
# Modern Modal Testing: A Cautionary Tale
# IMAC XXVII

James Akers & Kim Otten (NASA Glenn Research Center)
Joel Sills (NASA Johnson Space Center)
Curtis Larsen (Texas Christian University)

# Introduction

- Past 50 years have seen great advances in modal analysis and testing capabilities in Aerospace.
- However, young engineers entering this field are facing unique challenges.
  - Powerful automated software tools and computers.
  - Programmatic budgetary pressures.
  - Bimodal workforce.
- Goal is to point out 12 common pitfalls young engineers should avoid.

# Pitfall #1: Confusing Computer Jockeys and Engineers


- Engineers need to understand the key fundamental physics based concepts that underpin their analysis and testing.
  - Powerful software and hardware tools should not be used as “crutches” to make up for lack of understanding.
  - “Back of the envelope calculations” are a vital sanity check.
  - “Keep It Simple and Straightforward”.
    - Start analysis/testing simple and only add complexity as needed.
    - Don’t confuse complexity for sophistication.

# Pitfall #2: Too Much Blind Faith in Finite Element Models


- "All Models Are Wrong, But Some Are Useful."
- Modern powerful analysis tools allow novice engineers to generate FEM's that look exactly like the CAD.
  - A finely meshed FEM does not guarantee a valid FEM, just that the same approximations (which may be incorrect) have been made many many many times.
  - Unfortunately, there is a trend that decision makers erroneously believe that valid FEM's can be generated by inexperienced engineers.
- FEM validity is highly dependent upon the engineer's proficiency and experience.
  - Selecting appropriate FEM element types, modeling of joints and boundary conditions.
- FEM validity is uncertain until "grounded" to test results.

# Pitfall #3: Confusing Being Busy With Being Productive


- Everyone naturally wants to feel they are making progress to their end goal (which may not be well defined).
  - Common misconception is that being “busy” is productive.
- Take the necessary time to plan and prioritize.
  - Define the objectives, goals, and success criteria of the task.
  - What are the receivables and when will they be provided?
  - What are the deliverables and when are they due and to whom?
  - If possible, develop the schedule delivery dates relative to receivables.
  - Be sure to include some margin in the schedule.
  - Be wary of “Success Oriented Schedules”.

# Pitfall #4: Rushing To Analyze


- Perform “sanity checks” on any models or data prior to starting analysis.
  - Skipping these checks results in the very real risk that all of the analysis will be for naught resulting in not meeting schedule and the need to repeat the work.
- Be skeptical of any FEM.
  - Perform standard model checks.
  - *FEM needs to match the CAD or as-built hardware.*
- Be skeptical of data.
  - Perform time-domain and frequency-domain data quality checks.
- Perform intermediate checks throughout the analysis.
  - These intermediate and final checks verify the validity of the analysis.

# Pitfall #5: Rushing To Test

- Setting up and running a modal test is both exhilarating and stressful.
  - Physical exertion of mounting shakers and instrumentation.
  - Being in an unfamiliar locale.
  - Having upper management and programmatic personnel looking over your shoulder (i.e., fish bowl).
  - Naturally want to start collecting test data and extracting modal test parameters ASAP.
- Be sure to verify the test setup and validity of the test data being collected before starting the data collection and modal parameter extraction.
  - Acquire ambient backgrounds at least at the beginning of each day and when the test configuration is changed.
  - Perform standard time and frequency-domain data quality checks.
  - Animation of move response shapes at frequencies below the 1$^{st}$ resonance.
  - Important to perform pretest and post test low level characterization test runs to verify the structural health of the test article.

# Pitfall #6: Lack Of Documentation


- Analysts and test engineers need keep a running log of their work.
  - Analysts: Running summary memo calling out models used, findings/results, lessons learned, and file locations.
  - Test Engineers: Test log with data acquisition and post processing parameters, channel table, test run log, findings/results, lessons learned, and file locations.
- Start drafting the test report and presentation during the test so that key results, lessons learned, and key insights are accurately captured.
  - Generously photo document and start putting these pictures into the draft test report and presentation.
- These summary memos and test logs become the engineers personal “technical encyclopedia”.

# Pitfall #7: Designing Only For Design Loads


- Hardware needs to be designed for testing.
  - Test environments exceed design loads.
    - Random Vibration qualification testing environment envelopes the Maximum Expected Flight Level (MEFL) + 3 dB and the Minimum Workmanship Level (MML).
    - Don't forget to account for the upper test tolerances (i.e., upper test tolerance spectrum and maximum overall $g_{rms}$.
- Hardware needs to be designed so that it can be mounted and instrumented for testing.
- Concurrent with hardware design, test fixture needs to be designed.
  - Test fixture should not introduce any undesirable dynamics.

# Pitfall #8: Modal Analysis Not Accounting For Out-of-Band Dynamics


- Need to account for the contributions of modes below and above the frequency band of interest in both analysis and modal pretest analysis.
  - Modes below contribute a mass effect (i.e. add weight).
  - Modes above contribute a stiffness effect (i.e., add compliance).
    - Can be accounted for by using a mode acceleration or residual vector approach.

- If not accounted for, the modal analysis may show structure is significantly lighter and or stiffer than it actually is.
  - Modal pretest analysis may erroneously show shakers able to adequately excite the hardware. *This shaker shortfall may not be recoverable during modal testing.* ☹

# Pitfall #9: Asking For Help Or Seeking Advice/ Guidance Is A Sign Of Weakness


- No one knows everything!
  - You don't know what you don't know.
- Asking colleagues to look over your work and asking for advice should be an expected and welcomed behavior.
  - Senior engineers want to share their experience, knowledge, and insights.
- Unfortunately, due to current and foreseeable budgetary pressures, apprenticing of young engineers is being severely reduced or eliminated.
  - Burden then falls on the young engineers to actively seek out advisors.
- Apprenticeship of young engineers needs to become the norm again.

# Pitfall #10: Stove Piping: Separating Analysts and Test Engineers


- Common practice leading to unnecessary tension and disconnects between analysis and test groups.
  - Diminishes an organizations technical capability.
  - Adds risk to programs.
- Cross fertilization of the analysts and test engineers benefits both and is key to their development.
- Related to the common practice of organizationally "stove piping" individuals from different disciplines.
  - Interdisciplinary "Tiger Teams" are vital to developing a "good initial design".
    - Poor initial designs combined with limited component testing lead to design modifications late in the program that add cost and schedule risk.

# Pitfall #11: Test Is A Four Letter Word


- Tremendous pressure to reduce analysis and testing.
  - Budgetary pressures.
  - Decision makers becoming less technically knowledgeable.
- A common misconception is that testing increases a program's cost.
  - Because testing has defined resource allocations, decision makers incorrectly believe that by their elimination that they are reducing the programs cost.
    - What is not tracked is the additional analysis and meetings held to try and make up for this testing shortfall.
    - However, testing provides insight into the hardware not available from unverified/unvalidated FEM's.
    - FEM incurs additional residual risk that may not be well understood and therefore higher, but possibly not conservative, uncertainty factors must be retained.
  - Real cost culprits are poor initial designs and unrealistic schedules.

# Pitfall #12: Unrealistic Success Criteria

- Defining the success criteria and getting agreement from all stakeholders, at the very beginning of a task, is important.
  - Test engineers may be the “technical requirements translator” for the Customer.
  - Needed to define task scope, schedule, and deliverables.
  - Task creep is inevitable.,
    - Be sure to include some schedule margin.
    - Be ready to renegotiate it if task creep becomes too much.
- Successful modal testing is highly dependent upon the selection of the target modes.
  - Target modes are only those modes that are *absolutely needed* for correlation of the FEM.
  - Recommend success criteria not be tied to FEM correlation.

# Conclusions

- Advancements both in analytical and experimental modal analysis in the aerospace field are amazing.
- Exciting time for young engineers entering this field.
  - Their infusion will bring much needed energy, enthusiasm, and drive.
- However, young engineers need to be cognizant of the current engineering climate and realize they don't know what they don't know.
  - 12 pitfalls to avoid have been presented.
  - Need to take an active role in seeking out mentoring and apprenticing from senior engineers.
  - Retirement eligibility of the aging component of the bimodal workforce lends urgency to this knowledge transfer.


# End