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MANUFACTURE OF LOW CARBON ASTROLOY TURBINE DISK SHAPES BY HOT ISOSTATIC PRESSING

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16. Abstract

This report documents the performance of a HIP disk installed in an experimental engine and exposed to realistic operating conditions in a 150-hour engine test and a 1000 cycle endurance test. Post test analysis, based on visual, fluorescent penetrant and dimensional inspection, revealed no defects in the disk and indicated that the disk performed satisfactorily.

The results reported herein covers the work performed under Tasks IV and V of Project 1, and is presented as FEDD category 2 data. Work performed under Tasks I, II and III of this contract is presented in NASA Report No. CR-135409.

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1.0 SUMMARY

The purpose of this program was to develop the manufacturing procedures for fabrication of direct-HIP low carbon Astroloy to sonic shape with properties equivalent to conventionally forged Waspaloy® for commercial engine use. The specific objectives of Tasks III and V reported in this document were to demonstrate the performance of a HIP disk in an actual engine test.

The HIP disk was installed in a land-based experimental JT8D-17R engine for testing at realistic operating conditions. The HIP disk was successfully engine tested for 150 hours plus 1000 endurance cycles. Based on visual, fluorescent penetrant and dimensional inspection, the HIP disk performed satisfactorily in the engine test.

2.0 INTRODUCTION

BACKGROUND

Advanced aircraft turbine engines expected to enter commercial service in the 1980 to 1985 time period will have performance, cost, and weight requirements that will necessitate the use of advanced materials technologies in their construction. A number of technologies, which potentially meet these needs, have been identified and are currently in various stages of development. To accelerate the development of selected material technologies to the point where they can be verified through engine testing, a five-year cooperative Government/Industry effort, Materials In Advanced Turbine Engines (MATE), has been initiated under NASA sponsorship. The MATE effort was sub-divided into specific materials technology programs.

Hot isostatic press manufacture of Astroloy turbine disk shapes was the materials technology selected for the MATE Project I program.

Lower engine weight and higher operating temperatures needed to meet the higher thrust-to-weight requirements of advanced gas turbine engines has necessitated the development of advanced turbine disk materials with greater strength and cyclic life capabilities. To provide these capabilities, disk alloys must contain increased amounts of gamma prime forming elements (Ni_3Al, Ti). While this approach results in alloys with improved properties, obtaining these properties in large diameter engine disks fabricated from cast +forged billets is both difficult and costly. This is due to the chemical inhomogeneity in large ingots caused by the segregation during solidification which is inherent in these highly alloyed superalloys. Powder metallurgical processing techniques is the only effective way to produce disks from these advanced disk material in order to ensure compositional homogeneities and, thereby, mechanical property uniformity. An approach that can satisfy the uniform properties requirement is the direct hot isostatically pressing powder into disk shapes. By reducing raw material input, and thus the amount of excess material which must be machined to yield a finished part, it was anticipated that a reduction in material input weight and cost is possible for net sonic inspection shapes.

CATEGORY 2 - FEDD DATA

At Pratt & Whitney Aircraft, direct HIP low carbon Astroloy was demonstrated to have the potential to exceed the mechanical properties of conventionally forged Waspaloy®. Therefore, the low carbon Astroloy composition was selected for evaluation. An analysis of the existing forging configuration of a JT8D first stage turbine indicated that HIP consolidating to the sonic shape could reduce material requirements by 54.5 kg (120 lbs.) and cost by 20 percent.

This volume presents the FEDD category 2 technical effort accomplished in Project 1. Category 2 data includes an engine test program and post test analysis of a direct HIP turbine disk. Category 1 data is reported in Volume I.

PROGRAM SCOPE

The following tasks were accomplished under this program.

Task I established the manufacturing methods necessary to produce JT8D first stage turbine disks by hot isostatic pressing low carbon Astroloy powder of the composition shown in

Table I to net sonic shapes. Five disk shapes with a final target shape shown in Figure 1 were produced by the Udimet Powder Division of Special Metals Corporation. Preliminary mechanical properties were determined for the integral test coupon ring of each disk. The target properties are shown in Table II. These property goals are equivalent to conventionally forged Waspaloy®.

TABLE I

COMPOSITIONAL RANGE OF LOW CARBON ASTROLOY POWDER AND POWDER METAL COMPONENTS

	Weight Percent																PPM			
Element:	Ni	C	Mn	S	P	Si	Cr	Co	Mo	Ti	Al	B	Zr	W	Fe	Cu	Pb	Bi	O	N
Maximum:	R*	0.06	0.15	0.015	0.015	0.20	16	18	5.5	3.65	4.15	0.03	0.06	0.05	0.50	0.10	10	0.5	100	50
Minimum:	R*	0.02	–	–	–	–	14	16	4.5	3.35	3.85	0.02	–	–	–	–	–	–	–	–

R = remainder

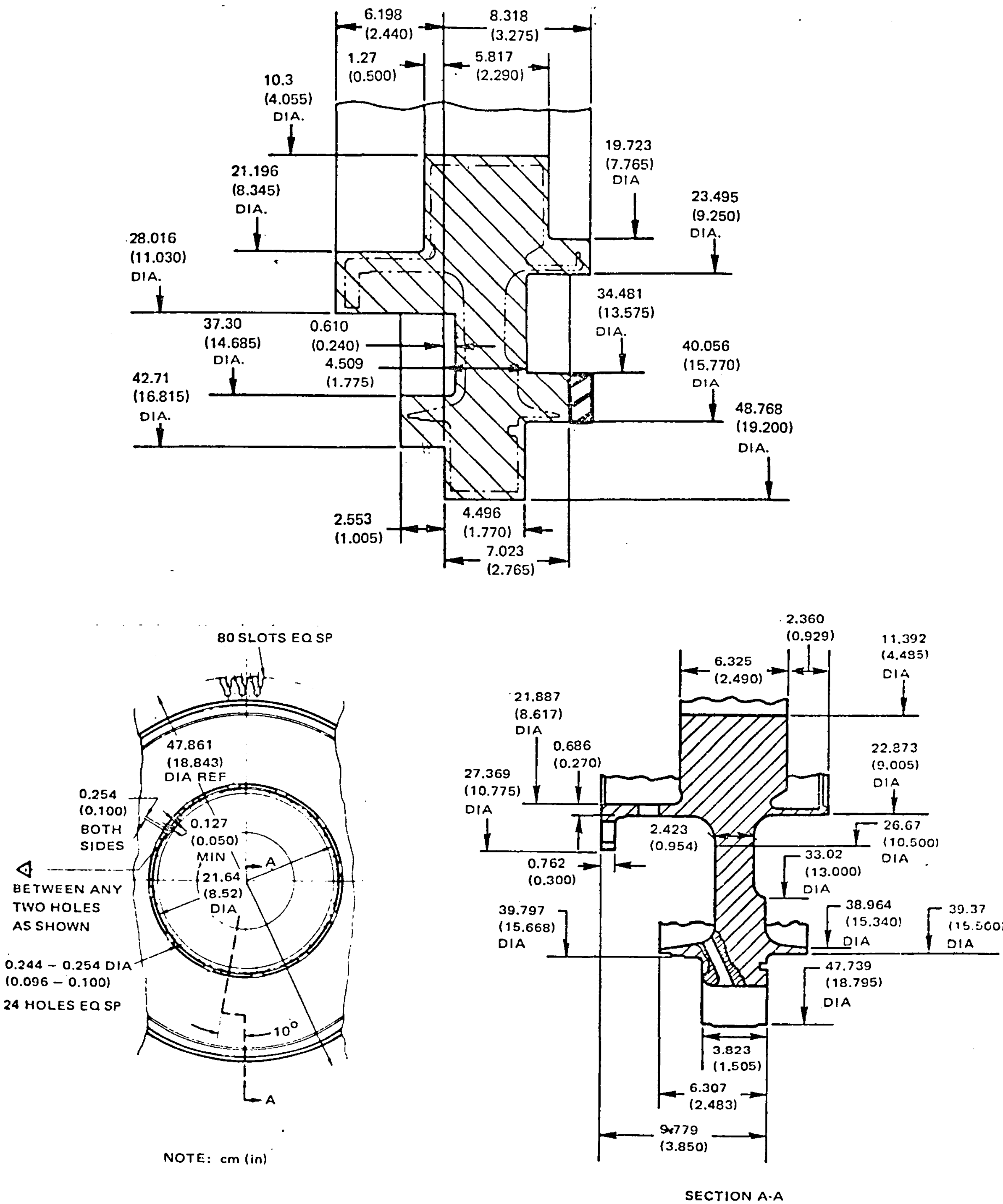

Figure 1 JT8D First Stage Turbine Disk Shown in the Net Sonic Configuration (Upper) and Finished Configuration (Lower). Location of integral test ring is shown on sonic shapes in dark reversed cross hatching.

TABLE II

MECHANICAL PROPERTY REQUIREMENTS FOR HIP ASTROLOY POWDER DISKS

	0.2% Yield Strength MPa (ksi)	Ultimate Tensile Strength MPa (ksi)	Elongation (%)	Reduction in Area (%)
RT Tensile	862 (125)	1241 (180)	15	18
538°C (1000°F) Tensile	758 (110)	1103 (160)	15	18

732°C/552 MPa Stress-Rupture (1350°F/80 ksi)	Life 23 hrs.	Elongation (%) 8
704°C/510 MPa Creep (1300°F/74 ksi)	Time to 0.1% Elongation 100 hrs.	

Task II finish-machined one disk for an engine demonstration test.

Task III concurrently characterized the microstructure, chemistry and mechanical properties of the disks produced in Task I.

Task IV subjected one disk to sea level experimental engine demonstration testing.

Task V provided the post test analysis including visual, fluorescent penetrant, and dimensional inspection of the turbine disk tested in Task IV and analyzed results of the entire Project 1.

3.0 DEMONSTRATION ENGINE TEST PROGRAM

A direct HIP low carbon Astrology first stage turbine disk 50-2 (P/N 767601, S/N G24302, H/C UKPM-2) was engine tested in a land-based JT8D-17R engine designated as X-368. The details of the manufacturing procedures for disk 50-2 (Figure 2) have been reported in Volume I, CR-135409. The HIP disk was exposed to realistic operation conditions consisting of two separate test program cycles. The first engine test conducted in build 62 included a variety of engine speeds and incremental changes in power setting. The complete 150 hour engine test, included 15 applications of a six (6) hour test cycle followed by ten (10) applications of a different six (6) hour test cycle. A summary of the accumulated exposure time for the 150-hour engine test is given in Table III. A second engine test was conducted in build 63 which consisted of a 1000 cycle endurance test. Some of the measured test conditions are included in Table III.

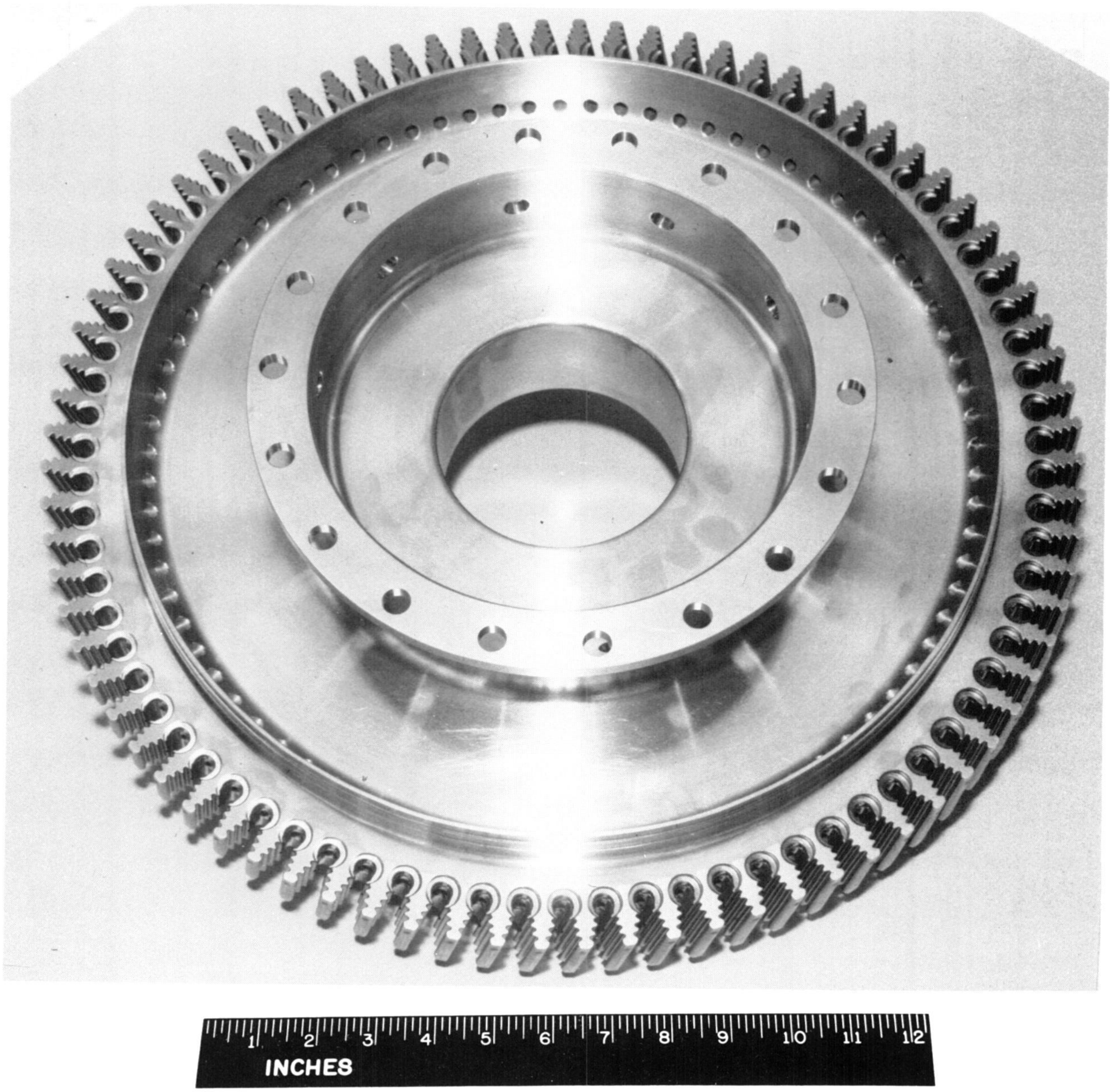

Figure 2 Disk 50-2 in the Finished Part Configuration

TABLE III

ACCUMULATED ENGINE EXPOSURE TIME FOR HIP LOW CARBON ASTROLOY DISK 50-2

Power Setting for Build 62	Total Time - Hrs
Take-off	18
High Power	45
Step-Down From High to Idle	86.5
Full-Reverse	0.5
Total	150 hours

Highlights of the engine test were as follows:

	Build 62 and 63 Idle	Build 62 Take-Off	Build 63 Take-Off
• Disk Average Temperature	149°C (300°F)	510°C (950°F)	538°C (1000°F)
• Average Tangential Stress	Negative	483 MPa (70 ksi)	483 MPa (70 ksi)
• Max. Disk Temperature	177°C (350°F)	524°C (975°F)	566°C (1050°F)
• Exhaust Gas Temperature	421°C (790°F)	649°C (1200°F)	690°C (1274°F)
• Thrust	473 kg (1040 lbs.)	7273 kg (16,000 lbs.)	7893 kg (17,400 lbs.)

This engine test program performed was typical of engine tests conducted for Federal Aviation Agency certification of new engine models and/or new engine components.

4.0 POST-ENGINE TEST ANALYSIS

After the 150 hour engine test and the 1000 cycle endurance test, the disk (P/N 767601, S/N G24302) was removed for visual, fluorescent penetrant, and dimensional inspection. Visual and fluorescent penetrant inspection of the disk showed no defects (i.e., cracks or corrosion). The diametral dimensions of the disk before and after each engine test are given in Table IV. The minor dimensional changes were within previous experience of prior Bill-of Material Waspaloy®disk testing.

5.0 CONCLUSIONS

This demonstration test was to expose a HIP low carbon Astroloy disk experimental land-based engine test utilizing realistic operation conditions.

After visual, fluorescent penetrant and dimensional inspection of the engine tested disk, we found that the first stage, direct HIP turbine disk performed successfully in the experimental JT8D-17 engine.

TABLE IV

DIAMETRAL DIMENSIONS OF HIP DISK BEFORE AND AFTER ENGINE TEST

	Min - cm (in)	Average - cm (in)	Max - cm (in)
Dia. # 1-Bore Front			
Pre Test	11.397 (4.487)	11.397 (4.487)	11.400 (4.488)
Post Test # 1	11.397 (4.487)	11.397 (4.487)	11.397 (4.487)
Post Test # 2	—	—	—
Dia. #1 - Bore Center			
Pre Test	11.397 (4.487)	11.397 (4.487)	11.397 (4.487)
Post Test # 1	11.397 (4.487)	11.397 (4.487)	11.397 (4.487)
Post Test # 2	11.394 (4.486)	11.394 (4.486)	11.397 (4.487)
Dia. #1 - Bore Rear			
Pre Test	11.397 (4.487)	11.397 (4.487)	11.400 (4.488)
Post Test # 1	11.397 (4.487)	11.397 (4.487)	11.397 (4.487)
Post Test # 2	—	—	—
Dia. #2 - Rear Knife Edge - ID			
Pre Test	41.321 (8.134)	41.321 (8.134)	41.321 (8.134)
Post Test # 1	41.326 (8.135)	41.326 (8.135)	41.326 (8.135)
Post Test # 2	41.321 (8.134)	41.326 (8.135)	41.326 (8.135)
Dia. #3 - Rear Knife Edge - OD			
Pre Test	22.878 (9.007)	22.878 (9.007)	22.878 (9.007)
Post Test # 1	22.875 (9.006)	22.875 (9.006)	20.660 (9.007)
Post Test # 2	22.870 (9.004)	22.873 (9.005)	22.873 (9.005)
Dia. #4 - Rear Seal Land - OD			
Pre Test	39.370 (15.500)	39.370 (15.500)	39.370 (15.500)
Post Test # 1	39.367 (15.499)	39.367 (15.499)	39.370 (15.500)
Post Test # 2	39.365 (15.498)	39.367 (15.499)	39.367 (15.499)
Dia. #5 - Z-Plane			
Pre Test	46.271 (18.217)	46.271 (18.217)	46.271 (18.217)
Post Test # 1	46.256 (18.211)	46.256 (18.211)	46.256 (18.211)
Post Test # 2	46.253 (18.210)	46.253 (18.210)	46.259 (8.212)
Dia. #6 - Front Seal Land OD - Rear			
Pre Test	39.797 (15.668)	39.797 (15.668)	39.797 (15.668)
Post Test # 1	39.797 (15.668)	39.797 (15.668)	39.797 (15.668)
Post Test # 2	39.797 (15.668)	39.799 (15.669)	39.799 (15.669)

TABLE IV (Cont'd)

	Min - cm (in)	Average - cm (in)	Max - cm (in)
Dia. #7 - Front Seal Land OD - Rear			
Pre Test	39.647 (15.609)	39.647 (15.609)	39.649 (15.610)
Post Test # 1	39.647 (15.609)	39.647 (15.609)	39.647 (15.609)
Post Test # 2	39.647 (15.609)	39.649 (15.610)	39.649 (15.610)
Dia. #8 - Front Seal Land OD - Front			
Pre Test	39.421 (15.520)	39.421 (15.520)	39.421 (15.520)
Post Test # 1	39.421 (15.520)	39.421 (15.520)	39.421 (15.520)
Post Test # 2	39.421 (15.520)	39.421 (15.520)	39.423 (15.521)
Dia. # 9 - Front Flange - OD			
Pre Test	27.374 (10.777)	27.374 (10.777)	27.376 (10.778)
Post Test # 1	27.371 (10.776)	27.371 (10.776)	27.371 (10.776)
Post Test # 2	—	—	—
Dia. #10 - Front Snap			
Pre Test	21.803 (8.584)	21.803 (8.584)	21.803 (8.584)
Post Test # 1	21.806 (8.585)	21.806 (8.585)	21.806 (8.585)
Post Test # 2	—	—	—