AD-A119 148 ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND ABERD--ETC F/G 19/6
A TWO-DIMENSIONAL, TWO-PHASE FLOW SIMULATION OF IGNITION, FLAME--ETC(U)
JUL 82 A W HORST, F W ROBBINS, P S GOUGH

UNCLASSIFIED ARBRL-TR-02414 SBI-AD-F300 066 NL

1 of 1
AD
A119148

END
DATE
FILMED
10 82
DTIC

AD A119148

AD-E 300 096

AD

TECHNICAL REPORT ARBRL-TR-02414

A TWO-DIMENSIONAL, TWO-PHASE FLOW SIMULATION OF IGNITION, FLAMESPREAD, AND PRESSURE-WAVE PHENOMENA IN THE 155-MM HOWITZER

A. W. Horst
F. W. Robbins
P. S. Gough

July 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

82 08 20 009

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report ARBRL-TR-02414

2. GOVT ACCESSION NO.
AD-A119 148

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
A Two-Dimensional, Two-Phase Flow Simulation of Ignition, Flamespread, and Pressure-Wave Phenomena in the 155-mm Howitzer

5. TYPE OF REPORT & PERIOD COVERED
October 1980-September 1981

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
A.W. Horst, F.W. Robbins,
P.S. Gough*

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
US Army Ballistic Research Laboratory
ATTN: DRDAR-BLI
Aberdeen Proving Ground, MD 21005

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
1L161102AH43

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Armament Research & Development Command
US Army Ballistic Research Laboratory (DRDAR-BL)
Aberdeen Proving Ground, MD. 21005

12. REPORT DATE
July 1982

13. NUMBER OF PAGES
33

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*Paul Gough Associates Inc. Portsmouth, NH

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Interior Ballistics
Guns
Flamespread
Pressure Waves
Computer Codes
TDNOVA

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Past attempts to simulate two-phase flow phenomena in high-performance, bagged-charge artillery using available one-dimensional, two-phase flow interior ballistic codes have met with only limited success, presumably because of the inability of these models to capture configural complexities associated with the charge/chamber interface. Previous work with a quasi-two-dimensional version of one such code (NOVA), in which the charge and unoccupied regions in the gun chamber were treated as disjoint but coupled regions of one-dimensional

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) flow, revealed that early flow external to the charge can alter the flame path and equilibrate pressures throughout the gun chamber. Moreover, characteristics of the bag material itself - strength and permeability, affecting both communication of gases between the charge and external regions and persistence of circumferential ullage - can have significant impact on the development of longitudinal pressure waves in the tube.

Yet these calculations recognized only an axial thermal stimulus in the propellant bed and ignored entirely the structure of the radial flow field in the two-phase medium. Current work addresses application of a fully two-dimensional, axisymmetric, two-phase flow model (TDNOVA) to the bagged-charge problem, providing for the first time an explicit treatment of two-dimensional flamespread in this configurally complex environment. Functioning of the basepad/centercore igniter is included within the physical scope of the model, as is the presence of reactive parasitic charge components which exhibit exothermic or endothermic properties in addition to resistance to gas and solid-phase flows.

Results are presented for the 155-mm, M198 Howitzer, firing the top-zone M203 Propelling Charge, with code input varied to reflect changes in the abovementioned parasitic-component characteristics and in charge/chamber interface. Comparison is made with previously published calculations as well as with experimental data.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. BACKGROUND

Theoretical and experimental efforts continue to bring about an improved understanding of the detailed phenomenology of the gun interior ballistic cycle. Investigators addressing ignition and combustion processes[1-3] have been joined by those interested in the details of heat transfer to and erosion of the bore surface[4,5]. Our work has focused on the process of flamespreading as a hydrodynamic problem and on the influence of the path of flamespreading on the longitudinal pressure field throughout the entire interior ballistic cycle. In this study, we further limit our attention to bagged propelling charges, the configural complexities of which are particularly challenging to modeler and designer alike.

In a previous paper[6], we presented simulations of a bagged charge based on two modeling representations: first, a one-dimensional-with-area-change treatment which assumed a uniform cross-sectional distribution of propellant within the chamber at any given axial location; and second, a quasi-two-dimensional analysis which treated the propelling charge and unoccupied regions in the gun chamber as disjoint but coupled regions of one-dimensional flow. The latter description also allowed some recognition of the permeability and strength of the bag sidewall to be embedded in the representation as boundary conditions linking the coaxial regions of one-dimensional flow.

---

[1] E.B. Fisher, "Continued Development and Documentation of the Calspan Interior Ballistics Code," Calspan Report No. 6689-D-1, Calspan Corporation, Buffalo, NY, February 1981.

[2] P.S. Gough, "The Flow of a Compressible Gas Through an Aggregate of Mobile Reacting Particles," IHCR 80-7, Naval ordnance Station, Indian Head, MD, December 1980.

[3] K.K. Kuo and J.H. Koo, "Transient Combustion in Granular Propellant Beds. Part 1: Theoretical Modeling and Numerical Solution of Transient Combustion Processes in Mobile Granular Propellant Beds," BRL-CR-346, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1977 (AD #A044998).

[4] H.J. Gibeling, R.C. Buggeln, and H. McDonald, "Development of a Two-Dimensional Implicit Interior Ballistic Code," ARBRL-CR-00411, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1980. (AD A084092)

[5] A.C. Buckingham, "Research on Gun Barrel Erosion Mechanisms," Energy and Technology Review, Lawrence Livermore Laboratory, CA, January 1979.

[6] A.W. Horst and P.S. Gough, "Modeling Ignition and Flamespread Phenomena in Bagged Artillery Charges," ARBRL-TR-02263, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1980. (AD A091790)

Calculations using the quasi-two-dimensional model revealed the path of flamespread to be sensitive to both bag configuration and material characteristics, with a persistence of circumferential ullage external to the bag providing a path for equilibration of the longitudinal pressure field. The influence of this path was greatly diminished, however, when axial ullage was not present at the downstream end of the chamber; in this case, predictions were essentially equivalent to those provided by the simpler, one-dimensional representation. The influence of radial flow, including flame propagation, within the two-phase medium itself could not, of course, be assessed with either of these models. We report herein on calculations performed using a fully two-dimensional, axisymmetric, two-phase flow model to describe igniter functioning, flamespread, and pressurization in a 155-mm howitzer.

II. TECHNICAL DISCUSSION

A. Description of the Problem

The 155-mm, M203 Propelling Charge is a conventional, top-zone, bagged charge currently employed with the 155-mm, M198 Towed Howitzer. Depicted in Figure 1, this charge employs about 11.8 kg of M30A1, triple-base, granular propellant. The ignition system is composed of a cloth basepad containing 28 g of Class 1 black powder and a molded-nitrocellulose centercore tube, which houses a cloth snake filled with an additional 113 g of black powder. The charge, confined within a resin-impregnated cloth bag, is encumbered with a number of parasitic components, each designed to perform a special function. A cloth donut filled with granular potassium sulfate serves to reduce muzzle flash. Lead foil, a de-coppering agent, and a titanium dioxide/wax wear-reducing additive are also present as liners which surround approximately the forward two-thirds of the charge. Finally, a cloth lacing jacket provides additional rigidity to the package.

The normal sequence of events during functioning of this charge begins when hot combustion products from the primer exit the spithole in the spindle face and impinge upon the basepad. As the basepad begins to burn, product gases and hot particles penetrate the several layers of cloth, enter the centercore tube, and ignite the snake as intended. However, basepad combustion products may also penetrate the rear of the bag and ignite the main propellant charge directly. This competition with centercore functioning is critical, and a victory for direct, local ignition of the propellant bed by the basepad could lead to catastrophic pressure waves in a high-loading-density charge. Basepad and other early combustion products can also flow into the axial ullage behind the charge, through the circumferential ullage around the bag, and into the axial ullage in front of the bag as shown in Figure 2. Such flow around the bag can equilibrate pressures throughout the chamber early in the cycle, but the persistence of this ullage is unknown and may depend heavily on charge-component characteristics. Further, a possible variation in charge standoff from the spindle face can be expected to affect coupling between primer spithole output and the basepad, as well as alter the initial distribution of propellant and ullage.

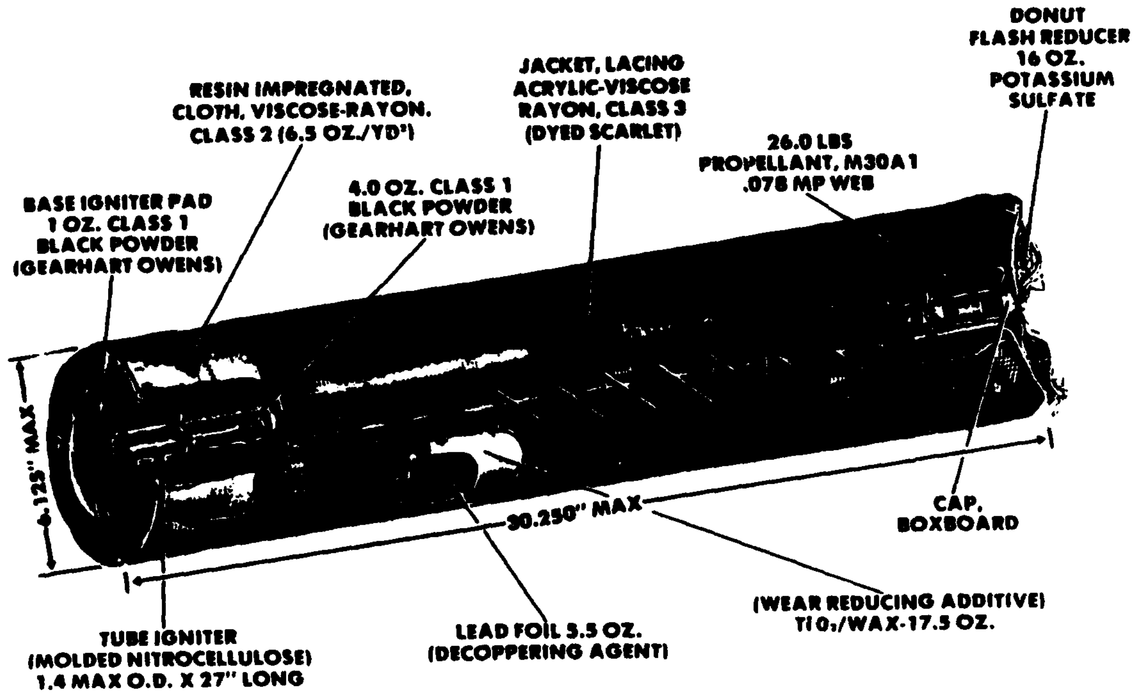


Figure 1. 155-mm, M203 Propelling Charge

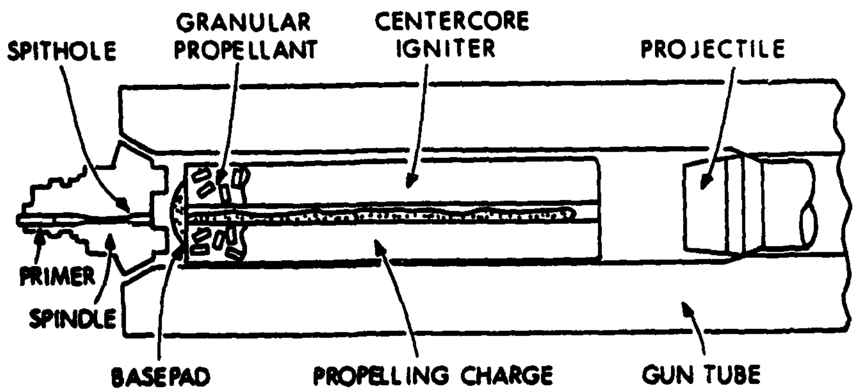


Figure 2. Bagged Charge/Gun Chamber Interface

B. Modeling Approach

Simulations presented in this paper were performed using TDNOVA[7], an unsteady, two-dimensional, axisymmetric, two-phase flow representation of the interior ballistic cycle. The development of TDNOVA was undertaken largely in response to the configural complexities of bagged charges which fell outside the physical scope of the previously-developed, one-dimensional NOVA code[8].

Flamespread through bag charges is believed to be influenced strongly by details of the ullage which initially surrounds the bag and by the behavior of the bag material itself. Accordingly, an explicit representation is made in TDNOVA of the region occupied by the propelling charge at any time. The flow in the ullage, which surrounds the region occupied by the propellant, is represented as unsteady, inviscid, and single phase.

The ullage is divided into several disjoint regions, coupled to one another and to the two-phase flow in the propelling charge by means of finite jump conditions at all their mutual boundaries. By formulating the theory in such a manner as to use directly the jump conditions at the boundary of the bag, we provide a direct mechanism for the representation of the influence of the bag. Impermeability is reflected directly within the momentum jump condition as a quasi-steady flow loss. Similarly, the influence of exothermically reactive components, such as the basepad and centercore tube, and endothermically reactive components, such as the salt bag, are reflected by means of source terms in the mass and energy jump conditions.

The division of the ullage into several regions is based on the instantaneous configuration of the external boundaries, namely the breech, the tube, and the moving projectile, and on the configuration of the bag which predicates regions of ullage behind it, ahead of it, around it, and within it. Each such region of ullage is treated as lumped parameter, quasi-one-dimensional, or as fully two-dimensional, in accordance with criteria based on its dimensions.

In addition to the representation of a basepad and centercore tube within the structure of the bag, the model recognizes the influence of a centercore ignition charge, coaxial with the bag and moving with it, and which is represented as a quasi-one-dimensional, two-phase flow. As with the ullage, the centercore is coupled to the state of the flow within the bag and, where applicable, the ullage at the ends of the chamber, by reference to finite jump conditions. The representation of the ignition

---

[7] *P.S. Gough, "A Two-Dimensional Model of the Interior Ballistics of Bagged Artillery Charges," ARBRL-CR-00452, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, April 1981. (AD A100751)*

[8] *P.S. Gough, "The NOVA Code: A User's Manual. Volume 1. Description and Use," IHCR 80-8, Naval Ordnance Station, Indian Head, MD, December 1980.*

train also admits the specification of an externally injected stimulus of predetermined flow rate and energy.

Each region of continuous flow properties is mapped onto a regular geometric figure, a line or a square, by means of a boundary-fitted-mesh-transformation algorithm. The method of solution is based on an explicit, two-step marching scheme which utilizes the characteristic forms of the balance equations at the external and the internal boundaries.

Figure 3 depicts schematically the level of representation provided by TDNOVA, along with the one-dimensional-with-area-change and quasi-two-dimensional approximations employed in our previous discussion[6].

C. Calculations

Those features of the input data base not associated with the multi-dimensionality of the problem have been reported previously[6]. A schematic representation of additional, configural information required by TDNOVA is provided as Figure 4. We observe that the assumption of axisymmetry leads to an annular distribution of ullage external to the bag sidewall.

Initially, a fully two-dimensional analysis of flow within the two-phase medium is provided. In the calculations described, however, the regions of ullage contiguous to the bounding surfaces of the bag are treated as quasi-one-dimensional (i.e., one-dimensional-with-area-change), the continuum coordinate being defined by the boundary. Corner regions of ullage are given a lumped-parameter representation. The centercore ignition charge is treated as a one-dimensional, two-phase flow, while the basepad is recognized in terms of an exothermic region of the rear boundary of the charge.

Following completion of flamespread, rupture of the bag sidewall, and equilibration of the radial structure of the pressure field to within some user-specified limit, a quasi-two-dimensional approach is introduced, similar to that reported previously[6]. For the duration of the interior ballistic cycle, the propelling charge is given a quasi-one-dimensional representation, as is the circumferential ullage, while regions of axial ullage at each end of the chamber are treated as lumped parameter.

It should be pointed out that a fully two-dimensional treatment of the ullage is available in TDNOVA. However, the two-dimensional nature of the flow in these regions may well be outside the scope of the inviscid gas flow equations currently used, and the quasi-one-dimensional description of flow in the ullage may be the better of the two options available.

We have provided quantitative estimates of the permeability and strength of various portions of the charge package; however, these values are based only on intuition or limited testing now underway at the Ballistic Research Laboratory. Further, it must be realized that no account is taken in the analysis of the independent motion of the bag, all packaging materials being treated as attributes of the surface of the propellant bed itself.

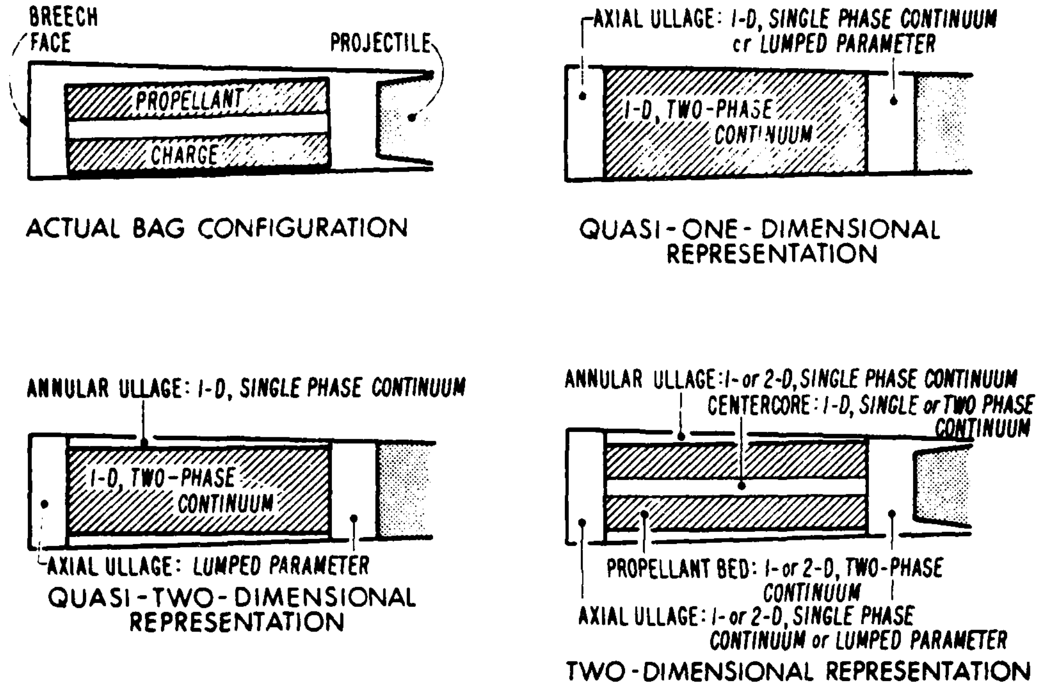


Figure 3. Schematic of Actual Interface and Model Representations

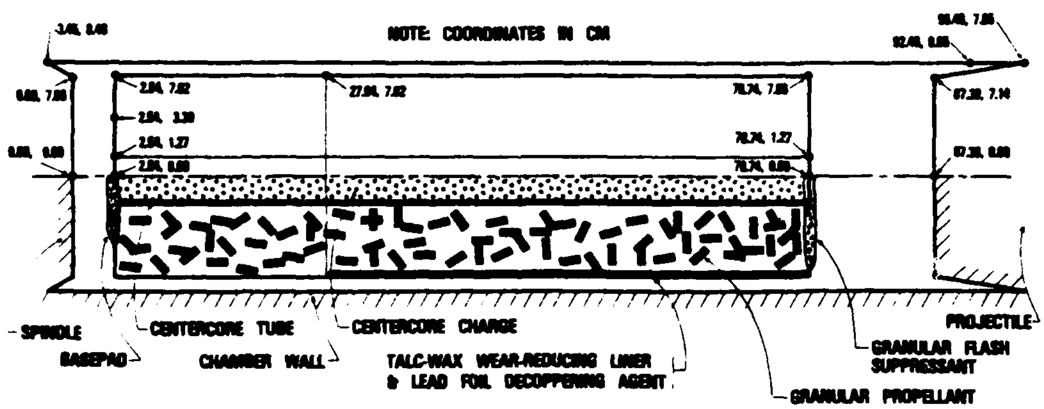


Figure 4. Two-Dimensional, Axisymmetric Representation of 155-mm, M203 Propelling Charge

Finally, we draw attention to the fact that an artificially-low ignition temperature (300 K) is provided for the black powder centercore to facilitate convectively-driven flamespread at low pressures, the discharge of hot molten salts being outside the current scope of the code. This compromise is consistent with our motive of treating the centercore igniter as a two-phase medium in order to capture the appropriate resistance to flow during the overall ignition event.

Turning now to the details of the solutions, we begin by addressing a calculation based on input data describing the 155-mm, M198 Howitzer firing the M203 Propelling Charge, positioned the nominal 25-mm from the spindle face. The initial thermal stimulus associated with functioning of a primer located in the breechblock lies outside the scope of the current representation and the calculation begins with combustion of the basepad. Figures 5 and 6 present isometric projections of the gas pressure and temperature fields at selected times during the early portion of the interior ballistic cycle. We note early pressurization and flamespread within the centercore, the centercore tube wall having been described as being initially impermeable to flow. However, a flow of hot combustion products external to the bag also takes place, which, because of the permeability of the rear portion of the bag sidewall, leads to early ($t = \sim 2$ ms) pressurization of the entire rear portion of the chamber. (The forward two-thirds of bag sidewall is given an initially-impermeable representation to reflect the presence of lead-foil and titanium dioxide/wax liners.) Indeed, a nearly one-dimensional pressure field results after only a few milliseconds. Nevertheless, flamespread, as depicted in Figure 7, clearly reflects the radial stimulus provided by the centercore igniter. Conversion to the quasi-two-dimensional representation rapidly follows the completion of flamespread, which occurs within 6 ms of the onset of basepad combustion for all calculations described. Resulting pressure-time and pressure-difference profiles are provided in Figure 8, along with previously-reported calculated results and experimental data. Also included in the figure is a recently-recorded, pressure-difference profile which is very closely approximated by the TDNOVA prediction. While providing an encouraging comparison between current theory and experiment, this difference from earlier experimental data highlights the problem of variability in pressure waves with bagged charges.

A companion calculation for the M203 Propelling Charge loaded at maximum standoff from the spindle face (i.e., pushed forward against the projectile base) yields the pressure-field plots presented in Figure 9. We note the presence of a strong, reverse pressure gradient (at ~3 ms), often described in the past to be the consequence of a grossly one-dimensional flamespreading event resulting from improper functioning of the centercore. We note, however, that Figure 10 clearly depicts radial flamespread, suggesting the locally-high forward pressurization to be more the result of the initial distribution of propellant in the chamber than of anomalous behavior associated with vigorous, two-phase flow dynamics. Predicted pressure-time and pressure-difference profiles for this calculation are provided in Figure 11.

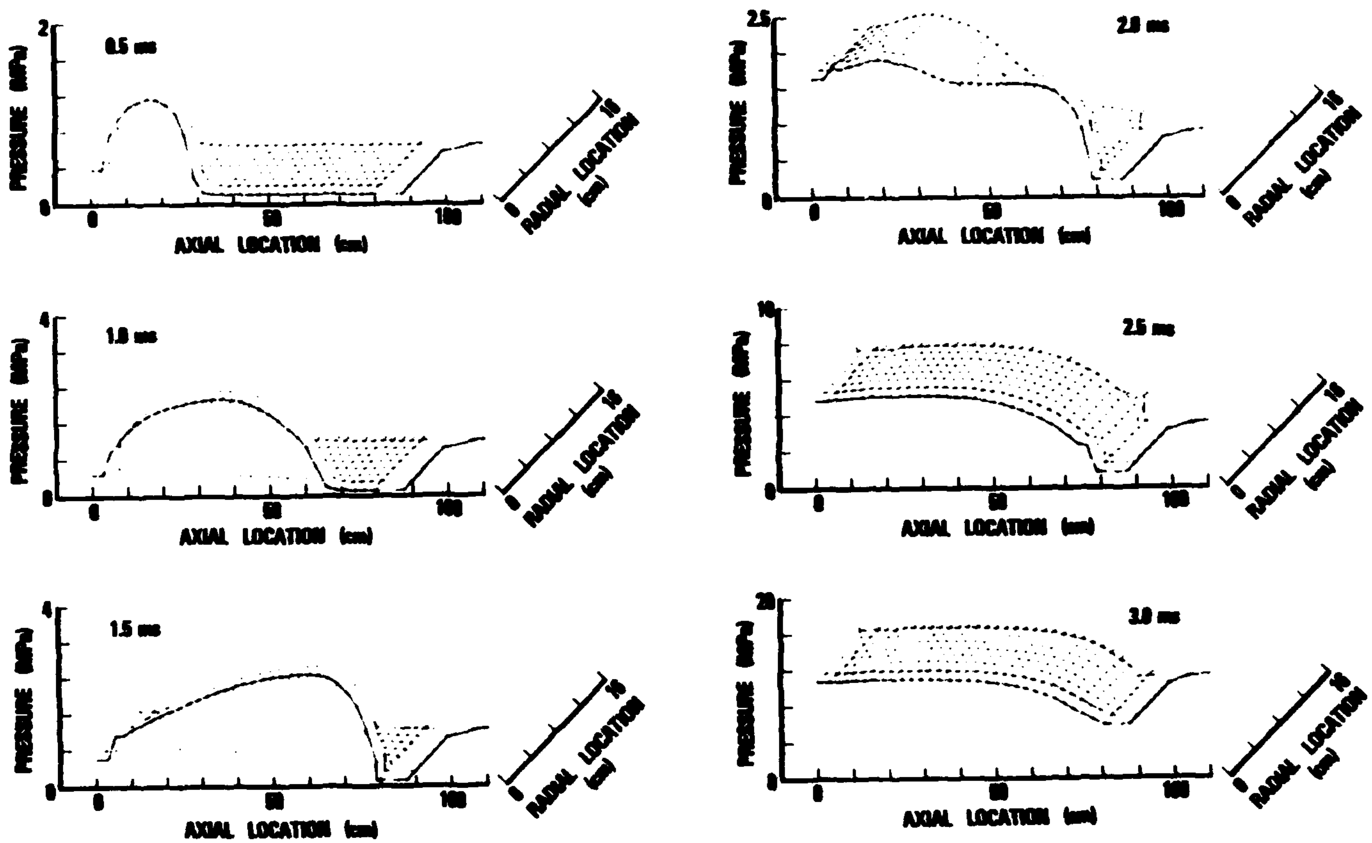


Figure 5. Predicted Pressure Field at Various Times for M203 Charge at 25-mm Standoff

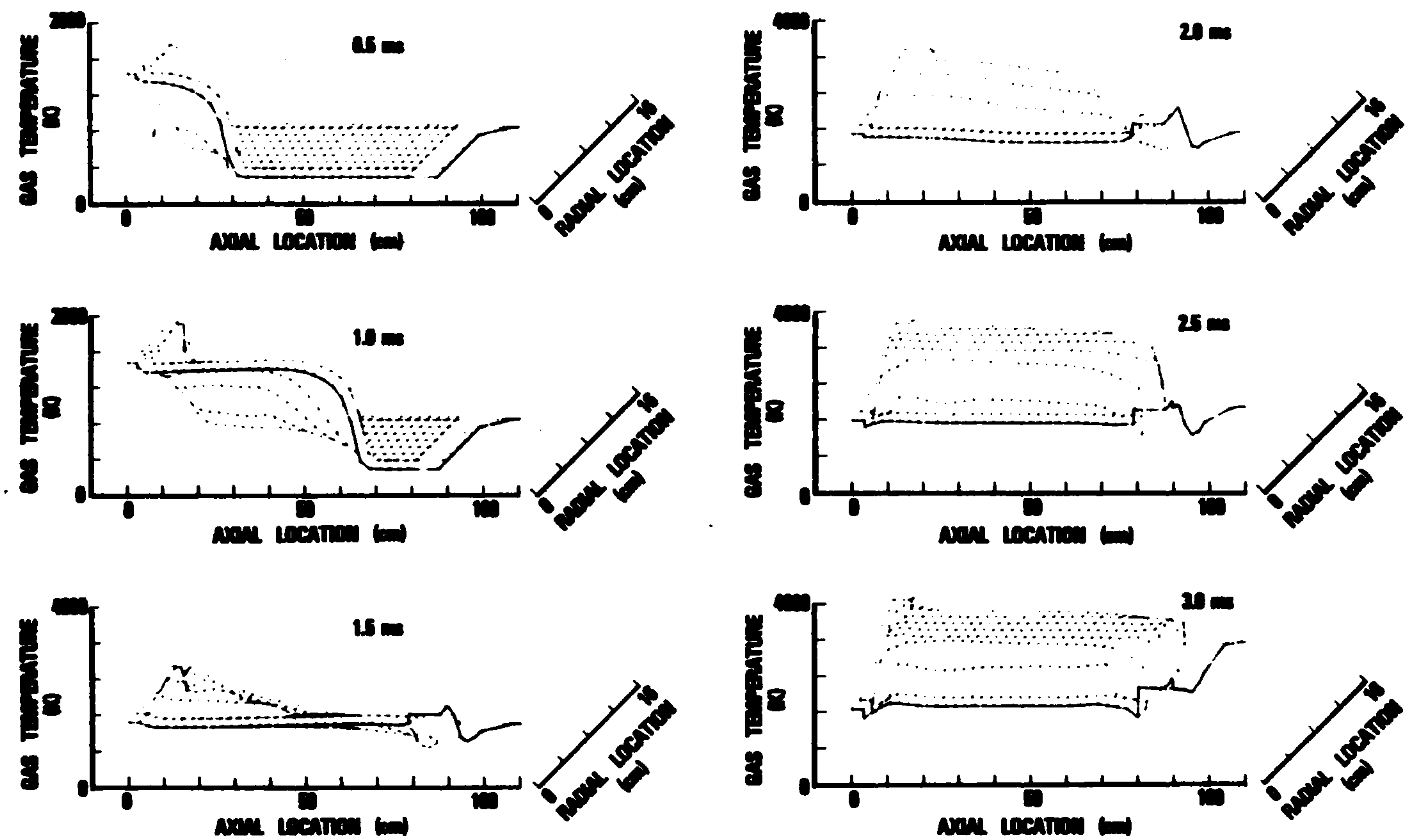


Figure 6. Predicted Gas Temperature Field at Various Times for M203 Charge at 25-mm Standoff

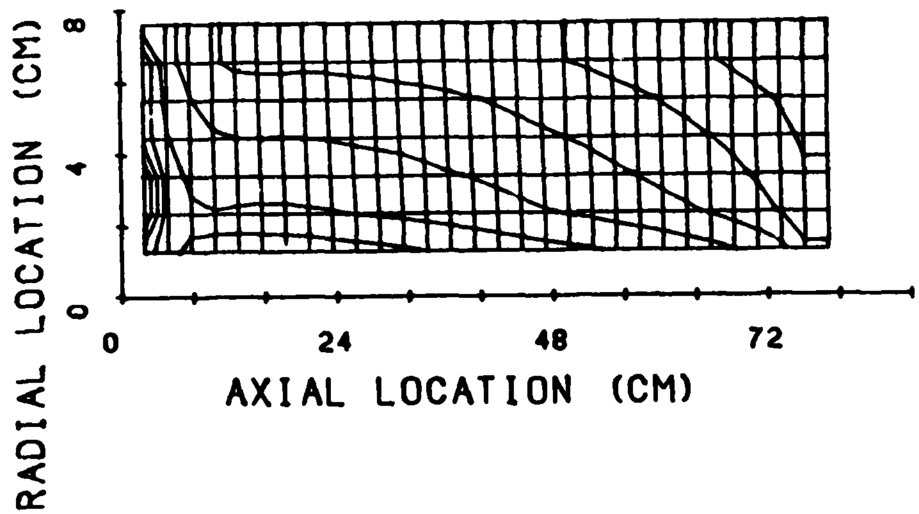


Figure 7. Predicted Flamespread Contours ($\Delta\tau$ = 0.24ms) for M203 Charge at 25-mm Standoff

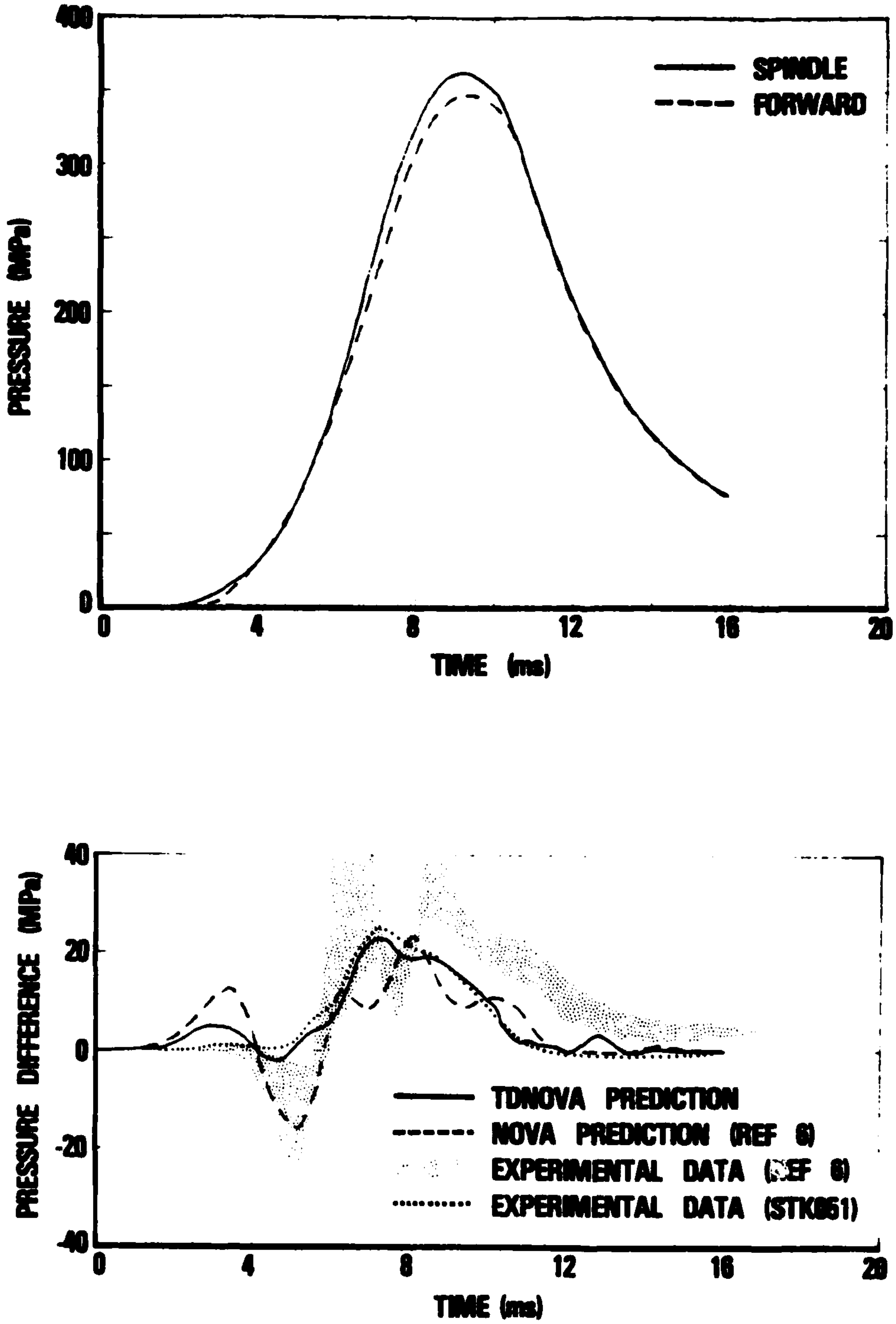


Figure 8. Pressure-Time and Pressure-Difference Profiles, Predicted and Experimental, for M203 Charge at 25-mm Standoff

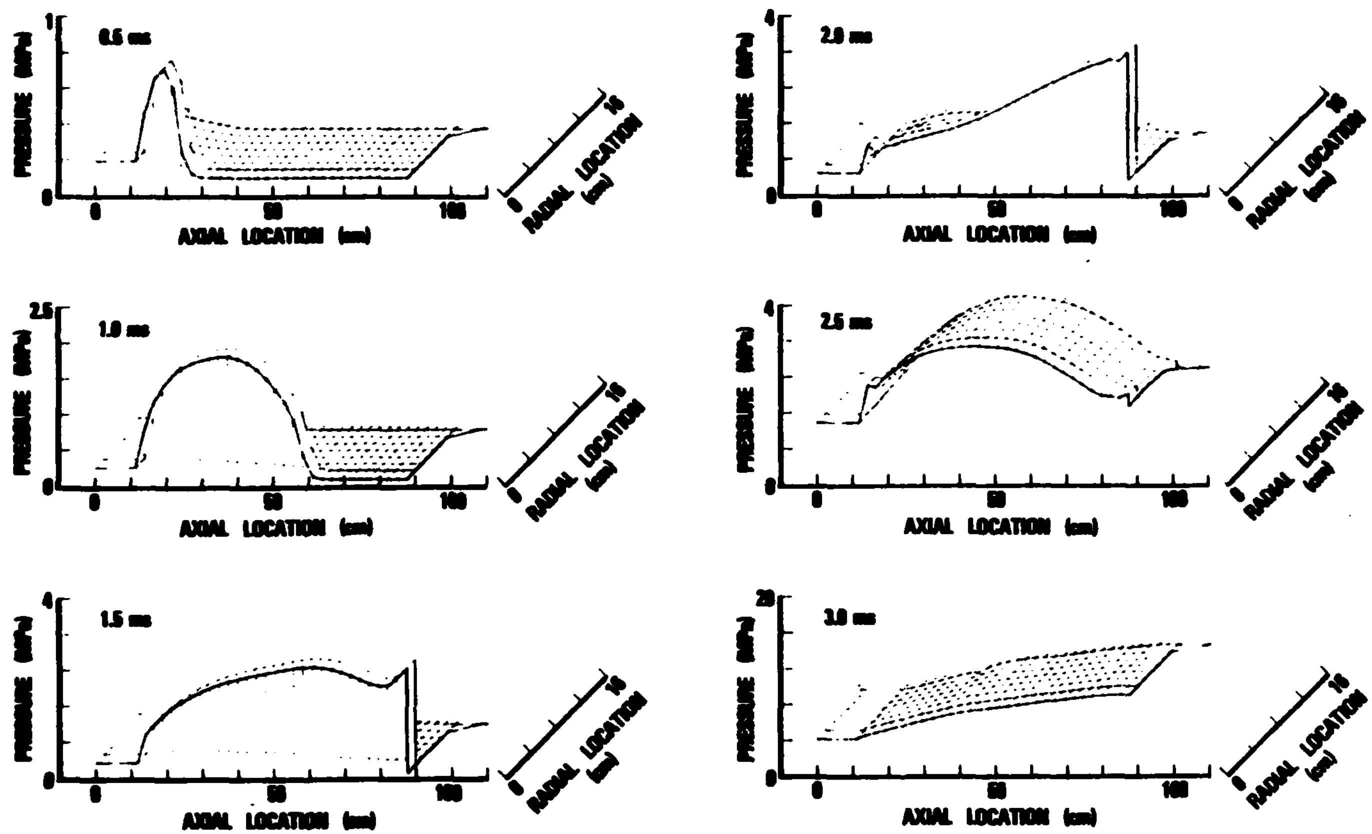


Figure 9. Predicted Pressure Field at Various Times for M203 Charge at Maximum Standoff

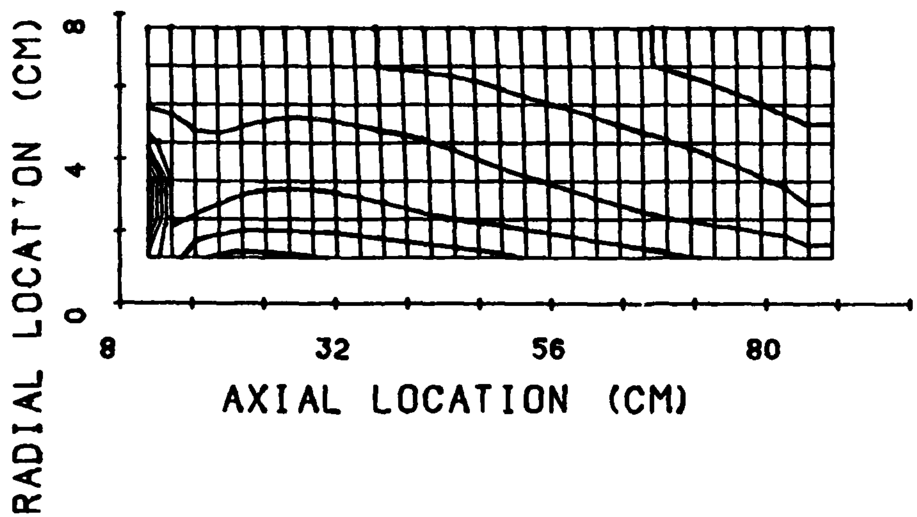
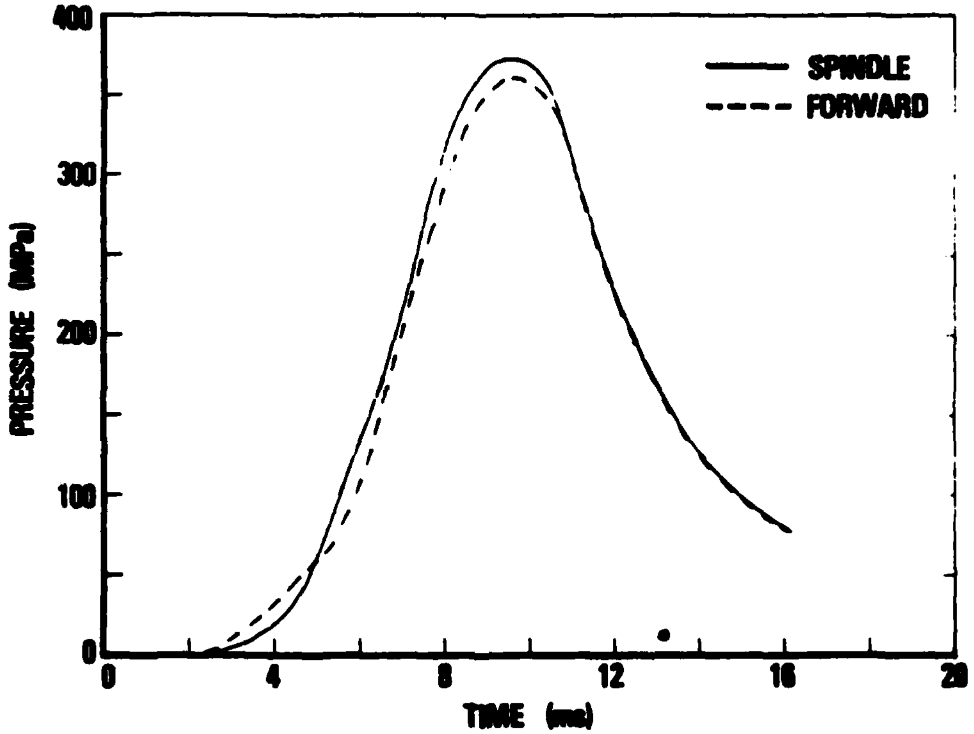


Figure 10. Predicted Flamespread Contours ($\Delta\tau$ = 0.24ms) for M203 Charge at Maximum Standoff



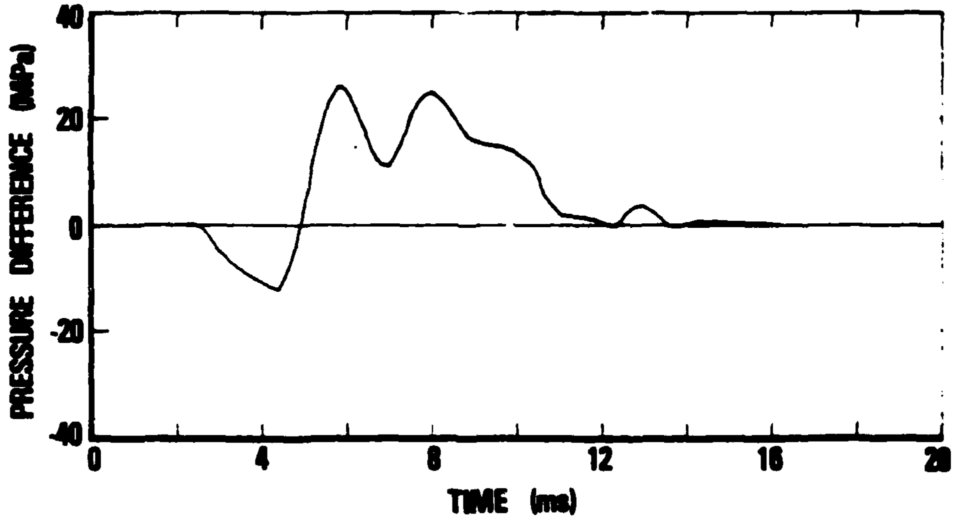


Figure 11. Predicted Pressure-Time and Pressure-Difference Profiles for M203 Charge at Maximum Standoff

Additional calculations were performed with TDNOVA using data bases altered to reflect the possible, early rupture of the bag sidewall and/or failure of the centercore igniter. Results from several of these calculations are displayed in Figures 12 and 13. Significant impact is observed, though the weak-bag condition (i.e., zero strength) did not lead to large pressure waves unless centercore functioning was delayed by at least a millisecond as well. This result suggests that localized ignition in addition to an unconfined propellant bed is required in order to effect the collapse of circumferential ullage against the chamber sidewall at a time when critical longitudinal pressure gradients exist. A calculation performed using a strong, permeable bag (i.e., 0.6-MPa rupture strength), however, exhibited a tolerance to this delay in centercore functioning without the formation of large pressure waves, evidently a result of pressure equilibration via the persistent, circumferential ullage external to the bag.

In addition, an approximately 10-percent decrease in peak chamber pressure was observed for both strong-bag and full-diameter (i.e., quasi-one-dimensional) charge configurations. While differences in effective, macroscopic permeability may be respons. le for this behavior, no single, consistent explanation has yet been formul ted.

III. CONCLUSIONS

We have demonstrated successful application of TDNOVA to the bagged-charge artillery problem. The treatment of radial flow in the vicinity of a centercore igniter, along with explicit recognition of flow of early combustion products external to the propellant package, is shown to impact significantly the predicted path of flame propagation and the resulting longitudinal structure of the pressure field, particularly in comparison to earlier one-dimensional simulations. Of major importance is the result that large differential pressures can accompany the maximum-charge-standoff configuration despite proper functioning of the centercore igniter.

We did not, however, reproduce the simple relationship between bag sidewall strength and pressure waves revealed in quasi-two-dimensional simulations reported previously[6]. The improved level of modeling afforded by TDNOVA paints an even more convincing picture of the complexity of the interplay between igniter, ullage, and packaging components. Interestingly, we even note a sensitivity of maximum chamber pressure to the degree of propellant confinement during flamespread.

We also observe, in agreement with earlier simulations, predicted ignition delays on the order of several milliseconds as opposed to the several tens of milliseconds experienced experimentally. Additional TDNOVA calculations performed with increased ignition temperatures for the black powder centercore and, indeed, with the centercore turned off entirely did not substantially increase ignition delays. Not unexpectedly, we find that a more complete picture of the sequence of events occurring during igniter functioning will be required to bring simulations of this portion of the cycle in accord with reality.

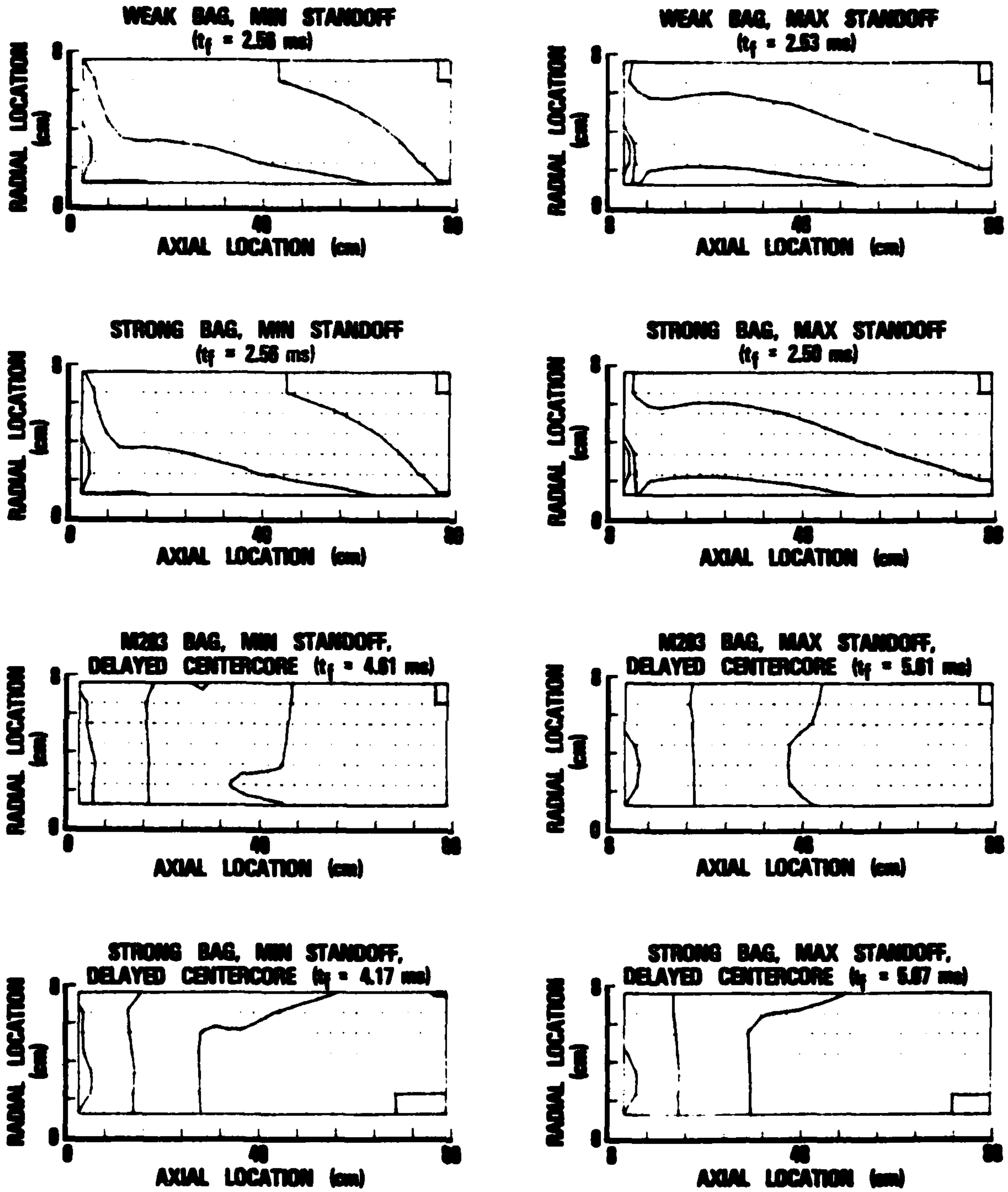


Figure 12. Predicted Flamespread Contours Using Altered Data Bases

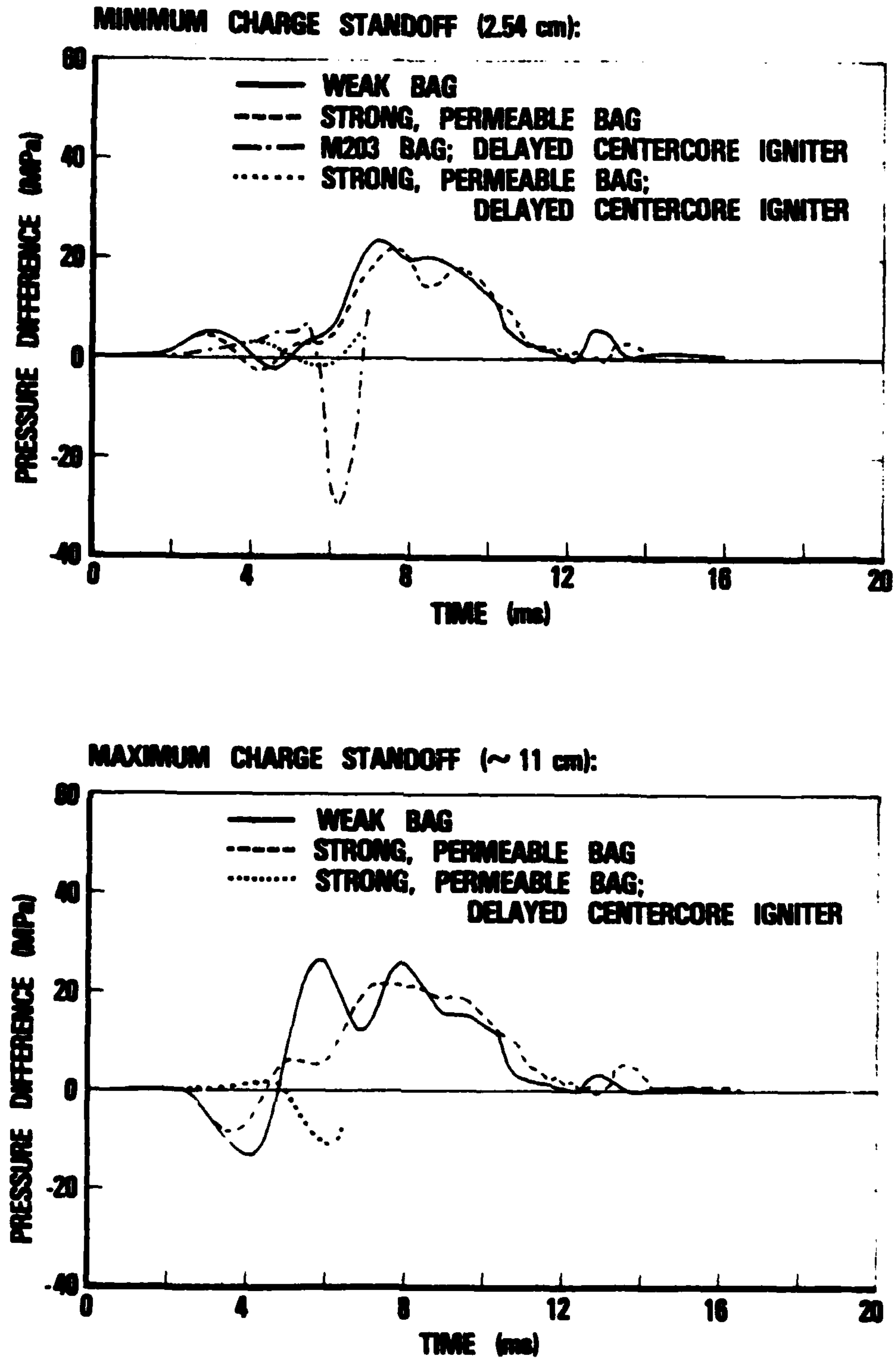


Figure 13. Predicted Pressure-Difference Profiles Using Altered Data Bases

REFERENCES

1. E.B. Fisher, "Continued Development and Documentation of the Calspan Interior Ballistics Code," Calspan Report No. 6689-D-1, Calspan Corporation, Buffalo, NY, February 1981.

2. P.S. Gough, "The Flow of a Compressible Gas Through An Aggregate of Mobile Reacting Particles," IHCR 80-7, Naval Ordnance Station, Indian Head, MD, December 1980.

3. K.K. Kuo and J.H. Koo, "Transient Combustion in Granular Propellant Beds. Part 1: Theoretical Modeling and Numerical Solution of Transient Combustion Processes in Mobile Granular Propellant Beds," BRL-CR-346, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1977. (AD #A044998)

4. H.J. Gibeling, R.C. Buggeln, and H. McDonald, "Development of a Two-Dimensional Implicit Interior Ballistic Code," ARBRL-CR-00411, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1980. (AD A084092)

5. A.C. Buckingham, "Research on Gun Barrel Erosion Mechanisms," Energy and Technology Review, Lawrence Livermore Laboratory, CA, January 1979.

6. A.W. Horst and P.S. Gough, "Modeling Ignition and Flamespread Phenomena in Bagged Artillery Charges," ARBRL-TR-02263, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1980. (AD A091790)

7. P.S. Gough, "A Two-Dimensional Model of the Interior Ballistics of Bagged Artillery Charges," ARBRL-CR-00452, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, April 1981. (AD A100751)

8. P.S. Gough, "The NOVA Code: A User's Manual. Volume 1. Description and Use," IHCR 80-8, Naval Ordnance Station, Indian Head, MD, December 1980.

DISTRIBUTION LIST

No. Of Copies	Organization
12	Administrator Defense Technical Info Center ATTN: DDC-DDA Cameron Station Alexandria, VA 22314
2	Office of the Under Secretary of Defense Research & Engineering ATTN: G. R. Makepeace R. Thorkildsen Washington, DC 20301
1	HQDA/SAUS-OR, D. Hardison Washington, DC 20301
1	HQDA/DAMA-ZA Washington, DC 20310
2	HQDA, DAMA-CSM, LTC A. German E. Lippi Washington, DC 20310
1	HQDA/SARDA Washington, DC 20310
1	Commander US Army War College ATTN: Library-FF229 Carlisle Barracks, PA 17013
1	Ballistic Missile Defense Advanced Technology Center P. O. Box 1500 Huntsville, AL 35804
1	Chairman DOD Explosives Safety Board Room 856-C Hoffman Bldg. 1 2461 Eisenhower Avenue Alexandria, VA 22331
3	Commander US Army Materiel Development and Readiness Command ATTN: DRCDMD-ST DCRSF-E, Safety Office DRCDE-DW 5001 Eisenhower Avenue Alexandria, VA 22333
14	Commander US Army Armament R&D Command ATTN: DRDAR-TSS (2 cys) DRDAR-TDC Dr. D. Gyorog DRDAR-LCA K. Russell A. Moss J. Lannon A. Beardell D. Downs W. Einstein L. Schlosberg S. Westley S. Bernstein P. Kemmey C. Heyman Dover, NJ 07801
9	US Army Armament R&D Command ATTN: DRDAR-SCA, L. Stiefel B. Brodman DRDAR-LCB-I, D Spring DRDAR-LCE, R. Walker DRDAR-LCU-CT, E. Barrieres R. Davitt DRDAR-LCU-CV C.Mandala E. Moore DRDAR-LCM-E, S. Kaplowitz Dover, NJ 07801

DISTRIBUTION LIST

No. Of Copies	Organization
5	Commander US Army Armament R&D Command ATTN: DRDAR-QAR, J. Rutkowski G. Allen J. Donner P. Serao D. Adams Dover, NJ 07801
1	Commander US Army Armament R&D Command ATTN: DRCPM-CAWS, F. Menke Dover, NJ 07801
3	Project Manager Munitions Production Base Modernization and Expansion ATTN: DRCPM-PMB, J. Ziegler M. Lohr A. Siklosi Dover, NJ 07801
3	Project Manager Tank Main Armament System ATTN: DRCPM-TMA, Col. D. Appling DRCPM-TMA-105 DRCPM-TMA-120 Dover, NJ 07801
4	Commander US Army Armament R&D Command ATTN: DRDAR-LCW-A M.Salsbury DRDAR-LCS, J. W. Gregorits DRDAR-LCU, A. Moss DRDAR-LC, J. Frasier Dover, NJ 07801
3	Project Manager Cannon Artillery Weapons System DRCPM-CAWS-AM, R. DeKleine H. Hassmann US Army Armament R&D Command Dover, NJ 07801
5	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-LEP-L, Tech Lib DRSAR-LC, L. Ambrosini DRSAR-IRC, G. Cowan DRSAR-LEM, W. Fortune R. Zastrow Rock Island, IL 61299
1	Commander US Army Watervliet Arsenal ATTN: SARWV-RD, R. Thierry Watervliet, NY 12189
1	Director US Army ARRADCOM Benet Weapons Laboratory ATTN: DRDAR-LCB-TL Watervliet, NY 12189
1	Commander US Army Aviation Research and Development Command ATTN: DRDAV-E 4300 Goodfellow Blvd. St. Louis, MO 63120
1	Commander US Army TSARCOM 4300 Goodfellow Blvd. St. Louis, MO 63120
1	Director US Army Air Mobility Research And Development Laboratory Ames Research Center Moffett Field, CA 94035

DISTRIBUTION LIST

No. Of Copies	Organization
1	Commander US Army Communications Research and Development Command ATTN: DRDCO-PPA-SA Fort Monmouth, NJ 07703
1	Commander US Army Electronics Research and Development Command Technical Support Activity ATTN: DELSD-L Fort Monmouth, NJ 07703
1	Commander US Army Harry Diamond Lab. ATTN: DELHD-TA-L 2800 Powder Mill Road Adelphi, MD 20783
2	Commander US Army Missile Command ATTN: DRSMI-R DRSMI-YDL Redstone Arsenal, AL 35898
1	Commander US Army Natick Research and Development Command ATTN: DRXRE, D. Sieling Natick, MA 01762
1	Commander US Army Tank Automotive Research and Development Command ATTN: DRDTA-UL Warren, MI 48090
1	US Army Tank Automotive Materiel Readiness Command ATTN: DRSTA-CG Warren, MI 48090

No. Of Copies	Organization
1	Project Manager Improved TOW Vehicle ATTN: DRCPM-ITV US Army Tank Automotive Research & Development Command Warren, MI 48090
2	Program Manager M1 Abrams Tank System ATTN: DRCPM-GMC-SA, J. Roossien Warren, MI 48090
1	Project Manager Fighting Vehicle Systems ATTN: DRCPM-FVS Warren, MI 48090
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Lib White Sands Missile Range, NM 88002
1	Project Manager M-60 Tank Development ATTN: DRCPM-M60TD Warren, MI 48090
1	Commander US Army Training & Doctrine Command ATTN: ATCD-MA/MAJ Williams Fort Monroe, VA 23651
2	Commander US Army Materials and Mechanics Research Center ATTN: DRXMR-ATL Tech Library Watertown, MA 02172

DISTRIBUTION LIST

No. Of Copies	Organization
1	Commander US Army Research Office ATTN: Tech Library P. O. Box 12211 Research Triangle Park, NC 27709
1	Commander US Army Mobility Equipment Research & Development Command ATTN: DRDME-WC Fort Belvoir, VA 22060
1	Commander US Army Logistics Mgmt Ctr Defense Logistics Studies Fort Lee, VA 23801
2	Commandant US Army Infantry School ATTN: Infantry Agency Fort Benning, GA 31905
1	US Army Armor & Engineer Board ATTN: STEBB-AD-S Fort Knox, KY 40121
1	Commandant US Army Aviation School ATTN: Aviation Agency Fort Rucker, AL 36360
1	Commandant US Army Command & General Staff College Fort Leavenworth, KS 66027
1	Commandant US Army Special Warfare School ATTN: Rev & Tng Lit Div Fort Bragg, NC 28307
1	Commandant US Army Engineer School ATTN: ATSE-CD Ft. Belvoir, VA 22060

No. Of Copies	Organization
1	Commander US Army Foreign Science & Technology Center ATTN: DRXST-MC-3 220 Seventh Street, NE Charlottesville, VA 22901
1	President US Army Artillery Board Ft. Sill, OK 73504
2	Commandant US Army Field Artillery School ATTN: ATSF-CO-MW, B. Willis Ft. Sill, OK 73503
3	Commandant US Army Armor School ATTN: ATZK-CD-MS/M. Falkovitch Armor Agency Fort Knox, KY 40120
1	Chief of Naval Materiel Department of the Navy ATTN: Dr. J. Amlie Washington, DC 20360
1	Chief Naval Research ATTN: Code 473, R. S. Miller 800 N. Quincy Street Arlington, VA 22217
2	Commander Naval Sea Systems Command ATTN: SEA-62R2, J. W. Murrin R. Beauregard National Center, Bldg. 2 Room 6E08 Washington, DC 20362
1	Commander Naval Air Systems Command ATTN: NAIR-954-Tech Lib Washington, DC 20360

DISTRIBUTION LIST

No. Of Copies	Organization
1	Strategic Systems Project Office Dept. of the Navy Room 901 ATTN: Dr. J. F. Kincaid Washington, DC 20376
1	Assistant Secretary of the Navy (R, E, and S) ATTN: Dr. R. Reichenbach Room 5E787 Pentagon Bldg. Washington, DC 20350
1	Naval Research Lab Tech Library Washington, DC 20375
5	Commander Naval Surface Weapons Center ATTN: Code G33, J. L. East D. McClure W. Burrell J. Johndrow Code DX-21 Tech Lib Dahlgren, VA 22448
2	Commander US Naval Ordnance Station ATTN: J. P. Consaga C. Gotzmer Indian Head, MD 20640
4	Commander Naval Surface Weapons Center ATTN: S. Jacobs/Code 240 Code 730 K. Kim/Code R-13 R. Bernecker Silver Spring, MD 20910
2	Commanding Officer Naval Underwater Systems Center Energy Conversion Dept. ATTN: CODE 5B331, R. S. Lazar Tech Lib Newport, RI 02840
4	Commander Naval Weapons Center ATTN: Code 388, R. L. Derr C. F. Price T. Boggs Info. Sci. Div. China Lake, CA 93555
2	Superintendent Naval Postgraduate School Dept. of Mechanical Engineering ATTN: A. E. Fuhs Code 1424 Library Monterey, CA 93940
6	Commander US Naval Ordnance Station ATTN: P. L. Stang C. Smith S. Mitchell C. Christensen D. Brooks Tech Library Indian Head, MD 20640
1	AFSC Andrews AFB Washington, DC 20331
1	Program Manager AFOSR Directorate of Aerospace Sciences ATTN: L. H. Caveny Bolling AFB, DC 20332
6	AFRPL (DYSC) ATTN: D. George J. N. Levine B. Goshgarian D. Thrasher N. Vander Hyde Tech Library Edwards AFB, CA 93523

DISTRIBUTION LIST

No. Of Copies	Organization	No. Of Copies	Organization
1	AFFTC ATTN: SSD-Tech LIb Edwards AFB, CA 93523	1	AVCO Everett Rsch Lab ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149
1	AFATL ATTN: DLYV Eglin AFB, FL 32542	2	Calspan Corporation ATTN: E. B. Fisher Tech Library P. O. Box 400 Buffalo, NY 14225
1	AFATL/DLDL ATTN: O. K. Heiney Eglin AFB, FL 32542	1	Foster Miller Associates ATTN: A. Erickson 135 Second Avenue Waltham, MA 02154
1	ADTC ATTN: DLODL Tech Lib Eglin AFB, FL 32542	1	General Applied Sciences Lab ATTN: J. Erdos Merrick & Stewart Avenues Westbury Long Island, NY 11590
1	Atlantic Research Corporation ATTN: M. K. King 5390 Cherokee Avenue Alexandria, VA 22314	1	General Electric Company Armament Systems Dept. ATTN: M. J. Bulman, Room 1311 Lakeside Avenue Burlington, VT 05412
1	NASA HQ 600 Independence Avenue, SW ATTN: Code JM6, Tech Lib. Washington, DC 20546	1	Hercules Powder Co. Allegheny Ballistics Laboratory ATTN: R. B. Miller P. O. Box 210 Cumberland, MD 21501
1	NASA/Lyndon B. Johnson Space Center ATTN: NHS-22, Library Section Houston, TX 77058	1	Hercules, Inc Bacchus Works ATTN: K. P. McCarty P. O. Box 98 Magna, UT 84044
1	Aerodyne Research, Inc. Bedford Research Park ATTN: V. Yousefian Bedford, MA 01730		
1	Aerojet Solid Propulsion Co. ATTN: P. Micheli Sacramento, CA 95813		
1	Atlantic Research Corporation ATTN: M. K. King 5390 Cheorokee Avenue Alexandria, VA 22314		

DISTRIBUTION LIST

No. Of Copies	Organization
1	Hercules, Inc. Eglin Operations AFATL DLDL ATTN: R. L. Simmons Eglin AFB, FL 32542
1	IITRI ATTN: M. J. Klein 10 W. 35th Street Chicago, IL 60616
2	Lawrence Livermore Laboratory ATTN: M. S. L-355, A. Buckingham Dr. M. Finger P. O. Box 808 Livermore, CA 94550
1	Olin Corporation Badger Army Ammunition Plant ATTN: R. J. Thiede Baraboo, WI 53913
1	Olin Corporation Smokeless Powder Operations ATTN: R. L.Cook P. O. Box 222 ST. Marks, FL 32355
1	Paul Gough Associates, Inc. ATTN: P. S. Gough P. O. Box 1614 Portsmouth, NH 03801
1	Physics International Company 2700 Merced Street Leandro, CA 94577
1	Princeton Combustion Research Lab., Inc. ATTN: M. Summerfield 1041 US Highway One North Princeton, NJ 08540
1	Pulsepower Systems, Inc. ATTN: L. C. Elmore 815 American Street San Carlos, CA 94070
2	Rockwell International Rocketdyne Division ATTN: BA08 J. E. Flanagan J. Grey 6633 Canoga Avenue Canoga Park, CA 91304
1	Science Applications, INC. ATTN: R. B.Edelman 23146 Cumorah Crest Woodland Hills, CA 91364
1	Scientific Research Assoc., Inc. ATTN: H. McDonald P. O. Box 498 Glastonbury, CT 06033
1	Shock Hydrodynamics, Inc. ATTN: W. H. Andersen 4710-16 Vineland Avenue North Hollywood, CA 91602
3	Thiokol Corporation Huntsville Division ATTN: D. Flanigan R. Glick Tech Library Huntsville, AL 35807
2	Thiokol Corporation Wasatch Division ATTN: J. Peterson Tech Library P. O. Box 524 Brigham City, UT 84302
2	Thiokol Corporation Elkton Division ATTN: R. Biddle Tech Lib. P. O. Box 241 Elkton, MD 21921

DISTRIBUTION LIST

No. Of Copies	Organization	No. Of Copies	Organization
2	United Technologies Chemical Systems Division ATTN: R. Brown Tech Library P. O. Box 358 Sunnyvale, CA 94086	1	University of Massachusetts Dept. of Mechanical Engineering ATTN: K. Jakus Amherst, MA 01002
1	Universal Propulsion Company ATTN: H. J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 85029	1	University of Minnesota Dept. of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55455
1	Southwest Research Institute 8500 Culebra Road San Antonio, TX 78228	1	Case Western Reserve University Division of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135
1	Battelle Memorial Institute ATTN: Tech Library 505 King Avenue Columbus, OH 43201	3	Georgia Institute of Tech School of Aerospace Eng. ATTN: B. T. Zinn E. Price W. C. Strahle Atlanta, GA 30332
1	Brigham Young University Dept. of Chemical Engineering ATTN: M. Beckstead Provo, UT 84601	1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616
1	California Institute of Tech 204 Karman Lab Main Stop 301-46 ATTN: F. E. C. Culick 1201 E. California Street Pasadena, CA 91125	1	Johns Hopkins University Applied Physics Laboratory Chemical Proplsion Information Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20707
1	California Institute of Tech Jet Propulsion Laboratory ATTN: L. D. Strand 4800 Oak Grove Drive Pasadena, CA 91103	1	Massachusetts Institute of Tech Dept of Mechanical Engineering ATTN: T. Toong Cambridge, MA 02139
1	University of Illinois Dept of Mech.Eng. ATTN: H. Krier 144 MED, 1206 W. Green St. Urbana, IL 61801		

DISTRIBUTION LIST

No. Of Copies	Organization
1	Pennsylvania State University Applied Research Lab ATTN: G. M. Faeth P. O. Box 30 State College, PA 16801
1	Pennsylvania State University Dept. Of Mechanical Engineering ATTN: K. Kuo University Park, PA 16802
1	Purdue University School of Mechanical Engineering ATTN: J. R. Osborn TSPC Chaffee Hall West Lafayette, IN 47906
1	Rensselaer Polytechnic Inst. Department of Mathematics Troy, NY 12181
1	Rutgers University Dept. of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903
1	SRI International Propulsion Sciences Division ATTN: Tech Library 333 Ravenswood Avenue Menlo Park, CA 94025
1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Hoboken, NJ 07030
2	Los Alamos Scientific Lab ATTN: T3, D. Butler M. Division, Dr. Craig P. O. Box 1663 Los Alamos, NM 87545

No. Of Copies	Organization
1	University of Southern California Mechanical Engineering Dept. ATTN: OHE200, M. Gerstein Los Angeles, CA 90007
2	University of Utah Dept. of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112
1	Washington State University Dept. of Mechanical Engineering ATTN: C. T. Crowe Pullman, WA 99164

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: DRXSY-D
DRXSY-MP, H. Cohen

Cdr, USATECOM
ATTN: DRSTE-TO-F
STEAP-MT, S. Walton
G. Rice
D. Lacey
C. Herud

Dir, Hel
ATTN: J. Weisz

Dir, USACSL
Bldg. E3516, EA
ATTN: DRDAR-CLB-PA
DRDAR-ACW

USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet, fold as indicated, staple or tape closed, and place in the mail. Your comments will provide us with information for improving future reports.

1. BRL Report Number ______________________________

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____
____
____

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) ______________________________

____
____

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

____
____

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) __________

____
____
____

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ______________________________

Telephone Number: ______________________________

Organization Address: ______________________________

____

____

— — — — — — — — — FOLD HERE — — — — — — — — — —

Director
US Army Ballistic Research Laboratory
Aberdeen Proving Ground, MD 21005

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO 12062 WASHINGTON,DC

POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY

Director
US Army Ballistic Research Laboratory
ATTN: DRDAR-TSB -S
Aberdeen Proving Ground, MD 21005

— — — — — — — — — FOLD HERE — — — — — — — — — —