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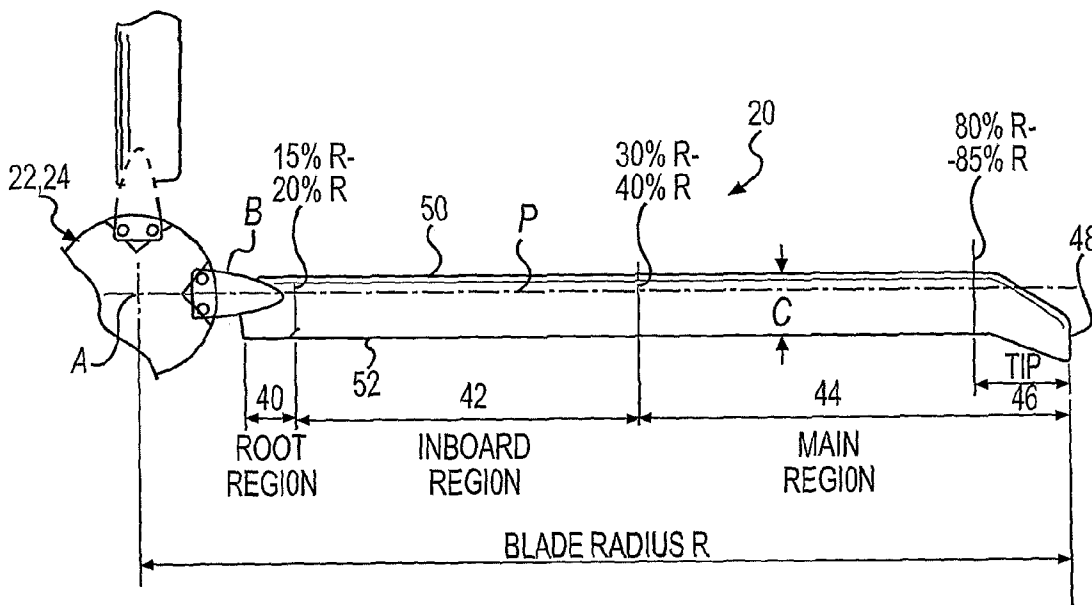
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(54) Title: AN AIRFOIL FOR A HELICOPTOR ROTOR BLADE



(57) Abstract: An airfoil family for a helicopter rotor blade, designated SC362XX. SC362XX essentially removes the large lower surface suction peak associated with 'drag creep' at moderate lift coefficients while reducing the peak Mach number and shock strength at high lift/Mach number conditions. Another optional airfoil family for use at inboard regions of the helicopter rotor, which is designated SC3252XX airfoil family, is a relatively thicker airfoil section that includes a significant increase in thickness forward of the 30% x/c location to provide a relatively thick and rigid inboard section. The lift coefficient at which the drag divergence Mach number was optimized is the same in both families thereby readily providing application to a single rotor blade.

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AN AIRFOIL FOR A HELICOPTOR ROTOR BLADE

BACKGROUND OF THE INVENTION

[0001] The present invention is directed to an improved airfoil for use with a helicopter rotor and more particularly to an airfoil section for at least partial use on a main rotor blade of a helicopter rotor.

[0002] Conventional rotary-wing aircraft have a forward airspeed limited by a number of factors. Among these is the tendency of the retreating blade to stall at high forward airspeeds. As the forward airspeed increases, the airflow velocity across the retreating blade slows such that the blade may approach a stall condition. In contrast, the airflow velocity across the advancing blade increases with increasing forward speed. Forward movement of the aircraft thereby generates a dissymmetry of lift between the advancing and retreating sides of the rotor. This dissymmetry may create an unstable condition if lift is not equalized across the advancing and retreating sides of the rotor.

[0003] At higher speeds, such as, at the outer tip regions of conventional rotary wing aircraft or on high-speed rotary wing aircrafts, for example, on a helicopter including a coaxial contra-rotating rotor system with an auxiliary translational propulsion system, high performance 2-dimensional airfoils are required. That is, the requirements on an airfoil section at higher speeds are generally more complex than those for a fixed wing aircraft because, on a single revolution of the rotor blade, an airfoil section thereof experiences lift coefficients from negative values to positive value with section Mach numbers from subsonic to transonic values. Since the ranges of lift coefficients and Mach numbers experienced by an airfoil section depend on its radial location along the rotor blade and the rotary-wing aircraft flight conditions, different airfoil sections have been used for a specified range of radial positions along the rotor blade span.

[0004] The maximum lift coefficient of an airfoil section is of considerable importance in the process of selecting airfoils for application to a rotary-wing aircraft rotor. When the maximum lift coefficient of an airfoil section is exceeded (i.e., the airfoil is stalled), the corresponding drag coefficient increases dramatically and the pitching moment coefficient can change direction (nose-up to nose-down) as well as change greatly in magnitude. When a significant part of the rotor blade is operating beyond the maximum lift coefficient of the local airfoil section, the power required to sustain flight exceeds the power

available, thus limiting the particular flight condition. This could occur with increases in aircraft gross weight, in maneuvers, or in forward flight.

[0005] The problem may occur over the outer portion of a rotor blade such as that utilized on high-speed rotary wing aircraft or at the outer tip regions of conventional rotary wing aircraft rotor blades where drag divergence Mach numbers of present state-of-the art rotary wing airfoils are exceeded. Reducing airfoil thickness ratios can alleviate this problem, however, typically at the expense of hover figure of merit due to the decrease in an airfoil's maximum lift capability when thickness is reduced.

[0006] Hover figure of merit can then be increased with additional blade area, however, this approach reduces cruise efficiency since the increased blade area is not required in this flight regime. Some compromise between hover figure of merit and cruise efficiency must thereby be achieved by the designer. Designing airfoils with higher maximum lift coefficients at a desired Mach number while simultaneously increasing the drag divergence Mach number for moderate lift coefficients provides the rotor designer the additional aerodynamic performance necessary to get cruise speeds up into the 400 knot range.

[0007] As manufacturers look at new ways to increase the speed of rotary wing aircraft significantly different rotor blade designs are required. Accordingly, it is desirable to provide an improved airfoil family for contra-rotating rotor systems as well as outboard stations of single rotor rotary-wing aircraft.

SUMMARY OF THE INVENTION

[0008] An airfoil family for a helicopter rotor blade according to the present invention is designated as a SC362XX airfoil family. The SC362XX family removes a lower surface suction peak associated with 'drag creep' at moderate lift coefficients and reduces the peak Mach number and shock strength at high lift/Mach number conditions of the prior art airfoil family. The resulting airfoil has significant improvements in maximum lift at moderate Mach numbers (0.4, 0.5 and 0.6), total elimination of the drag "creep" and improved drag divergence characteristics at moderate lift coefficients (0.1 and 0.2) when compared to prior art airfoils, such as, SC2110.

[0009] The airfoil includes a reduced thickness and camber of the leading edge region ($x/c \leq 0.3$) which delays the formation of shock waves at high Mach number/low lift

coefficient and moderate Mach number/high lift coefficient conditions. This results in improvements in maximum lift coefficient and drag divergence Mach number performance compared to the prior art. Further improvements in airfoil performance are achieved by enhancing the stability of the boundary layer on the trailing edge portion of the airfoil ($x/c \geq 0.5$) by thinning this portion of the airfoil.

[0010] Airfoil family SC362XX, according to the present invention, provides an improved airfoil optimized for use on helicopter rotors capable of higher speed. By helicopter rotors, the inventors intend to mean high speed compound rotary-wing aircrafts (as will be further discussed below) and more conventional aircraft configurations such as conventional single rotor helicopters and tandem helicopters. Furthermore, the airfoil could be incorporated onto the tail rotor blade or, preferably, onto the main rotor blade. Finally, the airfoil could be incorporated into the entire length of a rotor blade, or just a portion thereof, such as, for example, the outer 15% to 20% of the main rotor blade on a conventional single rotor helicopter.

[0011] According to the present invention, another separate, distinct and optional airfoil family, which is preferably for use at inboard regions of a helicopter rotor blade, is designated as SC3252XX. The SC3252XX airfoil is a relatively thick airfoil section which includes a significant increase in thickness forward of the 30% x/c location to provide a relatively thick and rigid inboard section. Since this family of airfoils is preferably located on the inboard portion of the rotor, rotational velocities at which they operate are significantly lower than their outboard counterparts. Therefore, the Mach number at which maximum lift was optimized for this family is significantly lower when compared to the SC362XX family (0.25 vs. 0.6). The lift coefficient at which the drag divergence Mach number was optimized remained the same as the SC362XX family (0.2).

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The various features and advantages of this invention will become apparent to those skilled in the art from the following detailed description of the currently preferred embodiment. The drawings that accompany the detailed description can be briefly described as follows:

[0013] Figure 1A is a general schematic view of an exemplary helicopter having a dual, contra-rotating, coaxial rotor system which may incorporate an airfoil designed according to the present invention;

[0014] Figure 1B is a schematic view of an exemplary rotary wing aircraft having a single rotor system.

[0015] Figure 2A is a plan view of a main rotor blade designed according to the present invention;

[0016] Figure 2B is a representative thickness over chord distribution (T/C) of the rotor blade illustrated in Figure 2A;

[0017] Figure 2C is a sectional view taken at the location indicated in Figure 2B;

[0018] Figure 2D is a sectional view taken at the location indicated in Figure 2B;

[0019] Figure 2E is a sectional view taken at the location indicated in Figure 2B;

[0020] Figure 3 is a graph of a prior art SC2110 airfoil drag level at moderate lift;

[0021] Figure 4 is a graph illustrating a prior art SC2110 airfoil local Mach number distribution near CL Max;

[0022] Figure 5 is a graph illustrating the lift and drag capabilities at Mach 0.6 comparing the prior art SC2110 airfoil with the SC36210 airfoil of the present invention;

[0023] Figure 6 is a graphical representation of the maximum lift capabilities at Mach 0.6 comparing the prior art SC2110 airfoil as compared to the SC36210 airfoil of the present invention;

[0024] Figure 7 is a graphical representation of the drag divergent capabilities at 0.2 lift coefficient comparing the prior art SC2110 airfoil as compared to the SC36210 airfoil of the present invention;

[0025] Figure 8A is an airfoil family comparison of an SC3252XX airfoil of different t/c of the present invention;

[0026] Figure 8B is an airfoil family comparison of an SC362XX airfoil of different t/c of the present invention

[0027] Figure 9 is a graphical representation of CL_{Max} vs. Mach number prediction for the SC36210 airfoil of the present invention as compared to other airfoils; and

[0028] Figure 10 is a graphical representation of the drag divergence Mach number (M_{dd}) vs. coefficient of lift prediction for the SC36210 airfoil as compared to other airfoils. Drag divergence Mach number is the Mach number at which the slope of a C_d vs. Mach number curve (at constant lift coefficient) is equal to 0.1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0029] Figure 1A illustrates an exemplary high speed compound rotary-wing aircraft 10 having a dual, contra-rotating, coaxial rotor system. 12. The aircraft 10 includes an airframe 14 that supports the rotor system 12 as well as a propulsive system 30 which provides translational thrust generally parallel to an aircraft longitudinal axis L. Although a particular aircraft configuration is illustrated in the disclosed embodiment, other helicopter configurations such as tandem rotors, as well as more conventional single rotor helicopters (Figure 1B) will also benefit from the present invention.

[0030] By way of background information, a high speed compound rotary-wing aircraft with a dual, contra-rotating, coaxial rotor system as shown in Fig. 1 is capable of higher speeds compared to conventional single rotor helicopters due in part to the balance of lift between the advancing sides of the main rotor blades on the upper and lower rotor systems. In addition, the retreating sides of the rotors are also generally free from classic retreating blade stall that conventional single or tandem rotor helicopters may suffer from. Design requirements for a high speed compound rotary-wing aircraft with a dual, contra-rotating, coaxial rotor system differ significantly from conventional rotary-wing aircraft. As with a conventional rotary-wing aircraft, the advancing blades of both the upper and lower rotors produce lift; however, unlike a conventional rotary-wing aircraft, the retreating blades of the a high speed compound rotary-wing aircraft are off-loaded commensurate with increasing flight velocity, and need not produce lift to balance lateral (rolling) moments. Rather, roll equilibrium is attained by balancing the net effects of the equal and opposite moments produced by the advancing side blades of the vertically separated counter-rotating rotors. The ability to off-load the retreating blades from producing lift alleviates retreating blade stall – a primary cause of speed limitation on conventional rotary wing aircraft - thereby permitting much greater forward flight speeds to be achieved

[0031] Referring back to Figure 1A, the dual, contra-rotating, coaxial rotor system 12 includes a first rotor system 16 and a second rotor system 18. Each rotor system 16 and 18 includes a plurality of rotor blades 20 mounted to a rotor hub assembly 22, 24 for rotation about a rotor axis of rotation A. The plurality of the main rotor blades 20 project substantially radially outward from each of the hub assemblies 22, 24 and are supported therefrom in one of numerous attachments arrangements typically including a blade cuff (illustrated schematically at 21). Any number of rotor blades 20 may be used with the dual, contra-rotating, coaxial rotor system 12. The dual, contra-rotating, coaxial rotor system 12 is driven by a main gearbox 26 that is driven by one or more engines E.

[0032] A translational thrust system 30 preferably includes a pusher propeller 32 having a propeller rotational axis T oriented substantially horizontal and parallel to the aircraft longitudinal axis L to provide thrust for high-speed flight. Preferably, the pusher propeller 32 is mounted within an aerodynamic cowling 34 mounted to the rear of the airframe 14. The translational thrust system 30 is driven by the same main gearbox 26 which drives the rotor system 12.

[0033] Figure 2A illustrates a general exemplary plan view of a main rotor blade 20 which includes the inventive airfoil sections designed according to the present invention. The exemplary plan view further illustrates an exemplary basic chord distribution and distribution of blade area relative to blade span. The rotor blade 20 can generally be divided into a root region 40, an inboard region 42, a main region 44, and a tip region 46. The root, inboard, main, and tip regions 40, 42, 44, 46 define the span of the rotor blade 20 and define a blade radius R between the axis of rotation A and a distal tip end 48 of the blade tip region 46. The rotor blade 20 defines a leading edge 50 and a trailing edge 52, which define the chord C of the rotor blade 20. A pitching or feathering axis P is the axis about which aerodynamic blade twist primarily occurs.

[0034] The blade region extending inboard of approximately 30%R, and preferably inboard of 15%R, defines the root region 40 and includes the blade to hub attachment system (schematically illustrated). Notably, the rotor blade 20 is mounted along the root region 40 so that the root region 40 has comparatively minimal aerodynamic significance since it is typically at least partially enclosed within the blade cuff B (illustrated schematically). The blade cuff mounts the rotor blade 20 to the rotor hub assembly 22, 24 as generally understood and thus further detailed discussion need not be provided herein. The region of the blade that lies between the root end 54 and main region 44 of the blade 20 is the

inboard region 42. The main region 44 of the blade 20 is the primary aerodynamic portion of the blade 20 inclusive of the tip region 46. The tip region 46 is preferably the outboard 15%R to 20% of the rotor blade 20. It should be understood that the blade is illustrated somewhat schematically and that various chord distributions along the blade span will also be usable with the present invention.

[0035] In order to provide performance goals for a helicopter rotor system, Applicant is specifically disclosing "base" airfoil profiles from which additional airfoil profiles can be extracted by varying thickness and camber levels (as illustrated in Figure 8A and 8B). The selected sections are preferably: a 10% thick outboard section designated SC36210 of the SC362XX airfoil family and an optional 18% thick inboard section designated SC325218 of the SC3252XX airfoil family. It was anticipated that the SC325218 would be utilized for a thickness range of 12 to 18% (SC325212 to SC325218) while the SC36210 would vary from 7 to 12% (SC36207 to SC36212).

[0036] The design methodology employed for designing these sections include beginning with an existing airfoil which was revised using the inverse and/or multi-point optimization techniques within ISES software until the appropriate level of performance was attained. As previously described however, it should be noted, that a helicopter rotor blade may incorporate airfoil section SC362XX throughout its entire length inclusive of the inboard, main and outboard regions. It is anticipated that this would be more beneficial to a high speed compound rotary-wing aircraft with a dual, contra-rotating, coaxial rotor system wherein the entire main rotor blade may be subjected to higher speeds. Alternatively, for example, a conventional single rotor helicopter may incorporate airfoil section SC362XX only on a portion of its length, preferably the outer tip region, which is subjected to higher speeds, and any other known airfoil section on its inboard and main regions, which are subjected to lower speeds as compared to the outboard tip region.

[0037] The airfoil thickness to chord ratios (t/c), are graphically represented in Figure 2B to generally correspond with the plan view of the rotor blade 20 (Figure 2A). Referring to Figure 2B, the exemplary rotor blade preferably includes at least two primary airfoil profile families. For example, inboard of approximately 0.4R an SC3252XX airfoil profile family may be utilized while outboard of approximately 0.35R an SC362XX airfoil profile family may be utilized. The SC36212 airfoil profile may be utilized at the transition therebetween. It should be understood that the overlap of airfoil profile sections as illustrated in Figure 2B provides for a smooth transition therebetween. The overlap may incorporate

intermediate airfoil profiles and may cover various spans as graphically represented by the smooth interface transitions and overlap.

[0038] Figures 2C, 2D and 2E illustrate the airfoil profiles utilized in construction of the exemplary rotor blade 20. The SC325218 airfoil profile is a relatively thick airfoil and hence is preferably utilized in the inboard region of the rotor blade 20. However, other airfoil families as generally known in the art may be utilized in the inboard region of the rotor blade. The SC36212 airfoil profile is a section preferably utilized in an intermediate region of the rotor blade and the SC36210 airfoil profile is a section preferably utilized in the outer tip region of the rotor blade. This particular airfoil arrangement has been found to reduce compressibility effects at the tip while maintaining lift.

[0039] As generally understood, the SC362XX family of airfoils maximize lift at 0.6 Mach and drag divergence Mach number (M_{dd}) at 0.2 lift coefficient.

[0040] A prior art SC2110 airfoil profile was utilized as a starting point for the SC36210 airfoil (Figure 2E). The SC2110 airfoil profile is a mid-span high lift rotor airfoil designed for maximum lift at Mach 0.4 and maximum drag divergence Mach number at a lift coefficient of 0.0. The SC2110 airfoil, however, exhibits a certain amount of “drag creep” prior to reaching divergence levels. These conditions differ significantly from a high speed helicopter rotor embodiment and this particular trait has been eliminated in Applicant’s inventive blade design.

[0041] The prior art SC2110 has strong shocks present on both the upper and lower surface at high mach number and moderate lift coefficients. The lower surface shock appears at Mach numbers well below M_{dd} producing the “drag creep” as Figure 3 illustrates. Meanwhile, the appearance and subsequent strengthening of the upper surface shock with increasing Mach number produces the wave drag associated with divergence. As Figure 4 illustrates, at Mach numbers between 0.5 and 0.6, a strong shock wave is present on the upper surface leading edge of the airfoil which induces boundary layer separation and limits the attainable maximum lift. The difficulty here is to improve drag divergence and maximum lift properties of the airfoil simultaneously since each requires changes to different portions of the airfoil. Reducing the leading edge shock at maximum lift conditions will almost invariably reduce the drag divergence performance.

[0042] As Figure 2E illustrates, Applicant significantly modified the upper and lower surface contour of the prior art SC2110 airfoil over the first 30% of the airfoil ($0.0 \leq x/c \leq 0.3$). These modifications removed the large lower surface suction peak associated with

the inherent 'drag creep' of the prior art SC2110 airfoil at moderate lift coefficients and reduced the peak Mach number and shock strength at high lift/Mach number conditions. The resulting airfoil has significant improvements in maximum lift at moderate Mach numbers (0.4, 0.5 and 0.6), total elimination of the prior art SC2110 airfoil drag "creep" and improved drag divergence characteristics at moderate lift coefficients (0.1 and 0.2)

[0043] The inventive SC362XX airfoil profile family was developed by reducing the thickness and camber of the leading edge region of the prior art airfoil ($x/c \leq 0.3$) delaying the formation of shock waves at high Mach number/low lift coefficient and moderate Mach number/high lift coefficient conditions. This results in improvements in maximum lift coefficient and drag divergence Mach number performance compared to the prior art airfoil. Further improvements in airfoil performance was achieved by enhancing the stability of the boundary layer on the trailing edge portion of the airfoil ($x/c \geq 0.5$) by thinning this portion of the airfoil.

[0044] Because of the difficulty involved in giving an adequate word description of the particular airfoil section being described, the coordinates for the invention airfoil section SC36210 of the SC362XX airfoil family is set forth in Table I, the coordinates for the inventive airfoil section designated SC36212 of the SC362XX airfoil family is set forth in Table II, and the coordinates for the inventive airfoil section designated SC325218 of the SC3252XX airfoil family is set forth in Table III.

[0045] From the above description of the structural arrangement of the airfoil sections, operation of the invention should now become apparent. The airfoil section critical 2-D conditions for a high speed helicopter rotor blade are a maximum lift coefficient and lift to drag ratio at Mach 0.6 (hover) and a drag divergence Mach Number at a lift coefficient of 0.2 (cruise).

[0046] Figures 5 and 6 illustrate the improvement in maximum lift capability afforded by the SC36210 airfoil. The increase in lift performance was advantageously not accompanied by a reduction in high speed transonic capability (Figure 7). The SC36210 drag divergence Mach number is comparable to the SC 2110 at 0.785 but the SC2110 "drag creep" between Mach numbers of 0.7 to 0.775 is effectively eliminated in the SC36210. Applicant has determined that the SC36210 increases the knot cruise efficiency of a high speed helicopter rotor by approximately 14% without reducing the hover figure of merit.

[0047] The SC36210 is one of a family of SC362XX airfoil profiles (Figure 8B) in which the airfoil thickness to chord ratios (t/c) are represented by the last two numerals of

the airfoil number such that the SC36212 airfoil profile is a 12% airfoil and the SC36210 airfoil profile is a 10% airfoil. The SC36212 is formed by scaling all SC36210 y/c values by a factor of 1.2. Therefore, the SC36212 is 20% thicker than the SC36210. All x/c values are unchanged.

[0048] The SC36212 airfoil profile section is preferably utilized in the inboard region 42 (Figure 2A) of the main rotor blade 20, such as, for example, inboard of approximately 0.5R, then transitions to the SC36210 airfoil profile section. The SC36210 airfoil profile may be maintained from approximately 0.5R to the outer tip end 48 of the rotor blade 20. Alternatively, the SC36210 airfoil profile section may be used in the tip region 46 of the rotor blade (approximately the outer 15 to 20%).

[0049] In addition to the SC362XX family of airfoils, which are preferably utilize in the main regions of the rotor blade 20, an inboard airfoil profile section with higher thickness ratios may be incorporated into the rotor blade 20. That is, inboard of the SC36212 airfoil profile may be the SC325218 airfoil profile. Figure 2C illustrates the significant increase in thickness forward of the 30% x/c location when compared to prior art airfoils of similar thickness to chord ratios. The SC3252XX airfoil family is a result of modifications to the thickness and camber distribution of the SC362XX airfoil family to provide the lift and drag characteristics necessary to insure optimum rotor performance.

[0050] Since the SC3252XX airfoil family is located on the inboard portion of the rotor blade 20, the rotational velocities at which they operate are significantly lower than their outboard counterparts. Therefore, the Mach number at which maximum lift was optimized for this family is significantly lower when compared to the SC362XX family (0.25 vs. 0.6). The lift coefficient at which the drag divergence Mach number was optimized remained the same as the SC362XX family (0.2).

[0051] Figures 8A and 8B provide contour plots of the SC3252XX family of airfoils (16% and 18% T/C) and the SC362XX family of airfoils (7%, 10% and 12% T/C) respectively. The thickness of the airfoil y/c is plotted against the nondimensional distance from the leading edge of the airfoil along the chord line of the airfoil x/c. The values define the thickness distribution curves and are proportional to each other or scaled from each other at a given x/c. An infinite number of thickness distribution curves may be formed in a similar manner

[0052] The results of this effort are presented in Figures 9 and 10 which compares C_{lmax} and M_{dd} ISES predictions respectively for the SC36210, its 7% cousin the SC36207,

and their prior art counterparts, the SC2110 and SSC-A07. These figures illustrate the improvement in maximum lift coefficient afforded by the new designs with little change in drag divergence characteristics.

TABLE I

SC36210			
Upper surface		Lower surface	
X/C	Y/C	X/C	Y/C
1.00000	0.00180	0.00000	0.00000
0.99543	0.00207	0.00026	-0.00199
0.98967	0.00245	0.00135	-0.00421
0.98252	0.00299	0.00305	-0.00602
0.97394	0.00373	0.00522	-0.00757
0.96424	0.00467	0.00784	-0.00898
0.95384	0.00576	0.01103	-0.01035
0.94308	0.00699	0.01493	-0.01172
0.93216	0.00832	0.01978	-0.01310
0.92116	0.00973	0.02583	-0.01453
0.91011	0.01122	0.03325	-0.01598
0.89905	0.01277	0.04200	-0.01740
0.88798	0.01437	0.05177	-0.01874
0.87690	0.01601	0.06218	-0.01995
0.86581	0.01768	0.07293	-0.02104
0.85471	0.01938	0.08385	-0.02200
0.84361	0.02110	0.09487	-0.02287
0.83250	0.02284	0.10595	-0.02365
0.82138	0.02459	0.11706	-0.02436
0.81026	0.02634	0.12819	-0.02502
0.79914	0.02810	0.13934	-0.02564
0.78804	0.02984	0.15050	-0.02622
0.77693	0.03157	0.16167	-0.02677
0.76584	0.03327	0.17284	-0.02731
0.75475	0.03494	0.18402	-0.02782

SC36210			
0.74367	0.03657	0.19520	-0.02832
0.73259	0.03816	0.20638	-0.02880
0.72151	0.03970	0.21756	-0.02926
0.71043	0.04120	0.22873	-0.02971
0.69935	0.04265	0.23991	-0.03013
0.68826	0.04405	0.25108	-0.03052
0.67717	0.04540	0.26224	-0.03090
0.66607	0.04671	0.27341	-0.03124
0.65498	0.04798	0.28457	-0.03156
0.64387	0.04920	0.29574	-0.03185
0.63276	0.05038	0.30690	-0.03211
0.62165	0.05151	0.31806	-0.03234
0.61054	0.05261	0.32922	-0.03254
0.59942	0.05367	0.34038	-0.03271
0.58830	0.05469	0.35154	-0.03285
0.57717	0.05567	0.36270	-0.03295
0.56604	0.05661	0.37386	-0.03303
0.55492	0.05752	0.38502	-0.03307
0.54379	0.05838	0.39618	-0.03309
0.53266	0.05921	0.40733	-0.03307
0.52152	0.06001	0.41849	-0.03302
0.51039	0.06076	0.42965	-0.03294
0.49925	0.06147	0.44081	-0.03283
0.48812	0.06215	0.45197	-0.03269
0.47698	0.06279	0.46313	-0.03251
0.46584	0.06339	0.47428	-0.03231
0.45470	0.06395	0.48544	-0.03207
0.44356	0.06448	0.49659	-0.03180

SC36210				
0.43243	0.06496		0.50775	-0.03149
0.42129	0.06540		0.51890	-0.03116
0.41015	0.06581		0.53006	-0.03079
0.39902	0.06616		0.54121	-0.03039
0.38788	0.06648		0.55237	-0.02996
0.37675	0.06674		0.56352	-0.02950
0.36563	0.06696		0.57468	-0.02901
0.35450	0.06712		0.58584	-0.02849
0.34700	0.06723		0.59700	-0.02794
0.33226	0.06729		0.60816	-0.02737
0.32115	0.06728		0.61932	-0.02677
0.31004	0.06721		0.63048	-0.02615
0.29893	0.06708		0.64164	-0.02551
0.28783	0.06688		0.65280	-0.02484
0.27673	0.06662		0.66397	-0.02414
0.26564	0.06628		0.67513	-0.02343
0.25456	0.06586		0.68629	-0.02269
0.24348	0.06537		0.69746	-0.02194
0.23241	0.06479		0.70863	-0.02116
0.22135	0.06412		0.71979	-0.02037
0.21030	0.06337		0.73096	-0.01956
0.19927	0.06252		0.74214	-0.01874
0.18824	0.06157		0.75331	-0.01790
0.17724	0.06051		0.76449	-0.01706
0.16625	0.05934		0.77566	-0.01620
0.15529	0.05804		0.78684	-0.01534
0.14436	0.05660		0.79802	-0.01448
0.13346	0.05502		0.80920	-0.01361

SC36210				
0.12260	0.05327		0.82039	-0.01274
0.11178	0.05134		0.83157	-0.01187
0.10102	0.04921		0.84274	-0.01101
0.09032	0.04688		0.85392	-0.01015
0.07971	0.04433		0.86509	-0.00930
0.06925	0.04153		0.87626	-0.00847
0.05900	0.03849		0.88742	-0.00765
0.04914	0.03520		0.89856	-0.00686
0.03988	0.03171		0.90970	-0.00610
0.03154	0.02813		0.92081	-0.00538
0.02438	0.02460		0.93187	-0.00471
0.01851	0.02125		0.94286	-0.00411
0.01380	0.01815		0.95368	-0.00359
0.01006	0.01530		0.96413	-0.00316
0.00709	0.01264		0.97387	-0.00284
0.00472	0.01011		0.98248	-0.00263
0.00287	0.00766		0.98965	-0.00252
0.00145	0.00526		0.99542	-0.00248
0.00047	0.00285		1.00000	-0.00248

Table II

SC36212				
Upper surface			Lower surface	
X/C	Y/C		X/C	Y/C
1.00000	0.00226		0.00000	0.00000
0.99543	0.00256		0.00026	-0.00236

SC36212			
0.98967	0.00298	0.00135	-0.00510
0.98252	0.00359	0.00305	-0.00738
0.97394	0.00443	0.00522	-0.00936
0.96424	0.00548	0.00784	-0.01118
0.95384	0.00673	0.01103	-0.01296
0.94308	0.00813	0.01493	-0.01475
0.93216	0.00965	0.01978	-0.01658
0.92116	0.01128	0.02583	-0.01848
0.91011	0.01299	0.03325	-0.02043
0.89905	0.01476	0.04200	-0.02236
0.88798	0.01660	0.05177	-0.02419
0.87690	0.01848	0.06218	-0.02586
0.86581	0.02040	0.07293	-0.02736
0.85471	0.02236	0.08385	-0.02870
0.84361	0.02434	0.09487	-0.02991
0.83250	0.02634	0.10595	-0.03100
0.82138	0.02835	0.11706	-0.03199
0.81026	0.03037	0.12819	-0.03291
0.79914	0.03238	0.13934	-0.03376
0.78804	0.03438	0.15050	-0.03455
0.77693	0.03637	0.16167	-0.03529
0.76584	0.03833	0.17284	-0.03601
0.75475	0.04025	0.18402	-0.03668
0.74367	0.04212	0.19520	-0.03733
0.73259	0.04395	0.20638	-0.03795
0.72151	0.04573	0.21756	-0.03854
0.71043	0.04746	0.22873	-0.03910
0.69935	0.04913	0.23991	-0.03962

SC36212				
0.68826	0.05075		0.25108	-0.04011
0.67717	0.05231		0.26224	-0.04057
0.66607	0.05382		0.27341	-0.04098
0.65498	0.05528		0.28457	-0.04136
0.64387	0.05669		0.29574	-0.04170
0.63276	0.05805		0.30690	-0.04200
0.62165	0.05937		0.31806	-0.04227
0.61054	0.06063		0.32922	-0.04249
0.59942	0.06185		0.34038	-0.04267
0.58830	0.06303		0.35154	-0.04281
0.57717	0.06416		0.36270	-0.04291
0.56604	0.06525		0.37386	-0.04298
0.55492	0.06629		0.38502	-0.04300
0.54379	0.06729		0.39618	-0.04299
0.53266	0.06824		0.40733	-0.04293
0.52152	0.06915		0.41849	-0.04284
0.51039	0.07001		0.42965	-0.04270
0.49925	0.07083		0.44081	-0.04254
0.48812	0.07160		0.45197	-0.04233
0.47698	0.07233		0.46313	-0.04208
0.46584	0.07301		0.47428	-0.04179
0.45470	0.07365		0.48544	-0.04147
0.44356	0.07424		0.49659	-0.04111
0.43243	0.07478		0.50775	-0.04070
0.42129	0.07528		0.51890	-0.04026
0.41015	0.07573		0.53006	-0.03977
0.39902	0.07613		0.54121	-0.03925
0.38788	0.07647		0.55237	-0.03869

SC36212			
0.37675	0.07676	0.56352	-0.03809
0.36563	0.07699	0.57468	-0.03746
0.35450	0.07716	0.58584	-0.03679
0.34338	0.07727	0.59700	-0.03609
0.33226	0.07731	0.60816	-0.03536
0.32115	0.07729	0.61932	-0.03459
0.31004	0.07719	0.63048	-0.03379
0.29893	0.07702	0.64164	-0.03296
0.28783	0.07677	0.65280	-0.03210
0.27673	0.07645	0.66397	-0.03122
0.26564	0.07604	0.67513	-0.03030
0.25456	0.07555	0.68629	-0.02935
0.24348	0.07496	0.69746	-0.02838
0.23241	0.07429	0.70863	-0.02739
0.22135	0.07351	0.71979	-0.02637
0.21030	0.07264	0.73096	-0.02532
0.19927	0.07166	0.74214	-0.02426
0.18824	0.07056	0.75331	-0.02317
0.17724	0.06935	0.76449	-0.02208
0.16625	0.06801	0.77566	-0.02096
0.15529	0.06653	0.78684	-0.01985
0.14436	0.06489	0.79802	-0.01872
0.13346	0.06309	0.80920	-0.01758
0.12260	0.06110	0.82039	-0.01645
0.11178	0.05891	0.83157	-0.01532
0.10102	0.05650	0.84274	-0.01419
0.09032	0.05386	0.85392	-0.01308
0.07971	0.05096	0.86509	-0.01197

SC36212				
0.06925	0.04779		0.87626	-0.01089
0.05900	0.04433		0.88742	-0.00982
0.04914	0.04060		0.89856	-0.00879
0.03988	0.03663		0.90970	-0.00780
0.03154	0.03254		0.92081	-0.00686
0.02438	0.02851		0.93187	-0.00598
0.01851	0.02469		0.94286	-0.00518
0.01380	0.02114		0.95368	-0.00449
0.01006	0.01786		0.96413	-0.00390
0.00709	0.01480		0.97387	-0.00346
0.00472	0.01188		0.98248	-0.00315
0.00287	0.00905		0.98965	-0.00298
0.00145	0.00625		0.99542	-0.00290
0.00047	0.00343		1.00000	-0.00287

Table III

SC325218				
Upper Surface			Lower Surface	
X/C	Y/C		X/C	Y/C
1.000000	0.002184		0.000000	0.000000
0.992070	0.003803		0.000007	-0.000717
0.980725	0.006075		0.000202	-0.003820
0.965813	0.009022		0.000669	-0.006919
0.948872	0.012333		0.001416	-0.010027
0.931296	0.015720		0.002456	-0.013091
0.913609	0.019073		0.003818	-0.016076
0.895878	0.022370		0.005540	-0.018986
0.878074	0.025621		0.007671	-0.021839

SC325218				
0.860171	0.028842		0.010277	-0.024690
0.842172	0.032054		0.013418	-0.027600
0.824187	0.035255		0.017177	-0.030607
0.806207	0.038467		0.021671	-0.033739
0.788226	0.041697		0.027055	-0.037012
0.770243	0.044951		0.033487	-0.040431
0.752225	0.048225		0.041112	-0.043977
0.734247	0.051496		0.050013	-0.047599
0.716311	0.054744		0.060146	-0.051208
0.698466	0.057945		0.071420	-0.054711
0.680742	0.061077		0.083675	-0.058038
0.663131	0.064121		0.096752	-0.061137
0.645572	0.067082		0.110532	-0.063979
0.628077	0.069950		0.124904	-0.066567
0.610626	0.072719		0.139743	-0.068884
0.593184	0.075394		0.154961	-0.070942
0.575774	0.077966		0.170446	-0.072733
0.558373	0.080434		0.186151	-0.074262
0.540992	0.082797		0.202019	-0.075537
0.523615	0.085054		0.218029	-0.076562
0.506261	0.087201		0.234149	-0.077345
0.488927	0.089235		0.250333	-0.077893
0.471626	0.091150		0.266550	-0.078201
0.454372	0.092942		0.282820	-0.078275
0.437182	0.094598		0.299135	-0.078121
0.420061	0.096114		0.315536	-0.077736
0.403036	0.097479		0.332050	-0.077137
0.386131	0.098676		0.348691	-0.076331

SC325218				
0.369354	0.099692		0.365467	-0.075332
0.352671	0.100518		0.382359	-0.074156
0.336106	0.101144		0.399353	-0.072813
0.319614	0.101556		0.416435	-0.071316
0.303158	0.101756		0.433588	-0.069672
0.286722	0.101741		0.450806	-0.067892
0.270266	0.101510		0.468090	-0.065979
0.253767	0.101064		0.485442	-0.063946
0.237213	0.100415		0.502864	-0.061798
0.220631	0.099565		0.520345	-0.059546
0.204065	0.098526		0.537880	-0.057197
0.187617	0.097305		0.555466	-0.054757
0.171516	0.095906		0.573102	-0.052236
0.155965	0.094311		0.590820	-0.049636
0.141137	0.092501		0.608582	-0.046973
0.127167	0.090438		0.626420	-0.044243
0.114078	0.088091		0.644353	-0.041462
0.101850	0.085439		0.662351	-0.038645
0.090465	0.082471		0.680407	-0.035800
0.079865	0.079174		0.698493	-0.032950
0.070018	0.075560		0.716537	-0.030119
0.060908	0.071651		0.734466	-0.027333
0.052517	0.067471		0.752265	-0.024612
0.044829	0.063053		0.769939	-0.021969
0.037843	0.058448		0.787492	-0.019422
0.031549	0.053700		0.804940	-0.016982
0.025928	0.048859		0.822259	-0.014662
0.020965	0.043987		0.839459	-0.012483

SC325218				
0.016639	0.039141		0.856553	-0.010448
0.012920	0.034378		0.873516	-0.008583
0.009774	0.029749		0.890343	-0.006898
0.007160	0.025284		0.907008	-0.005409
0.005028	0.020999		0.923459	-0.004141
0.003334	0.016907		0.939587	-0.003115
0.002035	0.013002		0.955129	-0.002364
0.001077	0.009283		0.969565	-0.001922
0.000430	0.005773		0.982102	-0.001796
0.000080	0.002457		0.992233	-0.001947
0.000000	0.000000		1.000000	-0.002222

[0053] It is to be understood that the Mach number at which drag divergence occurs over the range of lift coefficients will vary notably with the camber and percent thickness airfoil, but is also affected by the particular helicopter with which the rotor blade is utilized. This statement is also applicable to the advantage gained in the form of increased performance and power which will vary depending on the type of helicopter with which the airfoil sections are utilized.

[0054] It should be understood by one of ordinary skill in the art, the various blade characteristics disclosed herein may be utilized singularly or in any combination depending on the particular design requirements of the aircraft. Moreover, although the invention has been generally described in connection with a high speed compound rotary-wing aircraft having a dual, contra-rotating, coaxial rotor system, the invention is also equally applicable to more conventional aircraft configurations such as conventional single rotor helicopter or a tandem rotor helicopter, especially on the outer tip portion of the main rotor blade, such as, for example, the outer 15% to 20% of the main rotor blade on a conventional single rotor helicopter, where the rotor blade is subjected to higher speeds. In a particular preferred embodiment SC36210 of SC362XX airfoil family is used in combination with the tip planform as discussed in co-pending

Application No. 11/370,407, entitled "ROTOR BLADE TIP PLANFORM," which is assigned to the assignee of the instant invention and which is hereby incorporated herein in its entirety.

[0055] It should be understood that relative positional terms such as "forward," "aft," "upper," "lower," "above," "below," "inboard," "outboard," and the like are with reference to the normal operational attitude of the vehicle and should not be considered otherwise limiting.

[0056] Although particular step sequences are shown, described, and claimed, it should be understood that steps may be performed in any order, separated or combined unless otherwise indicated and will still benefit from the present invention.

[0057] The foregoing description is exemplary rather than defined by the limitations within many modifications and variations of the present invention are possible in light of the above teachings. The preferred embodiments of this invention have been disclosed, however, one of ordinary skill in the art would recognize that certain modifications would come within the scope of this invention. It is, therefore, to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described. For that reason the following claims should be studied to determine the true scope and content of this invention.

CLAIMS

What is claimed is:

1. A main rotor blade of a helicopter comprising:

an inboard region; and

a main region outboard of said inboard region, said main region including an airfoil profile section defined by a scaled set of coordinates in which said set of y/c coordinates listed in Table I are scaled by a desired factor.

2. The section as recited in claim 1, wherein said main region includes a tip region defined by said main region, said airfoil profile section located at least partially within said tip region.

3. The section as recited in claim 2, wherein said tip region is defined by an outboard 20% of the main rotor blade.

4. The section as recited in claim 1, wherein an airfoil profile section defined by a set of coordinates listed in Table II is located inboard of said airfoil profile section defined by said set of coordinates listed in Table I of said rotary wing aircraft rotor blade.

5. The section as recited in claim 4, wherein an airfoil profile section defined by a set of coordinates listed in Table III is located inboard of said airfoil profile section defined by said set of coordinates listed in Table II of said rotary wing aircraft rotor blade.

6. The section as recited in claim 1, wherein an airfoil profile section defined by a set of coordinates listed in Table III is located inboard of said airfoil profile section defined by said set of coordinates listed in Table I of said rotary wing aircraft rotor blade.

7. The section as recited in claim 1, wherein said airfoil profile section is defined by said set of coordinates listed in Table I.

8. The section as recited in claim 7, wherein said airfoil profile section is defined by a scaled set of coordinates in which said set of y/c coordinates listed in Table I are scaled by a factor of 1.2 while said x/c values are unchanged.

9. The section as recited in claim 1, wherein said associate x/c values in Table I are unchanged

10. The section as recited in claim 9, wherein said airfoil profile section extends into said main section of a main rotor blade.

11. The section as recited in claim 1, wherein the helicopter is a conventional single rotor helicopter.

12. A helicopter having a single rotor system with a plurality of rotor blades, each of said rotor blades comprising:

an inboard region, said inboard region including a first airfoil profile section;

a main region outboard of said inboard region;; and

a tip region of said main region including a second airfoil profile section defined by a scaled set of coordinates in which said set of y/c coordinates listed in Table I are scaled by a desired factor.

13. The helicopter main rotor blade of claim 12, wherein the tip region comprises approximately the outer 20% of the length of the main rotor blade.

14. The helicopter main rotor blade of claim 12, wherein the tip region comprises approximately the outer 15% of the length of the main rotor blade.

15. The helicopter as recited in claim 12, wherein said second airfoil profile section is optimized to provide maximum lift at approximately 0.6 MACH with an optimized drag divergence MACH number at a 0.2 lift coefficient.

16. The helicopter as recited in claim 15, wherein said first airfoil profile section is optimized to provide maximum lift at approximately 0.25 MACH with an optimized drag divergence MACH number at a 0.2 lift coefficient.

17. A helicopter having a dual, contra-rotating, coaxial rotor system with a plurality of main rotor blades, each of said main rotor blades comprising:

a main rotor blade rotor having a blade region including an airfoil profile section defined by a scaled set of coordinates in which said set of y/c coordinates listed in Table I are scaled by a desired factor.

18. The helicopter as recited in claim 17 wherein an airfoil profile section defined by a set of coordinates listed in Table II is located inboard of said airfoil profile section defined by said set of coordinates listed in Table I of said rotary wing aircraft rotor blade.

19. The helicopter as recited in claim 18, wherein an airfoil profile section defined by a set of coordinates listed in Table III is located inboard of said airfoil profile section defined by said set of coordinates listed in Table II of said rotary wing aircraft rotor blade.

20. The helicopter as recited in claim 17, wherein said airfoil profile section is located at least partially within a tip region defined by a 20% of the main rotor blade.

21. The helicopter as recited in claim 17 further comprising a translational thrust system having a rotational axis oriented substantially horizontal and parallel to an aircraft longitudinal axis.

22. A method of reducing a lower surface suction peak associated with an inherent 'drag creep' of an airfoil profile section at moderate lift coefficients and reducing the peak Mach number and shock strength at high lift/Mach number conditions of an airfoil profile section for a rotating airfoil profile section comprising the steps of:

(A) reducing a leading edge region a thickness and camber at $x/c \leq 0.3$ which delays the formation of shock waves at high Mach number/low lift coefficient and moderate Mach number/high lift coefficient conditions; and

(B) thinning a trailing edge region of the airfoil profile section at $x/c \geq 0.5$ and stabilizing a boundary layer of the trailing edge region of the airfoil profile section.

23. A main rotor blade of a single rotor helicopter comprising:

a tip region of a main rotor blade, said tip region including an airfoil profile section defined by a scaled set of coordinates in which said set of y/c coordinates listed in Table I are scaled by a desired factor.

24. The main rotor blade as recited in claim 23, wherein said tip region is defined by an outboard 15% of the main rotor blade.

25. The main rotor blade as recited in claim 23, wherein said airfoil profile section is defined by said set of coordinates listed in Table I.

26. The section as recited in claim 23, wherein said airfoil profile section is defined by a scaled set of coordinates in which said set of y/c coordinates listed in Table I are scaled by a factor of 1.2 while said x/c values are unchanged.

27. The section as recited in claim 23, wherein said associate x/c values in Table I are unchanged

28. The section as recited in claim 23, wherein said airfoil profile section extends into said main section of a main rotor blade.

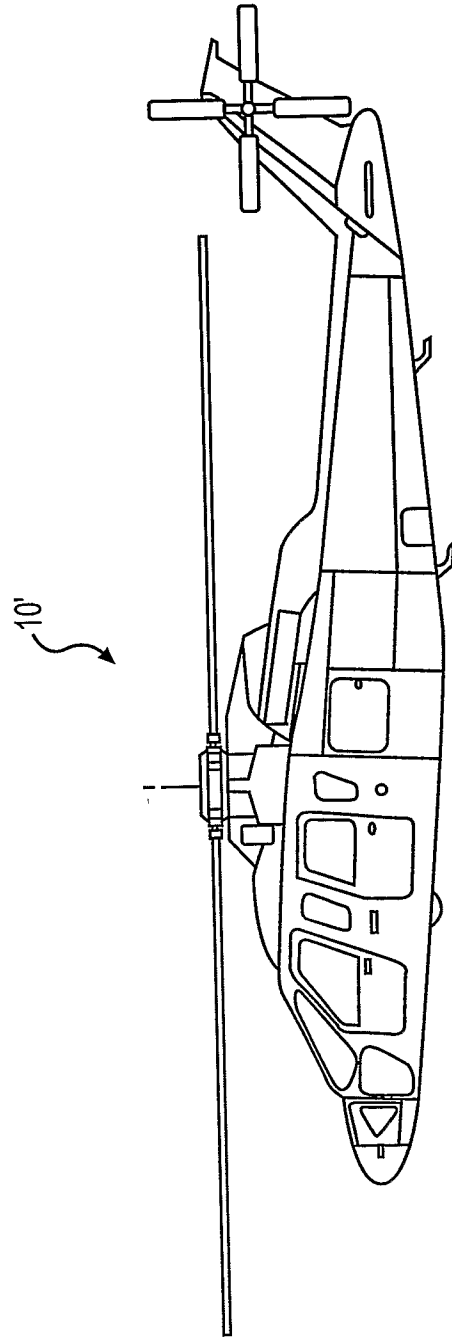


FIG. 1B

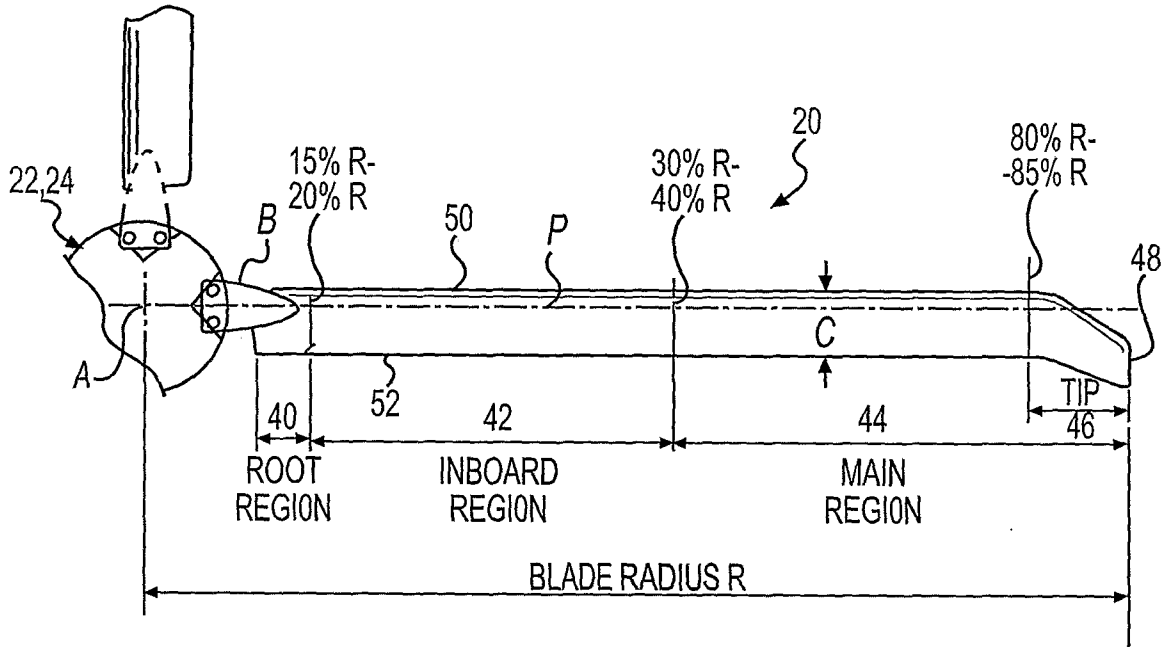


FIG. 2A

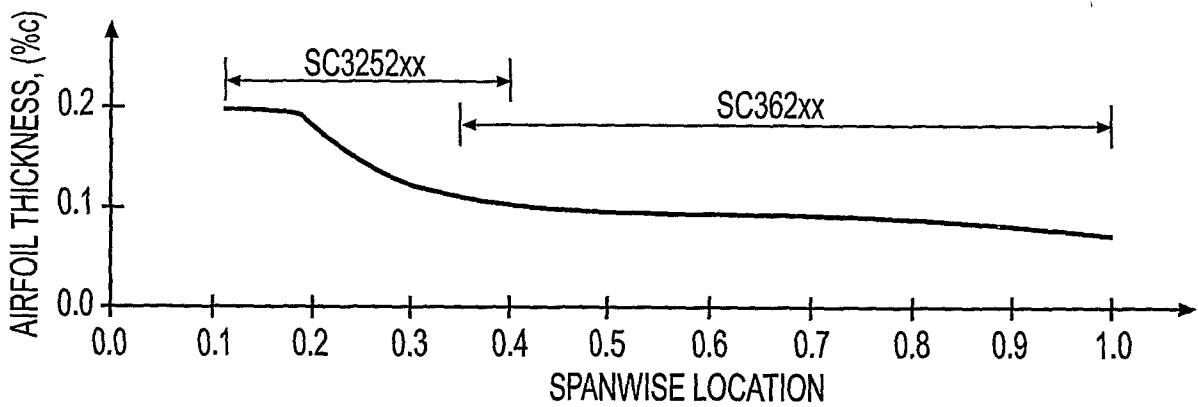


FIG. 2B

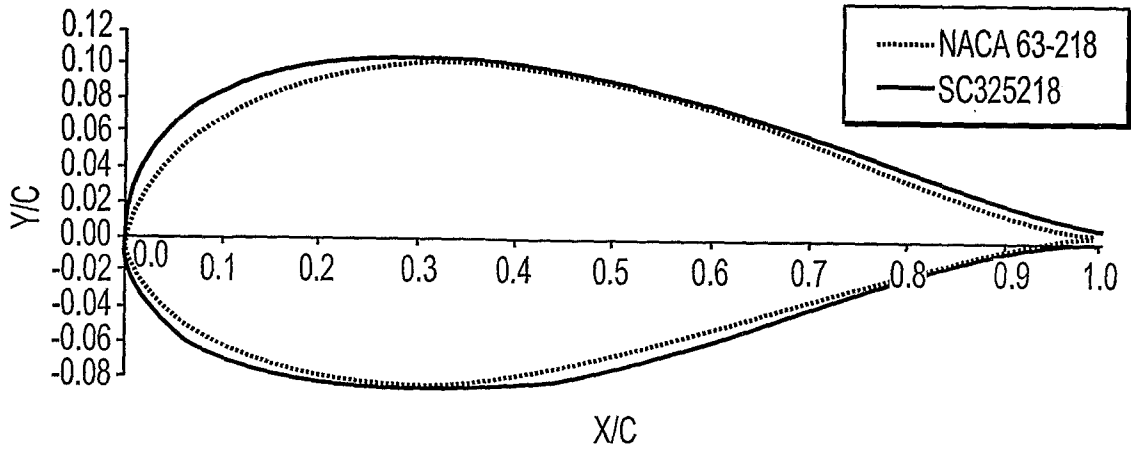


FIG. 2C

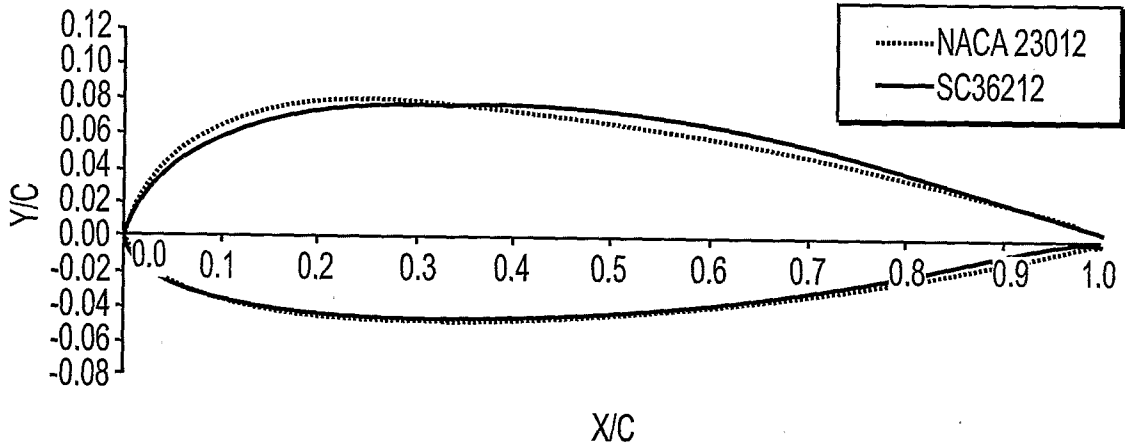


FIG. 2D

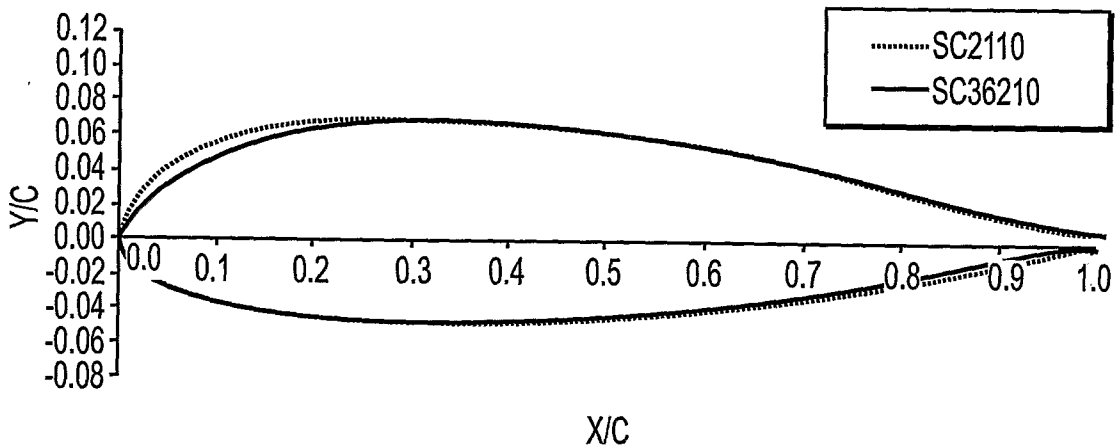


FIG. 2E

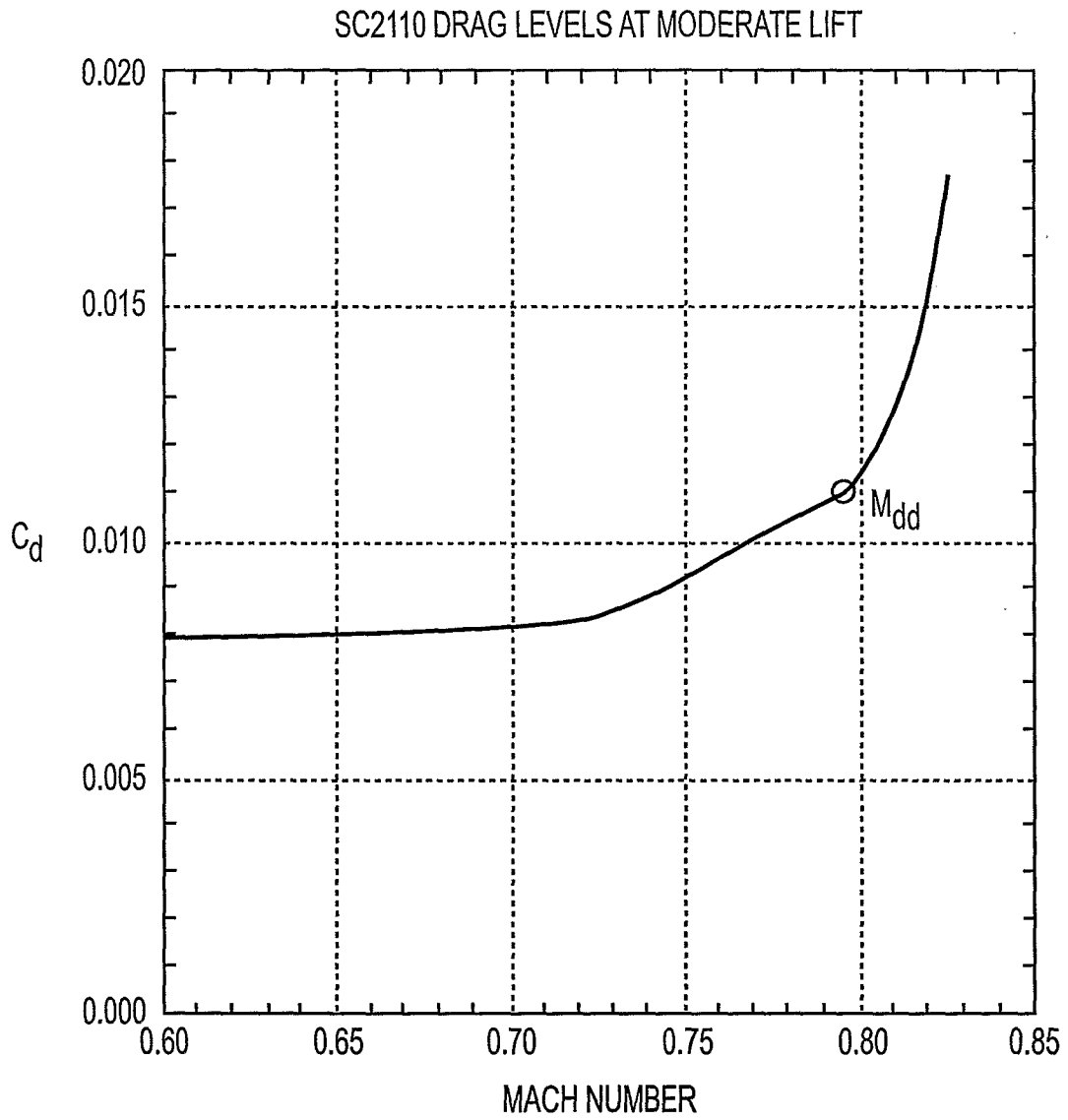


FIG. 3
PRIOR ART

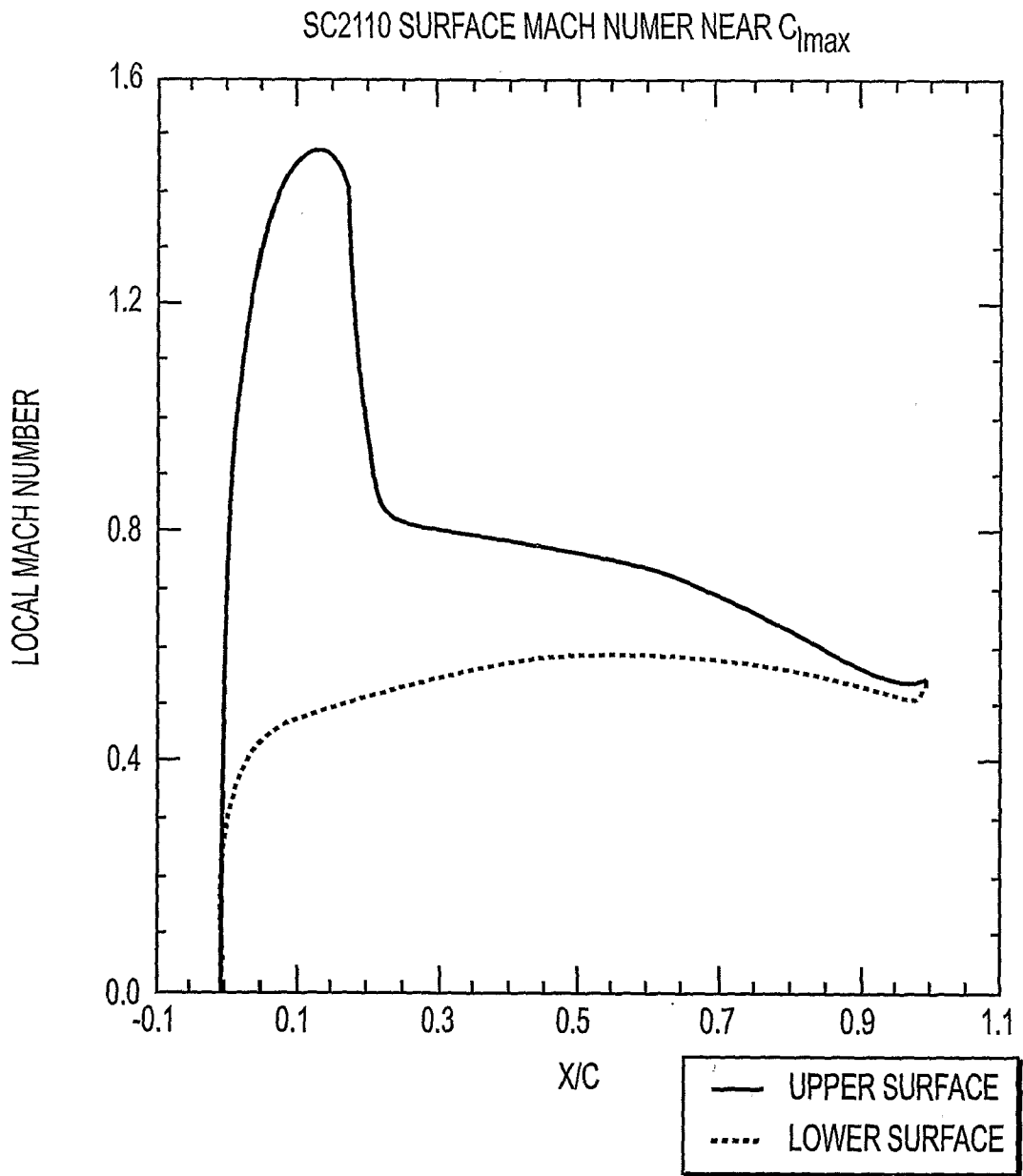


FIG. 4
PRIOR ART

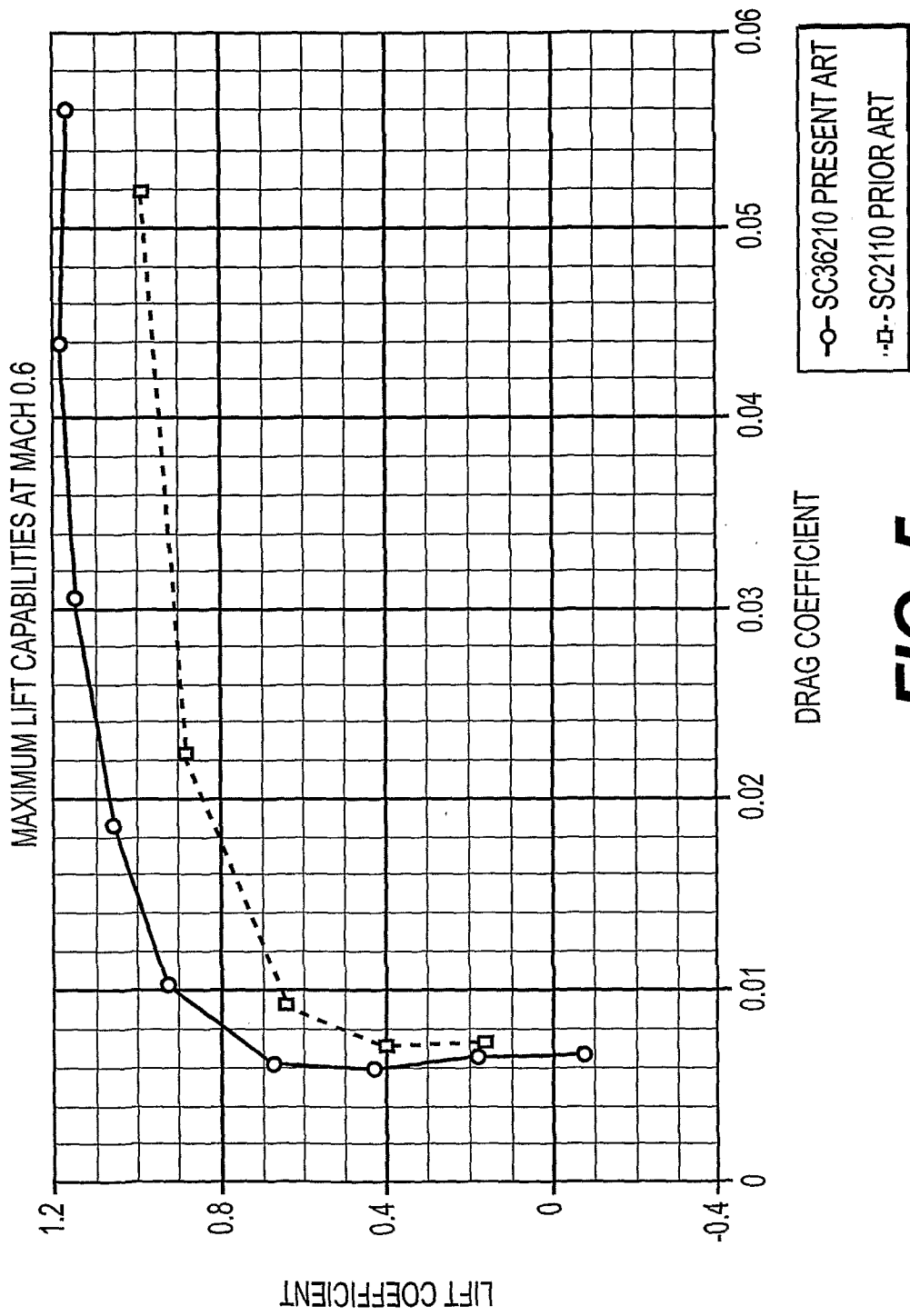


FIG. 5

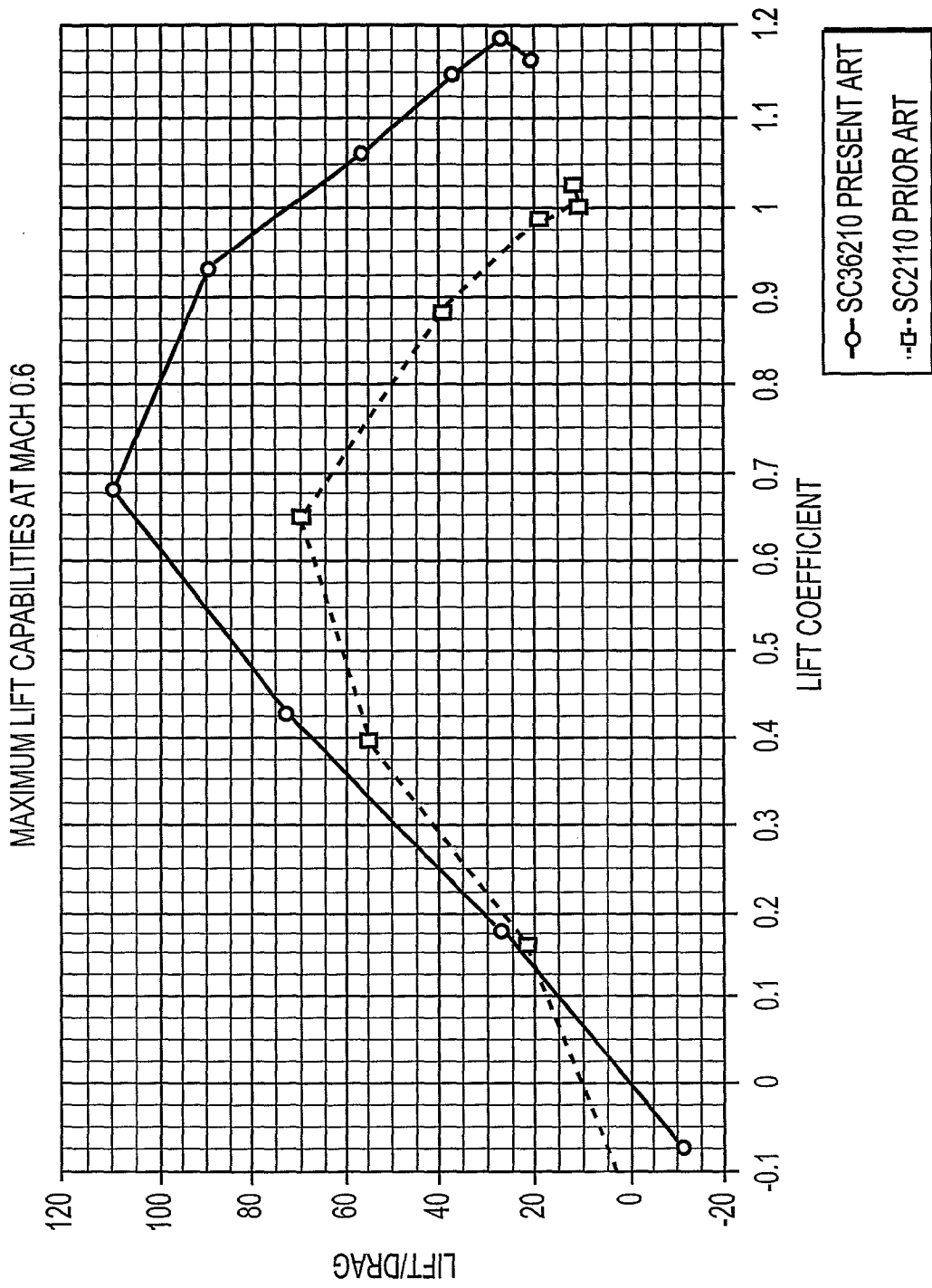


FIG. 6

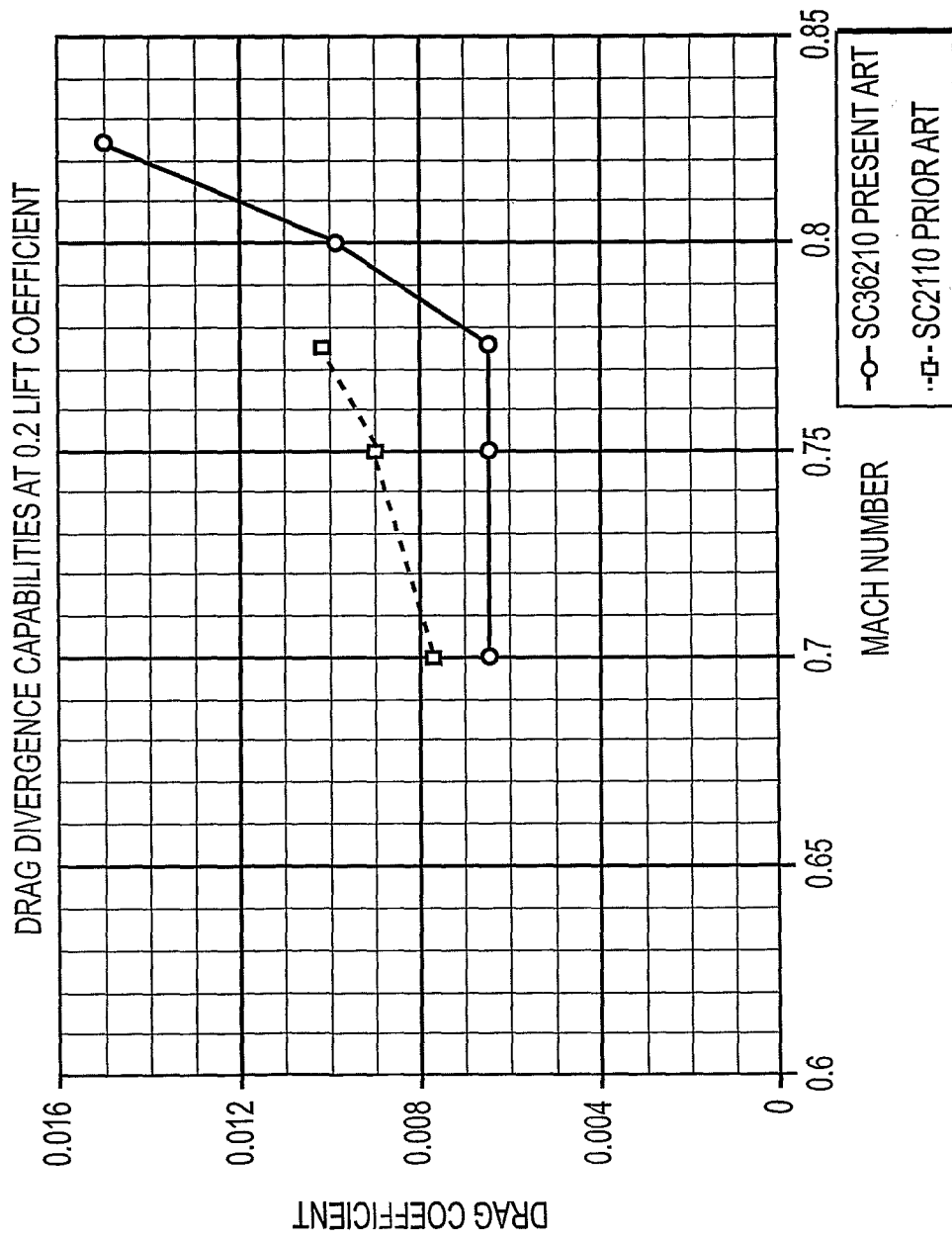


FIG. 7

ATTR INBOARD FAMILY COMPARISON

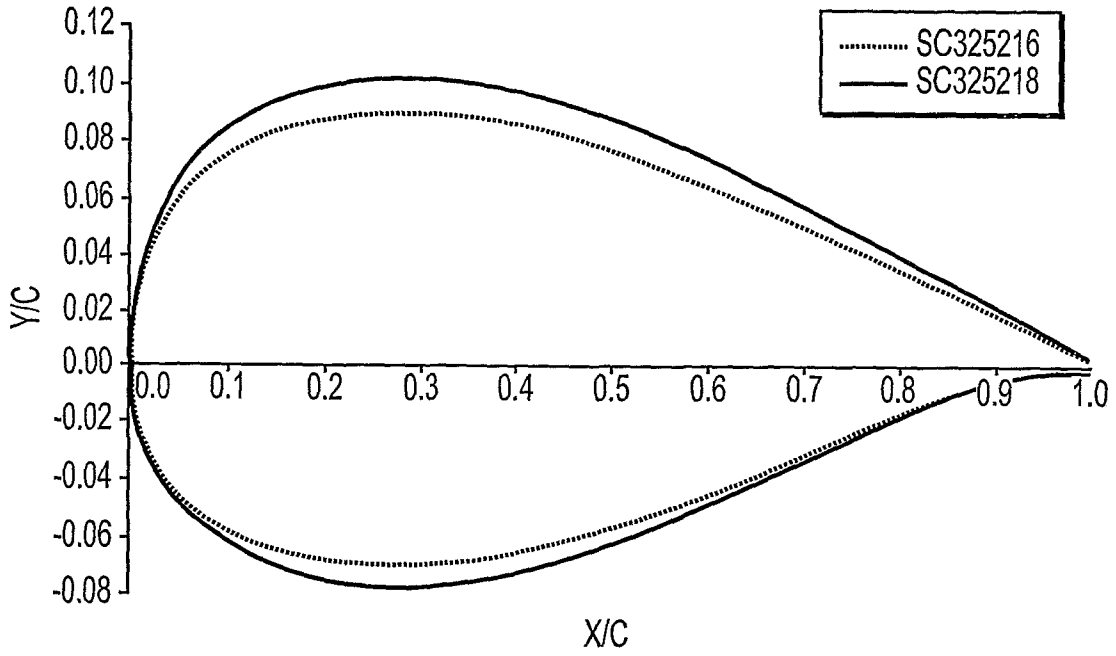


FIG. 8A

ATTR OUTBOARD FAMILY COMPARISON

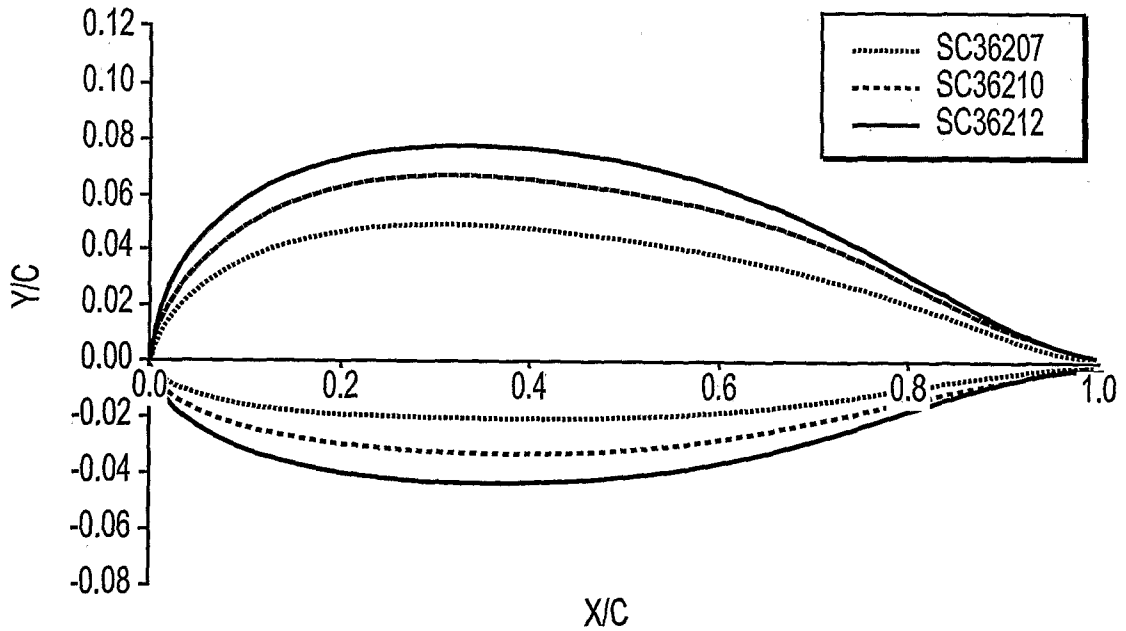


FIG. 8B

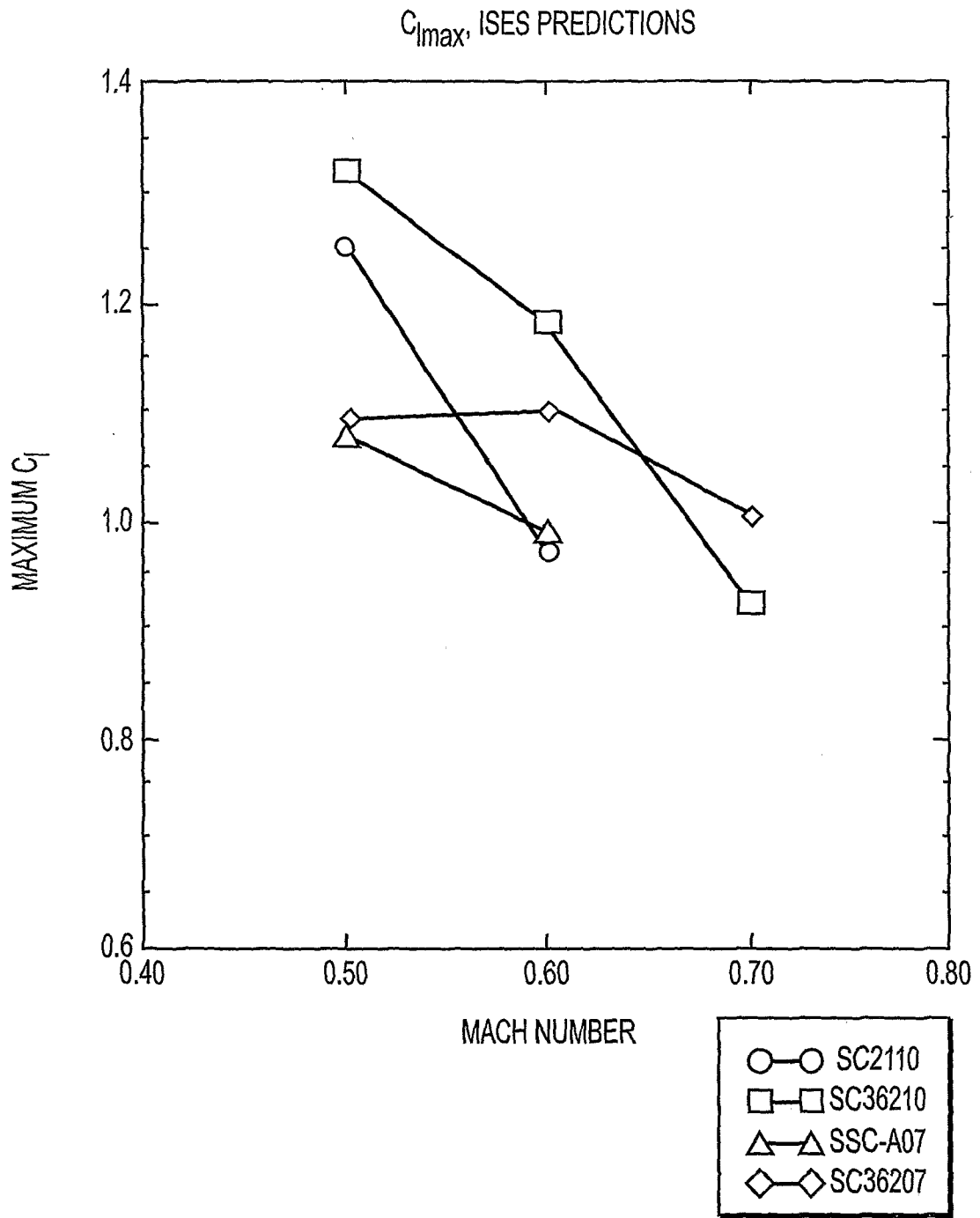


FIG. 9

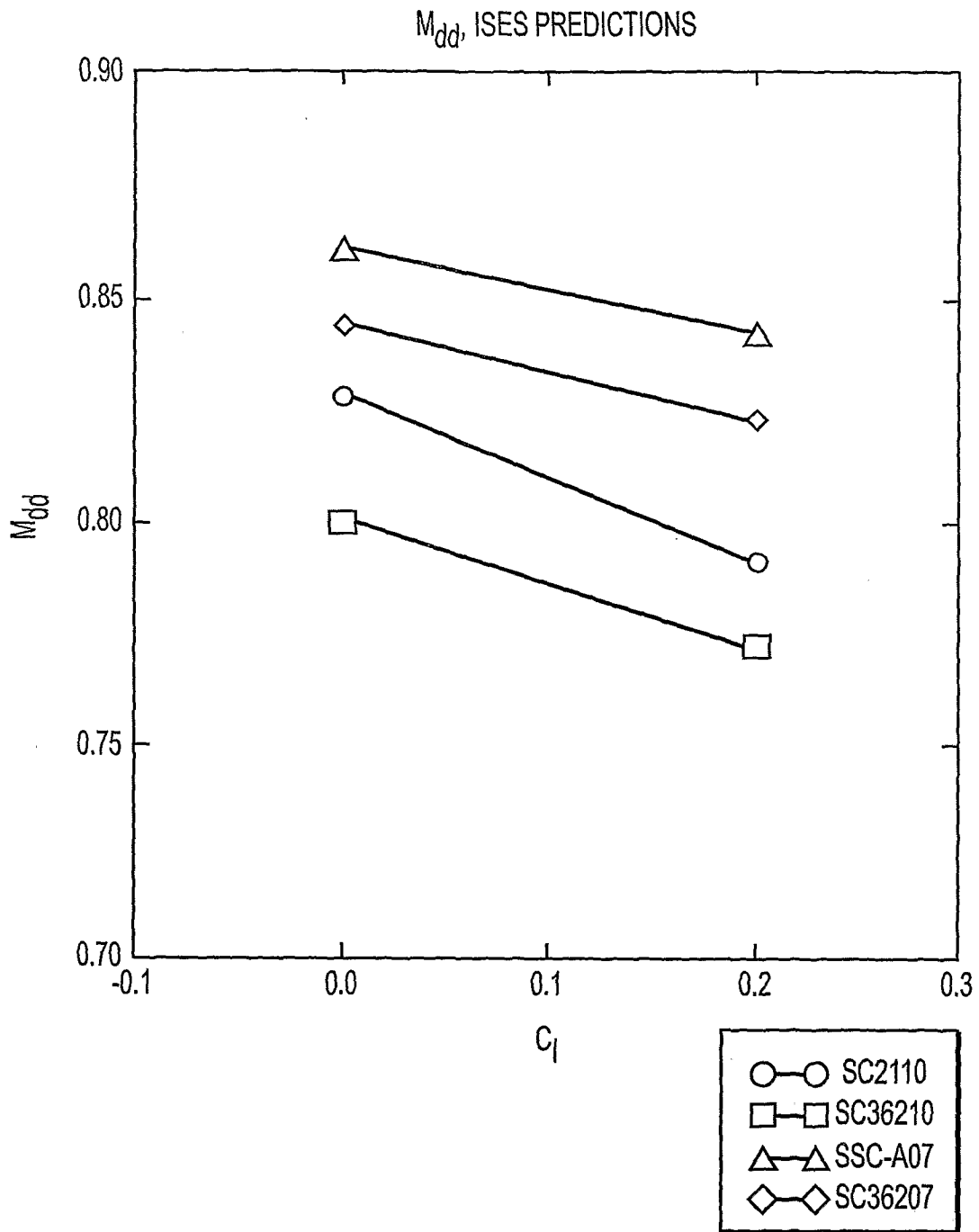


FIG. 10