



The Development of a Multifunctional Antenna Precursor for Ground Vehicle Structures

**by Shawn M. Walsh, Gregory Teitelbaum, John Cook,
Alvin Lim, and Kirk Tackitt**

ARL-TR-3699

December 2005

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

DESTRUCTION NOTICE—Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5069

ARL-TR-3699**December 2005**

The Development of a Multifunctional Antenna Precursor for Ground Vehicle Structures

Shawn M. Walsh, Gregory Teitelbaum, John Cook, and Kirk Tackitt
Weapons and Materials Research Directorate, ARL

Alvin Lim
Florida A&M University

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this 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 information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 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 any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) December 2005		2. REPORT TYPE Final		3. DATES COVERED (From - To) September to October 2005	
4. TITLE AND SUBTITLE The Development of a Multifunctional Antenna Precursor for Ground Vehicle Structures				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Shawn M. Walsh, Gregory Teitelbaum, John Cook, and Kirk Tackitt (all of ARL); Alvin Lim (FA&M U)				5d. PROJECT NUMBER 622618.H80	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Weapons and Materials Research Directorate Aberdeen Proving Ground, MD 21005-5069				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-3699	
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 is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT U.S. Army transformation will require lighter, more rapidly deployable ground vehicle systems. Equally important will be the need for superior communication and sensor capability to detect and respond to friendly and hostile entities. The challenge is to consolidate the required armor, infrastructure, electronic hardware, and other systems into a lightweight vehicle structure. This particular research provides a very preliminary but nevertheless representative effort to explore conformal and multifunctional material systems with the primary goal of reducing weight and volume. A typical structural armor is used as the starting point, and a metallic antenna element is integrated into the structure. Preliminary results are presented, and the intent is to use these results to identify issues, constraints, advantages/disadvantages, and to evolve toward a truly multifunctional solution wherein "atoms are shared" in more than one required function (e.g., armor, structure, electromagnetic radiation of modulated signals).					
15. SUBJECT TERMS antenna; multi-functional materials; structural antenna; structural composites					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 27	19a. NAME OF RESPONSIBLE PERSON Shawn M. Walsh
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) 410-306-0815

Contents

List of Figures	iv
Acknowledgments	v
1. Introduction	1
2. Background	1
3. Prototyping Embedded Antenna	2
4. Setup and Testing of Embedded Antenna	6
5. Results and Discussion	7
6. Summary	8
7. References	9
Distribution List	10

List of Figures

Figure 1. A conceptual FCS vehicle with embedded antenna armor.....	1
Figure 2. The VARTM process.	3
Figure 3. Fabricated E-glass frame for embedded antenna.....	3
Figure 4. Copper antenna design.	4
Figure 5. BNC connector accessible through rear of plate.	4
Figure 6. Tile array with embedded antenna and E-glass frame.....	5
Figure 7. Tile array placed in E-glass frame with two-ply E-glass cover panel.....	5
Figure 8. Panel in wooden frame with BNC cable connected.	6
Figure 9. Graph of incoming carrier wave.....	7

Acknowledgments

The authors acknowledge the support, technical exchange, and comments made by Dr. Eric Wetzel, Mr. Eric Adler, Ms. Ozlem Kilic, and Mr. Steven Weiss, all of the U.S. Army Research Laboratory.

INTENTIONALLY LEFT BLANK

1. Introduction

Continuing efforts to reduce the overall weight of U.S. Army systems while maintaining and/or increasing functionality have led to the need of innovative and efficient methods that can be employed to meet new demands. The U.S. Army's Future Combat Systems (FCS) will require systems to weigh 16 to 20 tons while still being fully armed, armored, and operational. The integration of multiple components of these systems may allow for rigorous FCS weight requirements to be met while sustaining a full level of serviceability. In parallel with this concept, the integration of a communications antenna into the armor of a vehicle (figure 1¹) may be an efficient approach to minimizing space and weight without sacrificing the characteristics of either sub-system.

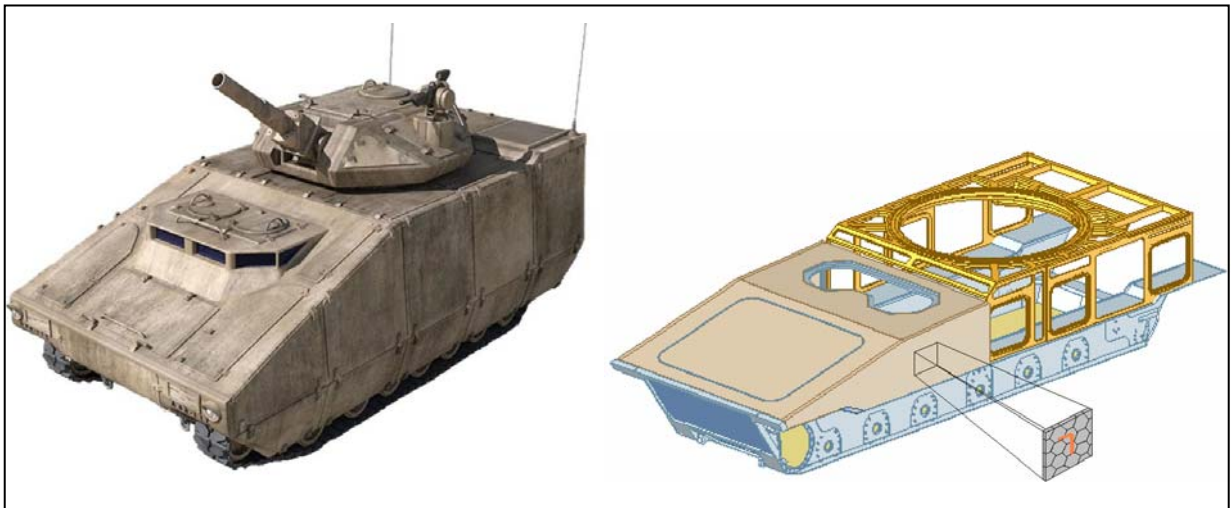


Figure 1. A conceptual FCS vehicle with embedded antenna armor.

2. Background

Development of a structurally embedded antenna involves the combination two previously separate fields of study: communications systems and structural armor. These issues fall under two categories of research. One concern is the ability to maintain performance levels of the armor after integration of the antenna (1,2,3,4). Research and development concerning embedded antenna structures, primarily in the aerospace industry, have traditionally relied on

¹The source of figure 1 was a manufacturing technology objective briefing on Future Combat Systems in March 2005.

composite sandwich structures. The materials in these preliminary structures have included S2² glass-epoxy panels, aluminum honeycomb structures, and more recently, graphite skins. These materials have been previously chosen over other combinations such as Kevlar³ 49-epoxy because they have higher dielectric constant and tangent loss that limit the performance of the embedded antenna. The ability to maintain structural requirements while allowing effective transmission of signal has dictated the choice of materials so far in this area of research.

Another focus of research in the field of embedded antennas is the design and implementation of the antenna itself. Typically, designs have relied on a single-ply antenna layer that has a two-dimensional geometry. In some cases, a dielectric layer was used to have the antenna itself to perform on the level of antennas many times larger. Radio frequency (RF) absorbers have also been implemented in early prototypical designs. Once the antenna assembly has been designed, it must be determined how to “feed” it with an RF signal. Most preliminary designs have allowed for a feed cone or feed lines to distribute the signal. The combination and integration of a highly capable structure and a fully functioning antenna are the ultimate goal in developing and prototyping a structurally embedded antenna.

3. Prototyping Embedded Antenna

To show the feasibility of a communications antenna embedded into vehicle armor, an armor “recipe” currently prototyped at the U.S. Army Research Laboratory was chosen to occupy the antenna. This recipe consisted of glass fibers (one panel using S2 glass and the other using E-glass) infused with an SC-15 resin along with a tile array composed of 0.75-inch hexagonal ceramic tiles. The prototype then consists of an antenna manufactured from thin copper sheeting that is embedded on either side of the tile array. The choice of this armor recipe allowed for an easy fabrication (because of our familiarity with the process) and showed that the antenna could be placed into an armor system with minimal changes in the recipe of the panel.

The fabrication of the armor panel with embedded antenna began with the construction of a 0.75-inch thick glass panel to act as a backing plate and frame for the tile array and antenna. Thirty-two plies of E-glass (30 inches by 30 inches) were then infused with an SC-15 resin via the vacuum-assisted resin transfer molding (VARTM) method. In this process, a composite pre-form is under vacuum, and resin at atmospheric pressure is pulled into the part until the fibers are completely infused (figure 2). After infusion and curing, this 0.75-inch thick panel was cut into a base plate of 20 inches by 20 inches and border panels consisting of two 20-inch by 2.5-inch and two 15-inch by 2.5-inch pieces. The border panels were then attached to the outside of the

²S2 glass was developed in the 1960s by Owens-Corning to bridge the gap between E-glass and mil-spec S-glass. Compared to E-glass, S-glass provides about 40% higher tensile and flexural strengths, about 10 to 20% higher compressive strength and flexural modulus, and greater abrasion resistance.

³Kevlar is a registered trademark of E. I. DuPont de Nemours and Co., Inc.

base plate with an E-120HP Hysol⁴ epoxy. This frame would allow for the tile array to be placed inside. To allow connection access to the copper antenna, a hole was then drilled in the rear of the panel. To complete the frame, strips of Velcro⁵ were placed on the edge of the panel so that a removable cover panel could be later attached. The final frame is shown in figure 3.

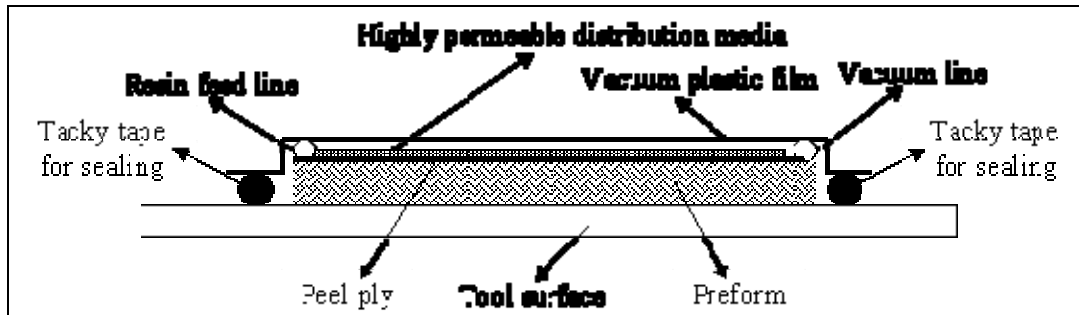


Figure 2. The VARTM process.

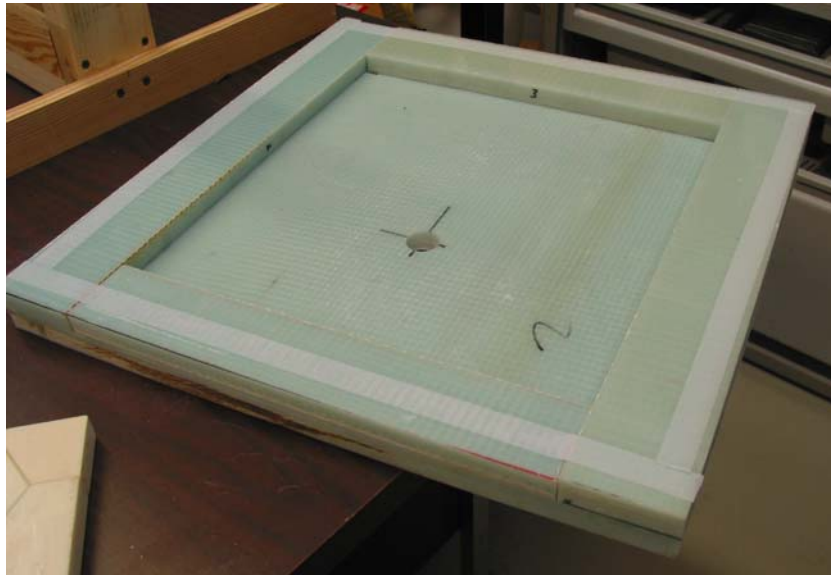


Figure 3. Fabricated E-glass frame for embedded antenna.

A tile array was constructed and installed inside the E-glass frame. A 15-inch by 15-inch array of 0.75-inch-thick hexagon ceramic tiles was bonded with an E-120HP Hysol epoxy. This tile array fit into the previously constructed glass frame. A copper antenna was designed to be attached to the tile array (5). A geometry was chosen that consisted of a large ground plane on one side of the tile array and a smaller transmitting plane on the opposite side. The two sides of the copper

⁴Hysol is a registered trademark of Henkel Loctite Corporation.

⁵Velcro is a registered trademark of Velcro USA, Inc.

antenna were attached to the tile array with a 3M⁶ Super 77 spray adhesive. The antenna designs can be seen in figure 4.



Figure 4. Copper antenna design.

To allow for a connection between the antenna and an electronic device, a BNC (Bayonet Neill-Concelman) connector was soldered to the ground plane of the antenna. This allowed a BNC cable to be connected to the antenna at one end and either a radio or oscilloscope at the opposite end. The hole drilled into the glass frame allowed for the BNC cable to run through the panel (figure 5). Figure 6 shows the completed tile array with the antenna attached along side the glass frame.



Figure 5. BNC connector accessible through rear of plate.

To allow for visibility of the tile array and antenna, a cover panel was fabricated to be attached over the glass frame. This was done by the VARTM method. The panel was composed of two

⁶3M and Super 77 are trademarks of the 3M Company.

20-inch by 20-inch plies of E-glass and was infused with SC-15 resin. After infusion and curing, Velcro was then placed the outer rim of the cover panel to allow it to be attached to the antenna frame (figure 7).



Figure 6. Tile array with embedded antenna and E-glass frame.

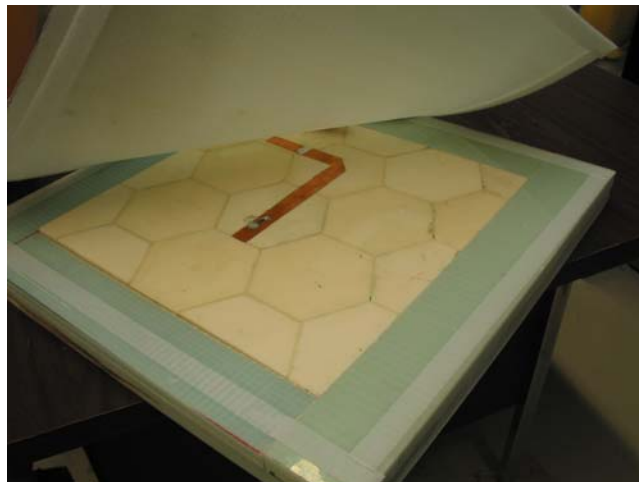


Figure 7. Tile array placed in E-glass frame with two-ply E-glass cover panel.

To enable the armor panels to be free standing, a wooden frame was constructed to house each armor panel. The frame was built to allow easy placement and removal of the panel from the frame, while allowing the BNC cable to pass through. The frame is shown in figure 8. After construction of the frame, the armor panels were completed and ready to be tested.



Figure 8. Panel in wooden frame with BNC cable connected.

4. Setup and Testing of Embedded Antenna

Once the antennas were embedded, it was necessary to test to see if the antennas could communicate with one another. To test their communicating ability, carrier wave strength was measured from a radio transmitting through an embedded antenna. An oscilloscope, which was connected to the other antenna, measured the change in intensity from the carrier wave as the transmitting radio was rapidly connected and disconnected from another embedded antenna.

The antenna systems were positioned about 70 feet away from each other with the transmitting planes facing each other. The radio was turned on and off rapidly for approximately 30 seconds. The data from the oscilloscope were recorded via a connected computer. This computer, using LabVIEW⁷ software, recorded voltage data points every 0.1 millisecond. Following the test, these data were then plotted via Microsoft Excel⁸. The resulting graph is shown in figure 9.

⁷LabVIEW is a trademark of National Instruments Corp.

⁸Excel is a trademark of Microsoft.

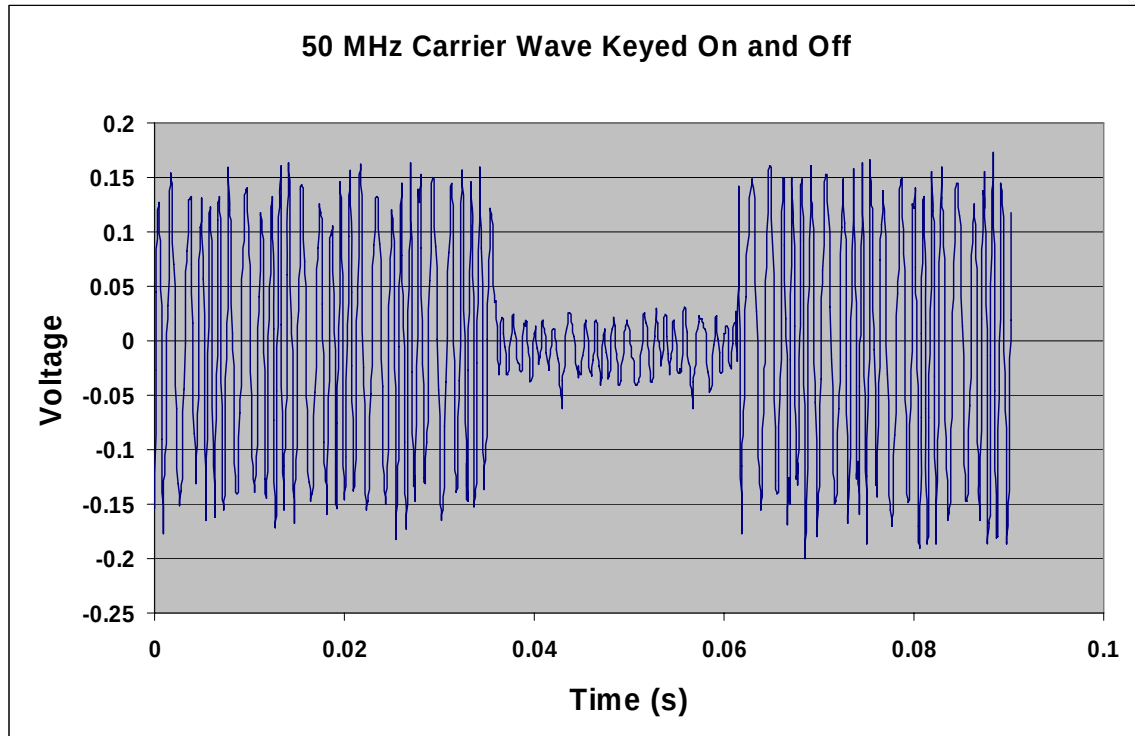


Figure 9. Graph of incoming carrier wave.

5. Results and Discussion

As can be seen from the preceding graph, it was instantly visible that the two embedded antennas possessed the capability of communicating with each other. A large difference in incoming voltage was detected as the carrier wave was turned on and off from the transmitting antenna. From this experiment, evidence in the form of tangible data was collected to support the feasibility of a communications system embedded into vehicle armor.

Because the research goal was to prototype the capability of such a communications system, we left room for optimization. A more in-depth analysis could have been used in researching the geometry of the antenna itself. This would have allowed for better transmission quality and range. However, the geometry used was sufficient in showing the feasibility of an integrated antenna, since a very visible change in the voltage of the carrier wave was seen as the antenna was rapidly turned on and off.

For further research, the effects that different fibers in the armor panel have on antenna performance may need to be examined. S2 and E-glass fibers were employed because of their common use in armor paneling, but different fibers may be able to increase transmission quality and range of the integrated antenna. The operating frequency of the item transmitting the signal

through the antenna was also a variable that could be examined in future research. Different operating frequencies may provide better antenna performance without otherwise altering the design of the armor or the antenna.

6. Summary

A prototype has been developed that has integrated an embedded antenna into structural armor. Through common fabrication practices and designs, it has been shown that the integration of such an antenna into existing armor recipes can be done so feasibly and effectively. Although in its very early stages, this preliminary research has shown enough possibility to warrant a more in-depth study concerning the effects of changing such variables as antenna geometry and fiber selection. Through future examination and research, the potential applications of an embedded antenna structure will be determined and more advanced and specialized prototypes can be designed and fabricated. This work has allowed for an advance in the design of such structural armor and has addressed some issues that may need to be further examined. As important, this work identified the potential for a truly multifunctional approach in realizing the simultaneous properties required in such a system.

7. References

1. Lockyer, Allen J.; Alt, Kevin H.; Kinslow, Robert W.; Kan, Han-Pin; Kudva, Jayanth N.; Tuss, Jim; Goetz, Allan. Development of a structurally integrated conformal load bearing multifunction antenna: Overview of the Air Force Smart Skin Structures Technology Demonstration Program. *SPIE*, 2722, 55-64.
2. Lockyer, Allen J.; Alt, Kevin H.; Kudva, Jayanth N.; Tuss, Jim. Air vehicle integration issues and considerations for CLAS successful Implementation. *SPIE* **2002**, 4332, 48-59.
3. Alt, Kevin H.; Lockyer, Allen J.; Coughlin, Daniel P.; Kudva, Jayanth N.; Tuss, Jim. Overview of the DoD's RF Multifunction Structural Aperture (MUSTRAP) Program. *SPIE* **2001**, 4334, 137-146.
4. Kim, C. K.; Lee, L. M.; Park, H. C.; Hwang, W.; Park, W. S. Impact damage and antenna performance of conformal load-bearing antenna structures. *Smart Mater. Struct.* **2003**, 12, 672-679.
5. Personal communication with Ozlem Kilic, Sensors and Electron Devices Directorate, U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, February 2005.

NO. OF COPIES	ORGANIZATION
1 (PDF ONLY)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	US ARMY RSRCH DEV & ENGRG CMD SYSTEMS OF SYSTEMS INTEGRATION AMSRD SS T 6000 6TH ST STE 100 FORT BELVOIR VA 22060-5608
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	DIRECTOR US ARMY RESEARCH LAB IMNE ALC IMS 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CI OK TL 2800 POWDER MILL RD ADELPHI MD 20783-1197
2	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CS OK T 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB ATTN AMSRD ARL SE DE R ATKINSON 2800 POWDER MILL RD ADELPHI MD 20783-1197
6	DIR US ARMY RESEARCH LAB ATTN AMSRD ARL WM MB T LI A ABRAHAMIAN M BERMAN M CHOWDHURY A FRYDMAN E SZYMANSKI 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
1	US ARMY RSRCH DEV & ENG CMD SYSTEMS OF SYSTEMS INTEGRATION ATTN AMSRD SS T 6000 6TH ST STE 100 FORT BELVOIR VA 22060-5608
1	COMMANDER US ARMY MATERIEL CMD ATTN AMXMI INT 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
3	PM MAS ATTN SFAE AMO MAS SFAE AMO MAS MC CHIEF ENGINEER PICATINNY ARSENAL NJ 07806-5000
2	PM MAS ATTN SFAE AMO MAS PS SFAE AMO MAS LC PICATINNY ARSENAL NJ 07806-5000
1	CDR US ARMY ARDEC ATTN AMSTA AR CC COL JENKER PICATINNY ARSENAL NJ 07806-5000
1	CDR US ARMY ARDEC ATTN AMSTA AR FSE PICATINNY ARSENAL NJ 07806-5000
1	CDR US ARMY ARDEC ATTN AMSTA AR TD PICATINNY ARSENAL NJ 07806-5000
7	CDR US ARMY ARDEC ATTN AMSTA AR CCH A D VO F ALTAMURA M NICOLICH M PALATHINGUL R HOWELL A VELLA M YOUNG PICATINNY ARSENAL NJ 07806-5000
6	CDR US ARMY ARDEC ATTN AMSTA AR CCH A L MANOLE S MUSALLI R CARR M LUCIANO E LOGSDEN T LOUZEIRO PICATINNY ARSENAL NJ 07806-5000

NO. OF
COPIES ORGANIZATION

1 CDR US ARMY ARDEC
ATTN AMSTA AR CCH P J LUTZ
PICATINNY ARSENAL NJ 07806-5000

1 CDR US ARMY ARDEC
ATTN AMSTA AR FSF T C LIVECCHIA
PICATINNY ARSENAL NJ 07806-5000

1 CDR US ARMY ARDEC
ATTN AMSTA ASF
PICATINNY ARSENAL NJ 07806-5000

1 CDR US ARMY ARDEC
ATTN AMSTA AR QAC T C J PAGE
PICATINNY ARSENAL NJ 07806-5000

1 CDR US ARMY ARDEC
ATTN AMSTA AR M D DEMELLA
PICATINNY ARSENAL NJ 07806-5000

3 CDR US ARMY ARDEC
ATTN AMSTA AR FSA A WARNASH
B MACHAK M CHIEFA
PICATINNY ARSENAL NJ 07806-5000

2 CDR US ARMY ARDEC
ATTN AMSTA AR FSP G M SCHIKSNIS
D CARLUCCI
PICATINNY ARSENAL NJ 07806-5000

2 CDR US ARMY ARDEC
ATTN AMSTA AR CCH C H CHANIN
S CHICO
PICATINNY ARSENAL NJ 07806-5000

1 CDR US ARMY ARDEC
ATTN AMSTA AR QAC T D RIGOGLIOSO
PICATINNY ARSENAL NJ 07806-5000

1 CDR US ARMY ARDEC
ATTN AMSTA AR WEL F M GUERRIERE
PICATINNY ARSENAL NJ 07806-5000

9 CDR US ARMY ARDEC
ATTN AMSTA AR CCH B P DONADIA
F DONLON P VALENTI
C KNUTSON G EUSTICE
K HENRY J MCNABOC
R SAYER F CHANG
PICATINNY ARSENAL NJ 07806-5000

1 PM ARMS
ATTN SFAE GCSS ARMS
BLDG 171
PICATINNY ARSENAL NJ 07806-5000

NO. OF
COPIES ORGANIZATION

1 CDR US ARMY ARDEC
ATTN AMSTA AR WEA J BRESCIA
PICATINNY ARSENAL NJ 07806-5000

1 CDR US ARMY TACOM
PM COMBAT SYSTEMS
ATTN SFAE GCS CS
6501 ELEVEN MILE RD
WARREN MI 48397-5000

1 CDR US ARMY TACOM
PM SURVIVABLE SYSTEMS
ATTN SFAE GCSS W GSI H M RYZYI
6501 ELEVEN MILE RD
WARREN MI 48397-5000

1 CDR US ARMY TACOM
CHIEF ABRAMS TESTING
ATTN SFAE GCSS W AB QT
T KRASKIEWICZ
6501 ELEVEN MILE RD
WARREN MI 48397-5000

1 COMMANDER
US ARMY TACOM
ATTN AMSTA SF
WARREN MI 48397-5000

1 DIR AIR FORCE RSCH LAB
ATTN MLLMD D MIRACLE
2230 TENTH ST
WRIGHT PATTERSON AFB OH 45433-7817

1 OFC OF NAVAL RESEARCH
ATTN J CHRISTODOULOU
ONR CODE 332
800 N QUINCY ST
ARLINGTON VA 22217-5600

1 CDR WATERVLIET ARSENAL
ATTN SMCWV QAE Q B VANINA
BLDG 44
WATERVLIET NY 12189-4050

2 HQ IOC TANK
AMMUNITION TEAM
ATTN AMSIO SMT R CRAWFORD
W HARRIS
ROCK ISLAND IL 61299-6000

2 COMMANDER
US ARMY AMCOM
AVIATION APPLIED TECH DIR
ATTN J SCHUCK
FORT EUSTIS VA 23604-5577

NO. OF
COPIES ORGANIZATION

- 1 NSWC
DAHLGREN DIV CODE G06
DAHLGREN VA 22448
- 2 US ARMY CORPS OF ENGINEERS
ATTN CERD C T LIU
CEW ET T TAN
20 MASSACHUSETTS AVE NW
WASHINGTON DC 20314
- 1 US ARMY COLD REGIONS
RSCH & ENGRNG LAB
ATTN P DUTTA
72 LYME RD
HANOVER NH 03755
- 4 CDR US ARMY TACOM
ATTN AMSTA TR R MCCLELLAND
D THOMAS J BENNETT
D HANSEN
WARREN MI 48397-5000
- 4 CDR US ARMY TACOM
ATTN AMSTA JSK S GOODMAN
J FLORENCE D TEMPLETON
A SCHUMACHER
WARREN MI 48397-5000
- 5 CDR US ARMY TACOM
ATTN AMSTA TR D D OSTBERG
L HINOJOSA B RAJU
AMSTA CS SF H HUTCHINSON
F SCHWARZ
WARREN MI 48397-5000
- 6 BENET LABS
ATTN AMSTA AR CCB R FISCELLA
M SOJA E KATHE G FRIAR
M SCAVULO G SPENCER
WATERVLIET NY 12189-4050
- 4 BENET LABS
ATTN AMSTA AR CCB P WHEELER
S KRUPSKI J VASILAKIS
R HASENBEIN
WATERVLIET NY 12189-4050
- 4 BENET LABS
ATTN AMSTA CCB R S SOPOK
E HYLAND D CRAYON
R DILLON
WATERVLIET NY 12189-4050

NO. OF
COPIES ORGANIZATION

- 1 USA SBCCOM PM SOLDIER SPT
ATTN AMSSB PM RSS A J CONNORS
KANSAS ST
NATICK MA 01760-5057
- 1 NSWC
TECH LIBRARY CODE B60
17320 DAHLGREN RD
DAHLGREN VA 22448
- 2 USA SBCCOM
MATERIAL SCIENCE TEAM
ATTN AMSSB RSS J HERBERT
M SENNETT
KANSAS ST
NATICK MA 01760-5057
- 2 OFC OF NAVAL RESEARCH
ATTN D SIEGEL CODE 351 J KELLY
800 N QUINCY ST
ARLINGTON VA 22217-5660
- 1 NSWC
CRANE DIVISION
M JOHNSON CODE 20H4
LOUISVILLE KY 40214-5245
- 2 NSWC
ATTN U SORATHIA
C WILLIAMS CODE 6551
9500 MACARTHUR BLVD
WEST BETHESDA MD 20817
- 2 CDR NSWC
CARDEROCK DIVISION
ATTN R PETERSON CODE 2020
M CRITCHFIELD CODE 1730
BETHESDA MD 20084
- 4 DIR US ARMY NGIC
ATTN D LEITER MS 404
J GASTON MS 301
M HOLTUS MS 301
M WOLFE MS 307
2055 BOULDERS RD
CHARLOTTESVILLE VA 22911-8318
- 4 DIR US ARMY NGIC
ATTN S MINGLEDORF MS 504
W GSTATTENBAUER MS 304
R WARNER MS 305
J CRIDER MS 306
2055 BOULDERS RD
CHARLOTTESVILLE VA 22911-8318

<u>NO. OF</u> <u>COPIES</u>	<u>ORGANIZATION</u>
1	NAVAL SEA SYSTEMS CMD ATTN D LIESE 1333 ISAAC HULL AVE SE 1100 WASHINGTON DC 20376-1100
4	US ARMY SBCCOM SOLDIER SYSTEMS CTR BALLISTICS TEAM ATTN J WARD W ZUKAS P CUNNIFF J SONG KANSAS ST NATICK MA 01760-5019
3	US ARMY SBCCOM SOLDIER SYSTEMS CTR MARINE CORPS TEAM J MACKIEWICZ ATTN AMSSB RCP SS W NYKVIST S BEAUDOIN KANSAS ST NATICK MA 01760-5019
7	US ARMY RESEARCH OFC ATTN A CROWSON H EVERITT J PRATER G ANDERSON D STEPP D KISEROW J CHANG PO BOX 12211 RSCH TRIANGLE PARK NC 27709-2211
1	AFRL MLBC 2941 P ST RM 136 WRIGHT PATTERSON AFB OH 45433-7750
1	DIRECTOR LOS ALAMOS NATL LAB ATTN F L ADDESSIO T 3 MS 5000 PO BOX 1633 LOS ALAMOS NM 87545
4	NSWC ATTN J FRANCIS CODE G30 D WILSON CODE G32 R D COOPER CODE G32 J FRAYSSE CODE G33 DAHLGREN VA 22448
4	NSWC ATTN T DURAN CODE G33 L DE SIMONE CODE G33 R HUBBARD CODE G33 DAHLGREN VA 22448

<u>NO. OF</u> <u>COPIES</u>	<u>ORGANIZATION</u>
1	NSWC CARDEROCK DIVISION R CRANE CODE 6553 9500 MACARTHUR BLVD WEST BETHESDA MD 20817-5700
1	AFRL MLSS ATTN R THOMSON 2179 12TH ST RM 122 WRIGHT PATTERSON AFB OH 45433-7718
2	AFRL ATTN F ABRAMS J BROWN BLDG 653 2977 P ST STE 6 WRIGHT PATTERSON AFB OH 45433-7739
5	DIR LAWRENCE LIVERMORE NATL LAB ATTN R CHRISTENSEN S DETERESA F MAGNESS M FINGER MS 313 M MURPHY L 282 PO BOX 808 LIVERMORE CA 94550
1	AFRL MLS OL ATTN L COULTER 5851 F AVE BLDG 849 RM AD1A HILL AFB UT 84056-5713
1	OSD JOINT CCD TEST FORCE ATTN OSD JCCD R WILLIAMS 3909 HALLS FERRY RD VICKSBURG MS 29180-6199
3	DARPA ATTN M VANFOSSEN S WAX L CHRISTODOULOU 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
3	OAK RIDGE NATL LAB ATTN R M DAVIS C EBERLE MS 8048 C D WARREN MS 8039 PO BOX 2008 OAK RIDGE TN 37831-6195

<u>NO. OF</u> <u>COPIES</u>	<u>ORGANIZATION</u>	<u>NO. OF</u> <u>COPIES</u>	<u>ORGANIZATION</u>
3	DIR SANDIA NATL LABS APPLIED MECHS DEPT ATTN MS 9042 J HANDROCK Y R KAN J LAUFFER PO BOX 969 LIVERMORE CA 94551-0969	1	DIR DEFENSE INTLGNC AGENCY TA 5 ATTN K CRELLING WASHINGTON DC 20310
4	NIST ATTN M VANLANDINGHAM MS 8621 J CHIN MS 8621 J MARTIN MS 8621 D DUTHINH MS 8611 100 BUREAU DR GAITHERSBURG MD 20899	1	COMPOSITE MATERIALS INC ATTN D SHORTT 19105 63 AVE NE PO BOX 25 ARLINGTON WA 98223
1	HYDROGEOLOGIC INC ATTN SERDP ESTCP SPT OFC S WALSH 1155 HERNDON PKWY STE 900 HERNDON VA 20170	1	JPS GLASS ATTN L CARTER PO BOX 260 SLATER RD SLATER SC 29683
3	NASA LANGLEY RSCH CAR ATTN AMSRD ARL VT W ELBER MS 266 F BARTLETT JR MS 266 G FARLEY MS 266 HAMPTON VA 23681-0001	1	COMPOSITE MATERIALS INC ATTN R HOLLAND 11 JEWEL CT ORINDA CA 94563
1	FHWA ATTN E MUNLEY 6300 GEORGETOWN PIKE MCLEAN VA 22101	1	COMPOSITE MATERIALS INC ATTN C RILEY 14530 S ANSON AVE SANTA FE SPRINGS CA 90670
1	USDOT FEDERAL RAILROAD ATTN M FATEH RDV 31 WASHINGTON DC 20590	1	SIMULA ATTN R HUYETT 10016 S 51ST ST PHOENIX AZ 85044
3	CYTEC FIBERITE ATTN R DUNNE D KOHLI R MAYHEW 1300 REVOLUTION ST HAVRE DE GRACE MD 21078	2	PROTECTION MATERIALS INC ATTN M MILLER F CRILLEY 14000 NW 58 CT MIAMI LAKES FL 33014
1	DIR NGIC ATTN IANG TMT 2055 BOULDERS RD CHARLOTTESVILLE VA 22911-8318	2	FOSTER MILLER ATTN M ROYLANCE W ZUKAS 195 BEAR HILL RD WALTHAM MA 02354-1196
2	3TEX CORP ATTN A BOGDANOVICH J SINGLETARY 109 MACKENAN DR CARY NC 27511	1	ROM DEVELOPMENT CORP ATTN R O MEARA 136 SWINEBURNE ROW BRICK MARKET PLACE NEWPORT RI 02840
		2	TEXTRON SYSTEMS ATTN M TREASURE T FOLTZ 1449 MIDDLESEX ST LOWELL MA 01851

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	O GARA HESS & EISENHARDT ATTN M GILLESPIE 9113 LESAINTE DR FAIRFIELD OH 45014
1	MILLIKEN RESEARCH CORP ATTN M MACLEOD PO BOX 1926 SPARTANBURG SC 29303
1	CONNEAUGHT INDUSTRIES INC ATTN J SANTOS PO BOX 1425 COVENTRY RI 02816
1	ARMTEC DEFENSE PRODUCTS ATTN S DYER 85 901 AVE 53 PO BOX 848 COACHELLA CA 92236
3	PACIFIC NORTHWEST LAB ATTN M SMITH G VAN ARSDALE R SHIPPELL PO BOX 999 RICHLAND WA 99352
1	ALLIANT TECHSYSTEMS INC 4700 NATHAN LN N PLYMOUTH MN 55442-2512
1	APPLIED COMPOSITES ATTN W GRISCH 333 NORTH SIXTH ST ST CHARLES IL 60174
1	CUSTOM ANALYTICAL ENG SYS INC ATTN A ALEXANDER 13000 TENSOR LANE NE FLINTSTONE MD 21530
1	AAI CORP ATTN DR N B MCNELLIS PO BOX 126 HUNT VALLEY MD 21030-0126
1	OFC DEPUTY UNDER SEC DEFNS ATTN J THOMPSON 1745 JEFFERSON DAVIS HWY CRYSTAL SQ 4 STE 501 ARLINGTON VA 22202

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
3	ALLIANT TECHSYSTEMS INC ATTN J CONDON E LYNAM J GERHARD WV01 16 STATE RT 956 PO BOX 210 ROCKET CENTER WV 26726-0210
1	PROJECTILE TECHNOLOGY INC 515 GILES ST HAVRE DE GRACE MD 21078
1	PRATT & WHITNEY ATTN C WATSON 400 MAIN ST MS 114 37 EAST HARTFORD CT 06108
5	NORTHROP GRUMMAN ATTN B IRWIN K EVANS D EWART J MCGLYNN A SHREKENHAMER BLDG 160 DEPT 3700 1100 W HOLLYVALE ST AZUSA CA 91701
1	BRIGS COMPANY ATTN J BACKOFEN 2668 PETERBOROUGH ST HERNDON VA 22071-2443
1	ZERNOW TECHNICAL SERVICES ATTN L ZERNOW 425 W BONITA AVE STE 208 SAN DIMAS CA 91773
2	GENERAL DYNAMICS OTS FLINCHBAUGH DIV ATTN K LINDE T LYNCH PO BOX 127 RED LION PA 17356
1	GKN WESTLAND AEROSPACE ATTN D OLDS 450 MURDOCK AVE MERIDEN CT 06450-8324
1	BOEING ROTORCRAFT ATTN P HANDEL 800 B PUTNAM BLVD WALLINGFORD PA 19086

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
5	SIKORSKY AIRCRAFT ATTN G JACARUSO J ADELMANN T CARSTENSAN B KAY S GARBO MS S330A 6900 MAIN ST PO BOX 9729 STRATFORD CT 06497-9729
1	AEROSPACE CORP ATTN G HAWKINS M4 945 2350 E EL SEGUNDO BLVD EL SEGUNDO CA 90245
2	CYTEC FIBERITE ATTN M LIN W WEB 1440 N KRAEMER BLVD ANAHEIM CA 92806
2	UDLP ATTN G THOMAS M MACLEAN PO BOX 58123 SANTA CLARA CA 95052
2	UDLP ATTN R BRYNSVOLD P JANKE MS 170 4800 E RIVER RD MINNEAPOLIS MN 55421-1498
1	LOCKHEED MARTIN SKUNK WORKS ATTN D FORTNEY 1011 LOCKHEED WAY PALMDALE CA 93599-2502
1	NORTHROP GRUMMAN CORP ELECTRONIC SENSORS & SYSTEMS DIV ATTN E SCHOCH MS V 16 1745A W NURSERY RD LINTHICUM MD 21090
1	GDLS DIVISION ATTN D BARTLE PO BOX 1901 WARREN MI 48090
2	GDLS ATTN D REES M PASIK PO BOX 2074 WARREN MI 48090-2074

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	GDLS MUSKEGON OPER ATTN M SOIMAR 76 GETTY ST MUSKEGON MI 49442
1	GENERAL DYNAMICS AMPHIBIOUS SYS SURVIVABILITY LEAD ATTN G WALKER 991 ANNAPOLIS WAY WOODBIDGE VA 22191
6	INST FOR ADVANCED TECH ATTN H FAIR I MCNAB P SULLIVAN S BLESS W REINECKE C PERSAD 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	ARROW TECH ASSOC 1233 SHELBURNE RD STE D8 SOUTH BURLINGTON VT 05403-7700
1	R EICHELBERGER CONSULTANT 409 W CATHERINE ST BEL AIR MD 21014-3613
1	SAIC ATTN G CHRYSSOMALLIS 8500 NORMANDALE LAKE BLVD SUITE 1610 BLOOMINGTON MN 55437-3828
1	UCLA MANE DEPT ENGR IV ATTN H T HAHN LOS ANGELES CA 90024-1597
1	UMASS LOWELL PLASTICS DEPT ATTN N SCHOTT 1 UNIVERSITY AVE LOWELL MA 01854
1	IIT RESEARCH CAR ATTN D ROSE 201 MILL ST ROME NY 13440-6916
1	GA TECH RESEARCH INST GA INST OF TCHNLGY ATTN P FRIEDERICH ATLANTA GA 30392

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	MICHIGAN ST UNIV MSM DEPT ATTN R AVERILL 3515 EB EAST LANSING MI 48824-1226
1	PENN STATE UNIV ATTN R S ENGEL 245 HAMMOND BLDG UNIVERSITY PARK PA 16801
1	PENN STATE UNIV ATTN C BAKIS 212 EARTH ENGR SCIENCES BLDG UNIVERSITY PARK PA 16802
1	PURDUE UNIV SCHOOL OF AERO & ASTRO ATTN C T SUN W LAFAYETTE IN 47907-1282
1	UNIV OF MAINE ADV STR & COMP LAB ATTN R LOPEZ ANIDO 5793 AEWB BLDG ORONO ME 04469-5793
1	JOHNS HOPKINS UNIV APPLIED PHYSICS LAB ATTN P WIENHOLD 11100 JOHNS HOPKINS RD LAUREL MD 20723-6099
1	UNIV OF DAYTON ATTN J M WHITNEY COLLEGE PARK AVE DAYTON OH 45469-0240
5	UNIV OF DELAWARE CTR FOR COMPOSITE MTRLS ATTN J GILLESPIE M SANTARE S YARLAGADDA S ADVANI D HEIDER 201 SPENCER LAB NEWARK DE 19716
1	DEPT OF MTRLS SCIENCE & ENGRG UNIV OF IL AT URBANA-CHAMPAIGN ATTN J ECONOMY 1304 W GREEN ST 115B URBANA IL 61801

<u>NO. OF COPIES</u>	<u>ORGANIZATION</u>
1	MISSISSIPPI STATE UNIV DEPT OF AEROSPACE ENGRG ATTN A J VIZZINI MISSISSIPPI STATE MS 39762
1	DREXEL UNIV ATTN A S D WANG 3141 CHESTNUT ST PHILADELPHIA PA 19104
3	UNIV OF TEXAS AT AUSTIN CAR FOR ELECTROMECHANICS ATTN J PRICE A WALLS J KITZMILLER 10100 BURNET RD AUSTIN TX 78758-4497
1	SOUTHWEST RESEARCH INST ENGR & MATL SCIENCES DIV ATTN J RIEGEL 6220 CULEBRA RD PO DRAWER 28510 SAN ANTONIO TX 78228-0510
	<u>ABERDEEN PROVING GROUND</u>
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL CI OK TECH LIB BLDG 4600
1	US ARMY ATC ATTN CSTE DTC AT AC I W C FRAZER BLDG 400
1	DIR USARL ATTN AMSRD ARL CI BLDG
1	DIR USARL ATTN AMSRD ARL O AP EG M ADAMSON BLDG
1	DIR USARL ATTN AMSRD ARL SL BB D BELY BLDG 328
2	DIR USARL ATTN AMSRD ARL WM J SMITH D LYON BLDG 4600

NO. OF
COPIES ORGANIZATION

2 DIR USARL
 ATTN AMSRD ARL WM B CHIEF
 T KOGLER
 BLDG 4600

2 DIR USARL
 ATTN AMSRD ARL WM BC P PLOSTINS
 J NEWILL
 BLDG 390

3 DIR USARL
 ATTN AMSRD ARL WM BD B FORCH
 R PESCE-RODRIGUEZ B RICE
 BLDG 4600

3 DIR USARL
 ATTN AMSRD ARL WM BD P CONROY
 C LEVERITT A ZIELINSKI
 BLDG 390

2 DIR USARL
 ATTN AMSRD ARL WM BE R LIEB
 M LEADORE
 BLDG 4600

1 DIR USARL
 ATTN AMSRD ARL WM BF
 S WILKERSON
 BLDG 390

2 DIR USARL
 ATTN AMSRD ARL WM M J MCCAULEY
 S MCKNIGHT
 BLDG 4600

2 DIR USARL
 ATTN AMSRD ARL WM MA
 L GHIORSE E WETZEL
 BLDG 4600

22 DIR USARL
 ATTN AMSRD ARL WM MB
 J BENDER T BOGETTI
 J BROWN L BURTON
 R CARTER K CHO W DE ROSSET
 G DEWING R DOWDING
 W DRYSDALE R EMERSON
 D GRAY D HOPKINS R KASTE
 L KECSKES M MINNICINO
 B POWERS D SNOHA
 J SOUTH M STAKER
 J SWAB J TZENG
 BLDG 4600

NO. OF
COPIES ORGANIZATION

11 DIR USARL
 ATTN AMSRD ARL WM MC J BEATTY
 R BOSSOLI E CHIN
 S CORNELISON D GRANVILLE
 B HART J LASALVIA
 J MONTGOMERY F PIERCE
 E RIGAS W SPURGEON
 BLDG 4600

11 DIR USARL
 ATTN AMSRD ARL WM MD P DEHMER
 B CHEESEMAN R DOOLEY
 G GAZONAS S GHIORSE
 M KLUSEWITZ W ROY J SANDS
 S WALSH D SPAGNUOLO S WOLF
 BLDG 4600

2 DIR USARL
 ATTN AMSRD ARL WM RP J BORNSTEIN
 C SHOEMAKER
 BLDG 1121

1 DIR USARL
 ATTN AMSRD ARL WM T B BURNS
 BLDG 309

1 DIR USARL
 ATTN AMSRD ARL WM TA W GILLICH
 BLDG 309

7 DIR USARL
 ATTN AMSRD ARL WM TA M BURKINS
 B GOOCH T HAVEL C HOPPEL
 E HORWATH J RUNYEON
 M ZOLTOSKI
 BLDG 393

1 DIR USARL
 ATTN AMSRD ARL WM TB P BAKER
 BLDG 309

1 DIR USARL
 ATTN AMSRD ARL WM TC R COATES
 BLDG 309

4 DIR USARL
 ATTN AMSRD ARL WM TD D DANDEKAR
 M RAFTENBERG S SCHOENFELD
 T WEERASOORIYA
 BLDG 4600

2 DIR USARL
 ATTN AMSRD ARL WM TE CHIEF
 J POWELL
 BLDG 1116A

NO. OF COPIES	ORGANIZATION
1	LTD R MARTIN MERL TAMWORTH RD HERTFORD SG13 7DG UK
1	CIVIL AVIATION ADMINSTRATION T GOTTESMAN PO BOX 8 BEN GURION INTRNL AIRPORT LOD 70150 ISRAEL
1	AEROSPATIALE S ANDRE A BTE CC RTE MD132 316 ROUTE DE BAYONNE TOULOUSE 31060 FRANCE
1	DRA FORT HALSTEAD P N JONES SEVEN OAKS KENT TN 147BP UK
1	SWISS FEDERAL ARMAMENTS WKS W LANZ ALLMENDSTRASSE 86 3602 THUN SWITZERLAND
1	DYNAMEC RESEARCH LAB AKE PERSSON BOX 201 SE 151 23 SODERTALJE SWEDEN
1	ISRAEL INST OF TECHLGY S BODNER FACULTY OF MECHANICAL ENGR HAIFA 3200 ISRAEL
1	DSTO WEAPONS SYSTEMS DIVISION N BURMAN RLLWS SALISBURY SOUTH AUSTRALIA 5108 AUSTRALIA

NO. OF COPIES	ORGANIZATION
1	DEF RES ESTABLISHMENT VALCARTIER A DUPUIS 2459 BLVD PIE XI NORTH VALCARTIER QUEBEC CANADA PO BOX 8800 COURCELETTE GOA IRO QUEBEC CANADA
1	ECOLE POLYTECH J MANSON DMX LTC CH 1015 LAUSANNE SWITZERLAND
1	TNO DEFENSE RESEARCH R IJSSELSTEIN ACCOUNT DIRECTOR R&D ARMEE PO BOX 6006 2600 JA DELFT THE NETHERLANDS
2	FOA NATL DEFENSE RESEARCH ESTAB DIR DEPT OF WEAPONS & PROTECTION B JANZON R HOLMLIN S 172 90 STOCKHOLM SWEDEN
2	DEFENSE TECH & PROC AGENCY GROUND I CREWTER GENERAL HERZOG HAUS 3602 THUN SWITZERLAND
1	MINISTRY OF DEFENCE RAFAEL ARMAMENT DEVELOPMENT AUTH M MAYSELESS PO BOX 2250 HAIFA 31021 ISRAEL
1	B HIRSCH TACHKEMONY ST 6 NETAMUA 42611 ISRAEL

NO. OF
COPIES ORGANIZATION

1 DEUTSCHE AEROSPACE AG
DYNAMICS SYSTEMS
M HELD
PO BOX 1340
D 86523 SCHROBENHAUSEN
GERMANY