

COUPLING OF CFD AND CSM CODES FOR THE STUDY OF PROJECTILE RESPONSE TO BALLISTICS ENVIRONMENT

Stephen E. Ray*

Army High Performance Computing Research Center (AHPCRC)
Minneapolis, MN 55415

James F. Newill, Michael J. Nusca, Albert W. Horst
U.S. Army Research Laboratory (ARL)
Aberdeen Proving Ground, MD 21005

ABSTRACT

The state-of-the-art interior ballistics (IB) code for the Army, ARL-NGEN3, is being used to predict the interior ballistics behavior of next-generation gun charges, which include densely-packed solid propellants. Recently, the results from ARL-NGEN3 code simulations were linked to structural dynamics codes in order to predict the in-bore behavior of the projectile afterbody. In the current paper results are presented from recent efforts to bring together the capabilities of ARL-NGEN3 and two of the prominent structural mechanics codes, DYNA3D and EPIC. Results from simulations of a test case show the effectiveness of this approach.

1. INTRODUCTION

An ongoing research effort between the US Army Research Laboratory and the Army High Performance Computing Research Center involves bringing together numerical models with different yet complementary capabilities and using these codes to study complex munitions systems (Newill, et al., 2004). One system of high interest is the smart munitions suite of the Army's Future Combat Systems. Densely packed charges can have poor burning characteristics that cause large pressure waves moving axially around the projectile afterbody. These pressure waves can cause damage to the electronics of a smart projectile. The authors are studying numerical means of predicting the size of pressure waves within the combustion chamber and the response of the projectile to this loading.

2. METHODOLOGY

The current state of the art interior ballistics code is ARL-NGEN3 (Nusca, 2002), and it is used in this work to predict the propellant combustion. ARL-NGEN3 is a multi-dimensional, multi-phase computational fluid dynamics code capable of modeling flamespreading and combustion in advanced direct-fire and indirect-fire gun

propulsion systems. The code uses a coupled Lagrangian-Eulerian approach, enabling it to simulate both the continuous component of the flow (gases) and the discrete component (solid propellant). ARL-NGEN3 predicts the propellant combustion and resulting pressure load on the projectile afterbody.

The mechanical response of the afterbody to the pressure load is predicted by two advanced solid mechanics codes, DYNA3D (Whirley, et al., 1993) and EPIC (Johnson, et al., 2003). They are among the foremost computational structural mechanics (CSM) codes available today. They are both finite-element-based Lagrangian hydrocodes, although the codes use different algorithms in some of their features, a notable example being the contact algorithms used by the codes. Both codes are currently being used in this work in order to determine the relative strengths and weaknesses (if any) of the codes in simulating this class of applications.

Presently, the ARL-NGEN3 code is coupled to the CSM codes using a one-way coupling technique. That is, the IB data produced by ARL-NGEN3 is used to drive the CSM simulations while an indication of possible structural deformation and failure, coming from the CSM code, does not affect the IB simulation. Future refinements to this technique are being investigated.

3. RESULTS

The test case involves a notional case telescope ammunition (CTA) projectile with a large afterbody intruding into the combustion chamber. ARL-NGEN3 was used to predict the combustion of the granular JA2 propellant initially placed around and behind the projectile afterbody. There were initially small amounts of M1 and black powder at the breech end of the chamber for igniting the charge. Figure 1 shows the color pressure contours (blue to red: 0 to 85 kpsi) and velocity vectors at 2.4 ms into the dynamic simulation. Figure 2 shows the computed pressure-time data on the chamber wall at the points labeled "R", "M", and "F" in Figure 1. The double

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 00 DEC 2004		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Coupling Of Cfd And Csm Codes For The Study Of Projectile Response To Ballistics Environment				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Army High Performance Computing Research Center (AHPCRC) Minneapolis, MN 55415; U.S. Army Research Laboratory (ARL) Aberdeen Proving Ground, MD 21005				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM001736, Proceedings for the Army Science Conference (24th) Held on 29 November - 2 December 2005 in Orlando, Florida. , The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 2	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

peaks of the curves in Figure 2 combined with the magnitude of the peak pressure indicate that there are large pressure waves moving longitudinally during the firing cycle.

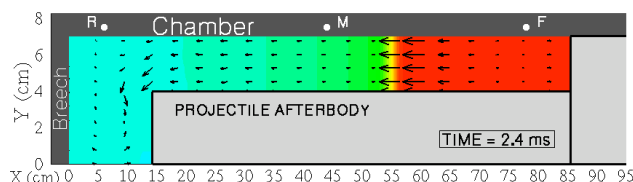


Figure 1. Pressure contours and velocity vectors at 2.4 ms predicted by the ARL-NGEN3 code.

Such waves pose a challenge for the design of the projectile. Determining the structural response of the projectile tail to these waves aids in the design process. The notional CTA projectile was given the front end shown in Figure 3. The resulting projectile is not used in any ammunition of current interest, but its use should point to and allow the study of issues facing other deeply intruding projectiles.

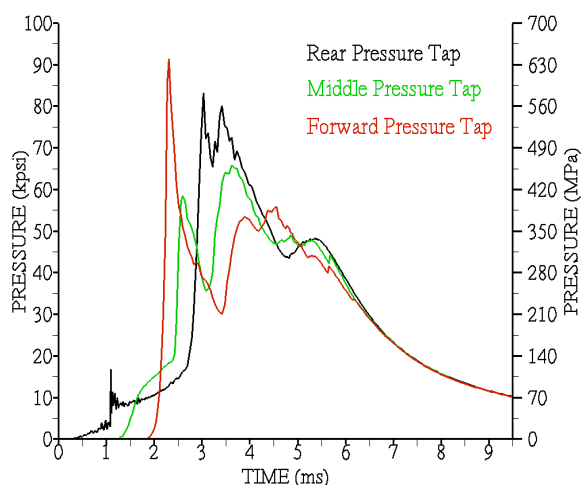


Figure 2. Pressure-time data computed by ARL-NGEN3 at three points in the combustion chamber.

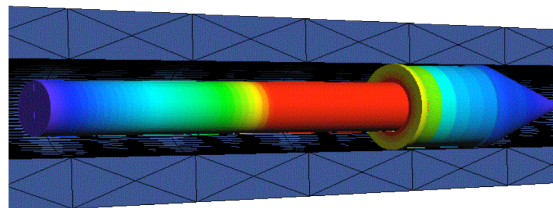
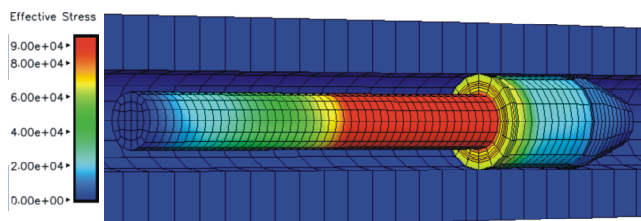


Figure 3. Equivalent strain in the projectile at 2.4 ms, DYN3D (left), EPIC (right).

Figure 3 shows the equivalent stress in the projectile at 2.4 ms into the dynamic simulation using the DYN3D and EPIC codes. The meshes used by the codes are not identical, but they do have comparable element sizes. The large red regions (i.e., 90 ksi) show that both codes predict that the projectile, if made of typical materials and having a reasonable amount of cargo space, would fail under this pressure loading. These results and others not included here indicate that the data from the CSM codes agree quite well. Further comparisons will be made.

ACKNOWLEDGMENTS

The research reported in this document was performed in part in connection with contract DAAD19-03-D-0001 with the U.S. Army Research Laboratory. The DoD Major Shared Resource Center (ARL) supplied computing time.

REFERENCES

- G.R. Johnson, S.R. Beissel, R.A. Stryk, C.A. Gerlach, T.J. Holmquist, *User Instructions for the 2003 Version of the EPIC Code*, Network Computing Services, Inc. Minneapolis, MN, Contract Report F08630-02-M-0077, October 2003.
- J.F. Newill, M.J. Nusca, and A.W. Horst, "Advances in Coupled Projectile-Dynamics/ Interior-Ballistics Simulations: Coupling the DYN3D Code and the ARL-NGEN3 code", *Proceedings of the 21st International Symposium on Ballistics*, Adelaide, South Australia, April 2004.
- M.J. Nusca, "High Performance Computing and Simulation for Advanced Armament Propulsion," *Proc. of the 23rd Army Science Conference*, Orlando, FL, 2-5 Dec 2002.
- R.G. Whirley, D.E. Englemann, and J.O. Hallquist, *DYN3D: A Nonlinear, Explicit, 3-D Finite Element Code for Solid and Structural Mechanics – User's Manual*, Lawrence Livermore National Lab Report UCRL-MA-107254, Livermore, CA, November 1993.