Guidelines for Interpreting the Results from a
Force Balance Finite Element Analysis

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Background:

Force balance stress analysis and acceptance criteria are under review due to the recent heightened awareness of LaRC wind tunnel operational safety. A force balance is an inherently critically stressed component due to the requirements of measurement sensitivity. In order to ensure measurement quality and to provide a safe testing environment, balances need to be analyzed and reviewed differently that most wind tunnel structural components. The analysis, review, and acceptance of a balance structural design needs to be based on a combination of engineering fundamentals and empirical knowledge of balance operational history.

LAPG 1710.15 (Wind Tunnel Model Systems Criteria) section 2.14 contains the only requirements for force balance stress analysis and documentation. This section does not require the use of finite element analysis (FEA), but FEA is typically used to due to the complex geometry. While FEA provides an excellent tool for the structural analyst, it is a representation of the physical structure and therefore requires interpretation. To date, the method of reporting the maximum stress from a FEA has been based on the standard practice used for wind tunnel model components. This standard practice quotes the peak stress found by the FEA software as the stress used for factor of safety calculation. This simplified practice is usually sufficient when adequate factors of safety are present, but in the case of a force balance, where factors of safety are low, it is not sufficient.

The standard peak stress approach does not consider the area or volume of the stress field. Based on FEA results to date, the area and volume of the peak stress is quite small and many times insignificant relative to the local geometric features of the structure. The determination of a relatively large area (RLA) is currently determined by the subjective opinion of a force balance engineer familiar with the balance manufacturing processes and proficient in the use of FEA software.

Application:

These guidelines are to be used on high-fidelity models of force balances that have been analyzed in Pro/MECHANICA or equivalent p-element technology finite element structural analysis software. Convergence of the model in the regions of interest must be well documented. Incomplete convergence of the model should be quantified by the comparison of results from a simplified model, possibly with a subset of loads, that has reached full convergence to the incomplete converged model.

Method:

Below is a step by step approach to perform the analysis and report the results of a force balance finite element analysis.

1) Perform a complete finite element analysis of the force balance. Verify the stress levels produced by the FEA with hand calculations in areas where a closed form analytical solution is well defined. Comparison within 10% of the local stress magnitude is considered acceptable.

2) Identify and interrogate areas of high stress, usually located in fillets and other areas of geometric transition, which create stress concentrations. Ensure that the solid model geometry is accurate compared to the actual force balance construction. The goal is to have the highest fidelity representation of these areas as possible without creating an excessive number of solid model features. For example, the intersection of two radii at the corner of a flexure will meet in a sharp mitered corner. It is unlikely that the actual force balance will contain this sharp corner, but adding an additional radius in this area is not typically justified due to the small effect on the stress concentration. On the other hand, the exclusion of the radii at the transition of a flexure is not an acceptable simplification due to the large effect it would have on the stress concentration.

3) Perform an iterative review of the stress intensity at each high-stress location. This is performed by using a results display of the FEA solution which represents the von-Mises stress intensity as a color spectrum. This color spectrum is typically described by a legend on the results plot. The maximum stress intensity is usually represented by the color red. The areas on the force balance structure colored in red exceed the stress value in the legend associated with red. This stress value should be iteratively reduced until a relatively large area (RLA) has been identified. The size of this RLA is based on the following criteria.

> a) The number of elements that the stress level crosses. There should be two or more elements that are covered by a portion of the stress level.
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> b) The size of the structural feature. The most common feature for stress concentrations to occur is a radius. The RLA should be on the same order of magnitude as the dimension of the radius. Other features may include flexure width or thickness. In the case of thin flexures the depth below the surface of the RLA should be considered at should not exceed 25% of the flexure cross section.
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> c) The flaw size that cannot be detected by the level of ultrasonic inspection (UT) used on the balance. Force balances typically undergo Class AAA UT according to NASA TM-84625. In general, a flaw size smaller that 1/64” diameter is not detectable, therefore the RLA must be at least this large.

4) After the RLA for a particular high-stress location has been determined, then the resultant value in the legend, which is associated with the RLA, is reported as the

maximum stress. This value is used for the subsequent calculation of the factor of safety at this particular area.

Summary:

These guidelines are intended to provide a more objective method to determine the size of the RLA and thereby the associated maximum stress. It should be noted that these guidelines are not intended to be a substitute for experienced engineering judgement, but rather are used in conjunction with the expertise of the structural analyst performing the analysis. These guidelines will serve as an interim document to be able to continue the operation of force balances, while additional experience gained and developmental research of force balance analysis is underway.