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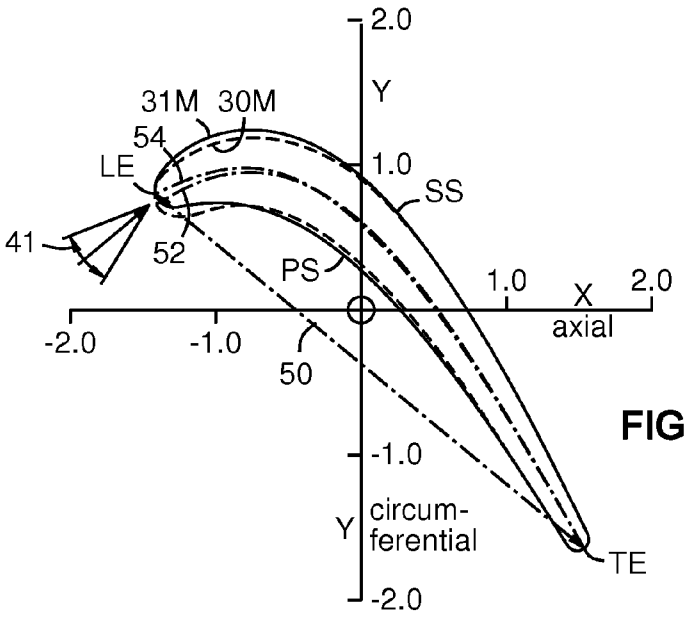

FIG 4b

(57) Abstract: A turbine blade airfoil (25, 31R, 31M, 31T, 72) comprising an outer surface shape defined by Cartesian coordinates of successive transverse profiles at radial increments as set forth in Tables 1a to 1k, wherein each table defines a transverse sectional profile characterized by a smooth curve connecting the coordinates, and the surface shape comprises a smooth surface connecting the sectional profiles. The blade may include a tip shroud with edge profiles defined by Cartesian coordinates set forth in Table 2a and 2b. A gusset/fillet may be provided between the blade airfoil and the tip shroud, with a planar diagonal surface over most of a diagonal bracing area of the gusset/fillet.

WO 2014/189902 A1

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TURBINE BLADE AIRFOIL AND TIP SHROUD

This application claims benefit of the 21 May 2013 filing date of United States provisional patent application number 61/825,642, incorporated by reference herein.

FIELD OF THE INVENTION

The invention relates to turbine blade design, and particularly to gas turbine blade airfoil shape and tip shroud shape for maximum aerodynamic efficiency and structural life.

BACKGROUND OF THE INVENTION

In a gas turbine engine, air is pressurized in a compressor, then mixed with fuel and burned in a combustor to generate hot combustion gases. The hot combustion gases are expanded within the turbine section where energy is extracted to power the compressor and to produce useful work, such as turning a generator to produce electricity. The hot combustion gas, also called the working gas, travels through a series of turbine stages that are numbered starting at 1 from front to back of the turbine section. A turbine stage includes a circular array of rotating turbine blades, and may also include a circular array of stationary vanes. The blades extract energy from the working gas for powering the compressor and providing output power. Commonly, each blade is removably mounted on the circumference of a disk.

A turbine blade has a tip that closely clears a surrounding shroud. The shroud channels the working gas through the turbine section. The inner lining of the shroud is made abradable so the blade tips can cut a path in it to minimize the tip-to-shroud clearance, and minimize leakage of the working gas from the pressure side to the suction side of each blade. Some blade designs include a tip shroud as shown in FIG 1. The shroud is a transverse plate on the blade tip. A seal rail may extend radially outward from the shroud. The term "radial" herein means along a radius from the turbine rotation axis. The rail is aligned circumferentially with the rotation direction. It cuts a narrow groove in the shroud lining for working gas sealing. The rail may include wider portions called teeth that cut the groove wider than the rail to minimize friction.

Cantilevered portions of the tip shroud must be rigid to resist flexing from centrifugal force.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in the following description in view of the drawings that show:

FIG. 1 is a perspective view of a prior art turbine blade with a tip shroud.

FIG. 2 is a top view of a prior art tip shroud and seal rail.

FIG. 3 is a sectional view taken on line 3-3 of FIG 2.

FIG. 4a is a transverse sectional profile of a blade tip, showing a prior art airfoil profile in dashed line and an embodiment of the invention in solid line.

FIG. 4b is a transverse sectional profile of a spanwise midpoint of a blade, showing a prior art airfoil profile in dashed line and an embodiment of the invention in solid line.

FIG. 4c is a transverse section of a blade root, showing a prior art airfoil profile in dashed line and an embodiment of the invention in solid line.

FIG 5 is a top view of a turbine blade tip shroud 56 according to an embodiment of the invention with an underlying blade tip profile 31T.

FIG 6 is a perspective view of a gusset/fillet between a tip shroud and a blade airfoil according to a further embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG 1 shows a prior art gas turbine blade 20A with a tip shroud 22A. The blade has a root 23, a platform 24, and an airfoil 25 with a leading edge LE and a trailing edge TE. A transverse profile 30M of the airfoil midsection is shown with a pressure side P and a suction side S. An axial direction 28 of the working gas flow and a circumferential direction 29 of blade rotation are shown. "Axial" means parallel to the turbine rotation axis. The circumferentially oriented seal rail 32A has wider portions or teeth 34, 35 for cutting a groove in the shroud liner. The root 23, platform 24, and airfoil 25 may have respective centers of mass stacked along a stacking axis 21, which is a radial line from the turbine rotation axis when the blade is installed.

FIG 2 is a top view of another prior art turbine blade 20B showing a tip shroud 22B, a platform 24, and an airfoil 25 with a leading edge LE and a trailing edge TE. A transverse profile 30T of the airfoil tip is shown with a dashed line. An axial direction 28 of the working gas flow and a circumferential direction 29 of blade rotation are shown. A circumferentially oriented seal rail 32B has first and second teeth 38, 39 for cutting a groove in the shroud liner. Cooling air outlets 40 pass through the tip shroud from cooling chambers in the airfoil 25. The rail and teeth have fillets 42.

FIG 3 is a sectional view taken on line 3-3 of FIG 2, showing an abradable shroud liner 44 with a groove 46 therein that is cut by the teeth 38, 39 on the seal rail 32B. Abradable shroud liners are often made of ceramic that may be porous and/or may have a honeycomb structure to increase abradability. Gas leakage over the blade tip is impeded by the seal rail 32B in the groove 46.

The present inventors have recognized a need for blades with an improved tip shroud and transitional structure between the airfoil and the tip shroud in order to reduce mechanical loading at the blade airfoil inner radial span and root regions, reduce tip shroud deflection, reduce aerodynamic losses, improved turbine efficiency and power generation, and increase blade tip thermo-mechanical fatigue life compared to known blade configurations.

FIG 4a is a transverse sectional profile of a blade tip, showing a prior art airfoil profile in dashed line and a replacement profile of an embodiment of the invention in solid line. A leading edge LE, trailing edge TE, pressure side PS, suction side SS, and chord line 50 of the replacement profile are shown. The replacement profile has a leading edge portion that may be at least 5% narrower in the front 20% of the chord length compared to the prior art profile.

FIG 4b is a transverse sectional profile of a midsection of a blade at 50% span, showing a prior art airfoil profile in dashed line and a replacement profile of an embodiment of the invention in solid line. A chord line 50 is shown. Mean camber lines 52, 54 of the respective prior art and inventive profiles are shown. The replacement profile may have at least 3 degrees less camber in the front 15% of the chord length compared to the prior art profile. This means the angular divergence between the respective mean camber lines 52, 54 of the prior art and inventive blades may be at

least 3 degrees at a chord position of greatest angular divergence there between within the front 15% of the chord length. The inventive profile may also have at least 3% narrower leading edge portion in the front 10% of the chord length compared to the prior art profile.

FIG 4c is a transverse section of a blade root, showing a prior art airfoil profile in dashed line and a replacement profile of an embodiment of the invention in solid line. A chord line 36 of the replacement profile is shown. The replacement profile may have at least 1 degree less camber in the front 25% of the chord length compared to the prior art profile.

A blade airfoil conforming to the replacement profiles 31T, 31M, and 31R provides the following aerodynamic improvements over the prior art blade of profiles 31T, 30M, 30R:

a) Increased tolerance to variations 41 in the angle of incidence of the working gas inflow at the leading edge of the airfoil.

b) Substantially reduced suction surface diffusion over most of the span of the blade. Suction surface diffusion is the increase in static pressure from airfoil trailing edge to a minimum static pressure location of the blade suction surface divided by velocity head (Pt-Ps) at the minimum pressure location.

c) Reduction in aerodynamic losses on the suction side of the airfoil, due to reduced friction on the airfoil surfaces.

d) Reduced peak Mach number in the trailing edge region, resulting in reduced trailing edge losses and increased aerodynamic efficiency.

e) Improved mass distribution resulting in reduced structural loading in the lower span and root of the blade.

Tables 1a-1k herein specify eleven sectional profiles of a blade airfoil according to an embodiment of the invention at successive 10% radial increments of the span of the airfoil starting at the root. The absolute values of the coordinates define one blade in inches. However, the coordinates may used as relative values that may be scaled up or down proportionally, along with the tolerance below, for larger or smaller turbines. Each radial profile is characterized by a smooth curve connecting the nominal X and Y coordinates in each table. The term "nominal" herein means a design goal

implemented within acceptable tolerance. An acceptable manufacturing tolerance is +/- 0.050 inches in a direction normal to the surface at each location at a temperature of 20 °C (293.15 K, 68 °F). The coordinates represent the uncoated outer surface of the airfoil. The airfoil surface is a smooth surface connecting the sectional profiles defined below from 0% to 100% of the span.

Table 1a 0% Radial Span	
X (Axial)	Y (Circum.)
-1.680	-0.091
-1.719	-0.021
-1.702	0.095
-1.670	0.167
-1.612	0.271
-1.570	0.338
-1.525	0.402
-1.450	0.494
-1.397	0.552
-1.310	0.633
-1.250	0.684
-1.186	0.731
-1.086	0.794
-1.016	0.830
-0.906	0.875
-0.831	0.899
-0.754	0.916
-0.637	0.932
-0.558	0.936
-0.440	0.930
-0.361	0.919
-0.284	0.902
-0.171	0.868
-0.097	0.839
0.010	0.789
0.079	0.751
0.147	0.710
0.245	0.644
0.309	0.597

0.401	0.523
0.460	0.471
0.518	0.417
0.601	0.333
0.655	0.276
0.734	0.187
0.784	0.126
0.834	0.065
0.906	-0.029
0.952	-0.093
1.021	-0.190
1.065	-0.255
1.109	-0.321
1.174	-0.420
1.216	-0.486
1.258	-0.554
1.319	-0.655
1.360	-0.722
1.400	-0.791
1.459	-0.893
1.498	-0.962
1.556	-1.065
1.594	-1.134
1.632	-1.203
1.688	-1.308
1.725	-1.378
1.784	-1.480
1.824	-1.548
1.862	-1.617
1.893	-1.668
1.913	-1.702
1.933	-1.736
1.951	-1.771
1.956	-1.790
1.957	-1.830
1.953	-1.849
1.936	-1.884
1.916	-1.906
1.891	-1.922
1.853	-1.933
1.833	-1.933

1.806	-1.923
1.784	-1.903
1.765	-1.880
1.747	-1.856
1.730	-1.832
1.719	-1.816
1.702	-1.792
1.691	-1.775
1.657	-1.727
1.623	-1.678
1.554	-1.582
1.508	-1.518
1.461	-1.454
1.389	-1.360
1.340	-1.298
1.265	-1.206
1.215	-1.146
1.163	-1.086
1.084	-0.998
1.030	-0.940
0.949	-0.854
0.893	-0.798
0.836	-0.744
0.749	-0.663
0.690	-0.611
0.599	-0.535
0.537	-0.486
0.474	-0.439
0.377	-0.371
0.311	-0.327
0.211	-0.265
0.142	-0.226
0.072	-0.188
-0.034	-0.136
-0.106	-0.104
-0.216	-0.061
-0.291	-0.036
-0.367	-0.014
-0.482	0.013
-0.560	0.027
-0.677	0.042

-0.756	0.048
-0.835	0.050
-0.953	0.047
-1.032	0.041
-1.149	0.025
-1.227	0.010
-1.304	-0.009
-1.417	-0.042
-1.491	-0.072
-1.603	-0.110
-1.680	-0.091

Table 1b 10% Radial Span	
X (Axial)	Y (Circum.)
-1.608	0.120
-1.639	0.190
-1.627	0.303
-1.599	0.373
-1.541	0.471
-1.495	0.532
-1.445	0.589
-1.364	0.669
-1.305	0.718
-1.212	0.784
-1.147	0.823
-1.080	0.857
-0.974	0.901
-0.902	0.923
-0.790	0.947
-0.715	0.956
-0.639	0.959
-0.525	0.954
-0.450	0.944
-0.339	0.920
-0.266	0.897
-0.195	0.871
-0.091	0.824
-0.024	0.788
0.073	0.729

0.136	0.686
0.197	0.641
0.285	0.569
0.342	0.519
0.425	0.440
0.478	0.386
0.530	0.331
0.606	0.246
0.655	0.188
0.727	0.099
0.773	0.039
0.819	-0.022
0.886	-0.114
0.929	-0.176
0.993	-0.271
1.035	-0.334
1.077	-0.398
1.138	-0.494
1.178	-0.558
1.217	-0.623
1.276	-0.721
1.314	-0.787
1.352	-0.852
1.408	-0.951
1.445	-1.018
1.500	-1.118
1.536	-1.184
1.572	-1.251
1.625	-1.352
1.660	-1.420
1.712	-1.521
1.738	-1.572
1.764	-1.623
1.773	-1.640
1.790	-1.673
1.803	-1.698
1.817	-1.724
1.831	-1.759
1.835	-1.787
1.831	-1.815
1.819	-1.841

1.799	-1.862
1.775	-1.876
1.747	-1.882
1.719	-1.879
1.693	-1.867
1.672	-1.848
1.654	-1.826
1.632	-1.795
1.621	-1.779
1.600	-1.748
1.578	-1.716
1.557	-1.685
1.515	-1.622
1.451	-1.528
1.408	-1.465
1.364	-1.403
1.298	-1.310
1.253	-1.249
1.208	-1.188
1.139	-1.097
1.093	-1.037
1.046	-0.977
0.974	-0.888
0.925	-0.830
0.851	-0.744
0.801	-0.687
0.750	-0.631
0.671	-0.548
0.618	-0.493
0.537	-0.414
0.481	-0.362
0.425	-0.311
0.338	-0.237
0.279	-0.189
0.188	-0.120
0.126	-0.077
0.063	-0.035
-0.035	0.023
-0.102	0.059
-0.206	0.107
-0.276	0.135

-0.348	0.160
-0.458	0.190
-0.532	0.206
-0.645	0.221
-0.721	0.226
-0.797	0.227
-0.911	0.222
-0.986	0.213
-1.098	0.194
-1.172	0.177
-1.246	0.158
-1.355	0.125
-1.427	0.102
-1.540	0.085
-1.608	0.120

Table 1c 20% Radial Span	
X (Axial)	Y (Circum.)
-1.522	0.255
-1.572	0.311
-1.577	0.421
-1.552	0.491
-1.495	0.587
-1.451	0.646
-1.401	0.702
-1.319	0.777
-1.261	0.823
-1.168	0.884
-1.103	0.919
-1.035	0.949
-0.965	0.975
-0.858	1.003
-0.784	1.015
-0.673	1.022
-0.599	1.020
-0.525	1.012
-0.416	0.992
-0.345	0.972
-0.240	0.934

-0.172	0.904
-0.106	0.870
-0.010	0.814
0.052	0.772
0.141	0.706
0.198	0.659
0.254	0.610
0.335	0.534
0.388	0.481
0.463	0.400
0.512	0.344
0.560	0.288
0.630	0.201
0.675	0.142
0.742	0.053
0.785	-0.007
0.828	-0.068
0.890	-0.160
0.931	-0.222
0.992	-0.315
1.031	-0.378
1.070	-0.441
1.128	-0.536
1.166	-0.600
1.223	-0.696
1.259	-0.760
1.296	-0.825
1.350	-0.922
1.386	-0.987
1.438	-1.085
1.473	-1.151
1.508	-1.216
1.559	-1.315
1.593	-1.381
1.627	-1.447
1.661	-1.513
1.686	-1.563
1.703	-1.596
1.720	-1.629
1.728	-1.645
1.744	-1.678

1.756	-1.704
1.763	-1.731
1.761	-1.768
1.754	-1.785
1.730	-1.813
1.706	-1.827
1.679	-1.832
1.651	-1.829
1.626	-1.817
1.599	-1.791
1.588	-1.776
1.568	-1.745
1.553	-1.722
1.538	-1.698
1.518	-1.667
1.498	-1.636
1.458	-1.574
1.396	-1.481
1.355	-1.419
1.313	-1.358
1.250	-1.266
1.208	-1.206
1.143	-1.115
1.099	-1.055
1.055	-0.995
0.988	-0.907
0.943	-0.848
0.874	-0.760
0.828	-0.702
0.781	-0.645
0.709	-0.560
0.661	-0.504
0.586	-0.421
0.536	-0.367
0.484	-0.313
0.406	-0.234
0.352	-0.183
0.270	-0.108
0.213	-0.060
0.156	-0.014
0.067	0.053

0.005	0.095
-0.089	0.154
-0.154	0.189
-0.221	0.222
-0.289	0.252
-0.393	0.290
-0.465	0.311
-0.573	0.334
-0.647	0.345
-0.721	0.351
-0.832	0.351
-0.906	0.347
-1.017	0.334
-1.090	0.321
-1.162	0.306
-1.270	0.278
-1.341	0.256
-1.450	0.236
-1.522	0.255

Table 1d 30% Radial Span	
X (Axial)	Y (Circum.)
-1.514	0.450
-1.530	0.522
-1.495	0.624
-1.458	0.686
-1.391	0.772
-1.341	0.824
-1.287	0.872
-1.199	0.937
-1.137	0.974
-1.039	1.022
-0.971	1.047
-0.901	1.067
-0.794	1.086
-0.722	1.092
-0.650	1.091
-0.541	1.081
-0.470	1.068

-0.400	1.049
-0.297	1.014
-0.231	0.985
-0.134	0.935
-0.072	0.898
-0.012	0.858
0.076	0.793
0.132	0.747
0.213	0.675
0.265	0.625
0.316	0.573
0.390	0.493
0.437	0.438
0.507	0.355
0.552	0.298
0.596	0.240
0.660	0.152
0.702	0.093
0.764	0.004
0.804	-0.056
0.844	-0.117
0.903	-0.208
0.941	-0.270
0.998	-0.362
1.036	-0.425
1.073	-0.487
1.127	-0.581
1.163	-0.644
1.217	-0.739
1.252	-0.802
1.286	-0.866
1.320	-0.930
1.371	-1.026
1.405	-1.090
1.455	-1.187
1.488	-1.251
1.521	-1.316
1.570	-1.413
1.602	-1.477
1.619	-1.510
1.635	-1.542

1.651	-1.575
1.659	-1.591
1.675	-1.623
1.692	-1.656
1.697	-1.673
1.697	-1.709
1.687	-1.735
1.669	-1.755
1.637	-1.772
1.619	-1.775
1.584	-1.769
1.561	-1.755
1.542	-1.734
1.522	-1.704
1.508	-1.681
1.494	-1.658
1.474	-1.628
1.455	-1.597
1.435	-1.566
1.396	-1.506
1.356	-1.445
1.297	-1.354
1.257	-1.293
1.216	-1.233
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1.051	-0.995
1.009	-0.936
0.966	-0.877
0.902	-0.790
0.858	-0.732
0.792	-0.645
0.748	-0.588
0.703	-0.532
0.634	-0.447
0.588	-0.392
0.516	-0.309
0.468	-0.255
0.419	-0.202
0.344	-0.123
0.293	-0.072

0.214	0.003
0.160	0.051
0.104	0.098
0.019	0.165
-0.040	0.207
-0.132	0.266
-0.194	0.302
-0.259	0.336
-0.358	0.380
-0.426	0.405
-0.495	0.426
-0.602	0.449
-0.673	0.460
-0.746	0.466
-0.854	0.467
-0.927	0.464
-1.035	0.452
-1.106	0.441
-1.177	0.427
-1.283	0.400
-1.354	0.384
-1.460	0.401
-1.514	0.450

Table 1e 40% Radial Span	
X (Axial)	Y (Circum.)
-1.447	0.592
-1.475	0.657
-1.446	0.758
-1.409	0.818
-1.341	0.900
-1.290	0.948
-1.235	0.992
-1.145	1.049
-1.083	1.082
-1.017	1.109
-0.916	1.139
-0.846	1.153
-0.776	1.160

-0.670	1.161
-0.600	1.155
-0.496	1.136
-0.427	1.117
-0.361	1.094
-0.263	1.052
-0.201	1.019
-0.110	0.965
-0.052	0.925
0.005	0.882
0.087	0.815
0.139	0.767
0.215	0.693
0.264	0.642
0.311	0.590
0.380	0.510
0.425	0.455
0.490	0.371
0.532	0.315
0.574	0.258
0.615	0.200
0.675	0.112
0.714	0.054
0.772	-0.035
0.810	-0.095
0.847	-0.155
0.903	-0.245
0.939	-0.305
0.993	-0.397
1.029	-0.458
1.064	-0.519
1.116	-0.612
1.150	-0.673
1.201	-0.766
1.234	-0.829
1.267	-0.891
1.316	-0.985
1.348	-1.048
1.396	-1.143
1.428	-1.206
1.460	-1.269

1.507	-1.364
1.531	-1.411
1.554	-1.459
1.570	-1.490
1.577	-1.506
1.593	-1.538
1.608	-1.570
1.616	-1.586
1.628	-1.619
1.628	-1.654
1.622	-1.671
1.600	-1.698
1.569	-1.714
1.551	-1.716
1.517	-1.708
1.495	-1.692
1.478	-1.672
1.459	-1.642
1.445	-1.619
1.431	-1.597
1.413	-1.567
1.394	-1.537
1.375	-1.507
1.337	-1.448
1.279	-1.359
1.241	-1.299
1.202	-1.240
1.144	-1.152
1.105	-1.093
1.045	-1.005
1.005	-0.947
0.965	-0.889
0.903	-0.802
0.862	-0.745
0.821	-0.688
0.758	-0.603
0.715	-0.546
0.672	-0.490
0.607	-0.406
0.563	-0.351
0.496	-0.269

0.450	-0.215
0.404	-0.162
0.333	-0.083
0.285	-0.032
0.210	0.044
0.160	0.094
0.108	0.142
0.028	0.211
-0.027	0.256
-0.111	0.320
-0.170	0.360
-0.229	0.397
-0.322	0.449
-0.385	0.480
-0.483	0.520
-0.551	0.542
-0.619	0.561
-0.723	0.581
-0.793	0.589
-0.864	0.594
-0.970	0.593
-1.040	0.588
-1.110	0.579
-1.214	0.560
-1.283	0.544
-1.389	0.551
-1.447	0.592

Table 1f 50% Radial Span	
X (Axial)	Y (Circum.)
-1.376	0.742
-1.414	0.800
-1.401	0.902
-1.365	0.961
-1.296	1.038
-1.243	1.082
-1.186	1.121
-1.126	1.155
-1.030	1.195

-0.964	1.215
-0.862	1.234
-0.794	1.240
-0.724	1.240
-0.621	1.230
-0.554	1.218
-0.454	1.189
-0.389	1.165
-0.326	1.137
-0.235	1.089
-0.176	1.052
-0.091	0.993
-0.036	0.951
0.016	0.906
0.093	0.836
0.141	0.787
0.189	0.737
0.258	0.660
0.302	0.607
0.345	0.553
0.409	0.471
0.450	0.416
0.510	0.332
0.550	0.275
0.588	0.218
0.645	0.132
0.683	0.074
0.738	-0.014
0.775	-0.073
0.811	-0.131
0.864	-0.220
0.899	-0.280
0.951	-0.369
0.985	-0.429
1.019	-0.490
1.069	-0.580
1.102	-0.641
1.134	-0.702
1.183	-0.793
1.215	-0.855
1.246	-0.916

1.293	-1.008
1.324	-1.070
1.370	-1.163
1.401	-1.225
1.432	-1.287
1.462	-1.348
1.485	-1.395
1.500	-1.426
1.515	-1.457
1.530	-1.488
1.542	-1.511
1.554	-1.534
1.565	-1.567
1.565	-1.593
1.557	-1.618
1.535	-1.644
1.503	-1.658
1.486	-1.660
1.453	-1.652
1.426	-1.630
1.416	-1.616
1.397	-1.587
1.379	-1.558
1.365	-1.536
1.351	-1.514
1.333	-1.485
1.305	-1.441
1.278	-1.397
1.222	-1.310
1.185	-1.252
1.148	-1.194
1.091	-1.107
1.054	-1.049
0.996	-0.963
0.958	-0.905
0.919	-0.848
0.860	-0.763
0.821	-0.706
0.761	-0.622
0.721	-0.566
0.680	-0.510

0.618	-0.427
0.577	-0.372
0.534	-0.317
0.470	-0.236
0.427	-0.182
0.382	-0.129
0.315	-0.051
0.269	0.001
0.199	0.077
0.151	0.127
0.103	0.176
0.028	0.248
-0.023	0.295
-0.101	0.362
-0.155	0.405
-0.210	0.447
-0.295	0.506
-0.353	0.543
-0.444	0.594
-0.505	0.625
-0.569	0.652
-0.666	0.687
-0.733	0.706
-0.834	0.727
-0.903	0.735
-0.972	0.738
-1.041	0.737
-1.144	0.728
-1.212	0.718
-1.315	0.709
-1.376	0.742

Table 1g 60% Radial Span	
X (Axial)	Y (Circum.)
-1.354	0.955
-1.361	1.023
-1.317	1.114
-1.271	1.164
-1.191	1.226

-1.132	1.259
-1.069	1.286
-0.972	1.314
-0.905	1.326
-0.838	1.332
-0.736	1.330
-0.669	1.321
-0.602	1.308
-0.505	1.280
-0.441	1.256
-0.349	1.212
-0.290	1.179
-0.232	1.144
-0.149	1.085
-0.096	1.043
-0.019	0.976
0.030	0.930
0.078	0.882
0.147	0.807
0.191	0.756
0.234	0.704
0.297	0.624
0.338	0.570
0.378	0.515
0.437	0.432
0.476	0.376
0.532	0.292
0.569	0.235
0.606	0.178
0.659	0.092
0.695	0.034
0.748	-0.053
0.782	-0.111
0.816	-0.170
0.867	-0.258
0.900	-0.317
0.950	-0.406
0.982	-0.465
1.015	-0.525
1.047	-0.585
1.094	-0.675

1.125	-0.735
1.171	-0.825
1.202	-0.886
1.232	-0.947
1.277	-1.038
1.307	-1.099
1.351	-1.190
1.381	-1.251
1.411	-1.312
1.425	-1.343
1.440	-1.373
1.455	-1.404
1.470	-1.434
1.481	-1.457
1.493	-1.479
1.506	-1.511
1.507	-1.545
1.498	-1.568
1.482	-1.588
1.452	-1.604
1.418	-1.606
1.402	-1.601
1.375	-1.581
1.355	-1.554
1.337	-1.525
1.328	-1.511
1.310	-1.482
1.291	-1.454
1.273	-1.425
1.255	-1.396
1.219	-1.339
1.164	-1.253
1.128	-1.196
1.092	-1.139
1.037	-1.053
1.000	-0.996
0.964	-0.939
0.908	-0.854
0.871	-0.797
0.833	-0.741
0.777	-0.656

0.739	-0.600
0.681	-0.517
0.641	-0.461
0.602	-0.406
0.542	-0.324
0.501	-0.270
0.440	-0.189
0.398	-0.136
0.356	-0.083
0.292	-0.004
0.248	0.048
0.204	0.100
0.136	0.176
0.090	0.225
0.044	0.274
-0.028	0.347
-0.077	0.394
-0.152	0.462
-0.203	0.507
-0.255	0.550
-0.336	0.612
-0.391	0.651
-0.476	0.706
-0.535	0.740
-0.595	0.772
-0.688	0.813
-0.752	0.836
-0.850	0.864
-0.916	0.876
-0.984	0.883
-1.051	0.885
-1.153	0.880
-1.220	0.870
-1.316	0.898
-1.354	0.955

Table 1h 70% Radial Span	
X (Axial)	Y (Circum.)
-1.290	1.098

-1.305	1.163
-1.270	1.256
-1.223	1.303
-1.141	1.359
-1.080	1.387
-1.017	1.407
-0.952	1.421
-0.852	1.429
-0.786	1.427
-0.687	1.414
-0.622	1.399
-0.558	1.380
-0.466	1.343
-0.406	1.314
-0.319	1.265
-0.263	1.228
-0.209	1.189
-0.131	1.127
-0.081	1.083
-0.033	1.037
0.037	0.966
0.083	0.918
0.127	0.868
0.190	0.791
0.231	0.739
0.292	0.659
0.331	0.605
0.369	0.551
0.425	0.468
0.462	0.413
0.516	0.329
0.552	0.273
0.587	0.216
0.639	0.131
0.673	0.074
0.707	0.016
0.757	-0.070
0.789	-0.128
0.822	-0.186
0.870	-0.273
0.902	-0.332

0.949	-0.420
0.980	-0.479
1.010	-0.538
1.056	-0.627
1.086	-0.686
1.130	-0.776
1.159	-0.836
1.189	-0.895
1.217	-0.955
1.261	-1.045
1.289	-1.105
1.332	-1.195
1.353	-1.241
1.375	-1.286
1.389	-1.316
1.403	-1.346
1.414	-1.368
1.424	-1.391
1.439	-1.421
1.450	-1.452
1.448	-1.486
1.442	-1.501
1.421	-1.526
1.391	-1.540
1.357	-1.540
1.334	-1.530
1.315	-1.514
1.296	-1.487
1.279	-1.458
1.265	-1.437
1.252	-1.416
1.235	-1.388
1.217	-1.359
1.191	-1.317
1.165	-1.274
1.112	-1.189
1.078	-1.133
1.043	-1.076
0.991	-0.991
0.956	-0.934
0.903	-0.850

0.867	-0.793
0.832	-0.737
0.778	-0.653
0.742	-0.597
0.687	-0.514
0.650	-0.459
0.613	-0.403
0.575	-0.348
0.518	-0.266
0.480	-0.212
0.422	-0.131
0.382	-0.077
0.342	-0.024
0.281	0.055
0.240	0.107
0.177	0.185
0.135	0.236
0.091	0.286
0.025	0.361
-0.021	0.410
-0.067	0.458
-0.137	0.528
-0.185	0.574
-0.234	0.619
-0.310	0.684
-0.362	0.726
-0.441	0.786
-0.496	0.824
-0.553	0.859
-0.640	0.908
-0.700	0.937
-0.793	0.974
-0.856	0.993
-0.921	1.009
-1.020	1.023
-1.086	1.027
-1.152	1.025
-1.249	1.044
-1.290	1.098

Table 1i 80% Radial Span	
X (Axial)	Y (Circum.)
-1.243	1.298
-1.232	1.363
-1.168	1.436
-1.113	1.471
-1.022	1.507
-0.958	1.521
-0.893	1.528
-0.827	1.528
-0.730	1.517
-0.666	1.503
-0.573	1.473
-0.512	1.448
-0.453	1.420
-0.368	1.371
-0.313	1.335
-0.234	1.278
-0.184	1.236
-0.134	1.193
-0.063	1.126
-0.017	1.079
0.027	1.032
0.092	0.958
0.134	0.908
0.175	0.857
0.234	0.779
0.273	0.726
0.330	0.646
0.366	0.592
0.403	0.538
0.456	0.456
0.491	0.400
0.542	0.317
0.576	0.261
0.609	0.205
0.642	0.148
0.691	0.063
0.723	0.006

0.770	-0.080
0.801	-0.137
0.832	-0.195
0.878	-0.282
0.908	-0.340
0.952	-0.427
0.982	-0.486
1.011	-0.544
1.054	-0.632
1.082	-0.691
1.110	-0.750
1.152	-0.839
1.180	-0.898
1.207	-0.957
1.248	-1.047
1.275	-1.106
1.302	-1.166
1.322	-1.210
1.336	-1.240
1.349	-1.270
1.363	-1.299
1.373	-1.322
1.383	-1.344
1.395	-1.374
1.398	-1.407
1.386	-1.437
1.375	-1.450
1.347	-1.467
1.315	-1.471
1.284	-1.460
1.260	-1.437
1.252	-1.424
1.235	-1.395
1.218	-1.367
1.202	-1.339
1.185	-1.311
1.168	-1.283
1.152	-1.255
1.118	-1.199
1.085	-1.143
1.035	-1.058

1.001	-1.002
0.968	-0.946
0.917	-0.862
0.883	-0.806
0.832	-0.722
0.798	-0.667
0.764	-0.611
0.712	-0.528
0.677	-0.473
0.624	-0.390
0.589	-0.335
0.553	-0.280
0.499	-0.198
0.463	-0.144
0.426	-0.090
0.370	-0.010
0.332	0.043
0.294	0.096
0.235	0.175
0.195	0.227
0.135	0.304
0.094	0.355
0.052	0.405
-0.012	0.480
-0.055	0.528
-0.122	0.600
-0.167	0.647
-0.214	0.694
-0.261	0.739
-0.334	0.804
-0.384	0.846
-0.461	0.906
-0.514	0.945
-0.569	0.981
-0.653	1.031
-0.711	1.061
-0.800	1.101
-0.862	1.123
-0.925	1.141
-1.021	1.160
-1.086	1.166

-1.151	1.173
-1.226	1.235
-1.243	1.298

Table 1j 90% Radial Span	
X (Axial)	Y (Circum.)
-1.179	1.430
-1.170	1.494
-1.105	1.564
-1.049	1.595
-0.957	1.622
-0.893	1.629
-0.829	1.629
-0.765	1.623
-0.671	1.602
-0.610	1.583
-0.521	1.545
-0.464	1.516
-0.409	1.483
-0.329	1.430
-0.278	1.391
-0.204	1.330
-0.156	1.287
-0.110	1.242
-0.065	1.197
0.000	1.126
0.042	1.077
0.103	1.003
0.142	0.952
0.181	0.901
0.238	0.823
0.275	0.771
0.329	0.691
0.364	0.638
0.399	0.584
0.433	0.529
0.483	0.447
0.516	0.393
0.565	0.310

0.597	0.254
0.629	0.198
0.676	0.114
0.706	0.058
0.752	-0.027
0.782	-0.084
0.811	-0.141
0.841	-0.198
0.884	-0.284
0.913	-0.341
0.955	-0.427
0.983	-0.485
1.010	-0.543
1.051	-0.630
1.078	-0.688
1.118	-0.776
1.145	-0.834
1.171	-0.893
1.197	-0.951
1.237	-1.039
1.262	-1.098
1.275	-1.127
1.288	-1.157
1.301	-1.186
1.314	-1.216
1.327	-1.245
1.340	-1.274
1.349	-1.305
1.348	-1.337
1.338	-1.359
1.322	-1.377
1.293	-1.390
1.261	-1.391
1.232	-1.378
1.211	-1.354
1.195	-1.326
1.178	-1.298
1.166	-1.278
1.153	-1.257
1.137	-1.230
1.121	-1.202

1.096	-1.161
1.072	-1.119
1.024	-1.036
0.992	-0.980
0.960	-0.925
0.912	-0.841
0.879	-0.786
0.830	-0.703
0.797	-0.648
0.764	-0.593
0.714	-0.511
0.680	-0.457
0.647	-0.402
0.595	-0.321
0.561	-0.267
0.526	-0.213
0.474	-0.132
0.438	-0.078
0.385	0.002
0.349	0.055
0.312	0.107
0.257	0.186
0.219	0.238
0.181	0.289
0.123	0.366
0.084	0.417
0.044	0.468
-0.016	0.542
-0.057	0.592
-0.120	0.665
-0.162	0.713
-0.206	0.760
-0.273	0.829
-0.318	0.874
-0.365	0.918
-0.437	0.982
-0.486	1.023
-0.537	1.063
-0.615	1.119
-0.668	1.154
-0.752	1.202

-0.809	1.231
-0.868	1.255
-0.929	1.276
-1.022	1.300
-1.085	1.312
-1.163	1.367
-1.179	1.430

Table 1k 100% Radial Span	
X (Axial)	Y (Circum.)
-1.114	1.549
-1.109	1.613
-1.050	1.685
-0.994	1.713
-0.933	1.730
-0.839	1.738
-0.777	1.733
-0.715	1.721
-0.624	1.693
-0.566	1.669
-0.482	1.626
-0.429	1.593
-0.376	1.558
-0.302	1.501
-0.253	1.460
-0.207	1.418
-0.140	1.352
-0.096	1.306
-0.054	1.259
0.007	1.187
0.046	1.138
0.104	1.063
0.141	1.013
0.178	0.961
0.231	0.884
0.266	0.831
0.318	0.752
0.351	0.699
0.384	0.645

0.417	0.591
0.465	0.510
0.496	0.456
0.543	0.374
0.574	0.319
0.604	0.264
0.649	0.181
0.679	0.125
0.723	0.042
0.752	-0.014
0.780	-0.070
0.809	-0.127
0.851	-0.211
0.879	-0.268
0.919	-0.353
0.947	-0.410
0.973	-0.467
1.013	-0.552
1.039	-0.609
1.078	-0.695
1.104	-0.753
1.129	-0.810
1.167	-0.897
1.192	-0.955
1.216	-1.013
1.228	-1.042
1.246	-1.086
1.252	-1.100
1.264	-1.129
1.276	-1.159
1.287	-1.188
1.296	-1.218
1.297	-1.249
1.290	-1.272
1.275	-1.290
1.248	-1.306
1.217	-1.308
1.188	-1.296
1.171	-1.280
1.156	-1.261
1.140	-1.234

1.124	-1.207
1.108	-1.180
1.092	-1.153
1.076	-1.126
1.060	-1.098
1.029	-1.044
0.982	-0.962
0.951	-0.907
0.920	-0.852
0.873	-0.770
0.842	-0.716
0.810	-0.661
0.762	-0.580
0.730	-0.526
0.697	-0.472
0.648	-0.392
0.614	-0.338
0.564	-0.258
0.531	-0.205
0.497	-0.152
0.445	-0.073
0.411	-0.020
0.358	0.058
0.323	0.110
0.287	0.162
0.252	0.214
0.197	0.291
0.160	0.342
0.105	0.418
0.067	0.469
0.029	0.519
-0.028	0.594
-0.067	0.643
-0.126	0.717
-0.166	0.766
-0.206	0.814
-0.268	0.886
-0.310	0.933
-0.353	0.979
-0.418	1.047
-0.462	1.092

-0.508	1.135
-0.577	1.199
-0.626	1.239
-0.701	1.297
-0.753	1.332
-0.807	1.364
-0.863	1.393
-0.949	1.430
-1.011	1.446
-1.093	1.489
-1.114	1.549

FIG 5 is a top view of a turbine blade tip shroud 56 according to an embodiment of the invention, showing an underlying blade tip profile 31T. This shape minimizes tip shroud stress and improves the tip shroud life over a prior art tip shroud by smoother curves. It also shifts mass toward the stacking axis compared to the prior art tip shroud. The shroud has a cantilevered front overhang 62 and a back overhang 64 relative to the rotation direction 66.

Table 2a specifies the shape of an axially forward edge of the tip shroud along the portion spanned by line 58. Table 2b specifies the shape of an axially aft edge profile spanned by line 60. The absolute values of the coordinates in inches define one airfoil. However, the coordinates may used as relative values that can be scaled up or down proportionally, along with the tolerance below, for larger or smaller turbines. Each profile 58, 60 is characterized by a smooth curve connecting the nominal X and Y coordinates in each table. An acceptable manufacturing tolerance is +/- 0.050 inches in a direction normal to the tip shroud edge at each location at a temperature of 20 °C (293.15 K, 68 °F). The coordinates represent the uncoated outer surface of the tip shroud. The X (axial), Y (circumferential) origin 0.0 of the coordinates for tables 2a, 2b is on the same turbine radius with the X, Y origins of tables 1a-1k. The Z or radial coordinate depends on the radius of the turbine shroud inner surface. The radially outer surface of the tip shroud 56 may form a cylindrical or conical surface of rotation parallel to that of the turbine shroud inner surface. The specified shape may be scaled circumferentially for turbines with fewer or more blades per disk, such that the tip shrouds have close clearance in the circular array of blades.

Table 2a Leading-Edge Profile	
X (Axial)	Y (Circum.)
-0.271	-1.114
-0.328	-0.942
-0.377	-0.768
-0.418	-0.593
-0.451	-0.417
-0.475	-0.239
-0.492	-0.059
-0.501	0.122
-0.520	0.301
-0.564	0.475
-0.633	0.641
-0.724	0.794
-0.835	0.934
-0.951	1.069
-1.067	1.205
-1.165	1.353
-1.179	1.530
-1.098	1.688
-0.960	1.802
-0.805	1.889
-0.638	1.947
-0.479	2.025
-0.349	2.146
-0.245	2.293
-0.142	2.440
-0.039	2.588
0.064	2.735

Table 2b Trailing-Edge Profile	
X (Axial)	Y (Circum.)
0.440	2.457
0.440	2.298

0.440	2.139
0.440	1.981
0.440	1.822
0.440	1.663
0.440	1.504
0.440	1.345
0.440	1.186
0.447	1.028
0.465	0.871
0.492	0.715
0.529	0.562
0.576	0.411
0.633	0.262
0.699	0.117
0.772	-0.024
0.845	-0.164
0.918	-0.304
0.991	-0.445
1.064	-0.585
1.137	-0.725
1.207	-0.869
1.261	-1.018
1.301	-1.172
1.324	-1.328
1.331	-1.486

FIG 6 is a perspective view of a fillet between a tip shroud 56 and a blade according to a further embodiment of the invention. For comparison, patent US 6857853 B1 shows a stage 2 blade design with a curved fillet between the tip shroud and blade. The present inventors recognized that the fillet could be improved to increased stiffness in the tip shroud to oppose bending from centrifugal force on one or both cantilevered overhangs 62, 64 (FIG 5). A gusset/fillet 68 in an embodiment of the invention is shown with a planar surface 70 over most of a diagonal bracing area (arrows) and two planar side facets 71 that merge with the blade airfoil 72 via a continuous fillet 74, and merge with the tip shroud 56 along a generally semicircular or semi-elliptical line 76. This shape maximizes stiffness while minimizing stress concentration and mass.

While various embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions may be made without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

CLAIMS

The invention claimed is:

1. A turbine blade airfoil comprising an outer surface shape defined by Cartesian coordinate values of X and Y at successive radial increments as set forth in Tables 1a to 1k, wherein each said table defines a transverse sectional profile characterized by a smooth curve connecting the X and Y coordinates, and the surface shape comprises a smooth surface connecting the sectional profiles.

2. The turbine blade airfoil of claim 1, wherein the Cartesian coordinate values are absolute values in inches, and a manufacturing tolerance of the smooth surface is +/- 0.050 inches measured normal to said surface.

3. The turbine blade airfoil of claim 1, wherein the Cartesian coordinate values are relative values, and a manufacturing tolerance of the smooth surface is a relative value of +/- 0.050 inches measured normal to said surface.

4. The turbine blade airfoil of claim 1, further comprising a tip shroud comprising an axially forward edge profile defined by Cartesian coordinate values of X and Y set forth in Table 2a, and an axially aft edge profile defined by Cartesian coordinate values of X and Y set forth in table 2b.

5. The turbine blade airfoil of claim 4, wherein the Cartesian coordinate values are absolute values in inches, and a manufacturing tolerance of the axially forward and aft profiles is +/- 0.050 inches measured normal to said profiles.

6. The turbine blade airfoil of claim 4, wherein the Cartesian coordinate values are relative values, and a manufacturing tolerance of the axially forward and aft profiles is a relative value of +/- 0.050 inches measured normal to said profiles.

7. The turbine blade airfoil of claim 1, further comprising a tip shroud on a tip of the blade airfoil, and a gusset/fillet between the blade airfoil the tip shroud, the gusset/fillet comprising a planar diagonal surface over most of a diagonal bracing area thereof, and two planar side facets, wherein the diagonal surface and side facets merge with the blade airfoil via a continuous fillet.

FIG 1
PRIOR ART

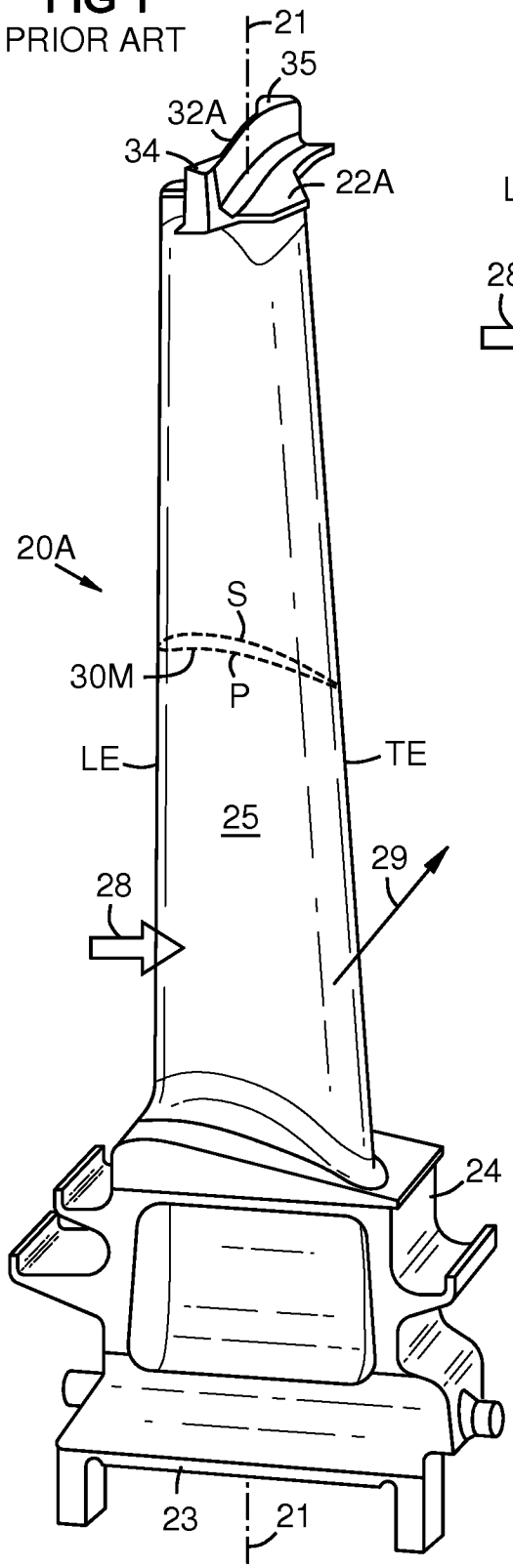
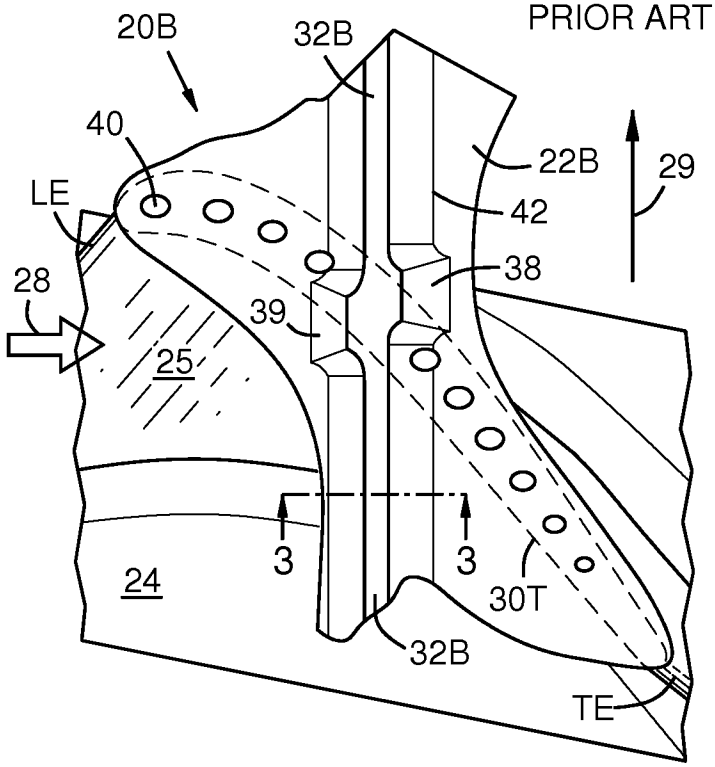


FIG 2
PRIOR ART



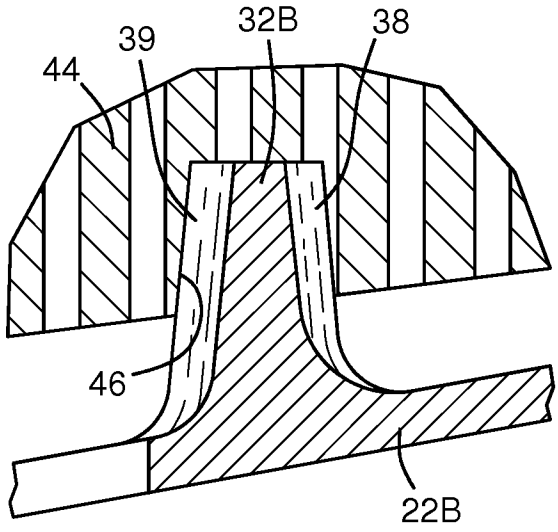


FIG 3
PRIOR ART

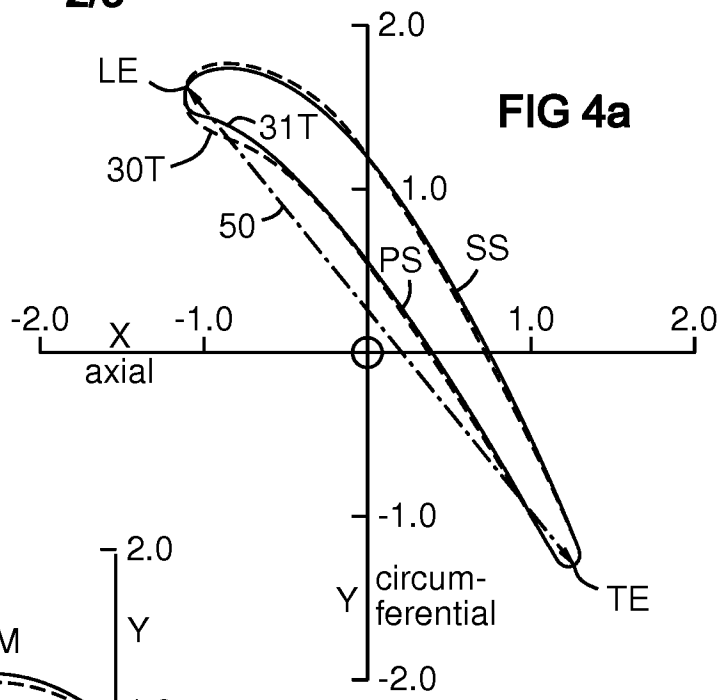


FIG 4a

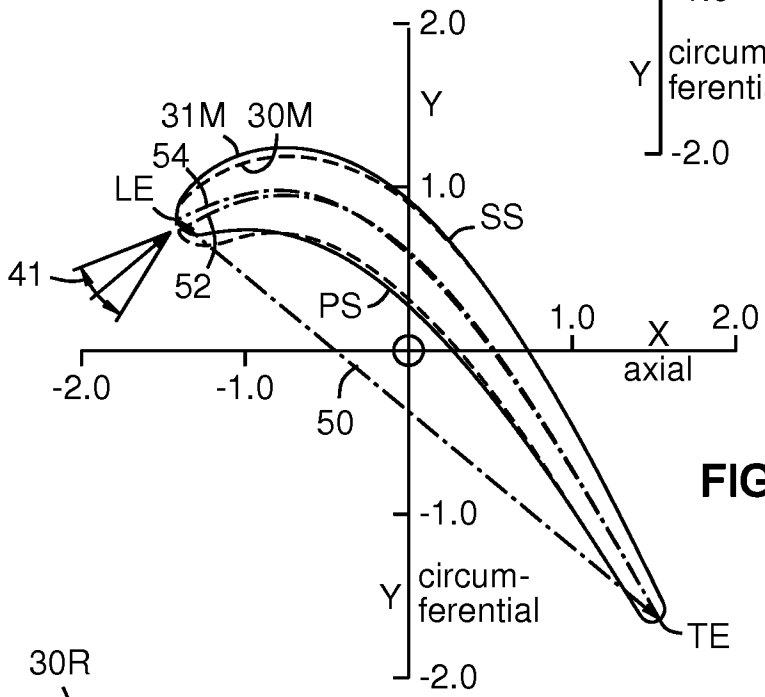


FIG 4b

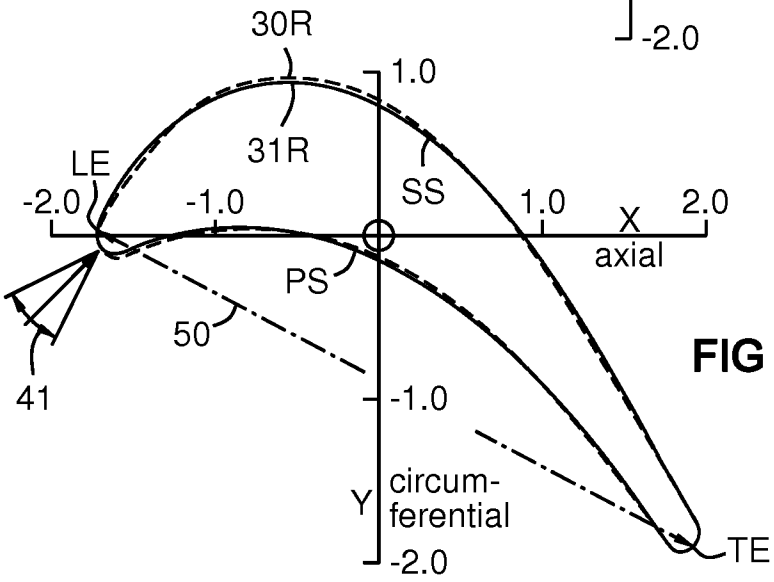


FIG 4c

FIG 5

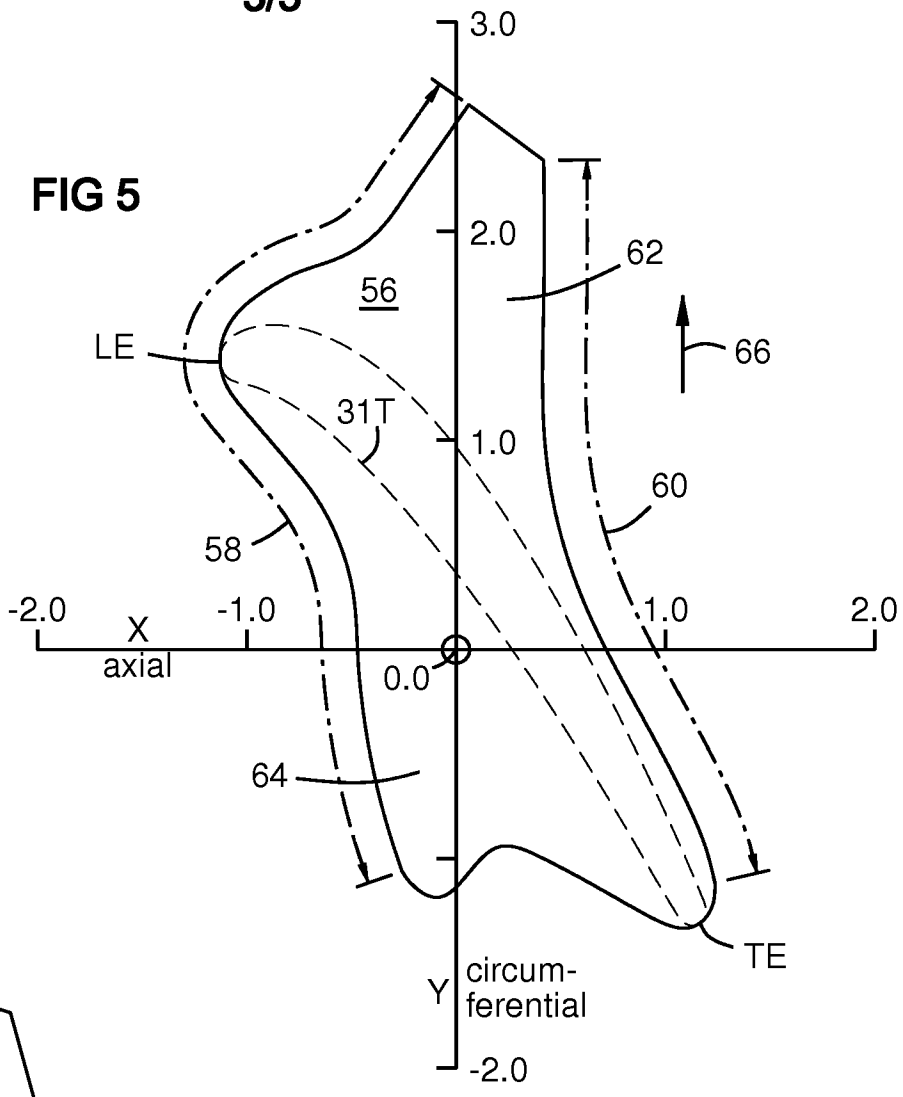
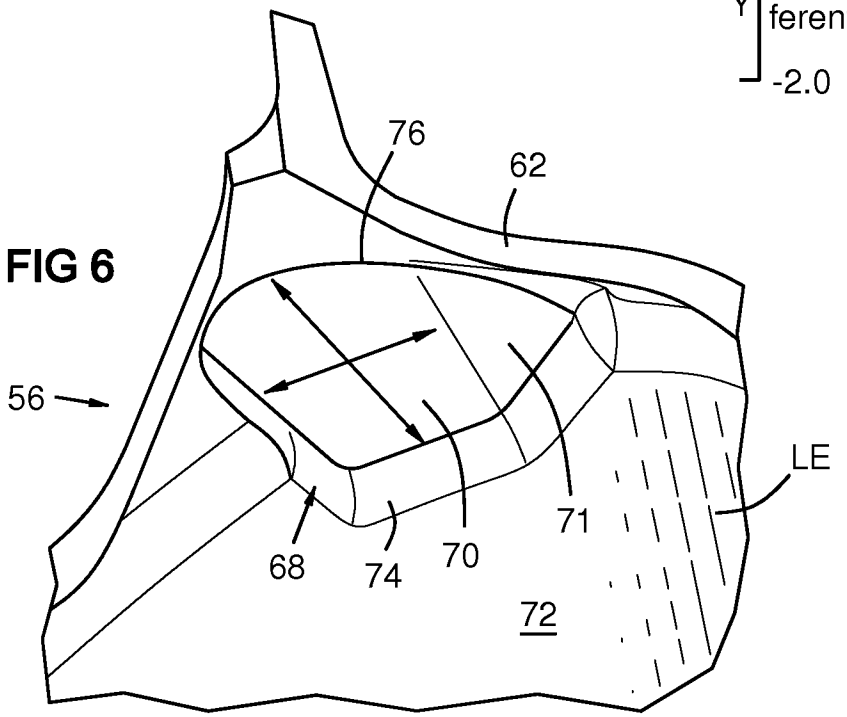

3.0
2.0
1.0
-2.0
-1.0
1.0
2.0
0.0
X
axial
Y
circum-
ferential
-2.0
56
62
66
LE
31T
60
58
64
TE

FIG 6


76
62
56
LE
71
68
74
70
72

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/038750

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/019160 A1 (HYDE SUSAN MARIE [US] ET AL) 27 January 2005 (2005-01-27) the whole document	1-7
X	US 6 857 853 B1 (TOMBERG STEVEN ERIC [US] ET AL) 22 February 2005 (2005-02-22) cited in the application the whole document	1-7
X	US 2011/243748 A1 (TSIFOURDARIS PANAGIOTA [CA]) 6 October 2011 (2011-10-06) the whole document	1-7
X	DE 10 2009 003794 A1 (GEN ELECTRIC [US]) 29 October 2009 (2009-10-29) the whole document	1-7

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 September 2014	30/09/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Teissier, Damien

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2014/038750

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