NOTICE

**CERTAIN DATA
CONTAINED IN THIS
DOCUMENT MAY BE
DIFFICULT TO READ
IN MICROFICHE
PRODUCTS.**

UCRL CR 105295

Received by OSTI
FEB 0 1991

CR-90-1182

Impulse Gage Development for the 100–200 Ktap Range

Final Report

by
Patrick C. Rose
Walter J. Naumann

July 31, 1990

Prepared for
Lawrence Livermore National Laboratory
Livermore, California 94550
Attention: Dr. M. Gerassimenko

Contract No. 6659605

ADVANCED TECHNOLOGIES DIVISION

GENERAL
RESEARCH **CORPORATION**
P.O. BOX 6770, SANTA BARBARA, CALIFORNIA 93160-6770

DISCLAIMER

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

UCRL-CR--105295

DE91 007161

ACKNOWLEDGEMENTS

The authors wish to thank J. Everson for his competent operation of the GRC gas gun and N. Hughes for preparing the final report.

MASTER

ABSTRACT

Special effects underground test (UGT) material response and source diagnostics data require impulse gages that can be used in the 50-150 ktap range and have equilibrated from electrical and mechanical noise sources within 0.001 s. Such gages were designed, analyzed, and tested under this program. One- and two-dimensional stress propagation calculations were performed and predictions were developed for deformation of the gage specimen cup. These predictions were conservative when compared to gas gun test results. The response of the gage will equilibrate within 5% to its final value within 300 μ sec. The impulse delivered to the gages for these tests exceeded 250 ktap. The code and experimental results provides a basis for confidence in the operability of the gage in an actual UGT environment.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
	ACKNOWLEDGEMENTS	i
	ABSTRACT	ii
	LIST OF ILLUSTRATIONS	iv
	LIST OF TABLES	vi
1	BACKGROUND	1
2	DESIGN AND CALCULATIONS	3
	2.1 INTRODUCTION	3
	2.2 GAGE DESIGN	7
3	TESTING	17
	3.1 LVT COIL CALIBRATION	17
	3.2 MECHANICAL RESPONSE TEST	24
	3.3 LVT COIL OUTPUT ATTENUATION	24
	3.4 GAS GUN TESTING	31
4	SUMMARY AND CONCLUSIONS	44
5	LIST OF REFERENCES	46
APPENDICES		
A	LISTING OF TFT INPUT FILE THAT MODELED GAS GUN TESTS	A-1
B	IMPULSE GAGE ENGINEERING DRAWINGS	B-1
C	MATERIAL CERTIFICATIONS	C-1

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
2-1	Carbon break-rod impulse gage for the 100 ktap range	4
2-2	Time-resolved impulse (TRI) gage for impulse resolved to 10-15 μ sec	5
2-3	Linear velocity transducer (LVT) impulse gage for small exposure areas	6
2-4	Gage design for the 150 ktap range (gage is ~ 15 inches long)	8
2-5	Pin switch design for impulse gage velocity readout	10
2-6	Stress-time comparison in aluminum for actual and gas gun cases	12
2-7	AUTODYN prediction of specimen cup response in gas gun	15
2-8	Material status and stress for the hypothetical UGT case at 23.33 msec	16
3-1	Photograph of impulse gage specimen cup showing specimen backers and teflon expansion ring	18
3-2	Photograph of impulse gage specimen cup showing pieces in cup and cup backer	18
3-3	Photograph impulse gage specimen cup and backer	19
3-4	Photograph of the front of impulse gage, showing aluminum specimen and surrounding specimen cup	19
3-5	Photograph of bottom of pin switch block with disassembled pin and spring	20
3-6	Photograph of top of pin switch block showing contacts used for switch readout	20
3-7	Photograph of LVT magnet, stainless steel spacers, and magnet enclosure tube	21
3-8	Photograph of magnet assembly in LVT coil	21
3-9	Photograph of gage upper block (holds the LVT coil)	22

LIST OF ILLUSTRATIONS

(Continued)

<u>Figure</u>		<u>Page</u>
3-10	Photograph of assembled impulse gage	22
3-11	Photograph of gas gun impactor (tungsten carbide) and sabot components	23
3-12	Photograph of assembled sabot	23
3-13	Oscilloscope photograph of LVT coil output, mechanical response test	25
3-14	PSPICE simulation of LVT coil with no impedance- matching circuit	27
3-15	Oscilloscope photograph of LVT coil impedance test with no impedance-matching circuit (compare to Figure 3-14)	28
3-16	PSPICE simulation of LVT coil with 100:1 attenuator	29
3-17	Oscilloscope photograph of LVT coil with impedance test with 100:1 attenuator installed (compare to Figure 3-15)	30
3-18	GRC 3 inch light gas gun	32
3-19	Detail of gas gun target chamber	34
3-20	Instrumentation used for gas gun testing	35
3-21	LVT coil output for gas gun shot 5835	37
3-22	Switch pin output for gas gun shot 5835	37
3-23	Modified switch pin wiring showing copper bar joining brass contacts, making contacts positive and pin ground	39
3-24	Predicted and measured deformation for 1/4 inch specimen cup wall	41
3-25	Predicted and measured deformation for 1/8 inch specimen cup wall	42
3-26	Predicted and measured deformation for 1/16 inch specimen cup wall	43

LIST OF TABLES

<u>Table</u>		<u>Page</u>
2-1	AUTODYN prediction of specimen cup bulge, 1/4 inch wall	14
2-2	AUTODYN prediction of specimen cup bulge, 1/8 inch wall	14
2-3	AUTODYN prediction of specimen cup bulge, 1/16 inch wall	14
3-1	LVT coil electrical calibration (into 1 MΩ)	24
3-2	PSPICE simulation inputs for the case of no impedance matching circuit	26
3-3	PSPICE simulation inputs for the 100:1 attenuating circuit	31
3-4	Summary of gas gun tests	36
3-5	Switch pin velocity measurements for shot 5835	38

SECTION 1

BACKGROUND

The testing of special effects nuclear devices requires instruments to record high stresses and impulses. This report presents work performed for Lawrence Livermore National Laboratory (LLNL) on the seventh, eighth, and ninth amendments to subcontract 6659605, UGT Instrumentation Development. The LLNL Technical Monitor was Dr. Michel Gerassimenko. General Research Corporation (GRC) has been working with LLNL for the past six years on developing stress and impulse measurement techniques for this application (Refs. 1-3).

The task objectives were to design and test impulse gages suitable for use in special effects UGT experiments. The contract Technical Scope of Work (SOW) specified:

1. Perform design of gage capable of measuring high impulse (30-150 ktaps) in the available time interval of 1 msec.
2. Perform aboveground tests (AGTs) to demonstrate gage operation and survival in the impulse range of interest for scaled stress environments.
3. Perform AGTs to demonstrate readout of the gage in the requisite time interval.
4. Perform calculations to demonstrate the ability to predict the gage failure threshold.

Design of the gage was guided by GRC's experience in several past UGTs. The GRC light gas gun was used for most of the gage tests. Several one- and two-dimensional computer codes were used to calculate gage response in the gas gun tests and in the UGT environment.

The remainder of this report describes the gage design and supporting calculations (Section 2) and gage testing (Section 3).

SECTION 2

DESIGN AND CALCULATIONS

This section describes the gage design and calculations which are compared to test results.

2.1 INTRODUCTION.

Several impulse gage designs were considered. The first of these is the GRC designed Carbon Break-Rod (CBR) gage which has been used in the 100 ktp range in past UGTs (Refs. 4-8). This gage is shown in Figure 2-1. CBR gages have returned data successfully in past Horizontal Line-Of-Site (HLOS) tests. The break-rod design was deemed unacceptable for the present application due to the fragility of the break-rods (it was felt that lowering the gage from the surface to the Vertical Line-Of-Site (VLOS) test environment might damage the breakrods prior to the test). Difficulties were also anticipated in finding a suitable insulator which would withstand the high stresses and prevent shorting of the broken rods.

A Time-Resolved Impulse (TRI) gage has been designed by GRC for use in HLOS tests, as shown in Figure 2-2 (Ref. 9). This gage was designed to fill the gap between the longest duration stress gages (about 5 μ sec maximum) and the fastest recoil impulse gages (about 50 μ sec minimum). Several TRI gage designs have been fielded in tests from DIABLO HAWK to the recent MINERAL QUARRY. The TRI gage is unacceptable for the current application because the moving coil and connections, suitable only for lower impulses, would fail at high impulses. Fortunately the fast response of the TRI gage is not required.

The Linear Velocity Transducer (LVT) impulse gage has been used by GRC for HLOS and VLOS tests (Refs. 1, 10, and 11). The MISSION CYBER design is shown in Figure 2-3. This gage was designed for small (1/2 inch diameter) exposure areas. The tube shown at the front of the gage

Figure 2-1. Carbon break-rod impulse gage for the 100 ktap range.

Figure 2-2. Time-resolved impulse (TRI) gage for impulse resolved to 10-15 μ sec.

Figure 2-3. Linear velocity transducer (LVT) impulse gage for small exposure areas.

was designed to collimate blowoff material, thus simulating a one-dimensional response. These gages returned data successfully in MISSION CYBER. These tests were intended to verify the performance of the small area impulse gages for future use in a VLOS environment. This experiment showed that for the conditions of the test, drag from the tube can enhance coupling to compensate for losses in coupling due to three-dimensional expansion and condensation on the tube walls.

However this compensation could not be verified for the special environments of interest so this design was rejected in favor of larger exposure areas without tubes. The LVT itself, with a different specimen geometry is known by analysis and test (Refs. 9 and 11) to be capable of measuring the required velocities within the allowed one millisecond and was selected as appropriate for the subject gage.

A Make Wire Gage (MWG) design (Ref. 12) frequently used by GRC was unsuitable because its sliding contacts would not operate reliably within the one millisecond time allowed.

2.2 GAGE DESIGN.

The proposed design for the present work is shown in Figure 2-4. This gage uses two independent means of recording the velocity of the moving mass.

First, a conventional LVT is housed at the back of the gage. The LVT magnet is housed in a stainless steel shaft which is attached to the back of the specimen cup, as shown in Figure 2-4.

The second means of readout is a new simple technique consisting of four spring-loaded pins which protrude through the Delrin "Switch Block". Each pin has a unique length. As the specimen cup travels backward (or up in a VLOS environment) it strikes each pin and lifts the pin off its contact, opening an electrical circuit. This design is

Figure 2-4. Gage design for the 150 ktap range (gage is ~ 15 inches long).

shown in Figure 2-5. The circuit is closed at zero-time since an open circuit at zero-time would experience greater radiation induced noise.

A concern when designing a gage for the present environment is the response of the specimen/specimen cup to the impulse and stress generated by the source. It is important that the part of the specimen that is not blown off the front surface be retained in the specimen cup, and that all remaining parts are constrained to move together during the recording time.

The front surface stresses expected in the VLOS environment of interest are much higher than the stresses obtainable in gas guns (Ref. 13). While the stress versus time resulting from the VLOS environment of interest cannot be simulated in available simulators, the impulse can be simulated. The initial stresses need not be simulated to verify operation of the gage because of the attenuation of the stresses as they propagate through the gage. As the stress propagates its magnitude decreases and the duration increases to conserve momentum. Initially, the stress and internal energy are such that the specimen material is vaporized, melted or spalled and therefore removed from the gage moving mass. This is part of the impulse generation process and not part of the gage response process. It is completed before impulse is measured and therefore does not need to be simulated to assess response time and integrity of the gage.

However, the stress as the wave travels from the specimen into the gage cup and components is important. The gage components can be allowed to yield but must not fail so that no parts are lost or loose which could result in errors. These stresses at potential failure locations must be simulated to validate gage operation.

The gas gun tests are based on the fact that the stresses from the LOS environment attenuate rapidly and soon cannot be distinguished from

Figure 2-5. Pin switch design for impulse gage velocity readout.

the wave resulting from a lower stress but equal impulse wave resulting from a gas gun impact.

Since the expected stresses over the area of the specimen cup could not be reproduced in an aboveground simulator, it was decided to conduct a series of calculations that would assess the ability of hydrodynamic methods to predict specimen cup response in the GRC 3 inch light gas gun. If the code could predict stress effects in the gas gun, and the same code predicted gage survival in the VLOS environment, then some basis for confidence in the code would exist. This of course assumes that the code and its material models are valid enough in the regime of stress produced by the VLOS source to accurately predict the stresses in the potential gage failure regions. Since, as discussed above, the gage stresses are not sensitive to front surface conditions this assumption is likely valid.

To predict specimen cup response in the GRC gas gun, the one-dimensional hydrodynamic code TFT (Ref. 14) was used. TFT was used to calculate the stress generated at the front surface of the specimen due to the impact of a tungsten carbide flyer. The two-dimensional hydrodynamic code AUTODYN (Ref. 15) was used to propagate the stress from the front surface to the rear of the specimen cup. AUTODYN has been used to successfully predict the results of armor/anti-armor studies (Ref. 16) involving 4340 steel, the alloy used in the subject gage.

AUTODYN was also used to predict performance of the specimen cup in the UGT VLOS environment. The HYPUPF code (Refs. 17 and 18) was used to provide initial front surface stress-time histories which were input to AUTODYN. The code predicted survival of a specimen cup with a 1/4 inch thick wall.

Figure 2-6 shows the UGT prediction for a generic, hypothetical source at a depth of 5.6 cm into aluminum. Also plotted is the front

STRESS GENERATION - ACTUAL AND GAS GUN ENVIRONMENTS

Figure 2-6. Stress-time comparison in aluminum for actual and gas gun cases.

surface stress generated by a 0.112 inch thick tungsten carbide flyer plate. Both cases generated an impulse of 200 ktap. This is the closest simulation achievable with the GRC gas gun and agreement will improve as the waves propagate into the gage. It is evident that near the front of the specimen cup the gas gun can generate stresses significantly over the yield strength of 4340 steel (10 kbar or 145,000 psi) and therefore can exercise potential failure mechanisms.

The TFT input file used to generate the "Gas Gun" curve of Figure 2-6 is listed in Appendix A.

The amount of deformation as a function of location as predicted by AUTODYN was tabulated and compared with the gas gun test results. The thickness of the specimen cup was varied from 1/4 inch to 1/16 inch, both in the code predictions and the tests. This was done to provide correlation between code and experiment over a range of deformations. The tungsten carbide flyer was sized to impact only the Aluminum-1100F specimen and not the surrounding steel (alloy 4340-NT) specimen cup. Tables 2-1 through 2-3 contain the AUTODYN predictions of specimen cup bulge which are plotted in Figure 2-7 and with results in Section 3 of this report.

Figure 2-8 is the AUTODYN prediction of the hypothetical UGT response. It shows the specimen cup intact well beyond the read time of the gage.

Table 2-1. AUTODYN prediction of specimen cup bulge, 1/4 inch wall.

Location from front of cup, inches	Sideways displacement of cup wall, inches
0.003	0.090
0.243	0.072
0.420	0.072
1.493	0.031
2.005	0.014
2.404	0.005

Table 2-2. AUTODYN prediction of specimen cup bulge, 1/8 inch wall.

Location from front of cup, inches	Sideways displacement of cup wall, inches
0.007	0.139
0.240	0.118
0.456	0.128
1.711	0.024
2.693	0.003

Table 2-3. AUTODYN prediction of specimen cup bulge, 1/16 inch wall.

Location from front of cup, inches	Sideways displacement of cup wall, inches
0.207	0.139
0.447	0.189
0.670	0.160
0.776	0.145
1.557	0.045
2.660	0.005

Figure 2-7. AUTODYN prediction of specimen cup response in gas gun.

Figure 2-8. Material status and stress for the hypothetical UGT case at 23.33 msec.

SECTION 3

TESTING

The gage shown in Figure 2-4 was fabricated from the drawings contained in Appendix B. The impactor and sabot used in the gas gun tests are shown in drawings 98750-2-3 through 98750-2-6. Photographs of gage parts and the assembled gage are shown in Figures 3-1 through 3-10. Photographs of the gas gun impactor and sabot are shown in Figures 3-11 and 3-12.

To assure reproducibility of the test results it was necessary to control the materials used in fabricating the specimens (aluminum 1100F) and the specimen cups (4340 steel) except as noted in Section 3.4. Appendix C contains certifications for these materials. The aluminum was analyzed to verify the 1100 alloy; the report of the test laboratory is included in Appendix C. The 4340 steel was specified in terms of MIL-S-5000E to be supplied in condition E-3. This specification is also included in Appendix C.

3.1 LVT COIL CALIBRATION.

Prior to assembly of the gages, the LVT coils were calibrated in terms of electrical output at a given magnet velocity. The LVT coils used for these gages were Trans-Tek (Ref. 19) model 0111-0000 with magnet model M000-0000. These were undersized magnets for the 0111-0000 coils and were enclosed in a stainless steel tube (see Figure 3-7). The magnets were enclosed to provide a strong and straight attachment of the magnet to the specimen cup. The results of the LVT coil calibrations are given in Table 3-1. It has been shown that up to magnet velocities of 3000 cm/sec, LVT coil output is linear with magnet velocity (Reference 11 page 30). The calibrations reported here used magnet velocities of approximately 100 cm/sec and gage velocity during use is on the order of 1000 cm/sec. Coil number 24940-3-1 was purchased from a different lot than the other coils, which may explain its reduced sensitivity.

Figure 3-1. Photograph of impulse gage specimen cup showing specimen backers and teflon expansion ring.

Figure 3-2. Photograph of impulse gage specimen cup showing pieces in cup and cup backer.

Figure 3-3. Photograph impulse gage specimen cup and backer.

Figure 3-4. Photograph of the front of impulse gage, showing aluminum specimen and surrounding specimen cup.

Figure 3-5. Photograph of bottom of pin switch block with disassembled pin and spring.

Figure 3-6. Photograph of top of pin switch block showing contacts used for switch readout.

Figure 3-7. Photograph of LVT magnet, stainless steel spacers, and magnet enclosure tube.

Figure 3-8. Photograph of magnet assembly in LVT coil.

Figure 3-9. Photograph of gage upper block (holds the LVT coil).

Figure 3-10. Photograph of assembled impulse gage.

Figure 3-11. Photograph of gas gun impactor (tungsten carbide) and sabot components.

Figure 3-12. Photograph of assembled sabot.

Table 3-1. LVT coil electrical calibration (into 1 M Ω).

LVT Coil #	Calibration (mV/cm/sec)
24940-3-1	46
30557-3-1	101
30557-3-2	109
30557-3-3	91
30557-3-4	89

3.2 MECHANICAL RESPONSE TEST.

Following assembly of the gages a test was performed to measure the mechanical response time of the gage. Gage #1 was held with the front of the gage pointed down, as it would be for a UGT VLOS test. The specimen was struck with a low velocity impactor which triggered a recording oscilloscope. The output of the LVT coil was recorded on the oscilloscope. A representative trace is shown in Figure 3-13. The trace shows that the LVT coil has equilibrated to within $\pm 5\%$ in about 400 μ sec, which was deemed an acceptable mechanical response. The ringing was due in part to electrical effects as shown in the following section of this report.

3.3 LVT COIL OUTPUT ATTENUATION.

Electrical isolation of the LVT coil from the cable is necessary to achieve a fast response without ringing. This is achieved with an attenuator. Attenuation was also required by the range of the recorders.

The anticipated velocity of the impulse gage moving mass during the gas gun tests was 600 cm/sec. Using this magnet velocity and the LVT calibrations of Table 3-1 the expected LVT electrical output would be 60 volts. This signal is too large for either oscilloscopes or the transient recorders used in the gas gun laboratory, so the LVT output required attenuation.

1 volt/div

0.1 msec/div

Figure 3-13. Oscilloscope photograph of LVT coil output, mechanical response test.

The PSPICE (Ref. 20) code was used to model the LVT coil and the capacitance of the RG-8/U cable which connected the coil to the recorders. The cable capacitance was 830 pF. The impedance of the LVT coil was 13 k Ω . Trans-Tek documentation specified a coil inductance of 1.6 Henrys.

A PSPICE simulation of the above coil and cable connected to a 1 M Ω load is shown in Figure 3-14. The ringing of the coil is evident. This simulation was verified by injecting a signal into the LVT and recording the LVT output. The oscilloscope photograph is shown in Figure 3-15.

A 100:1 attenuator was added to the LVT coil circuit and the above modeling and test were repeated. The attenuator was an 86 k Ω resistor in series with the coil output followed by a 1 k Ω resistor across the coil output. The corresponding PSPICE prediction and bench test are shown in Figures 3-16 and 3-17. The small overshoot in Figure 3-17 is attributed to shunt capacitance in the LVT coil which was not modeled. The output has been attenuated by a factor of 100 which enables the use of the LeCroy transient recorders for the gas gun tests. The coil has also been isolated from the cable capacitance to eliminate the ringing seen in Figures 3-14 and 3-15. The PSPICE input files used to produce these simulations are shown in Tables 3-2 and 3-3.

Table 3-2. PSPICE simulation inputs for the case of no impedance matching circuit.

```
.TRAN 2E-5 1E-3
VIN 1 0 PULSE(0 1 1E-6)
L1 1 2 1.6
R1 2 3 1.3E4
C1 0 3 830E-12
R2 0 3 1E6
.PLOT TRAN V(3)
.PLOT TRAN V(1)
.END
```

LVT COIL SIMULATION WITH PSPICE
With no attenuation

Figure 3-14. PSPICE simulation of LVT coil with no impedance-matching circuit.

Figure 3-15. Oscilloscope photograph of LVT coil impedance test with no impedance-matching circuit (compare to Figure 3-14).

LVT COIL SIMULATION WITH PSPICE
With 100:1 attenuator

Figure 3-16. PSPICE simulation of LVT coil with 100:1 attenuator.

Figure 3-17. Oscilloscope photograph of LVT coil with impedance test with 100:1 attenuator installed (compare to Figure 3-15).

Table 3-3. PSPICE simulation inputs for the 100:1 attenuating circuit.

```
.TRAN 2E-5 1E-3
VIN 1 0 PULSE(0 1 1E-6)
L1 1 2 1.6
R1 2 3 1.3E4
R3 3 4 8.6E4
C1 0 4 830E-12
R2 0 4 1E3
.PLOT TRAN V(4)
.PLOT TRAN V(1)
.END
```

3.4 GAS GUN TESTING.

After the response tests the gages were prepared for gas gun testing. The GRC 3 inch light gas gun is shown in Figure 3-18. For impulse gage testing the "Target Board" is replaced with an impulse gage in the target chamber. This gun is capable of accelerating projectiles to impact velocities ranging from 0.005 to 0.70 mm/ μ s with impact tilt less than 0.5 mrad.

The projectile is propelled by a maximum pressure of 2000 psi nitrogen or helium gas, expelled by a single stage breech mounted on wheels and backed by a shock absorber. The gas is released by a pneumatically driven, fast opening valve.

Impact velocity is measured using three pins extending radially into the gun barrel that are sequentially shorted by the projectile as it leaves the muzzle. The relative time between pins is measured by time interval counters and the distance between pins measured using electrical micrometers prior to the shot. The accuracy of the measurement is better than 0.5 percent.

The gun barrel and target chamber are evacuated to a pressure less than 200 microns of mercury to eliminate air shock. Following impact, the projectile and target debris rupture a Mylar diaphragm at the rear of the target chamber and come to rest in a massive rolling catcher tank.

Figure 3-18. GRC 3 inch light gas gun.

A sabot stripper was installed in the target chamber to remove the impactor from the sabot just prior to impact with the impulse gage. A detail of the target chamber is shown in Figure 3-19. The impact velocity measurement system supplies a trigger to the impulse gage recorders, which arrives about 50 μ sec prior to the impact of the flyer on the gage.

Both oscilloscopes and electronic digitizers were used to record the impulse gage output. The instrumentation schematic is shown in Figure 3-20.

Table 3-4 summarizes the gas gun tests. As the gas gun facility was being used after extensive modifications, data from the LVT coil and switch pins were not recorded successfully on all shots. Figure 3-21 shows LVT coil output from shot 5835. Figure 3-22 is the switch pin data for the same shot.

From Figure 3-21, the LVT indicates the velocity of the moving mass as 1095 cm/sec. This data reduction disregards the first 600 μ sec of the trace, the time before and during the gage acceleration. The impulse delivered to the gage, based on a total moving mass of 3478.4 grams, an "exposure area" of 14.64 cm², and a gage velocity of 1095 cm/sec (the average of the four switch pin intervals) was 260 ktap.

The indicated velocity from the switch pins for this measurement is summarized in Table 3-5. Variations in the velocity given by the pins is attributed to non planarity of the gage with the projectile, a problem which is not relevant in the VLOS environment. The average velocity indicated by the last three switch pin intervals is 1152 cm/sec. This is within 5% of the indicated LVT velocity over the same time interval.

Figure 3-19. Detail of gas gun target chamber.

Figure 3-20. Instrumentation used for gas gun testing.

Table 3-4. Summary of gas gun tests.

Gas Gun Shot #	Impactor Velocity (mm/ μ sec)	Impactor Mass (grams)	LVT Coil #	Specimen Cup Wall Thickness (inches)	Maximum Predicted Deformation (inches)	Maximum Measured Deformation (inches)	Deformation Percent Error (Predicted - Measured)/Predicted*100
5716	- ²	59.5	24940-3-1	1/4	0.072 @ 0.420	-	-
5730	0.497	59.0	24940-3-1	1/4	0.072 @ 0.420	0.03 @ 0.63	58
5832	0.513	62.4	30557-3-1	1/4	0.072 @ 0.420	0.04 @ 0.65	44
5833	0.510	61.3	30557-3-4	1/8	0.128 @ 0.456	0.09 @ 0.59	30
5835	(0.48) ³	59.0	30557-3-2	1/16	0.189 @ 0.447	0.13 @ 0.55	30
5836	0.498	60.0	30557-3-3	3/32	(0.158) ⁴	0.11 @ 0.62	30

- 1 This column is the largest predicted increase in cup radius at the specified distance from the front surface of the cup.
- 2 Sabot failed prior to impact with gage, no data on this shot.
- 3 Velocity measurement system failed; based on pressure data the velocity should have been ~ 0.48 mm/msec.
- 4 No code prediction for this wall thickness; value is the average of 1/8 and 1/16 inch cases.

Figure 3-21. LVT coil output for gas gun shot 5835.

Figure 3-22. Switch pin output for gas gun shot 5835.

Table 3-5. Switch pin velocity measurements for shot 5835.

	Distance (cm)	Time Interval (μ sec)	Velocity (cm/sec)
Start to Pin 4	0.427	500	854
Pin 4 to Pin 3	0.249	220	1131
Pin 3 to Pin 2	0.249	250	996
Pin 2 to Pin 1	0.086	65	1328

The free travel of the moving mass was 0.5 inch. Examination of the LVT trace shows that the full width, half maximum duration of the velocity record is 1.20 msec or 1058 cm/sec which correlates well with other measurements.

At 1.3 msec the switch pin trace indicates a short. The short is probably due to the gage reaching the end of travel which causes large motions in the gage. Data following the end of travel should be disregarded.

Data from the first three shots (not shown) indicated that the switch pins may have broken contact for a short period of time as the gun was fired. Springs were used to seat the pins to mitigate this effect, but it seemed the pins were opening nonetheless. The springs were selected to cause no more than a 5% correction in impulse over the distance they were compressed.

To eliminate the early time opening of the pins, they were modified to work as shown in Figure 3-23. For the first three shots the copper jumper bar was not present. The circuit worked by making one brass contact positive and the other brass contact ground. The head of the pin shorted the two contacts. When the bottom of the pin was struck by the moving mass, the head lifted off the contacts and the circuit opened.

Figure 3-23. Modified switch pin wiring showing copper bar joining brass contacts, making contacts positive and pin ground.

For shot 5835 the copper jumper bar was added and the wiring of the circuit was modified. The pin was grounded and the jumper bar/brass contacts were made positive. In this configuration, even if the pin rocked slightly to one side at zero-time, the circuit would not open. The switch pin data trace (Figure 3-22) shows that no early opening of the pins occurred.

The specimen cup deformations of Tables 2-1, 2-2, and 2-3 are plotted in Figures 3-24, 3-25, and 3-26. The measured specimen cup deformations are also shown. Figure 3-24, for the 1/4 inch specimen cup wall, also contains a prediction for the generic, hypothetical UGT environment. Common to the predictions for all three specimen cup thicknesses is an over-prediction of deformation near the front surface of the specimen/specimen cup. This may be due to a small gap that was not modeled between the side of the specimen and the inside of the specimen cup, at the front surface. This gap is evident in Figure 3-4. The gap allowed some free expansion of the specimen before the specimen cup started to expand, and may explain the over-prediction of the observed damage.

The amount of deformation experienced by the specimen cups is predicted by the code to within 30% for the thin wall cases. In all cases less deformation was experienced by the specimen cups than was predicted. The 1/4 inch wall is less well predicted, with an average error of 51%. It should be noted that the specimen cup used in shot 5716 and shot 5730 was not fabricated from the lot of certified 4340 material used for all the other cups. The material used in shots 5716 and 5730 was A-2 tool steel. This may explain the large difference in predicted versus measured deformation seen in shot 5730. If the deformation from shot 5730 is disregarded, then the difference in prediction versus measurement becomes 44%.

Figure 3-24. Predicted and measured deformation for 1/4 inch specimen cup wall.

Figure 3-25. Predicted and measured deformation for 1/8 inch specimen cup wall.

Figure 3-26. Predicted and measured deformation for 1/16 inch specimen cup wall.

SECTION 4

SUMMARY AND CONCLUSIONS

Impulse gages were constructed and tested via flyer plate impact techniques in a 3 inch gas gun. Lessons were learned concerning readout design and model applicability which will allow these gages to be used in VLOS UGT events.

The gage operated at an impulse level of over 250 ktap. Gages with intentionally weakened walls ($1/2$ and $1/4$ of the design thickness) also successfully measured 250 ktaps, which demonstrated a large strength margin.

The two-dimensional hydrocode used for gage predictions in the VLOS UGT event environment predicts gage survival at 150 ktaps, the highest impulse predicted. The same code overpredicted the gas gun test results by 30-44% while still predicting gage survival even for the reduced wall thickness tests, giving confidence to the UGT survival prediction.

The gage will provide sufficient information to be read out in 1 msec. Both bench measurements and the gas gun tests show that it takes about 300 μ sec for the gage to come to mechanical equilibrium. Accurate velocity measurements can be made in the remaining 700 μ sec.

Modifications were made to the switch pin design to ensure noise-free operation through early-time vibrations.

It was demonstrated that LVTs will work for this application. Use of an LVT requires care in impedance matching and recording to ensure good results.

These gages should undergo a shot-configuration proof-test prior to fielding. The tests should produce high stress in the specimen cup

to allow direct verification of the design. The gages should be operated vertically for these tests which limits the choice of testbeds. Explosive testing may be the solution to achieving high stress in the vertical orientation. The successful completion of such a test series should result in the confidence required to field these gages in a VLOS UGT.

This gage design is predicted to be able to measure impulses greater than 150 kbar within 1 millisecond in special effects UGTs.

SECTION 5

LIST OF REFERENCES

1. R. Globus, W. Naumann, D. Hunt, and E. Chang, GOLDSTONE Instrumentation Development Report (U), General Research Corporation, CR-86-1065, September 1986 (SECRET/RESTRICTED DATA).
2. W. Naumann and K. Peterman, DELAMAR Final Report (U), General Research Corporation, CR-88-1032, November 1987 (SECRET/RESTRICTED DATA/CNWDI).
3. P.C. Rose and W.J. Naumann, Stress and Impulse Gage Development, General Research Corporation, CR-89-1083, 1 March 1989.
4. D.V. Keller et. al., Differential Momentum Experiments on CYPRESS (U), Effects Technology Inc., DASA-2413, 29 August 1969 (RESTRICTED DATA).
5. E.J. Steele, R.E. Wengler, and E.A. Anderson, MINUTE GUN Series, MINT LEAF Event, Project Officers Report-Project 8.92, Composite Vulnerability Experiments (U), Effects Technology Inc., POR-6412, 14 May 1971 (SECRET/RESTRICTED DATA).
6. E.J. Steele, W.J. Naumann, and D.V. Keller, MINUTE GUN Series, HUDSON MOON Event, Project Officers Report, Copper and Tantalum Stress-Time and Momentum Experiments (U), Effects Technology Inc., POR-6458, 20 August 1971 (SECRET/RESTRICTED DATA).
7. M.H. Subilia, E.J. Steele, and P. Boettcher, Experiment Plan-DIDO QUEEN Experiment Nos L1060-L1063, L1072-L1077, L1080-L1085: HFR Lethality and Overlay Phenomenology Experiments (U), Effects Technology Inc., ETI-73-1029, 12 January 1973 (SECRET/RESTRICTED DATA).
8. W.R. Myers, D.A. Suppes, E.L. Walsh, and D. C. Williams, MINUTE GUN Series, DIDO QUEEN Event, Lethality Phenomenology Experiments Kaman Sciences Corp., POR-6783, 9 April 1975 (SECRET/ RESTRICTED DATA).
9. W.M. Isbell and W.J. Naumann, TRI...The Development of a Fast-Response Time-Resolved Impulse Gage, Effects Technology Inc., DNA-4658F, 30 April 1978.
10. E. Chang et. al., DNA/DFSP Experiments in MISSION CYBER, Final Data Summary Report, General Research Corporation., CR-88-1012, 4 March 1988.
11. C.W. Cook, E.S. Ames, and R.W. Morris, The Linear Velocity Transducer Momentum Gage (U), Sandia National Laboratories, Albuquerque, SC-DR-69-531, November 1969 (SECRET/RESTRICTED DATA).

12. K.D. Peterman, Makewire Gage Operation and Characteristics, General Research Corporation, CR-89-1093, 23 April 1990.
13. R.E. Tokeim et. al., Special Effects Program Stress Wave Response Lethality Study, SRI International, DNA-TR-82-193, 15 October 1983 (SECRET/FORMERLY RESTRICTED DATA).
14. A.J. Watts et. al., Thin Film Transport (PUFF-TFT) Computer Code Development, Ktech Corporation, AFWL-TR-88-66 Parts 1 and 2, June 1988.
15. AUTODYN Users Manual Version 2.1, Century Dynamics Inc., 903 Paramount Road, Oakland, CA. 94610, 1989.
16. P.M. Holland et. al., Hydrocode Results for the Penetration of Continuous, Segmented, and Hybrid Rods Compared With Ballistic Experiments, to be published in the International Journal of Impact Engineering.
17. P.J. Mallozzi, B.P. Fairand, and R.G. Jung, Effects of High-Intensity Photon Fluences (U), Battelle Memorial Institute, AFWL-TR-71-101, July 1972 (SECRET/RESTRICTED DATA).
18. D.L. Johnson, HYPUF Upgrade Final Report, McDonnell Douglas Astronautics Co., MDC-H5234, January 1989 (to be published as a Defense Nuclear Agency report).
19. Trans-Tek Incorporated, P.O. Box 338, Route 83, Ellington, Connecticut 06029 (203/872-8351).
20. PSPICE User's Manual, May 1986, MicroSim Corporation, 23175 La Cadena Drive, Laguna Hills, CA. 92653 (714/770-3022).

APPENDIX A
LISTING OF TFT INPUT FILE THAT MODELED GAS GUN TESTS

TFT	-1	6	-3	0	0	0	0	0	0	500	500	-1	20	40	0
1	99999	5.000E+00	2.700E-05	1.000E-12	4.970E+04	0	0	0	0	0	0	0	0	0	0
6	2	0	0									00000	0	0	0
2	0.00100	2	0.50000	2	0.99900										
0	0.000E+00	0.000E+00													
LE006	2.845E-01	1	0	0	0	0	0	0	0	0	0	01.000-3.000E+10	0.000E+00	0.000E+00	
7	626E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
1	599E-01	7.743E-05	-1.241E-08	1.336E-01	2.680E+02	8.290E-02	3.560E+03								
7	521E-02	2.173E-05	-1.443E-11	1.460E-01											
LE006	0	1	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
1	426E+01	4.032E+12	5.331E+12	2.710E+10	2.000E+00	6.700E-01	1.853E+12								
AL1100	3.632E+00	1	0	0	0	1	0	0	0	0	0	01.000-6.000E+09	0.000E+00	0.000E+00	
1	549E+02	0.060E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
3	500E+08	2.730E+11	0.000E+00	6.403E-04											
0	000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
2	042E-01	1.262E-04	4.792E-08	2.780E-01	9.600E+01	1.727E-01	2.720E+03								
2	585E-01	8.385E-04	-9.892E-07	4.063E-01											
AL1100	0	1	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
2	700E+00	7.400E+11	1.281E+12	3.138E+10	2.000E+00	6.700E-01	1.703E+12								
SS304	1.295E+00	1	0	0	1	0	0	0	0	0	0	01.000-3.000E+10	0.000E+00	0.000E+00	
1	991E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
1	327E+09	7.686E+11	0.000E+00	5.632E+08											
0	000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
1	176E-01	4.342E-05	-5.141E-09	1.940E-01	6.500E+01	9.020E-02	1.504E+03								
3	480E-02	3.958E-05	-5.363E-09	7.960E-02											
SS304	0	1	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
7	896E+00	1.640E+12	2.944E+12	2.710E+10	1.160E+00	6.700E-01	5.001E+12								
AL1100	1.295E+00	1	0	0	1	0	0	0	0	0	0	01.000-6.000E+09	0.000E+00	0.000E+00	
1	549E														

DISK2:[PCROSE.AUX]TFT0009.DAT;1

1.176E-01	4.342E-05-5.141E-09	1.940E-01	6.500E+01	9.020E-02	1.504E+03
3.480E-02	3.958E-05-5.363E-09	7.960E-02			
SS304	0 1 0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7.896E+00	1.640E+12 2.944E+12	2.710E+10	1.160E+00	6.700E-01	5.001E+12
AL1100	1.295E+00 1 0 0	0	1 0	01.000-6.000E+09	0.000E+00
1.549E+02	0.000E+00 0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00
3.500E+08	2.730E+11 0.000E+00	6.403E-04			
0.000E+00	0.000E+00 0.000E+00	0.000E+00	0.000E+00		
2.042E-01	1.262E-04 4.792E-08	2.780E-01	9.600E+01	1.727E-01	2.720E+03
2.585E-01	8.385E-04-9.892E-07	4.063E-01			
AL1100	0 1 0.000E+00	0.000E+00	0.000E+00	0.000E+00-1.000E+26	0.000E+00
2.700E+00	7.400E+11 1.281E+12	3.138E+10	2.000E+00	6.700E-01	1.703E+12

APPENDIX B
IMPULSE GAGE ENGINEERING DRAWINGS

DRAWING NUMBER	98750-1-1	C	REV		
			REV	DESCRIPTION	DATE

REVISIONS

NOTES UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED MATERIALS SHALL BE THE BEST AVAILABLE AND THE DRAWING SHALL BE THE FINAL AUTHORITY.		R. SANCHEZ DATE 5/22/90		GENERAL RESEARCH 3430 HOLLYER SANTA BARBARA, CALIFORNIA 93111	
XX ± .01	Y ± .1	ZZ ± .005	7	32	
MATERIAL			SPECIMEN-ALUMINUM		
AL-1100 F			FSCM NO 9A890		
FRESH			REV C		
			SCALE 1/1		
			CUST NO GRC060		
			SHEET 1		

DRAWING NUMBER		98750-1-4		REV		A	
REVISIONS				DESCRIPTION			
REV		DATE		APPR

1. QTY 2 PER ASSEMBLY
2. MATCH DRILL TO PARTS REFERENCED:
98750-1-5
98750-1-6
98750-1-13
98750-1-14

NOTES: UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED INTERPRET DRAWING PER ANSI Y14 DIMENSIONS ARE IN INCHES AND APPLY AFTER PLATING BREAK SHARP EDGES		R. SANCHEZ		DATE 5/8/90	
XX ± .01	X ± .1	CHECK	PROJ	ENG	APPR
XXX ± .005	Y ± .32	NEXT ASSY USED ON			
MATERIAL 4340 STEEL		THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION IT MAY NOT BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS ELECTRONIC OR MECHANICAL WITHOUT PRIOR WRITTEN PERMISSION			
FINISH NOTED		GAGE BODY-LOWER		DRAWING NUMBER 98750-1-4	
		SCALE 2/1		CUST NO GRC030	
		SHEET 2/1		OF A	

DRAWING NUMBER 98750-1-5	REV	A	REVISIONS DESCRIPTION	DATE	APPR

1. MATCH DRILL TO PARTS REFERENCED.
- 98750-1-4
 - 98750-1-6
 - 98750-1-13
 - 98750-1-14

UNLESS OTHERWISE SPECIFIED INTERPRET DRAWING PER ANSI Y14 DIMENSIONS ARE IN INCHES AND APPLY AFTER PLATING BREAK SHARP EDGES		DATE 5/8/90	GENERAL RESEARCH	
XX ± .01	X ± .1	CHECK R. SANCHEZ		
XXX ± .005	✓ .32	PROJ ENC		
MATERIAL DEFIN		APPV		
FINISH NONE		PIN SWITCH BLOCK		
		SIZE C	DRAWING NUMBER 98750-1-5	REV A
		SCALE 1/1	CUST NO GRC028	SHEET OF

NOTES: UNLESS OTHERWISE SPECIFIED

① MATCH DRILL TO PARTS REFERENCED:

- 98750-1-4
98750-1-5
98750-1-15
98750-1-14

NOTES: UNLESS OTHERWISE SPECIFIED

[illegible]

DRAWING NUMBER <div style="display: flex; justify-content: space-between; align-items: center;"> 98750-1-7 <div style="border: 1px solid black; padding: 2px;"> D REV </div> </div>		REVISIONS <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">REV</th> <th style="width: 70%;">DESCRIPTION</th> <th style="width: 10%;">DATE</th> <th style="width: 10%;">APPR</th> </tr> </thead> <tbody> <tr> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </tbody> </table>		REV	DESCRIPTION	DATE	APPR				
REV	DESCRIPTION	DATE	APPR								

DASH NO. A QTY

-1	9.75	1
-2	10.75	1

.187 DIA
X .280 WALL

NOTES UNLESS OTHERWISE SPECIFIED

GENERAL RESEARCH 		2343 HOLLYER SANTA BARBARA, CALIFORNIA 93111
UNLESS OTHERWISE SPECIFIED MATERIALS SHALL BE AS SPECIFIED DIMENSIONS ARE IN INCHES AND FRACTIONS AFTER PLATING BEHALD COATS	R. SANCHEZ DATE 5/29/90 CHECK PREP INC	MAGNET ENCLOSURE SIZE B SCALE NONE US31 HQ GRC06-1 SHEET 01
304 SS 7 32 MATERIAL

SECTION A - A

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND APPLY AFTER PLATING, BURN, SHARP LOCES		DATE 5/29/90 CHECK R. SANCHEZ DESIGNED APPROVED	GENERAL RESEARCH 5383 HOLISTER SANTA BARBARA, CALIFORNIA 93111	COIL HOUSING	SIZE FSCM NO 9A890 DRAWING NUMBER 98750-1-10 REV C
XX : 01 XXX : 005 MATERIAL 304 SS	USED ON THIS DRAWING FOR INFORMATION OR TRANSFERRED TO OTHER DRAWINGS OR EMPLOYED TO OTHERS OR USED FOR ANY OTHER PURPOSES WITHOUT THE WRITTEN PERMISSION OF THE DRAWING OFFICE				

NOTES: UNLESS OTHERWISE SPECIFIED

<div style="display: flex; justify-content: space-between;"> <div style="width: 40%;"> <p style="margin: 0;">DRAWING NUMBER</p> <p style="font-size: 1.2em; margin: 0;">98750-1-11</p> </div> <div style="width: 10%; text-align: center;"> <p style="font-size: 0.8em; margin: 0;">REV</p> </div> <div style="width: 45%;"> <p style="margin: 0; text-align: center;">REVISIONS</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%; font-size: 0.8em;">REV</th> <th style="width: 60%; font-size: 0.8em;">DESCRIPTION</th> <th style="width: 15%; font-size: 0.8em;">DATE</th> <th style="width: 15%; font-size: 0.8em;">APPR</th> </tr> </thead> <tbody> <tr> <td style="height: 40px;"> </td> <td> </td> <td> </td> <td> </td> </tr> </tbody> </table> </div> </div>		REV	DESCRIPTION	DATE	APPR						
REV	DESCRIPTION	DATE	APPR								
<p style="margin: 0;">UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND DECIMALS OF AN INCH UNLESS OTHERWISE SPECIFIED</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%; font-size: 0.8em;">XX = 01</td> <td style="width: 20%; font-size: 0.8em;">K = 1</td> </tr> <tr> <td style="width: 20%; font-size: 0.8em;">XX = 005</td> <td style="width: 20%; font-size: 0.8em;">Z</td> </tr> </table> <p style="margin: 0;">MATERIAL</p> <p style="margin: 0; font-weight: bold;">BRASS</p> <p style="margin: 0; font-size: 0.8em;">FINISH</p>		XX = 01	K = 1	XX = 005	Z	<p style="margin: 0;">R. SANCHEZ</p> <p style="margin: 0; font-size: 0.8em;">DATE 5/8/90</p> <p style="margin: 0; font-size: 0.8em;">DESIGN</p> <p style="margin: 0; font-size: 0.8em;">PROJ</p> <p style="margin: 0; font-size: 0.8em;">APP</p>					
XX = 01	K = 1										
XX = 005	Z										
<p style="margin: 0;">1. 8 PER ASSEMBLY</p> <p style="margin: 0;">NOTES UNLESS OTHERWISE SPECIFIED</p>		<p style="margin: 0; font-weight: bold;">GENERAL RESEARCH</p> <p style="margin: 0;">PIN SWITCH CONTACT</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%; font-size: 0.8em;">SIZE</td> <td style="width: 20%; font-size: 0.8em;">DRAWING NUMBER</td> <td style="width: 20%; font-size: 0.8em;">REV</td> <td style="width: 40%; font-size: 0.8em;">SHEET NO. OF</td> </tr> <tr> <td style="text-align: center;">B</td> <td style="text-align: center;">98750-1-11</td> <td style="text-align: center;"> </td> <td style="text-align: center;">5.1 100027 1</td> </tr> </table>		SIZE	DRAWING NUMBER	REV	SHEET NO. OF	B	98750-1-11		5.1 100027 1
SIZE	DRAWING NUMBER	REV	SHEET NO. OF								
B	98750-1-11		5.1 100027 1								

DRAWING NUMBER <div style="border: 1px solid black; padding: 2px; display: inline-block;">98750-1-12</div>	REVISIONS <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 10%;">REV</th> <th style="width: 50%;">DESCRIPTION</th> <th style="width: 10%;">DATE</th> <th style="width: 10%;">APPR</th> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </table>	REV	DESCRIPTION	DATE	APPR					
REV	DESCRIPTION	DATE	APPR							

STAMP APPROPRIATE NUMBER AS
INDICATED IN TABLE BELOW

A	STAMP #	QTY
950	1	1
1,000	2	1
1,100	3	1
1,200	4	1

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES AND DECIMALS
FRACTIONS ARE TO BE SHOWN TO THREE DECIMALS
FRACTIONS ARE TO BE SHOWN TO THREE DECIMALS
FRACTIONS ARE TO BE SHOWN TO THREE DECIMALS

GENERAL RESEARCH

PIN SWITCH

DATE 5/8/90

DRAWING NUMBER 98750-1-12

REV A

UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES AND DECIMAL EQUIVALENTS		R SANCHEZ DATE 5/29/70		GENERAL RESEARCH		3303 HOLLYHUR SANTA BARBARA, CALIFORNIA 93111	
XX ± 0.1 XXX ± 0.05		304 SS 7-32		GAGE BODY SPACER 1		1500 IN. DRAMING NUMBER 98750-1-13	
PART USE THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION. IT IS NOT TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM, WITHOUT PERMISSION IN WRITING FROM THE GENERAL RESEARCH COMPANY.		DATE 5/29/70 BY 10101 NO 98750-1-13		SIZE B 54930		REV C	

DRAWING NUMBER	98750-1-15	REV	C	REVISIONS	
				REV	DATE
				DESCRIPTION

DASH NO.	MATERIAL	QTY
-1	AL-1100 F	2
-2	4340 STEEL	2

UNLESS OTHERWISE SPECIFIED MATERIALS SHALL BE AS SPECIFIED IN THE DRAWING AND SHALL BE AS SHOWN IN THE DRAWING		R SANCHEZ DATE 5/28/90		 GENERAL RESEARCH 3853 HELLER SANTA BARBARA, CALIFORNIA 93111	
XX # 01	X # 1	XX # 005	7 32	SIZE	8
MATERIAL				FSM NO	94890
NOTED				REV	1-15 C
NOTES: UNLESS OTHERWISE SPECIFIED 1. ALL DIMENSIONS ARE IN INCHES 2. ALL DIMENSIONS ARE TO CENTER UNLESS OTHERWISE SPECIFIED 3. ALL DIMENSIONS ARE TO BE AS SHOWN IN THE DRAWING 4. ALL DIMENSIONS ARE TO BE AS SHOWN IN THE DRAWING 5. ALL DIMENSIONS ARE TO BE AS SHOWN IN THE DRAWING				SPECIMEN BACKER SCALE 2:1 LUST NO. GRC069 SHEET 18	

DRAWING NUMBER	98750-1-16	A	REV	REVISIONS		DATE	APPR
				REV	DESCRIPTION

NOTES UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND DECIMALS FRACTIONS ARE IN INCHES AND 32nds FRACTIONS ARE IN INCHES AND 16ths FRACTIONS ARE IN INCHES AND 8ths FRACTIONS ARE IN INCHES AND 4ths FRACTIONS ARE IN INCHES AND 2ths FRACTIONS ARE IN INCHES AND 1st	DATE	5/29/90	DESIGN	R. SANCHEZ	5303 HOLMES SANTA BARBARA, CALIFORNIA 93111								
	XX = 01	XX = 02	XX = 03	XX = 04	XX = 05								
MATERIAL													
TETLON													
SPECIMEN RING													
<table border="1"> <tr> <td>SIZE</td> <td>FSUM NO</td> <td>DRAWING NUMBER</td> <td>REV</td> </tr> <tr> <td>B</td> <td>9A259U</td> <td>98750-1-16</td> <td>A</td> </tr> </table>						SIZE	FSUM NO	DRAWING NUMBER	REV	B	9A259U	98750-1-16	A
SIZE	FSUM NO	DRAWING NUMBER	REV										
B	9A259U	98750-1-16	A										
<table border="1"> <tr> <td>DATE</td> <td>11</td> <td>LOGI NO</td> <td>GR0070</td> <td>SHEET</td> <td>10</td> </tr> </table>						DATE	11	LOGI NO	GR0070	SHEET	10		
DATE	11	LOGI NO	GR0070	SHEET	10								

DRAWING NUMBER <div style="border: 1px solid black; padding: 2px; display: inline-block;">98750-1-17</div>	REV <div style="border: 1px solid black; padding: 2px; display: inline-block;">B</div>	<div style="text-align: center;"> REVISIONS <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">REV</th> <th style="width: 50%;">DESCRIPTION</th> <th style="width: 10%;">DATE</th> <th style="width: 10%;">APPR</th> </tr> </thead> <tbody> <tr> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </tbody> </table> </div> <div style="text-align: center; margin-top: 50px;"> <p style="font-size: 1.2em; margin-top: 10px;">4.38 ± .01</p> <p style="font-size: 1.2em; margin-top: 10px;">.125 ± .005 DIA</p> </div>	REV	DESCRIPTION	DATE	APPR					NOTES UNLESS OTHERWISE SPECIFIED
REV	DESCRIPTION	DATE	APPR								

UNLESS OTHERWISE SPECIFIED MATERIALS SHALL BE AS SHOWN AND APPLIED AFTER PLATING XX ± .01 K ± .1 XXX ± .005 Z 32 MATERIAL 304 SS FINISH	R SANCHEZ DATE 5/7/70	GENERAL RESEARCH 3383 HOLLYER SANTA BARBARA CALIFORNIA 93111	MAGNET SPACER-LOWER SIZE B FSC# NO 94090 DRAWING NUMBER 98750-1-17 SCALE NONE CUST NO GRU 071 SHEET 12
--	-----------------------------	---	--

DRAWING NUMBER <div style="border: 1px solid black; padding: 2px; display: inline-block;">98750-1-18</div>	REVISIONS		
	REV	DESCRIPTION	DATE
<div style="border: 1px solid black; padding: 2px; display: inline-block;">B</div>	APPR		

3.00 ± .01

.125 ± .005 DIA

NOTES UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND APPLY AFTER PLATING BEHOLD SHARP EDGES XX ± .01 X ± .1 XXX ± .005 Z ± .32 MATERIAL 504 SS	R. SANCHEZ DATE 5/29/90 CHECK PRO LOC APPR	GENERAL RESEARCH 3183 HOLLOER SANTA BARBARA CALIFORNIA 93111	MAGNETIC SPACER-UPPER SIZE B 98750-1-18 REV B
---	--	--	--

98750-2-3
DRAWING NUMBER

REV B
DATE
APPRO

REVISIONS
DESCRIPTION

GENERAL RESEARCH 5383 HOLISTER SANTA BARBARA, CALIFORNIA 93111		SABOT BODY	
CHECK DATE R. SANCHEZ	DRAWING NUMBER 98750-2-3	REV B	SHEET 3 OF 3
UNLESS OTHERWISE SPECIFIED INTERPRET DRAWING PER ANSI Y14 DIMENSIONS ARE IN INCHES AND APPLY AFTER PLATING BEAT SHARP EDGES		THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION IT MAY NOT BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS WITHOUT THE WRITTEN PERMISSION OF GENERAL RESEARCH	
XX = 01 XXX = 005		MATERIAL 4140	
FINISH 1 MAIL MADE FROM PATTERN DURING 312 OP		NOTE: UNLESS OTHERWISE SPECIFIED	

DRAWING NUMBER	98750-2-4	A	REV	REVISIONS		
				REV	DESCRIPTION	DATE

UNLESS OTHERWISE SPECIFIED INTERPRET DRAWING PER AMS 111 DIMENSIONS ARE IN INCHES AND ANGLES ARE IN DEGREES UNLESS OTHERWISE SPECIFIED		R. SANCHEZ		DATE	5/28/90
XX ± .01	K ± .1	CHECK			
XXX ± .005	J	PDR			
MATERIAL		USED ON			
6061-T6 AL		NO DOCUMENT CONTAINS PROPER LAYER			
FINISH		OR TRANSFERRED TO OTHER DOCUMENTS			
		UNLESS OTHERWISE SPECIFIED			
		WITHOUT FURTHER WRITTEN PERMISSION			
		GENERAL RESEARCH		3103 HOLIDER SANTA BARBARA CALIFORNIA 93111	
		SABOT REAR PLATE			
		SIZE		FSM NO	DRAWING NUMBER
		B		98750	98750-2-4
		REV		A	
		SCALE		1/1	UNIT NO
				GR0076	SHEET
				2	2

NOTES UNLESS OTHERWISE SPECIFIED

98750-2-5 DRAWING NUMBER		A REV	REVISIONS DESCRIPTION DATE APPR	
------------------------------------	--	-----------------	--	--

NOTES UNLESS OTHERWISE SPECIFIED

GENERAL RESEARCH <small>3383 HOLLOMAN SANTA BARBARA, CALIFORNIA 93111</small>	
IMPACTOR MOUNT	
R. SANCHEZ <small>DESIGNER</small>	5/29/90 <small>DATE</small>
<small>UNLESS OTHERWISE SPECIFIED MATERIALS SHALL BE THE STANDARD MATERIALS OF THE FEDERAL BUREAU OF INVESTIGATION</small>	
XX ± 01 XXX ± 005	X ± 1 Y ± 1 Z ± 1 MATERIAL
6061-T6 AL FIRST	
<small>DO NOT SCALE DRAWING OR DIMENSIONS TO OTHER DOCUMENTS OR TO THIS DRAWING FOR DIMENSIONS UNLESS SPECIFICALLY NOTED UNLESS OTHERWISE SPECIFIED</small>	

98750-2-6		A		REV	
DRAWING NUMBER		REV		DATE	
98750-2-6		A		APR	

REVISIONS	
REV	DESCRIPTION

1.700 DIA

.112 ±.002

IMPACTOR - GRC

NOTES UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND DECIMALS AFTER PLACING DECIMAL POINTS		R. SANCHEZ		DATE 5/29/90	
XX ± .01		CNC		GENERAL RESEARCH	
XXX ± .005		CNC		3403 MILLER BLVD SANTA BARBARA CALIFORNIA 93102	
MATERIAL		JPM		IMPACTOR - GRC	
TUNGSTEN CARBIDE		USE OF TUNGSTEN CARBIDE DIMENSIONS IF NOT ALL AT REFERENCE DIMENSIONS IF NOT ALL AT REFERENCE DIMENSIONS IF NOT ALL AT REFERENCE DIMENSIONS IF NOT ALL AT REFERENCE		SHEET NO. 98750-2-6	
FRESH		SHEET NO. 98750-2-6		REV A	

98750-2-7		A	
DRAWING NUMBER		REV	
REV		DATE	
M-1		M-11	
REV		DATE

UNLESS OTHERWISE SPECIFIED INTERPRET DRAWING PER ANSI Y14 DIMENSIONS ARE IN INCHES AND APPLY AT ALL PLATING BREAK SHARP EDGES		R. SANCHEZ		DATE 5/29/90	
XX	01	X	1	CHECK	
XXX	005	7	PROJ. ENG. APPR.		
MATERIAL 4340 STEEL FRESH		NEXT ASSY. USED ON			
NOT FOR CONSTRUCTION OR TRANSFERRED TO OTHER DOCUMENTS OR DISCLOSED TO OTHERS OR USED FOR ANY OTHER PURPOSE WITHOUT WRITTEN PERMISSION					
GENERAL RESEARCH		5383 HOLISTER SANTA BARBARA, CALIFORNIA 93111		SABOT STRIPPER	
SIZE 9A890		FSCM NO 9A890		DRAWING NUMBER 98750-2-7	
SCALE 1/2		CUST NO GRC079		REV A	
SHEET		OF		SHEET	

NOTES: UNLESS OTHERWISE SPECIFIED

APPENDIX C
MATERIAL CERTIFICATIONS

A.D. MACKAY, Inc.

10 North Broadway
P.O. Box G
Red Hook, NY 12571-0046
(914) 758-1033

PACKING SLIP

INVOICE NO: 27178

I N V O I C E

CUSTOMER ORDER No. 24874-3

GENERAL RESEARCH CORPORATION
ACCOUNTS PAYABLE DEPARTMENT
5083 HOLLISTER AVENUE
SANTA BARBARA, CA 93111

DATE SHIPPED	INVOICE DATE	TERMS U.S. FUNDS	F.O.B.
JUN 8 89	JUNE 8, 1989	NET 30 DAYS	RED HOOK, NY

SHIPPING CHARGES	PCS/WEIGHT	B/L NUMBER	ROUTING
Added to Invoice	1/14-LBS	340,655,97-6	U.P.S. 2/AIR

QUANTITY	BACK	DESCRIPTION	PRICE/UNIT	AMOUNT
ORDERED	SHIPPED			
1	1	0	PC., ALUMINUM ROD, 1100-F, 99%, 2" Dia. x 3-FT LONG, FILE: 15478	77.50/FT \$ 232.50
			SHIPPING/HANDLING	\$ 22.45
			TOTAL DUE, NET 30 DAYS	\$ 254.95

PACKING SLIP

PLEASE NOTE ON REMIT TO ADDRESS & CORRECT YOUR RECORDS ACCORDINGLY

PAYMENT DUE DATE: JULY 7, 1989

F.E.I.N.: 13-5558303

REMIT TO:

A. D. MACKAY, Inc.
Accounts Receivable Dept.
P.O. Box 'G'
RED HOOK, NY 12571-0046

THANK YOU. WE APPRECIATE THE BUSINESS YOU HAVE PLACED WITH US. Claims for credit or damages on account of shortage or defective material must be within 30 days. RETURNS WILL NOT BE ACCEPTED WITHOUT AUTHORIZATION AND RMA NUMBERS. ALL RETURNS SUBJECT TO A MINIMUM 25% RE-STOCKING CHARGE.

ALL PRICES SUBJECT TO CHANGE WITHOUT NOTICE BASED UPON THE PRICE IN EFFECT AT THE TIME OF SHIPMENT.

METALLURGICAL
TESTING

CORPORATION

15750 SALT LAKE AVENUE, CITY OF INDUSTRY, CALIFORNIA 91743

26 Jun 89

(818) 968-0404
(213) 283-2020

TO: GENERAL RESEARCH CORPORATION

DATE

June 22, 1989

YOUR P.O. NO.

MATERIAL

1100 Aluminum Bar

Attn: Patrick C. Rose

SPECIFICATION

QQ-A-225/1D(2)

REPORT OF CHEMICAL ANALYSIS

Size: 2" Diameter
Job No. 987.53

LABORATORY NO. 69-2605C

Copper -----	.13%
Iron -----	.56%
Silicon -----	.07%
Zinc -----	.03%
Manganese -----	.01%
Aluminum -----	Rem.

MEETS SPECIFICATION REQUIREMENTS

RESPECTFULLY SUBMITTED

METALLURGICAL TESTING CORPORATION
Gregory J. Lobosky, General Manager

ALL REPORTS ARE SUBMITTED AS THE CONFIDENTIAL PROPERTY OF CLIENTS. AUTHORIZATION FOR PUBLICATION OF OUR REPORTS, CONCLUSIONS OR EXTRACTS FROM OR REGARDING THEM IS PENDING OUR WRITTEN APPROVAL AS A MUTUAL PROTECTION TO CLIENTS, THE PUBLIC AND OURSELVES.

13325 MOLET.

SANTA FE SPRINGS, CA 90670

(213) 802-2721

CERTIFICATE OF COMPLIANCE

SOLD TO

[illegible]

I

94111

2

15558

51111111

588

11

[illegible]

2122

THIS MATERIAL IS FREE FROM URIC ACID AND RADIUM CONTAMINATION AT TIME OF SHIPPING.

STATE OF MICHIGAN DEPARTMENT OF TREASURY

LOCAL AND GLOBAL ANALYSIS

CHEMICAL AND PHYSICAL ANALYSIS FOR ABOVE ITEM(S) ATTACHED

THESE ARE THE RECORDS OF THE COURT

THE NEW YORK PUBLIC LIBRARY
ASTOR LENOX TILDEN FOUNDATION
500 5TH AVENUE
NEW YORK, N.Y. 10017

ITEM(S) ATTACHED

Copperweld
110-103 1

COPPERWELD

STEEL COMPANY

P.O. Box 351 / Warren, Ohio 44482

TEST REPORT

DISTRICT	CUSTOMER'S PURCHASE ORDER NUMBER	DATE OF TEST REPORT	SALES ORDER
1A	21771	04/10/89	46776

SOLD TO:	SHIP TO:
FRY STEEL COMPANY 13325 VOLANTE STREET SANTA FE SPRINGS, CALIFORNIA 92670	FRY STEEL COMPANY SANTA FE SPRINGS, CALIFORNIA 92670

DESCRIPTION OF MATERIAL ORDERED				
FEET	PIECES	LBS.	SIZE AND SHAPE	LENGTH
		10,000	2.125" RD	13/11' ATN 12'
PRODUCT DESCRIPTION			SPECIFICATION NO.	
NORM & TEMP 7.5 S 2 AQ			MIL-S-5700E COND E3 EX HT 1	
PART			MARK AMS 5415K EX MARK 5 AMS 2201G	
GRADE			ASTM-A-331-87 DMS 1555F EX MARK DMS	
			7-28-G CVA 1585-G EX ELGRA AMS 2211	

WEAT NO. -C-- -MN- -P-- -S-- -SI- -NI- -CR- -MO- -CU
69304 H 0.42 0.75 .007 .005 0.30 1.72 0.37 0.23 .12

JOMINY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	24	28	32	GR	SIZE
-1-	53	57	57	57	57	57	56	56		56		56		55		55		54	53	52	52		7-3
-2-																							

HARDNESS FB
229
FREQ/SEV .00/.00
DECARB: NIL
NORMALIZE: 1600F 3 HOURS
TEMPER: 1300F 6 HOURS

MACHINING EQUAL TO OR BETTER THAN
S2 RL C2 IN ACCORDANCE WITH
ASTM E381-79 (24).

FRY STEEL CO. CERTIFIES THAT THIS IS
A TRUE COPY OF THE ORIGINAL MILL TEST
REPORT NO ON FILE
RECEIVED AND INSPECTED

APR 20 1989

BY
LARRY D. LONG, QC MANAGER

WE HEREBY CERTIFY THAT THE ABOVE DATA
ARE CORRECT AS CONTAINED IN THE
RECORDS OF COPPERWELD STEEL COMPANY.

MATERIAL PRODUCED AND CERTIFIED TO SPECIFICATIONS SHOWN
ABOVE. NO ADDITIONAL CERTIFICATION IS IMPLIED OR WARRANTED.

VERYL D. KIPER,
MET RELEASE SUPV.

TIMKEN

THE TIMKEN COMPANY

STEEL OPERATIONS

1835 DUEBER AVE. S.W.

CERTIFICATE OF TEST

CANTON, OHIO 44708

DECEMBER 12, 1986

SOLD TO: FRY STEEL COMPANY
13325 MOLETTE ST
SANTA FE SPRINGS CALIFORNIA 90670

SHIP TO: FRY STEEL COMPANY
13325 MOLETTE ST
SANTA FE SPRINGS CALIFORNIA 90670

X1784
MATERIAL: ELECTRIC FURNACE "DEGRADED" 4340 AIRCRAFT QUALITY, GRAIN-REFINED, SUB-CRITICAL ANNEALED - TURNED SPEC. ALL DIMENSIONS TO 1/2" TOLERANCE. CERT. TOLD & AMS-5413K EXCEPT CONTINUOUS STENCILING - H10000-320-92

TIMKEN ORDER 33302 CUSTOMER ORDER 24365 NT
SIZE 2.875" RD

HEAT	C	MN	P	CHEMICAL ANALYSIS						PIECE NO.	CV NO.
				S	SI	CR	NI	MO	CU		
X1784 LADLE	.40	.76	.010	.009	.24	.84	1.82	.25	.13		

HEAT	GRAIN SIZE	PIECE NO.	CV NO.
X1784	8		

HARDENABILITY DATA

HEAT	LOC	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24	28	32	36	40
X1784		56	56	55	55	54	54	54	54	54	53	53	52	52		51	50	48	48		45

BRINELL HARDNESS

HEAT	PIECE NO.	RESULTS	
		1	2
X1784		212.0	212.0
		217.0	217.0
		212.0	

HEAT X1784 MAGNETIC PARTICLE RATING: AMS 2301G FREQUENCY .00 SEVERITY .00

2 7/8 R/L
WHEN SHIPPING NOTICE IS ATTACHED IT BECOMES PART OF THIS CERTIFICATION

WE CERTIFY THE ABOVE MATERIALS HAVE BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS, AND THE RESULTS OF SUCH INSPECTIONS AND TESTS CONFORM WITH THE APPLICABLE REQUIREMENTS.

NOTARY PUBLIC

BY

Beth H. Hays
CERTIFICATION CLERK

MILITARY SPECIFICATION

STEEL, CHROME-NICKEL-MOLYBDENUM (E4340) BARS AND REFORGING STOCK

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers electric furnace steel bars and reforging stock of aircraft quality.

1.2 Classification.

1.2.1 Physical condition. Bars shall be furnished in one of the following physical conditions, as specified (see 6.2):

- (A) As forged
- (B) As rolled
- (C) Annealed
- (D) Normalized
- (E) Normalized and tempered
- (F) Hardened and tempered, 130,000 psi minimum yield strength

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Engineering Specifications and Standards Department (Code 93), Naval Air Engineering Center, Lakehurst, NJ 08733, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FSC 9510

1.2.2 Surface conditions. Bars shall be furnished in one of the following conditions, as specified (see 6.2):

- (1) Black as forged or rolled
- (2) Pickled or blast cleaned
- (3) Rough turned
- (4) Cold drawn
- (5) Turned, ground, and polished
- (6) Turned and polished

1.3 Sizes and shapes. Bars and reforcing stock shall be furnished in the sizes and shapes specified (see 6.2).

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications and standards. Unless otherwise specified, the following specifications and standards of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation, form a part of this specification to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-I-6868 Inspection Process, Magnetic Particle

MIL-I-8950 Inspection, Ultrasonic, Wrought Metals, Process for

STANDARDS

FEDERAL

FED-TEST
METHOD-STD 151 Metals; Test Methods

FED-STD-183 Continuous Identification Marking of Iron and Steel
Products

STANDARDS

MILITARY

MIL-STD-163 Steel Mill Products Preparation for Shipment and
Storage

MIL-S-5000E

(Copies of specifications and standards required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. The issues of the documents which are indicated as DoD adopted shall be the issue listed in the current DoDISS and the supplement thereto, if applicable.

SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

AMS 2301 Aircraft Quality Steel Cleanliness, Magnetic Particle Inspection Procedure

(Applications for copies should be addressed to: Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096).

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM A 29	General Requirements for Hot-rolled and Cold Finished Carbon and Alloy Steel Bars
ASTM A 255	End Quench Test for Hardenability of Steels, Method of
ASTM E 8	Tension Testing of Metallic Materials, Methods of
ASTM E 10	Brinell Hardness of Metallic Materials, Test Method for
ASTM E 18	Rockwell Hardness and Rockwell Superficial Hardness of of Metallic Materials, Test Methods for
ASTM E 112	Estimating Average Grain Size of Metals, Methods for
ASTM E 381	Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms and Forgings

(Applications for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103).

(Industry association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies).

2.3 Order of precedence. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

3. REQUIREMENTS

3.1 Material quality. The steel shall be produced by electric furnace practice and shall be of aircraft quality conforming to AMS 2301 except that a maximum average frequency (F) rating of 0.34 and a maximum average severity (S) rating of 0.25 shall apply for all sizes and products. In addition, AMS 2301 specimens which contain indications representing non-metallic inclusions over 1.00 inch in length shall be subject to rejection.

3.1.1 Ultrasonic inspection. When specified, bars or intermediate mill products and reforging stock shall be ultrasonically inspected in accordance with MIL-I-8950. The minimum quality level shall be as specified below (see 4.6):

<u>Dimensions (inches)</u>	<u>Ultrasonic Classification</u>
1-1/2 to 9 thickness	A
Larger than 9	B

3.2 Chemical composition. The chemical composition shall be as specified in Table I.

TABLE I. Chemical Composition.

<u>Element</u>	<u>Analysis (percent)</u>	<u>Check Analysis Tolerance (percent) 1/</u>
Carbon	0.38 - 0.43	+ 0.02
Manganese	0.65 - 0.85	+ 0.03
Phosphorus	0.025 (max)	+ 0.005, -0.00
Sulfur	0.025 (max)	+ 0.005, -0.00
Silicon	0.15 - 0.35	+ 0.02
Nickel	1.65 - 2.00	+ 0.05
Chromium	0.70 - 0.90	+ 0.03
Molybdenum	0.20 - 0.30	+ 0.02
Copper	0.35 (max)	+ 0.03, -0.00

1/ Individual determinations may vary from the specified range to the extent shown in the check analysis column, except that the elements in any heat shall not vary both above and below the specified range. For sizes over 100 square inches in cross-sectional area, the check analysis shall be negotiated.

3.3 Hardenability. End-quench hardenability values for the steel in all specified conditions shall be Rockwell C-50 minimum at 20/16 inch and Rockwell C-45 minimum at 32/16 inch.

3.4 Grain size. The austenite grain size shall be predominantly No. 5 or finer with grains as large as No. 3 permissible.

MIL-S-5000E

3.5 Macrostructure. Visual examination of deep-acid-etched reforcing stock in sizes up to and including 36 square inches shall be equal to or better than S-2, R-1 and C-2; sizes over 36 to and including 100 square inches shall be equal to or better than S-2, R-2, and C-2 of ASTM E 381. Product forms other than reforcing stock shall be macroscopic examined at a section thickness not less than 3 inches and shall be equal to or better than S-2, R-1, and C-2 of ASTM E 381.

3.6 Decarburization. Unless otherwise specified, the depth of decarburization of products in surface condition (2) or (4) shall be not greater than the following limits (see 6.2):

Nominal Diameter or Distance Between Opposite Faces (Inches)	Maximum Depth of Decarburization (Inches) ^{1/}
Up to 0.375 incl.	0.010
Over 0.375 to 0.500 incl.	0.012
Over 0.500 to 0.625 incl.	0.014
Over 0.625 to 1.000 incl.	0.017
Over 1.00 to 1.50 incl.	0.020
Over 1.50 to 2.00 incl.	0.025
Over 2.00 to 2.50 incl.	0.030
Over 2.50 to 3.00 incl.	0.035

^{1/} The value specified as the maximum depth of decarburization is the sum of the complete plus the partial decarburization.

3.6.1 When determining the depth of decarburization, it is permissible to disregard local areas provided the decarburization of such areas does not exceed the limits specified in 3.6 by more than 0.005 inch and the width is 0.064 inch or less.

3.6.2 Products furnished in surface conditions (3), (5), and (6) shall be free from decarburization.

3.6.3 When intended for reforcing purposes, the above decarburization limits shall not apply.

3.7 Surface and physical conditions. Unless otherwise specified, bars 1-1/2 inches or less in diameter or thickness shall be furnished in condition (C)-(4), and bars over 1-1/2 inches in diameter or thickness shall be furnished in condition (C)-(2).

3.8 Hardness limits.

3.8.1 The hardness for material in physical conditions (C) and (E) shall be not more than Brinell 235 (Rockwell C 22) when furnished in surface conditions (1), (2), or (3).

MIL-S-5000E

3.8.2 The hardness for material in physical conditions (C) and (E) shall be not more than Brinell 265 (Rockwell C-27) when furnished in surface condition (4).

3.9 Mechanical properties of condition (F) steel. Unless otherwise specified, the mechanical properties of products supplied in condition (F) in sizes up to and including 3 inches in the least dimension shall conform to the limits specified in Table II (see 6.2).

TABLE II. Mechanical properties of condition (F) steel.^{1/}

Tensile Strength (min)	Yield Strength at 0.2 percent offset or extension indicated (min) Extension under load		Elongation in 2 in. (min)	Reduction in area (min)
psi	psi	inches in 2 inches	percent	percent
150,000	130,000	0.0127	14	53

^{1/} When products in condition (F) are ordered with mechanical properties differing from those specified in 3.9 or when products in condition (F) are offered in sizes larger than 3 inches in the least dimension, the mechanical properties shall be as agreed upon the supplier and the purchaser.

3.10 Identification of product. Each bar shall be identified in accordance with FED-STD-183. The markings shall include the heat number of the metal and number of this specification.

3.11 Tolerances. Tolerances shall conform to the limits of ASTM A 29.

3.12 Workmanship. Material shall be sound, of uniform quality and condition, free from pipes, and shall not contain laps, cracks, twists, seams, or other defects detrimental to the fabrication or performance of parts. Steel melting practice shall produce metal complying with all requirements of this specification.

3.12.1 Cold drawn bars. Cold drawn bars shall be free from scale. Drawing shall be accomplished after all heat-treating operations have been completed; however, stress relieving should be accomplished after drawing.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the contractor may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of tests. All the tests required for the testing of the product are classified as acceptance tests, for which necessary sampling techniques and methods of testing are specified in this section.

4.2.1 Inspection conditions. Unless otherwise specified, all inspections shall be performed in accordance with the test conditions specified in the applicable test method document or applicable paragraph(s) in the specification.

4.2.2 Inspection lot. An inspection lot shall include all mill forms of one heat, condition and size presented for acceptance at one time, and when heat treated, from the same process and the same batch.

4.3 Examination of product. Samples selected at random in accordance with Table III shall be examined for compliance with surface condition, identification, dimensional, marking, workmanship, and preparation for delivery requirements.

TABLE III. Sampling for examination of product.

Lot Size	Sample Size	Acceptance number
1 to 65	4	0
66 to 110	5	0
111 to 300	7	0
301 to 500	10	0
501 to 800	15	0
Over 800	25	0

4.4 Chemical analysis.

4.4.1 Sampling. Samples for check chemical analysis shall be selected to represent each heat of steel in accordance with requirements of method 111.2 of Federal Test Method Standard No. 151.

4.4.2 Specimens. Samples for check chemical analysis shall be taken parallel to the axis of the billet selected, at a point midway between the center and surface, except that material less than 1 1/4 inches thick shall be sampled through the entire cross-section. The sample shall consist of not less than 2 ounces of material.

4.4.3 Test method. Samples shall be prepared in accordance with Method 111.2 of Federal Test Method Standard No. 151, and shall be tested by wet chemical, spectrographic, or other analytical methods. In the event of dispute, analysis shall be wet chemical methods.

4.5 Steel cleanliness inspection. The material shall be magnetic particle inspected in accordance with MIL-I-6868 to comply with the steel cleanliness requirements of AMS 2301.

4.6 Ultrasonic inspection. Inspection shall be in accordance with MIL-I-8950. Surface roughness shall not exceed 125 roughness height rating (RHR) at 5 megahertz (mhz) and 250 RHR at 2.25 mhz and lower frequencies. The surface roughness of the reference standards shall not vary more than plus or minus 25 RHR from the surface roughness of material being tested.

4.7 Hardenability.

4.7.1 Sampling. One or more samples for end-quench hardenability test shall be selected from each heat of steel from which material is presented for acceptance.

4.7.2 Preparation of specimens. Specimens for the end-quench hardenability test shall conform to ASTM A 255. The steel shall be normalized prior to machining the test specimen by heating $1,600^{\circ} \pm 10^{\circ}\text{F}$, holding at this temperature for 1 hour and cooling in still air.

4.7.3 Test method. End-quench hardenability test shall be conducted in accordance with ASTM A 255. Specimens shall be austenitized at $1,550^{\circ} \pm 10^{\circ}\text{F}$. Tests shall establish compliance with 3.3.

4.8 Grain size.

4.8.1 Sampling. One or more samples shall be selected to represent each heat of steel from which material is submitted for acceptance.

4.8.2 Test method. Specimens shall be sectioned and polished to appropriate fineness by metallographic methods and suitably etched to reveal the grain structure. The austenite grain size shall be determined in accordance with ASTM E 112.

4.9 Macrostructure.

4.9.1 Sampling. Two or more sample slices at least 1/4 inch thick shall be selected to represent each heat of steel from which material is submitted for acceptance.

4.9.2 Procedure. The samples shall be prepared in accordance with ASTM E 381. The etched samples shall meet the requirements of 3.5.

4.10 Decarburization.

4.10.1 Sampling. If the purchaser has reason to suspect that the decarburization limits specified herein may have been exceeded, samples shall be selected for determination of the depth of decarburization.

4.10.2 Test method. Depth of the zone of decarburization below a surface shall be determined by examination of a metallographic specimen or specimens representing the entire cross section of bars 1 inch or less in diameter or width. With bars of 1 inch in diameter, the section shall exhibit not less than 1 linear inch of the original surface of the bar. This specimen shall be polished, etched with 5 percent nital, and examined at 100X magnification.

4.11 Hardness of bars in physical conditions (C) and (E).

4.11.1 Sampling. At least five bars of each condition and size shall be tested to determine conformance with hardness values of 3.8. When less than five bars are ordered, each bar shall be tested.

4.11.2 Test method. Hardness testing shall conform to ASTM E 10 or ASTM E 18.

4.12 Mechanical properties of condition (F) steel.

4.12.1 Sampling. One or more samples shall be selected from the lot.

4.12.2 Specimens. Tensile test specimens shall conform to the round type specimens of ASTM E 8. For bars up to 1 1/2 inches in diameter or thickness, the axis of the test specimen shall coincide with the central axis of the bar; for bars 1 1/2 inches and over, the axis shall be located midway between the center and the surface of the bar. The axis of specimens shall be parallel to the direction of rolling or drawing.

4.12.3 Test method. Tensile tests shall be conducted in accordance with ASTM E 8. Yield strength shall be determined by the offset or extension-under-load methods.

4.13 Certified test reports. Heats which have been tested and found to comply with the requirements of this specification shall be acceptable. Each shipment from these heats shall be accompanied by test reports, in duplicate, showing compliance with requirements for chemistry, hardenability, mechanical properties, grain size, ultrasonic properties, macrostructure and magnetic particle frequency/severity ratings.

4.14 Rejection and retest. Failure of a specimen to comply with specified requirements shall cause rejection of the materials represented. However, at the discretion of the contractor/supplier, retest will be permitted. A retest sample of five specimens, one from each of five bars, shall be tested to replace each failed specimen from the original sample. If one retest specimen fails, the materials represented shall be rejected. Rejected material may be reprocessed and resubmitted.

4.15 Packaging. Packaging shall be examined for conformance to section 5.

5. PACKAGING

5.1 Packaging.

5.1.1 Level A. The materials shall be properly separated by condition and size when prepared for delivery. The bars shall be preserved and packaged in accordance with MIL-STD-163.

5.1.2 Level C. The material shall be preserved and packaged in accordance with commercial practice.

5.2 Packing.

5.2.1 Level A. The material shall be packed in accordance with MIL-STD-163.

5.2.2 Level C. The materials shall be prepared for shipment in accordance with commercial practice to assure carrier acceptance and safe transportation at the lowest rate to the point of delivery and shall meet, as a minimum, the requirements of carrier rules and regulations applicable to the mode of transportation.

5.3 Marking of shipments. Marking and labeling shall be in accordance with MIL-STD-163.

6. NOTES

6.1 Intended use. Steel covered by this specification is intended for use in the manufacture of highly stressed aircraft parts requiring high hardenability.

6.2 Ordering data. Procurement documents should specify the following:

- a. Title, number, and date of this specification.
- b. Physical and surface conditions. (See 1.2.1, 1.2.2, and 3.9.1).
- c. Size and shape.
- d. When bars are intended for reforging purposes, it should be so stated.
- e. If decarburization limits closer than those specified in 3.6 are described.
- f. Exact lengths and length tolerances, if mill lengths are not acceptable.
- g. Levels of packaging and packing required (see section 5).
- h. Whether ultrasonic inspection is required (see 3.1.1).

6.3 Changes from previous issue. Asterisks are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodians:

Army - MR

Navy - AS

Air Force - 20

Preparing activity:

Navy - AS

(Project No. 9510-0370)

Review activities:

Army - EA, ER, MI

Air Force - 99

DLA - IS

User activities:

Army - AT

Form Approved
OMB No. 0704-0230
Expires Dec 31, 1991

[illegible]

--	--	--	--	--	--	--	--

11

IF YOUR ADDRESS HAS CHANGED, X THIS
BLOCK.

3. ATTENTION:

4. DOCUMENTS REQUESTED

a. STANDARDIZATION DOCUMENT NUMBER	b. QUANTITY (Restricted to 5)	c. TITLE (From DoD Index of Specifications and Standards)

INSTRUCTIONS

- 1 PRINT OR TYPE ALL INFORMATION
- 2 Enter your customer number, CAGE (formerly FSCM), or UIC number at the top of this form. It will expedite your order.
- 3 If you have a customer number use the Telephone Order entry System (T.O.S.) for telephone orders. (215)697-1187 between the hours of 8 a.m. and 8 p.m. Eastern Standard Time, Monday through Friday. See "Guide to Private Industry" for details.
- 4 Documents ordered must appear in the DoD Index of Specifications and Standards (DODISS) or DODISS Notice. Requests submitted on this form will speed service. Reorder forms will be enclosed with each shipment.
- 5 Requests for Official Use Documents or documents without Distribution Statement "A" must be submitted via cognizant DoD Inspector, Officer or Contract Administrator for verification of need to know.
- 6 Non Government Standardization Documents will not be furnished to commercial concerns. Copies may be purchased from the appropriate Non Government Standards Body.
- 7 Questions concerning documents not listed in the Department of Defense Index of Specifications and Standards (DODISS) or DODISS Notice should be directed to AFIC Act. Code 103 Telephone (215)697-2667 or (215)697-2179.
- 8 Further information may be obtained from NPFC "Guide to Private Industry" Order as GUIDE-1.
- 9 FORWARD REQUEST TO
Standardization Document Order Desk
701 Fobbins Avenue
Building #4, Section D
Philadelphia, PA 19111-5096

5 SIGNATURE OF REQUESTER

b DATE SIGNED (r r m a c o)

7 CLOSING DATE ☐ MONTH
(IFB RFO or RFP)

INSTRUCTIONS: In a continuing effort to make our standardization documents better, the DoD provides this form for use in submitting comments and suggestions for improvements. All users of military standardization documents are invited to provide suggestions. This form may be detached, folded along the lines indicated, taped along the loose edge (*DO NOT STAPLE*), and mailed. In block 5, be as specific as possible about particular problem areas such as wording which required interpretation, was too rigid, restrictive, loose, ambiguous, or was incompatible, and give proposed wording changes which would alleviate the problems. Enter in block 6 any remarks not related to a specific paragraph of the document. If block 7 is filled out, an acknowledgement will be mailed to you within 30 days to let you know that your comments were received and are being considered.

NOTE: This form may not be used to request copies of documents, nor to request waivers, deviations, or clarification of specification requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

(Fold along this line)

(Fold along this line)

DEPARTMENT OF THE NAVY
Commanding Officer
Naval Air Engineering Center
Systems Engineering Standardization Department
(SESD), Code 93
Lakehurst, NJ 08733

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE \$300

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO 12503 WASHINGTON D C

POSTAGE WILL BE PAID BY THE DEPARTMENT OF THE NAVY

Commanding Officer
Naval Air Engineering Center
Systems Engineering Standardization Department
(SESD), Code 93
Lakehurst, NJ 08733

ATTN: TJM (9322)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions - Reverse Side)

1. DOCUMENT NUMBER		2. DOCUMENT TITLE	
3a. NAME OF SUBMITTING ORGANIZATION		4. TYPE OF ORGANIZATION (Mark one) ☐ VENDOR ☐ USER ☐ MANUFACTURER ☐ OTHER (Specify): _____	
b. ADDRESS (Street, City, State, ZIP Code)			
5. PROBLEM AREAS			
a. Paragraph Number and Wording:			
b. Recommended Wording:			
c. Reason/Rationale for Recommendation:			
6. REMARKS			
7a. NAME OF SUBMITTER (Last, First, MI) - Optional		b. WORK TELEPHONE NUMBER (Include Area Code) - Optional	
c. MAILING ADDRESS (Street, City, State, ZIP Code) - Optional		8. DATE OF SUBMISSION (YYMMDD)	

DD FORM 1426
82 MAR

PREVIOUS EDITION IS OBSOLETE.

END

DATE FILMED

03 / 05 / 91