UNCLASSIFIED

AD

AD-E403 499

Technical Report ARMET-TR-13004

SIMULATION OF A CANARD IN FLUID FLOW DRIVEN BY A PIEZOELECTRIC BEAM AND A SOFTWARE CONTROL LOOP

L. Reinhardt
P. Carlucci
A. Haynes

April 2014

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Munitions Engineering Technology Center

Picatinny Arsenal, New Jersey

Approved for public release; distribution is unlimited.

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-01-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (*From - To*)
April 2014	Final	December 2011 to January 2012

4. TITLE AND SUBTITLE

SIMULATION OF A CANARD IN FLUID FLOW DRIVEN BY A PIEZOELECTRIC BEAM WITH A SOFTWARE CONTROL LOOP

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHORS

L. Reinhardt, P. Carlucci, and A. Haynes

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army ARDEC, METC
Fuze and Precision Armaments Technology Directorate
(RDAR-MEF-E)
Picatinny Arsenal, NJ 07806-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army ARDEC, ESIC
Knowledge & Process Management (RDAR-EIK)
Picatinny Arsenal, NJ 07806-5000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

Technical Report ARMET-TR-13004

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

To model today's complex systems requires the ability to combine multiple physical phenomena. The objective of this report is to model the actuation of a canard that could be used to control a projectile. To include the fluid solid interaction, a finite element model of the canard has been interfaced with the computational fluid dynamics code, which models the fluid flow. The canard is actuated by a piezoelectric beam that bends as voltage is applied. The voltage is controlled by a software subroutine that measures the angle of the canard and uses the value of that angle to calculate a new voltage. The combined fluid solid interaction was successfully combined with electrical control to fully model the actuation of a canard in a fluid flow.

15. SUBJECT TERMS

Canard Closed loop control system Dynamic system Modeling Co-simulation Simulation Abaqus Finite element analysis (FEA) Finite element method (FEM) Computational fluid dynamic (CFD) Fluid structure interaction (FSI)

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			L. Reinhardt
U	U	U	SAR	15	19b. TELEPHONE NUMBER (Include area code) (973) 724-5850

CONTENTS

FIGURES

INTRODUCTION

Multiple physical phenomena can be simulated with closed loop controls. There are applications throughout the industry from robotics to flight control systems. This can include the physics of thermal, structural, and fluid flow, which can be combined with software simulations of a control system.

A structural finite element analysis (FEA) has been coupled with a computational fluid dynamic (CFD) analysis. The FEA and CFD analyses were run simultaneously using co-simulation. Both of these analyses interact with a user subroutine that simulates a control system. In this demonstration model, the canard is rotated (fig. 1) using a piezoelectric beam and, as the beam bends, the canard rotates. Voltage differences control the amount of bending in the beam. The voltage is controlled by a user subroutine that reads the angle of the canard and then varies the voltage to reach the target angle. The CFD analysis applies a load on the canard due to the flow of fluid around it.

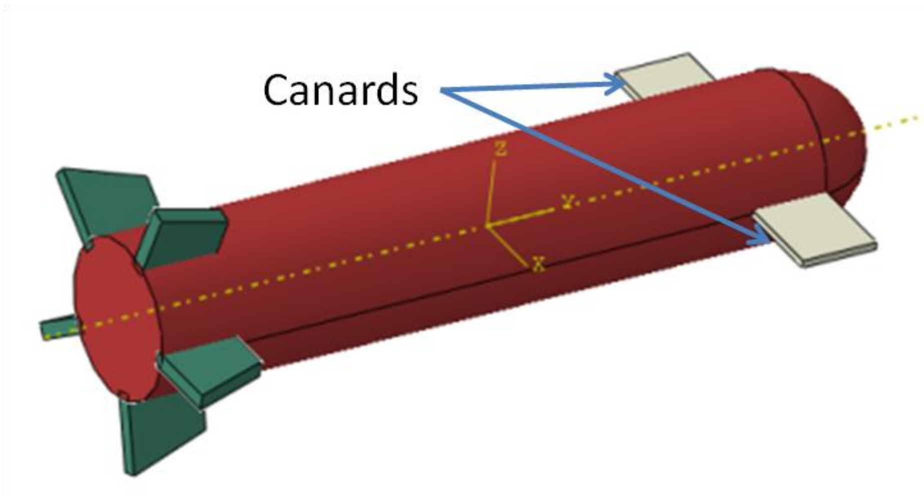

Figure 1
Typical canards

MODEL DESCRIPTION

The model has three major components (fig. 2), which are a CFD portion to simulate fluid flow, a finite element method portion to simulate structural response, and a user subroutine to simulate a control system.

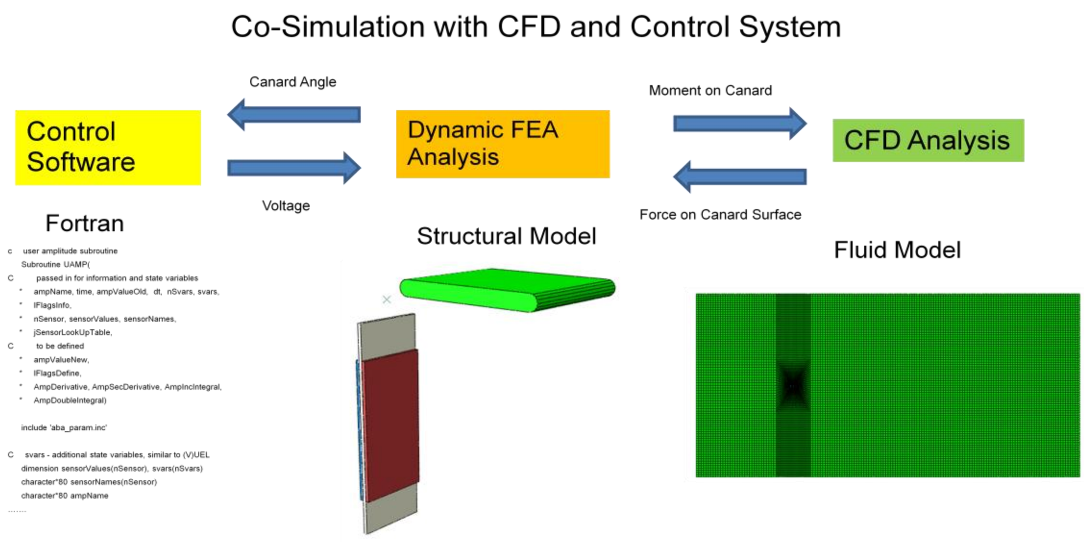

Figure 2
Major components

Fluid Model

The CFD model consists of a 2-D fluid domain with an inlet flow on the left and an exit on the right (fig. 3). There is a boundary layer around the canard. The flow is transient, incompressible, and laminar.

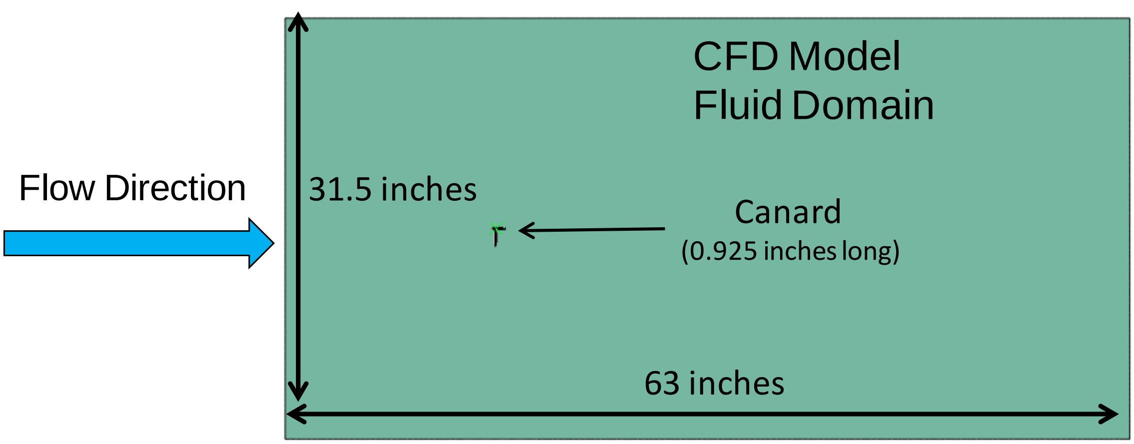

Figure 3
CFD model

The fluid structure interaction occurs at the interface between the CFD mesh and the finite FEA mesh (fig. 4). There is a two-way interaction at the interface that is created by a tied constraint. As the canard rotates, the mesh adapts to conform to the new shape.

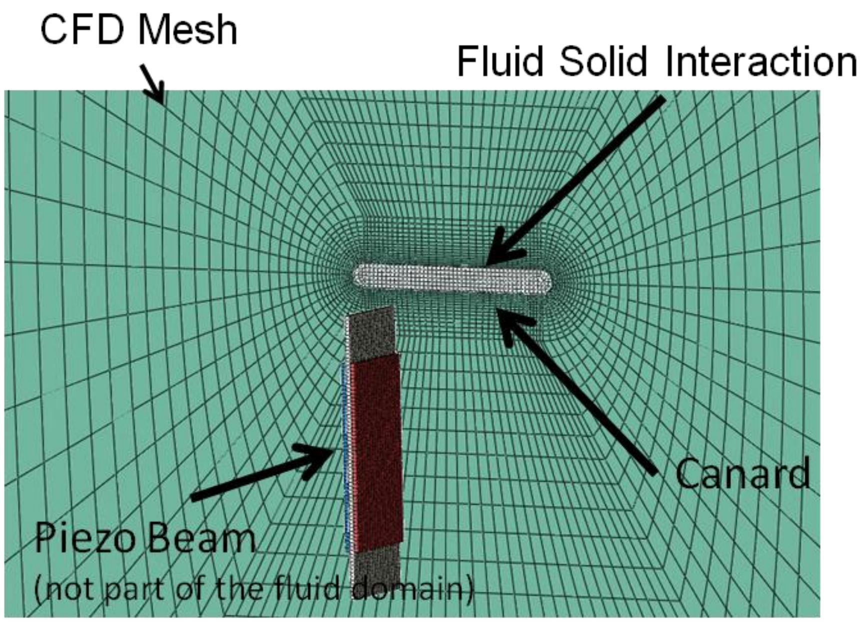

Figure 4
CFD and FEA interface

Structural Model

The FEA structural model (fig. 5) consists of a canard and a piezoelectric beam. The beam and canard are connected by a rigid connector and are both deformable bodies. An implicit dynamic solver was used to calculate the deformation of the structural model.

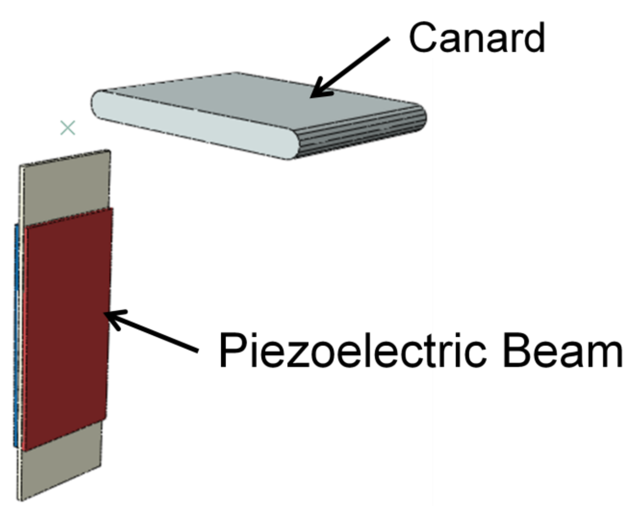

Figure 5
FEA model

When there is a difference in voltage across the piezoelectric material, the material expands or contracts (fig. 6) depending on the material orientation. This expansion and contraction causes the beam to bend. As the difference in voltage increases, the bending of the beam increases.

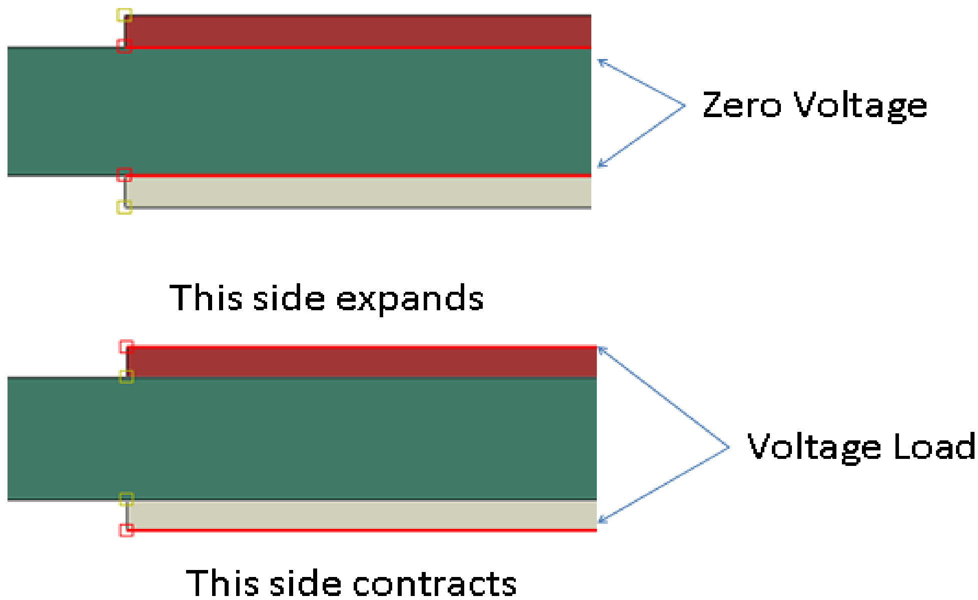

Figure 6
Operation of piezoelectric beam

Control Subroutine

The voltage applied to the piezoelectric beam is controlled by a user subroutine. This subroutine can read the current angle of the canard and then calculate a new voltage to be applied to the piezoelectric material. This cycle continues throughout the analysis.

Two simple control schemes were implemented. In the first case, the voltage is ramped up quickly and then kept constant, and the canard and beam are allowed to move freely. In the second case, the voltage was turned off when the angle of the canard exceeded a target value, and then the voltage is turned back on when the angle of the canard is below the target value. These control routines are intentionally simplistic to demonstrate the coupled approach. More sophisticated routines can be implemented as needed by the user by rewriting the FORTRAN subroutine.

RESULTS

Computational Fluid Dynamic Results

The pressure profile when the canard is in its initial horizontal state is shown in figure 7. The pressure is higher in the forward edge of the canard and lower at the trailing edge as expected. The pressure profile after the canard has rotated is shown in figure 8. As expected, the low pressure area has moved to the top surface of the canard and the high pressure area has moved to the lower surface of the canard.

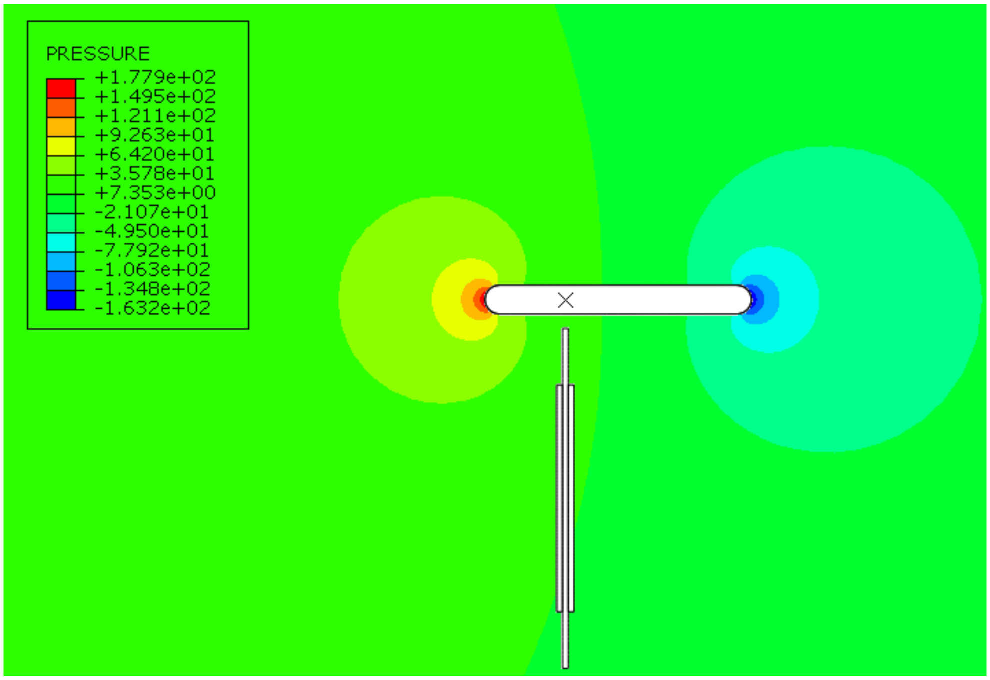

Figure 7
Pressure profile of horizontal canard

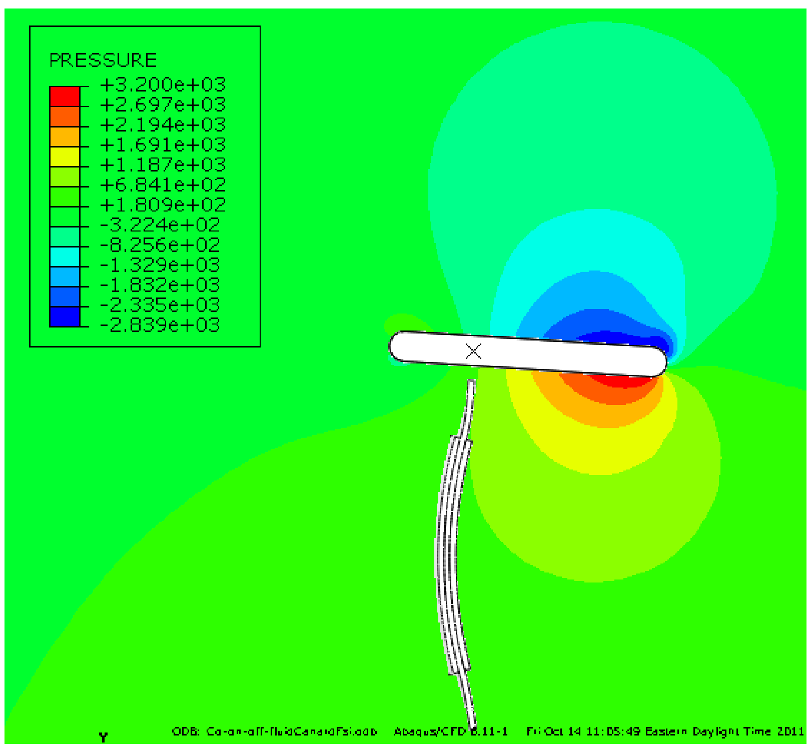

Figure 8
Pressure profile of canard at an angle

Finite Element Analysis Results

The von Mises stress is shown in figures 9 and 10. In figure 9, the beam and canard assembly are shown in their initial neutral state with zero stress. In figure 10, the assembly is shown in its deformed state, where the beam is bent and the canard has rotated. The high stress in the piezoelectric material is easily visible on the beam.

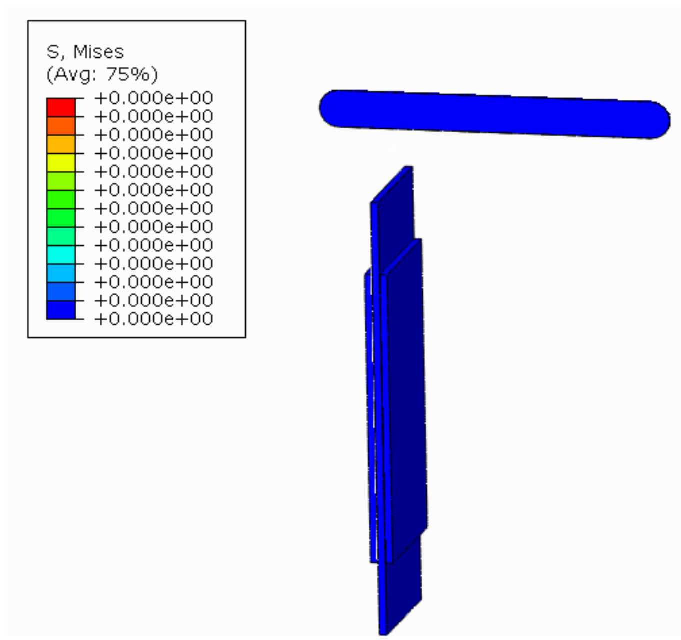

Figure 9
Stress in piezoelectric beam with zero voltage

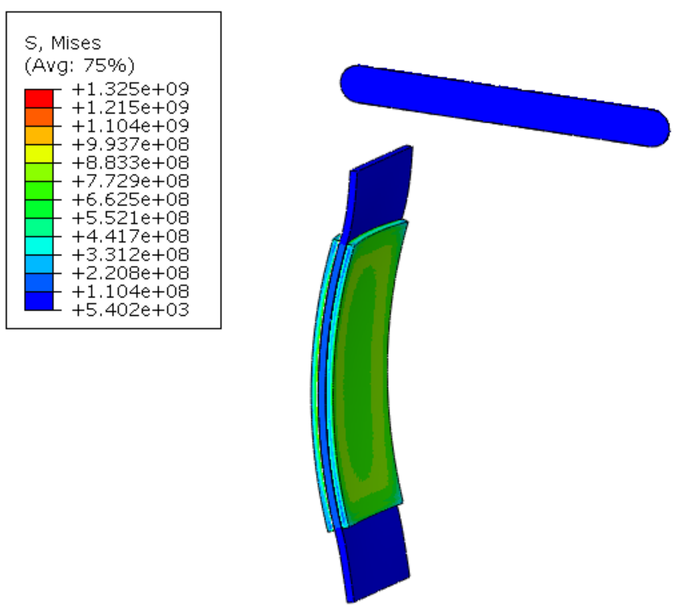

Figure 10
Stress in piezoelectric beam with voltage applied

Control Results

Plots of the voltage and canard angle are shown in figures 11, 12, and 13. Figure 11 shows case one, where the voltage is quickly ramped up and kept constant. The canard angle shows how the canard motion damps out over time converging to a constant angle. Figure 12 shows case two, where the voltage is turned off when the canard angle goes above the target value. The voltage is turned on again when the angle drops below the target value. The plot of the canard angle shows it is slowly damping down toward the target angle. Figure 13 shows a comparison between the canard rotations in case one with constant voltage and case two with voltage being turned on and off.

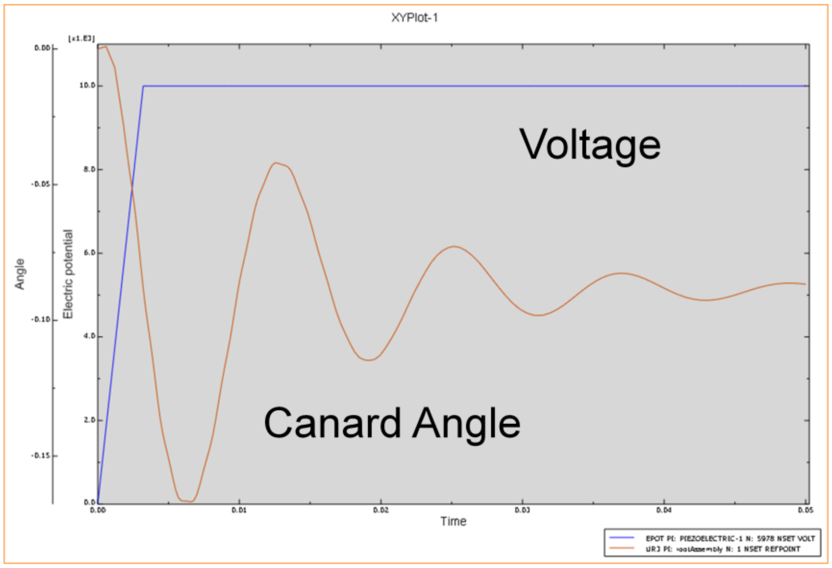

Figure 11
Plot of constant voltage and canard angle

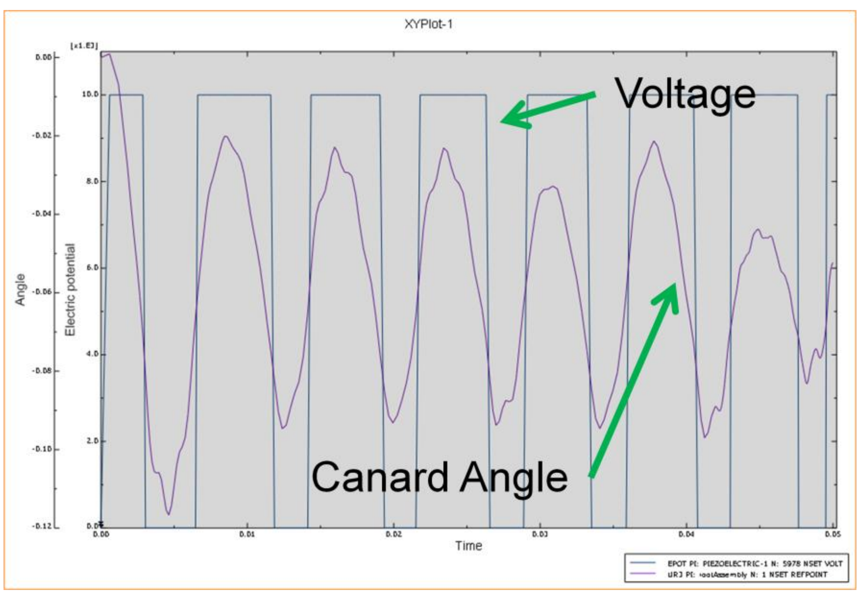

Figure 12
Plot of varying voltage and canard angle

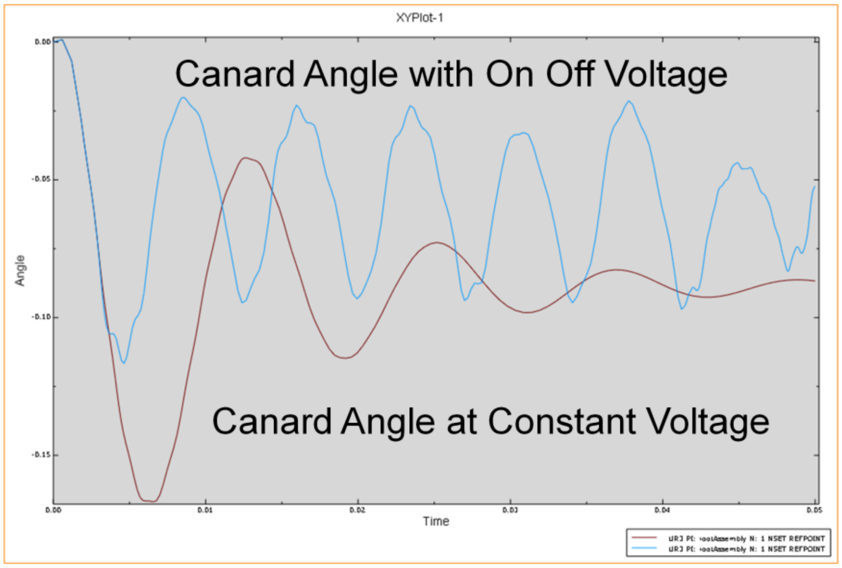

Figure 13
Plot comparing canard angles

CONCLUSIONS

A combination of structural finite element analysis with computational fluid (CFD) analysis controlled by a FORTRAN user subroutine was successfully demonstrated. There was a bidirectional interaction between all three processes or, in other words, a fully coupled analysis. The CFD model can be expanded to a full 3-D and third party codes, such as STAR-CCM+, can be used instead of the ABAQUS solver. Both the ABAQUS implicit and/or explicit solver can be used with co-simulation. The control routine can be written in both FORTRAN and C++ programming languages. This creates a very flexible system for solving complex multiphysics problems with control systems.

BIBLIOGRAPHY

1. ABAQUS Analysis Users Manual, version. 6.11, section 7.1 “Piezoelectric Analysis,” 2011.

2. ABAQUS Introduction of Abaqus/CFD for Multiphysics Applications, version. 6.11, workshop1, “Unsteady flow across a circular cylinder,” 2011.

DISTRIBUTION LIST

U.S. Army ARDEC
ATTN: RDAR-EIK
RDAR-GC
RDAR-MEF-E, L. Reinhardt (10)
P. Carlucci
A. Haynes
RDAR-MEF, W. Smith
RDAR-ME, J. Hedderich III
Picatinny Arsenal, NJ 07806-5000

Defense Technical Information Center (DTIC)
ATTN: Accessions Division
8725 John J. Kingman Road, Ste 0944
Fort Belvoir, VA 22060-6218

GIDEP Operations Center
P.O. Box 8000
Corona, CA 91718-8000
gidep@gidep.org

REVIEW AND APPROVAL OF ARDEC TECHNICAL REPORTS

Simulation of a Canard in Fluid Flow Driven by a Piezoelctrin Beam with a Software Control Loop
Title   Date received by LCSD

___Lyonel Reinhardt___________________   ARMET-TR-13004
Author/Project Engineer   Report number (to be assigned by LCSD)

__5850 bld 94__________________   _____________RDAR-MEF-E______
Extension   Building   Author's/Project Engineers Office
                                                                        (Division, Laboratory, Symbol)

PART 1. **Must be signed before the report can be edited.**

a. The draft copy of this report has been reviewed for technical accuracy and is approved for editing.

b. Use Distribution Statement A_X__, B____, C____, D____, E____, F____ or X____ for the reason

checked on the continuation of this form. Reason: There is no classified, FOUO or Military critical technology in this report

1. If Statement A is selected, the report will be released to the National Technical Information Service (NTIS) for sale to the general public. Only unclassified reports whose distribution is not limited or controlled in any way are released to NTIS.

2. If Statement B, C, D, E, F, or X is selected, the report will be released to the Defense Technical Information Center (DTIC) which will limit distribution according to the conditions indicated in the statement.

c. The distribution list for this report has been reviewed for accuracy and completeness.

Douglas C. Troast   17 Jan 2013
Division Chief   (Date)

PART 2. To be signed either when draft report is submitted or after review of reproduction copy.

This report is approved for publication.

Douglas C. Troast   17 Jan 2013
Division Chief   (Date)

Andrew Pskowski   4/11/14
RDAR-CIS   (Date)