Finite Element Model of Large Civil Aircraft Engine for the Evaluation on Its Impact to the Nuclear Power Plant Structures

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1. Introduction

Concern about the safety evaluation on the large civil aircraft impact to the nuclear power plant (NPP) structures has been increased after the aircraft impact to the World Trade Center. Researches on accident of the large civil aircraft impact to the NPP structures have been continued in local and foreign institutes. In 2010, the US Government specified that an obligatory safety evaluation on the aircraft impact shall be carried out for NPP structures to be constructed in the future. This study is ongoing as one of the studies accomplishing the safety evaluation of aircraft impact to the NPP structures.

2. Evaluation methods on aircraft impact

Before the aircraft impact to the WTC, studies on aircraft impact accidents and the safety evaluation of the NPPs impacted by an aircraft were accomplished by the few and were focused on the safety evaluation related with the high speed (215m/sec) impact test of a full-sized military aircraft or its actual engine (GE-J79) to reinforced concrete wall [1]. For the large civil aircraft, high speed impact test with a full-sized aircraft or its actual engine has never been accomplished globally but the safety evaluation by numerical approaches using mainly finite element analysis program have been accomplished [2-4]. These numerical approaches are being accomplished by applying the external forces using the impact load-time history curves proposed by Riera [5], or recently solving the explicit nonlinear dynamics which are implementing the direct impact/contact between the large civil aircraft model and the structure model. In these methods, the most finite element models of the large civil aircraft are guessed using shell elements geometrically coinciding to the aircraft figure with appropriate stiffness and mass.

3. Evaluation methods on aircraft engine impact

One can say that the impact load induced by aircraft engine is larger than that induced by aircraft fuselage or wing part, because the aircraft engine is most heavy and strong part in the aircraft. However, the impact effects by the aircraft engine cannot be considered directly or severely in the evaluations on the NPP-large civil aircraft impact by using Riera curves. To quantify the impact load of the large civil aircraft engine, it is the best way to do the high speed impact test of full-scaled actual engines but this seems to be unrealistic or infeasible. A practical alternative in spite of many limitations and restrictions is to accomplish the impact analysis using a detailed finite element model by solving explicit nonlinear dynamics. With this approach, impact analyses or proposal of impact load are accomplished by NIST [3] and CRIEPI [6]. NIST accomplished aircraft impact analyses to WTC towers with a detailed FE model of Boeing 767 aircraft and its popular engine PW4000-94, shown in Fig.1, manufactured by Pratt & Whitney Company. CRIEPI also accomplished spent nuclear fuel storage facilities structural evaluation under aircraft crash impact with a detailed FE model of an aircraft engine CF6-80C2, shown in Fig.2, manufactured by General Electric Company. According to the report published by NIST, as shown in Table I, the engines JT9D-7R4, PW4000-94 and CF6-80C2 adopted in the large civil aircrafts including Boeing 767 are similar in sizes, weights and shapes.

Table I: Boeing 767 engine comparison [3]

Model	PW4000-94	JT9D-7R4	CF6-80C2
Blade Dia.	94in	94in	93in
Length	153in	153in	161-168in
Dry weight	9,400lb	8,885lb	9,135-9,860lb

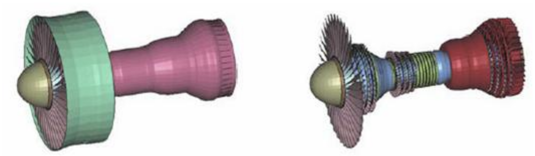

Fig 1. FE model of PW4000-96 proposed by NIST[3].

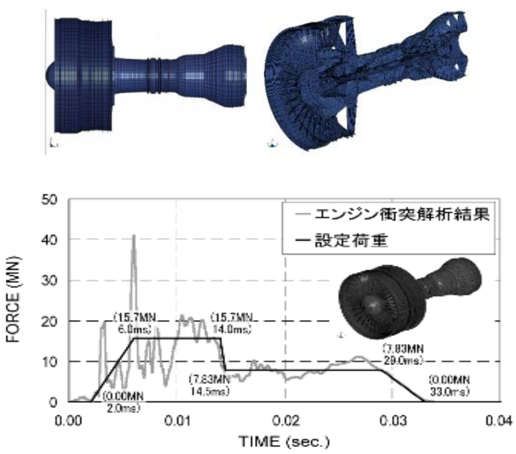

Fig 2. FE model of CF6-80C2 and its impact load-time history curve proposed by CRIEPI [6].

4. Proposed FE model and impact load-time history

In this study, a detailed FE model of PW4000-94 among the engines adopted in the large civil aircraft including B767 is preliminarily developed. The large civil aircraft engine is typically a turbo fan engine and has the shapes as shown in Fig. 3. Turbo fan engine generally has 4 major components with coaxial shaft structures: Lower Pressure Compressor including the large fan and Lower Pressure Turbine with one shaft, and high pressure compressor and High Pressure Turbine with another shaft.

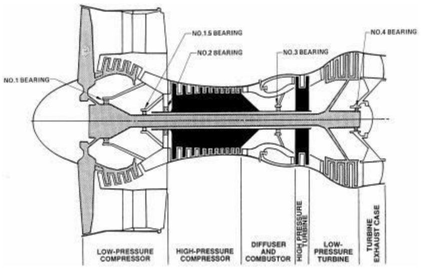

Fig 3. Cutaway view of turbo fan engine.

The proposed FE model of the engine has total 75,800 nodes and 60,000 shell and 44,700 solid elements shown in Fig 4. The largest size of one element does not exceed 1.5inch, i.e., 3.75cm. Total weight is tuned to be 9,400lb (4,264kg) of the specified dry weight of the engine. The deformed configuration of the engine just after impact to the rigid wall with velocity of 60m/sec is also shown in Fig 4. The computed and averaged impact load-time histories are compared with that of the CRIEPI model in Fig 5. Finally the impulse time histories are shown in Fig. 6.

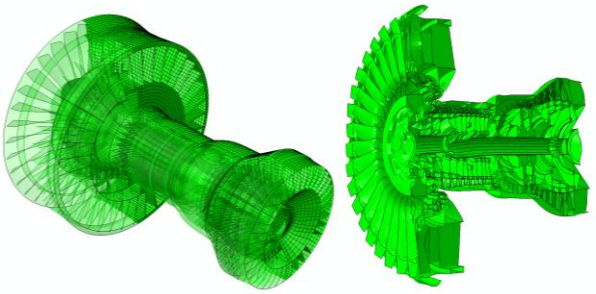

Fig 4. Proposed FE model and deformed configuration.

5. Conclusions

Evaluation on impact load of a large civil aircraft engine (PW4000-94) impacting to rigid wall by numerical analysis method has been performed. The results show some differences in peak value and impact time in comparison to that proposed by CRIEPI. It is thought that these differences might be caused by the finite element modeling details, and the impulses do not have large differences from theoretical ones. Also it may solidify the foundation so that the evaluation on the large civil aircraft engine impact and its secondary impact to structures is possible indirectly, not by the high speed impact test of full-sized actual engine. More advanced and detailed modeling on a large civil aircraft and its engine is ongoing.

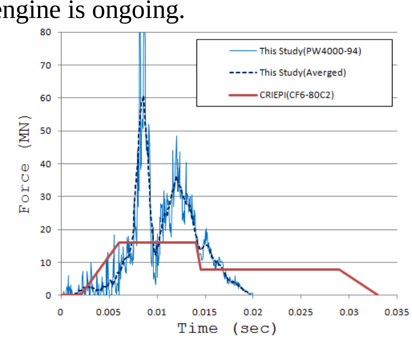

Fig 5. Comparison of impact load-time histories.

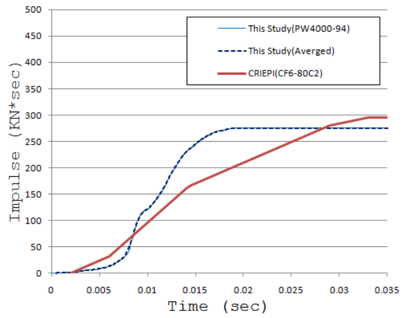

Fig 6. Comparison of impulse time histories.

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REFERENCES

[1] T. Sugano, H. Tsubota, Y. Kasai, N. Koshika, H. Ohnuma, W.A. von Riesemann, D.C. Bickel and M.B. Parks, Local Damage to Reinforced Concrete Structures Caused by Impact of Aircraft Engine Missiles, Nuclear Engineering and Design 140, p.387-405, 1993.
[2] Daewoo Institute of Construction Technology, Resistance Ability Evaluation of Safety-Related Structures for the Simulated Aircraft Accident, KINS/HR-654, KINS, 2005.
[3] Analysis of Aircraft Impacts into the World Trade Center Towers, Federal Building and Fire Safety Investigation of the World Trade Center Disaster, NIST NCSTAR 1-2B, NIST, 2005.
[4] Y. Takeuchi, Aircraft Collision Study to the SB Air-inlet Portion, APP-1000-S2C-84, Westinghouse, 2007.
[5] J.D. Riera, On the Stress Analysis of Structures Subjected to Aircraft Impact Forces, Nuclear Engineering and Design, Vol.8, p. 415-426, 1968.
[6] K. Namba, K. Shirai and T. Saegusa, Structural Evaluation of Spent Nuclear Fuel Storage Facilities under Aircraft Crash Impact-Numerical Study on Evaluation of Sealing Performance of Metal Cask subjected to Impact Force, CRIEPI Research Report N07040, CRIEPI, 2008.