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INVESTIGATION ON OBLIQUE IMPACT RESPONSE OF COMPOSITE CYLINDRICAL SHELLS

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ABSTRACT

As the simulation of a subcomponent of jet engine fan case under blade-out loads, the dynamic behavior of a composite cylindrical shell impacted obliquely by a flat projectile has been investigated using explicit numerical method. In order to understand the feasibility of utilizing partial configurations to represent the full subcomponent in experiments and analyses, a half, quarter and half-quarter symmetric FEA models of the shell have been analyzed for both pure elastic and elastic-brittle failure material model. The results suggest that a half configuration of the shell could be well used in place of a full shell for the whole response, while the quarter configuration merely for the impact stage when the evaluation of local damage is the main purpose. In addition, analysis indicates that the damage in the initial impact is not significantly affected by the boundary conditions while the subsequent deformation is strongly influenced by the boundary conditions.

KEYWORDS

Composite laminates, impact, damage and penetration, shell, explicit dynamics, jet engine

INTRODUCTION

The dynamic response of a cylindrical composite shell impacted obliquely by a projectile has a vast practical background in aeronautical engineering. Recently, the impact on composite structures has been a subject of extensive research [1-3]. Lots of factors are involved in impact problems such as the projectile versus target structure mass ratio [4], impact kinetic energy, the shape and length of the projectile, impact angle of obliquity, the dimension of target structure and its boundary conditions etc.

The interest of this research is focused on the influence of structure dimension and boundary condition on the overall dynamic response nature in the oblique impact of cylindrical composite shells. This has obvious practical and economic value in providing guidelines for choosing appropriate simple test models and planning experimental studies. No test data and report were shown to confirm whether a partial configuration of the structure could be used to represent the whole structure in a dynamic impact response test or analysis quantitatively so far. On the other hand, the complexity of impact problems also leads us to choose to combine theoretical, numerical and experimental approaches.

In this research, the numerical analysis of a composite laminate shell, subjected to the oblique impact by a thin flat rigid cylinder with a certain mass, is conducted using explicit dynamic method by ABAQUS. Five cases of analysis are performed for different dimensions of the shell configuration with both free and fully fixed boundary conditions. The strain and kinetic energy transfer and deforming history are examined from the numerical results. Especially, the influence of constraints on the cut boundary of partial configurations taken from the full shell is observed. Only the cases with free and fully fixed boundary condition are studied in consideration that the real constraints on the whole shell should lie between these two extreme situations. Both linear elastic and elastic-brittle failure material model are employed to obtain an understanding of the overall response of the shell and insight into the local damage and mutual influence between them. The localized damage/penetration is simulated using a brittle failure model combined with an element removal mechanism for failed part of the structure.

ANALYSIS MODEL

Illustrated in Figure 1 is a full-ring shell subcomponent proposed for testing of jet engine fan case by NASA Glenn Research Center, to evaluate the performance of a composite structure under blade-out loads. In this research, the transient impact response analysis of the subcomponent was performed using the commercial FEA code ABAQUS/Explicit. The impact velocity was 182.9m/s (600ft/s) and the composite ring was taken to be $7.62X10^{-3}$m (0.3”) thick with the following properties, which are representative of a glass/epoxy laminate with a 0°/90° lay-up. $E_{11}=E_{22}=17237$Mpa ($2.5X10^{6}$ lbf/in^2), $G_{12}=6894.8$Mpa ($1.0X10^{6}$ lbf/in^2), $G_{13}=G_{23}=4136.9$Mpa ($6.0X10^{5}$ lbf/in^2), $\upsilon_{12}=\upsilon_{21}=0.14$ and $\rho=1715.6$ kg/m^3 (0.00016 lbf s^2/in^4).

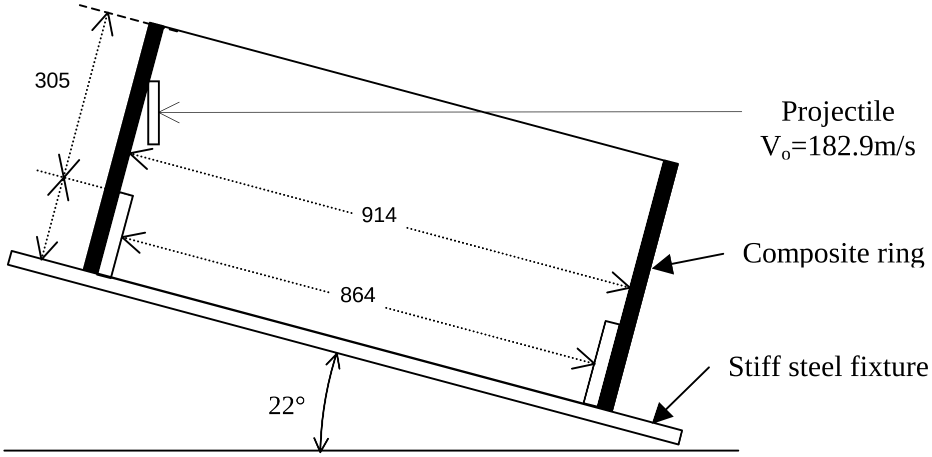
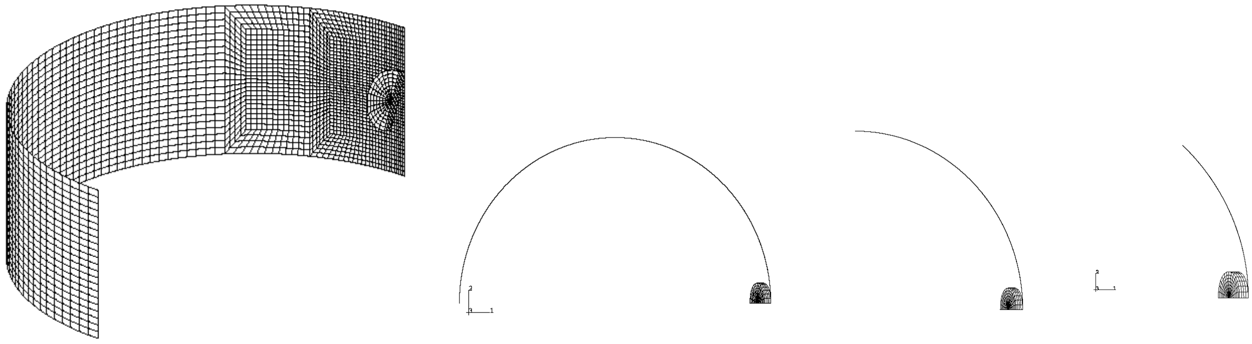


Figure 1: Illustration of the analysis model of the subcomponent (unit: mm)

In addition to the pure elastic model, an elastic-brittle failure model was also included in the analysis to simulate the local damage. The brittle failure model was characterized by a tensile strength σ_t^I =275.8Mpa (40000 lbf/in^2) and a failure strain ε_f =0.023. An element would be removed from the analysis process whenever all of its material points failed. The projectile was a flat circular cylinder with diameter of 114.3mm (4.5”), thickness of 19mm (0.75”), and mass of 0.85kg (1.9lb). It was ideally modeled as a rigid body with a density of 4366.7 kg/m^3 (0.00041 lbf s^2/in^4) since tracking waves and stress distributions in the projectile were not important in the present study. The shell was inclined at an angle of 22° to the horizontal.

In order to examine the effects of the shell dimension and boundary conditions, a half-shell and a quarter-shell model with both free and fixed end conditions at the cut boundary were analyzed in addition to the whole shell, as showed in Figure 2. All the analysis cases are listed in table 1. Because of the symmetry, only half of the structure geometry was modeled for all cases with symmetry condition about mid plane imposed. For simplicity, no friction between the projectile and shell during contact was considered. Four-node thin shell element S4R was used for the shell, and six-node and eight-node solid element C3D6 and C3D8R for the projectile. In addition, relax stiffness type of hourglass viscosity was used to restrict the element mechanisms, i.e. the zero-energy hourglass deformation mode, due to the degradation of first-order element integration. Also, in order to limit numerical oscillations due to discretization, a linear bulk viscosity with damping coefficient b_1=0.0001 was introduced.



The Meshing (Half Model) Half Model Quarter Model Half Quarter

Figure 2: Symmetric FEA models of the structure

TABLE 1
ANALYSIS CASES

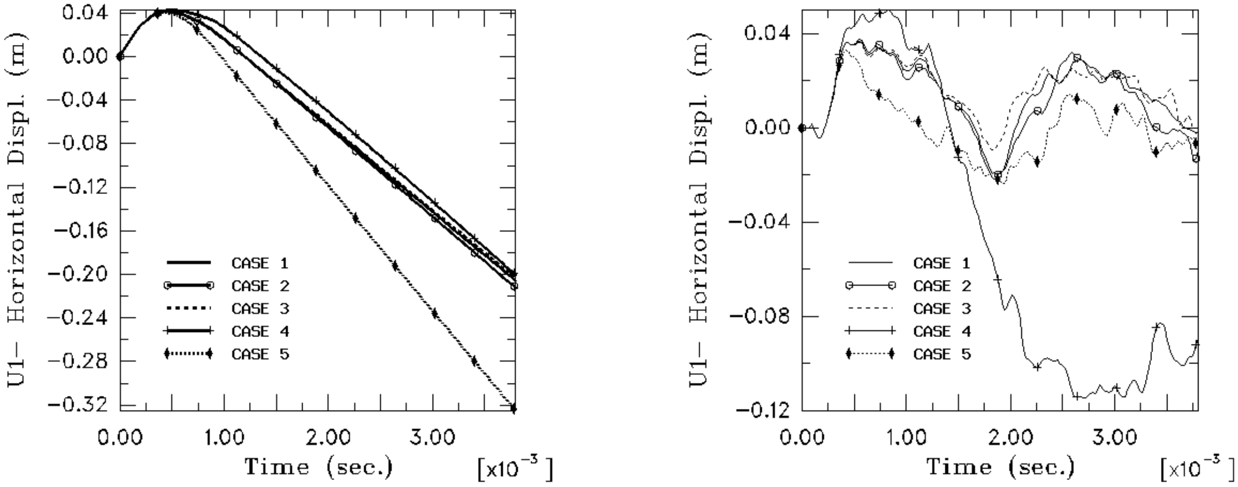
Case	Structure	FEA model	Cut-end boundary	Bottom boundary
1	Whole	Half	-	Fixed
2	Half	Quarter	Free	Fixed
3	Half	Quarter	Fixed	Fixed
4	Quarter	Half quarter	Free	Fixed
5	Quarter	Half quarter	Fixed	Fixed

NUMERICAL RESULTS AND DISCUSSION

Deformation

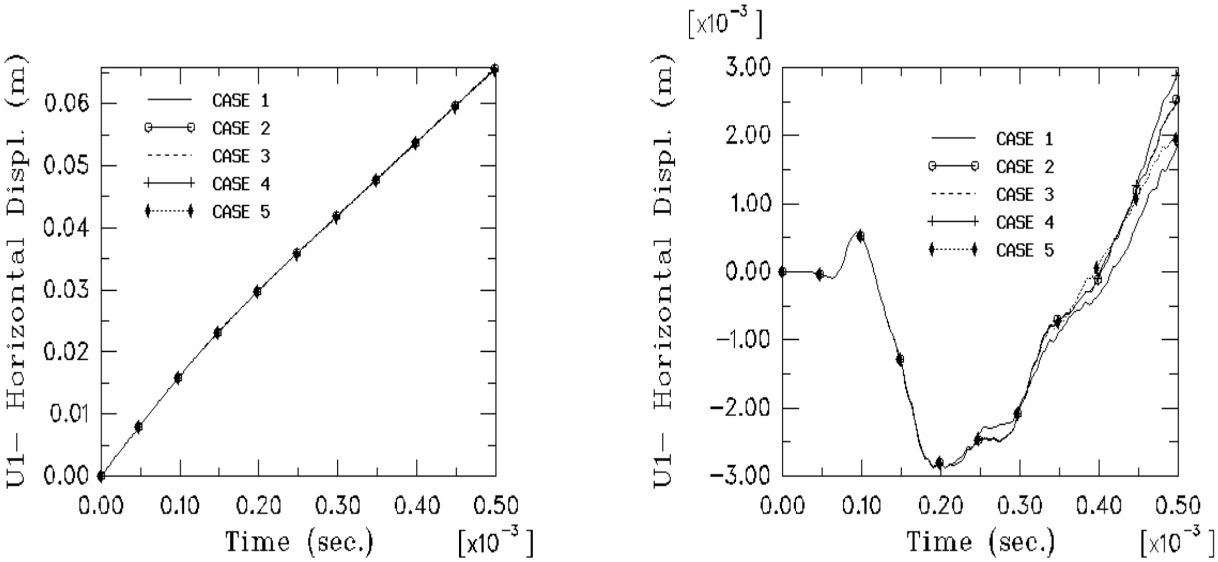
Displacements at the projectile center and top edge of the shell above the impact point are shown in Figures 3(a) and 3(b) for pure elastic analysis of case 1-5. For about the first 1.0ms the projectile is in contact with the shell. For times up to 1.5ms the response is very similar for the full shell and the half-shells with both free and fixed boundary conditions. The response of the quarter-shells is similar to that of the other configurations only for times below about 0.4ms, which corresponds to the initial impact of the upper edge of the projectile. These results suggest that a half-shell configuration could be used in place of a full shell to evaluate local damage; either free or fixed boundary conditions could be used. Figure 4(a) and 4(b) show the displacement history of the projectile center and the impact edge of the shells for all cases 1-5, respectively, when material failure was taken into account. It is seen that the responses for all the 5 cases are almost identical throughout the entire response, indicating that partial configurations could provide perfect approximation to the full model when local failure is involved. The evolution of local damage at the impact area is shown in Figure 5 for case 1 when a brittle-failure model is employed.

It is noticed that for the partial shell configurations (case 2-5), those with free end boundary condition at the cut line provide a more similar response to the full shell (case 1) compared with the fixed end boundary condition. This indicates that the free-end condition provided a better approximation for a partial configuration to replace the full shell. This is valuable because free boundary is always convenient to be implemented in practice.



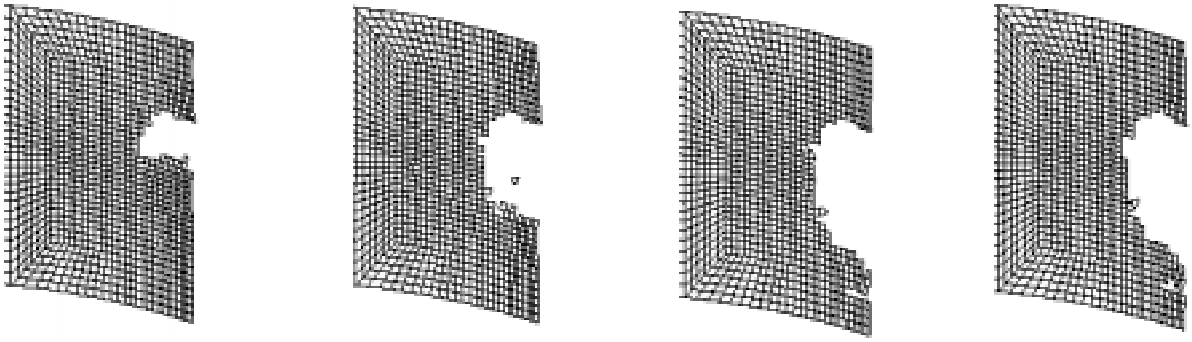
(a): at the projectile center **(b):** at the shell edge above the impact point

Figure 3: Comparison of displacement for case 1-5 (elastic model)



(a): at the projectile center **(b):** at the shell edge above the impact point

Figure 4: comparison of displacement for case 1-5 (elastic-brittle failure model)



t=0.1 ms t=0.2 ms t=0.5 ms t=1.0 ms

Figure 5: Evolution of local damage and penetration (case 1)

Energy transfer and absorption

An observation of strain and kinetic energy possessed by different portions of the shell helps understand the mechanism of energy transferring and distribution in the structure. Strain energies stored in arcs of various sizes around the impact area are shown in Figure 6 for the pure elastic full-shell configuration. The total energy (strain energy + kinetic energy) is shown in Figure 7. In Figure 6 the strain energy grows to a maximum value at about 0.45ms as the projectile comes into contact with the shell. The maximum strain energy is a little over half of the initial kinetic energy of the projectile. In Figure 7 the total energy in the full shell remains constant after about 1.0ms because the projectile has rebounded from the ring. It is seen that during impact and at the early stage of the later response, the 90°(half) arc portion of the shell almost possesses all the energy of the whole structure. As the deformation develops, the energy gradually transfers to the rest part of the structure.

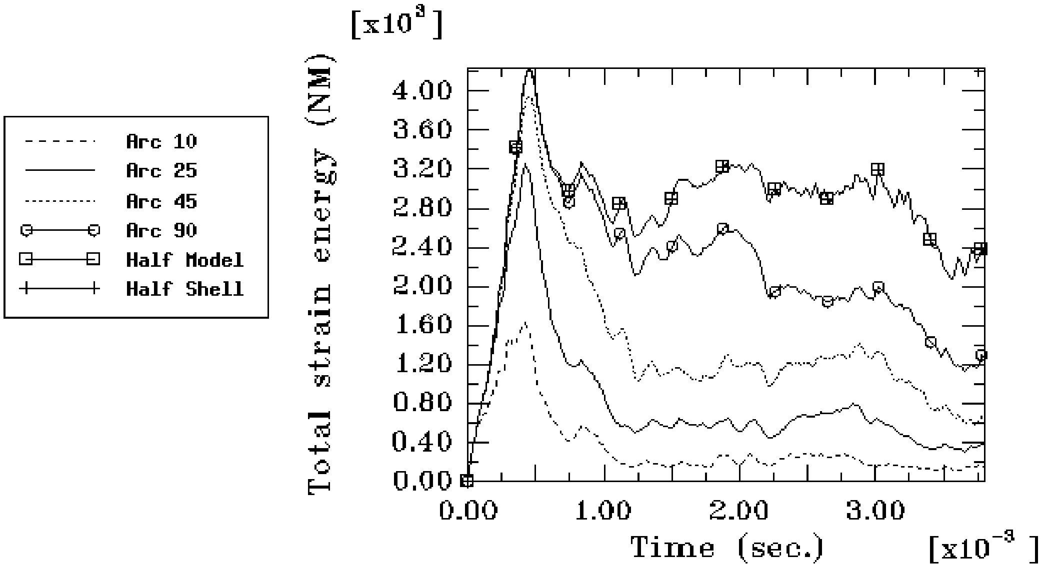


Figure 6: Strain energy in the arc of 10°, 25°, 45°, quarter, and half-shell (without and with the projectile included) for case 1 (elastic model)

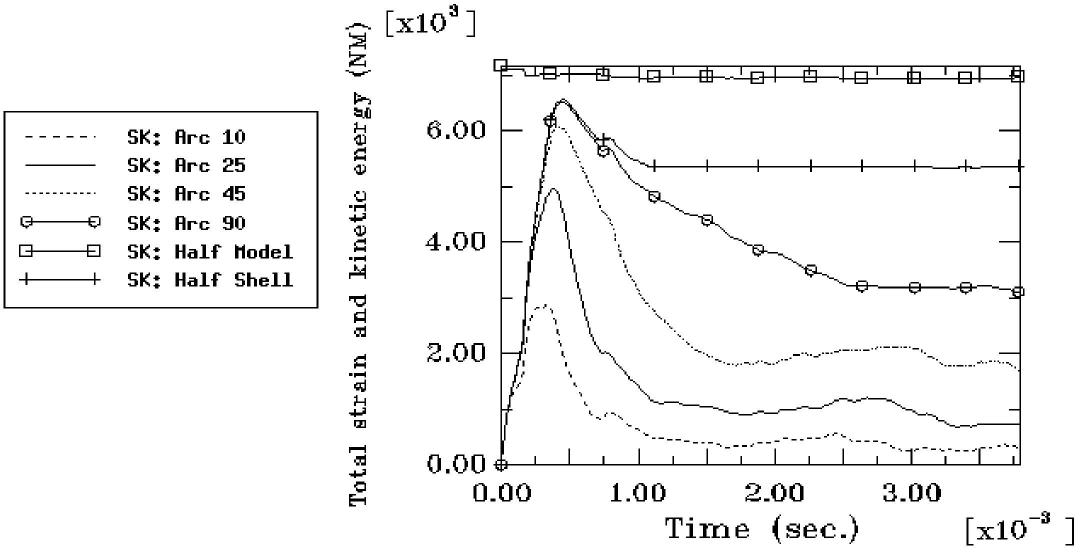


Figure 7: Strain and kinetic energy in the arc of 10 °, 25 °, 45 °, quarter, and Half-shell (without and with the projectile included) for case 1 (elastic model)

CONCLUSIONS

1. The initial local damage is not significantly affected by the boundary conditions while the subsequent deformation is strongly influenced by the boundary conditions.
2. A half shell could be used to replace the full shell when performing an impact experiment or analysis. Especially, an even better approximation could be obtained if local damage is involved.
3. Should a partial configuration be devised to simulate the response of the whole structure as a substitute, a free boundary condition could provide a closer result than a fixed boundary.
4. It is more reliable for a partial configuration to substitute the full shell when the localized damage is mainly concerned. This is because the impact times in the order of transition time for through-the-thickness waves is shorter than that required for the flexural wave reach the boundary [5].

It must be stressed that the projectile versus shell mass ratio drastically changes the response style [6]. Also glass/epoxy composite material is strongly strain-rate dependent. How these factors affect the response characteristics is to be further reported.

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