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Langley Research Center, Hampton, Virginia

May 2009
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January 12, 2006
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Volume I: Technical Consultation Report

1.0 Authorization and Notification

The request to conduct an independent review of regression models, developed for determining the expected Launch Commit Criteria (LCC) External Tank (ET)-04 cycle count for the Space Shuttle ET tanking process, was submitted to the NESC on September 20, 2005.

NESC acceptance of this task was approved in an out-of-board action on October 7, 2005.
2.0 Signature Page

Consultation Team Members

Vickie S. Parsons, NESC Lead

K. Preston White, University of Virginia
3.0 Team Members, Ex Officio Members, and Consultants

Vickie Parsons  NESC Systems Engineer  NASA LaRC
K. Preston White  Statistical Consultant  University of Virginia
Bernie Mylnczak  NESC Program Analyst  MTSO, LaRC
Erin Moran  Technical Writer  Swales Aerospace, LaRC
4.0 Executive Summary

The NESC team performed an independent review of regression models documented in Prepress Regression Analysis, Tom Clark and Angela Krenn, 10/27/05. These regressions were developed for determining the expected cycle count described in LCC ET-04. This independent review was limited to regression models developed based on variable measurements that are available prior to launch and corresponding to the development of “regression #1”, pp 4-7, in Prepress Regression Analysis.

5.0 Consultation Plan

This consultation consisted of a peer review by statistical experts of the proposed regression models provided in the Prepress Regression Analysis. Both primary members of the NESC team reviewed the following documents:

- Prepress Regression Analysis, Tom Clark & Angela Krenn (10/27/05)
- STS-114 S0007#2 LCC ET-04 LH2 Prepress Cycle Count, Diane Stees (7/29/05)
- STS-114 S0037#2 LH2 Prepress Test Cycle Count, Diane Stees (5/26/05)
- Define Mechanization of GH2 Prepress Cycle Count LCC ET-04, Diane Stees (2/12/03)
- Launch Commit Criteria (LCC) ET-04
- Launch Commit Criteria (LCC) ET-05
- LH2 Tank Prepress Overview (LCCs ET-04 & ET-05), B. Piekarski (10/27/05)
- Flight Pressurization System ET-04 Assessment LH2 Vent Vale Hazard Review, Kathryn Kynard & Jonathan Looser (10/24/05)
- Transient Analysis of LH2 Tank Prepress Helium Mass Flow, Adam Baran (10/27/05)
- Lockheed Martin Pressurization Program, B. Piekarski (10/27/05)
- Flight Pressurization System ET-04 Assessment ER21 Pressurization Model Sensitivity ER21, Tim Olive (10/24/05)

A telephone conference was also conducted between the NESC team and Space Shuttle Program (SSP) members knowledgeable of the ET tanking process, LCC ET-04, LCC ET-05, and the cycle count process.
6.0 Description of the Problem, Proposed Solutions, and Risk Assessment

The SSP uses LCC ET-04 as an indirect method to monitor ET LH₂ vent valve leakage. LCC ET-04 monitors the LH₂ tank pre-press system by counting GHe press valve command cycles. A larger than predicted command-cycle count is an indicator of potentially dangerous leakage and can lead to aborting the launch. The most recent valve replacements appear to have faster cycle times than those for the valves previously employed. Because the shorter pulse time leads to a lower helium make-up input per command cycle, a higher cycle count is required to maintain the ET pressure. The STS-114 ET tank loading observed 11 cycles which constituted 2 greater than predicted for the prior valves. This highlighted the need for revised modeling to better predict expected cycles with the current valves.

The SSP’s intent is to use modeling that is currently under development to determine appropriate modifications to the applicable LCCs. The intended application of these regressions is to provide a simple tool to validate the NASA-accredited, analytical (first principles) model currently under development, against empirical data available since the transition to half-second valve pulses. Additional analyses have been performed to verify that ground valve cycle timing does approximate the average cycle count.

7.0 Data Analysis

The data set for the review is provided in Table 7.0-1. The set comprises a total of twenty-seven data records, including records for seventeen flights (STS-88, -92, -93, -95, and -114), as well as one tanking test for STS-91 and three tanking tests for STS-114.

The dependent (output) variable in each data record is:

\[ \text{ActLCC: } \text{Actual (integer) number of cycles experienced plus the amount of time (as a fraction) between last and subsequent cycle at which point the LCC expires (T-43s). This combination variable was chosen by the SSP team rather than the integer number of cycles because a continuous variable is better suited to regression analyses.} \]
The independent (predictor) variables are:

- **Mission**: Mission identifying number.
- **Orbiter**: Orbiter number.
- **MLP**: Mobile launch pad number.
- **Diffuser**: Indicator variable for the diffuser material (0 indicating Single Dutch Twill and 1 indicating Double Dutch Twill).
- **UllagePres**: The trigger point software to control the tank at flight pressure (pulse fired when 2 of 3 ullage pressure transducers fall below the trigger point).
- **SupplyPres**: The GHe pressure coming into the panel and remains fairly constant throughout launch operations.
- **SFOutPres**: Peak (steady state) panel outlet pressure during initial pressurization in Slow Fill (to 5 percent full).
- **TCOutPres**: Peak panel outlet pressure during initial pressurization in Terminal Count.
- **CycleTime**: Average prepress s/o valve cycle time in Terminal Count (LCC prepress cycles only). Similar data can be obtained prior to loading to predict an LCC cycle count.
- **PeakPress**: Average peak panel outlet pressure during Terminal Count (LCC prepress cycles only).
- **Temp**: Ambient outside temperature during Slow Fill (to 5 percent full).
- **Prepres**: Peak Orbiter prepress line pressure during initial pressurization in Slow Fill (to 5 percent full).

Other variables that were provided in the data set were discounted because they were not known early enough in the tanking process. For analysis, the three category variables Orbiter, MLP, and Diffuser were translated to 0-1 indicator (dummy) variables.
Table 7.0-1. Data Set for the Review

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All three tanking tests for STS-114 yielded large cycle counts resulting from a known anomaly caused by use of an out-of-specification material (Double Dutch Twill) for diffusers. This anomaly is illustrated in the box plot in Figure 7.0-1. Appendix B provides a key for interpreting box plots.
Figure 7.0-1. Comparison of Elevated Cycle Counts Resulting from Incorrect Diffuser Material on Three STS-114 Tanking Tests with Cycle Counts for the Remaining Data Records

Additionally, the set of eight launches using MLP-2 (STS-95, -96, -98, -103, -104, -106, -109, and -113) have larger cycle counts, resulting from a known anomaly caused by a restrictive upstream orifice. This anomaly is illustrated in the box plot in Figure 7.0-2 (where the anomalous STS-114 tanking tests have been removed from the data set).
The causes of these anomalous cases have been corrected and are unlikely to be repeated.

Meaningful regressions require that the independent variables be unrelated. To assess potential co-linearities in the predictor variables, cross-correlation coefficients were computed for each pair of predictor variables, as shown in Table 7.0-2. When both variables were interval level measurements, Pearson’s correlation coefficient was used; when either variable was categorical, Spearman’s correlation coefficient was used.

Those values that were significant at .05 or better are shown in bold, indicating that those pairs of variables would not be good candidates within the same regression.

Figure 7.0-2. Comparison of Elevated Cycle Counts Resulting from Undersized Orifice on MLP-2 with Cycle Counts for the Remaining Data Records
A stepwise linear regression was performed using all of the data records except STS-114 tanking test 2 (where data values were missing for three predictors). The results using \( p \)-values to determine the significance levels of the variable entering are shown in Table 7.0-3. The results using \( F \)-ratio values to determine the significance levels of the variable entering is shown in Table 7.0-4. The results are clearly very similar, with Diffuser, UllagePres, MLP=2 all significant predictors in both cases. In the first regression, CycleTime also is significant; in the second regression, PeakPres replaces CycleTime (in the final step) and Temp is also significant.

- **Diffuser** variable dominates the regression. In essence, diffuser is an indicator for the known anomalies on the STS-114 tanking tests included in the data.
- Similarly, MLP=2 is an indicator for the known anomalies caused by an undersized upstream orifice.

In other words, the regression flags the anomalies, as it should.

- **PeakPres** and **CycleTime** are known to be highly correlated and one or the other (but not both) will be included, if the associated data indicate significance, as these do.
- **Temp** is included in the second regression and not the first, but is an order of magnitude less significant than any of the other included predictors.

These results confirm that Clark and Krenn have included the appropriate, and only the most appropriate, predictors in their regression.
Table 7.0-3. Stepwise Regression on all Data using P-Value to Determine Significance of Entering Variables

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<td>10.73676745</td>
<td>5.096139221</td>
<td>2.1068</td>
<td>0.0473</td>
<td>0.138765773</td>
<td>21.33476913</td>
</tr>
<tr>
<td>Diffuser</td>
<td>3.999890394</td>
<td>0.532004437</td>
<td>7.5185</td>
<td>&lt; 0.0001</td>
<td>2.8935266</td>
<td>5.106254187</td>
</tr>
<tr>
<td>CycleTime</td>
<td>-26.5983152</td>
<td>7.861564618</td>
<td>-3.3833</td>
<td>0.0028</td>
<td>-42.9473338</td>
<td>-10.2492966</td>
</tr>
<tr>
<td>UllagePres</td>
<td>0.265240602</td>
<td>0.061726836</td>
<td>4.2970</td>
<td>0.0003</td>
<td>0.136872618</td>
<td>0.393608586</td>
</tr>
<tr>
<td>MLP = 2</td>
<td>1.077573737</td>
<td>0.347955906</td>
<td>3.0969</td>
<td>0.0055</td>
<td>0.353959817</td>
<td>1.801187657</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step Information</th>
<th>Multiple R</th>
<th>R-Square</th>
<th>Adjusted R-Square</th>
<th>StErr of Estimate</th>
<th>Enter or Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuser</td>
<td>0.7108</td>
<td>0.5052</td>
<td>0.4846</td>
<td>1.189133891</td>
<td>Enter</td>
</tr>
<tr>
<td>CycleTime</td>
<td>0.8458</td>
<td>0.7154</td>
<td>0.6906</td>
<td>0.921254182</td>
<td>Enter</td>
</tr>
<tr>
<td>UllagePres</td>
<td>0.8939</td>
<td>0.7990</td>
<td>0.7716</td>
<td>0.791489885</td>
<td>Enter</td>
</tr>
<tr>
<td>MLP = 2</td>
<td>0.9285</td>
<td>0.8620</td>
<td>0.8358</td>
<td>0.671216686</td>
<td>Enter</td>
</tr>
</tbody>
</table>
Table 7.0- 4. Stepwise Regression on all Data using \( F \)-ratio Values to Determine Significance of Entering Variables

<table>
<thead>
<tr>
<th>Summary</th>
<th>Multiple R</th>
<th>R-Square</th>
<th>Adjusted R-Square</th>
<th>StErr of Estimate</th>
<th>Durbin Watson</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.9367</td>
<td>0.8774</td>
<td>0.8467</td>
<td>0.648478308</td>
<td>2.2195</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ANOVA Table</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F-Ratio</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explained</td>
<td>5</td>
<td>61.44086087</td>
<td>12.28817217</td>
<td>34.4074</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Unexplained</td>
<td>20</td>
<td>7.142754517</td>
<td>0.357137726</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regression Table</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>t-Value</th>
<th>p-Value</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6.847746674</td>
<td>3.728120462</td>
<td>1.8368</td>
<td>0.0812</td>
<td>-0.928976336</td>
<td>14.62446968</td>
</tr>
<tr>
<td>Diffuser</td>
<td>3.817194075</td>
<td>0.477827428</td>
<td>7.9886</td>
<td>&lt; 0.0001</td>
<td>2.820463526</td>
<td>4.813924625</td>
</tr>
<tr>
<td>UllagePres</td>
<td>0.298677801</td>
<td>0.05454566</td>
<td>5.4757</td>
<td>&lt; 0.0001</td>
<td>0.184897548</td>
<td>0.412458053</td>
</tr>
<tr>
<td>MLP = 2</td>
<td>0.93811152</td>
<td>0.322786866</td>
<td>2.9063</td>
<td>0.0087</td>
<td>0.264789916</td>
<td>1.611433125</td>
</tr>
<tr>
<td>Temp</td>
<td>0.021727083</td>
<td>0.010771308</td>
<td>2.0171</td>
<td>0.0573</td>
<td>-0.00074147</td>
<td>0.044195638</td>
</tr>
<tr>
<td>PeakPres</td>
<td>-0.01552637</td>
<td>0.003583316</td>
<td>-4.3330</td>
<td>0.0003</td>
<td>-0.02300103</td>
<td>-0.00805170</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step Information</th>
<th>Multiple R</th>
<th>R-Square</th>
<th>Adjusted R-Square</th>
<th>StErr of Estimate</th>
<th>Enter or Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuser</td>
<td>0.7108</td>
<td>0.5052</td>
<td>0.4846</td>
<td>1.189133891</td>
<td>Enter</td>
</tr>
<tr>
<td>CycleTime</td>
<td>0.8458</td>
<td>0.7154</td>
<td>0.6906</td>
<td>0.921254182</td>
<td>Enter</td>
</tr>
<tr>
<td>UllagePres</td>
<td>0.8939</td>
<td>0.7990</td>
<td>0.7716</td>
<td>0.791489885</td>
<td>Enter</td>
</tr>
<tr>
<td>MLP = 2</td>
<td>0.9285</td>
<td>0.8620</td>
<td>0.8358</td>
<td>0.671216686</td>
<td>Enter</td>
</tr>
<tr>
<td>Temp</td>
<td>0.9367</td>
<td>0.8774</td>
<td>0.8467</td>
<td>0.648478308</td>
<td>Enter</td>
</tr>
<tr>
<td>PeakPres</td>
<td>0.9473</td>
<td>0.8974</td>
<td>0.8650</td>
<td>0.608639466</td>
<td>Enter</td>
</tr>
<tr>
<td>CycleTime</td>
<td>0.9465</td>
<td>0.8959</td>
<td>0.8698</td>
<td>0.597610012</td>
<td>Exit</td>
</tr>
</tbody>
</table>

The scatterplot of the fit versus the actual cycle count output in Figure 7.0-3 confirms that the residuals appear to be random and that the linear model correctly captures the relationships in the data.
Next, *CycleTime*, *MLP-2*, and *Orbiter* variables were eliminated from the data set to be consistent with the data employed by Clark and Krenn in *Prepress Regression Analysis*, which also restored the record for STS-114 tanking data omitted from the previous regression.

Stepwise regression was applied to the resulting data set. The results agree exactly with the two-variable “regression #1” reported by Clark and Krenn, as shown in Table 7.0-5.
The regression was repeated with the same data scaled from 0 to 1. The scaled value of any variable \( x_i \) is \( z_i = (x_i - x_{i\text{min}})/(x_{i\text{max}} - x_{i\text{min}}) \). The regression statistics shown in Table 7.0-6 are the same (as these must be) as before, but the scaling makes the regression coefficients easier to interpret — the coefficients are now proportional to the significance of the corresponding variables in the regression.
Table 7.0-6. Stepwise Regression Corresponding to Clark and Krenn using Scaled Values

<table>
<thead>
<tr>
<th>Summary</th>
<th>Multiple R</th>
<th>R-Square</th>
<th>Adjusted R-Square</th>
<th>StErr of Durbin</th>
<th>Estimate</th>
<th>Watson</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.9297</td>
<td>0.8643</td>
<td>0.8466</td>
<td>0.10186907</td>
<td>2.1341</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ANOVA Table</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F-Ratio</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explained</td>
<td>3</td>
<td>1.519720543</td>
<td>0.506573514</td>
<td>48.8155</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Unexplained</td>
<td>23</td>
<td>0.23867807</td>
<td>0.010377307</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regression Table</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>t-Value</th>
<th>p-Value</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.465006748</td>
<td>0.042789934</td>
<td>10.8672</td>
<td>&lt; 0.0001</td>
<td>0.376489024</td>
<td>0.553524471</td>
</tr>
<tr>
<td>Scaled Diffuser</td>
<td>0.539683551</td>
<td>0.068758007</td>
<td>7.8490</td>
<td>&lt; 0.0001</td>
<td>0.397446778</td>
<td>0.681920325</td>
</tr>
<tr>
<td>Scaled PeakPress</td>
<td>-0.39715663</td>
<td>0.07024602</td>
<td>-5.6538</td>
<td>&lt; 0.0001</td>
<td>-0.542471598</td>
<td>-0.25184167</td>
</tr>
<tr>
<td>Scaled Ullage</td>
<td>0.193194206</td>
<td>0.047348862</td>
<td>4.0802</td>
<td>0.0005</td>
<td>0.095245623</td>
<td>0.291142789</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step Information</th>
<th>Multiple R</th>
<th>R-Square</th>
<th>Adjusted R-Square</th>
<th>StErr of Estimate</th>
<th>Enter or Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaled Diffuser</td>
<td>0.7841</td>
<td>0.6147</td>
<td>0.5993</td>
<td>0.164613516</td>
<td>Enter</td>
</tr>
<tr>
<td>Scaled PeakPress</td>
<td>0.8752</td>
<td>0.7660</td>
<td>0.7465</td>
<td>0.130932916</td>
<td>Enter</td>
</tr>
</tbody>
</table>

The three-variable regression yields an adjusted R$^2$ of .8466. However, the regression again is dominated by the Diffuser variable, which alone explains about 61.47 percent of the variation.

The scatterplot of the fit versus the actual cycle count output shown in Figure 7.0-4 confirms that the residuals appear to be random and that the linear model correctly captures the relationships in the data.
Figure 7.0-4. Scatterplot of the Fit Versus Scaled Actual Cycle Count for the Regression on all Variables

Scaling the data also permits box plots for all of the variables and variable interactions in the regression on the same scale, as shown in Figure 7.0-5. The data anomalies previously described are clearly reflected in the outliers in these plots.
Box Plot Comparison

Figure 7.0-5. Comparison of Scaled Output and Predictor Variables for the Clark and Kreen Comparison

Scatterplots of the output versus each of the three predictor variables included are shown in Appendix B.

It should be noted that examining the residuals (the differences between the observed and predicted output at each data point) for randomness is important in any regression analysis. A pattern in the residuals indicates that the underlying relationship is nonlinear and that superior regression can be achieved by a suitable transformation of the data. In all of the regressions developed in this review, examination of the residuals confirmed the apparent linearity of the relationship modeled.

Regression #1, developed by Clark and Krenn, is based on three independent (predictor) variables which can be measured well prior to launch. However, the data set used to develop this regression includes data that is no longer representative of the tanking operations that should occur in the future. Primarily, the diffuser variable dominates the regression and the out-of-specification material problem with the diffusers in the STS-114 tanking tests has been resolved. All diffuser material will be single twill in the future. In addition, the MLP-2 restriction problem upstream of the panel has been fixed and MLP-2 cycles should be within the realm of the other MLPs in the future. Since the data on which this regression was based are not homogenous,
replacing variables (Diffuser & UllagePress) with values that have now become standard is not statistically acceptable.

Therefore, an additional stepwise linear regression was performed excluding the data points where the Double Dutch Twill Diffuser was used (STS 114 tanking tests) and where MLP was equal to 2. The results of this regression are shown in Table 7.0-7.

**Table 7.0-7. Stepwise Regression Based on Subset of Data that is Relevant to Current and Future Conditions**

<table>
<thead>
<tr>
<th>Summary</th>
<th>Multiple R-Square</th>
<th>Adjusted R-Square</th>
<th>StdErr of Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0.8419</td>
<td>0.7088</td>
<td>0.6640</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ANOVA Table</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>F-Ratio</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explained</td>
<td>2</td>
<td>13.58341936</td>
<td>6.791709681</td>
<td>15.8193</td>
<td>0.0003</td>
</tr>
<tr>
<td>Unexplained</td>
<td>13</td>
<td>5.581280638</td>
<td>0.42932928</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regression Table</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>t-Value</th>
<th>p-Value</th>
<th>Confidence Interval 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>11.76671334</td>
<td>6.039583426</td>
<td>1.9483</td>
<td>0.0733</td>
<td>-1.281013396 to 24.81444007</td>
</tr>
<tr>
<td>UllagePres</td>
<td>0.275004813</td>
<td>0.067714984</td>
<td>4.0612</td>
<td>0.0013</td>
<td>0.128715484 to 0.421294141</td>
</tr>
<tr>
<td>CycleTime</td>
<td>-29.4660737</td>
<td>9.404504049</td>
<td>-3.1332</td>
<td>0.0079</td>
<td>-49.78326915 to -9.148877596</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step Information</th>
<th>Multiple R-Square</th>
<th>Adjusted R-Square</th>
<th>StdErr of Estimate</th>
<th>Enter or Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>UllagePres</td>
<td>0.6992</td>
<td>0.4889</td>
<td>0.4523</td>
</tr>
<tr>
<td></td>
<td>CycleTime</td>
<td>0.8419</td>
<td>0.7088</td>
<td>0.6640</td>
</tr>
</tbody>
</table>

While this regression equates to an $R^2$ of 0.664, the somewhat lower significance than the proposed three-variable regression is balanced by the logic of using data points that are representative of the future configuration.
8.0 Findings, Root Causes, Observations and Recommendations

8.1 Findings

F-1. Using the same assumptions, regression results obtained during this review confirmed that the SSP regressions have included appropriate, and only the most appropriate, predictors in their regression.

F-2. A linear model is the correct choice for this regression and correctly captures the relationships in the data.

F-3. Use of the full data set provided is not justified since several of the independent variables reflected out-of-specification materials and components, which will not be repeated in the future. The reduced data set of 16 data points is adequate for regression with less than four independent variables.

8.2 Recommendations

R-1. Linear regression is an appropriate tool to validate the NASA-accredited analytical (first principles) model, currently under development, against empirical data available since the transition to half-second valve pulses. (F-1 and F-2)

R-2. Regression should be based on the reduced data set, excluding STS-114 tanking tests where the incorrect diffuser material was used and MLP-2 restricted flow was created from out-of-specification conditions, since these situations have been corrected. (F-3)

9.0 Lessons Learned

There were no lessons learned during this consultation.

10.0 Definition of Terms

Corrective Actions Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem.
Finding

A conclusion based on facts established during the assessment/inspection by the investigating authority.

Lessons Learned

Knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or limits the potential for failures and mishaps, or reinforces a positive result.

Observation

A factor, event, or circumstance identified during the assessment/inspection that did not contribute to the problem, but if left uncorrected has the potential to cause a mishap, injury, or increase the severity should a mishap occur.

Problem

The subject of the technical assessment/inspection.

11.0 Minority Report (Dissenting Opinions)

There were no dissenting opinions during this consultation.

Volume II: Appendices

A NESC ITA/I Request Form (NESC-PR-003-FM-01)
B Key for Interpreting Box Plots and Scatterplots
C List of Acronyms
Appendix A. NESC ITA/I Request Form (NESC-PR-003-FM-01)
**Title:** External Tank Liquid Hydrogen (LH₂) Prepress Regression Analysis Independent Review Technical Consultation Report

---

**NASA Engineering and Safety Center Request Form**

Submit this IT/IA Request, with associated artifacts attached, to [nrbexecsec@nasa.gov](mailto:nrbexecsec@nasa.gov) or to NRB Executive Secretary, M/S 105, NASA Langley Research Center, Hampton, VA 23681

**Section 1: NESC Review Board (NRB) Executive Secretary Record of Receipt**

- **Received (mm/dd/yyyy hh:mm am/pm):** 9/20/2005 12:00 AM
- **Status:** New
- **Reference #:** 05-171-E

- **Initiator Name:** Billy Stover
- **E-mail:** Billy.R.Stover@nasa.gov
- **Center:** KSC
- **Phone:** (321)-861-8554, Ext.
- **Mail Stop:**

**Short Title:** Data expertise for independent verification for FT LH2 Prepress LCC Issues
Description: Ralph --

The guys here are requesting our help in reviewing and validating a
>regression analysis tool developed to predict ET prepress cycles. This
>relates to the LCC and the problems we had during SSTS-14 with the
>unexpected cycle count.
>
> We don’t need to have the work completed until mid-November or so, but we
>do need to be able to tell them whether or not we can assist before they
>go to the NICB on October 18. Since we don’t have another NRB scheduled
>before then, I’m requesting out-of-board approval for this project as a
>consultation. Primary need will be for statistical expertise. If you
>could assist, I’ll ask Dawn and Vickie to identify the experts and put a
>plan of some kind together for presentation at an upcoming NRB.
>
>Tim

---
>
>From: Brown, Dilly R
>sent: Friday, October 07, 2005 11:59 AM
>to: Wilson, Timmy R.
subject: FW: Data Expertise Needed For ET LH2 Prepress LCC
>
>Hi Tim,

Here is the information and stuff that we would appreciate an independent
verification on. Thanks,

Dilly

From: Stoes, Diane S
sent: Thursday, October 06, 2005 3:33 PM
>
>to: Storer, Dilly R
>subject: FW: Data Expertise Needed For ET LH2 Prepress LCC
>Dilly,
>
>This is the original email I sent to Lisa with additional data. Diane J

From: Stoes, Diane S
sent: Tuesday, October 04, 2005 4:20 PM

to: Huddleston, Lisa L
>subject: RE: Data Expertise Needed For ET LH2 Prepress LCC

Lisa,

Here are some files to get you started. This includes data matrices,
>regression analysis and charts that explain how this is done...
>
>counts prepress cycles for LCC ET-04. Let me know what else you need. Thanks!
>
>---
>
>---
>
>From: Huddleston, Lisa L
>sent: Monday, October 03, 2005 4:16 PM
>to: Stoes, Diane S
>subject: RE: Data Expertise Needed For ET LH2 Prepress LCC
>
>Hi Diane,

NESC Request No.: 05-171-E
Title: External Tank Liquid Hydrogen (LH₂) Prepress Regression Analysis Independent Review Technical Consultation Report

Section 2: Systems Engineering Office Screening

Section 2.1 Potential ITA/I Identification

Received by SEO: (mm/dd/yyyy h:mm am/pm): 10/7/2005 12:00 AM
Potential ITA/I candidate? ☑ Yes ☐ No
Assigned Initial Evaluator (IE):
Date assigned (mm/dd/yyyy):
Due date for ITA/I Screening (mm/dd/yyyy):

Section 2.2 Non-ITA/I Action

Requires additional NESC action (non-ITA/I)? ☑ Yes ☐ No
If yes:
Description of action: Data Review for Independent Verification
Actionee: Tim Wilson to lead; approved Out-of-Board by Ralph Roe on 10/7/2005
Is follow-up required? ☐ Yes ☑ No If yes: Due Date:
Follow-up status/date: Provide plan and status
If no:
NESC Director Concurrence (signature):
Request closure date:

Section 3: Initial Evaluation

Received by IE: (mm/dd/yyyy h:mm am/pm):
Screening complete date:
Valid ITA/I candidate? ☑ Yes ☐ No
Initial Evaluation Report #: NESC-PN-
Target NRB Review Date:

Section 4: NRB Review and Disposition of NCE Response Report

ITA/I Approved: ☑ Yes ☐ No Date Approved:
Priority: - Select -
ITA/I Lead: , Phone ( ) - , x

Section 5: ITA/I Lead, Planning, Conduct, and Reporting

Plan Development Start Date:
ITA/I Plan #: NESC-PL-
Plan Approval Date:
ITA/I Start Date Planned: Actual:
ITA/I Completed Date:
ITA/I Final Report #: NESC-PN-
ITA/I Briefing Package #: NESC-PN-
Follow-up Required? ☑ Yes ☐ No

Section 6: Follow-up

Date Findings Briefed to Customer:
Follow-up Accepted? ☑ Yes ☐ No
Follow-up Completed Date:
Follow-up Report #: NESC-RP-
### Section 7: Disposition and Notification

<table>
<thead>
<tr>
<th>Notification type: - Select -</th>
<th>Details:</th>
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</thead>
<tbody>
<tr>
<td>Date of Notification:</td>
<td></td>
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Appendix B. Key for Interpreting Box Plots and Scatterplots

![Diagram of a box plot with annotations]

Whiskers extend to the furthest observations that are no more than 1.5 IQR from the edges of the box. Mild outliers are observations between 1.5 IQR and 3 IQR from the edges of the box. Extreme outliers are greater than 3 IQR from the edges of the box.

Figure B-1. Key for Interpreting Box Plots
Scatterplot of Scaled ActLCC vs Scaled Diffuser of Scaled data

B-2. Scatterplot for the Scaled Output and *Diffuser* Predictor

Scatterplot of Scaled ActLCC vs Scaled Ullage of Scaled data

B-3. Scatterplot for the Scaled Output and *UllagePres* Predictor
B-4. Scatterplot for the Scaled Output and PeakPress Predictor
Appendix C. List of Acronyms

ET       External Tank
GHe      Gaseous Helium
GN₂      Gaseous Nitrogen
LaRC     Langley Research Center
LCC      Launch Commit Criteria
LH₂      Liquid Hydrogen
MLP      Mobile Launch Pad
MTSO     Management Technical and Support Office
NASA     National Aeronautics and Space Administration
NESC     NASA Engineering and Safety Center
NRB      NESC Review Board
SEO      Systems Engineering Office
SSP      Space Shuttle Program
STS      Space Transportation System
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**External Tank Liquid Hydrogen (LH2) Prepress Regression Analysis**

**Independent Review Technical Consultation Report**

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**14. ABSTRACT**

The request to conduct an independent review of regression models, developed for determining the expected Launch Commit Criteria (LCC) External Tank (ET)-04 cycle count for the Space Shuttle ET tanking process, was submitted to the NASA Engineering and Safety Center NESC on September 20, 2005. The NESC team performed an independent review of regression models documented in Prepress Regression Analysis, Tom Clark and Angela Krenn, 10/27/05. This consultation consisted of a peer review by statistical experts of the proposed regression models provided in the Prepress Regression Analysis. This document is the consultation's final report.

**15. SUBJECT TERMS**

ET; LCC, NESC, SSP; STS

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