Optimization of Containment Shield using LS-DYNA

Lohith M S[1] Dr. B M Nandeeshaiah[2] Chandan R[3]
[1]P.G. Student [2]Professor [3]Assistant Professor
[1,2,3]Department of Mechanical Engineering
[1,2,3]Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka

Abstract— The potential hazard resulting from uncontained turbine engine rotor blade failure has always been the long-term concern of each aero engine manufacturer. Usually, there are many factors involving the engine containment capability which need to be reviewed during engine design such as; case thickness, rotor support structure, blade weight and shape. By using INCONEL 625 alloy which is austenitic nickel-chromium-based superalloy, which is resistant to oxidation and corrosion and this material is well suited for service in extreme environment i.e., subjected to high pressure and kinetic energy. The first structure was a flat plate representing a standard case configuration. The second structure was a flat plate with a convex curve section at the impact point. The curved surface was designed to force the blade to deform plastically, dissipating energy before the full impact of the blade is received by the plate. The curved geometry of the casing was able to tolerate the higher impact velocity before failure. The computation model was developed and study is performed using ANSYS –LS DYNA. The optimization of weight is considered, by optimizing the shape of the casing by plane geometry to the convex curve geometry of casing.

Key words: Containment Shield, INCONEL 625 Alloy, Shape Optimization, Weight Optimization

I. Introduction

For ensuring the crew and passengers safety, regulatory bodies such as, Federal aviation Federal Aviation Administration in the United States and the Joint Aviation Authorities in Europe decided that in commercial jet engines, a system must be present which will not allow compressor or turbine blade to perforate the engine casing during the event it is released from disk during the engine operation. This requirement made of safety shield, which made the fan case as the heaviest single part/component of an engine. The much more critical blade in the engine, in terms of the maximum kinetic energy is the nothing but the fan blade and the system which is designed to prevent the blade from penetrating the engine is called as the fan containment system. The fan containment system, which includes a cylindrical case, which surrounds the fan blades and the disk. In the modern high bypass turbine engines, the fan blades are large and due to large diameter of the fan section of the engine, the fan cases contribute majority of weight to the overall engine weight.

The geometry of the fan case may affect the containment response. A careful cautious selection of the geometry can improve the containment and efficiency, allowing for the case thickness reduction and reducing the engine weight. Turbine rotor failure occurs for a number of reasons, the primary one being fatigue due to normal engine operation in a high-temperature environment for a sustained period of time. In the modern jet powered commercial and military aviation, the major hazard is the failure of a turbine blade or the disc rotating with high speeds. The penalty for such an event can range from very minor to catastrophic, depending upon number factors and the circumstances. The fragments with high energy released during the turbine failure could damage fluid lines, airframes, control system hardware and such kind of events can affect the flying performance in a number of direct and indirect ways and some can lead to a loss of airplane and loss of hundreds of passengers.

Fig. 1: Fan containment ring with radial convex curve in its geometry.

A high level of quality control, inspection and maintenance procedures have kept these failures to a minimum, but statistics over the last 15 years indicate that the reliability approach has reached its limit and a certain number of turbine failures are bound to happen each year. Under such circumstances, it is necessary to develop preventive measures that will contain the high-energy fragments in a manner so that all potentially dangerous situations can be averted. Rotor failure produces both high-energy disc fragments and relatively low-energy blade fragments.

II. Problem Definition

Enhancing containment capability and reducing weight are always great concerns in the design of casings. Here we find the maximum blade speed that a particular geometry of the containment ring withstands before failure, and to find the amount of weight saving that could be done by change in the geometry of the casing.

III. Description of the Model

Two different geometries of the containment ring are considered to study the optimization of the containment ring. One is the plane geometry of the containment ring and the other is convex curve geometry of the containment ring. The containment rings are made of material INCONEL 625 alloy and the rotor blade is of a material INCONEL 718 alloy.

Internal diameter of the casing	344 mm
External diameter of the casing	350 mm
Thickness of the casing	3 mm
Width of the casing	100 mm
Mass of the casing	2.76 kg
Tip clearance	3 mm

Table 1: Geometric properties of the plane

The convex curve geometrical properties remain similar to the plane geometry. For the plane geometry of the containment ring, a convex curve is introduced. For the analysis purpose the height of the convex curve is varied from 5 mm to 10 mm to find the maximum stability. The width of the convex curve is 35 mm and the distance from both ends to the convex curve is 32.5 mm.

Density	8.19 gm/cm^3
Young's modulus	200 Gpa
Poisson's ratio	0.3
Yield stress	690 Mpa
Tangent modulus	4522 Mpa
Failure strain	0.2

Table 2: material property of the rotor blade

Density	8.44 gm/cm^3
Young's modulus	200 Gpa
Poisons ratio	0.3
Yield stress	355 Mpa
Tangent modulus	1265 Mpa
Failure strain	0.4

Table 3: material property of the containment ring

The purpose of convex curve geometry is, the energy absorbed by the rotor blade in the convex curved geometry initially lags the energy absorbed in the plane geometry due to its having to travel a little farther distance for the full contact to be done. Then as the rotor blade travels into the convex curved geometry, then its tips are bent backward, absorbing the energy. Since more of the total energy is absorbed by the rotor blades in the convex curved geometries, the containment ring structure is required to absorb less of the total impact energy.

Fig 2: The containment casing which shows the convex curve geometry

As a result, the containment ring structure can be made lighter, or used to absorb higher impact velocities.

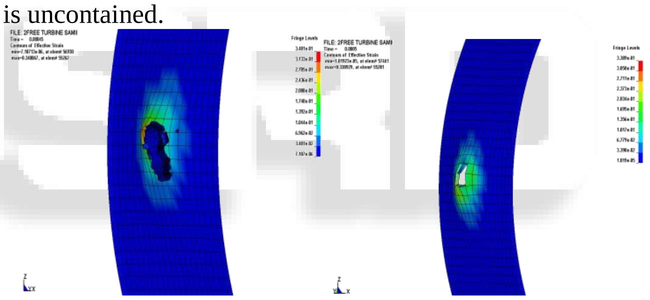
IV. ANALYSIS

The analysis is carried out in 4 different cases and it includes two different geometries, to study the effect of optimization of shape of the containment ring/fan blade casing. Fig3, Half section of the containment ring is considered for the analysis and it is carried out for 5 mili seconds. The single blade of the rotor is released to impact against the containment ring structure. The analysis is carried out using ANSYS LS-DYNA.

ANSYS LS-DYNA combines the LS-DYNA explicit finite element program with the powerful pre and post processing capabilities of the ANSYS program. The explicit method of solution used by LS-DYNA provides fast solutions for short-time, large deformation dynamics, quasi-static problems with large deformations and multiple nonlinearities, and complex contact/impact problems. Using this integrated product, we can model our structure in ANSYS, obtain the explicit dynamic solution via LS-DYNA and review results using the standard ANSYS post processing tools.

Fig. 3: Blade with containment ring with convex curve geometry.

The ANSYS/LS-DYNA explicit finite element transient dynamics analysis employed a piecewise linear plasticity material law with strain rate dependence to represent the nonlinear material behavior of the containment shell. In addition, segment-based eroding contact was defined between the disk fragments and the containment shell in order to be able to simulate penetration of the disk through the shell. Simulation sensitivity parameters included failure strain, mesh density and time step size. Case I. Considering Flat Geometry of the containment ring and varying the blade speed. The flat plate geometry of the containment ring is of 3 mm thickness. The rotor blade speed is varied from the speed of 21000 to 23750 rpm. The containment ring with flat geometry was able to contain the blade speeds ranging from 21000 rpm to 23500 rpm. At the speed of 23750 rpm the flat geometry of the containment ring fails to contain the blade. The blade impacting with high velocity displaces some elements of the containment ring completely and some of the elements of the blade pears through the containment ring ensuring the containment ring is uncontained.



Fig, 4: Deformation of the containment ring for the blade speed of 23500 rpm and 23750 rpm respectively.

Case II. Considering convex curve Geometry for the containment ring and varying the height of convex curve and the speed of blade. In this case we consider the convexcurve geometry for the containment ring replacing the flat plate geometry.

Height of convex curve	**Speed of blade**	**Damage description**
5 mm	25750	contained
	25850	Uncontained
6 mm	26000	Contained
	26250	Uncontained
7 mm	26750	Contained
	27000	Uncontained
8 mm	27250	Contained
	27500	Uncontained
9 mm	27350	Contained
	27500	Uncontained
10mm	26500	contained
	26750	Uncontained

Table 4: Behavior of convex curve geometry at different height and speed.

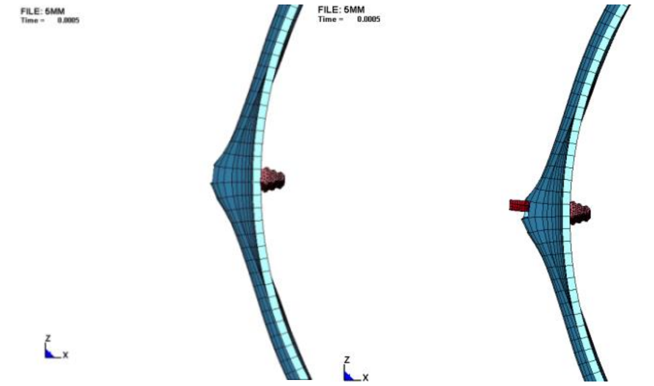


Fig. 6: condition of the containment ring at 5 mm thickness.

The thickness of the containment ring is 3mm, the height of the convexcurve is varied from 5mm to 10mm simultaneously the speed of the blade is varied. For the convex curve height of 5 mm, the containment ring was able to contain the blade speed of 25750 rpm. containment ring was able to contain the blade speed of 25750 rpm.

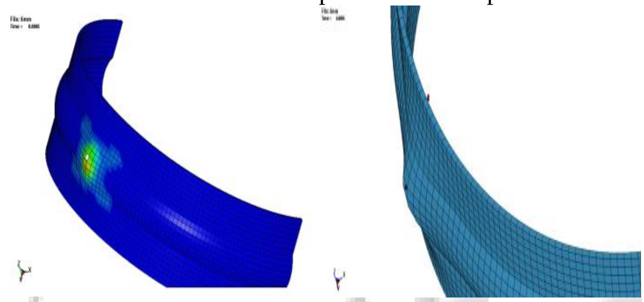


Fig. 7: condition of the containment ring at 6 mm thickness.

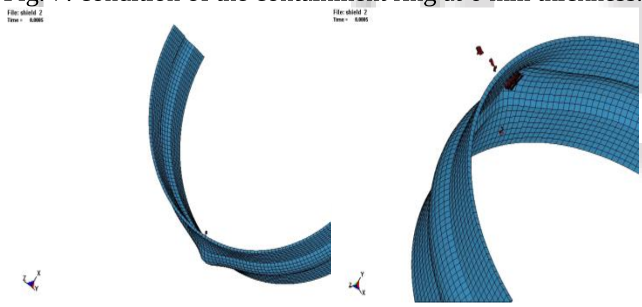


Fig. 8: condition of the containment ring at 7 mm thickness.

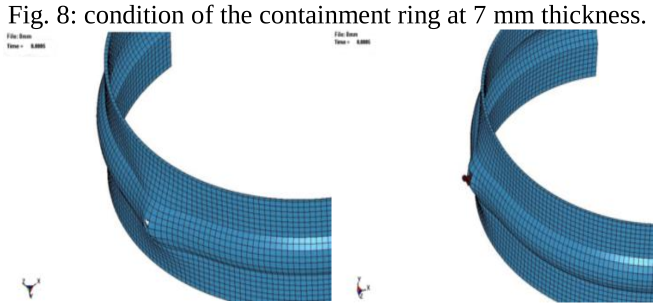


Fig. 9: condition of the containment ring at 8 mm thickness.

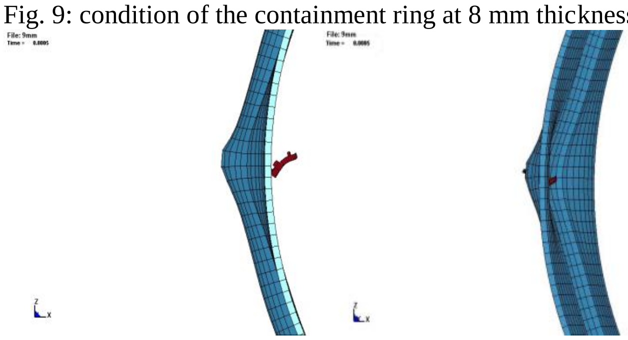


Fig. 10: condition of the containment ring at 9 mm thickness.

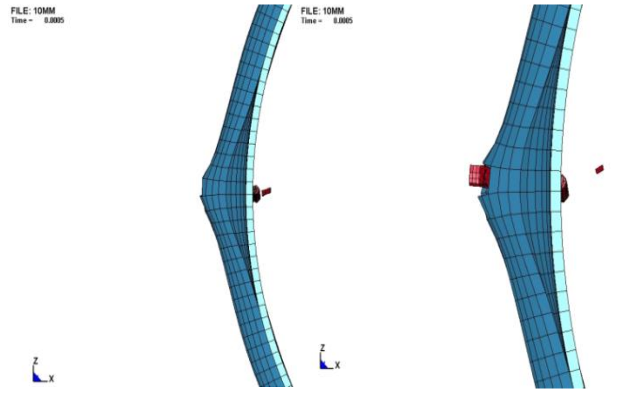


Fig. 11: condition of the containment ring at 10 mm thickness.

Case III. Considering plane Geometry, keeping the blade speed as constant and varying the thickness of the containment ring. In this case we consider the plane geometry with the blade impacting with the speed of 27350 rpm by varying the thickness of the containment ring. The convex geometry of 9 mm convexcurve height was able to sustain the maximum blade speed of 27350 rpm.

Here we find what should be the thickness of the plane geometry if it has to contain the speed of 27350 rpm. In the First case it is observed that the plane geometry of the containment ring with the thickness of 3mm was able to sustain the blade speed of 23500 rpm. The speed of the blade remains constant at 27350 rpm and the thickness of the containment ring considered are 3.5 mm and 3.75 mm.

The containment ring of 3.5mm was not sufficiently strong enough to contain the high speed blade, thus the blade with the speed of 27350 rpm was uncontained by the containment ring. The 3.75 mm thick containment ring was able to contain the speed of 27350 rpm. Case IV. Considering convexcurve Geometry, keeping the blade speed as constant and varying the thickness of the containment ring. In this case we consider the convexcurve geometry with the blade impacting with the speed of 23500 rpm by varying the thickness of the containment ring.

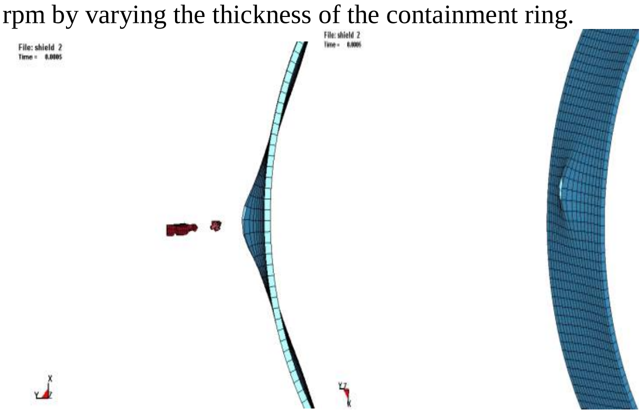


Fig. 12: condition of the containment ring at 3.5 mm and 3.75 mm thickness.

Here we find what should be the minimum thickness of the convexcurve geometry if it has to contain the speed of 23500 rpm. In the second case it is observed that the plane geometry of the containment ring with the thickness of 3 mm and convexcurve height of 9 mm was able to sustain the blade speed of 27350 rpm. The speed of the blade remains constant at 23500 rpm and the thickness of the containment ring considered are 2.5 mm and 2.25 mm.

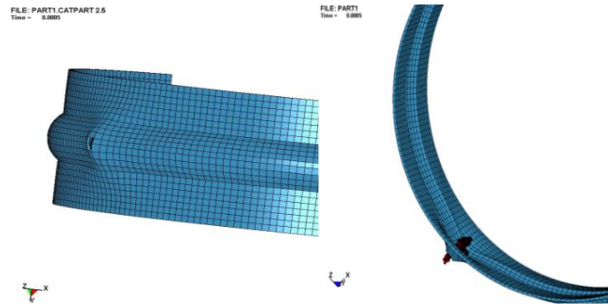


Fig. 13: condition of the containment ring at 2.5 mm and 2.25 mm thickness.

The containment ring with 2.5 mm was efficient enough to contain the blade speed of 23500 rpm impacting with the velocity of 303.18 m/s. The containment ring of 2.25 mm was not sufficiently strong enough to contain the high speed blade, thus the blade with the speed of 23500 rpm was uncontained by the containment ring.

V. RESULTS

The results of each cases are shown in the previous section. The use of convex curve geometry is, in convex curve geometry the blade undergoes curling motion after its impact with the containment ring. The ring also undergoes large plastic deformation even though the maximum plastic strain is below the effective plastic strain at the failure. In fig 14, the speed of blade is plotted against the curvature of the containment ring as in case II, we can notice that the speed of blade that can be sustained by the each convex curvature, the convex curve of 9mm is able to contain the speed of 27350 rpm while the rest of the radius of convex curvature fails to contain maximum speed but while increasing the radius of curvature to 10 mm the casing fails to contain the maximum speed and able to contain the speed of 26500 rpm.

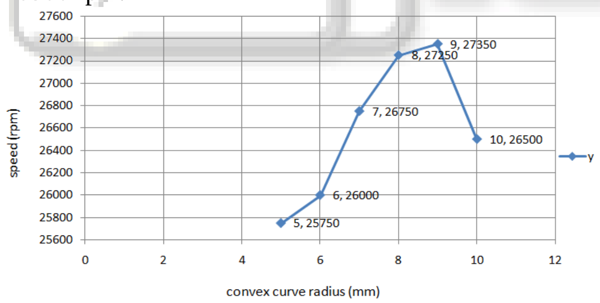


Fig. 14: speed of blade vs. curvature of the containment ring.

In case III, The speed is taken from the convex curve geometry of casing 9 mm which is able to contain the maximum speed of 27350 rpm. The analysis is run for the speed of 27350 rpm and the thickness is increased to 3.5 mm, the casing fails to contain.

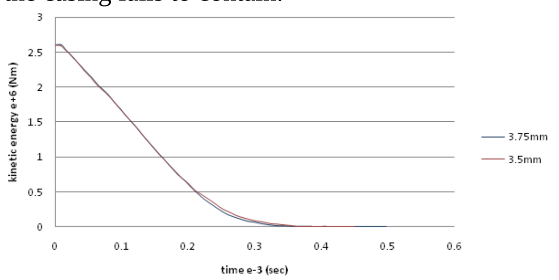


Fig. 15: kinetic energy variation of blade speed (27350 rpm) with time on flat geometry.

The next run is made for the thickness of 3.75mm and the casing is able to sustain the blade speed of 27350 rpm. Kinetic energy variation in Fig.15 is same for these two cases for about little more than 0.2 ms, the casing of thickness 3.75 mm receives the initial strike from the blade and the blade leaves an indentation in the containment ring.

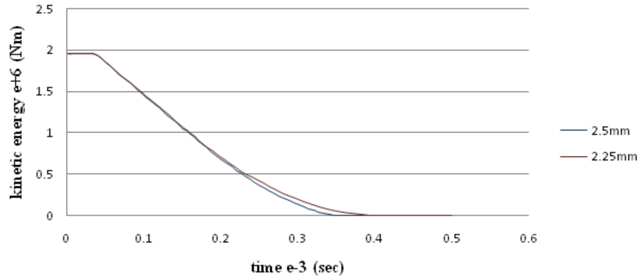


Fig. 16: kinetic energy variation of blade speed (23500 rpm) with time on convex curve geometry.

When the thickness of the ring is reduced to 3.5 mm the casing thickness is not sufficient to contain the speed of blade, which results in failure of the containment ring catastrophically. In case IV, by introducing the convex curve geometry and the thickness of 2.75 mm, casing was able to contain the same speed. Kinetic energy variation is same for these two cases for about little more than 0.2 ms, the casing of thickness 3.75 mm receives the initial strike from the blade and the blade leaves an indentation in the containment ring.

Thickness	Speed(rpm)	Geometry	Damage Description	Weight of containment ring (kg)
3mm	23500	Flat	Contained	2.7602
	23750	Flat	Uncontained	
3mm	27350	Convex curve of radius 9mm	Contained	2.7955
	27500	Convex curve of radius 9mm	Uncontained	
3.75mm	27350	Flat	Contained	3.4584
3.5mm	27350	Flat	Uncontained	
2.5mm	23500	Convex curve of radius 9mm	Contained	2.3262
2.25mm	23500	Convex curve of radius 9mm	Uncontained	

Table 5: Result of weight optimization by optimizing shape of the containment ring.

The mass of the casing with plane geometry in case I is 2.7602 kg which sustains the blade speed of 23500 rpm, the mass of the casing with convexcurve geometry in case II is 2.7954 kg which sustains the speed of 27350 rpm. In case III the casing of plane geometry sustains the speed of 27350 rpm will have the thickness of 3.75 mm will have the mass of 3.4583 kg, to sustain the same speed of 27350 rpm with convex curve geometry and the plane geometry the mass of the containment ring is increased by 0.6628 kg, there by using the convex curve geometry for the speed of 27350 rpm the mass of the containment ring is reduced by 0.6628 kg.

VI. CONCLUSION

A transient dynamic, nonlinear finite element method is used to analyze the impact force of high speed blade on ring type containment structure. INCONEL nickel-chromium alloy 625 is used for its high strength, excellent fabricability, outstanding corrosion resistance and can used under elevated temperatures. The use of engine containment with a convex curved geometry to increase the containment efficiency has been demonstrated in this analysis.

By using the convexcurve geometry over the plane geometry to sustain the speed of 23500 rpm, the mass of the containment ring is reduced by 0.434 kg and for the blade speed of 27350 rpm the mass of the containment ring is reduced by 0.6628 kg. The observed advantage is obtained by radial convex curve geometry over the flat plate geometry, it is due to energy that is absorbed by the plastic deformation of the blade tips as they impact the convex curved surface. The results obtained from models shows an increase in the containment capability using the radial convex curved geometry.

There by using the convexcurve geometry could lead to a significant weight savings in the containment of the turbine fan and in turn reduces the weight of the engine.

VII. Scope for Future Work

The alloy material used for the fan case is INCONEL 625 and for the blade is INCONEL 718 and the design of convex curve geometry is used for the analysis. As a future work, different super alloys can be used and the design of fan case can be further improved for the better performance and obtain accurate results for determining the failure of the fan case and contain the blade and its fragments damaging the engine and its parts and reducing the overall weight of the engine.

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