Hydrodynamic Compressive Forging of Commercial pure aluminum with an upset ratio of 19:1 has been achieved in one operation at room temperature. The outside edge of the formed part remained square with the face throughout the forming operation. The maximum upset ratios were obtained with back pressure in the cavity in excess of the work-hardened tensile strength.
HYDRODYNAMIC COMPRESSIVE FORGING

Richard M. Cogan

THE GENERAL ELECTRIC COMPANY

Hydrodynamic Compressive Forging of Commercial pure aluminum with an upset ratio of 19:1 has been achieved in one operation at room temperature. The outside edge of the formed part remained square with the face throughout the forming operation. The maximum upset ratios were obtained with back pressure in the cavity in excess of the work-hardened tensile strength.

The hydrodynamic compressive die with inserts has been designed and built to withstand operating pressures of 600,000 psi at room temperature. The maximum applied load so far has been 540,000 psi, or 90% of the design limit.

Various matrix materials have been evaluated with Cerrobend having the best overall properties for use in this type die system.

The aluminum billets worked by Hydrodynamic Compressive Forging increased in Brinell hardness (500kg load - 10mm ball) from 25 to the 60/65 range.
HYDRODYNAMIC COMPRESSION FORGING

Richard M. Cogan

THE GENERAL ELECTRIC COMPANY
SMALL AIRCRAFT ENGINE DEPARTMENT
Contract No. AF 33(657)-8793
A. S. D. Project 7-890
Interim Technical Engineering Report
9 October 1962 - 9 April 1963

Hydrodynamic Compressive Forging of Commercial pure aluminum with an upset ratio of 19:1 has been achieved in one operation at room temperature. The outside edge of the formed part remained square with the face throughout the forming operation. The maximum upset ratios were obtained with back pressure in the cavity in excess of the work-hardened tensile strength.

MANUFACTURING TECHNOLOGY LABORATORY

Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio
NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any right or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified requesters may obtain copies of this report from ASTIA, Document Service Center, Arlington Hall Station, Arlington 12, Virginia.

Copies of ASD Technical Reports should not be returned to the Aeronautical Systems Division unless return is required by security considerations, contractual obligations, or notice on a specific document.
FOREWORD

This Interim Technical Documentary Progress Report covers the work performed under Contract AF 33 (657) 8793 from 9 July 1962 to 9 October 1962. It is released by the authors for information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This program is being performed by the Small Aircraft Engine Department, Flight Propulsion Division, General Electric Company for the Aeronautical Systems Division Manufacturing Technology Laboratory Project Number 7-890 "Hydrodynamic Compressive Forging." It is being administered under the direction of Mr. G. W. Trickett (ASRCTB) Aeronautical Systems Division Wright-Patterson Air Force Base, Ohio.

Mr. Richard M. Cogan is the Project Manager, others co-operating in the investigation and preparation of the report are F. S. Dorman and A. R. Arsenault. The primary objective of the Air Force Manufacturing Methods Program is to increase producibility, and improve the quality and efficiency of fabrication of aircraft, missiles, and components thereof. This report is being disseminated in order that methods and/or equipment developed may be used throughout industry, thereby reducing cost and giving "MORE AIR FORCE PER DOLLAR."

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional manufacturing methods development required on this or other subjects will be appreciated.
PUBLICATION REVIEW

Approved by Jerome B. Malerich
Manager, Metalworking Research Operation
Thomson Engineering Laboratory

Approved by Robert D. Halverstadt
Manager, Thomson Engineering Laboratory
TABLE of CONTENTS

Abstract-Summary ..................................................... i
Title Page .......................................................... ii
Notices .............................................................. iii
Foreword ............................................................. iv
Table of Contents ..................................................... vi
Introduction ........................................................... 1
Tooling ................................................................. 3
Flow Study ............................................................ 8
Matrix Test ............................................................ 11
Lubrication Test ....................................................... 12
Forging Test ........................................................... 13
References .............................................................. 19
Official Distribution List ............................................. 20
HYDRODYNAMIC COMPRESSIVE FORGING

BY

Richard M. Cogan

INTRODUCTION

This report covers the work done from 9 October 1962 to 9 April 1963 under contract with the Aeronautical Systems Division Wright-Patterson Air Force Base to investigate the basic parameters of the process and its application to a complex shape.

The phenomenon of increased ductility of materials in a hydrostatic environment has been demonstrated by previous investigations. The effect has been studied on simple tension with a superimposed hydrostatic pressure by P. W. Bridgman at Harvard University as early as 1909 which showed an increase in plastic deformation prior to fracture.

The initial feasibility investigations of the phenomenon, as it applied to closed die forging, was conducted in 1958 by the General Electric Company in Cincinnati, Ohio.

Additional work at Small Aircraft Engine Department was done in early 1962 to determine the effect on various materials. Figures 1 and 2 show the deformation achieved on two aluminum alloys.

An explanation of this increased ductility could be the high hydrostatic pressure prevents the formation of voids about discontinuities or internal flaws in the material which may act as points of fracture initiation. Another theory to explain the large amounts of deformation obtained with a superimposed hydrostatic pressure is; fracture actually occurs on a minute continuous basis but the surfaces across the fracture are not removed from each other and the hydrostatic pressure restores the integrity of the material by pressure welding.

The concept of upset forging, or closed die cavity forging at room temperature into a high hydrostatic pressure then should increase the amount of plastic flow of the material prior to fracture.

The approach taken in this contract to apply the hydrostatic pressure is as follows:
A die was manufactured to withstand low cycle loads up to 600,000 psi by prestressing a carbide chamber with shrink fit steel rings. The carbide has an entrance chamber to the die cavity having the shape of the part to be formed. The cavity is first filled with a matrix material that becomes viscous under pressure and able to transmit pressure hydrostatically. As the billet material enters the shaped cavity it displaces the matrix material via exhaust ports provided for this...
The billet material replaces the matrix in the die cavity which exerts a pressure on the deforming billet due to the restricted flow of the matrix. The pressure in the die cavity is dependent on the strength of the matrix material, area of the exhaust ports, the rate it is displaced and the general die design.

**TOOLING**

The Clifton 600 ton press was used with a top cylinder to actuate a .375" diameter x 2.25" long carbide punch (Figure 3) independent of the press movements. This allows the 600 tons to be applied as a means of clamping the dies together. With the maximum die cavity of 1-5/8" in diameter this provides a die cavity pressure capability of 600,000 psi. As a safety measure, the punch movement is remote control with a means of reducing the applied pressure at a given rate.

The die design as reported in the first quarter report (A.S.D. Interim Report 7-890 (I)) was based on prestressing the carbide center to 500,000 psi with shrink rings. With this as a target, interference for each ring was calculated (Figure 4).

After manufacture, the die rings were strain gaged with Budd Metalfilm type CG-121 gages. These were bonded to the die rings as shown in Figure 5 with Eastman 910 cement.

The carbide center was pressed into the buffer ring which required 60 tons using Molykote as a lubricant between the interfaces. Ring "D" was then pressed into "E" with a press load of 150 tons. Ring "C" was then placed into the assembly of "D and E" to check the drop dimension (Figure 6). This was done to check the amount of interference the next ring would be subjected to against the calculated amount.

As the rings were assembled, the various strain gages were checked with a Baldwin SR-4 strain indicator and drop checks were taken at each stage of assembly.

The drop check on sub-assembly "A and B" with "C, D and E" was found to be within the expected tolerance so they were loaded to the maximum press capacity of 600 tons. This set the assembly within .060" of bottom, additional tonage was then applied with no success in final setting of the assembly.
Figure 3. 600 Ton Press and Controls
Figure 4. Interference fit between cylinders to produce compressive prestress on the carbide center ring (A).
A close examination of the die showed the sub-assembly "A and B" was cocked. The die was then disassembled which fractured the carbide center and its buffer ring (Figure 7). Another set of rings was then prepared with a lower amount of prestress, 400,000 psi, using the same procedure for assembly as on the first die. This level of prestress allows the internal pressure to be run at 500,000 to 550,000 psi which is high enough to determine the process capabilities and the majority of its control parameters on the low strength alloys.
Figure 6. Drop check of height to determine interference.

Figure 7. Fractured carbide center from the first die assembly.
FLOW STUDY

To determine the flow characteristics of a material being upset into a shaped cavity, laminated color molding clay was built up into one (1) inch diameter billets. Two lamination directions were checked as shown in Figure 8.

The die used was made of aluminum rings (Figure 9) to allow for changing:

1. Cavity height
2. Feeding the billet from both ends
3. Using tubular shaped billets
4. Changing the type exhaust ports

Observations made due to the above changes were:

1. In all cases the flow pattern remained the same (Figure 10), when the billet was fed from both sides a mirror image was produced (Figure 11).
2. Billets pushed into a matrix of Dux Seal did not fracture.
3. Changing the method of matrix exhaust caused the material to flow toward the ports, the path of least resistance.

It can be concluded from these tests that: orifice design has a controlling effect on shape. For a symmetrical part the split die or ring type orifice should be used, (other shapes could be formed with various size exhaust ports). The billet height to diameter ratio required to produce a shape could be reduced by feeding the stock from both sides.

An advantage of a tubular blank is the amount of work the material would undergo to make a disc could be reduced by flowing the material to the inside (I. D.) diameter at the same time as the outside (O. D.) diameter (Figure 12).

![Figure 8. Typical flow pattern of laminated clay upset into a cavity.](image-url)
Figure 9. Multi-ring aluminum die for use with clay flow studies.

Figure 10. Superimposed flow pattern of the two clay laminates.
Figure 11. Possible method of reducing length/diameter ratio of billet for large volume parts by feeding stock from both sides of die.

Figure 12. Possible method of reducing length/diameter ratio of billet for high upset ratios and reduce the amount of work on the material formed.
MATRIX TESTS

A suitable matrix material for the die system to be used for this contract needs to be viscous to keep the sealing problem under the high pressures to a minimum, but still be able to transmit pressure hydrostatically.

Six materials were tested by extruding them through various orifice sizes and length; lead, cerrobend, Wood's metal, Asarco Lo 117, Asarco Lo 281 and mold wax.

The subject material was introduced into 7/8" diameter chamber as a pre-form cylinder. A press driven punch caused extrusion of the material out radial holes or a split at the bottom of the chamber.

The cubic inches of material extruded was determined by timing the extrusion of a known quantity of material. This is plotted vs the unit pressure required in Figure 13.

There are no curves for Asarco Lo 281 or mold wax since materials could not be extruded within the pressure limitations of the setup.

The other materials, with the exception of Wood's metal, exhibit a linear relation between applied force and extrusion rate. Wood's metal extruded in steps. Apparently the liquified metal recrystalized during extrusion and required additional pressure build-up to liquify again.

![Figure 13. Plot of pressure required to extrude a given volume of matrix material through various orifice configurations.](image-url)
LUBRICATION TESTS

Since the unit loading involved in upsetting materials at room temperature are high, tests were conducted to determine how the most promising matrix materials compared with various lubricants.

The tests involved the upsetting of cylindrically shaped specimens (0.750" diameter x 1.00" high) of A.I.S.I. 4340 to exactly half their height.

The ends of the specimens were machined, polished and coated with the lubricant to be compared. Lubricants and matrix checked were: lead, mineral oil, glass, teflon, colloidal graphite, and cerrobend. Lubricating qualities were measured as a function of end restraint on the final diameter of the cylinder ends. Figure 14 shows two of the specimens tested, the barreled part had no lubricant, the other cerrobend.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Lubricant</th>
<th>Average End Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>None</td>
<td>.9026</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>.9051</td>
</tr>
<tr>
<td>2a</td>
<td>Lead</td>
<td>.9782</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>.9833</td>
</tr>
<tr>
<td>3a</td>
<td>Cerro</td>
<td>.9974</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>1.0020</td>
</tr>
<tr>
<td>c</td>
<td></td>
<td>1.0015</td>
</tr>
<tr>
<td>d</td>
<td></td>
<td>1.0010</td>
</tr>
<tr>
<td>4a</td>
<td>Mineral Oil</td>
<td>.9458</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>.9473</td>
</tr>
<tr>
<td>5a</td>
<td>Glass</td>
<td>.9458</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>.9473</td>
</tr>
<tr>
<td>6a</td>
<td>Teflon</td>
<td>.9949</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>.9910</td>
</tr>
<tr>
<td>7a</td>
<td>Colloidal Graphite</td>
<td>1.0010</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>.9906</td>
</tr>
</tbody>
</table>

Table I
Figure 14. Billet on the left was upset with cerrobend as a lubricant, the billet on the right had no lubrication.

FORGING TESTS

The main purpose of the initial forging trials was to evaluate the die system and forging technique. This was done by upsetting aluminum into the die cavity to the maximum ratio of 19:1 (based on billet and cavity area). Some steel was also tried to test the high pressure capability of the die, one test took the punch to failure or 540,000 psi 90% of design operational requirement of the tooling.

For the die tryout billets only the cavity pressure was changed for a given material, all parts were formed with rate as a constant.

The die insert used, 1-5/8" diameter provided a pocket .100" thick.

The aluminum billets were machined from 1100 bar stock annealed to 32 BHN (500 - kg load, 10-mim. ball). The steel billets were machined from vacuum melted A.I.S.I. 4340 after a 72-hour spheroidizing cycle.

Upset ratios were controlled by the length of billet stock pushed into the die, the maximum ratio being 19:1. Forming rate with the equipment can be varied from 5 inches per minute down to .02 inches per minute or less.

Based on previous tests and the information gathered for this report, cerrobend was used for the matrix material because of its lubrication qualities and its properties under high pressure.

In conducting the tests, the pressure in the cavity was set by varying the clamping pressure of the dies. For any given clamp pressure a definite cavity pressure had to be built up to cause separation of the dies and allow the matrix to be exhausted. This occurred when the cavity pressure times its area just exceeded the clamping force. The cavity pressure is also monitored by a pressure probe.
(Figure 15). A Budd Metalfilm gage mounted on a carbide pin and read with a Baldwin SR-4 strain indicator gives the cavity pressure at the maximum diameter. Under setup conditions a pressure transducer in the punch ram hydraulics provides the cavity pressure at the center or the total force necessary to upset the billet into the matrix-filled cavity plus overcome the friction of the complete system.

To establish a basis for determining the effect of back pressure on the aluminum's ability to be upset into such a die system, a number of billets were processed with no matrix. The maximum upset ratio achieved without fracture was 4:1 (Figure 16).

A number of aluminum billets were then upset with different levels of back pressure in the cavity (Figure 17). As a general observation, the cracks became less severe as the pressure was increased. At 20,000 psi to 30,000 psi, depending on the upset ratio, there is no evidence of cracks. It was also noted the discontinuities in the top surface of the formed part indicating a differential stress existed across the thickness during deformation. This along with the edge appearance shows the matrix material is not being exhausted from the top surface of the cavity.

It would be desirable to have the billet upset in such a manner that it would appear to extrude in a radial direction. This could occur by a incremental expansion of the part diameters. As the part is formed the outer diameters of the part are expanded due to the introduction of new stock at the center. As the diameter increases the part thickness tends to decrease, to prevent this thinning a hydrostatic pressure sufficient to upset the edge re-establishes the part thickness.

In order for this to happen, the billet must seal the cavity at the start of the deformation and maintain it throughout the operation.

Observation of parts just started to deform in the cavity, are mushroomed such that the cavity pressure act on the top surface as well as the diameter. To create a seal at the onset was first accomplished by machining and later by an upset operation. This was done by using the closing action of the dies to upset an extended length of billet prior to the actual pressure forming.

The same series of tests were run as before, the only difference being the preshaped seal (Figure 18). Again the cracking can be noted at the low back pressures and decreasing in magnitude as the pressure is increased until no cracks are apparent. The top surface on these parts do not show any discontinuities on the surface and the edge is square and normal to the part face.
<table>
<thead>
<tr>
<th>Cavity P.S.I.</th>
<th>Upset Ratio</th>
<th>Matrix</th>
<th>Clamp Press Tons</th>
<th>Ram P.S.I.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.0</td>
<td>None</td>
<td>50</td>
<td>16,200</td>
<td>No Cracks</td>
</tr>
<tr>
<td>0</td>
<td>3.8</td>
<td>None</td>
<td>50</td>
<td>16,200</td>
<td>No Cracks</td>
</tr>
<tr>
<td>0</td>
<td>4.0</td>
<td>None</td>
<td>50</td>
<td>16,200</td>
<td>Surface Cracks</td>
</tr>
<tr>
<td>0</td>
<td>4.7</td>
<td>None</td>
<td>50</td>
<td>16,200</td>
<td>Split Open</td>
</tr>
<tr>
<td>0</td>
<td>6.0</td>
<td>None</td>
<td>50</td>
<td>16,200</td>
<td>Split Open</td>
</tr>
<tr>
<td>0</td>
<td>7.0</td>
<td>None</td>
<td>50</td>
<td>16,200</td>
<td>Split Open</td>
</tr>
<tr>
<td>7.0</td>
<td>Lead</td>
<td>25</td>
<td></td>
<td></td>
<td>Surface Cracks</td>
</tr>
<tr>
<td>7.0</td>
<td>Lead</td>
<td>50</td>
<td></td>
<td></td>
<td>No Cracks</td>
</tr>
<tr>
<td>11.0</td>
<td>Lead</td>
<td>25</td>
<td></td>
<td>80,900</td>
<td>No Cracks</td>
</tr>
<tr>
<td>12.0</td>
<td>Lead</td>
<td>50</td>
<td></td>
<td></td>
<td>No Cracks</td>
</tr>
<tr>
<td>15.0</td>
<td>Lead</td>
<td>50</td>
<td></td>
<td>81,000</td>
<td>No Cracks</td>
</tr>
<tr>
<td>10,000</td>
<td>15.0</td>
<td>Cerro</td>
<td>25</td>
<td>26,700</td>
<td>Cracked</td>
</tr>
<tr>
<td>10,000</td>
<td>15.0</td>
<td>Cerro</td>
<td>25</td>
<td>26,800</td>
<td>Cracked - Sealed*</td>
</tr>
<tr>
<td>16,000</td>
<td>15.0</td>
<td>Cerro</td>
<td>30</td>
<td>32,400</td>
<td>Cracked</td>
</tr>
<tr>
<td>16,000</td>
<td>16.0</td>
<td>Cerro</td>
<td>25</td>
<td>32,200</td>
<td>Cracked - Sealed*</td>
</tr>
<tr>
<td>21,000</td>
<td>15.0</td>
<td>Cerro</td>
<td>45</td>
<td>38,000</td>
<td>No Cracks - Matrix Trapped</td>
</tr>
<tr>
<td>20,400</td>
<td>16.0</td>
<td>Cerro</td>
<td>40</td>
<td>36,400</td>
<td>No Cracks - Sealed*</td>
</tr>
<tr>
<td>25,500</td>
<td>19.0</td>
<td>Cerro</td>
<td>50</td>
<td>41,700</td>
<td>No Cracks, Fold</td>
</tr>
<tr>
<td>32,000</td>
<td>16.0</td>
<td>Cerro</td>
<td>50</td>
<td>48,600</td>
<td>No Cracks</td>
</tr>
<tr>
<td>32,000</td>
<td>15.0</td>
<td>Cerro</td>
<td>35</td>
<td>48,600</td>
<td>No Cracks - Sealed*</td>
</tr>
<tr>
<td>40,000</td>
<td>14.0</td>
<td>Cerro</td>
<td>50</td>
<td>56,700</td>
<td>No Cracks - Sealed*</td>
</tr>
<tr>
<td>100,000</td>
<td>13.0</td>
<td>Dux Seal</td>
<td>100</td>
<td>129,000</td>
<td>No Cracks - No Flow</td>
</tr>
<tr>
<td>100,000</td>
<td>15.0</td>
<td>Dux Seal</td>
<td>100</td>
<td>129,000</td>
<td>No Cracks - Uniform</td>
</tr>
<tr>
<td>100,000</td>
<td>16.0</td>
<td>Dux Seal</td>
<td>100</td>
<td>129,000</td>
<td>No Cracks - No Flow</td>
</tr>
</tbody>
</table>

* Blank used was preformed as shown in Figure 18.

Table II.
Figure 15. Die setup showing method of measuring cavity pressure with strain gaged carbide probe.

Figure 16. 1100°F aluminum upset into the die cavity with no back pressure. The maximum upset ratio without fracture attainable was 4:1.
Figure 17. 1100°F aluminum billets upset into a die cavity of cerrobend starting with a straight billet.

Figure 18. 1100°F aluminum billets upset into a die cavity of cerrobend starting with a preshaped billet to seal the cavity.
To develop as much information out of the test as possible, an estimate of tensile strength of the material was made based on hardness (Figure 19). From this preliminary data it would appear the hydrostatic pressure has to be in excess of the tensile strength of the material being worked to allow increased deformation.

Figure 19.

(1) ANNEALED

(2) HALF HARD (H-14)

(3) FULL HARD (H-18)

(4) ANNEALED + H.C. FORGING
REFERENCES


Fracturing of Metals — American Society for Metals.

Cold Working of Metals — American Society for Metals.


DISTRIBUTION LIST
Contract AF 33(657)-8793

ASD (ASRCTB)
Wright-Patterson AFB, Ohio (6)

ASD (ASRCEE, Mr. J. Teres)
Wright-Patterson AFB, Ohio

ASD (ASRCMP-4)
Wright-Patterson AFB, Ohio

ASD (ASRCEE-1)
Wright-Patterson AFB, Ohio

ASD (ASRMSD-21)
Wright-Patterson AFB, Ohio

ASD (ASRCMP-1, Mr. K. Kojols)
Wright-Patterson AFB, Ohio

ASD (ASRC, Mr. A. M. Lovelace)
Wright-Patterson AFB, Ohio

ASD (ASRCEM-1A, Mrs. N. Ragen)
Wright-Patterson AFB, Ohio (2)

Bureau of Naval Weapons
Department of the Navy
ATTN: Mr. N. E. Promisel
Research and Engineering Division
Washington 25, D. C.

Climax Bolybdenum Company
1270 Avenue of the Americas
New York 20, New York

Curtiss-Wright Corporation
Wright Aeronautical Division
ATTN: Manager, Metallurgy
Wood Ridge, New Jersey

Douglas Aircraft Company, Inc.
Materials Division Group
El Segundo, California

The Martin Company
ATTN: Chief Librarian
Engineering Library
Baltimore 3, Maryland

Battelle Memorial Institute
Metalworking Research Division
505 King Avenue
Columbus 1, Ohio
ATTN: Mr. A. Sabroff

FTD (TD-E2b)
Wright-Patterson AFB, Ohio

Aerojet-General Corporation
ATTN: Mr. Kenneth F. Mundt
P. O. Box 296
Azusa, California

Armed Services Technical Information Agency
ATTN: Document Service Center (TISIA-2)
Arlington Hall Station
Arlington 12, Virginia

Bell Aerospace Corporation
ATTN: Mr. H. D. Elliott
Manager, Production Engineering
P. O. Box 1
Fort Worth 1, Texas

The Boeing Company
ATTN: Mr. Boyd K. Bucey
Assistant to Vice President - Mfg.
P. O. Box 3707
Seattle 24, Washington

The Boeing Company
Wichita Division
ATTN: Manufacturing Manager
Wichita, Kansas

Curtiss-Wright Company
Curtiss Division
ATTN: Chief Engineer, Materials
U. S. Route No. 46
Caldwell, New Jersey

Curtiss-Wright Corporation
Metals Processing Division
ATTN: Chief Engineer
760 Northland Avenue
P. O. Box 13
Buffalo 15, New York

Defense Metals Information Center
Battelle Memorial Institute
505 King Avenue
Columbus 1, Ohio

General Motors Institute
ATTN: Mr. Norman F. Snyder
Head of Process Design
Flint 2, Michigan

General Dynamics Corporation/Convair
ATTN: Director, Mfg. Development
Mail Zone 2-22
San Diego, California
General Dynamics Corporation/Pomona
Attn: Chief of Mfg. Engineering
P. O. Box 1011
Pomona, California

General Electric Company
Attn: Manager, Engineering
21800 Tungsten Road
Cleveland 17, Ohio

Ladish Company
Attn: Mr. Robert Dakin
Cudahy, Wisconsin

Lockheed Aircraft Corporation
Attn: Manufacturing Manager
Marietta, Georgia

Lockheed Aircraft Corporation
Attn: Director of Manufacturing
P. O. Box 511
Burbank, California

Ling-Temco-Vought, Inc.
P. O. Box 5907
Dallas, Texas

Universal-Cyclops Steel Corporation
Bridgeville, Pennsylvania

Armour Research Foundation
Technology Center
10 West 35th Street
Chicago 16, Illinois

The Marquardt Corporation
Attn: Director of Manufacturing
16555 Staticoy Street
Van Nuys, California

Aerojet-General Corporation
Attn: Mr. George Hall
Downey, California

University of California
Los Alamos Scientific Laboratory
Attn: Dr. John Hockett
P. O. Box 1663
Los Alamos, New Mexico

McDonnell Aircraft Corporation
Attn: Mr. Howard Siegel
P. O. Box 516, Department 272
Lambert-St. Louis Airport
St. Louis, Missouri

North American Aviation
Attn: Mr. Jim Huffman
Materials Engineer
International Airport
Los Angeles 45, California

Northrop Corporation
Attn: Mr. R. R. Nolan
1001 East Broadway
Hawthorne, California

Rohr Aircraft Corporation
Attn: Mr. Ed Pederson
Manufacturing Manager
P. O. Box 878
Chula Vista, California

Ryan Aeronautical Company
Attn: Mr. J. A. Smithson
P. O. Box 311
San Diego 12, California

Westinghouse Electric Corporation
Materials Manufacturing Division
Blairsville, Pennsylvania

Harvey Engineering Laboratories
19200 South Western Avenue
Torrance, California

Aluminum Company of America
Attn: Mr. Fredrick Pyne
1200 Ring Building
Washington, D. C.

Lear Seigler
Astro Structures Division
Attn: Mr. Walter Kruei
1700 East Grand
El Segundo, California
<table>
<thead>
<tr>
<th>AD</th>
<th>UNCLASSIFIED</th>
<th>AD</th>
<th>UNCLASSIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYDRODYNAMIC COMPRESSIVE FORGING, by R. M. Cogan, April 1963</td>
<td>2. Forging</td>
<td>HYDRODYNAMIC COMPRESSIVE FORGING, by R. M. Cogan, April 1963</td>
<td>2. Forging</td>
</tr>
<tr>
<td></td>
<td>3. Die Design</td>
<td></td>
<td>3. Die Design</td>
</tr>
<tr>
<td>27 pages include, illustrations and tables. (Project 7-890) (ASD TR 7-890 (I) ) (Contract AF 33 (657)-8793</td>
<td></td>
<td>27 pages include, illustrations and tables. (Project 7-890) (ASD TR 7-890 (I) ) (Contract AF 33 (657)-8793</td>
<td></td>
</tr>
<tr>
<td>Unclassified Report</td>
<td></td>
<td>Unclassified Report</td>
<td></td>
</tr>
<tr>
<td>Hydrostatic environment increases</td>
<td></td>
<td>Hydrostatic environment increases</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AD</th>
<th>UNCLASSIFIED</th>
<th>AD</th>
<th>UNCLASSIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYDRODYNAMIC COMPRESSIVE FORGING, by R. M. Cogan, April 1963</td>
<td>2. Forging</td>
<td>HYDRODYNAMIC COMPRESSIVE FORGING, by R. M. Cogan, April 1963</td>
<td>2. Forging</td>
</tr>
<tr>
<td></td>
<td>3. Die Design</td>
<td></td>
<td>3. Die Design</td>
</tr>
<tr>
<td>27 pages include, illustrations and tables. (Project 7-890) (ASD TR 7-890 (I) ) (Contract AF 33 (657)-8793</td>
<td></td>
<td>27 pages include, illustrations and tables. (Project 7-890) (ASD TR 7-890 (I) ) (Contract AF 33 (657)-8793</td>
<td></td>
</tr>
<tr>
<td>Unclassified Report</td>
<td></td>
<td>Unclassified Report</td>
<td></td>
</tr>
<tr>
<td>Hydrostatic environment increases</td>
<td></td>
<td>Hydrostatic environment increases</td>
<td></td>
</tr>
<tr>
<td>the effective ductility of materials. Dies can be built to retain 750,000 psi by use of prestressed cylinders. Non-( \text{c} )</td>
<td>V. ASD Project 7-890</td>
<td>the effective ductility of materials. Dies can be built to retain 750,000 psi by use of prestressed cylinders. Non-( \text{c} )</td>
<td>V. ASD Project 7-890</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1100°F Aluminum upset to a 20:1 ratio at room temperature in a pressure environment of 20,000 to 30,000 psi did not fracture.</td>
<td></td>
<td>1100°F Aluminum upset to a 20:1 ratio at room temperature in a pressure environment of 20,000 to 30,000 psi did not fracture.</td>
<td></td>
</tr>
</tbody>
</table>