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AERODYNAMIC DESIGN OF LOW-SPEED AIRCRAFT WITH A NASA FUSELAGE/WAKE-PROPELLER CONFIGURATION

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Abstract

A brief parametric study has been carried out on the application of a NASA axisymmetric fuselage/wake-propeller configuration, using full-scale wind-tunnel data, to low-speed general aviation aircraft with conventional NACA wings. The design matrix comprises two wing aspect ratios, (8 and 10), two wing loadings (15 and 21 PSF), five fuselage diameters (40", 42", 48", 55" and 65") and five corresponding gross weights (800, 1200, 1400, 2400 and 3200 lb). The experimental propulsive efficiency of the NASA fuselage/wake-propeller configuration goes from 103% for the bare fuselage to a range between 96% and 85% for the aircraft. The aerodynamic efficiency index ranges from 17.95 to 11.47 while that for conventional aircraft ranges from 7.95 to 5.00, as shown by a survey of 76 general aviation and sport aircraft. A 50% power reduction, for the same gross weight and speed, is a very practical possibility.

Finally, a specific comparison has been carried out between the 55" diameter 4-seat design and one of the latest 4-seat pusher aircraft, for the same 2400-lb gross weight and 180 MPH speed, yielding 78 HP for the former and 180 HP for the latter; this demonstrates that, while a wake-propeller is a pusher, a pusher propeller is not necessarily a wake-propeller.

Nomenclature

$a = \frac{U_o}{nd}$	Propeller advance ratio
A	Wing area, ft^2
$AEI = \frac{W_o U_o}{HP}$	Aerodynamic efficiency index
$AR = \frac{b^2}{A}$	Wing aspect ratio
b	Wing span, ft
$C_D = \frac{F}{q_o V^{0.66}}$	Volume axial drag coeff. of fuselage/wake-propeller
$C_{Do} = 0.0190$	Volume axial drag coeff. of bare fuselage
$C_T = -C_D$	Volume axial thrust coeff. of fuselage/wake-propeller
$C_{DA} = \frac{F}{q_o A}$	Area axial drag coeff. of wings etc.
$C_L = \frac{W_o}{q_o A}$	Wing area lift coeff.
C_L/C_D	Lift/drag ratio
$C_P = \frac{HP}{\rho n^3 d^5}$	Propeller power coeff.
$CHP = \frac{HP}{q_o U_o V^{0.66}}$	Volume power coeff. of fuselage/wake-propeller
d	Propeller diameter, ft
D	Fuselage diameter, ft
$f = \frac{L}{D}$	Fuselage fineness ratio
F	Net axial drag force on fuselage/wake-propeller, lb
F_o	Axial drag force on bare fuselage (no propeller), lb
$T = -F$	Net axial thrust force on fuselage/wake-propeller, lb
T_o	Thrust produced by propeller, lb
L	Fuselage length, ft
n	Propeller speed, RPS
$q_o = \frac{1}{2}\rho U_o^2$	Free-stream dynamic pressure, PSF
$R_L = \frac{LU_o}{\nu}$	Length Reynolds Number
$R_V = \frac{V^{0.33}U_o}{\nu}$	Volume Reynolds Number
$U_o = U_\infty$	Free-stream velocity, FPS
V	Fuselage volume, ft^3
$V^{0.66}$	Fuselage equivalent area, ft^2
$V^{0.33}$	Fuselage equivalent length, ft
W_o	Aircraft gross weight = wing lift, lb
β	Propeller blade angle
$\eta = \frac{T_o U_o}{HP}$	Propeller efficiency
$\eta_p = \frac{F_o U_o}{HP}$	Propulsive efficiency
ν	Air kinematic viscosity, ft^2/sec
ρ	Air mass density, lb sec^2/ft^4

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I. Introduction

The concept of body wake regeneration for propulsion originated in 1865 with Froude[1]; his thinking was based on the overall momentum balance of the moving vehicle and he believed that the Rankin drag/thrust concept was an anachronism from the days when canal barges were towed by horses. When a force in one medium must be overcome by power input in another medium, or more generally when there is an impedance matching problem, the drag/thrust concept may have great merit. In steady motion through a single fluid, however, as with an aircraft, a LTA or a submarine, the drag/thrust concept is misleading in its apparent simplicity and it invariably results in the adoption of reduced performance targets. For instance, when a fuselage is said to have a certain drag at a given speed, it is implied that the fuselage wake's momentum is condemned to useless dissipation, without possible recourse of any kind; it is implied that the drag can only be balanced by an equal propeller thrust, according to the Rankin concept. Still today, general aviation aircraft are viewed essentially as powered gliders, with the thruster (propeller or jet unit) installed in a manner not conducive to efficient wake regeneration. Even fuselage-mounted pusher propellers are too large and are not tailored to the specific wake, as will be seen in Section V, where the wake-propeller aircraft is compared to a conventional pusher-propeller aircraft.

The rational approach is to follow Froude's concept[1] and to expend power to prevent or to minimize the occurrence of the wake. Smith and Roberts,[2] Kuchemann and Weber,[3] Edwards,[4 5] Davidson,[6] Goldschmied[7 8 9 10] and many others have contributed to the development of wake regeneration, with and without active boundary-layer control. For instance, Goldschmied[7 8] has shown that, for an axisymmetric fuselage, the wake drag can be reduced by a factor of 10 with an efficient single-slot suction boundary-layer control aftbody design; the overall power was reduced by a factor of 2, for equal fuselage volume and speed.[10] In hydrodynamics, the application of wake-propellers has become standard practice for all high-speed underwater vehicles such as submarines, torpedoes, etc. An excellent reference on this subject is given by Huang, Wang, Santelli and Groves.[11]

It has been this author's experience that communications between hydrodynamicists and aerodynamicists have not been good; even within the AIAA itself, papers in the Journal of Hydronautics failed to get many readers from the aircraft community. As a typical example, a very significant 1976 paper[12] was ignored by at least four AIAA authors.[13 14 15 16]

The objective of this brief preliminary parametric study is to acquaint the general aviation community with the aerodynamic potential of fuselage/wake-propeller configurations for single-engine low-speed aircraft. This potential was demonstrated experimentally by a NASA wind-tunnel test of a full-scale fuselage (50.88" diameter, 246" length) with its custom-tailored wake-propeller (24.00" diameter) at 100 MPH.

The very extensive test results were reported by McLemore[17] in 1962 but it appears that they have been ignored for aircraft application simply because the project had been funded by the LTA program and the fuselage was designated as a "1/20-Scale Airship Model."

A recent NASA-funded survey of propeller propulsion system integration by Miley and von Lavante[18] does not include any reference to McLemore's[17] excellent work, although a majority of the survey's effort is claimed to have been directed to the time period before 1964; no other investigation of fuselage/wake-propeller integration is to be found among the 121 references reviewed by Miley and von Lavante. In their authoritative textbook on airplane aerodynamics and performance, Lan and Roskam[19] simply do not recognize even the possibility of wake-propulsion; on page 269 of Ref. 19 it is stated: "In pusher configurations .... the propeller will be operating inside the nacelle (fuselage?) wake. In this situation, the propeller efficiency can be greatly reduced."

The power assessment of aircraft is carried out on the basis of the Aerodynamic Efficiency Index (AEI) which is defined as follows:

$$\text{AEI} = \frac{\text{Gross Wt. x Speed}}{\text{Propeller Power}}$$

$$= \frac{\text{Lift}}{\text{Drag}} \text{ x Propulsive Efficiency}$$

Since there is no readily available AEI data base for general aviation aircraft, such a data base has been compiled for 76 aircraft and it is tabulated in Appendix I and II for convenient referral. The AEI data points have also been plotted against aircraft speed in Fig. 12.

II. NASA Wind-Tunnel Test

The NASA wind-tunnel test program was carried out in the Langley 30' x 60' Wind-Tunnel and was reported by McLemore.[17] The axisymmetric fuselage had 50.88" diameter and 246.46" length, with a fineness ratio f = 4.84 and an enclosed volume V = 184 ft^3. The profile shape of the body was of the well-known "Akron" airship family[20 21] but shortened from the Akron's f = 5.9 to f = 4.84. It can be noted that a body with f = 4.5 had also been tested in the wind-tunnel by Abbott,[22] yielding no higher drag. It is interesting to note that the Akron wind-tunnel test model[20 21] had a length of 236" and a diameter of 40", with a length Reynolds number of $R_L = 1.8 \times 10^6$ and a volume drag coefficient $C_D = 0.022$.

On the other hand, the drag coefficient of McLemore's[17] model was (without propeller) $C_D = 0.021$, including the three tail fins and the "gondola" at the same Reynolds number. The net drag coefficient of the bare body can be estimated from the test results of Abbott[22] (Fig. 8 of Ref. 22): the drag coefficient increment due to the presence of the fins is $\Delta C_D = 0.002$ and the drag increment due to the gondola is $\Delta C_D = 0.001$. Thus an increment of 0.003 must be added to the net thrust data, so as to truly portray the bare body performance.

It can be noted that the minimum pressure occurs at 18% length, thus laminar flow can play only a minor role in the performance; Abbott[22] found no drag difference for his f = 4.5 body when the test model was polished all over (Fig. 5 of Ref. 22). The maximum diameter occurs at 40% length; Table I below lists the length and diameter coordinates of the test body for convenient reference, since they are not given by McLemore.[17]

The wake-propeller had 4 blades and 24" diameter (less than half body diameter); the diameter corresponds to the measured diameter of the wake (without propeller).

Although the test model was labeled a 1/20-Scale Airship Model, it happens also to be a full-scale fuselage for general aviation aircraft, being large enough for side-by-side seating!

Figure 1 presents the schematic of the test model with 3 tail fins and the "gondola"; it is reproduced from Fig. 1 of Ref. 17. It can be noted that the drag of an aircraft empennage would not be significantly higher than the total drag of the tail fins and of the gondola.

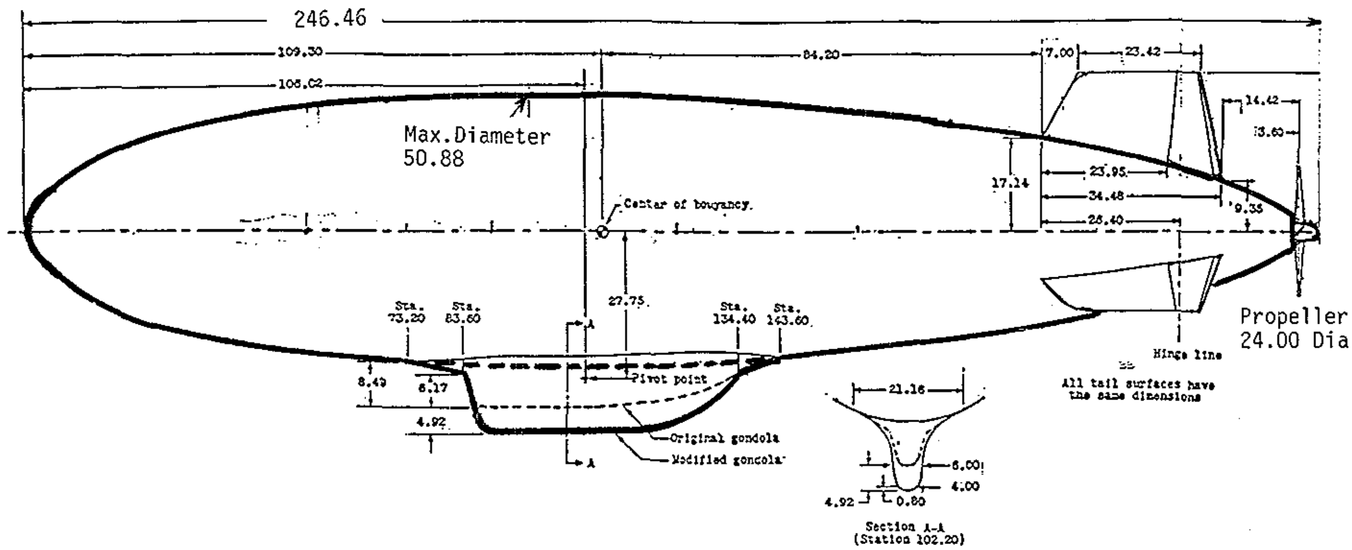

FIG.1 - SCHEMATIC LAYOUT OF NASA WIND-TUNNEL TEST MODEL, SHOWING HULL, GONDOLA AND TAIL, REPRODUCED FROM FIG. 1 OF NASA TN D-1026.

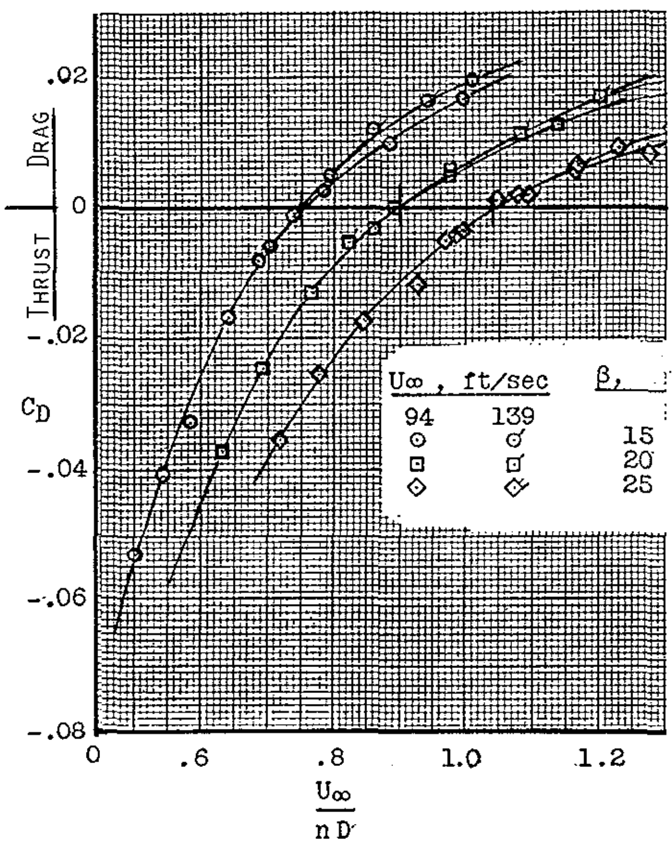

FIG.2 - AXIAL FORCE COEFF. C_D VS. PROPELLER ADVANCE RATIO. REPRODUCED FROM FIG.4 D) OF NASA TN D-1026

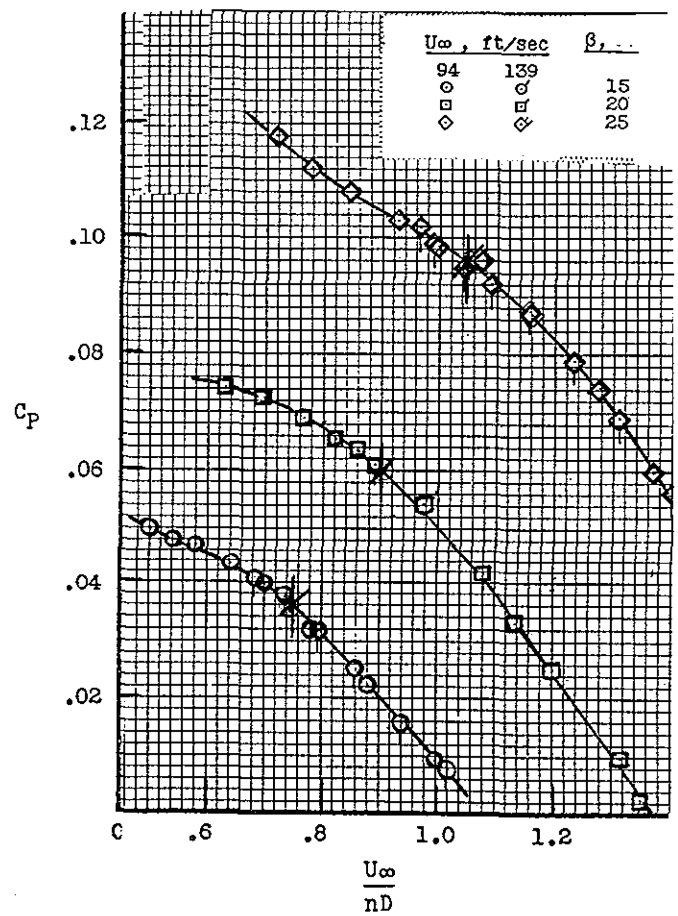

FIG.3 - PROPELLER POWER COEFF. C_P VS. PROPELLER ADVANCE RATIO, REPRODUCED FROM FIG.4 B) OF NASA TN D-1026.

Table I NASA Test Body Coordinates

Length, in.	Diameter, in.
0	0
2.462	5.418
4.924	17.881
9.849	22.095
12.312	25.467
14.774	28.297
17.236	30.585
24.624	36.304
36.936	42.564
49.248	47.020
61.560	48.885
73.872	50.149
86.184	50.753
98.496	50.880
110.808	50.880
123.120	50.633
135.432	50.642
147.745	48.888
160.056	47.200
172.369	49.732
184.68	41.299
196.993	36.904
209.305	31.426
215.461	27.867
225.000	24.564
227.773	20.977
233.929	16.677
240.085	9.493
246.46	0

Figure 2 presents the net body/propeller drag coefficient $C_D = F/q_0V^{0.66}$ against propeller advance ratio $a = U_0/nd$ for 3 blade angles 15°, 20° and 25°; it is reproduced from Fig. 4d) of Ref. 17. It can be noted that negative drag coefficient C_D values represent net thrust; it can be seen that more than enough net thrust was generated to tow two other identical bodies. Indeed the maximum thrust coefficient was $C_D = -0.053$ and the drag coefficient of the body (without propeller) was $C_D = 0.021$!

Figure 3 presents the propeller power coefficient $Cp = HP/\rho n^3d^5$ against the propeller advance ratio $a = U_0/nd$ for 3 blade angles 15°, 20° and 25°; it is reproduced from Fig. 4b) of Ref. 17. It must be noted that this power coefficient Cp does not include any body dimensions as such; it has to be translated into the volume power coefficient $CHP = HP/q_0U_0V^{0.66}$ so as to be used for a parametric fuselage analysis.

Figure 4 presents the propeller efficiency $\eta = T_0U_0/HP$ against the propeller advance ratio $a = U_0/nd$ for 3 blade angles 15°, 20° and 25°; it is reproduced from Fig. 4c) of Ref. 17. T_0 is the actual measured thrust of the propeller, U_0 is the measured free-stream velocity and HP is the measured shaft power to the propeller. The seemingly impossible evidence is that propeller efficiency is up to 122% for advance ratios yielding zero net thrust (equilibrium flight of body): this is conclusive proof that the wake-propeller does indeed operate within an area of lower velocities and that the efficiency does not have to decrease, as predicted by Lan and Roskam.[19]

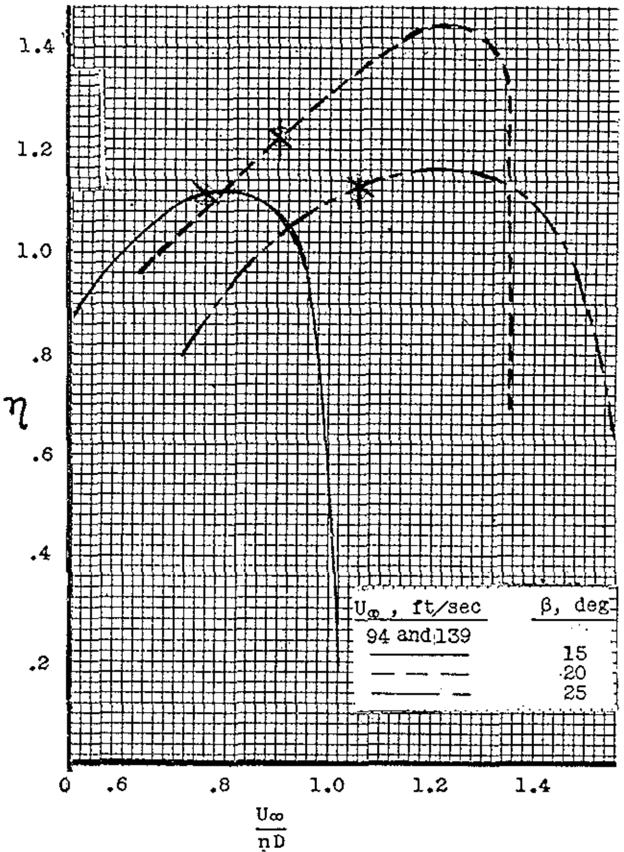

FIG.4 - PROPELLER EFFICIENCY VS PROPELLER ADVANCE RATIO, REPRODUCED FROM FIG.4 C) OF NASA TN D-1026

However, the propulsive efficiency $\eta_p = F_0U_0/HP$ is down to a mere 103% at equilibrium because the propeller-induced flow field over the body causes additional drag, as compared to the bare body, or a so-called "thrust-deduction" of the propeller thrust. The same propeller, mounted in a conventional free-stream installation, achieved 73% propeller and propulsive efficiencies. Thus despite the "thrust-deduction," the power gain of the wake-propeller was an impressive 41% over the freestream propeller. This illustrates the power that can be extracted from the fuselage wake's kinetic energy and which is going to waste today in the general aviation aircraft. It can be added that the "thrust-deduction" is not a necessary evil: it can be eliminated by designing the body shape through a complex iterative process that includes the propeller's effect on the body pressure distribution and boundary-layer development. The final body shape is such that maximum pressure recovery is achieved on the fuselage's aftbody with the propeller, while the aftbody flow would be fully separated without the propeller's effect. This maximum pressure recovery is assumed to be that given by the Goldschmied turbulent separation criterion.[27]

The NASA experimental test data are tabulated below in Table II for convenient reference; in addition, the volume power efficient CHP has been computed from the propeller power coefficient Cp.

Table II Experimental Parameters of NASA Fuselage/Wake-Propeller Test

Advance Ratio a	Axial *Drag* Coeff. C_D	Propeller *Power* Coeff. Cp	Volume *Power* Coeff. CHP	Propeller *Efficiency* η
PROPELLER BLADE ANGLE β = 15°				
0.505	-0.053	0.050	0.0960	0.87
0.545	-0.041	0.048	0.0730	0.92
0.640	-0.017	0.0435	0.0412	1.04
0.685	-0.0085	0.0410	0.0317	1.08
0.700	-0.0060	0.040	0.0289	1.09
0.740	-0.0015	0.0370	0.0227	1.10
PROPELLER BLADE ANGLE β = 20°				
0.63	-0.0370	0.077	0.0764	0.96
0.69	-0.0245	0.073	0.0552	1.01
0.765	-0.0135	0.069	0.0383	1.08
0.825	-0.0055	0.065	0.0287	1.14
0.860	-0.0035	0.063	0.0245	1.18
0.890	0.00	0.061	0.0214	1.21
PROPELLER BLADE ANGLE β = 25°				
0.720	-0.0355	0.118	0.0785	0.80
0.775	-0.0255	0.112	0.0597	0.90
0.845	-0.0175	0.108	0.0444	0.97
0.930	-0.0120	0.103	0.0318	1.05
0.965	-0.0055	0.101	0.0279	1.08
0.990	-0.0035	0.099	0.0253	1.10

Table III below presents the parameters to be used for the parametric aerodynamic design procedure. The net thrust of the body/wake-propeller system T has been corrected for the tail and gondola drag, i.e. 0.003 has been added to the given experimental values of the thrust coefficient.

Table III Fuselage/Wake-Propeller Parameters (Corrected for Tail & Gondola Drag)

Advance Ratio a	Thrust Coeff. C_T	Volume Power Coeff. CHP
PROPELLER BLADE ANGLE β = 15°		
0.505	0.056	0.0960
0.545	0.044	0.0730
0.640	0.020	0.0412
0.685	0.0115	0.0317
0.700	0.009	0.0289
0.740	0.0045	0.0227
PROPELLER BLADE ANGLE β = 20°		
0.63	0.040	0.0764
0.69	0.0275	0.0552
0.765	0.0165	0.0383
0.825	0.0085	0.0287
0.860	0.0065	0.0245
0.890	0.0030	0.0214
PROPELLER BLADE ANGLE β = 25°		
0.720	0.0385	0.0785
0.775	0.0285	0.0597
0.845	0.0205	0.0444
0.930	0.0150	0.0318
0.965	0.0085	0.0279
0.990	0.0065	0.0253

Figure 5 presents the plot of CHP vs CT and Fig. 6 presents the plot of a vs. C_T.

It is to be noted that the propeller was designed for speeds of 100 MPH; at speeds above 120 MPH, the propeller tip-speed becomes excessive. As suggested by McLemore, a larger number of blades should be used, such as 6 or 8.

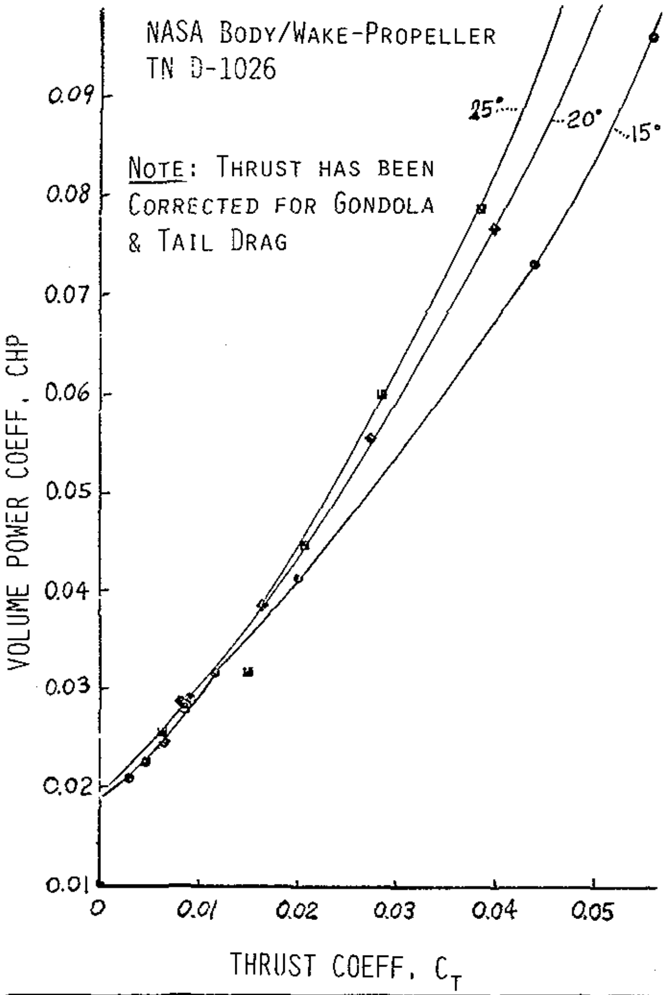

FIG.5 - VOLUME POWER COEFF.CHP VS.THRUST COEFF, C_T.

III. Aerodynamic Design Objectives

The aerodynamic design objective of this brief preliminary study is to determine the Aerodynamic Efficiency Index AEI of the NASA fuselage/wake-propeller aircraft with conventional NACA wings at the maximum cruise speed.

These AEI values will then be compared to the corresponding data of U.S. Business, Utility and Personal Aircraft (tabulated in Appendix I) and of Sport and Home-built Aircraft (tabulated in Appendix II), as computed from gross weight, maximum engine power and maximum aircraft speed.

From the data of Appendix II it is seen that one-seat aircraft range from 500 to 800 lb, from 115 to 150 MPH and from 22 to 60 HP. For the present study an appropriate fuselage diameter is 40", so as to allow ample elbow room to the pilot.

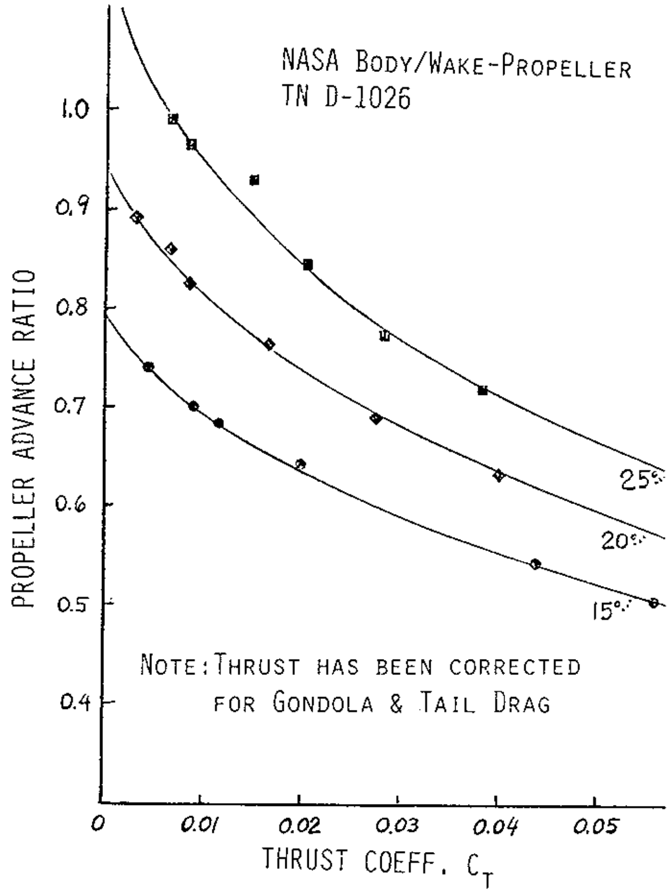

FIG. 6 - PROPELLER ADVANCE RATIO VS. THRUST COEFF. C_T.

From the data of Appendix I and II, it is seen that two-seat aircraft range from 950 to 2400 lb, from 110 to 276 MPH and from 50 to 300 HP. For the present study an appropriate fuselage diameter is 42" for tandem seating and 48" for side-by-side seating.

From the data of Appendix I and II, it is seen that four-seat aircraft range from 2400 to 3900 lb, from 138 to 230 MPH and from 160 to 235 HP. For the present study an appropriate fuselage diameter is 55". From the data of Appendix I, it is seen that six-seat aircraft range from 2750 to 6775 lb, from 158 to 302 MPH and from 200 to 760 HP. For the present study an appropriate fuselage diameter is 65", so as to allow room between the seats.

For this preliminary study, the speed range has been limited to 140-180 MPH and the gross weight range has been limited to 800-3200 lb. The table below lists the matrix of configurations to be analyzed.

In order to assess the roominess of the fuselage diameters, it can be noted that a cross-section of 24" x 36" is often quoted for sport single-seat aircraft as satisfactory to accommodate the pilot, as against the selected 40" diameter. A cross-section of 42" x 40" is quoted as satisfactory for side-by-side two-seat aircraft, as against the selected 48" diameter for the 2-seat side-by-side and 55" diameter for 4-seat aircraft. Wing aspect-ratios of 8 and 10 will be considered, as well as wing loadings of 15 and 21 PSF.

IV. Parametric Analysis

The first wing parameter to be considered is the wing aspect-ratio (AR); Fig. 7 presents the general aviation survey of wing aspect-ratio against wing lift coefficient from the data tabulated in Appendix III. It can be seen that there doesn't seem to be any trend: the range is from 6 to 10, with a preponderance of points between 7.25 and 8.50. For this brief preliminary study, in order to keep a solid wind-tunnel experimental basis, NACA AR = 10 and AR = 8 wings have been selected; the wind-tunnel test data are shown in Fig. 8 (reproduced from Fig. 18 of Ref. 23) for the AR = 8 NACA 65_2-415 wing and in Fig. 9 for the AR = 10 NACA 65_3-418 wing.

Table IV Summary of Aircraft Parameters

Number of Seats	1	2 Tandem	2 Side-by-Side	4	6	NASA Wind-Tunnel Model
Fuselage Diameter D in.	40	42	48	55	65	50.88
Fuselage Length L in.	193	202	231	265	313	246
Fuselage Volume V ft^3	90.0	104.0	155.0	234.0	386.0	184
Equiv. Area $V^{0.66}$ ft^2	20.0	22.0	28.7	37.8	52.8	32.2
Propeller Diameter d in.	18.85	19.80	22.65	26.00	30.65	24.00
Gross Wt. W_0 lb	800	1200	1400	2400	3200	--
Speed U_0 MPH	140 - 180					100

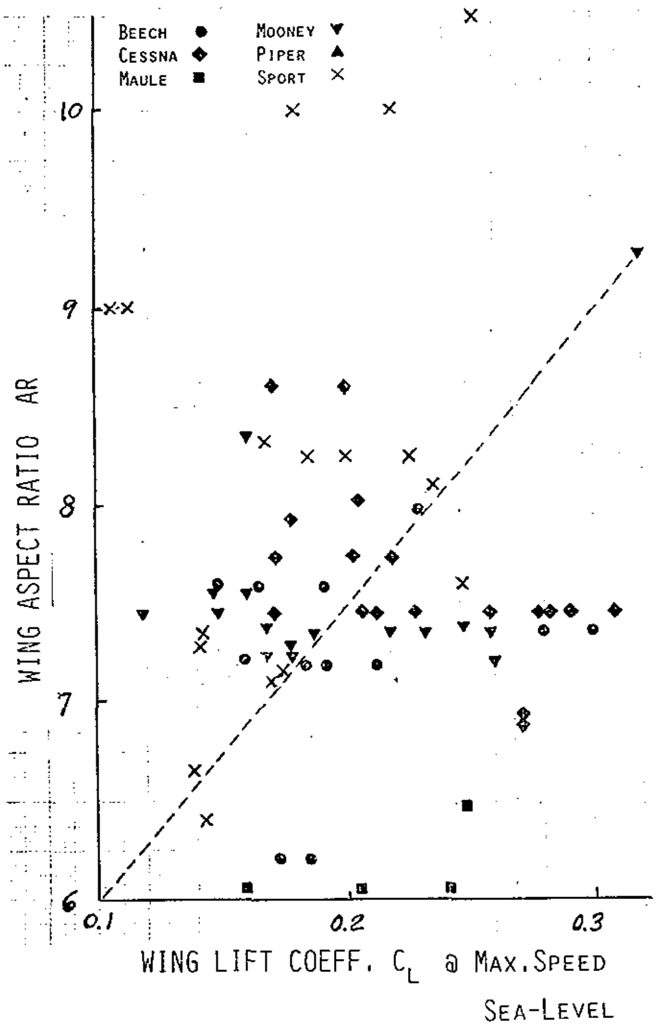

FIG.7 - GENERAL AVIATION SURVEY : WING ASPECT RATIO AR VS. WING LIFT COEFF. C @ MAX. SPEED & SEA LEVEL

The lift/drag ratios of the two wings are plotted in Fig. 10; it can be seen that top lift/drag values are in the lift coefficient range from 0.25 to 0.50.

The next question is to examine the general aviation practice in terms of wing lift coefficient against aircraft speed: such a survey is presented in Fig. 11 from the data tabulated in Appendix III. Three plots are shown with dotted curves: the top plot indicates the highest lift coefficients actually *used in general aviation aircraft* design and it shows a very consistent trend. If C_L = 0.30 is chosen, it can be seen that it intersects the plot @ 140 MPH, yielding a wing loading of 15 PSF, while if C_L = 0.25 is chosen, it intersects the plot @ 180 MPH, yielding a wing loading of 21 PSF.

Table V presents the summary of wing areas and wing spans for the matrix of AR = 8 and AR = 10 and of 15 PSF and 21 PSF wing loading. The wing area ranges from 38.1 ft^2 (800 lb, 21 PSF) to 211.2 ft^2 (3200 lb, 15 PSF); the wing span ranges from

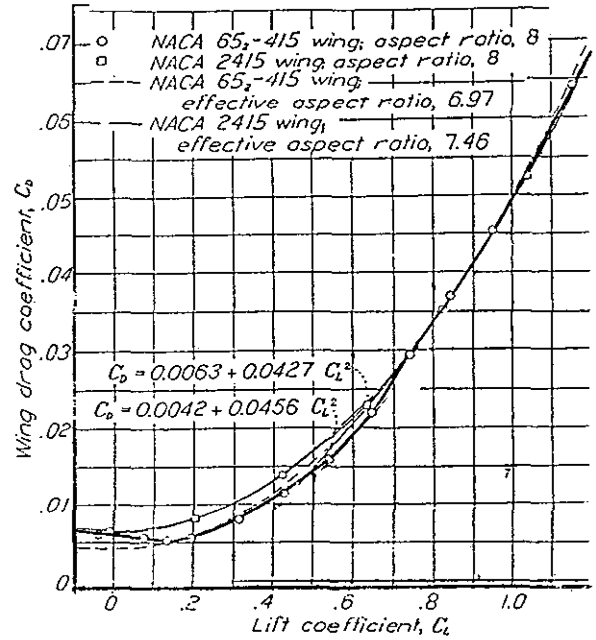

FIG.8 - WING DRAG COEFF. C_D VS. WING LIFT COEFF. C_L . NACA 65_2-415 & 2415 WINGS OF AR=8. REPRODUCED FROM FIG.18 OF NACA REPORT 824 .

17.4 ft (800 lb, AR = 8, 21 PSF) to 45.9 ft (3200 lb, AR = 10, 15 PSF).

Table VI presents the summary of wing lift coefficients C_L for 140, 160 and 180 MPH and for 15 PSF and 21 PSF wing loading. The lift coefficient ranges from 0.180 (180 MPH, 15 PSF) to 0.415 (140 MPH, 21 PSF).

Table VII presents the summary of wing lift/drag ratios (as obtained from Fig. 10) for 140, 160 and 180 MPH, AR = 8 and AR = 10 and for 15 PSF and 21 PSF wing loading. The ratio ranges from 32.0 (180 MPH, AR = 8, 15 PSF) to 41.5 (140 MPH, AR = 10, 15 PSF).

From the gross weight W_0 and the lift/drag *ratio, the wing drag is computed; a 10% wing/fuse*lage interference drag is added. The empennage drag is assumed to be 27.5% of the wing drag. From the total drag F, the propeller thrust coefficient C_T is computed:

$$C_T = \frac{F}{q_0 V^{0.66}}$$

Note: The $V^{0.66}$ values are given in Table IV

From Fig. 5, the corresponding values of the volume power coefficient CHP are determined for 15° blade angle (best propeller performance).

The summary of C_T and CHP values is presented in Table VIII for convenient reference. The thrust coeff. C_T ranges from 0.0163 to 0.0473, while the *volume power coeff. CHP ranges from 0.0370 to* 0.0780. It can be noted that in Table III the highest experimental value of the power coefficient is CHP = 0.0960 and the corresponding thrust coefficient is C_T = 0.056.

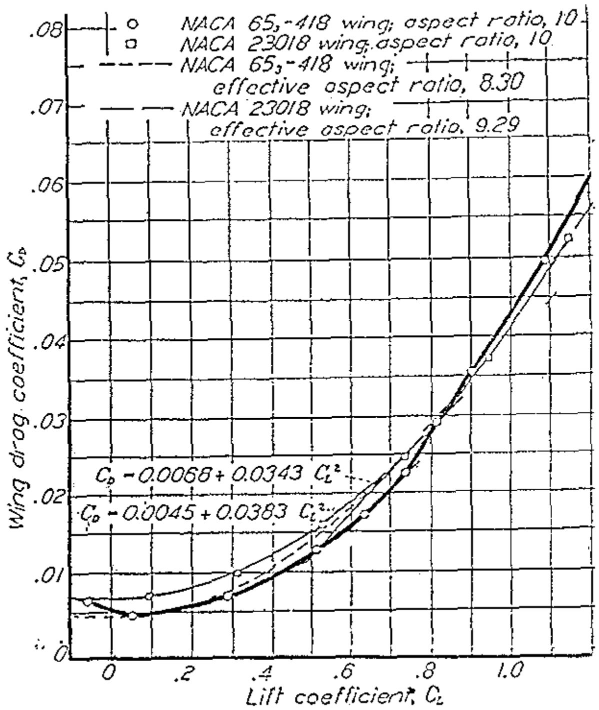

FIG.9 - WING DRAG COEFF. C_D VS. WING LIFT COEFF. C_L.
NACA 65$_3$-418 AND 23018 WINGS OF AR=10. REPRODUCED FROM FIG.18 OF NACA RPT.824.

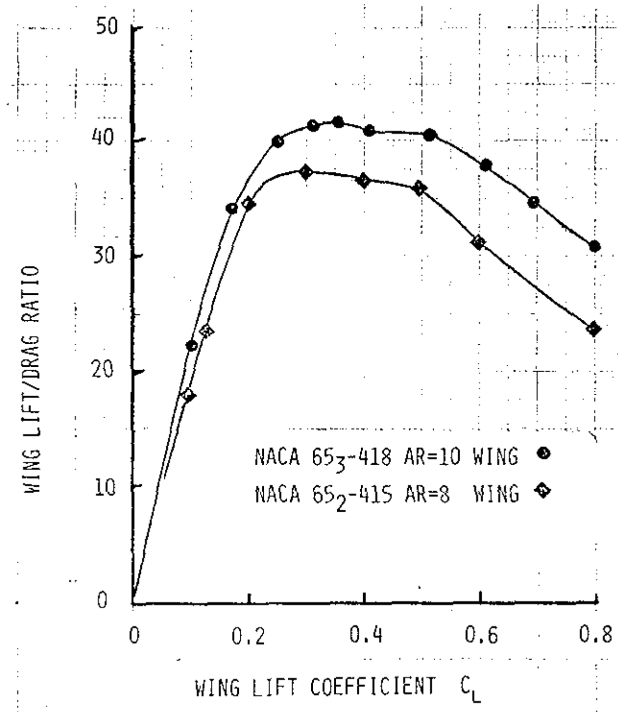

FIG.10 - WING LIFT/DRAG RATIO VS. WING LIFT COEFF. C_L.
NACA 65$_3$-418 AR=10 WING
NACA 65$_2$-415 AR=8 WING

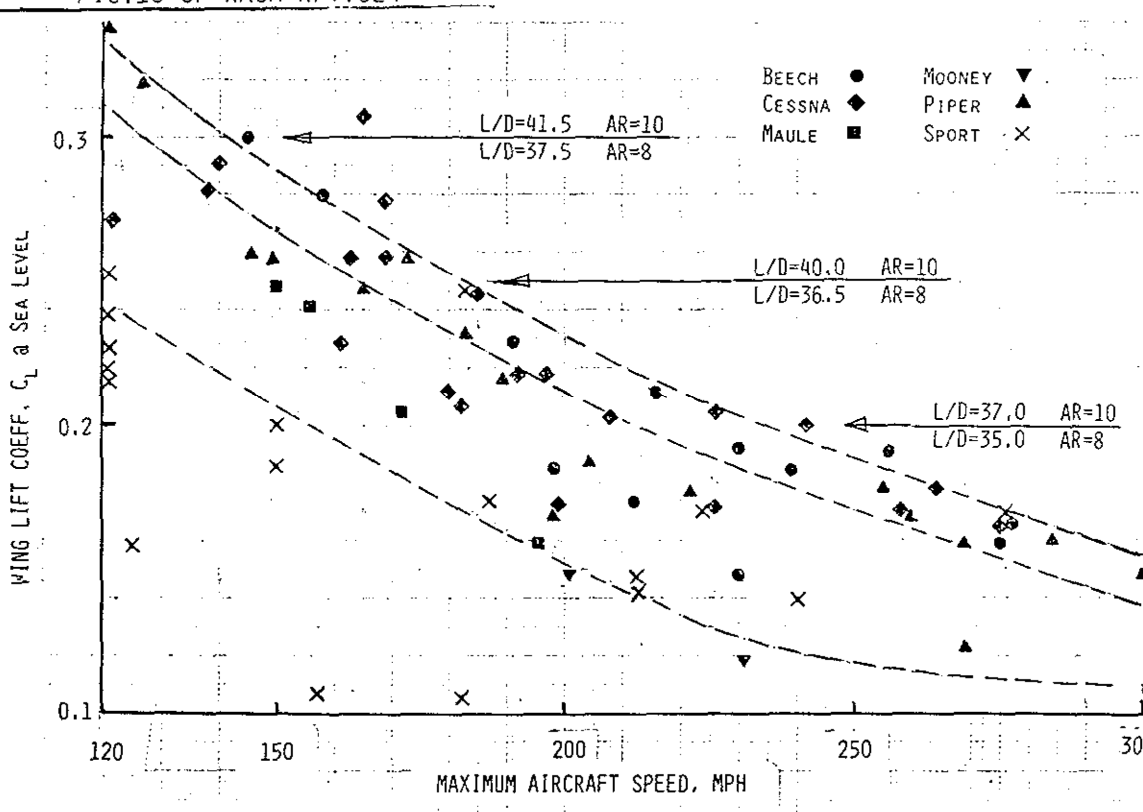

FIG.11 - GENERAL AVIATION SURVEY : WING LIFT COEFF. C_L @ SEA-LEVEL VS. MAXIMUM AIRCRAFT SPEED, MPH

Table V Summary of Wing Areas and Spans

Gross Wt. W_0 lb	800	1200	1400	2400	3200
Wing Area, A ft^2 15 PSF Loading	52.8	79.2	92.4	158.4	211.2
Wing Area, A ft^2 21 PSF Loading	38.1	57.1	66.6	114.2	152.3
Wing Span, b ft AR = 8 15 PSF	20.55	25.17	27.18	35.59	41.10
Wing Span, b ft AR = 8 21 PSF	17.4	21.3	23.0	30.2	34.9
Wing Span, b ft AR = 10 15 PSF	22.9	28.1	30.4	39.8	45.9
Wing Span, b ft AR = 10 21 PSF	19.5	23.9	25.8	33.8	39.0

Table VI Summary of Wing Lift Coefficients

Wing Loading PSF	15	21
140 MPH Speed	0.30	0.415
160 MPH	0.228	0.317
180 MPH	0.180	0.25

Table VII Summary of Wing Lift/Drag Ratios

Speed	Wing AR = 10		Wing AR = 8	
	15 PSF	21 PSF	15 PSF	21 PSF
140 MPH	41.5	41.0	37.5	36.5
160	39.0	41.5	36.5	37.25
180	35.5	40.0	32.0	37.0

The next parameter to be considered is the propulsive efficiency in the high thrust area required for aircraft design. The propulsive efficiency is computed as follows:

$$\eta_p = \frac{(T + F_o)U_o}{HP} = \frac{C_T + C_{Do}}{CHP} = \frac{C_T + 0.0190}{CHP}$$

The bare body drag F_o must be added to the net thrust T to compute the total thrust power; the ratio of this power over the actual propeller power is the propulsive efficiency of the aircraft. Table IX presents the summary of propulsive efficiency: it can be seen that it ranges from 91.2% to 96.6% for the 800 lb gross weight, from 87.6% to 93.8% for the 1250 lb, from 88.5% to 92.8% for the 1400 lb, from 85.0% to 92.8% for the 2400 lb and from 85.6% to 93.8% for the 3200 lb. These values can be compared to 103% for the propulsion of the body alone and to 65% for a typical tractor aircraft.

The next step is the computation of the actual propeller power

$$HP = \frac{CHP\ q_p U_o V^{0.66}}{550}$$

Table X presents the summary of the propeller power results. The power ranges from 18.30 HP for the 800 lb aircraft @ 140 MPH to 117 HP for the 3200 lb aircraft @ 180 MPH.

Table VIII Summary of Thrust and Power Coefficients

Gross Wt. W_0 lb		800	1200	1400	2400	3200
AR = 10, 15 PSF Wing						
U_0 = 140 MPH	C_T	0.0262	0.0357	0.0319	0.0415	0.0400
	CHP	0.0485	0.0610	0.0560	0.0695	0.0675
U_0 = 160 MPH	C_T	0.0212	0.0290	0.0260	0.0338	0.0322
	CHP	0.0425	0.0525	0.0485	0.0590	0.0570
U_0 = 180 MPH	C_T	0.0184	0.0251	0.0224	0.0292	0.0279
	CHP	0.0390	0.0475	0.0440	0.0530	0.0510
AR = 10, 21 PSF Wing						
U_0 = 140 MPH	C_T	0.0265	0.0361	0.0323	0.0420	0.0400
	CHP	0.0490	0.0615	0.0570	0.0700	0.0675
U_0 = 160 MPH	C_T	0.0200	0.0271	0.0244	0.0317	0.0303
	CHP	0.0410	0.0500	0.0465	0.0555	0.0540
U_0 = 180 MPH	C_T	0.0163	0.0223	0.0185	0.0260	0.0232
	CHP	0.0370	0.0440	0.0390	0.0485	0.0450
AR = 8, 15 PSF Wing						
U_0 = 140 MPH	C_T	0.0290	0.0396	0.0353	0.0460	0.0439
	CHP	0.0525	0.0665	0.0610	0.0760	0.0730
U_0 = 160 MPH	C_T	0.0227	0.0310	0.0277	0.0361	0.0344
	CHP	0.0440	0.0550	0.0505	0.0615	0.0600
U_0 = 180 MPH	C_T	0.0205	0.0278	0.0249	0.0324	0.0310
	CHP	0.0415	0.0505	0.0470	0.0570	0.0550
AR = 8, 21 PSF Wing						
U_0 = 140 MPH	C_T	0.0298	0.0406	0.0363	0.0473	0.0452
	CHP	0.0535	0.0680	0.0625	0.0780	0.0750
U_0 = 160 MPH	C_T	0.0223	0.0304	0.0272	0.0354	0.0338
	CHP	0.0440	0.0540	0.0505	0.0610	0.0590
U_0 = 180 MPH	C_T	0.0177	0.0241	0.0215	0.0280	0.0268
	CHP	0.0380	0.0460	0.0430	0.0510	0.0495

Table IX Summary of Propulsive Efficiency

Gross Wt. W_0 lb	800	1200	1400	2400	3200
AR = 10, 15 PSF Wing					
U_0 = 140 MPH	0.932	0.896	0.909	0.870	0.874
U_0 = 160 MPH	0.946	0.914	0.928	0.895	0.898
U_0 = 180 MPH	0.959	0.928	0.941	0.909	0.919
AR = 10, 21 PSF Wing					
U_0 = 140 MPH	0.928	0.896	0.900	0.871	0.874
U_0 = 160 MPH	0.951	0.922	0.933	0.913	0.913
U_0 = 180 MPH	0.954	0.938	0.961	0.928	0.938
AR = 8, 15 PSF Wing					
U_0 = 140 MPH	0.914	0.881	0.890	0.855	0.862
U_0 = 160 MPH	0.948	0.909	0.925	0.896	0.890
U_0 = 180 MPH	0.952	0.927	0.934	0.902	0.909
AR = 8, 21 PSF Wing					
U_0 = 140 MPH	0.912	0.876	0.885	0.850	0.856
U_0 = 160 MPH	0.939	0.915	0.915	0.892	0.895
U_0 = 180 MPH	0.966	0.937	0.942	0.921	0.925

Table X Summary of Propeller Power, BHP

Gross Wt. W_0 lb	800	1200	1400	2400	3200
AR = 10, 15 PSF Wing					
U_0 = 140 MPH	18.30	25.23	30.29	49.50	67.26
U_0 = 160	24.03	32.66	39.35	63.06	85.11
U_0 = 180	31.38	42.05	50.89	80.74	108.50
AR = 10, 21 PSF Wing					
U_0 = 140 MPH	18.46	25.49	30.83	49.86	67.18
U_0 = 160	23.14	31.10	37.74	59.12	80.54
U_0 = 180	29.83	38.95	45.12	73.89	95.72
AR = 8, 15 PSF Wing					
U_0 = 140 MPH	19.80	27.63	33.00	54.13	72.62
U_0 = 160	24.85	34.19	40.94	65.66	89.48
U_0 = 180	33.46	44.79	54.39	86.87	117.00
AR = 8, 21 PSF Wing					
U_0 = 140 MPH	20.12	28.13	33.81	55.53	74.64
U_0 = 160	24.85	33.55	40.60	65.13	88.00
U_0 = 180	30.63	40.80	49.75	77.72	105.35

In regard to propeller speed, the advance ratio can be found from Fig. 6 and the speed can be computed; however, it has been found that for speeds above 120 MPH the NASA 4-blades propeller requires excessively high tip-speeds. Thus the propeller RPM has not been reported for the 140-180 MPH speed range. McLemore himself suggested the use of larger number of propeller blades: 6 and 8 blades would be entirely practical to reduce the tip-speed while maintaining or improving the efficiency. The new propfan technology can be put to excellent use for the development of optimized wake-propellers in the 200-350 MPH speed range.

Finally the aerodynamic efficiency index can be computed from the given gross weight and speed and the computed propeller power. The results are given in Table XI; the range is from 11.47 to 17.95.

In order to assess the meaning of the AEI numbers, Fig. 12 presents the general aviation survey of the aerodynamic efficiency index against aircraft velocity. It can be seen that the range is from a low of 5.00 to a high of 7.95.

On the other hand, the data of Table XI are presented in the plot of Fig. 13 for convenient visual evidence: it seems to be clear that in the 140-180 MPH, 800-3200 lb range the NASA fuselage/wake-propeller aircraft offers substantial aerodynamic efficiency index improvements over 100%.

It can be argued that the AEI data of Fig. 12 represent actual operational "dirty" aircraft while the AEI data of Fig. 13 represent "clean" wind-tunnel model performance, with neglect of several miscellaneous drags.

A 15% speed reduction is a most generous allowance for such miscellaneous drags; as an example, for the single-seat Moni aircraft, the fixed landing gear causes a speed reduction of only 5 MPH (4.1%) as compared to the retracted gear. Thus the highest points of Fig. 13 would drop to the 15.0 level and the lowest points to the 10.0 level; the aerodynamic efficiency index improvements are still very substantial, as compared to the Fig. 12 range from 5.0 to 7.95.

Table XI Summary of Aerodynamic Efficiency Index AEI

Gross Wt. W_0 lb	800	1200	1400	2400	3200
AR = 10, 15 PSF Wing					
U_0 = 140 MPH	16.28	17.74	17.26	17.95	17.72
U_0 = 160	14.15	15.63	15.08	16.14	16.00
U_0 = 180	12.23	13.66	13.12	14.22	14.14
AR = 10, 21 PSF Wing					
U_0 = 140 MPH	16.09	17.53	16.86	17.89	17.71
U_0 = 160	14.72	16.35	15.80	17.23	16.93
U_0 = 180	12.86	14.73	13.79	15.57	15.00
AR = 8, 15 PSF Wing					
U_0 = 140	15.09	16.21	15.84	16.52	16.47
U_0 = 160	13.72	14.95	14.57	15.58	15.23
U_0 = 180	11.47	12.87	12.35	13.26	13.10
AR = 8, 21 PSF Wing					
U_0 = 140 MPH	14.77	15.88	15.45	16.16	16.00
U_0 = 160	13.72	15.23	14.68	15.69	15.50
U_0 = 180	12.50	14.06	13.45	14.81	14.53

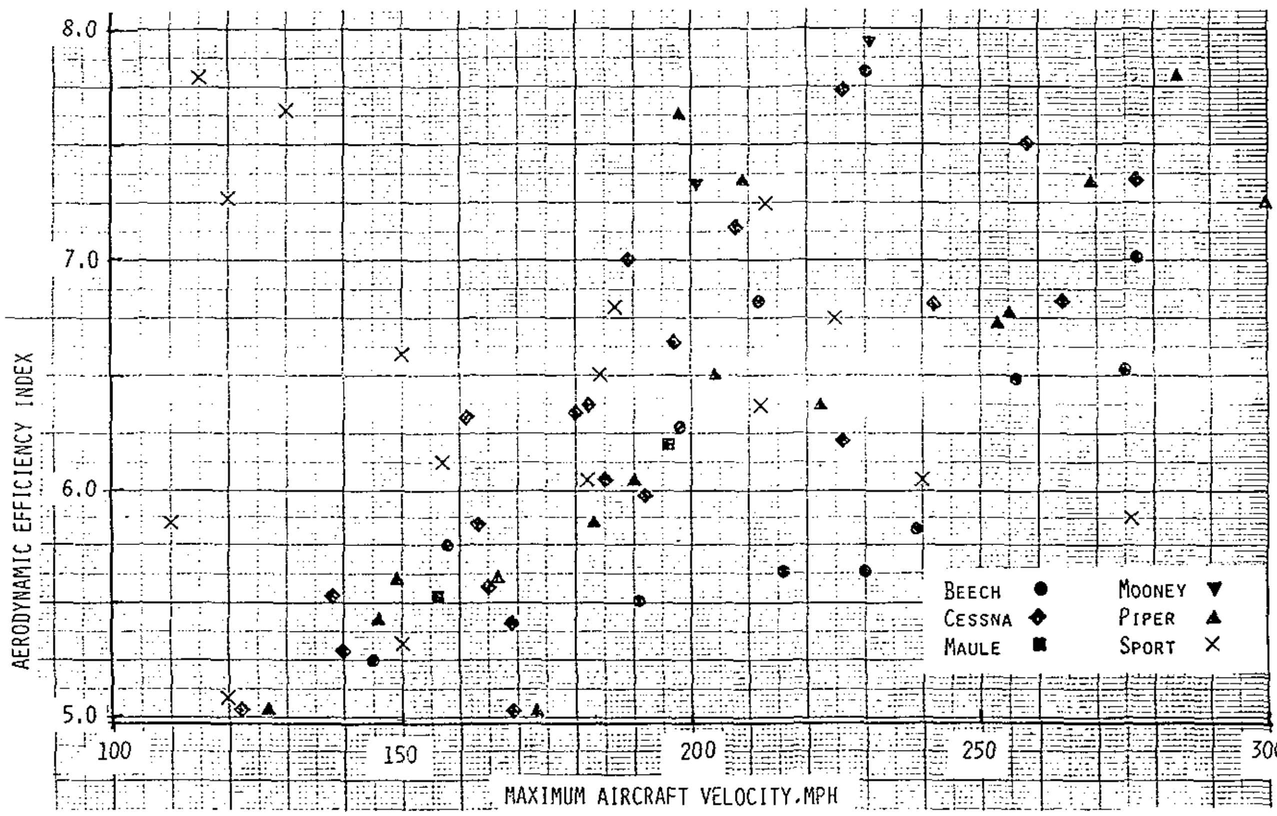

FIG.12 - GENERAL AVIATION SURVEY : AERODYNAMIC EFFICIENCY INDEX AEI VS. MAXIMUM SPEED

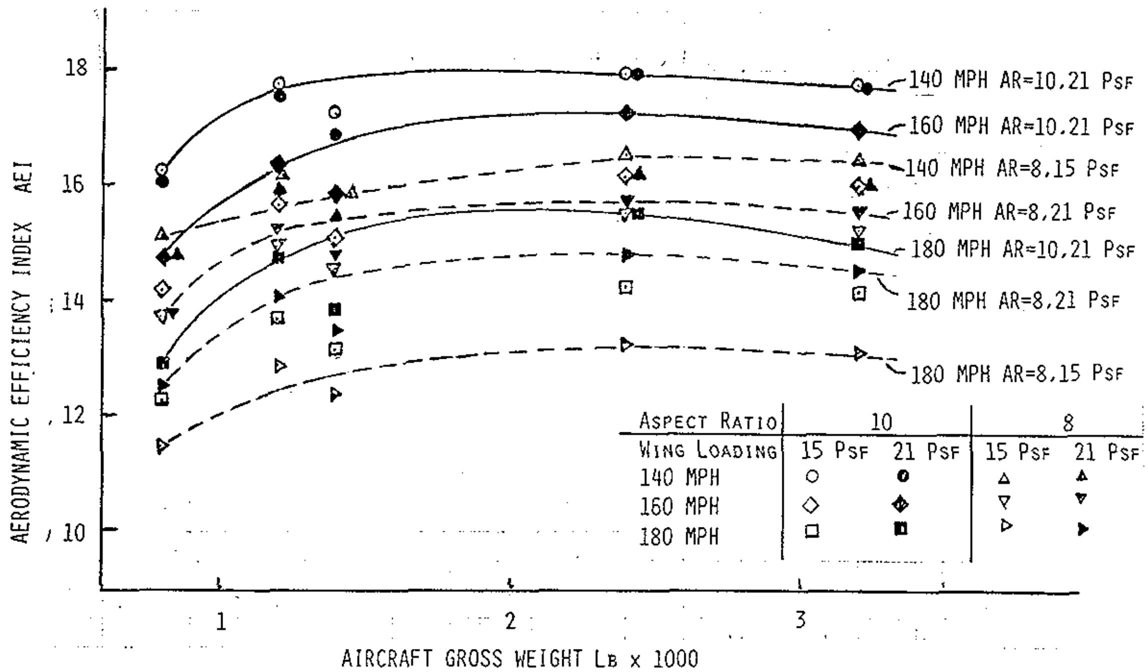

FIG.13 - NASA FUSELAGE/WAKE-PROPELLER : AERODYNAMIC EFFICIENCY INDEX AEI Vs. AIRCRAFT GROSS WEIGHT FOR 140 - 180 MPH SPEED RANGE

V. Fuselage Power Ratio

The power required for the propulsion of the fuselage is the largest contributor to the total conventional aircraft power. For a typical single-engine tractor general-aviation aircraft, the drag distribution is as follows:

Total Aircraft Drag Coeff.	C_{DA} = 0.0275	100%
Wing Drag Coeff.	C_{DA} = 0.010	36%
Empennage Drag Coeff.	C_{DA} = 0.0025	9%
Fuselage Drag Coeff.	C_{DA} = 0.0150	54%

(Note: C_{DA} is based on wing area)

The fuselage is the largest contributor to aircraft drag; despite this obvious fact, aerodynamic optimization of the fuselage has not received much attention.[24] Most of the research has been focused on the wing, which accounts for only 36% of the total drag. In conclusion, with the assumption that the propeller thrust can only make the fuselage drag higher, then the typical fuselage is responsible for 54% of the power, at the least.

It is most interesting to examine the fuselage power ratio (fuselage power/total power) for the NASA fuselage/wake-propeller configuration with NACA AR = 10 and AR = 8 wings, with wing loadings of 15 and 21 PSF.

From Fig. 5 it is seen that the fuselage power coeff. CHP (corrected for gondola and tail drag) is 0.0190 for zero net thrust, i.e. for equilibrium flight conditions, with 103% propulsive efficiency. The power ratio 0.019/CHP has been computed and is presented in Table XII for the five gross weights, the two wing aspect ratio and the two wing loadings.

It can be seen that the range is from a maximum of 0.513 (corresponding to AEI = 12.86) to a minimum of 0.243 (corresponding to AEI = 16.52). Also it can be noted that the maximum AEI = 17.95 corresponds to a ratio of 0.273 and the minimum AEI = 11.47 corresponds to a ratio of 0.457.

In conclusion, the NASA fuselage/wake-propeller configuration has made it possible to reduce the fuselage power contribution from 54% to 25%.

VI. Assessment of 4-Seat Pusher Aircraft

The 4-seat 2400 lb configuration has turned out to have the highest AEI values, as shown above in Table X and in Fig. 13, in the speed range between 140 and 180 MPH. Also the 4-seat aircraft is the most popular general aviation model to-date; economy, roominess and range are among the most desirable characteristics.

An ideal engine would be the Teledyne Continental GR-36 85 HP rotary unit, with RPM in the area of 7000, a dry weight of 110 lb and a specific fuel consumption of 0.45 lb/HP hr, as reported by DeMeis.[25] As shown in Table IX, the power required @ 180 MPH with 21.0 PSF wing loading is 77.72 HP for AR = 8 and 73.89 for AR = 10 wing.

An assessment should be carried out against the latest and most advanced 4-seat pusher aircraft available today; one such aircraft is the Prescott Pusher, as described by Cox.[26] Table XIII below presents a side-by-side listing of all relevant parameters for the two designs, so as to allow easy comparison.

Table XII Summary of Fuselage Power Ratio

Gross Wt. W_0 lb	800	1200	1400	2400	3200
AR = 10, 15 PSF Wing					
U_0 = 140 MPH	0.390	0.311	0.339	0.273	0.281
U_0 = 160	0.447	0.362	0.391	0.322	0.333
U_0 = 0.487	0.400	0.431	0.358	0.372	
AR = 10, 21 PSF Wing					
U_0 = 140 MPH	0.387	0.308	0.333	0.271	0.281
U_0 = 160	0.463	0.380	0.408	0.342	0.352
U_0 = 180	0.513	0.431	0.487	0.391	0.422
AR = 8, 15 PSF Wing					
U_0 = 140 MPH	0.362	0.285	0.311	0.250	0.260
U_0 = 160	0.431	0.345	0.376	0.309	0.316
U_0 = 180	0.457	0.376	0.404	0.333	0.345
AR = 8, 21 PSF Wing					
U_0 = 140 MPH	0.355	0.279	0.304	0.243	0.253
U_0 = 160	0.431	0.352	0.376	0.311	0.322
U_0 = 180	0.500	0.413	0.441	0.372	0.383

Table XIII Tabulation of 4-Seat Pusher Aircraft Parameters

Parameter	Fuselage/Wake-Propeller	Prescott Pusher
No. of Seats	4	4
Gross Weight, lb	2400	2400
Fuselage Length, ft	22.08	20.25
Fuselage Cross-Section	55" diameter	42" width x 40" ht.
Wing Area, ft^2	114.2	111.0
Wing Span, ft	30.2	29.33
Wing Aspect-Ratio	8.0	7.75
Wing Loading, PSF	21.0	21.6
Power @ Speed	77.72 HP @ 180 MPH 65.13 HP @ 160 MPH 55.53 HP @ 140 MPH	180 HP @ 184 MPH
Engine: Type Power RPM Dry Weight, lb	GR-36 Continental 85 HP 7000 110	0-360 Lycoming 180 HP 2700 257
Fuel Tank	45 gal. = 270 lb	45 gal. = 270 lb
Propeller dia. RPM No. of Blades	26" dia. 7000 8	72" dia. 2700 2
Fuel Consumption	0.45 lb/HP hr	0.42 lb/HP hr
Full Power Fuel Rate	5.82 gal./hr	12.0 gal./hr
Mileage, MPG	30.9	15.3
Range, miles	1390	690

The economy is enhanced by the 85 HP engine against the 180 HP; the roominess is enhanced by the 55" dia. cross-section against the 42" x 40"; the range is increased from 690 to 1300 miles, using the same 45-gal. tank.

The AEI value for the Prescott Pusher @ 184 MPH is 6.5 while it is 15.57 for AR = 10 21 PSF wing and 14.81 for AR = 8 21 PSF wing; it is clear that a very substantial improvement potential has been made available by the NASA fuselage/wake-propeller configuration.

VII. Conclusions

1. The NASA fuselage/wake-propeller configuration, as applied to a matrix of aircraft designs in the 140-180 MPH speed range, has shown conclusively that a 50% power reduction is a practical possibility, for the same gross weight and speed; the basis for this comparison is provided by a survey of 76 general aviation aircraft (Appendix I and II).

2. The propulsive efficiency for the aircraft design matrix ranges from 85% to 96%; this can be substantially improved by elimination of fuselage drag increments induced by the propeller through fuselage shape optimization. This is the area where further theoretical and wind-tunnel research is highly recommended. It can be remembered that conventional tractor aircraft have 65% propulsive efficiencies.

3. While the conventional fuselage accounts for 54% of the total drag and power, the fuselage power of the NASA configuration ranges from 51% down to 24%; this represents a substantial design improvement over conventional practice.

4. The most popular general aviation aircraft is the 4-seat model in the 140-180 MPH speed range. A detailed comparison has been carried out against the 4-seat Prescott Pusher, for the same 2400 lb gross weight and 180 MPH speed, indicating 78 HP against 180 HP, 5.8 gallons/hr against 12.0, 30.9 MPG against 15.3 and 1300 miles range against 690.

5. Clyde McLemore was 20 years ahead of his time; his excellent work will bear fruition now for the general aviation industry.

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APPENDIX I AERODYNAMIC EFFICIENCY INDEX OF U.S. BUSINESS, UTILITY AND PERSONAL AIRCRAFT

Designation	Seats	Gross Wt lb	Max. Power HP	Max. Speed MPH	AEI
BEECH AIRCRAFT CORP.					
C-23 Sundowner	4	2450	180	145	5.26
C-24R Sierra	4-6	2750	200	158	5.77
F-33A Bonanza	4-5	3400	285	198	6.28
V-35B Bonanza	4-5	3400	285	198	6.28
A-36 Bonanza	4-6	3650	300	212	6.86
B-36TC Bonanza	6	3850	300	230	7.85
B-55 Baron	4-6	5100	520	216	5.63
E-55 Baron	4-6	5300	570	230	5.62
58 Baron	4-6	5500	600	239	5.82
58P Baron	4-6	6200	650	256	6.49
58TC Baron	4-6	6200	650	277	7.02
B60 Duke	4-6	6775	760	275	6.52
76 Duchess C/R	4	3900	360	191	5.50
77 Skipper	2	1675	115	121	4.68
CESSNA AIRCRAFT CO.					
152	2	1675	108	122	5.03
152 Aerobat	2	1675	108	122	5.03
172 Skyhawk	4	2407	160	138	5.52
172 Cutlass	4	2558	180	140	5.29
172 Cutlass RG	4	2658	180	161	6.32
182 Skylane	4	3110	230	163	5.86
182 Skylane RG	4	3110	235	180	6.34
Turbo 182 Skylane	4	3100	235	182	6.38
Turbo 182 Skylane RG	4	3112	235	189	7.00
185 Skywagon	6	3362	300	169	5.03
206 Stationair 6	6	3612	300	169	5.41
T-206 Turbo Stationair 6	6	3616	310	192	5.97
207 Stationair 8	8	3812	300	165	5.57
T-207 Turbo Stationair 8	8	3816	310	185	6.05
210 Centurion	6	3812	300	197	6.65
T-210 Turbo Centurion	6	4016	310	226	7.75
P-210 Centurion	6	4016	310	208	7.16
T-303 Crusader	6	5176	500	226	6.22
340-A	6	6025	620	264	6.82
402-C Business Liner	6-10	6885	650	242	6.81
402-C Utililiner	6-10	6885	650	242	6.81
414 Chancellor	6-8	6785	620	258	7.51
421 Golden Eagle	6-8	7500	750	277	7.36
MAULE AIRCRAFT CORP.					
M5-180C	4	2400	180	156	5.53
MS-210TC	4	2500	210	196	6.20
M5-235C	4	2500	235	172	4.86
M6-235	4	2500	235	150	4.24

Designation	Seats	Gross Wt lb	Max. Power HP	Max. Speed MPH	AEI
MOONEY AIRCRAFT CORP.					
M20J201	4	2740	200	201	7.32
M20K231	4	2900	225	231	7.94
PIPER AIRCRAFT CORP.					
PA-28-161 Warrior 2	4	2440	160	146	5.92
PA-28-181 Archer 2	4	2550	180	149	5.61
PA-28RT-201T Arrow 4	4	2990	200	198	7.63
PA-28-236 Dakota	4	3000	235	165	5.60
PA-31-325 Navajo C/R	6	6500	650	253	6.72
PA-31-350 Chieftain	10	7000	700	255	6.78
PA-31P-350 Mojave	7	7200	700	269	7.35
PA-32-301 Saratoga	6	3600	300	173	5.52
PA-32R-301 Saratoga SP	6	3600	300	183	5.84
PA-32R-301T Saratoga SP	6	3600	300	204	6.51
PA-32-301T Turbo Saratoga	6	3600	300	190	6.06
PA-34-220T Seneca 3	6	4750	440	222	6.37
PA-38-112 Tomahawk 2	2	1670	112	127	5.03
PA-46-310P Malibu	6	4100	310	209	7.35
PA-60-602P Aerostar	6	6000	580	284	7.81
PA-60-700P Aerostar	6	6315	700	302	7.24

NOTE: Weights, Powers and Speeds quoted from: Aviation Week & Space Technology, March 12, 1984, p. 144.

APPENDIX II AERODYNAMIC EFFICIENCY INDEX OF U.S. SPORT AND HOME-BUILT AIRCRAFT

Designation	Ref.	Seats	Gross Wt lb	Max. Power HP	Max. Speed MPH	AEI
Taylor Mini-Imp	(1)	1	800	60	150	5.33
Taylor Bullet	(2)	2	1650	100	150	6.60
Swearingen SX-300	(3)	2	2400	300	276	5.88
Falco	(4)	2	1808	160	212	6.38
Windex 1100	(5)	1	506	22	125	7.66
Moni	(6)	1	500	22	120	7.27
Moni Tri-Gear	(7)	1	560	22	115	7.80
Prescott Pusher	(8)	4	2400	180	184	6.50
Whisper	(9)	2	1800	160	225	6.75
Star-Lite	(10)	1	500	40	120	4.00
Silhouette	(11)	1	700	44	120	5.09
Lancair (Lancer) 200	(12)	2	1275	100	213	7.24
Glasair FT-180	(13)	2	1700	180	240	6.04
Sparrow Hawk MK II	(14)	2	1000	50	110	5.86
Cozy	(15)	2	1500	118	187	6.80
Whitehawk-65	(16)	2	950	65	157	6.12
Whitehawk-100	(17)	2	1250	100	182	6.06

NOTE: Weights, Powers and Speeds are quoted from the following sources as listed below.

(1) Sport Aviation, August 1984, p. 24.
(2) Homebuilt Aircraft, May 1986, p. 24.
(3) Homebuilt Aircraft, October 1985, p. 29.
(4) Homebuilt Aircraft, August 1985, p. 27.
(5) Builder's specifications.
(6) Builder's specifications.
(7) Builder's specifications.
(8) Homebuilt Aircraft, May 1986, p. 62.
(9) Sport Aviation, March 1986, p. 47.
(10) Sport Aviation, April 1986, p. 20.
(11) Sport Aviation, March 1985, p. 42.
(12) Sport Aviation, April 1985, p. 14.
(13) Sport Aviation, August 1985, p. 15.
(14) Sport Aviation, June 1985, p. 52.
(15) Homebuilt Aircraft, April 1986, p. 29.
(16) Builder's specifications.
(17) Builder's specifications.

NOTE: 76 aircraft see listed in Appendix I and II. Category AEI between 4 and 5 has 4 aircraft or 5.2% ... Category AEI between 5 and 6 has 26 aircraft or 34.2% ... Category AEI between 6 and 7 has 28 aircraft or 36.8% ... Category AEI between 7 and 8 has 18 aircraft or 23.6% ... The lowest AEI value is 4.50 and the highest 7.94.

APPENDIX III WING PARAMETERS OF U.S. BUSINESS, UTILITY, PERSONAL SPORT & HOME-BUILT AIRCRAFT

Designation	Wing Aspect Ratio	Wing Loading PSF	Power Loading lb/HP	Wing Lift Coeff.	
				C_L @ S.L. @ Max. Speed	C_L @ 6000 ft
BEECH AIRCRAFT CORP.					
C-23 Sundowner	7.36	16.78	13.60	0.300	0.359
C-24R Sierra	7.36	18.83	13.75	0.280	0.335
F-33A Bonanza	6.20	18.78	11.92	0.185	0.221
V-35B Bonanza	6.20	18.78	11.92	0.185	0.221
A-36 Bonanza	6.20	20.16	12.16	0.173	0.207
B-36TC Bonanza	7.60	20.47	12.83	0.148	0.177
B-55 Baron	7.17	25.60	9.80	0.211	0.252
E-55 Baron	7.17	26.60	9.30	0.192	0.230
58 Baron	7.17	27.60	9.16	0.184	0.220
58P Baron	7.59	32.96	9.53	0.191	0.228
58TC Baron	7.59	32.96	9.53	0.165	0.197
B60 Duke	7.21	31.82	8.91	0.159	0.190
76 Duchess C/R	7.97	21.54	10.83	0.229	0.274
77 Skipper	6.92	12.88	14.50	0.338	0.404
CESSNA AIRCRAFT CO.					
151	6.88	10.46	15.50	0.271	0.324
152 Aerobat	6.93	10.46	15.50	0.271	0.324
172 Skyhawk	7.44	13.83	15.00	0.282	0.337
172 Cutlass	7.44	14.70	14.20	0.291	0.348
172 Cutlass RG	7.44	15.27	14.70	0.228	0.273
182 Skylane	7.44	17.87	13.50	0.258	0.308
182 Skylane RG	7.44	17.84	13.20	0.212	0.253
Turbo 182 Skylane	7.44	17.81	13.10	0.207	0.248
Turbo 182 Skylane RG	7.44	17.88	13.20	0.173	0.207
185 Skywagon	7.44	19.32	11.20	0.259	0.310
206 Stationair 6	7.44	20.75	12.00	0.278	0.332
T-206 Turbo Stationair 6	7.44	20.78	11.60	0.218	0.261
207 Stationair 8	7.44	21.90	12.70	0.308	0.368
T-207 Turbo Stationair 8	7.44	21.93	12.30	0.246	0.294
210 Centurion	7.73	21.78	12.70	0.218	0.261
T-210 Turbo Centurion	7.73	22.94	12.90	0.172	0.205
P-210 Centurion	7.73	22.94	12.90	0.203	0.243
T-303 Crusader	8.03	27.35	9.70	0.205	0.245
340-A	7.93	32.74	9.20	0.178	0.213
402-C Business Liner	8.61	30.49	10.60	0.200	0.239
402-C Utiliner	8.61	30.49	10.60	0.200	0.239
414 Chancellor	8.61	30.04	10.90	0.171	0.204
421 Golden Eagle	9.48	33.18	10.00	0.165	0.197
MAULE AIRCRAFT CORP.					
M5-180C	6.04	15.20	13.30	0.241	0.288
M5-219TC	6.04	15.80	11.90	0.159	0.190
M5-235C	6.04	15.80	10.60	0.205	0.245
M6-235	6.37	14.40	10.60	0.248	0.297
MOONEY AIRCRAFT CORP.					
M20J201	7.44	15.60	13.70	0.148	0.177
M20K231	7.44	16.50	13.80	0.118	0.141

Designation	Wing Aspect Ratio	Wing Loading PSF	Power Loading lb/HP	Wing Lift Coeff.	
				C_L @ S.L. @ Max. Speed	C_L @ 6000 ft
PIPER AIRCRAFT CORP.					
PA-28-161 Warrior 2	7.20	14.30	15.20	0.260	0.311
PA-28-181 Archer 2	7.20	15.00	14.10	0.258	0.308
PA-28RT-201T Arrow 4	7.37	17.00	14.50	0.168	0.201
PA-28-236 Dakota	7.37	17.60	12.70	0.247	0.295
PA-31-325 Navajo C/R	7.23	28.30	10.00	0.168	0.201
PA-31-350 Chieftain	7.23	30.50	10.00	0.178	0.213
PA-31P-350 Mojave	8.35	30.30	10.28	0.159	0.190
PA-32-301 Saratoga	7.35	20.20	12.00	0.258	0.308
PA-32R-301 Saratoga SP	7.35	20.20	12.00	0.232	0.278
PA-32R-301T Saratoga SP	7.35	20.20	12.00	0.187	0.223
PA-32-301T Turbo Saratoga	7.35	20.20	12.00	0.217	0.260
PA-34-220T Seneca 3	7.25	22.70	10.80	0.177	0.212
PA-38-112 Tomahawk 2	9.27	13.40	14.90	0.319	0.382
PA-46-310P Malibu	10.56	23.40	13.20	0.123	0.147
PA-60-602P Aerostar	7.56	33.70	10.34	0.160	0.191
PA-60-700P Aerostar	7.56	35.40	9.02	0.147	0.176
SPORT & HOME-BUILT					
Taylor Mini-Imp	8.25	10.75	13.30	0.185	0.222
Taylor Bullet	8.25	11.78	23.50	0.200	0.239
Swearingen SX-300	8.32	33.60	8.00	0.168	0.201
Falco	6.40	16.81	11.30	0.143	0.171
Windex 1100	16.20	6.34	23.00	0.158	0.189
Moni	10.00	6.66	22.70	0.180	0.215
Moni Tri-Gear	10.00	7.46	25.45	0.219	0.262
Prescott Pusher	7.60	21.60	13.30	0.247	0.296
Whisper	7.10	22.20	11.25	0.170	0.204
Star-Lite	8.10	8.77	12.00	0.237	0.284
Silhouette	12.90	9.33	15.90	0.252	0.301
Lancair (Lancer) 200	7.27	16.80	12.75	0.142	0.170
Glasair FT-180	6.65	20.90	9.44	0.139	0.166
Sparrow Hawk MK II	8.25	7.14	20.00	0.226	0.270
Cozy	7.12	15.60	13.60	0.174	0.208
Whitehawk-65	9.00	6.78	14.60	0.106	0.127
Whitehawk-100	9.00	8.93	12.50	0.105	0.125