How VLM Integrates Into the Design Process

Goal ➡ **Conceptual Design** ➡ **Preliminary Design** ➡ **Final Design** ➡ **Testing** ➡ **Production**

Conceptual Design

The design process starts with conceptual design. This step is where the design goal is first broken down and evaluated in terms of design requirements such as weight, size, estimated operating temperatures, durability, and cost. These constraints are then evaluated and conceptual designs are formulated that MAY potentially meet the design requirements. The difficulty is that each of the design requirements interact with one another and produces a very complex problem requiring detailed information that is just not available at this point in the design process. As an example, consider a circuit board with a chip that generates significant heat. The durability of the circuit board is directly influenced by the thermal gradients generated during operation and the thermal cycles generated by powering the chip on/off. Now the stress and strain can be evaluated accurately with a finite element analysis and the durability can be accurately assessed with VLM. However, in the conceptual design phase FEA is not normally used since there are several potential designs being considered and the boundary conditions, a requirement for accurate FEA, are not known. However, a sensitivity study based on simple hand calculations and VLM can quickly provide relative merit between competing design configurations and provide a good understanding of the design limitations for use in the preliminary design phase. This capability is fundamental to minimize/eliminate false starts in the design process and the associated cost and schedule impact.

Preliminary Design

The Preliminary design usually starts with 2 or 3 design configurations that looked to be most promising in the conceptual design phase. The intent of this phase is to select the optimum configuration for further development. In this phase, material selections are finalized, preliminary thermals are developed, 2-D FEA is performed and durability evaluated. The design configurations and their merits are evaluated relative to the design goals and a configuration is selected for further development. However, the design interactions and the preliminary nature of the analysis is still a major problem. Consider a turbocharger wheel which experiences significant thermal gradients during operation. The preliminary design thermals are normally steady state values representing idle and max normal operating temperatures. The transient thermals are not yet available since they are a function of the rotor dimensions, speed, and transient gas flow which have not yet been determined. The transient conditions can easily lead to thermally induced stress of 20% to 30% of the total mechanical stress which can produce a 100% to 300% change in durability. So once again a sensitivity study combined with a design of experiments can be performed with the VLM analysis to evaluate the relative merits of the design configurations and their ability to meet or exceed the design goals and minimize risk.

Final Design

The final design is normally where a detailed analysis is performed to insure that the design configuration will meet the design intent. Detailed thermals (both steady state and transient), performance, speed, stress, weight and duty cycles are available. The major problem remaining is that the traditional approach still considers the material to homogeneous as was assumed in the previous design phases. In reality, the material is a collection of individual single crystals whose processing can produce orders of magnitude variation in durability. The VLM process is uniquely capable of evaluation the durability impact of these variations. The influence of grain size, grain orientation, surface treatments, and surface finish, to list a few, are all durability drivers that can be assessed with VLM as a direct analysis, sensitivity study or design of experiments.

Testing

Testing usually consists of three types; a) bench testing of material specimens, b) rig testing of components or subcomponents, c) full scale testing. There are advantages and disadvantages of each. Bench testing or specimen testing is the least expensive and has the smallest schedule impact. However, it can provide a false sense of security. It is normally done on a small scale, simple geometry, at constant temperature and with simple load states. Each of these test limitations can produce results that are significantly different than those observed in actual component operation. An advantage of the VLM methodology is that it can incorporate existing test data and project the impact of operational conditions and geometry on the component of interest. The rig test can eliminate several of the specimen test limitations. It is normally performed on the actual component thus eliminating size effects, and is usually fabricated similar to the production part will be thus having the same fabrication process, surface finish, and residual stress states. Usually it can match some, but not all of the operational conditions in terms of speed, temperature, static and dynamic loading and mission profiles. The main disadvantage is the cost and schedule impact to develop the rig test stand and perform the test sequence. It is not uncommon for the rig test to cost several hundred thousand dollars and take several months to complete. Since the rig test is a substantial undertaking, it is quite common for the VLM approach to evaluate the potential test series and prioritize the test conditions and protocols to maximize the test information and minimize the test schedule and cost. The final test method is full scale component or system level testing. This is without a doubt the best technical approach eliminating all the areas of concern with the prior test methods. It is however, the most expensive and time consuming approach possible. A limited number of components can be tested; sometimes only one; so statistical evaluations cannot be performed. Often times no full scale testing can be performed due to limited assets available for test or the prohibitive cost and schedule impacts that such testing would demand. In these situations, computational simulation, such as VLM, is the only option.

Production

In Production there are several areas of potential concern, first is dimensional tolerances and critical dimensions. Dimensional tolerances are usually specified as a nominal dimension plus or minus a specific amount. While this quite adequate for a single dimension it is not necessarily acceptable for tolerance stack up of several dimensions. In addition, it is rare that actual component dimension is normally distributed about the nominal. For example a turning operation is usually stopped once the dimension is inside the maximum allowable. Therefore the dimension meets the print requirement but the nominal dimension may vary considerable from the print nominal. Since the component is most commonly designed to nominal dimensions, the actual product may have significant stress differences. The critical dimensions are those dimensions that if outside the specified tolerances will produce unacceptable stress states. Again, since nominal dimensions are most commonly used in the design, these locations can be very difficult to identify. The second common area of concern is disposition of deviated parts. Quite often in machining, a component is made “out of print” or the material is found to be “out of spec”. Again, since components are evaluated to nominal dimensions and generally to minimum material specs, a deviated part may be scraped since the cost and schedule to evaluate the component is prohibitive. However, far too often this occurs on a number of components in the production line and the cost and schedule impact to scrap all of the components is too great. In this case an analysis of the specific component geometry (FEA) is required and a test series must be performed to assess the durability of the parts. This may take several months and cost many thousands of dollars only to find that the parts are not acceptable. VLM offers the ability to quickly evaluate the impact on durability through the sensitivity studies and disposition the parts in a timely manner.

Why Use VLM?

Simulating part geometry and stresses can be done with widely available tools such as CAD and FEA. No tools are available for simulating the true material strength. Subtleties in casting, forging and heat treatments will vary the material microstructure properties widely. Therefore creating simulations with sufficient fidelity is difficult, if not impossible, without an expensive and expansive large reliability test program. VLM changes this by allowing us to simulate the material as well as the geometry and stresses.

VEXTEC recognizes that for prediction of reliability to be complete and useful, the potential risk and mitigation of unavailable original equipment manufacturer (OEM) data must be resolved. Majority of VEXTEC's clients are not OEMs. They have little data. They simply have parts failing. To service our clients, we have in-house engineering expertise including design and analysis experience, CAD, FEA, testing, metallography and fractography to get the data our clients do not have.

The objective of VLM is to combine physics based models specific to any material or alloy with the knowledge of scatter that exists in material properties and develop an efficient simulation scheme to predict the fatigue and corrosion behavior.