TURBINE ROTOR BURST CONTAINMENT ANALYSIS USING MSC/DYTRAN

AN ANALYTICAL APPROACH TO PREDICTING PRIMARY CONTAINMENT

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ABSTRACT

With the common use of turbo-fluid machinery in the aerospace industry, rotor burst containment is an important design requirement. More demanding weight reduction goals are pushing containment structures to the brink of containment efficiency. Design engineers at Hamilton Standard have been reliant on design similarities and empirical data, to predict containability. However, limitations in the current methodology make detailed predictions difficult, especially if the geometry is not based on a previous design. In some cases, the limitations in the empirical method can lead to many costly tests. With the use of MSC/DYTRAN, and the help of the MacNeal-Schwendler Corp., Hamilton Standard has been developing an analytical method to predict rotor burst containment. Preliminary case studies have shown that MSC/DYTRAN can handle the physics involved with turbine rotor containment. Using the analytical methodology, structural damage and material response are characterized from the physics. Therefore, the prediction is independent of similar designs.

INTRODUCTION

With the common use of turbo-fluid machinery in the aerospace industry, rotor burst containment is an important design requirement. More aggressive weight reduction goals are pushing containment structures to the brink of containment. Design engineers at Hamilton Standard have been reliant on design similarities and empirical data to predict containability. However, limitations in the current methodology make detailed predictions difficult; especially if the geometry is not based on a previous design. In some cases, the limitations in the empirical method can lead to many costly tests. With the use of MSC/DYTRAN, and the help of the MacNeal-Schwendler Corp., Hamilton Standard has been developing an analytical method to predict rotor burst containment. The MSC/DYTRAN simulation would add necessary details to supplement the empirical approach. This would lead newly designed structures to meet the containment criteria with fewer costly tests.

PROBLEM DEFINITION

Currently, primary rotor containment is predicted using an empirical approach that uses either a “Penetration” theory or a “Maximum Hoop” theory. Depending on the rotor type, the appropriate theory is used. With the “Maximum Hoop” theory, a PE/KE[1] ratio determines the potential energy needed from the containing structure. If the “Penetration” theory is used, a T/KE[2] ratio determines how thick a containment ring must be to prevent penetration. Both the PE/KE and T/KE ratios are determined experimentally. However,

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[1] The PE/KE ratio is the ratio of the potential energy from the housing, to the kinetic energy of the rotor at its burst speed.

[2] The T/KE ratio is the ratio of a cylindrical containment ring thickness, to the kinetic energy of the rotor at its burst speed.

for the PE/KE ratio to be accurate, the tested hardware must be similar in geometry and material to the new design. In summary, the empirical method lacks the following:

1. ability to predict what amount of material contributes to containment
2. ability to show the margin of containment
3. results of secondary containment (response of retaining hardware)

ANALYSIS

The approach to developing the analytical method was to use MSC/DYTRAN to simulate a series of containment tests on jet engine starter turbines. A schematic of the production version of the DESIGN1 starter is shown in Figure 1. The series of tests involved using variations of the turbine housing with the same turbine rotor. Table 1 lists the cases used.

Table 1. Physical containment tests for analytical correlations.

Test Hardware	Description
DESIGN1 housing & turbine Qualification test	turbine fuse burst test using production hardware
DESIGN1 housing #1 & turbine 1st Variation	turbine fuse burst test using a thinned down version of the production housing
DESIGN1 housing #2 & turbine 2nd Variation	turbine fuse burst test using a modified DESIGN1 single containment tooth housing

By incrementally adding detail to the analysis, a correlation was obtained for the test series. Given the nature of a containment event, the correlations were based upon a pass/fail criterion rather than strain gage data. Figures 2 and 3 show the results of the DESIGN1 qualification test. Once a working technique was found, MSC/DYTRAN was used to predict a new untested design. A successful prediction was then made on the DESIGN2 jet engine starter. Figure 4 shows the results of the DESIGN2 containment test.

DISCUSSION

In the first few iterations with the MSC/DYTRAN, simulations were showing failed containment. However, the DESIGN1 tests showed successful containment. Since the simulations did not correlate to the physical test, subsequent refinements were made. The most significant change involved non-linear material models. When the strain rate sensitive material characteristics were added, the simulations started to correlate. Figure 5 is an example of strain rate sensitive properties. In version 2.2 of MSC/DYTRAN, no dynamic failure models exist. Since material failure is also a function of strain rate, an iterative approach was taken. An initial run with no failure models was used to obtain the effective strain rates. Then regions of the model were given adjusted "constant strain" failure models to account for rate effects. In addition, MSC has been developing more dynamic material models that should be available in later versions.

Since large amounts of material failures occur in containment, adaptive contact algorithms were used. The algorithms dynamically redefine contact surfaces as elements fail. For the purpose of momentum transfer, the contact algorithms worked well. However, the master-slave adaptive contact was not flawless. In rotor containment, the addition of an adaptive single surface contact is needed. This flaw is evident in Figure 6 where a successful containment still shows free floating fragments. However, through careful post processing, the housing surface showed no regions of penetration.

In addition, the contact definitions also included velocity sensitive friction models. By adding the friction models, the effects on the retention structure correlated better.

With the above effects defined, the finite element (FE) simulations showed good correlation to the DESIGN1. Since the DESIGN2 materials were similar, the material models used the similar trends for strain rate sensitivity. The main differences were in the starting values (or static properties), and the geometry. Table 2 shows the results.

Table 2. Results from containment tests and FE simulations.

Test Hardware (see table 1)	**Physical Test**	**FE Simulation**
DESIGN1 housing & turbine Qualification test	passed with large margin of containment	passed
DESIGN1 housing #1 & turbine 1st Variation	marginally passed with multiple cracks	marginally passed
DESIGN1 housing #2 & turbine 2nd Variation	failed containment	(not simulated)
DESIGN1 housing #3 & turbine 3rd Variation (very similar to housing #2)	(not tested)	failed containment
DESIGN2 housing & turbine Qualification test	passed with large margin of containment	passed

Due to time limitations, the DESIGN1 housing #2 test was not modeled. Since the FE simulation of the DESIGN1 housing #3 was not tested, this case was not a correlation point (see rows 3 and 4 in Table 2). However, both the model and the hardware were very similar. Therefore, removing any more material from the DESIGN1 housing #1 model will result in a failed containment. That would be consistent with the failed test on the DESIGN1 housing #2 model. Figures 6 to 9 show the results from the MSC/DYTRAN simulations.

CONCLUSIONS

MSC/DYTRAN is an effective tool for predicting rotor containment in turbo-fluid machinery. The strain rate sensitive material models available in MSC/DYTRAN are essential to model high velocity impact. FE analysis results show correlation with physical test results. Due to current version limitations in version 2.2, dynamic failure models are not available. Therefore, multiple runs are required to correct for strain rate effects.

By modeling both the test conditions as well as various operating conditions, detailed analyses can be made. Since the analysis is based on the physics involved, design similarities are not required. The FE simulations can determine:

1. what material contributes to containing the rotor fragments
2. how effective the retention hardware is
3. the margin of containment

ACKNOWLEDGMENTS

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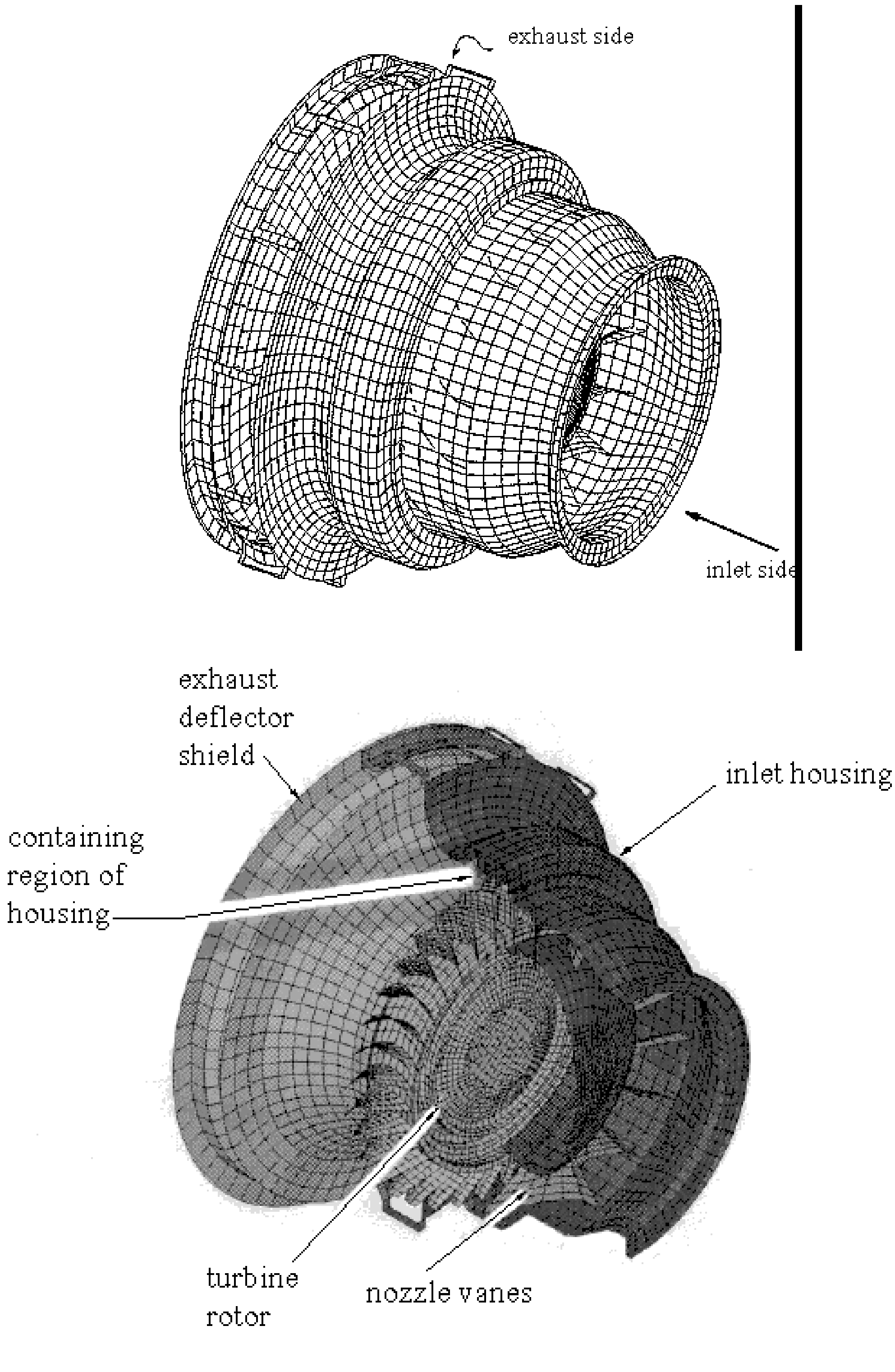
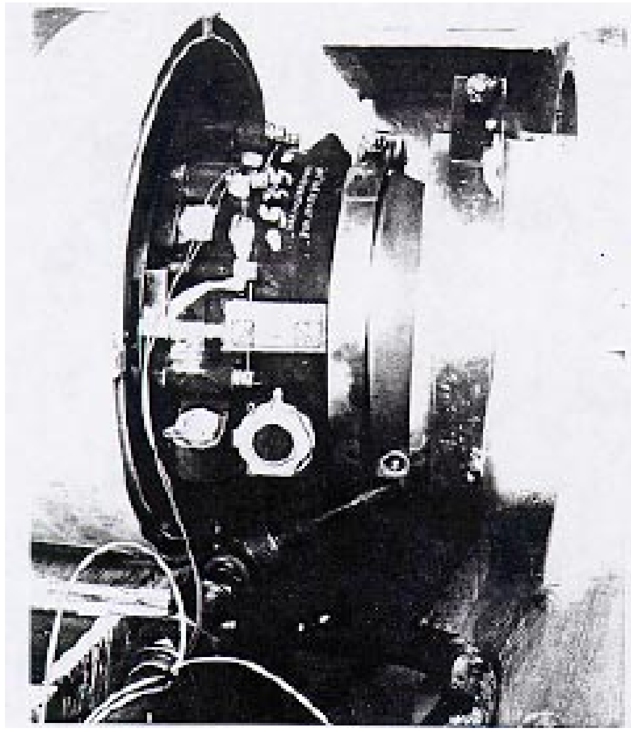


(b) Cut-away view

Figure 1. Schematic of DESIGN1 starter MSC/DYTRAN model.


Starter engine mount intact after test

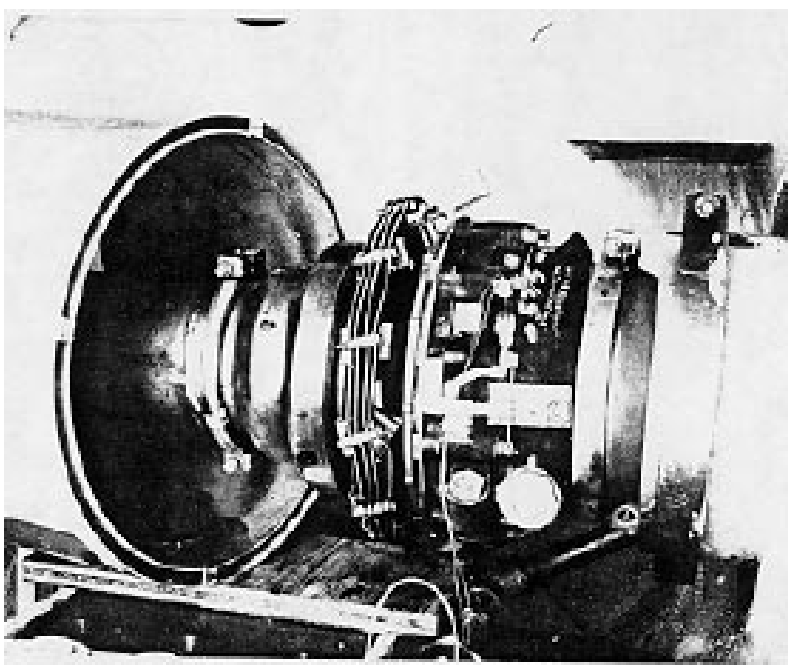
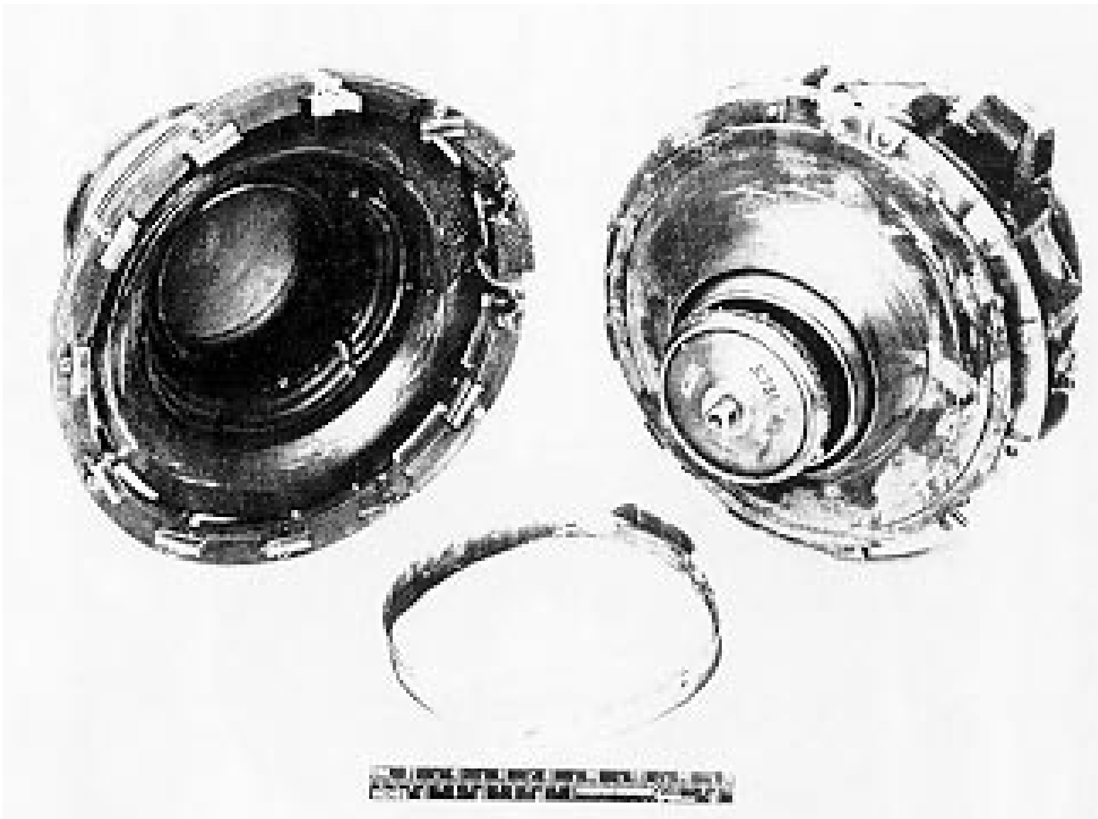

Starter overall view - witness shield withdrawn

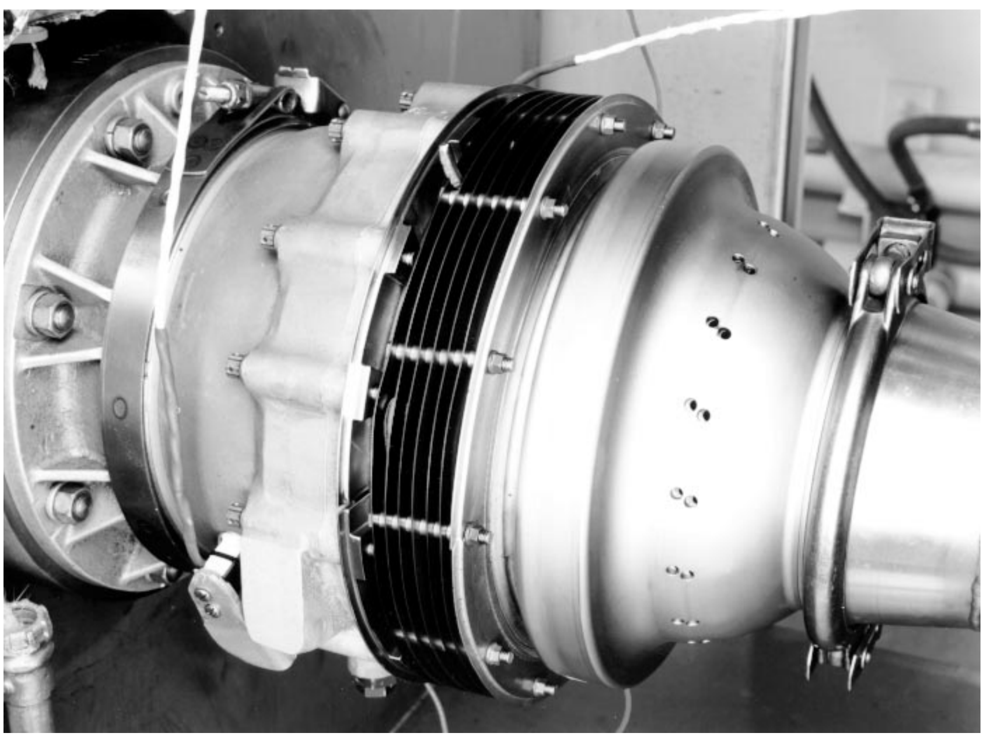
Figure 2. Results of DESIGN1 qualification test.



Starter inlet and gearbox assemblies

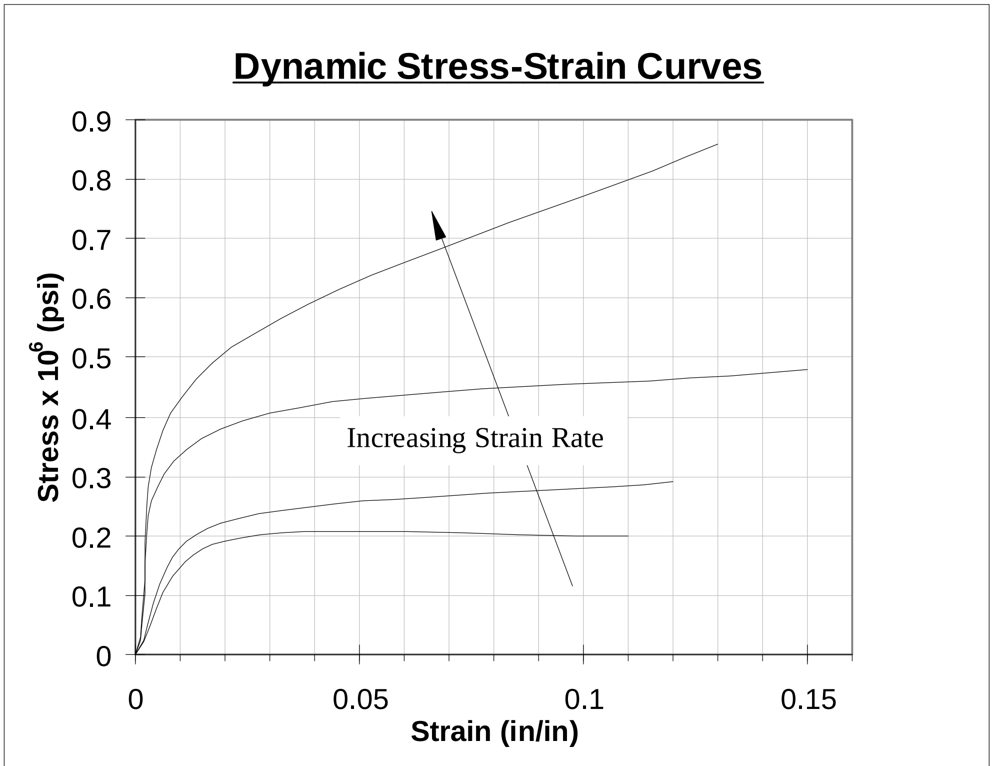
Figure 3. Results of DESIGN1 qualification test.

Inlet housing after rim and blade test



DESIGN2 starter after test

Figure 4. Results of DESIGN2 qualification test (rim and blade containment on inlet housing.)



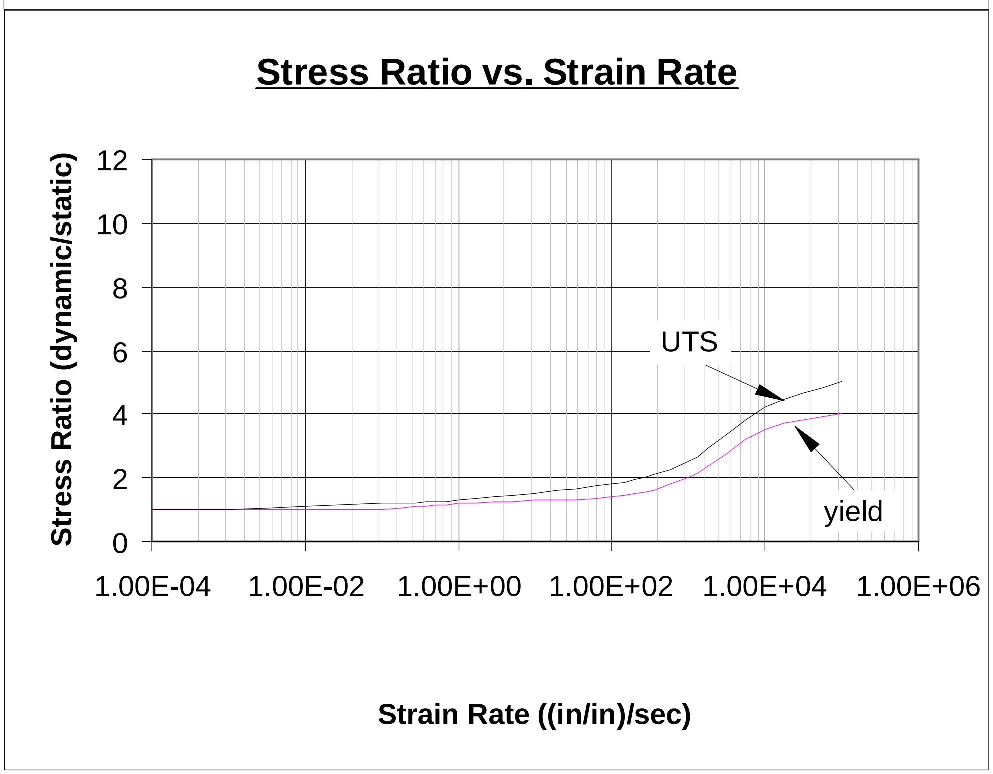


Figure 5. Contrived sample curves of strain rate sensitive properties used in MSC/DYTRAN simulation. The dynamic strain to failure values were used from Stress-Strain curves (top), and the dynamic yield stress was used (bottom).

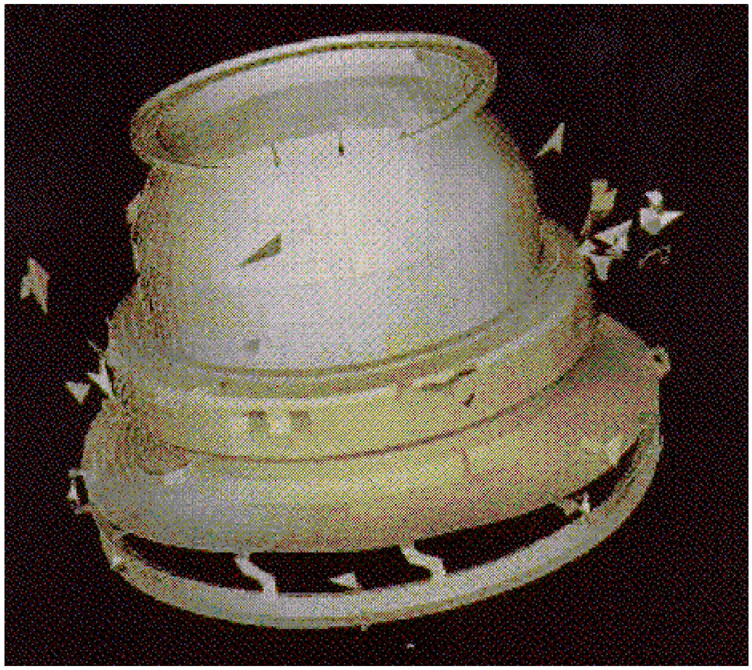


Figure 6. DESIGN1 qualification simulation using MSC/DYTRAN v2.2.

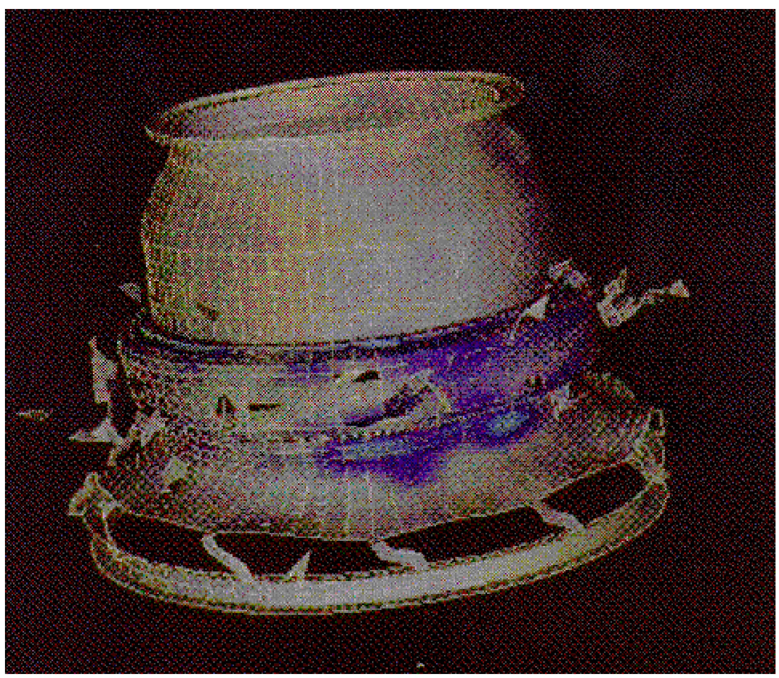


Figure 7. DESIGN1 housing #1 (1st variation) simulation using MSC/DYTRAN v2.2.

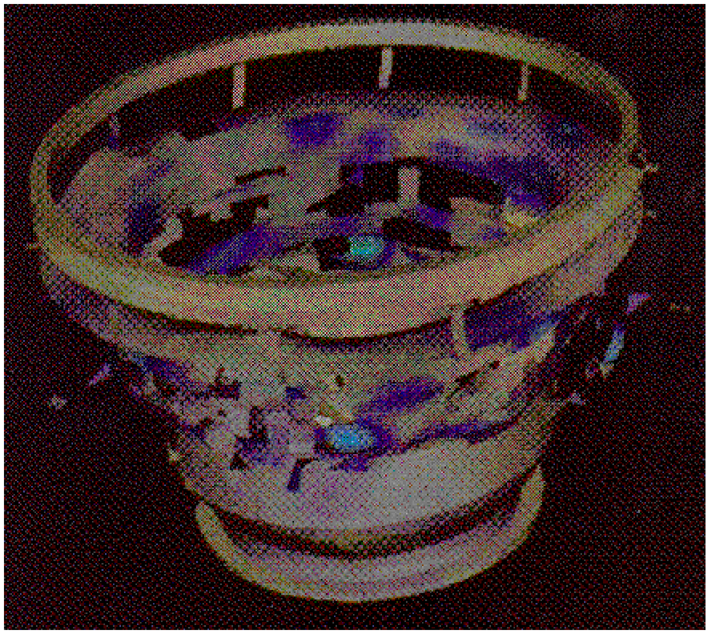


Figure 8. DESIGN1 housing #3 (3nd variation) simulation using MSC/DYTRAN v2.2.

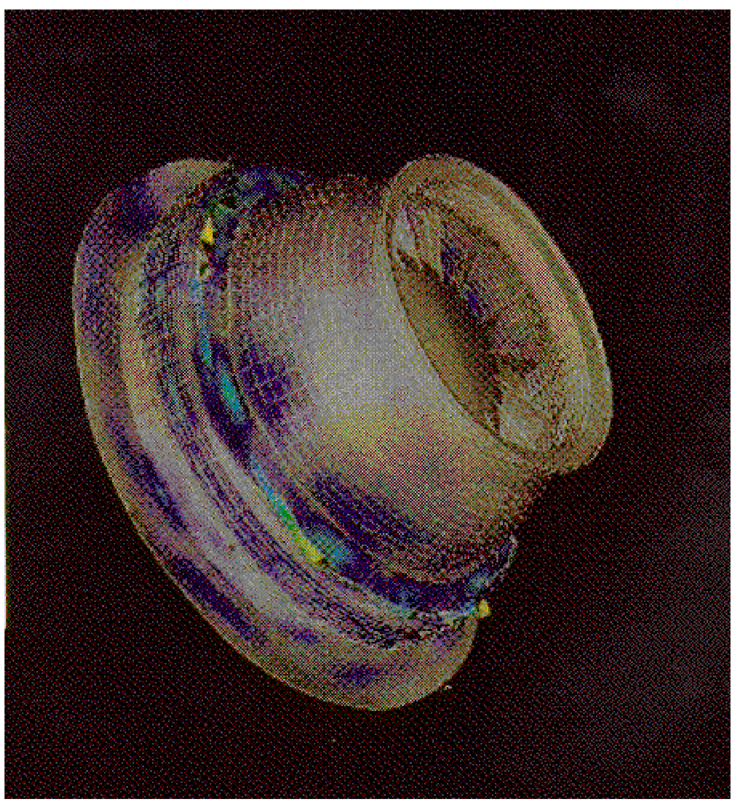


Figure 9. DESIGN2 qualification simulation using MSC/DYTRAN v2.2.