PREDICTION OF BREAK-OUT PATTERNS FOR AIRCRAFT CANOPIES FRAGILIZED MECHANICALLY OR WITH DETONATING CORD

By

Rocky Richard Arnold
Patrick S. Collins

Leapfrog Technologies, Incorporated
One Waters Park Drive, Suite 231
San Mateo, CA 94403

Presented at the
1996 MSC World Users' Conference
Newport Beach, California

June 3-7, 1996

PREDICTION OF BREAK-OUT PATTERNS FOR AIRCRAFT CANOPIES FRAGILIZED MECHANICALLY OR WITH DETONATING CORD

Rocky Richard Arnold
Patrick S. Collins

Leapfrog Technologies, Incorporated
San Mateo, California

ABSTRACT

This paper presents a methodology for predicting the fragilization behavior of aircraft canopies subjected to either mechanical loading or explosive pressures, or both. Fragilization refers to the process whereby an intrinsically strong and tough polymer canopy material (such as stretched-acrylic or polycarbonate) is cracked, damaged or otherwise weakened in such a manner as to destroy its resistance to mechanical loading created by an egressing pilot or crewmember. The approach adopted uses MSC/NASTRAN as the foundation of a computational procedure that uses fracture mechanics principles to predict crack generation, growth, and propagation (including branching). The computational procedure, called PACE, for Program for Automatic Crack Extension, automatically reconstructs finite element grids according to the growth of crack(s). MSC/NASTRAN is used to predict the dynamic state of stress at, and around a crack tip(s), and PACE includes fracture mechanics modules which use the existing stress state to predict propensity for further cracking. The entire process is automated allowing users to perform a complete analysis without concern for the need for new finite element meshes. At conclusion, the trace of cracks provides the break-out pattern. Ideally, the break-out pattern generates small pieces of material which are estimated to not be harmful to the pilot and crewmembers. This paper reviews the progress of work accomplished to date.

INTRODUCTION

Aircraft canopies (or transparencies) are designed to provide both high visibility and resistance to damage from foreign objects (i.e., birds, projectiles, etc.). The trend in aircraft canopy design is towards stronger, tougher, and thicker canopies; however, for emergency situations in which immediate pilot and crew escape are required, there is an emerging need for systems which fragilize, or noticeably weaken, the canopy prior to ejecting the crewmember through the plastic. Existing methods of escape relying upon either ejection of the canopy or destruction via the use of detonating appliqués are not adequate as they neither provide immediate egress nor are they completely safe.

Design of aircraft canopies, historically, has been largely based on prior experience, good engineering judgment, and a relatively large amount of testing. With experienced canopy designers in short supply, experience has declined. The emergence of new canopy materials and new requirements has left existing designers with complicated problems involving difficult trade-offs between visibility, strength, resistance to bird-strike damage, and crew safety. The drive towards lighter aircraft is leading towards pressure to reduce weight associated with some systems, notably, those systems which involve the complete removal of a canopy prior to ejection of the pilot or crewmember. In addition, the Navy has special problems associated with the need to immediately eject a pilot if that pilot encounters a situation where his/her aircraft may hit the end of a pitching/rolling carrier. Time is of the essence, and only egress systems which push the pilot through the canopy are fast enough.

Through the canopy ejection systems necessitate that the canopy be fragilized just prior to egress otherwise the pilot could be injured or killed. This secondary ejection system (the first is removal of the canopy followed by ejection) is becoming the desired goal of a primary system. Thus, a fragilization system must be reliable, safe, lightweight, and cost-effective if future fighter aircraft are to realize the benefits of modern technology.

PROBLEM DEFINITION

New systems for fragilizing transparencies (e.g., mechanical breakers and/or explosive devices) are difficult to design, engineer, and assess prior to full-scale testing because predictive capabilities for the behavior of the transparencies are lacking. Thus, a need exist for design/analysis software that can predict the frangibility of aircraft canopies under a variety of differing mechanical and explosive forces (as from detonating cord). The software must be able to predict crack initiation, crack propagation, and multiple crack events for a three-dimensional curved structure such as a canopy. Furthermore, given the effect that propagating cracks have on the global structural response of a canopy, crack tracking and continual computation of the local and global stress states is required. Calculations of stress state and crack topology must be automatic. New finite element meshes must also be generated automatically to allow designers the ability to evaluate multiple design options in the fastest time possible.

DISCUSSIONS

The work discussed herein discusses a predictive approach for aircraft canopies that relies upon the close cooperation of MSC/NASTRAN and fracture mechanics to predict the growth of crack(s) and their propagation. Most significantly, the program (PACE) includes a re-meshing algorithm that automatically re-derives a new finite element mesh after each cycle of crack growth. This enables the user to perform analysis relatively effortlessly. In an earlier paper [1], the authors described the overall functionality of PACE and provided correlation between PACE and flat plate experiments. Those earlier studies showed that, qualitatively, PACE was performing as intended. Given the degree of random behavior associated with crack propagation, it is difficult to establish precise correlation in a quantitative fashion between predictions and experiments; nevertheless, the intent of PACE is to provide designers with an ability to evaluate design alternatives in an analytical fashion. Hypothetically, a designer could establish a number of potential designs (e.g., configurations of mechanical breakers and detonating cord patterns) for analysis with PACE. Once the analysis is completed, break-out patterns for each design could be examined from which the designer, using various criteria such as fragment size, degree of fragilization, etc., could select the best designs for further analysis. Through a process of analysis, evaluation, and iteration, several best designs would be developed for experimental evaluation. Such a process reduces greatly the expense associated with full-scale evaluation (estimated at over $100,000 per test), reduces the time dedicated to initial design (from many months to perhaps one month), and enables the more consistent design of new canopy fragilization systems.

The general computation process is reviewed In Figure 1. As depicted in the lower left-hand corner of the figure, the designer/analyst provides an initial finite element model complete with specifications of boundary conditions, environmental conditions, loads, material properties, and normal and special geometrical or construction details that felt to be germane to the problem. Next, the analyst performs an analysis without detonating cord (DC). The initial finite element analysis provides information about deformations, strains, stresses, and strain energy distributions throughout the model (structure). In the next step, the designer/analyst would rely upon engineering judgment to specify an initial configuration for the detonating cord (and mechanical breakers if such was a design option). Based upon this initial specification, the damage created from the detonating cord (based on experimental observations) would be modeled with crack(s) and crack-tip elements implanted into the finite element mesh (automatically by PACE). The next analysis using MSC/NASTRAN would provide information about the state of stress around the crack tip. These stresses would be used by the PACE fracture mechanics modules to predict the propensity of the crack to propagate, in what direction, and how far. Crack branching would also be predicted. The finite element mesh would be re-created to model the new cracks. The process of iteration in which new cracks are formed and old cracks continue to propagate, branch, or become arrested is continued until the canopy is fragilized sufficiently for the designer/analyst to understand the result of placing the detonating cord in the locations chosen.

A finite element mesh of an F-18 canopy is shown in Figure 2. The model, approximately 1000 elements in size, is being used to evaluate the software being developed. Once developed, models would be larger (perhaps 2,000 elements). MSC/NASTRAN is used to perform the stress analysis which is required each time a new finite element mesh and included crack elements are generated.

The three-dimensional canopy is “mapped” into a two-dimensional space for which PACE’s fracture mechanics predictive algorithms are valid. Predictions made in the two-dimensional space (e.g., predictions of crack growth directions, branching, and amount of propagation) are then translated back to the original three-dimensional mesh. This mapping permits three-dimensional structures to be modeled within the context of two-dimensional fracture mechanics and the associated two-dimensional crack-tip element used within MSC/NASTRAN.

CONCLUSIONS

Presently, PACE is under development. The basic functionality depicted in Figure 1 is established and work with PHIGS software from DEC is underway. The intent of the graphical interface is to allow designers/analysts the opportunity to intercede in the computational process to review results, change finite element mesh topology (to preempt the use of obviously inferior mesh topologies), and, in general, control the progress of the analysis. When operational, PACE would likely reside on a supercomputer allowing analysis to proceed quickly. It is estimated that several hundred to a thousand iterations would be required to execute a complete analysis.

ACKNOWLEDGMENTS

The authors would like to thank the Naval Air Warfare Center, U.S. Navy, Warminster, Pennsylvania for their support under the auspices of a DoD Small Business Innovation Research (SBIR) contract. MSC has provided important assistance with the effort by granting access to the MSC/NASTRAN computer code. MSC’s interest in this work is duly noted and appreciated.

REFERENCES

1. Arnold, R. R., Collins, P. S., Ayoub, P. S., and Tung, R., “Methodology for Predicting Canopy Fracturing Patterns During Ejection,” Fracture Mechanics: Twenty-Fourth Symposium, ASTM STP 1207, John D. Landes and D. E. McCabe, Eds., American Society for Testing and Materials, Philadelphia, 1994, pp xxx.

Methodology for Predicting Canopy Fracturing Patterns During Ejection
(Navy Contract N62269-89-C-0210)

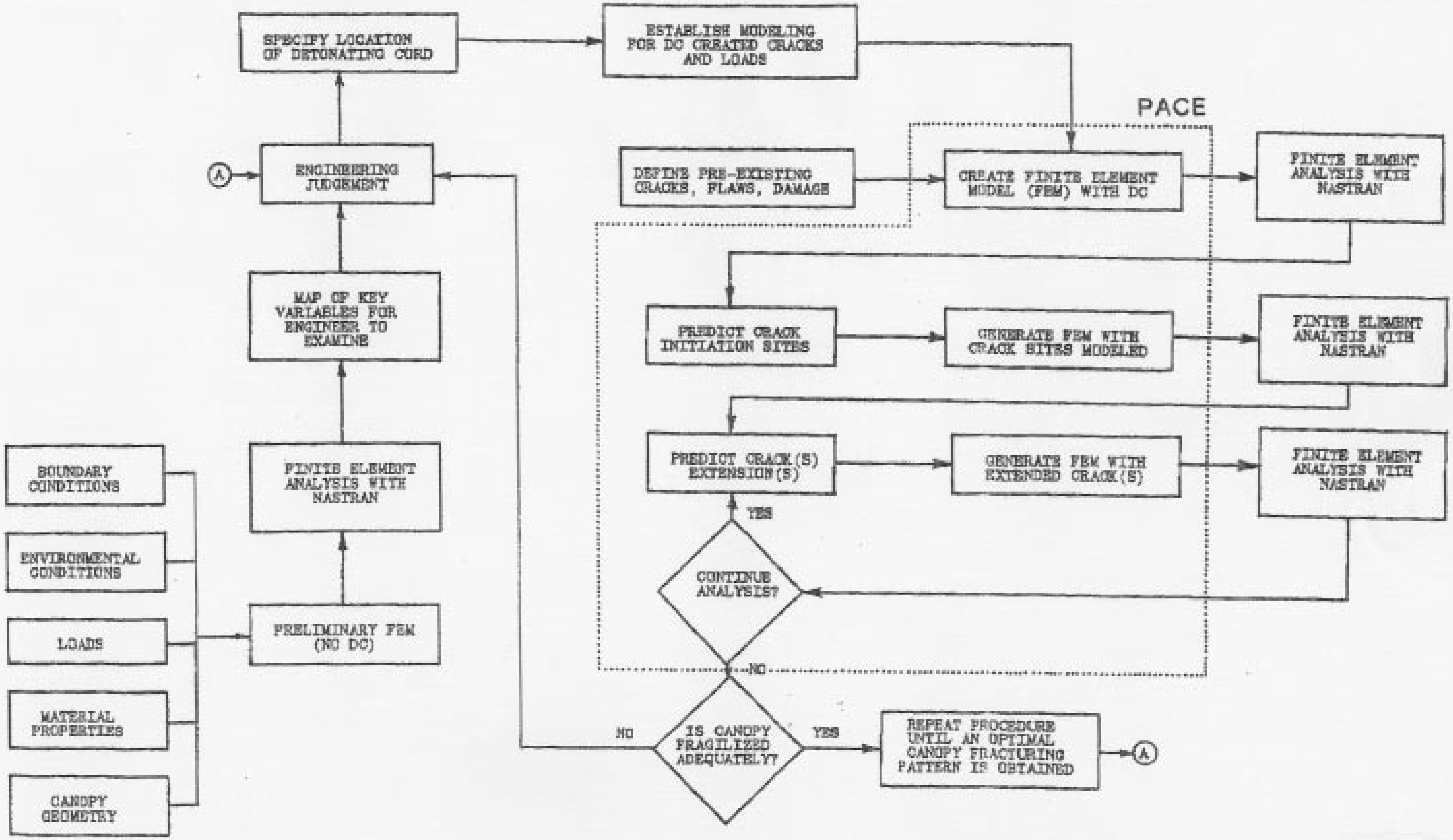

Figure 1 Schematic of PACE Computational Flow

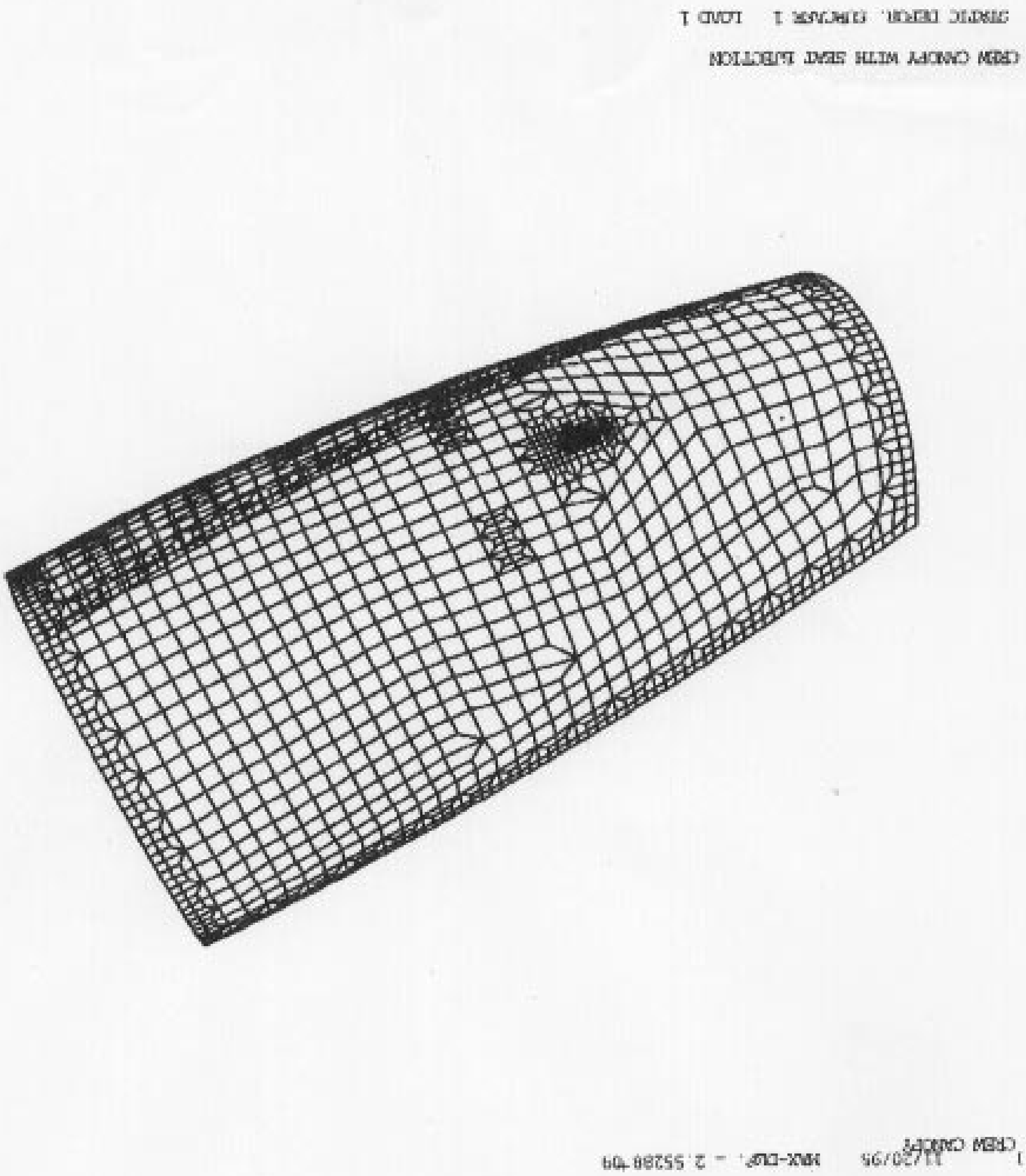

Figure 2 Finite Element Mesh of F-18 Canopy