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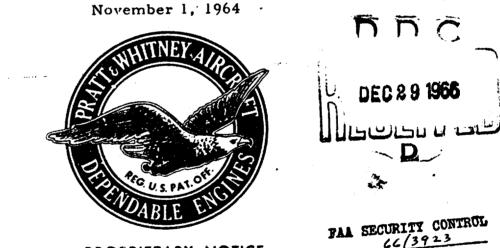
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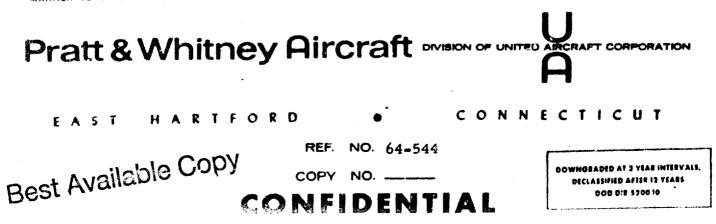
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### 1. MANUFACTURING TECHNIQUES

In general, the STF219 design configuration does not present unusually difficult manufacturing problems. Although some of the parts differ geometrically from existing engines, they use materials which are successfully machined, welded, heat and surface treated, etc., as a normal part of Pratt & Whitney Aircraft factory activity. The major portion of the engine can be classified a "standard" to Pratt & Whitney Aircraft production departments due to the experience gained with the TF30, J58, and thrust reverser parts and assemblies.

1.1 Blades and Vanes

Air-cooled turbine vanes are presently being manufactured by Pratt & Whitney Aircraft for use in the TF30 and J58 engines.

The STF219 design calls for more complex machining practices. Slots in the leading edge of turbine blades and vanes present no major problem; these slots may be integrally cast or electrochemical and electrodischarge machining can be used. Electron beam drilling of very small holes is now being developed, and is proving satisfactory for the installation of the air holes or slots in the trailing edge. The electron beam and normal fusion welding and the brazing required by the various airfoil designs either currently falls within standard Pratt & Whitney Aircraft production practices or are projections of same.

1.2 Surface Coatings

Supplemental surface coatings, which are applied to increase the useful life of jet engine parts, have been in use for some time at Pratt & Whitney Aircraft. Intensive development work and testing programs have yielded several methods by which these coatings can be applied. These methods include application of a slurry of metal powder in a suitable vehicle which is then diffused into the surface of the base metal, applying molten metals and metal carbides or oxides using an oxyacetylene flame torch or using an ionized gas (plasma) torch system. Many types of materials are coated ranging from stainless steels, nickel, and cobalt base alloys to titanium alloys. Typical coating materials are aluminum, molybdenum, nickel-aluminide, and various metal oxides and carbides.

A recent innovation is the manufacture of turbine seals using a metal sprayed porous abradable coating, which permits more efficient operation of the turbine section of gas turbine engines through

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reduced operating clearances.

At present there are two plasma spray installations in the production plus one unit which is in use for continuing development work. There are also various types of flame spraying equipment in use. Additional plasma spray equipment is being procured to meet the increasing demand for the application of these coatings to engine parts.

### 1.3 Use of Titanium

The forward portion of the STF219 engine is largely titanium. This includes such items as:

- Fan Cases
- Fan Blades
- Fan Discs
- 2nd Stage Vane & Shroud Assemblies
- High Compressor Guide Vanes
- Fan Diffuser Ducting
- Outer Duct Cases

Pratt & Whitney Aircraft initiated the use of titanium alloys in its engines over ten years ago. Today, after a great deal of development, machining such as turning, grinding, drilling, broaching, etc. has become very common to our production. Through the careful control of the metallurgical properties of alloys and welding atmospheres, the "in line" production of quality heat-treated aircraft weldments is now routine.

### 1.4 Compressor Section

This compressor section is similar to the J58 compressor, which is currently in production. The advanced design of integral spacer to fan disk and integral spacer to turbine disk call for contour turning, which is standard machining practice at Pratt & Whitney Aircraft.

### 1.5 Intermediate Case

This case presents average complexity of heat treating and machining problems. 54" O.D. cases can be handled on conventional turning, boring and profiling equ. ment using standard processing.

### 1.6 Burner Assembly

The annular burner for the STF219 engine presents no particular

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problem. It is a Hastelloy "X" weldment, that will be processed to allow sufficient material for weld shrinkage and for machining. Smaller parts will be machined from forgings and castings. The sheet metal will be formed on presses and sized by sizing machines. We have had considerable experience in all phases of this type of fabrication.

1.7 Shroud Containment Rings on the 3rd and 7th Stage Compressor Blades

Although the use of containment rings for retaining blades in the discs is an advanced design, present equipment and processes allow the machining of 30" diameter rings to close tolerances. Grinding tolerances and flatness and surface finishes can be maintained to meet design requirements.

1.8 Floating Seal

The floating seal at the rear of the high pressure compressor follows conventional turning and grinding. Mechanical air seals and labyrinth seals are widely used in this engine. Pratt & Whitney Aircraft has used this type of seal in most turbine engines, and has developed highly specialized cutting tools for machining these configurations.

1.9 Outer Compressor Duct

Skip milling or skip turning is required on this part to form the joining flanges and 2 bosses. This process is an approved method of machining and currently applied to the TF30 engine diffuser duct and similar parts.

1.10 Exhaust Nozzie Section

This section is similar to the TF30 engine nozzle.

1.11 Duct Heater

The design of the corrugated inner section which is resistance wolded to the outer skin, is the same type of construction that is now being used on the JT11 combustion chamber case-inner assembly.

1.12 The Thrust Reverser

This section is made up of pie shaped plates with standard draw bars

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and hydraulic actuators. These items are similar to the afterburner doors which Pratt & Whitney Aircraft are manufacturing for the JT4 and other type engines.

1.13 Cases with Airfoil Buttresses for Welded Struts, etc.

The buttress configuration will be machined by the electro-chemical method. The lightening slots in the buttresses are produced by the electrodischarge method. Both of these methods are highly developed, and are in regular production use at Pratt & Whitney Aircraft on the JT8D and TF30 engines.

1.14 Assembly

The manufacture of the JT8D engine has provided considerable assembly experience on full dusted fan engines. No unusual difficulties are anticipated with the STF219 outer duct design. The majority of the engine is amenable to #\*andard Pratt & Whitney Aircraft assembly practices.

The assembly and balancing of "overhung" compressor (3rd) and farstages are accomplished on the JT8D engine. The STF219 will be handled similarly.

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### 2. MATERIALS

The materials selected for major components of the STF219 engine are listed in Tables F2-1 and F2-2. Table F2-1 also shows the materials previously proposed for the JT11F-11 and JT11F-12 in the Phase I Report, and an indication of the reason for any differences between the Phase I and Phase II-A Reports. Table F2-2 relates these materials to applications in current Pratt & Whitney Aircra.. engines.

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TABLE F2-1 MATERIALS FOR GAS TURBINE ENGINE FOR SUPERSONIC TRANSPORT

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	53 550	STF219	Previous Froposal (1)	roposal (1)	
	Mach 2.7 65, 6001	Mach 3.0 65,0001	JT11F-11 Mach 2.5-2.7	JT115-12 Mack 3.0	Reason for Difference
TAN SECTION					
Front Mount Ring Fan Cases	PWA 1302 PWA 1202	PWA 1202 PWA 1202	Saine (2)	Some 23	No comparable part
НиЪ	D'WA 1202		ļ		
Elade-Ist Stage	AMS 2028	2021 AWA		3	No comparable part
Blade-2nd Stage	AMS 4928	026F 0 275	2021 VM-1	PWA 1202	To avoid pussible
Disk-1st Stage	PWA 1202	5021 S WY	5021 AM-4	FWA 1202	ëltess-corrosion
Disk-2nd Stage	PWA 1202	PWA 1203	Same.	on the second	
Vane - lat Stage	P% A 1262	PWA 1202	AMS 4010	ANC ADD	
Shroud, Inner ist Stage	AMS 4926	AMS 4926	Sarde	5 CM2	Different construction
	AMS 4910	AMS 4910		ame	
Vane-2nd Stage	PWA 1202	PWA 1202	50 miles	COLL AND	
Shroud, Inner 2nd Stage	PWA 1202	PWA 1202		COST VALA	
Shroud. Outer 2nd Stage	AMS 4926	AMS 4926	PWA 1202	LINCI VAL	Dutevent construction
	AMS 4910	AMS 4910		6 1031 043	
vane, ran Exit Guide	A.M.S 5667	AMS 5667	AMS 4966	AMS 4966	Different construction
INTERMEDIATE SECTION					
Main fearings					
-Balls and Races	AMS 6490	AMS 6490	č	:	
-Cages	AMS 64)5	ANS 6415	Same	Same	
Bearing Support	AMS 5613	CITO CIMA	Jame	Same	
Seal Support Assy's	4 MG 6413		04 me	Same	
Intermediate Case	CIDC CIVIL	AMS 5613	Same	Same	
Towershaft Bearings	0106 0100	0106 SW:/	7	•	No comparable part
-Balls, Rollers and Races	PWA 724 CVM or	PWA CVM of	Same		
	AMS 6490	AMS 6490			
-Cages	AMS 0415	AMS 6415	Saros	52.00	
Towershaft	PWA 724	PWA 774	ANCE LICE		
Ger w	PWA 724	PWA 724	6425 5760 AMS 5260	AMS 5265	Improved case hardness
Vane, High Comp. Inlet Guide	PWA 1202	PWA 1202	-	1 0020 CINY	refention in hot oil No comparable part
(1) Rei. Vol. (2) Same as S	<ol> <li>Rei. Vol. E-VIII, Table 1-)</li> <li>Same as STF210 Mark 2-7</li> </ol>				
	Same as STF219 Mach 5, 0				

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TABLE F2-1 (Cont)

## MATERIALS FOR GAS TURBINE ENGINE FOR SUPERSONIC TRANSPORT

Previous Proposal

	STEVIG	STF214	Previous Proposal	ronosal	
	Mach 7 65.000'	Mach 3. 0	JT115-11 Mach 2.5-2.7	JT1)F-12 Mach 3.0	Reason for Difference
	000 000		WIRCH 41 2-4.1	MACH 3. 0	
HIGH COMPRESSOR SECTION					
Blade-3rd Stage	FWA 1003	PWA 1003	PWA 1202	Same	Higher tamp. and stress
Blade-4th Stage	PWA 1003	PWA 1603	PWA 121,2	Same	Migher Jemp, and stress
Blade-5/b Stage	PWA 1003	PWA 1003	Same	Same	•
Bisde-6th Stage	PWA 1003	PWA 1007	Same	Same	
Blade-7th Stage	PWA 1003	PWA 1007	Same	Same	
Disk-3rd Stage	PWA 1003	PWA 1003	Same	Same	
Disk-4th Stage	PWA 1003	PWA 1003	Same	Same	
Disk-5th Stage	FWA 1003	FWA 1007	Same	FWA 1003	Higher temp. and stress
Disk-6th Stage	PWA 1003	PWA 1007	Stme	Same	
Disk - 7th: Stage	PWA 1007	PWA 1013	PWA 1003	Same	Higher temp. and stress
Spacer Inner 3rd-4th	PWA 1003	PWA 1003	Same	Same	
Spacer Inner 4th-5th	PWA 1003	PWA 1003	Same	Same	
Spacer Inner 5th-6th	PWA 1003	PWA 1007	Same	Same	
Spacer Inner 6th-7th	PWA 1007	PWA 1015	PWA 1003	Same	Higher temp. and atreas
Spacer chater 3rd-4th	PWA 1003	PWA 1003	Same	Same	
Spacer Uniter 4th-5th	PWA 1003	PWA 1007	Same	Same	
Spacer Outer 5th-6th	PWA 1003	PWA 1007	Same	Sar	
Spacer Outer 6th-7th	PWA 1007	PWA 1013	PWA 1003	\$ S	Higher temp. and stress
Front Hub	PWA 1003	PWA 1003	AMS 6304	- M5 6304	Higher temp.
Rear Hub	PWA 1003	PWA 1603	DWA 1010	0101 VA-	New Jesign allows economy
Tie Bolt	PWA 90	06 V.M.d	Same	Same	
Seal Disk	PWA 1003	PWA 1007	Same	PWA 1013	New design allows economy
Vane3rd Stage	AMS 5667	AMS 5667	AMS 5616	Same (	Improved corrosion
Var 2-4th Stage	AMS 5667	AMS 5667	AMS 5616	Same I	resistance
Vane-Sch Stage	A.MS 5667	PWA 687	Sarne	AMS 5667	Higher temp.
Vare-6th Stage	PWA 687	PWA 687	AMS 5667	AMS 5667	Higher temp.
Vane, Exit Guids	AMS 5754	AMS 5754	AMS 5667	PWA 687	Different construction
Shroud, Incer and Stage	AMS 5667	AMS \$667	AMS 5616	Same	Improved currosion
Shroud, Inner 4th Stage	AMS 5667	AMS 5667	AMS 5616	Same	79#181#76#
Shroud, Inner 5th Stage	AMS 5561	AMS 5668	Same	AMS 5667	Higher temp.
Shroud Inner 6th Stage	AMS 5668	PWA 1004	AMS 5667	AMS 5667	Higher temp.
Shroud Insier Exit Guide	AMS 5754	AMS 3754	Same	Same	
Inner Sealt	AMS 5754	AMS 5754	Same	<b>Serve</b>	
Case Cutel 3rd St-ge	AMS 5667		AMS 3616	Same (	Improved corrocion
Case Other Ath State	AMS 5667	AMS 5667	A AKS 5616	Same j	

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TABLE F2-1 (Cont)

## MATERIALS FOR GAS TURBINE ENGINE FOR SUPERSONIC TRANSPORT

	6.TE210	S 7767 2 1 4	Previous Proposal	roposel	
	Mach 2.7	Mach 3. 0	JT11F-11 Mach. 2.5-2.7	JT11F-12 Mach 3.9	Rescon for Difference
HIGH COMPRESSON SECTION (Cont)					
Case Outer 5th Stare	AMS 5667	AMS 5667	Same	Same	
Case Outer 6th Stage	AMS 5667	AMS 3667	Same	Same	
Case Outer Rear	AMS 5667	AMS 5667	•	ſ	No comparable part
Elaroud. Outer exit Guide	A.MS 5754	AMS 5734	Same	Same	
LIFFUSER AND COMBUSTION SECTION					
Liffuser Case, Inser and Cuter	PWA 1033	PWA 1030	Same	PWA 1033	Higher tamp.
	PWA 1009	PWA 687		PWA 1065	•
Comb. Case - Ottar Forward	PWA 1009	PWA 687	Same	Same	
C glab. Case - Outer Rear	PWA 1009	PWA 687	Same	Sume	
Coreb. Case - Inner Jorward	PWA 1004	PWA 1004	Same	Same	
Comb. Cane - Inter Rear	PWA 667	PWA 687	Same	Same	
	PWA 1030	PWA 1030			
Comb. Lúners	AMS 5536	AMS 5536	Game	Same	
Fuel Mazifold	AMS 5646	AMS 5646	Same	Same	
	0901 VMd	PWA 1060			
Fuel Nossle	AMS 5616	AASS 5610	Same	Same	
Bearing Rollers	PWA 724 CVM. or	PWA 724 CVM or	•	•	No comparable part
	AMS 6190	AMS 6440			
Bearing Races	PWA 724 CVM or	PWA 724 CVM OF	,		No comparable part
	AMS 6490	AMS 6490			
Bearing Cage	AMS 6415	AMS 5415		;	No comparable part
Bearing Support, inner	AMS 5615	AMS 5613	e	•	No comparable part
Bearing Support, Outer	PWA 687	PWA 587	ı		No comparable part
Seal Supports, Inner	AMJ 5613	AMS 5613	,	,	No comparable part
Seel Supports. Outer	AMS 3667	AMS 5667	1	1	No comparable part
TURBINE SECTION					
Case-Outer Front and Rear	PWA 1004	PWA 1:004	Same	Same	
Shaft. Low Turbine	FWA 1005	PWA 1003	3	•	No comparable part
Freat Coupling	PWA 1003	PWA 1003	Same	Same Dava 1010	New Josian allowed and some
Shaft, High Turbine	FULL 1003	CODI VAN		0101 CEL	

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TABLE F2-1 (Cont)

## MATERIALS FOR GAS TURBINE ENGINE FOR SUPERSONIC TRANSPORT

	61241.5	877219	Previous Eroposal	F s'sposel	
	Mach 2. 7	N'ach 3. 0 65,000*	JTHF-18 Mech 2.5-2.7	JT118-12	Rescon for
TURBINE SFCTION (Cont)					Difference
Vane-7 et Strge	Total 6. 6.6 a				
Vare-2nd Stree		FWA 653	P#A 437	PWA 657	
Vane-3rd Stace		V & A 653	220 A.G.S.	PWA 550	
Diade - Let Stave	PWA 558	PWA, 658	PWA 615	PYA 644	
Blade-2nd Stane	PWA 658	PWA 558	PWA 659	A DEAL ALWER	2010 2000 1000 2. 1 274 2. 2
	PWA 658	PWA 854	PWA 644	A CONTRACT	
	PWA 658	PWA 658	PWA. Act		
	PWA 1007	PWA 1027	PWA LANK		
	E001 VAd	PWA 1007	Same a	TWA 1005	Higher temp.
	PWA 1003	PWA 1007		PWA 1003	Higher temp.
Hub-Low Turbine	PWA 1003	ENEL AWG		PWA 2003	Higher temp.
Seal-Outer let Stage Tip	AMS 5754	A NASS 276A	oame Service		
Seal-Outer 2nd Stage Tip	AMS 5754	ANC STEL	came	Sarge	
Seal-Outer 3rd Stage Tip	AMS 5754		Sartes	Service Service	
Inner Shroud, Diaphragms and Seals	D'ar & Kon	SCIE EXEL	Sume	Sarra	
-lst Stage	DUA 1	PWA 087	Same	Same	
Inter Shroud, Distohraoms and Saale	DUY 1030	PWA 1030		2	
-2nd Stage	THA 001	PWA 687	Game	Same	
laner Shroud Dianiversan	PWA 1030	PWA 1030			
- Bud Staat	PWA 697	PWA 687	Same	Same	
	PWA 1030	PWA 1030			
Tisholts	PWA 1007	PWA 1007	PWA 1003	DWA 1001	
8449 3 3 4	PWA 90	PWA 90	Same	Same	nighter temp.
TURBINE EXHAUST SECTION					
Case. Turbine Exhaust Assembly.					
	189 A 481	PWA 687	Same	Same	•
Heatshields - Fyhanet Case Community	5.01 VAL	PWA 1030			
Tailcone	AMS 5536	AMS 5536	Same	Same	
Duct. Exhaust	ALAS 5536	AMS 5536	Same	Same	
	PWA 687	I.W.A. 687	Same		
	PWA 1030	1 WA 1030		- Carline	
PE'LE BEARING SECTION					
	E 2 A 724 CVM or AMS 6490	PWA 724 CVM of AMS 6490	<i>w</i> ame	Same	
<b>会争し内心</b>	PWA 724 CVM 2r AMS 6490	FWA 724 CVM OF AMS 6490	Same	Same	

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	RANSPORT		Resear for Difference		Different construction		•		No comparable part	No comparable part		Different construction	No comparable part	Different construction					No comparable part			Different construction		(Typographical error)	Improved corrocion resistance
	RSONIC TI	roposal	JT117-12 Mack 3.0		Sarte Alds 5613 Seine			Same	•	ŧ		0164 SMA	•	0164 SMA	Same	Same	Signation of the second s	Same	•		EE01 AW4	PWA 1009	Same	AMS 5504	atac ener
Cont)	FOR SUPE	Previous Proposal	JT11F-11 Mach 2.5-2.7		Seme AMS 56:3 Seme		Same	Same	•	ı		0167 LANA	•	AMS 4910	Same	Same	Same	Sante			. PWA 1033	PWA 1009	Same	AMS 5504	ater cours
TABLE F2-1 (Cont)	FOR GAS TURBINE ENGINE FOR SUPERSONIC TRANSPORT	37 <b>7</b> 219	Mach 3.0		AME 6415 PWA 1004 AMS 5413		0165 SMA	AMS 4966	AMS 4910 AMS 4968	0164 EMA		PWA 1202	PWA 1202	AMS 5508 AMS 4414	AMS 5536	PWA 45	AMS 5754	A.M.S. 5754	AMS 5536		AMS 4910	AMS 4966	PWA 658	AMS 5540	12.02 Mary
T	R GAS TURBI	577.2	Mach 2.7		ANSS 6415 FWA 1004 Ands 5613		A 1455 4910	AMS 4966	AMS 4910 AMS 4966	016t SILA		PWA 1202	PWA 1206	AHCS 5508 AMS 4626	AMS 5536	26 VMd	AMS 5154	AMS 5754	OFCC SMV		AMS 4910	AMS 4566	PWA 658	AMS 5540	
	MATERIALS FOI			REAR DEAUNC SECTION (Coat)	Cages Bearing Support Seal Support Aney	FAN DIFFUSTA SECTION	Duct Inner	Duct, Ostar	Strute	Turning Vanse	DUCT HEATER SECTION	Case - Forward	Case-Rear Mount	Case - Rear	Front Liner-Inder and Outer	Rear Linuz-Innar and Outer	Figme Holder	South State		DUCT NOZZLE SECTION	Unison Ring	; ;	Fiaps - Nossie	usul Veritrente - Muduel A transport - Modtan (1)	

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### TABLE F2-1 (Cont)

## MATERIALS FOR GAS TURBINE ENGINE FOR SUPERSONIC TRANSPORT

	Reach for Difference		New design of the second second	Autonosa santia utitati wat	Lower terms.	Lower terms.	Lower tents	Lower temp.		Different constantion	Improved corrogion registance
Toposal	JTILF-12 Mach 3.0		FWA 1013	PWA 1010	AMS 5525	Same	PWA 658	PWA 1061	Same	AMS 5536	9895 SWV
Previous Proposal	JTALF-11 Mach 2.5-2.7		PWA 1033	PWA 1010	AMS 5525	AMS 5525	PWA 658	PWA 1061	Same	AMS 3536	AMS 5616
STF 219	Mach 3.0		<b>AMS</b> 5542	AMS 5667	AMS 4910	AMS 5525	PWA 655	AMS 5582 AMS 5667	FWA 1010	PWA 687	AMS 5643
STF219	Mach 2. 7 65,0001		AMS 5542	AME 5667			200 C M L	AMS 5667	PWA 1030	PWA 687	AMS 5643
		RI VERSER	Ejector Shrad Assembly	Biew-la Doors Front	Blow-Is Deors Rear	Reverses Flans	Revereer Links		Frailing Edge Flage	Arthurtown Hartwells	The second se

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TABLE F2-2

PROPOSED SST MATERIALS RELATED TO CURRENT ENGINE APPLICATIONS

Major Component in SST Engine	Fan stator shrouds, rotor blades Fan diffuser dact weldment Reverser-ejector blow-in doors	Mount ringe Fan cases Vones and shrouds Fan disks, hub	niga compressor diske Fan compressor diske	Roller bearings, races	Ball and roller bearings, races		Bearing support weldmants Seal support weldmants	Compressor intermediate case Duct heater case Fuel norales	Air and oil lines
Engines Where Used Currently	357, JT3, J75, JT4, TF30	JTF10, JT11, TF30	Experimenta]	JT3D, JT8D, TF30, JT11	JT3D, JT8D, TF30, JT11		IIV	117	A1I
Specifications	AMS 4910 Sheet AMS 4926 Zara AMS 4966 Forgings	PWA 1202 Forgings PWA 1204 Bars	PWA 1203 Bars, forgings	PWA 724 CVM Dare, forgings	AME 6490 Bars, forgings, Whing		AMS 5504 Sheet AMS 5513 Bars, forgings AMS 5591 Seamless tubing	AMS 5616 Bare, forgings AMS 5508 Sheet	AMS 5645 Bars, forgings AMS 5510 sheet AMS 5570 Seamless tubing
TITANUM ALLOYS		TI-BAI-IMC-IV	T1-5A1-52 r-58a ALLOYS STEELS	Bower 315 (vacuum meited;	M-50 (vacuum melted)	STAINLESS STRELS	ALSI 410 (12 CF)	Greek Ascoloy (12Cr-2Ni-3W)	AL <sup>E</sup> T 321

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STAINLESS STEELS (Cort) Abi 347 Ai	specifications Cont) AMS 5046 Bars. forgings AMS 5512 Sheet	Engines Where Used Currently A11	Major Component in SST Engine Air and oil line≠ Fuel line fittings
NICKEL ALLOYS Inconel	AMS 5571 Seamless tubing PWA. 1060 Seamless tubing AMS 5540 Sheet AMS 5665 Bars, forgings	IIV	Fuel Lines Heat shields
Hattelloy X	AMS 5536 Sheet AMS 5754 Bars, lorgings	All	Compr. exit guide vanes and shrouds Burner liners Transition duct Turbine hlade tip seals Tailcone, duct heater liner Heatshields Spray ring assembiles
N-155 Rigimesh	PWA 35 Porous strip. sintered	JTII	Duct heater liner
Inconel X	AMS 5667 Bars, forgings AMS 5668 Bars, forgings	AII	Fan exit guide vanes Compressor vanes and shrouds
	AMS 5542 Shref		Seal support weldments Reverser-ejector shroud assy and links
Incopel 718	PWA 1009 Bars, forgings PWA 1010 Bars, forgings FWA 1033 Sheet	TF30, JT11	Diffuser case weldment Combustion case weldments

TABLE F2-2 (Cont)

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TABLE F2.2 (Cont)

# PROPOSED SST MATERIALS RELATED TO CURRENT ENGINE APPLICATIONS

Major Component in SST Engine	Compressor blades, disks. spacer, hubs Turbine disks, spacers, hubs sh <u>e</u> fts	Compressor vanes and shrouds Compressor blades, dicks, spacers Tiebolts Combustion case weldments Turbine disks and spacer Turbine cases, shroudo, ducts	Compressor disks, spacers	Turbine blades 2nd and 3rd stage turbine vanes Duct heater nozzle flaps	Turbine blades (alternate) 2nd and 3rd stage turbine vanes (alternate)	Turbine blades (alternate) Turbine vanes (alternate)	Reverser flaps	lst Stage turbine vanes
Engines Where Used Currently	11V	A11	JTLI	JT1 I	JTI	Éxperimental	J52, JT8, TF30	J52, JT8, JT3, TF33, GG4, JT12
Specifications at)	PWA 1003 Forgings	PWA 687 Bars, forgings PWA 1004 Bars, forgings PWA 1007 Forgings PWA 1030 Sheet PWA 90 Bolts	PWA 1013 Forgings	PWA 658 Investment castings	PWA 559 Investment castings	PWA 663 Investment castings	PWA 655 Invertment castings	PWA 553 Investment castuigs
NICHEL ALLOYS (Cont)	Inc. Joy 901	Wanpaloy	A.troloy	1N-100	SM 200	599 VAd	Incone) /? S	COBALT ALLOYS

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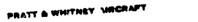
### 2.1 Turbine Blades

A primary factor in the development of turbojet engines having improved thrust ratings has been the development of turbine blade alloys with mechanical and physical properties capable of withstanding the high temperatures and stresses involved. Early in the development of the J48 centrifugal compressor turbojet engine it became apparent that the properties of the current turbine blade alloy, Nimonic 80A, limited the performance and hindered the development of advanced powerplants. The attainment of increased thrust ratings was closely linked to the development by Pratt & Whitney Aircraft of a new nickel-base precipitation hardening alloy. This alloy was the original Waspaloy, with the following composition - 19.5Cr, 13.5Co, 3.5Mo, 2.5Ti, 1.2Al, balance nickel. Initial development efforts were concerned with defining the composition, directing programs at the fabricators leading to improvements in melting and forging practice, and establishing the heat treatment which is basic for this and similar alloys. This alloy system proved to be so successful that it formed the basis for a family of forged alloys, including Udimet 500 and Udimet 700, which are basically similar to Waspaloy, but with higher hardener contents (Ti and Al). With each level of increase of strength due to additional alloying elements, the forgeability of the material was reduced. Beyond the Udimet 700 composition a family of nickel-base alloys has been developed which achieved such high creep and rupture strength that the alloys are currently considered non-forgeable and therefore are employed as castings. The relationship of forgeability to composition is illustrated schematically in Figure F2-1. During the period of development of the family of nickel-base superalloys, performance improvements of Dratt & Whitney Aircraft turbojet engines have been realized because of the development of higher-strength, higher-temperature, better quality, and more reliable alloys. To illustrate this, the temperature capability of these alloys has increased more than 300°F from 1947 to 1954. This progress is shown in Figure F2-2.

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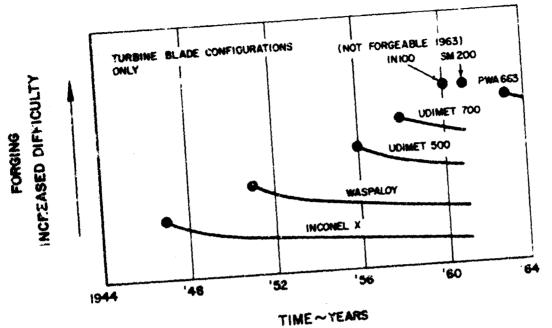
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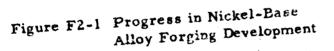
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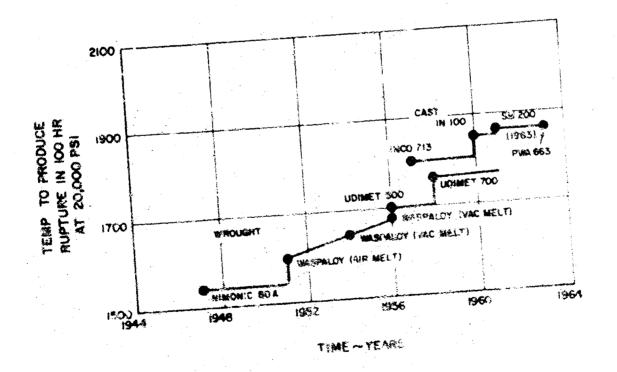


Figure F2-2 Progress in Mickel-Base Alloy Developmen

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2.1.1 Amoy Selection for the SST Turbine Blades - Selection of the alloy for the turbine blades of the SST engine is based on successful JT11 (J58) engine experience, which was in turn based on thousands of hours of laboratory and test rig evaluation. The results of this testing are discussed in Section 15 of the Final Contract Report. Primary factors evaluated in these extensive Pratt & Whitney Aircraft materials programs include:

Mechanical properties at elevated temperatures

- Creep and stress-rupture strength and ductility
- Tensile strength and ductility
- Fatigue behavior of test bars and prototype blades
- Thermal fatigur, both coated and uncoated
- Oxidation-corrosion and erosion resistance
- Coating requirements for high temperature operation
- Metallurgical stability during long exposures to temperature and stress
- Reliability of castings as related to melting, casting and quality control - actices.

Based on an analysis of such factors as detailed above, three nickelbase alloys, PWA 658 (IN 109), Phile 659 (SM 200), and PWA 663, are proposed as the most promising candidates for first, second, and third stage turbine blades. CarA 658, 659 and 663 are complex nickel-base casting alloys which derive their strengths from dispersions of carbides and Ni3 (Ti, A1, M) type intermetallic compounds. Nominal compositions and stress-rupture acceptance requirements of the alloys are listed in Tables F2-3 and F2-4.

### TABLE F2-3

### ALLOY COMPOSITION

Alloy	Туре	Composition
PWA 658	Nickel-base	9.50r-15Co-3Mo-4.8Ti-5.5A1-1V-0.0158- 0.062r
PWA 659 PWA 663		SCr-10Co-12.5W-1Cb-2Ti-5A1-0.015B-0.0cZr 8Cr-10Co-6Mo-4.3Ta-1Ti-6A1-0.015B-0.07Zr

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### TABLE F2-4

### PWA SPECIFICATION REQUIREMENTS FOR STRESS-RUPTURE PROPERTIES

Alloy	Temp.	Stress	Life (min.)	Elongation (min.)
PWA 658	1800F	29,000psi	23 Hrs.	4%
	1400	85,000	23	2
PWA 659	1800	29,000	23	3
	1400	94,000	23	]
PWA 663	1800	29,000	30	3
	1400	94,000	23	1

(Elongation at 1400F is determined 2 hours before rupture).

The PWA 658 alloy selected as the primary candidate material for the three turbine stages has been demonstrated to be a highly reliable creep-resistant, commercially available cast material by considerable rig, experimental engine, and accumulated service experience in J58 engines. The alloy is readily castable into the intricate configurations required for cooled turbine blades. Furthermore, though it possesses high creep-rupture strength in the cast condition, a 1600°F heat-treatment for 12 hours significantly improves the 1400 and 1800°F creeprupture properties over the as-cast condition. The most significant improvement in PWA 658 properties occurs in 1400°F creep-rupture life and prior creep elongation. This is of primary importance, since the 1400°F ductility of nickel-base alloys is often a limiting factor, particularly when highly stressed configurations such as blade roots are to operate at this temperature.

Materials design criteria for turbine blade alloys are based on creep and rupture data for the proposed operating temperatures. Time to 1 per cent creep is one of the limiting factors in blade design, and it defines the capability of any alloy to withstand long time operation. In addition to strength to resist the tendency to creep at high temperatures, a useful alloy must have sufficient ductility to resist the adverse effects of stress concentration. Using fundamental information of this type, the designer must then provide for supplemental cooling, where operating conditions require gas temperatures which are incompatible with the

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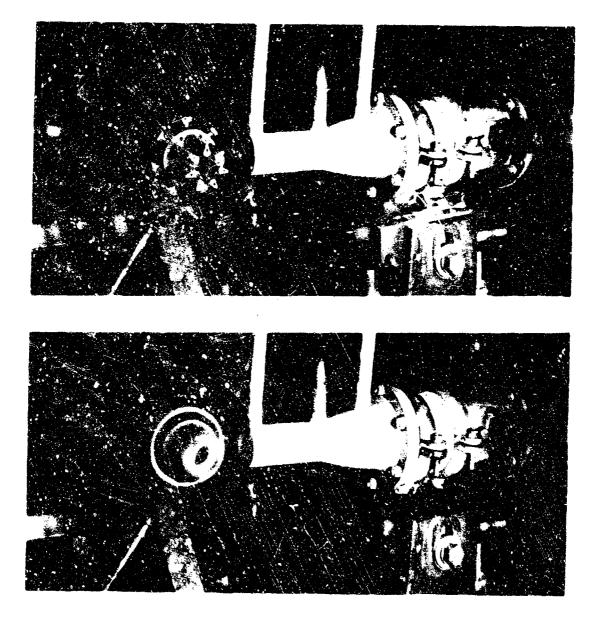
long-time, high-temperature properties of the material. Conventional creep and rupture tests unfortunately show only the effects of steady stress and temperature on the deformation behavior of an alloy. Thermal gradients produced in both cooled and uncooled parts have a significant effect on the alloy's performance, but do not yield themselves to simple prior analysis. Pratt & Whitney Aircraft has built up a tremendous fund of practical experience on the applicability and reliability of both cast and wrought nickel alloys under many varied conditions of engine operation, and is, therefore, fully aware of the limitations of these systems. Continual studies of effects of thermal gradients associated with air cooling, combined stress fatigue, and thermal fatigue supplement standard creep, rupture, and fatigue testing in order to understand more fully the complex behavior of turbine blade materials.

Oxidation, sulphidation, corrosion, and erosion resistance are also of importance. Because these material properties as revealed by conventional laboratory methods often do not correlate with behavior exhibited in an actual engine, new testing methods have had to be devised. The rotating specimen rig, pictured in Figure F2-3 shows one type of apparatus. This rig is capable of simultaneously exposing several samples of promising blade or vane materials and coatings to high velocity, high temperature gases, with or without additives, to simulate engine service. Through laboratory rig tests and experimental engine tests, the sources of failure in the cobalt-and ...ickel-base alloy systems have been defined. It has been found that coatings could be tailored to retard sulphidation, erosion, corrosion, and thermal fatigue triggered by oxidation at grain boundaries. One of the significant results of this program has been the development by Pratt & Whitney Aircraft of an aluminum-silicon coating (PWA 47) which is used to protect nickel-base turbine blades from intergranular oxidation. The effectiveness of this coating in protecting the metal surface is illustrated in Figure F2-4. A high temperature diffusion cycle is employed to produce a layer of intermetallic compounds closely controlled in thickness. The coated surface is an effective barrier against surface reactions generated by the combusted gases. The factors which limit coating life, exclusive of the prospect of foreign particle damage, are the physical changes associated with the diffusion mechanism, the surface melting temperature, and the erosion resistance of the coating. The PWA coating is known to melt at approximately 2100°F and the test data which have been collected under rig tests predict that metal surface temperatures should not exceed 1900°F for extended engine operation. Test data in excess of 1400 hours at 1700°F have demonstrated that the rWA coating maintains its integrity with no significant signs of distress. Because of the importance of coatings in the operation of nickel alloy hardware at temperatures above 1700°F, Pratt & Whitney Aircraft has maintained a development

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Figure F2-3. Rotating Specimen Rig

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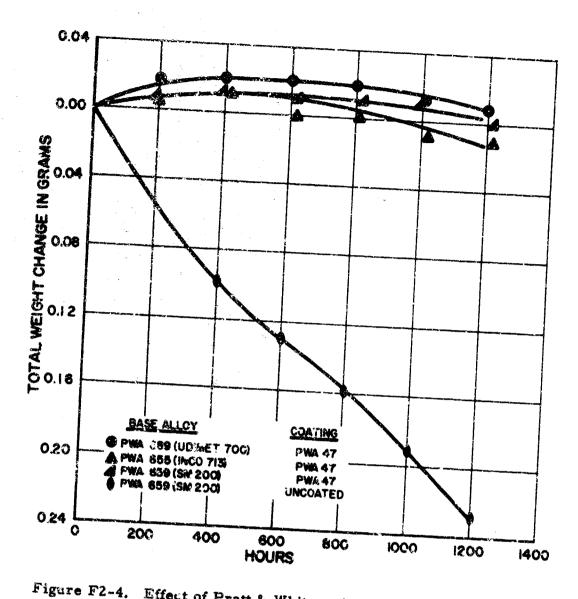


Figure F2-4. Effect of Pratt & Whitney Aircraft Coatings on 1000 Hour Erosion Properties of Three Nickel - Base Alloy Turbine Materials at 1700°F

program aimed at increasing the effectiveness of coating-base metal protective systems. One coating, on which many hundreds of hours of rig data are available, has a 200°F melting point advantage over the present commercially used FWA 47 coating.

Metallurgical stability during long time exposure to temperature and stress has been of concern in commercial operation with the precipitaion hardening nickel-base alloys, chiefly Waspaloy, Udimet 500 and Udimet 700. Pratt & Whitney Aircraft has conducted extensive electron metallographic and microprobe phase identification studies of carbide, boride, and sigma phases in both wrought and cast blade alloys. These

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results are presented in Section 15 of the Final Contract Report. Overaging and attendant loss of rupture strength, as well as embrittlement due to (a) precipitation of M23C6 or M6C carbides at grain boundaries, or (b) duplexed grain structure resulting from forging and intergranular cracks associated with creep deformation mechanisms, have been encountered. Although Pratt & Whitney Aircraft has millions of hours of commercial and military experience on wrought and cast nickel alloys, it continues to direct considerable attention towards defining the effects of the above factors in order to extend the useful life of wrought turbine olade material and to improve the temperature-time capability of the cast nickel alloys.

The two alternate cast alloys, PWA 659 and PWA 663, considered for turbine blade application have also undergone extensive rig and experimental engine testing. Comparison of all three cast alloys on the bar is of stress for 1 per cent creep at 1600°, 1700° and 1800°F indicates that PWA 659 is more creep resistant than PWA 658 or PWA 663 for times of 1000 to 10,000 hours. These results are shown in Figures F2-5 to F2-7. These materials are considered on the more realistic basis of strength-density relationship in Figures F2-8 through F2-10. The cast alloys are more nearly equivalent in strength-density.

the PWA 659 alloy has performed favorably in advanced JT-4 and JT-11D engines. PWA 663 also has experienced engine tests in JT-8 and TF33 engines, showing impressive performance in creep and thermal fatigue. Although PWA 659 shows superiority in creep and thermal stability to all other cast alloys, the alloy shows lower creep ductility at intermediate temperatures (1200° to 1400°F). Since PWA 659 and PWA 663 alloys offer considerable promise, improvements in master heat production methods and investment casting techniques are being explored by vendors and Pratt & Whitney Aircraft. Based on current data, encouraging ductility advances have been noted. In fact, when thermal stability and mechanical strength (exclusive of ductility) are considered, PWA 659 and PWA 663 are equivalent to PWA 658, and when the expected ductility advances are confirmed by extensive rig and angine testing, these alloys may well surpass the best performance of PWA 658

Although evaluation of all candidate alloys has been discussed largely in terms of creep-rapture, thermal fatigue, and oxidation-crossion resistance, a significant factor concerning the mechanical behavior of these cast nickel-base alloys should be noted. Reversed bending fatigue data for PWA 658 and PWA 659 show high fatigue strength, with notched fatigue strength ( $10^{5}$  cycles) equivalent to or higher than smooth strength at elevated temperatures. Note that PWA 659 is superior to PWA 658. These notch strengths, which range as high or higher than smooth bar strengths, are most encouraging from a design standpoint. These results are listed in Table F2-5.

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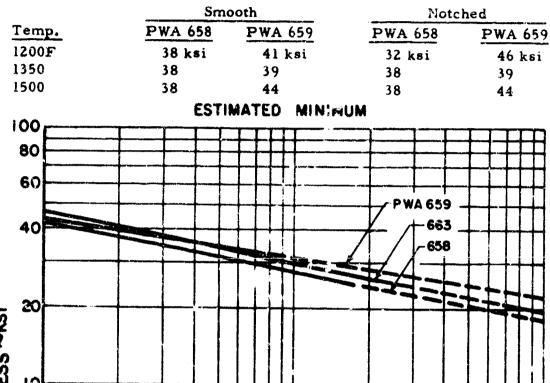
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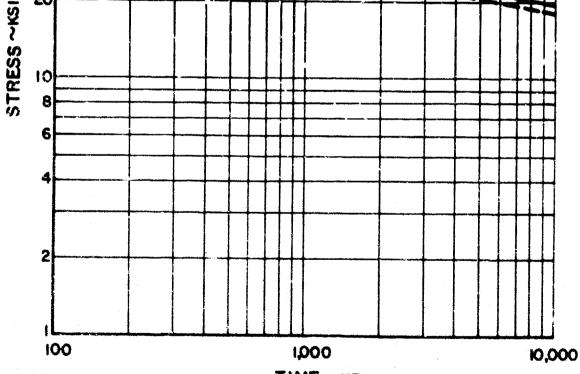
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### TABLE F2-5

### FATIGUE PROPERTIES (108 CYCLES) FOR

### PWA 658 AND PWA 659 ALLOYS





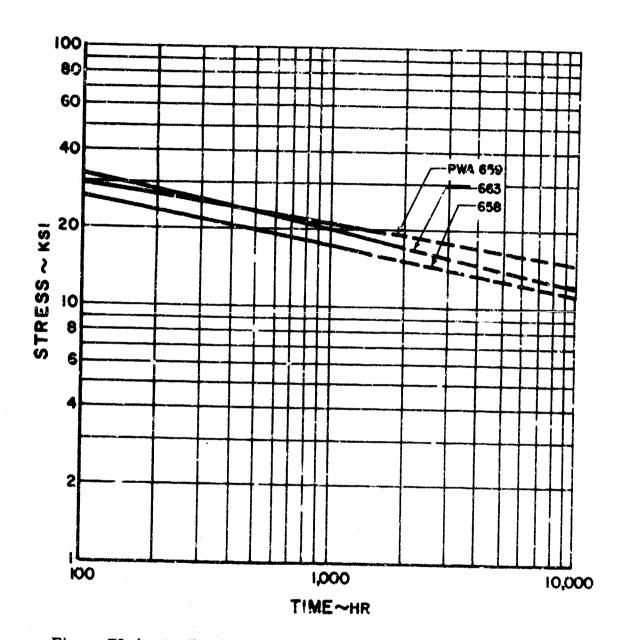


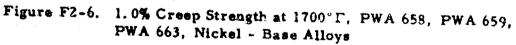
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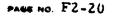
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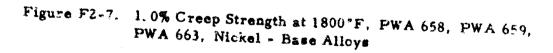
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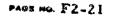
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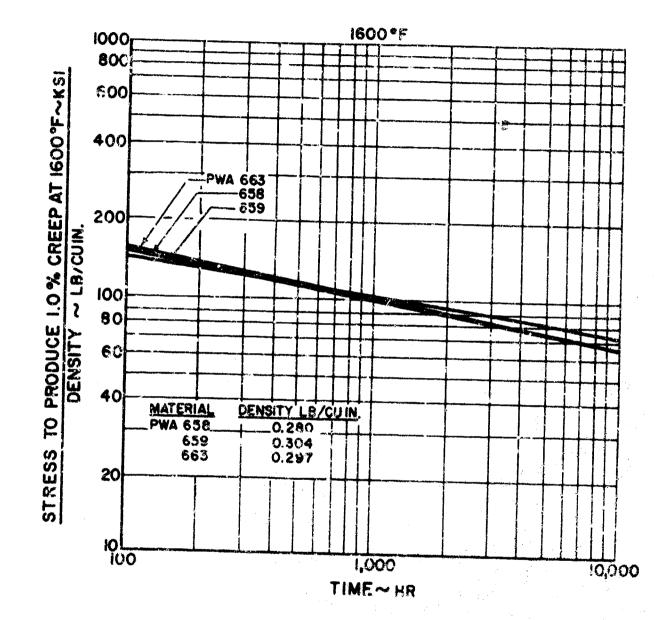


Figure F2-8. Time to 1.0% Creep at 1600°F

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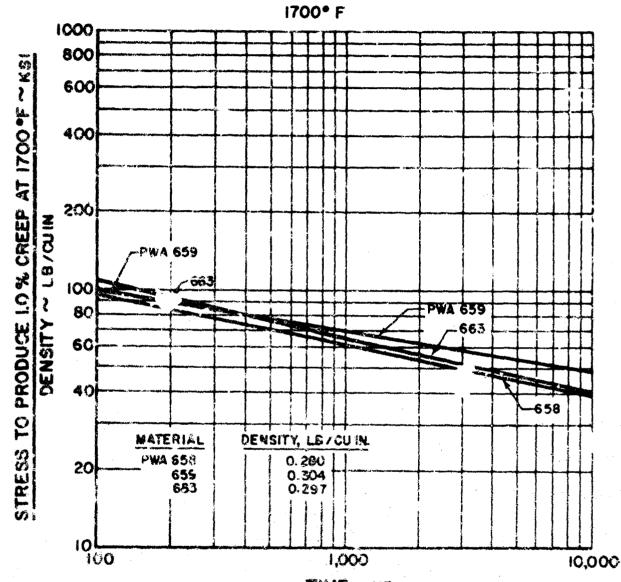
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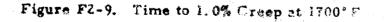
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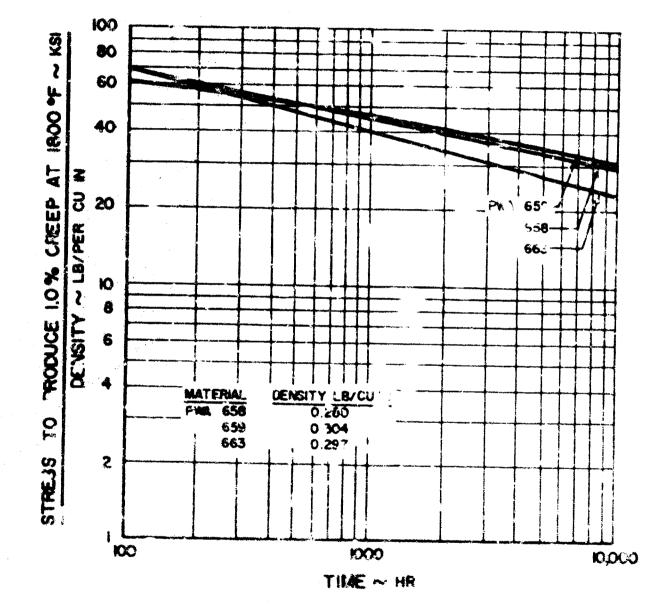
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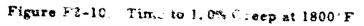
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### 2.2 Turbine vanes

Pratt & Whitney Aircraft has inade extensive use of cobalt-base alloys, particularly as precision-case first stage turbine vanes, because of their excellent resistance to thermal shock, high melting temperature (cobalt has some 70°F superiority over nickel in melting point, 272)°F vs. 2651°F), and good castability. The cobalt alloys gain their strength principally from complex refractory metal carbides, which are difficult to dissolve and diffuse. This carbide strengthening, although effective at high temperatures, is less effective than the strengthening process of the nickel alloys at intermediate temperatures. Thus, cobalt alloys are used more in vane (high temperature) than in blade (intermediate temperature) applications. Pratt & Whitney Aircraft use of cast cobalt alloys includes Stellite 21 (AMS 5385), Stellite 31 (AMS 5382), WI-52 (PWA 653) and SM 302 (PWA 637). The latter two alloys, which use increased amounts of the refractory metals tungsten and tan'alum, are significantly stronger than the Stellite 21 and 31 alloys. W7-52 alloy, containing 21Cr-11W-2Fe-1.75Cb-0.45C, has been shown to have the greatest how resistance of any current dast cobalt base alloy. It does require a suitable protective coating for long time use, and it has been found that a diffused aluminum coating (PWA 45) provides adequate protection for this alloy. The properties and characteristics of the nickel-base superalloys being considered for SST application are described under the turbine blade portion of this section.

The alloys under discussion are fundamentally subject to damaging structural changes dependent upon certain c inditions of stress, temperature, and time. Some cobalt-chromium alloys strengthened by refractory metal carbides are susceptible at high temperatures to the formation of a brittle chromium-cobalt intermetallic known as sigma phase. Further, the strengthening carbides under conditio s of high heat may collesce and eventually dissol.e, causing loss of strength. The nickel-base alloys strengthened by the Ni3 (Al, Ti) compound are. of course, also susceptible to loss in strength when overaging (increase in particle size) or dissolving of the hardening constituent occurs at high temperatures. Further, these alloys are to varying degrees susceptible to damage under conditions of thermal cycling and thermal fatigue. Pratt & Whitney Aircraft is very aware of the limitations of the nickel and cobalt systems with regard to long time stability and has, over the years, built up a tremendous amount of experience in this area Additional information in this area is provided in Section 15 of the Final Contract Report. Materials for the turbine comprisons of Pratt & Whitney Aircraft cogines are selected on the basis of meeting long time durability requirements.

FWA 653 (W1-52) has been selected as the first stage vane alloy for the SST engine. This selection was based on the material's good thermal

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shock and bow resistance, and the accumulated flight experience in various models of the J52, JT8, JT3, and J75 engines. The alloy revaires a protective coating for service above 1700°F but, as stated previously, an established aluminum-base coating has been found to be adequate for this purpose.

PWA 658 (IN 100) has been selected for both the second and third stage vanes in the SST engine based on the excellent performance of this Ch y in the J58 engine. The higher stresses in these stages require a stre.ger alloy than PWA 653. The outstanding properties of PWA 658 alloy, excellent castability and excellent high temperature and thermal fatigue strengt's, have been demonstrated in turbine blade applications as described earlier in this section. Stress-rupture acceptance requirements for these two alloys are listed in Table F2-6.

### TABLE F2-6

### ALLOY STRESS RUPTURE REQUIREMENTS

	Temperature (°F)	Stress (psi)	Life (Hrs. Min.)	Elongation (% Min.)
PWA 653	1800	15,500	23	5,
PWA 658	1800	29,000	23	4

These properties and others are controlled by specification. In addition, Pratt & Whitney Aircraft alloy qualification includes stringent rig and experimental engine testing to evaluate bow, thermal fatigue and thermal shock resistance. Average results of such testing are shown in Table F2-7.

All three vane stages will be coated for protection against surface oxidation and corrosion and cooled to decrease metal temperatures to acceptable levels. As indicated previously, PWA 45, a diffusion coating, will be used on WI-52. This alloy-coating system has been used successfully in the J52, JT3, JT3 and J75 engines for millions of hours of commercial and military operation. PWA 47, diffused aluminum-silicon coating, will be used to coat the PWA 658 (IN 100) vanes. Based on maximum expected turbine inlet temperatures and the cooling schemes to be employed, average vane metal temperatures of 1750°F. will be experienced, with maximum temperatures not exceeding 1800°F.

Of several alternate alloys considered for vane use, FWA 559 has been selected as the back-up material to PWA 658 in second and third stage vanes, and PWA 663 for use in all three stages. PWA 563 has demonstrated outstanding thermal shock and thermal fatigue chacacteristics in both rig and experimental engine tests.

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## TABLE F2-7

## RIG TRAILING EDGE BOW AND THERMAL SHOCK DATA FOR VARIOUS COATED AND UNCOATED NICKEL AND COBALT-BASE ALLOYS

Alloy	Coating	Trailing Edge(1) Bow (Incheo)	Trailing Eage Bow(2) in Thermal Shock Bow Test (Inches)	Cycles to Crack(2) In Thermal Shock Bow Test (Cycles)
Nickel-Base			-	
PWA 658 (IN 100)	None	0.004	0.004	600
FWA 658 (2 100)	PWA 47	0.003	0.004	900
PWA 659 (SM 200)	None	0.003 - 0.007	0,003 - 0.010	100 - 400
PWA 659 (3M 200)	PWA 47	0.001 - 0.002	9, 902 - 0, 906	300 - 1200
PWA 663	None	0.002 - 0.000	0.004 - 0.015	200 - 600
PWA 663	PWA 47	0.002 - 0.003	0.003 - 0.094	900 - 1300
Cobalt-Base				
PWA 653 (WI 52)	None	0.005 007	0.007 - 0.023	100 - 500
PWA 653 (WI 52)	PWA 45	0,90 <b>4 - 0.008</b>	0.009 - 0.017	500 - 700
PWA 657 (SM 102)	None	0.014 - 0.024	0.029 - 0.072	400 - 600
PWA 657 (SM 392)	PWA 45	0.005	0. 025	900

(1) 12 hours at 1950°F and 5000 psi.

(2) 12 hours at 1950°F and 5000 psi + 400 thermal cycles (2100°F - 15 seconds hot, 30 seconds cold)

For future vane and blade consideration new nickel-base alloys recently developed by Prait & Whitney Aircraft and designated PWA 664, PWA 1401, and PWA 1402 promise thermal fatigue properties far above any existing alloy. The anticipated thermal fatigue life should lead to longer lived and more reliable turbines.

In a more advanced class, the duPont developed dispersion strengthened alloy, TD nickel is a promising vane material. This alloy is attractive because of higher melting point (2650°F). and higher thermal conductivity than conventional superalloys, permitting higher vane operating temperatures and greater resistance to thermal fatigue and shock by minimizing thermal gradients. Uncoated TD nickel sheet metal vanes have shown excellent endurance in 2000°F. rig tests. TD nickel vanes have been engine tested or scheduled for test early in 1965 in J58, TF30, TF33P-7 and JT8D engines. TD nickrome, recently released

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Martine of China Line haves

by duPont also is receiving a great deal of attention since it has greater oxidation resistance than TD nickel.

Furthermore, a new nickel-base alloy recently developed by Pratt & Whitney Aircraft and designated PWA 664 promises thermal fatigue properties far above any existing alloy. Operating temperatures will necessarily be limited by coating melting point and stability; however, the anticipated thermal fatigue life should lead to longer lived and more reliable turbines.

2.3 Material Descriptions

General descriptions of the chemical composition, mechanical properties, and fabrication characteristics of the materials selected for use in the supersonic engine are presented on the following pages.

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#### AMS 4910 AMS 1926 AMS 4966 USNERAL INFORMATION SPECIPICATIONS: LHS 6910 \* 35 4926 AMS 4966 Sheet, strip, plute 904089+ Porgings, forging stock Bara CADITION: Annealed (Rc 36 max) Antealed Amusaled (Rc 36 max) C-12.0. DESIGNATION: A-1104T, TI-5A1-2,50 %

#### MALTING PRA .TICE: Nultiple consumable electrode melted under vacuum

GENERAL DESCRIPTION: Ti-5A1-2,55n is an alpha titanium alloy which is not hardenable We description: Ti-SAl-2.55n is an alpha titanium alloy which is not hardenable by isatreatment. Alloy is applicable to compressor components which must be welded and/or which require strength operior to that of ANS 4001 at temperatures up to 8000 P. Tensile strength of alley is inferior to that of ANS 4028 (Ti -6Al-4V) out its creep strength is superior at temperatures above 800 P. Alloy forges with slightly more efficiently than ANS 4928 and its machinability is comparable to that of the other titsmium alloys (similar to a stanitic stainless steels). Weldability poses no problem men accomplished with proper techniques. Oridation resistance is good at temperatures up to 1000 P. Corrosion resistance in general is excellent; however, with advance combinations of stress, taxperature, and halogen media, stress corrosion cracking is possible.

APPLICAT: "5: Titenium parts requiring good weldsbillty and strength superior to chat of ANS 4901 and ANS 4921 at temperatures up to 800 F. Particularly applicable to compressor components.

CHEMICAL ONEPOSITION (Nominal):

0.155°	<u>81</u> 5,C	<u>Sn</u> 2.5	0.50°	0.30*	0.11	N 0.07∺	Ti ramainder
"Ken lang							

HEATHEATEISNTE

GATESNT: Not hardenable by heatment. Solution inneal: 1500 F  $\pm$  25, air cool. Vacuum or inert atmosphere required for heatmentment of sheet and finish machined surfaces at temperatures chowe LSO F. Stress-relief: 1156 F for 2 hours in air, air gool.

MBILLTY: Good formesbility, but more difficult than AMS 4928 (T1 - GAl-4V). Recommended forging range is 1900 - 1600 P. FULLIGABILITY:

while the set of the OHINCILLTY:

INABILITY: Somewhat difficult; more difficult than that of commercially pure grades and austenitic stainless steels. Essential requirements for successful mechining are: sharp tools, heavy feeds, slow speeds, rigid support, and soundant supply of coolant. MCHINABILITY:

SILITY: keediiy weldable by resistance or fusion methods. Fusion welding is done in protective inert as staosphere with ANS 4951 (commercially pure titanium) filter motel. Stress-relief at 1150 P for 2 hours in air required for large or complex fusion weldments. YELEABILITY:

BRAZEABILITY: WFILITY: Not readily brazeable. Limited experimental brazing has produced ductile joints with pure silver brazing metal. For specific applications consult Design Metallurgy.

#### CHEMICAL MOPERTIES

CORMUSICH MESISTANUS: General correlation resistance is excellent. Subject to str correlation failure when exposed under stress to helogen-containing strespheres at temperatures above 500 F. Subject to stress

UXIDATION HUBISTANCE: Resists exidation at temperatures up to approximately 1000 F. Extended exposure at 1000 F and higher results in loss of ductility and fatigue strength due to diffusion or exygen.

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				\ <u></u>				
SPECIFICATION		1902, 1		ì				
	-		ing stor	1				
CONDITION:				ution and ed by for		ition anne	aled - HC 3	9 maximum
COMMON DESIGN	NTION:	T1-8A]	1-1Mo-1V					
KELTING PRAUT	ICE:	haltiple	consume	ble elect:	rode melte	ed under v	B C ILLUM	
COMPRESSO temperatur (Ti-uAl-4) and siria more diffi titanium a	r compon re range V) alphs co stabi iculty t illoys ( b to the ifficult	ealed co ents wid 500 - 3 -beta al .lity are ban AlS similar	ondition. Ich requi LONO F. Lloy jart bood up 4928 and to suate	<pre>. Alloy is re good s Alloy is a :culerly ( ) to appro; ! its machinitic stat</pre>	articul trength an superior f at tempera ximately 1 inability nless at	larly appl nd thermal in strengt tures abo 1000 F. a 18 comper- als). We	icanle to stability h to anneal ve SOC F. lloy fortan able to the Idebility f	which is used by solution within the led Abu 4928 resultantics is with alight it of the othe someworth is by welding may at of Abu 491
AFFLICATIONS: within the and discs	e tempar	nium par ature re	rts pequi Lige of f	iring supe. 500 - 900	rior train P. Used	lle yield : primarily	ard groop i Tor compre	trengths ssor blades
CHARLESULP	OSITION	(homins)	•					
0.08	8.0 8.0	1.0	1.0 1.0	Pe 0.30+	0.15*	0.05+	0.015	Ti remainder
*haximum						(500 ppm)	(150 ppm)	
HATKAATI MIT I								
Stabi)/se Normal he atabilizin	anneal: atreatme Ng arnea Ne atren	1035 - nt 1s a ls. 301 with and	lll5 F i duplex t ation an rorm tog	usaling vi perature i	min.), air Mich inco thin 1775	process - 1975 F		lon and inces slevate; of some loss
FORGEABLITY: Hecommod				lightly = ) - 1650 F		cult than	AHS 4928 (1	[1-6A1-4V).
AGAINA HILTY accomplision but with	hea with	7 7200 Pe	meral to	schniques -	sh nate of amployed i	f work har for austan	duning. Ha Itic stain	ichining Lusa steels,
consult D	nera'iy hea'ia suign Ne	used fo tments : tallurg	or ANS 49 Required For e	10 (A-110) after fua	T) alpha ion weldir dment in	type tite ng large o volving jo	nium alloy. r complex d	nce or fusion . For stress assemblies, lerate to high
Bhazdadility; Successi: general a	Pre) 1 joint: hould me	liminary • can be • similar	hateria) produces r to the	is Develops 2 with Ad t of A-110	ment fa a base toras b	natory dat lig. alloy.	a indicates Prazesbi	e that lity in
			CHARL	LAL PAURAA	<u>. 1.23</u>			
CORNULION RUL correstor	creck1:		exposed i	ro <b>sion re</b> n inger stro	istance i: su to hale	s e⊷silen 9 <sub>0</sub> en costa	s. Lubjec Inic atmo	t to stress- apheres at
temperatu.			ises oxi-	higher tem	perstures	res up to results i	approximat n loss of	ely 1000 F. duct11ty and
UNIUM II UM MAIS	periods	ar esta ar bro	perties	in several	•			
UXIDAIIGE MAG Billandes	periods	of erro all pro	erties	in seeral	•			

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PWA 1203

#### GENERAL INFORMATION

SPECIFICATION: PMR 1903

CONKON DESIGNATION: T1-5A1-6ZF-6SB

Public Bars, forgings, forging stock, sheet

CUBDITION: Annealed

Millik PHACTICs: Multiple consumable electrice melted under vacuum

Gingmal Daschirflös: Ti-5A1-5Zr-5Sn is an alpha titanium alloy which is not hardenable by heatreatment. Alloy is applicable to jet engine compressor components which require good strength and stability within dO0 to LOCO F range. Compared with PMR 1202 (Ti-cal-1Ko-LV), alloy has lower elevated temperature cansile properties and higher creep resistance above BOO F, and has comparably good scability up to 1000 F. rorgeability of alloy is similar to that of Ti-7A1-12" but considerably poorer than that of PML 1202. Weldebility is roughly comparable to rWA 1202 and alightly more difficult than A-110AT for weldrents with high weld joint restraint. Oxidation and cormanian resistance are comparable to the. of A-110AT and PWA 1202.

APPLICATIONS: Compressor components requiring creep resistance superior to that of ANS even (A-110AT) and rai 1202 (T1-MA1-1No-1V) within 800 - 1000 F temperature range.

CHEMICAL COMPOSITION (Nominal):

C D.D. Magimum	5.0	5.0	8 <u>0</u> 8.0	7.15°	0.10	0,03 (300 pps)	<u>E</u> 0.015" (130 pc)	Ti remilador

HaaTKhaTkaaT: Not hardenable by heatrestmont. Generally used in sinche or duplex annealed condition. Best hestreatment to date for optimum combination of tendio, creep, and stability has been: 1650 F/4 hr/air cool.

PURGENEILITY: Difficult. Similar to Ti-7Al-17Zr titanium alloy, but considerably more difficult than PMA 1202 (Ti-8Al-1No-1V) and AMS 4920 (Ti-6Al-4V). Usually forged between 1025 P and 1700 P.

MACHIMABILITY: Somewhat difficult due to high rate of work hardening. Comparable to other titanium alloys and slightly more difficult than the sustainiess steels.

MolEAFLITY: So PMA experience to date. rublished literature indicates that dustile welds with good strengths are possible by techniques used for A-HIGAT. For a given weldsucht involving joints of moderate to high restreint, alloy may be more difficult to weld than A-HIGAT or Ti-dai-lRo-LV. For streas relieving hestreatments required for large or complex weldments, consult lession Metallury.

#### CHARICAL PROPERTIAS

CORROSION RESISTANCE: General correcton resistance is excellent. Subject to stress correction cracking when exposed under stress to haloget containing stmospheres st temperatures above 500 F.

OLIDATION MESISTANCE: Comparable to PMA 1202.

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## AME 5613 AMS 5504 AMS 5591

#### OFFICIAL INPOSEATION

SPECIFICATION:	ANN 5613	ANS 5004	AMB 5591
AVAILABLE PORNS:	Bars, Sorgings	Sheet, strip, plate	Seamless tubing

Nar: Not and sold finished, Bhn 941 mag Forgings: As ordered Sheet: Annealed CONDITION

COMPON DESIGNATION: AISI Type 410, SAN 51410

MELFING PRACTICR: Generally air melted in electric furnace. Vacuum melted and vacuum degaseed materials are available for special applications.

Within temperod minimum terms and the martaneitic, corrosion resistant steel which is heatreatable over herdmess range of ED 60 - Rc 46. Stress-rupture and creep strengths of siloy are infector to those of Greek Ascolog (AMS 5616, AMS 5509) when heatreated to same hardmess. Yield strength of alloy is comparable to that of Greek Ascolog (came hardmess level) at temperatures up to approximately 800 P, but inferior at higher temperatures. Yorgeability, machinebility, and weidebility of alloy are slightly superior to 0, set Ascoloy. General correction resistance of alloy is superior to that of low alloy steels and comparable to Greek Ascolog. When tempered within 700 - 1100 P range, alloy 1, susceptible to stress corrosion eracking. Oxidation resistance of alloy is good up to approximately 1000 P. GENERAL DESCRIPTION:

APPLICATIONS: A wide variety of structural parts requiring moderate to high strength and rust resistance at temperatures up to approximately SCO F and which might require welding or brasing. Also used where low expansion is desirable.

CHREICAL COMPOSITION (Nominal):

• Marimu

HEATREATMENT: Austonitise: 1750 - 1880 F for t - t hr, sir cool or oil quench Tamper range: 900 - 1880 F for t hr, sir cool (See "Bardness vs. Tempering Temperature" curve for a pecific hardness levels and temperature) Process anneal: 1800 - 1400 F for 1 - 2 hr, air erol; typical hardness - Bhu 10 Pull annual: 1850 - 1650 F (1 hr per section inch); furnase cool to 900 F, sir cool; typical hardness - Bhu 1850 185

FOROMABY ITY: Readil resistant steel. Readily forged, more easily than ANE SUIS hardenable, corrosion teel. Usual forging temperature range is 2130 - 1500 P.

BILITY: Pair. Nore difficult to form in annealed condition than the sustenitic stainless steels, but more easily formed them ANS 3808 hardenable, correction resistant steel. "In process" anneals may  $\gamma$  necessary depending upon degree and nature of forming operation. Fevere deforming operations should be followed by stress relief or anneal. PORMABILITY:

RABILITY: Pair to good. Slightly better then ANS U616 hardenable, corrosion resistant steel and the quatentitic stainless steels. Optimum condition for machining is herdeued and tempered, or annealed and cold worked to hardness of Rhn 800 - 260. MACHIBABILITY: corrosion

BILITY: Pair to good. Can be fusion or resistance velded with less difficulty than AMS 5503 hardenable, sorrosion resistant steel. High strength assemblies are usually unlied in the annualled condition, and subsequently sustenitized and tempered. Fusion welding is usually done with fillor metal of parent metal chemistry; use of sustemitic type filler metals is permitted when hardened details are to be joined and/or welded joints have low strength requirements. WELDARILITY:

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#### AMS 5613 AMS 5504 AMS 5591

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#### GENERAL INFORMATION (cont.)

BRAZMABILITY: Readily breased by all methods. Assemblies gold-nickel brazed per FMA 10 or silver brazed per ANS 3666 may be hardened in the brazing cycle. Copper brazing per ANS 9671 should be followed by separate hardening and tempering operations. Stress relief or tamper heatreatment is required after ANS 2666 silver brazing and gold-nickel brazing; no heatreatment necessary after ANS 2665 silver brazing.

#### CHENICAL PROPERTIES

CORROSION RedJISTANCE: General correction resistance of alloy is superior to that of low alloy steels but is inferior to that of sustanitic stainless steels. Correction resistance is reduced by exposures to temperatures above 600 F; hardened me terial has best correction resistance when bastreated per PMA 12. Alloy, like ANS 5616 (Ureek Ascoloy), is susceptible to stress correction creaking when tempered within 700 - 1100 F range. For tempering temperatures up to 700 P, ANS 5613 and LMS 5616 both have equally good stress correction ...sistance; at equal strength levels produced by tempering above 1000 P. ANS 5613 is somewait inferior to ANS 5516.

OXIDATION RESISTANCE: Slightly inferior to ANS 5616, hardenable, corrosion resistant steel and substantially superior to low alloy steels. Resists oridation at temperatures up to approximately 1000 P.

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#### AMS 5616 AMS 5508

		GENERAL I			
SPECIFICATION:		AN3 6616	ANS 5508		
AVAILABLE PO	NUS :	Bars, forgings	Sheet, strip, plate		
CONDITIONS	Par: Annealod; I Forgings: At are				

Sheet: Annealed

COMMON DESIGNATION: Greek Ascoloy, Uniloy 1415 NW

MELFING PRACTICE: Generally air melted in electric furnace; however, vacuum melted and vacuum degessed materials are available.

AL DESCRIPTION: AND 5616 is a martensitic, correction resistant steel whose strength at elevated temperatures is enhanced by additions of nickel and tungsten. Alloy is hestreatable over hardcess range of Ro 20 - 50. Stress-rupture and oresp strengths of alloy are superior to those of ANS 5615 (AISI Type 410 steel) but inferior to those of AND 5735 (A-295) and AND 5304 (low alloy steel). Forgestility, mekinability, and weldebility of alloy are alightly inferior to ANS 5613. General correstor resistance of alloy is superior to that of low alloy steels. Naterial tempered within 700 - 1100 F range is rusceptible to stress correston pracking. Oxidation resistance of alloy is good we to approximately 1000 F. DESCRIPTION:

APPLICATIONS: CATIONS: Parts requiring crosp strength and tempering resistance superior to that of AMS 3613. Used primurily for compressor blades and vanes, turbine discs, muts, bolts, and miscellaneous structurel parts exposed to temperatures up to 1000 P.

CHAPICAL COMPOSITION (Nomion1):

C Gr #1 W Ko Ma 31 P 3 Al Cu Sn Pe 0.1755 13.0 3.0 0.8 0.8 0.8 0.04 0.0. 0.15 0.5 0.08 reminder Kaziman

HEATRGATHERT :

REATMENT: Austenitics: 1750 - 1850 P for h hr, air or oil quench. Through hardening attained in section sizes up to approximately 3.0 inches by either air cool or oil quench. Larger sizes require oil quench for muriners hardness. Temper range: 450 - 600 P and 1000 - 1850 P for 2 hr, air cool (See "Mardness vo. Tempering Temperature" curve for specific hardners levels And temperatures). Double temper or cold treatment recommended for parts hardened to Ro 45 - 50. Process anneel: 1300 P for 1 - 2 hr, air cool; resulting hardness Bhn "70. Full anneal: 1450 - 1500 P (1 hr per section inch), furnace cool at 30 P/hr to 800 F, air cool; resulting hardness Bhn 250 - 277.

FORGEABILITY: Readily forged; slightly more difficult than ANS 5613 (A151 Type 410). Usual forging targersture range 2100 - 1750 P.

BILITY: Fair. More difficult to form in armsted condition than annealed ANN 5504 (AISI Type 410) and austenitic stainless steels. Doer not work harden as repidly as automitic stainless steels; however, intermittent process enneals may be mecasary depending upon degree and nature of forming operation. Pull anneal recommanded after severe deformations. PORMARTLY TY

MABILITY: Pair. Similar to the austenitic stainless steels but slightly inferior to AMS S613. Fully annealed condition is optimum for machining. MACHIMABILITYI

ABILITY: Fair. Can be fusion and resistance weided buy with more difficulty than 2NS 5504 (AISI Type 410) due to its higher hardenability. Air hardening charesteristics of alloy necessitate post weld strass relief within reasonably short time after weiding. Meldments requiring high strength should be joined in athenied condition, and subsequently subscritting and tampered. Filler metal of parent metal composition is recommanded for high strength weldments. MELDARILITY:

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AMS 5616

# AMS 5508

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## GRANNAL INFORMATION (sont.)

BRAIMABILITT: Bradily brazed by sli methods. Assemblies gold-nickel brazed per PMA 19 or silver brazed per ANS 3666 may be hardened in the brazing cycle. Copper brazing per ANS 2671 should be followed by separate hardening and tempering operations. Stress reliaf or temper bestreatment is required after ANS 2666 sliver brazing and gold-nickel brazing; no bestreatment mecessary after ANS 2665 sliver brazing.

#### CHENICAL PROPERTIES

OSIGE RESISTANCE: General corrosion resistance of alloy is superior to that of low alley steels but is inferior to that of anstanitic stainless steels. Corrosion resistance is reduced by exposures to temperatures above 800 P; hardward material has best corrocion resistance when heatrested per PMA 18. Alloy, like AND 5613 (AISI Type 410), is museeptible to stress correctom cracking when tempered within 700 - 1100 F range. For tempering temperatures up to 700 P. AND 5613 and ANM 5618 both have equally good stress accruaian resistance; at equal strengt lavals produced by tempering above 1000 P. AND 5616 is somewhat better than AND 5613. CONDOSICE RESISTANCE:

OXIDAT ... RESISTANCE: Slightly better then AISI Type 410 and substantially superior to low alloy steeld. Resists oxidation at temperatures up to approximately 1000 F.



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#### ANS 550 AMS 5570 AMS 5576 AMS 5645

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		GENERAL IPPORT	CONTRACT PROPERTY CONTRACTOR			
SPECIFICATIONS:	ANN 5610	ANR 5570	ANB 5676	ANS 5645		
2080B1	Most, plate, strip	Seamless tubiry	Wolded tubing	Bars, forgings, mechanical tubing		
CONDITION: Sola	stion bestrested					

NYION:

COMMON DESIGNATIONS: Type 12 Stainless Storl; AISI 321; SAE 30321; Ti stabilized 18-8 Stainless Stock

MERING PRACTICE: Risstrie furnees, sir molted

Whi DERCHIPTION: AISI Type 341 is an 'A-8 type sustanitic stainless steal with titenium additions which stabilize this alloy against intergranular sarbide precipitation and subsequent corrosive attack. Alloy is not hardenable by isotreetment and is used in case solution terteated condition for maximum corrocion resistance and dustility. Alloy is within same general strength category as AISI NLO, 116, and 347 sustainies statics. Furmace brasing requires and to andigeration but otherwise fabrication is readily achieved by procedures and to another and only on the stainless steels. Assists or distingues and to approxime a size static stainless steels. Assists or subsequent, but is inferior to AISI 310 and Incompl.

CATIONS: Parts requiring axidation and corrector resistance at temperatures up to approximately 1500 F; useful only where operating stresses are low. For assemblies fabricated by brazing or welding. APPLICATIONS:

CHRICAL CONPOSITION (Noninal)

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RMATHENT: Bet herdemable through bestreatment. Solution (full emanal): 1750 - 1960 F for ½ to 1 hour per section inch; coul to below 500 F is less that 3 minutes. Balation heatrost sheet at 1875 F for 7 - 10 minutes after severe forming operations. Streas-relieve complex fusion weldments at 1800 F for 1 hour.

PORESABILITY: Readily forged. Usually forged within \$300 - 1700 7 mange.

BLETT: Sheet can be best in0 deg around a diameter equal to its thickness. Excellent drawing and spinning characteristics. Solution heatreat at 1975 F for 7 - 10 minutes after revers roraling operations. PORPARILITY:

MALLITY: Somechat difficult due to high rate of work-hardening. Slightly superior to that a Incoreal or Matalloy I mithel-base clipys. Bequirescois: rigidly supported work; accurately ground, highly sharpened, rigidly supported tools; positive, uniform for positive ship resoval; edequate cooling with supported-base pils. Somemagnetic. MACHINALILITY

FIDABLINY: Sectily reside or resistance wided. Filler metal of 4131 347 composition used for fusion welding. Large or complex weldmonte require stress-cellef at 1900 F for 1 moir. Mimor Festic weldments and resistance weldmonte meet not be stress-relieved.

MAXRADILITY: Boodily brased with eilwar, copper, nickel, sod gold-nickel. Furnace brains in hydrogen simesphere not feasible unless paper to be brased are mirsel plated. So stress-reliaf required after brasing.

#### CONTENT PROPERTY AN

Cond. (G. MAINTANCE) - Excellent corrosise resistance in gos turbine engine cimospheres st temperatures up to eperation tay 5400 F. "Makiitaed" by titenium runteni egalosi intergramater chromium varbine crecipitation in the range 200 - 1650 F. Louis corrosion resistance of parts remaine gred after processing or ups film in rbet respe.

CEIDETS NEEDENCE: Out at themese in the oppositential 1600 f. Contraction to a'if did and de? machemitic stainiers staring, but inferior to all IIC stainies start and in yet minimum alloy.

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			AMS 5371 IS 5° 16 PWA 770	
		GARDAL IN 3		
ICATIONS:	AHB 5512	ANG 5571	ANS 5575, FM 770	112 5046
	Sheet, strip, plate	Seamless tubing	Walded tubing	Bars, forcings, eschanical subing

COMDITION: Solution heatmated

SPECIF ROUND.

COMON DESIGNATIONS: Type 347 Statnless Steel; AISI 3-7; SAE 30347; Columbium Stabilined 18-8 Stainless Stewl

MELTING PRACTICE: Electric furnees ale malt. Induction and consumable electrode vacuum melted.

GENERAL DESCRIPTION: AISI Type 347 is an lo-M type sustenitic stainless steel in which addition of columpium atabilises material against intergranular carbide precipitation and subsequent corrosive attack. Alloy is not herdenable by hestreatment and is used in the solution hestreated condition for markmaps corrosion resistance and ductility. Alloy is within same general strength category as AISI 316, 321 and 310 austenition rained attacks. Rescally fabricable by procedures and techniques roomon to other austenitic stainless iteels. Hestation at temperatures up to approximately 1600 P and is like AISI 316 and 321 in this respect, but is inferior to AISI 310 and Inconel.

APPulCAllusS: For corrosion and ovidation resistant parts ordenting under low strust temperatures to 1500 P, and for essenblies fabricated by brasing or welding. stresses

CHARICAL CONFUSITION (Nominel):

C. CP H1 CD X1 31 K0 CU 7 S S Po 5.000 13.5 11.0 1.1" 2.0" 5.3" 5.3" 5.5" .64 .03" reminder \* Yikatan ik

. . . . . . .

**EATHERS:** Not hardenally through heatreatment. Solution: 1000 - 1950 F for  $\frac{1}{2} = 1$  hm per section inch; soll to below 600 F in less than 3 minutes. Solution heatment at sheet at 1925 F for 7 = 10 minutes after severe forming operations. Streas-relieve complex fusion weldments at 1900 F for 3 hour. FEATREATNER? .

CUNSCREDITY: - Readily Forged. Usually forged between 2300 F and 1700 F

ABILITY: Sheet can be benu 160 deg shound a diameter equal to its thickness. Specificat drawing and animning characteristics. Solution beatrest at 1975  $\pm$  for 7 = 10 munutes alter severe forming operations. FORMABILITY:

NUMEDIAITY: Compared to that of all type 321 and the other austanitic stainless (simulated to the control of the stainless (simulated to the stainless (simulated to the stainless)). See MACHINARILITY:

STILLFILTT: Asedity fusion and resistance welded. Siller metal of pare . metal composition used for fusion welding. Large or complex weldents should be starso relieved at 1800 F for 1 Juan. Riggn fusion weldments and resistance weldents meet not be stress-relieved.

GARLITY: sandly brased with aliver, copper, micaol, and guid-micael. Bo enress-relief re wired after breating. Shis material (AISI (4<sup>31)</sup> is recommended for use more fur are breating is required. HENTAGET LITY :

#### AND AL . YAITION .

Cumuiside Aulistance: Excellent correction resistance in gas surbine angine atmosphares at languantumes up to appointmately level P. "Stabilized" by columbium content signing interplanular curvatue carbine precipitation in the ringe box - 1000 P, thus curvation resistance of parts remains good witer processing to open ion in unst range.

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## AMS 3540 AMS 5590 AMS 5665 AMD 5697

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## PWA KOSO

		SECTIONAL.	LEROSMATINE	
DECORPICATIONE	ANE 6840	ANG 1860 718 1860	ANT 1545	ans 5667
POREL	Bbeat, strip, plate	Svamicss Juting	Sare, forginge, welded rings	Wise
CONDITIONS	Annoaled	Ansee 194	andoclon, hol finished	*III.# <b>#</b> lad

CONSIDE DESIGRATION: Inconcl

MELTIN' PHACE "It Induction furnace, air mated

This is a superior to the austantit stanless steels and 1.605, but slightly fightly the superior to the sustantit stanles to the sustantial stanles and 1.605 but slightly inferior to the sustantial stanles and 1.605 but slightly inferior to the sustantial stanles and 1.605 but slightly inferior to the sustantial transition to the sustantial stanles and 1.605 but slightly inferior to the sustantial stanles are also and 1.605 but slightly inferior to instance is excellent. PRICEAL DESCRIPTION

#### UNERICAL CONFOSITION (Nominal);

0.195 18.7 8.6 Max	<u>50</u> 1.5 1.5	T.J BAX	81 0.5 45x	Cu D.S PAX	8 0.015 842	E1 Fom 1560P	5.5 5.5 76.2	0.18 641 x	A1 • T1 0,4 202*
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"Applicable to FMM 1060 only.

HEATERATURET: Anneal (Solution): 1925 P g in for h to 1 hr - air cool, forgings 1800 F for .0 - 15 min - air cool, pheet Strass relief: 1600 - 1700 F is: 1 hr, air cool Optimum heatree\* " is for good formability or 1800 P for 10 - 1A minute\* followed by air cool or " for saveral seconds. Cores grain six produced by stressive times at 1900 : above results in restance in fold strength and ductility. All betreaking of warve should be performed in sulty.-from schoopheres. Alloy rest. is bright anneasing . triding, and car uniting starspheres.

#### Deumlay forged in tem ure range of 2150 - 1760 P. FORGELSTITTY (

PORMABILITY: bblilTY: Good, superior to Hastelloy X and subtenitic stainists steels. High rate of work hardening requires interwediety anneals for severally formed purts.

MACHIMABILITY: Difficule, similar to Mastalloy X and more difficul: than standar austanitic stainless steels. Sulfur bearing cutting fluids must be some d pri-to matreatment or high temperature service.

ABLITY: Readily welded in solution issuested condition by fusion and resistance wethods. Filler metal of parent metal composition used for fusion wells. Complex fusion veloments require post-weld stress relief. WEDARTLITY:

BHAZEABILITY: Can be silver, copper, and gold mickel brased without post-brase streve relief. Purples brased assemblies require use of FMA 2060 (furnage brasing quality material). Brased details should be in solution beatreated condition or stress relieved prior to brasing.

#### CHENICAL PROIERTIES

CORRESION RESISTANCE: Egoellent.

OLIDATION RESISTANCE: Excellent in sulfur free "tmospheres at temperatures up to 2000 P and in sulfur stmospheres up to 1800 P. Superior to sustanizic stainless steel: and 5.605 but slightly inferior to Eastelloy X.

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## COMPROENTIAL

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AMS 5536 AMS 5754

	OTHERS L	INFORMATION
APRCIPICATION:	ANG 5556	ANB 5754
AVAILABLE FORMS:	Sheet	Bars, forgings

CONDITION: Solution heatvested

COUNCE OFFIC ATICNESS Nastelloy X, Eastelloy Alloy X

KELTING PRACTICE: Electric furnace, air melted

ML DESCRIPTION: ANS 55% is a mickel base alloy fiehi; alloyed primarily with chromium. Alloy is essentially non-bardenable by bestreatment and is normally used in solution metreated condition. Presistation occurs in alloy during long exposures within temporature range of 1800 - 1807 F; however, subsequent increase in hardeness and desrease in ductility are tolerable in so far as performance in service is sonserned. Minimum yield strangths range from 37.0 ksi at 600 F to 10.0 ksi at 1800 F. Minimum 100 hr stress-rupture strength au 180 kr, 0.65 creep strength at 1800 F. Minimum 100 hr stress-rupture strength au 180 kr, 0.65 creep strength at 1800 F are 10.0 ksi and 5.0 ksi, respectively. Yield and rupture strengths of alloy are superior to those of AME 3640 (Incomel). AME 3510 (ATSI 381), and AMS 5512 (ATSI 347) but injector to those of AME 3587 (i=605). Slir; forges, forms, mediane, and weids at h slightly more difficulty than austentito stainless steels commonly used at PM. Oridation resistance of alloy is outstanding at tamperatures up to 2200 F and is superior to that of AMS 5510, AMS 5540, and AMS 3537. Corrotion resistance of alloy is excellent. ORNERAL DESCRIPTION:

ICATIONS: Parts requiring moderate strength, and excellent exidation and correction resistance within temperature range of 1400 - 2050 P. Used primarily for burner liner parts, turbine seels, turbine exhaust weldments, and afterburner parts. APPLICATIONS:

CHEWICAL COMPOSITION (Nominal):

0.10%	C: 22.0	<u>Co</u> 1.5	Mo 9.0	5.8	P: 18.3	1.0	<del>51</del> 1.0**	0.04*	0.05	H1 Femilader

MATRAINERT: Solution: 2150 F g 25 - 1 hr per secvion inch - water quench or rapid air cool. Resulting bardness Rb 85 - 100. Anneal (Process or full): Same as solution hestratisent. Furnace atmospheres for annealing or hesting for bot working should be free from sulfur.

PORGEASILITY: Usually forged in temperature range of 2200 - 1800 F. More Pair. readily forged than L-605.

ABILITY: Good. Slightly more difficult to form than austenitic stainless steels. Depending upon degree and mature of forming operation, several in-process anneals may be necessary due to high rate of work hardening. PORNABILITYS

MABILITY: Difficult. Slightly more difficult to machine than austeritic stainless steels and Incomel. All traces of sulfur bearing catting fluid sust be removed prior to heatreatment or high comparature service. MACHINABILITYI

BILITY: Gen be fusion and resistance welded. Some thickness and material combinations offer difficulty in resistance welding. Filler metal of parent matal composition used for fusion welding. WELDABILITY:

ABILITY: Readily braxed by all methods (silver, copper, gold-nickel). Cold formed details muxt be annealed prior to braxing. Post braxing stress relief not BRATEABILITY: essential

#### CHENICAL PROPERTIES

OXIDATION RESISTANCE: Excellent resistance to oxidizing atmospheres at temperatures up to 2200 F. Resistance to reducing and inert media at temperatures up to 2150 F is also outstanding. Superior to sustanitic stainless starls, Inconel, and L-608.

CORROSION RESISTANCE: Excellent.

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# ANS 3342 AMS 3382 AMS 3657 AMS 3668

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	GESTINAL INFORMAT	100
SPHCIFICATION:	<b>POR01</b>	2 MOITICH 2
ANG 5542 Pua 1031 ANG 5567	Shoot, strip, plate Strip (vac. molted) Bars, forgings, rings, forging stock	Annesled Annesled Equelised
ANS 5663	hare, lorgings, forging stock	Solution, stabilization, and precipitation hestreated
AND 5588	Seculess tubing	Annesled
PHA 1063	Wolded tubing	Anneeled
A566 5698	Vire	Cold reduced 15 - 205
ANS 5699	sire	Cold reduced 50 - 65%

COMMON DEFIGRATION: Incomel X, Incomel alloy X-750

MELTING PRACTICE: Primarily induction molted in sir; PWA 1031 is induction or consumable electrode molted under vacuum.

electrode malted under vacuum.
 OENERAL DESCRIPTION: Incomel X is a michai-base alloy which has useful strengths at temperatures up to 1350 P or 1500 P, depending upon its hestreated condition, and has good oxidation and corresion resistance in gas turbine engine stmospheres up to 1800 P. Line Waspaloy, subject alloy is capable of a wide range of machanical properties which san be optimized by appropriate heatreatment for specific operating conditions. In general, tennils and the respertures trengths with 1300 F age fail between those of ANS 5085 (A-986) and PMA 1035 (Incomel 718) at temperatures up to 1350 - 1400 P. Alloy becomes match sensitive in stress-rupture after prolonged exposures at 1100 - 1350 F. Alloy is weidable but with considerable difficulty. Machining, forging, and forming characteristics of Incomel X are similar to those of Incoloy 901 (PMA 1003) and Incomel 718 (PMA 1010, PMA 1033).

APPLICATIONS: Parts requiring good strength at temperatures up to 1350 F or 1500 F plus good axidation and corresion resistance. Used primarily for non-rotating structural parts, non-structural parts (springs, seals), and tube assemblies.

CHEMICAL COMPOSITION (Nominal):

matchla by wartous			
comply with partic parts used at tempe as precipitation has sations over same to prior to precipit we llow F are affor lisation and aging ments provided for fill anneal: 1900 condi	ular applicat ratures up to atreat at 120 emperature ra atlos heatrea ded optimum p ; treatments a : in specifica - \$200 P for tion)?*	ion and/or fa 1100 F solut 0 - 1400 F pr ngs higher at tmant. varts roperties by t 1550 F and tions are as 15 - 20 min.,	oride optimum properties. rengths are stainable which are used at solution hestreatment of 1300 F, respectively. follows: air sool (specification
Precipitation: 130 lolution heatreated stabilization: 155 bel	0 F ± 25 for 1: 2100 F ± 2 0 F ± 25 for .ow 1300 F	20 hr, air so 5 for 2 - 4 h 24 hr, air so	ol r, air cool cl ar furnace cool to or
old worked 15 - 20 recipitation: 135 old worked 50 - 66 recipitation: 120 cid worked 50 - 66 vull heatwatment 1	% (specificat % P ± R5 for % (specificat % (specificat % (specificat ike A% 5008	ion condition 16 hr, air co ion condition 6 hr, air coe ion condition	) ol - 700 - 1000 F service ) 1 - RT - 706 F service ) - 1000 - 1300 F service
	as precipitation has instions over same to instions over same to instion and aging ments provided for dill santen and aging ments provided for dill santen 1900 condi- recipitation: 136 loction heatreated bablisation: 135 Precipitation: 135 Precipitation	<pre>is precipitation heatreat at 130 intions over same temperature ys is prior to precipitation heatrea re 1100 F are afforded optimum p lisation and aging treatments a ments provided for in specifica dill anneal: 1900 - 2000 F for condition)<sup>344</sup> recipitation: 1300 F ± 25 for Housing 1625 F ± 25 for 24 h Precipitation: 1300 F ± 25 for holution heatreated: 2100 F ± 25 for holution heatreated: 2100 F ± 25 for holution heatreated: 2100 F ± 25 for holution heatreated: 2100 F ± 25 for hold worked 15 - 20% (specificat Precipitation: 1300 F ± 25 for hold worked 15 - 65% (specificat Precipitation: 1200 F ± 25 for hold worked 50 - 65% (specificat heatreatment like Ar&amp; 566 hold worked 50 - 65% (specificat hold worked 50 - 65% (specificat heatreatment like Ar&amp; 566 heatreatment like Ar&amp; 566 heatreatment heatreatment heatreatmentheatment heatreatment h</pre>	Presipitation: $1300 \text{ F} \pm 25$ for 20 hr, air col equalized: $1625 \text{ F} \pm 25$ for 24 hr, air cool ( Presipitation: $1300 \text{ F} \pm 25$ for 20 hr, air co solution heatrested: $2100 \text{ F} \pm 25$ for 2 + a isobilization: $1550 \text{ F} \pm 25$ for 2 + kr, air co

\*\* Air scoling after solution heatreat or mill anneal is considered adequate for normal subsequent heatrest response; where optimum forming characteristics are desirable, oil or water quench is recommended.

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#### AMS 5542 AMS 5582 AMS 5667 AMS 5668 AMS 5686 AMS 5599 PWA 1031 PWA 1063

#### OCOMPAL INPORMATION (cont.)

PORUSABILITY: Fair to good. Similar to FWA 1003 (Incolay 901) and superior to that of FWA 1007 (Waspaloy). Usually forged within 2250 F to 1500 F range.

FORMABILITY: Good forming abilities in annealed or solution beatreated condition; comparable to PMA 1036 (Maspaloy) and FMA 1033 (Increal 718) but inferior to ANE 5526 (A-986) and the sustenitic stainless steels. Armsaled sheet can be bent 180 deg around a dismeter equal to its nominal thickness at room temperature. Solution heatreat at 1925 F for 7 - 10 minutes and air cool after severe forming operations.

MACHIMABILITY: Difficult. Machined with same techniques and degree of difficulty as FMM 1030 and FMM 1033; more difficult to machine than austenitic stainless steels. Hachimable in all conditions; fully bestreated condition is preferred for finish machining.

WELDABILITY: Difficult, Weldable by either resistance or fusion methods. Pusion welded by either gas tungstex-arc or inert gas metallic-arc process with parent metal filler material. Welding by any method is generally done in the solution hestreated condition. Solution hestreatment of 1800 P for 1 hr, sir cool plus precipitation hestreat of 1850 P for 16 hours required after welding. Comparable to ANS 5525 (A-236) and PMM 1030 (Wespaloy), and more difficult than PMA 1033 (Incomel 718).

BRAZEABILITY: Can be silver, copper, nickel, and gold-nickel brazed. Faying surfaces of brazed joints should be nickel plated prior to brazing. Because of hewtrest complexities of siloy, special metallurgical considerations are required to ensure testred properties in the finished brazements.

#### CHENICAL PROPERTIES

COMPOSION RESISTANCE: General resistance to corrosion in gas turbine engine atmospheres is good. Stress-corrosion cracking is a possibility when subjected to certain tensile stresses in the presence of halides.

UXIDATION RESISTANCE: Good resistance to atmospheres encountered in gas turbine engines at temperatures up to approximately 1800 F.

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#### PWA 1009 PWA 1010 PWA 1033

	ORISENAL INFORMATION		
SPECIFICATIONS:	PMA 1009 (Dev) PMA 1010 (Dev)	PMA 1053 (Dev)	
PORM3 :	Bars, forgings, welded rings, forging stock	Sheet, strip, plate	
	1009 - solution bestreated	admitation bestmested	

FWL 1010 - Bers and forgings - solution and precipitation he Other forms - at ordered FWL 1035 - annealed (1750 F for 30 min., sir cool or factor)

COMMON DESIGNATIONS: Inconel 718

TING FRACTICS: Multiple molting using vacuum consumable electrode process in the remain cycle, or vacuum induction plus consumable electrode remain, or vacuum induction molt. MELPING PRACTICS:

CRAL DESCRIPTION: Incomel 718 is a heatreatable nickel-base alloy which has good strength at temperatures up to 1100 - 1300 F, and good oxidation and corrosion resistance in gas turbine engine atmospheres up to approximately 1800 F. Yield strength is superior to that of PMA 1005 (incoloy 901), and PMA 1005 (inspalor) up to 1300 F. Stress-rupture and 0.1% oresp strengths are superior to those of PMA 1005 up to 1850 F, but inferior to those of PMA 1005 above 1100 F. Weldability is superior to that of Incomel X or Wespaloy, particularly where joints of high restraint are interfaced. Alloy forges and machines somewhat like PMA 1003. GENERAL DESCRIPTION:

LICATIONS: Parts requiring high strength, good weldability, and good corrosion and oxidation resistance at tugeratures up to 1100 - 1300 P. Particularly applicable to compressor components. APPLICATIONS:

CHENICAL COMPOSITION (Nominal):

<u>C</u> <u>CP</u> <u>CP</u> <u>TR</u> <u>Mo</u> <u>Ti</u> <u>Al</u> <u>B</u> <u>Mn</u> <u>Si</u> <u>P</u> <u>S</u> <u>Ni</u> <u>Fe</u> .055 <u>19</u> <u>5.5</u> <u>5</u> <u>0.9</u> <u>0.6</u> .0056 .356 .0156 .0156 52.5 remainder

• Maximu

HEATNEATHENT: Solution: 1750 F for 1 hour, air cool or faster Precipitation: 1385 F for 8 hours, furmace cool (100 F/hr) to 1150 F, hold at 1150 F for 8 hours and air cool. Sheet and parts not to be machined all over after hestreatment require 5 protective atmosphere for solution hestreatment.

EABILITY: Fair to good characteristics. More readily forgeable than PMA 1005 (waspeloy) and PMA 1008 (Astroloy). PORGRABILITY:

FORMABILITY: Good forming abilities in solution heatreated condition; comparable to PA 1030 (Mespaloy). Sheet under 0.080 in, can be bent 180 deg around a diameter equal to its thickness at room temperature; sheet thicknesses of 0.050 - 0.187 in. can be bent around diameters which are twice their thickness.

URABILITY: Difficult. Machined with same general techniques and degree of difficulty as ANS 5668 (Inconel X) and PMA 1003 (Incoloy 901). Machinable in all conditions; fully hestreated condition is preferred for finish machining. MACHIMABILITY:

MBILITY: Welding is accomplished with same general techniques used for incomel X and Waspaloy, but with considerably less susceptability to strain cracking. Fusion welding is done in the solution bestreated condition with parent material filler metal (pin 1001). Full bestreatment recommended after weiding to repair best-affected some WELDABILITY: of weld and to achieve optimum properties.

WABILITY: Can be silver, copper, nickel, or gold-nickel brazed. Because of heatreat complexities of alloy, special metallurgical considerations are required to ensure desired properties in finished brazements. Faying surfaces of brazed joints shall be nickel plated prior to brazing. BRATHABILITY

#### CHEMICAL PROPERTIES

CORNOSION NESISTANCE: Good corrests tance; similar to that of Incomel X. OXIDATION RESISTANCE: Oxidation resistance in gas turbine angins atmospheres is good at temperatures up to 1800 F.

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AMS 5660 PWA 1003

	GENERAL INFORMATION	
SPECIPICATION:	ANS 5660	FMA 1003
Porni	Bars, forgings	Porgings
CONDITION:	Solution, stabilization and $\gamma$ precipitation heatreated	Solution, stabilization, and precipitation heatreated

COMEON DESIGNATION: Incolog 901

MALTING PRACTICA: ARS 5560 forgings - consumable electrode or induction vacuum melted bars - air melt permissible PMA 1003 - consumable electrode or induction vacuum melted

GENERAL DESCRIPTION: ANS 5660 and its higher strength modification, PMA 1003, are austenitic, iron-nickel alloys which achieve optimum properties through combination heatreat (solution, stabilization, and precipitation). Yield strengths of alloys are substantially reduced at temperatures above 1400 F. Stress-rupture and creep strengths of alloys are superior to those of AMS 5735 precip.stion hardemable steel and AMS 6304 hardenable low alloy steel but inferior to those of PMA 1004 (Waspaloy). Alloys forge and suching with slightly less difficulty than PUA 1004 but are inferior to AMS 5735 and AMS 6304 in these respects. Weldebility of alloys is poor. Alloys have oxidation resistance comparable to the austenitic stainless steels and good corrosion resistance.

APPLICATIONS: Parts requiring high strength within temperature range 1000 - 1400 F and/or oxidation and corrosion resistance at temperatures up to approximately 1600 F. Used primarily for discs, shafts, spacers, and tierods.

CHERICAL CORPOSITION (Nominal):

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AMS 5060 - 0.13\* 12.5 42.5 1.0\* 5.75 2.85 0.5\* 0.4\* 0.35\* 0.015 0.5\* remainder PMA 1003 - 0.13\* 12.5 42.5 1.0\* 5.75 2.85 0.5\* 0.4\* 0.35\* 0.015 0.5\* remainder

ATREATESNT :	AMS 5660	PWA 1003
Solution: Stabilization:	2000 $F \pm 25/2 hr/N.Q.$ 1450 - 1500 $F \pm 15/2 - 4 hr/A.C.$	$1975 = 2025 F \pm 25/2 hr/W.Q.$ 1425 = 1475 F/2 = 4 hr/A.C.
Precipitation:	1325 - 1375 F : 15/24 hr/A.C.	1300 - 1375 P ± 15/24 hr/A.C. (Resulting hardness Ehn 302 - 388)

Annealing: Same as solution heatreatment. Annealing and solution heatreating should be done in slightly reducing atmospheres free from sulfur.

FOHUMABILITY: Pair. Superior to PMA 1004 (Waspaloy) nickel base alloy. More difficult than AMS 5735 precipitation hardenable steel and AMS 5616 hardenable, corrosion resistant steel. Usual forging temperature range is 2050 - 1800 F. Preheating recommended for large forgings.

FORMABILITY: Fair. Slightly more difficult in solution heatreated condition than the austenitic stainless steels. Severe deformations may require several intermittent anneals.

HACHINABILITY: Difficult. Sates similar to PMA 1004 nickel base alloy and more difficult than ANS 5735 precipitation hardenable steel and ANS 5616 hardenable corrosion resistant steel. Machinable in all conditions; however, fully bescreated is preferred for finish machining.

WallDABILITY: Difficult. Welding not generally recommended.

BRAZEABILITY: Not usually brased. Can be silver, copper, and gold-mickel brased; howev r, heatrest complexities of slloy require special metallurgical considerations to ensure desired properties of finished brasements.

#### CHENICAL PROPERTIES

COMMOSION RESISTANCE: Excellent resistance to corresive media commonly encountered in turbine applications. Corresion resistance similar to that of the austenitic stainless steels.

OXIDATION RESISTANCE: Resists oxidation of temperatures up to 1600 %.

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#### PWA 687 PWB 1004 PWA 1030 PWA 1061

	GINGAL INFORMATION				
APECIFICATION:	PHL 1004	PWA 687	PHR 1050	PM 1061	
POINE	Bars, forgings, rings, forging stook	Bars, forgings, rings, forging stock	Sheet, strip, plate	Wolded tubing	
Condition:	Solution, stabilization and presipitation hestreated	Solution hestreated	Annealed	Under 2.0 in. diam - annealed and cold drawn Cwer 2.0 in. diam - annealed	

COMMON DESIGNATION: Maspaloy

MELTING FRACTICE: PMA 1004: Multiple melting using consumable electrode process in the remait cycle, or vacuum induction malted.
PME 587: Multiple melting using consumable electrode process in the remait cycle, or vacuum induction melted.
PME 1030: Multiple melting using vacuum consumable electrode process in remait cycle or vacuum induction plus consumable electrode result, or vacuum induction melted.
PME 1061: Vacuum induction or vacuum consumable electrode melted.

ERAL DESCRIPTION: Maspaloy is a heatreatable nickel-base alloy which has good strength at temperatures up to 1400 - 1500 P, and good oxidation and corrosion resistance in gas turbine engine atmospheres at temperatures up to 1600 P. Tensile strength of subject specification meterials are superior to those of Inconel X, and inferior to those of Incomel 718 at temperatures up to 1350 P. Greep-rupture strengths are superior to those of Incomel X and to those of Inconel 718 at temperatures above 1150 - 1200 P. Alloy is weldeble; but with no small degree of difficulty. Machines like other precipitation hardenable nickel-base alloys and has forming characteristics like those of Incomel 718. ORNERAL DESCRIPTION:

JCATIONS: Parts requiring high strength plus good oxidation and corrosion resistance at temperatures up to 1400 - 1500 P. PMA 667, PMA 1030, and PMA 1061 are applicable to parts which require welding. PMA 1004 used for stationary parts which do not require welding or the higher strengths obtainable with PMA 1005 and PMA 1007. APPLICATIONS:

CHEMICAL COMPOSITION (Nominal):

 C
 Cr
 Co
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 Al
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 B
 Fe
 Mn
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 S
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 5.065%
 19.5
 13.5
 4.0
 3.0
 1.4
 0.06
 0.007
 7.0\*
 0.15\*
 0.015\*
 remainder

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 - values for PME 1004 and PME 1061.
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HEATHEATHENT:

THEATHENT:PMA 1006 & PMA 687PMA 1030 & PMA 1061Anneal:1975 <  $\pm$  95 for 30 min, AC or fasterSolution:1800 - 1925 F for 4 hr, Ou or Mu1325 F  $\pm$  25 for 2 hr, AC or fasterStabilization:1500 F  $\pm$  15 for 4 hr, AC1550 F  $\pm$  15 for 4 hr, ACFreeipitation:1400 F  $\pm$  15 for 16 hr, AC1400 F  $\pm$  15 for 16 hr, ACFWA 1006 and PMA 1667 parts which are not subsequently machined all over require asuitable protective atmosphere for solution heatreatment and need only to be rapidsinceling and solution heatreatment.

EABILITY: Fair, better than that of PMA 1098 (Astroloy), but peoper than that of PMA 1003 (Incoley 901) or PMA 1010 (Income) 718). Generally forged within 2050 - 1850 F range. PORCEARILITY

**MBILITY:** Good forming abilities in annealed or solution heatreated condition; comparable to PMA 1035 (incompl 710) but inferior to sustaintic stainless steels. Sheet under 0.080 in, can be bent 180 deg around a dismeter equal to its thickness at room temperature; sheet thicknesses of 0.050 - 0.187 in. can be bent around diameters which are twice their thickness. FORMABILITY:

(IMABILITY: Difficult. Machined with same general techniques and degree of difficulty as PME 1003 (Incolgr 901) and PME 1010 (Income1 716); more difficult than the austentic stainlass steels. Machineble in all conditions; fully heatrosted condition is preferred for finish machining. MCHIMBILITY:

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## PWA 587 PWA 1004 PWA 1030 PWA 1061

## GENERAL INFORMATION (cont.)

WEIDABILITY: Difficult. Comparable to Inconel X and A-286 but more difficult than Inconel 712. Can be fusion welded by either inert gas tungsten-arc or inert gas matalle-are process. Welding is accomplished in the solution heatreated condition with perent metal filler material (PMA 1080). Full heatreatment required after welding to repair heat-affected zone of the weld and to achieve optimum properties.

EMAZBABILITY: Can be silver, coper, nickel, and gold-nickel brased. Faying surfaces of brased joints should be nickel plated prior to brasing. Because of heatrest complexities of alloy, special metallurgical considerations are required to ensure desired properties in the finished brasements. In same instances, assemblies are solution heatreated and gold-nickel brased (n) the same operation; the resultant assembly requires only stabilisation and precipitation heatreats to complete the heatreat cycle.

#### CHENICAL PROPERTIES

CORROSION MESISTANCE: Good resistance to corrosion in gas turbine engine environments.

OXIDATION RESISTANCE: Good resistance to atmospheres encountered in gas turbine engines at temperatures up to 1600 F for intermittent service and up to 1800 F for continuous service.

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#### PRATT & WHITNEY AIRCRAFT

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#### PWA 1005 PWA 1007

#### GRNERAL INFORMATION

214 1007

SPECIFICATION: PMA 1005

FORMS: Forgings and forging stock Forgings and forging stock

CUNDITION: Forgings - solution, stabilization, and precipitation hestreated Forging stock - as ordered by forging manufacturer,

CONNON DESIGNATION: Waspaloy

MELTING PRACTICE: PWA 1005: Multiple maiting using consumable electrode process in the remeth cycle or vacuum induction selted. PWA 1007: Vacuum induction plus consumable electrode melt.

GENERAL DESCHIPTION: Maspeloy is a heatreatable nickel-base elloy thich has good atrongth at temperatures up to 1400 - 1500 F, and good extistion and corresion resistance in gas turbine atmospheres up to temperatures of approximately 1600 F. Tensile yield atrongth is slightly superior to that of PMA 1003 (Incolog 901), but inferior to that of PMA 1010 (Incoleg 901), but inferior to that of PMA 1010 (Incoleg 901), but inferior to that of PMA 1010 (Incoleg 901), but inferior to that of PMA 1010 (Incoleg 901), but inferior to that of PMA 1010 (Incoleg 901), but inferior to the to the to the strongent see \_onerally superior to those of PMA 1003 and PMA 1006. Porges more readily than PMA 1006 but with more difficulty than rMA 1010 and PMA 1003. Machines like PMA 1003 - wasier than PMA 1005.

APPLICATIONS: Parts requiring high strength plus good oxidation and corrosion resiliance at temperatures up to 1400 - 1500 F. Farticularly applicable to rotating parts in compressor and turbine sections.

CHERICAL COPPOSITIO: (Nominal):

<u>Cr</u> <u>Co</u> <u>Ko</u> <u>Ti</u> <u>Al</u> <u>Zr</u> <u>B</u> <u>Fe</u> <u>Cu</u> <u>Fn</u> <u>Si</u> <u>S</u> <u>Xi</u> 0.065 <u>17.5</u> <u>13.5</u> <u>4.0</u> <u>3.0</u> <u>1.4</u> <u>0.07</u> <u>0.007</u> <u>2.0\*</u> <u>C.1\*</u> <u>0.75\*</u> <u>0.75\*</u> <u>0.02\*</u> <u>remainder</u> \*Eximum

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Internation: \*\*1800 - 1925 F for 4 hr, oil or water quench
 \*\*\*1800 - 1925 F for 4 hr (protective stm), air cool or faster
 Stabilization: 1850 F 2 15 for 4 hr, sir cool
 Precipitation: 1400 F a 15 for 4c hr, air cool

"Forgings to be machined all over "Forgings not to be machined all over

POREEABLEITY: Fair, better than that of PMA 1008 (Astroloy), but poorer than that of PMA 1003 (Incoloy 201) or FMA 1010 (Income) 718). Generally forged Within 7050 - Jobo F temperature range.

MACHINABLITY: Difficult. Machined with asses general techniques and degree of difficulty as PHA 1003 and PMA 1910 Nachinebis in a conditions; fully heatmeasse condition is preferred for filles machining.

WELDABILITY: Difficult. PML 007 (Waspeloy in Solution heat autod sonsition) coverely recommended when welding is required; so Section 7.28.

BRANKABILIT: And usually brained. Can be stiver, copper, and gold-mickel present homever, nestreat complexities of saley require special metallocities considerations to answe desired properties of finished presents.

#### GROCIELL PROPERTING

CURROSION RESISTANCE: Sood concasion resistance in gas turbins anging atmospherer. CIIDATICS (SSIDTANCE: Sood restatence to atmospheres encounters) in gas turbine atgines at temptediones up to 2000 P.

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#### 9001 AW9 PWA 1013

		OTHERA L	INFORMATION	
SPECIFICATION:	PMA 1008		PWF 1013	
PORNI	Forgings and	forging stock	Forgings and forging	stock
OMDITION: Sol	lution, stabil	ization, precipita	tion bestreated	
COMMON DESIGNATIO	ON: Astrolo	1		
ENLING PHACTICE:			plus consumple elect or vacuum induction p	
which require up to approxi to those of	high strengt imately 1500 F PMA 1005 and P	h, and good oxidat . Tensile, creep MA 1007 (Mespaloy)	and stress-rupture str	stance al temperatures
at temperatu	Ferts requiri res up to appr and cover pla	oximately 1500 P.	and good exidation an Particularly appliesh	d corresion Fosistance le to turbine discs,
CHEMICAL COMPOSI	TION (Nominal)	;		
РИА 1008 <mark>.0</mark>	K 15.5 17 5.3	3.3 4.5 .02 .15	P 3 51 Fe Cu	2r Ni .06 reminder
PWA 1013 .0	<b>6≸ 15.0 17 5.0</b>	3.4 4.5 ,05 .15*	.015* .015* .2* .5* .1	.06* re_mindsz
Magimum				
BATH ATMERT:		PWA 1008	P	A 1013
Solution:	931: 2125 P : 1975 8 :	25/4 hr/AC or fam 25/4 hr/AC or fam	ter 1975-~075 P + 15/	
Stabilization	n; 1550 P ±	15/4 hr/AC or fas	ite 1000 P + 15/24 hr	AC to MT
Precipitatio	n: 1400 F 1	15/16 hr/AC or fac	ter 1800 P + 15/24 hr	AC to RT
Annealing -	Same as soluti	on heatreatment.		-,
Stabilization Precipitation Annealing - PORUSABILITY:	n; 1550 P g n: 1400 P g Siam as soluti Pair in annil	15/4 hr/AC or fas 15/16 hr/AC or fas on heatreatment. sizes; difficult	bath at 600 F ± 1 ster 1600 F ± 15/24 hr + 1800 F ± 15/4 h	0, stabilize 600 P/4 /AC to AT u/AC /AC to RT u/AC u/AC

FURMENILITY: Fair. Comparable to Waspiloy and more difficult than the austanitic stainless steple. High rate of work hardening necessitates intermittent annexls for severe deformation operations.

NACHINAGILITY: Difficult. Machining accomplished with same general techniques used for FMA 1005 and FMA 1007 (Waspeloy), but at th slightly more difficulty. Machinable in all conditions; however, fully heatreated condition is preferred for finish machining.

WELGABLITY: Nore difficult to weld than Waspeloy. hot generally recommenced.

"MarkaBillTy: Not usually brazed. Can be silver, copper, and gold-nickel brazed; however, heatreds complexities of alloy require special metallurgical considerations to ensure desired properties of finished brazemane.

## CHEMICAL PROFESTIES

(SERGETOR RESIDERED - Good correlation restations to gas turoine engine stanopheres.

-MIDSTICH - SISTANCE: - Good resistance to atmosphures encountered in ges turbine engines st temperatures up to approximately 1600 V.

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PWA 656

#### OFDERAL INFURNATION

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SPRCIFICATION: PWR 650

PORR: Investiont costings

COMDITION: Blade and wans castings are thermal shock tested (2000 F for 20 minutes, air scoled) twice, Farts other than blades and wanss - as cast.

COMMON DESIGRATION: IN 100

MELTING PRACTICS: Vecuum smilled and cast

OHEMMAL DESCRIPTION: Cast misbel-base sloy used in the as-cast condition. Stress-rupture and energy strengths of alloy are comparable to those if PMA 559 (SM 200) and superior to those of PMA 555 (Inco 713), PMA 1011 (Himonis 11...), and PMA 689 (0-700). Bulfidation-o...dation resistance, like that of PMA 659, is poor; deterant costing: required for applications at temperatures above 1400 F.

APPLICATION: Primarily turbing blades and vaner.

CHENICAL CONFOSITION (Nominal):

 C
 C
 C
 Ho
 V
 Ti
 Ai
 Po
 B
 Zr
 Hi

 0.17936
 9.5
 1510
 310
 0.388
 510
 515
 110"
 01315
 0136
 reaminader

 \*Nextman

MPATREATNENT: Turbine blades - Aged at 1600 F : 25 for 15 hr, air cooled.

CASTABILITY: Sair, similar to PM 659 (SH 200).

MackiMABILITI: Difficult. Machining accomplished with mame general (schniques and degree of ifficulty as PMA 655 (Inco 713), PMA 689 (U-7/0), and PMA 659 (SH 000).

WELDABLEITY: LIFFicult. Not usually usided.

#### CODUCAL PROPERTIES

CORROSION AND CRITCHION MESISTAMENT: General correction resistance of alloy is good. Alloy is subject to cultidation-oxidation intercorrection when operating in gas turbine sugjes atmospheres which contain certain value - hallde comminations at temperatures above 1400 P. In atmospheres where sither or balldes are essent, alloy is capable of resisting exidation at temperatures up to approximately 1600 P. Since presence of deleterious selfur-ballde commination are juite common in air-propulsion applications sulfishing-determine to alloy are required for all turbine blade and rank applications of this alloy.



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PWA 659

ORDERAL INFORMATION

SPECIFICATION: PMA :59

PorM: Investment castings

CONVITION: Blade and came castings are thermal shock tested (2000 P for 20 minutes, air cooled) twice, Parts other than blades and wanes - as cast.

COMMON DESIGNATION: SP 200

NALTING FRACTICE: Vacuum melted and cast

USNEMAL DaSchipTick: Cast nickel-base elloy used in the as-cast curdition Stress-rupture and creep strengths of alloy are comparable to those of Pak 658 (11.100) and superi to those of Pak 650 (inco 713), Pak 1011 (simonic 120), and ram 669 (1-200). Suiridation-estidation resistance, lise that of Pak 650, is poor: deterent cretings we required for applications at semperatures above 1400 P.

APplicationS: Primarity toping tandes and value.

CHE TOAL COMPOSITION (\* Mainel):

## C. CP Co M CE Al 71 Fo B 20 B DISS 2.0 10:0 TFL 1.0 5.0 7.0 1.5 D. D. F. Formalizier

SXA . ATMENT: Turping blauss a lged at 1800 F 1 25 for 50 hr, sie cooled.

CAUTABILY Yo - Fair. Similar to PMA 658 (18 120).

Buthist BillST: Difficult. Raching accomplished with same general techniques and degree of difficulty as 7MA nuc. PMA 649, and FMA 656.

WIREBILITY: Difficult. Lot usually welded.

#### CREMEAL P. WESTINS

CHROSION AND URIDATING MADISTANCE: General concentration resistance of allop 10 or 1. Alloy is abject to sulfidetion-oridation Sectoristics when oper asing in gas turtime engine sumspheres which contain cestain sulfur-ballide continue at lenguestures above 1400 F. In a mappleres where allow sulfur or ballies are stacks, alloy is capable of resisting on a futur-ballie continues of the capable met f. Since presence of teleterious sulfur-ballie continent on are quite at in alloypopulation applications, sulfidences terms rotings are registed for all turtime teletering of the stations of this alloy.

RAGE NO POLA

#### PWA 663

#### GENERAL INFORMATION

SPECIFICATION: PMA 663 (Development)

POPM: Investment castings

CONDITION: Slades are thermal shock tested (2000 F for 20 minutes, sir cooled) twice, Non-blade applications - as cast

MELTING PRACTICE: Vecuum melted and cast

GENERAL DESCRIPTION: PWM 663 is a cast nickel-base alloy which has strength and oxidation resistance comparable to that of PMA 659, but slightly better dustility. Although oxidation resistance is very good, marginal sulfidation resistance will probably necessitate coating protection. Castability is considered good.

APPLICATIONS: Primarily applicable to turbine blades and vanes.

CHEMICAL COMPOSITION (Nominal):

C Cr Co Mo Ta Al Ti Pe B Zr Mi 0.10% 8.0 10.0 8.0 4.3 6.0 1.0 .35 mm .015 .07 remainder

HRATREATHENT: Precipitation age - 1050 F ± 25 for 4 hr, air cool

CASTABILITY: Good. Similar to that of PWA 655 (Income! 713) and significantly better than that of PWA 659 (SN 200) and PWA 658 (IN 100).

MACHINABILITY: Difficult. Accompliated with same general techniques and degree of difficulty as PMA 655, PMA 658, and PMA 659.

#### CHEMICAL PROPERTIES

OXIDATION AND CORROSION RESISTANCE: General corrosion resistance of alloy is good. Subject to sulfidation-oxidation deterioration when operated at temperatures above 1400 F in gas turbine engine atmospheres which contain contrain sulfur-halide combinations. Sulfidation resistance of alloy is reportedly similar to simple of PMA 655 (Inmone 713); therefore the alloy will probably require coating protection. General oxidation resistance of alloy is better than that of PMA 659 (SM 200).

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PWA 655

#### CENERAL INFORMATION

SPECIFICATION: PWA 655

COPMON DECIGNATION: Incomel 713c, Emphas Alloy 713c

AVAILABLE FORM: Investment castings

CONDITION: As cast

MELTING PRACTICE: Vacuum melted, vacuum cast

GENERAL DESCRIPTION: Cast nickel base alloy normally used in as cast condition. Minimum 100 hr stress-rupture and 1.0% creep strengths at 1650 F are 33.0 ksi and 23.0 ksi, respectively. Stress-rupture and creep strengths of alloy are superior to those of U-700 but inferior to those of 3N 200, IN 100, and PMA 663. Oxidation resistance of alloy is good to 1900 F. Thermal shock properties are superior to those of most commonly used heat resistant nickel base alloys. Alloy is subject to sulfidation; better than IN 100, 3M 900 and FMA 503 but inferior to U-700 and Maspaloy.

APPLICATIONS: Turbine blades and vanes.

CHEMICAL COMPOSITION (Nominal):

#### C Cr Ko Cb + Ta Ti Al R Zr Ni + Co 0.20% mm t 14.0 4.5 2.0 1.0 6.0 0.01 0.08 remainder

HEATREATMENT: Normally used in as cast condition. Stress relief: 1600 F for 2 hr, air cool.

CASTABILITY: Good, vacuum melting and casting required to maintain control of reactive alloy elements (Ti, Al). Air and inert gas atmosphere melted and cast products are substantially inferior.

MACKINABILITY: Diffigstit. Comparable to IN 100, SN 200, PMA 863. Use of carbide tools with slow speeds and light loads recommended. Finishing done by careful grinding.

WELDABILITY: Difficult, not generally welded. FWA experience limited to bardfacing of turbine blade shrouds with FWA 694 (mear resistant cobalt base alloy). Post weld stress relief required.

BRAZLABILITY: No data available.

#### CHEMICAL PROPERTIES

CORNOSION RESISTANCE: Generally good; but, marginal resistance to sulfidation makes use of a protestive coating (FMA 47-16L) desirable.

OXIDATION RESISTANCE: Good up to 1900 F.

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PWA 653

#### GENERAL INFORMATION

SPECIFICATION: PWE 603

CONMON DESIGNATION: WI-52

AVAILABLE FORMS: Investment castings

CONDITION: As cast

MELTING PRACTICE: Air molt, air cast

GENERAL DESCRIPTION: Cast cobalt base alloy generally used in as cast condition. Minimum 100 hour stress-rupture and 1.0% group strengths at 1700 P are 17.0 ksi and 15.0 ksi, respectively. Stress-rupture and creep strengths of alloy are comparable to those of PMA 657 and substantially superior to those of AMS 5388 and AMS 5385 cast sobalt base alloys. Alloy exhibits good thermal shock and corrosion resistance. Oxidation resistance is poorest of cast, cobalt base blade and wane alloys. Protective oxidation and erosion resistant coatings required for applications in visinity of 1800 F.

APPLICATIONS: Turbine vanes.

CHEMICAL COMPOSITION (Nominal):

C 485.0	<u>21.0</u>	11.0	<u>Cb + Te</u> 8.0	2.0	Co rsminder
HEATHEATHERT: Normally used in as cast condition. Stress relief: 1600 F $\pm$ 20 for 2 hr, air cool					
CASTABILITY:	Good; similar	to AMS 5369	•		
MCHINABILITYI	Difficult;	similar to A	NS 5382 and Pi	A 657.	

WELDABILITY: Difficult, not generally recommended; however, can be accomplished with special techniques. Stress relief required after welding.

BRAZE-BILITY: No data available.

#### CHEMICAL PROPERTIES

CONRUSION RESISTANCE: Good.

OXIDATION RESISTANCE: 900d up to 1600 F. Frotestive oxidation and erosion resistent coatings required for applications at temperatures of 1800 F and above. PMA 55 and PMA 44 procestive coatings improve oxidation resistance in 1800 - 2000 F range.

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AMS 6415 /MS 6359

		(	JENERAL INFORMATION
SPSCIFICATIO	im :	AMS 5415	AMS 0359
AVAILABLE PO	nMa :	Sars, forgings	Plate, shaet, strip
CORDITIONI	Forning	ot or cold finished s: As ordered Annemled (Rc 25 max)	or normalized and tempered (Rc 30 msx)

" INON DESIGNATION: AISI 4340, SAN 4340

ALTING PRACTICE: Gon is sist available. Generally air melted in electric furnace. Vacuum melted material

RAL DASCRIPTION: AISI 4340 is a low alloy steel which is heatrestable over a wide range of yiel: strengths = 100 to 210 ksl. Must commonly heatrested to 140 = 165 ksi (Rc 35 = 46) yield strength level for application, at temperatures up to 700 P. Yield strength (6.%, offset) of alloy is slightly higher than that of AMS 5613 (AISI 410) steel at comparable hardness at temperatures up to 800 P. Streas-supture and creep strengths of alloy are inferior to those of AMS 6304 low alloy steel at comparable hardness levels. Forging, machining, and hardening characteristics are comparable to those of AMS 630 and superior to those of AMS 5015 to that of AMS 6304 but inferior to that of AMS 5613 and AMS 5616. GENERAL DESCRIPTION:

CATIONS: Farts requiring high hardenability, high strength, and reasonable toughness at moderate tomperatures (up to  $70^\circ$  F). Used primurike for shafts, hubs, and compressor discs. APPLICATIOUS:

CHEMICAL CONFOSITION (Nominal):

# C. Cr N2 Mo Nn Si P 3 Pe C.407 0.30 1.30 0.25 0.75 0.27 0.04 max 0.04 max required

HEATHER PREAT :

NGATEST: Hormalise: 15<sup>TF</sup> = 1700 F/1 hr per section inch, sin cool Auguentitie: 1475 = 1600 F, oil quench. Through hardening attained in section Hizes up to 3.0 inches with oil quench. Temper range: 600 = 1200 F for 2 hours and air cooled. (Sec temper curve for minted properties and tempering tedgeratures.) Anneal: 1525 = 1600 F, furnace cool; resulting hardness Bhy 215. Heatreatment at temperatures above 1000 P requires suitable protective atmosphere to avoid decarburitation.

to avoid decarbarization.

ABILITY: Readily forged; comparable to AMS 6304 low alloy steel and AMS 5013 (Algi 410) hardenable corrosion resistant atesi. Usually forged in 2250 - 1050 F temperature ranks. Generally normalized before subsequent bardening and tempering FURGABILITY: hestreatments.

ELLITY: Pair; cold forming experience very limited. Forms in full moneshed condition momentat like ALS 5566 (ALSI 410). FORTABILITY:

LARILITY: Feir to good. Similar to AbS 5013 (AISI 610) and AKS 0304 low alloy ateal out superior to Abs 5515 (Greek Ascoloy) and the sustenitic stainies steels. Optimum condition for rough machining is normalised and tempered to Sockwell C 30 mex. Finishing can be performed on material hardened and tempered to any strength and hardness level. MCHINAHILITY:

ELLITY: - Mair to poor. Can be fusion weided; however weiding is not generally recommended unless phosphorus and sulfur contents are restricted to 0.0164 max. ALDARILITY:

EABLETY: Readily brezed by all methods, Gold-nickel and copper brazing should procede handening and tempering. Heatreatment required after w25 2005 high tem rature silver brazing; no heatreatment necessary after AMS 2005 him temperature silver rating. PRAZEABILITY:

#### CHEMICAL PROPERTIES

SIDN AUDISTANCE: Foor corresion resistance. Protective costing of cadmium piste is required for applications at temperatures up to 500 P. Above 500 F, diffused nickel-cadmium (ANS 2416) pists is used. CORROSION ALGISTANCE:

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AMS 6304

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#### GENERAL INFORMATION

SPECIFICATION AMS 6304

FORME Bars, forgings

Bar - machinable; Bhn 229 max if cold finished Forgings - annealed; Bhn 241 max CONDITIONS

COMMON DESIGNATION: 17-22-A: Tompler

MELTING PRACTICE: Electric furnace, air molt.

RAL DESCRIPTION: ANS 6304 is a low alloy steel which is generally used in the mormalised and tempered condition for miximum elevated temperature strength. Yield strength (0.2% offast) at temperatures above 600 % for ANS 6304 hardened to Rc 35 is superior to that of ANS 6415 low alloy steel and ANS 6516 (Greek Ascoloy). Greep strengths are superior to those of ANS 5516 (Greek Ascoloy) and ANS 6415 (low alloy steel) but inferior to those of ANS 5735 (A-286) or ANS 5660 and PMA 1003 (Inco #01). Forgestility and maximability are like ANS 6415 and superior to ANS 5516 and ANS 5735. Correction egainst oxidation is required at temperatures above 750 F. GENERAL DESCRIPTION:

CATIONS: Parts requiring rupture and areap strengths superior to those of other low alloy and hardenable corrosion resistant stoels at temperatures up to 1000 F. Used primarily for compressor discs, spacers, and shafts, and for high temperature APPLICATIONS:

CHEMICAL COMPOSITION (Nominal):

## MAXING

REATREATMENT :

 Normalise in 1750 F for 1 - 1.5 hr, sir cool
 Temper: 1000 F min. for 6 hr, sir cool. (Large forgings require additional temper of 1000 F for 4 hr, sir cool)
 Process an.esi: 1250 F for g hr, sir cool
 Pull anneai: 1450 F for 1 hr per section inch, furnace cool 20 deg F per hr to 1000 F, sir cool (Hardbess Bhn 160 - 190)
 Normalise and anneal heatrestments require suitable protective atmosphere to svoid deventue for the section inch. decarburisation.

FORGEABILITY: Readily forged; similar to ANS 6415 low alloy steel, Superior to ANS 5735 (A-286), PMA 1003 (Inco 901) and F#A 1005 (Wespeloy). Usual forging range - 2250 F down to 1600 F.

MACHINABILITY: Fair to good. Similar to AMS 6415 and superior to the austenitic stainless stable.

WELDADILITY: Fair to poor. Fol usually welded: however, with some chemistry modifications material can be astisfactorily welded by techniques used for other high strength, low alloy steels.

EABLITY: Readily brased by all methods. Gold-nickel and copper bresing should precede normalise and temper heatreatments. Heatreatment required after AND 2806 high temperature silver brating; no heatreatment necessary after AND food low temperature silver brazing. BRAZEABILITY:

#### CHEMICAL PROPERTIES

CURNOSION RESISTANUE: Fuor; stailar to AMS 6415. Provocing costing of cadmium plate required for applications at temperatures up to 500 F. Above 500 F diffused rickel-cadmium plate (AMS 2410)16 used.

OlIDATION FASISTANCa: Poor to fair; not rust resistant. Forms thin adherent oxide film in dry air at temperatures up to approximately 700 P. Scaling becomes appreciable above 1000 P. Comparable to ANS 6615 but inferior to ANS 5615 (AISI 610) and ANS bold (ureak Ascolog).

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