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AFRPL-TR-69-22

MINIMUM COST DESIGN (MCD) MATERIAL SCREENING
TEST REPORT NO. 2 - DOW CORNING DC93-104

James A. Hintz, Capt, USAF

TECHNICAL REPORT AFRPL-TR-69-22

January 1969

Project 305803KRD

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TEST REPORT NO. 2 - DOW CORNING DC93-104

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FOREWORD

This report was prepared by the Engine Components Section, Engine Research Branch, and covers one of the articles tested in the Minimum Cost Design (MCD) Material Screening Program, Project Number 305803KRD. This project is under the technical direction of Capt J. Hintz, the Project Engineer. Others participating in the program include Lt D. Riedl, Lt A. Tsugawa, Mr. L. Tepe and Mr. G. Bergen.

Many of the items tested in this program are commercial items that were not developed or manufactured to meet government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

This technical report has been reviewed and is approved.

George Mushalko

GEORGE MUSHALKO, Major, USAF
Chief, Engine Research Branch
Liquid Rocket Division

ABSTRACT

This is the second of a series of reports describing the results of test firings conducted to determine the performance of low cost ablative materials which are candidates for use as thrust chamber and nozzle liners for MCD Booster engines. This report describes the test of Dow Corning DC93-104, an ablative composed of silicone rubber with a filler material which is proprietary to Dow Corning.

Information pertinent to this particular test is included in the body of the report. A general description of the program and information common to all tests may be found in the Appendix.

The DC93-104 test article survived the full planned test duty cycle. In general, the performance of this material in its initial screening test was quite good, and it will be a likely candidate for further testing under other environments later in the program.,

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MINIMUM COST DESIGN (MCD) MATERIAL SCREENING

TEST REPORT NO. 2 - DC93-104

I. DESCRIPTION OF MATERIAL

Dow Corning DC93-104 is composed of approximately 50% silicone rubber and approximately 50% of a filler whose formulation is proprietary to Dow Corning. This is a new material which is not yet being used in any ablative applications, although it is receiving evaluation for a wide range of potential applications at the present time. The material cures at ambient temperature and pressure, and bonds well to a steel surface primed with a suitable agent such as DC1200 Primer. The cure requires seven days at ambient temperatures, or can be accelerated to four hours at 160°F. Shrinkage due to cure is virtually zero at ambient temperature and less than .5% at elevated temperatures. Because of these cure characteristics, MCD chamber liners of DC93-104 could be fabricated and bonded by injection molding directly into the primed structural shell and cured in place. Dow Corning is also developing a thixotropic formulation of this material which could be applied by troweling. The projected cost for large quantities of DC93-104 raw materials is $5/lb, and the estimated cost of a liner in place is $7/lb.

Pertinent properties of DC93-104 are as follows:

Specific Gravity	1.46
Coefficient of Thermal Expansion	2.97×10^{-4} in/in/°F
Coefficient of Thermal Conductivity	2.42 BTU/in/hr-ft^2-°F
Specific Heat	.30 BTU/lbm-°F

DC93-104 has been tested in programs at Philco Aeronautics and TRW Systems. In both programs, which were subscale screening programs in support of the AFRPL screening effort, this was one of the best materials tested because of the erosion-resistant char layer which it forms and the relatively shallow char penetration its low thermal conductivity affords.

The DC93-104 liner for the AFRPL screening program was fabricated by casting directly into the structural shell, using a male mandrel to cast the liner directly to the finished contour (see Appendix, Fig. 2). The shell and mandrel were standing on end, and the ablative material was pumped into the mold cavity from the bottom while a vacuum was pulled from the top to insure a void-free liner. This evacuation of the cavity would not be required in fabricating a large liner where mixing equipment which prevents the introduction of air could be used. The liner was cured under ambient conditions. Upon receipt of the liner at the AFRPL, thermocouples were embedded in the ablative as a safety device to monitor the thermal degradation of the material during firing.

II. TEST

The DC93-104 liner was tested on 22 Nov 68 in run number 497 at the AFRPL Test Area 1-46-A1. To avoid the extensive head end streaking which had occurred on the Haveg 41 liner, as described in AFRPL-TR-69-10, a 10-inch long, 8-inch I.D., water-cooled chamber section (see Fig. 1) was installed between the injector and the ablative test article assembly (see Appendix). The propellant combination was NTO/UDMH, and the duty cycle consisted of a one-second checkout pulse to verify the operating conditions and the structural soundness of the liner, followed by a 60-second continuous burn to establish erosion and char rates. The operating conditions during the 60-second burn were as follows:

	Target	Delivered	
		Initial	Final
Pc (psia)	195	190	177
Mixture Ratio	1.60	1.59	1.59
Thrust (lbf)	5200	5100	5160

The target operating conditions were selected on the basis of heat transfer characterization tests with a copper calorimeter chamber so as to give a heat transfer environment to the wall of recovery temperature in the range 3500 - 4500°F and convective heat transfer coefficient in the range .0008 - .0010 BTU/in^2-sec-°F, which were the ranges of these parameters in the originally planned test matrix for this program. These conditions will be used in all the baseline screening tests in the screening phase of testing in this program (see Appendix). A more exact determination of the heat transfer environment which these operating conditions provide to the ablative chamber wall will be made through more refined calorimeter chamber testing later in the program.

The shift in operating conditions during the long duration burn was caused by throat erosion and the lack of cavitating venturis in the flow system (see Appendix). Plots of the measured chamber pressure and calculated throat area as functions of time during the long duration firing are shown in Figs. 2 and 3.

III. RESULTS

Visual inspection of the liner immediately after the 60-second firing revealed that the molten silica char layer, after cooldown, was very hard and brittle, and was coming loose from the virgin substrate in some locations. One piece of char approximately two inches by three inches was missing in the chamber, but the virgin appearance of the exposed substrate material indicated this piece must have been expelled during shutdown. This same phenomenon had occurred in an earlier test of this material at Philco Aeronautronics, and is not interpreted to be a problem of the material itself.

The surface recession was somewhat non-uniform, with both circumferential and axial flow of the molten char layer having occurred due to non-uniform heating caused by plugged injector orifices. However, the use of the water-cooled chamber length upstream of the ablative chamber prevented the non-uniformity from being very pronounced. Only one major and two minor streaks occurred (see Figs. 4 and 5).

To determine the performance of the material in depth, the liner was removed from the steel shell and sectioned longitudinally in the center of the worst streak as well as in a region of uniform surface recession away from the streaks. Measurements of the char and surface recession were then taken along these cut surfaces.

The surface and char profiles in the non-streaking region are shown in Fig. 6 and represent the behavior of the material under the environment of the baseline operating conditions. In the chamber region the char front penetrated .3 inch below the original surface. The final thickness of the chamber liner was greater than the original thickness, indicating that the char layer swelled up during the firing and that any flow of surface material which might have occurred was very minor. The material was able to hold a thick char layer in all regions of the liner, but surface recession did occur in the convergent, throat and exit regions. The surface recession in the throat region was .1 inch, for an average of under 2 mils/second. Penetration of the char front below the original surface was .4 inch in the throat and .3 inch in the exit plane.

The region of the worst streak may perhaps be considered as representative of the worst case of environmental non-uniformity which large-scale MCD injectors could have. Along this streak, surface recession was .25 inch in the chamber and .4 inch in the throat. The char front penetration below the original surface was .4 inch in the chamber and .5 inch in the throat. Thus, at no point in the chamber was there less than .4 inch of virgin material (out of the original .8 inch) remaining after the firing.

Overall, a particular advantage of DC93-104 is that melting and flowing of surface material in the convergent region tends to retard throat growth, as may be seen in the plots of chamber pressure and throat area in Figs. 2 and 3.

IV. CONCLUSIONS

On the basis of this test, DC93-104 is a promising material and will be a likely candidate for further testing under other environments later in this program. However, sound conclusions as to the applicability of this material to the 250K long duration chambers (see Appendix) cannot be drawn until (1) the heat transfer environment of this screening test is more closely determined, (2) additional data are generated on this material under other environments, and (3) the environment provided by the 250K injector is determined.

OFFICIAL PHOTOGRAPH
AIR FORCE FLIGHT TEST CENTER
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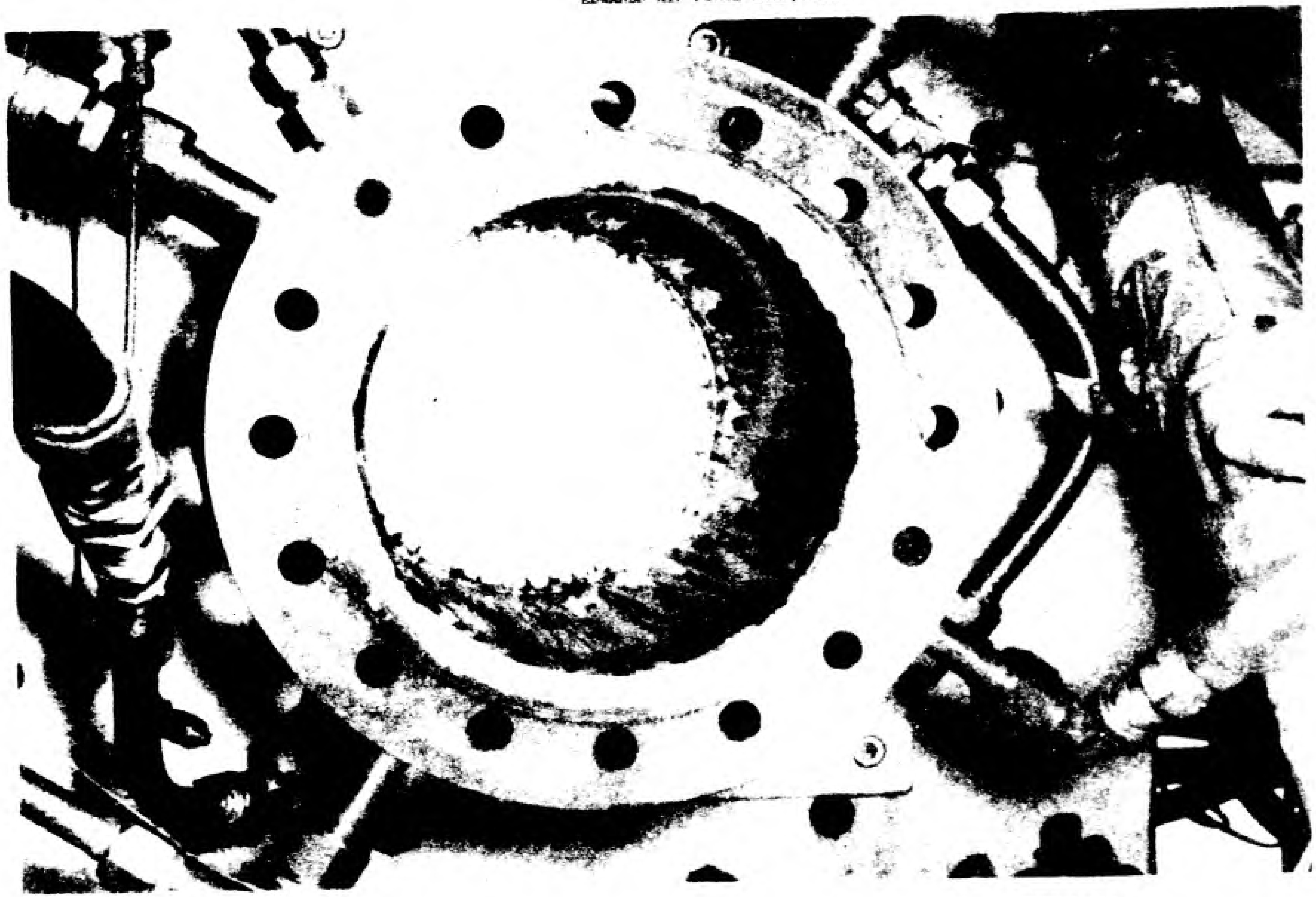
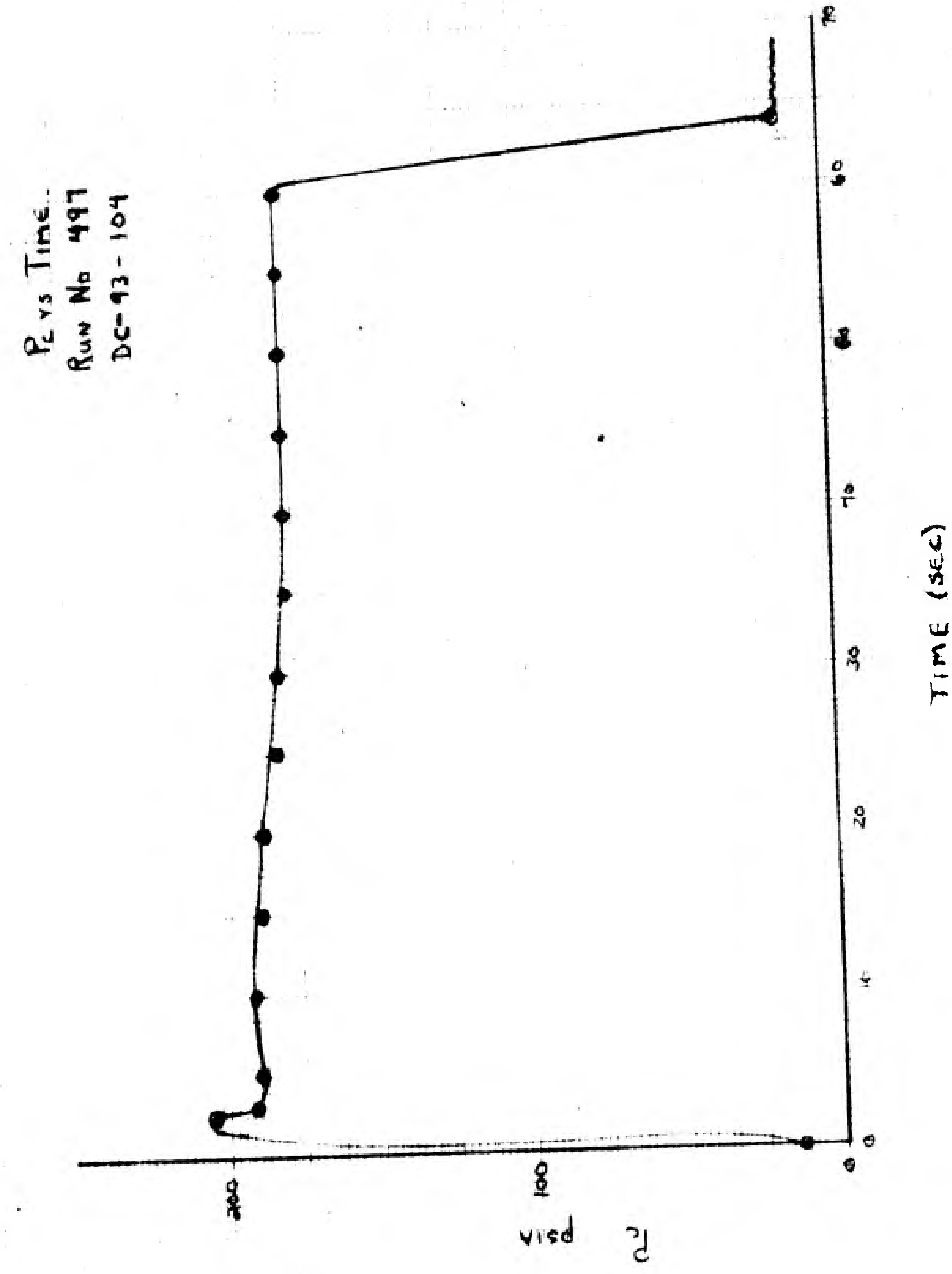


8771-68 AFFTC 22 NOV, UNCL.
T.S. 1-464-1 HOT FIRE RUN

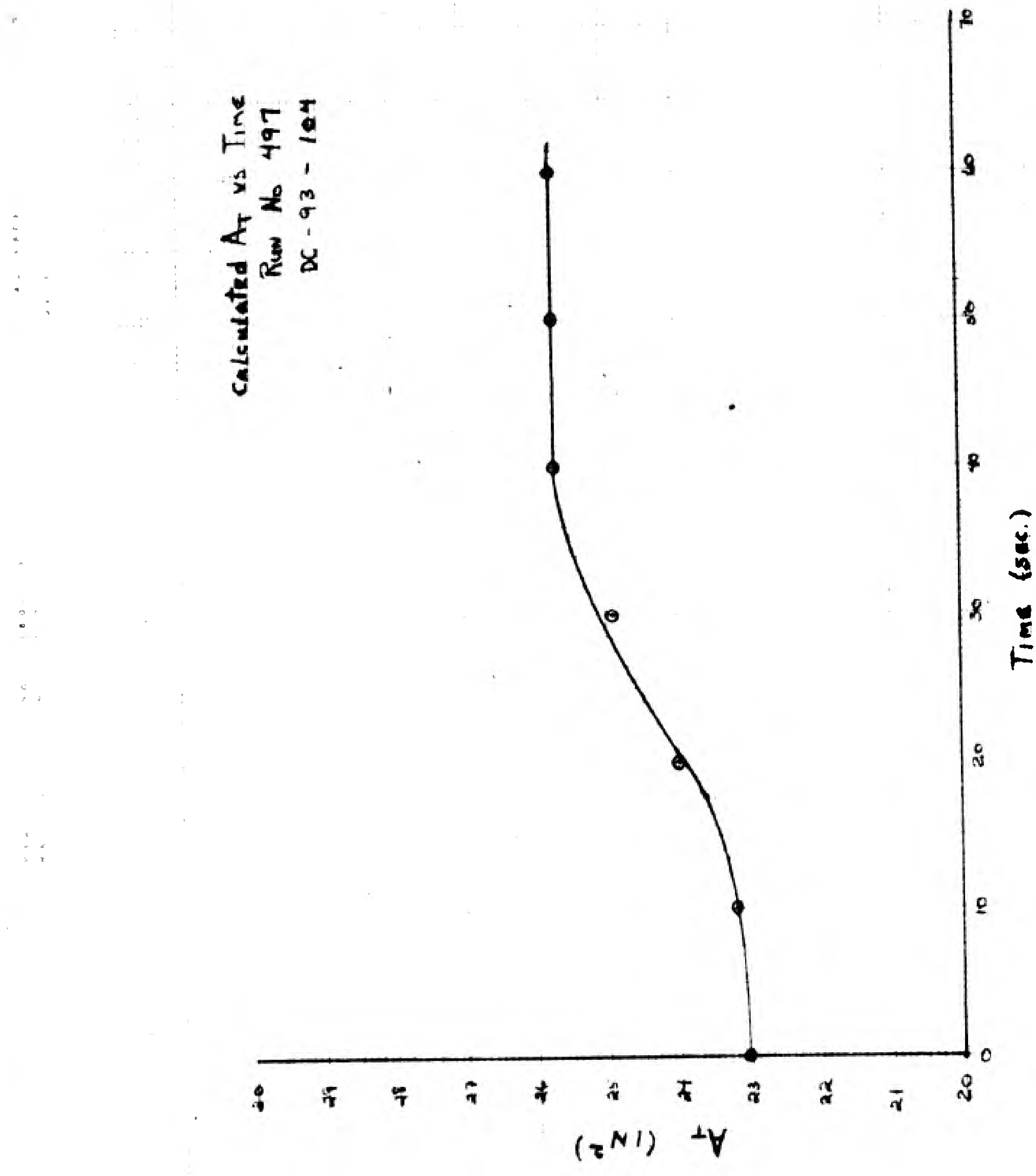
INJECTOR AND WATER-COOLED
CHAMBER SECTION

PHOTOGRAPH BY
A1C



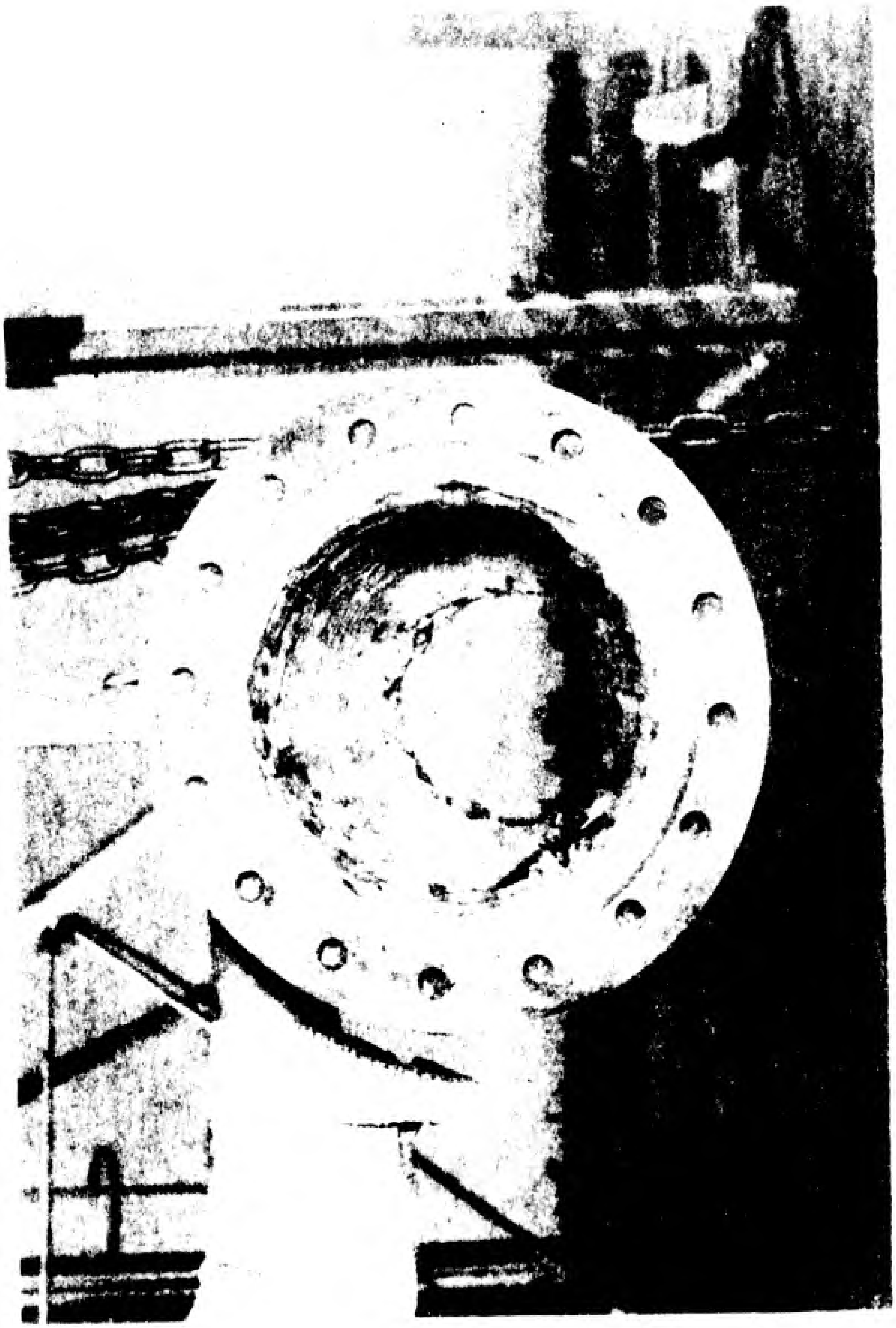
Pc vs Time
Run No 497
DC-93-104
TIME (SEC)
Pc psia
0
100
200
0
10
20
30
40
50
60
70

Fig. 2



Calculated A_T vs Time
Run No 497
DC - 93 - 104
A_T (IN²)
20
21
22
23
24
25
0
10
20
30
40
50
60
70
Time (sec.)

Fig. 3



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AIR FORCE FLIGHT TEST CENTER
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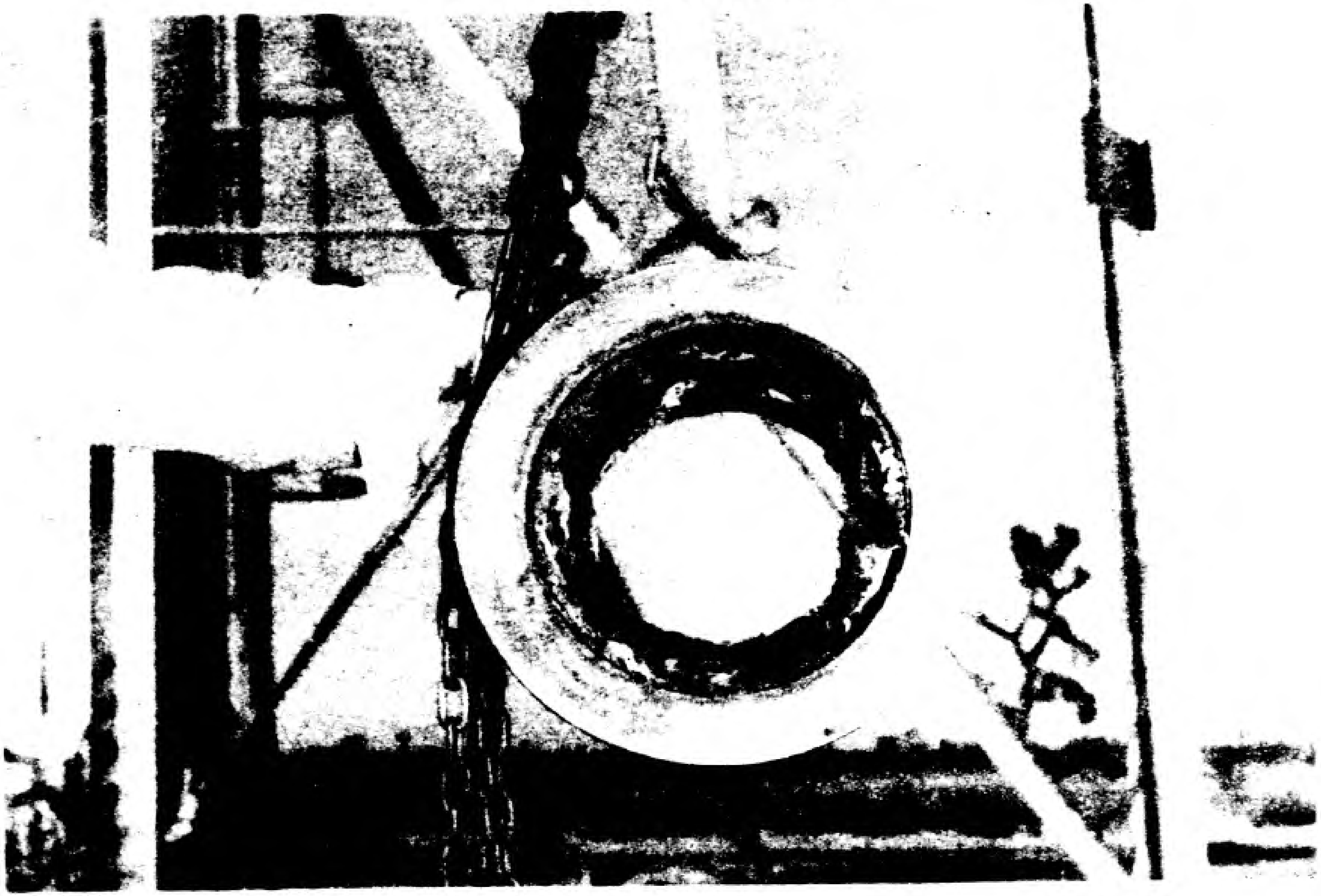

8770-68 AFFTC 22 NOV, UNCL.
T.S. 1-46A-1 POST FIRE RUN # 497

PHOTOGRAPH BY
A1C E. [illegible] WEIN

DC93-104 - FROM EXIT END

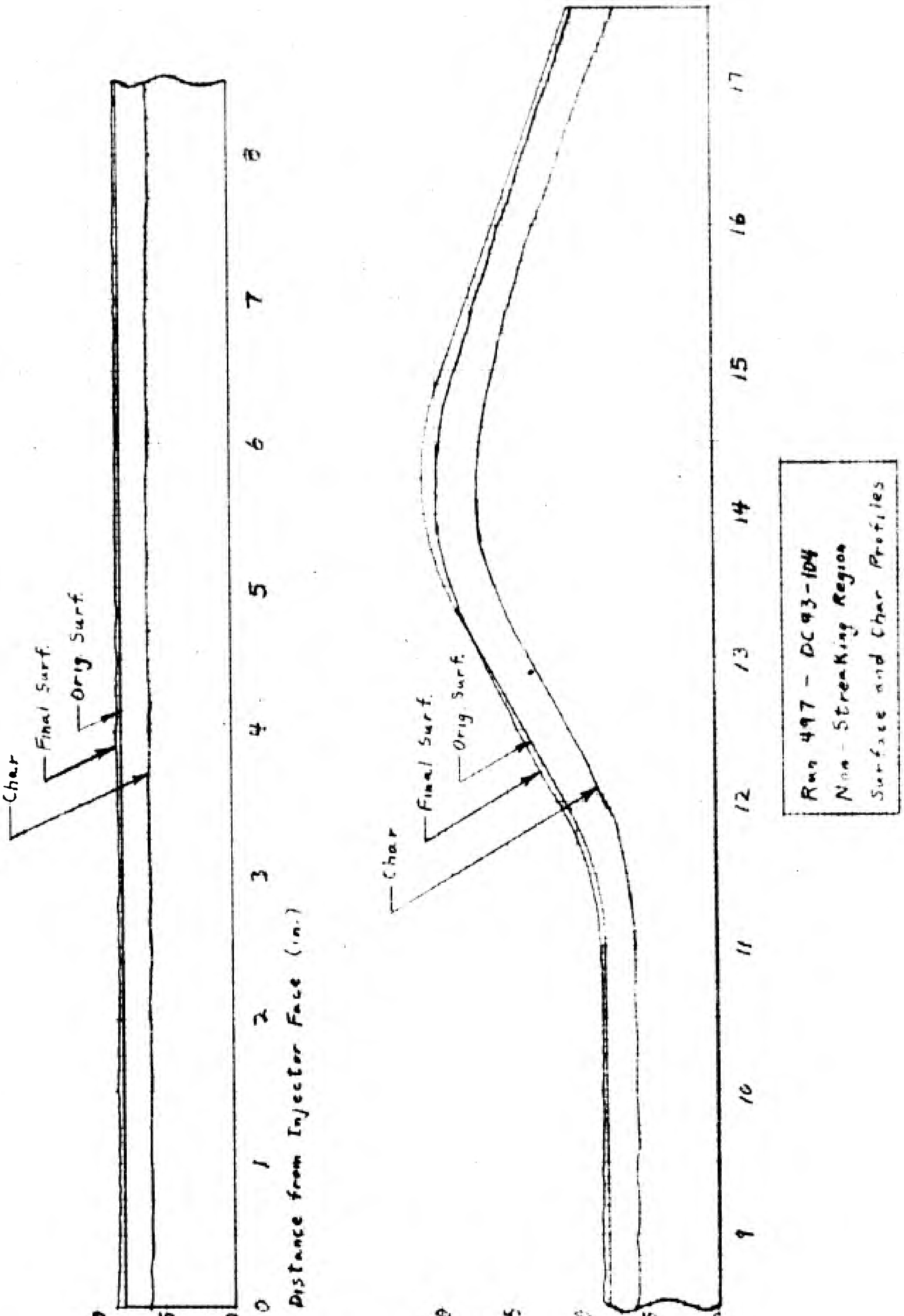
Run 497 - DC 93-104
Non-Streaking Region
Surface and Char Profiles
Distance from Injector Face (in.)
Dist. from Backside (in.)
Char
Final Surf.
Orig. Surf.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
0.0
0.5
1.0
1.5
2.0

Fig. 6

APPENDIX

PROGRAM DESCRIPTION

The objective of this program is to identify and generate design data on low cost ablative materials suitable for use as thrust chamber liners for MCD Booster engines. Candidate materials being tested not only have low raw material costs, but also lend themselves to low cost fabrication techniques such as molding, spraying or troweling. Candidate materials for this program are being identified in preliminary screening programs conducted by Philco Aeronutronics and TRW Systems as well as by a nationwide survey being conducted by the AFSC STLO system.

All testing of ablative materials in this program is being done in a subscale rocket engine using the NTO/UDMH propellant combination of the MCD Booster. The testing is divided into two phases. In the first, or material screening phase, which is scheduled from 1 Nov 68 through 30 Jan 69, approximately 15 candidate materials are being tested at a baseline set of operating conditions to identify those candidates worthy of further study. In the second, or materials characterization phase, which is scheduled from 30 Jan 69 through 1 Apr 69, the better materials from the screening phase are being retested at other operating conditions to characterize their performance as ablatives over the range of heat transfer, chemical and gas dynamic environments anticipated for the family of MCD Booster thrust chambers.

The injector being used for all testing has a pattern consisting of 481 like doublet elements on a 7.2 in. face diameter (see Fig. 1). This injector was selected because the fine pattern should present a uniform environment to the ablative chamber wall with delivered C* efficiency not less than 95%, and the like doublet elements allow variation of the mixture ratio and chamber pressure from one operating point to another, without varying the resultant momentum angle, simply by varying propellant flowrates. The heat transfer environment along the ablative chamber wall at each of the operating points being used in the two phases of testing in the program is being characterized with workhorse calorimetry chamber hardware to aid in interpreting the performance of the ablatives tested.

The configuration of the standard ablative test article in this program is shown in Fig. 2. The candidate ablative material is used in the nozzle as well as the chamber in order to gather erosion and char rate data in all regions in each test. The geometry is the same for all articles in the program, with changes in operating conditions being accomplished by changing propellant flowrates. In order to minimize the extent of chamber pressure decay as the ablative throat erodes during the firing, no cavitating venturis are being used in the flow system. The desired initial flowrates are being achieved by appropriate settings of the propellant tank pressures which then remain constant during the firing. Thus any enlargement of the throat during firing is accompanied by an increase in thrust and flowrates and a slight decay in chamber pressure.

Instrumentation used in each test measures thrust, chamber pressure at the injector face, injector manifold pressures and propellant flow-rates. In addition to the low frequency pressure transducer used to collect chamber pressure data, there is also a high frequency Kistler pressure transducer mounted on the injector face and connected to a high frequency shutdown device to terminate the firing should high frequency combustion instability develop. Thermocouples are embedded in the ablative material to monitor temperature rises as the thermal degradation of the ablative progresses during the firing.

The test of each article consists of a one-second checkout pulse to verify the operating conditions and the structural soundness of the liner, followed by a continuous burn of 60 seconds duration or until excessive thermal degradation of the ablative forces termination of the test, whichever comes first.

The end product of this program will be char and erosion rate data on promising ablative materials under a range of heat transfer, chemical and gas dynamic environments. These data will be used to select materials and size liner thicknesses for the long duration chambers in the AFRPL 250K Injector Scale-Up Programs, which will in turn provide liner design guidance for MCD Booster thrust chamber development efforts which follow.

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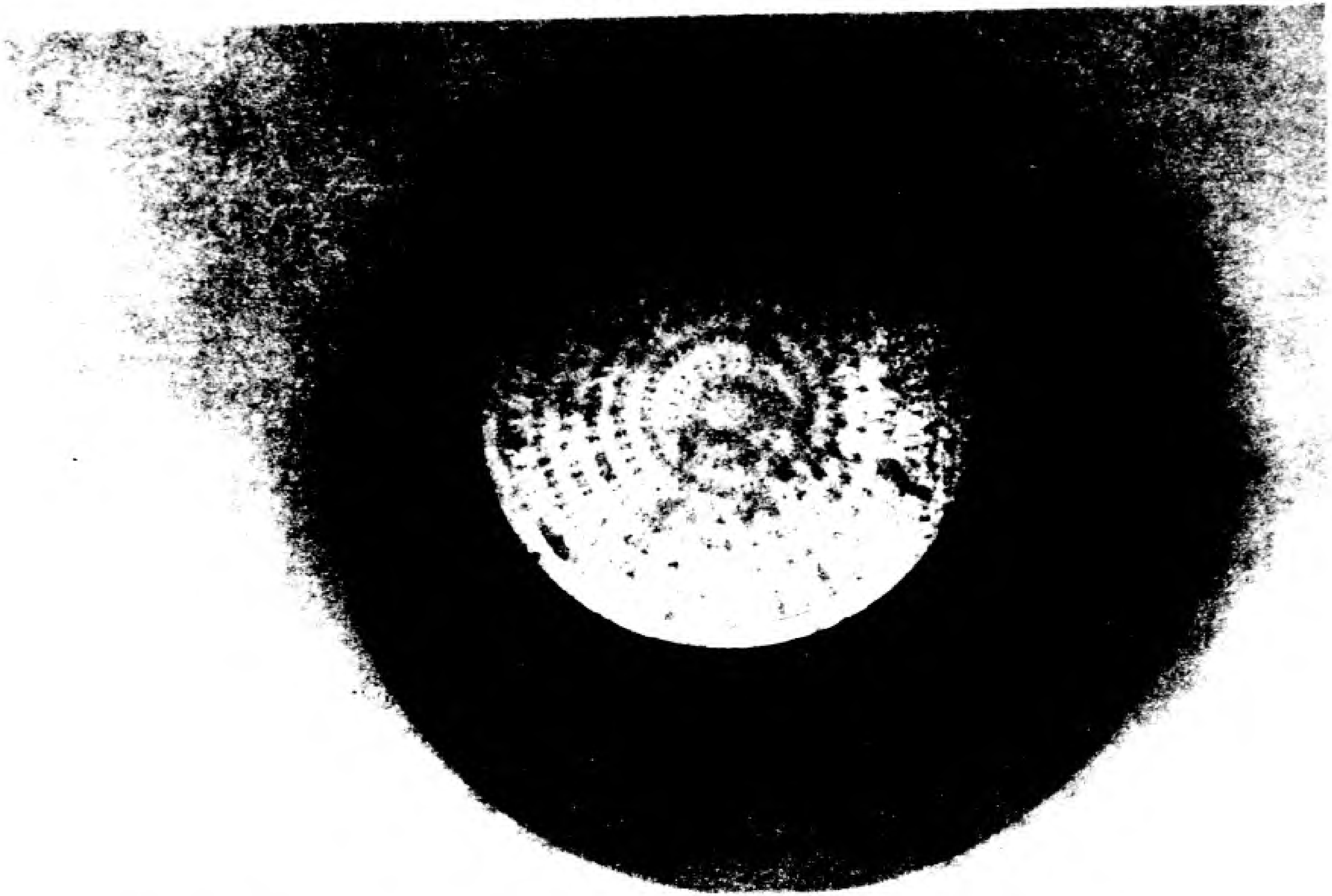
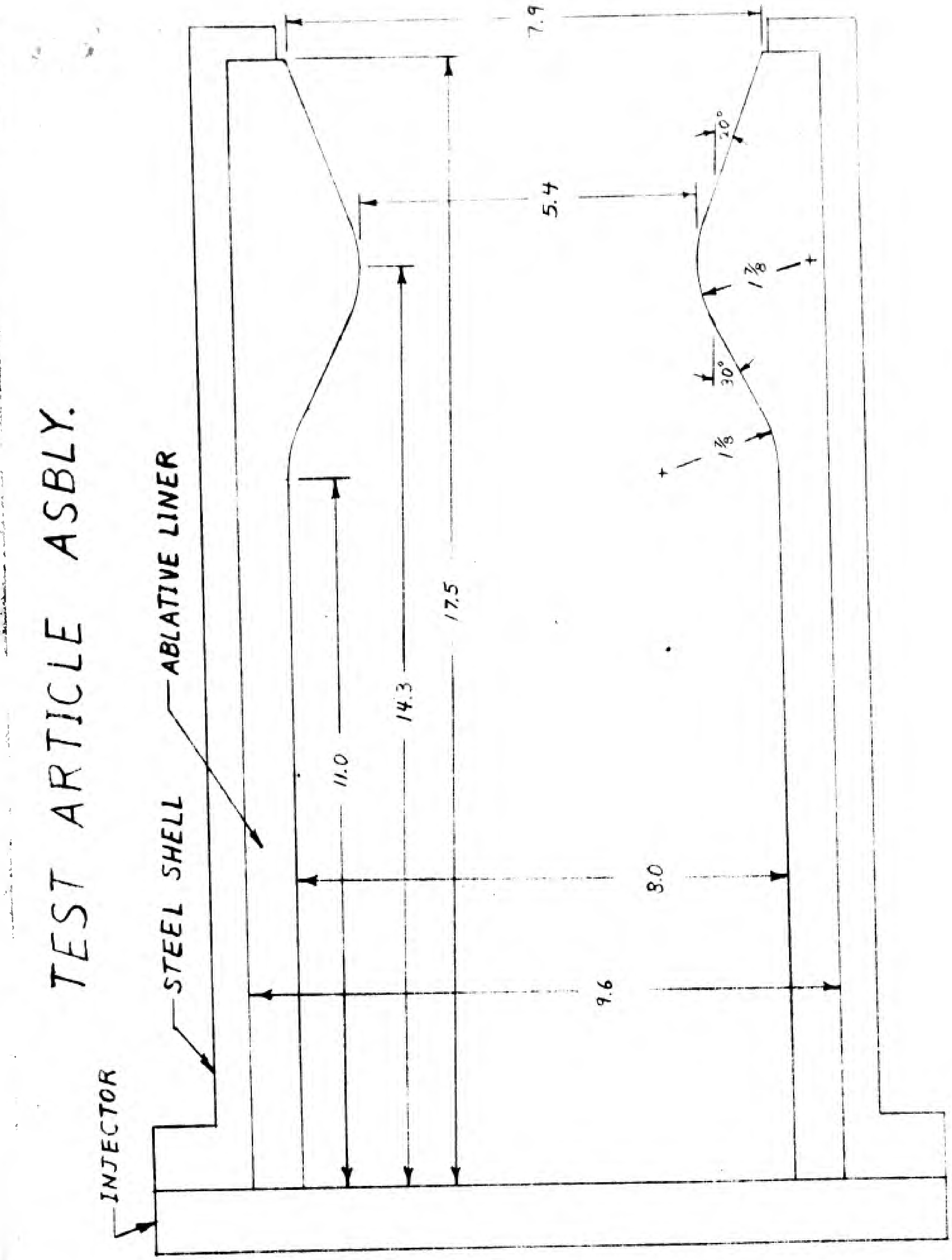


PHOTOGRAPH BY


TEST ARTICLE ASBLY.
ABLATIVE LINER
STEEL SHELL
INJECTOR
7.9
5.4
20°
1⅞
30°
1⅞
17.5
14.3
11.0
8.0
9.6

APP. FIG. 2

Unclassified

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* (Minimum Cost Design)

307 720

DD FORM 1 NOV 65 1473

Unclassified

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