(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 890 506 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
13.01.1999 Bulletin 1999/02

(21) Application number: **97918440.5**

(22) Date of filing: **25.03.1997**

(51) Int. Cl.^{6}: **B63H 1/26**

(86) International application number:
PCT/RU97/00084

(87) International publication number:
WO 97/37889 (16.10.1997 Gazette 1997/44)

(84) Designated Contracting States:
DE DK ES FI FR GB IT NL SE

(30) Priority: **26.03.1996 RU 96105463**

(71) Applicant:
OAO "Baltiisky Zavod", Filial Baltiiskaya Mashinostroitelnaya Compania
St.Petersburg, 199106 (RU)

(72) Inventors:
- **TITOV, Alexandr I.**
  St.Petersburg, 196244 (RU)
- **SLEPOV, Alexandr V.**
  St.Petersburg, 199155 (RU)
- **FIRSUKOV, Jury J.**
  St.Petersburg, 199397 (RU)

(74) Representative:
Herrmann-Trentepohl, Werner, Dipl.-Ing. et al
Patentanwälte
Herrmann-Trentepohl
Grosse - Bockhorni & Partner
Forstenrieder Allee 59
81476 München (DE)

(54) BLADE OF A HYDRAULIC PROPULSION SYSTEM

(57) A novel profile is proposed for a hydraulic propulsion system blade intended for use in conditions of no cavitation and no ventilation and having a significantly higher efficiency, lifting force or cavitation-free flow indicators. The blade has a convex suction surface and a convex-concave compression surface, and leading and trailing edges. The suction surface has a section of increased curvature in the region of the trailing edge, whilst the inflection point of the line forming the compression surface is at a distance from the trailing edge of 0.6-0.9 times the length of the cord.

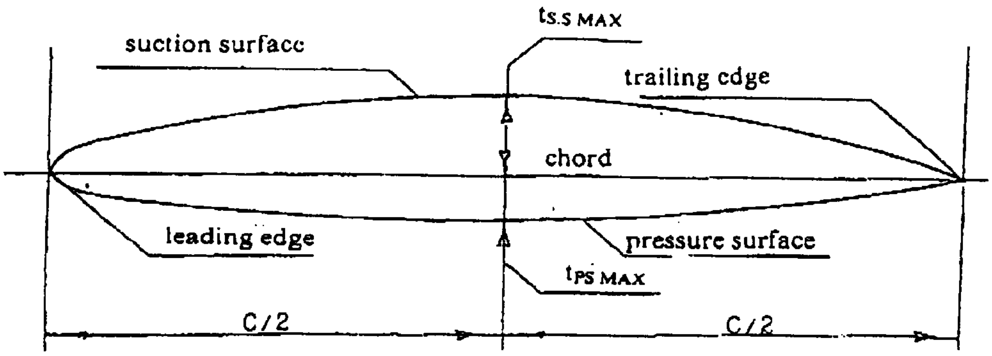


Fig. 1

EP 0 890 506 A1

Description

Field of invention

The invention relates to shipbuilding, concerning to working parts of hydraulic propulsion devices, and more particularly to the propeller, water jet, tunnel and azimuth thruster blades.

Prior Art

It is known the blades of the propellers having non-cavitation profile such as segment, NACA - 66, NACA - 16 and elliptic with mean line a = 0.8.

Every such blade has same non linear profile composed of a suction and pressure surfaces and a leading and trailing edges. The some blade for better compromise of cavitation, hydrodynamic and strength characteristics can have parts with different profile blade sections.

For exact description of blade section profile it can be taken a section of the blade, generated by cylindrical surface with the same axle as hydraulic propulsion device with the mentioned blade.

The term "blade section" will be used for such section below.

The line, connected the extreme, most outstanding points of the leading and trailing edges calls section chord, and is an abscissa line, from which, in, perpendicular direction, ordinates t of lines that form suction and pressure surfaces are measured.

The length of chord is identified C. In this case all lengths concerning the blade, determine along the chord in relation to the chord length C, and thickness - ordinates in relation to t_{max}. The curvature of lines that form suction and pressure surface, is a second derivative dt/dx function $t_{S.S} = f_1x$ and $t_{P.S.} = f_2x$, where x - an abciss of the point, measured from leading edge.

The advantage of these existing blades is that it section profile provide rather uniform pressure distribution at the suction and pressure surface at relatively low profile drag, and that the rounded leading edge leads to lower negative pressure peak at the leading edge region.

The disadvantage of the existing blades is that when the speed and power of ships increase, the problems concerning the cavitation at the suction surface, erosion, vibration, excessive noise and lowering of efficiency arouse. The suction surface of existing blades has close to uniform curvature from loading to trailing edge, or steady decreasing from the leading edge to the point with minimum curvature located approximately at the middle of the chord and then steady increasing to the trailing edge in consequence of the general point of view, that the increasing of the curvature caused to the danger of cavitation appearance at the early stage, and leads to the profile drug increasing.

The most close to the proposed invention is the blade of the hydraulic propulsion device described in the US Patent No 4 780 058, B63H 1/26 published on 25.10.1988. This blade has concave suction surface and concave - convex pressure surface and rounded leading and sharp trailing edge. The profile of blade section has a suction surface line with a constant curvature with the maximum ordinate at the point located no longer than 0.5 chord length from the leading edge. The line that forms the pressure surface has a concave part forward and convex part aft, cross the chord line at the sharp angle at the aft part of the blade with the transition of the concave part to the convex located at the distance of 0.5 chord length from the loading edge. Due to concave - convex shape of the pressure surface of this blade some improvement in performance was achieved in defined cavitation conditions.

Introducing a convex part of the pressure surface in the trailing edge region caused problem of the very thin trailing edge. In addition the location the point of the concave - convex transition at the middle of chord length avoid the non cavitation work of the blade in a big number of conditions.

Summary of the invention

The aim of proposed invention is a creation of the hydraulic propulsion system blade intended for use in conditions of no cavitation and ventilation and having an improved cavitation performance, higher cavitation resistance and efficiency, and consequently reduced danger of cavitation erosion, noise, and vibration.

The improvement in performance that can be achieved using the invention, will be the increasing of flow speed when cavitation occur keeping the same blade thickness and lift coefficient, or increasing lift coefficient keeping the same non cavitation speed flow and blade thickness, or increasing the thickness and, consequently, the leading edge radius keeping the same non cavitation speed flow and lift coefficient.

To achieve above mentioned improvement in cavitation and hydrodynamic performance the blade with improved section profile, described below, is proposed.

A blade of propulsion device, according to this invention, has leading edge and sharp trailing edge, suction surface and pressure surface The blade, or the part of the blade, has sectional profile, in which the line that forms the suction surface is an arc, i. e. has the constant curvature, or is a line with curvature decreasing steady from the leading edge to the point of the minimum curvature, located at the position of 0.45 0.55 chord length from the leading edge and steady increasing from the point of minimum curvature to the point, located at the position of 0.1 chord length from the trailing edge. The strait line, laying tangentially and touched the suction surface line at the point of minimum curvature, had to be parallel the chord line, or to cross it continue at the point located forward of the leading edge at the angle no more than 7°, and the distance from the points at this tangentially laying strait line to the points at the line that formed the suction surface measured at the points located at the equal distance from the point of minimum curvature in directions to leading and trailing edges, equal or more at the point located between the minimum curvature point and trailing edge. The line that formed pressure surface, has a concave part at the forward part of the blade and convex part at the aft part of the blade that cross the chord line at the aft part of the blade. In difference of the prototype, the concave - convex transition point located at the position 0.6 0.9 chord length measured from the leading edge. The line that forms suction surface, has a part with bigger curvature located at the distance from 0.03 to 0.1 chord length measured from the trailing edge. The ordinate of the line that forms suction surface, at the point located at the distance 0.05 chord length has a value of 0.4 - 0.7 maximum ordinate of this line.

Ordinates mean lines NACA a= 0.8, NACA a = 1.0, segment line or it modifications can be added to the ordinates of the line that forms suction surface, and can be deducted of the ordinates of the line that forms pressure surface.

The leading edge of the blade according to invention can be made rounded or wedge shaped with the angle no less than 30°.

If the leading edge is rounded, the curvature of the line that forms suction surface at the part from the leading edge to the point located at the distance 0.05 chord length can be more, less or equal than the curvature of the line that forms pressure surface of the blade at this part of the blade.

When the leading edge made wedge shaped, the angle between the line that forms the suction surface and chord line at the ultimate point of the leading edge more, less or equal than the angle between the line that forms pressure surface and chord line.

The part of the line that forms suction surface from trailing edge to point located at the distance 0.03 chord length from the trailing edge can be made concave and non linear or strait.

The part of the line that forms suction surface from trailing edge to point located at the distance 0.03 chord length from the trailing edge can incorporate a strait part connected to the trailing edge positioned perpendicular to the chord line with a length no more than 0.015 chord length.

In order to significant removal of the concave convex transition point of the line that forms the pressure surface to the trailing edge it becomes possible to increase the curvature of the convex part of the pressure surface and increase the value of the positive pressure peak at the aft part of the blade consequently.

At the same time, the increasing of curvature of the suction surface in a region of the trailing edge also allows to increase the curvature of the convex part of the pressure surface, and increase the value of the positive pressure peak at the aft part of the blade consequently.

Both this technical solutions allows to obtain the positive pressure peak approximately two times greater than at the existing blade.

The presence of the positive pressure peak at the aft part of the pressure surface allows, keeping the same value of lift coefficient, to decrease the curvature of suction surface and, consequently, the value of the negative pressure coefficient, and therefore the value of non cavitation speed.

In another case, keeping the same given thickness of the blade, it is possible to increase the value of lift coefficient.

Theoretical and experimental investigations show that the increasing of the curvature of suction surface in mentioned region of the trailing edge do not lead to cavitation inception at this place and/ or sufficient increasing profile drag, as it usually predicted at the background of the common methods of hydraulic propulsion systems design. This negative effects do not arose because of that the thickness of profile at the distance about 0.05 chord length from the trailing edge is comparable with the thickness of the boundary layer, and existence of the positive pressure peak in a region of the trailing edge decreasing the value of negative pressure in a region of local increasing of curvature.

Above mentioned possibility of addition to ordinates of suction surface line and deduction from ordinates of pressure surface line the ordinates of the mean line a = 0.8, a = 1.0, segment or it modifications allows to obtain different combinations of the values of lift coefficient, thickness and negative pressure coefficient, that is quite necessary in hydraulic propulsion system blade design. Using this, it is possible to create a profile series without complex and difficult calculations.

Rounded or wedge shaped with angle no less than 30°, leading edge form improved the flow in a leading edge region. The relation of the curvature of the suction and pressure surfaces in the region of leading edge, or the angles between the suction and pressure surfaces lines and chord line determine the value of the shock free entrance angle for given value of the lift coefficient and allows to eliminate negative pressure peak at the leading edge when working in the desired condition.

The flat part of the suction surface in a trailing edge region prevent the "singing" of the propeller.

Brief Description of the Drawings

Fig. 1 is a blade section with the conventional elliptic profile.

Fig. 2 is a blade section described in the US patent a 4 780 058.

Fig. 3 is a blade section according to the invention.

Fig. 4 represents a pressure distribution at suction and pressure surfaces of the blade with elliptic section profile.

Fig. 5 represents a pressure distribution at suction and pressure surfaces of the blade according to the US patent No 4 780 058.

Fig. 6 represents a pressure distribution at suction and pressure surfaces according to the invention.

Fig. 7a is a blade section trailing edge region.

Fig. 7b is a blade section trailing edge region with a flat part at the suction surface.

Fig. 7c is a blade suction trailing edge region with a strait part, positioned perpendicularly to the chord line.

Fig. 8a is a blade section leading edge region with rounded leading edge with the curvature of suction surface line less than the curvature of pressure surface line.

Fig. 8b is a blade section leading edge region with rounded leading edge with the curvature of suction surface line equal to the curvature of pressure surface line.

Fig. 8c is a blade section leading edge region with rounded loading edge with the curvature of suction surface line more than the curvature of pressure surface line.

Fig. 9a is a blade section leading edge region with wedge shaped leading edge with suction surface line crossing the chord line at the angle more than the angle, at witch the pressure surface line cross the chord line.

Fig. 9b is a blade section leading edge region with wedge shaped leading edge with suction surface line crossing the chord line at the angle equal to the angle, at witch the pressure surface line cross the chord line.

Fig. 9c is a blade section leading edge region with wedge shaped leading edge with suction surface line crossing the chord line at the angle less than the angle, at witch the pressure surface line cross the chord line.

Fig. 10 represents K_T, K_Q functions and efficiency coefficient η in cavitation and non cavitation conditions obtained in comparative model tests of the propellers (having the same geometrical characteristics with conventional profile type NACA - 16 a = 0.8 and the profile according to the invention.

Fig. 11 represents propeller blade drawing according to the invention.

Detailed Description of an Embodiment

Figure 3 - 11 represent the blade designed according to proposed invention. As can be seen from the drawing blade section profile has the lines that forms suction and pressure surfaces, and rounded leading and sharp trailing edges. The line, that forms suction surface, is concave from the leading edge up to the trailing edge and has the maximum thickness t_{MAX} at the point located at the distance 0.60 C from the leading edge. In addition the line that forms the suction surface has a part with increased curvature from the trailing edge to the point located at a distance not more than 0.1 C from the trailing edge. The ordinate of the line, that forms suction surface, at the point, located at the distance 0.05 C from the leading edge, is 0.5 of maximum ordinate of this line. The line, that forms pressure surface has a concave part in the forward part of the blade and convex part that cross the chord line at the sharp angle in the aft region of the blade. The concave - convex transition point located at the distance 0.65 C from the leading edge.

Comparison of pressure distributions represented at the Fig 4 -6 shows, that the blade with profile shaped according the proposed invention has the value of pressure coefficient C_P at the suction surface higher that corresponds to lower suction at this surface and in consequence, to cavitation inception at lower values of cavitation number σ at the same conditions, as a result of the technical solutions applied in this blade design according to proposed invention. Fig. 7 -8 represent the different variants of the leading edge that can be chosen for better performance of the certain blade at the desired conditions.

Fig. 10 represents the comparative tests at the cavitation tunnel two propeller models of the high speed vessel. These models have the same geometrical characteristics: blade area ratio A_E/A_O = 0.99, P/D = 1.15 at r/R = 0.7, number of blades Z = 4, but one model has the blades with conventional profiles type NACA 16 a = 0.8 and the other has the blades, designed according to proposed invention. As can be seen at the Fig. 10, at the desired advance ratio J = 0.9 and desired cavitation number σ = 0.63 calculated as:

$$\sigma = (P - P_d)/0.5pV^2$$

where:

v - ship speed
P - static pressure at the shaft line
P_d - vapour pressure
p - density of water.

Propeller with blades designed according to proposed invention, has no cavitation and has efficiency coefficient η = 0.66, when the propeller with blade section profile NACA - 16 a = 0.8 suffered with cavitation and has the efficiency coefficient η = 0.57. The value of the relation σ/C_{TI} , where C_{TI} - the maximum value of load coefficient when cavitation do not affect the trust coefficient K_T for propeller with blades, designed according to proposed invention is σ/C_{TI} = 1.1 compared with σ/C_{TI} = 1.9 for propellers with traditional blade sections.

Claims

1. A hydraulic propulsion system blade intended for use in conditions of no cavitation and ventilation,

with leading edge and sharp trailing edge, suction surface and pressure surface, and the blade, or the part of the blade, has sectional profile that is a section of the blade surface by cylindrical surface with the axis that coincide with the axis of hydraulic propulsion system, in which the line, that forms the suction surface is an arc, i. e. has the constant curvature, or is a line with curvature decreasing steady from the leading edge to the point of the minimum curvature, located at the position of 0.45 - 0.55 chord length from the leading edge and steady increasing from the point of minimum curvature to the point, located at the position of 0.1 chord length from the trailing edge, and the strait line, laying tangentially and touched the suction surface line at the point of minimum curvature, had to be parallel the chord line, or to cross it continue at the point located forward of the leading edge at the angle no more than 7°, and the distance from the points at this tangentially laying strait line to the points at the line that formed the suction surface measured at the points located at the equal distance from the point of minimum curvature in directions to leading and trailing edges, equal, or more at the point, located between the minimum curvature point and trailing edge, and the line, that formed pressure surface, has a concave part at the forward part of the blade and convex part at the aft part of the blade that cross the chord line at the aft part of the blade, <u>characterised</u> in that the concave - convex transition located at the position 0.6 - 0.9 chord length measured from the leading edge, and the line that forms suction surface has a part with bigger curvature located at the distance from 0.03 to 0.10 chord length measured from the trailing edge, and the ordinate of the line, that forms suction surface, at the point, located at the distance 0.05 chord length has a value of 0.4 - 0.7 maximum ordinate of this line.

2. The blade as set forth in claim 1, characterised in that the ordinates mean lines NACA a= 0.8, NACA a = 1.0, segment line or it modifications added to the ordinates of the line that forms suction surface, deducted of the ordinates of the line that forms pressure surface.

3. The blade as set forth in claim 1, 2, characterized in that the leading edge is rounded.

4. The blade as set forth in claim 1, 2, characterized in that the leading edge is wedge shaped with the angle no less than 30°

5. The blade as set forth in claim 3, characterised in that the curvature of the line that forms suction surface at the part from the leading edge to the point located at the distance 0.05 chord length less than the curvature of the line that forms pressure surface of the blade at this part of the blade

6. The blade as set forth in claim 3, characterized in that the curvature of the line that forms suction surface at the part from the leading edge to the point located at the distance 0.05 chord length more, or equal than the curvature of the line that forms pressure surface of the blade at this part of the blade.

7. The blade as set forth in claim 4, characterised in that the angle between the line that forms the suction surface and chord line at the ultimate point of the leading edge more, than the angle between the line that forms pressure surface and chord line.

8. The blade as set forth in claim 4, characterized in that the angle between the line that forms the suction and chord line at the ultimate point of the leading edge less or equal than the angle between the line that forms pressure surface and chord line.

9. The blade as set forth in one of the claims 1 8, characterized in that the part of the line that forms suction surface from trailing edge to point located at the distance 0.03 chord length from the trailing edge is concave and non linear.

10. The blade as set forth in one of the claims 1 - 8, characterized in that the part of the line that forms suction surface from trailing edge to point located at the distance 0.03 chord length from the trailing edge is strait.

11. The blade as set forth in one of the claims 1 - 8, characterized in that the part of the line that forms suction surface from trailing edge to point located at the distance 0.03 chord length from the trailing edge incorporates a strait part connected to the trailing edge positioned perpendicular to the chord line with a length no more than 0.015 chord length.

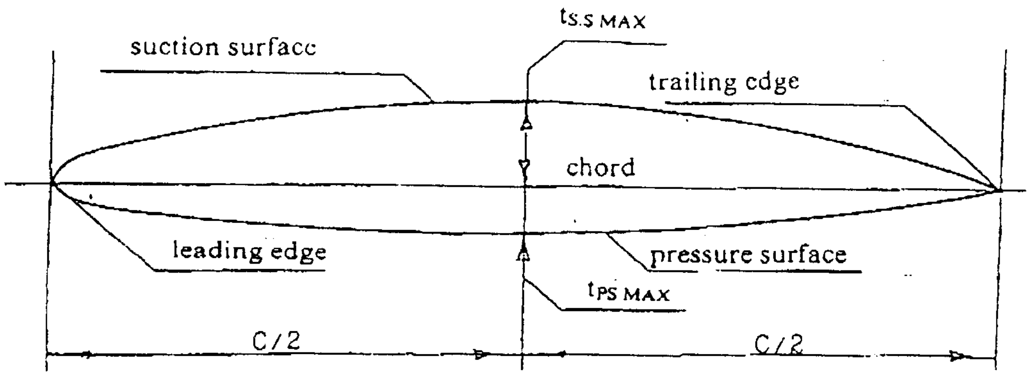


Fig. 1

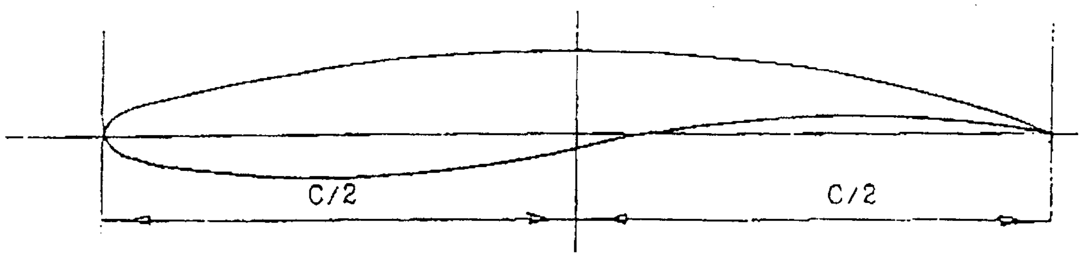


Fig. 2

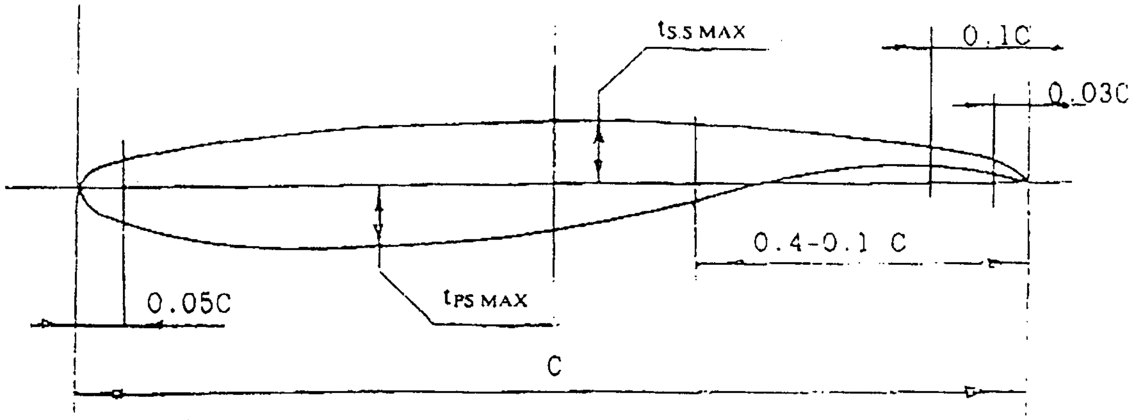


Fig. 3

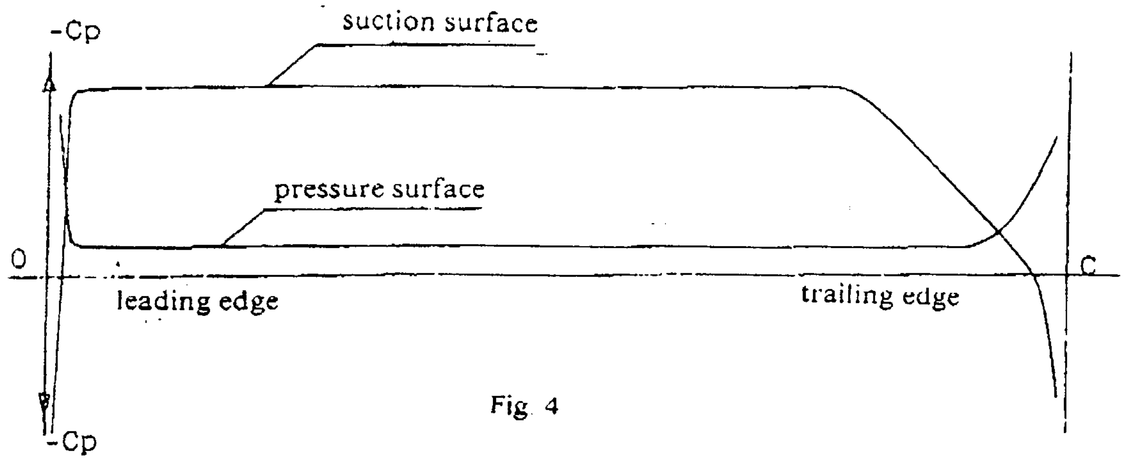


Fig. 4

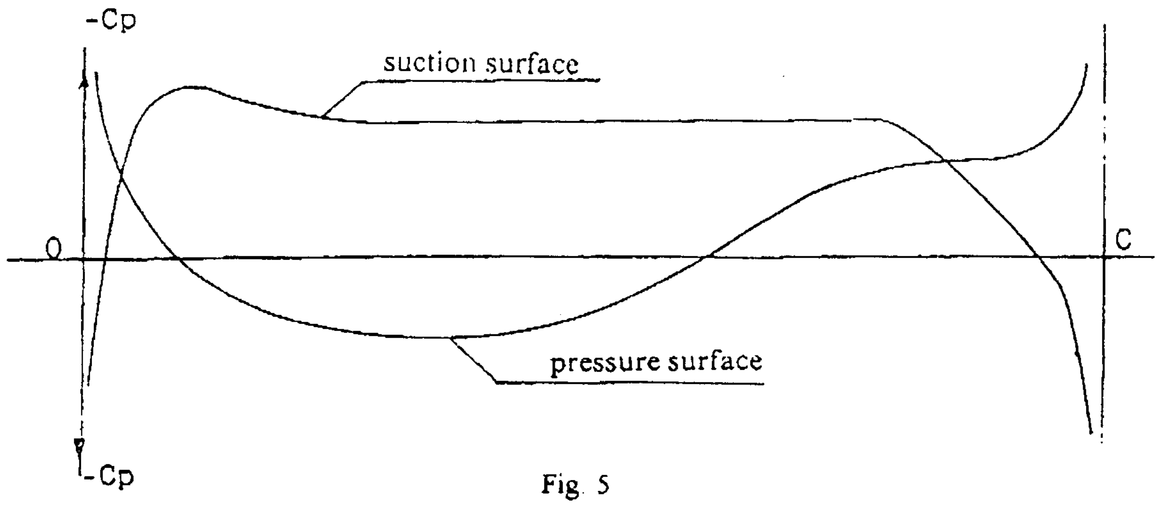


Fig. 5

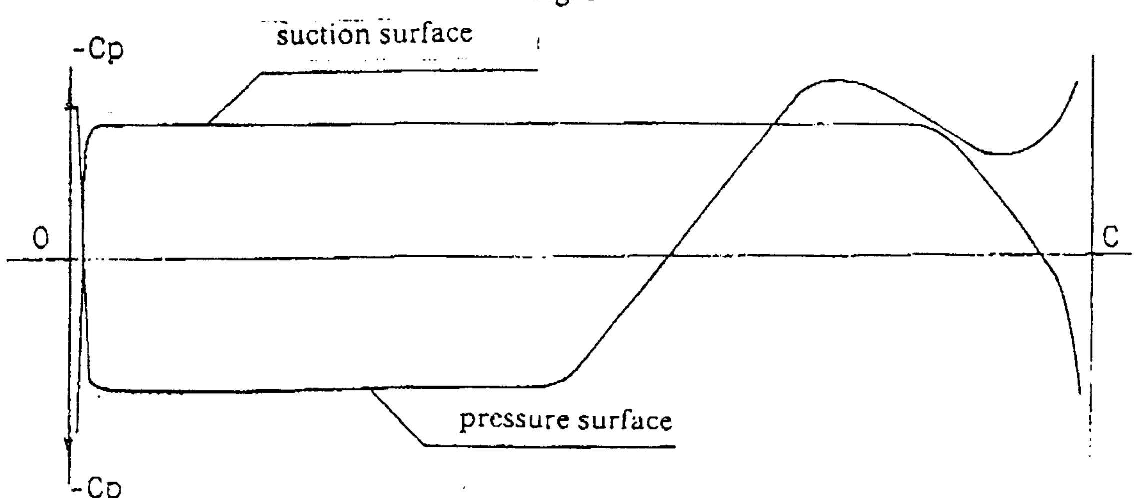


Fig. 6

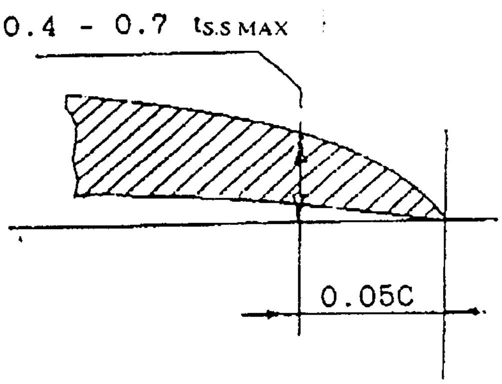


Fig. 7a

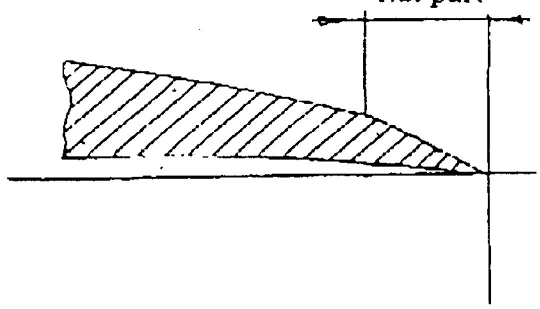


Fig. 7b

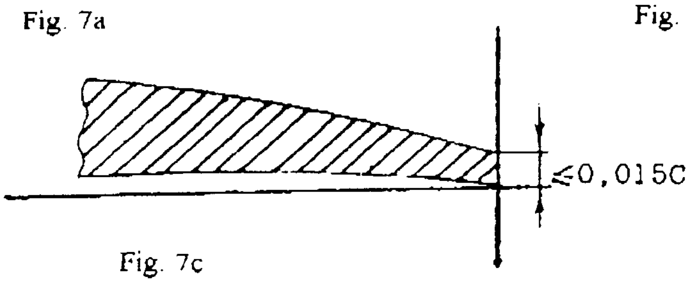


Fig. 7c

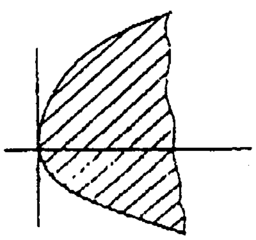


Fig. 8a

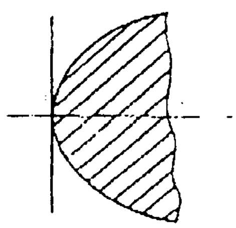


Fig. 8b

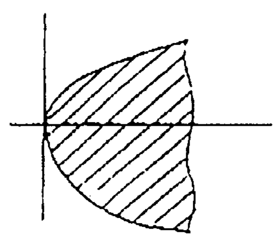


Fig. 8c

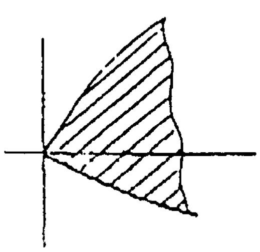


Fig. 9a

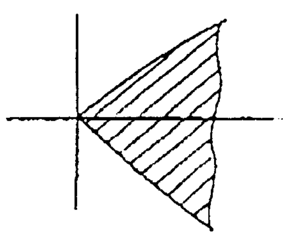


Fig. 9b

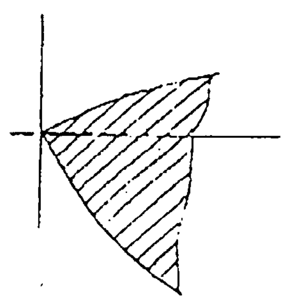
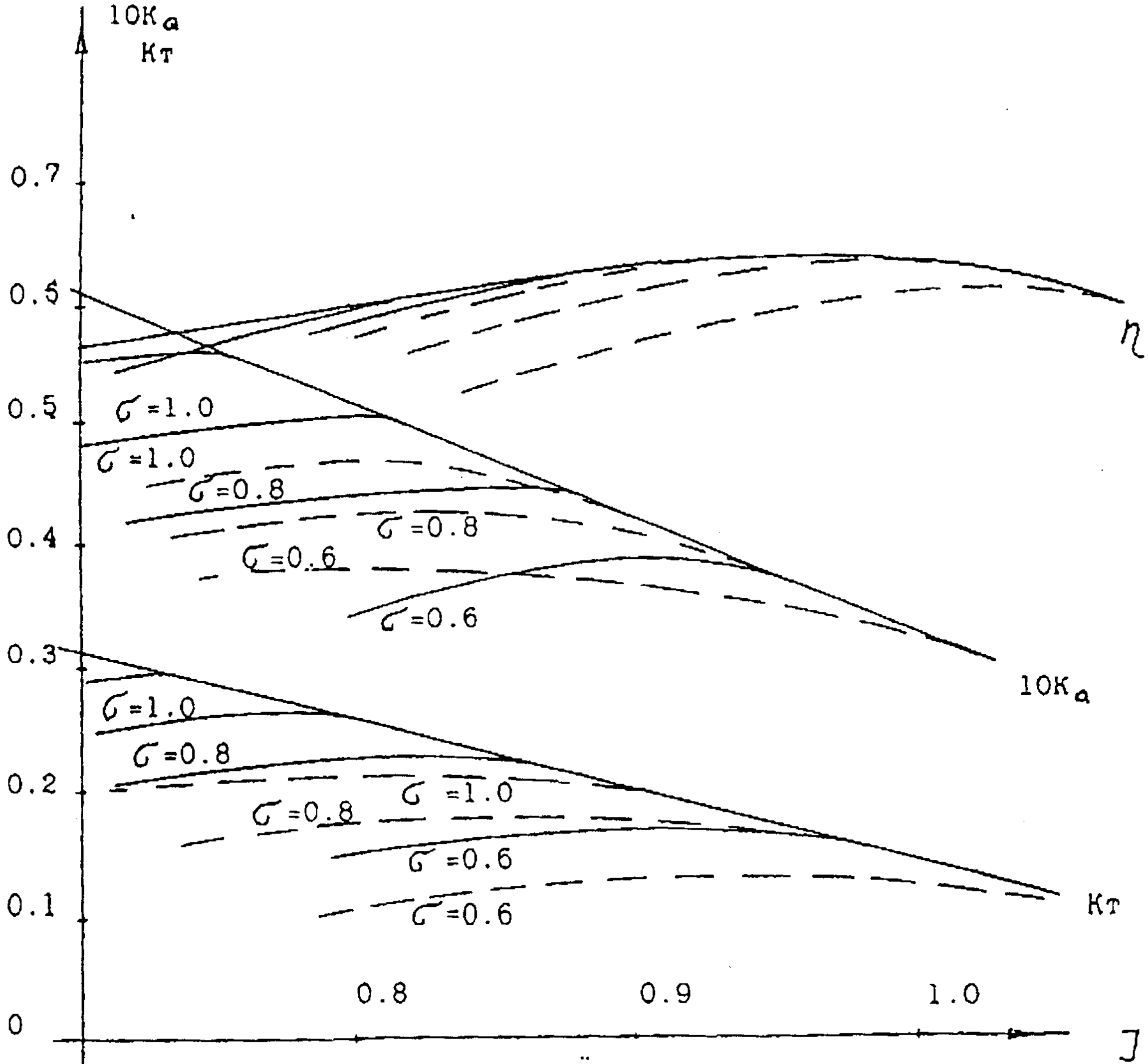


Fig. 9c



propeller with blades section profile according to proposed invention

propeller with conventional blade section profile NACA - 16 a = 0.8

Fig. 10

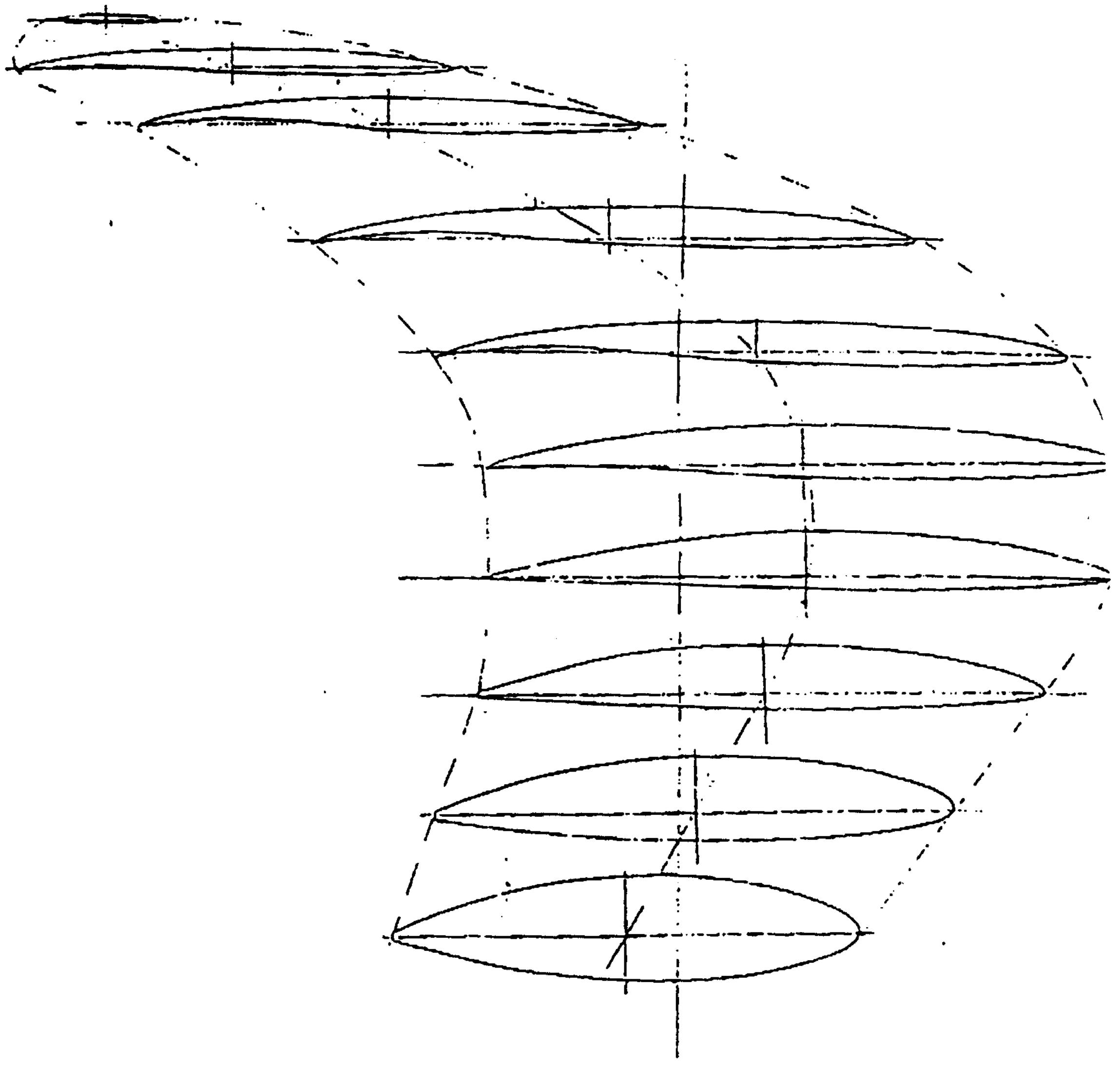


Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 97/00084

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 : B63H 1/26

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)

IPC 6 : B63H 1/00-1/02, 1/12-1/15, 1/18, 1/26, F03B 3/12, F04D 29/24, 29/30, F01D 5/00, 5/12-5/14

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4073601 A (DANA CORPORATION) 14 February 1978 (14.02.78)	1,4-5,8-9
A	US 4780058 A (MARIE SISTEMS RESEARCH INC.,) 25 October 1988 (25.10.88), (cited in the description)	1,4-5,8-9
A	SU 249960 A (M.B. MASEEV et al) 12 January 1970 (12.01.70)	1-2,4,6-7,10
A	US 4552511 A (SANSHIN KOGYO KABUSHIKI KAISHA) 12 November 1985 (12.11.85)	1,3,11
A	SU 656493 A ("AKTIEBOLAGET KARLSTADS MEKANISKA VERKSTAD") 05 April 1979 (05.04.79)	1,11
A	FR 2600971 A1 (ALSTHOM, SOSIETE ANONYME) 08 January 1988 (08.01.88)	1-3,6-10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 August 1997 (25.08.97)	11 September 1997 (11.09.97)
Name and mailing address of the ISA/ RU	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)