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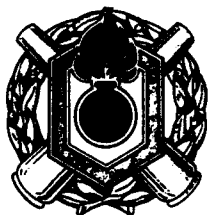
Technical Report ARAED-TR-93021

**DESIGN OF A COMPUTER EXPERT SYSTEM FOR ADHESIVE
SELECTION USING ARTIFICIAL INTELLIGENCE TECHNIQUES**

Karen Meyler
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INTRODUCTION

The Adhesives Section, Materials Technology Branch of the U.S. Army Armament Research, Development and Engineering Center (ARDEC) was funded in FY 92 and FY 93 by the U.S. Army Artificial Intelligence Center to design and build an expert system prototype capable of using artificial intelligence (AI) techniques to aid in the selection of a proper adhesive or sealant for Army material.

Because of the demand for strong, lightweight, and durable weapon systems, structural adhesive bonding is being used with increasing frequency. Optimum adhesive selection results from thoroughly analyzing the weapon system design in terms of performance requirements, ease of manufacture, as well as anticipated repair/maintenance requirements. This is both a very labor- and knowledge-intensive task since this information exists in various formats, is produced by different groups, and not directly comparable with other sources. In order to make a selection, this new information is normally combined with the engineer's own previous experiences, if any, or that of some consulted expert in the field. In real world situations, however, deadline constraints imposed by production schedules, or the unavailability of an expert may result in the selection of an adhesive without adequate supporting data. This frequently causes suboptimal engineering decisions to be made which are costly to correct later in the life cycle of the item. Clearly, in order to best select an adhesive for a given application in the quickest, most cost-effective manner, an expert system is needed that captures and more efficiently uses existing knowledge.

A large database of adhesives knowledge already exists as a part of the AMC adhesives database developed by ARDEC engineers using dBASEIV software. The database contains information on generic adhesive types and properties, lessons learned, and basic tenets related to design and manufacturing of bonded joints. It also contains physical and mechanical property data sheets for over 1000 commercially available adhesives and sealants. However, what the adhesives database in its present form cannot do is make a selection based on the data stored in the system. A database can contain basic information as well as empirical and theoretical rules to make use of this information, but the database cannot combine information and rules to make the decision itself.

Development of an expert system for adhesives selection will serve as a powerful tool for materials engineers in design and repair processes associated with properties of adhesives and their applications to Army materiel. Benefits of such a system include improved product quality, shortening of design time, increased ease of locating necessary design parameters, decreased need for engineering change proposals, and a decrease in repair-related problems.

The U.S. Army Logistics Management College (ALMC), Decision Sciences Department, AI Team, Ft. Lee, Virginia was chosen as the performing agency for expert system programming and development. ALMC chose to take on this project in order to gain valuable experience in developing expert systems. In addition, they have used this project for demonstration and "hands-on" experience purposes in their expert system development training programs taught at ALMC.

Knowledge acquisition sessions with adhesives expert representatives from government, industry, and academia were conducted to develop a prototype knowledge base. In addition, interviews with potential government users were conducted to help design an optimal structure for the expert system.

PROJECT SUMMARY

Hardware/Software Development Tools

The adhesives expert system is designed to operate on an IBM-PC compatible 80486 computer having a minimum of four MD RAM and eight MB hard disk space. The system will operate using MS-DOS 5.0 and Windows 3.1.

Kappa PC version 2.1, a C-based application development and delivery environment for PC's by IntelliCorp, Inc. was identified as a suitable expert system shell program. The adhesives selector expert system (ASES) is currently being developed with this system using object-oriented programming techniques and rule-based reasoning (refs 1 and 2).

In object-oriented programming, information is represented in object-attribute-value triplets. Objects have an identity of their own which incorporates within them program code and actual data to fully describe the object. Attributes are general characteristics associated with an object and the value is the value of the attribute (ref 3). Object-oriented programming differs greatly from conventional programming. Conventional programming is a series of codes which manipulates data, whereas, object-oriented programming is concerned with the interactions between different objects. A distinct advantage of object-oriented programming is that objects can be reused and obsolete objects can be easily removed from the program and replaced with new ones without disrupting the remainder of the program. This property will aid in the maintenance of the adhesives expert system (ref 4).

Object-oriented programming also exhibits what is known as inheritance. Therefore, all subclasses inherit the attributes of the parent object to reduce repetition for each subclass (refs 3 and 4). For example, if 'adhesive' is a class with important

attributes such as viscosity, shear strength, etc., all subclasses of the class 'adhesive' such as 'epoxy' or 'urethane' would also automatically look for values of the same attributes as the parent class. However, each subclass would have their own set of values of attributes.

Kappa-PC consists of a hierarchical object system supporting classes, subclasses, and instances each of which are types of objects. Class objects which represent related objects with similar attributes and functionality are used to describe groups of similar objects known as instances. Subclasses represent a subset of a class and instances represent a single unique entity. Information is passed down through this hierarchy by inheritance. Objects contain slots (or attributes) which have specific values. Methods consist of programming codes, and are used in Kappa-PC to represent behavior of objects. The slots (attributes) and methods (behavior) associated with a class are inherited by the instances of the class.

Kappa-PC version 2.1 provides a wide range of development tools for constructing and using applications. The main Kappa window displays icons that allow access to the tools. The tools include the object browser, sessions, edit tools, KAL interpreter, KALview debugger, find replace, rule relations, rule trace, and inference browser. the object browser allows the user to create, display, and modify images that define the end-user interface. Different graphical editors used for defining and modifying classes, instances, functions, rules, and goals can be accessed through the edit tools window. From the KAL Interpreter the user can enter the Kappa application language (KAL) code and see immediate results, eliminating the code-compile-test-debug loop. KAL is a higher level language consisting of over 250 predefined functions that are designed specifically for an object-oriented development system. The KAL view debugger assists the user in debugging KAL code. The find replace provides the ability to search and replace strings in the application. The rule relations, rule trace, and inference browser windows are tools used to create, trace, and debug rules within an application.

Expert System Development

Conceptual Design

A flow diagram of the current conceptual design of the ASES prototype can be seen in figure 1. Users are initially given a choice of either having ASES generate a list of candidate adhesives for their specific application or reviewing previously encountered problem sessions initiated by themselves or another party. This feature enables current users to review problems similar to their own which may have been encountered on the same or similar weapon systems and to see how these problems were solved. All sessions require the user to give their session an appropriate name and to enter a description of their problem. These descriptions can be edited at any

time by the user. These problems will be sent back to a central agency where they will be compiled and redistributed to all users along with system updates. This creation/maintenance module is not a part of the current prototype, but is planned for future development.

If the user has chosen to have the system generate a new list of candidate adhesives for their application, they will next be asked if their application is a well known special application such as a threadlocker, potting compound, etc., that could greatly narrow down the list of candidate adhesives. If the user's application does not fit into one of these special categories, ASES will proceed to the basic conditions module. Here the user will be asked a series of questions related to adherends, primary function (adhesive or sealant), consequence of failure, and anticipated surface preparation of adherends which are considered basic pertinent questions for all applications. ASES will generate an initial list of appropriate adhesives based on the answers to these questions. The list of available adhesives (LOAA) generator will then further narrow down the candidate adhesive list by allowing the user to further define their requirements in the form of a constraints/considerations list. These features will be discussed in further detail in the Session Windows section.

ASES Object Hierarchy

The object hierarchy and current classes of the ASES prototype are shown in figure 2. The adhesives class consists of the subclasses AdhSet (adhesives set) and Selected Adh Set (selected adhesives set). AdhSet contains all of the adhesives available in the system (fig. 3). As the user specifies specific requirements, all adhesives meeting these requirements are moved to the Selected Adh Set subclass.

The considerations class consists of the subclasses constraints and conditions (fig. 4). These subclasses represent all of the factors which may be relevant to selecting a candidate adhesive for a particular application. The conditions subclass contains the initial questions relevant to all adhesive selection cases as a part of the already described basic conditions module. The constraints subclass contains additional considerations which may or may not be relevant to the user's application.

The adherends class categorizes and identifies possible types of adherends which adhesives are used to bond. The main subclasses of adherends include metal, plastic, rubber elastomer, composite, honeycomb, and other. The plastic subclass is further broken down into two additional subclasses which are thermoplastics and thermosets. All subclasses are further broken down into specific types (i.e., metal subclass includes aluminum, titanium, etc.).

The summary info class contains summary information for each user application which includes information obtained from the user and generated by the system that allows for inferencing over the data and generating a list of possible adhesives for an application.

The special application, primary function, and substrate options classes directly relate to any adhesive application and allow ASES to reason over information more efficiently. The control class contains system control data.

Session Windows/Screens

The current ASES prototype contains 10 screens designed for the user interface. Each screen represents a window that the end user will see. Each screen is treated as an object by the system. The 10 screens include a title window (TitleW), disclaimer window (DisclaimerW), begin session or review previous session window (BeginReviewW), a problem description window (ProblemDescW), an enter problem description window (EnterPDW), a special applications window (SpecialAppW), and an edit problem description window (EditProbDescW). The flow pattern from one screen to the next for nine of the windows is described in figure 5. The EditProbDescW (fig. 6) is currently not accessible by any other screen, but will be used in the future to edit problem descriptions of previously entered adhesive applications. This feature will allow a user to enter comments on how well an adhesive recommendation by the expert system worked. The SummaryW screen has not been designed for the current prototype, but will be used in the future to consolidate all information for a particular adhesive application and create a report including considerations/constraints chosen by the user, recommended adhesives, and reasoning behind choices.

The TitleW and the DisclaimerW, respectively, are contained in figures 7 and 8. The BeginReviewW screen which prompts the user to either begin the process of generating a list of candidate adhesives for a particular adhesive problem or review a previous adhesive application problem is contained in figure 9.

The ProblemDescW screen which prompts the user for a suitable name for their session and a description of the problem which they are trying to solve is shown in figure 10. This feature will allow the program developers to monitor what types of adhesives problems are being encountered by the users, which will aid in future upgrades to the system. These problems will be monitored by a central control agency. Problems and suggested solutions as well as user comments on the expert system choices will be compiled and added to the expert system along with future updates for the benefit of all users. The system will advance temporarily to the EnterPDW (fig. 11) after the application has been named in order for the user to type a problem description. When the user indicates he is finished by choosing the done button, the system will return to the ProblemDescW in figure 10. The ProblemDescW will then prompt the user to identify whether their problem is a special application.

If the user identifies his application as a special application, he will be asked to identify the type of special application from the list shown in figure 12. The special applications include: core splice adhesive foams-film type, conductive adhesives, fairing/smoothing compounds, syntactic core fill liquids or pastes, potting compounds, retaining compounds, threadlockers, pipe sealants, gasketing compounds, electrical encapsulants, fuel tank sealants, and firewall sealants. An explanation button is available for the user to choose if a definition of any of these special applications is needed. An example of the explanation facility is given in figure 13. If the user chooses a special application, he will be prompted to identify the substrates which will be bonded or sealed. The adhesive selection button will then prune the list of available adhesives based on the user's choices and display an initial list of candidate adhesives. The program will then move to the LOAAW screen where the user will be able to identify further constraints and considerations unique to their problem. It should be noted at this point that the list of considerations present in the LOAAW will differ for each type of special application to avoid having the user answer nonrelevant questions to his application.

If the user does not identify his problem as a special application, the program will proceed to the InitialCondW (fig. 14). In this window, the user will choose the primary function of the application as either to bond, seal, or do both. He will then choose the adherends which will be bonded or sealed. Explanation buttons are again available to the user to explain the relevance of each question. Additional questions will then be asked relating to the consequences of bond failure (i.e., mission termination, significant repair problems, etc.) and the anticipated surface preparation techniques of the adherends. The adhesive selection button will then prune the list of available adhesives based on the user's choices and display an initial list of candidate adhesives.

The program will then advance to the LOAAW screen (fig. 15) where the user will be able to identify further constraints and considerations unique to his problem. These considerations include available equipment, preferred adhesive forms, adhesive setting time, gap filling capabilities, surface geometries, service temperatures and environments, military specifications, mechanical strength requirements of the adhesive, and many others. The user will choose only those considerations which are of concern to him. For example, if the user is operating in a production environment with all standard bonding equipment available to him, he will not choose bonding equipment as a consideration. Once the user has identified the constraints of importance, the system will ask a series of questions whose answers will continuously update the candidate adhesive list displayed on the right side of the screen. The expert system will reason over the user answers and internal adhesive rules in order to update the candidate adhesive list. Using the menu at the top of the screen, the user will be able to add or remove constraints and change the answers to

any related questions. If at any time all candidate adhesives have been eliminated, a message will be displayed to the user. At this point the user may want to relax some of the constraints imposed. An explain button is available to both explain the importance of a listed constraint/consideration and to show how many adhesives were affected by the addition or removal of a certain constraint. Users will be able to save the session as well as print out constraints and candidate adhesives along with their property data sheets from the top menu of this screen. At any point in the LOAAW screen, the user may choose the view summary button which will advance the system to the SummaryW. This screen which is still under development will contain all information pertaining to the current adhesive application problem including constraints applied and their values and recommended adhesives.

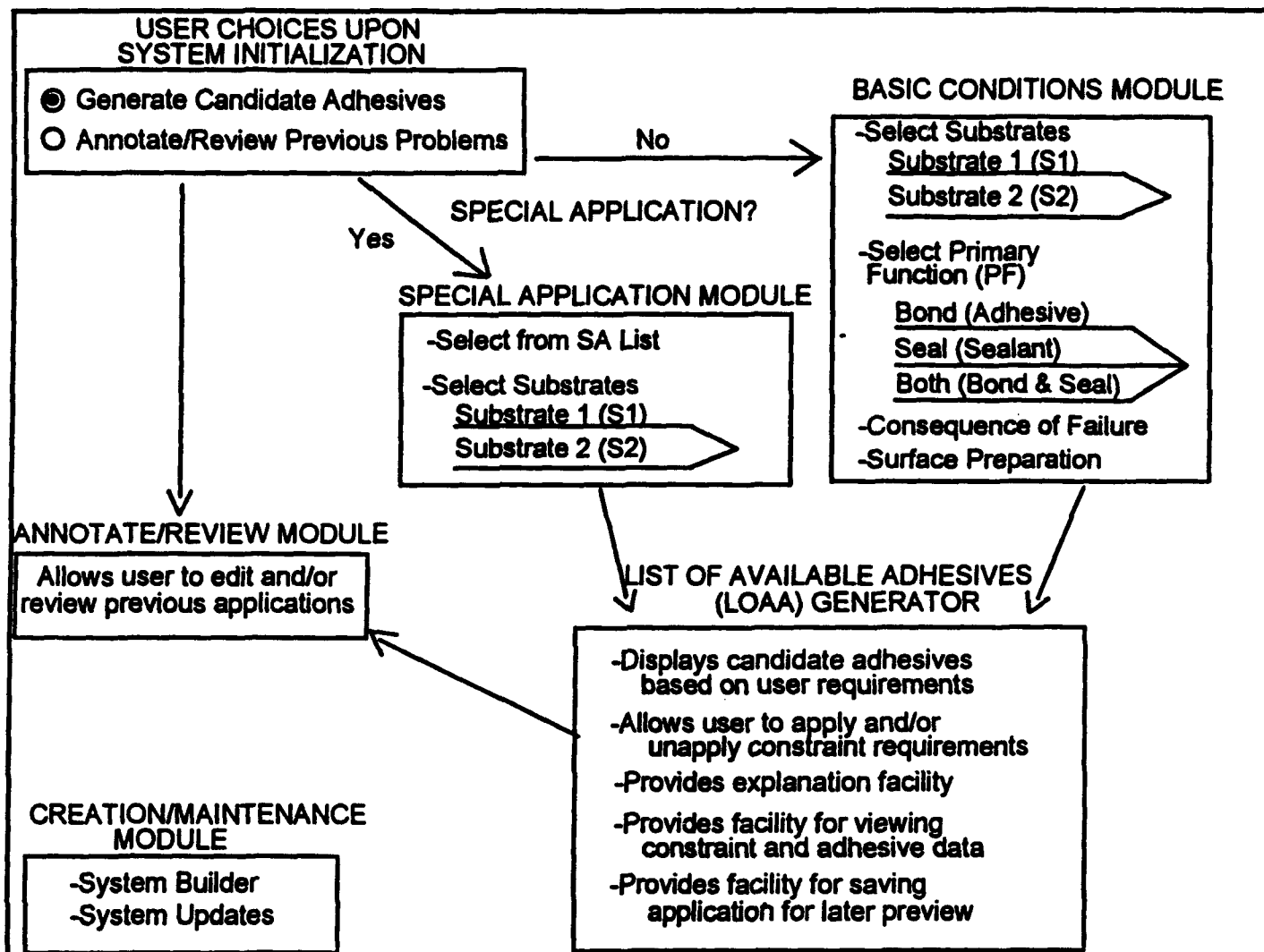


Figure 1. Conceptual design of the adhesive selector expert system

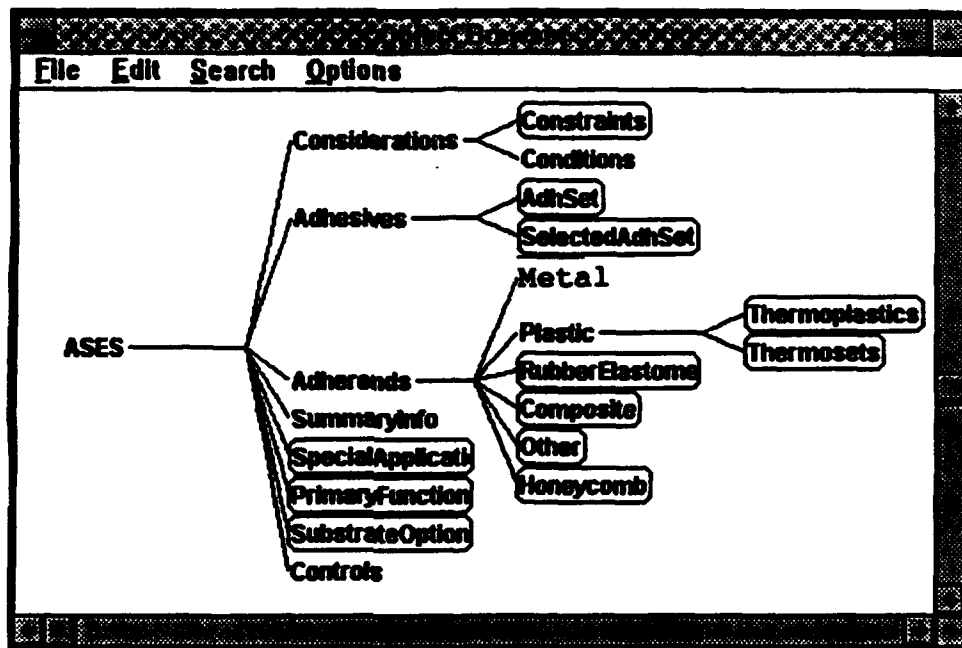


Figure 2. Object hierarchy of ASES

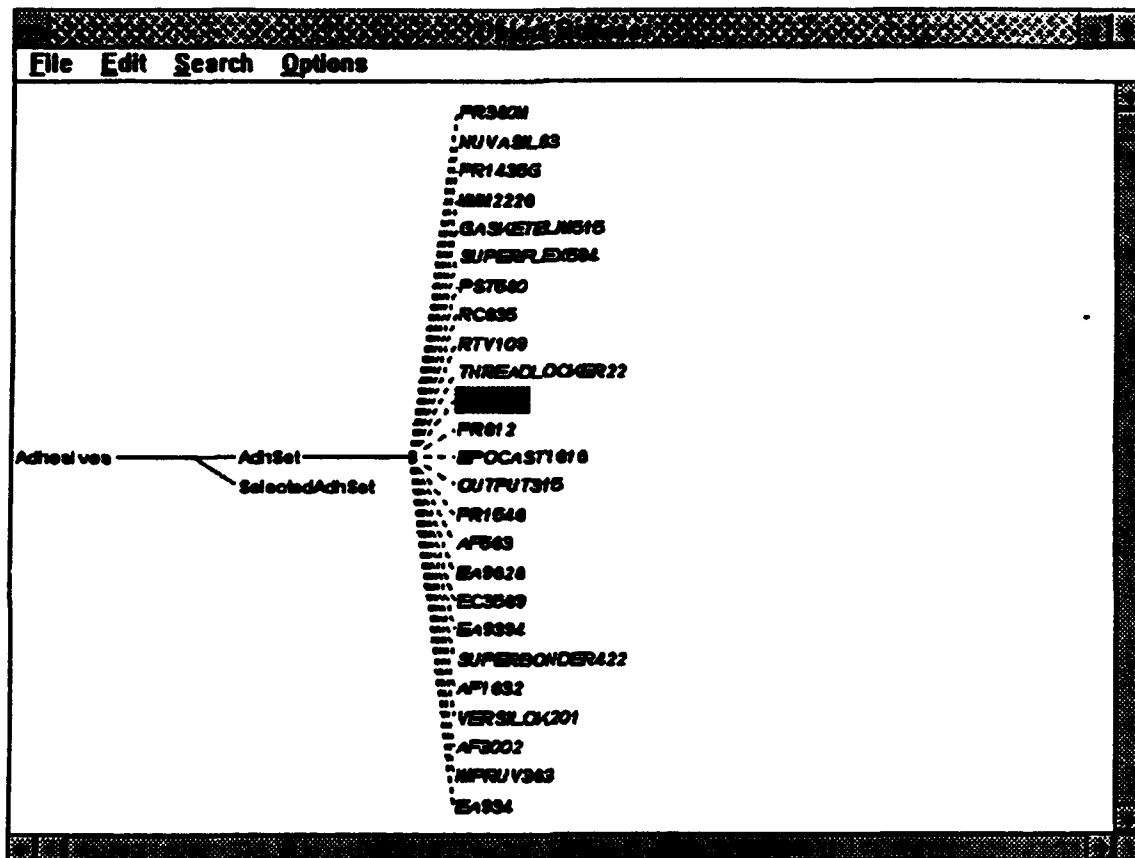


Figure 3. Object structure of the adhesive class

ASES Constraint Object Structure

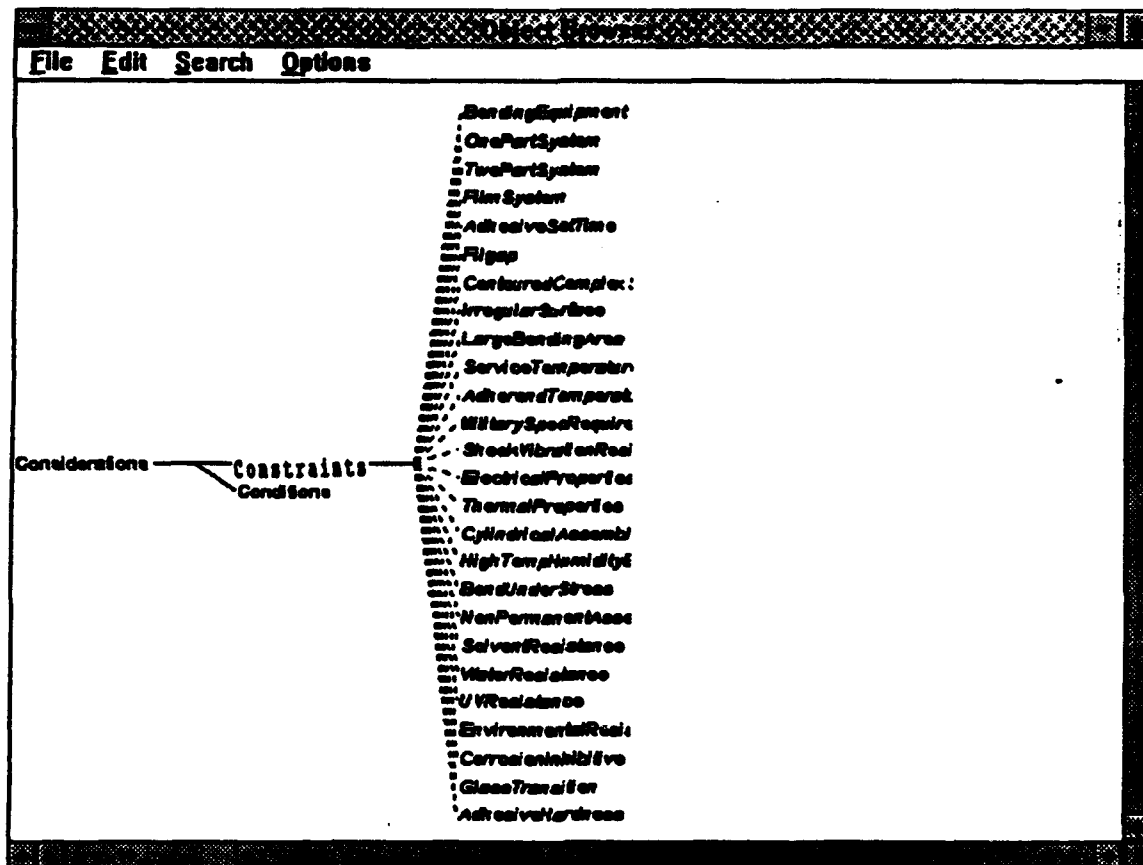


Figure 4. Object structure of the considerations class

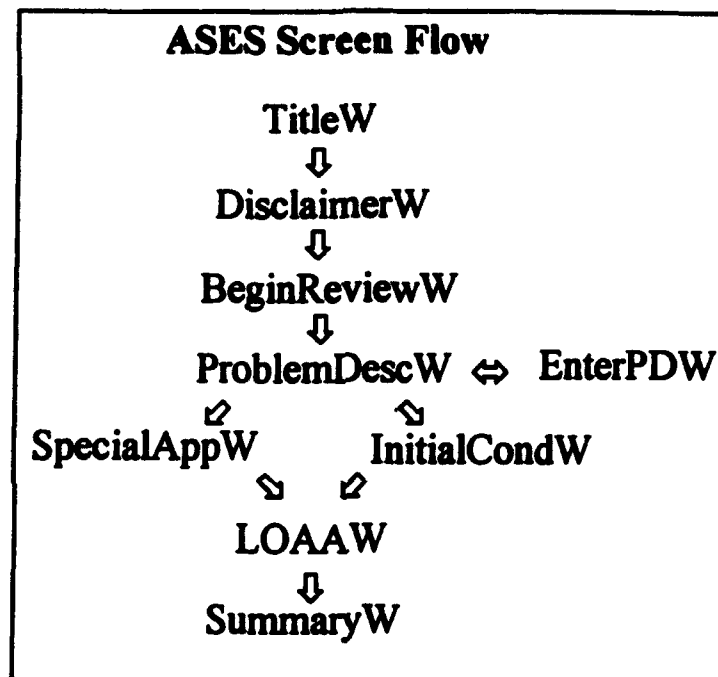


Figure 5. Flow pattern of the ASES windows

EditProbDescW

Adhesive Selection Expert System

Editing File:

C:\ASES\ROTOR.TXT

Please enter modifications to your problem description. You must press enter when you reach the end of a line. When finished Click DONE otherwise click RETURN.

Reter Blade subassembly for AH-64. This is new information.

EXIT

Figure 6. Edit problem description window

TitleW

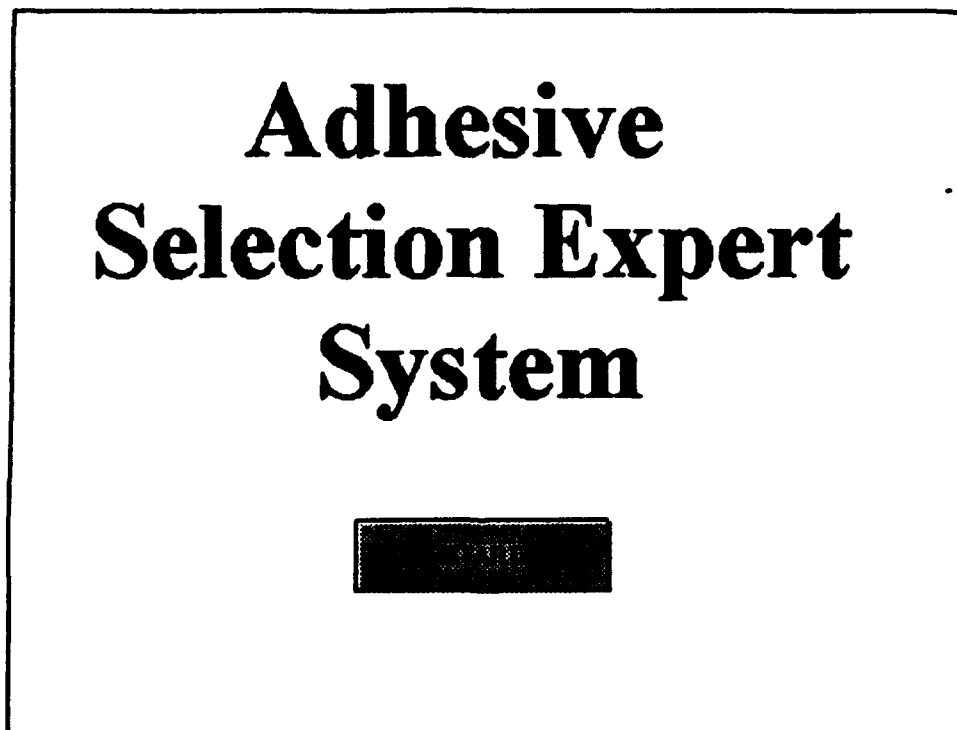


Figure 7. Title window

DisclaimerW

Adhesive Selection Expert System

DISCLAIMER

Users are reminded that the views, opinions, and/or findings contained in this program should not be construed as an official Department of the Army position, policy, or decision and that the citation in this program of the names of commercial firms or commercially available products or services does not constitute official endorsement or approval by the United States Government. In addition, users are reminded that the Adhesive Selection Expert System has been developed as a design tool to aid the engineer/scientist in the decision making process, and that the United States Army or Government shall not be liable for any misapplication or use of the information contained herein by the user.

Figure 8. Disclaimer window

BeginReviewW

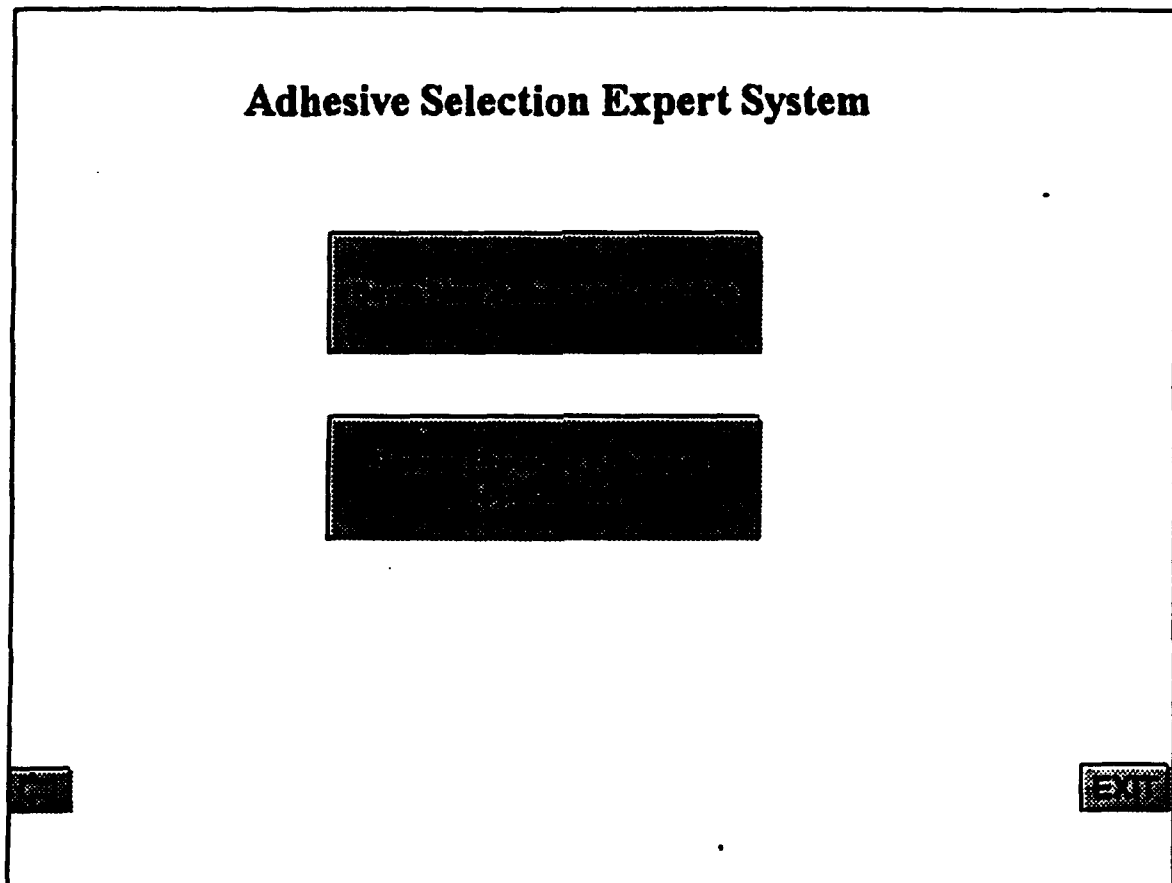


Figure 9. Begin session or review previous session window

ProblemDescW

Adhesive Selection Expert System

Please enter a name for your application in the box :

AH-64 Rotor Blade Assembly - Subassembly

Certain adhesives and sealants are grouped according to specialized functions they perform, i.e., potting compounds, threadlockers, etc. Does your application fit into this category?

Choose One

☒ Yes

☐ No

☐ Not Sure

EXIT

Figure 10. Problem description window

EnterPDW

AH-64 Rotor Blade Assembly - Subassembly

Please Enter 8 characters for a file name and click OK

rotor

Please enter a description of the problem. You must press enter when you reach the end of a line. When finished, Click DONE.

Rotor Blade subassembly for AH-64.

Figure 11. Enter problem description window

SpecialAppW

AH-64 Rotor Blade Assembly - Subassembly

Make Appropriate Selection

- ☐ Core Splice Adhesive Foam - Film
- ☐ Conductive Adhesive
- ☐ Fairing/Smoothing Compound
- ☒ Syntactic Core Fill Liquid/Paste
- ☐ Potting Compound
- ☐ Retaining Compound
- ☐ Threadlocker
- ☐ Pipe Sealant
- ☐ Gasketing Compound
- ☐ Electrical Encapsulant
- ☐ Fuel Tank Sealant
- ☐ Firewall Sealant

Select a Substrate Option

- ☒ Single Material Substrate
- ☐ Different Material Substrate

ADHESIVE SELECTION

EXIT

Figure 12. Special applications window

Explain Facility

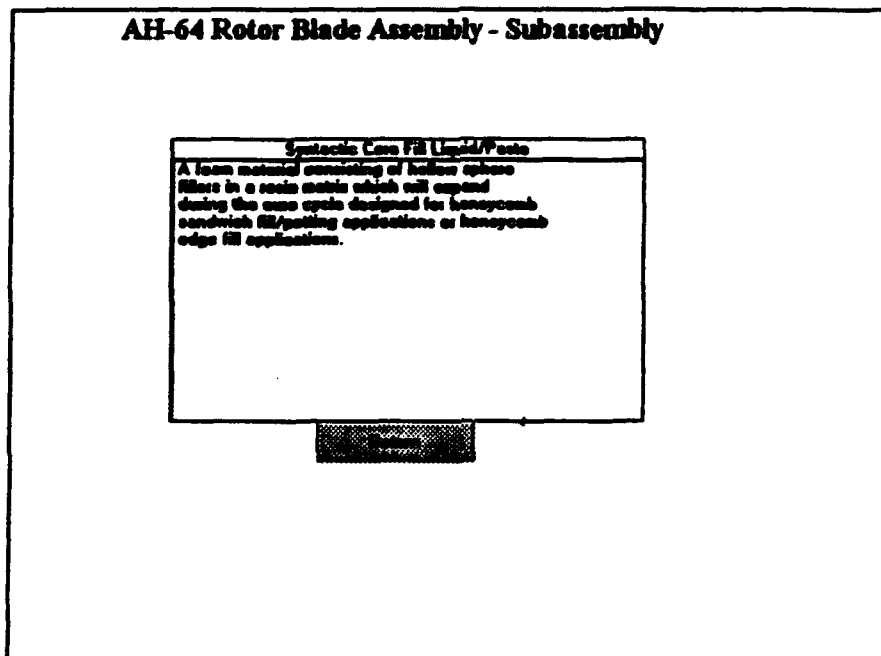


Figure 13. Example of the explanation facility

IntialCondW

AH-64 Rotor Blade Assembly - Subassembly

Make Appropriate Selection ☒ Bond (Adhesive) ☐ Seal (Sealant) ☐ Both (Bond And Seal)	Select a Substrate Option ☒ Single Material Substrate ☐ Different Material Substrate
--	---

POSITIVE SELECTION

OK**EXIT**

Figure 14. Initial conditions window

LOAAW

File
Constraints
Adhesives
Options

AH-64 Rotor Blade Assembly - Subassembly

Constraints

Bonding Equipment
One Part System
Two Part System
Film System
Adhesive Set Time
Filgap
Contoured/Complex Shape
Irregular Surface (not smooth)
Large Bonding Area
Service Temperature
Adherend Temperature Limit
Military Spec Required *
Shock/Vibration Resistance
Electrical Properties

Adhesives

3M EPOXY AF-163-2
3M EPOXY AF-3002
3M EPOXY EC-3569
3M THERMOSET AF-563
ALUMINUM EA 934 NA
DEXTER EPOXY EA 9394
DEXTER EPOXY EA 9628
LOCTITE INPRUV 363
LOCTITE SUPERBONDER 422

EXPLAIN

EXPLAIN

VIEW SUMMARY

OK

EXIT

Figure 15. List of available adhesives window

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