

Optimizing the Engineering Process At Rocketdyne Using MSC/MVISION

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ABSTRACT

In a market where engineers are increasingly being called upon to consider cost and process cycle times in addition to the technical merits of a design, many companies are beginning to realize the important role that materials play in the design of a part. In order to produce a product in a timely and cost efficient manner, a materials engineer who develops design properties must be able to turn test data into design data quickly and accurately. This data must then be made available to the users in a timely fashion. Merely having an abundance of materials properties data is not sufficient to meet the growing demands of a competitive marketplace. The data must be easily retrieved and easily sorted by the user. There must also be a process which can convert the data to a form that is easily usable by software products and processes, such as Computer Aided Design (CAD) and structural analysis programs.

Faced with the above demands, the Rocketdyne Division of Boeing North American decided to implement a materials properties database to meet the above needs. After taking input from engineers in various processes, reviewing several commercially available software packages and even looking into building our own database, we decided to use MSC/MVISION [1] as our official database. We are in the early stages of the database implementation and have already reaped many benefits from its use, and foresee more benefits once the database becomes part of the routine design-to-production process. The implementation of the materials database has not come without difficulties. This paper will discuss both the benefits that Rocketdyne has experienced and the difficulties that we face in the implementation of a material design properties database.

Introduction

In 1981, an internal letter was circulated within the then Rocketdyne Division of Rockwell International (now a division of the Boeing Company) summarizing the possible applications of computers in the Materials Engineering department. This letter actually showed a lot of vision considering the fact that the use of computers at that time was in the infancy stages. The authors envisioned “placing all design curves from the Rocketdyne Materials Properties Manual and other primary sources (e.g., MIL-HDBK-5) [so that] instant retrieval can then be made conveniently near one’s desk.” [2] They also understood that a computerized database of materials properties would give engineers “the ability to plot a given property for a number of alloys on one graph.” [2] And since “updating and revisions could be done on a continuing basis. . .engineers would always be accessing the most recent design curves.” [2] Many of the “wishes” expressed in that internal letter are only now being realized. Computer technology and budget constraints proved to be the greatest obstacles in our pursuit to actualize the goals of that 1981 letter.

As is obvious to all, computer technology has grown by leaps and bounds since 1981 and can no longer be considered a limiting factor. However, budgets have not grown quite as rapidly. In 1990, Rocketdyne was involved in a NASA funded project in which we needed to be able to share materials property data with a “materials consortium” including NASA, Pratt & Whitney and Aerojet. It was determined that the best way of sharing data would be through the use of an electronic materials database. MSC/MVISION was chosen as the database by which the materials consortium would share data with each other. Unfortunately, this program was cut early in 1993 and work on a materials database was stopped as a result.

Later in 1993, Rocketdyne laid out a five year vision which included the goal of reducing product cost and process cycle time by a factor of 5 to 100. Tools were identified that would help meet these goals. One of those tools identified as necessary was a materials properties database. Since that time, Rocketdyne has set aside internal money to fund development of a materials properties database.

Entire Process Approach

On the surface, creating a materials properties database seems simple. It’s simple if the chief customers of the database are other materials engineers. It’s simple if the goal is simply to have an electronic version of a hardcopy manual. Life and engineering, however, are not that simple. Rocketdyne’s goal is not merely to create an electronic materials properties manual, but to reduce product

cost and process cycle time by a factor of 5 to 100. Though it would be unrealistic to expect that a materials database would alone achieve this goal; it is not unrealistic to aim at developing a database that would significantly contribute to reducing product cost and process cycle time by a factor of 5 to 100.

The materials properties database created must take into consideration the entire engineering process (see Figure 1). In other words the database must improve the cycle time at every stage of the engineering process in which materials properties are used. At Rocketdyne, the engineering processes where materials data plays a significant role are the design of a product, the analysis of the stresses on a part, and the construction of materials properties curves and tables to support those activities.

Disciplines That Interact with Materials Properties Data

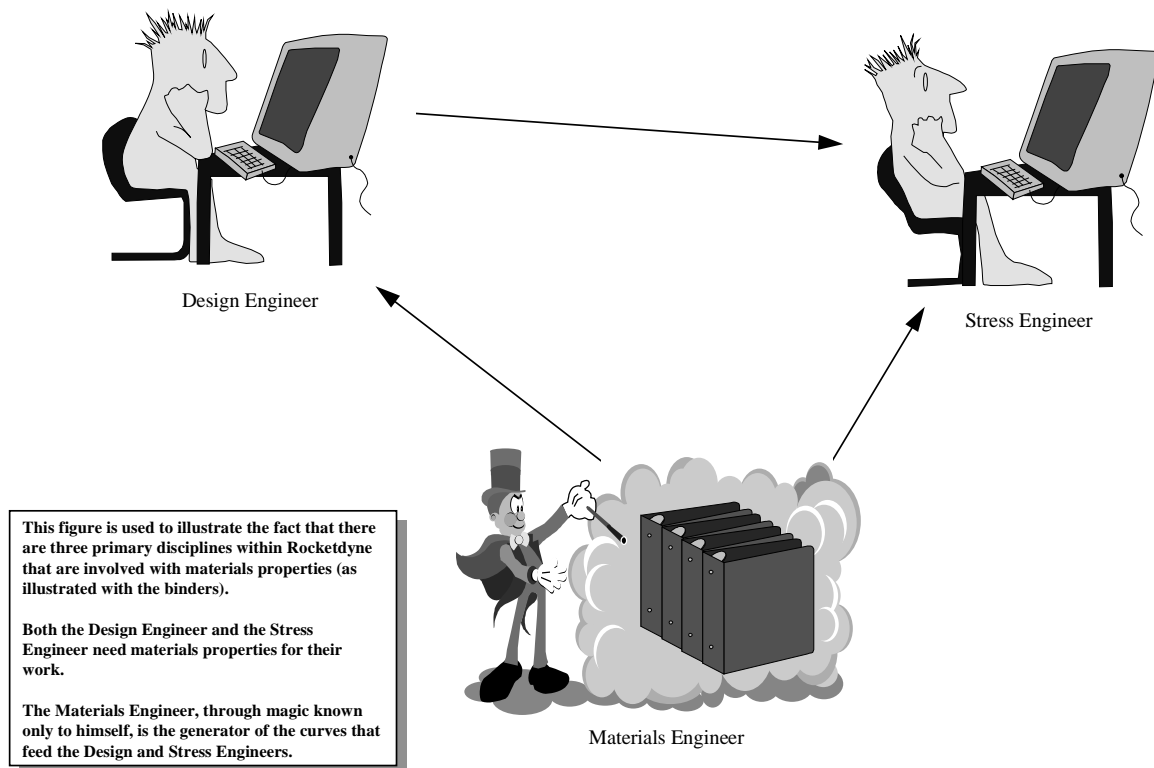


Figure 1: The Interaction of Materials Properties with Engineering Processes

Materials Properties

Any source of materials properties data, whether it be hardcopy or electronic, must first be accurate. It is useless to have a computerized materials properties database if that database is filled with materials properties that are unreliable. At first thought, it is conceivable that a database might reduce the time it takes to determine materials properties allowables from raw test data, but the quality of

the data does not appear to be a function of whether or not such a database exists. A mere electronic representation of a hardcopy manual is not an improvement on the quality of the data; it is just a different presentation of the same data. The quality of any materials properties database created must be at least as good as the previous hardcopy manual.

When Rocketdyne looked more closely at the process of developing material property allowables from raw test data (Figure 2), we saw that an electronic materials properties database would help both to reduce the cycle time it took to develop these properties and to improve the quality of the data developed. The process that had been followed to get from test data to materials design properties is shown in Figure 2 and can be outlined in the following manner:

1. Test data obtained from vendor was typed into a curve fitting program.
2. A best fit curve was constructed based on the test data.
3. Archived data and data from other sources for the same material and test condition were retrieved to compare with the newly constructed curve.
4. If a difference existed between the new curve and past data, the difference was reconciled in one way or another, and the new curve was finalized.
5. A written report was generated for distribution to those who immediately needed the data.
6. The report was archived in the files.
7. The newly constructed curve would eventually be entered in the hardcopy manual. Since the hardcopy manual was difficult to update, it may have taken up to a year.

As outlined above, the time taken to turn test data into a design curve for general distribution in a hardcopy manual could take up to a year, and at times even longer. In the above outline, the slow steps were “3”, “5” and “7”. Step “3” was time consuming because it involved manually searching through several file cabinets full of old reports and searching through standard handbooks such as Military Handbook 5 [3]. Step “5” was not a difficult nor necessarily a time consuming task, but it was tedious and as a result would take longer than it should. This documentation step was essential to insure that the data would be usable and traceable for years to come. Step “7” was a major undertaking. Rocketdyne’s hardcopy materials properties manual is four volumes large with over 1,500 pages and 5,000 curves. Any revision to this manual involved a major effort in terms of time as well as paper.

Baseline Materials Process Data Input Steps

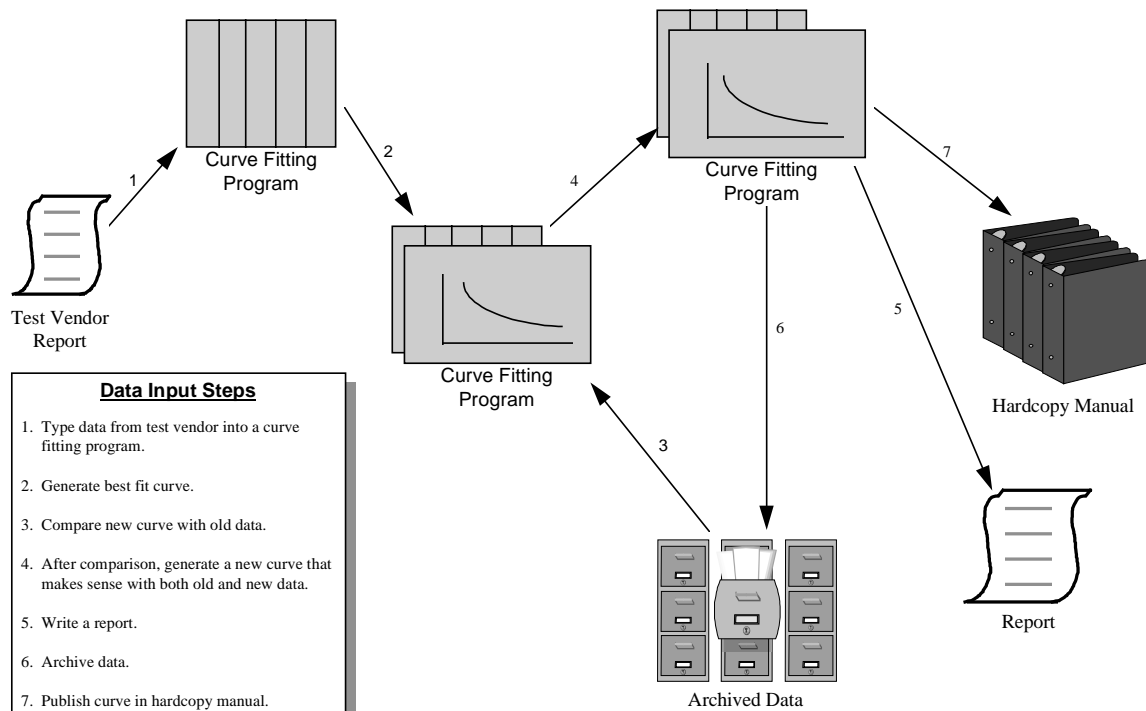


Figure 2: Steps Taken to Create Design Allowable Properties from Test Data
(Pre-Electronic Materials Properties Database)

Maintaining high quality also takes an effort. Steps “3” and “7” were keys to ensuring that the engineers at Rocketdyne were using high quality data. Step “3” was needed to make sure that the newly tested data was not based on an unusual lot of material. Step “7” was vital because the hardcopy manual was what the engineers at Rocketdyne turned to for materials properties data. On top of the problem of slow distribution of updates, many of the owners of these hardcopy manuals did not physically update the manuals since it was such a tedious task. If the manual does not contain the latest information, the engineers may be using data that is inaccurate.

We at Rocketdyne felt that an electronic materials database could improve both the quality and cycle time by addressing the above key steps.

Design Process

One of the critical elements that must be considered in the design of any new product or component is the choice of materials. The choice of materials can literally make or break the part. Many design engineers base their choice of materials on past experience. They will then run some basic stress analysis on the new design using the material they have chosen and for the most part, it will

work. Experience is a significant help in the choice of a materials for the design of any product. However, experience may also hinder advancement in the design of products. Simply choosing the same material as in the past may “work” but it may not necessarily be the best choice. New materials are constantly being developed and many of these new materials may allow the designers to develop a part with either higher quality, lower cost, reduced process cycle time or some combination of these.

The key to optimizing the choice of materials is to make designers aware of the variety of materials available to them and to make the properties of these materials easily accessible. Hardcopy manuals, standard handbooks and other publications with materials data are available, but searching through all these sources is tedious and time consuming.

In order to achieve Rocketdyne’s goal of reduced cost and process cycle time, the time needed to choose a material and to examine the properties of that material must be reduced. Not only must the time be reduced, but the tools for examining material properties should be made simple and easy to use. Any materials properties database must be able to achieve these goals.

Analysis Process

The stress analyst’s job, simply put, is to make sure that the part is able to withstand the stresses that it might see in actual use. Key to this analysis is the mechanical properties of the material from which the part is made. These materials properties must be input to a stress analysis program that the engineer uses. This will require the analyst to look up the necessary material properties and then generate a materials properties input file based on the particular formatting requirements of the analysis software. The creation of the data file, though not a difficult task, is often very tedious (see Figure 3). A conscientious engineer will put comments in the data file necessary to trace back the analysis, but too often this is ignored.

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$ This record will be written as an isotropic, temperature-dependent material.
$
$ The following TABLEM1 entry defines the temperature variation of E:
$
TABLEM1      1                                +M      1
+M  1-400,000 0,30200      0,0 0,29750 300,000 0,28900 600,000 0,27600+M      2
+M  2 800,000 0,26500 1200,00 0,24000 1400,00 0,22400 1560,00 0,20000+M      3
+M  3 ENDT
$
$ The following TABLEM1 entry defines the temperature variation of NU:
$
TABLEM1      2                                +M      4
+M  4-423,000 0,24000-320,000 0,25000-200,000 0,27200-100,0000 0,28200+M
+M  5 75,0000 0,29000 100,0000 0,29000 200,000 0,29000 400,000 0,28600+M
+M  6 600,000 0,28100 800,000 0,27800 1000,00 0,28100 1200,00 0,29000+M      7
+M  7 1400,00 0,30600 1600,00 0,32000 1800,00 0,36000 2000,00 0,40000+M      8
+M  8 ENDT
$
$ The following TABLEM1 entry defines the temperature variation of ST:
$
TABLEM1      3                                +M      9
+M  9-400,000 184,000-200,000 162,000      0,0 151,600 200,000 146,000+M     10
+M  10 600,000 140,000 820,000 137,000 1000,00 134,000 1100,00 130,000+M     11

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Figure 3: Typical NASTRAN Materials Input File

This process can be improved by reducing the time it takes for the engineer to look up the material property and by making it simple and fast to generate data files for his analysis programs. To do this, the materials properties database must not only be able to retrieve data but also be able to export that data into a file format of the engineer's choice.

Engineering Process With A Materials Properties Database

Initially, it was thought that Rocketdyne should write our own materials properties database. This thought was short-lived in light of our requirements and the effort needed to create such a database. A search was initiated for a third party materials properties database product. Our search ended with the selection of MSC/MVISION. At the time of our first evaluation, MSC/MVISION did not meet many of the requirements laid out above. Nevertheless, it was still clearly the best out of a small field. Since then it has grown to meet almost every one of our requirements.

Engineering Process for Materials Engineers

Referring to the above outline on the steps taken to generate a design property curve from test data, it was noted that steps "3", "5" and "7" are steps in which a

materials properties database can help improve both quality and cycle time. The question needs to be asked if Rocketdyne's implementation of MSC/MVISION has actually helped improve those steps. A look at Figure 4 will show how the process now works using an electronic materials properties database.

Using An Electronic Materials Database

Data Input Steps

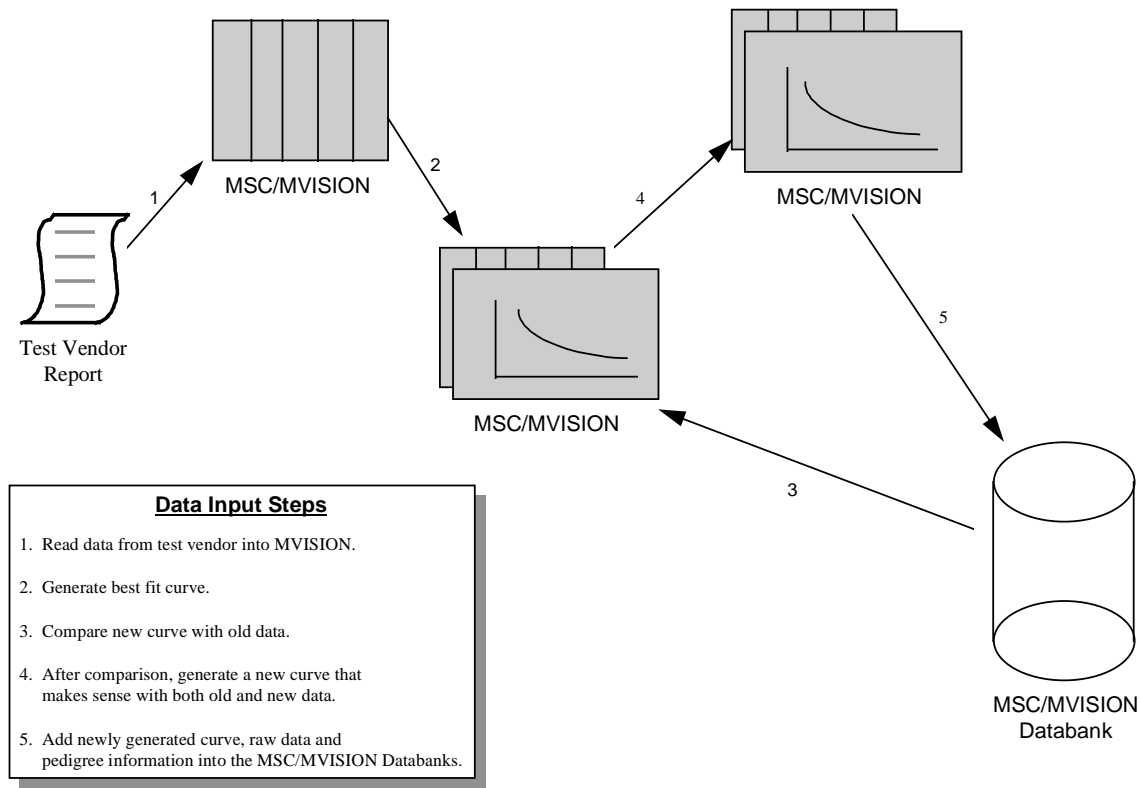


Figure 4: Showing Steps Taken to Produce Design Allowable Data Using MSC/MVISION

Theoretically, step "3" should be vastly improved. No longer will a materials engineer need to rummage through file cabinets full of old data in order to find comparison data. Since all of the historical test data should be loaded in an electronic database, all the engineer has to do is query the database and the computer does all the work in a matter of seconds. Unfortunately, all the past data has not yet been loaded into an electronic format, so this step is only faster in theory. But we have laid the foundation to speed up this step.

Again referring to the outline above, Step "5" is critical since it is the step by which data was archived. A report was written in order to keep material pedigree information and test data in one place and to understand how the design curve was constructed. Using an electronic data system, the material pedigree, test data and a description of how the curve was constructed are all stored within the database, therefore the documentation is built into the process of our

construction of these curves. A written report in addition to this would contain a lot of redundant information.

Under the old system, updates were at best once a year due to the large amount of effort needed to produce and distribute hardcopy manuals. With an electronics materials database in place, updates to the database can be done immediately. For procedural reasons, formal updates will be performed every quarter and sooner if the need arises. This is a reduction on the average of 75%. This increase in speed will also result in an increase in quality. The data that the engineers sees when accessing the database will be the very latest.

As far as the materials allowables, we have with this database both a reduction in cycle time and an improvement of quality.

Design Engineers Using An Electronic Materials Database

The benefits of an electronic materials properties database is not limited to materials engineers only. The design engineers at Rocketdyne using Pro Engineering [4] also will reap the benefits of an electronic database. MSC/MVISION Pro [5] enables the user to access the MSC/MVISION materials databanks directly from within Pro-Engineer (See Figure 5). Designers now can make their drawings in Pro-Engineer and search for an appropriate material for that part without ever leaving the drawing. For example, they can ask query the database to look for a material with a tensile strength at 1000°F greater than 100 ksi and a fatigue strength at 10^7 cycles at 250°F greater than 25 ksi, and then rank the result based on density. With this capability the designer is no longer restricted to materials that are familiar.

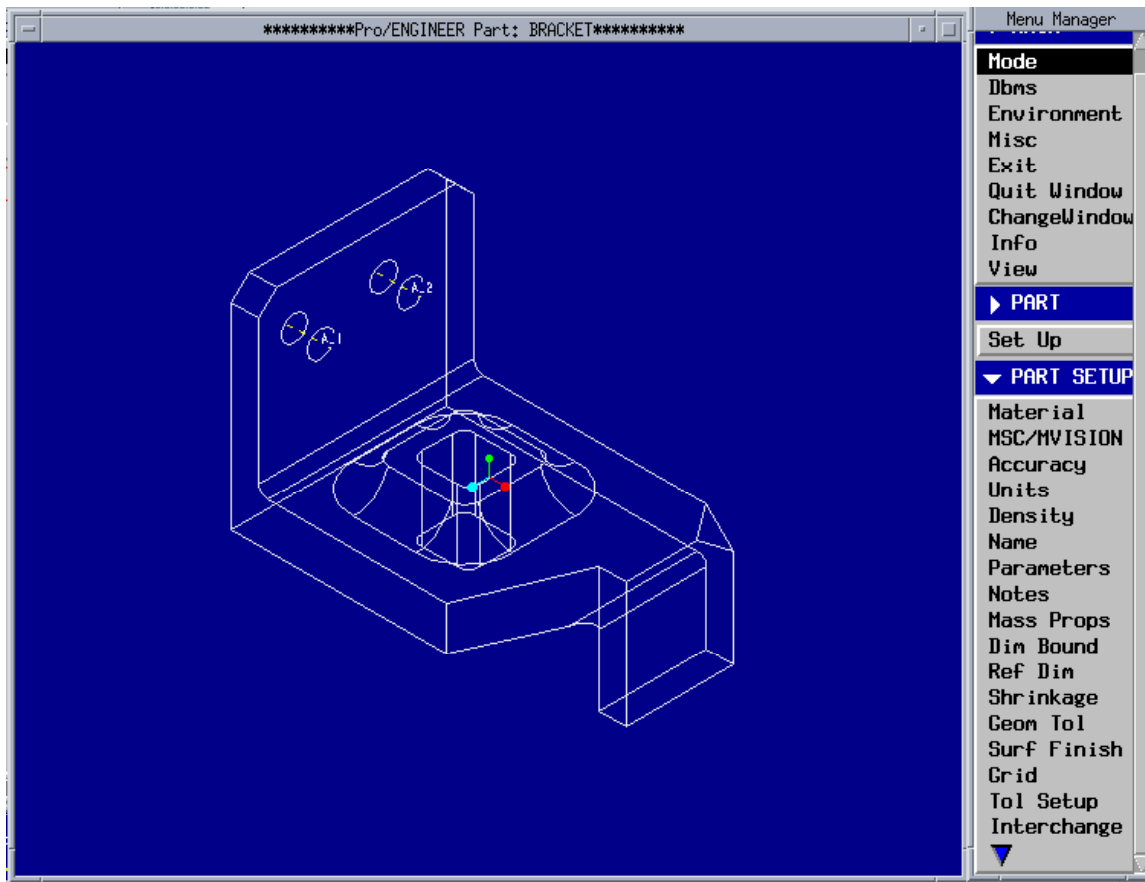


Figure 5: Note the MSC/MVISION Pick On the Right.

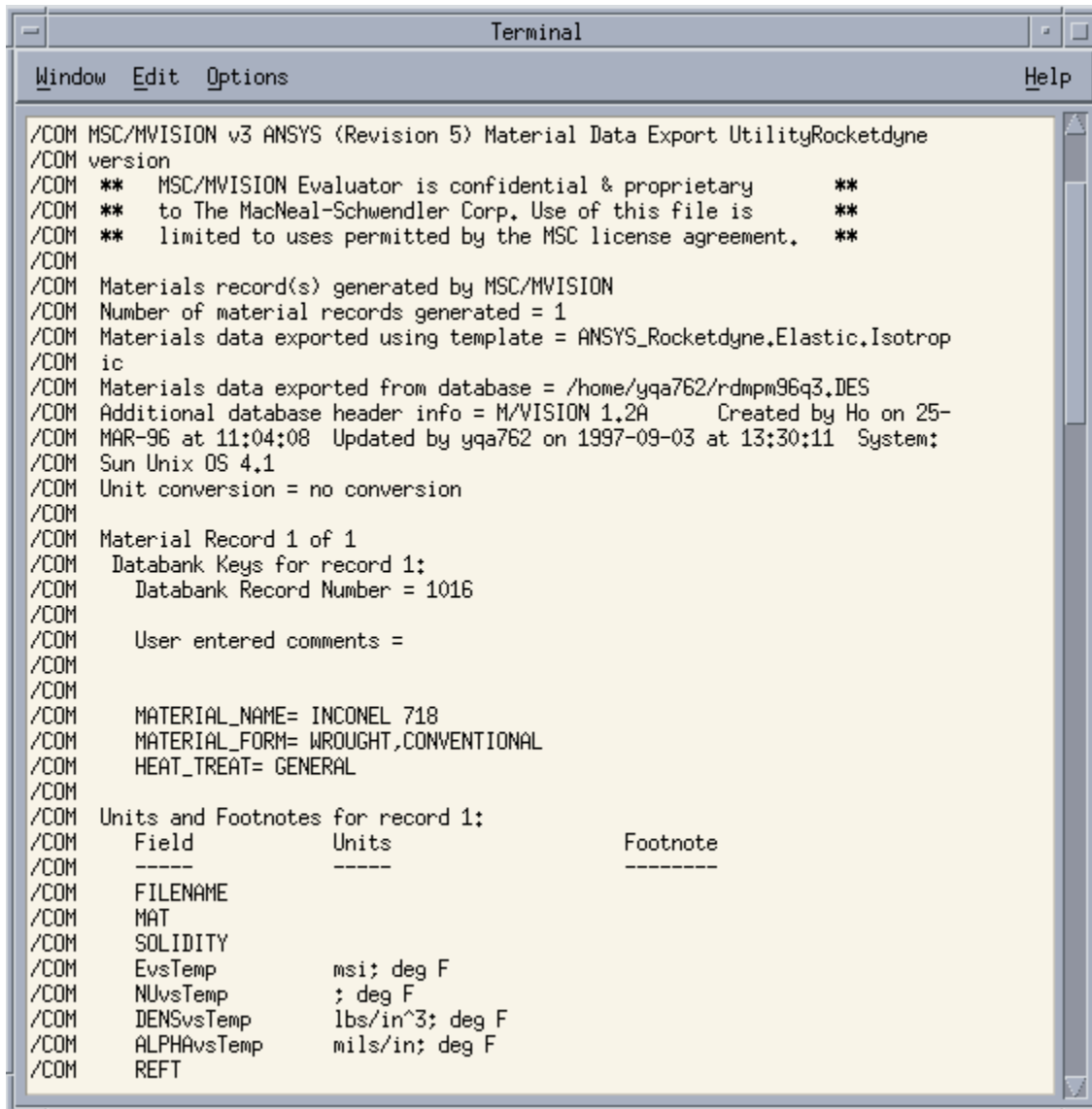
However, all is not as smooth as it first appears. MSC/MVISION Pro does not have the ability to search across databanks. This limits the designer's search to only the single databank that is open. Ideally, the tool should allow for a search across every databank available to it. As it is, the designers must manually load each of those databases and search them one by one. Elimination of that step would truly achieve the goals that Rocketdyne desires.

MSC/MVISION Pro also provides the capability to assign a material and its properties to a part. Once the designer finds the ideal material, the engineer may then assign this material to the part. The part will have associated with it the necessary properties to do some simple analysis work as well as a link back to the full materials properties.

Stress Analysts Using An Electronic Materials Properties Database

One requirement that the stress analyst desires is the elimination of the need for creating material data files for analysis programs by hand. The electronic materials properties database that Rocketdyne is implementing can quickly generate a properly formatted data file with the necessary data, including all the

pedigree information and comments needed to allow the user to trace back the analysis to the exact source of the materials data used (Figure 6).



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/COM MSC/MVISION v3 ANSYS (Revision 5) Material Data Export UtilityRocketdyne
/COM version
/COM ** MSC/MVISION Evaluator is confidential & proprietary **
/COM ** to The MacNeal-Schwendler Corp. Use of this file is **
/COM ** limited to uses permitted by the MSC license agreement. **
/COM
/COM Materials record(s) generated by MSC/MVISION
/COM Number of material records generated = 1
/COM Materials data exported using template = ANSYS_Rocketdyne,Elastic,Isotrop
/COM ic
/COM Materials data exported from database = /home/yqa762/rdmpm96q3.DES
/COM Additional database header info = M/VISION 1.2A Created by Ho on 25-
/COM MAR-96 at 11:04:08 Updated by yqa762 on 1997-09-03 at 13:30:11 System:
/COM Sun Unix OS 4.1
/COM Unit conversion = no conversion
/COM
/COM Material Record 1 of 1
/COM Databank Keys for record 1:
/COM Databank Record Number = 1016
/COM
/COM User entered comments =
/COM
/COM MATERIAL_NAME= INCONEL 718
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/COM
/COM Units and Footnotes for record 1:
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/COM -----
/COM FILENAME
/COM MAT
/COM SOLIDITY
/COM EvsTemp msi; deg F
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/COM REFT

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Figure 6: A Small Portion of the Materials Data File MSC/MVISION Creates for ANSYS (This is just the comments, the data is further below).

This feature is available for use when exporting a file for linear analysis in ANSYS [6]. The export of a file for bi-linear analysis in ANSYS is currently being improved. Although this is not a common type of analysis in industry, it is important for Rocketdyne, and MSC is working with our analysts to make sure this feature is available. Without the ability of exporting bi-linear curves, it takes our analysts about 8 hours to produce a materials file for ANSYS to use. When this feature is implemented, the export file is created in a matter of minutes with tools to do visual verification before the information exported. This will also allow

a consistent procedure for all the analysts at Rocketdyne, which will improve both the quality and reproducibility of the stress analysis.

The initial impressions from stress analysts using the linear analysis export feature have been very positive, and we expect the implementation of the bi-linear analysis export to get the same response. Overall these features will reduce the time and the quality of the analysis.

Conclusion

Even in the early stages of our MSC/MVISION implementation, we are reaping the benefits of using it. The greatest benefit has been to the materials engineering department, where the time it takes to release a design curve has been greatly reduced, and the need to write test reports has been nearly eliminated. We also see improvement in the quality of our materials properties manual because it is online and readily updated.

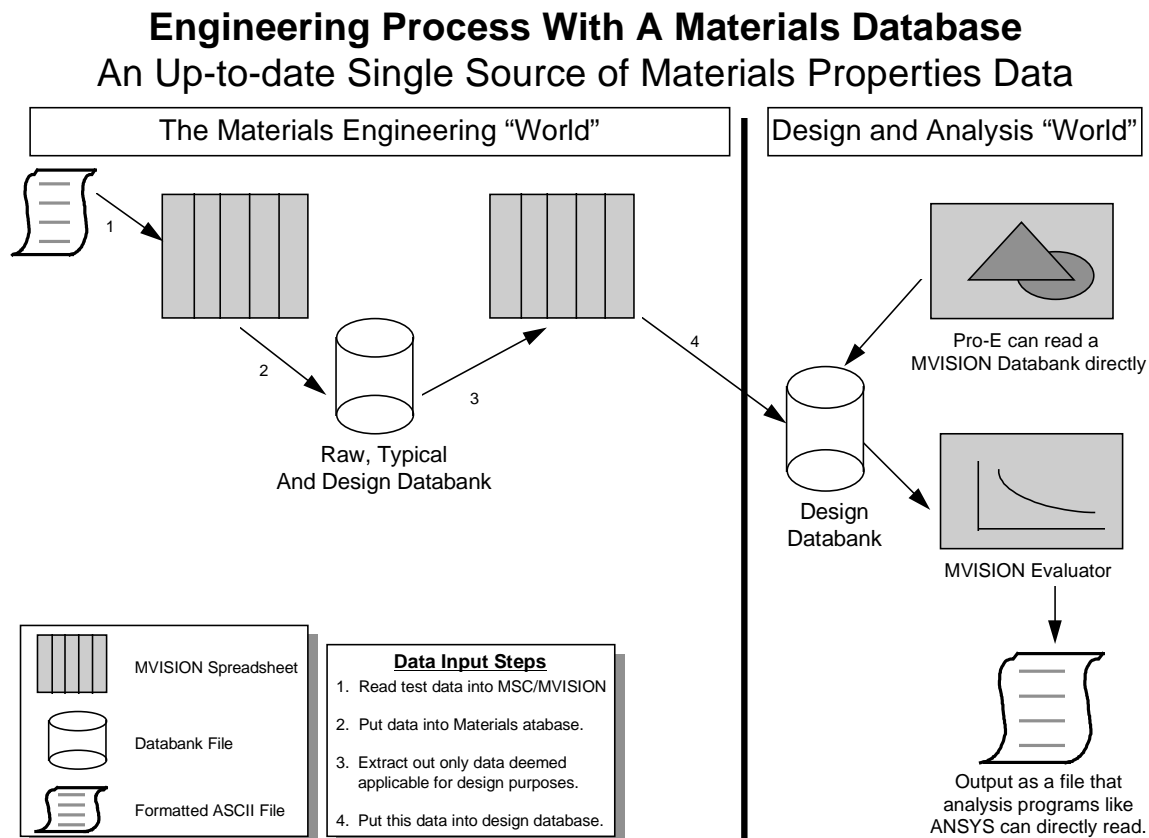


Figure 7: A Paperless, Single-Source of Materials Properties Data

These updates are made immediately available to the users from a single source (Figure 7). A comparison of Figures 2 and 7 reveals that we've reduced the number of sources for materials properties data from three to one. This

reduction means that every engineer at Rocketdyne will be using the same data, and it will be the latest data. Reports and hardcopy manuals are difficult to track down and revise, but the single source database greatly simplifies revisions. Note also that every step in the process shown in Figure 7 is completely paperless. This not only saves paper but eliminates possible typographical errors and is much easier to use.

The improvements for our stress analysts and designers have been less obvious. Our exporting capability to ANSYS is a great benefit to our users, and will be even more so once the bi-linear export feature is fully implemented. MSC/MVISION's capability to export a materials file to NASTRAN will also be a helpful feature to our NASTRAN [7] users. Rocketdyne also has users of ABAQUS [8] which takes a file format that the database can write. That feature has yet to be examined. The integration of MSC/MVISION Pro is further behind, but, this feature is available for the designers to use. As our use of MSC/MVISION matures, we fully expect to see it play a significant role in reducing process cycle time for design and analysis.

Another area that requires further work is to quantify the amount of time saved by using an electronic materials database. As it is, the savings are real but not easily measured. We are in the process of determining how we may quantify the actual benefits we see in using this tool.

One author has stated that the "development of a materials properties database is obviously a never-ending task." [9] He goes on to state that "advances in computer technology continue to provide exciting new opportunities for enhancing existing systems." [9] Those of us working to implement a materials properties database at Rocketdyne echo these words. In pursuit of our improvement goals, Rocketdyne is at present very satisfied to be using MSC/MVISION, and we expect to be even more pleased as we grow in our use of it and as the product itself grows in response to our needs.

Acknowledgments

The implementation of MSC/MVISION at Rocketdyne and the writing of this paper was not done alone. Many people have been involved in this project and deserve recognition for their work. Nancy Abesamis, whose insight and wise counsel is seen throughout this paper and throughout the implementation of MSC/MVISION at Rocketdyne, has played a major role in the success of the materials properties database at Rocketdyne. Acknowledgment is also given to Tony Eastland and Aryeh Meisels who provided the managerial leadership and support needed to move this project from an idea to reality and to Rocketdyne for providing financial support for this entire project.

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