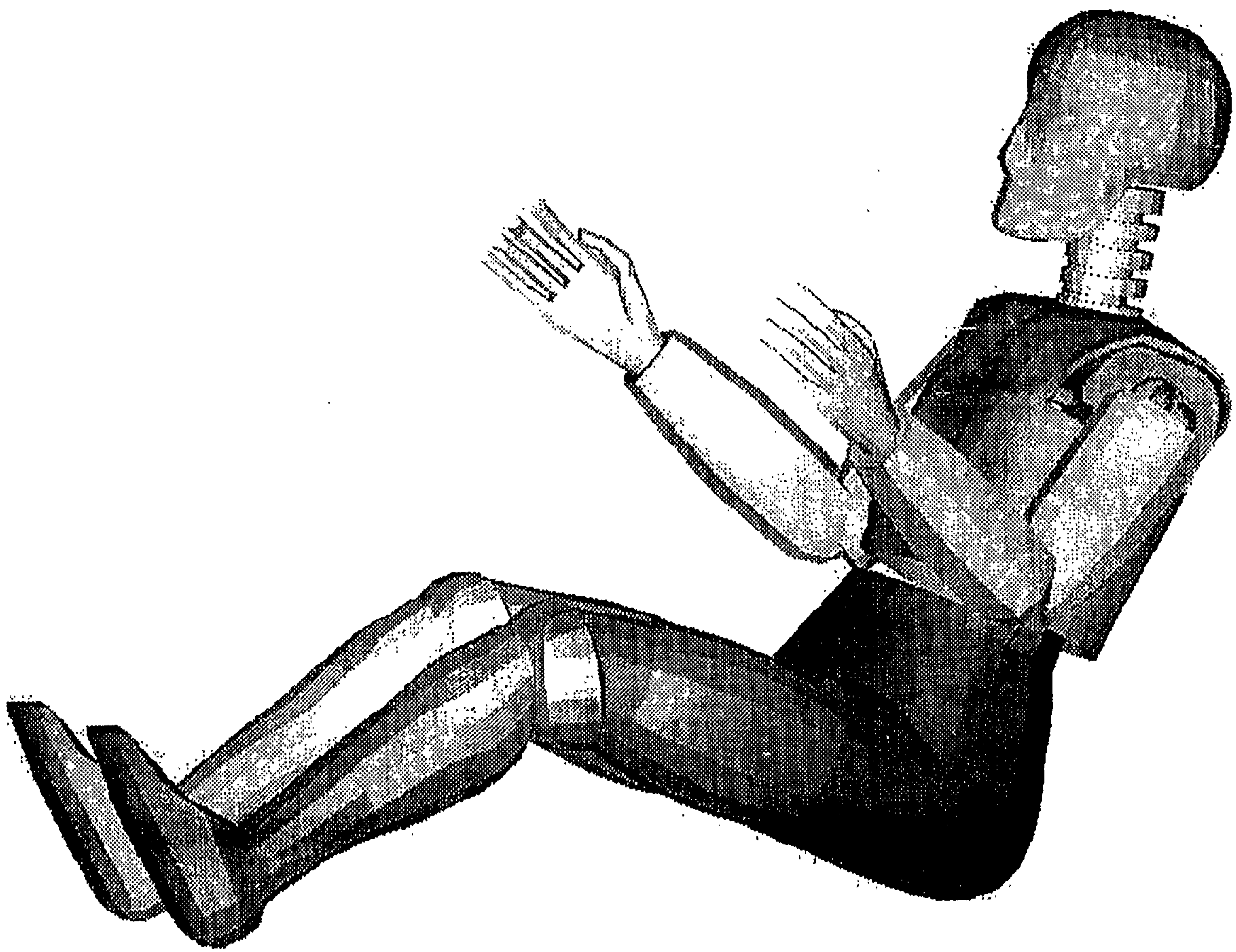


Figure [illegible]. The Hybrid III 50th percentile group male ATD.

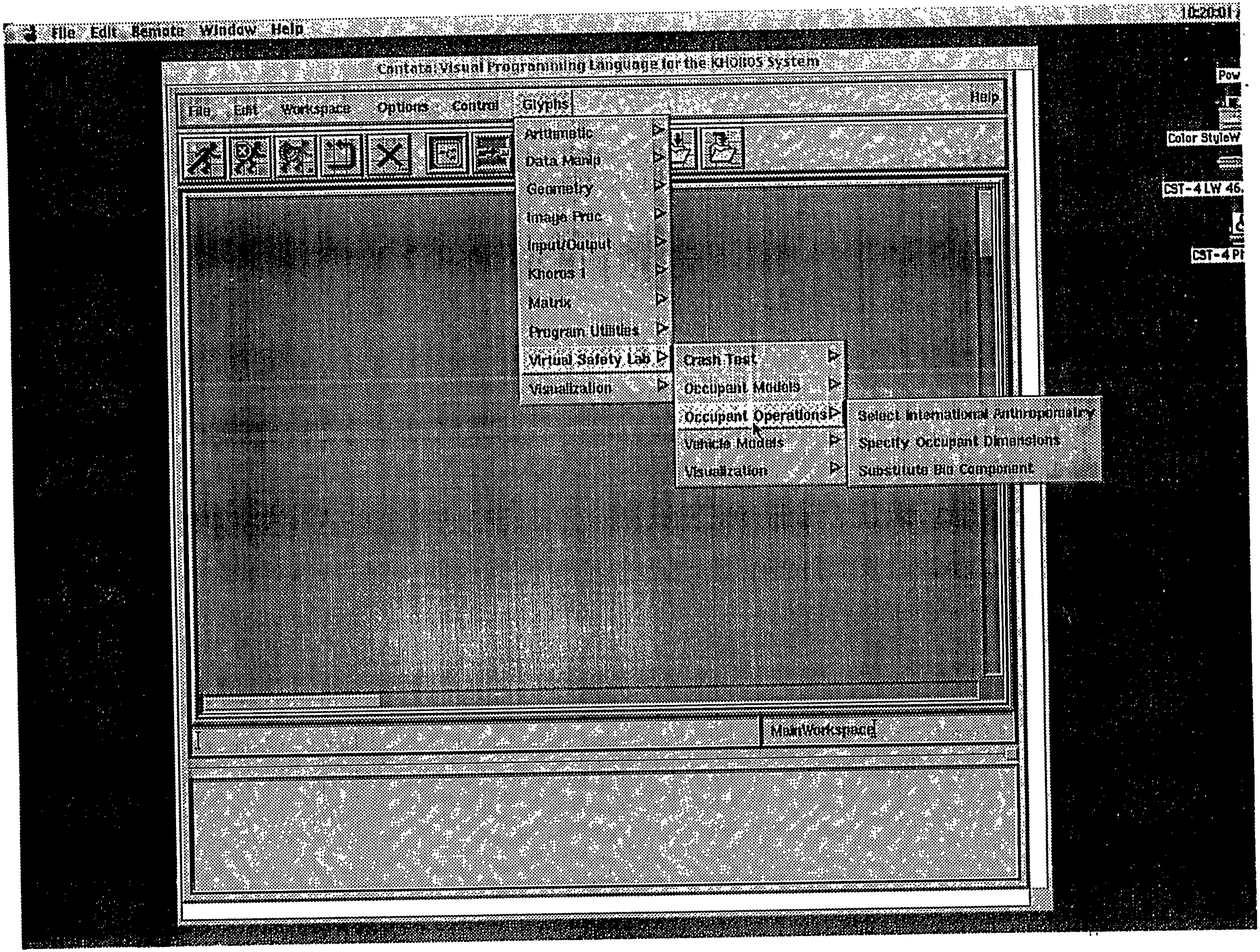


Figure 10: The *Occupant Operations* Tool Drawer.

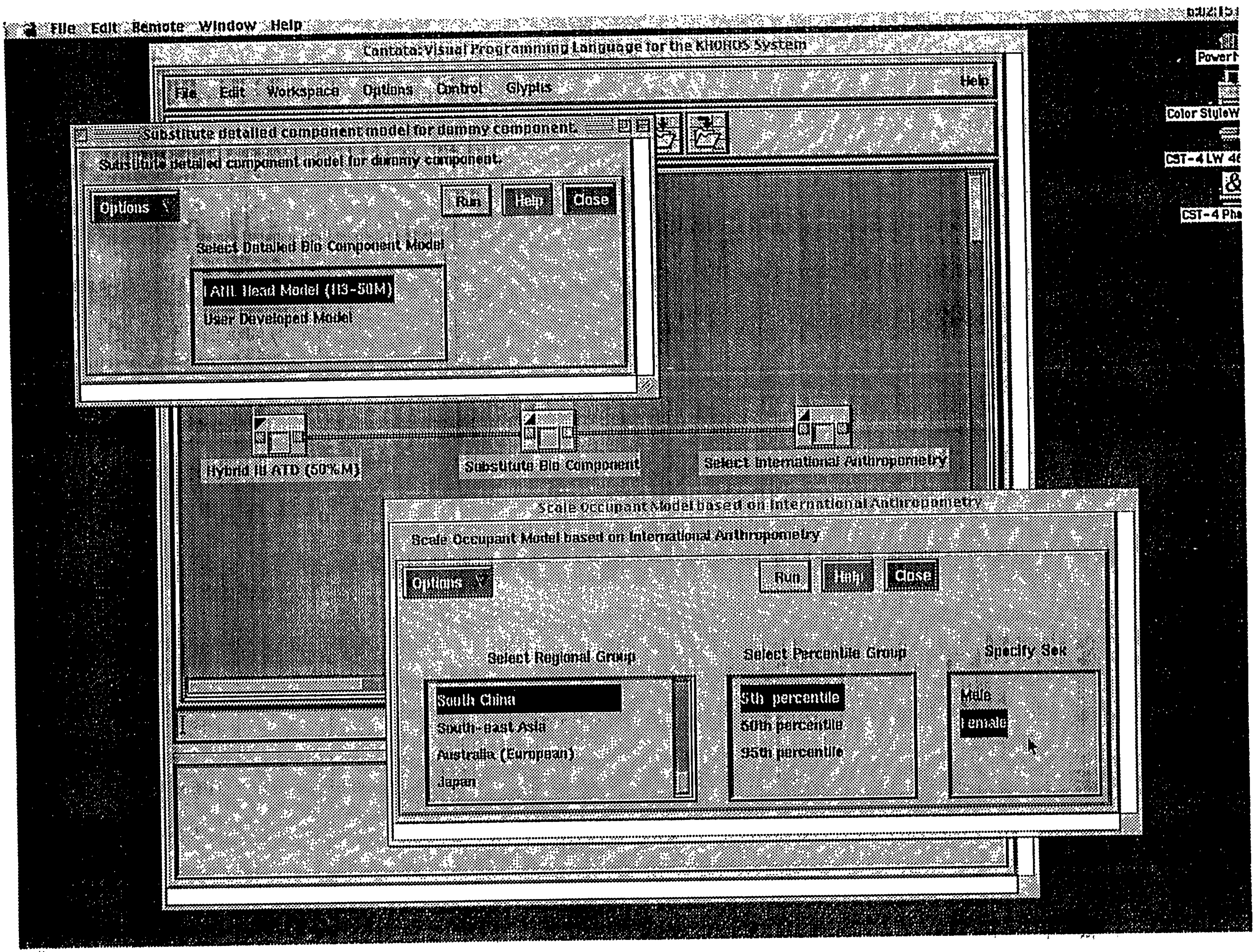


Figure 11: Example procedure for setting up occupant model.

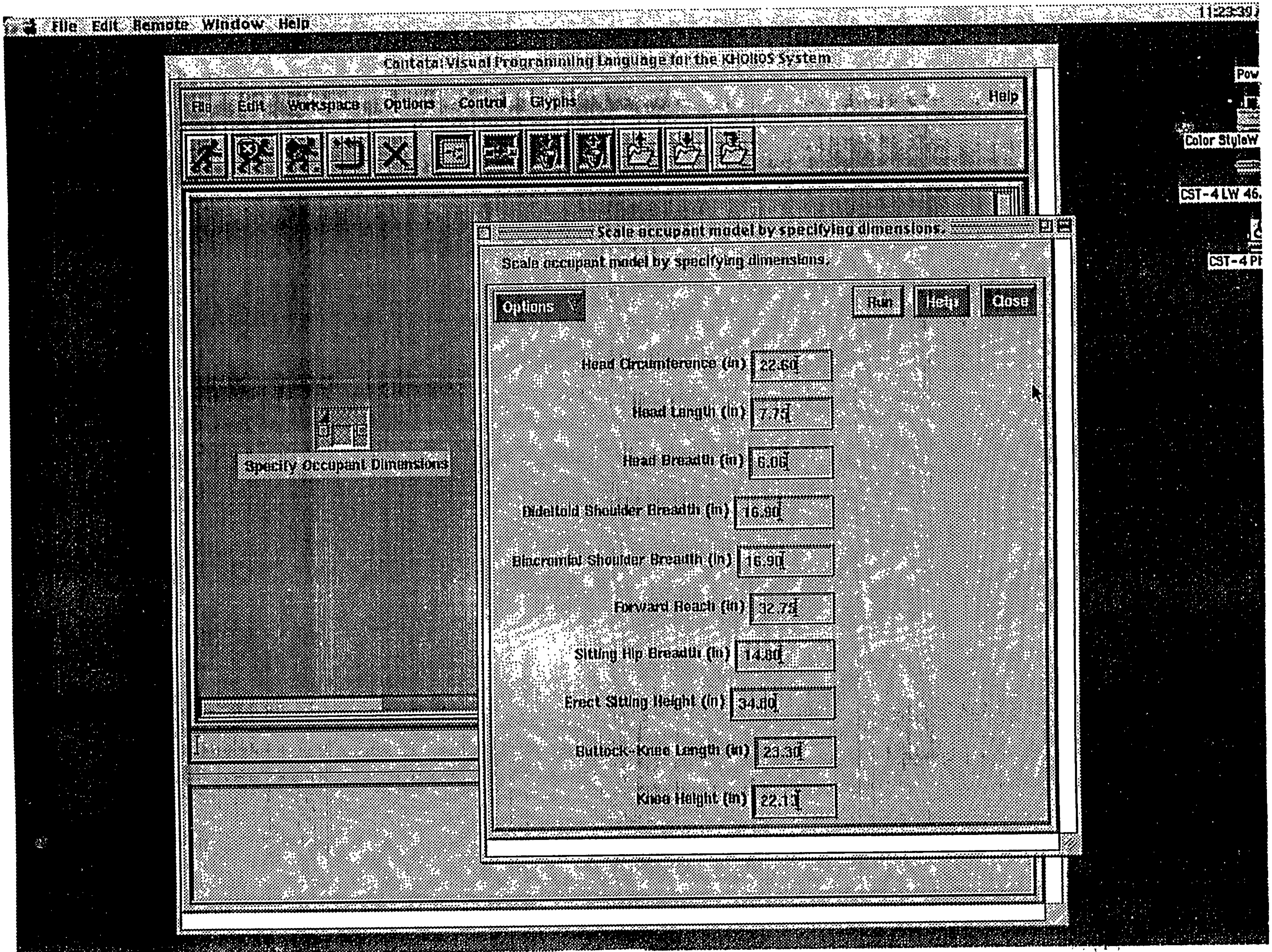


Figure 12: The *Specify Occupant Dimensions* Glyph.

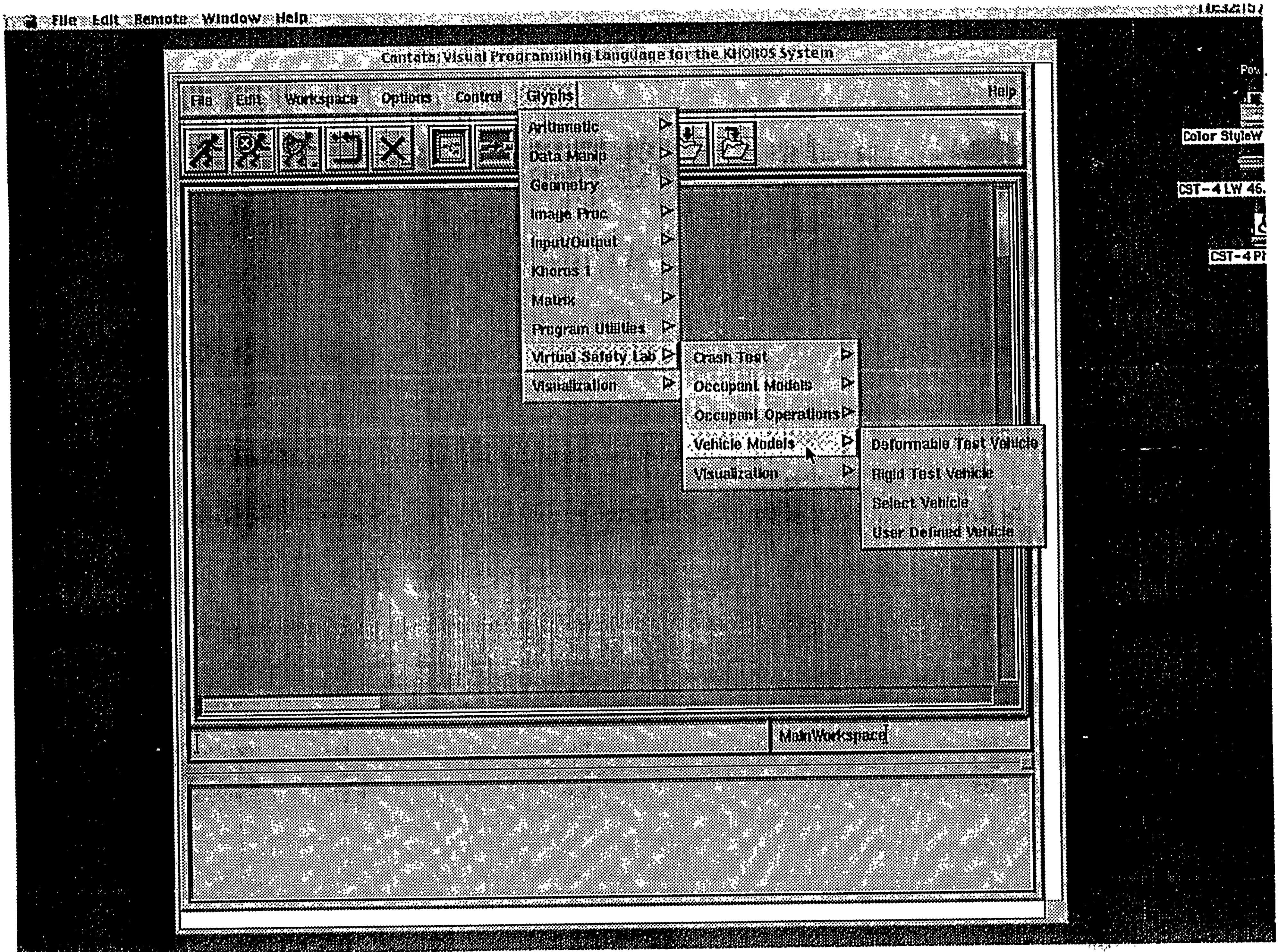


Figure 13: The *Vehicle Models* Tool Drawer.

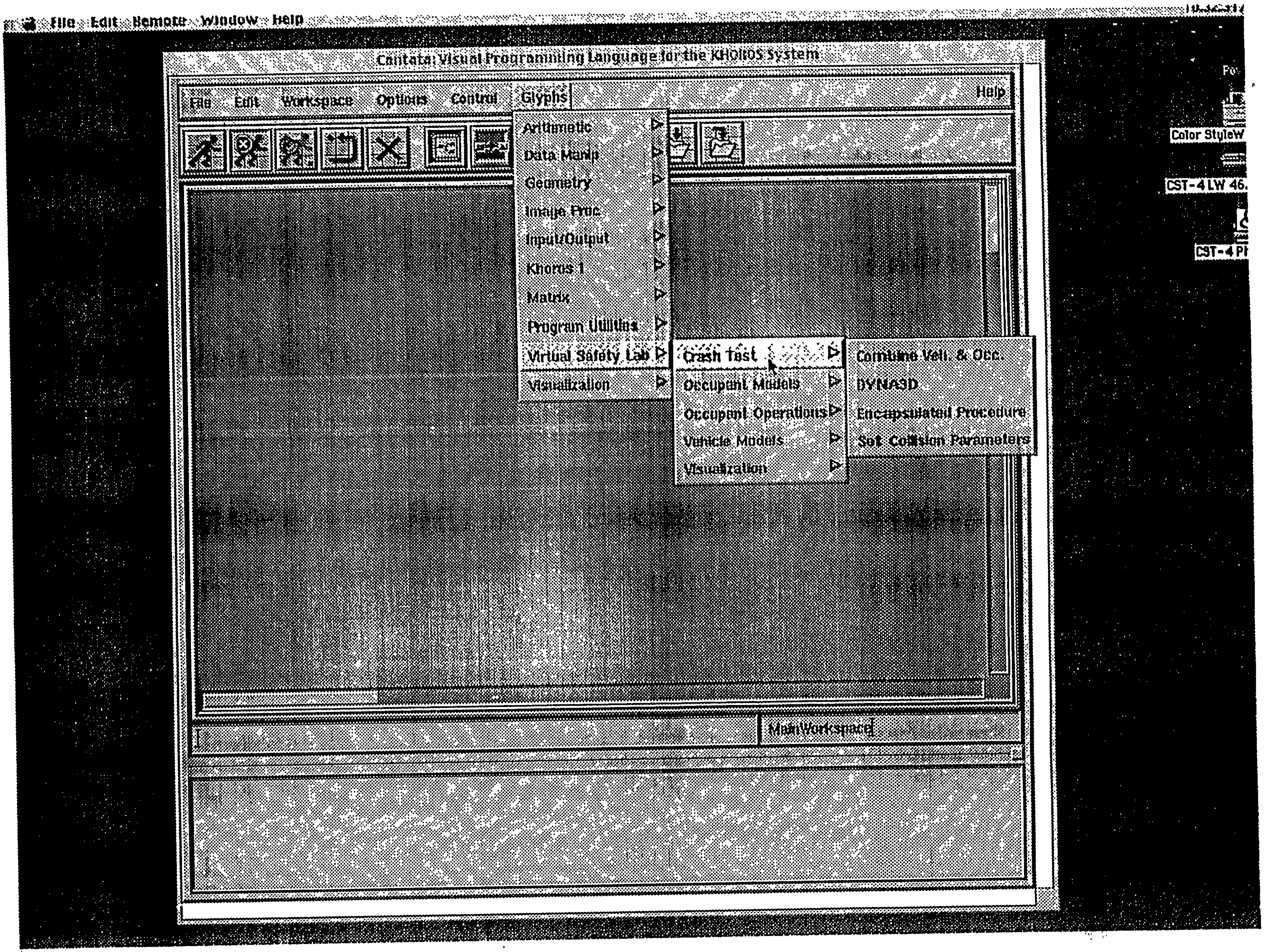


Figure 14: The *Crash Test* Tool Drawer

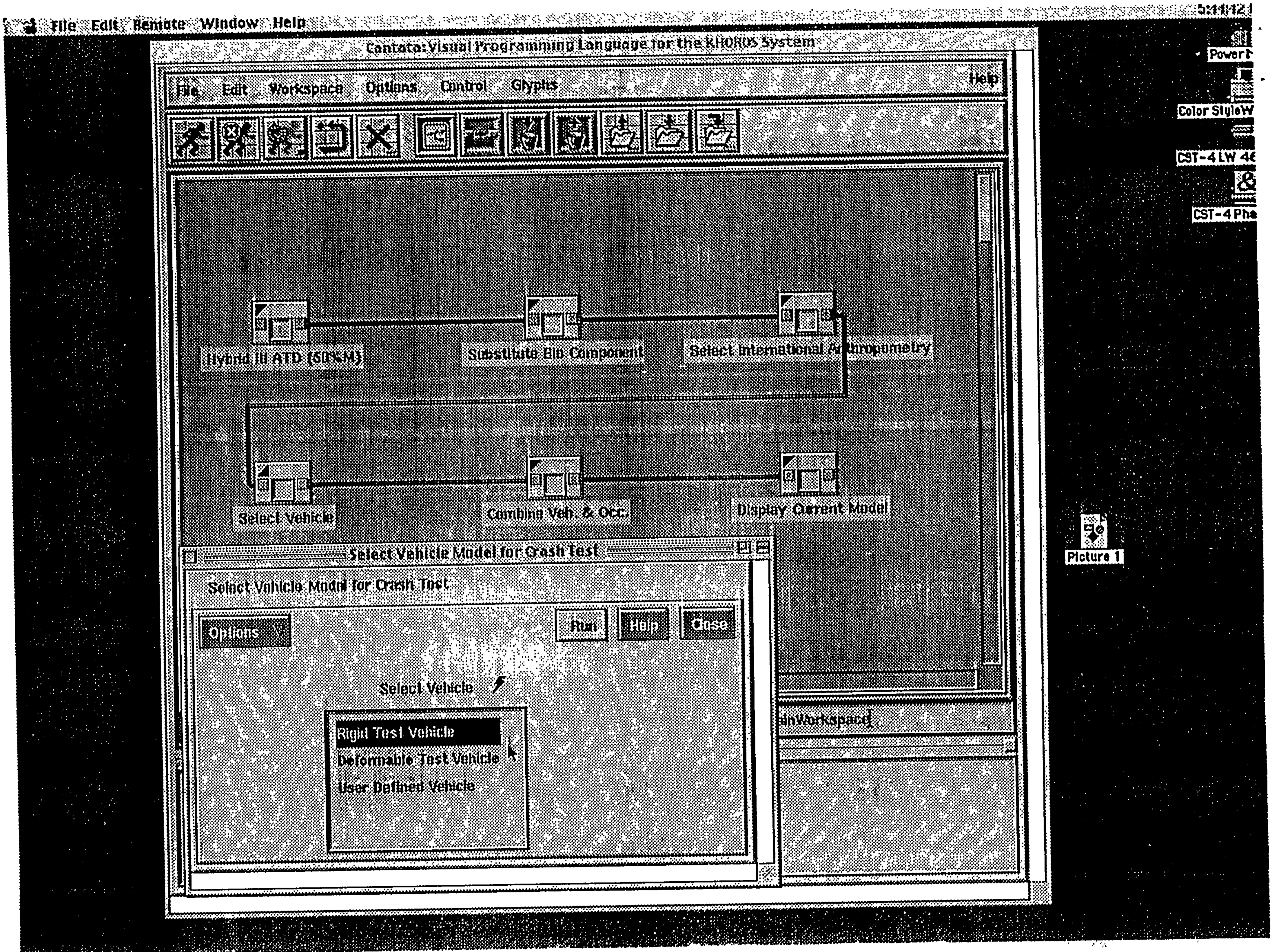


Figure 15: Example procedure for selecting the Hybrid III dummy model, substituting the LANL head model, scaling to represent a 5th percentile group South China woman, selecting the rigid test vehicle, combining vehicle and occupant models, and displaying the result.

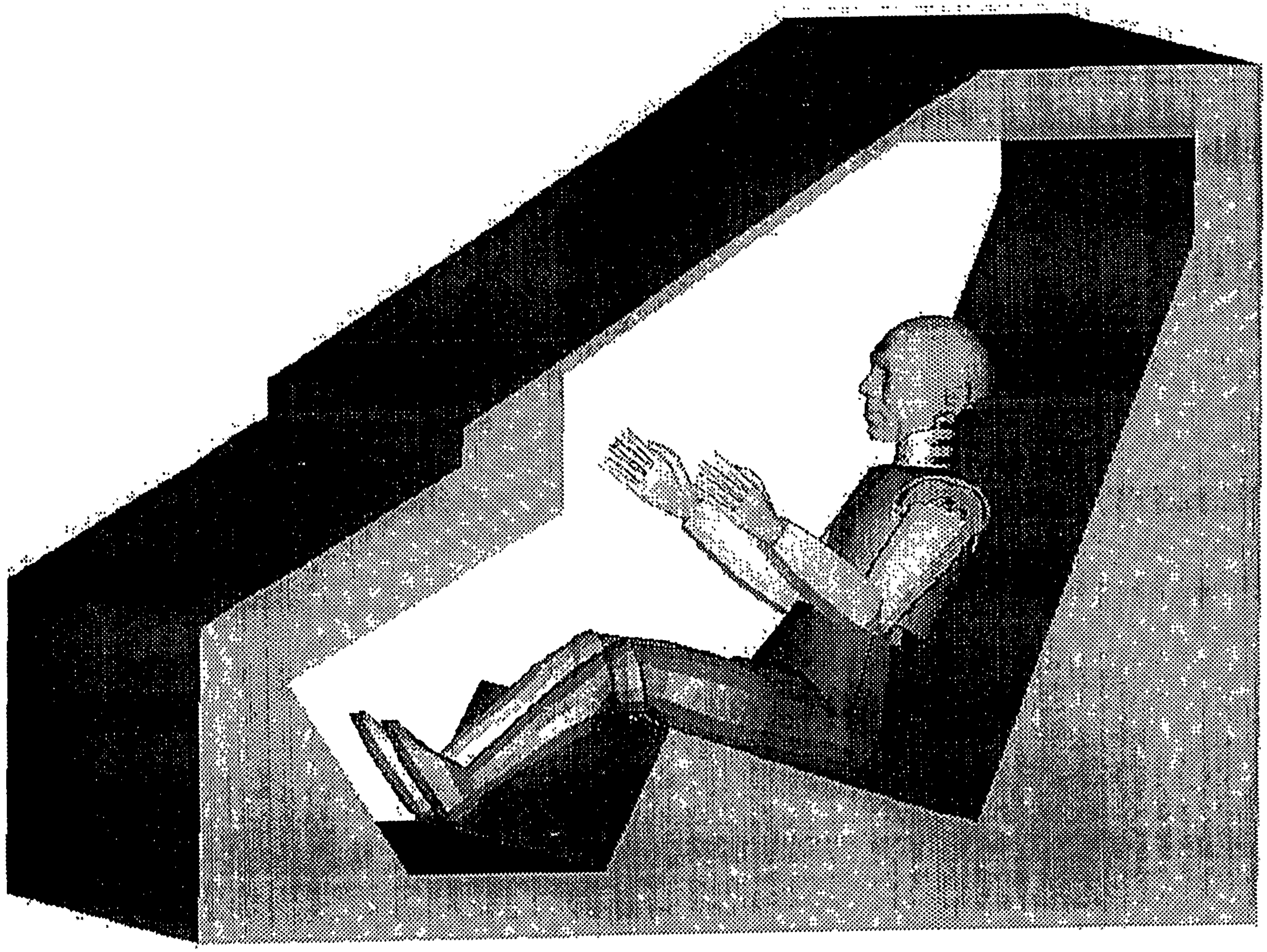


Figure 16: Fifth percentile group South China woman with LANL head model seated in rigid test vehicle.

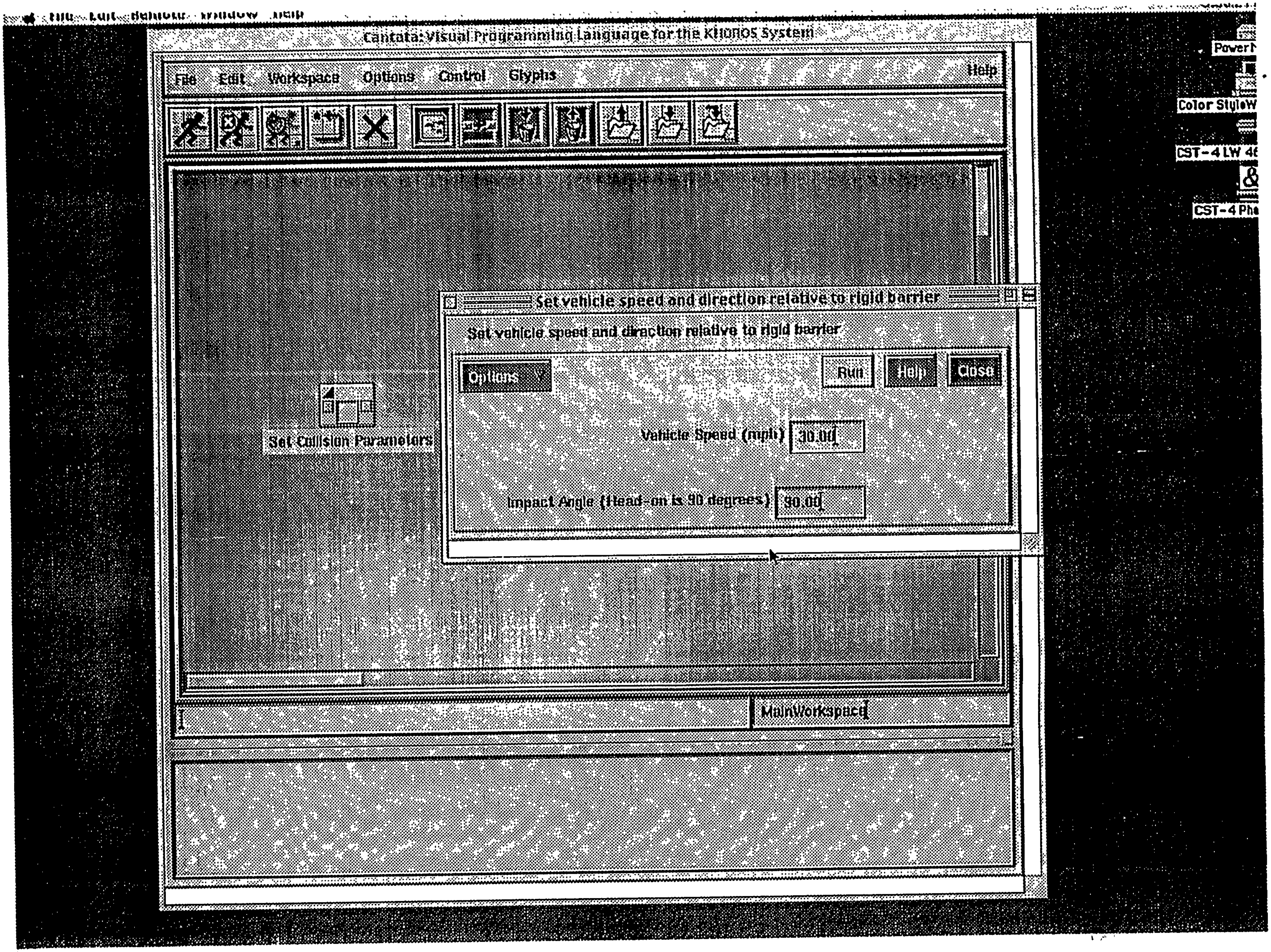


Figure 17: The *Set Collision Parameters* Glyph.

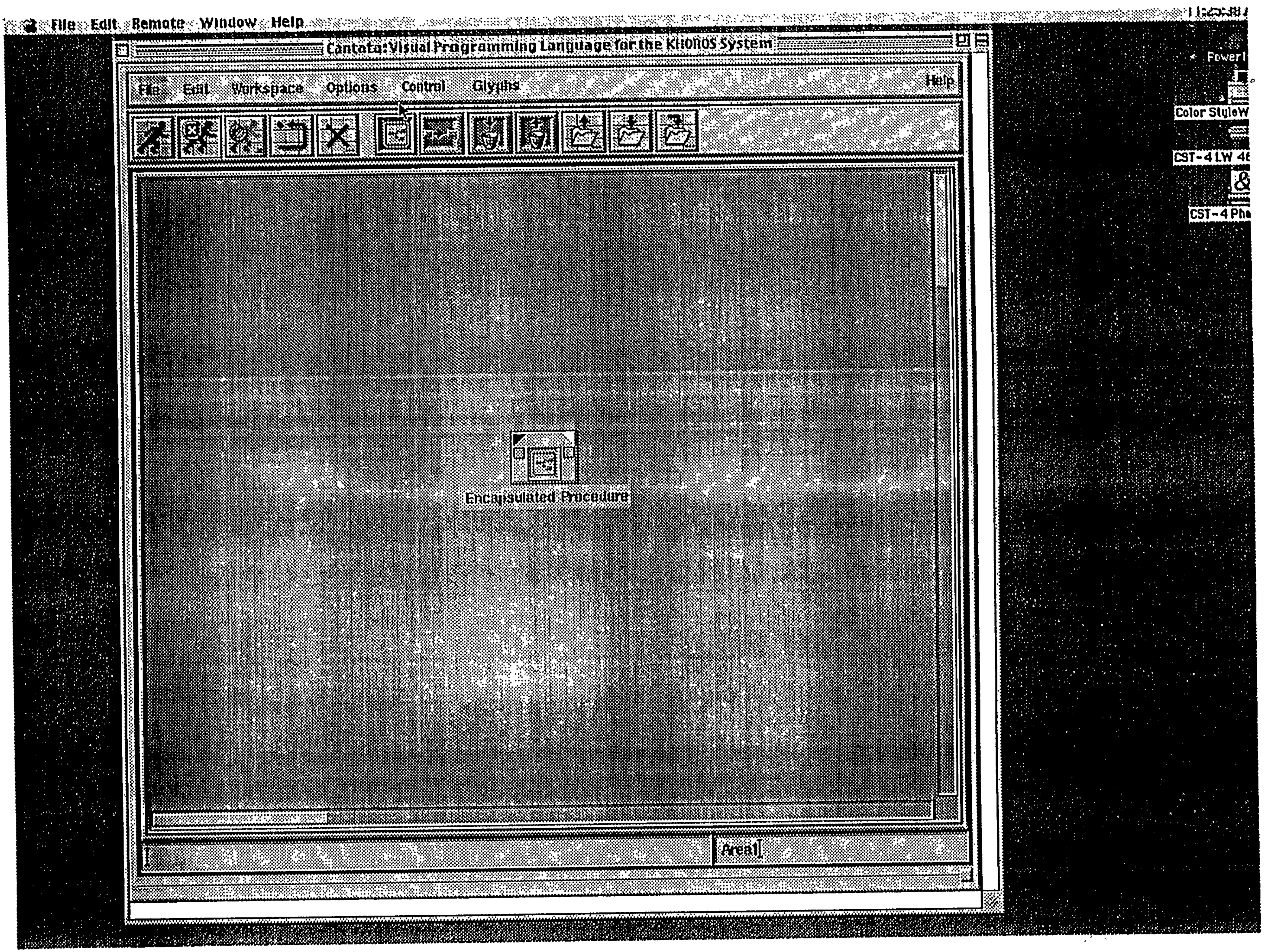


Figure 18: The *Encapsulated Procedure* Glyph.

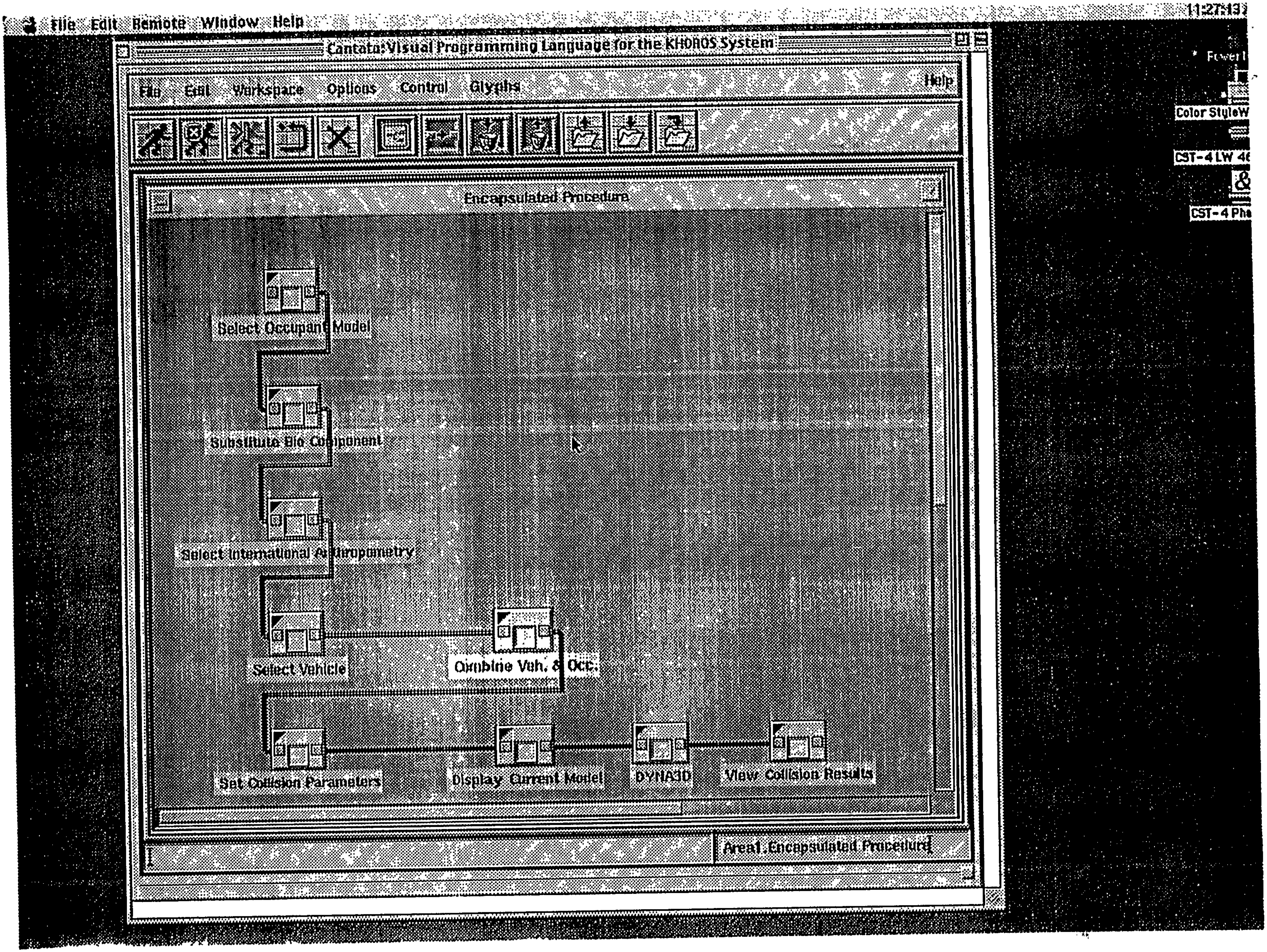


Figure 19: Display of encapsulated crash test procedure.

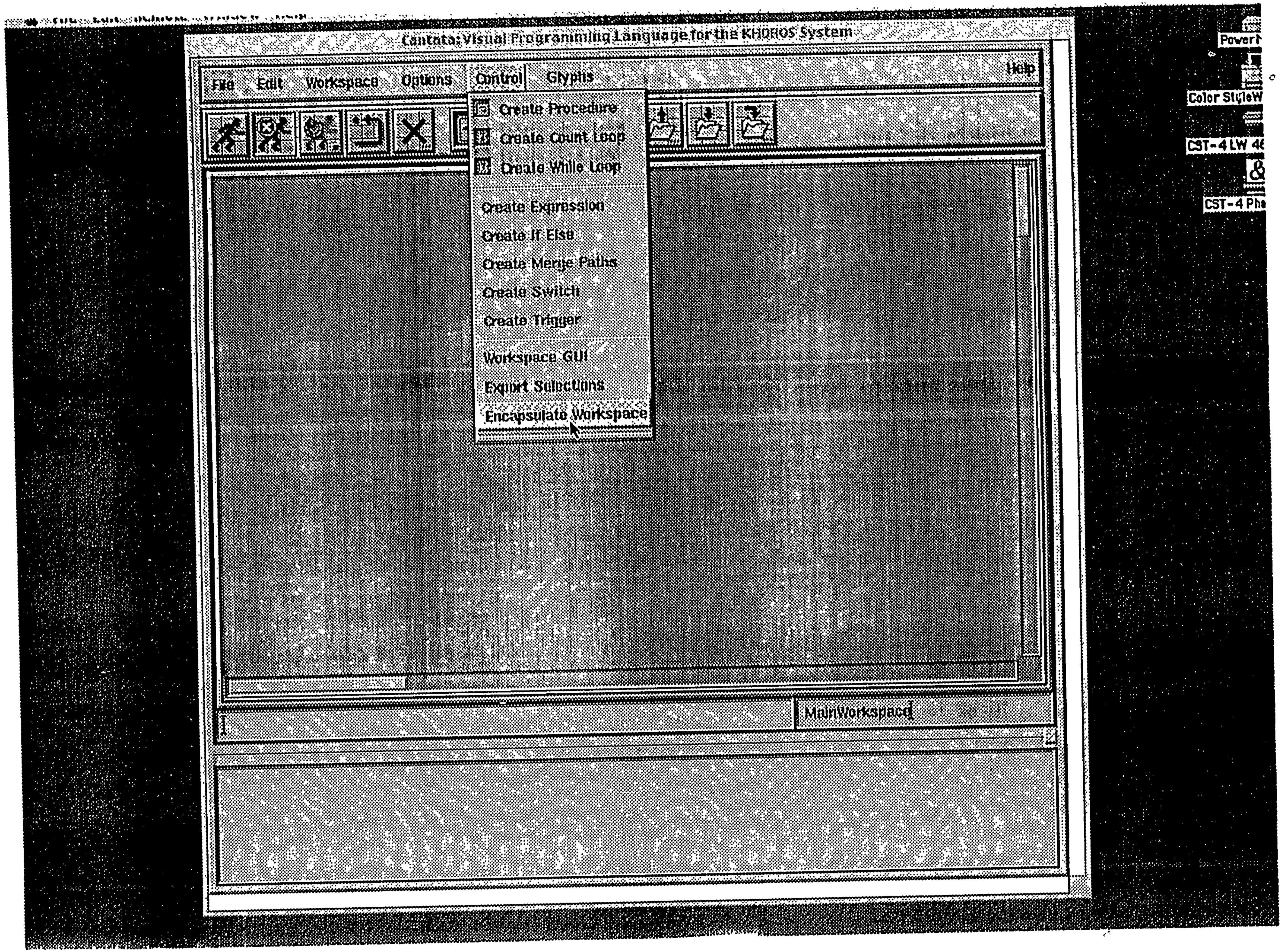


Figure 20: The *Control* Menu showing the *Encapsulate Workspace* Glyph.