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# QFD Analysis of RSRM Aqueous Cleaners

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## ABSTRACT

This paper presents a Quality Function Deployment (QFD) analysis of the final down-selected aqueous cleaners to be used on the Redesigned Solid Rocket Motor (RSRM) program. The new cleaner will replace solvent vapor degreasing. The RSRM Ozone Depleting Compound Elimination program is discontinuing the methyl chloroform vapor degreasing process and replacing it with a spray-in-air aqueous cleaning process. Previously, 15 cleaners were down-selected to two candidates by passing screening tests involving toxicity, flammability, cleaning efficiency, contaminant solubility, corrosion potential, cost, and bond strength. The two down-selected cleaners were further evaluated with more intensive testing and evaluated using QFD techniques to assess suitability for cleaning RSRM case and nozzle surfaces in preparation for adhesive bonding.

## INTRODUCTION

Quality Function Deployment (QFD) is a team method to plan and design new or improved products, processes, or services. The design is based upon customer requirements and the approach is to do it right the first time and document what you are doing and thinking. The concept was first proposed in 1966 by Yoji Akao, vice president of the Japan Society for Quality Control and professor of industrial engineering at Tamagawa University in Tokyo, Japan. The purpose of QFD was spawned from the need to find a way to get production to grasp the notion of quality assurance at the stage of planning before going into production. This notion was later named "concurrent engineering." QFD was introduced in 1972 by Akao at the Kobe shipyards of Mitsubishi Heavy Industries to coordinate the logistics for building complex supertanker cargo ships. The technique developed further sophistication at Toyota and has gained worldwide acceptance as a powerful product planning method in numerous industrial and service sectors.

Rocketdyne[1] used QFD to redesign a fuel turbopump for a heavy-lift launch vehicle, Thiokol uses QFD on the RSRM program to the point that a QFD training course[2] was developed, and NASA Marshall Space Flight Center (MSFC) has prepared a technical paper[3] to encourage NASA wide usage of the technique.

The strategy of QFD is to focus development and improvement activities on the customer. Multidisciplinary teams are used to arrive at decisions by consensus. This approach allows customer requirements to be deployed from features to characteristics to operations to requirements. It provides a framework for concurrent engineering. Documentation is simple and consistent, and results in a optimum design that allows qualitative requirements to be converted in measurable activities.

Thiokol engineering is using the technique to assist in the down-selection of new processes as a result of the Montreal Protocol ban on certain ozone depleting chemicals. The schedule for implementation is short and the task is awesome; perfect reasons to use QFD.

## DISCUSSION

The QFD analysis followed a logic flow as illustrated in Figure 1. A brainstorming session was held with members of Materials and Processes Engineering. The process was facilitated by a Total Quality Management (TQM) advisor. Quality characteristics were identified which would answer all major program concerns. Safety, processability, and finished product performance were key elements in arriving at the final characteristics. The number of items was limited to 12 as recommended by good TQM practice. A binary comparison analysis was conducted using the 12 items. Using a scale of 0.1 to 10, key members of safety, engineering, quality, waste disposal, facilities engineering, and NASA were asked to compare between two criteria at a time, working through all 12 characteristics (Figure 2). The results provided a weight by item for each individual criteria which was then grouped by organization (Figure 3). A QFD form was developed for material selection that listed the quality characteristics, weight factors, ranking of data, total score, and total grand score for each material, and provided space for lab data (Figure 4). The laboratory tests were then conducted on each candidate and the data were entered, weighted, and ranked. A total score for each item as well as a grand total score for each material was obtained.

The first series of tests was designed to down-select 15 cleaners to five by comparing each to the others and to the control, which was methyl chloroform vapor degreasing. Figure 5 shows the total QFD scores with three semi-aqueous and two aqueous cleaners winning out. The organic cleaners were eliminated due to their volatile nature during a spray in air mode.

Since the first series of tests satisfied all of the safety concerns, the second series of tests designed to down-select five cleaners to two could concentrate on processability and product performance factors. Again, a binary comparison analysis was conducted to obtain the weighted value for the next series of tests. The five cleaners were submitted for lab tests and the results were analyzed.

Residue from contaminants and cleaners was determined by surface chemistry analysis. Hydrocarbons were quantified by measuring carbon levels and silicates were measured by ratioing the silica peak to the zirconium peak. A typical ratio of the Si/Zr is 2.0 for a surface cleaned by grit blasting with zirconium silicate media. Any ratio higher than 2.0 indicates the presence of excess silicates which is a constituent in some of the cleaners.

Cleaning efficiency was measured by optical stimulating electron emission (OSEE). The OSEE unit scans the surface with ultraviolet light in the 185 nanometer region and provides surface cleanliness measurements in centivolt units which are correlatable to contaminant levels. The higher the centivolt reading, the cleaner the surface. The technique is sensitive to 1 $mg/ft^2$ of hydrocarbon contaminant. The acceptance level for bonding ranges from 10 to 25 $mg/ft^2$ depending upon the bond criticality.

Bond strength was determined using tensile adhesion of an epoxy adhesive (Hysol EA913NA) with D6AC steel and 7075 aluminum buttons. Fracture toughness was measured using tapered double cantilever beams with the same adhesive per a modified American Society for Testing Materials (ASTM) method. Fracture toughness was chosen because of its sensitivity to lower levels of surface contaminants which provides a clearer distinction between cleaner candidates.

Various process options were tested for bond strength including no grit blasting with and without aging prior to bond, grit blasting with no aging, and soil loading with no grit blast or aging. Aging conditions were 135°F and 100 percent RH for four weeks. Soil was added to the cleaner in successive cycles to establish a saturation level that would affect strength. Five mg/l of soil simulated a typical years worth of soils the hardware would see.

Corrosion potential was tested three ways: visual inspection, electrochemical potential per an ASTM method, and corrosion rate in mils lost per year.

The major difference that separated the cleaners was soil loading capability. One semi-aqueous cleaner performed equally with the aqueous cleaners except for the soil loading test, where it was eliminated (Figure 6). The two final candidates were Brulin 815GD and Jettacin. They are both aqueous alkaline cleaners. Jettacin also contains a terpene solvent.

As the number of cleaners were reduced, more tests were performed to establish some statistical confidence. The third series of down-selection, two cleaners to one, introduced design of experiments (DOE) as a tool to gain maximum information with minimum testing.

The DOE (Figure 7) was a seven-variable, two-level design requiring 16 coupons for each alloy. The variables were carefully chosen after lengthy discussions with processing experts. Additionally, two repeat sets were run to establish process and testing variability levels. The 2-sigma bands show in Figure 8 establish these statistical boundaries for this set of experiments. Therefore, only parameters that exceed these levels are considered as significant changes. When reviewing the main effects, the response to each variable could be measured against the 2-sigma window and each cleaner could be scored accordingly (Figure 8). Again, a new QFD matrix was developed to make the 2-to-1 down-selection. This matrix showed that both cleaners were acceptable in the product performance category. However, subscale cleaning tests highlighted potential processability issues, i.e. foaming and cleaner life.

In addition to the standard laboratory tests, processability tests were expanded to further define the transition from subscale to full-scale processing. During this scaleup, some cleaner foaming was encountered. Therefore, further testing will study low foaming cleaners from the same chemical family. Preliminary work with one such cleaner, Brulin 1990, using electron spectroscopy for chemical analysis (ESCA) showed that at the molecular level, the nonfoaming and standard aqueous cleaners produced similar surface chemistry. Preliminary bond testing with Brulin 1990 (tensile and fracture energy) showed equal strengths to the foaming version. Thus Brulin 1990 appears to be a viable cleaner for our application.

## CONCLUSIONS

The QFD approach has proven to be an effective way to assimilate the varied concerns and opinions of various organizations early in the design process. The QFD format allows clear and concise reporting of the test data in a nonbiased manner. Many technical factors are used in an engineering decision. By limiting the factors of customer concern, speedy decisions can be made about numerous cleaner systems. However, as the selection of cleaners narrows more engineering judgement from technical data is necessary. A lesson learned is that any issue, even if given minimal weight in the scoring process, can impact the final decision.

## ACKNOWLEDGEMENT

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## REFERENCES

[1]Butler, K.N., Aerospace America, April 1993, pp. 28-30
[2]Thiokol Corporation, QFD Training Workbook, 1992
[3]Cruit,W.,et.al., Prioritization Methodology for Chemical Replacement, NASA Technical Paper 3421, 1993

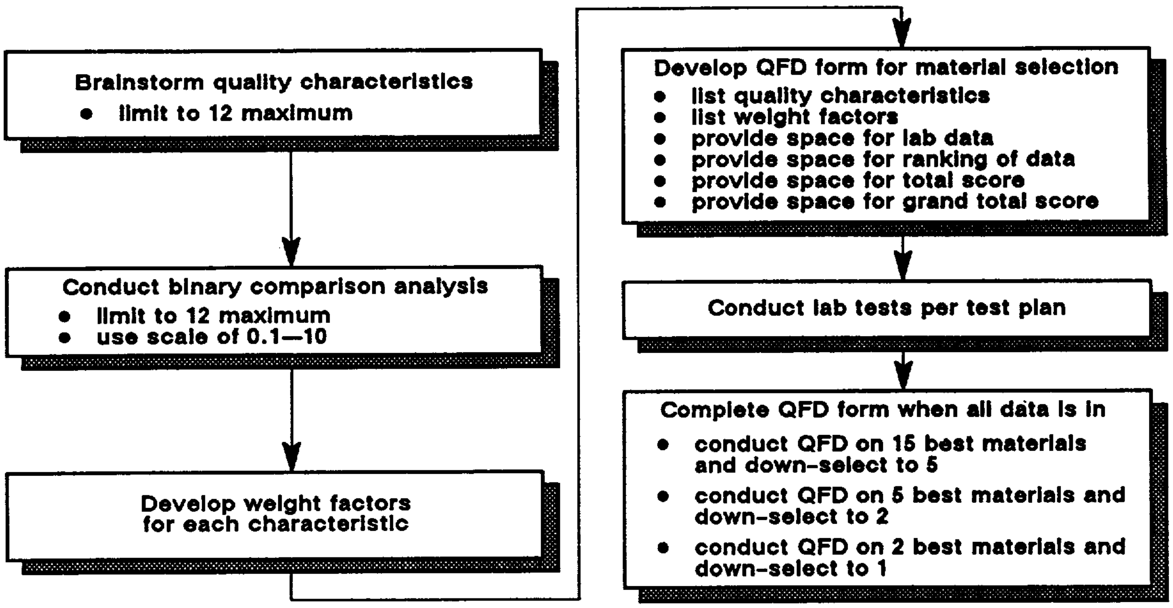
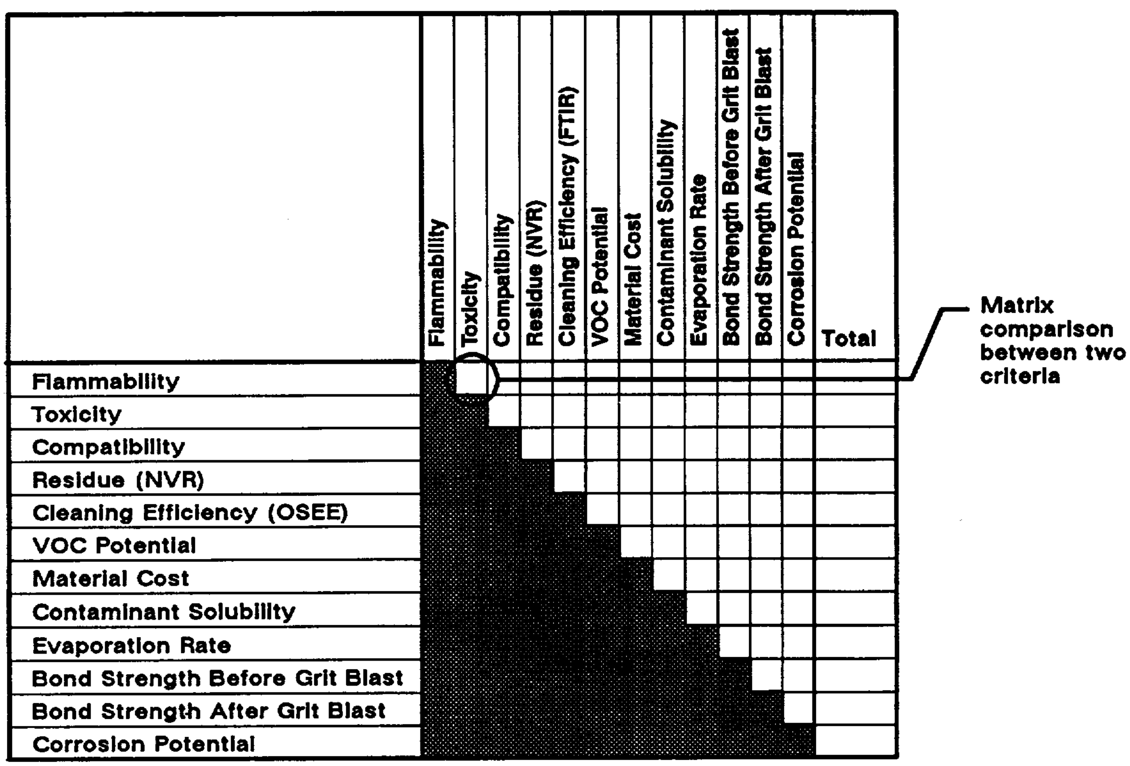



Figure 1. QFD Liquid Flow

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- Individual cells contain the comparison between two criteria
- The reviewer should read the comparison from row to column as in the following example:
  - Flammability is: (choose one)
    - Exceedingly more important
    - Significantly more important
    - Equally important
    - Significantly less important
    - Exceedingly less important than toxicity
- The reviewer decides which statement is true, then marks the appropriate score in the cell. Calculations will be done on the other cells to determine total weight of each criteria
- Do not calculate totals at this time.

Figure 2. Binary Comparison Analysis

| Criteria | Design Engineering | Program Management | Labs | Materials and Processes | Facilities | Customer | Materials and Processes | Project Engineering | Total | Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| Flammability | 10.8 | 85.0 | 58.2 | 51.2 | 77.0 | 73.2 | 34.1 | 38.4 | 427.9 | 13 |
| Toxicity | 39.6 | 38.2 | 58.2 | 38.2 | 77.0 | 103.2 | 34.1 | 38.4 | 426.9 | 13 |
| Compatibility | 52.4 | 15.0 | 9.1 | 39.0 | 28.4 | 76.4 | 13.3 | 61.0 | 294.6 | 9 |
| Residue (NVR) | 13.6 | 18.8 | 9.3 | 7.0 | 23.6 | 26.4 | 7.7 | 11.0 | 117.4 | 3 |
| Cleaning Efficiency (OSEE) | 70.0 | 20.5 | 33.6 | 28.9 | 24.4 | 65.2 | 20.5 | 33.6 | 296.7 | 9 |
| VOC Potential | 88.0 | 38.2 | 35.2 | 9.2 | 47.0 | 75.2 | 6.9 | 1.8 | 301.5 | 9 |
| Material Cost | 22.6 | 1.7 | 1.5 | 12.3 | 1.7 | 24.8 | 6.9 | 9.3 | 80.8 | 2 |
| Contaminant Solubility | 41.6 | 23.9 | 9.1 | 19.0 | 27.0 | 20.2 | 7.7 | 10.2 | 158.7 | 5 |
| Evaporation Rate | 51.2 | 13.3 | 9.1 | 10.1 | 32.6 | 8.8 | 10.9 | 9.9 | 145.9 | 4 |
| Bond Strength Before Grit Blast | 59.2 | 19.0 | 39.2 | 31.9 | 13.6 | 10.8 | 26.1 | 42.4 | 242.2 | 7 |
| Bond Strength After Grit Blast | 78.4 | 67.2 | 85.0 | 68.0 | 17.6 | 140.0 | 110.0 | 61.0 | 627.2 | 19 |
| Corrosion Potential | 80.4 | 24.7 | 32.7 | 34.5 | 15.0 | 41.2 | 10.1 | 14.2 | 252.8 | 7 |
| Total | 607.8 | 365.5 | 380.2 | 349.3 | 384.9 | 665.4 | 288.3 | 331.2 | 3,372.6 | 100 |

Figure 3. Voting Comparison and Totals

Product Name: ______________________

Application: ______________________

| Criteria/Baseline | Test | Results | | Weight | Rank | Total |
|---|---|---|---|---|---|---|
| Toxicity | | | | 0.13 | | |
| Flammability | Ignitability | | | 0.13 | | |
| VOC Potential | | | | 0.09 | | |
| Residue | NVR | | | 0.03 | | |
| Cleaning Efficiency | OSEE | | | 0.09 | | |
| Contaminant Solubility | | | | 0.05 | | |
| Corrosion Potential | pH | | | 0.07 | | |
| Evaporation Rate | | | | 0.04 | | |
| Compatibility | | | | 0.09 | | |
| Bond Strength, No Grit Blast (as cleaned) | Tensile Fracture | D6AC | 7075 | 0.07 | | |
| Bond Strength, with Grit Blast | | D6AC | 7075 | 0.19 | | |
| Material Cost | | | | 0.02 | | |
| | | | Total | 1.00 | | |

This rank is a rating between 1 and 10. This rating is based on the actual data and predetermined ground rules.

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Figure 4. OPTIC Team Material Selection

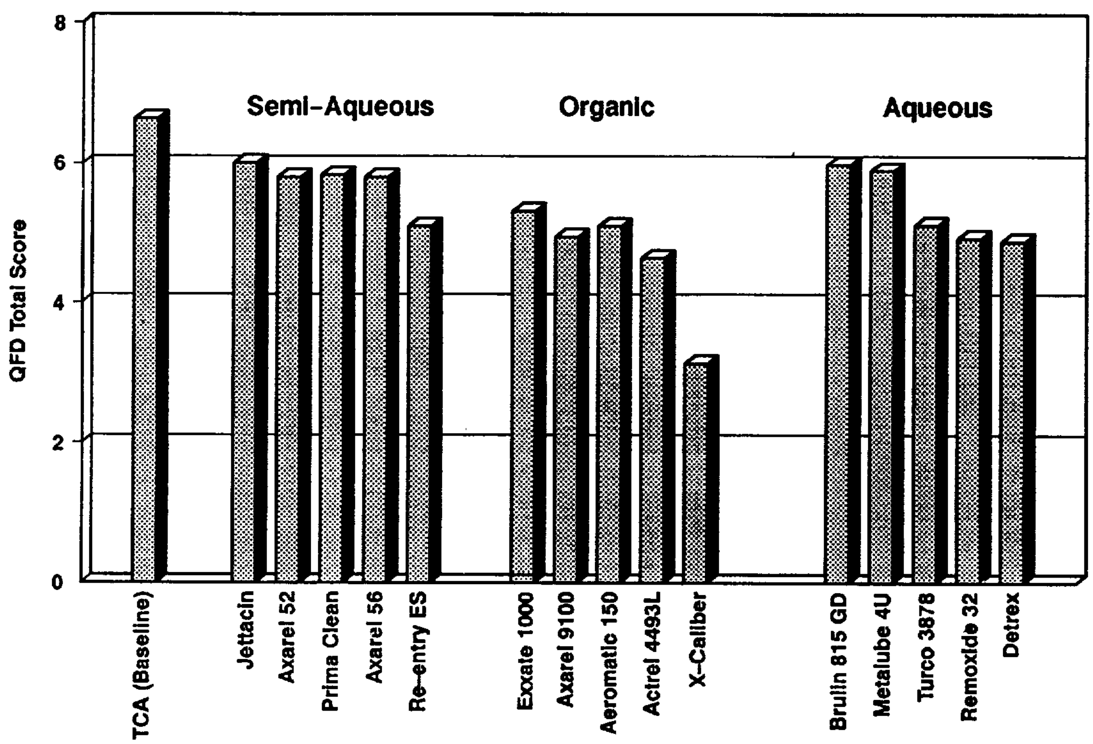


Figure 5. OPTIC Team QFD Results. Down-selection from 15 to 5. (total scores)

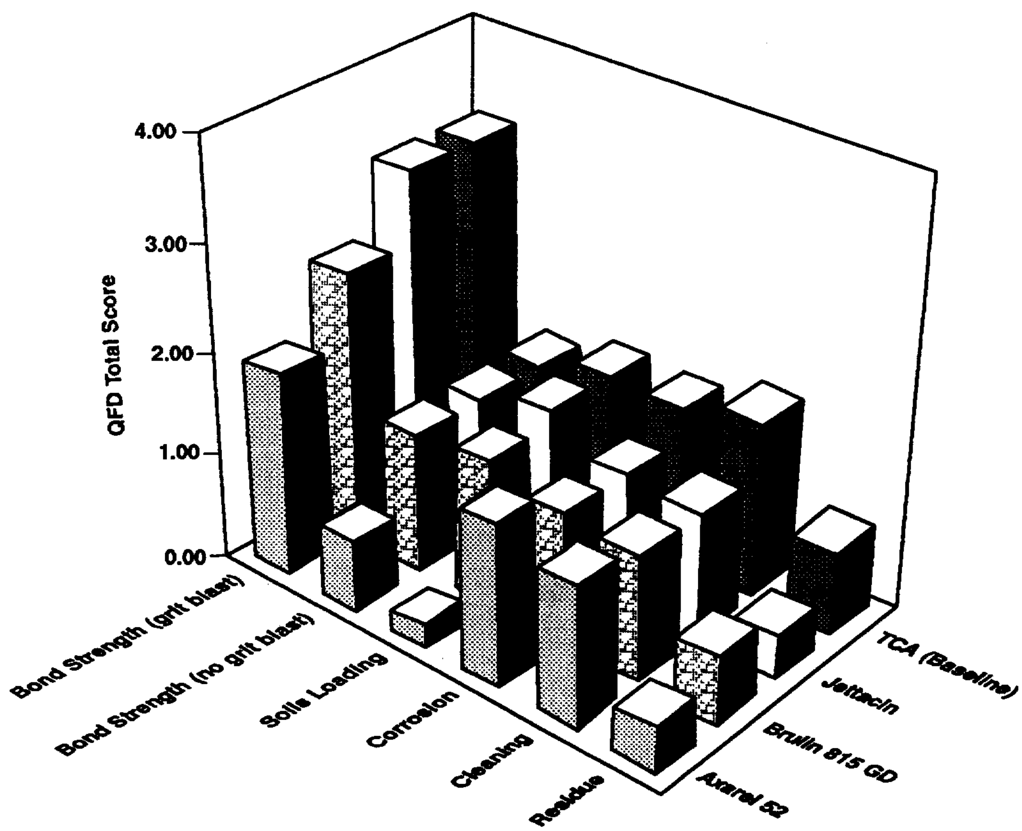


Figure 6. OPTIC Team QFD Results. Down-selection from 5 to 2. (total scores)

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For each cleaner:

| Test | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | + | + | + | + | + | + |
| 2 | + | + | + | - | + | - |
| 3 | + | + | - | + | - | - |
| 4 | + | + | - | - | - | + |
| 5 | + | - | + | + | - | - |
| 6 | + | - | + | - | - | + |
| 7 | + | - | - | + | + | + |
| 8 | + | - | - | - | + | - |
| 9 | - | + | + | + | - | + |
| 10 | - | + | + | - | - | - |
| 11 | - | + | - | + | + | - |
| 12 | - | + | - | - | + | + |
| 13 | - | - | + | + | + | - |
| 14 | - | - | + | - | + | + |
| 15 | - | - | - | + | - | + |
| 16 | - | - | - | - | - | - |

| Variables | High Level ( + ) | Low Level ( - ) |
|---|---|---|
| A = Cleaner Temperature | 135°F ± 5° | 70°F ± 5° |
| B = Cleaner Concentration | 30% | 10% |
| C = Wash Density | 2.3 gpm | 1.5 gpm |
| D = Wash Pressure | 250 ± 25 psi | 70 psi |
| E = Rinse Pressure | 250 ± 25 psi | 70 psi |
| F = Lab Location | HSO | S&E |
| G = Cleaner | Jettacin | Brulin |

Figure 7. Design of Experiments, 6 Variables (2 levels)

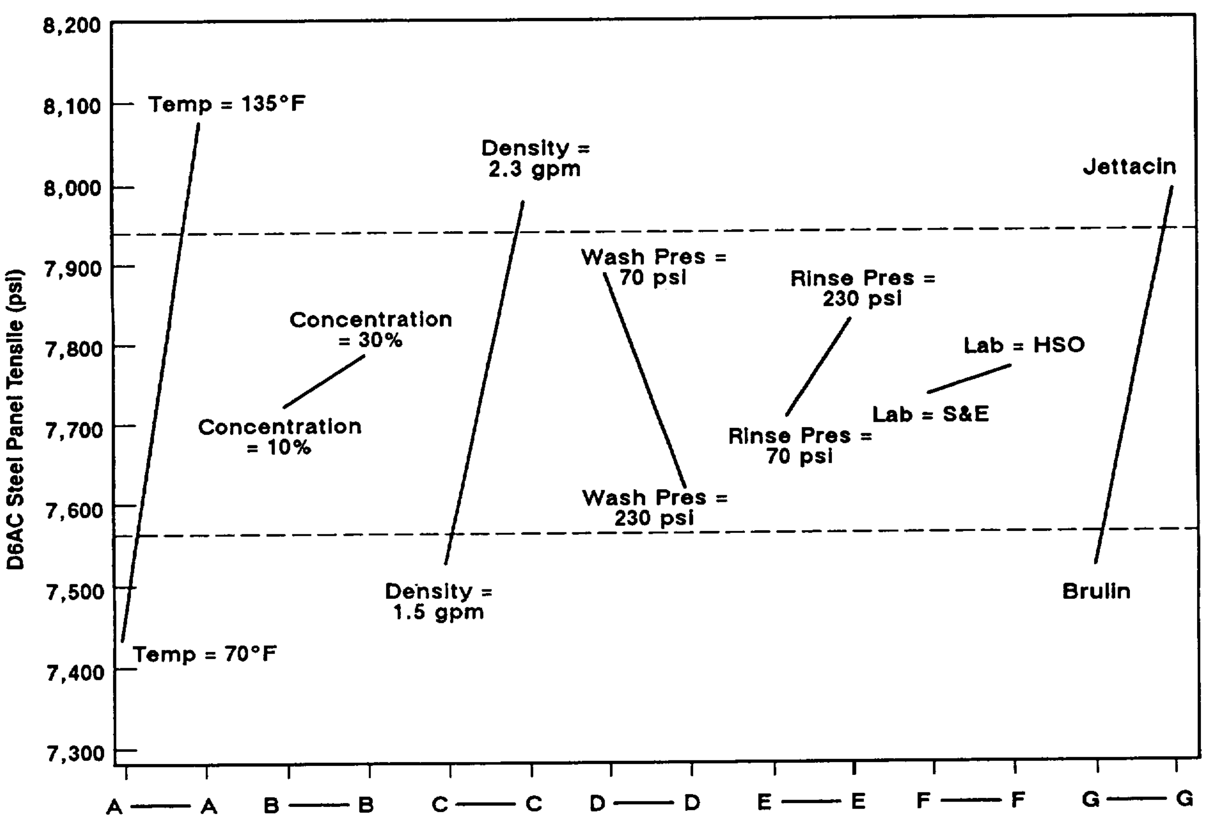


Figure 8. Test Matrix Variable Code