

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/US84/00071 (22) International Filing Date: 16 January 1984 (16.01.84) (71) Applicant (for all designated States except US): THE BOEING COMPANY [US/US]; Post Office Box 3707, Mail Stop 7E-25, Seattle, WA 98124 (US). (72) Inventor; and (75) Inventor/Applicant (for US only) : HINKLEMAN, Michael, Jay [US/US]; 12938 Southeast 246th Street, Kent, WA 98031 (US). (74) Agents: DeVOGEL, Nicolaas et al.; Boeing Commercial Airplane Company, Post Office Box 3707, Mail Stop 7E-25, Seattle, WA 98124 (US). (81) Designated States: DE (European patent), FR (European patent), GB (European patent), NL (European patent), US.		Published <i>With international search report.</i>
(54) Title: AN AIRFOIL HAVING IMPROVED LIFT CAPABILITY		
(57) Abstract <p>An airfoil (10) having improved lift capability and having airfoil curves including a camber divided into three regions I, II and III. Region I has a starting point aft and adjacent a leading edge (12) and encompasses the airfoil stagnation point. Region I has a high curvature around the leading edge and decreases aft along the chord to a first local minimum value of less than 3 for K times C, where C is the length of the chord and K is the reciprocal of the local radius of curvature. The curvature region II starts at the after end of the region I within 10% of the chord length and the curvature in region II first increases from the first local minimum at the aft end of region I and then decreases to a second local minimum within 40% of the chord length.</p>		

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Description

AN AIRFOIL HAVING IMPROVED LIFT CAPABILITY

Technical Field

5 The invention relates to an airfoil and more particularly, to the leading edge of an airfoil having high lift capability.

Background Art

10 In the design of an airfoil forming an aircraft wing, particularly, the leading edge thereof on a fixed wing or in the form of a leading edge comprising a movable slat on a fixed wing, within a required parameter or envelope, it is attempted to improve the lift capability, reduce the pitch-up, reduce the cruise drag, and improve the buffet in comparison with the prior art. Typically, aircraft wings
15 have been shaped to provide a required lift with least possible cruise drag. The shape of the wing is generally comprised between the aerodynamic shape that is most efficient for aircraft cruising speed and the aerodynamic shape required for low air speeds such as encountered
20 during takeoff and landing. It is also known that reduction in pitch-up generally penalizes cruise drag performance.

A search of the patent literature discloses the following patents, International Application, and article,
25 which are of general interest:

U.S. Patent No. 1,780,838
U.S. Patent No. 2,257,260
U.S. Patent No. 2,448,698
U.S. Patent No. 2,541,565
30 U.S. Patent No. 2,793,826
U.S. Patent No. 2,938,680
U.S. Patent No. 3,077,173
U.S. Patent No. 3,195,836



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U.S. Patent No. 3,244,384

U.S. Patent No. 3,273,826

U.S. Patent No. 3,917,193

U.S. Patent No. 3,952,971

5 U.S. Patent No. 4,050,651

U.S. Patent No. 4,189,120

U.S. Patent No. 4,200,253

U.S. Patent No. 4,240,598

10 International Application published under P.C.T.
International Pub. No. WO 81/02557,

International Pub. Date 17 Sept. 1981

Article: "Computer-aided design: Aerodynamics, by A.
B. Haines, pps. 81-91, Aeronautical Journal, March 1979Disclosure of the Invention15 The present invention provides for improved low-speed
handling and high-speed performance in slats or in a fixed
leading edge airfoil on airplane wings or in stabilizers,
for example.20 According to the present invention, an airfoil was
developed to increase lift capability, particularly at Mach
numbers from 0.72 to 0.84, and improve the load balance of
the wing at high angles of attack.The unique geometric configuration, according to the
invention, also was found to substantially reduce pitch-up
25 without penalizing cruise drag performance.Generally, the airfoil may be described as having
multiple local curvature minima on the upper or negative
pressure surface. The airfoil according to the invention
when used as a stabilizer would generally have the
30 geometric configuration on the lower surface, an exception
being the case of an uncambered stabilizer for which both
upper and lower surfaces would be identical.The airfoil has curves including camber divided into
three regions, I, II, and III. Region I has a starting
35 point aft and adjacent the leading edge and encompasses the

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airfoil stagnation point. It has a high curvature around the leading edge and the curvature decreases aft measured along the chord from the leading edge on an upper or negative pressure side of the airfoil to a first local
5 minimum value of less than 3 for K times C at the end of region I, where C is the length of chord and K is the reciprocal of the local radius of curvature. Region I is within 10% of the chord length and region II starts at the aft end of region I within 10% of the chord length. The
10 curvature in region II first increases from the first minimum and then decreases to a second local minimum within 40% of the chord length.

The starting point of region I is below the chord, lower than the ordinate value of the leading edge, and is
15 aft of the leading edge by not more than 3% of chord length measured along the chord. The high curvature at the leading edge has a value for K times C equal to or greater than 35 but less than or equal to 120. In region II the maximum value for K times C is greater than 1 but less than
20 6.

The second local minimum is at the end of region II and the value of K times C initially increases from the second local minimum and may remain constant to the trailing end of the airfoil or may have one or more greater points
25 relative to the first and second minimums.

Within the required parameter the airfoil, according to the invention, is considered to be the first to provide pitch-up improvement without penalizing cruise drag performance. It provides a substantially greater lift and
30 improved buffet to permit the aircraft to carry substantially higher weights.

Further advantages of the invention may be brought in the following part of the specification wherein small details have been described for the competence of the
35 disclosure, without intending to limit the scope of the invention which is set forth in the appended claims.



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Brief Description of the Drawings

Referring to the accompanying drawings which are for illustrative purposes:

Fig. 1 is a profile view of an airfoil, according to the invention, the invention being substantially in the upper surface of the airfoil;

Fig. 2 is an enlarged profile view of the invention as it may be applied to a wing fixed leading edge in the form of a slat or in the form of the leading edge as a part of a wing and integral therewith; shown for comparison with the invention is a prior art leading edge of the 1960's and a recent leading edge concept which is not prior art;

Fig. 3 is a graph illustrating curvature (K) times chord length plotted against percent chord, illustrating the invention in graph form;

Fig. 4 shows a comparison of the curvature of the three profiles illustrated in Fig. 2;

Fig. 4A illustrates the position of angle ϕ in Fig. 4;

Fig. 5 is a graph illustrating curvature plotted against distance from the leading edge prior art airfoil normalized by chord length for comparison of the 1960's prior art, a recent concept, and the invention;

Fig. 6 is a graph for the invention and a graph for the recent concept in which pressure coefficient is plotted against the distance from the leading edge measured aft on the chord and divided by the length of the entire chord at various angles of attack;

Fig. 7 is a graph in which the lift coefficient is plotted against profile drag, comparing the invention with the recent concept to show the effect of leading edge shapes on drag;

Fig. 8 is a graph in which the lift coefficient is plotted against critical Mach number and shows comparison of the effect of leading edge shapes of the 1960's prior



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art, the recent concept, and the invention;

Fig. 9 is a graph illustrating the lift coefficient buffet plotted against the Mach number in which curves for the present invention, recent concept, and the 1960's prior art are compared;

Fig. 10 is a graph of airplane lift coefficient plotted against the degrees of angle of attack for Mach point 0.72 and Mach 0.78, illustrating the improvement of lift in the invention over applicant's recent concept; and

Fig. 11 is a view illustrating the configuration of the invention in the form of a leading edge slat along with applicant's recent concept, and the 1960's prior art.

Best Mode for Carrying out the Invention

Referring again to the drawings, the invention is shown in the airfoil 10, shown as the profile of a wing, and being substantially in the upper surface starting at point A to include the stagnation point, extending around leading edge 12, and terminating in the trailing edge 14 of the airfoil and wing. Airfoil chord 16 is shown in phantom lines extending from the leading edge to the trailing edge.

Region I of the airfoil, extending between points A and B, extends below the upper surface far enough to encompass the airfoil stagnation point. Point A is thus lower than the ordinate value of the leading edge 12 and is aft of the leading edge by no more than 3% of the chord distance as measured along the chord. The airfoil leading edge has curvature (K) times chord length (C) equal to or greater than 35 but less than or equal to 120, Figs. 3 and 5, where K is the reciprocal of the local radius of curvature. Region I has a minimum of curvature, K times C, of less than 3 at its end, point B, and the start of region II. As best seen in Fig. 3, region I has a continuously decreasing curvature to a minimum within the first 10% of the airfoil as measured along the chord.

Point B at the end of region I lies aft of the leading



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edge and within 10% of the chord length on the upper surface of the airfoil.

The forward or first local minimum point of curvature B, Fig. 3, is a significant aspect of the inventive leading edge shape. After point B the curvature first increases then decreases to a second local minimum value occurring within the first 40% of the airfoil, the second local minimum value being at point C at the end of region II and the start of region III. In region II the maximum value for K times C is greater than 1 but less than 6.

As shown in Fig. 3, region I plus region II are within the first 40% of the chord, and point C, Fig. 1, lies aft and within 40% chord of the leading edge of the upper surface of the airfoil. The curvature of region III initially increases from the second local minimum at the end of region II and may remain at a constant level or may have one or more maximum/minimum points, as indicated in Figs. 3 and 5. Region III is about twice the length of region II.

From the foregoing, it is noted that the overall airfoil upper surface has at least two local curvature minima, both occurring within the first 40% of the chord length.

In Fig. 2, the invention is shown along with the profile of prior art, in broken lines, developed in the 1960's and with a recent airfoil concept, in phantom lines, of applicant which is not prior art. The wing fixed leading edge illustrates an airfoil on which the invention, the recent concept and the prior art would be suitable for employment as slats. The three profiles forming leading edges forwardly of the fixed leading edge could also be employed as airfoils forming a fixed leading edge on a wing.

In Fig. 4, the nose curvature of the three airfoils is illustrated. Fig. 4A shows the position of the angle ϕ .



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The prior art curve shows curvature typical of older technology airfoils whereas the recent concept curve is similar to some of the current state of the art (peaky-type) airfoils. The curve showing the invention has
5 a nose curvature that falls between the other two and the graph shows the substantial distinction.

In Fig. 5 curvature is plotted against the distance from the leading edge of the prior art airfoil normalized by chord length. The forward minimum point of curvature of
10 the invention illustrates the distinction between the prior art, the recent concept. The curvature of the recent concept, which is less than that of the prior art from 4% to 12% chord, does not reach a true minimum until the crest of the main airfoil, although it is almost constant from
15 about 25% chord length to the crest.

The net effect of the varying curvature regions of the inventive leading edge is illustrated in Fig. 6, where outboard upper wing pressures at Mach 0.78 on the invention and of the recent concept are shown. As the angle of
20 attack increases from 2° to 8°, the character of the pressure distribution of the new airfoil changes from non-peaky (almost no leading edge suction) to peaky (a roof-top shape with suction all the way up to the leading edge). The pressure distribution in the invention fills
25 out about the forward minimum curvature point near 5% chord. In a like manner, the recent concept airfoil distribution fills out about its effective miniature curvature point, which is about 25% chord. This is significant because the recent concept airfoil carries
30 additional lift with angle of attack, the shock strength near the airfoil crest growing faster than it does on the invention airfoil. The trailing edge pressures correspondingly are more positive on the invention than on the recent concept, indicating a thinner shed wake for the
35 invention airfoil. At 8° angle of attack, the pressure



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distribution in the recent concept airfoil has effectively collapsed due to shock-induced separation while the inventive airfoil distribution is still reasonably well formed.

5 As shown in Fig. 10, for Mach numbers ranging from 0.72 to 0.84 the effect of the inventive leading edge on wing pressures is virtually the same, resulting in delayed shock-induced stall of the wing. The lift improvement shown in Fig. 10 in the invention with respect to the
10 recent concept is substantial.

The delayed shock stall, Fig. 6, with the present invention also significantly improved the buffet boundary, Fig. 9, compared with the recent concept and the prior art.

As shown in Fig. 7, from a drag standpoint, the leading
15 edge of the invention is the same or better than the recent concept. In Fig. 7 and 8, comparisons of the Mach 0.72 (cruise) drag polar and the critical Mach number with the invention and recent concept are made and also with the prior art relative to the critical Mach number.

20 The fact that the present invention performs well at high lift values is obvious and what is more important, is that there is no performance trade-off with the inventive leading edge at lower lift values.

In summary, the inventive leading edge opens up the
25 Mach/lift operating envelope in the lift direction. The Mach number capability at low lift values, where the leading edge shape plays a less significant role, was not affected. It is expected that the present invention can be used to open up the Mach/lift boundary of any given
30 airfoil. This is certainly true of the older technology airfoils on nearly all commercial airplanes flying today. The new leading edge invention will also improve the off-design (lower Mach number) performance of a point designed peaky-type airfoil.

35 Fig. 11 illustrates the invention of the airfoils in



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the position and configuration of slats, rather than as an entire wing for complete airfoil, shown in Figs. 1 and 2. The curves in regions IA, IIA and IIIA can be made to apply to the graphs in the same manner as regions I, II and III.

5 The invention and its attendant advantages will be understood from the foregoing description and it will be apparent that various changes may be made in the form, construction, and arrangements of the parts of the invention without departing from the spirit and scope
10 thereof or sacrificing its material advantages, the arrangements hereinbefore described being merely by way of example. I do not wish to be restricted to specific forms shown or uses mentioned except as defined in the accompanying claims.



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What is claimed is:

1. An airfoil having improved lift capability, comprising:

a chord extending from a leading edge to a trailing edge of the airfoil;

5 airfoil curves divided into three regions, I, II, and III,

region I having a starting point aft and adjacent the leading edge and encompassing the airfoil stagnation point;

region I having a high curvature around the leading edge, and curvature decreasing aft along chord from leading edge on upper or negative pressure side of airfoil to a first local minimum value of less than 3 for K times C at the aft end of region I,

where C is the length of chord and K is the reciprocal of the local radius of curvature;

region I being within 10% of chord length;

region II starting at the aft end of region I within 10% of chord length; and

the curvature in region II first increases from the first minimum at the aft end of region I and then decreasing to a second local minimum within 40% of the chord length.

2. The invention according to claim 1 in which:

the starting point of region I is below the chord, lower than ordinate value of the leading edge, and is aft of leading edge by not more than 3% of chord length measured along chord.

3. The invention according to claim 1 in which:

the high curvature at the leading edge has a value for K times C equal to or greater than 35 but less than or equal to 120.

4. The invention according to claim 1 in which:

region III starts at the end of region II within 40% of



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the chord length.

5. The invention according to claim 1 in which:
in region II the maximum value for K times C is greater than one but less than 6.

6. The invention according to claim 1 in which:
the airfoil is symmetrical about the chord.

7. The invention according to claim 1 in which:
region III lies aft of and within 40% of the chord from the leading edge.

8. The invention according to claim 7 in which:
region III extends to the trailing edge of the chord.

9. The invention according to claim 7 in which:
region III extends to the trailing end of the airfoil.

10. The invention according to claim 7 in which:
the second local minimum is at the end of region II and the beginning of region III;

the value of K times C initially increases from the
5 second local minimum and may remain constant to the trailing end of the airfoil.

11. The invention according to claim 7 in which:
the second local minimum is at the end of region II and the beginning of region III;

the value of K times C initially increases from the
5 second local minimum and may have one or more greater points relative to the first and second minimums.

12. The invention according to claim 7 in which:
the length of region III along the chord is at least twice as long as region II.

13. In an airfoil, a leading edge portion having improved lifting capability, comprising:

a chord extending from a leading edge of a leading portion of an airfoil to a trailing end of the portion;

5 said portion having curves divided into three regions, I, II, and III;

region I having a starting point aft and adjacent the



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leading edge of the portion and encompassing the airfoil stagnation point of the portion;

10 region I having a high curvature around the leading edge, and curvature decreasing aft along the chord from said leading edge of the portion on the upper or negative pressure side of the airfoil to a first local minimum value of less than 3 for K times C at the end of region I,

15 where C is the length of chord and K is the reciprocal of the local radius of curvature;

region I being within 10% of the chord length of the portion;

20 region II starting at the aft end of region I within 10% of said chord length; and

the curvature in region II first increasing from the first minimum at the end of region I and then decreasing to a second local minimum adjacent the end of region II.

14. The invention according to claim 13 in which:

5 the starting point of region I is below the chord, lower than the ordinate value of the leading edge of the leading edge portion, and is aft of the leading edge of the portion by not more than 3% of the chord length measured along the chord of said portion.

15. The invention according to claim 13 in which:

the high curvature at the leading edge of the portion has a value for K times C equal to or greater than 35 but less than or equal to 120.

16. The invention according to claim 13 in which:

region III starts at the end of region II within 40% of the chord length within the portion.

17. The invention according to claim 13 in which:

in region II the maximum value for K times C is greater than 1 but less than 6.

18. The invention according to claim 13 in which:

the airfoil is symmetrical about the chord.

19. The invention according to claim 13 in which:



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region III lies aft of and within 40% of the chord of the portion from the leading edge of the portion.

20. The invention according to claim 19 in which:

region III extends to the trailing edge of the portion.

21. The invention according to claim 19 in which:

the second local minimum is at the end of region II and the beginning of region III;

5 the value of K times C initially increases from the second local minimum and may remain constant to the trailing end of the portion.

22. The invention according to claim 19 in which:

the second local minimum is at the end of region II and the beginning of region III;

5 the value of K times C initially increases from the second local minimum and may have one or more greater points relative to the first and second minimums.

23. The invention according to claim 19 in which:

the length of region III along the chord is at least twice as long as region II.



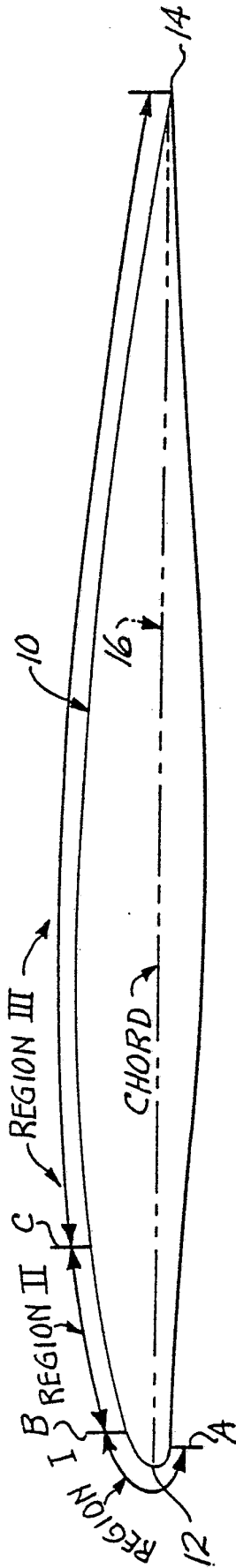


Fig. 1

TO
TRAILING
EDGE
OF
AIRFOIL $1/8$

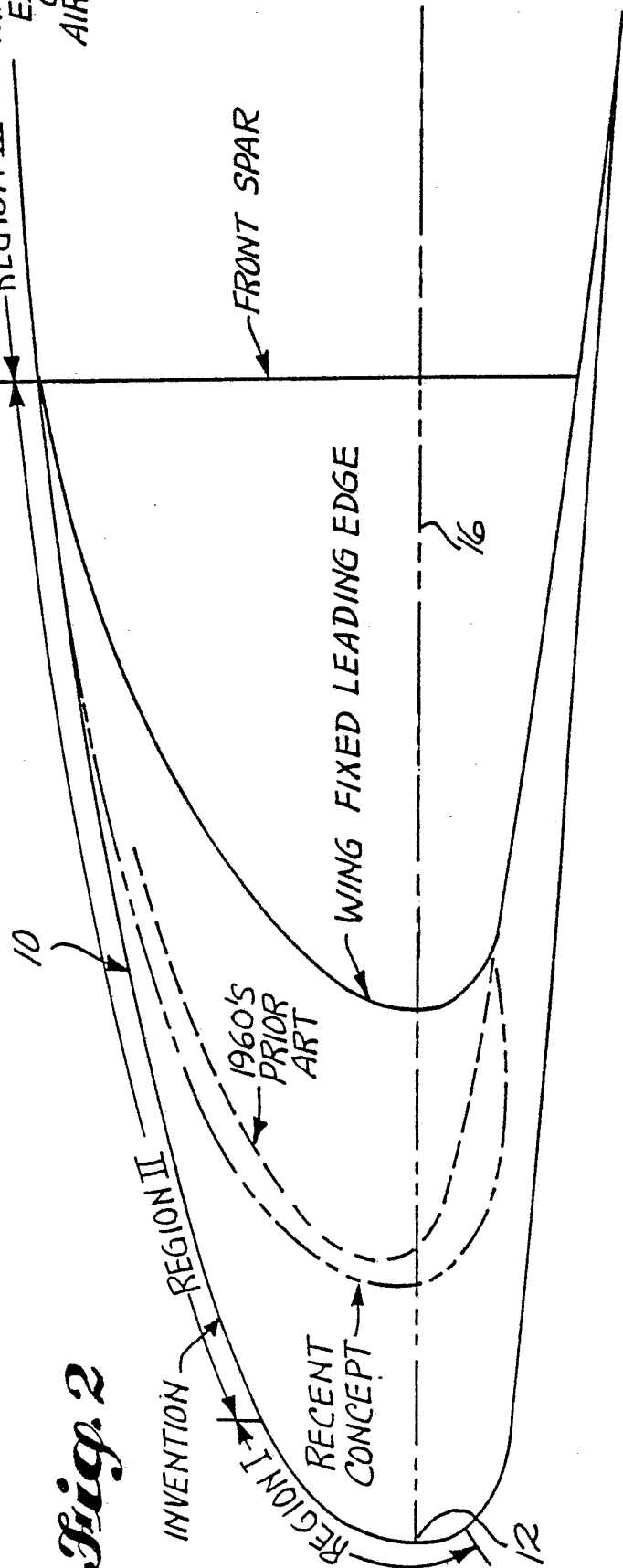


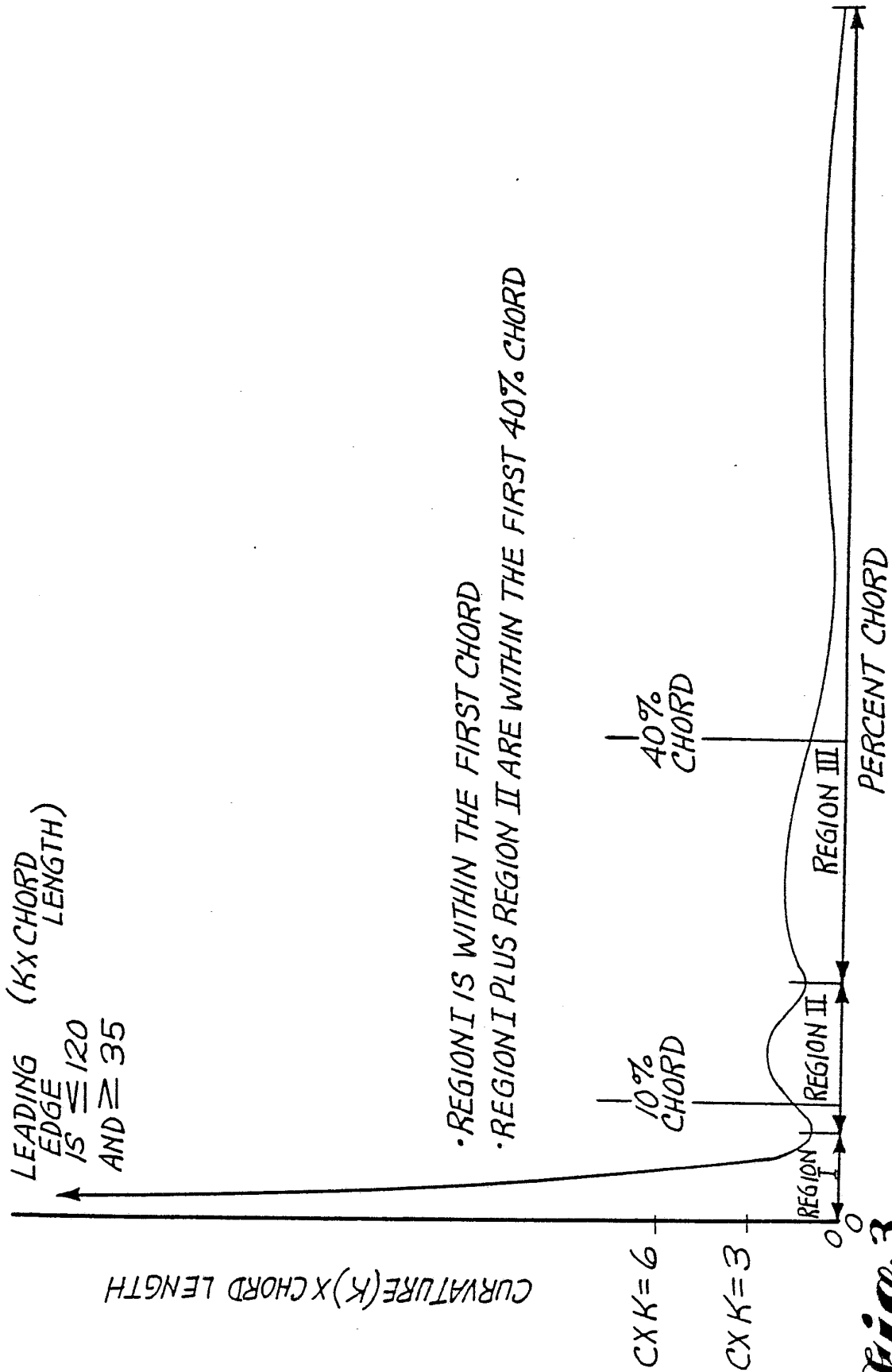
Fig. 2

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UPPER SURFACE CURVATURE



- REGION I IS WITHIN THE FIRST CHORD
- REGION I PLUS REGION II ARE WITHIN THE FIRST 40% CHORD

Fig. 3



Fig. 4A

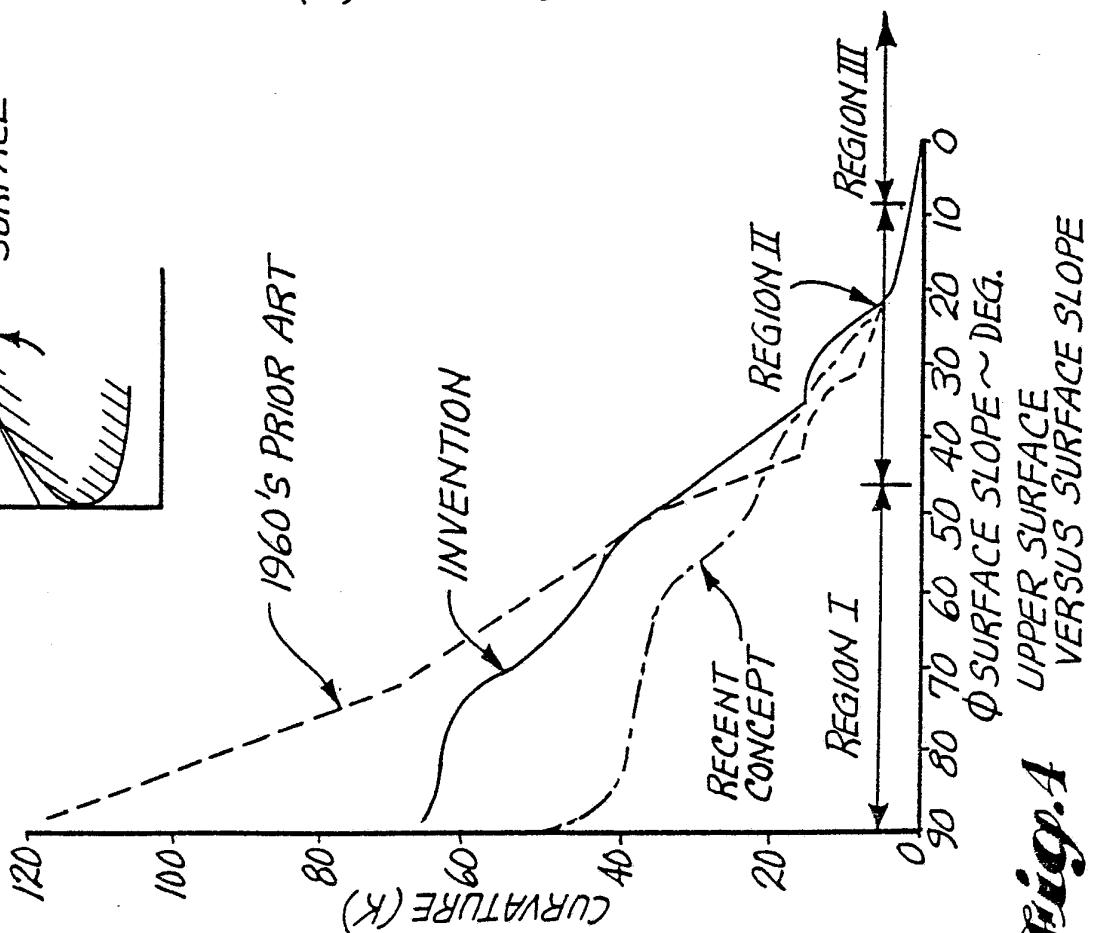
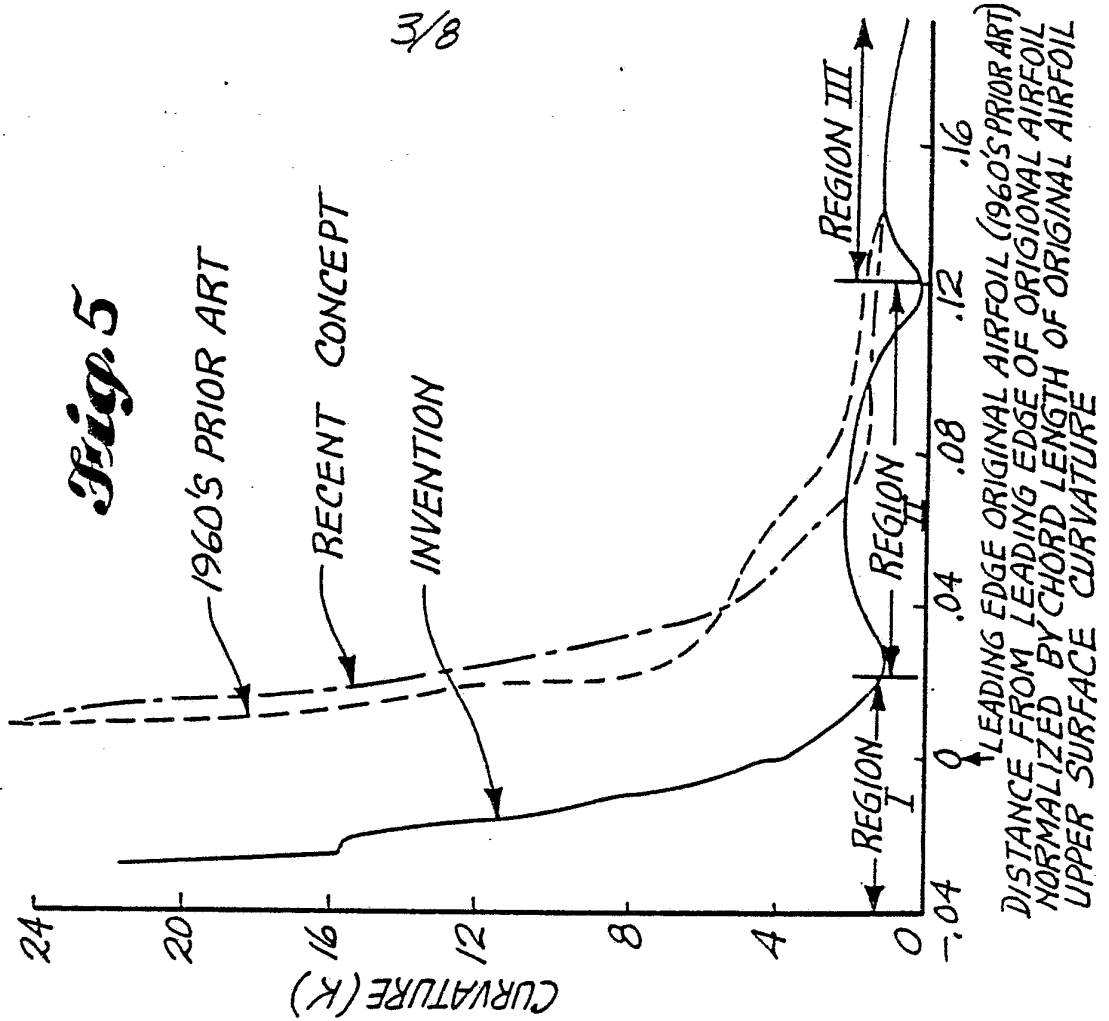


Fig. 4

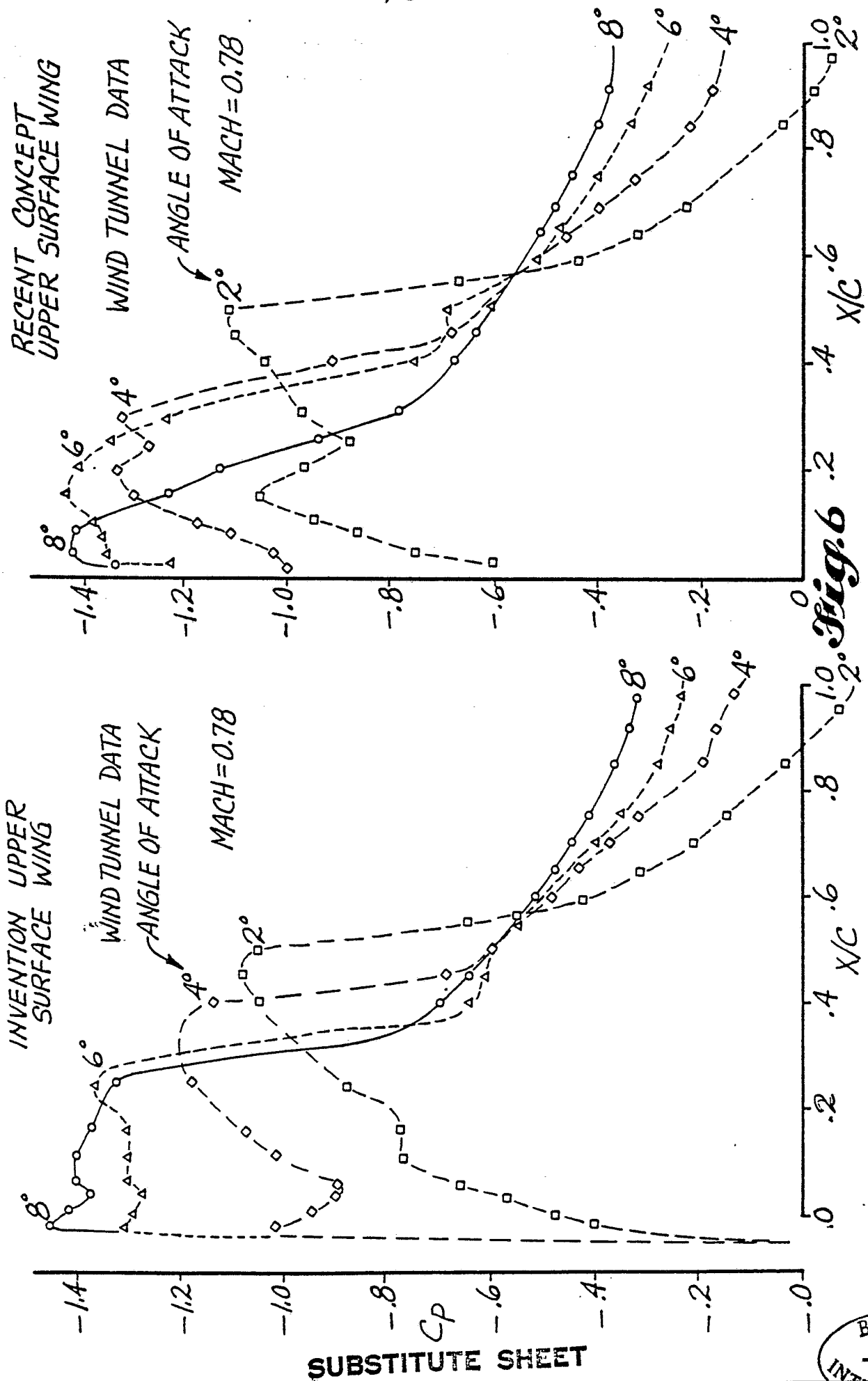
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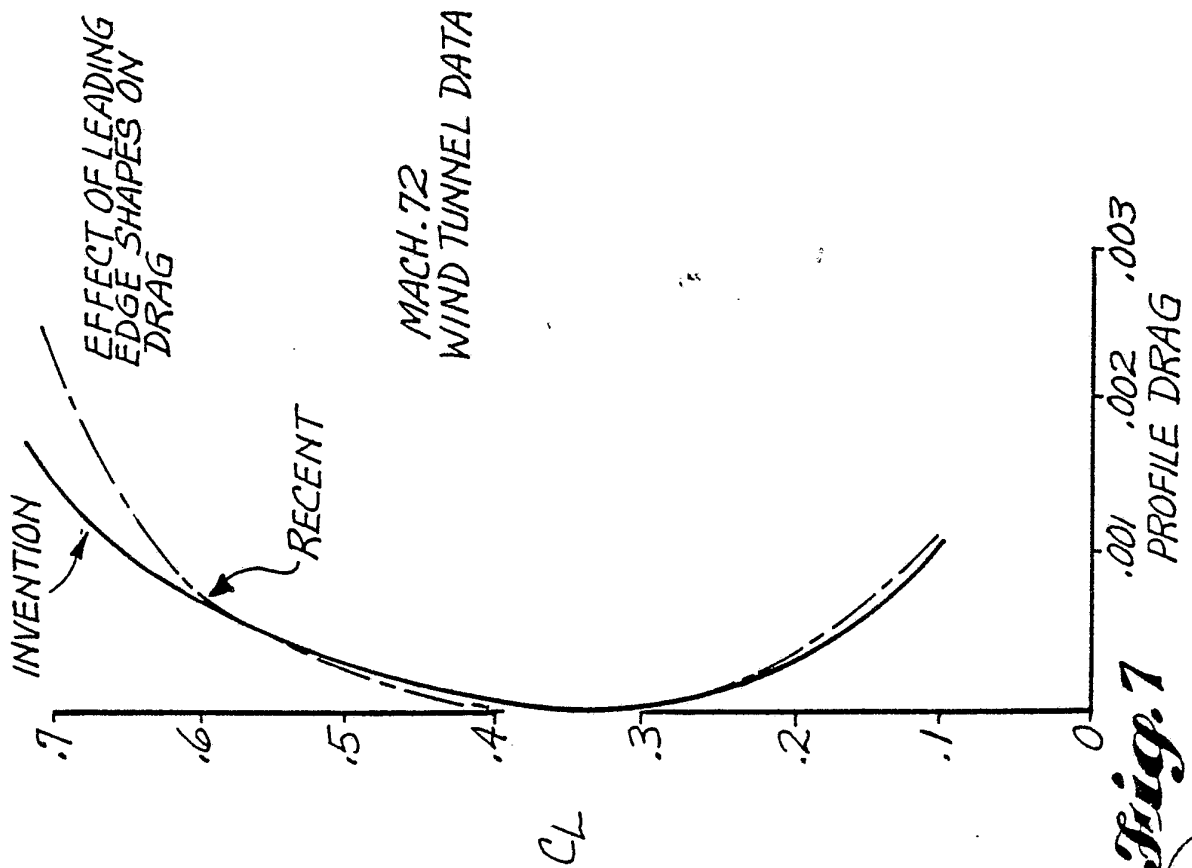
Fig. 5



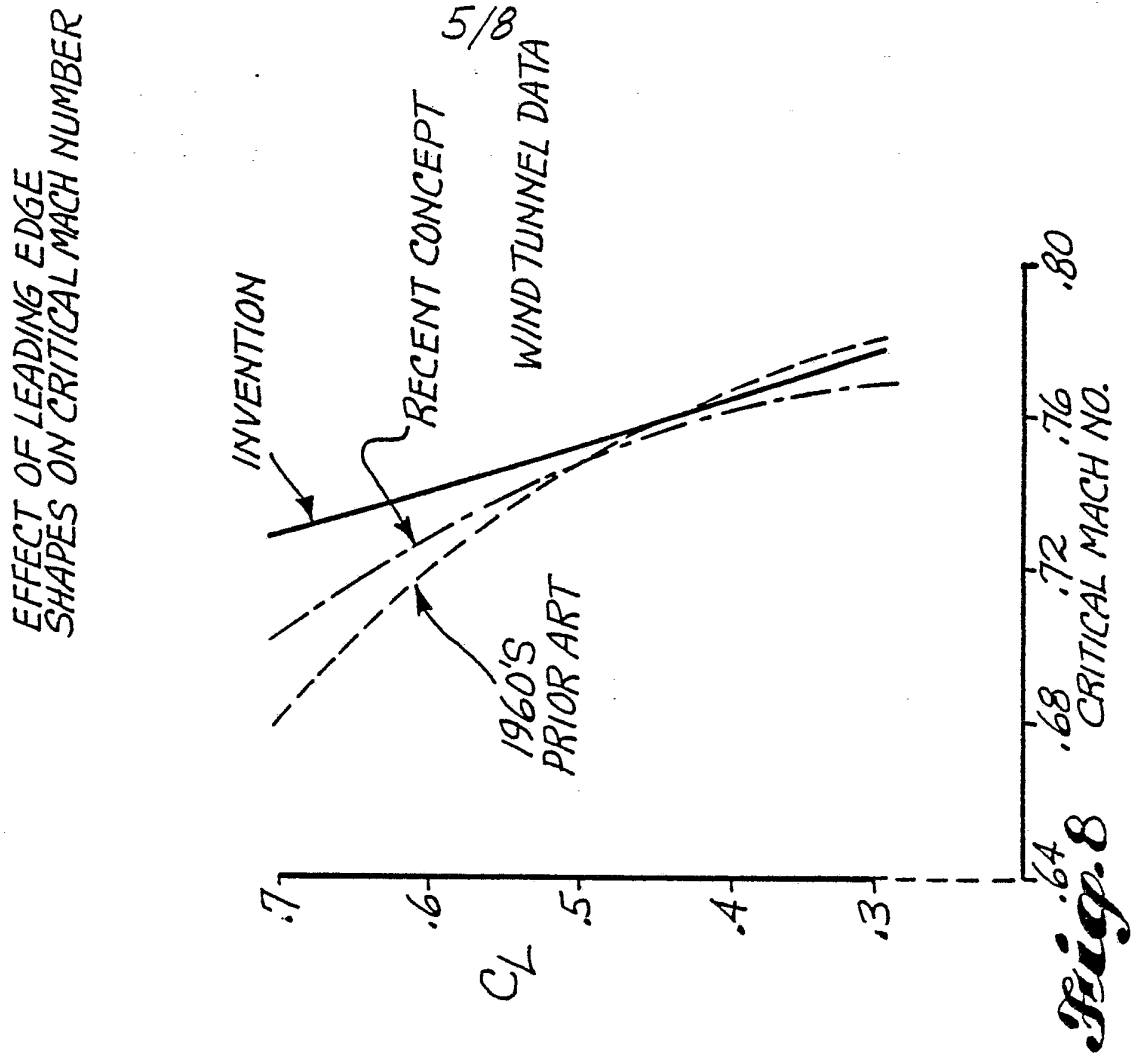
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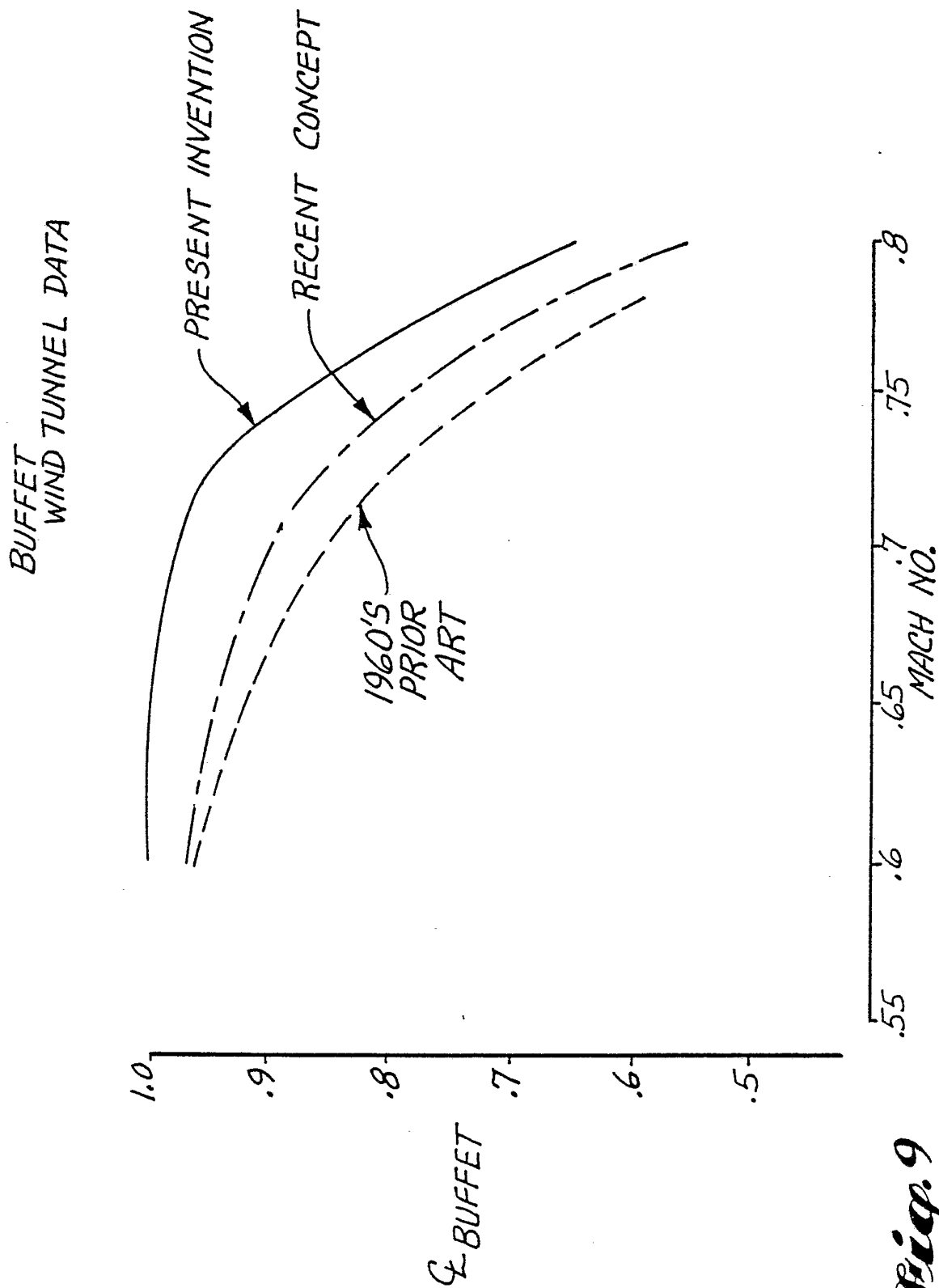




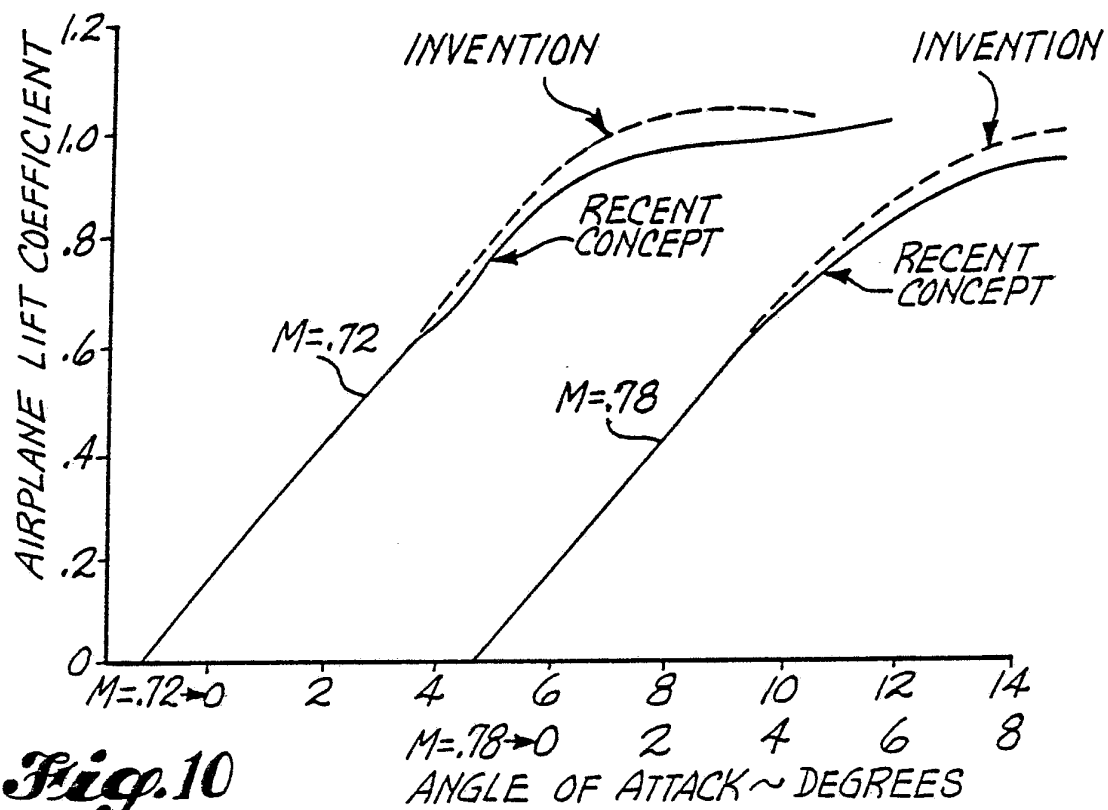
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**Fig.10**

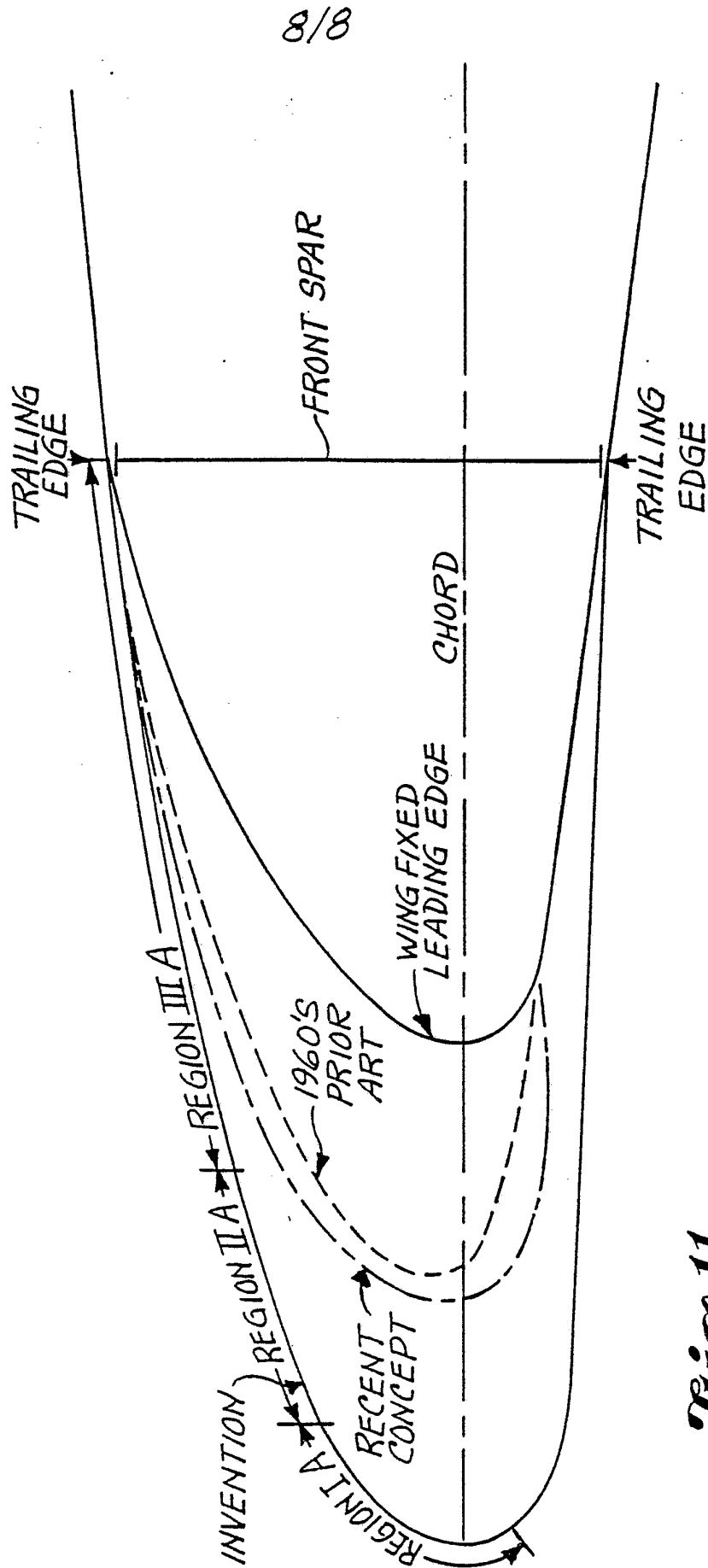


Fig. 11

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 84/00071

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ³ According to International Patent Classification (IPC) or to both National Classification and IPC IPC ³ : B 64 C 3/14						
II. FIELDS SEARCHED <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Minimum Documentation Searched ⁴</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 20%; border-bottom: 1px solid black;">Classification System</th> <th style="border-bottom: 1px solid black;">Classification Symbols</th> </tr> <tr> <td style="border-right: 1px solid black; padding: 5px;">IPC³</td> <td style="padding: 5px;">B 64 C</td> </tr> </table> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵</div>			Classification System	Classification Symbols	IPC ³	B 64 C
Classification System	Classification Symbols					
IPC ³	B 64 C					
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴						
Category *	Citation of Document, ¹⁵ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸				
A	EP, A, 0076936 (DORNIER) 20 April 1983, see page 7, lines 18-25; figures 1-3, 8,9 --	1,3				
A	EP, A, 0048649 (AEROSPATIALE) 31 March 1982, see page 3, lines 3-19; page 8, lines 24-29; page 10, lines 21-33; page 11, lines 1-5 and 22-26; figure 2 --	1,3				
A	WO, A, 81/02557 (THE SECRETARY OF STATE FOR DEFENCE OF U.K.) 17 September 1981 see page 1, lines 1-6; page 2, lines 27-33; page 3, lines 25-32; figure 5 cited in the application --	1,13				
A	US, A, 4240597 (ELLIS) 23 December 1980 -----					
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>* Special categories of cited documents: ¹⁵</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"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</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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.</p> <p>"Z" document member of the same patent family</p> </div> </div>						
IV. CERTIFICATION						
Date of the Actual Completion of the International Search ¹ <div style="text-align: center;">7th August 1984</div>	Date of Mailing of this International Search Report ² <div style="text-align: center;">21 AOUT 1984</div>					
International Searching Authority ¹ <div style="text-align: center;">EUROPEAN PATENT OFFICE</div>	Signature of Authorized Officer ¹⁰ <div style="text-align: right;"> G.L.M. Krausenberg </div>					

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO.

PCT/US 84/00071 (SA 6988)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 15/08/84

The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0076936	20/04/83	DE-A- 3140351 JP-A- 58076399	28/04/83 09/05/83
EP-A- 0048649	31/03/82	FR-A, B 2490586 JP-A- 57084298 US-A- 4416434	26/03/82 26/05/82 22/11/83
WO-A- 8102557	17/09/81	GB-A, B 2072600 EP-A- 0047319	07/10/81 17/03/82
US-A- 4240597	23/12/80	None	

For more details about this annex :
see Official Journal of the European Patent Office, No. 12/82