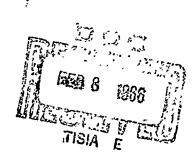
EVALUATION OF LARGE
TITANIUM ALLOY FORGINGS
SECOND QUARTERLY REPORT

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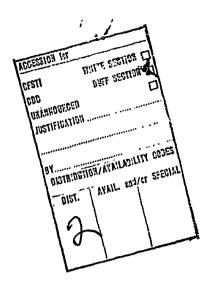
EPORTING PERIOD 1 'ULY 1965 THROUGH 30 SEPTEMBER 1965

CONTRACT NUMBER AF33(615)-2690

Air Force Materials Laboratory Research and Technology Division Air Force Systems Command United States Air Force



LOCKHEED-CALIFORNIA COMPANY - BURBANK



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SECOND QUARTERLY PROGRESS REPORT. no.2, 1 Jul - 30 Sep 65,

EVALUATION OF LARGE TITANIUM

ALLOY FORGINGS.

(5) AF 33(615)-2690

BPSN Number 65-(687381-738106-62405514)

1) 30 Sep 65, 13) 31 p. 14) LR-19190 Rod F. Simenz.

Approved by

H. B. Sipple () ()
R&D Engineer, Materials
and Processes

Ohiei Administrative Engineer

LOCKHEED-CALIFORNIA COMPANY, BURBANK, CALIFORNIA

#### **FOREWORD**

This report was prepared by the Lockheed-California Company, Burbank, California, under Contract No. AF 33(615)-2690. The program is administered under the direction of the Air Force Materials Laboratory, Research and Technology Division by Lt. D. C. LaGrone.

This work is conducted under the direction of Mr. H. B. Sipple, R & D Engineer, Materials and Processes, Mr. R. F. Simenz is Project Leader, assisted by Mr. W. L. Macoritto. Technical consultation is being profided by Mr. V. E. Dress and Mr. G. G. Wald, Research Specialist and Design Specialist, respectively.

Static testing is under the direction of Mr. R. L. Adamson, Materials Evaluation, assisted by Mr. S. L. Pendleberry. Fatigue testing is under the direction of Mr. R. H. Wells, Structures Test, assisted by Mr. C. S. Oswell.

Wyman-Gordon Company personnel who are actively participating in the program include:

Mr. J. J. Zecco, Jr., Research Project Engineer Mr. R. E. Sparks, Senior Research Metallurgist

The period covered by this report is 1 July 1965 through 30 September 1965.

### ABSTRACT

The purpose of this program is to evaluate large titanium forgings for reliable use in advanced weapon systems. Four forgings of Ti-6Al-4V and four forgings of IMI679 will be used in the evaluation. Two forgings of each alloy will be machined into test coupons for material property tests, one forging will be full scale fatigue tested and the other forging will be full scale static tested.

This report summarizes the work accomplished during the second quarterly period. All forgings have been produced and heat treated.

Machining of two forgings each of Ti-6Al-4V and IMI679 to a modified F-10% aft fuselage ring fitting is nearly completed.

Preparation of material property test coupons removed from forgings of IMI679 was started and some testing cor sted. Preliminary smooth tension, notched tension, compression and tatigue data on IMI679 are presented.

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### INTROLUCTION

Substantially increased usage of titanium alloy forgings is anticipated in future weapon systems because of the structural advantages offered by these materials. The purpose of this program is to provide data which will form a basis for the reliable use of titanium alloy forgings. Two titanium alloys will be evaluated in this program, Ti-6Al-4V and IMI679.

A total of four forgings will be produced in each alloy. Two forgings of each alloy will be machined into test coupons for material property tests, one forging will be full scale static tested and the other will be full scale fatigue tested. Mechanical property data to be obtained will include tensile, compression, bearing, shear, fracture toughness, and axial fatigue at temperatures of -110° to 550°F.

In a previous Air Force program AF 33(615)-1635, a similar evaluation was conducted on two other titanium alloy forgings Ti-6Al-6V-2Sn and Ti-13V-11Cr-3Al. Data obtained in the AF 33(615)-1635 program will be compared with data obtained in this program to illustrate the relative merits of four of the leading candidate titanium forging alloys.

### PROCEDURE AND RESULTS

### RAW MATERIAL DATA

Billet stock chemical analysis and test properties reported by TMCA are given in the Appendix.

#### FORGINGS

Four forgings of Ti-6Al-4V and four forgings of IMI679 have been received from Wyman-Gordon. Details on the forging operations used to produce these parts are presented in the Appendix.

### HEAT TREATMENT

The IMI679 forgings were heat treated in full section size at Wyman-Gordon. The heat treatment recommended by the supplier for this alloy was used. This treatment consisted of heating at 1650°F for one hour, followed by fan cooling and then aging at 930°F for twenty-four hours.

The Ti-6Al-4V forgings were rough machined to a maximum thickness of 2-1/2 inches prior to heat treatment. The standard solution treatment and age was used for this alloy (i.e., 1750°F - 1 hour, water quench; age 4 hours at 1000°F.)

# MATERIAL PROPERTY TESTS

Tensile tests on Ti-6Al-4V and IMI679 were conducted in all three grain directions on the billet stock from which the forgings were produced. The heat treatment procedures used on the billet stock were the same as those used on the forgings. The data obtained are given in the Appendix.

Two forgings of each allow are being machined into test coupons for material property tests. The tests to be conducted include smooth and notched tension, compression, fatigue, shear, bearing and fracture

toughness. The location and orientation of test coupons in each forging are presented in Figures 1 through 6.

Preliminary data have been obtained on IMI679. Smooth tension, notched tension, compression and fatigue data are presented in Tables 1 through 6. Additional tensile data were obtained by Wyman-Gordon on forgings of Ti-6Al-4V and IMI-679. These tests were conducted on test material forged integral with the parts. Specimen location for these tests are shown in Figure 7. Test data are given in Tables 7 and 8.

### FULL SCALE TESTING

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Full scale static and fatigue testing will be conducted in the same test set-up as that used in Contract AF33(615)-1635. Final machining of two forgings of each alloy for full scale testing is nearing completion.

# FUTURE WORK

During the next quarterly period, 1 October through 31 December, it is anticipated that the following work will be accomplished:

- 1. Machining of all parts and test coupons will be completed.
- 2. Material property testing will continue and additional metallographic work will be accomplished.
- 3. Test fixtures will be set up and full scale static testing will be initiated.

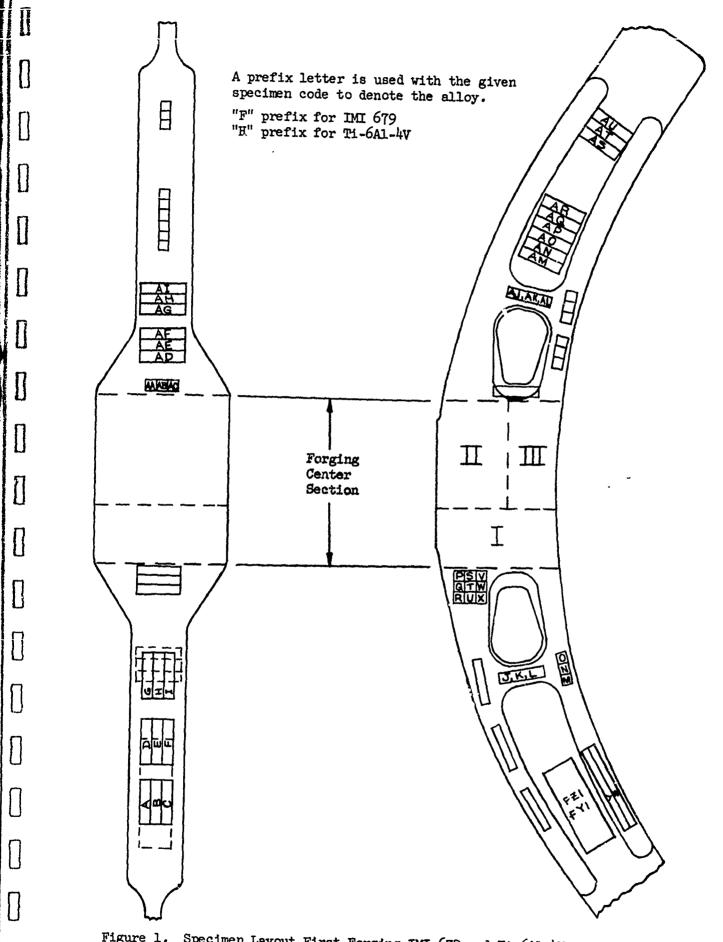


Figure 1. Specimen Layout First Forging IMI 679 and Ti-6Al-4V

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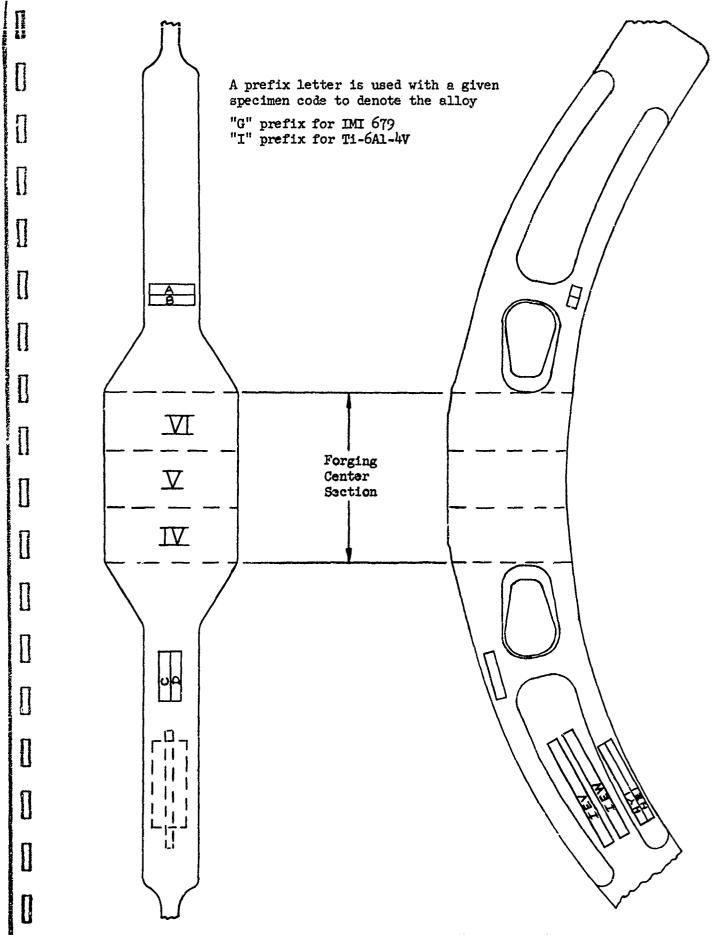
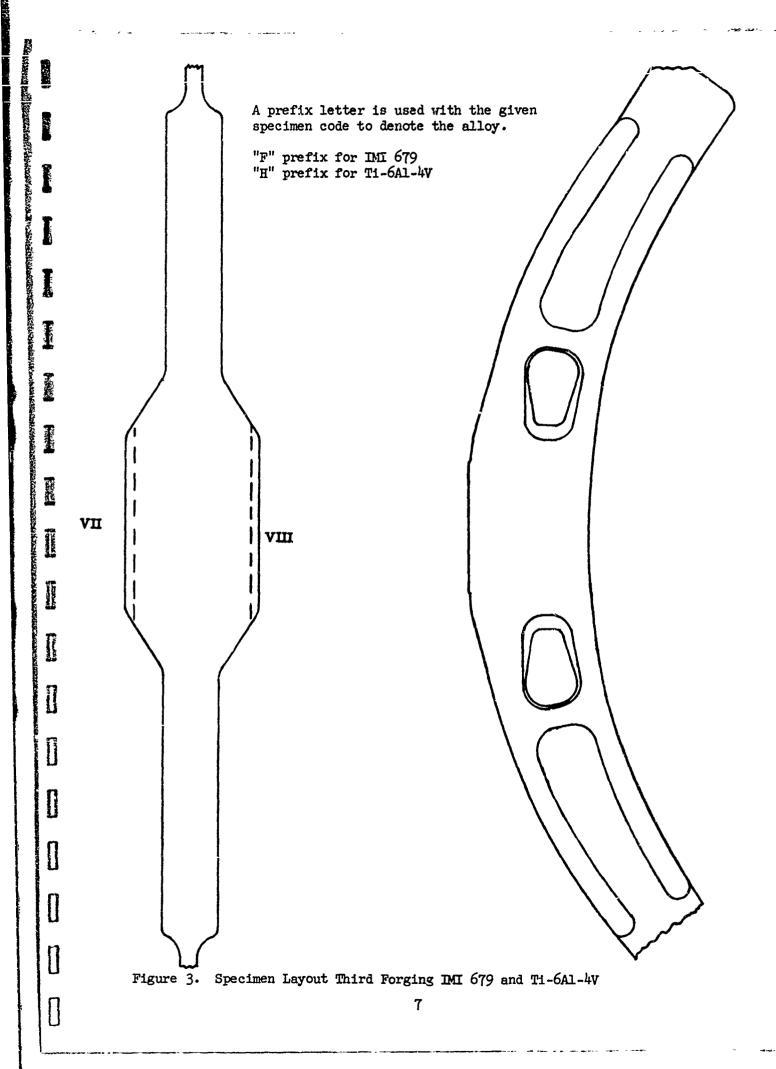
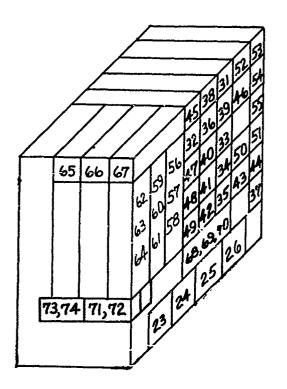


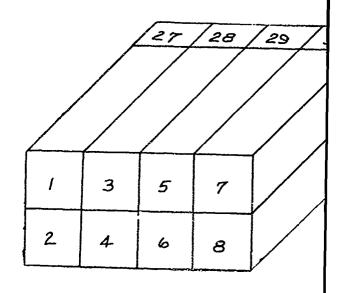
Figure 2. Specimen Layout Second Forging IMI 679 and Ti-6Al-4V





SUB-BLOCK I

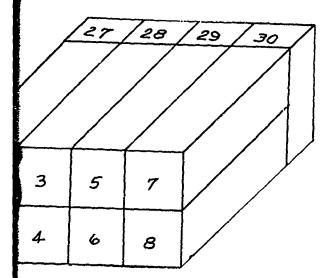
| Туре                   | Specimen Number |  |  |
|------------------------|-----------------|--|--|
| 23 through 26          | Compression     |  |  |
| 39, 43, 46, 50, 52, 53 | Notched Tensile |  |  |
| 71 through 74          | Shear           |  |  |
| All Others             | Tensile         |  |  |



SUB-BLOCK II

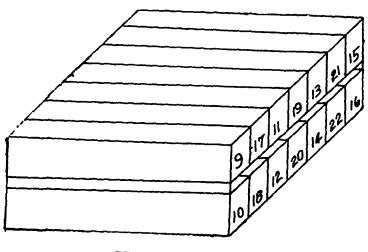
| Specimen Number | Туре                  |
|-----------------|-----------------------|
| 1 through 8     | Fracture<br>Toughness |
| 27 through 30   | Compressio            |

Figure 4. Specimen Layout for IMI 679 and Ti-6Al-4V First Forging Center Section



SUB-BLOCK II

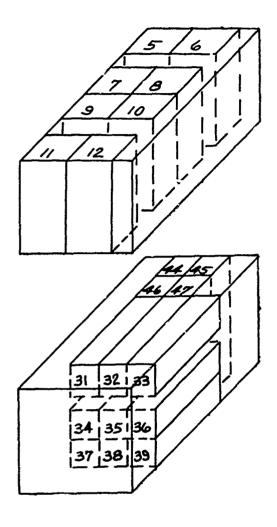
| nen Number | Туре                  |  |  |  |
|------------|-----------------------|--|--|--|
| ough 8     | Fracture<br>Toughness |  |  |  |
| rough 30   | Compression           |  |  |  |



SUB-BLOCK III

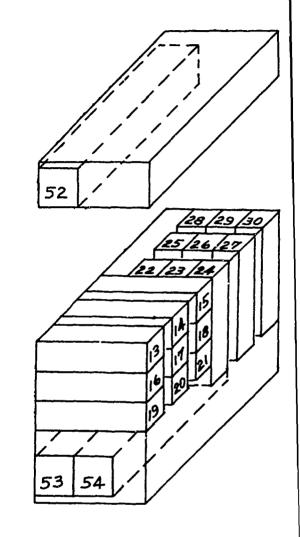
| Specimen Number | Туре    |
|-----------------|---------|
| 9 through 22    | Fatigue |
|                 |         |

Center Section



SUB-BLOCK IV

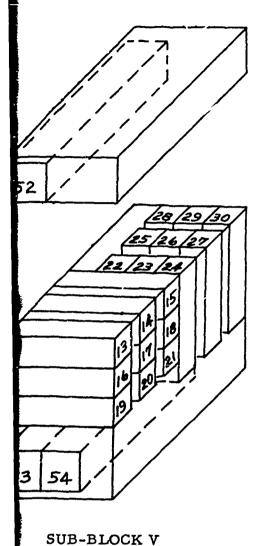
| Specimen Number | Туре          |  |  |
|-----------------|---------------|--|--|
| 5 through 12    | Compression   |  |  |
| 44, 45, 46, 47  | Notch Tensile |  |  |
| All Others      | Tensile       |  |  |



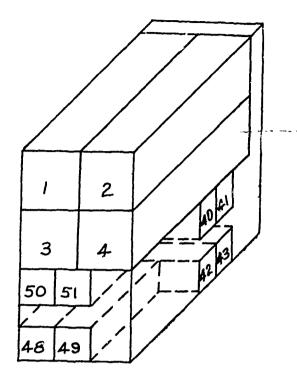
SUB-BLOCK V

| Specimen Number | Туре    |  |
|-----------------|---------|--|
| 52, 53, 54      | Fatigue |  |
| All Others      | Tensile |  |
|                 |         |  |

Figure 5. Specimen Layout For IMI 679 and Ti-6A1-4V Second Forging Center Section



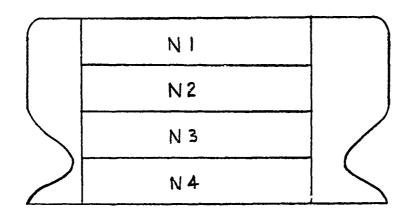
| n Number | Туре    |
|----------|---------|
| 3, 54    | Fatigue |
| thers    | Tensile |
|          |         |

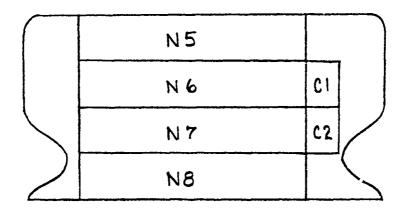


SUB-BLOCK VI

| Specimen Number | Туре                            |  |  |
|-----------------|---------------------------------|--|--|
| 1, 2, 3, 4      | Fracture<br>Toughness           |  |  |
| All Others      | No <b>tc</b> h Ten <b>sil</b> e |  |  |

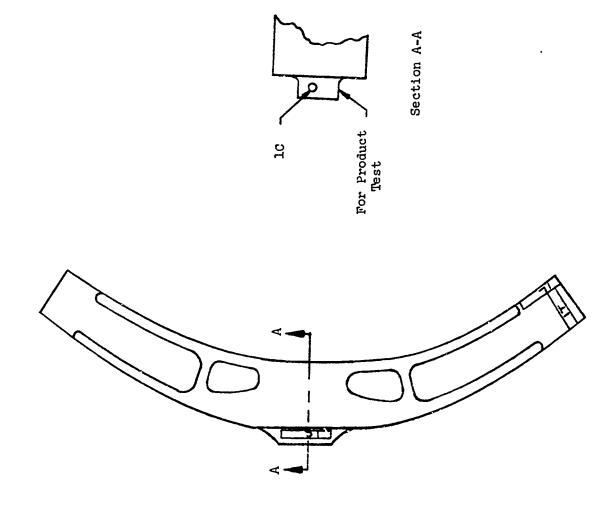
Forging Center Section





NOTE: N1 through N8 Fatigue
C1 and C2 Compression

Figure 6. Fatigue and Compression Specimen Layout Detail



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Figure 7. Capability Tests - Integrally Forged Coupons

TABLE 1 TENSILE RESULTS IMI 679 FORGING NUMBER HJU-1

| R.A.                                | 43.7<br>45.5<br>45.0    | 41.7<br>47.8<br>42.5      | 44.0                    | 101<br>101<br>101<br>101<br>101<br>101<br>101<br>101<br>101<br>101 | 25.55<br>25.55<br>26.54<br>26.54 | 70.0<br>70.0<br>149.0                   |
|-------------------------------------|-------------------------|---------------------------|-------------------------|--|----------------------------------|---|
| Elong.<br>%<br>1 in.                | 15.0                    | 15.5                      | 12.0                    | 17.0   | 17.0                             | 17.2<br>16.5<br>16.5<br>16.5            |
| Yield Strength<br>0.2%<br>ksi       | 133.0<br>127.6<br>130.2 | 133.0<br>133.0<br>138.2   | 130.4<br>130.0<br>130.0 | 130.7<br>93.0<br>87.2<br>89.8                                      | 889<br>85.8<br>86.0              | 88.0<br>88.0<br>88.0<br>88.0            |
| Ultimate Tensile<br>Strength<br>ksi | 150.8<br>144.0<br>147.0 | 150.0                     | 147.1                   | 146.5<br>120.6<br>111.4  | 115.2                            | 114.0                                   |
| Test<br>Temp.                       | RT                      | RT                        | RT                      | 550  | 550                              | 550                                     |
| Grain<br>Direction                  | ы                       | T.                        | ВŢ                      | н  | II.                              | ET                                      |
| Specimen<br>Location                | Flange                  | Complex<br>Grain Flow     | Flange                  | Flange   | Complex<br>Grain Flow            | Flange                                  |
| Specimen                            | FG<br>FH<br>FI          | Average<br>FJ<br>FK<br>FL | Average<br>FM<br>FN     | FO<br>Average<br>FD<br>FE  |                                  | Average<br>FAG<br>FAH<br>FAI<br>Average |

Somer

IMI679 THICK SECTION TENSILE PROPERTIES FURGING HJU-1 TABLE 2.

|                                     | <del></del> |     |      |     |        |            |     |     |        |  |
|-------------------------------------|-------------|-----|------|-----|--------|------------|-----|-----|--------|--|
| R.A.                                | 04          | 9   | 75   | 33  | 44     | <b>1</b> 7 | 3   | 143 | 147    |  |
| Elong.                              | 15          | 16  | 15   | 13  | 15     | 14         | 16  | 1.5 | 13     |  |
| Yield Strength<br>0.2%<br>ksi       | 127         | 129 | 132  | 134 | 121    | 136        | 136 | 134 | 129    |  |
| Ultimate fensile<br>Strength<br>ksi | 141         | 143 | 941  | 148 | 136    | 150        | 151 | 149 | 144    |  |
| Test<br>Temp.<br>°F                 | RT          |     | RT   |     | RT     | RT         |     |     | RT     |  |
| Grain<br>Dir.                       | 'n          |     | ㅂ    |     | LT     | ST         |     |     | ST     |  |
| Specimen<br>Location                | Center      |     | Edge |     | Center | Edge       |     |     | Center |  |
| Specimen<br>Number                  | F34         | F35 | F38  | F45 | F58    | F65        | P66 | F67 | F70    |  |

TABLE 3. IMI679 THICK SECTION TENSILE PROPERTIES FORGING HJU-2

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|-------------------------------------|--|
| R.A.                                | 30<br>43<br>43<br>41.0<br>41.0<br>40.0                                     |
| Elong.                              | 11<br>14<br>14<br>15<br>15<br>14.6<br>14.0                                 |
| Yield Strength<br>0.2%<br>ksi       | 121<br>123<br>127<br>129<br>130<br>134<br>135<br>134.0                     |
| Ultimate Tensile<br>Strength<br>ksi | 137<br>138.3<br>144<br>145<br>148<br>150<br>147<br>148.5                   |
| Test<br>Temp.                       | RT RT  |
| Grain<br>Dir.                       | TS ES  |
| Specimen<br>Location                | Center<br>Mid-radius<br>Edge   |
| Specimen<br>Number                  | G32<br>G32<br>Average<br>G34<br>G35<br>G35<br>G37<br>G38<br>G39<br>Average |

|                                   | NTS/UTS<br>(K <sub>t</sub> = 3.9)  |            |                            |  |                          |                       |                     |                          |         |
|-----------------------------------|------------------------------------|------------|----------------------------|--|--------------------------|-----------------------|---------------------|--------------------------|---------|
|                                   | Notched<br>Tensile Strength<br>ksi | 196<br>207 | 201.5<br>206<br>204<br>204 | 200<br>200<br>200<br>200<br>200<br>200<br>200<br>200<br>200<br>200 | 208<br>208<br>208<br>206 | 207.0<br>205<br>201   | 203.0<br>204<br>204 | 202<br>202<br>200<br>200 | 201.0   |
| PERTIES                           | Test<br>Temp.                      | RT         | RT                         | RT   | RT                       | RT                    | RT                  | RT                       |         |
| TENSILE PRC                       | Grain<br>Dir.                      | ST         | H                          | ы  | TT.                      | ŢŢ.                   | ST                  | ST                       |         |
| IMI679 NOTCHED TENSILE PROPERTIES | Specimen<br>Location               | Flange     | Center                     | Edge   | Edge                     | Mid-radius            | Edge                | Mid-radius               |         |
| TAELE 4.                          | Specimen<br>Number                 | GA<br>GB   | Average<br>G40<br>G41      | Average<br>G42<br>G43  | Average<br>Ghù<br>G45    | Average<br>G46<br>G47 | Average<br>G48      | Average<br>G50<br>G51    | Average |
|                                   | Forging<br>Number                  | HJU-2      |                            |  |                          |                       |                     |                          |         |

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TABLE 5. IMI679 THICK SECTION COMPRESSION PROPERTIES

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|--------------------------------------|--|--|
| Compression<br>Yield Strength<br>ksi | 136<br>141<br>144<br>145<br>144.5              | 149<br>148<br>138<br>142<br>142            |
| Test<br>Temp.                        | RT<br>KT                                       | RT<br>RT                                   |
| Grain<br>Dir.                        | J.<br>LT.                                      | II.  |
| Specimen<br>Location                 | Edge<br>Bdge                                   | Edge<br>Center                             |
| Specimen<br>Number                   | F23<br>F24<br>Average<br>F27<br>F28<br>Average | G5<br>G6<br>Average<br>G7<br>G8<br>Average |
| Forging<br>Number                    | HJU-1  | HJU-2                                      |

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|   | Cycles<br>to<br>Failure | 8,640<br>28,440<br>562,500<br>1,583,460<br>3,845,160<br>781,200<br>7,380,000 (2) |
|---|-------------------------|--|
| SUE PROPERTIES                                  | Stress (1)<br>max ksi   | 80<br>60<br>50<br>40<br>38<br>35<br>30<br>LOST IN TEST                           |
| IMI679 NOTCHED AXIAL TENSION FATIGUE PROPERTIES | Test<br>Temp.           | RT   |
| NOTCHED AXIA                                    | Grain<br>Dir.           | ь  |
| TABLE 6. IMI679                                 | Specimen<br>Number      | FN FN FN S S FN FN FN S FN                   |
| TAI   | Forging<br>Number       | GWN-13   |

(1) Stress Ratio R = 0.1;  $K_t = 3.0$ 

(2) Test still in progress.

TABLE 7 PRODUCT TEST RESULTS - IMI-679 - TMCA HEAT 8427 (1)
ALL SAMPLES WERE INTEGRAL WITH FORGINGS AT TIME OF HEAT TREATMENT

| Forging<br>Number | Spec<br>No. | Location         | Ultimate<br>Tensile<br>Strength<br>ksi | Yield<br>Strength<br>0•2%<br>ksi | Elong.<br>%<br>l in. | R.A.<br>%         |
|-------------------|-------------|------------------|--|----------------------------------|----------------------|-------------------|
| HJU-1             | 1L          | End Pad Long.    | 152.4                                  | 134.0                            | 15.0                 | 46.7              |
|                   | 1T          | End Pad Trans.   | 149.0                                  | 134.0                            | 16.0                 | 46.1              |
|                   | 1L          | Center Pad Long. | 146.4                                  | 131.2                            | 15.0                 | 37.6              |
| HJU-2             | 1L          | End Pad Long.    | 153.0                                  | 134.0                            | 15.0                 | 47.8              |
|                   | 1T          | End Pad Trans.   | 146.2                                  | 131.6                            | 16.0                 | 43.1              |
|                   | 1L          | Center Pad Long. | 150.0                                  | 133.6                            | 13.5                 | 36.3              |
| HJU-3             | 1L          | End Pad Long.    | 153.8                                  | 134.6                            | 15.0                 | 43•7              |
|                   | 1T          | End Pad Trans.   | 146.8                                  | 131.6                            | 14.5                 | 45•5              |
|                   | 1L          | Center Pad Long. | 150.0                                  | 131.6                            | 14.5                 | 42 <sub>•</sub> 5 |
| HJU-4             | 1L          | End Pad Long.    | 152.0                                  | 134.2                            | 15.0                 | 46.1              |
|                   | 1T          | End Pad Trans.   | 150.0                                  | 132.0                            | 15.0                 | 39.5              |
|                   | 1L          | Center Pad Long. | 148.0                                  | 130.0                            | 13.5                 | 39.5              |

(1) Heat Treatment
Solution Treated 1650°F (1 hour ) Fan Cool
Aged 930°F (24 hours) Air Cool

TABLE 8 PRODUCT TEST RESULTS T1-6Al-4V TMCA HEAT D-7976 MATERIAL CUT FROM FORGING, HEAT TREATED AS COUPONS (1)

| Forging | Spec. | Location         | Ultimate | Yield          | Elong. | R.A.     |
|---------|-------|------------------|----------|----------------|--------|----------|
| Number  | No.   |                  | Tensile  | Strength       | %      | <b>%</b> |
|         |       |                  | Strength | 0.2%           | 1 in.  |          |
|         |       |                  | ks1      | ksi            |        |          |
| GWN-11  | 1L    | End Pad Long.    | 178.0    | 164.0          | 10.0   | 29.9     |
|         | 1T    | End Pad Trans.   | 170.6    | 156.0          | 11.0   | 33.8     |
|         | 1C    | Center Pad Long. | 168.0    | 154.0          | 10.5   | 31.8     |
| GWN-12  | 1L    | End Pad Long.    | 171.4    | 157.0          | 13.0   | 35•7     |
|         | 1T    | End Pad Trans.   | 173.6    | 158.0          | 11.0   | 35•7     |
|         | 1C    | Center Pad Long. | 169.6    | 154.8          | 10.5   | 32•7     |
| GWN-13  | 1L    | End Pad Long.    | 181.6    | 169 <b>.</b> 2 | 10.5   | 35•7     |
|         | 1T    | End Pad Trans.   | 174.0    | 160.8          | 11.5   | 34•4     |
|         | 1C    | Center Pad Long. | 168.4    | 155 <b>.</b> 8 | 10.5   | 34•4     |
| GWN-14  | 1L    | End Pad Long.    | 176.2    | 163.4          | 12.0   | 38.2     |
|         | 1T    | End Pad Trans.   | 168.0    | 153.8          | 13.5   | 45.0     |
|         | 1C    | Center Pad Long. | 170.0    | 158.0          | 8.5    | 23.1     |

(1) Heat Treatment:
Solution Treated 1750°F (1 hour) W.Q.
Aged 1000°F (4 hours) A.C.

### APPENDIX

TMCA chemical analysis for the Ti-6Al-4V and IMI679 billet stock are given in Table 9. Mechanical properties for both alloys reported by TMCA are presented in Table 10.

Wyman-Gordon data on tensile properties for all three grain directions on Ti-6Al-4V and IMI679 billet stock are given in Tables 11 and 12. The billet material was four inches thick at time of heat treatment.

Longitudinal and transverse macrosections of IMI679 billet are shown in Figures 8, 9, and 10. Microstructures of IMI679 and Ti-6Al-4V billet material are presented in Figures 11 and 12.

Basic details related to production of the Ti-6Al-4V and IMI679 closed die forgings are presented in Tables 13 and 14.

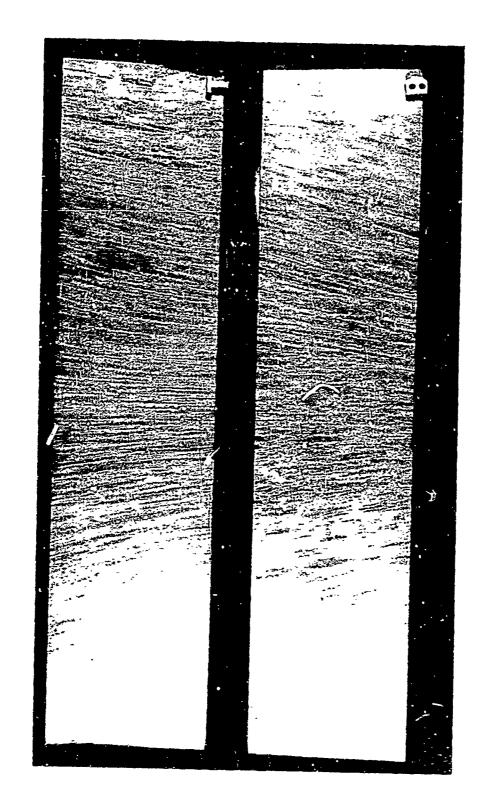


Figure 8. Macrosection of 7-Inch RCS Billet Stock IMI 679, Longitudinal Top (Upper) and Transverse Bottom (Lower)

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Figure 9. Macrosection of 7-Inch RCS Billet Stock IMI 679, Transverse - Bottom

Figure 10. Macrosection of 7-Inch RCS Billet Stock IMI 679, Transverse - Top





Figure 11. Microstructure of Heat Treated IMI-679 Billet Stock (Longitudinal - Upper, Transverse - Lower)
Etchant: Benzal Stain 250X



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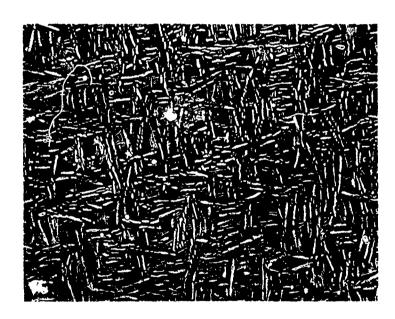


Figure 12. Microstructure of Heat Treated Ti-6Al-4V Billet Stock (Longitudinal - Upper, Transverse - Lower)
Etchant: NAOH 100X

TABLE 9. IMCA CHEMICAL ANALYSIS

| Si          |   | . 23<br>. 24     |
|-------------|---|------------------|
| 02          | .20   | 11.              |
| Sn          |   | 11.11<br>11.3    |
| Zr          |   | ф°†<br>6°†       |
| H           | .000<br>600.  | ÷00.             |
| Мо          |   | e. 1.            |
| Λ           | 7. 4. 4. 4. 0. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4. 4. |                  |
| A1          | 6.3   | 0 0<br>0 0       |
| N           | .018<br>.018  | .009             |
| H<br>e      | .12<br>.08<br>.08                                     | .05              |
| υ           | . 022   | . 022            |
| Heat<br>No. | D-7976<br>T<br>M<br>B                                 | D-8427<br>T<br>M |
| Alloy       | T1-6A1-4V   | 619-IMI          |

TABLE 10 TMCA MECHANICAL PROPERTIES

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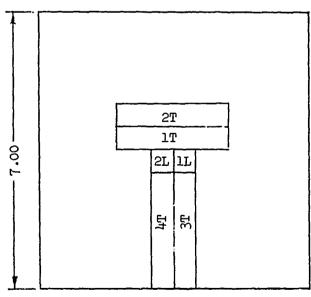
| Hardness | Rc              | 31.5<br>30.5   | 34.5<br>31.5              |   |  |   |
|----------|-----------------|--|---------------------------|---|--|---|
| R.A.     | <b>76</b> 2     | 38.2<br>34.9   | 32.5<br>40.1              | 40.6<br>39.3                                | 31.7<br>38.7                               | 6°111   |
| Elong.   | %<br>inch       | 18.0   | 16.0                      | 13.0  | 13.c<br>15.0                               | 19.0  |
| Yield    | Strength<br>ksi | 133.9<br>138.9   | 137.0<br>138.4            | 156.2<br>158.1                              | 157.0                                      | 133.9<br>134.3  |
| Tensile  | Strength<br>ks1 | 144.8<br>149.2   | 147.6<br>145.9            | 171.1<br>168.3                              | 167.5<br>168.7                             | 152.6<br>151.2  |
| Test     | No.             | (top)<br>Rad.<br>Tang.   | (bottom)<br>Rad.<br>Tang. | (top)<br>Rad.<br>Tang.                      | (bottom)<br>Rad.<br>Tang.                  | Rad.<br>Tang.   |
| Heat     | Treatment       | Upset 2" to 3/4" (top) at 1750°F Rad Annealed 2 hrs. Tar at 1300°F |                           | Solution Treat-<br>ed (1 hr.<br>1725 F W.Q. | Lab. Aged<br>(3 hrs)<br>900 <sup>0</sup> F | Upset 2" to 3/4" at 1650°F Solution Treated 1 hr.at 1650°F Aged 24 hours at 930°F |
| Heat     | No.             | D-7976   |                           | D-7976                                      |  | D-8427  |
|          | Alloy           | T1-6A1-4V  |                           |   |  | 1MI-679   |

TABLE 11. BILLET STOCK TENSILE TEST RESULTS Ti-IMI 679 - TMCA HEAT D-8427(1) (7 x 7 x 4 Billet)

| Specimen<br>Number | Ultimate<br>Tensile<br>Strength<br>ksi | Yield<br>Strength<br>0.2%<br>ksi | Elong.<br>%<br>l in. | R.A.<br>% |
|--------------------|--|----------------------------------|----------------------|-----------|
| 1L                 | 144.0                                  | 125.6                            | 13.5                 | 35•7      |
| 1 <b>T</b>         | 139.0                                  | 118.0                            | 14.0                 | 33.8      |
| 2L                 | 140.0                                  | 121.8                            | 15.0                 | 38.2      |
| 2T                 | 142.0                                  | 122.0                            | 11.5                 | 29.9      |
| 3 <b>T</b>         | 152.0                                  | 134.0                            | 15.0                 | 31.1      |
| <b>4</b> T         | 150.0                                  | 133.8                            | 10.0                 | 29.9      |

(1) Heat Treatment:

Solution Treated 1650°F (1 hour ) Fan Cool Aged 930°F (24 hours) Air Cool

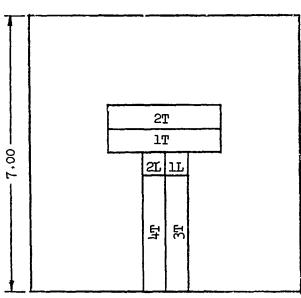


Test Locations

TABLE 12. BILLET STOCK TENSILE TEST RESULTS Ti-6Al-4V TMCA HEAT D-7976 (1) (7 x 7 x 4 Billet)

| Specimen<br>Number | Ultimate<br>Tensile<br>Strength<br>ksi | Yield<br>Strength<br>0.2%<br>ksi | Elong.<br>%<br>l in. | R.A. |
|--------------------|--|----------------------------------|----------------------|------|
| 1L                 | 143.0                                  | 127.0                            | 13.0                 | 32.7 |
| 2L                 | 137.6                                  | 114.0                            | 14.5                 | 33.8 |
| 1 <b>T</b>         | 143.4                                  | 128.4                            | 12.5                 | 26.6 |
| ST                 | 140.0                                  | 128.8                            | 15.0                 | 28.3 |
| 3 <b>T</b>         | 150.0                                  | 132.0                            | 10.0                 | 21.7 |
| 4 <b>T</b>         | 148.0                                  | 129.2                            | 10.0                 | 25.1 |

(1) Heat Treatment:
Solution Treated 1750°F (1 hour) W.Q.
Aged 1000 F (4 hours) A.C.



Test Locations

TABLE 13. T1-6A1-4V FORGING PROCESS DATA

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|                         |                   |                                      |                                      | <del> </del>                         |                                      |  |
|-------------------------|-------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--|
| Forging, <sup>O</sup> F | Off<br>Dies       | 1450<br>1450<br>1450<br>1450         | 1500<br>1540<br>1500<br>1500         |                                      |                                      |  |
| Temperature of Fo       | On<br>Dies        | 1665<br>1665<br>1665<br>1660         | 1670<br>1665<br>1680                 | 1665<br>1660<br>1600<br>1670         | 1660<br>1660<br>1670<br>1670         |  |
| Tempe                   | Out<br>Furnace    | 1725<br>1720<br>1725<br>1725         | 1730<br>1725<br>1730<br>1740         | 1735<br>1725<br>1720<br>1725         | 1725<br>1730<br>1725<br>1720         |  |
| Furnace                 | Temp.<br>OF       | 1800                                 | 1800                                 | 1775                                 | 1775                                 |  |
| Heat                    | Cycle<br>hrs.     | 9                                    | 2/1-2                                | 2-1/2                                | 1/2                                  |  |
| Press                   | Equipment<br>tons | 1,500                                | 009                                  | 18,000                               | 13,000                               |  |
| Forge                   | Operations        | Огам                                 | Bend                                 | lst Finish                           | 2nd Finish                           |  |
| Cut                     | Weight<br>lbs.    | 106<br>106-1/2<br>107<br>108         |                                      |                                      |                                      |  |
| Forging                 | Number            | GWN-11<br>GWN-12<br>GWN-13<br>GWN-14 | GWN-11<br>GWN-12<br>GWN-13<br>GWN-14 | GWN-11<br>GWN-12<br>GWN-13<br>GWN-14 | GWN-12<br>GWN-12<br>GWN-13<br>GWN-14 |  |

All cooling was in air

TABLE 14. T1 IMI 679 FORGING PROCESS DATA

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|                         | 1         |                |                |                |       |                              |       |            |                |        |            |             |       |          |              | <br> |
|-------------------------|-----------|----------------|----------------|----------------|-------|------------------------------|-------|------------|----------------|--------|------------|-------------|-------|----------|--------------|------|
| Forging, <sup>O</sup> F | Off       | Dies           | 1450           |                |       | 1500<br>1485<br>1495<br>1500 |       |            | 1400           |        |            | !<br>!<br>! | !!!   | :<br>: : |              |      |
| of G                    | on        | Dies           | 1550           | 1540           | 1550  | 1555                         | 1535  |            | 1470           | 1500   | )          | 1545        | 1550  | 1545     |              |      |
| Temperature             | Out       | Furnace        | 1600           | 1600           | TOZO  | 1630                         | 1625  | , , ,      | 1580           | 1580   |            | 1620        | 1610  | 1615     | <del>-</del> |      |
| Furnace                 | Temp.     | O <sub>F</sub> | 1675           |                |       | 5 <i>).</i> 9T               |       | 3671       |                |        | 11         | C) 0T       |       |          |              |      |
| Heat                    | Cycle     | hrs.           | رد.<br>در در   | 7-1/2          |       | ν,                           |       | 0/1-0      | 7/1            |        | 0/10       | 5/4-7       |       |          |              |      |
| Press                   | Equipment | tons           | 1,500          |                | 9     | 8                            |       | 18.000     |                |        | 35,000     |             |       |          |              |      |
| Forge                   | Operation |                | Draw           |                | Bend  |                              |       | 1st Finish |                |        | 2nd Finish |             |       |          |              |      |
| Cut                     | Weight    | lbs.           | 108            | 109            | 1 !   | 1                            | ! !   | !          | : :            | !      | 1          | !!!         | !     |          |              |      |
| Forging                 | Number    |                | HJU-1<br>HJU-2 | HJU-3<br>HJU-4 | ਜਹਾ-1 | HJU-2                        | HJU-4 | HJU-1      | HJU-2<br>HJU-3 | HJU-14 | HJU-J.     | HJU-2       | HJU-3 | h20-4    |              |      |

All cooling was in air