Notes on Ryan Vogel's thesis [Structural-Acoustic analysis & Optimization of EEWS]

Saturday, January 2, 2016 4:15 PM

Introduction section notes:

- In classic aircraft design methodologies acoustic loading has received little to no consideration due to its relatively small contribution to the total fatigue life impact when compared to other structural and thermal loads. Additionally, quantification of dynamic acoustic loading has been difficult to predict.
- This approach might have been sufficient in the past aircraft design but falls short when complex aircraft structures of today are designed. This is particularly true for generation 5 airframes where it is typical to encounter embedded engine design with complex exhaust passages, which are required to reduce visibility signatures of the subject aircraft.
- Because structural response is dependent on the combined loading environment that requires consideration from all disciplines. The high cycle fatigue environment created by the vibro-acoustic loading can be significant in nature when combined with other loading conditions. This can and will result in severely degraded fatigue performance of the airframe leading to premature cracking and failure. Because inclusion of more physics at the initial design stage is crucial to the Air Force directives, it is imperative to also include acoustic effects in order to reduce costly repairs and redesigns that may arise.
- During aircraft operation, random vibrations generated by the embedded propulsion systems are transmitted throughout the aircraft skin and frame. Exhaust washed structures are especially sensitive to acoustic loading because exhaust gases are in direct contact with the exhaust structure and transmit acoustic loads generated by the engines. Similar effect can be experienced by the outer skin of the fuselage at hypersonic speeds due to turbulent airflow and wake vortices.
- Addition of acoustic loading on certain aircraft structures at critical excitation frequencies can deleteriously affect the high cycle fatigue limit. Typically, this effect is most prominent on highly loaded aircraft component via structural, aerodynamic and thermal loading.
- Substructures that surround the aircraft power-plants and exhaust nozzles can experience increased levels of acoustic excitations. Past research initiatives studied premature fatigue failures of the aft deck found on the Northcorp B-2 Sprit Stealth Bomber. Previous study attributed the premature failures to intense thermal stresses and random acoustic loading. (See reference #1)
- In the past it was acceptable to only include limited disciplined in the initial aircraft design in order to produce timely and cost effective designs. This methodology is not viable in todays high performance stealth aircraft and multidisciplinary analysis is essential in order to obtain feasible aircraft design. This is particularly important for Efficient Supersonic Air Vehicles (ESAV) concepts where technological challenges are vastly more critical for cost effective and timely design.
- Challenge is to create structural designs based on finite element of boundary element analysis procedures that can account for acoustic pressures generated by high lift devices, landing gears, and acoustic pressures found in exhaust gasses. (See reference #2)
- Important acoustic goals include quantifying the loads generated by the subject source of the noise and study what type of effects acoustic pressures and mechanical vibrations have on the system and how they travel throughout the structure. It is also important to identify areas of high stress

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Literature Review section notes:

- The study of structural-acoustics and the associated pressure waves has been a field of interest that, although explored in the 60's and 70's, has received more attention in recent years.
- From review of current literature it is apparent that the deformable structure cavity and the accompanying fluid domain can be coupled in order to quantify the total dynamic response of the system. As such the entire system can be studied in its entirety to capture natural frequency response and modal analysis. Also can capture true response of the dynamic system.
- In acoustic review by Atalla and Bernhard [8]. Numerical methods such as FEA and BEM were studied and compared to analytical methods in order to gauge the efficiency and accuracy of the numerical techniques. Numerical methods provide the means to accurately solve problems that incorporate complicated geometries and material non-linarites.
- Additional structural-acoustic studies have been performed by Brunner [9], Mejdi and Atalla [10], and Dominiquez [11]. In the work by Brunner it was illustrated that strong coupling schemes are even more important when simulating vibro-acoustic response in thin walled structures with dense fluids, which can readily be found in the exhaust environment of today's aircrafts.
- In the work presented above it was determine that FEA techniques are more than sufficient to accurately model complex structural-acoustic systems. One source of significant error arises from the element resolution of the acoustic elements. Paper published by Ihlenburg [12], resolution rules were developed, which if followed result in negligible solution errors.
- Another critical aspect of structure-acoustic analysis is the reduction of noise. This is especially important to military aircraft since excessive noise can lead to aircraft detection over enemy territory, which is directly jeopardize the mission. Goal of reducing aircraft noise emissions has currently been incorporated in the US Intelligence Advanced Research Projects Activity (IARPA). Reduction of acoustic noise generated by aircraft has gained high interest in the UAV community.
- Structural borne sources of acoustic and vibration emissions has been studies extensively [27-30]. However, direct airborne characterization effects along with coupled vibrations has received less attention. The majority of research will be focused on characterization of acoustic loading that is observed in intense acoustic fields enclosed within a structure such as EEWS. Primary goal is to reduce the acoustic load impact on the surrounding flexible structure.
- Addition of sound detening materials has been used in the car industry to reduce acoustic noise [31]. This strategy however is not feasible for high performing next generation aircraft where extreme thermal environments are present as a result of exhaust gases or increased skin temperature caused by hypersonic travel. Additionally, added weight is typically not welcome in aerospace community.

- Work done here by Vogel focused on optimizing thicknesses of the supporting ribs in order to minimize effects of acoustic loading. Lot of work was spent relating acoustic pressures to structural stresses, and couple these effects with the structural vibrations to accurately model the response.
- Some optimization work done by using acoustic-structural optimization was performed on plates and beams. Goal of the optimization was to shift the natural frequency of the system so as to reduce the impact of the acoustic loads [32,33]. Typically, optimization is very difficult to perform due to time and frequency dependencies. Additionally, it is very time consuming.
- When it comes to topology optimization read papers [41-46]. As this may lay ground work for the proposed work in the proposal. So far no topology optimization has been done on the EEWS.
- Very little work has been done on reducing acoustic loading on deformable solid surroundings from the structural health point of view. Majority of work done deals with reducing the acoustic noise only. See paper [51], which so far is the only attempt to modify the surrounding structure on order to improve fatigue life performance.

Notes on Ryan Vogel's thesis [Structural-Acoustic analysis & Optimization of EEWS]

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Methodology section notes:

- This section goes through the mathematical rigors to derive the necessary set of equations to describe acoustic phenomena that occur in the working fluid and how it is transferred to the surrounding elastic media. Irrotational flow is assumed and equations are linear. They apply to subsonic cases only.
- Multiple boundary conditions are also disused. One important BC considered is the infinite acoustic finite elements that allow for simply defining boundary conditions where the incident wave is completely transmitted to the outside environment (no part of the wave is reflected). These types of elements are very handy because they minimize the total amount of external acoustic elements that would be needed otherwise.
- Go back at later date and complete these notes. For now need to move on to section 4
- Also read reference 4.

Notes on Ryan Vogel's thesis [Structural-Acoustic analysis & Optimization of EEWS]

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Finite Element Analysis in Structural-Acoustics:

- Simplified structural-acoustic model which mimics a exhaust washed structure was generated. Frequency analysis for coupled and uncoupled models was carried out for both the fluid and solid continuum. FEA analysis determined that the coupled analysis was required to completely capture the system response.
- Frequency analysis was used to define a frequency response function by applying a dynamic load of 1500 pa at the front of the model.
- Load was applied via a aluminum panel in the front which was coupled with the fluid and remaining structure. The coupling allowed for the pressure load to propagate through the fluid and as a result, the fluid load interacted with the remaining structure.
- 4 types of elements were used, see page 50.
- Not sure but I don’t think this method can be used for supersonic flow. May want to try and figure out how to adapt this method in some way to accomplish this feat. Mainly need to account for density changes in the fluid. Also adiabatic and isotropic assumptions may not be applicable in this domain. Also need to look into studying a converging duct shape where the flow will 'choke'. For this CFD will most likely be required.
- Additional notes will be added at later date.

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Structural-Acoustic Optimization section:

- Problem statement goal was to optimize the thickness of the duct and the substructures. This is in essence a size optimization scheme. Cost function is the weight of the structure. The constraint for this problem is the max stress allowed in the structure.
- Since monitoring stress in each element can be computationally expensive, only certain elements were selected based on the assumption that stress and displacement will be highest in these elements. This method is called 'critical point constraint technique'.
- Due to the modal nature of the problem, the optimizer needs to be able to come up with an optimal solution that will work across a range of frequencies. Because in these instances the optimized result will strongly depend on the starting design (optimizer will typically converge to a local min that may not work for entire frequency range using gradient search option). A hybrid optimization technique was implemented where a global feasible solution was obtained first. The these results were used to perform local optimization (sequential quadratic programming [SQP] method).
- Using this optimization scheme a feasible design was obtained that reduced mass of the structure and meet stress constraints of 100 MPa in the selected elements.

Notes on Ryan Vogel's thesis [Structural-Acoustic analysis & Optimization of EEWS]

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Future Work section:

- In future work utilize a more realistic (complex shape) exhaust duct for acoustic-structure analysis. In the thesis it was shown that more complex geometry had more acoustic-structure interaction.
- Since ultimate goal is to reduce fatigue damage, more detailed fatigue analysis can be incorporated.
- Introduce thermal loading to the model in order to obtain a more realistic combined loading case that is of higher fidelity.
- Can also include CFD analysis.
- This work used size optimization. Future work can try and use topology optimization.
- Can also include thermal analysis to determine 'hot-spots' in the exhaust structure, which can be used to determine material properties degradation as well as model thermal stresses that arise in the structure.
- Addition of thermal loading can expose snap-through effect of the reinforced exhaust structure panels, which can have negative effect on fatigue. Temperature dependent analysis was not carried out in Ryan's thesis but can be a continuation of research efforts. This idea was obtained from paper 'Thermo-acoustic random response of temperature dependent functionally graded material panels'

Nonlinear Response and Sonic Fatigue of National Aerospace Space Plane Surface Panels

Saturday, January 2, 2016 4:25 PM

Notes on the paper:

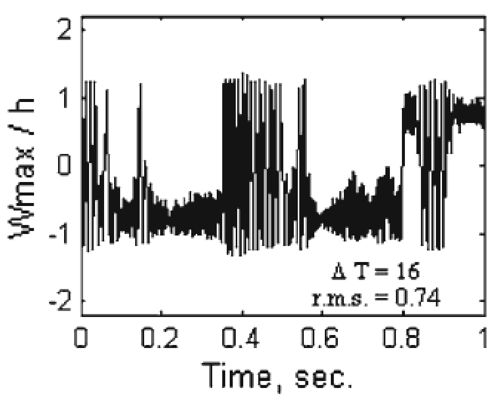
- This paper does attempt uncertainty quantification as it attempts to model fatigue response by generating random acoustic loading in order to predict fatigue performance of the panels under study.
- Paper stresses the need for a comprehensive treatment of combined loading that is experienced in advanced aircraft that travel at supersonic and hypersonic speeds. These loading sources include aerodynamic, acoustic, and thermal loading.
- Use of composite and other orthotropic materials further facilitates the need for better fatigue prediction models.
- Above mentioned loads need to be considered for the entire flight envelope of the proposed aerospace structure.
- At early stages of takeoff the aft surfaces of the exhaust structures will be greatly affected by the acoustic loading from the engines.
- This effect is expected to decrease as vehicle speed increases to supersonic regime. Acoustic loading can again become significant if the vehicle reaches high supersonic and hypersonic speeds due to convecting turbulent boundary layer and impinging shocks on the aircraft skin.
- Supersonic/Hypersonic vehicles will be subject to severe surface temps that reach 3000 F [can site references 1-4 from this paper here as well]
- Due to high operation temperatures multi-wall and multi-layer panel constructions are utilized to prevent thermal degradation of the aircraft. High cycle fatigue has been known to create failures near stiffeners for these panels [can use references 5-13 here if needed].
- Thermal loads can cause material performance degradation. It can also cause in-plane loading in the panels, which can cause buckling due to thermal expansion. When acoustic loads are added this can give rise to a phenomenon known as 'snap-through'
- Paper stresses that for high performance supersonic and hypersonic vehicles linear models (which are typically used for design) are not sufficient for analysis and can miss out on the actual behavior of the system. Therefore non-linear analysis is required with acoustic loading well defined across the entire flight envelope.
- Typical acoustic loading will come from engine vibrations, turbulent boundary layer, oscillating and impinging shocks. Furthermore, the above mentioned sources of acoustic loading can interact with each other to produce random and increased stress profiles in the panels.
- Convective high speed flow can induce large nonlinear vibrations (flutter) in the surface panels.
- Panels that are stiffened usually fail in the neighborhood of the stiffeners
- Typically, stress response due to acoustic loading in aerospace vehicles is found at high frequency range of 100-1000 Hz.
- Linear stress-strain relationships are not applicable for high levels of acoustic loading.

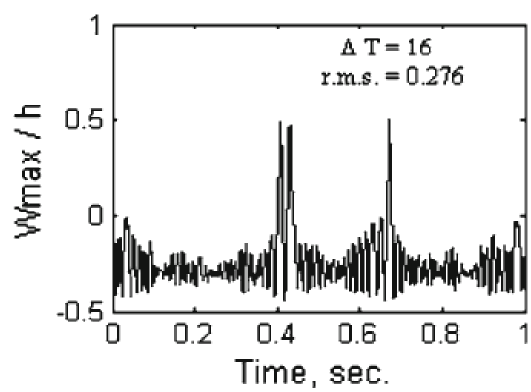
Thermo-acoustic random response of temperature-dependent functionally graded material panels

Saturday, January 2, 2016 5:41 PM

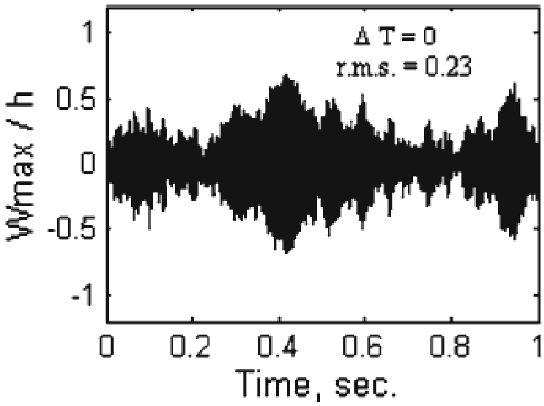
Notes on the paper:

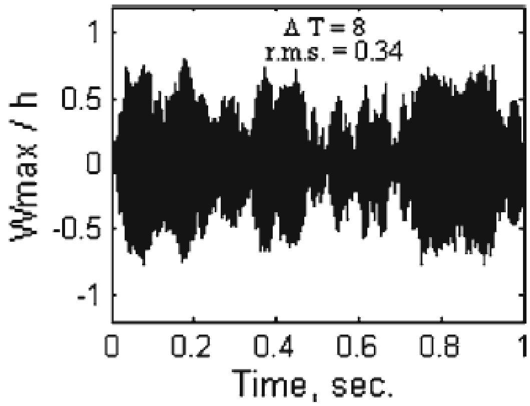
- Paper simulates response of functionally graded materials (FGM's), which have their material properties varied through thickness and also along length if needed. This is typically accomplished by use of metal matrix composites where metal and ceramic are bound to form a composite that has smooth transitions in material deformation response. This is favorable with respect to conventional laminated composites since no abrupt discrete discontinuities occur in material properties when you cross over from one laminate to the next across the boundary.
- Analysis was non-linear.
- FMG's are used on aircraft skins where high temp environments are expected.
- Thermal loading was incorporated via temperature increases in the panel of study. Due to the c constraints on the panel. The increase on temp lead to panel expansion, which lead to plate buckling due to increased in-plane stresses.
- Depending on the severity of acoustic loading, the plate was observed to 'snap through' about the buckling point if the acoustic load was sufficient enough to force it to jump from one buckling position (bottom) to the next buckling position (top). If the plate buckles and vibrates about the buckled steady state point, then the mean stress will be increased. This can in turn reduce fatigue performance of the panel.
- If the panel expansion was not great enough to cause buckling, then deformation was about mean of 0 and the deformation amplitude was driven by the severity of the acoustic loads.
- Cases of snap through can be seen below:





- If there is not snap though due to increased temp then the panel deflections are governed solely by the acoustic loading as can be seen below:





- From this paper read references 2, 3, 4, 5

Design Sensitivity Analysis of Structure-Induced Noise and Vibration

Saturday, January 2, 2016 8:14 PM

Notes on the Paper:

- Noise and structural vibration of motorized vehicles, such as automobiles, aircraft and marine vehicles, are of increasing significance due to the lightweight design in these structures.
- The paper goal was to develop a continuous sensitivity analysis which is to be used to minimize noise and vibration experience by automobile passengers while minimizing fame weight.
- Design variables in this case were the thickness of the frame components.
- Constraint are the sound intensities experienced by the passengers.
- Method used was adjoint variable method.
- Not a very significant paper but try and use it if possible.

Finite element vibration and dynamic response analysis of engineering structures

Saturday, January 2, 2016 8:32 PM

- This is just a list of pertinent FEA work done for dynamic systems.
- Add this reference at the end.
- Nice to look at it for sample problems at a later date.

The effect of fluid-structural coupling on sound waves in an enclosure - theoretical part

Saturday, January 2, 2016 9:59 PM

Paper notes:

- Modes of structure and fluid in the room can be affected by the coupling characteristics of the system.
- Paper uses modal coupling analysis to determine sound decay times and resonance frequency of each acoustical mode.
- Well coupled panel and cavity modes signify maximum panel absorption of cavity controlled modes.
- Experiments on the interaction between a sound field and its boundaries have demonstrated that the walls of a reverberation room are modally reactive, rather than locally reactive.
- Work in this paper deals with sound transmission into a rectangular enclosure through a panel.
- In the field of room acoustics, the decay behavior of an enclosure has been taken as an important measure of its acoustical quality. Dependence of the sound decay on fluid-structure is deemed significant and is the focus of this study.
- Cavity controlled mode has most of its energy stored in the cavity sound field
- Conversely, panel controlled mode has most of its energy stored as panel vibrational energy.
- Wave number is the corresponding eigenvalue for the subject mode.
- Weak coupling between the fluid and structure is usually defined as having very small energy levels in the interactions between the fluid and structure when compared to the energies found in the fluid or structure separately.
- Motion of a weakly coupled system is not much different that motion of the respective uncoupled systems.
- Because of the low density of the air and the high stiffness of the panel, the radiation loading generally has little effect upon the panel vibration, and the actual motion of the panel normal to its surface is so small that the mode shapes of the sound field (air) in the cavity will not be strongly affected.
- However if the cavity that is in contact with the panel is very shallow and the panel is light or the density of the fluid is high, then the coupling may turn out to be very strong.
- In general the power flow from one oscillator to the other increases as the difference of their resonance frequencies decreases.
- Modal decay (sound intensity) time reduces as the difference between the natural frequencies of the cavity (air) and panel decrease.
- If the panel is thin and its damping is low, radiation into the external space (internal space is defined as the enclosed box filled with air) is an important cause of sound energy loss in the cavity itself.

Structural acoustic analysis and design of aircraft components

Sunday, January 3, 2016 1:03 PM

Paper notes:

- This paper concerns itself with investigating acoustic excitations generated from airflow, which in this case is exhaust gases expelled from the aircraft power plant. The goal is to study the interactions between fluid-structure interactions by use of uncoupled and coupled systems.
- As aerospace technology continues to advance across the globe, demand is evet increasing for the future capabilities of aircraft. These requests call for improvements in extended flight intervals, rapid attack and defense, reusable launch system techniques, and improved low observability configurations.
- Due to high demand on the next generation aircraft designs, certain structures are exposed to extreme operating environments that may cause failure in aircraft subsystems such as aircraft skin, landing gears, exhaust nozzles, and vibrating machinery.
- Extreme environments typically consist of elevated temperatures, aerodynamic loading, acoustic loading.
- Most of these disciplines have been addressed in the past studies but separately. Ultimate goal is to use a multidisciplinary approach to aircraft design in order to generate feasible designs based on complete engineering analysis.
- Addition of vibro-acoustic loading directly to the surface structures at certain excitation frequencies creates high cycle fatigue in the aircraft component. When additional loading sources such as thermal loads and aerodynamics loads are considered this can lead to a situation of premature failure that is not accurately captured by conventional design techniques used for prior generation of aircraft.
- For the B2 bomber, when it comes to embedded exhaust nozzles, cracks are initiated by thermal loads and propagated at rapid pace by the high cycle fatigue characteristics of the acoustic loads.
- It is very critical to determine if coupled analysis is necessary for a given system because failure to account for the coupled interaction can yield incorrect values for the simulated natural frequencies, mode shapes, and frequency response functions.
- Advantage of frequency response functions is that it gives the peak pressures within the air cavity and the corresponding frequencies at which they occur.
- Acoustic pressure can be directly related to the stress experienced within the panels of the exhaust nozzles. Therefore, by reducing sound pressure levels one can effectively improve the fatigue performance of the surrounding structure.
- Exhaust panels inside the embedded exhaust structure can experience sound pressure loads up to 180 dB (can also use reference 11 for this claim).
- Small change in natural frequency between the coupled and uncoupled model can produce significant difference in the estimated pressure loads given by the frequency response function as seen below.

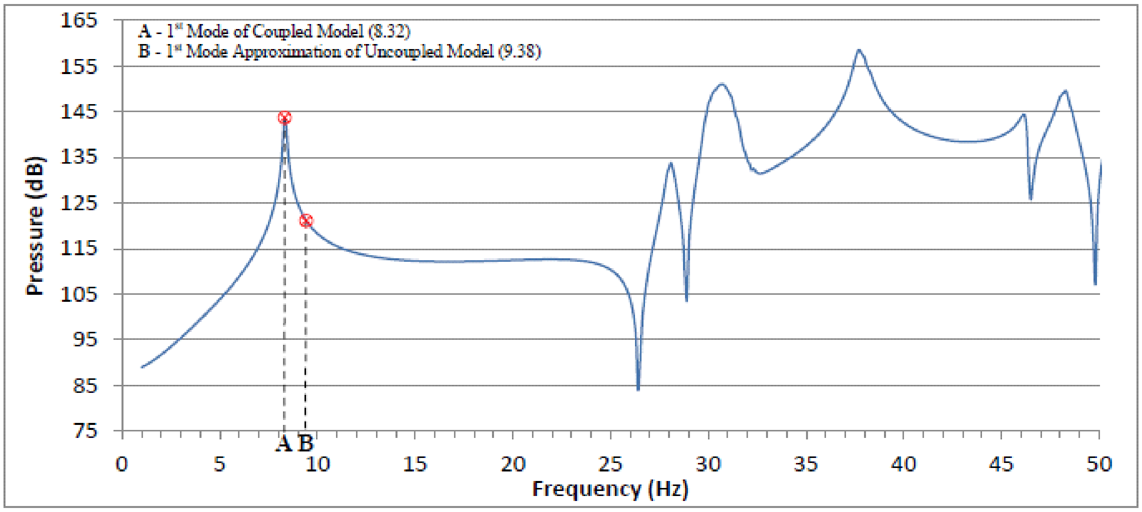


Figure 9: Frequency response function of the coupled duct model

- Increasing material thickness of the exhaust panels can act to reduce the sound pressure levels. This can in theory increase the fatigue life but the weight penalty may be too much to accept this design solution. Additionally, adding thickness to the exhaust panels can adversely affect thermal loading properties of the embedded structure.

Calculated and measured stresses in simple panels subject to intense random acoustic loading including the near noise field of a turbojet engine. (1957)

Sunday, January 3, 2016 4:49 PM

Paper notes:

- Even in 1957 the need to account for the acoustic loading generated by the turbine engines was identified as significant for feasible aircraft design methodologies.
- Acoustic pressure fluctuations may induce many millions of loading cycles in a single flight and can thus cause fatigue in the panels and secondary structures. If millions of cycles can be accrued in a single flight, then fatigue failure can be expected rather soon if damage is present early in the aircraft operation. This can make panels fail much sooner than otherwise assumed. This is especially true if combined loading due to thermal effects are present as is the case for exhaust washed structures.
- This paper uses the method of power spectrum approach in order to predict stresses in the panels, which can be utilized to predict fatigue performance of the system.
- Flat and curved panels were tested in laboratory using an acoustic siren as well as performing panel tests where an actual turbine engine was used to generate random loading onto the panels. Panels were made of 2024-T3 aluminum and varied in thickness. Test panels were mounted on rigid aluminum fixtures by the use of rivets.
- A randomly excited linear 1-D system excited with random input will respond at the natural frequency of the system.
- When looking at the frequency response function. At lower acoustic loads the panel response at the natural frequency is symmetric about the response peak. As the acoustic load rises, the response peak will start to skew to either left or right. This 'skew' phenomenon is attributed to increase in panel stiffness due to non-linear response in the material that can cause it to 'harden'. Frequency response function figures depicting this can be seen below. It should be noted that when the skew is to the right then we have stiffening, when the graph skews to the left then we have a softening phenomenon.

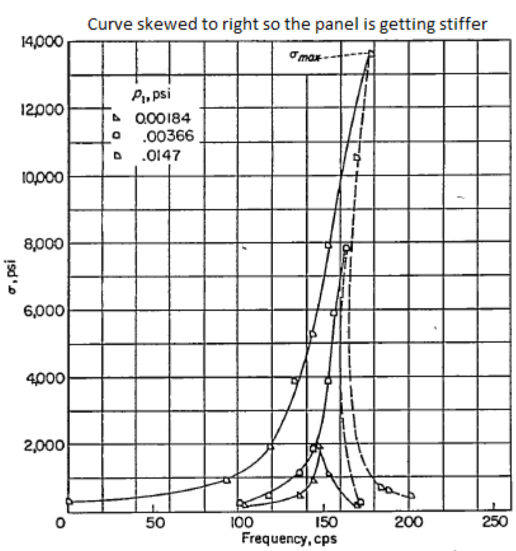


FIGURE 8.—Frequency-response characteristics of flat panels. t=0.040 inch.

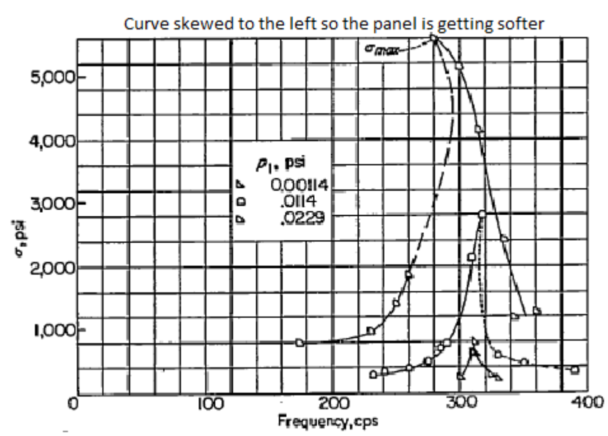


FIGURE 9.—Frequency-response characteristics of curved panels. t=0.032; R=4 feet.

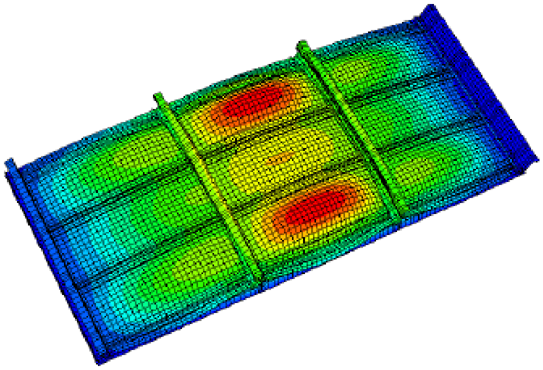
- Resonant frequencies are typically higher for thicker panels. This was also observed in Ryan's thesis.

Nonlinear acoustic response of an aircraft fuselage sidewall structure by a reduced order analysis

Sunday, January 3, 2016 6:02 PM

Paper notes:

- Paper deals with demonstrating a reduced order model in order to simulate the response of a fuselage panel in the non-linear region of system response. Doing complete analysis of all the degrees of freedom is not feasible due to computational and time constraints. Therefore, a modal participation factor was used to determine which modes contributed the most to the system response. This in turn reduced run time while allowing a non-linear approximation of the panel response. This method gave reasonable results but was susceptible to truncation errors at higher frequencies.
- Fuselage model was solved using MSC NASTRAN. Rivets were modeled using CBEAM elements.
- Paper discussed how shape modes of the system can be classified, which is outlined below:
  - Global mode: these are modes that are generally at low frequency whose shapes are not influenced by the substructure.
  - Local Mode: these modes are where reinforcing substructure is stiff relative to the individual bays of the panel section. As such each bay moved independently of one another and the complete structure.
  - Substructure modes: those modes where the substructure experiences the majority of the motion and the bays are relatively non-moving.
  - Mixed Mode: these modes can be a varying combination of the simple modes described above.
- These mode shapes can be seen in figure below.



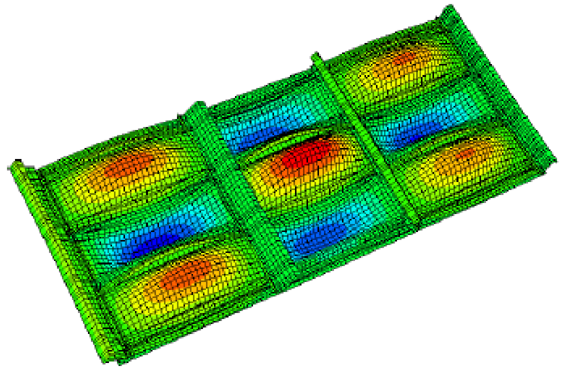


Figure 2: Global mode (Mode 1 – 68.13 Hz) Figure 3: Local mode (Mode 6 – 122.3 Hz)

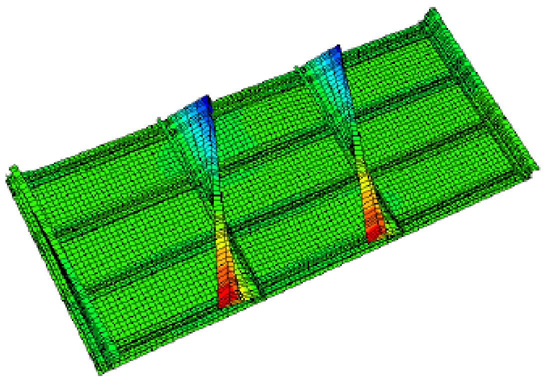


Figure 4: Substructure mode
(Mode 7 – 124.9 Hz)

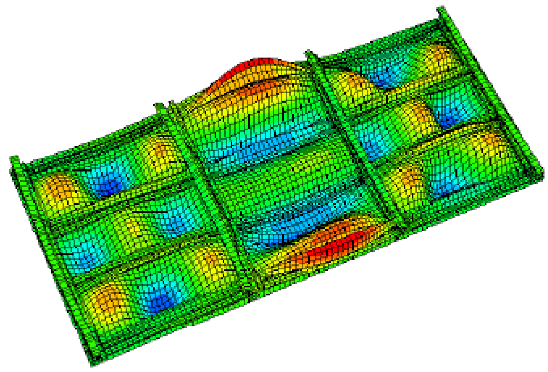


Figure 5: Mixed local-substructure mode
(Mode 37 – 271.4 Hz).

- Random loading spectrums were generated based on aircraft data at sea level. Loading time histories were generated by summing sine waves with prescribed amplitudes and random phase shift
- By using modal participation factor a set of modes is used. But their respective participation either increases or decreases based on load variation. In other terms mode participation is load dependent. This may pose errors because with the load changing some of the excluded modes may become significant, which will results in result errors.
- Authors conclude in the end that a better method for identifying modal participation is needed for the non-linear regime.

Reduced order models for acoustic response prediction

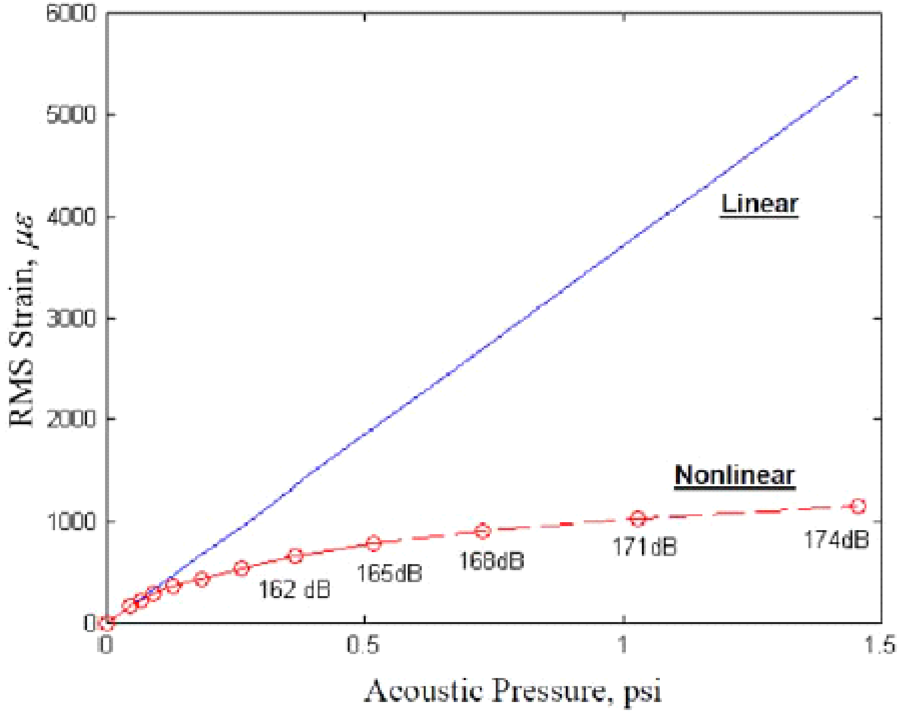
Sunday, January 3, 2016 9:45 PM

Paper notes:

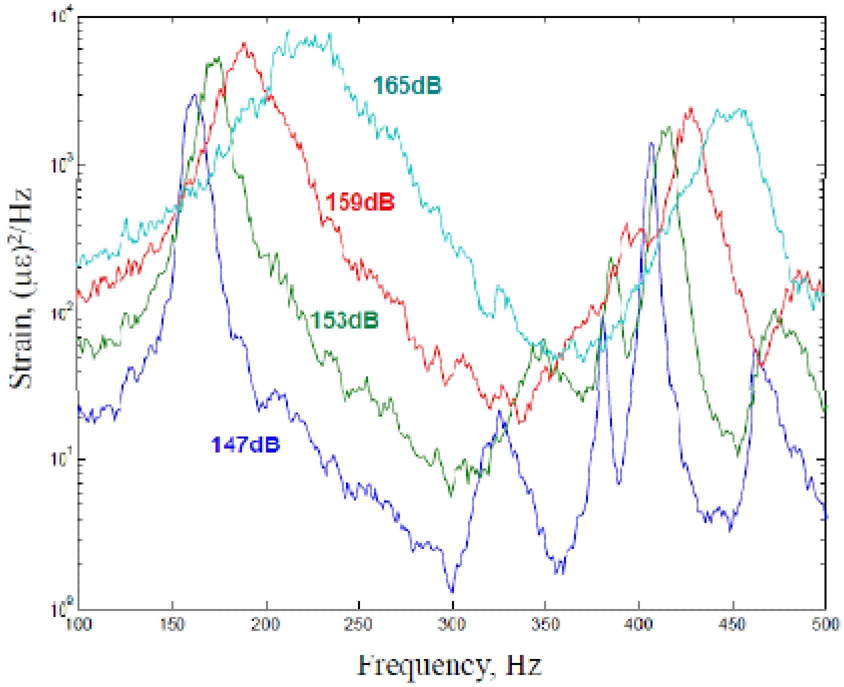
- This research initiative is geared toward developing methods of solving models which include nonlinearities in the dynamic response that is not computationally expensive as is the case for a complete DOF FEA model. The paper develops a reduced order model methodology which only incorporated significant modes of deformation (which can number in 10's and 10000's as is the case for the whole FEA model). This way the nonlinear solution can be obtained without suffering from expensive time and computational issues.
- Sonic fatigue has been a concern for the airforce aircraft since the advent of the jet engine. High level acoustic loads can produce cracks in thin aircraft skins or panels. Acoustic input is typically a band-limited random excitation due to jet engine exhaust, turbulent boundary layer or separated flow. Fatigue occurs when there are lightly damped resonant vibration modes of the skin/panels within the excitation bandwidth. The dynamic response becomes highly nonlinear for large response amplitudes.
- The upper outer wing skin on the F-15 is a good example of sonic fatigue in primary structures. The F15 was originally designed for a 8000 hour life. However, sonic fatigue cracks limited the initial service life to only 250 hours.
- For hypersonic vehicles accounting for acoustic fatigue is of even greater importance since cracks in the secondary structures can produce catastrophic structural failure.
- A one mode dynamic model for the beam is given by the Duffing equation without damping as seen below. This equation is for a non-linear system.

$$\ddot{q} + \omega_n^2 q + \alpha q^3 = f(t),$$

- Geometric nonlinearity produces interesting characteristics in the response of thin skin panels to broadband aeroacoustic loading.
    - First the nonlinearity tends to limit the max response amplitude, which is illustrated in figure below. In the figure it can be seen that measured nonlinear response is essentially capped at high sound pressures

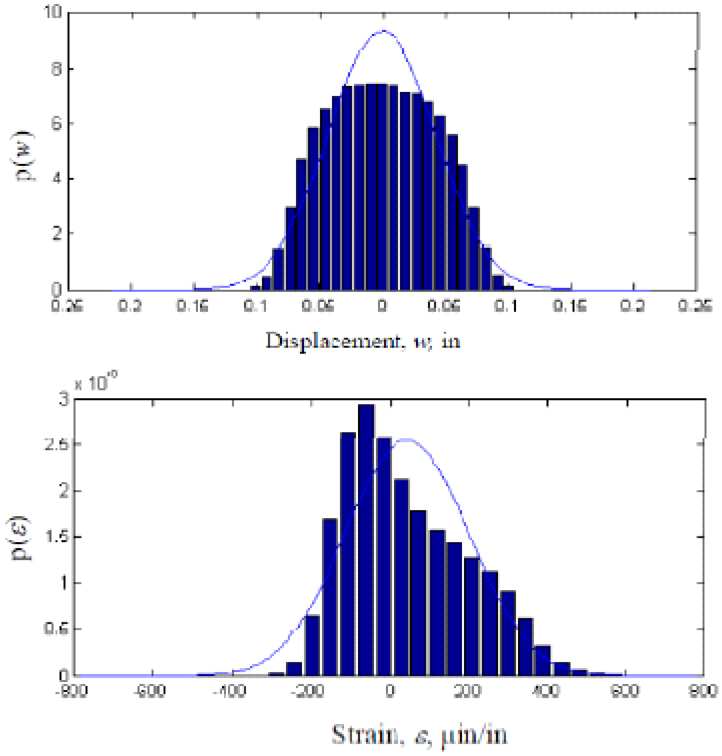


- Second characteristic of nonlinear acoustic response is a broadening of resonant peaks, which is shown in figure below in the power spectral density (PSD) plot. The response is plotted for four acoustic loading condition with the nonlinear effect becoming increasingly prevalent with increasing loads. If the response is linear that the peak at the resonant frequency will be symmetric and it broadens as nonlinearities increase. Broadening of the peaks is indicative of increasing stiffness in the model.



- Third characteristic, which can be seen in the figure above is the shifting of the peaks as the nonlinearities increase. This is again the result of increasing stiffness in the model (or another way put: system has hard spring nonlinearity). As the excitation amplitude increases the structure stiffens, increasing the average frequency of the response.

- Fourth characteristic is the impact of nonlinearities on response statistics. For the linear case displacement and strain probability density function should be Gaussian based on some random spectral acoustic loading input. However, for a nonlinear case the distribution for deformation and strain will not be Gaussian as seen in figure below.



- Nonlinear acoustic response of curved panels can be more complex than that of flat panels. Curvature adds linear coupling to the equations of motion in addition to the nonlinear coupling from large amplitude response. This linear coupling produces normal mode shapes which possess both bending and membrane(axial) displacements. In contrast, the normal models of flat plates contain either bending or membrane displacement exclusively. Furthermore, curved structures can exhibit nonlinear softening resulting from quadratic nonlinear effects. Nonlinear softening is physically expressed as resonant frequencies that decrease with increasing response amplitude.
- Temperature changes can have a significant effect on the acoustic response of skin panels. Thermal stresses resulting from the constrained thermal expansion of flat panels under heating induce linear stress softening which will reduce resonant frequencies and ultimately cause buckling. The post buckled panel can then oscillate about the buckled position under acoustic loading or 'snap-through' dynamically if the acoustic loading is high enough. The response of curved panels to applied temperatures is even more complex. Thermal stresses produce stress stiffening and a change in the geometry with can cause resonant frequencies to increase or decrease depending on the specific problem. Thermal stress directly affects linear stiffness, but the acoustic response of the curved or post-buckled panes is still greatly affected by nonlinearities.
- For numerical analysis containing high frequency modes the time step needs to be very small to capture the response correctly.
- Typically low-frequency modes involving bending displacements are of primary importance in the model response.

Acoustic loads generated by the propulsion system

Tuesday, January 5, 2016 1:18 PM

Paper notes:

- Paper is a 1971 NASA document which goes through a detailed discussion on how to estimate acoustic loading on the rocket structure and substructures during lift off and subsonic flight. Methods presented in the paper are heavily influenced by test data that is cure fitted and used in conjunction with analytical functions.
- For rockets, once the vehicle is supersonic the acoustic effects are negligible since the rocket is traveling faster than the sound loads generated at the aft by the propulsion system. Remaining loads would come from the turbulent layer mixing near the vehicle skin and shock waves that are formed, which are not discussed in detail here.
- The acoustic loading results from the broad frequency-spectrum acoustic field generated by the mixing of the rocket-engine exhaust stream with the ambient atmosphere. Acoustic loads are a principal source of structural vibration and internal noise during launch or static-firing operations but do not generally present a critical design condition for the main carrying structure.
- Paper does attribute fatigue effects to the acoustic loading, which mainly affects lightweight exterior structures such as aerodynamic fins and antenna panels.
- Ejecting water into the exhaust plume can serve to reduce the acoustic loading, this becomes infeasible for large engine rockets since tremendous amounts of water would be required to produce any meaningful noise level reductions. Approx 10 dB of noise reduction can occur with this method.
- Directing the exhaust gages into a body of water can also serve to reduce noise power levels by about 10 dB. To make this feasible a large manmade or natural body of water is required, which can be costly to build.
- Test and launch stands can be designed to reduce noise levels by directing the exhaust gasses through minimum angles of deflection. Also use of tunnels to direct exhaust flow away from the rocket body can serve to reduce noise levels.
- Study recommends that acoustic loading effects should be considered in the early design stages. This not only applies to rockets by aircraft as well.

The 1988 Rayleigh medal lecture: Fluid loading, the interaction between sound and vibration

Tuesday, January 5, 2016 2:34 PM

Paper notes:

- Paper mainly deals with a thorough review of analytical methods available to treat fluid structure interaction problems. They mainly deal with infinite plates, some finite plate theory, and plates with regularly and irregularly spaced rib reinforcement structures.
- Some discussion is also given on the mean flow effects of fluid over the subject structure.
- Lord Rayleigh performed experiments on fluid loading on a vibrating structure (reaction of the air on a vibrating circular plate). These experiments were carried out roughly in 1896. This info can be used as the intro of the proposal.
- Added mass and radiation damping depend on the vibration mode shape and must in a fully coupled problem with significant fluid loading be determined simultaneously with the structural vibration and fluid motion.
- See reference 2 in more detail.
- Advances in scientific understanding of fluid structure interactions have been driven by widespread occurrence of technological processes in which fluid loading of vibrating structures is important. This includes the aerospace field.

A study of the response of the panels to random acoustic excitation

Tuesday, January 5, 2016 3:29 PM

Paper notes:

- Paper outlines some simple calculations that can be used to predict acoustic loading on simple aluminum panels based on some experimental data procured from laboratory setting where an air horn was used and also experiments where a miniature jet engine was used
- Jet engine noise causes fatigue failures in airplane skin in the proximity of the jet-engine exhaust stream. Paper notes in 1957 skin failures in airframe configurations which place engines in the very aft part of the aircraft (typical aircraft configurations of today like F15, F16, B2)
- Paper points out the severe costs of not accounting for acoustic loading in terms of ad-hoc modifications to the existing design via the addition of skin gage or addition of stiffeners. These late modifications and requirement of frequent inspection and repair can increase cost of aircraft maintenance significantly. This observation was made in 1957 and sadly this issue still persists today with B2 and F15.
- Transfer function is also know was the frequency response function. It is necessary in relating the input with the output. It can be in terms of load or displacement.
- In this paper stress in the test panel is a function of 4 parameters;
    - Panel natural frequency
    - Input noise at panel natural frequency
    - Static stress
    - Panel damping, which varies with input pressure.
- Nonlinearities in the response curve of the panel were evident since the peak at the resonant frequency of the panel was not symmetric.
- When the panel was exposed to random jet noise the subsequent panel responded at its first bending frequency mode where the frequency remained constant but the amplitude of the panel response was changing. This was attributed to low damping in the panel.

Studies of structural failure due to acoustic loading

Tuesday, January 5, 2016 4:20 PM

Paper notes:

- Paper deal with fatigue testing of plate panels and cantilever beam. The specimens were loaded using acoustic loads that were either periodic in nature (air horn) or random (jet engine). Based on sound intensity the plate samples loaded by the air horn lasted longer with respect to the random loading case. However, when root mean square stress was plotted with respect to life in hours then random loading had the worst fatigue performance. This was attributed to the root mean square calculation having higher peak stresses when compared to the root mean square calculation for the air horn. Curved panels had the best fatigue performance even though natural frequency of the curved panels was higher when compared to their flat counterparts.
- Damage due to acoustic loading typically occurs in secondary structures of the aircraft as a results of large number of relatively small loads applied at the rate of several hundred cycles per second.
- Structure characteristics (geometry, method of construction and fastening) will drive a certain dynamic response. This response will influence the stress patterns in the structure, which in turn will determine fatigue life performance.
- Paper points out in 1957 that as jet engines become more powerful (pressure ratio increase) the corresponding acoustic loading from the exhaust gasses will also increase.
- For the type of random spectra generated by these engines, fatigue damage can occur at overall levels of the order of 140 dB or higher. The amount of damage incurred at any given level, of course, is a function of the design, the length of exposure to noise, spectrum of the noise.
- Failures of the simple panels occurred near the bolt head where the panel was secured to the test fixture. This was true for both flat and curved panels.
- More complicated structures which involved reinforcing ribs were tested. It was shown that these panels tend to fail near or on the actual stiffener ribs. This type of failure is also seen in today's panel configurations.

Prediction of the dynamic response and fatigue life of panels subjected to thermo-acoustic loading

Wednesday, January 6, 2016 12:16 PM

Paper notes:

- Paper purpose is to use reduced order modeling in order to simulate thermo-acoustic nonlinear response of simple panel without any reinforcement or duct work. The displacement and stress response of the panel is to be used to predict fatigue life by use of damage accumulation methods although no explicit life predictions were performed on the simulated panels and there is no experimental data to confirm life predictions by the work done in the paper.
- Paper acknowledges the importance of accounting for the acoustic loading aircraft panels experience in service. These panels can be exposed to sound pressure levels greater than 150 dB in conjunction with severe heating that reach as high as 3000 F.
- Temperature typically reduces the panel stiffness and induces buckling.
- The combined effects of acoustic loading and thermal effects renders life estimation a very difficult task.
- Paper states that nonlinearities in the system can be helpful by reducing the stresses the panels experience but it does increase computational time significantly.
- Typically structural dynamic analysis of aircraft panels subjected to acoustic excitation and thermal loading has been done in following ways.
    - Use of very simplified structural models and relying on available exact/approximate solutions of the corresponding random vibration problem. This is considered to be a single mode analysis and it lacks a good quantitative prediction of the panel response.
    - Another way is to use Monte Carlo simulations of a finite element model. This is very time consuming to perform, especially at design stage.
    - As such reduced order models are used in this paper because they incorporate the critical modes which yield an accurate solution while keeping computational time low relatively speaking.

Analysis of dynamic and acoustic radiation characters for a flat plate under thermal environments

Wednesday, January 6, 2016 1:51 PM

Paper notes:

- Paper studies the effect of temperature increase within simply supported plates on plate dynamic response such as natural frequency. The temperature rise is maintained below bucking temperature. The paper surmises that temperature increase reduces the natural frequency of the plate. It also reduces the mean square velocity of the plate surface. This in turn directly reduces the sound pressure levels and sound power that is emanated in to the working fluid, which in this case is air. The mode shapes remained the same and the response obtained was linear.
- The paper has good theoretical results for plates that can be used as a sample problem to verify ABAQUS competency. On that note the paper compared theoretical results with ABAQUS which when it comes to natural frequency estimation agreed quite well with theoretical results.
- When the fluid was modeled in order to calculate sound intensity within the fluid the results from ABAQUS did not match well with theoretical approach. This is due to the fact that the appropriate boundary conditions were not applied to the edge of the fluid domain. As a result, sound pressures generated by the vibrating plate that should have been emanated to the atmosphere were erroneously reflected back into the system. This caused additional peaks in the response which should not be there. If appropriate impedance or infinite boundary layer is applied this issue should be resolved.
- Temperature effects can have a marked effect on material properties and structure response.
- Study of sound radiation from structures was first carried out by Lord Rayleigh in 1896. He derived the Rayleigh integral to calculate the far-field acoustic response.
- Addition of ribs to the plate seems to reduce the amount of sound vibration imparted into the working fluid. This basically means any sort of stiffness increase to the solid component will work to reduce the sound pressure levels within the fluid.
- In this paper wave number is defined as the natural frequency divided by sound of speed within that particular fluid. k=omega/c
- Paper has an expression on how to calculate critical temperature for buckling.
- When calculating sound pressure level (dB) the reference sound pressure used is 2e-5 Pa
- Paper also talks about how to calculate sound radiation efficiency. See bottom of page 9

Effects of non-linear damping on random response of beams to acoustic loading

Wednesday, January 6, 2016 2:51 PM

Paper notes:

- Paper studies the effect of non-linear damping on structure response. Mainly it uses non-linear beam theoretical expressions in conjunction with some experimental data to predict how non-linear damping affects the displacement, strain, and natural frequencies of the beam models. It was discovered that non-linear damping is predominantly responsible for the broadening of the spectral density functions as the SPL are increased.
- Problem of acoustic fatigue failure was introduced by the advent of the jet engine, which produces high intensity acoustic pressure fluctuations on aircraft surfaces. Fatigue failures due to acoustic loading have given rise to unacceptable repair and inspection burdens which are commonly associated with performing aircraft.
- Majority of analysis and studies is done assuming linear small deflection analysis.
- Studies have shown that acoustic loading at or exciding 120 dB can lead to nonlinear behavior in aircraft panels.
- Typically linear analysis techniques over predict the actual displacements and strains experienced by aircraft panels. This leads to poor fatigue predictions. Linear analysis also underestimates that natural frequencies the panel poses in the non-linear regime.
- The estimation of system fatigue life is based on the root mean square stress/strain and natural frequency in conjunction with the appropriate SN curve to predict component life.
- Paper studies the non-linear damping effects on aircraft structures at high sound pressure levels (SPLs)
- Increase in natural frequencies of panels experiments illustrated in the paper is attributed to the presence of in-plane forces in the panel due to large deflections.
- Peak broadening of the spectral density functions at high SPLs is attributed to non-linear damping induced by large deflections of the panel.
- Damping is the removal of energy for a vibratory system. The energy lost is either transmitted away from the system by some mechanism of radiation or dissipated within the system.
- For metal these mechanism include thermo-elasticity on both micro and macro levels, grain boundary viscosity, point-defect relaxations, eddy-current effects, strain induced ordering, and electronic effects.
- Common approach is to only include viscus damping in the model because the model remains linear and easy to solve.
- Nonlinear damping examples:
  - Coulomb damping
  - Velocity squared damping
  - Solid damping
  - Displacement squared damping
- Effective resistance to motion increases with the amplitude of the response in the non-linear region of the response.
- Paper also concludes that the non-linear stiffness term does not does not contribute to the broadening of the peaks in the spectral density graphs.

Influence of thermal loading on the dynamic response of this walled structure under thermo-acoustic loading

Wednesday, January 6, 2016 3:45 PM

Paper notes:

- Paper studies the effect of thermal loads that are superimposed with acoustic loads which can reach as high as 160 dB. For thin aluminum panels studied here, thermal loads cause buckling rather fast and as a result two equilibrium positions can occur where the plate will vibrate about one of these locations until the acoustic load bumps it into the other equilibrium position. This is identified as snap-through and becomes harder to accomplish in post-buckled plates as the thermal load is increased leading to higher buckling deflections that are harder to overcome by the acoustic load. At very low temps where no buckling occur the plate will simply oscillate about its natural unreformed position (this has only one root, where buckled situation has 2 roots, therefore, a bifurcation occurs once buckling occurs because we go from 1 root to 2 roots).
- When there is no buckling the plate experiences large amplitude stress response but low mean stress effects. Conversely, when buckling occurs the plate will experience smaller stress amplitudes about one of the buckled states but the mean stress is increased significantly.
- Which one of these conditions is worse needs to be determined on a case by case basis based on the material chosen.
- Large deflection dynamic response of future flight vehicle structures under thermo-acoustic loadings can lead to significant reduction in fatigue life.
- There is a decline of modal frequencies right before the buckling temperature. This shows a decrease of stiffness in the panel due to compressive thermal stresses. Post buckled plate regains its stiffness due to change in shape (now its bowed/curved).

A hybrid approach for efficient robust design of dynamic systems

Wednesday, January 6, 2016 6:18 PM

Paper notes:

- Paper introduces the idea of using non-linear dynamic analysis to optimize a fermentation plant process while at the same time ensuring that the optimal point is stable not only at that particular point but also within some confidence interval about the actual optimized point (center of the uncertainty region).
- The reason that there may be some uncertainty within the optimal solution is due to the fact that some of the design variables are uncertain in nature. Meaning that their values can only be guaranteed within some interval of operation, which is true of any real world process.
- If the optimal solution is close to instability then this small variation in design parameters may cause the whole system to go into a unstable operating condition (a bifurcation may occur).
- Since bifurcations are possible this system is non-linear. In this paper the type of bifurcations possible are hofp and saddle node bifurcations.
- Corresponding manifolds for the two types of bifurcations mentioned above are constructed in order to identify when an optimized point is near a critical point where the manifold may go unstable.
- The goal of the optimizer process is to ensure that the feasible point stays away from the unstable manifolds within some parameter uncertainty limit. This addition of non-linear analysis to the optimization process is the novelty of the presented work.

Hybrid multi-objective shape design optimization using Taguchi's method and genetic algorithm

Wednesday, January 6, 2016 7:29 PM

Paper notes:

- The paper uses the principles of design of experiments (mainly ANOVA) to determine sensitivity of the feasible design with respect to the design variables. By evaluating the impact of the design variables at this early stage it is possible to resize the design space (usually reduce the design space to some degree), which allows for faster solution times and enhanced possibility that the solution will be a global optimum. Basically ANOVA is used to define optimal bounds on the design variables.
- This technique of Taguchi method (ANOVA analysis) was combined with genetic algorithm optimization subroutines in order to obtain optimal solutions to multi-objective problems.
- In recent years, there is a growing interest in shape design due to the effectiveness of the shape optimization for improving the quality characteristics of the products.
- Argument behind the hybrid approaches is the strength of one algorithm ca be used to improve the performance of another approach by handling the limitations.
- Topology and shape optimization are computationally complex procedures and require intensive computational evaluations to obtain the desired solution.
- Reliability based approach to design optimization has also been used in design optimization because of the existence of uncertainties in physical quantities such as manufacturing tolerances, material properties, and loads.
- In this research the refinements of the population space for genetic algorithm is introduced to overcome the cost caused by working with large population of solution in pure multi-objective genetic algorithm (MGOA).
- Most of the design optimization problems in real world applications are usually multi-objective, often conflicting, and they have uncontrollable variations in their design parameters.
- The main contribution of this paper is that the importance of the refinement of design solution space for genetic search is clearly demonstrated with computational experiments for solving multi-objective design optimization problems.