Inference Corporation

Automated Software Development Workstation

Phase I - Final Report

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Inference Corporation

Automated Software Development Workstation

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Phase I - Final Report

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1. Introduction and Purpose

This document describes the final status of the Automated Software Development Workstation at the end of Phase I, and as such, provides the *Final Report*, one of the contract deliverables.

This project automates engineering software development using an expert system (rule-based) approach. The use of this new technology offers benefits not available from current software development and maintenance methodologies. The belief that current methodologies will be capable of producing needed productivity increases is constrained by limitations in

- the flexibility of information representation in a dynamic development environment,
- the ability to incorporate engineering domain expertise for construction of new designs, and
- the recording methods of design histories to support maintenance.

The approach taken in this project does endeavor to overcome these limitations, although not all in Phase I. This project is viewed in the light of a multiphase effort with Phase I just concluded. It produced a basic workstation capability with which to prove the advantages of an expert system approach to software development in Phase II. The workstation now stands as a framework for incorporation of engineering design expertise and recording of design histories. The current capabilities assist the engineer in software development to bring about an improvement in software life cycle costs - development and maintenance costs particularly. Yet, the real benefits to be achieved require a continued project. It is assumed that Phase II will begin in the near future.

As proposed for Phase I and required by the SOW, tasks have been completed that built a workstation with

- a library or program data base with methods for browsing the designs stored there,
- a system for graphical specification of designs including a capability for hierarchical refinement and definition in a graphical design system,

- an automated code generation capability in Fortran.

This workstation was then used in a demonstration at NASA with examples from an attitude control subsystem design for the space station. Subsequently, a fifteen minute videotape presentation was provided to NASA.

The list of deliverables as a result of Phase I include:

- Final Report (this document),
- Symbolics 3600 Release 6.1 and ART 2.0 compatible 1/4 inch cartridge tape of the source and binary code,
- Documentation of the code in hardcopy (and on the tape),
- Brief tutorials on Phase I workstation use and installation.

The results of the Phase I effort are documented here in a manner that allows quick cross-reference with the original proposal. After an overview of Phase I accomplishments in Chapter 2, Chapter 3, presents the main technical body. It corresponds closely with Chapter 3 of the proposal. In conclusion, Chapter 4 recommends Phase II activities and goals, as well as points towards a possible integration of effort between the Automated Software Development Workstation and the Trajectory Control Environment projects.

2. Workstation Overview - Phase I

The current workstation automates engineering software design at a fundamental level. An electronic card catalog system connects the user to any stored designs (software). Any user-selected design is loaded for editing, copying, etc. A loaded design or specification encompasses information regarding purpose, functional description, author, creation and update dates, subroutine name, graphical block diagram or engineering mathematical description (in SMP), etc. User manipulation of these designs and their interconnection in an automated environment allows basic design construction - software development.

The workstation functionality is accomplished though use of the latest in software and hardware technology. It employs ART as a rule-based programming paradigm to facilitate storage of expert knowledge regarding design construction, SMP as a computer mathematical paradigm for allowing engineering expressions and automated Fortran code generation, and the Symbolics 3600 series computer with menus, windows, and mousable areas to automate the man-machine interaction. The use of these technologies is believed esssential to achieving the goal of automated software development, due to limitations of other technologies as pointed out in the introduction.

2.1 Design Data Structures

The workstation conceptually considers all software developed within its environment to be a "design data structure" or DDS. This simply implies that any library software module is itself an engineering design. This design or module may be tied in at at any conceptual level of abstraction in another design, thus the term - design data structure.

These DDS's make up the workstation library and are addressed by the card catalog system. Any design stored in the library has been saved by a previous user and is intended to be fully documented as a "formal" specification for that design. Thus reloaded or "reused" library DDS's can be edited or copied for new development, and a subsequent "formally specified" design can again be saved. With this approach, the software maintenance problems should be eased. This method assumes the user has entered appropriate information that is not automatically supplied by the workstation.

The "workstation" encompasses two modes of operation - 1) building, and 2) using a domain-specific incarnation of the workstation. The first mode is one primarily of initialization, since all users can add knowledge to the workstation. The second more heavily emphasizes the construction of new designs using existing domain design expertise. In either case the domain-specific knowledge refers to an engineering area of application. The next two sections present overviews of the progress made during Phase I in these two modes.

2.2 Mode 1: Building an Application Workstation

When a new engineering domain is to be supported, a new workstation incarnation must be initialized. This is accomplished by:

- building an initially catalogued library of available designs,
- building an initially supported graphical equivalence vocabulary (graphical icons -> software designs in library),
- building initial domain specific rule sets for use in automatic code generation or design assistance.

During Phase I, an ability to add and catalog designs was completed; an initial set of designs for an *attitude control system* was produced that was adequate for demonstration of concept. Automatic coupling of graphical vocabulary elements (specific icons) with the attitude control library was supported by presenting the user with the list of library options after the user entered the desired design name. Little effort was placed on allowing user defined vocabulary additions to the graphical design palette for quicker reference. Finally, a small rule set was established for the attitude control to aid in automated programming. These rules automatically transform coordinate systems for variables as required between designs. All the rules were written in ART. There was not an intention to supply an overlayed capability on top of ART to support capture and storage of domain expertise, i.e. a knowledge acquisition aid.

It is possible to perform all the proposed building operations at the end of Phase I. Limitations remaining to be overcome involve allowing user additions to the palette depicted vocabulary and easier access to pertinent design information via domain specific rules. A possible drawback of the rule-based approach is that the users are required to know ART in order toadd domain specific expertise. Phase II might attempt to overcome this limitation.

2.3 Mode 2: Using an Application Workstation

Phase I progress in supporting use of an attitude control workstation was significant. The only desired goal not achieved was an exectuable simulation. Time ran out prior to its completion. A graphical design system was built for use in all application workstations, with scrolling, layout, deletion, linking, etc. available to users. An ability to link designs together, whether new or from the library, at various levels of abstraction was incorporated. The leaf elements of the designs were considered to be engineering mathematics written in the computer mathematics language SMP. At all levels of design abstraction a set of specification information was captured that described the purpose, function, author, variables, etc. to support maintenance and reuse. Once the design was completed, automatic generation of Fortran code was possible. For the leaf elments, SMP was used to automatically generate the Fortran code for the subroutine body and variable declarations. The specification information supplied by the user was then stored in a catalogued file of the library, as well as in a card catalog system and documented Fortran source file. At the higher level block diagrams, ART was used to generate the subroutine and variable declarations. The attitude control "expertise" was used to aid in automating this operation. Finally, access to a capability for results presentation was added. However, since plotting, formatting, etc. are typically available and familiar at each location, no effort was expended at actually producing results features.

3. Workstation Design

The Automated Software Development Workstation is itself designed so that several domain specific incarnations may be supported. There are therefore two modes of operation - building new incarnations and using those that exist. The tools supplied from Phase I allow a developer to initially build and catalog utility designs and to incorporate domain specific utility knowledge, that is, *Mode 1* of the workstation. This initial prototype evolves as the workstation is used - additional designs are catalogued and reused, additional rules are added to the knowledge base, etc., that is, *Mode 2* of the workstation.

The detailed description of actual workstation operation is found in the Mode 2 discussion, since, that portion of the Mode 1 functionality is nearly identical. Mode 1 simply initializes the libraries with generally useful designs, icons (or language elements), and domain rules and follows the same procedures as in Mode 2 to accomplish its goals.

Prior to either usage, a login procedure is encountered. This procedure is ancillary to the main workstation description and is therefore left for description in the usage tutorial.

3.1 Mode 1 - Building a Workstation

This mode primarily consists of constructing libraries of utility designs, icons, and rules for use in the specific domain - attitude control system. Three very limited libraries were created in Phase I.

- Program library: DDS's catalogued for reuse
- Icon Library: Icons - only generic icons actually entered in Library in Phase I
- Application Expertise Library: ART rules for use in attitude control system demonstration

3.1.1 Design Data Structure Library Initialization - Program Library

The workstation supports building the DDS library through the graphical and mathematical specification systems. All pertinent information is acquired from the user to allow the DDS's to be reused. A small set of attitude control system designs and utility DDS's were catalogued into the program library for Phase I demonstration.

The initialization of the library requires only standard functionality use to build and catalogue needed domain utility designs. The detailed description of the standard workstation DDS building activities is found in Section 3.2.

3.1.2 DDS Library Browsing

The ART schema browser is used while ART is running to browse the DDS library. The program or design library is referenced by an "electronic card catalog" system that is based on ART schemata. The library is then browsed for viewing the purpose of designs and for loading the designs for editing. A facility allows the user to pick from the catagories of designer, project, design, or keyword much like the author, subject, title system of common public libraries (no Dewey Decimal or Library of Congress System yet!). A graphical network of all designs referenced by any combination of the above categories is displayed just as in the normal schema browser. The mouse is used to scroll the network, select viewing a purpose for some design, or for loading it.

Again, the details of library usage and operation are found in Section 3.2.

3.1.3 Icon Library Initialization

A generic set of icons was established for use in design efforts. They allow building designs and inserting the design name. The typed name references all existing designs of that name. A facility as described in the proposal that parallels the specification of designs has not been completed and remains for Phase II.

3.1.4 Icon Library Browsing

This facility has not been completed but conceptually parallels the card catalog system but for graphical icons (domain specific vocabulary). Loading of the desired icon(s) would then be accomplished via mousing on a graphically displayed hierarchy.

3.1.5 Application Expertise Library

This data base is totally domain specific and consists of rule sets. It is the intent that these domain rule sets be available as "design assistance modules" and that they may be loaded as desired (an initally specified set would typically be loaded).

An initial rule set for automatic attitude control system cooordinate system transformations was written. This rule set automates code generation when library designs are reused by automatically inserting the necessary variable transformations between DDSs.

It is the intent of Phase II to focus on enhancing the rule sets, providing additional tools to capture them, and generally provide the *expert* for the software developer with design assistance.

3.1.6 Expertise Library Browsing

This facility was not mentioned in the proposal, but some similar facility is recommended for Phase II that conceptually parallels the card catalog system but for domain rule sets or design assistance modules.

Loading of the desired rule set(s) would then be accomplished via mousing on a graphically displayed hierarchy.

3.2 Mode 2 - Using a Workstation

The design engineer now has a basic capability to enhance the domain design library. The engineer uses functionality presented using the latest in hardware and software on the Symbolics 3600 series computer. The menu, mouse, and window system embodies the essential ingredients to support the DDS system. The DDS system embraces all the mechanisms necessary to allow linking designs of mixed levels of abstraction, from high level block diagrams to low level leaf elements. Recall that a DDS is the data structure element that exists at each level, as well as a reference to all the lower level DDS's that it may contain. Each DDS level consists of several "pages" of specification information. These pages allow entry of the specificaiton information in a formatted manner for reuse and maintenance. The most obvious pages of an individual DDS level are either the graphical specification page for a control flow graph (block diagram like) or the mathematical specification page, i.e. the guts of the design. There are, however, about four other pages to be filled-in for a relatively formal specification. A graphical design system provides for the control-flow representation for higher level abstraction information. A mathematical language (SMP) page presents the capability for definition of leaf elements of the design hierarchy. Once the "formal" specification of a DDS level is completed, Fortran code may be generated automatically. SMP transforms the mathematical specifications for the leaf elements, ART for the control flow of higher level elements. This code could then be used in a simulation. An executable simulation capability was not finished during Phase I as hoped.

3.2.1 DDS Specifications

3.2.1.1 Introduction

A major activity of the workstation is the creation or editing of DDS specifications at any level of abstraction or refinement. There are two types of DDS specifications - graphical and mathematical. Graphical DDS specifications describe control flow between DDSs at lower levels of abtraction (i.e. like a block diagram). The DDSs at the next lower level are represented as mouse sensitive icons on the terminal screen and are refered to as inferior DDSs. The mathematical DDS specifications entail engineering mathematics for a leaf design element. They are atomic units and cannot be decomposed into inferior elements. Both types of specification are used to generate source code to implement the DDS specified.

3.2.1.2 Hierarchy

DDSs may be organized in a hierarchical fashion by linking graphical DDSs to lower level abstractions or leaf elements. The DDS concept allows for linkages between all DDSs (other than the same DDS).

3.2.1.3 Specification Pages

To fully describe a DDS the user must specify the following items:

- Functional Description
- Assumptions and Limitations
- Special Comments
- References (to published documents, etc.)
- Purpose
- Keywords
- Project
- Current Development Comments and Status
- Variables (input, output and local)
- Subroutine Name (for automatically generated source code subroutine)
- Control flow or Mathematical Specification

The workstation itself also maintains a history of which user edited each version of the DDS, and this history is part of the DDS description.

The following material describes the screen layout for specifying DDSs, with added figures for easier visualization. Seperate sections describe the implementation.

User interaction consists of mousing sensitive areas on the screen for choice selection, and entering textual information from the keyboard.

At a given point in time a particular DDS will be in the editing buffer and may be presented on the terminal screen. Since the full description of a DDS does not fit on one screen, various items are shown on seperate pages. The user can toggle between these pages via mouse sensitive text icons. Many of these items are potentially too big to be displayed on the screen, so scrollable viewports are used. Particularly, graphical specifications and input, output, and local variables, author history, etc. support scrolling.

All the pages are divided into several parts. They are implemented using two ART windows and divide the screen into three sections. The upper part of the page contains the Design Data Structure name. The large area in the middle section is the editable area of the page. The lower part of the page lists non-editing operations that may be performed.

Since the upper and lower section are relatively static this discussion will focus on the middle section here. The description is in terms of user interaction. Section 3.2.2 discusses the bottom section in some detail.

Specification Page A: Common Elements on Every Page

Each middle section contains a bottom area of mouse sensitive text icons used for toggling between pages (see Figure 3-1). Clicking the mouse on a text icon will cause the corresponding screen to be presented. The "Exit Current DDS" icon causes the editing of the current DDS to cease. The previously edited DDS is brought into the editing buffer. In effect this causes a swap of the two most current DDSs on the editor buffer list, which is maintained by recency of editing. It does not save the DDS or cause any other side effect.

Text fields consist of underlined areas of the screen. A field is selected for editing by clicking left on the mouse sensitive text field. Clicking on the title of a text field will also cause it to be selected. The text field editor incorporates most of the control commands of the Symbolics EMACS editor such as c-A. In addition, the mouse may be used to position the cursor in any location by clicking on the mouse within the text field while

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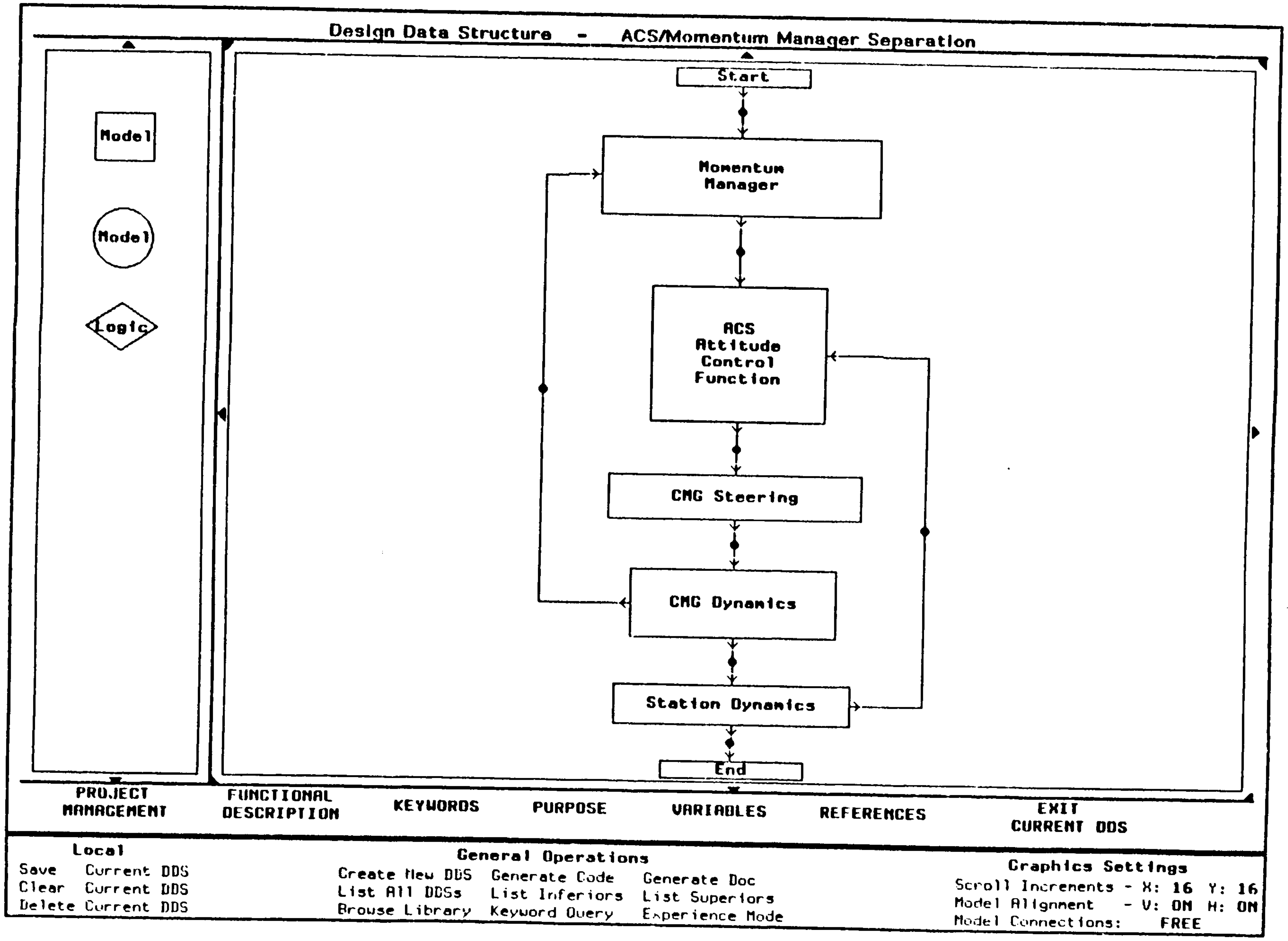
OF POOR QUALITY



Scroll Increments - X: 16 Y: 16
Model Alignment - V: ON H: ON
Model Connections: FREE

Figure 3-1: Graphical Specification Page

editing the text field. Pressing the <END> key or clicking the mouse outside the text field causes the editing to cease. In general the text field title is placed in reverse video while the field is edited.

The triangles to the right of a text field indicate that it is a scrollable field. Only the portion shown on the screen may be edited while the field is selected. However, at other times the triangles are used to scroll the field, in order to peruse it or edit it. A left click causes the continuous scrolling, a middle click scrolls one page (one line at a time), and a right click scrolls one line. The user may scroll from the first line of the text field until the last line entered. They can grow indefinitely. Continuous scrolling is terminated by clicking again on the triangle.

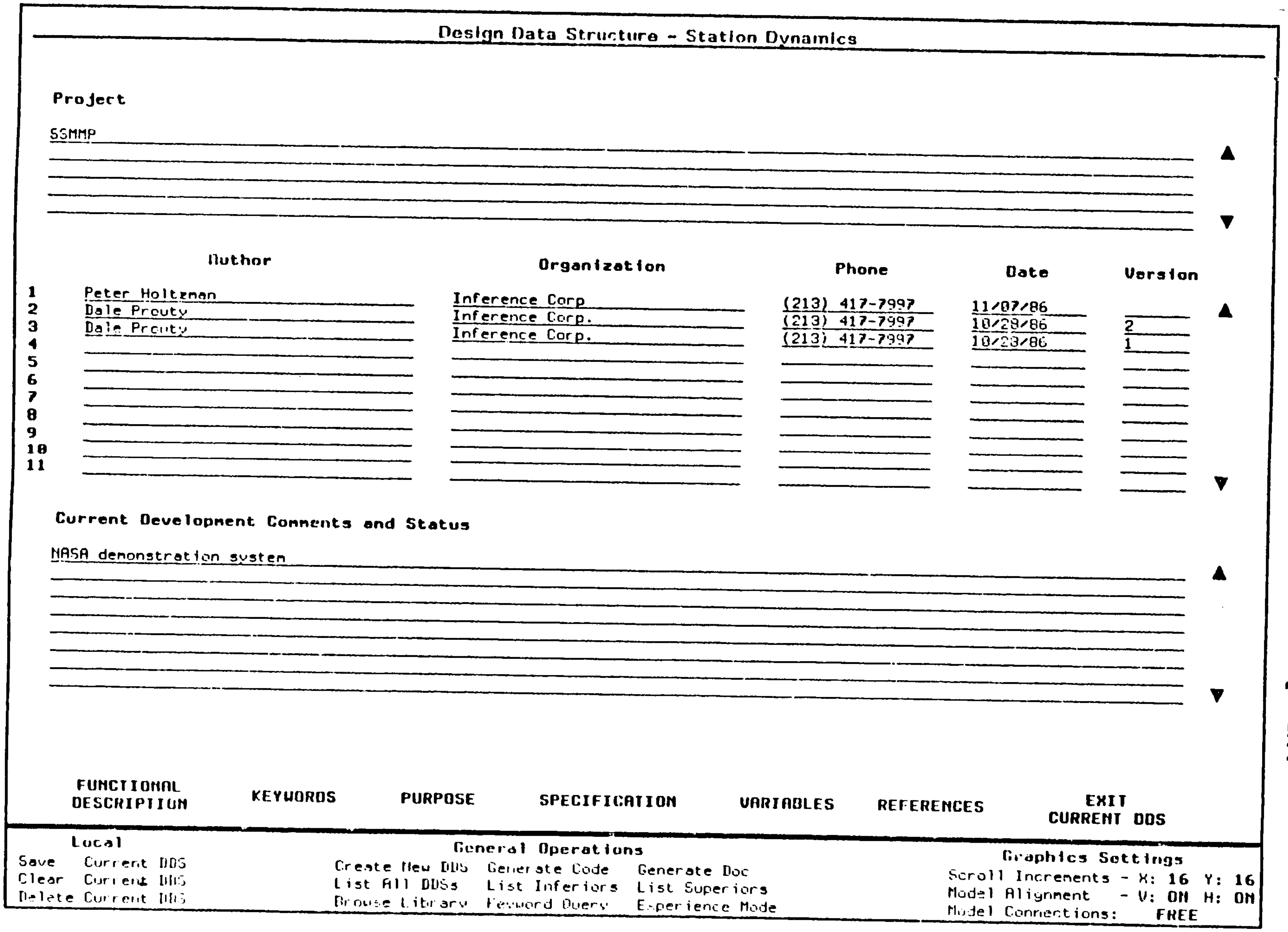
Specification Page B: Project Management Page

The Project Management page consists of three scrollable text fields used for project management: *Project*, *Version History*, and *Current Development Comments and Status* (see Figure 3-2 below).

The *Project* field is a scrollable text field used to describe the project and role of this DDS within the project.

The *Version History* is maintained by the system and displayed only. It is not entered by the user and cannot be edited by the user. It gives the author, organization and phone number of the logged in user who saved the version, as well as the date it was saved. The list is displayed by recency. The first line represents the DDS in the buffer, and is not assigned a version number.

The *Current Development Comments and Status* field is a scrollable field for comments on the current state of DDS design. It is used by the user to indicate what has been done and needs to be done to complete work on a partially developed DDS.



Design Data Structure – Station Dynamics

Project

SSMMP

	Author	Organization	Phone	Date	Version
1	Peter Holtzman	Inference Corp	(213) 417-7997	11/07/86	
2	Dale Prouty	Inference Corp.	(213) 417-7997	10/28/86	2
3	Dale Prouty	Inference Corp.	(213) 417-7997	10/28/86	1
4					
5					
6					
7					
8					
9					
10					
11					

Current Development Comments and Status

NASA demonstration system

FUNCTIONAL DESCRIPTION | KEYWORDS | PURPOSE | SPECIFICATION | VARIABLES | REFERENCES | EXIT CURRENT DDS

Local		General Operations			Graphics Settings
Save	Current DDS	Create New DDS	Generate Code	Generate Doc	Scroll Increments - X: 16 Y: 16
Clear	Current DDS	List All DDSs	List Inferiors	List Superiors	Model Alignment - V: ON H: ON
Delete	Current DDS	Browse Library	Keyword Query	Experience Mode	Model Connections: FREE

Figure 3-2: Project Management Page

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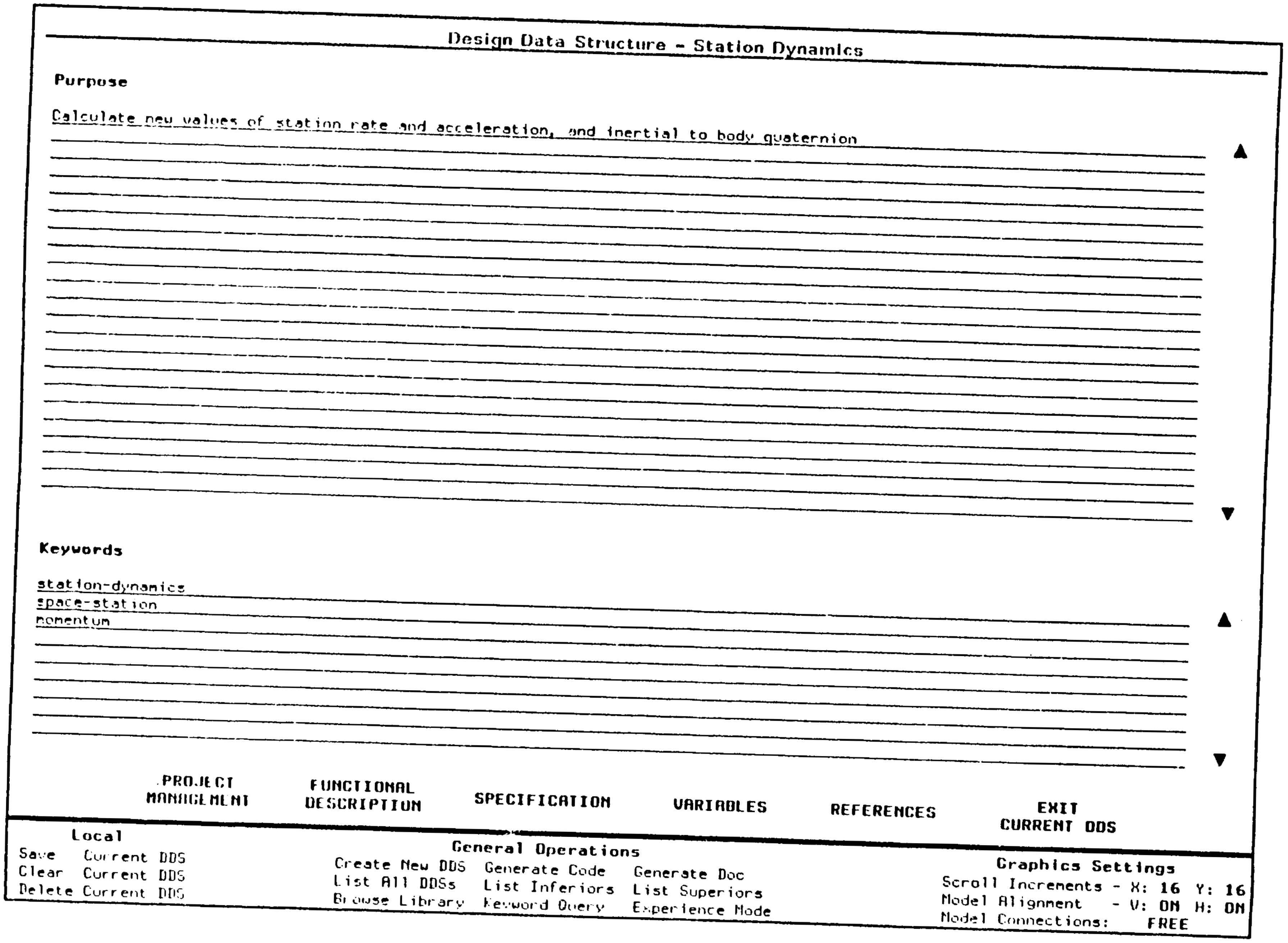

Design Data Structure - Station Dynamics

Purpose

Calculate new values of station rate and acceleration, and inertial to body quaternion

Keywords

station-dynamics
space-station
momentum

Graphics Settings
Scroll Increments - X: 16 Y: 16
Model Alignment - V: ON H: ON
Model Connections: FREE

Figure 3-3: Purpose and Keywords Page

Specification Page C: Purpose and Keywords Page

The Purpose and Keywords page contains the *Purpose* and *Keywords* text fields. These fields are important for both documentation and the browsing facility (see Figure 3-3).

The *Purpose* field is a scrollable field used to describe the purpose of the DDS. This field can be viewed from the library browser and is also used for generating documentation.

The *Keywords* field is a scrollable field used to specify the keywords for this DDS to be used in the cataloguing facility and for documentation purposes.

Specification Page D: Functional Description Page

The Functional Description page contains four scrollable text fields: *Functional Description*, *Assumptions and Limitations*, *Special Comments*, and *References* (see Figure 3-4).

The *Functional Description* field is documents the functional description of the DDS.

The *Assumptions and Limitations* field is for documents any assumptions or limitations of the design specification.

The *Special Comments* field documents any special comments about the DDS that will of interest for the user when the DDS is completed. A separate field is provided for development comments (Current Development Comments and Status)

The *References* field documents any reference to other documents (books, papers, memos) that may be relevant to the DDS.

Specification Page E: Variables Page - Graphically Specified DDS ONLY

The Variables page for a graphically specified DDS consists of a *Subroutine Name* field and three scrollable regions for describing *input*, *output* and *local* variables (see Figure 3-5). Local variables are used within the DDS but do not serve as either inputs or outputs.

The *Subroutine Name* field specifies the name to be used by the automatic code generator when generating the source code subroutine that corresponds to the DDS. The DDS name may be longer and more descriptive.

The information about variables is used for code generation, and automatic generation of coordinate system transformations.

Scrolling in a scrollable region scrolls the variables lines so that an indefinite number of variables may be used.

Each variable line has the following fields: Name, Description, Units, Variable Type, Dimension, Coordinate System, and Data Type.

Several of these fields are choice fields. When the user selects these fields, a menu of allowable choices is presented. The user selects the appropriate choice from the menu by clicking the mouse on it. If the mouse leaves the choice menu no change is made.

The Name is a text field to specify the variable name.

The Description is a text field to provide a short description what the variable represents.

The Units field is a text field to indicate the physical units associated with the variable e.g. grams

The Variable Type field is a choice field that specifies the variable as one of the following mathematical types: scalar, vector, matrix or quaternion.

The Dimension field specifies the dimensions of a vector or matrix. The dimension of a scalar is 1. The dimension of a quaternion is 4. The dimension of a vector must be a positive integer. The dimension of a matrix must be two positive integers separated by spaces. The dimension of a 3 x 3 matrix is entered as "3 3".

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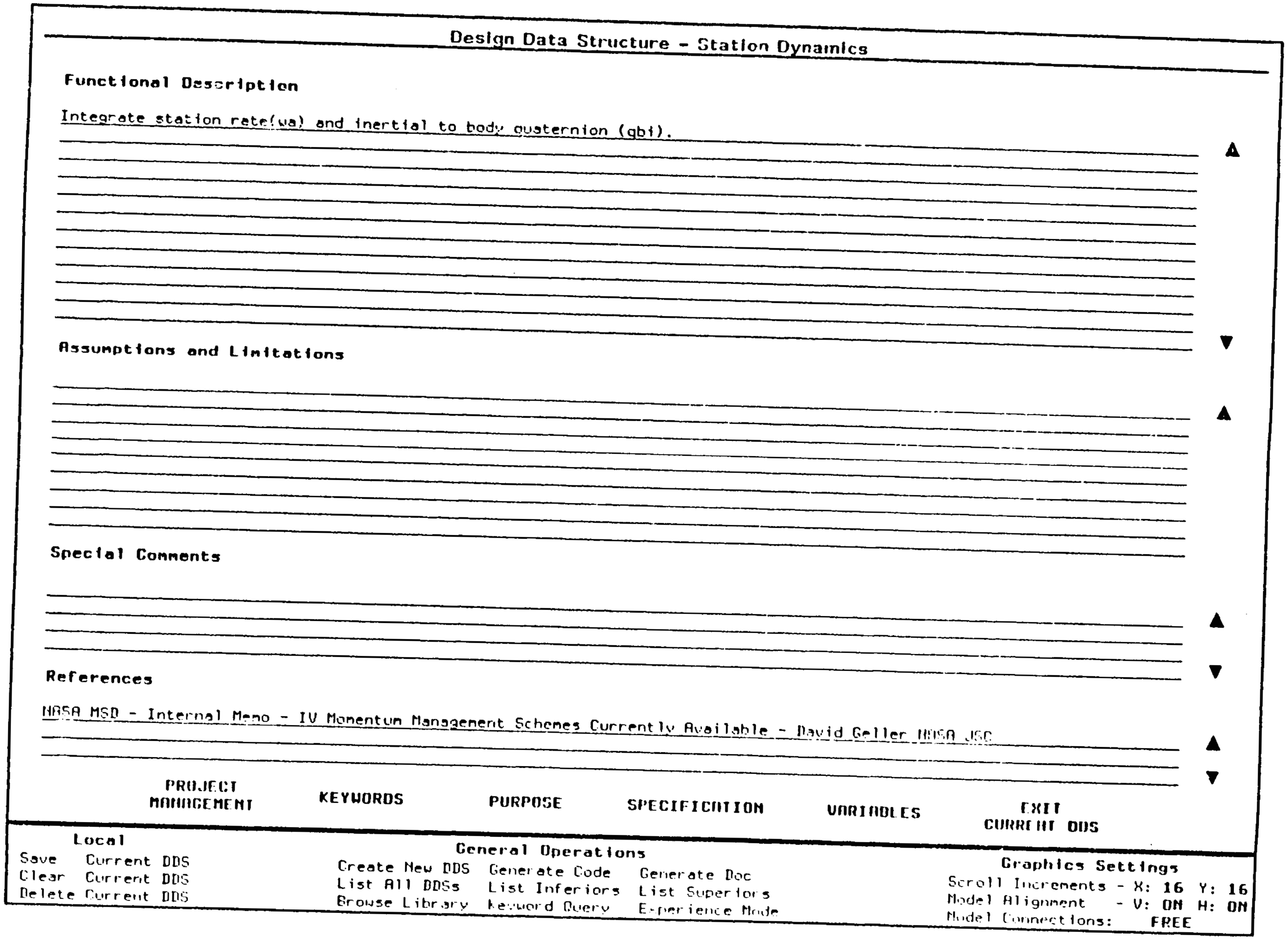

Design Data Structure - Station Dynamics

Functional Description

Integrate station rate(wa) and inertial to body quaternion (qbi).

Assumptions and Limitations

Special Comments

References

NASA MSD - Internal Memo - IV Momentum Management Schemes Currently Available - David Geller NASA JSC

Graphics Settings
Scroll Increments - X: 16 Y: 16
Model Alignment - V: ON H: ON
Model Connections: FREE

Figure 3-4: Functional Description Page

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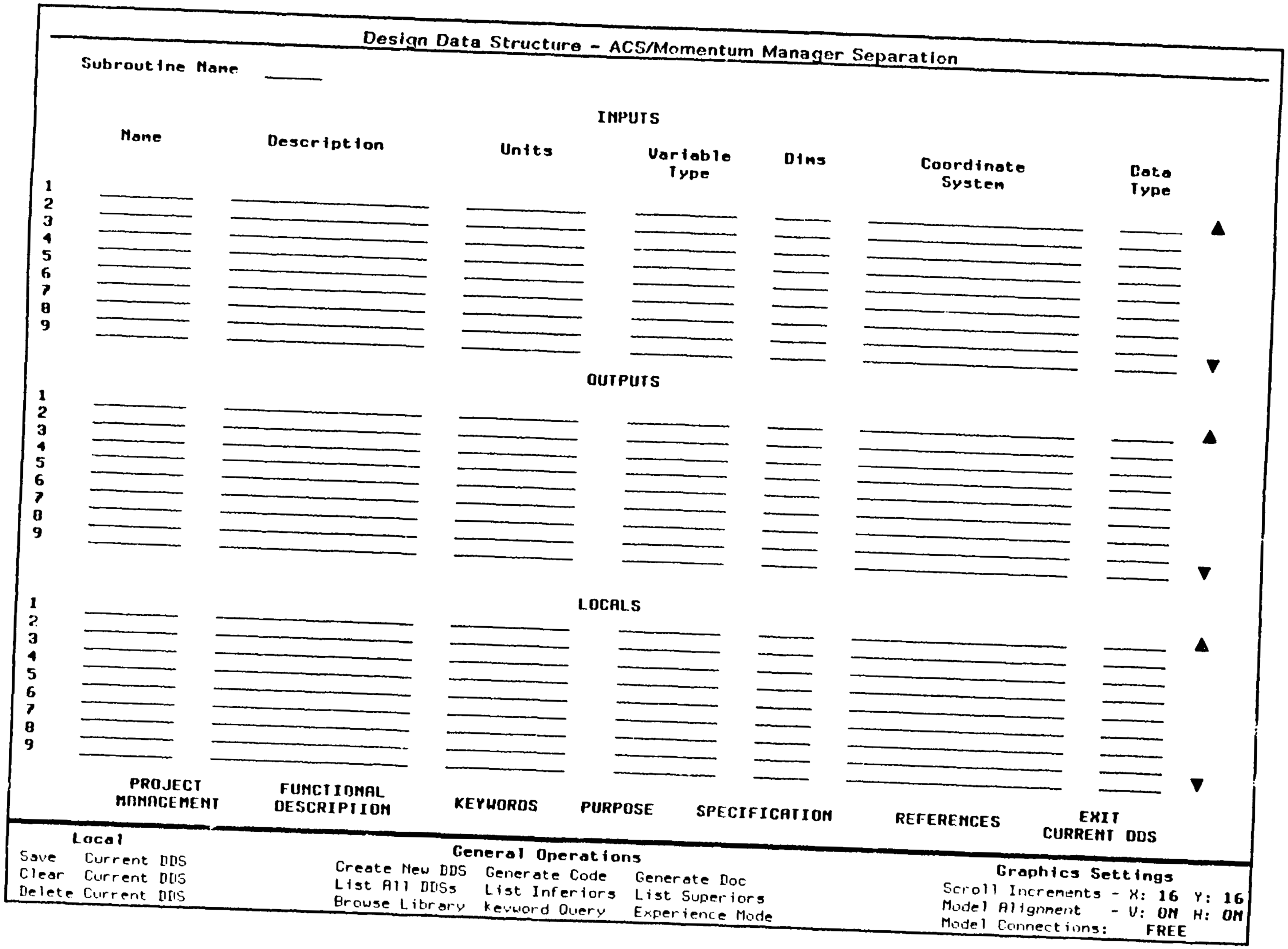


Design Data Structure - ACS/Momentum Manager Separation

Subroutine Name

INPUTS

Name | Description | Units | Variable Type | Dims | Coordinate System | Data Type

1 2 3 4 5 6 7 8 9

OUTPUTS

1 2 3 4 5 6 7 8 9

LOCALS

1 2 3 4 5 6 7 8 9

PROJECT MANAGEMENT | FUNCTIONAL DESCRIPTION | KEYWORDS | PURPOSE | SPECIFICATION | REFERENCES | EXIT CURRENT DDS

Local
Save Current DDS
Clear Current DDS
Delete Current DDS

General Operations
Create New DDS | Generate Code | Generate Doc
List All DDSs | List Inferiors | List Superiors
Browse Library | keyword Query | Experience Mode

Graphics Settings
Scroll Increments - X: 16 Y: 16
Model Alignment - V: ON H: ON
Model Connections: FREE

Figure 3-5: Variables Page - Graphical DDS

The Coordinate System field is a choice field thatt specifies the coordinate system. The current acceptable systems are: inertial, LVLH, body centered, principal axis, and N/A. The user selects this field with the mouse and is presented with a choice menu, as with the Variable Type field.

The Data Type field is a choice field that specifies the data type to be DOUBLE or INTEGER.

The variable lines are provided with default values and constaints.

When a variable is first defined by entering the name, the following defaults are assumed: scalar, dimension 1, coordinate system N/A, and data type DOUBLE.

The default dimensions are: scalar 1, vector 3, matrix 3 3, quaternion 4.

Scalars are constrained to be of dimension 1 and quaternions of dimension 4, no matter what the user may enter.

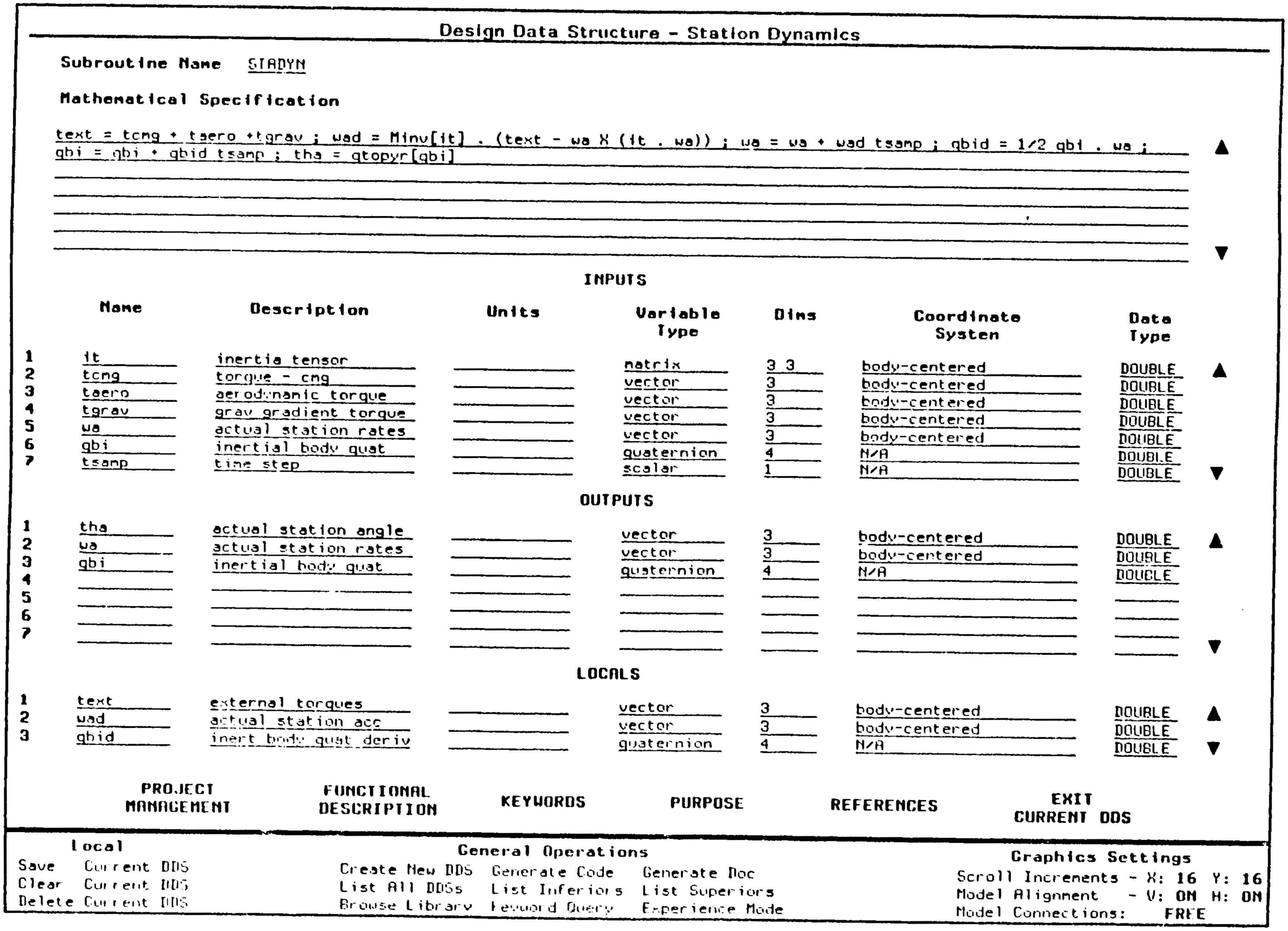
Specification Page F: Mathematical Specification and Variables Page

The Mathematical Specification and Variables page for a mathematically specified DDS consists of a *Subroutine Name* field, a Mathematical Specification field and three scrollable regions for describing ***input***, ***output*** and ***local*** variables (see Figure 3-6). Section 3.2.1.5 discusses the use of the mathematical specification field in more depth.

This screen is similar to the Variables page for a graphically specified DDS. It consists of the Subroutine Name field, the Mathematical Specification field, and three scrollable variable regions for input, output and local variables.

The Subroutine Name and variable regions are used as in the Variables page above.

The Mathematical Specification field is a scrollable text field used for entering equations that specify the DDS. These equations are written in SMP syntax and allow variables to represent vectors and matrixes. This high level mathematical language is



Design Data Structure - Station Dynamics

Subroutine Name STADYN

Mathematical Specification

```
text = tcng + taero +tgrav ; wad = Minv[it] . (text - wa X (it . wa)) ; wa = wa + wad tsamp ; qbid = 1/2 qbi . wa ;
qbi = qbi + qbid tsamp ; tha = qtopyr[qbi]
```

INPUTS

	Name	Description	Units	Variable Type	Dims	Coordinate System	Data Type
1	it	inertia tensor		matrix	3 3	body-centered	DOUBLE
2	tcng	torque - cmg		vector	3	body-centered	DOUBLE
3	taero	aerodynamic torque		vector	3	body-centered	DOUBLE
4	tgrav	grav gradient torque		vector	3	body-centered	DOUBLE
5	wa	actual station rates		vector	3	body-centered	DOUBLE
6	qbi	inertial body quat		quaternion	4	N/A	DOUBLE
7	tsamp	time step		scalar	1	N/A	DOUBLE

OUTPUTS

	Name	Description	Units	Variable Type	Dims	Coordinate System	Data Type
1	tha	actual station angle		vector	3	body-centered	DOUBLE
2	wa	actual station rates		vector	3	body-centered	DOUBLE
3	qbi	inertial body quat		quaternion	4	N/A	DOUBLE
4							
5							
6							
7							

LOCALS

	Name	Description	Units	Variable Type	Dims	Coordinate System	Data Type
1	text	external torques		vector	3	body-centered	DOUBLE
2	wad	actual station acc		vector	3	body-centered	DOUBLE
3	qbid	inert body quat deriv		quaternion	4	N/A	DOUBLE

PROJECT MANAGEMENT | FUNCTIONAL DESCRIPTION | KEYWORDS | PURPOSE | REFERENCES | EXIT CURRENT DDS

Local
Save Current DDS
Clear Current DDS
Delete Current DDS

General Operations
Create New DDS | Generate Code | Generate Doc
List All DDSs | List Inferiors | List Superiors
Browse Library | Keyword Query | Experience Mode

Graphics Settings
Scroll Increments - X: 16 Y: 16
Model Alignment - V: ON H: ON
Model Connections: FREE

Figure 3-6: Mathmematical Specification Page

appropriate for indicating the specification of a DDS at a mathematical level without having to write DO loops and programming constructs, although such constructs are available in the SMP syntax.

The high level mathematical specification together with the variable description are used to generate source code automatically.

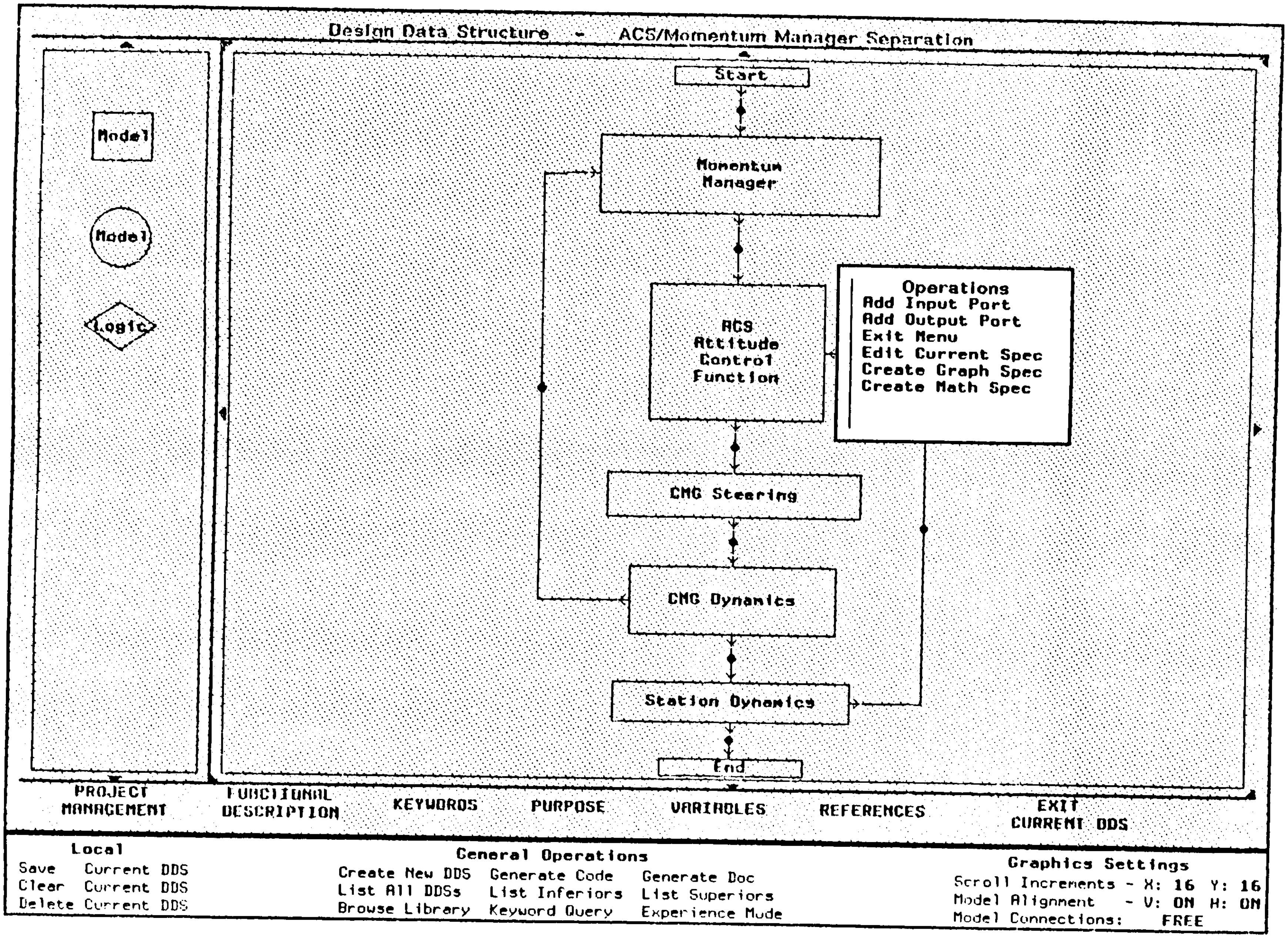
3.2.1.4 Graphical Design System

The graphical design system allows a designer to build or edit control flow diagrams. The diagrams are built by mousing on a "vocabulary" element from a palette of choices and positioning them within an editable region, the design area (see Figure 3-7). The Phase I palette icons represent generic design elements. No specialization was attempted. When a design is located in the control flow and given a name, that name is tied to all library designs matching it by name. Several coices may be available for linkage of the control block to a lower level, more descriptive DDS. These are all presented when the user begins the linkage operation.

The graphical design system supports most of the basicly desired operations for editing - deletion, scrolling through a "file", clearing the "file" of buffer, and graphic-specific ports on design blocks and connections amongst them. Deletions allow removal of single elements from the design area (or buffer); scrolling allows flow diagrams larger than design area size to be viewed, built, and stored; and clearing removes all elements from the buffer. Ports are positioned after a menu selection that arises via mouse click on a specific design block. Connections are then added between blocks by mousing the respective port mouse sensitive areas. Each connector is given its own mouse sensitive are for use in obtaining a menu of observation or results options.

Certain operations (displayed at the bottom right of the screen) relate to default settings for the graphical design system. These may be adjusted as the user desires for such things as scrolling increments and alignment of control blocks.

The general intent is to make the graphical editing area similar in nature to an EMACS buffer, but with graphic-specifc operations.



Scroll Increments - X: 16 Y: 16
Model Alignment - V: ON H: ON
Model Connections: FREE

Figure 3-7: Graphical Specification - Model Operations Menu

The implementation of the graphical design system is accomplished by dividing the middle section of the screen into two scrolling areas, one, a palette, for the generic or specific graphical design vocabulary, and the other, a design are for laying out or editing control flow diagrams. Scrolling is available via mouse sensitive "scroll markers". The design layout is accomplished via mousing a palette icon, positioning the replica in the design area, and, if the icon is generic, filling in the design name. Additional graphical operations are reachable via a mouse click on the design "icon", or via the bottom section operations (such as delete, etc.). Ports and degin flow connections are accomplished by selecting the input or output port operation from the design icon menu, locating the port on the design icon, then connecting ports by clicking on the port mouse sensitive areas, input to output or vice versa.

3.2.1.5 Mathematical Design Level

The mathematical design level or leaf allows a designer to build or edit engineering mathematical specifications. The mathematics is written in SMP using engineering terminology and syntax, including dealing with vector manipulation such as dot and cross products. The SMP code written is later used as input to the Fortran code generation process. The specifications written in Phase I were for the attitude control system.

3.2.1.6 Implementation

This section describes the implementation of the DDS description screens, with the exception of the graphical specification.

Each DDS is implemented as an ART schema together with some associated facts. The schema name is internally generated so that various DDSs can have the same textual name. This is possible because the name is actually a slot of the DDS schema.

Inferior DDSs within a graphical DDS are represented by a model fact which describes inferior DDS in relation to its superior. The actual icon on the screen is represented by a model-icon-description fact. The model fact ties the unique icon name to an inferior DDS schema. Thus the actual inferior schema may be changed within the model fact without affecting the model-icon-descriptor fact.

A pushdown list of DDSs are maintained in the design-process-buffer-list fact as a variable length sequence and the current schema is at the top of this list.

The current DDS is also maintained in the wksta-current-dds-type fact.

The presentation and editing of the all screens, except for the graphical specification screen, is performed by a set of general rules, facts and schema for handling a multiple screen form in an ART graphics window. The form associated with the DDS also uses some specific rules and uses variants of the general rules. Each form has a specific name that is not seen by the user. The form used for the DDS screens is called "model-descriptor".

The form rules are driven by certain facts and schema.

The form-window-schema fact identifies the form name, the windows involved, the schema that the form represents (in this case the particular DDS schema), the particular scroll schema, and slots corrosponding to scrollable fields.

The scroll schema uses its slots to maintain the scroll position of all scrollable textual fields and regions (authors and variables).

Most fields are represented as form-value-field-run facts. These facts describe each form. They tie together information necessary to identify the field (the form name, window, and field tag), the corresponding slot name in the underlying schema, the position of the field in the window, and the field type. The field type specifies whether the user interacts with the form via the keyboard or a choice menu.

There is also a facility for handling related related fields such as the component fields of a variable or version history line.

These fields are represented in the DDS as subsequence elements in a DDS slot. The slot is a multiple-value slot to allow for several lines or blocks of related fields - and each slot instance has a number associated with it as part of its value.

Each type of block has an associated name. Each window region where the blocks may occur is given a region name.

The scroll schema contains a form-complex-field-region slot that describes the window region containing repeating blocks to be scrolled simultaneously. It defines the window coordinates of the region, how many blocks are displayed, and the first block actually displayed. A form-complex-field-subfield slot describes the block - i.e. the relation of the subfields to the subsequence values and acts as a form-value-field-run fact.

Form rules exist to display form pages (screens), to update individual fields, and to perform scrolling.

The display rules draw the form on a background form window, and then bitblt it to the foreground window, create the mouseable areas and expose the foreground window. This allows an clean visual transition from one form page to another. The rules access the current values of the DDS via the ART get-schema-value function. They also use this function to get values from the scroll schema to determine what parts of the DDS schema values and slots should be displayed on the limited window area.

Whenever the form-window-schema fact specifies a DDS which is different from the current DDS as specified by the wksta-current-dds-type fact, the form-window-schema fact is updated to tie the form to the current DDS and the scroll schema is reset.

The utterances asserted from mouse clicks on the mouse sensitive area of the form indicate the form name, the window, the field tag and some indication of the field type.

One rule responds to utterances with associated form-value-field-run facts that specify input from the keyboard. They pass current slot value to a lisp function which accepts input from the keyboard and provides many of the normal editor commands. This function returns the new value. The slot value is then changed via retract-schema-value and assert.

A similar rules handles utterances with an associated form-value-field-run fact that indicates a choice menu. The choice menu is constructed and exposed and returns the appropriate choice. The form-value-field-run specifies the allowable choices (or enumerated values as they are refered to in the ART source code). In addition to modifying the schema value, this rule prints the new value on the form window.

The associated fields described by form-complex-field-subfield slots are handled differently. In this case the utterance specifies the field tag that describes the field on the window. Two rules pick up this utterance and calculates the corresponding slot in the DDS schema, based upon the scroll schema's information as to which slot is the first slot displayed in the window region and either calls the lisp function or constructs a choice function as above. There is one rule for keyboard entry and one for choice menus. These rules differ from the above rules in that they are of high salience, and assert that the corresponding window block should be redrawn by using a form-region-display fact.

In the case of variable lines, which have associated rules to implement defaults and constraints, this allows these medium salience rules to fire and modify other subsequence elements in the modified slot value.

Finally a normal salience display rule fires to display the block. There are two such rules. One for variable blocks and one for version history blocks. These rules actually call special lisp functions to draw on the window. This is so the page display rules can call the same lisp functions directly, without going through the overhead of asserting multiple form-region-display facts and causing multiple rule firings.

Scrolling is handled by a set of rules which modifies the scroll schema, bitblts the portion of the form window that remains visible to an offset position in the same window and displays the new part of the screen produced by scrolling.

There are general rules for doing this. One set handles normal fields, the other complex fields that use form-region-display facts to redraw the new block.

3.2.2 DDS Operations

As any DDS is edited there are a set of possible operations that are supported outside the actual editing environment. These are all rather straight forward. The commands are reached via text and mousable regions at the lower portion of the screen (see several of the previous Figures, e.g. Figure 3-7, p.23). Each is recorded below with a brief descriptor. They are implemented via a LISP function that sets up the text and mouse areas, and utterances arrive into ART where rules respond appropriately.

Local Operations:

- Save Current DDS - catalog the design in the card catalog system and enter it in the library
- Clear Current DDS - remove all designs and connections from the current DDS, clear the design area
- Delete Current DDS - delete this design from the buffer

Global Operations:

- Create New DDS - create new design buffer
- Generate Code - generate Fortran code for DDS
- Generate Doc - not implemented in Phase I
- List All DDSs - bring up the buffer list
- List Inferiors - not implemented (list of inferior DDSs)
- List Superiors - not implemented (list of possible superior DDSs)
- Browse Library - enter the browsing facility
- Print Screen - not implemented (hardcopy facility - site specific)
- Experience Mode - not implemented (Usage of Help facility)

Graphics Settings:

- Scroll Increments - x and y default scroll increments

- Model Alignment - vertical and horizontal alignment of design icons
- Model Connections - not fully implemented (free drawn connectors between DDSs or rectangular line connectors)

3.2.3 DDS Librarian

Design Data Structures within the Automated Software Development Workstation are persistent objects which are managed by the DDS librarian. The librarian is a service that organizes information about the DDSs in a conceptual manner that is appropriate for the user of the workstation, and uses the underlying file system to actually store and retrieve information. This relieves the user of the burden of managing the file system manually and keeping track of which files are related to others, and allows the user to browse the library according to meaningful categories such as DDS names or keywords, rather than file names. This is especially useful because a single conceptual DDS may have several files associated with it.

The library is maintained as schemata within the ART database, which point to all files associated with a DDS. It is also maintained in the file system as a system file.

The librarian performs the basic operations of cataloguing and browsing. It is also used in the selection of inferior DDSs in a design hierarchy.

3.2.3.1 Cataloguing

The catalogue operation, is invoked when the users mouse selects the Save DDS field whiled editing a DDS. It saves the information associated with a DDS in file(s) and catalogues the DDS in the library. Other modules, such as source and data files may eventually be catalogued with the DDS entry. The librarian maintains its own version system to distinguish various versions of a design or separate designs with an identical name.

3.2.3.2 Browsing

The browse operation of the Librarian is the Electronic Card Catalogue System which is organized in a fashion similar to manual card catalogue systems in traditional public libraries. DDSs may be browsed by Design (title), Designer (author) or keyword (subject), as in a traditional library. Additionally designs may be browsed by Project. Unlike traditional systems, several topics may be browsed at once such as designs for a Space Station Momentum Manager, or designs having to do with "momentum" or designs authored by John Smith. This allows the user to specify sufficient information in a single query.

In keeping with the graphical presentation style used throughout the workstation, the librarian represents the DDSs graphically using the the terminal screen as a scrollable viewport on the graph of DDSs and the user can interact with the librarian via mouse selection. This is implemented by the use of the "ART graphical schema browser".

Individual designs are represented in the browser by appending a parenthetic expression of the form: (design-number . version-number) The design number indicates differentiates between various DDSs which have identical names. The version number identifies different versions of the same DDS.

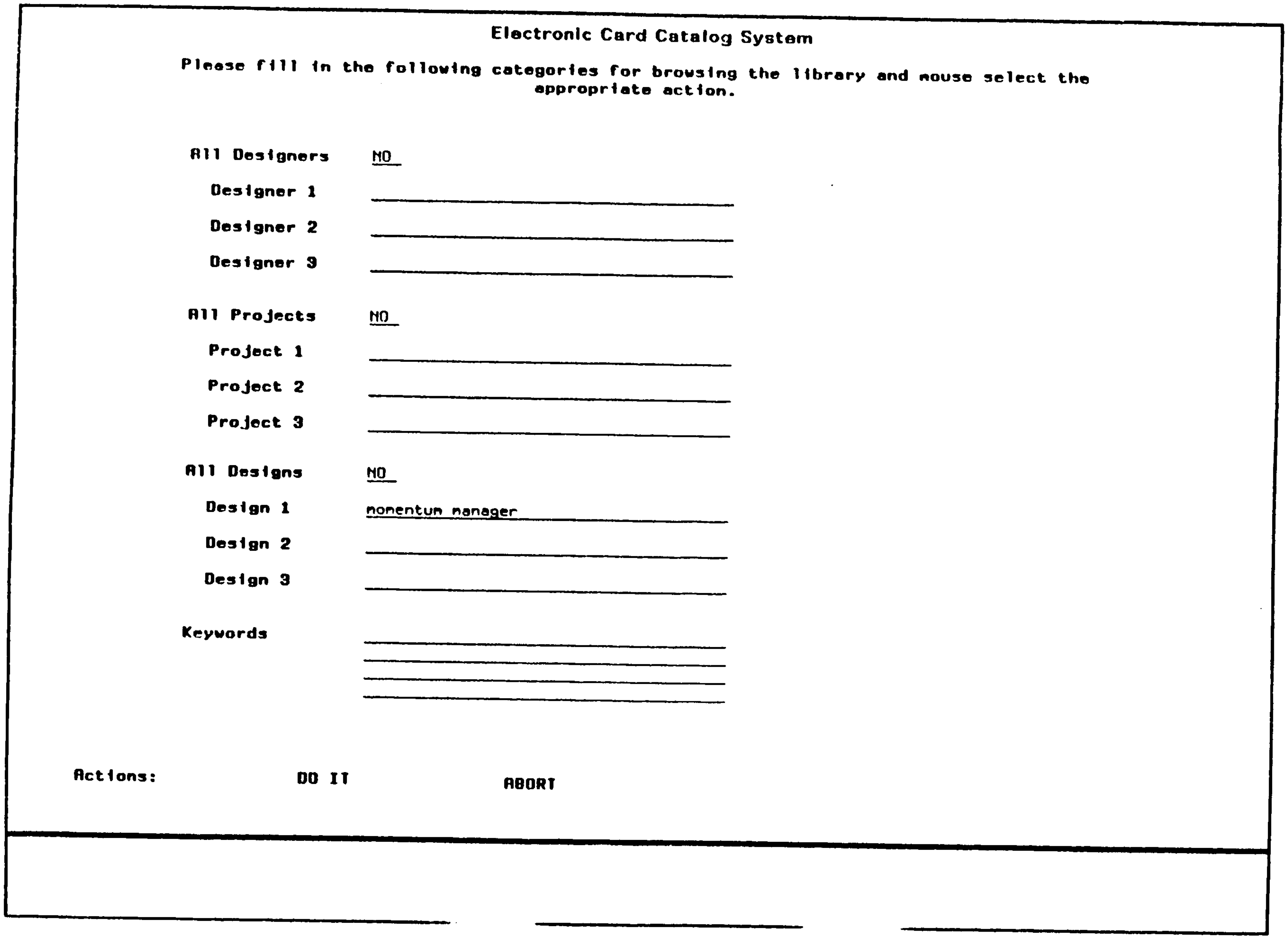
Figure 3-8 shows the screen which represents a user query to browse the library.

Figure 3-9 shows the resulting graphical presentation of the associated DDSs.

Figure 3-10 shows viewing the purpose of a library design from the browser for purposes of possible editing or inclusion, i.e. reuse.

While browsing the library, the user may mouse select a particular DDS to either view its purpose or to load it into a workstation editing buffer. Viewing the purpose produces a scrollable window, showing the purpose associated with the DDS.

It is important to note that the DDS is not actually part of the running database, only its library schema is present.



Electronic Card Catalog System

Please fill in the following categories for browsing the library and mouse select the appropriate action.

All Designers	NO
Designer 1	
Designer 2	
Designer 3	
All Projects	NO
Project 1	
Project 2	
Project 3	
All Designs	NO
Design 1	momentum manager
Design 2	
Design 3	
Keywords	

Actions: DO IT ABORT

Figure 3-8: Browse Library Query

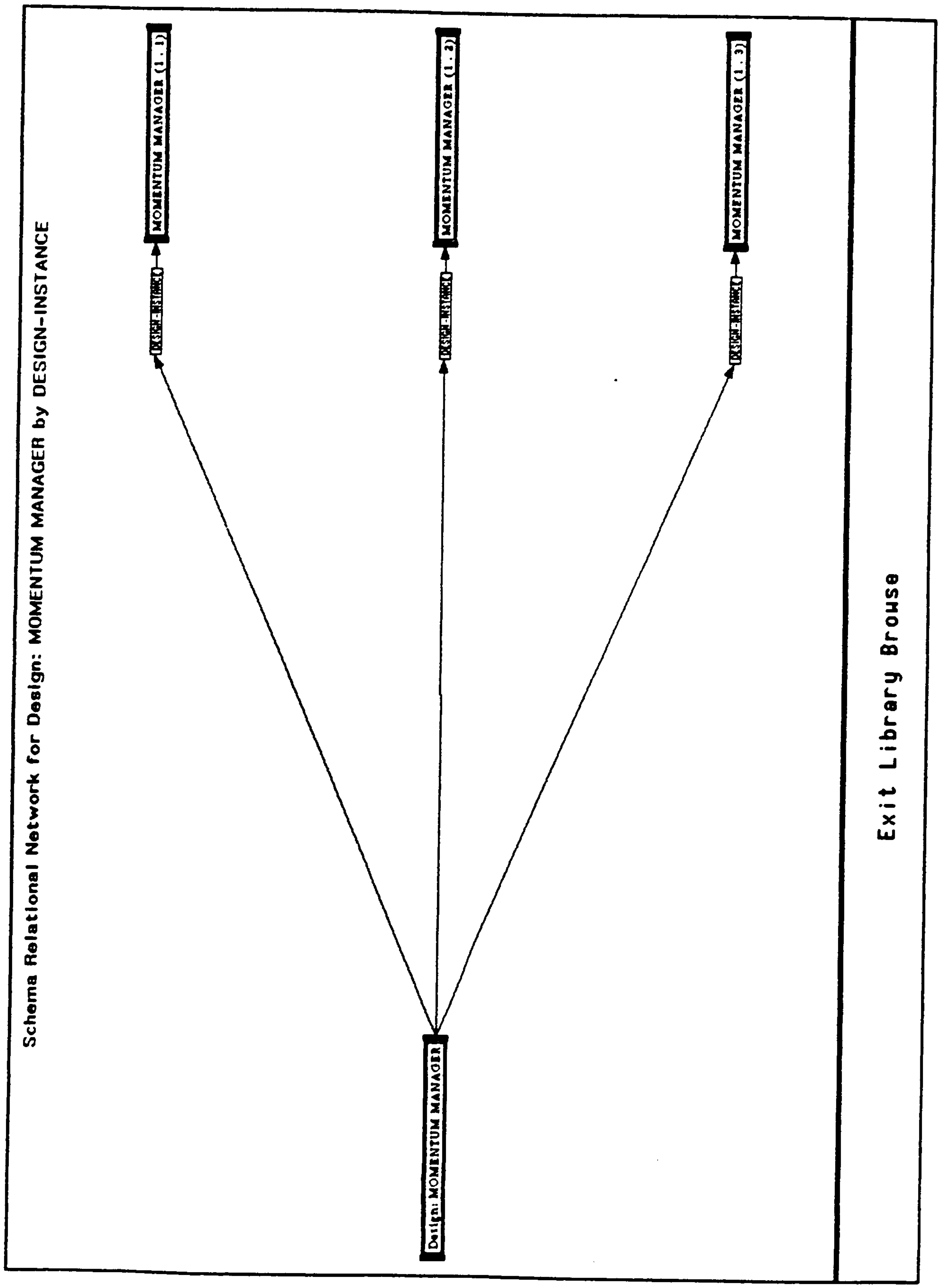
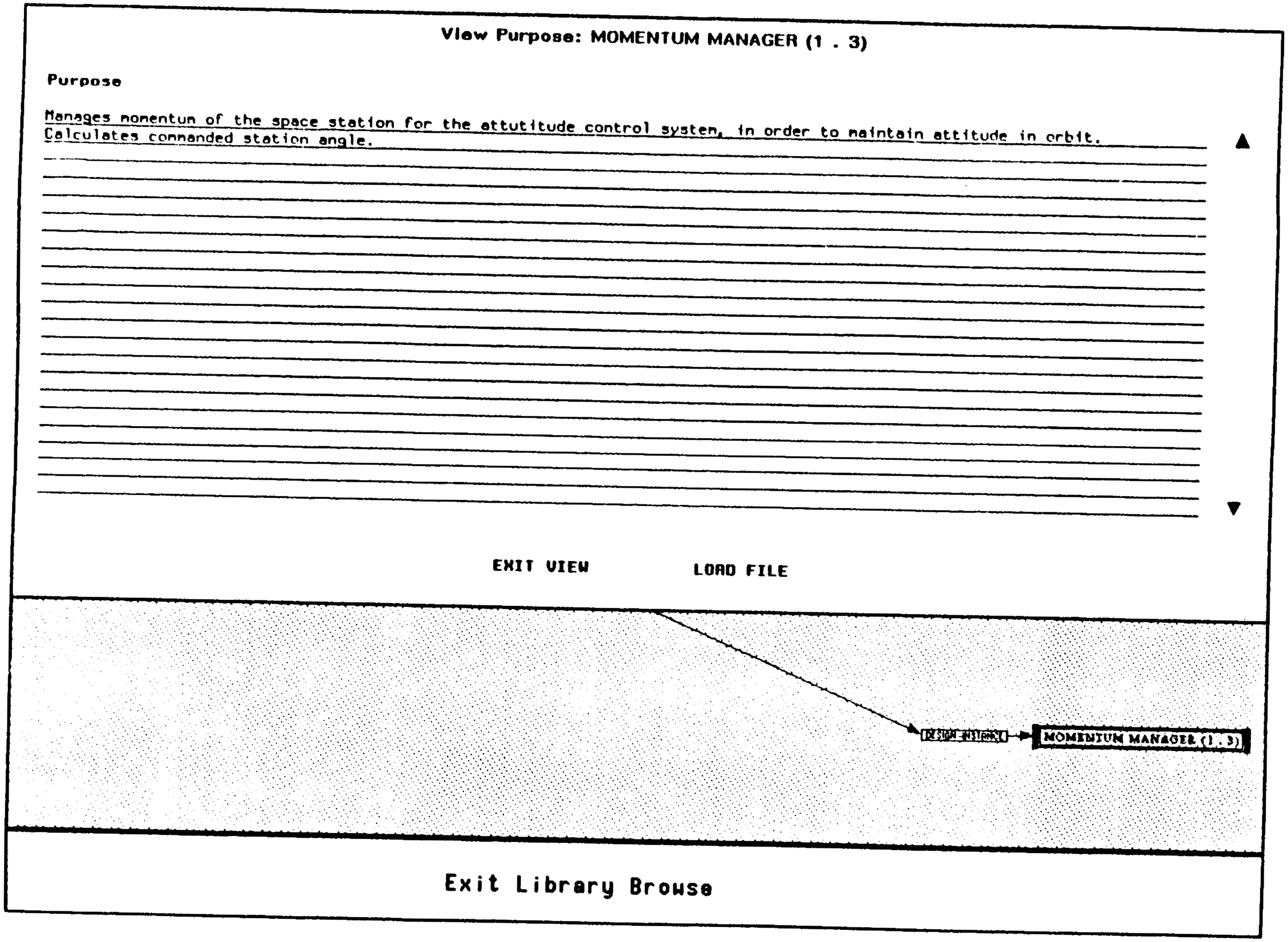


Figure 3-9: Library Browse



View Purpose: MOMENTUM MANAGER (1 . 3)

Purpose

Manages momentum of the space station for the attutitude control system, in order to maintain attitude in orbit.
Calculates commanded station angle.

Figure 3-10: Library View Purpose

The load operation, actually loads the associated file(s) into the database, and places the DDS into an editing buffer which is then selected to be edited.

For Phase II the browser should be enhanced to present the design hierarchy. Context sensitive synonym tables should also be introduced to allow reference to design with similar purposes but different names.

3.2.3.3 Selection

The third use of the librarian is for the construction of hierarchical designs. When a user is working on a DDS in any level he represents inferior embedded DDSs as graphical icons. At any time during the editing process he may obtain a list of DDSs which same name as the graphical icon by clicking on the mouse sensitive icon. All DDSs in the library and in any graphical buffer (which may not have been saved into the library) with the same name are listed.

The user may elect to view any of these DDSs or to link the graphical icon to one of them. Linking the icon implies that that particular DDS is selected to be the inferior DDS. The librarian is used both to view and link an inferior DDS when it resides in the library and is not currently in a graphical editing buffer.

3.2.3.4 Implementation

The library is maintained as a collection of ART design instance schemata representing the various DDSs. A schema that represents a DDS has slots that point to the files that contain its definition, its design number, version number, textual name, purpose and other associated information.

A schema is created for each design name, designer, project and keyword. These are linked to schema that represent designs appropriately, and also to the special schema all-designs, all-designers and all-projects.

We will first describe browsing.

The Electronic Card Catalogue System window is handled by the same form rules that implement most of the DDS screen windows. These collect the users specification as slots in a fixed known schema.

When the user activates a browse two groups of rules are invoked.

The first groups uses the fixed schema to collect all initial schemata and relations to be browsed. It then traces out the schema subnetwork to be browsed and "shadows" the relations by temporary relations which are logically dependent on a wksta-library-shadow fact. This prevents many unwanted schemata to be browsed. This is because the schema browser browses by both primary and inverse relations.

The second group actually calls the schema browse function. This function must be called with a unique initial schema. If several initial schemata are needed they are temporarily joined to a unique initial schema by asserting relations which depend logically on the temporary-join-in-progress fact.

The ART interface browse function is called to display the library subnet graphically.

In addition, the rules will first retract the wksta-library-shadow and temporary-join-in-progress facts if present, to clean up any temporary relations created by previous browses.

There are rules to respond to mouse clicks in the browser window in the appropriate fashion - i.e. either loading the file or displaying the purpose. A file is not loaded if the DDS is already in a buffer list - to avoid merging two versions. The rule to actually load the file, uses the dds-name slot in the library design instance schema and a not pattern for finding this dds schema on a buffer list.

Catalogueing schema consists of creating the design schema and also any missing keyword, project, designer or design name schemata and writing out dds schema and associated facts as well as lisp file which is also compiled.

The catalogueing rule first asserts the most of the necessary schema slots, and also appends their definition to the library file. It uses a wksta-dds-descriptor to pass the design instance schema and library file stream to the actual save rules. These save the ART and lisp files, assert the pointers to these files, and write out the slots to library schema.

The librarian supports the linking of a DDS inferior icon to a DDS by providing a rule that will load the most recent version of a dds schema file when a wksta-load-most-recent-dds fact is asserted. It locates the most recent version and essentially asserts a fake load utterance from the schema browser.

The rules associated with the schema browser also maintain the appropriate icon in the bottom operations window at all times.

3.2.4 Automated Programming

A facility for automated generation of Fortran code was produced. Fortran subroutines can be written that represent each DDS level from high level graphical to the leaf mathematical specifications. Thus the graphical specifications consist of a subroutine which itself contains a set of variable declarations and other subroutine calls. The mathematical specifications lead, via SMP, to Fortran subroutines that contain engineering mathematics and appropriate calls to accomplish required lower level mathematical functionality.

3.2.4.1 Graphical Program Generation

ART rules write Fortran subroutine calls and do variable declarations for graphical program generation. The subroutine calls get written in sequence simply by having rules that wait until all inputs are known, then propogate this to the outputs, on to the next inputs, etc. The process is begun at the "START" DDS found at each graphical level. All the inputs to this DDS reside here. The outputs of START are propogated forward to become known inputs for the next designs, code is written, and END is reached. This closes the subroutine with the normal "RETURN/END" lines.

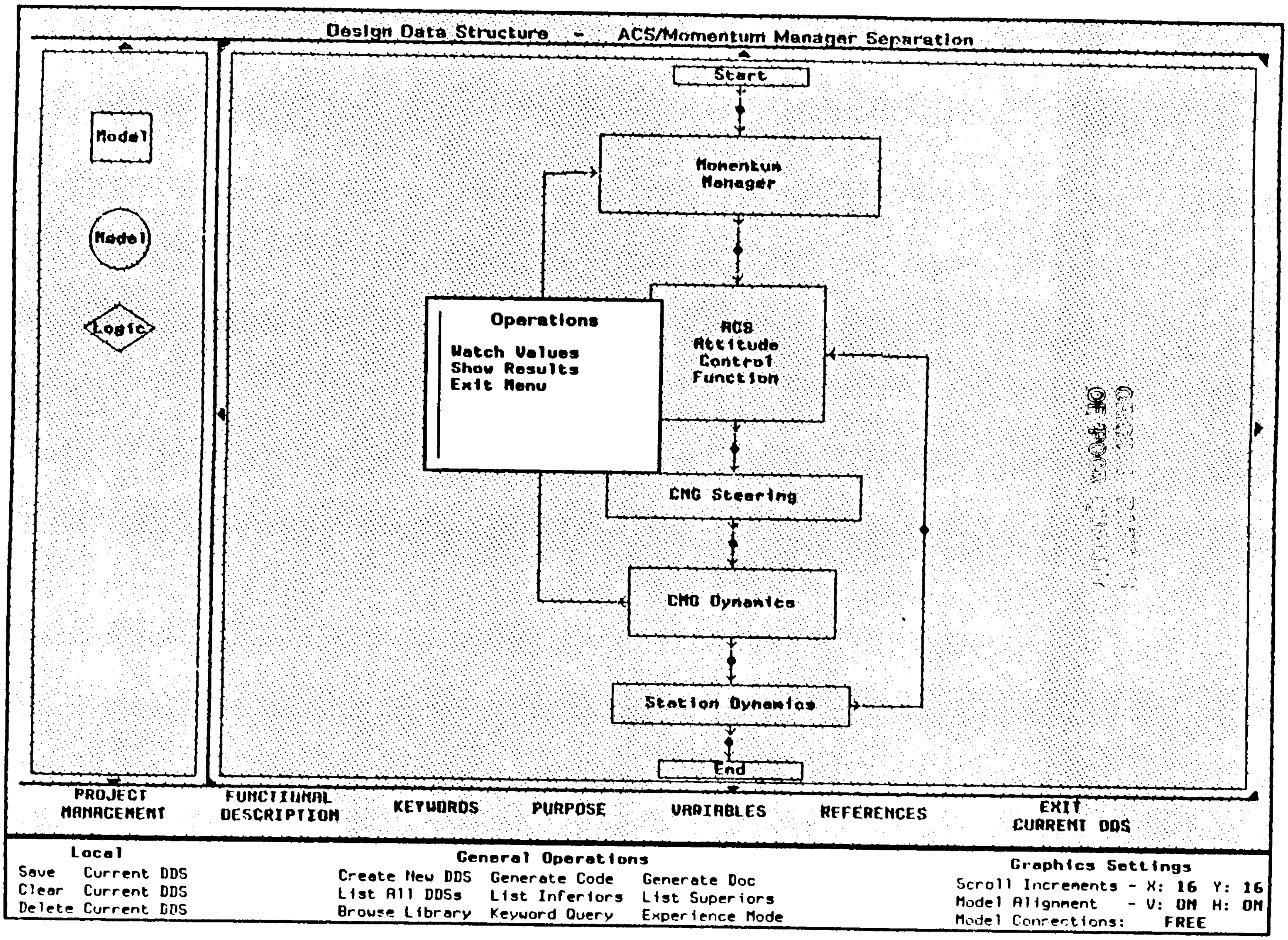
3.2.4.2 Mathematical Program Generation

SMP code is written on the leaf element mathematical specification page. This code is translated into Fortran with variable declarations as specified on that same page for input, output, and local varaiables. A Fortran subroutine results with most of the several pages of specification added as in-line documentation.

To accomplish program generation, SMP is put in a loop running on the VAX (via a VMS command routine) so that SMP is awaiting arrival of a specific file over the network. When this file arrives, the SMP processing begins. The result of this processing is the Fortran code generation. To accomodate the appropriate variable declarations and code generation several SMP utility functions are utilized on the VAX. These functions deal with the vector mathematics required in most engineering disciplines, the variable specifications from the specification page, and standardization of mathematical syntax from that which typically exists in the field. The processing is primarily done by the SMP function "Wkstaprog" which uses SMP functionality appropriately to accomplish the code generation via "Prog", a standard SMP function for code generation from analytic expressions. SMP does not fully support all necessary variable declarations as desired, so a brief C program does a final editing of SMP generated code before passing the code back to the Symbolics for final file (module) construction and storage.

3.2.5 Results Presentation

A presentation of results facility is necessary for both batch and interactive simulation. This facility has not been produced in Phase I since it relies heavily on extant plotting facilities and is of limited interest to the demonstration of AI's usefulness. A menu can be chosen on all graphical links that introduce a form and/or plot specification package, see Figure 3-11. These packages should allow full specification of the plot DDS similar to those of the design DDSs. Thus, for example, solar array occlusion of the sun by the earth could be plotted versus orbit location and/or time, and could be reused just as a design could. The results facility is intended to be an integrated DDS type capability.



```
Graphics Settings
Scroll Increments - X: 16  Y: 16
Model Alignment   - V: ON  H: ON
Model Connections:    FREE
```

Figure 3-11: Results Presentation

3.2.6 Execution

Phase I did not complete an executable simulation due to time limitations. Code was generated for various DDSs that could be incorporated into a program, but no specific facilities were made available for establishing linking and compilation of these DDS software modules, nor was an effort made to provide the more sophisticated interactive simulation capability.

3.2.7 Debugging Designs

Debugging designs is a topic for executable simulations. Since no execution facility was completed this is left to Phase II.

3.2.8 Automated Documentation

As called out in the SOW, no Phase I effort was to be spent at this effort and none was.

3.3 Tutorials

There are two cursory tutorials on current workstation functionality - installation and usage. The installation briefly describes the necessities in setting up the workstation; the usage tutorial leads a user through an example of starting an attitude control subsystem design and cataloguing.

3.3.1 Installation

An automated installation procedure has been provided with the workstation.

The workstation software is combined to run under ART 2.0 on a SYMBOLICS computer which is networked to a Digital Equipment Corporation VAX computer which runs SMP under the VMS operating system.

The workstation requires the use of a Symbolics - Philips terminal.

To install a workstation the system manager must create an SMP account on the VAX, a workstation login on the SYMBOLICS, and create a workstation band. Each

SYMBOLICS running a workstation should have its own associated VAX account. The SYMBOLICS host is part of the ART database, so each SYMBOLICS must currently have its own band. More specifically:

- Set up a SYMBOLICS top-level directory to be used to hold the workstation source library and perform a "(tape:carry-load (&key :host))" to load the source files onto the SYMBOLICS directory. This directory is referred to below as the "Art-Source-Directory" and is typically *host:>wksta>*. The user should have this as his default SYMBOLICS directory when he logs into the SYMBOLICS as the workstation.

- Set up an account on the VAX VMS to be used by the workstation (each workstation copy must have its own account). This account must have a *LOGIN.COM* file that allows it to run the SMP program (see SMP Installation Notes).

- Setup a subdirectory of that account for use by the workstation - this subdirectory is usually *[.transfer]* that is typically *my$disk:[user.wksta.transfer]*

- Logon to the Symbolics as the workstation.

- Load the file *initialize-workstation.bin* from the "Art-Source-Directory".

- Invoke the function "(initialize-workstation)".

```
This requests the following information:
    a) SYMBOLICS Host Name (typically "host:>wksta>")
    b) SYMBOLICS Workstation Logon Name (user name or nickname)
    c) SYMBOLICS Default Directory After Logon ("host:>wksta>")
    d) SYMBOLICS Path From Logon Directory
         To Workstation Directory (make it - "")
    d) VAX Host Name (example "v3")
    e) VAX Logon Name (example "dap")
    f) VAX Logon Password (example "secret")
    g) VAX Full Pathname To Transfer Directory
         ("my$disk:[user.dap.transfer]")
   This function will transfer the appropriate files
   to the VAX, and compile a version of the workstation
   with the necessary information declared as an ART fact
   to control networking between the SYMBOLICS and the VAX.
```

- Create a workstation band. From the LISP Listener

```
    a) Perform (gc-immediately)
    b) Perform disk-save
```

- Create a boot file for loading the workstation band.

The workstation stores its program libraries in the workstation "logon" directory. If you wish to use the initial library provided with the workstation you should copy the "library" subdirectory of the "Workstation-Directory" up to the workstation logon directory. In addition you must edit the file "dds-browser-library.art" in the workstation logon directory. This file contains the full pathname to the actual files. Please use ZMACS to replace the string "CHANGE-ME" with the actual workstation directory (e.g. "host:>wksta>").

3.3.2 Usage

Usage consists of logging in, obtaining the desired designs from the library, editing or establishing new designs, and generating Fortran code from the graphical or mathematical specifications.

3.3.2.1 Logging In

With the workstation band loaded, you should go to ART via select-A, as usual. The "RUN" menu option should be selected from the ART command window. Some initialization of windows, etc. will occur and a login form will appear. If you are known to the system when you enter your name on the top line, your stored vitiae will be presented. If any adjustment is to be made, each region is mouse sensitive, and may be selected for modification. If you are new, the information should all be filled in, as this data is used to automatically finish design specifications regarding author, etc. When this procedure is completed, the card catalog system is loaded, and the library is available for browsing, loading designs, or starting new ones.

3.3.2.2 Library Browsing

After login, you are presented with an option to enter the library browsing facility, via a mouse sensitive region at the bottom of the screen, or to choose a current project. The project organization is intended to allow a user quick access to a list of current project designs. This facility is not fully implemented and just leads you currently to starting new designs. More interesting is the facility for browsing the library. Select this at the bottom of the screen.

A form appears for the user to fill out. The options parallel those of a normal card catalog system such as author, title, subject (project is added). The options are designer, design, project, and keyword (subject). You may fill in any of the slots and a complete hierarchy of all included information will be presented. A more sophisticated presentation format awaits Phase II, as ART internals will have to be adapted and more pruning of the browse information would be needed. However, the Phase I browser presents the library through use of the graphical ART schema browser and its mouse sensitive icons. Mousing left on one of the leaf icons loads that design. Mousing middle allows you to view the purpose of the catalogued design. While viewing the purpose, you will find a selectable option to load the design or to return to the browser.

Toggle the "NO" for ALL DESIGNS to "YES" and mouse DO IT.

Currently each catalogued design must be individually selected from the browser. No facility for loading multiple designs simultaneously exists. As each design is selected it is loaded and it is entered in the buffer list similar to an EMACS file buffer list. Each design consists of multiple pages of design specification. The page first displayed is always the graphical flow diagramn or the mathematical specification page, as this is likely to be of most interest. Note that you will leave the browsing system when you load a design. You will be in the design editor facility. You may return to the browser by selecting one of the options at the bottom of the screen when the design has been loaded, if you wish to load additional designs.

Load the design from the library that is titled "ACS/Momentum Manager Separation" with the largest version number.

3.3.2.3 Editing Facility

The flow diagram should appear for the attitude control subsystem. The diagram does not need to be edited, but should give you an idea of the type of diagram that you might construct. You should note several things. Within the design region there are scroll markers to allow for diagrams that are larger than screen size. The palette on the left is used for creation of new designs. The palette currently used is generic, but specific palettes that are project, or at least workstation incarnation specific will later be added with a facility for the user to add new icons. The graphical icons represent effectively the language available to you. Specific icons would imply specific vocabulary otpions that are frequently used, but currently the generic ones are presented. Later we will build a new one.

At the bottom of the editing and palette regions you will see the specification categories required to be filled out for full design specification. Each will lead you to a page of the specification that must be filled in. These have already been filled out. Just browse the various pages by mousing any of the various options. Observe all the information that is required for a design to be fully specified for the library.

At the bottom of the screen, you will see many options. Most have been implemented, some have not. On the far left are the options available regarding the current design. You may save it to the library - this means storing the entire multi-page specification. Currently, you may save a design without all specification pages being filled out, this is likely to change in later Phases. You may clear it - this means start the diagram over and wipe out the current graphical diagram. You may also delete it - this means starting over entirely on the specification.

In the middle of the bottom of the screen you will find many options. They are described elsewhere, but the ones worthy of note for the tutorial are "Browse Library" whcih leads you back to the browsing facility, the "Generate Code" option which should only be used as described below, and the "List All Buffers" option which brings up your current buffer list just as in EMACS. The buffer list allows you to select other loaded designs for editing just as in EMACS.

At the far right of the bottom of the screen you will find options that are used for the graphical layout. Default values are shown for scrolling increments, block alignment, and line type. The first two are implemented. The scrolling increments determine the jumps made when scrolling in pixels. The block alignment allows you to keep blocks aligned vertically or horizontally in a diagram.

You may try various of the botom screen options as you desire. Beware of the consequences if clearing or deleting. Hoever, library designs may be reloaded.

Generating code for the diagram is described below.

3.3.2.4 Graphical Spec

Let's begin anew, and just draw a simple flow digram. Select the "Create New DDS" option from the bottom menus. You are now to enter a name for the block by typing. Call it "ACS/Momentum Manager Integration". Then the editing region and palette will appear. You may exit this design and return to the previous via the "Exit Current DDS" option at the bottom of the editor and palette, or via the "List All DDSs" option from the bottom menu. Note that all pages of the specification may be reached by the region containing the "Exit Current DDS" option.

Let's draw a diagram. Mouse left on the rectangle of the palette. We first must build a "START" block. This block is intended to contain initialization statements for the design (i.e. later for Fortran DATA statements). Position the first mouse click at the location below but near the top center of the editing region where you wish the upper left corner of the block to appear. A rubber rectangle will then appear and you must position the lower right. Next you must type "START" in the block. Next go back to the palette and mouse the rectangle again. Position it an inch or more below the START block. It will align automatically. Type the name "Momentum Manager" in the box with a carriage return between Momentum and Manager. Note that the text is centered automatically. Note that is you make an error you may delete a block by clicking right. You will then have to mouse the palette and locate and name the new block.

Now, you may link the START block to this one. First, ports must be constructed on each block, then links can be made. Click middle on the START block. A menu will appear that contains INPUT PORT, OUTPUT PORT, and other items. Select OUTPUT PORT. The menu will disappear and the mouse can now be seen to locate the position of the port line. Simply observe the line on the block as you move the mouse. Four center lines have been provided for you to align ports that are desired on the center lines of any side. Click at some location for the port construction. The orinigal menu will appear for additonal port construction. Choose the Exit Menu option. A small mouse sensitive area for the port may be found at the farthest edge of the arrow from the block. You may delete the port by clicking right on this area if you have positioned it in error. Also the mouse area is later used to connect with the other block. We will see this in a minute. Next, click middle on the Momentum Manager block and choose the INPUT PORT option. Position it as before. After these two ports are created, you may link blocks. Simply, click left on the small port area of one of the blocks. Then move the mouse to the other port area and click left. You will see a mouse sensitive area at the mid-point of the connecting line. This is to be used in later Phases for results presentation and data flow observation during simulations. For now it allows deletion of the connection if an error has been made by clicking right on it to delete the connection.

Additionally, the conection link may be a segmented line by simply clicking at any chosen point to make a bend in the line. As many segments as desired may be added, then proceed to a port mouse area to finish the line. Note that clicking right during this procedure deletes the last line segment so that you may reposition it.

Now you see how to build flow diagrams. You may continue to build further block and link them as appropriate for an attitude control system. Next you may want to fill in other pages of the specification. Please browse and enter some appropriate information for this design assuming it regards the building of a space station attitude control subsystem that integrates the momentum manager and attitude control functions. Note that it is difficult to fill in the variables for input, local, and output to this design. Currently the user must fill these in. Later Phases would aid you by percolating the information from lower level specs.

Now return to the graphical flow diagram. Click middle on the Momentum Manager block. You will see in the list of options "DDS 1". If other library deisgn were of this same name it would list them as options also. If you desired to connect this block to the stored one you would select DDS 1. Otherwise, you would choose to create a new graphical or mathematical specification. Creating another graphical spec is identical in nature to this one, so let's create a leaf mathematical specification. Click left on the create math spec option.

3.3.2.5 Mathematical Spec

The specification page will appear for entering mathematical design information. This leaf level routine should be named for Fortran purposes. The next entry is a mathematical specification of the design. SMP is used later to translate this mathematics into Fortran code. Vector mathematics may be used with dot products, etc.

Before attempting to create this mathematical specification, let's review one that already exists. Simply click on "Browse Library" at the bottom of the screen. Next, click on the DESIGN 1 mouse area , and enter "ACS Attitude Control Function". Then hit the END key or click outside the DESIGN 1 region to enter the information. Then click on DO IT. When the design hierarchy appears, select the latest version of the leaf design, and load it by clicking left. You will see the mathematical specification with all pages available as usual. View the mathematical design for an example of the engineering mathematics supported.

Then click on the EXIT CURRENT DDS option in the row of specification page options. This will return us to the last spec we were working on.

First, let's name this routine "ATTCF" by mousing the subroutine name area and entering the data. To exit, simply press end after typing or click outside that mouse area.

Now let's enter some simple mathematics for the specification (inappropriate to this design, but possibly instructive). Enter this continuoulsy on the first line of the Mathematical specification. Note that most of the simple EMACS editing commands work in all text entry areas.

```
    thc =  {thtea,
0 ,
(Sign[Cos[w0 t]] hcmg[3] + Sign[Sin[w0 t]] hcmg[1])/
    (16 w0 (imom[2] - imom[3]))}
```

All variables must be also be declared and typed as you saw in the other mathematical design. If you wish to review it, simply go to the bottom center menu and select "List All DDSs". Select the Attitude Control Function design and review the variables page, then return by mousing "EXIT CURRENT DDS".

For our variables we will enter inputs, outputs, and locals. Under Input 1, mouse the variable name area and enter *hcmg* then click outside. Next enter the descriptive data by mousing in that area and entering *CMG momentum*. Again click outside. You will note that two separate mouse clicks are required - one to finish the entry and one to begin another. Continue filling in the appropriate data for *hcmg*. Note that menus of options appear for coordinate system, variable data type, etc. The control moment gyro momentum is a vector with the default dimensions (3). After *hcmg* is completed with an INERTIAL coordinate system and DOUBLE precision., enter *imom* as Input 2, and continue as before. The variable *imom* contains the principal moments of inertia for the space station (i.e. it is a vector of dimension 3 with the coodinate system "N/A" and is the default DOUBLE precision. Next enter Input 3 *w0*, a double precision scalar that is the orbit frequency; then *t* as the orbit time, a scalar; then *thtea* a scalar angle; etc. The enter *thc* as Output 1, which contains the commanded station angles (a vector of dimension 3). There are no local variables specified by the user here. SMP may generate local variables to optimize computation, such as for *w0*t*.

Next fill in some information that might be appriopriate on the various specification pages and finally click on "Save Current DDS" at the bottom left. This will store your design away, and place it in the library card catalog system.

Finally, we are ready to "Generate Code" for this design.

Special notes: the START blocks are always to be mathematical specifications and the data entered is to be initialization data for Fortran DATA statements. See the example provided by browsing the library and reviewing Fortran code generated at the flow diagram level. End blocks must finish each diagram, and require no lower level specification.

3.3.2.6 Code Generation

The mathematical code generation is accomplished by SMP on the VAX. When selecting generate code a file is created with the same name as the unique design name (like "DDS-06/23/86 12:00:00") with a type extension of ".FTN". ART puts all the specified information in the Fortran file as header information (just as NASA currently does for in-line documentation). SMP generates the declarations and body of the code. To view the results, you must go to EMACS and look at the file. It contains the documented Fortran source code.

If vector mathematics has been used, a set of Fortran low-level utilities is called to perform the vector algebra. These have the following syntax: each starts with the letter specifying the variable result type - S for scalar, V for vector, M for matrix, and Q for quaternion. The second letter tells of the first argument with the same notation; the next letters specify the function, nd the last specifies the second argument type. For examples, QQADDQ implies adding two quaternions which returns a quaternion, VVDOTM implies a dot product of a vector with a matrix that returns a vector. The utilities perform dot products, cross products, and multiply, add, subtract, etc. These utilities are trivial Fortran routines and would have to be loaded during linking from a utility library. Later, with more sophistication, in-line code could be placed for these functions based on user selection to optimize the Fortran execution.

Go ahead and try it. The result should be roughly identical to that shown in file "DDS-10/28/86 11:07:08.FTN".

We will not generate code for a graphical specification in this tutorial, but it proceeds identically. ART calculates the flow and builds the Fortran source file in the graphical case. For graphical code generation, however, note 1) you should save the current design prior to code generation so that the code is consistent with the design, and 2) all designs referenced by the flow graph (at one level lower) must have been saved previously so that the subroutine calls can be referenced appropriately. This should lead to successful code generation.

Go to EMACS and view the file "DDS-10/28/86 10:55:09.FTN" for the "ACS/Momentum Manager Separation".

3.3.2.7 Domain Expertise Rule Use

This is to be the main area for focus in Phase II. Phase I only attempted to perform coordinate system transformations between graphical blocks as necessary to connect two slightly disparate library modules. This capability is demonstrated for the top level "ACS/Momentum Manager Separation". See library file "DDS-10/28/86 10:55:09.FTN".

3.3.2.8 Simulation Capability

No real simulation capability was attempted during Phase I. Thus feedback in flow diagrams does not produce DO loops based on some time granularity specified by the user. This executable simulation capability is the second main topic of Phase II.

3.4 Conclusion

At this point you have a cursory look at the facilities produced during Phase I and the current state of the workstation design. You should be able to move around within these facilities with a little more practice.

Many of the Phase I efforts continue in Phase II. NASA input would be appreciated regarding usefulness of Phase I functionality, desired features that are missing, etc.

Phase I admittedly has only used AI in a very limited context. Phase II needed this basic functionality to achieve the longer term goals. It is the hope that Phase I accomplishments have provided adequate underpinnings for successful Phase II demonstration of an AI approach to software development automation.

3.5 Documentation

The Automated Software Development Workstation documentation consists of:

- Proposal - Phase I (Technical Volume)
- Conceptual Design Document - Phase I
- Final Report - Phase I
- Source Code with In-line Documentation
- Tutorials

The proposal introduce the original ideas regarding the workstation functionality and purpose. This is further detailed in the Conceptual Design Document. This Final Report (Phase I) documents the accomplished tasks through descriptions of the current workstation operations. The Source code contains in-line documentation per file, rule, LISP function, defrelation, defschema, deffacts, etc. The format for each is presented below. Finally, the brief tutorials lead a user through the current functionality.

3.5.1 File Documentation

The format for File documentation consists of a source code language and version descriptor, a copyright header, then a brief description of the file contents - why these rules, schema, etc. are bundled together in this file. The file organization is an attempt to subdivide workstation functionality into rule sets, etc. The format including an example is:

```
;;; Machine: Symbolics - release 6.1
;;; ART Version: 2.0
;;; Lisp: Zetalisp

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;                                                                 ;
;;; Copyright (c) 1986, Inference Corporation, Los Angeles, California ;
;;;        COPYRIGHT (C) 1986 INFERENCE CORPORATION,                ;
;;;        5300 W. Century Blvd., Los Angeles, California 90045.    ;
;;;        AN UNPUBLISHED WORK - ALL RIGHTS RESERVED.               ;
;;;                                                                 ;
;;;     3) RESTRICTED RIGHTS LEGEND:                                ;
;;;       When the Licensee is the U.S. Government or a duly           ;
;;;       authorized agency thereof, use, duplication, or disclosure   ;
;;;       by the U.S. Government is subject to restrictions as set     ;
;;;       forth in the Rights in Data - General Clause at 18-52.227-74 ;
;;;       of the NFS as specified in NASA Contract #NAS 9-17515.       ;
;;;                                                                    ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;This program contains confidential information of Inference Corporation.;
; Use or copying without express written authorization of Inference      ;
; Corporation is strictly prohibited. Copyright ownership rights hereby  ;
; asserted by Inference Corporation.  Copyright 1986.                    ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

;;; *****
;;; Documentation:
;;;     relations for scrolling in a graphical editing buffer
;;; *****
```

3.5.2 Rule Documentation

The format for Rule documentation including an example is as follows:

```
;;; Ruleset (if any): editor scrolling
;;; Rulename: scroll-manager-init-display-palette
;;; Author: Dale Prouty
;;; Date: 9/29/86
;;; Salience: 0
;;; Referenced relations (schemata or facts):
;     buffer-array-size
;     buffer-world-array
;     scroll-tmp-screen
;;; Asserted   relations (schemata or facts):
;     buffer-world-array
;;; Retracted  relations (schemata or facts):
;     none
;;; Modified   relations (schemata):
;     none
;;; (Significant) External Function Calls:
;;; LISP:
;     make-world-array
;;; Rule Documentation (salience and rule):
;     make a palette world array
;;; References:
;;; Edit History -
;;;;;  U: author, date , reason , what changed
```

```
;;;
```

3.5.3 Relation Documentation

The format for Relation documentation including an example is as follows:

```
;;; Relation:
;;; Author: Dale Prouty
;;; Date: 9/29/86
;;; Relation Documentation:
;
;;; Edit History -
;;;;;  U: author, date , reason , what changed
;;;
```

3.5.4 Initial Schemata Documentation

The format for initial schemata documentation including an example is as follows:

```
;;; Schemata:
;;; Author: Dale Prouty
;;; Date: 9/29/86
;;; Schemata Documentation:
;
;;; Edit History -
;;;;;  U: author, date , reason , what changed
;;;
```

3.5.5 Initial Facts Documentation

The format for initial facts documentation including an example is as follows:

```
;;; Schemata:
;;; Author: Dale Prouty
;;; Date: 9/29/86
;;; Facts Documentation:
;
;;; Edit History -
;;;;;  U: author, date , reason , what changed
;;;
```

3.5.6 LISP Function Documentation

The format for LISP function documentation including an example is as follows:

```
;;; LISP function:
;;; Author: Dale Prouty
;;; Date: 9/29/86
;;; Referenced functions:
;;; Documentation:
;
;;; Edit History -
;;;;;  U: author, date , reason , what changed
;;;
```

3.5.7 SMP Code Documentation

```
/* SMP function: Wkstaprog */
/* Author: Dale Prouty */
/* Date: 9/29/86 */
/* Documentation: */
/* Edit History -
      U: author, date , reason , what changed */
```

3.5.8 C Code Documentation

```
/* C function: Wkstaprog */
/* Author: Peter Holtzman */
/* Date: 9/29/86 */
/* Documentation: */
/* Edit History -
      U: author, date , reason , what changed */
```

3.5.9 VAX-VMS Code Documentation

All VMS code existis in a single, simple file, and as such is only documented on a file basis.

4. Phase II Recommendations

Phase II should enhance the current workstation functionality and add software development aids based on AI technology (rule-based and object-oriented programming) where AI can overcome limitations of current software methodologies, as mentioned in the introduction.

Several specific areas where an AI based approach may benefit software development include:

- domain specific expertise - its acquisition, storage, representation, and reuse,
- transformational implementation of designs in Fortran,
- significantly enhanced interactive classifier or cataloguer of library information, and
- capturing of design and implementation history.

The domain expertise is the cornerstone of expert systems. A method of reusing this engineering expertise should be encompassed in Phase II, as well as automation of the knowledge acquisition process. The designs developed with this expert assistance should then more readily and efficiently be implemented in low level procedural code. The cataloguing of designs should significantly improved so that the knowledge regarding the design is reusable, especially the design decisions made by the engineer.

Other significant accomplishments that should be addressed in Phase II include:

- support for execution and analysis of graphical specifications, including interacitve simulation capability, and
- automated documentation of designs.

It is desirable for the user to be able to test designs directly from the interface in a modular and interactive fashion, in a way similar to that of the interactive use of LISP. Finally, the automated recording of documentation is a process to be heralded for removing the biggest existing headache for software developers and certainly deserves a place in any workstation that seriously addresses developers needs.

A. Phase I Source Code Listing

The source code listing is over 500 pages long. A single copy has supplied to Robert Savely, NASA JSC. Also, a tape has been supplied for a Symbolics computer. Please refer to Mr. Savely for any associated information.