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(54) COMPRESSOR BLADE WITH MODIFIED STAGGER ANGLE SPANWISE DISTRIBUTION

(57) A compressor blade (5) extending spanwise from a hub section (6) to a tip section (7) and having intermediate airfoil cross sections (S), said cross sections having a stagger angle (γ) comprised between a chord (c) and a meridional axis (m), characterized in that the blade (5) has a spanwise stagger angle distribution γ(s) defined as a function of the relative span (s) of the blade by the equation:

$$\gamma(s)= \gamma(0)+s[\gamma(1) - \gamma(0)] + [\gamma(1)/\gamma(0)]*WSA(s),$$

where WSA(s) is a weighted stagger angle defined, as a function of the relative span, by a curve comprised between the following equations:

$$WSA_{min}(s) = - 43.5987s^6 + 108.76701s^5 - 69.1667s^4 - 22.5948s^3 + 27.9252s^2 - 1.3318s;$$

and

$$WSA_{max}(s) = -20s^2 + 20s.$$

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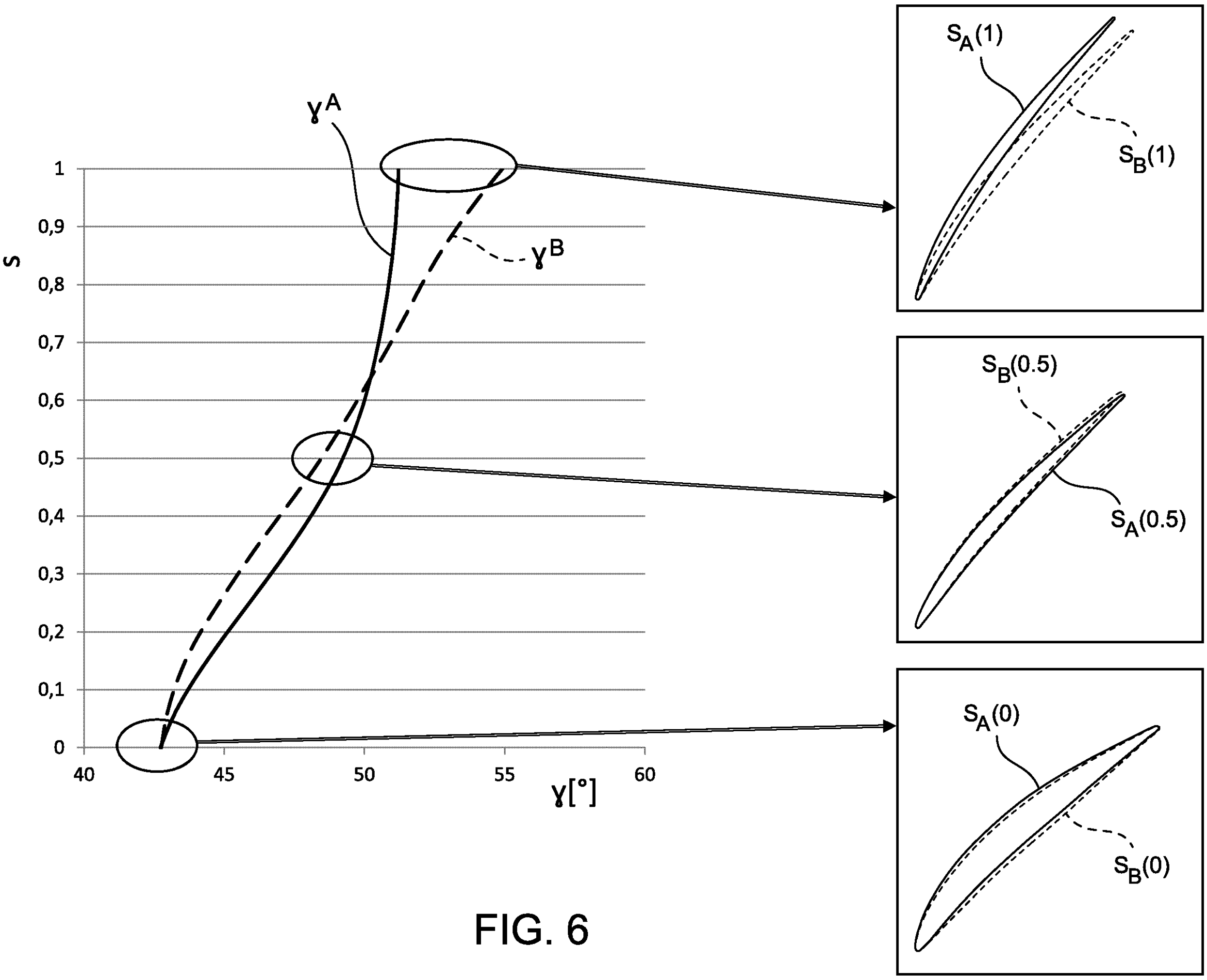

γA
γB
s
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
40
45
50
55
60
γ[°]
SA(1)
SB(1)
SB(0.5)
SA(0.5)
SA(0)
SB(0)

FIG. 6

Description

BACKGROUND OF THE INVENTION

Field of the invention

[0001] The present invention relates to a compressor blade for a compressor of a gas turbine power plant.

[0002] More particularly, the present invention relates to a modified spanwise distribution of the stagger angle of a compressor blade.

Description of prior art

[0003] As is known, a gas turbine power generation plant (herein after: "the plant") comprises an upstream compressor, a combustor assembly and a downstream turbine.

[0004] The terms downstream and upstream as used herein refer to the direction of the main gas flow passing through the plant.

[0005] The plant includes a stator and a rotor housed within the stator and comprising a compressor section with a plurality of rows of compressor blades and a turbine section with a plurality of turbine blades.

[0006] The compressor blades extend spanwise from a hub section to a tip section which radially faces the stator and is separated therefrom by a tip gap.

[0007] The main goal of a compressor design, along with high efficiency, is a high operating range. The operating range of a compressor blade is limited by aerodynamic losses in the region of the tip gap.

[0008] Efficiency and operating range are contradictory requirements: efficiency is maximized at high loadings, but in these conditions the operating range is decreased.

[0009] Known prior art solutions to achieve high efficiency and operating range include so called "casing treatments", i.e. casing structures in the area of the rotating blades configured to reduce aerodynamic blockage. Although this technology has been known since the early days of turbomachinery, it is not widely used because of the cost of additional parts and servicing needs.

SUMMARY OF THE INVENTION

[0010] An object of the present invention is to provide a compressor blade with a modified design aimed at reducing aerodynamic blockage in the tip region.

[0011] According to the present invention, this object is attained by a compressor blade extending spanwise from a hub section to a tip section and having intermediate airfoil cross sections, said cross sections having a stagger angle comprised between a chord and a meridional axis, characterized in that the blade has a spanwise stagger angle distribution $\gamma(s)$ defined as a function of the relative span (s) by the equation

$$\gamma(s)= \gamma(0)+s[\gamma(1) - \gamma(0)] + [\gamma(1)/\gamma(0)]*WSA(s),$$

where WSA(s) is a weighted stagger angle defined, as a function of the relative span, by a curve comprised between the following equations:

$$WSA_{min}(s) = - 43.5987s^6 + 108.76701s^5 - 69.1667s^4 -22.5948s^3 + 27.9252s^2 - 1.3318s;$$

and

$$WSA_{max}(s) = -20s^2 + 20s.$$

Blades with a stagger spanwise distribution in this range proved to have a greater operating range due to lower aerodynamic losses in the tip region, where the stagger angle increases less than in the prior art.

[0012] According to a preferred embodiment of the invention, the weighted stagger angle distribution curve has a maximum in the range of relative span (s) between s=0.4 and s=0.6, and preferably at s=0.5, which means that the stagger angle distribution diverges from a linear progression from the hub section up to an intermediate portion of the blade, and then progressively converges with the linear progression at the tip.

[0013] Preferably, the curve has a downward concavity in the range between the maximum and a zero point at s=1; this has the effect that the non-linear component of the stagger angle distribution decreases sharply in the tip region.

[0014] Preferably, the stagger angle does not increase in the tip region of the blade, which reduces aerodynamic blockage and thus increases operating range.

[0015] The present invention also relates to a compressor including at least a compressor stage comprising a circumferential row of blades as defined above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] For a better comprehension of the present invention, a preferred embodiments thereof will be described hereafter, by way of a non-limiting example and referring to the attached drawings, where:

Figure 1 is schematic elevation view of a compressor blade;
Figure 2 is a cross section of a compressor blade;
Figure 3 is a diagram showing limit curves for weighted stagger angle spanwise distribution in accordance with the present invention;
Figure 4 is a diagram showing embodiments of the weighted stagger angle spanwise distribution according to the invention against the prior art;
Figure 5 is a diagram showing stage compression characteristic curves comparing the blade geometry according to the invention to the prior art; and
Figure 6 is a diagram showing the stagger angle spanwise distribution of a blade according to an embodiment of the present invention compared to the prior art, as well as airfoil section comparisons at different relative spans.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0017] Referring now to figure 1, a compressor 1 for a gas turbine power plant (not shown) includes a stator 2 and a rotor 3. Rotor 3 includes a hub 4 and plurality of circumferential rows of blades 5, only one of which is schematically shown. Blade 5 is fixed to hub 4 in a known manner, and extends from a hub section 6 to a tip section 7.

[0018] Stator 2 includes a casing 8 housing the rotor in a rotation-free manner and a plurality of circumferential rows of vanes (not shown)fixed to casing 8.

[0019] A tip gap 9 separates tip section 7 of each blade 5 from casing 8.

[0020] Blade 5 can be thought of as composed by a plurality of radially stacked cross sections S, each of which constitutes an airfoil (fig. 2). It is to be noted that in figure 1 both hub 4 and casing 8 are schematically shown as cylindrical, and therefore flow lines 14 are parallel to the rotor axis and so are blade cross section. In actual compressors, this is generally not the case, and cross sections are taken along flow lines that are not parallel to the rotor axis.

[0021] Referring to fig. 2, a stagger angle γ of the airfoil is defined between a chord ***c*** and a meridional axis ***m,*** where chord ***c*** is the line connecting point ***L*** of intersection between leading edge 15 and camber line 16 to point ***T*** of intersection between trailing edge 17 and camber line 16.

[0022] According to the present invention, a distribution or progression of stagger angle γ from hub section 6 to tip section 7 of blade 5 is defined as a function of the relative span s(r):

$$s(r) = h(r)/H \qquad [1]$$

where h(r) is the distance of the cross section with respect to the hub cross section (i.e. the difference between the cross section mean radius and the hub section mean radius, radiuses being measured from the rotor axis) and H is the total height of the blade 5, i.e. the difference between the tip section mean radius and the hub section mean radius.

[0023] Such stagger angle distribution is given by the sum of a linear distribution from hub section to tip section and a non-linear distribution in the form:

$$\gamma(s)= \gamma(0)+s[\gamma(1) - \gamma(0)]+ [\gamma(1)/\gamma(0)]*WSA(s) \qquad [2]$$

[0024] Parameter WSA or "Weighted Stagger Angle" is defined as follows (from [2]):

$$WSA(s) = [\gamma(s) - s(\gamma(1) - \gamma(0)) - \gamma(0)] * \gamma(0)/\gamma(1). \qquad [2A]$$

[0025] ***WSA(s)*** is, by definition, a function that equals 0 at the hub section (where ***s(r)=0*** and γ***(s)*** = γ***(0)*** and at the tip section (where ***s(r)=1*** and γ***(s)*** = γ***(1)*)**.

[0026] According to the present invention, ***WSA(s)*** is a function comprised between the limit curves defined by the following equations:

$$WSA_{min}(s) = -43.5987s^6 + 108.76701s^5 - 69.1667s^4 - 22.5948s^3 + 27.9252s^2 - 1.3318s; \qquad [3]$$

and

$$WSA_{max}(s) = -20s^2 + 20s \qquad [4]$$

[0027] Limits curves WSA_{min} *(s)* and WSA_{max} *(s)* are shown in fig. 3, and the hatched area therebetween defines the range for ***WSA(s),*** so that, for each value of ***s***, the following relation applies:

$$WSA_{max}(s) \geq WSA(s) \geq WSA_{min}(s) \qquad [5]$$

[0028] As can be noted from figure 3, both curves $WSA_{min}(s)$ and $WSA_{max}(s)$ have their maximum at about s=0.5, and have a downwards concavity from the maximum to the zero point at S=1.

[0029] Figure 4 discloses three examples of curves ***WSA1, WSA2, WSA3*** in accordance with the present invention, which lie within the area between curves $WSA_{min}(s)$ and WSA_{max} *(s),* as opposed to comparative curves ***WSA4, WSA5*** according to the prior art. Each of the curves according to the invention has a maximum in the range between s=0.4 and s=0.6, and preferably at about s=0.5. The following table includes values for each of the curves ***WAS1*** to ***WSA5,*** as well as $WSA_{min}(s)$ and $WSA_{max}(s)$, for values of ***s*** ranging from 0 to 1 by 0.1 increments. The table also includes the deriving values of stagger angle γ***(s)*** for each of the curves.

s	WSA1	WSA2	WSA3	WSA4	WSA5	WSA_{min}	WSA_{max}	γ1	γ2	γ3	γ4	γ5
0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	47,41	48,25	47,35	47,32	47,05
0,1	0,23	0,71	1,31	-0,28	0,05	0,12	1,80	48,37	49,76	49,53	48,08	48,37
0,2	0,93	1,53	2,51	-0,32	0,16	0,59	3,20	49,85	51,41	51,59	49,12	49,76
0,3	1,68	2,27	3,51	-0,27	0,32	1,18	4,20	51,39	52,96	53,42	50,29	51,23
0,4	2,18	2,78	4,26	-0,10	0,53	1,65	4,80	52,66	54,25	54,97	51,59	52,74
0,5	2,38	2,98	4,63	0,04	0,68	1,89	5,00	53,57	55,17	56,07	52,87	54,18
0,6	2,27	2,82	4,49	0,03	0,64	1,83	4,80	54,13	55,70	56,60	53,96	55,39
0,7	1,90	2,35	3,86	-0,04	0,49	1,55	4,20	54,40	55,86	56,57	54,97	56,45
0,8	1,35	1,65	2,80	-0,15	0,22	1,12	3,20	54,45	55,76	56,04	55,94	57,37
0,9	0,68	0,82	1,45	-0,16	0,03	0,62	1,80	54,37	55,51	55,19	57,03	58,38
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	54,28	55,28	54,21	58,32	59,60

[0030] As can be readily seen comparing the two sets of curves, according to the invention the contribution of the non-linear portion of γ***(s)*** decreases sharply in the tip region and, compared to prior art bladed designs having the same hub and tip stagger angle values, the stagger angle does not increase or even decreases in the tip region.

[0031] This is reflected in figure 6, which discloses the spanwise distribution of stagger angle γ in a representative blade according to the invention (curve γ**A*)*** and in a corresponding prior art blade (curve γ***B)***.

[0032] A direct comparison between cross sections S_A and S_B of the two blades at values s = 0, s = 0.5 and s=1 are shown in the right hand side of the figure. The stagger angle distribution according to the invention is characterized by a "flatter" tip region were the stagger angle tends not to increase as in the prior art.

[0033] Figure 5 discloses characteristic curves (stage compression ratio **CR** against flow coefficient Φ) for a representative compressor stage. Different design variants have been assessed (curves A, B, C) and are compared to a prior art embodiment(curve D).

[0034] As can be clearly seen, prior art compressor stage features a maximum in the design area, with a substantial decrease of compression ratio for lower flow rates, while compressor stages according to the present invention show a much more extended operating range with limited decrease of compression ratio at reduced flows.

[0035] Although the invention has been explained in relation to its preferred embodiments as mentioned above, it is to be understood that modifications and variations can be made without departing from the scope of the appended claims.

Claims

1. A compressor blade (5) extending spanwise from a hub section (6) to a tip section (7) and having intermediate airfoil cross sections (S), said cross sections having a stagger angle (γ) comprised between a chord (**c**) and a meridional axis (**m**), **characterized in that** the blade (5) has a spanwise stagger angle distribution $\gamma(s)$ defined as a function of a relative span (**s**) of the blade by the equation:

$$\gamma(s)= \gamma(0)+s[\gamma(1) - \gamma(0)] + [\gamma(1)/\gamma(0)]*WSA(s),$$

where ***WSA(s)*** is a weighted stagger angle defined, as a function of the relative span, by a curve comprised between the following equations:

$$WSA_{min}(s) = - 43.5987s^6 + 108.76701s^5 - 69.1667s^4 - 22.5948s^3 + 27.9252s^2 - 1.3318s;$$

and

$$WSA_{max}(s) = -20s^2 + 20s.$$

2. A blade as claimed in claim 1, **characterized in that** said curve has a maximum in the range of relative span (**s**) between ***s***=0.4 and ***s***=0.6.

3. A blade as claimed in claim 1, **characterized in that** said curve has a maximum at a value of relative span ***(s)*** of about ***s***=0.5.

4. A blade as claimed in claim 2 or 3, **characterized in that** said curve has a downward concavity in the range between said maximum and a zero point at ***s***=1.

5. A blade as claimed in any of the preceding claims, **characterized in that** the stagger angle (γ) does not increase in the tip region of the blade.

6. A compressor including at least a compressor stage comprising a circumferential row of blades according to any of the preceding claims.

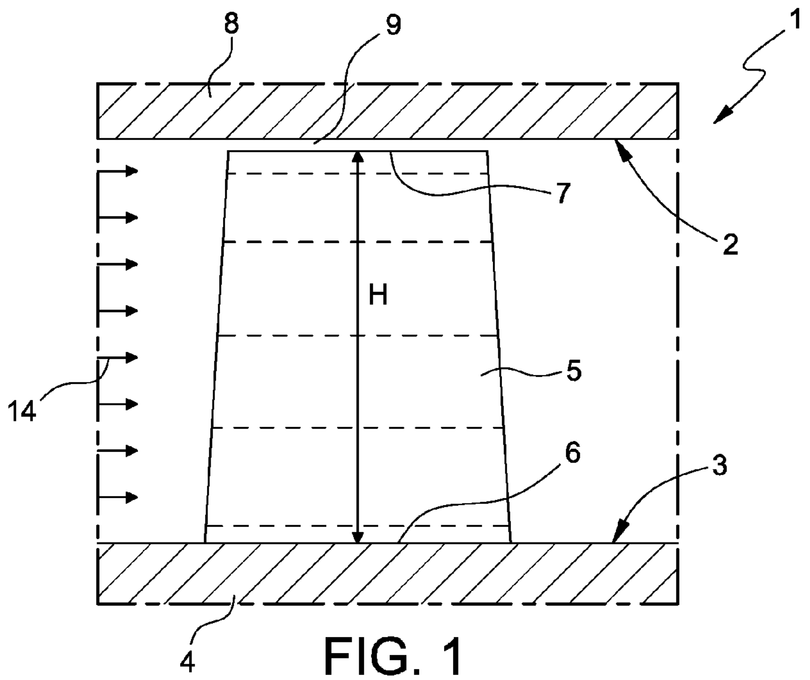


FIG. 1

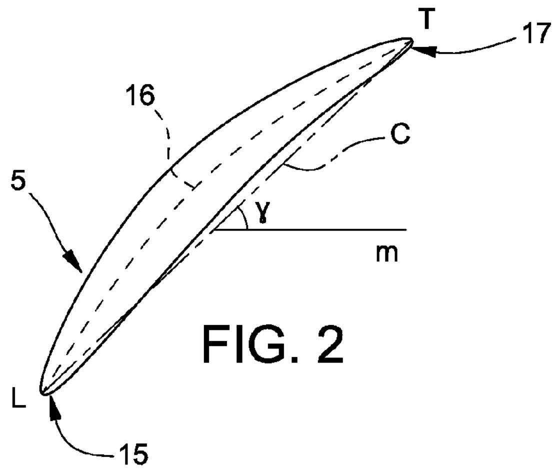


FIG. 2

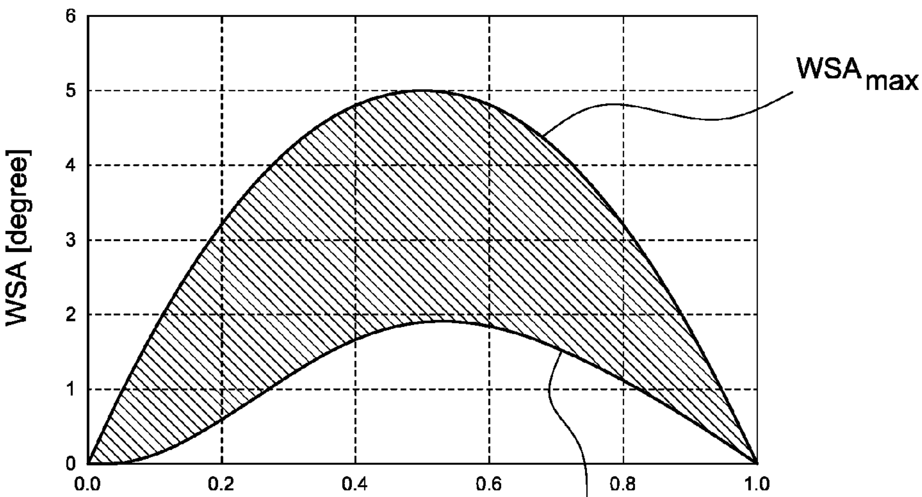


FIG. 3

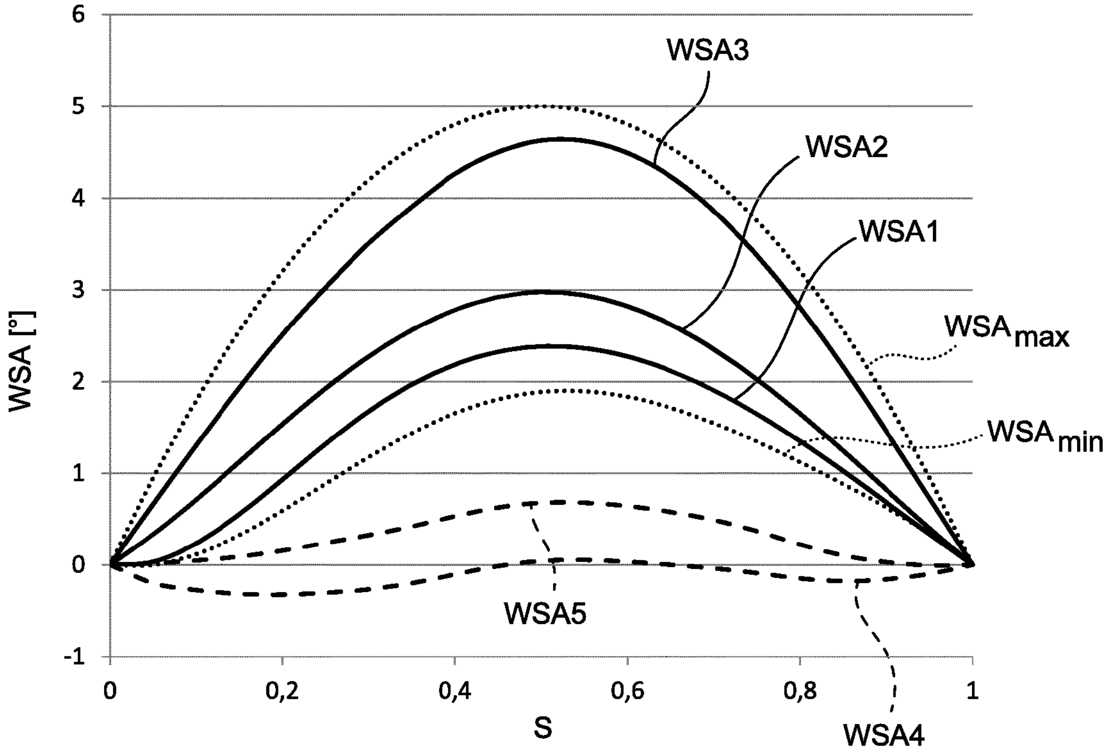

6
5
4
3
2
1
0
-1
WSA [°]
0
0,2
0,4
0,6
0,8
1
S
WSA3
WSA2
WSA1
WSAmax
WSAmin
WSA5
WSA4

FIG. 4

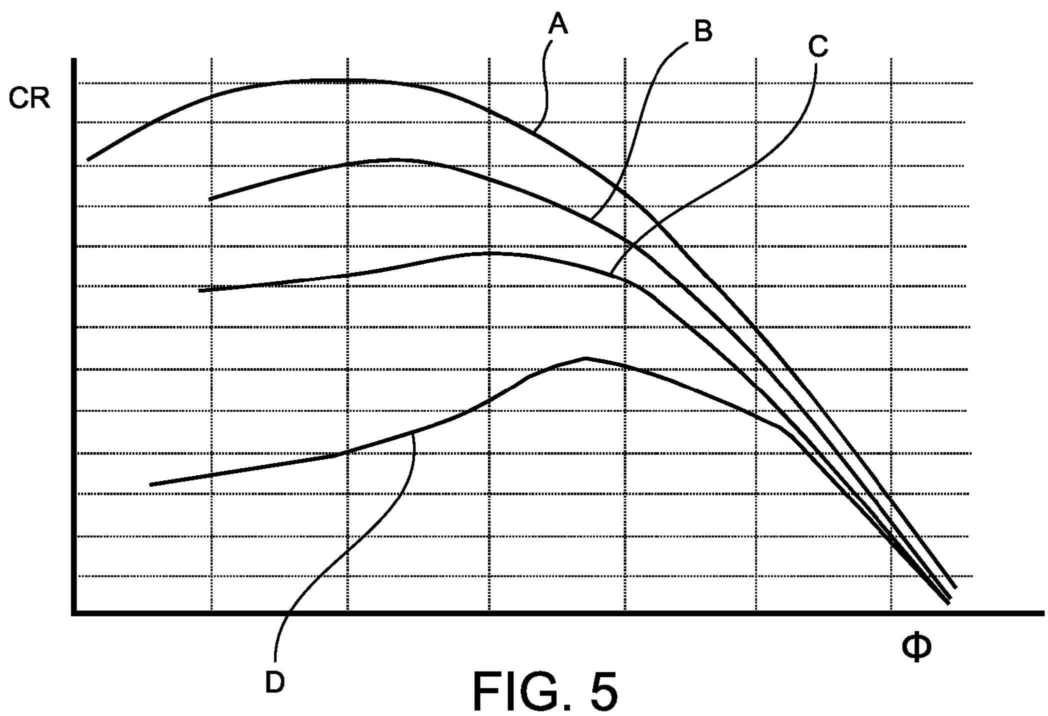
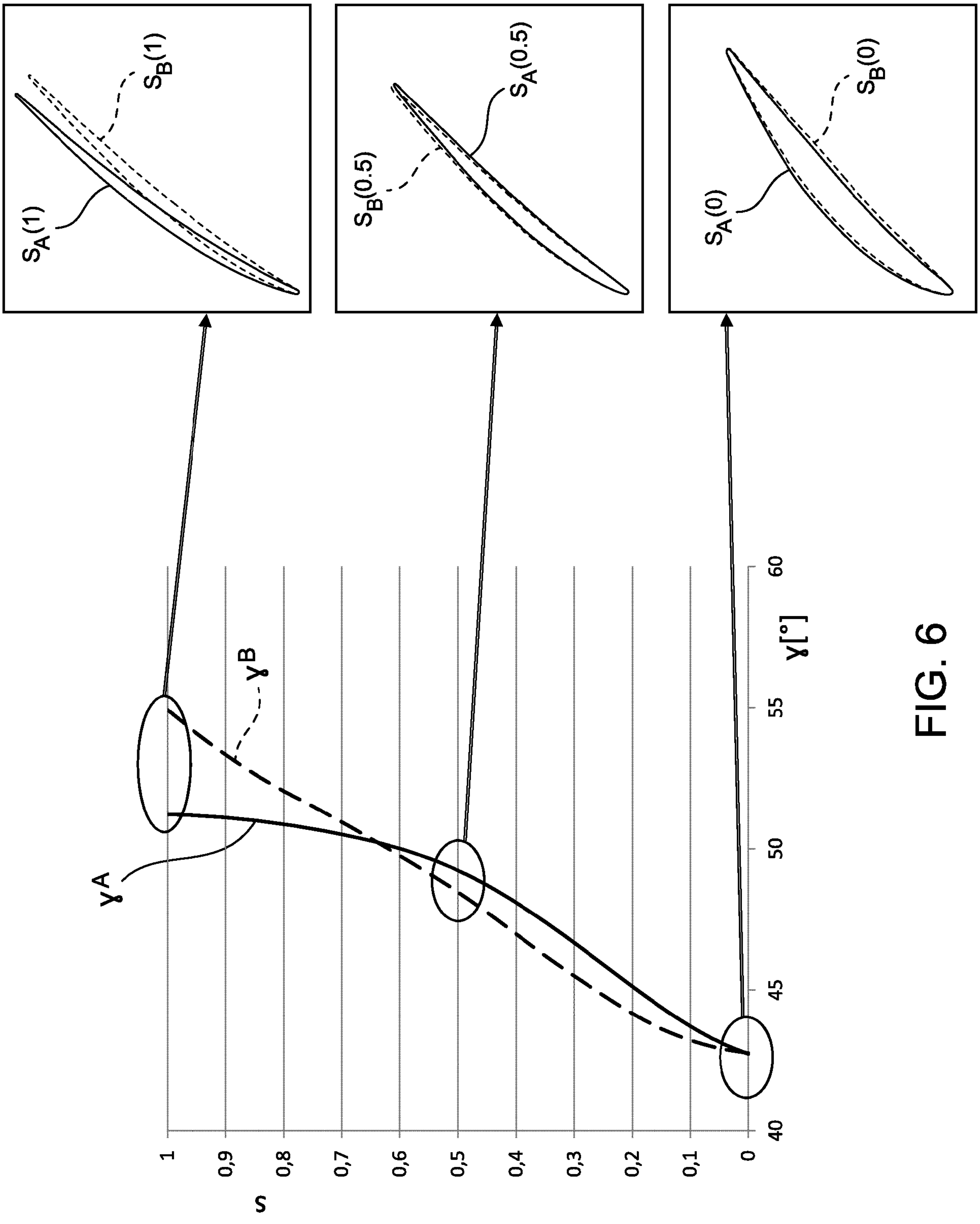

CR
A
B
C
D
Φ

FIG. 5



S_A(1)
S_B(1)
S_B(0.5)
S_A(0.5)
S_A(0)
S_B(0)
γ^A
γ^B
s
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
40
45
50
55
60
γ[°]

FIG. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 17 20 9156

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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X	US 2005/031454 A1 (DOLORESCO BRYAN KEITH [US] ET AL) 10 February 2005 (2005-02-10) * paragraph [0012] * * figure 4 * -----	1-6	
X A	US 2011/150660 A1 (MICHELI MARCO [CH] ET AL) 23 June 2011 (2011-06-23) * paragraphs [0016], [0017] * * figure 5; table 1 * -----	1,5,6 4	
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TECHNICAL FIELDS SEARCHED (IPC)

F04D
F01D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	4 June 2018	De Tobel, David

CATEGORY OF CITED DOCUMENTS

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04-06-2018

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