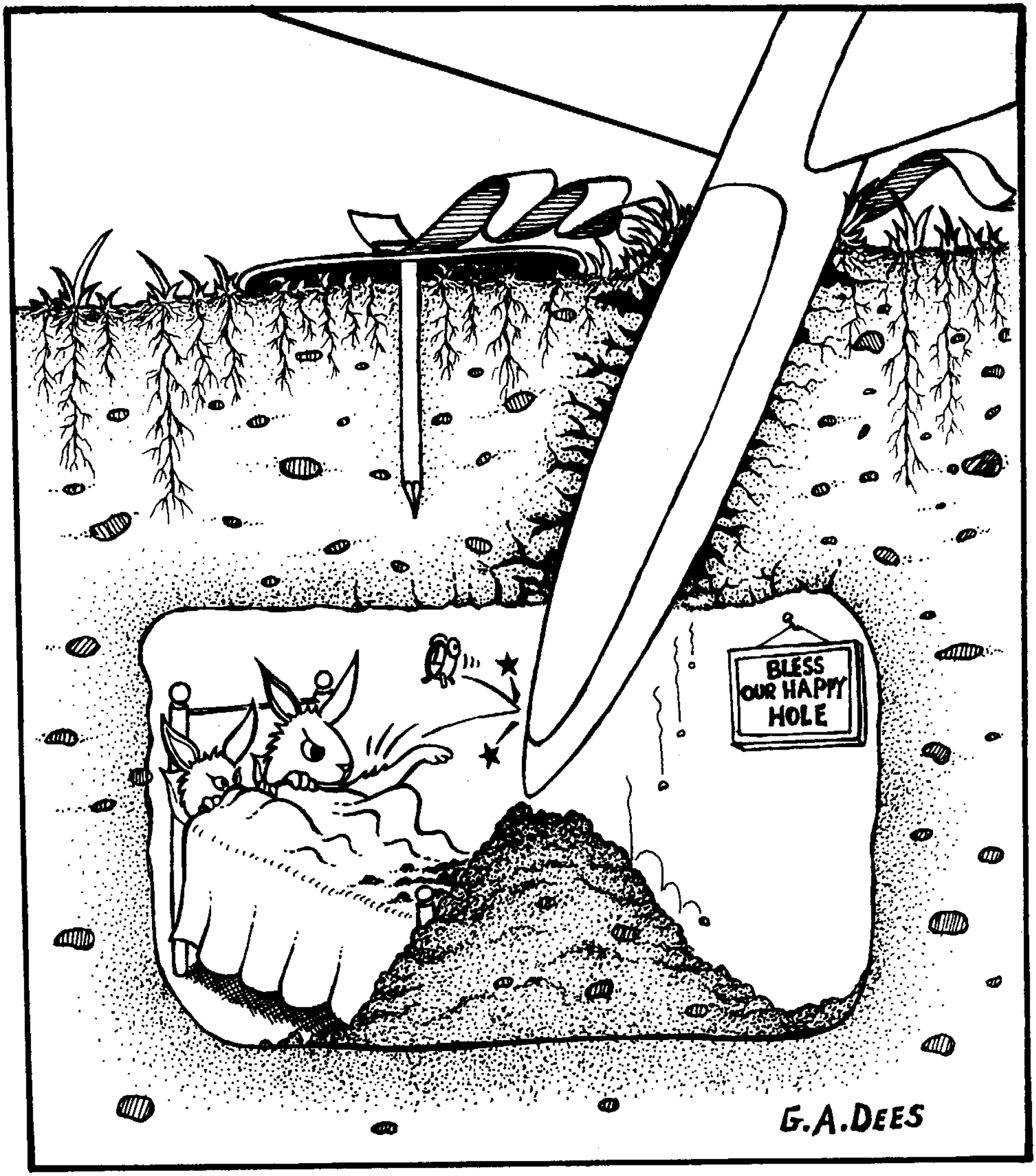
SOARTECH #6



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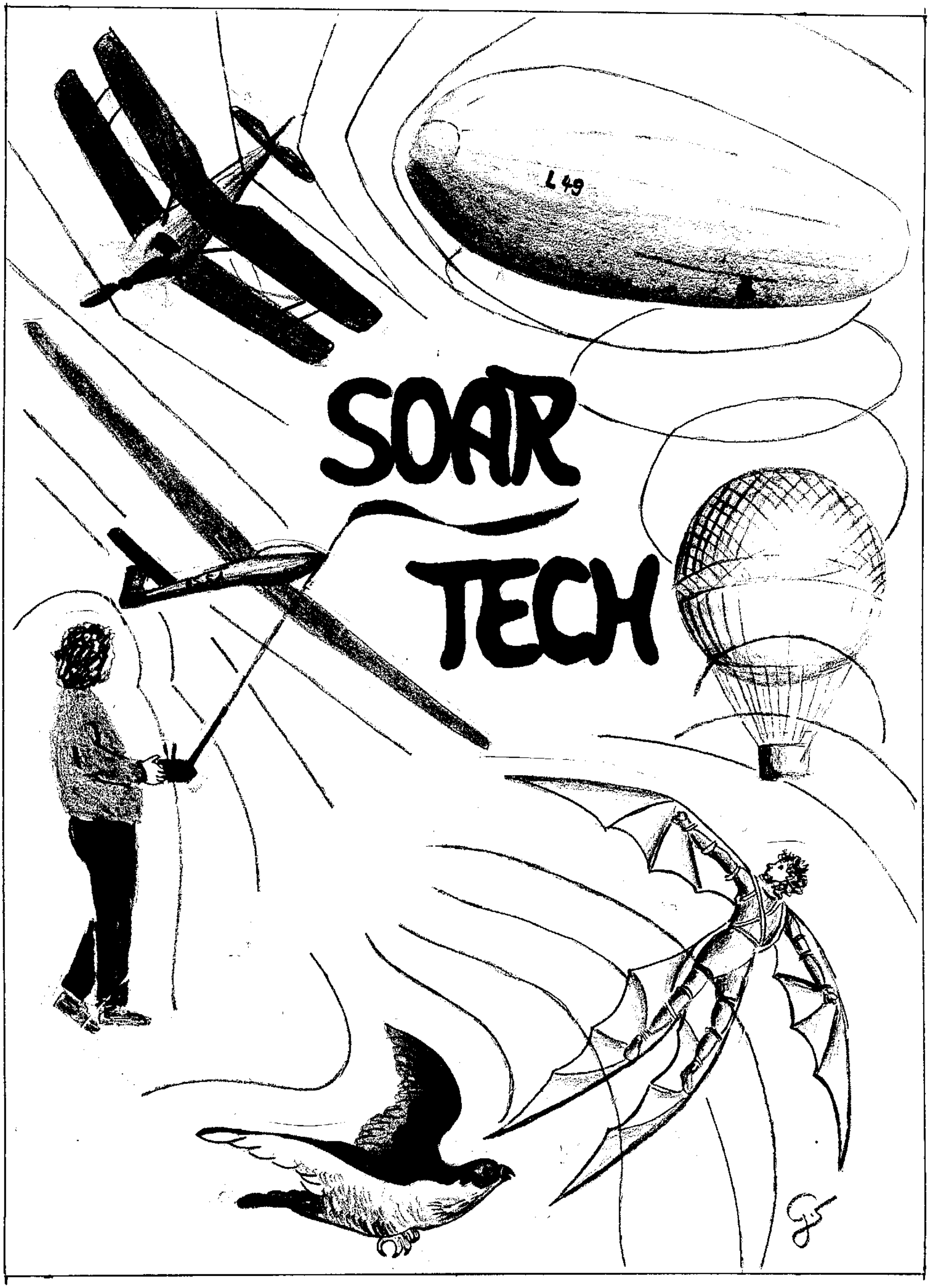
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SOARTECH JOURNAL

"SoarTech", began in 1978 as a series of technical papers in the Tidewater Model Soaring Society newsletter which we called the TMSS Technical Journal. With encouragement and ideas from Jim Gray and Bruce Abell, it began to be published by TMSS as the "SoarTech" Journal. It is an English language technical forum for Radio Control Soaring; containing papers submitted by interested modelers, and from other publications. It's intended to provide a vehicle for the publication of information and data which is too lengthy or too technical for publication in the popular press.

It is now edited, published and distributed by H. A. (Herk) Stokely, 1504 North Horseshoe Circle, Virginia Beach VA 23451 Phone (804) 428-8064. The mission and purpose of SoarTech is to make available to RC Soaring enthusiasts (and others), technical information and data that may not be available from other sources.

PAPERS INCLUDED IN THE SIXTH ISSUE

SOARTECH JOURNAL
c/o H A (HERK) STOKELY
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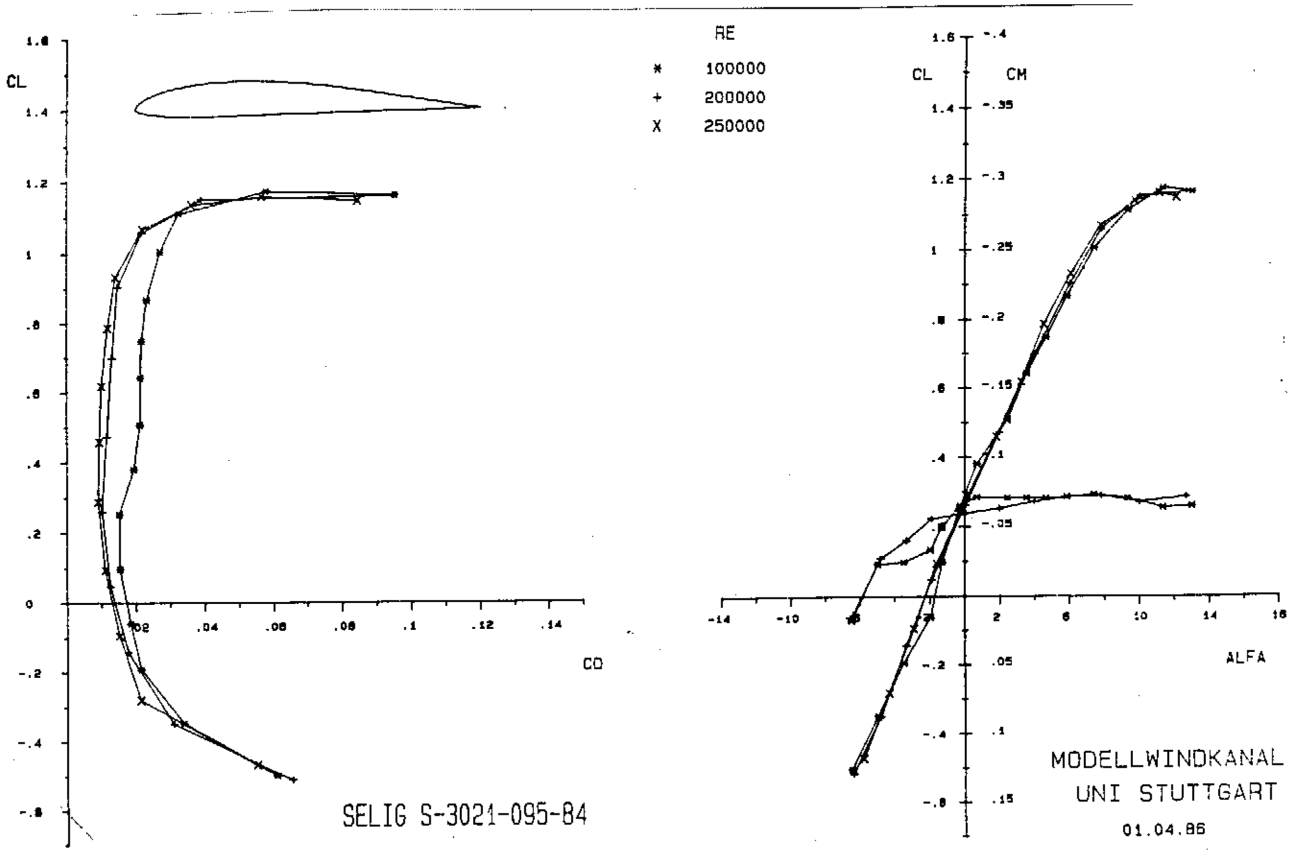
MICHAEL SELIG BEGINS WIND TUNNEL RESEARCH AT PRINCETON

The following letter is the kickoff of a project by, Michael Selig, which should be very exciting to readers of SOARTECH. The letter is quite self-explanatory, and I won´t waste your time by doing a long preamble. I expect the results of this research to make up Soartech 8 which I´ll publish as soon as Michael finishes his work. Not included in his letter is the fact that Michael needs some financial help to get the most out of this opportunity. If you want to be a part of it write him directly. Since Michael will be leaving Princeton this summer, you´ll have to move quickly to get in on the support.



1/10/87
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LOW REYNOLDS NUMBER AIRFOIL TEST AT PRINCETON UNIVERSITY

I am searching for a group of experienced modelers to build a variety of wind tunnel models for tests at Princeton University. John Donovan, my co-worker, and I have fully insturmented a large, low-speed, low-turbulence wind tunnel to take accurate measurements of lift and drag on airfoils at low Reynolds numbers, but we lack a generous supply of wind tunnel models. If you can help us, it will be acknowledged in the final report to be published in Soartech and any other publications which may follow. Also during the tests, our preliminary results will be mailed directly to you as they become available.

For several years now I have wanted to set aside a large block of time and money to test airfoils specifically for R/C sailplanes, but could not escape from my academic responsibilities or find the support, until now. For this I have Prof. Smits, my thesis advisor, and Prof. Curtiss to thank. Also, without the experimental expertise of John Donovan this whole endeavor would have remained just talk. To take full advantage of this unique situation we need your help.

We want to test thirty or more airfoils. Our goal is ambitious but possible. We will be limited only by the number of wind tunnel models we receive. Unlike previous tests by others, the focus of our experiments will be not only on testing known airfoils but also on developing by experiment a new and better class of airfoils for R/C sailplanes. This we are sure to achieve since the project will be done on such a large scale. Without your support, progress in this area will remain slow. With it we can settle many issues and ultimately accelerate the quality of our sport.

The wind tunnel models will be 33 5/8" in span with a 12" chord and can either be built-up or foam core. For built-up models two plots of the 12" chord airfoil will be plotted by Doug Dorton and supplied to you. So that the contour is true, they need to be fully sheeted. To be consistent, we would like to have them covered with Super-monokote. For foam core models, two 12" chord wing templates laser cut by Lee Murray with funding from Ray Olsen can be supplied; however, there may be a short delay. The surface finish can be either fiberglass or monokote, although fiberglass is prefered for its durability.

The models attach to the wind tunnel balance by standard model wing rods. The details are given on the enclosed drawings. As for the strength, they should be able to support 15-20 lbs lift when pinned at both ends. Standard model construction techniques will provide the neccessary strength, especially when sheeted.

I have enclosed a drawing of our wind tunnel. It is capable of speeds up to 45 ft/sec. So for the one foot chord we can test up to 300,000 in Reynolds number. As the drawing reveals, this is a large wind tunnel and therefore highly suitable for testing models with small forces. We have measured the turbulence (using a hot-wire) to be .0003 (.03%) at 3.5 ft/sec and .0012 (.12%) at 36.5 ft/sec. With the improvements that we are making, this already low-turbulence level should decrease.

The following is a tentative list of airfoils that we plan to test along with a brief description of our motive for testing it. If you feel the we have left out an important airfoil, please write to us.

CLARK-Y

No matter where you look this airfoil seems to crop up. When this airfoil was tested by Althaus it showed a very low drag - lower than that predicted by Eppler. I would like to know who is right and so would Stan Watson who has already started construction on a CLARK-Y wind tunnel model.

E193

The main reason for testing this one is to compare the results with Althaus' tests.

E205

The 205 is basically a decambered 193 so it should perform similarly, but with lower lift. This is what we expect but will it be shown by experiment. I wonder also if the 205 is truly as good as its fame suggests or is it sheer momentum that keeps it going.

E214

After seeing this airfoil on the Windsong, I have been curious about it ever since. Right away the shape of this airfoil should tell you something. It is not designed like the rest of the Eppler pack (193, 201, 203, 205, 207, 209, 385, 387) with the exception of the 211. It needs to be stripped off the mighty Windsong's back and inspected more closely.

FX 60-100

Like the CLARK-Y, this airfoil came in with flying colors when tested by Althaus and did better than predicted by Eppler. Is there something special about the FX 60-100 and the CLARK-Y or have we entered into the world of experimental error? Furthermore, why isn't this airfoil popular since it has such low drag experimentally compared with other more popular airfoils.

HQ 1.5/9.0 & 2.5/9.0

These airfoils impress people and I want to know why. From what Quabeck has published, these airfoils were not designed in any sophisticated way. Apparently they were designed like the old NACA series airfoils, except this time Quabeck did it without a wind tunnel! I would like to shed some light on this very grey area.

MB253515

This airfoil has always had my attention. If anything the intense E205 vs. MB253515 debate of the 80's started my interest in airfoils. Guided by the Eppler analysis of these two airfoils, I thought those on the 15% thick side were 100% crazy because they really believed that thicker was better. Now, however, after comparing an inadequate theoretical model with experiment for airfoil after airfoil, I'm not so quick to believe the Eppler results anymore. It is time to put the two in a wind tunnel and compare them without bias. I have a hunch that the MB does have some surprises in store for us.

S2027

This airfoil is a redesigned MB253515, but is it better as theory suggests? Can you believe the theory for this airfoil? From the letters I have received it seems just as good or better, but only experiment can say for sure.

S3002

I have been told by a reliable source that this airfoil won't get out of its own way! I'd like to get this one in a wind tunnel and re-evaluate the reliability of my source - no hard feelings.

S3021

This airfoil was designed to be an improvement over the E205. From the recent wind tunnel tests by Althaus on this airfoil and flight tests on the Algebra 2.5 m equipped with this airfoil, it seems to have accomplished its goal. But to be more certian, Althaus needs to test the 205 for comparison. In any event, we plan to test them both here at Princeton to convince ourselves.

S4061

Is this a thoroughbred or could Paul Carlson fly a flat-plated Prodigy at any NATS and win? After building and flying a Prodigy of my own, I think it's a super airfoil/plane with a great L/D that must come from the airfoil. If this doesn't show up in wind tunnel tests we are all in trouble.

S4062

This is a new lower drag, higher Rn version of the 4061 for large cross-country sailplanes. According to the Eppler program, it is possible to design an airfoil with lower drag and a higher L/D than this new one. Is this true in the real world however? Only by wind tunnel experiments can we push and find the limits. The 4062 is a start and will be the first candidate in this new line of nonconservative airfoils. Stan Watson has started construction on this one too.

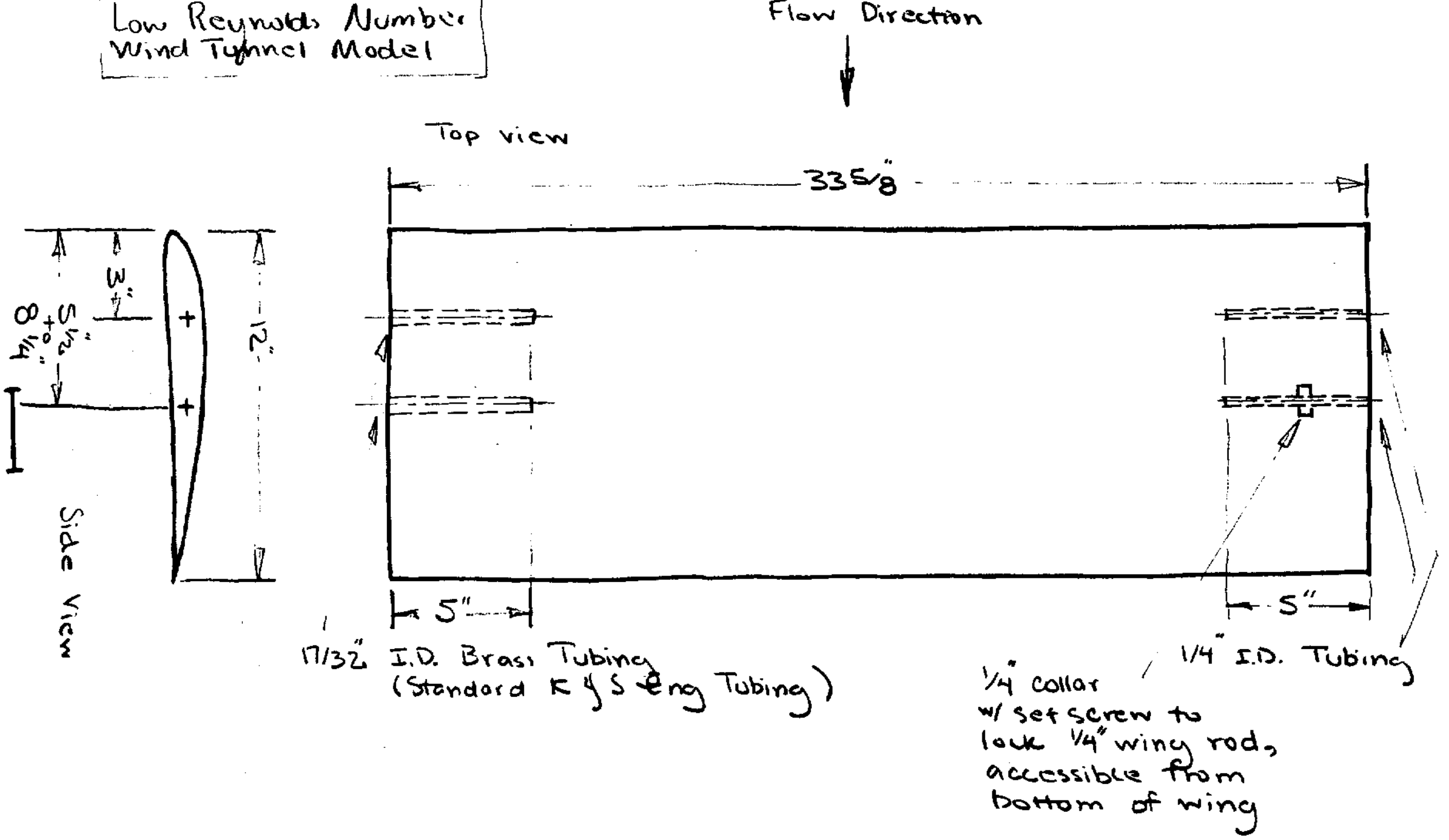
If you would like to contribute to our efforts, either by building models or in any other way, please write or call. The sooner the better. I plan on finishing at Princeton by July 87; so there is not much time to complete all that we want to do. In any case would you please indicate your interest on the enclosed self-addressed postcard and mail it back to me. This way I will have some feeling as to what we can expect and can plan accordingly. If you like, feel free to circulate this letter on to someone who might have an interest in our plans.

Sincerely,

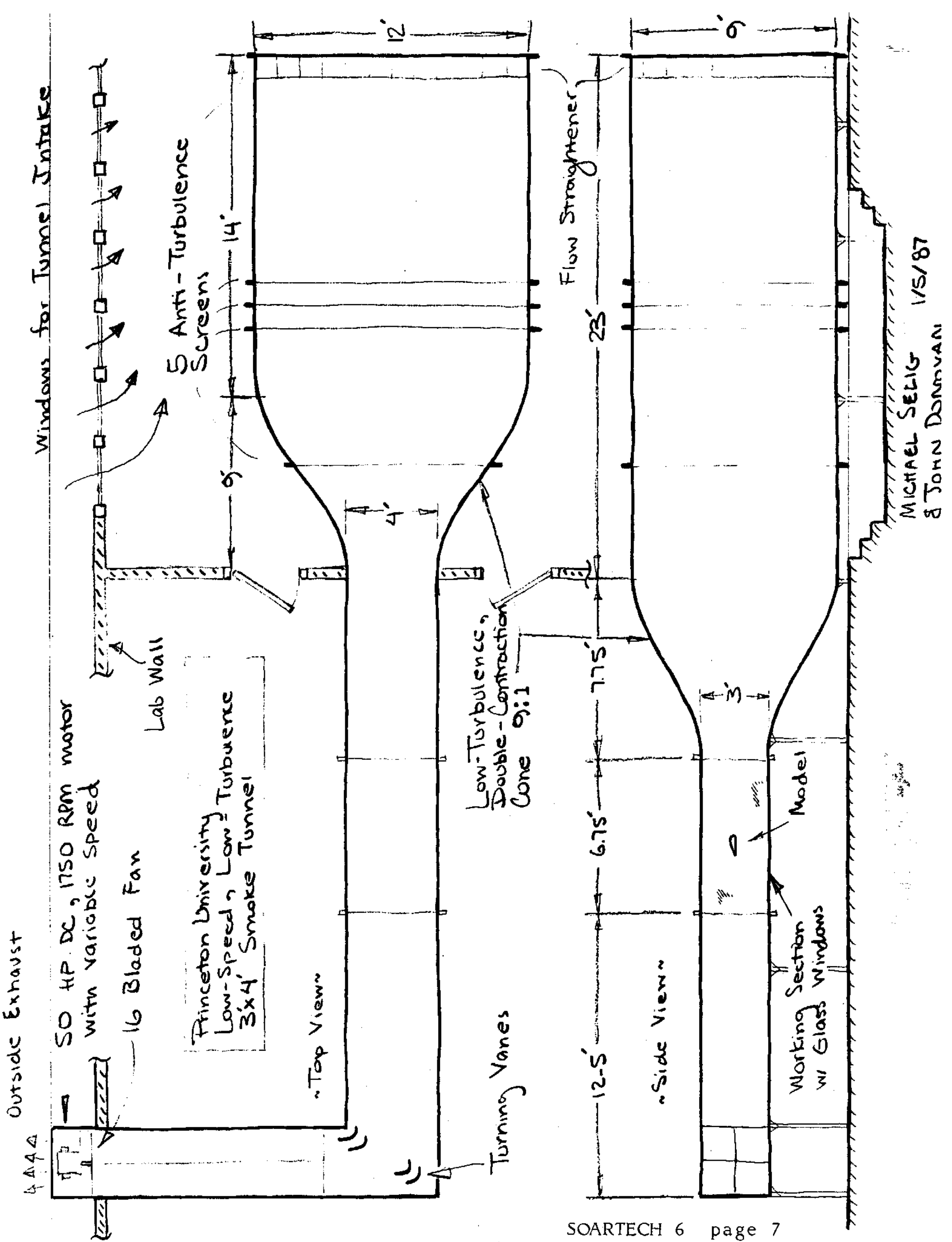
MICHAEL SELIG

Michael Selig

Low Reynolds Number Wind Tunnel Model



MICHAEL SELIG & JOHN DONOVAN 1/5/87


Windows for Tunnel Intake
12'
14'
9'
5 Anti-Turbulence Screens
Flow Straightener
9'
23'
4'
Lab Wall
Outside Exhaust
50 HP DC, 1750 RPM motor with variable speed
16 Bladed Fan
Princeton University Low-Speed, Low-Turbulence 3'x4' Smoke Tunnel
"Top View"
Turning Vanes
Low-Turbulence, Double-Contraction Cone 9:1
7.75'
3'
Model
6.75'
12.5'
"Side View"
Working Section w/ Glass Windows
MICHAEL SELIG & JOHN DONOVAN
1/5/87

GERMAN - ENGLISH and ENGLISH - GERMAN DICTIONARY OF SOARING TERMS

Armin Saxer has worked up this invaluable dictionary of Aeronautical and RC Soaring terms for people who read one of these languages but not the other. So much of what is interesting and new in Soaring comes from countries where German is the principal language. This will help anyone who is trying to keep abreast of new developments in soaring.

A	A
abdrehen	veer off
Abendthermik	evening thermal
Abfangen	flattening out, righting
Abheben	take- off
Ablaufseite eines Profiles	trailing edge of an airfoil
ablenken	deflect
Ablenkung von Luft	deflection of air
Abloeseblase	separation bubble
abloesen	separate, detach
Abloesung der Stroemung	flow separation
Abloesung,laminar	laminar separation
Abloesungspunkt	separation or transition point
Abmessungen	measurements,over-all dimensions
Abreissen	change from laminar to turbulent flow
Abriss bei hoher Geschwindigkeit	stall at high speed
Abriss oder Abreissen der Stroemung	stall
Abrisswinkel	stall angle
Abwind	downcurrent, sinking air, sink
Abwind	descending air current, downwash
Abwindgebiet	downwind area
Abwindwinkel	downwash angle
Abwindwirkung	downwash effect
Achse	axis
Aehnlichkeit	similarity,resemblance
Aerodynamik	aerodynamics
aerodynamisch	aerodynamic
aerodynamische Grundgleichung	basic equation of aerodynamics
aerodynamische Rolldaempfung	aerodynamic damping of roll
aerodynamische Schraenkung	aerodynamic washout
aerodynamische Theorie	aerodynamic theory
aerodynamische Waage	windtunnel balance
Aeroelastizitaet	aero- elasticity
Aeronautik	aeronautics
aeronautische Wetterkunde	aerology
aerophysikalisches Messverfahren	method of aerophysical measurement
Akkumulator	rechargeable battery pack
Anblasegeschwindigkeit	velocity of air flow
Anblasrichtung	direction of airflow
Anblaswinkel	air flow angle
Anemomesser	anemometer
Anstellwinkel	angle of attack, angle of pitch
Anstellwinkel reduziert durch Abwind	angle of attack reduced by downwash
Anstellwinkel,aerodynamisch	angle of attack,aerodynamic
Anstellwinkel,geometrisch	angle of attack,geometric
Anstellwinkel,wahrer	true angle of attack
Anstellwinkelsteigung	slope of the lift curve
Antenne	antenna (USA), aerial (Brit.)
Aufbau	structure,system,arrangement,setup
aufsteigen	climb, rise, ascend
aufsteigender Luftstrom	upwind, upcurrent
Aufteilen von Kraeften in Komponenten	resolution of forces in components
Auftrieb	lift, aerodynamic lift
Auftrieb des ganzen Modelles	lift of the whole model
Auftrieb, schwach	lift, weak
Auftrieb-Widerstands-Verhaeltnis	lift to drag ratio
Auftriebsachse	lift axis
Auftriebsbeiwert	lift coefficient
Auftriebsbeiwert lokal	section lift coefficient
Auftriebsbeizahl	lift factor
Auftriebskraft	lifting force
Auftriebsmittelpunkt	center of lift
Auftriebsrichtung	direction of lift
Auftriebsschwankung	lift change or variation
Auftriebsverteilung	lift distribution
Aufwind	upcurrent, ascending air current
Ausbrechen beim Start	swing on take- off
auswiegen des RC- Seglers	balance the RC sailplane
B	B
Ballast	ballast
Ballastrohr	ballast tube
Ballasttank	ballast tank
Balsaholz	balsa wood
Bart (lokaler Aufwind)	patchy lift
Baugenauigkeit (des Modells)	accuracy of construction (of model)
Baukasten	kit
Befestigung	fixture
Beiwert (z.B. fuer Auftrieb)	coefficient (for example of lift)
Beiwert fuer induzierten Widerstand	induced drag coefficient

Beiwert fuer Luftkraft	coefficient for air reaction
bemanntes Segelflugzeug	full- sized or manned sailplane
beplanken	to cover with
Beplankung (der Tragflaeche)	covering, planking, sheeting(of wing)
berechnen	compute, calculate, estimate
berechnete Polare	computed polar curve
Berechnung	computation, calculation, estimation
Berechnung, zahlenmaessig	numerical calculation
Bereich	area, zone, range
Bereich des geringen Widerstandes	low drag range
Bernoulli's Lehrsatz	Bernoulli's theorem
beschleunigen	accelerate, speed up
Beschleunigung	acceleration, speeding up
Bespannung (der Tragflaeche)	covering or skin of fabric (of wing)
Bespannungseinfallen	tissue sag
Bestimmungsstueck, Einflussgroesse	parameter, characteristic
Beulfestigkeit	buckling strength
Beulsteifigkeit	buckling stiffness
bewegen	move
beweglich	movable, mobile, portable
Bewegung	movement, motion
Bewegungsgesetz	law of motion
Biegefestigkeit	bending strength
Biegesteifigkeit	bending or flexural stiffness
Bilanz (der Widerstaende)	budget (of drags)
Boden	ground, soil, earth
Bodeneinfluss	ground effect
Bodenstart	rise off ground
Boe	gust, sqall, bump
Bowdenzug	Bowden wire,control cable
Bremsfallschirm	drag or braking parachute
Bremsklappe	air brake, air deflector, air flap
Bruchfestigkeit	ultimate strength
C	C
Celsius (C)	centigrade
charakteristische Eigenschaft	characteristic property
D	D
Daempfer	stabilizer
Daempfung	damping, stabilization
Daempfungsflaeche	damping surface
Dauerfestigkeit	endurance limit
Dauerflug	duration flight
Dehnung	elongation, extension
deltafoermig	delta shaped
Deltakonstruktion	delta layout
destabilisierende Wirkung	destabilizing effect
Diagramm	diagram, curve, graph
Diagrammschreiber	diagram recorder
Dichte (z.B. der Luft)	density, mass density (for ex.of air)
Dickenverteilung eines Profils	thickness form of an airfoil
Differenzierung der Querruder	ailerons differential
Dimension (Ausmessung, Mass)	dimension, size
Distanzflug	distance flight
Doppeldecker	biplane
Doppelseitenruder	twin fins
Drehfestigkeit	torsional or twisting strength
Drehmoment	torque, twisting moment
Drehmoment der Luftschraube	propeller torque
Drehrichtung	direction or sense of rotation
Drehsteifigkeit	torsional rigidity or stiffness
Drehzahl	number or rate of revolutions
Druckfestigkeit	compressive strength
Druckminimum	minimum pressure
Druckpunkt, Druckmittelpunkt	center of pressure
Druckpunktwanderung	shift of center of pressure
Druckwiderstand	pressure drag
Dynamik	dynamics
dynamisch	dynamic
dynamische Instabilitaet	dynamic instability
dynamischer Segelflug	dynamic soaring
dynamisches Gleichgewicht	dynamical equilibrium
E	E
Eigenstabilitaet	inherent stability
Einfliegen	trial flight
Einstellung	setting, trim, adjustment
Einstellwinkel	angle of incidence, rigging angle
Einstellwinkelbereich	angle of incidence range
Einstellwinkeldifferenz	difference of angle of incidence
Einstellwinkeldifferenz, laengs	longitudinal dihedral or decalage
Einstellwinkelsteuerung	angle of incidence control

Elastizitaetsgrenze	elastic limit
Elastizitaetsmodul	modulus of elasticity
elektrisch angetrieben	electric- powered
elektrische Bohrmaschine	electric drill
Elektroantrieb	electric propulsion or power
elliptische V- Form	elliptical dihedral
Endleiste	trailing edge
Endscheibe (von Tragflaeche)	end plate (of wing)
Endscheibe am Leitwerk	vertical fin
Entenflugmodell	canard model sailplane
Entwurf	design, draft, scetch, outline
Epoxydharz	epoxy resin
Erdbeschleunigung	acceleration due to gravity
Ermuedungsriss	fatigue cracking
Experiment	experiment, test
experimentelle Arbeit	experimental work
F	F
F.A.I.- Sportgesetz	F.A.I. sporting code
F3B- Wettbewerb	F3B competition or contest
Fahrtwind	relative wind
Faktor fuer induzierten Widerstand	factor of induced drag
Fallboe	air pocket, descending or down gust
Fallschirmflugbremse	parachute airbrake
Fallwind	down draft, down gust of wind
Fassrolle	dutch roll
Fehlstart	faulty launch
Fernlenkflug	radio controlled flight
Fernlenkmodell	radio controlled model
Fernsteuerung	radio control, remote control
Fertigmodell	finished model
Flaeche	area, zone
Flaeche (Oberflaeche)	area, surface, plane
Flaeche, Tragflaeche, Fluegel	wing
Flaechenbelastung linear	span loading
Flaechenformzahl	planform number
Flaechenmittelpunkt	center of lateral area
Flaechensehne	wing chord
Flaechentiefe, mittlere	cord, mean chord
Flaechentiefezahl	chord number
Flattern (z.B. der Tragflaeche)	flutter (for example of wing)
fliegen- flog- geflogen	fly- flew- flown
Flosse (fester Leitwerkteil)	fixed or stabilizing surface
Fluegelbauart	wing design
Fluegelbefestigung	wing fixing
Fluegelflaeche, veraenderlich	variable wing surface
Fluegelnase	leading wing edge
Fluegelstrak	wing loft
Fluegelumriss	wing contour or plan
Flug	flight or flying
Flugapparat	flying machine or device
Flugaufgabe	flight task, flight mission
Flugausbildung	flight training
Flugbahn	flight path
Flugbahn, gerade	flight path, straight
Flugbereich	flight envelope
Flugbremse, eingebaut	airbrake under surface
Fluggeschwind.,waagerechte Komponente	flight speed, horizontal component
Fluggeschwindigkeit	speed of flight, flight velocity
Fluggeschwindigkeit, horizontal	ground speed
Fluggeschwindigkeit,senkrechte Komp.	flight speed, vertical component
Fluggewicht	gross loading, flight weight
Flughoehe	flight altitude or height
Fluglehre	aerodynamics, theory of flight
Flugleistung	flying performance
Flugmechanik	mechanics of flight
Flugmodell	flying model, glider model
Flugmodellbau	airplane model construction
Flugmodellsport	model- airplane flying
Flugmodellwettbewerb	model- aircraft competition
Flugsicht	flight visibility
Flugverhalten	attitude of flight
Flugwetter	flying weather
Flugwetterkunde	aeronautical meteorology
Flugwind	relative wind for flying
Flugwinkel	angle of flight
Flugzeugart	type of aircraft
Flugzeugschlepp	towing by aircraft
Flugziel	flying or air target
Flugzustand	flight condition
Form, Giessform	mo(u)lding

formen, giessen	mo(u)ld
Formgebung	design, profiling
Formwiderstand	form or pressure drag
freier Fall	free fall
Freiflugmodell	free flight model
Frise- Querruder	Frise ailerons
Fuehrerraum	pilot's cockpit
Funkempfaenger	receiver
Funkfernsteuerung	radio control, radio telecontrol
Funksender	transmitter
G	G
G- Kraefte	G- forces
Gaskonstante	gas constant
gebundener Wirbel	bound vortex
Gegensteuern in Kurve	top aileron or 'top rudder' in a bank
gekoppelte Quer- und Seitenruder	coupled ailerons and rudder
gemahlene Faserverstaerkung	milled fibers
geometrische Schraenkung	geometric washout
geometrischer Abrisswinkel	geometric stall angle
Gesamtflaeche (Fluegel und Leitwerk)	total area (wing and tailplane)
Gesamtwiderstand	total drag
Geschwindigkeit	velocity, speed
Geschwindigkeit, relativ	ground speed
Geschwindigkeitsflug	flight at high velocity
Geschwindigkeitspolare	speed polar
Geschwindigkeitsspanne	speed range
Geschwindigkeitsverlauf am Profil	velocity profile on airfoil
Gewicht	weight
Gewicht des Modelles	model weight, model mass
Gewichtsersparnis	saving in weight
Gewichtsformel	weight formula
Gewichtsfunktion	weight function
Gewichtskomponente	weight component
Gewichtstrimmen	trimming by weights
Gewichtszahl	weight number, weight factor
gewoelbte Platte	curved plate
Giermoment	yawing moment
Gierschwingung	yawing, oscillatory yaw
Gierwinkel oder Gierungswinkel	yawing angle, angle of yaw
Glasfasergewebe	fiber glass cloth
Glasfasern	fiberglass or glass fiber
glasfaserverstaerkter Kunststoff	glass reinforced plastic
gleiches Gewicht	equal weight
gleichfoermige Geschwindigkeit	constant speed
Gleichgewicht und Lage- Einstellung	balance and trim
Gleichgewicht, statisch ,dynamisch	equilibrium, static, dynamic
Gleit- (oder Flug-) Geschwindigkeit	gliding speed or flight velocity
gleiten	glide
Gleitflug	gliding flight
Gleitflugzeug	glider
Gleitverhaeltnis	lift to drag ratio
Gleitwinkel	angle of glide or descent
Gleitzahl	glide ratio
Gleitzahl, flachste	flattest glide
Gleitzahl,grosse,bei hoher Geschwind.	penetration
Grad Celsius (C)	centigrade
Grad Fahrenheit (F)	degree Fahrenheit
Grenzschicht	boundary layer
Grenzschichtabloesung	layer separation
Grenzschichtdicke	boundary layer thickness
Grenzschichtsteuerung	boundary layer control
Grenzschichttheorie	boundary layer theory
Grenzschichtzaun	boundary layer separation
Groesse (eines Modells)	size (of a model)
Grossausfuehrung	full sized
Gummiseilstart	launch by an elastic cable
H	H
Haerter (z.B. bei Epoxydharz)	hardener (for ex. with epoxy resin)
Handstart	hand launching
Hangsegeln, Hangflug	hill or slope soaring
Hangwind	upcurrent due to a slope
Hangwinkel	gradient of slope
Hebelarm des Hoehenleitwerkes	tail moment arm or length
Hellingtisch	slip, building cradle
Herauskommen aus Trudeln	spinning recovery
Hinterkante	trailing edge
Hochachse	vertical axis
Hochauftriebsprofil	high- lift airfoil
Hochdecker- Modell	high- wing airplane model
Hochgeschwindigkeitsabriss	high speed stall

Hochstart	launch with rubber line
Hochstartseil	elastic launching cord, towline
Hochstartwinde	launching wind
Hoehe ueber Ablugstelle	altitude above starting point
Hoehe ueber Meer	altitude
Hoehenleitwerk	elevator, tailplane
Hoehenleitwerk, Pendel-	elevators, all- moving
Hoehenleitwerksflattern	elevator flutter
Hoehenleitwerkwirksamkeit	tailplane efficiency
Hoehenruder	pitch fin, elevator
Hoehenruderausschlagwinkel	elevator deflection angle
Hoehenverlust	height loss
Hoerner- Randbogen	Hoerner tip
Holm	spar
Horizontalgeschwindigkeit	horizontal or level flying speed
Hufeisenwirbelschleppe	horseshoe vortex
Hystereseschleife	hysteresis loop
I	I
idealer Auftriebsbeiwert	ideal lift coefficient
idealer Stromlinienkoerper	ideal streamlined body
induzierter Anstellwinkel	induced angle of attack
induzierter oder Rand- Widerstand	induced drag
instabil, unstabil	unstable, unsteady
Instabilitaet	instability
Interferenzwiderstand	interference drag
Inversion (Wetterkunde)	inversion (meteorology)
J	J
Jedelsky- Tragfluegel	Jedelsky wing
Justierung	adjustment, setting
K	K
Kabine	control cabin
Kabinenhaube	canopy, enclosure
Kastenrumpf	box- type fuselage
Katapultstart	catapult launching
kinematische Viskositaet	kinematical viscosity
Kippmoment	pitching moment
Kisseneffekt, Bodenwirkung	ground effect
Klappe	flap
Klappenbetaetigung	flap control
Klappenverstellung	change in flap angle
Klappenwinkel	flap angle
kleben	stick, glue, adhere to, cement
Kleber (bei Epoxydharz)	basic resin (with epoxy)
Klebstoff, Kleber	adhesive, binding material
Knickfestigkeit	buckling strength
Knickfluegel	cranked wing, gull wing
Kohlenstoffaser	carbon fiber
Komponente (horizontal, vertikal)	component (horizontal, vertical)
Konfiguration	configuration
konkave Kruemmung	concave curvature
Konstruktion	construction, structure, design
konvexe Kruemmung	convex curvature
kopflastig	nose- heavy
Kosinus (eines Winkels)	cosine (of an angle)
Kraefte, in einem Punkt angreifend	concurrent forces
Kraeftediagramm	force diagram
Kraeftegleichgewicht	equilibrium of forces
Kraft (Groesse und Richtung)	force (strength and direction)
Kreiselkraft	gyroscopic force
Kreiselpraezession	gyroscopic precession
kreisen in Thermik	circle in a thermal
kritische Reynoldsche Zahl	critical Reynolds number
kritischer Anstellwinkel	critical angle, stall angle
Kunstfaser	synthetic fiber
kunstfliegen	to carry out acrobatics
Kunstflug	acrobatics, acrobatic flying
Kunstflug- RC- Segler	acrobatic RC sailplane
Kunstflugprogramm	acrobatic flying program
Kunstharz	synthetic resin plastic
Kunstschaummaterial	artificial foam material
Kurve	turn
Kurve (nach innen oder aussen)	curve (inward, outward)
Kurve mit Querneigung	banked turn
Kurvenflug	turn, banking, curvilinear flight
Kurvengleitflug	spiral gliding
Kurvenneigung	bank
Kurvenradius	radius of turn
Kurvensteuerung	turn control or banking control
Kurvenwinkel	angle of bank
L	L

Laenge	length
Laengs- oder Nickmoment	longitudinal or pitching moment
Laengs- V- Form	longitudinal dihedral or decalage
Laengsachse	longitudinal or roll axis
Laengsinstabilitaet	longitudinal instability
Laengsneigung	longitudinal slope or inclination
Laengsstabilitaet	longitudinal stability
laminar	laminar
Laminardelle	low drag bucket
laminare Abloesung	laminar separation
Laminarprofil	laminar airfoil
Laminarstroemung	laminar flow
Landebremse	air brake
Landeklappe	landing flap, spoiler, airbrakes
Landung	landing, touch down
Langsamflug	slow flight, stalling flight
Last	load
Lastvielfaches	load factor
Lee	lee, leeward or sheltered side
Leichtwindmodell	free flight model
Leim	glue
leiser Flug (Segel- und Elektroflug)	silent flight (sailplane, electric)
Leistung	performance, efficiency, power
Leistungs- RC- Segler	performance RC sailplane
Leistungsflugzeug	high- performance airplane
Leistungskennzahl	performance characteristic
Leistungskurve	performance graph or curve
Leistungsschwaeche	inefficiency
Leitwerk	tail plane or unit, control surfaces
Leitwerkflattern	tail flutter
Leitwerkhebelarm	tailplane lever
Leitwerksflaeche	area of tail unit
Leitwerksmoment	moment of tail unit
Leitwerkswiderstand	tail unit or tailplane drag
Loesungsmittel	solvent
Luft	air, atmosphere
Luftdichte	air density
Luftdruck	air or atmospheric pressure
Luftfeuchtigkeit	humidity of the air
Luftkraft	air force
Luftschraube	propeller
Luftschrauben- Wirkungsgrad	propeller efficiency
Luftsport	aerial sport
Luftstroemung	air current or flow or stream
Lufttemperatur	air temperature
Luftverkehrsgesetz	air-traffic law
Luftwiderstand	drag or air resistance
Luftzaehigkeit	viscosity of air
Luftzustand	atmospheric condition
Luftzustandswerte	air condition values
Luke	hatch
Luv, Luvseite	luff, windward side
M	M
Masse (gross, klein)	mass (large, small)
Masseinheit	measuring unit
Massenausgleich von Rudern	mass balancing of control surfaces
Masstab (Naturgroesse, reduziert	scale (full size, reduced scale)
Masstabeffekt	scale effect
masstaebliches Modell	scale model
mathematisches Modell	mathematical model
Maximum	maximum
Mechanik des Flugmodells	mechanics of model aircraft
Meereshoehe	sea level
mehrfache V- Form	polyhedral
Messtragflaeche	test or measuring wing
Messung	measuring, testing, test
Messung im Windkanal	wind tunnel measurement or test
Messwert	measured value
Meter Wassersaeule	meter head of water
Minimum	minimum
Mittellinie eines Profiles	mean line of an airfoil
Modell	model
Modellauslegung	model design
Modellbaukasten	model kit
Modellflugkommission	Model Airplane Committee
Modellflugsport	model airplane competition
Modellflugwesen	model aeronautics
Modellflugzeug	model aircraft
Modellgewicht	model weight
Modellneutralpunkt	aerodynamic center of whole model

Modellsegelflieger	modeler, sailplaner
Modellsegelflugzeug	model sailplane
Modellteil	component of model
Modelltragflaeche, Modellfluegel	model wing
Modellwiderstand total	total drag of model
Modellwirksamkeit	model efficiency
Moment	moment, momentum
Momentenbeiwert	moment coefficient
Momentenbeiwert bei Nullauftrieb	moment coefficient at zero lift
Momentenfreiheit	neutral stability
Momentengleichgewicht	equilibrium of moments
Momentengleichung	equation of moments
N	N
Nase des Modelles	nose of the model
Nasenleiste	leading edge strip, cap strip
Nasenradits	leading edge radius
Neutralpunkt	neutral point,aerodynamic center
Neutralpunkt der Tragflaeche	aerodynamic center of wing
Nickmoment	pitching moment
Nickwinkel	angle of pitch
Normathmospaere	normal air pressure
Nullauftriebswinkel	zero lift angle of attack
Nur- Seitenrudersteuerung	rudder- only control
Nurfluegel- RC- Segelmodell	allwing, flying wing,taillessRC plane
Nurfluegelmodell	tailless model
O	O
Oberflaeche des Tragfluegels	wing area
Oberflaechenfeinheit	surface finish
Oberflaechenwiderstand	skin friction or viscous drag
oertliches Minimum	local minimum
optimaler Einstellwinkel	optimum angle of incidence
optimaler Wert	optimum value
Optimierung	optimization
Optimum	optimum, best, most favorable
P	P
papierbespannter Tragfluegel	paper- covered wing
Parameter, Einflussgroesse	parameter
Pendelhoehenleitwerk	all- mouving elevators
Penetration des Segelmodells	penetration of model sailplane
Pfeiltragflaeche	arrow wing
Pfeilung (Trag- oder Steuerflaeche)	sweep (of wing or control surface)
Pilot	pilot, operator
Polare eines Modelles	model polar curve
Polarenpunkt	polar point
Polarenwerte, gemessen	values of polars, measured
Polyesterharz	polyester resin
Profil	airfoil, profile
Profilabmessungen	airfoil data or measurement
Profilauftriebskoeffizient lokal	section lift coefficient
Profilbeiwert	airfoil coefficient
Profildicke (Maximum)	airfoil thickness (maximum)
Profilfamilie	airfoil familiy
Profilgeometrie	airfoil geometry
Profilgleitzahl	airfoil glide coefficient
Profilhinterkante	trailing edge
Profilkoordinaten	airfoil coordinates
Profilmittellinie	airfoil lean line
Profilpolare	polar curve or polar diagram
Profilsehne	profile chord, chord line
Profiltiefe	chord of airfoil
Profilvergleich	airfoil comparison
Profilvorderkante	leading edge
Profilwiderstand	profhle drag
Profilwiderstandsbeiwert	profile drag coefficient
Prozentuale Profildicke	percentage of airfoil thickness
Q	Q
Querachse	lateral axis or roll axis
Querneigungswinkel	angle of bank
Querruder	aileron, wing flap
Querruderausschlag	aileron deflection or movement
Querruderdiffernzierung	aileron differential
Querruderflattern	aileron flutter
Querruderumkehrung	aileron reversal
Querruderwiderstand beim Gieren	ailerons drag in yaw
Querschnittsflaeche	cross sectional area, area og section
Querstabilitaet	lateral stability
R	R
Randbogen (an Fluegelspitze)	tip (wing tip)
Randbogenabriss	stall of tip
Randbogenwirbel	tip vortex

RC- Segelflugmodell	radio-controlled sailplane
Reibungswiderstand	frictional resistance
Resultierende Luftkraft	resultant air force
Reynoldsche Zahl (Re- Zahl)	Reynolds number
Richtungsstabilitaet	directional stability
Rippe (mit Doppel- T- Form)	rib (with double- T section)
Rohrholm	tubular spar
Rollachse	rolling axis
Rolldaempfung	damping of rolling
Rolle	roll, aileron roll
Rollmoment	rolling moment
Ruder	rudder, control surface
Ruder, selbsteinstellend	auto rudder
Rudergestaenge	rudddr linkage
Ruderhorn	rudder lever or horn
Rudermoment	control- surface moment
Ruderscharnier	rudder or control hinge
Ruderspalt	rudder gap
Ruderstellung	position of rudder
Rudertiefe	chord of control surface
rueckdrehendes Moment	restoring moment
Rueckenflug	inverted flight
ruhige Luft	calm air
Rumpf	fuselage
Rumpfbreite	width of fuselage
Rumpfgewicht	fuselage weight
Rumpfkonstruktion, Rumpfbauweise	fuselage design
Rumpfwiderstand	fuselage drag, body resistance
S	S
S- Schlag der Profilhinterseite	reflexing of trailing edge
S- Schlag- Profil	reflex profile
S.I.- Einheit	S.I. unit
Saalflugmodell	indoor model
Scale- Segelflugmodell	scale model sailplane
schaedlicher Widerstand	parasite drag
schaeften (einen Holm)	splice (a spar)
Schalenbauweise	shell structure
Schalter	switch, interruptor
Schaltung, Steuerung	control
Schaltungsschema	circuit scheme
Scherfestigkeit	shear strength
Schiebeflugzustand	yawing conditions
Schiebewinkel	angle of sideslip
schleifen	sand
Schleppantenne	trailing antenna
Schleppen, abschleppen	tow
Schleppflug	towed flight
Schnelladeakkumulator	rapid charging battery pack
Schnellflug	high speed flight
Schraenkung, aerodynamisch	wash- out, aerodynamic
Schraenkung, negative, aerodynamisch	wash- in, aerodynamic
Schubstange	push rod
Schwanzfallschirm	tail parachute
schwanzlastig	nose up
schwanzloses Flugzeug	tailless airplane
Schwerkraft	gravity, force of gravity
Schwerpunkt	center of gravity (c.g.)
Schwerpunktslage	position of center of gravity
Schwingung	vibration
Segelflugmodell	soaring model
Segelflugzeug	full size glider
segeln	glide, soar, gliding
Seglerbaukasten	sailplane kit
Seglerpolare	sailplane polar
Seilstart	tow launching
Seitenleitwerk	fin
Seitenleitwerksflaeche	fin area
Seitenruder	rudder
Seitenstabilitaet (-instabilitaet)	lateral stability (instability)
Seitensteuerung	lateral control
Seitenverhaeltnis (1 / Streckung)	chord- span ratio (1 / aspect ratio)
Servo	servo
simulieren	simulate
Sinkgeschwindigkeit	sinking speed
Sinkzahl	rate of descent
Sinus (eines Winkels)	sine (of an angle)
Slippen	sideslip
Spalte im Tragfluegel	gap in wing
Spannlack	stiffening varnish
Spannweite	span

Spannweite, wirksame	span, effective
Spannweitenbelastung	span loading
Spannweitezahl	span ratio or span number
Spant des Rumpfes	frame of fuselage
Sperrholz	plywood
Spezifisches Gewicht	specific weigtht
spezifisches Gewicht der Luft	specific weight of air
Spiralinstabilitaet	spiral instability
Spiralsturzflug	spiral dive
Spreizklappen	split flaps
Stabilitaet	stability
Stabilitaet um die Rollachse	stability on rolling axis
Stabilitaet von RC- Seglern	stability of RC sailplanes
Stabilitaetsfaktor	stability factor
Stabilitaetsmass	static margin
Start, Hochstart	launch, launching
stationaerer Flug	steady, stationary gliding or soaring
statische Stabilitaet	static stability
Staudruck	dynamic or aerodynamic pressure
Staupunkt	stagnation point
Steifigkeit	stiffness, rigidity
Steigflug	climb
Steuerflaeche	control, control surface
Steuerkraft	control force
Steuerstange	control rod
Steuerung, Regelung	control
Stillstand	standstill
Stoerklappe	spoiler, disrupter flap
Stoerung	disturbance
Stomlinienform	streamline shape
Stoss- Stange	push rod
Strak	smooth outline of a body
straken	loft
Streckung	aspect or span- chord ratio
Streifenturbulator	strip turbulator
Stroemungsabloesung	separation of flow, stalling
Stromlinie	stream line
Stromlinienfluss	streamlined flow
stromlinienfoermiger Rumpf	streamlined fuselage
Stromlinienkoerper, ideal	streamlined body, ideal
Sturzflug	vertical dive
Styropor	styrofoam
symmetrisches Profil	symmetrical airfoil
T	T
T- Leitwerk	T-tail
t/4- Punkt	quarter chord point
Tandemtraglaechen	tandem layout of wings
Tangens (eines Winkels)	tangent (of an angle)
Thermik	thermal, upcurrent due to hot air
Thermikblase	thermal bubble
Thermikbremse	dethermalizer, tip- up- tail
Thermikkern	core of the thermal
Thermiksegelflug	thermal gliding
Thermiksegler	thermal soarer
thermische Abloesung	thermal separation
thermischer Ausdehnungskoeffizient	coefficient of thermal expansion
totale Luftkraft	total air reaction force
totaler Widerstand	total drag
Traegheit	inertia
Traegheitskraft	mass force
tragendes Hoehenleitwerk	lifting tailplane
Tragflaeche, Fluegel, Tragfluegel	wing
Tragflaechenbefestigung	wing fastening
Tragflaechenbelastung	wing loading
Tragflaechendaten	wing data
Tragflaechendicke	wing thickness
Tragflaechenende	wing tip
Tragflaechenfgewicht	wing weight
Tragflaechenform	planform of wings, wing planform
Tragflaechengeometrie	wing geometry
Tragflaechengrundriss, elliptisch	planform, elliptical
Tragflaechenmoment	wing moment or momentum
Tragflaechenoberflaeche oben,unten	wing, upper and lower surface
Tragflaechenprofil	wing profile or wing airfoil
Tragflaechenquerschnitt	wing section
Tragflaechenstreckung	wing span-chord or aspect ratio
Tragflaechentiefe an Spitze	wing tip chord
Tragflaechentiefe an Wurzel	wing root chord
Tragflaechentiefe, mittlere	mean wing chord
Tragflaechenverjuengung	wing taper

Tragflaechenverwindung	wing twist
Tragflaechenverwindung nach oben	washin
Tragflaechenverwindung nach unten	washout
Tragfluegel, Tragflaeche, Fluegel	wing
Tragfluegeleinschnuerung an Wurzel	wing root cut out
Tragfluegelflattern	wing flutter
Tragfluegelgerippe	wing structure
Tragfluegelhinterkante	trailing edge of wing
Tragfluegelholm	wing spar
Tragfluegelpfeilung	sweep of wing
Tragfluegelpfeilung negativ (vorn)	sweep forward
Tragfluegelpfeilung positiv (hinten)	sweep- back
Tragfluegelumriss	wing planform
Tragfluegelverformung unter Last	wing distortion under load
Tragfluegelwirkung auf Leitwerke	wing effects of tail
Trapeztragflaeche	tapered wing
trimmen	trim
Trimmgewicht	trim or trimming ballast
Trimmruder	trimming tab
Trimmung (Einstellung)	trim, trimming, trim compensation
Trimmvorrichtung	surface used for trimming
Tropfzeit	pot life
Trudeln	spinning
Turbulator	turbulator
turbulent	turbulent
Turbulente Stroemung	turbulent flow or current
Turbulenz, Wirbelstroemung	turbulence
Turbulenzdraht	wire turbulator
typische Groesse	typical dimension
U	U
Uebergang Rumpf- Tragfluegel	fillet wing- fuselage
Uebergangszone	transition zone
Ueberlandflug	cross-country flight
uebersteuern	over control
ueberziehen	stall
ueberzogener Flug	stall
uebriger Widerstand	miscellaneous drag
Umlenkhebel	shift lever
Umrissform der Tragflaeche	shape or outer contour of wing
Umschlag der Grenzschicht	boundary layer transition
Umschlagpunkt am Profil	transition point on airfoil
Umwelt	environment
Ungleichgewicht	inbalance
unstationaer, nicht stationaer	instationary
Unterschneiden	'tucking under'
V	V
V- Form	dihedral
V- Form mehrfach	polyhedral
V- Leitwerk	V- tail
veraenderliche Fluegelflaeche	variable wing surface
veraenderliche Tragflaechen-Geometrie	variable wing geometry
veraenderliche Woelbung	variable camber
Verbundbauweise	sandwich construction
verdreht	twisted, deformed, out of shape
Verhaeltnis	ratio, rate, relation
Verhaeltnis Auftrieb/Widerstand	lift to drag ratio
Verhaeltnis Hoehenverlust/Distanz	ratio of height loss to distance
Verhalten	behavior, attitude
Verwindung (positiv, negativ)	wash in, wash out
Verziehen	distortion, buckling
verzoegern	decelerate, slowing down
Verzoegerung	deceleration, negative acceleration
Volumen	volume
vorbildgetreues Modell	scale model
Vorderkante	leading edge
W	W
Wende- oder Gierbewegung	yawing, motion in yaw
Wende- oder Giermoment	yawing moment
Wendeachse	axis of turn
Wendemoment	moment of turn
Werkstatt	workshop, shop
Werte gemessen, theoretisch	values measured, calculated
Wettbewerb	competition, contest
Wettbewerbswertung	competition classification,evaluation
Wetter	weather, atmosphere
Wetterbeobachtung	meteorological observation
Wetterbericht	weather report
Wettereinfluss	weather influence
wetterfest	weatherproof
Wetterforschung	weather research

Wetterkarte	weather map or weather chart
Wetterkunde	meteorology
Wetterprognose	weather forecast
Wetterverhaeltnisse	atmospheric conditions
Wetterzone	zone of weather
Widerstand	drag
Widerstand, induzierter	induced drag
Widerstand, Interferenz-	interference drag
Widerstandsanstieg	drag increase
Widerstandsbeiwert	drag coefficient
Widerstandsbilanz	drag budget
Widerstandskraft	drag force
Wiederanlegen der Luftstroemung	reattachment of airflow
Wiederauffangen	recovery
Windfahnenstabilitaet	weathercock stability
Windgeschwindigkeit	wind velocity
Windgeschwindigkeitsmesser	wind-velocity indicator, anemometer
Windkanal	wind tunnel
Windmesser	wind gage
Windmessgeraet	wind gage, anemometer
Windscherung	wind shear
windschief	twisted, deformed, out of shape
Windstaerke nach Beaufort	Beaufort's scale
Windstille	calm
Windstoss	gust, gust of wind
Winkel	angle
Wirbel	vortex
Wirbel, gebunden	bound vortex
Wirbelbewegung	vortex motion
Wirbelschleppe	turbulent wake
Wirbelwiderstand	vortex drag
Woelbklappe	flap
Woelbklappen-Hoehenruder-Koppelung	flaps elevator coupling
Woelbung (der Profilmittellinie)	camber (of airfoil meanline)
Woelbungsaenderung	camber change
Woelbungsverhaeltnis	camber ratio
X	X
X- Achse (Abszisse)	X axis (abscissa)
Y	Y
Y- Achse (Ordinate)	Y axis (ordinate)
Z	Z
Z- Achse (Senkrechte)	Z axis (vertical axis)
Zaehigkeit	viscosity, stickiness
Zeit	time
Zerlegung einer Kraft	resolution of a force
Zielgroesse bei Optimierung	value to be optimized
Ziellandung	precision landing
Zubehoer	accessories
Zugfestigkeit	tensile strength
Zuladung, Nutzladung	useful load, payload
zulaessig	admissible, allowable
Zusatzwiderstand	parasite drag
Zweiachssteuerung	rudder-only control

'tucking under'	Unterschneiden
A	A
accelerate, speed up	beschleunigen
acceleration due to gravity	Erdbeschleunigung
acceleration, speeding up	Beschleunigung
accessories	Zubehoer
accuracy of construction (of model)	Baugenauigkeit (des Modells)
acrobatic flying program	Kunstflugprogramm
acrobatic RC sailplane	Kunstflug- RC- Segler
acrobatics, acrobatic flying	Kunstflug
adhesive, binding material	Klebstoff, Kleber
adjustment, setting	Justierung
admissible, allowable	zulaessig
aerial sport	Luftsport
aero- elasticity	Aeroelastizitaet
aerodynamic	aerodynamisch
aerodynamic center of whole model	Modellneutralpunkt
aerodynamic center of wing	Neutralpunkt der Tragflaeche
aerodynamic damping of roll	aerodynamische Rolldaempfung
aerodynamic theory	aerodynamische Theorie
aerodynamic washout	aerodynamische Schraenkung
aerodynamics	Aerodynamik
aerodynamics, theory of flight	Fluglehre
aerology	aeronautische Wetterkunde
aeronautical meteorology	Flugwetterkunde
aeronautics	Aeronautik
aileron deflection or movement	Querruderausschlag
aileron differential	Querruderdiffernzierung
aileron flutter	Querruderflattern
aileron reversal	Querruderumkehrung
aileron, wing flap	Querruder
ailerons differential	Differenzierung der Querruder
ailerons drag in yaw	Querruderwiderstand beim Gieren
air brake	Landebremse
air brake, air deflector, air flap	Bremsklappe
air condition values	Luftzustandswerte
air current or flow or stream	Luftstroemung
air density	Luftdichte
air flow angle	Anblaswinkel
air force	Luftkraft
air or atmospheric pressure	Luftdruck
air pocket, descending or down gust	Fallboe
air temperature	Lufttemperatur
air, atmosphere	Luft
air-traffic law	Luftverkehrsgesetz
airbrake under surface	Flugbremse, eingebaut
airfoil coefficient	Profilbeiwert
airfoil comparison	Profilvergleich
airfoil coordinates	Profilkoordinaten
airfoil data or measurement	Profilabmessungen
airfoil familiy	Profilfamilie
airfoil geometry	Profilgeometrie
airfoil glide coefficient	Profilgleitzahl
airfoil mean line	Profilmittellinie
airfoil thickness (maximum)	Profildicke (Maximum)
airfoil, profile	Profil
airplane model construction	Flugmodellbau
all- mouving elevators	Pendelhoehenleitwerk
allwing, flying wing,taillessRC plane	Nurfluegel- RC- Segelmodell
altitude	Hoehe ueber Meer
altitude above starting point	Hoehe ueber Ablugstelle
anemometer	Anemomesser
angle	Winkel
angle of attack reduced by downwash	Anstellwinkel reduziert durch Abwind
angle of attack, angle of pitch	Anstellwinkel
angle of attack,aerodynamic	Anstellwinkel,aerodynamisch
angle of attack,geometric	Anstellwinkel,geometrisch
angle of bank	Querneigungs- oder Kurvenwinkel
angle of bank	Kurvenwinkel
angle of flight	Flugwinkel
angle of glide or descent	Gleitwinkel
angle of incidence control	Einstellwinkelsteuerung
angle of incidence range	Einstellwinkelbereich
angle of incidence, rigging angle	Einstellwinkel
angle of pitch	Nickwinkel
angle of sideslip	Schiebewinkel
antenna (USA), aerial (Brit.)	Antenne
area of tail unit	Leitwerksflaeche
area, surface, plane	Flaeche (Oberflaeche)

area, zone	Flaeche
area, zone, range	Bereich
arrow wing	Pfeiltragflaeche
artificial foam material	Kunstschaummaterial
aspect or span- chord ratio	Streckung
atmospheric condition	Luftzustand
atmospheric conditions	Wetterverhaeltnisse
attitude of flight	Flugverhalten
auto rudder	Ruder, selbsteinstellend
axis	Achse
axis of turn	Wendeachse
B	B
balance and trim	Gleichgewicht und Lage- Einstellung
balance the RC sailplane	auswiegen des RC- Seglers
ballast	Ballast
ballast tank	Ballasttank
ballast tube	Ballastrohr
balsa wood	Balsaholz
bank	Kurvenneigung
banked turn	Kurve mit Querneigung
basic equation of aerodynamics	aerodynamische Grundgleichung
basic resin (with epoxy)	Kleber (bei Epoxydharz)
Beaufort's scale	Windstaerke nach Beaufort
behavior, attitude	Verhalten
bending or flexural stiffness	Biegesteifigkeit
bending strength	Biegefestigkeit
Bernoulli's theorem	Bernoulli's Lehrsatz
biplane	Doppeldecker
bound vortex	gebundener Wirbel
bound vortex	Wirbel, gebunden
boundary layer	Grenzschicht
boundary layer control	Grenzschichtsteuerung
boundary layer separation	Grenzschichtzaun
boundary layer theory	Grenzschichttheorie
boundary layer thickness	Grenzschichtdicke
boundary layer transition	Umschlag der Grenzschicht
Bowden wire,control cable	Bowdenzug
box- type fuselage	Kastenrumpf
buckling stiffness	Beulsteifigkeit
buckling strength	Beulfestigkeit
buckling strength	Knickfestigkeit
budget (of drags)	Bilanz (der Widerstaende)
C	C
calm	Windstille
calm air	ruhige Luft
camber (of airfoil meanline)	Woelbung (der Profilmittellinie)
camber change	Woelbungsaenderung
camber ratio	Woelbungsverhaeltnis
canard model sailplane	Entenflugmodell
canopy, enclosure	Kabinenhaube
carbon fiber	Kohlenstoffaser
catapult launching	Katapultstart
center of gravity (c.g.)	Schwerpunkt
center of lateral area	Flaechenmittelpunkt
center of lift	Auftriebsmittelpunkt
center of pressure	Druckpunkt, Druckmittelpunkt
centigrade	Celsius (C)
centigrade	Grad Celsius (C)
change from laminar to turbulent flow	Abreissen
change in flap angle	Klappenverstellung
characteristic property	charakteristische Eigenschaft
chord number	Flaechentiefezahl
chord of airfoil	Profiltiefe
chord of control surface	Rudertiefe
chord- span ratio (1 / aspect ratio)	Seitenverhaeltnis (1 / Streckung)
circle in a thermal	kreisen in Thermik
circuit scheme	Schaltungsschema
climb	Steigflug
climb, rise, ascend	aufsteigen
coefficient (for example of lift)	Beiwert (z.B. fuer Auftrieb)
coefficient for air reaction	Beiwert fuer Luftkraft
coefficient of thermal expansion	thermischer Ausdehnungskoeffizient
competition classification,evaluation	Wettbewerbswertung
competition, contest	Wettbewerb
component (horizontal, vertical)	Komponente (horizontal, vertikal)
component of model	Modellteil
compressive strength	Druckfestigkeit
computation, calculation, estimation	Berechnung
compute, calculate, estimate	berechnen
computed polar curve	berechnete Polare

concave curvature	konkave Kruemmung
concurrent forces	Kraefte, in einem Punkt angreifend
configuration	Konfiguration
constant speed	gleichfoermige Geschwindigkeit
construction, structure, design	Konstruktion
control	Steuerung, Regelung
control	Schaltung, Steuerung
control cabin	Kabine
control force	Steuerkraft
control rod	Steuerstange
control, control surface	Steuerflaeche
control- surface moment	Rudermoment
convex curvature	konvexe Kruemmung
cord, mean chord	Flaechentiefe, mittlere
core of the thermal	Thermikkern
cosine (of an angle)	Kosinus (eines Winkels)
coupled ailerons and rudder	gekoppelte Quer- und Seitenruder
covering or skin of fabric (of wing)	Bespannung (der Tragflaeche)
covering, planking, sheeting(of wing)	Beplankung (der Tragflaeche)
cranked wing, gull wing	Knickfluegel
critical angle, stall angle	kritischer Anstellwinkel
critical Reynolds number	kritische Reynoldsche Zahl
cross sectional area, area of sebtion	Querschnittsflaeche
cross-country flight	Ueberlandflug
curve (inward, outward)	Kurve (nach innen oder aussen)
curved plate	gewoelbte Platte
D	D
damping of rolling	Rolldaempfung
damping surface	Daempfungsflaeche
damping, stabilization	Daempfung
decelerate, slowing down	verzoegern
deceleration, negative acceleration	Verzoegerung
deflect	ablenken
deflection of air	Ablenkung von Luft
degree Fahrenheit	Grad Fahrenheit (F)
delta layout	Deltakonstruktion
delta shaped	deltafoermig
density, mass density (for ex.of air)	Dichte (z.B. der Luft)
descending air current, downwash	Abwind
design, draft, scetch, outline	Entwurf
design, profiling	Formgebung
destabilizing effect	destabilisierende Wirkung
dethermalizer, tip- up- tail	Thermikbremse
diagram recorder	Diagrammschreiber
diagram, curve, graph	Diagramm
difference of angle of incidence	Einstellwinkeldifferenz
dihedral	V- Form
dimension, size	Dimension (Ausmessung, Mass)
direction of airflow	Anblasrichtung
direction of lift	Auftriebsrichtung
direction or sense of rotation	Drehrichtung
directional stability	Richtungsstabilitaet
distance flight	Distanzflug
distortion, buckling	Verziehen
disturbance	Stoerung
down draft, down gust of wind	Fallwind
downcurrent, sinking air, sink	Abwind
downwash angle	Abwindwinkel
downwash effect	Abwindwirkung
downwind area	Abwindgebiet
drag	Widerstand
drag budget	Widerstandsbilanz
drag coefficient	Widerstandsbeiwert
drag force	Widerstandskraft
drag increase	Widerstandsanstieg
drag or air resistance	Luftwiderstand
drag or braking parachute	Bremsfallschirm
duration flight	Dauerflug
dutch roll	Fassrolle
dynamic	dynamisch
dynamic instability	dynamische Instabilitaet
dynamic or aerodynamic pressure	Staudruck
dynamic soaring	dynamischer Segelflug
dynamical equilibrium	dynamisches Gleichgewicht
dynamics	Dynamik
E	E
elastic launching cord, towline	Hochstartseil
elastic limit	Elastizitaetsgrenze
electric drill	elektrische Bohrmaschine
electric propulsion or power	Elektroantrieb

electric- powered	elektrisch angetrieben
elevator deflection angle	Hoehenruderausschlagwinkel
elevator flutter	Hoehenleitwerksflattern
elevator, tailplane	Hoehenleitwerk
elevators, all- moving	Hoehenleitwerk, Pendel-
elliptical dihedral	elliptische V- Form
elongation, extension	Dehnung
end plate (of wing)	Endscheibe (von Tragflaeche)
endurance limit	Dauerfestigkeit
environment	Umwelt
epoxy resin	Epoxydharz
equal weight	gleiches Gewicht
equation of moments	Momentengleichung
equilibrium of forces	Kraeftegleichgewicht
equilibrium of moments	Momentengleichgewicht
equilibrium, static, dynamic	Gleichgewicht, statisch ,dynamisch
evening thermal	Abendthermik
experiment, test	Experiment
experimental work	experimentelle Arbeit
F	F
F.A.I. sporting code	F.A.I.- Sportgesetz
F3B competition or contest	F3B- Wettbewerb
factor of induced drag	Faktor fuer induzierten Widerstand
fatigue cracking	Ermuedungsriss
faulty launch	Fehlstart
fiber glass cloth	Glasfasergewebe
fiberglass or glass fiber	Glasfasern
fillet wing- fuselage	Uebergang Rumpf- Tragfluegel
fin	Seitenleitwerk
fin area	Seitenleitwerksflaeche
finished model	Fertigmodell
fixed or stabilizing surface	Flosse (fester Leitwerkteil)
fixture	Befestigung
flap	Klappe
flap	Woelbklappe
flap angle	Klappenwinkel
flap control	Klappenbetaetigung
flaps elevator coupling	Woelbklappen-Hoehenruder-Koppelung
flattening out, righting	Abfangen
flattest glide	Gleitzahl, flachste
flight altitude or height	Flughoehe
flight at high velocity	Geschwindigkeitsflug
flight condition	Flugzustand
flight envelope	Flugbereich
flight or flying	Flug
flight path	Flugbahn
flight path, straight	Flugbahn, gerade
flight speed, horizontal component	Fluggeschwind.,waagerechte Komponente
flight speed, vertical component	Fluggeschwindigkeit,senkrechte Komp.
flight task, flight mission	Flugaufgabe
flight training	Flugausbildung
flight visibility	Flugsicht
flow separation	Abloesung der Stroemung
flutter (for example of wing)	Flattern (z.B. der Tragflaeche)
fly- flew- flown	fliegen- flog- geflogen
flying machine or device	Flugapparat
flying model, glider model	Flugmodell
flying or air target	Flugziel
flying performance	Flugleistung
flying weather	Flugwetter
force (strength and direction)	Kraft (Groesse und Richtung)
force diagram	Kraeftediagramm
form or pressure drag	Formwiderstand
frame of fuselage	Spant des Rumpfes
free fall	freier Fall
free flight model	Freiflugmodell
free flight model	Leichtwindmodell
frictional resistance	Reibungswiderstand
Frise ailerons	Frise- Querruder
full size glider	Segelflugzeug
full sized	Grossausfuehrung
full- sized or manned sailplane	bemanntes Segelflugzeug
fuselage	Rumpf
fuselage design	Rumpfkonstruktion, Rumpfbauweise
fuselage drag, body resistance	Rumpfwiderstand
fuselage weight	Rumpfgewicht
G	G
G- forces	G- Kraefte
gap in wing	Spalte im Tragfluegel
gas constant	Gaskonstante

geometric stall angle	geometrischer Abrisswinkel
geometric washout	geometrische Schraenkung
glass reinforced plastic	glasfaserverstaerkter Kunststoff
glide	gleiten
glide ratio	Gleitzahl
glide, soar, gliding	segeln
glider	Gleitflugzeug
gliding flight	Gleitflug
gliding speed or flight velocity	Gleit- (oder Flug-) Geschwindigkeit
glue	Leim
gradient of slope	Hangwinkel
gravity, force of gravity	Schwerkraft
gross loading, flight weight	Fluggewicht
ground effect	Bodeneinfluss
ground effect	Kisseneffekt, Bodenwirkung
ground speed	Fluggeschwindigkeit, horizontal
ground speed	Geschwindigkeit, relativ
ground, soil, earth	Boden
gust, gust of wind	Windstoss
gust, sqall, bump	Boe
gyroscopic force	Kreiselkraft
gyroscopic precession	Kreiselpraezession
H	H
hand launching	Handstart
hardener (for ex. with epoxy resin)	Haerter (z.B. bei Epoxydharz)
hatch	Luke
height loss	Hoehenverlust
high speed flight	Schnellflug
high speed stall	Hochgeschwindigkeitsabriss
high- lift airfoil	Hochauftriebsprofil
high- performance airplane	Leistungsflugzeug
high- wing airplane model	Hochdecker- Modell
hill or slope soaring	Hangsegeln, Hangflug
Hoerner tip	Hoerner- Randbogen
horizontal or level flying speed	Horizontalgeschwindigkeit
horseshoe vortex	Hufeisenwirbelschleppe
humidity of the air	Luftfeuchtigkeit
hysteresis loop	Hystereseschleife
I	I
ideal lift coefficient	idealer Auftriebsbeiwert
ideal streamlined body	idealer Stromlinienkoerper
inbalance	Ungleichgewicht
indoor model	Saalflugmodell
induced angle of attack	induzierter Anstellwinkel
induced drag	induzierter oder Rand- Widerstand
induced drag	Widerstand, induzierter
induced drag coefficient	Beiwert fuer induzierten Widerstand
inefficiency	Leistungsschwaeche
inertia	Traegheit
inherent stability	Eigenstabilitaet
instability	Instabilitaet
instationary	unstationaer, nicht stationaer
interference drag	Interferenzwiderstand
interference drag	Widerstand, Interferenz-
inversion (meteorology)	Inversion (Wetterkunde)
inverted flight	Rueckenflug
J	J
Jedelsky wing	Jedelsky- Tragfluegel
K	K
kinematical viscosity	kinematische Viskositaet
kit	Baukasten
L	L
laminar	laminar
laminar airfoil	Laminarprofil
laminar flow	Laminarstroemung
laminar separation	Abloesung, laminar
laminar separation	laminare Abloesung
landing flap, spoiler, airbrakes	Landeklappe
landing, touch down	Landung
lateral axis or roll axis	Querachse
lateral control	Seitensteuerung
lateral stability	Querstabilitaet
lateral stability (instability)	Seitenstabilitaet (-instabilitaet)
launch by an elastic cable	Gummiseilstart
launch with rubber line	Hochstart
launch, launching	Start, Hochstart
launching wind	Hochstartwinde
law of motion	Bewegungsgesetz
layer separation	Grenzschichtabloesung
leading edge	Profilvorderkante

leading edge	Vorderkante
leading edge radius	Nasenradius
leading edge strip, cap strip	Nasenleiste
leading wing edge	Fluegelnase
lee, leeward or sheltered side	Lee
length	Laenge
lift axis	Auftriebsachse
lift change or variation	Auftriebsschwankung
lift coefficient	Auftriebsbeiwert
lift distribution	Auftriebsverteilung
lift factor	Auftriebsbeizahl
lift of the whole model	Auftrieb des ganzen Modelles
lift to drag ratio	Auftrieb-Widerstands-Verhaeltnis
lift to drag ratio	Gleitverhaeltnis
lift to drag ratio	Verhaeltnis Auftrieb/Widerstand
lift, aerodynamic lift	Auftrieb
lift, weak	Auftrieb, schwach
lifting force	Auftriebskraft
lifting tailplane	tragendes Hoehenleitwerk
load	Last
load factor	Lastvielfaches
local minimum	oertliches Minimum
loft	straken
longitudinal dihedral or decalage	Einstellwinkeldifferenz, laengs
longitudinal dihedral or decalage	Laengs- V- Form
longitudinal instability	Laengsinstabilitaet
longitudinal or pitching moment	Laengs- oder Nickmoment
longitudinal or roll axis	Laengsachse
longitudinal slope or inclination	Laengsneigung
longitudinal stability	Laengsstabilitaet
low drag bucket	Laminardelle
low drag range	Bereich des geringen Widerstandes
luff, windward side	Luv, Luvseite
M	M
mass (large, small)	Masse (gross, klein)
mass balancing of control surfaces	Massenausgleich von Rudern
mass force	Traegheitskraft
mathematical model	mathematisches Modell
maximum	Maximum
mean line of an airfoil	Mittellinie eines Profiles
mean wing chord	Tragflaechentiefe, mittlere
measured value	Messwert
measurements,over-all dimensions	Abmessungen
measuring unit	Masseinheit
measuring, testing, test	Messung
mechanics of flight	Flugmechanik
mechanics of model aircraft	Mechanik des Flugmodells
meteorological observation	Wetterbeobachtung
meteorology	Wetterkunde
meter head of water	Meter Wassersaeule
method of aerophysical measurement	aerophysikalisches Messverfahren
milled fibers	gemahlene Faserverstaerkung
minimum	Minimum
minimum pressure	Druckminimum
miscellaneous drag	uebriger Widerstand
mo(u)ld	formen, giessen
mo(u)lding	Form, Giessform
model	Modell
model aeronautics	Modellflugwesen
model aircraft	Modellflugzeug
Model Airplane Committee	Modellflugkommission
model airplane competition	Modellflugsport
model design	Modellauslegung
model efficiency	Modellwirksamkeit
model kit	Modellbaukasten
model polar curve	Polare eines Modelles
model sailplane	Modellsegelflugzeug
model weight	Modellgewicht
model weight, model mass	Gewicht des Modelles
model wing	Modelltragflaeche, Modellfluegel
model- aircraft competition	Flugmodellwettbewerb
model- airplane flying	Flugmodellsport
modeler, sailplaner	Modellsegelflieger
modulus of elasticity	Elastizitaetsmodul
moment coefficient	Momentenbeiwert
moment coefficient at zero lift	Momentenbeiwert bei Nullauftrieb
moment of tail unit	Leitwerksmoment
moment of turn	Wendemoment
moment, momentum	Moment
movable, mobile, portable	beweglich

move	bewegen
movement, motion	Bewegung
N	N
neutral point,aerodynamic center	Neutralpunkt
neutral stability	Momentenfreiheit
normal air pressure	Normathmospaere
nose of the model	Nase des Modelles
nose up	schwanzlastig
nose- heavy	kopflastig
number or rate of revolutions	Drehzahl
numerical calculation	Berechnung, zahlenmaessig
O	O
optimization	Optimierung
optimum angle of incidence	optimaler Einstellwinkel
optimum value	optimaler Wert
optimum, best, most favorable	Optimum
over control	uebersteuern
P	P
paper- covered wing	papierbespannter Tragfluegel
parachute airbrake	Fallschirmflugbremse
parameter	Parameter, Einflussgroesse
parameter, characteristic	Bestimmungsstueck, Einflussgroesse
parasite drag	schaedlicher Widerstand
parasite drag	Zusatzwiderstand
patchy lift	Bart (lokaler Aufwind)
penetration	Gleitzahl,grosse,bei hoher Geschwind.
penetration of model sailplane	Penetration des Segelmodells
percentage of airfoil thickness	Prozentuale Profildicke
performance characteristic	Leistungskennzahl
performance graph or curve	Leistungskurve
performance RC sailplane	Leistungs- RC- Segler
performance, efficiency, power	Leistung
pilot's cockpit	Fuehrerraum
pilot, operator	Pilot
pitch fin, elevator	Hoehenruder
pitching moment	Nickmoment
pitching moment	Kippmoment
planform number	Flaechenformzahl
planform of wings, wing planform	Tragflaechenform
planform, elliptical	Tragflaechengrundriss, elliptisch
plywood	Sperrholz
polar curve or polar diagram	Profilpolare
polar point	Polarenpunkt
polyester resin	Polyesterharz
polyhedral	mehrfache V- Form
polyhedral	V- Form mehrfach
position of center of gravity	Schwerpunktslage
position of rudder	Ruderstellung
pot life	Tropfzeit
precision landing	Ziellandung
pressure drag	Druckwiderstand
profile chord, chord line	Profilsehne
profile drag	Profilwiderstand
profile drag coefficient	Profilwiderstandsbeiwert
propeller	Luftschraube
propeller efficiency	Luftschrauben- Wirkungsgrad
propeller torque	Drehmoment der Luftschraube
push rod	Schubstange
push rod	Stoss- Stange
Q	Q
quarter chord point	t/4- Punkt
R	R
radio control, radio telecontrol	Funkfernsteuerung
radio control, remote control	Fernsteuerung
radio controlled flight	Fernlenkflug
radio controlled model	Fernlenkmodell
radio-controlled sailplane	RC- Segelflugmodell
radius of turn	Kurvenradius
rapid charging battery pack	Schnelladeakkumulator
rate of descent	Sinkzahl
ratio of height loss to distance	Verhaeltnis Hoehenverlust/Distanz
ratio, rate, relation	Verhaeltnis
reattachment of airflow	Wiederanlegen der Luftstroemung
receiver	Funkempfaenger
rechargeable battery pack	Akkumulator
recovery	Wiederauffangen
reflex profile	S- Schlag- Profil
reflexing of trailing edge	S- Schlag der Profilhinterseite
relative wind	Fahrtwind
relative wind for flying	Flugwind

resolution of a force	Zerlegung einer Kraft
resolution of forces in components	Aufteilen von Kraeften in Komponenten
restoring moment	rueckdrehendes Moment
resultant air force	Resultierende Luftkraft
Reynolds number	Reynoldsche Zahl (Re- Zahl)
rib (with double- T section)	Rippe (mit Doppel- T- Form)
rise off ground	Bodenstart
roll, aileron roll	Rolle
rolling axis	Rollachse
rolling moment	Rollmoment
rudder	Seitenruder
rudder gap	Ruderspalt
rudder lever or horn	Ruderhorn
rudder linkage	Rudergestaenge
rudder or control hinge	Ruderscharnier
rudder, control surface	Ruder
rudder- only control	Nur- Seitenrudersteuerung
rudder-only control	Zweiachssteuerung
S	S
S.I. unit	S.I.- Einheit
sailplane kit	Seglerbaukasten
sailplane polar	Seglerpolare
sand	schleifen
sandwich construction	Verbundbauweise
saving in weight	Gewichtsersparnis
scale (full size, reduced scale)	Masstab (Naturgroesse, reduziert
scale effect	Masstabeffekt
scale model	masstaebliches Modell
scale model	vorbildgetreues Modell
scale model sailplane	Scale- Segelflugmodell
sea level	Meereshoehe
section lift coefficient	Profilauftriebskoeffizient lokal
section lift coefficient	Auftriebsbeiwert lokal
separate, detach	abloesen
separation bubble	Abloeseblase
separation of flow, stalling	Stroemungsabloesung
separation or transition point	Abloesungspunkt
servo	Servn
setting, trim, adjustment	Einstellung
shape or outer contour of wing	Umrissform der Tragflaeche
shear strength	Scherfestigkeit
shell structure	Schalenbauweise
shift lever	Umlenkhebel
shift of center of pressure	Druckpunktwanderung
sideslip	Slippen
silent flight (sailplane, electric)	leiser Flug (Segel- und Elektroflug)
similarity,resemblance	Aehnlichkeit
simulate	simulieren
sine (of an angle)	Sinus (eines Winkels)
sinking speed	Sinkgeschwindigkeit
size (of a model)	Groesse (eines Modells)
skin friction or viscous drag	Oberflaechenwiderstand
slip, building cradle	Hellingtisch
slope of the lift curve	Anstellwinkelsteigung
slow flight, stalling flight	Langsamflug
smooth outline of a body	Strak
soaring model	Segelflugmodell
solvent	Loesungsmittel
span	Spannweite
span loading	Flaechenbelastung linear
span loading	Spannweitenbelastung
span ratio or span number	Spannweitezahl
span, effective	Spannweite, wirksame
spar	Holm
specific weight of air	spezifisches Gewicht der Luft
specific weigtht	Spezifisches Gewicht
speed of flight, flight velocity	Fluggeschwindigkeit
speed polar	Geschwindigkeitspolare
speed range	Geschwindigkeitsspanne
spinning	Trudeln
spinning recovery	Herauskommen aus Trudeln
spiral dive	Spiralsturzflug
spiral gliding	Kurvengleitflug
spiral instability	Spiralinstabilitaet
splice (a spar)	schaeften (einen Holm)
split flaps	Spreizklappen
spoiler, disrupter flap	Stoerklappe
stability	Stabilitaet
stability factor	Stabilitaetsfaktor
stability of RC sailplanes	Stabilitaet von RC- Seglern

stability on rolling axis	Stabilitaet um die Rollachse
stabilizer	Daempfer
stagnation point	Staupunkt
stall	Abriss oder Abreissen der Stroemung
stall	ueberzogener Flug
stall	ueberziehen
stall angle	Abrisswinkel
stall at high speed	Abriss bei hoher Geschwindigkeit
stall of tip	Randbogenabriss
standstill	Stillstand
static margin	Stabilitaetsmass
static stability	statische Stabilitaet
steady, stationary gliding or soaring	stationaerer Flug
stick, glue, adhere to, cement	kleben
stiffening varnish	Spannlack
stiffness, rigidity	Steifigkeit
stream line	Stromlinie
streamline shape	Stomlinienform
streamlined body, ideal	Stromlinienkoerper, ideal
streamlined flow	Stromlinienfluss
streamlined fuselage	stromlinienfoermiger Rumpf
strip turbulator	Streifenturbulator
structure,system,arrangement,setup	Aufbau
styrofoam	Styropor
surface finish	Oberflaechenfeinheit
surface used for trimming	Trimmvorrichtung
sweep (of wing or control surface)	Pfeilung (Trag- oder Steuerflaeche)
sweep forward	Tragfluegelpfeilung negativ (vorn)
sweep of wing	Tragfluegelpfeilung
sweep- back	Tragfluegelpfeilung positiv (hinten)
swing on take- off	Ausbrechen beim Start
switch, interruptor	Schalter
symmetrical airfoil	symmetrisches Profil
synthetic fiber	Kunstfaser
synthetic resin plastic	Kunstharz
T	T
T-tail	T- Leitwerk
tail flutter	Leitwerkflattern
tail moment arm or length	Hebelarm des Hoehenleitwerkes
tail parachute	Schwanzfallschirm
tail plane or unit, control surfaces	Leitwerk
tail unit or tailplane drag	Leitwerkswiderstand
tailless airplane	schwanzloses Flugzeug
tailless model	Nurfluegelmodell
tailplane efficiency	Hoehenleitwerkwirksamkeit
tailplane lever	Leitwerkhebelarm
take- off	Abheben
tandem layout of wings	Tandemtraglaechen
tangent (of an angle)	Tangens (eines Winkels)
tapered wing	Trapeztragflaeche
tensile strength	Zugfestigkeit
test or measuring wing	Messtragflaeche
thermal bubble	Thermikblase
thermal gliding	Thermiksegelflug
thermal separation	thermische Abloesung
thermal soarer	Thermiksegler
thermal, upcurrent due to hot air	Thermik
thickness form of an airfoil	Dickenverteilung eines Profils
time	Zeit
tip (wing tip)	Randbogen (an Fluegelspitze)
tip vortex	Randbogenwirbel
tissue sag	Bespannungseinfallen
to carry out acrobatics	kunstfliegen
to cover with	beplanken
top aileron or 'top rudder' in a bank	Gegensteuern in Kurve
torque, twisting moment	Drehmoment
torsional or twisting strength	Drehfestigkeit
torsional rigidity or stiffness	Drehsteifigkeit
total air reaction force	totale Luftkraft
total area (wing and tailplane)	Gesamtflaeche (Fluegel und Leitwerk)
total drag	Gesamtwiderstand
total drag	totaler Widerstand
total drag of model	Modellwiderstand total
tow	Schleppen, abschleppen
tow launching	Seilstart
towed flight	Schleppflug
towing by aircraft	Flugzeugschlepp
trailing antenna	Schleppantenne
trailing edge	Profilhinterkante
trailing edge	Endleiste

trailing edge	Hinterkante
trailing edge of an airfoil	Ablaufseite eines Profiles
trailing edge of wing	Tragfluegelhinterkante
transition point on airfoil	Umschlagpunkt am Profil
transition zone	Uebergangszone
transmitter	Funksender
trial flight	Einfliegen
trim	trimmen
trim or trimming ballast	Trimmgewicht
trim, trimming, trim compensation	Trimmung (Einstellung)
trimming by weights	Gewichtstrimmen
trimming tab	Trimmruder
true angle of attack	Anstellwinkel,wahrer
tubular spar	Rohrholm
turbulator	Turbulator
turbulence	Turbulenz, Wirbelstroemung
turbulent	turbulent
turbulent flow or current	Turbulente Stroemung
turbulent wake	Wirbelschleppe
turn	Kurve
turn control or banking control	Kurvensteuerung
turn, banking, curvilinear flight	Kurvenflug
twin fins	Doppelseitenruder
twisted, deformed, out of shape	verdreht
twisted, deformed, out of shape	windschief
type of aircraft	Flugzeugart
typical dimension	typische Groesse
U	U
ultimate strength	Bruchfestigkeit
unstable, unsteady	instabil, unstabil
upcurrent due to a slope	Hangwind
upcurrent, ascending air current	Aufwind
upwind, upcurrent	aufsteigender Luftstrom
useful load, payload	Zuladung, Nutzladung
V	V
V- tail	V- Leitwerk
value to be optimized	Zielgroesse bei Optimierung
values measured, calculated	Werte gemessen, theoretisch
values of polars, measured	Polarenwerte, gemessen
variable camber	veraenderliche Woelbung
variable wing geometry	veraenderliche Tragflaechen-Geometrie
variable wing surface	Fluegelflaeche, veraenderlich
variable wing surface	veraenderliche Fluegelflaeche
veer off	abdrehen
velocity of air flow	Anblasegeschwindigkeit
velocity profile on airfoil	Geschwindigkeitsverlauf am Profil
velocity, speed	Geschwindigkeit
vertical axis	Hochachse
vertical dive	Sturzflug
vertical fin	Endscheibe am Leitwerk
vibration	Schwingung
viscosity of air	Luftzaehigkeit
viscosity, stickiness	Zaehigkeit
volume	Volumen
vortex	Wirbel
vortex drag	Wirbelwiderstand
vortex motion	Wirbelbewegung
W	W
wash in, wash out	Verwindung (positiv, negativ)
wash- in, aerodynamic	Schraenkung, negative, aerodynamisch
wash- out, aerodynamic	Schraenkung, aerodynamisch
washin	Tragflaechenverwindung nach oben
washout	Tragflaechenverwindung nach unten
weather forecast	Wetterprognose
weather influence	Wettereinfluss
weather map or weather chart	Wetterkarte
weather report	Wetterbericht
weather research	Wetterforschung
weather, atmosphere	Wetter
weathercock stability	Windfahnenstabilitaet
weatherproof	wetterfest
weight	Gewicht
weight component	Gewichtskomponente
weight formula	Gewichtsformel
weight function	Gewichtsfunktion
weight number, weight factor	Gewichtszahl
width of fuselage	Rumpfbreite
wind gage	Windmesser
wind gage, anemometer	Windmessgeraet
wind shear	Windscherung

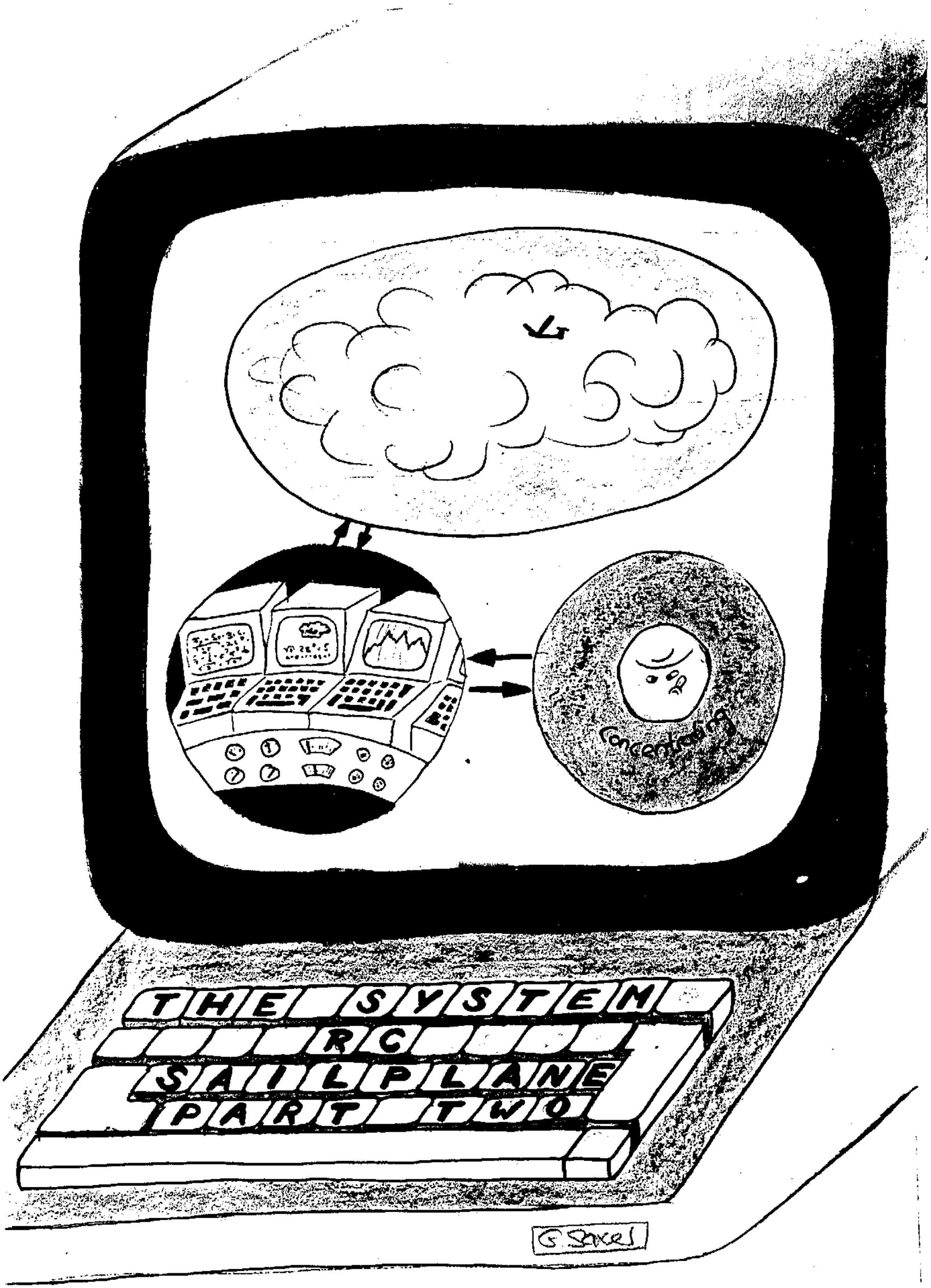
wind tunnel	Windkanal
wind tunnel measurement or test	Messung im Windkanal
wind velocity	Windgeschwindigkeit
wind-velocity indicator, anemometer	Windgeschwindigkeitsmesser
windtunnel balance	aerodynamische Waage
wing	Tragflaeche, Fluegel, Tragfluegel
wing	Flaeche, Tragflaeche, Fluegel
wing	Tragfluegel, Tragflaeche, Fluegel
wing area	Oberflaeche des Tragfluegels
wing chord	Flaechensehne
wing contour or plan	Fluegelumriss
wing data	Tragflaechendaten
wing design	Fluegelbauart
wing distortion under load	Tragfluegelverformung unter Last
wing effects of tail	Tragfluegelwirkung auf Leitwerke
wing fastening	Tragflaechenbefestigung
wing fixing	Fluegelbefestigung
wing flutter	Tragfluegelflattern
wing geometry	Tragflaechengeometrie
wing loading	Tragflaechenbelastung
wing loft	Fluegelstrak
wing moment or momentum	Tragflaechenmoment
wing planform	Tragfluegelumriss
wing profile or wing airfoil	Tragflaechenprofil
wing root chord	Tragflaechentiefe an Wurzel
wing root cut out	Tragfluegeleinschnuerung an Wurzel
wing section	Tragflaechenquerschnitt
wing span-chord or aspect ratio	Tragflaechenstreckung
wing spar	Tragfluegelholm
wing structure	Tragfluegelgerippe
wing taper	Tragflaechenverjuengung
wing thickness	Tragflaechendicke
wing tip	Tragflaechenende
wing tip chord	Tragflaechentiefe an Spitze
wing twist	Tragflaechenverwindung
wing weight	Tragflaechenfgewicht
wing, upper and lower surface	Tragflaechenoberflaeche oben,unten
wire turbulator	Turbulenzdraht
workshop, shop	Werkstatt
X	X
X axis (abscissa)	X- Achse (Abszisse)
Y	Y
Y axis (ordinate)	Y- Achse (Ordinate)
yawing angle, angle of yaw	Gierwinkel oder Gierungswinkel
yawing conditions	Schiebeflugzustand
yawing moment	Giermoment
yawing moment	Wende- oder Giermoment
yawing, motion in yaw	Wende- oder Gierbewegung
yawing, oscillatory yaw	Gierschwingung
Z	Z
Z axis (vertical axis)	Z- Achse (Senkrechte)
zero lift angle of attack	Nullauftriebswinkel
zone of weather	Wetterzone

RC SAILPLANE PERFORMANCE ANALYSIS

When Armin Saxer wrote the paper, "THE SYSTEM RC SAILPLANE" for Soartech 2, I thought that I had perhaps published enough on the subject of performance analysis. I was definitely wrong. As we learn more, there seems to be more interest in developing new ways of doing a more complete and thorough analysis of performance possibilities. In part one, Mr Saxer simplified the analysis somewhat: he was, after all, using a hand held programmable calculator to run the programs. In part two we find that he has, after going to a more powerful computer, added much sophistication to the analysis and leads us to some very solid conclusions about RC sailplane performance improvement.

As you will notice, this paper alludes to the computer programs within which the analysis is run. Mr Saxer has developed very extensive computer programs to accomplish this analysis using the PASCAL programming language on an APPLE IIE computer. I´m sure he´d be interested in working with an experienced PASCAL user to convert his analysis to English input, and output. If this should be accomplished, I´ll be very happy to publish details in a future Soartech.

Correspond with Mr. Saxer at Lindenweg 29, CH-3053 Münchenbuchsee, Switzerland.


concentrating
THE SYSTEM
RC
SAILPLANE
PART TWO

THE SYSTEM RC SAILPLANE PART II

A REFINED MATHEMATICAL AND COMPUTER MODEL OF THE STATIONARY STRAIGHT FLIGHT

Armin Saxer

Table of contents

1 SUMMARY

> "The aeroplane is a challenge to the human creativity, intelligence and courage; in short to phantasy and reason."
>
> Le Corbusier (architect)

Our goal is a better understanding of the flight behavior of a radio controlled sailplane to achieve an improved flight performance. This paper concentrates on the important stationary straight flight.

Mathematical models usually consider a flying sailplane with its forces being in a dynamic equilibrium.(Fig.2) This contribution takes also into consideration the longitudinal moments. (see Fig.3)

Solving the 3 equilibrium equations using aerodynamic formulas and computer iteration, the results give a better insight to

- longitudinal control behavior
- performance qualities
- longitudinal stability

A detailed insight to the straight flight condition is shown by many diagrams.

1

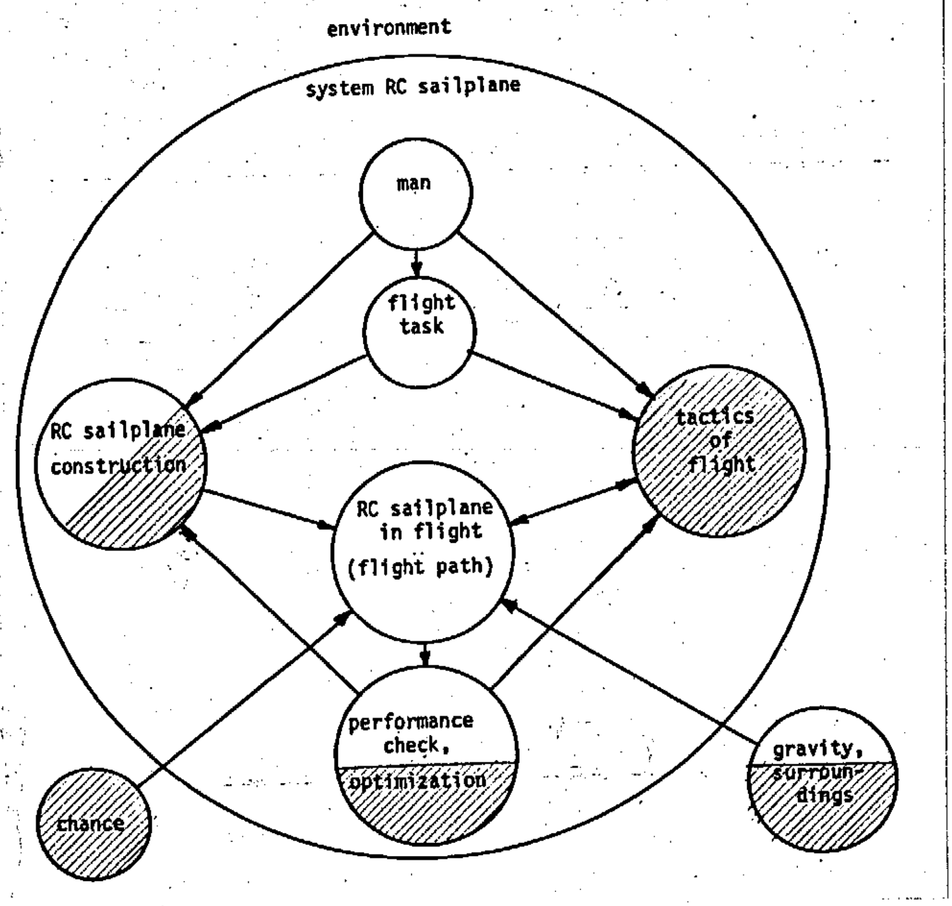
2 GENERAL INTRODUCTION

> "Processes of natural science are understood much better, if they are penetrated by calculation."
>
> Modellflug in Theorie und Praxis

To get an overview of the stationary straight flight of an RC sailplane *), a system was developed. (Fig.1 and lit.4) In this contribution, the following parts of this system are not taken in consideration: (These topics may give you, dear reader, ideas for your paper in a future SOARTECH.)

Fig.1 The general system "RC sailplane"

(☐ considered in this paper)



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*) An RC sailplane is an unmanned, unpowered flying device. The term "model" is avoided 1) to escape confusion with the "mathematic model" and 2) to point out the difference to the scaled down copy of a full size (manned) sailplane.

- RC sailplane construction: The material sailplane is replaced by an immaterial one, a so-called mathematic model.
- tactics of flight: the actions and reactions of the pilot.
- the everlasting chance.
- optimization is considered in a future paper.
- surroundings: ground influence, air in motion and microclimate are also neglected.

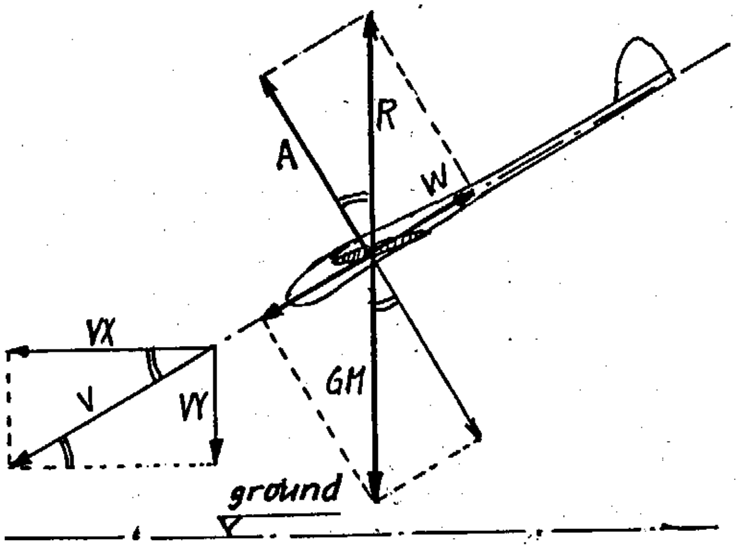
A mathematic model may express then the relationships of the system components with formulas. These are based on a dynamic equilibrium of the flying sailplane and the laws of aerodynamics.

In a simplified assumption, lift, drag and weight forces act in such a way, that no moments exist. (Fig.2 and lit.4)

In a more detailed assumption of this paper, forces, weights and longitudinal moments are taken into consideration and the position of the sailplane's center of gravity (C.G.) is introduced.(Fig.3). This assumtion will give us a more detailed understanding of the nature of the RC sailplane flight and should give us hints to construct better sailplanes. The consideration of moments is supported by the recent (first) publication of measured moment coefficients of various airfoils at low Reynolds numbers by D. Althaus. (lit.1)

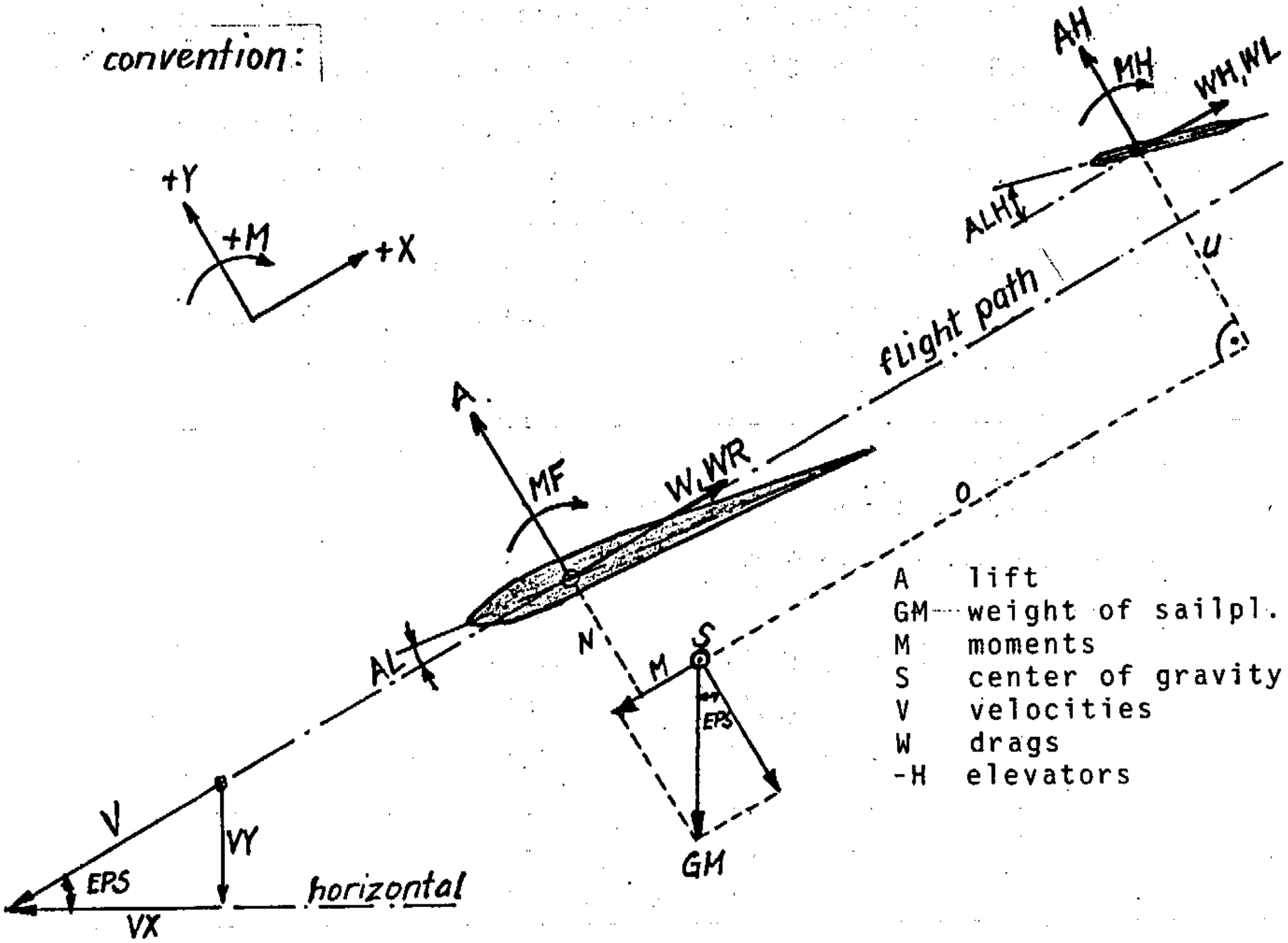
To test the mathematic model, examples, applications and comparisons with measurements are worked out.

Fig.2 Sailplane flight, simple assumption



A (CA)	lift (coefficient)
W (CW)	drag (")
R (CR)	resultant(")
GM	sailplane weight
V	flight speed
VX	horizontal speed component
VY	sinking speed

Fig.3 Sailplane flight, extended assumption



A	lift
GM	weight of sailpl.
M	moments
S	center of gravity
V	velocities
W	drags
-H	elevators

3 THE MATHEMATICAL MODEL

> "Without theory, practice is not more than
> routine coming from customary procedure"
> Louis Pasteur

3.1 Introduction

Instead of constructing, flying and measuring an RC sailplane, we create a simplified image of this sailplane, an immaterial mathematical model of the straight flight condition. The descriptive mathematical model consists of mathematical formulas, based on aerodynamics. The computer model reflects the structure of the computer calculation and the calculation model uses quantities. These 3 types of model are, in general, not exactly identical. The most important advantage of such an immaterial model is, that it can be analyzed, evaluated and optimized more easily than a material RC sailplane. Simulating or just playing with the immaterial model may give us a better understanding of the sailplane's behavior. We should, of course, never forget to face and check the immaterial model of the sailplane with reality.

3.2 The descriptive mathematical model

The descriptive mathematical model is based on the following 3 equations of dynamic equilibrium of the RC sailplane being in a stationary straight flight: (Fig.4, flight path oriented coordinate system)

Algebraic sum of forces in X- direction is zero or

-GM*SIN(EPS)+W+WR+WH+WL = 0 1)

Algebraic sum of forces in Y- direction is zero or

A+AH-GM*COS(EPS) = 0 2)

Algebraic sum of moments with respect to C.G. is zero or

MF+A*M+(W+WR)*N+MH-AH*O+(WH+WL)*U = 0 3)

For the meaning of symbols see ANNEX 1 and Fig. 4.

Consulting the laws of aerodynamics lifts, drags and moments are depending on:

- angle of attack of airfoil
- flight speed
- geometry of the sailplane

For a given angle of attack of the wing AL "juggling" with the

5

formulas we obtain

from equations 1) and 2): f(RE,ALH)=0 --> RE=m(ALH)   4)
from equation 3)   : g(RE,ALH)=0 --> ALH=n(RE)   5)

Substituting the value of ALH of equation 5) in equation 4) gives

RE = m (n (RE))   6)

This means, that the wing's Reynolds number RE may be computed. The flight speed is easily determined also the elevators' angle of attack and all the other flight characteristics. (sinking speed, glide ratio etc.)

As it was not possible to find a direct solution of equation 6) computer iteration was used to solve the problem.

For simplicity, the iteration is made with angles of attack assuming wings of infinite span before the induced angles of attack (for wings of finite span) and the downwash angle (wing influence on elevators) are computed. As these angles are small in comparison with the angle of attack, the errors are estimated to be also small. (see also Fig.5). It would be an interesting problem for you, dear reader, to correct this simplification. (ask the EDITOR of SOARTECH for the detailed formulas; consult also Fig.5)

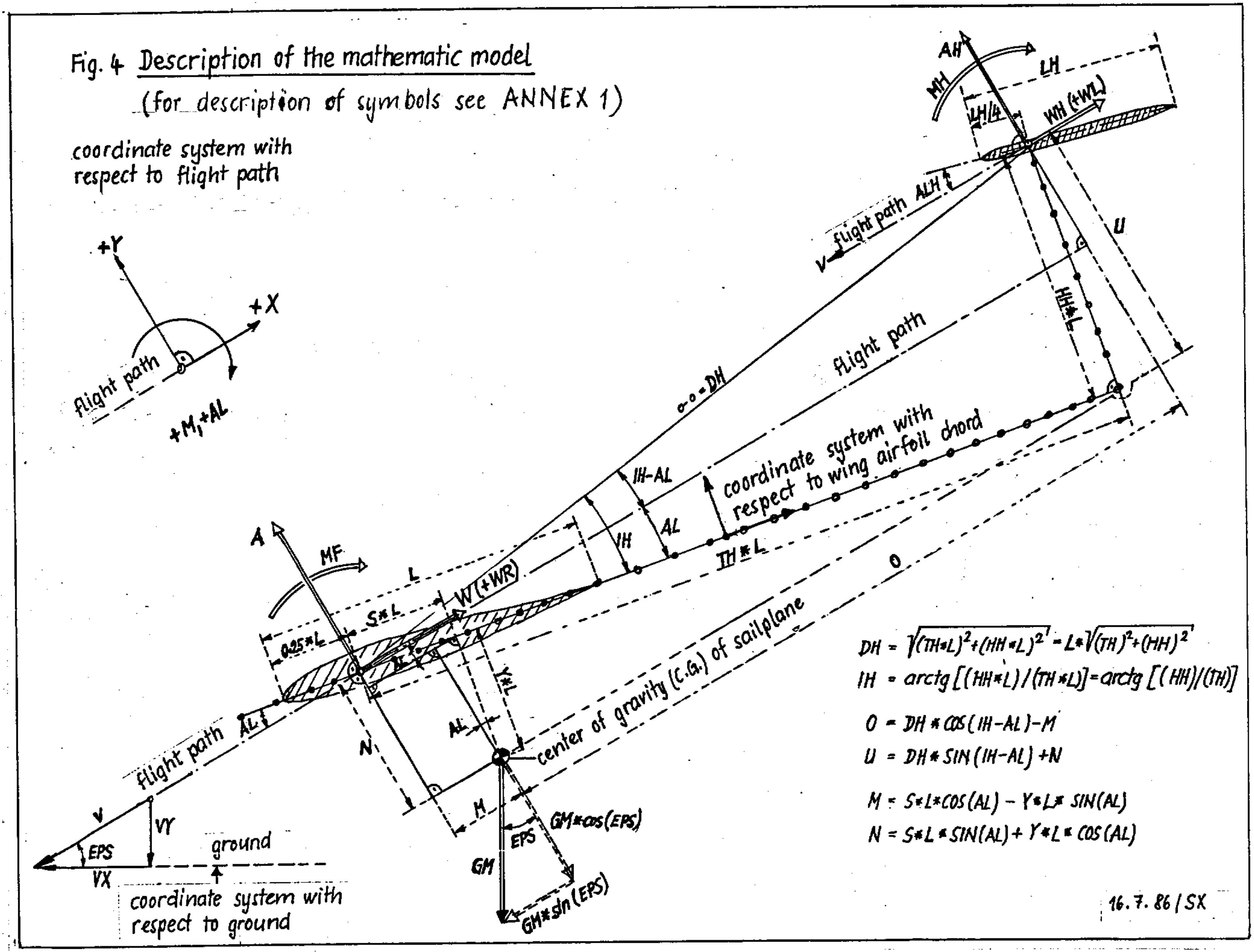
Static longitudinal stability

Let us imagine, that our sailplane is in a stationary straight flight as calculated above. (see Fig.6, position I) Simulating the effects of a gust, we turn (in theory) suddenly the whole plane around its center of gravity CG with a rotation angle of +ALD, maintainig flight direction and flight speed. (see Fig.6, position II) With angles of attack of wing and elevators changed, forces and moments are different and produce a longitudinal moment M with respect to the sailplane's C.G. If this moment tends to restore the original equilibrium status, we conclude, that the sailplane's flight is stable. The magnitude of the restoring moment and the slope of the moment/rotation angle curve (Fig.7)are a measure for the degree of longitudinal static stability. To make the restoring moment independent of the flight speed, this moment is divided by the dynamic pressure, which is a function of the flight speed. (see also lit.2)

6

Fig. 4 Description of the mathematic model

(for description of symbols see ANNEX 1)



$$DH = \sqrt{(TH*L)^2+(HH*L)^2} = L*\sqrt{(TH)^2+(HH)^2}$$

$$IH = arctg\,[(HH*L)/(TH*L)] = arctg\,[(HH)/(TH)]$$

$$O = DH*COS(IH-AL)-M$$

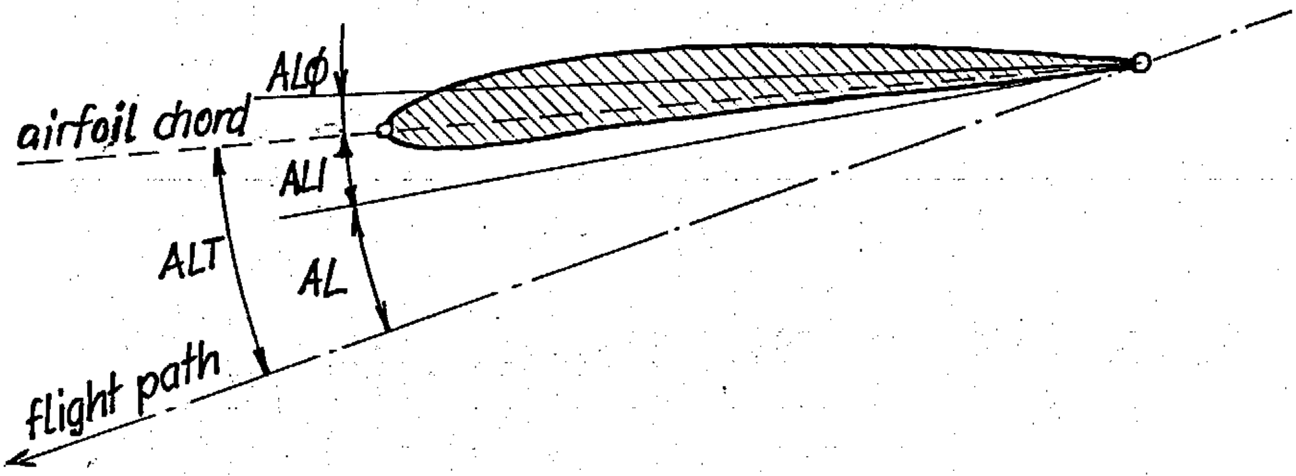
$$U = DH*SIN(IH-AL)+N$$

$$M = S*L*COS(AL) - Y*L*SIN(AL)$$

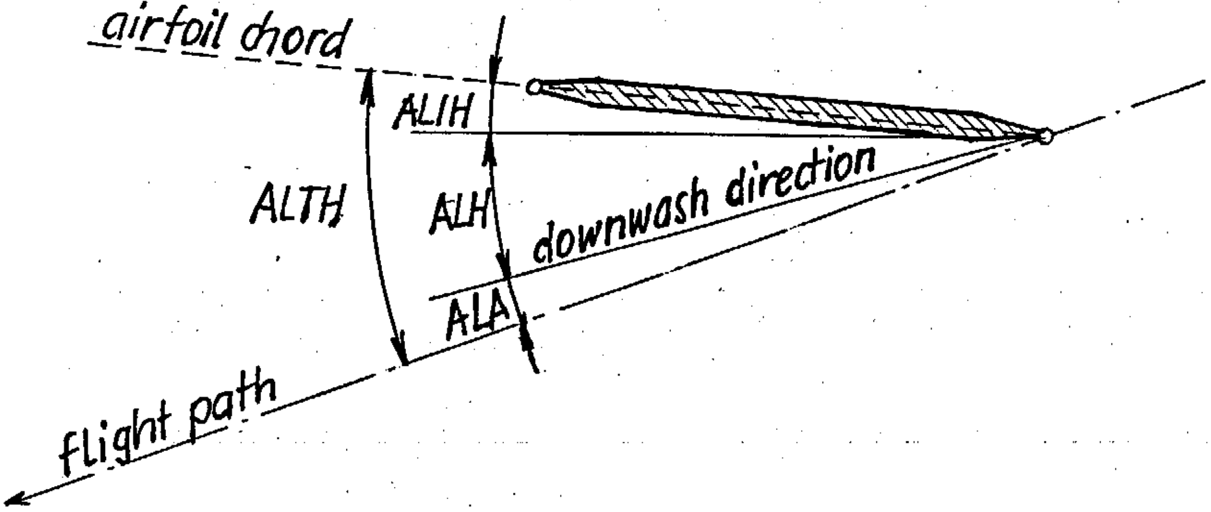
$$N = S*L*SIN(AL) + Y*L*COS(AL)$$

Fig.5 Angles of a flying RC sailplane

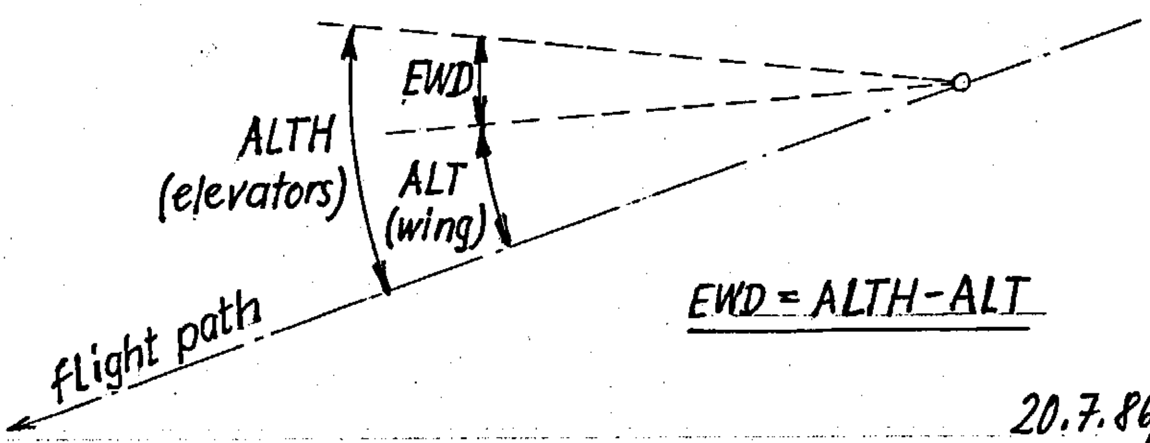
Wing



Elevators



RC sailplane



20.7.86/SX

Fig.6 Simulation of the effects of a gust on a straight flying RC sailplane

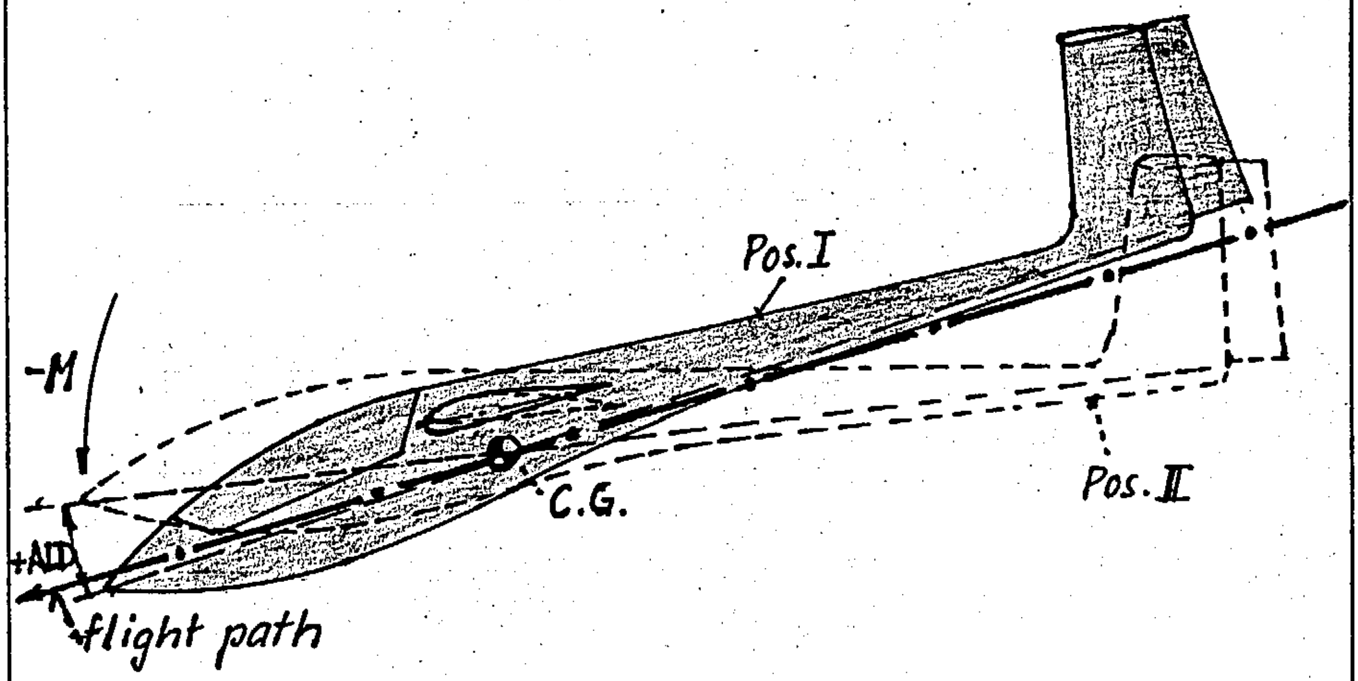
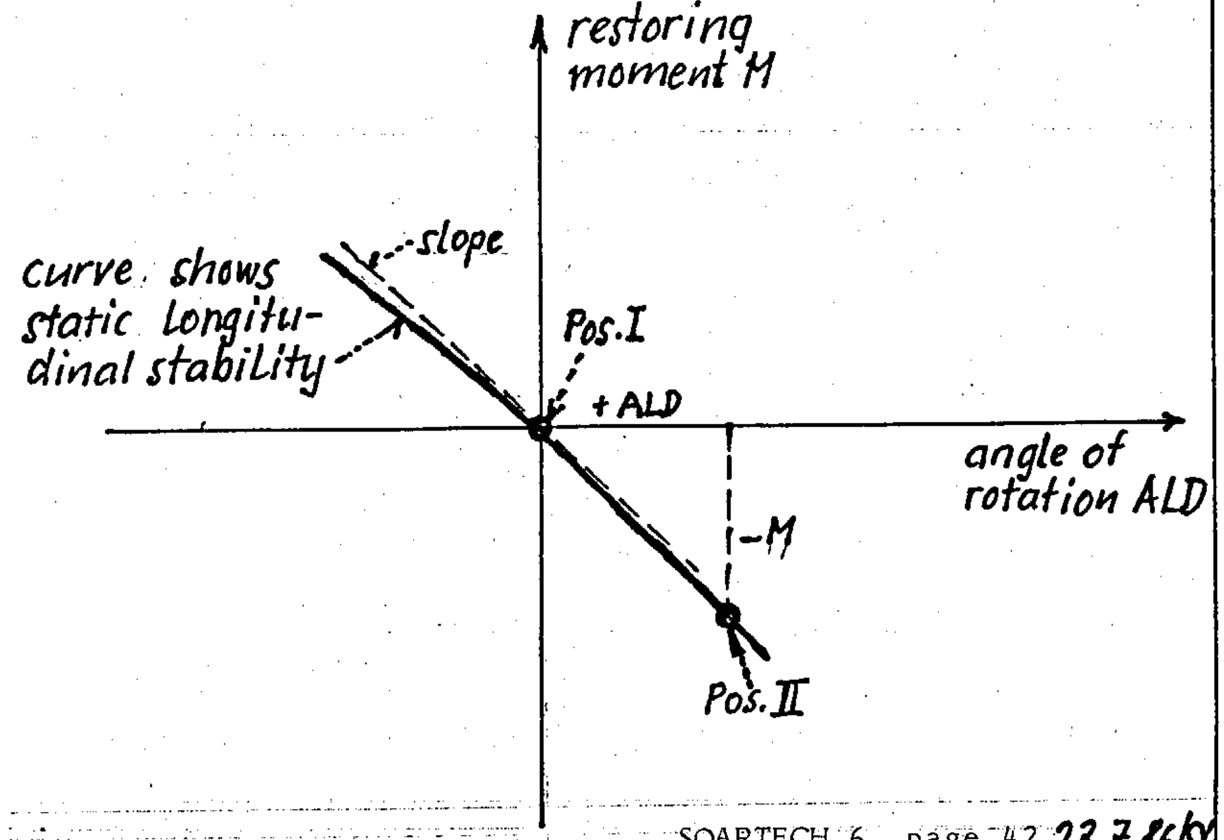


Fig. 7 Restoring moment / rotation angle curve



3.3 The computer model.

The programs are written in UCSD- Pascal running on a APPLE II+ computer. The following information is general. If you are interested in details, please ask the Editor of SOARTECH.

Fig.8 Data structure for airfoil coefficients

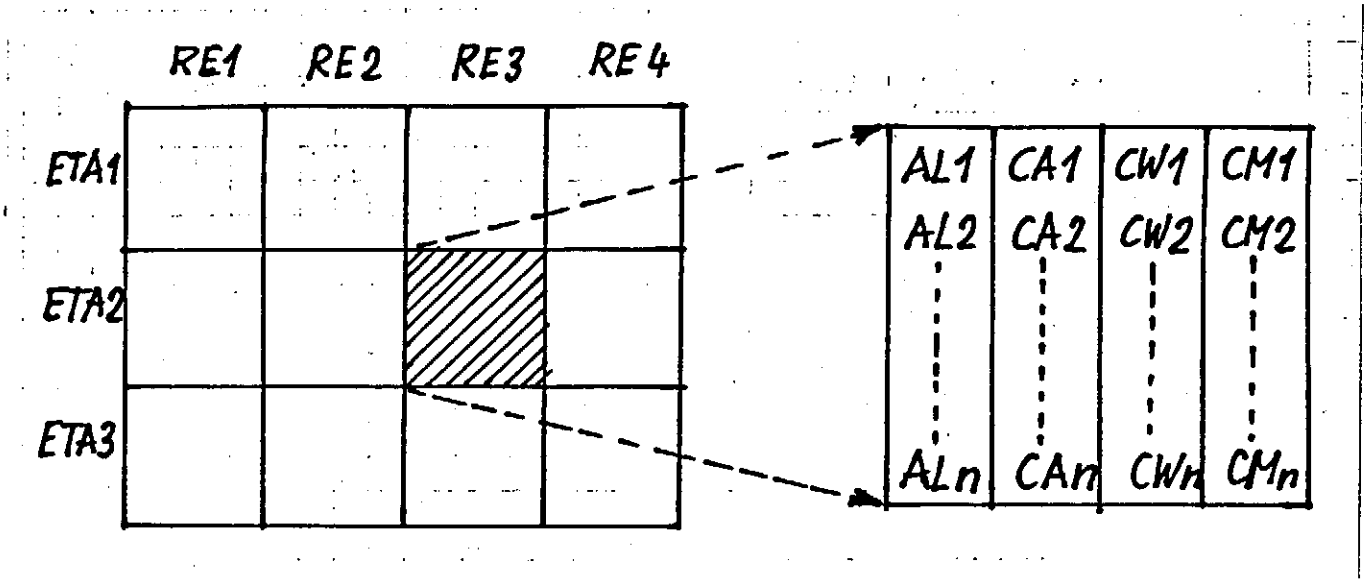
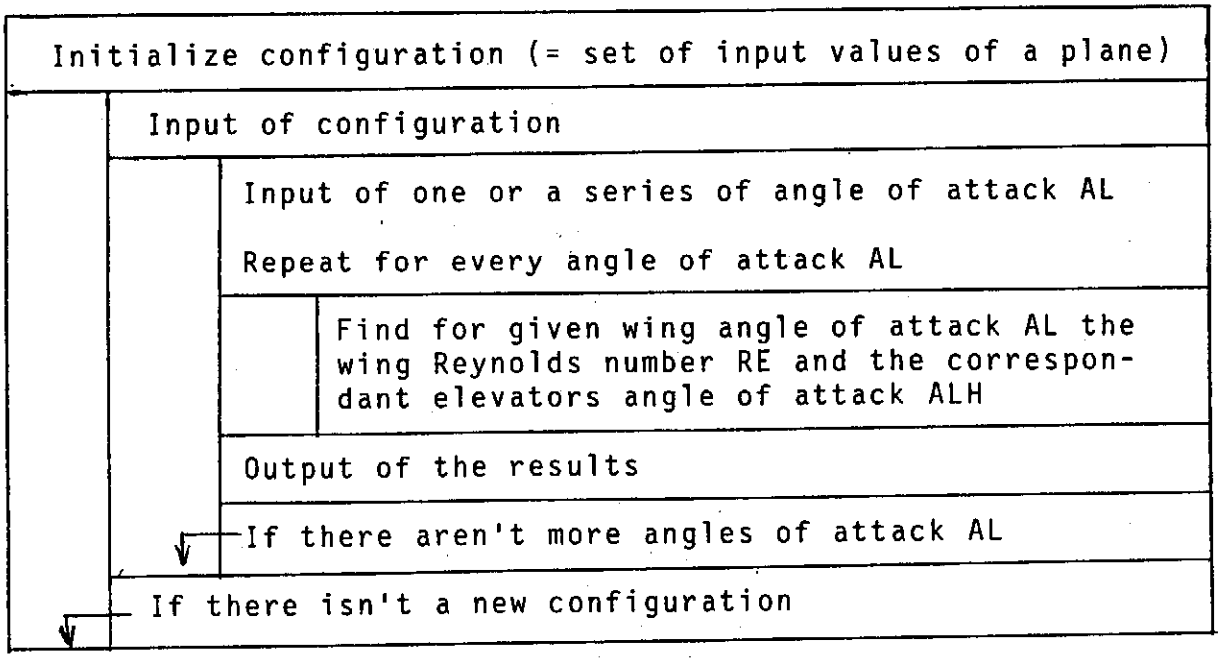


Fig.9 General Program Structure

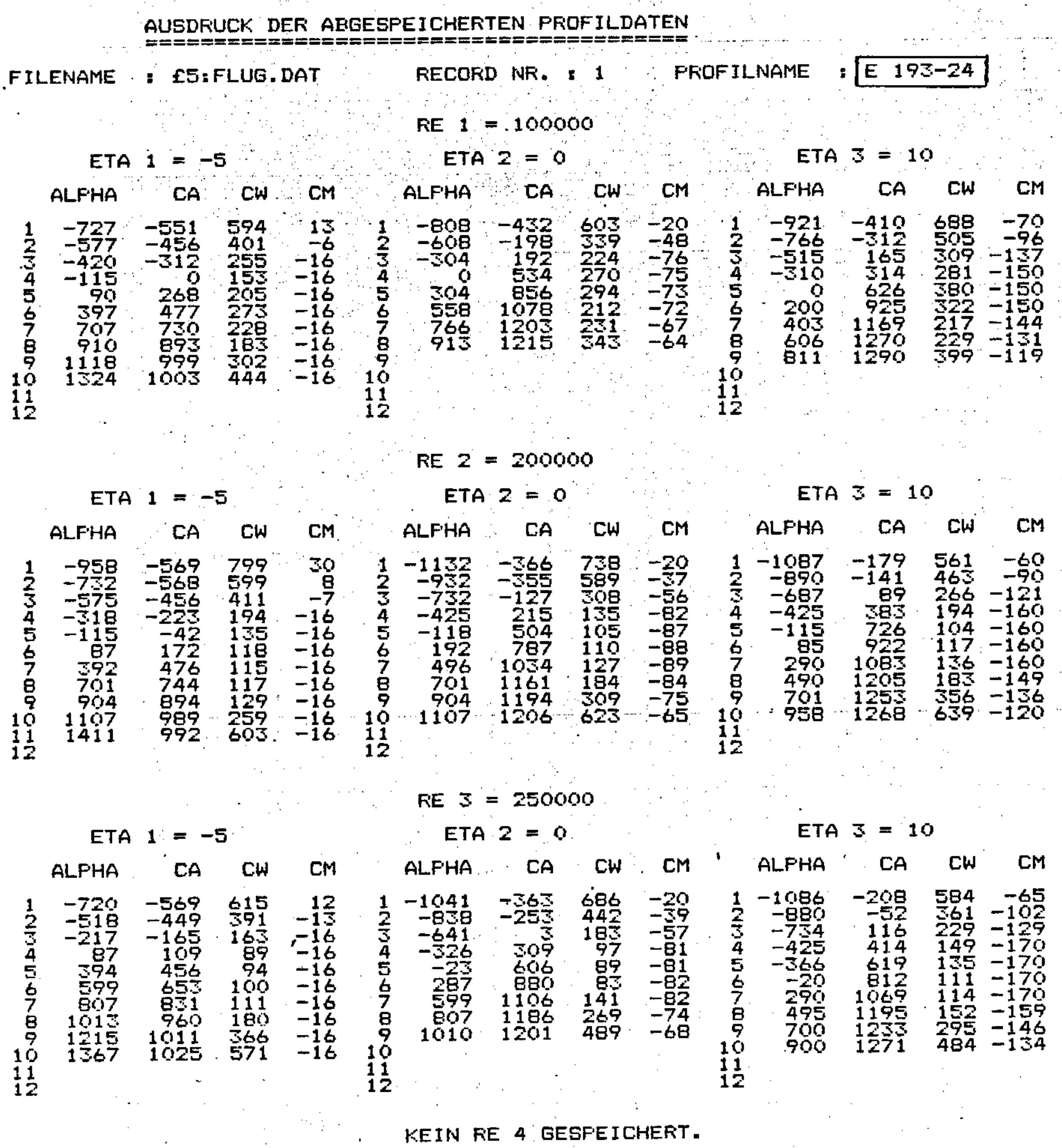


```
Initialize configuration (= set of input values of a plane)
    Input of configuration
        Input of one or a series of angle of attack AL
        Repeat for every angle of attack AL
            Find for given wing angle of attack AL the
            wing Reynolds number RE and the correspon-
            dant elevators angle of attack ALH
        Output of the results
        If there aren't more angles of attack AL
    If there isn't a new configuration
```

3.4 The calculation model

An example, consisting of a typical RC sailplane, shows airfoil data, sailplane data input, printed output and some graphs. With the description of the symbols on ANNEX 1, these figures are self explaining. A more detailed discussion of results follows in the next chapter.

Fig.10 Stored data for airfoil E 193-24 (see lit.1)



```
                 AUSDRUCK DER ABGESPEICHERTEN PROFILDATEN
                 ========================================

FILENAME  : £5:FLUG.DAT        RECORD NR. : 1      PROFILNAME  : E 193-24

                                  RE 1 =.100000

        ETA 1 = -5                   ETA 2 = 0                   ETA 3 = 10

     ALPHA    CA    CW   CM     ALPHA    CA    CW   CM     ALPHA    CA    CW   CM

 1   -727   -551   594   13   1  -808   -432   603  -20   1  -921   -410   688  -70
 2   -577   -456   401   -6   2  -608   -198   339  -48   2  -766   -312   505  -96
 3   -420   -312   255  -16   3  -304    192   224  -76   3  -515    165   309 -137
 4   -115      0   153  -16   4     0    534   270  -75   4  -310    314   281 -150
 5     90    268   205  -16   5   304    856   294  -73   5     0    626   380 -150
 6    397    477   273  -16   6   558   1078   212  -72   6   200    925   322 -150
 7    707    730   228  -16   7   766   1203   231  -67   7   403   1169   217 -144
 8    910    893   183  -16   8   913   1215   343  -64   8   606   1270   229 -131
 9   1118    999   302  -16   9                           9   811   1290   399 -119
10   1324   1003   444  -16  10                          10
11                            11                          11
12                            12                          12

                                  RE 2 = 200000

        ETA 1 = -5                   ETA 2 = 0                   ETA 3 = 10

     ALPHA    CA    CW   CM     ALPHA    CA    CW   CM     ALPHA    CA    CW   CM

 1   -958   -569   799   30   1 -1132   -366   738  -20   1 -1087   -179   561  -60
 2   -732   -568   599    8   2  -932   -355   589  -37   2  -890   -141   463  -90
 3   -575   -456   411   -7   3  -732   -127   308  -56   3  -687     89   266 -121
 4   -318   -223   194  -16   4  -425    215   135  -82   4  -425    383   194 -160
 5   -115    -42   135  -16   5  -118    504   105  -87   5  -115    726   104 -160
 6     87    172   118  -16   6   192    787   110  -88   6    85    922   117 -160
 7    392    476   115  -16   7   496   1034   127  -89   7   290   1083   136 -160
 8    701    744   117  -16   8   701   1161   184  -84   8   490   1205   183 -149
 9    904    894   129  -16   9   904   1194   309  -75   9   701   1253   356 -136
10   1107    989   259  -16  10  1107   1206   623  -65  10   958   1268   639 -120
11   1411    992   603. -16  11                          11
12                            12                          12

                                  RE 3 = 250000

        ETA 1 = -5                   ETA 2 = 0                   ETA 3 = 10

     ALPHA    CA    CW   CM     ALPHA    CA    CW   CM     ALPHA    CA    CW   CM

 1   -720   -569   615   12   1 -1041   -363   686  -20   1 -1086   -208   584  -65
 2   -518   -449   391  -13   2  -838   -253   442  -39   2  -880    -52   361 -102
 3   -217   -165   163  -16   3  -641      3   183  -57   3  -734    116   229 -129
 4     87    109    89  -16   4  -326    309    97  -81   4  -425    414   149 -170
 5    394    456    94  -16   5   -23    606    89  -81   5  -366    619   135 -170
 6    599    653   100  -16   6   287    880    83  -82   6   -20    812   111 -170
 7    807    831   111  -16   7   599   1106   141  -82   7   290   1069   114 -170
 8   1013    960   180  -16   8   807   1186   269  -74   8   495   1195   152 -159
 9   1215   1011   366  -16   9  1010   1201   489  -68   9   700   1233   295 -146
10   1367   1025   571  -16  10                          10   900   1271   484 -134
11                            11                          11
12                            12                          12

                          KEIN RE 4 GESPEICHERT.
```

Fig.11 Graph of coefficients of airfoil E 193-24

ETA	angle of wing flaps
RE	Reynolds number of wing
AL	wing angle of attack
CA	lift coefficient
CW	drag coefficient
CM	moment coefficent

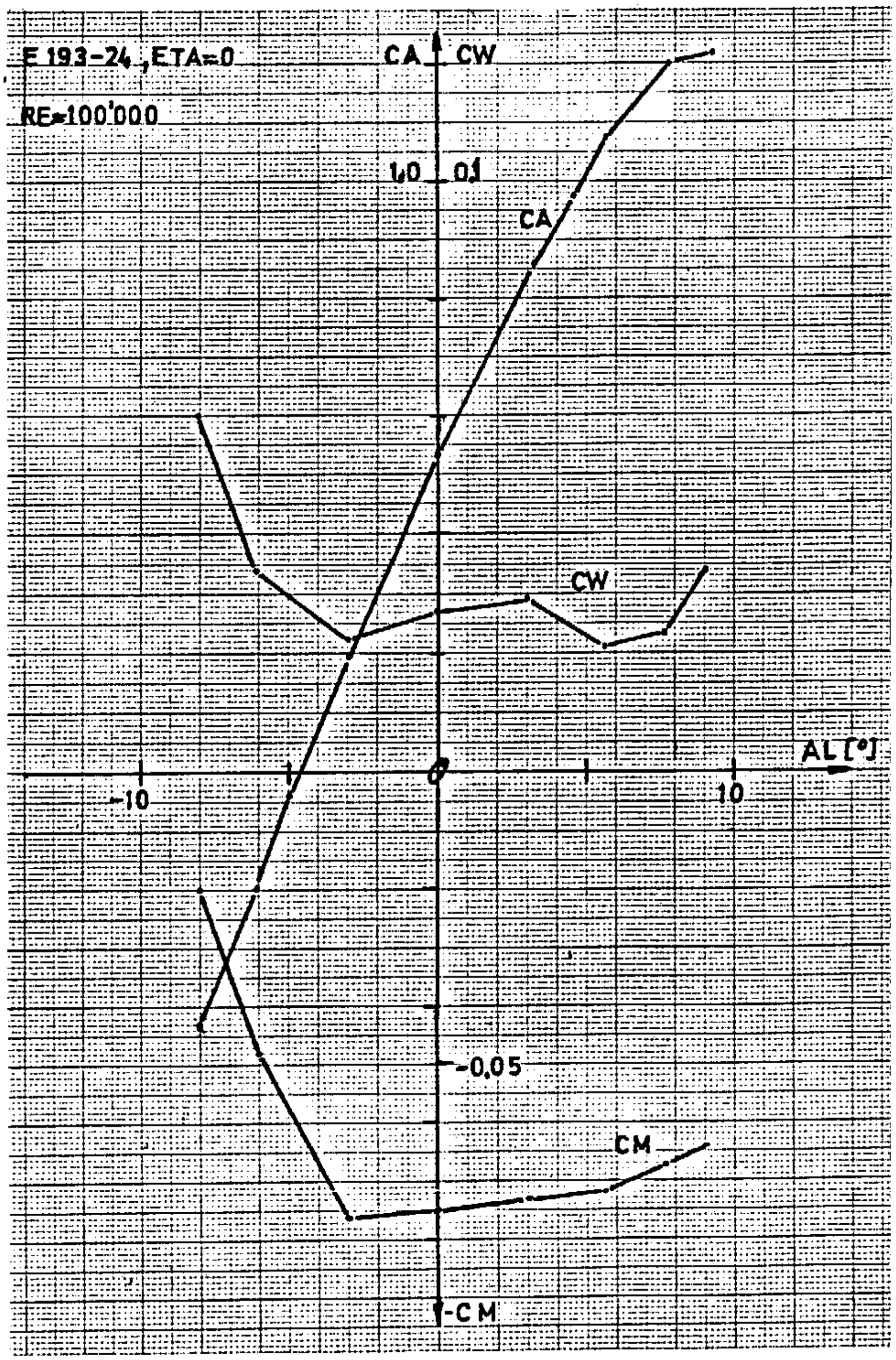
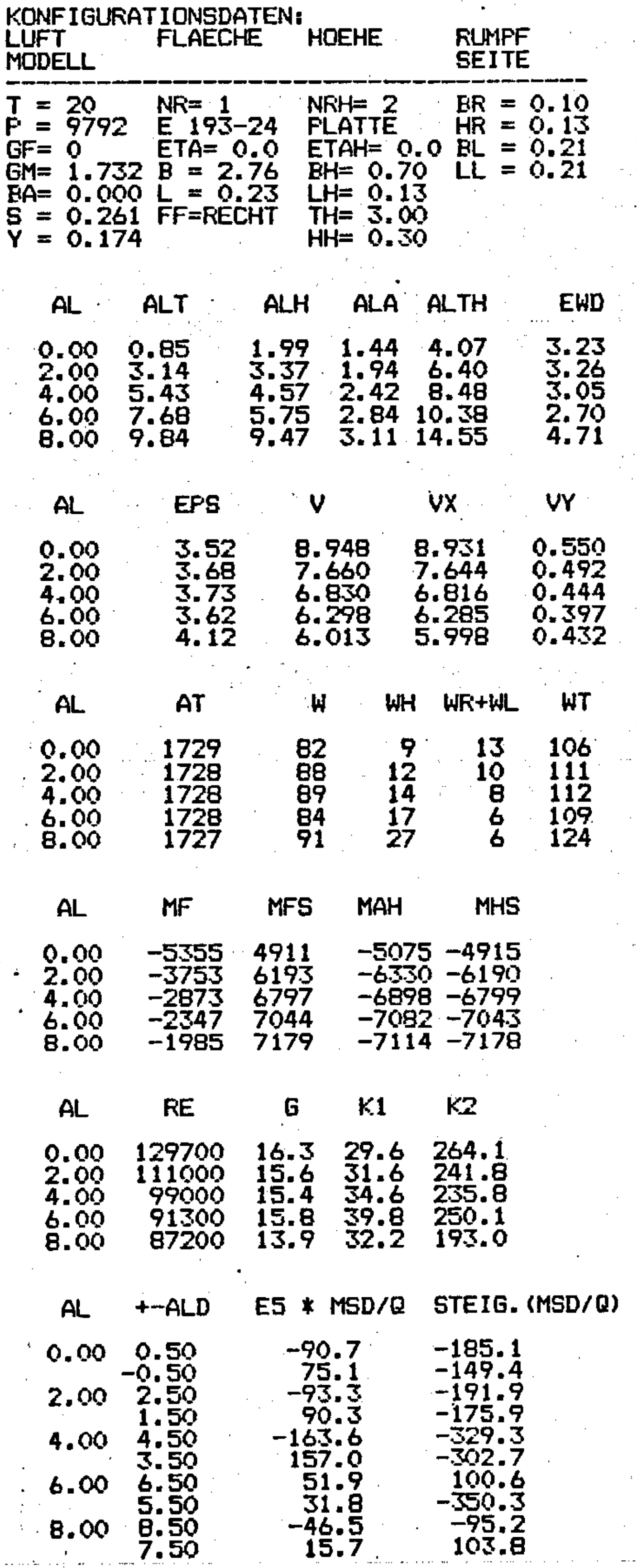


Fig.12 Screen mask and output



```
KONFIGURATIONSDATEN:
LUFT      FLAECHE   HOEHE     RUMPF
MODELL                        SEITE
------------------------------------
T = 20    NR= 1     NRH= 2    BR = 0.10
P = 9792  E 193-24  PLATTE    HR = 0.13
GF= 0     ETA= 0.0  ETAH= 0.0 BL = 0.21
GM= 1.732 B = 2.76  BH= 0.70  LL = 0.21
BA= 0.000 L = 0.23  LH= 0.13
S = 0.261 FF=RECHT  TH= 3.00
Y = 0.174           HH= 0.30

   AL    ALT      ALH   ALA  ALTH      EWD

  0.00  0.85     1.99  1.44  4.07     3.23
  2.00  3.14     3.37  1.94  6.40     3.26
  4.00  5.43     4.57  2.42  8.48     3.05
  6.00  7.68     5.75  2.84 10.38     2.70
  8.00  9.84     9.47  3.11 14.55     4.71

   AL       EPS      V        VX       VY

  0.00      3.52    8.948    8.931    0.550
  2.00      3.68    7.660    7.644    0.492
  4.00      3.73    6.830    6.816    0.444
  6.00      3.62    6.298    6.285    0.397
  8.00      4.12    6.013    5.998    0.432

   AL       AT        W     WH  WR+WL   WT

  0.00     1729      82      9     13  106
  2.00     1728      88     12     10  111
  4.00     1728      89     14      8  112
  6.00     1728      84     17      6  109
  8.00     1727      91     27      6  124

   AL     MF     MFS    MAH      MHS

  0.00   -5355  4911    -5075 -4915
  2.00   -3753  6193    -6330 -6190
  4.00   -2873  6797    -6898 -6799
  6.00   -2347  7044    -7082 -7043
  8.00   -1985  7179    -7114 -7178

   AL     RE      G    K1    K2

  0.00  129700  16.3  29.6  264.1
  2.00  111000  15.6  31.6  241.8
  4.00   99000  15.4  34.6  235.8
  6.00   91300  15.8  39.8  250.1
  8.00   87200  13.9  32.2  193.0

   AL   +-ALD   E5 * MSD/Q  STEIG.(MSD/Q)

  0.00  0.50      -90.7      -185.1
       -0.50       75.1      -149.4
  2.00  2.50      -93.3      -191.9
        1.50       90.3      -175.9
  4.00  4.50     -163.6      -329.3
        3.50      157.0      -302.7
  6.00  6.50       51.9       100.6
        5.50       31.8      -350.3
  8.00  8.50      -46.5       -95.2
        7.50       15.7       103.8
```

INPUT

OUTPUT

Angles

Speeds

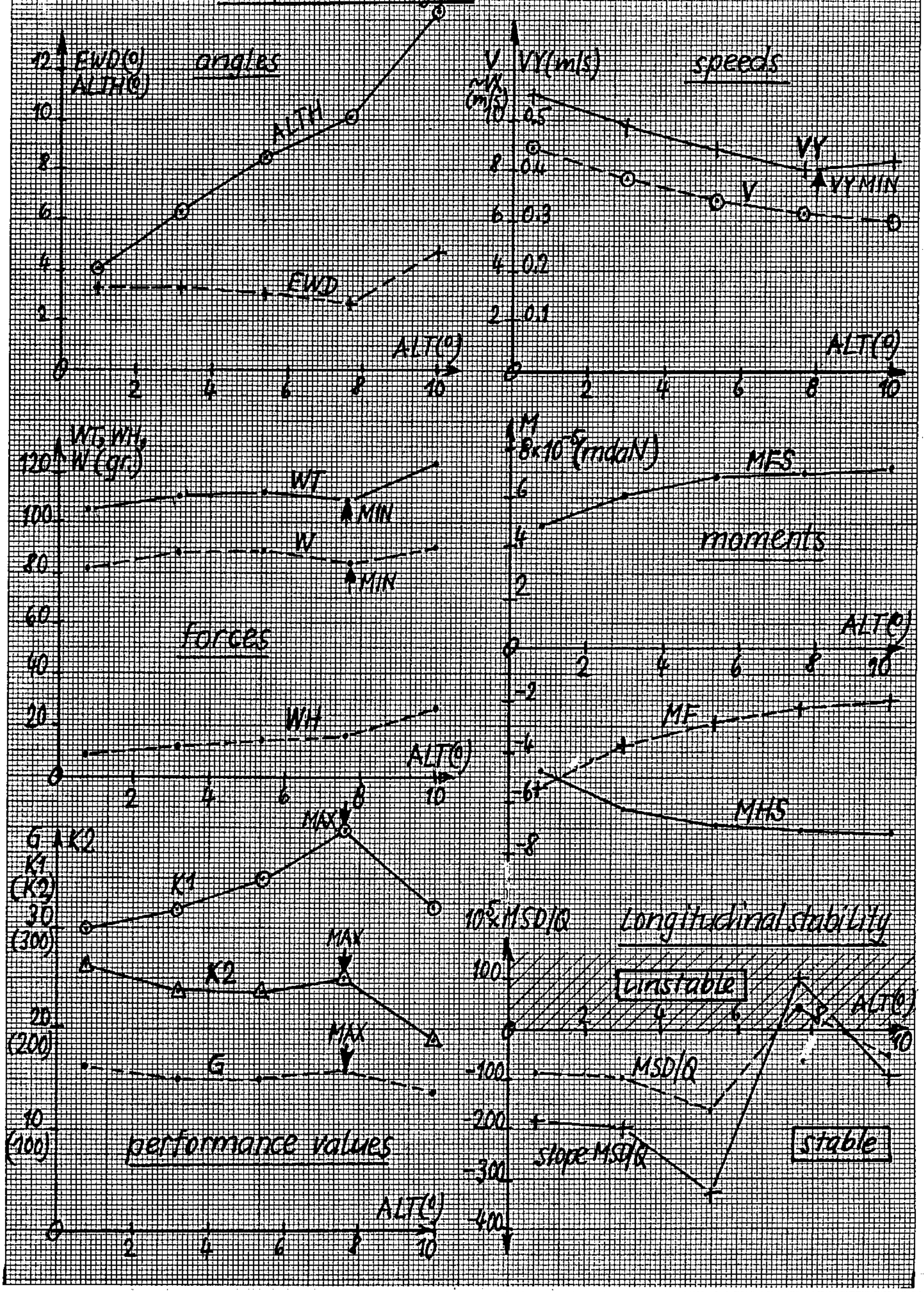
Forces

Moments

Performance values

Longitudinal stability

Fig. 13 Graphs of fig 12



Comments on graphs of Fig. 13

Warning: These graphs represent a special case with defined input and calculated output values. Changing one input parameter may alter the whole situation. Therefore do not generalize the following results; calculate each case.

All the calculated values are plotted in function of the total angle of attack ALT of the RC sailplane's wing. (not the angle of attack AL of a wing of infinite span)

It was impossible to calculate with the iteration method flight patterns up to vertical dive for numerical reasons.

Angles: Curve ALTH shows the position of the elevators and curve EWD indicates the longitudinal dihedral. The discontinuity of the EWD curve indicates longitudinal control problems. (with certain values of EWD there are 2 possible values of ALT)

Speeds: With increasing wing angle of attack ALT gliding speed V and sinking speed VY are decreasing. The sinking speed VY shows a minimum at wing angle of attack ALT=8.5 degree.

Forces: The drag force of the sailplane WT, of the wing W and the elevators WH are increasing with increasing wing angle of attack ALT. W and WT reach at ALT of about 8 degree a minimum af drag, which corresponds with the minimum of the sinking speed of the speed graph.

Moments: MF represents the wing longitudinal moment with respect to its quarter- chord point. MFS (wing longitudinal moment with respect to the sailplane's center of gravity C.G.) and MHS (elevator longitudinal moment with respect to the sailplane's C.G.) are identical in values for a determined angle of attack ALT but of different signs. (In a state of equilibrium, the algebraic sum of the moments should be zero)

Performance values: There is a local maximum of curve G (glide ratio) and K2 (performanc factor 2) and an absolute one of curve K1 (performance factor 1).The glide ratio is high in a wide range of ALT.

Longitudinal static stability: With a positive angle of rotation of ALD=0.5 degrees the restoring moment MSD/Q and the slope of its curve are, with small angles of attack, negative which means that longitudinal static stability is maintained. At an angle of attack ALT of 7.5 degrees positive values are shown which means static instability. The reason of this instability is the erroneous input of S=0.261*L (position of C.G. in flight direction with respect to the wing nose) instead of S=0.011*L. (L=medium wing chord)

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4 PRACTICAL APPLICATIONS

Most of the following figures were calculated basing on a sailplane "ASW 17",Carrera- kit. For details see Annex 2. In all cases, discrete values of the curves were calculated, plotted and connected with straight lines.

Be careful in generalizing the present results. because an alteration may affect theo whole situation!

4.1 Longitudinal control behavior (longitudinal dihedral EWD)

An important factor is the longitudinal dihedral or decalage EWD which signifies the difference of angles of attack elevators- wing.

The relation longitudinal dihedral vs. wing alnge of attack AL is mainly influenced by:

- center of gravity of sailplane position (Fig. 14)
- type of elevators airfoil (Fig. 15)
- elevators dimensions (Fig. 16)
- " moment arm (not calculated)
- wing airfoil and dimension (not calculated)

A steep negative slope of the dihedral curve indicates an excellent longitudinal control behavior whereas negative or no slope means problematic control behavior. (see Fig. 14 and 15)

Fig. 14 Longitudinal control behavior (longitudinal dihedral) as function of sailplane C.G. position

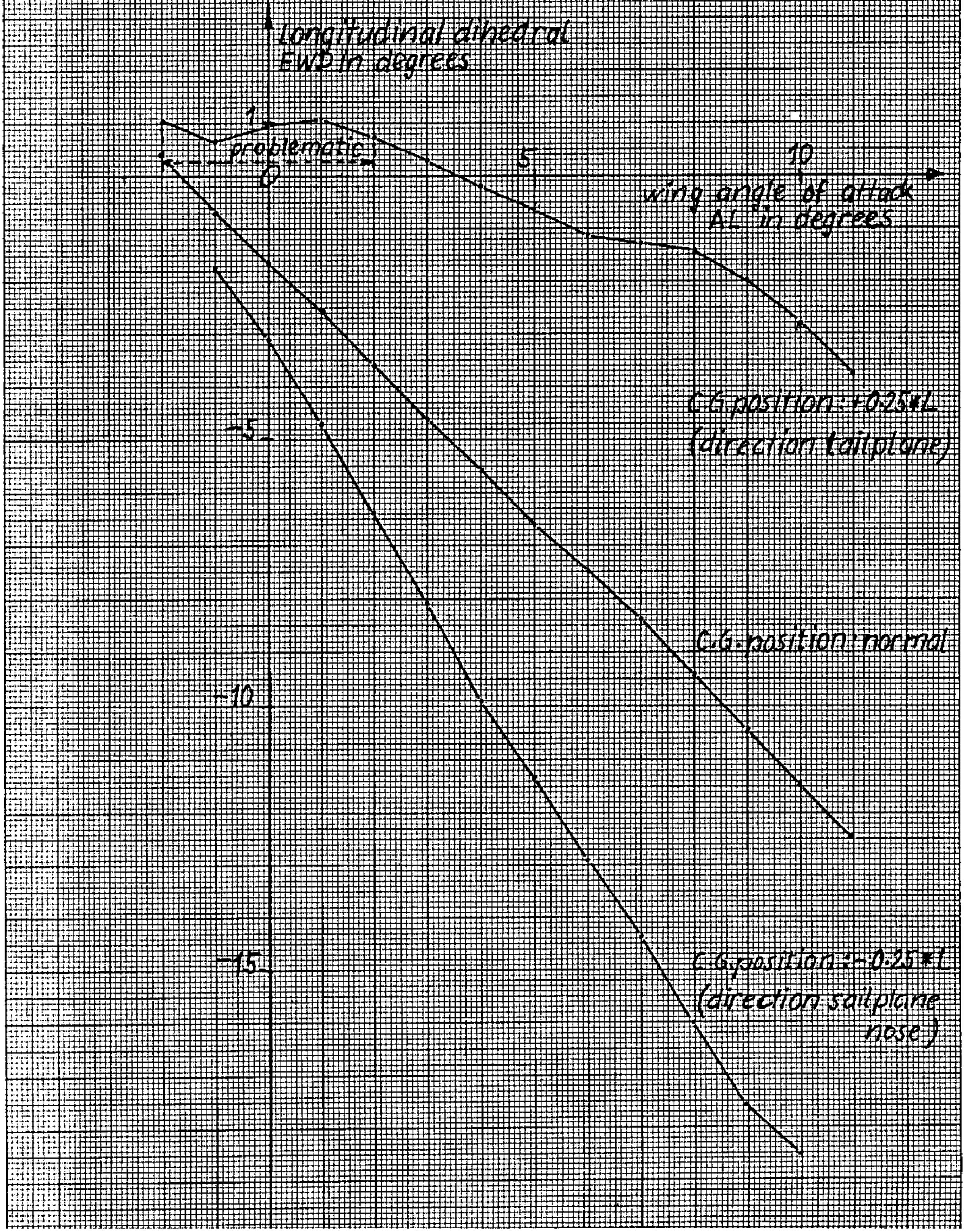

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Fig. 15 Longitudinal control behavior (longitudinal dihedral) as function of elevators airfoil type

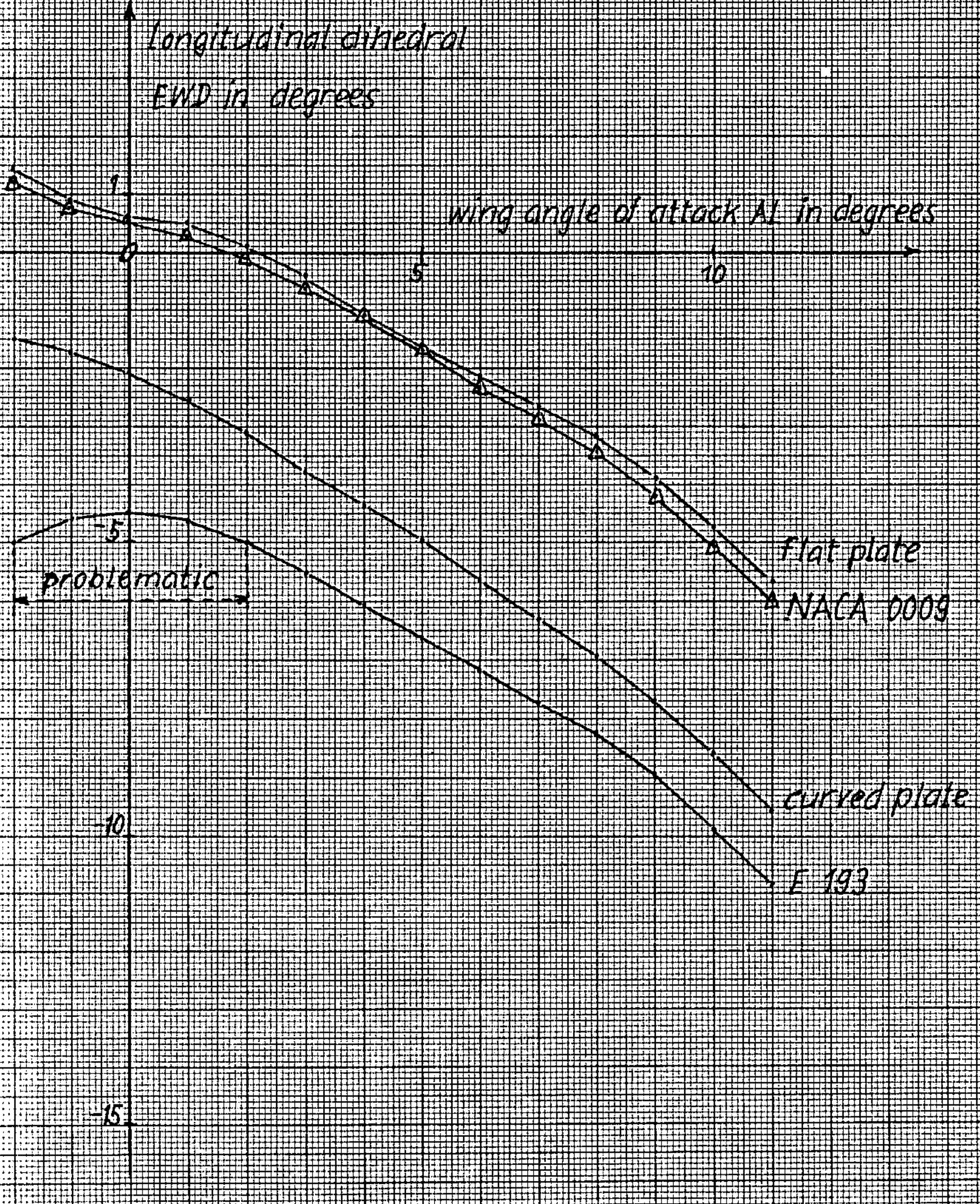
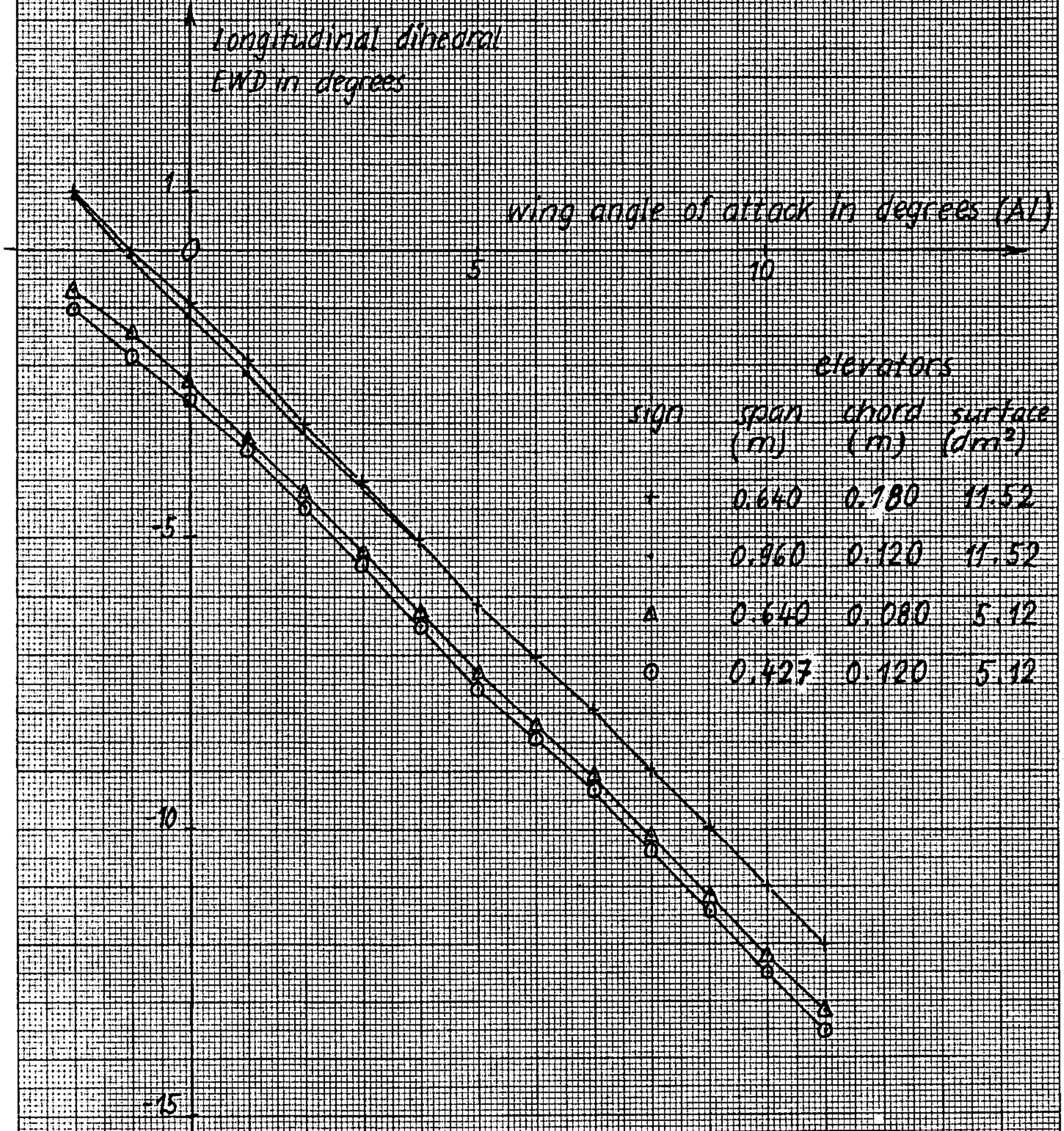


Fig.16 Longitudinal control behavior (longitudinal dihedral) as function of elevators dimensions



elevators

sign	span (m)	chord (m)	surface (dm²)
+	0.640	0.180	11.52
·	0.960	0.120	11.52
Δ	0.640	0.080	5.12
⊙	0.427	0.120	5.12

4.2 Longitudinal static stability

In this section, the ideas of page 6 and Fig. 6 and 7 are applicated on the RC sailplane "ASW 17" (see annex 2)

Fig. 17 shows the restoring moment vs. rotation angle curve of a stable straight flight (curve slope is negative) at an angle of attack AL of 8 degrees. In theory, this curve is replaced by a straight line.

Fig. 18 shows the same kind of curve but with a portion of instable flight. The abscissa contains the wing angle of attack AL combined with the sailplane angle of rotation.

Fig. 19 combines a series of curves of fig. 18 with different wing angles of attack. (-2, -1, 0, 1, 2, ...11 degrees).

Fig. 20 to 22 indicate the amount of restoring sailplane moments which is a measure for the amount and kind of longitudinal static stability depending on position of sailplane C.G., airfoil type and dimensions of the elevators. Small, propably not sufficient negative restoring moments were found on a sailplane with its C.G. in the middle of the wing airfoil chord. (see Fig. 20)

Fig.17 Longitudinal static stability : restoring moment MSD/Q vs. angle of rotation ALD

working point : AL = 8 degrees
curve indicates stability (negative slope)

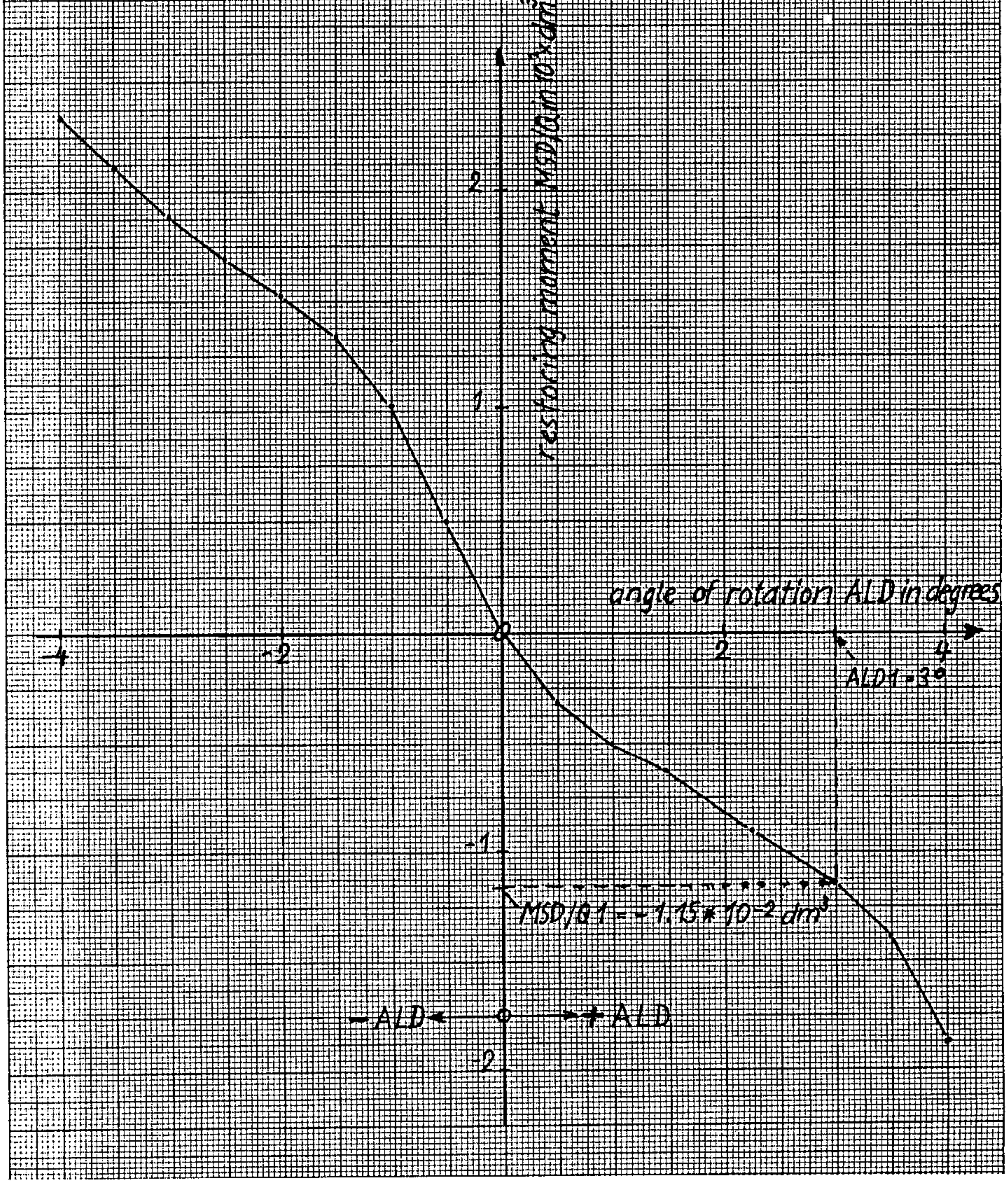


Fig. 18 Longitudinal static stability:
restoring moment MSD/Q vs. angle of rotation ALD

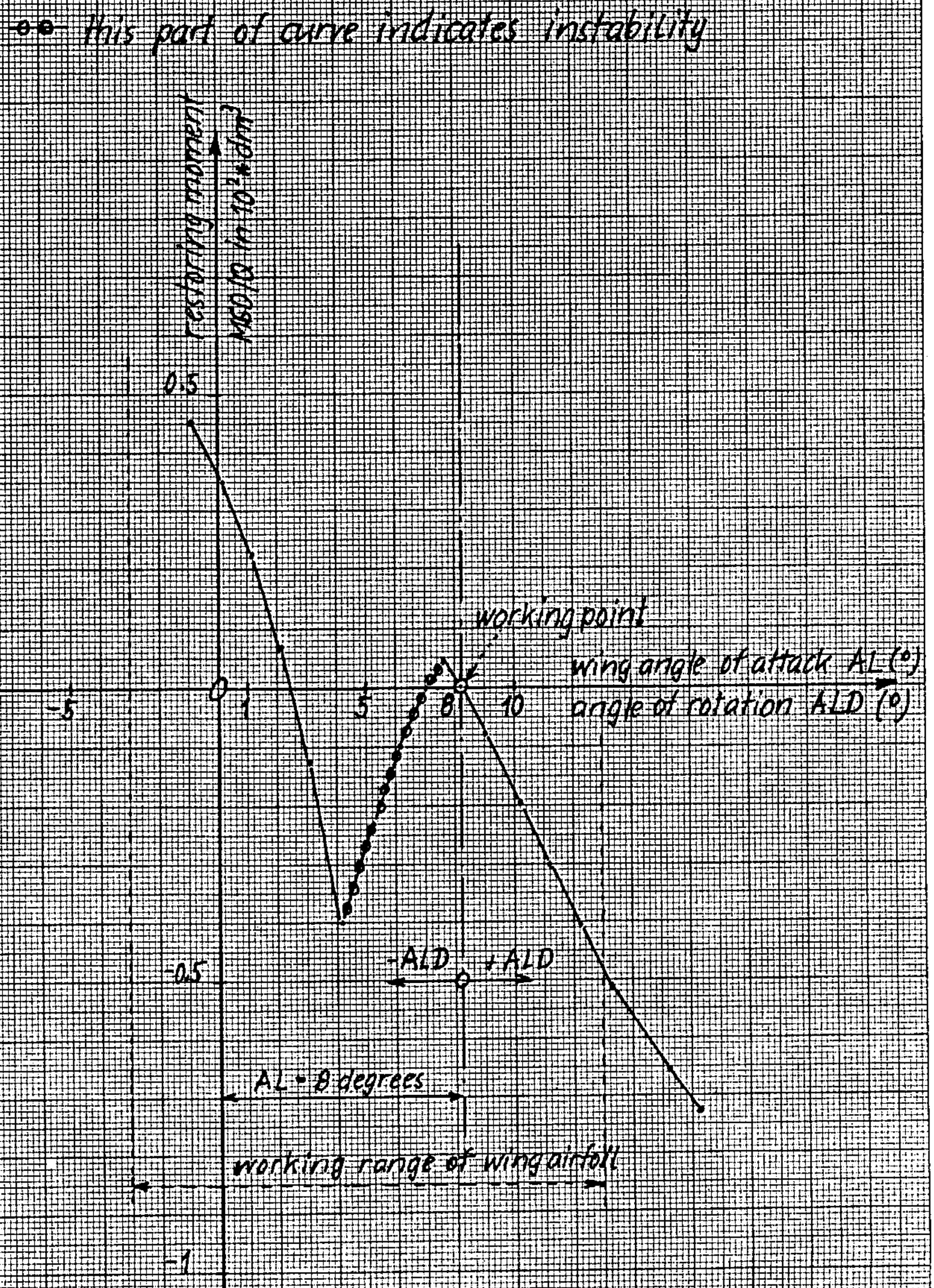


Fig. 19 Longitudinal static stability: rest. moments MSD/Q vs. AL,ALD

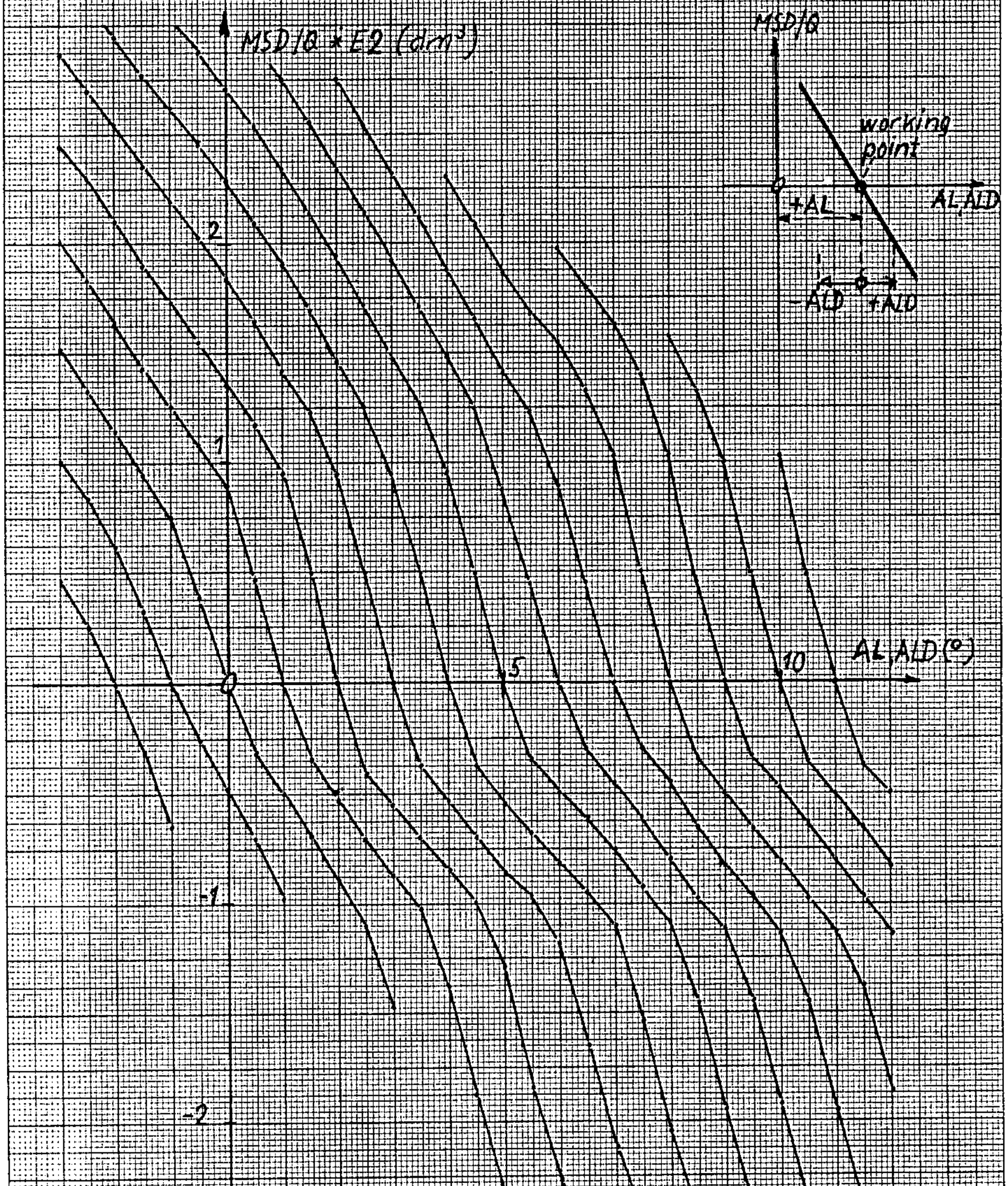


Fig. 20 Longitudinal static stability:
restoring moments MSD/Q vs. sailplane C.G. position

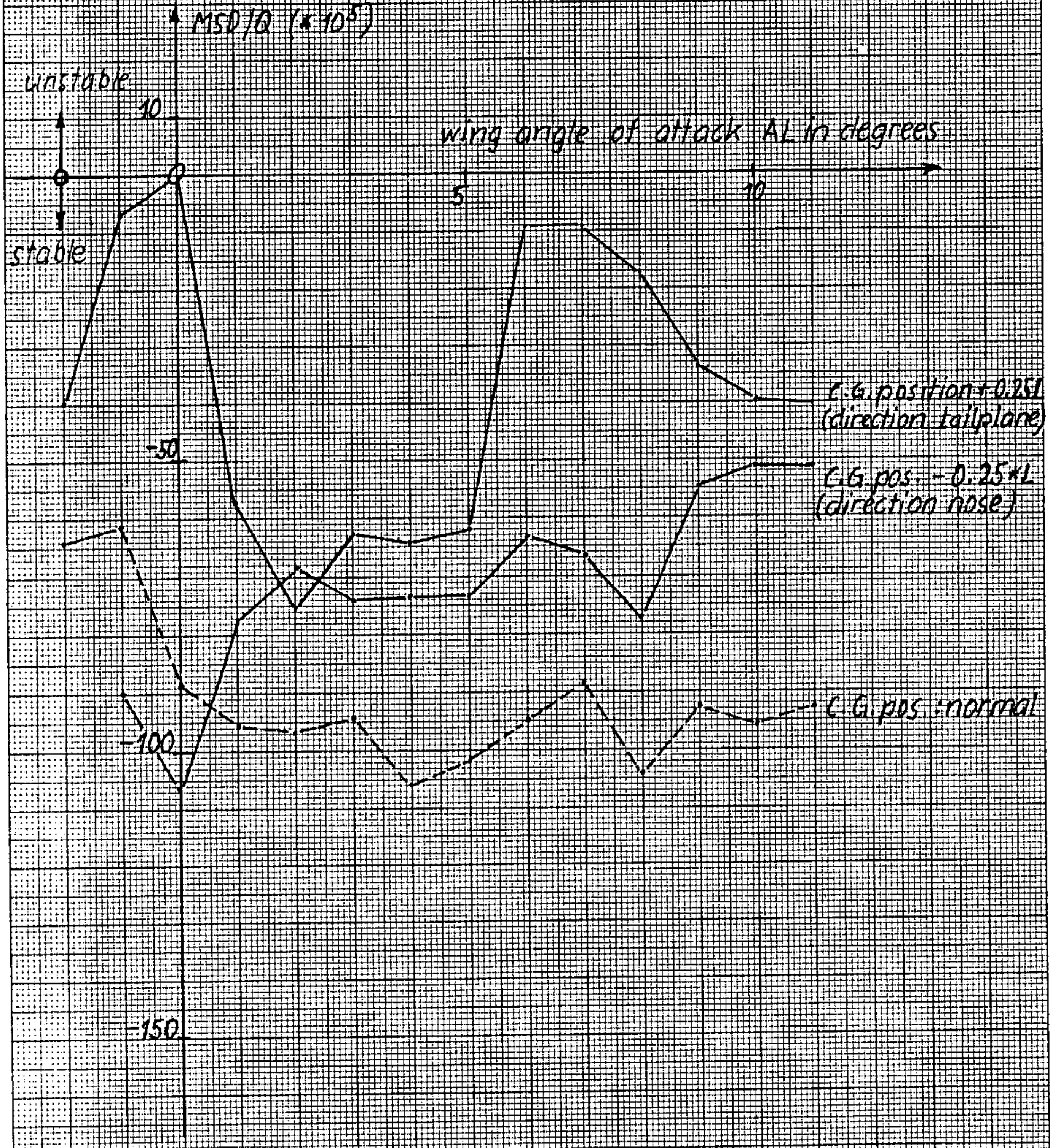


Fig. 21 Longitudinal static stability: Restoring moments MSD/Q vs. airfoil type of elevators

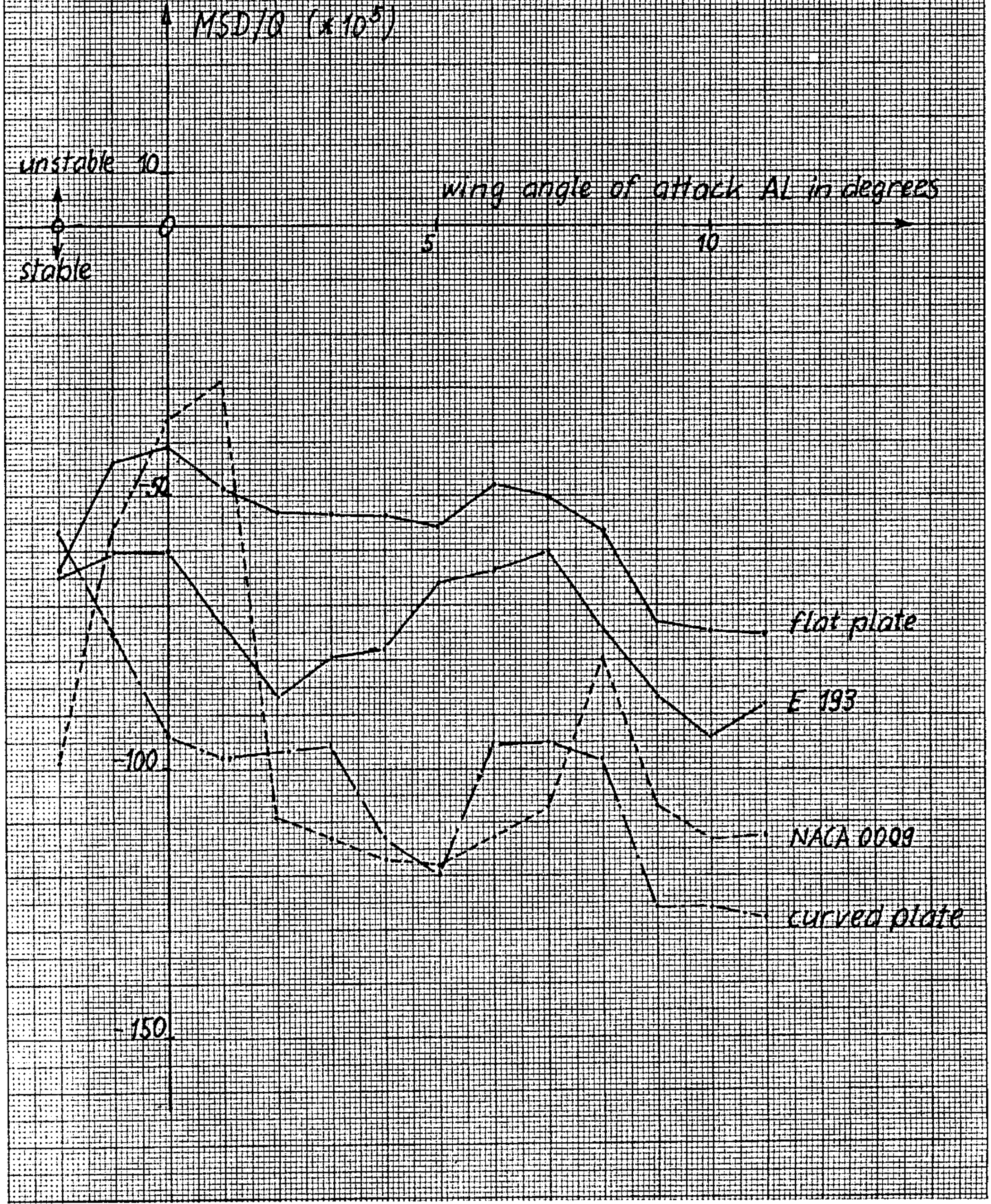


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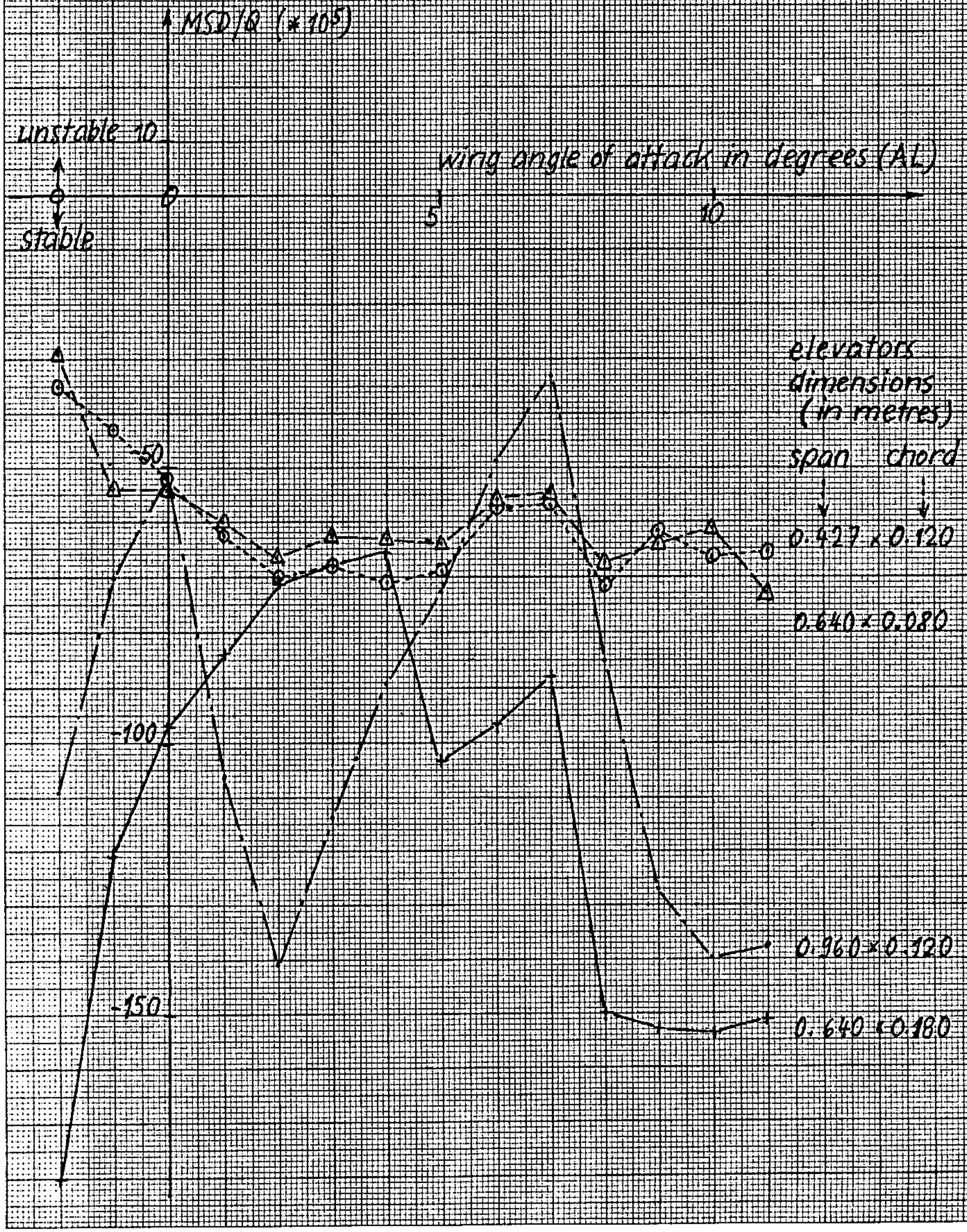
Fig. 22 Longitudinal static stability:
Restoring moments MSD/Q vs. elevators dimensions



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4.3 Comparison of an RC sailplane with 2 different wing airfoils

The RC sailplane "ASW 17" (see Annex 2) has the following wing airfoils:

- E 387 (designed by Prof. Eppler)
- HQ 1.5-9 (designed by Dr. Quabeck, no flaps are used)

In both cases a flat plate is used as elevators airfoil.

Measured airfoil coefficients:(Fig. 23, 24, 25)

The values are based on measurements made by D. Althaus.(lit.1) E 387 has higher values of lift coefficients but also of drag coeffients. Typical is the drag peak L at AL of 5 degrees (see Fig. 24) due to a laminar bubble. The coefficients are plotted versus wing angle of attack AL.

Angles: (Fig. 26)

An important value is the longitudinal dihedral EWD responsible for longitudinal control behavior. A positive slope of this curve indicates problematic flight behavior.

Performance values: (Fig. 27)

The minimum sinking speeds and the glide ratios show extreme values. The influence of the laminar bubble with the E 387 is obvious.

Longitudinal wing moments with respect to the quarter chord point (Fig.28)

Important moments were calculated. A symmetrical airfoil E 168 has moments of zero at all angles of attack.

Longitudinal wing moments with respect to the sailplane C.G. (Fig. 29)

These moments are balanced by those of the elevators, which are not plotted. Small moments at a wide range of wing angles of attack AL are prefered. (less drag)

Restoring moments for longitudinal static stability (Fig. 30)

Both airfoils show suffient negative restoring moments to guarantee longitudinal static stability. Practical tests will fix an admissible restoring moment.

RC sailplane glide polar: (Fig. 31)

This graph indicates best the sailplane performance. E 387 has a narrow range of minimal sinking speed difficult to fly in practice.

Fig. 23 Comparison of 2 wing airfoils: Lift coefficients

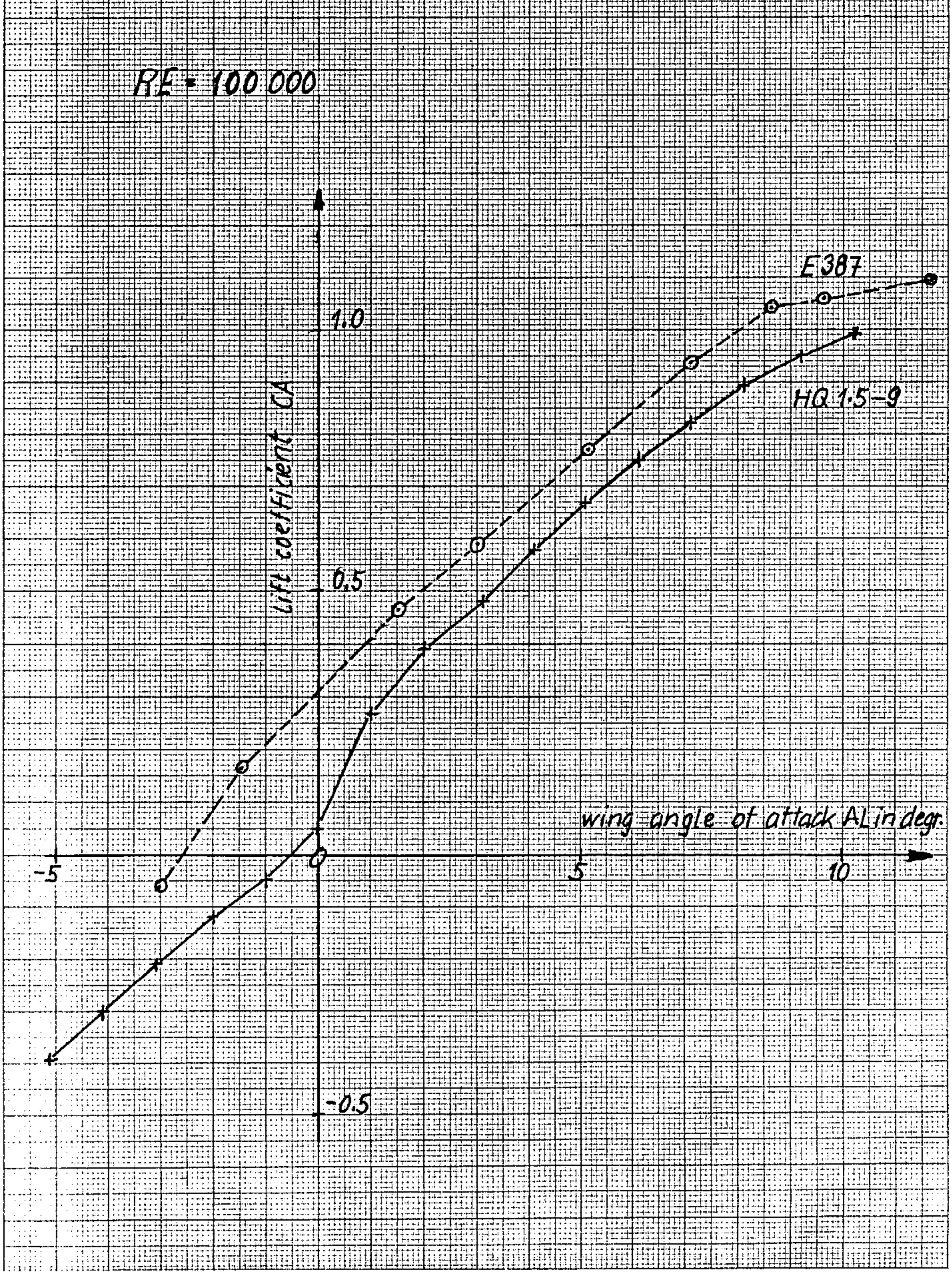


Fig. 24 Comparison of 2 wing airfoils : drag coefficients

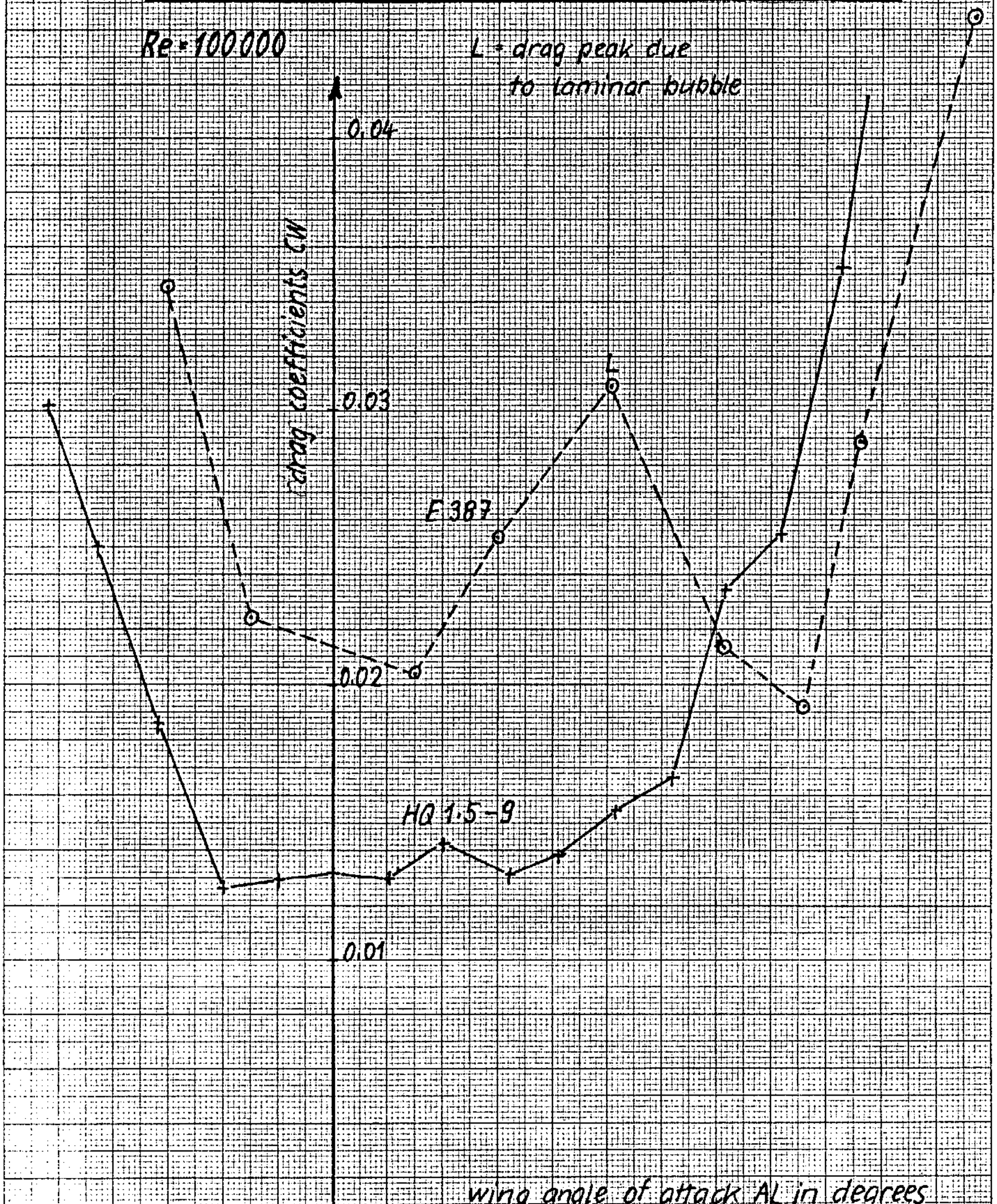


Fig. 25 Comparison of 2 wing airfoils: moment coefficients

RE = 100 000

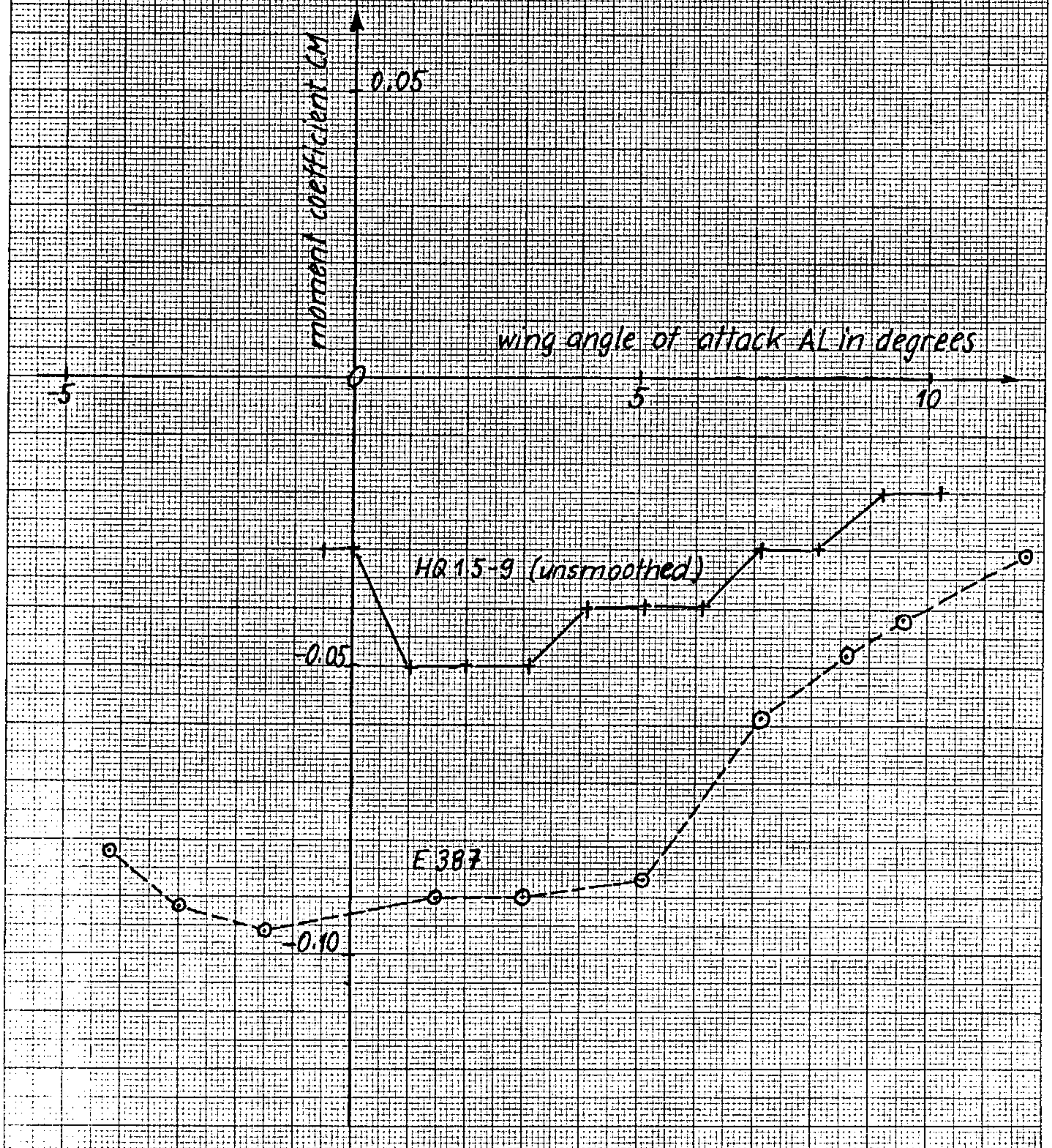


Fig. 26 Comparison of 2 wing airfoils : angles

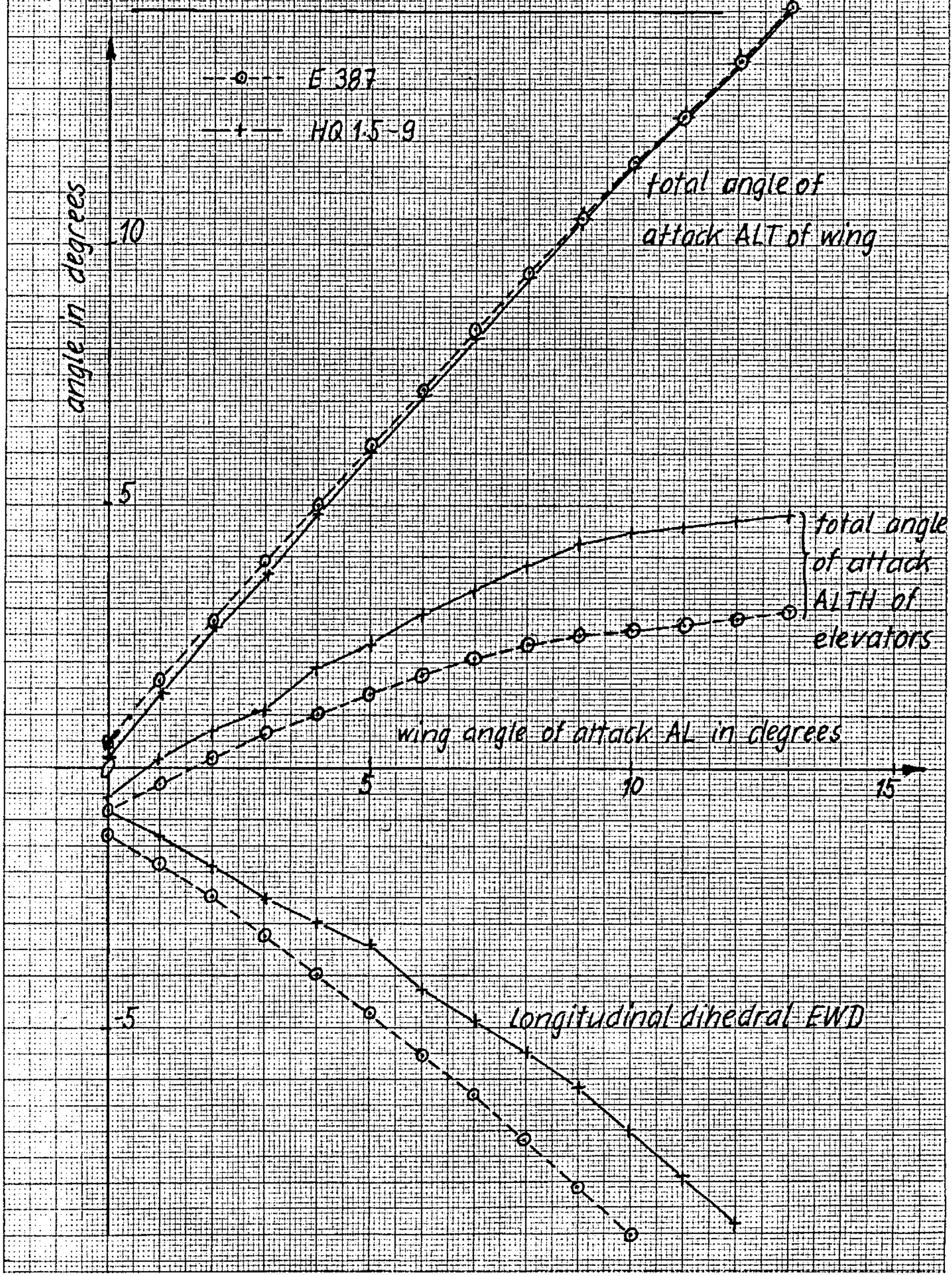


Fig. 27 Comparison of 2 wing airfoils: speeds and glide ratio

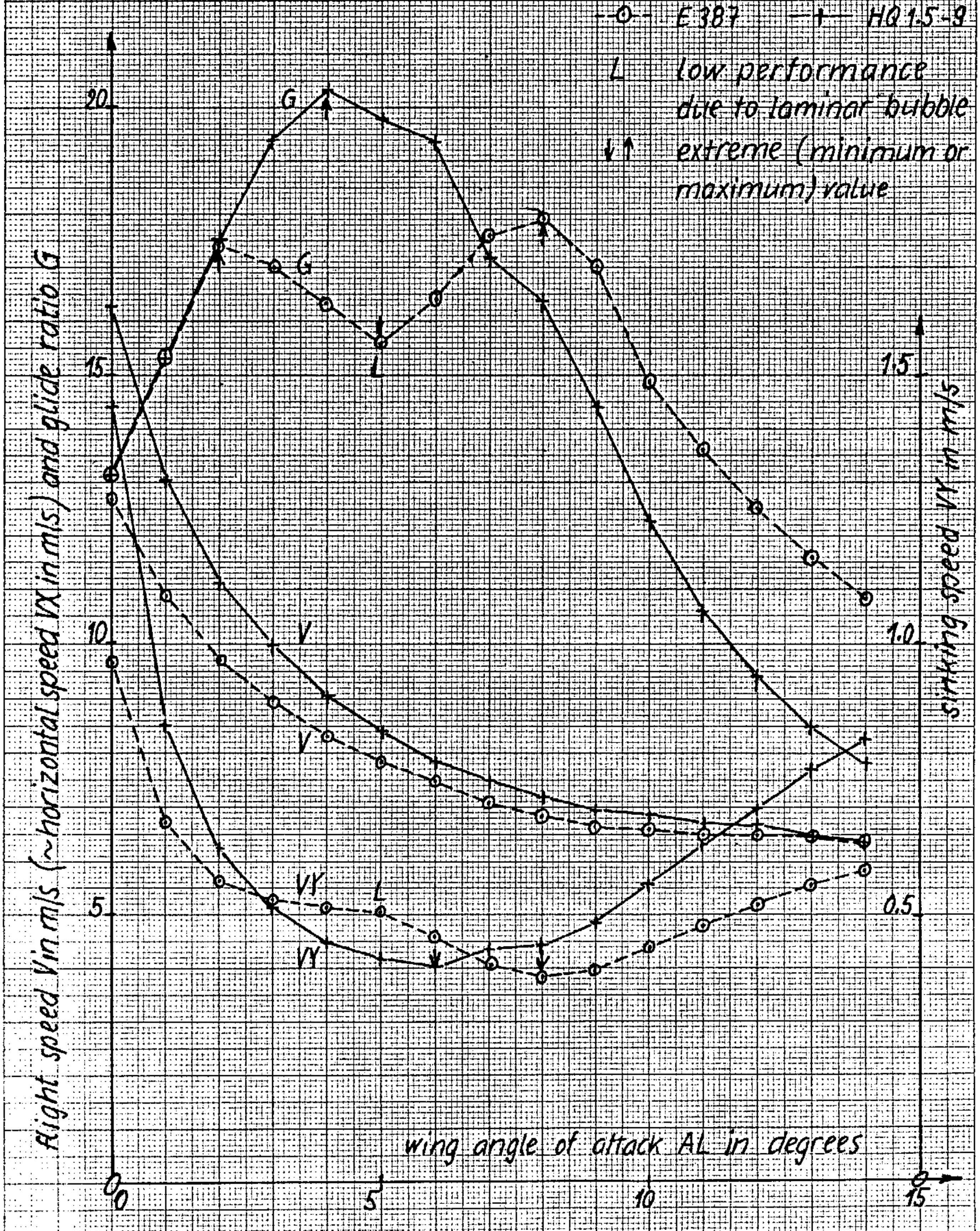


Fig. 28 Comparison of 3 airfoils: long. wing moments MF (quarter point)

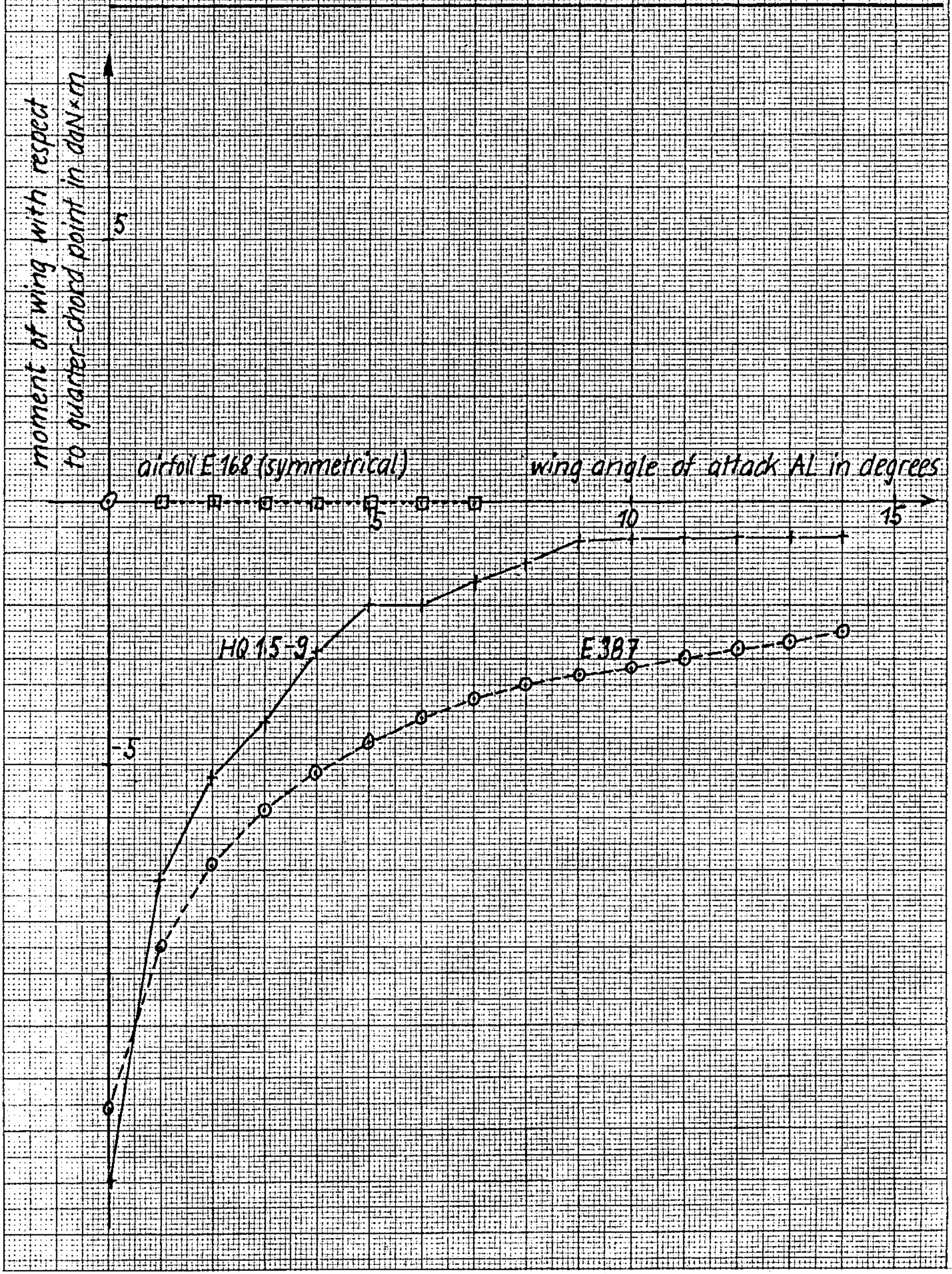


Fig. 29 Comparison of 3 airfoils: wing long. moments MFS (C.G. sailplane)

(these moments are equal bat of opposite sign with elevators moments)

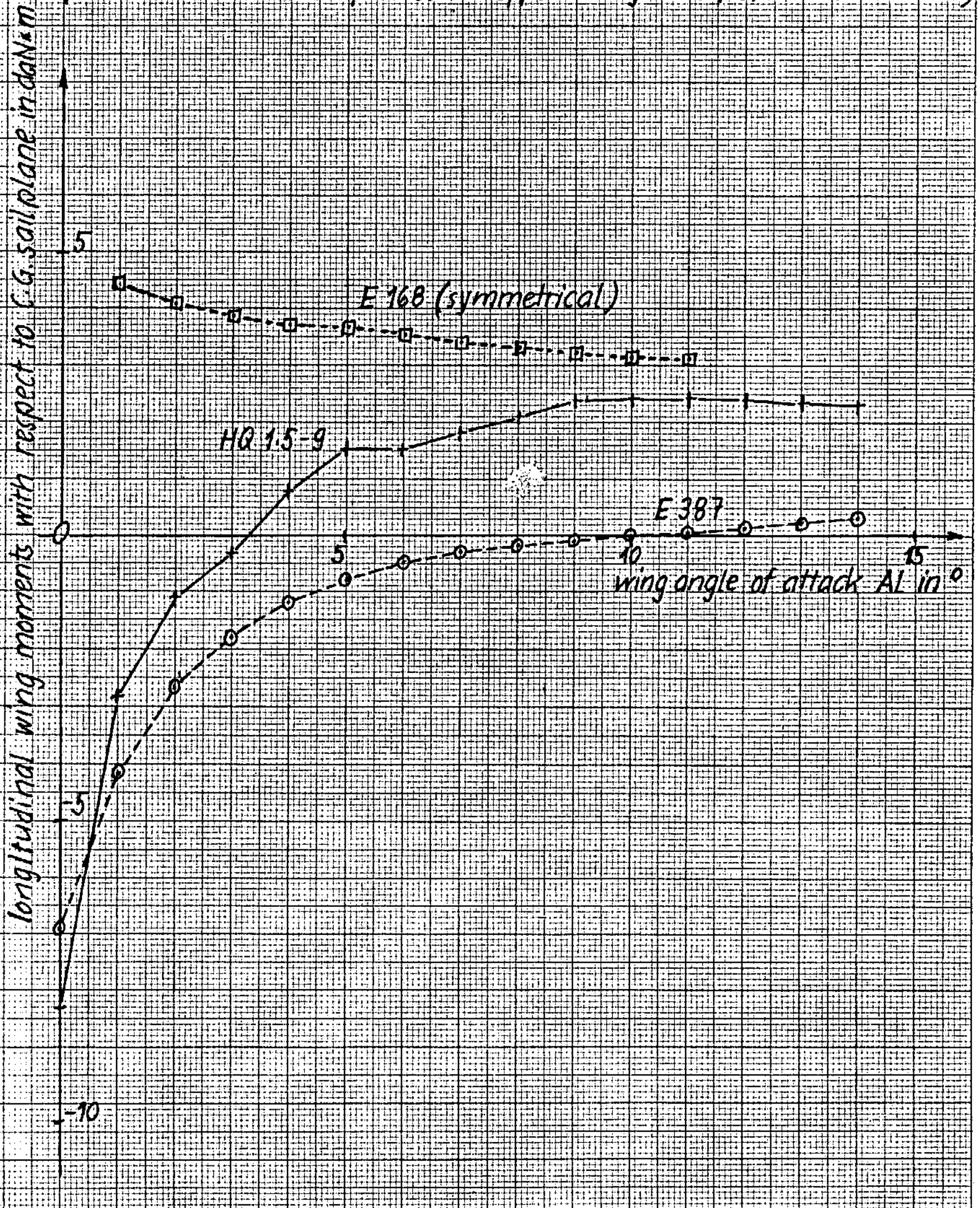


Fig. 30 Comparison of 2 airfoils: restoring moments MSD/Q for longitudinal static stability (ALD = +0.1°)

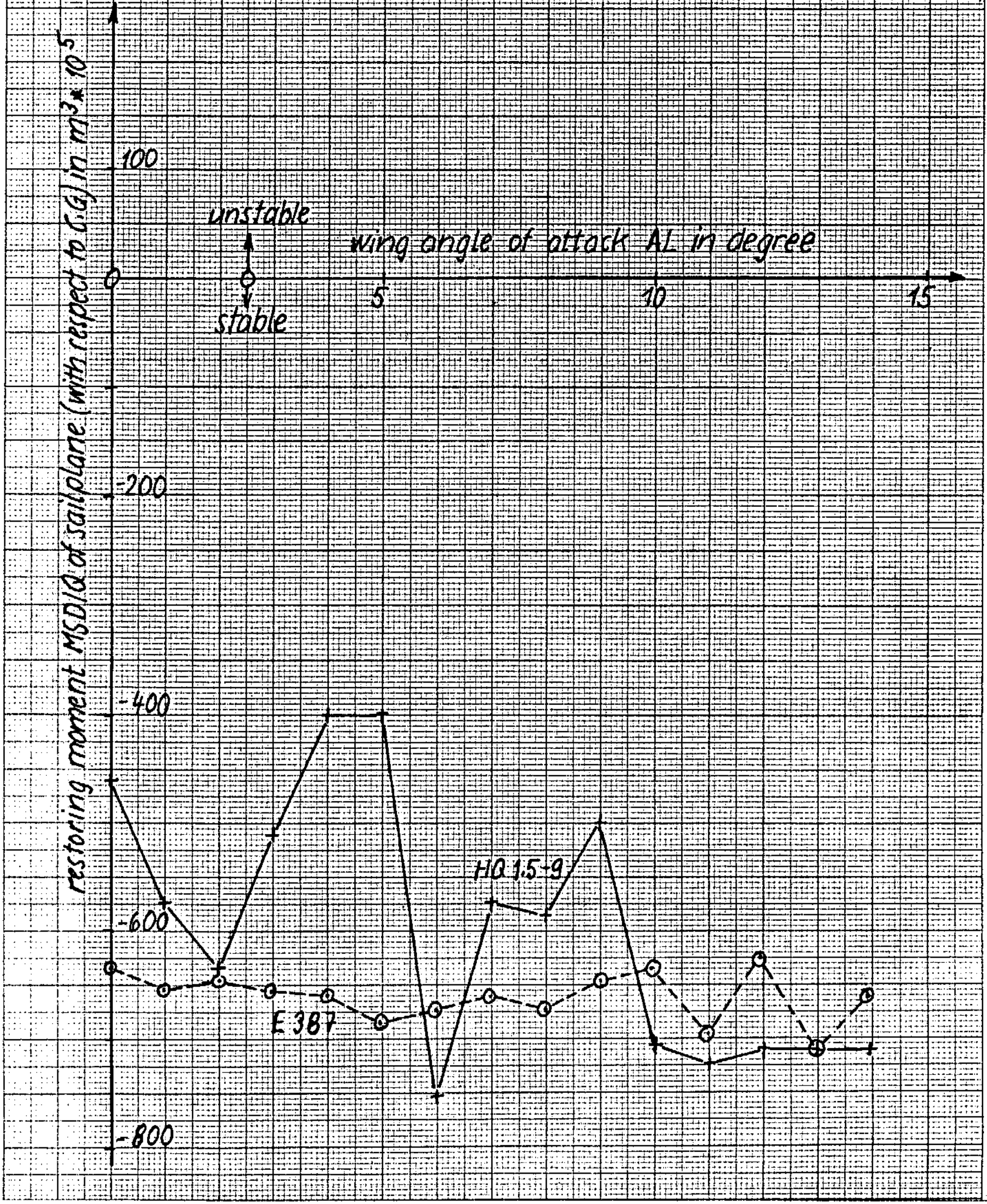
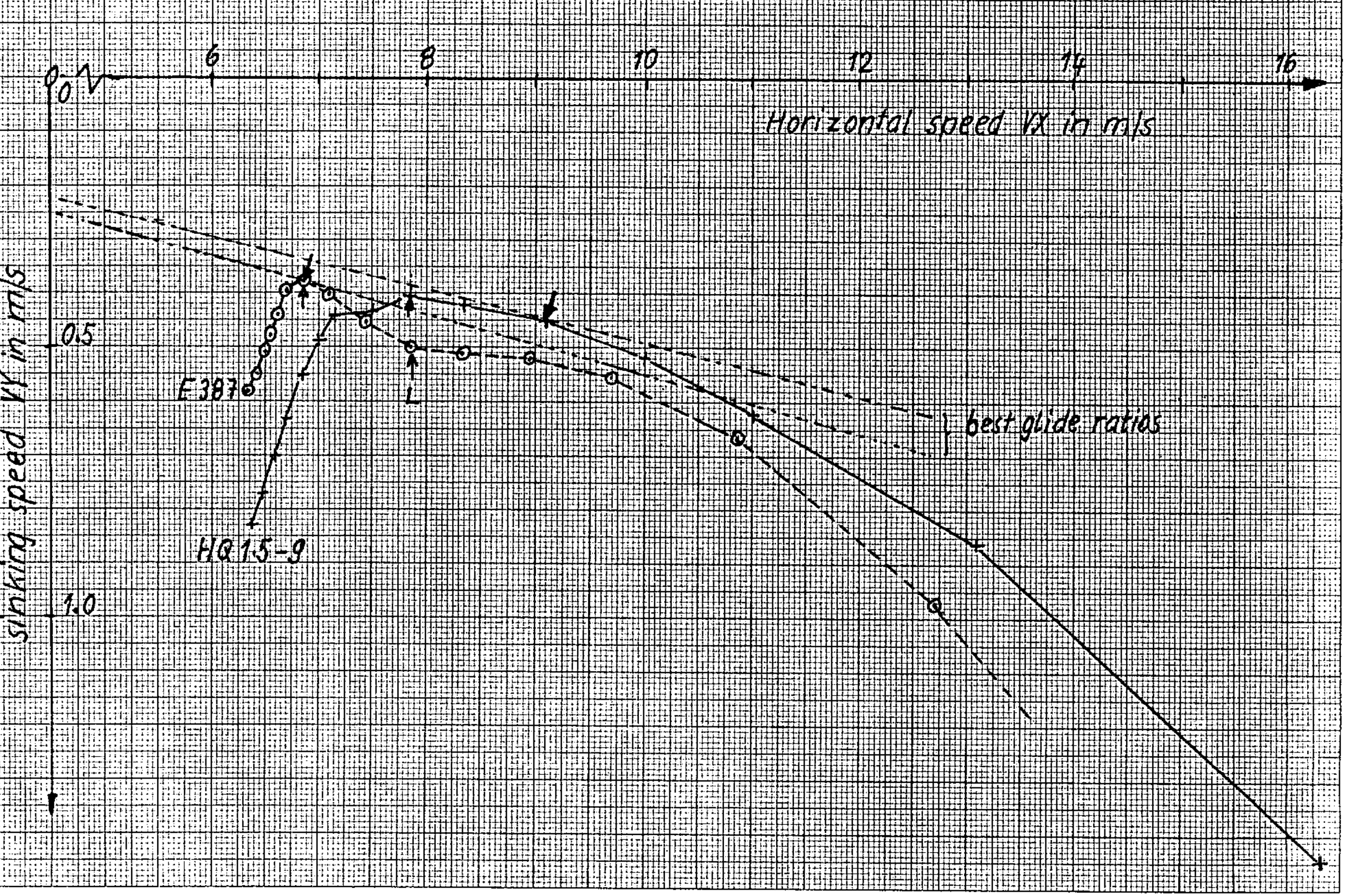


Fig. 31 Comparison of 2 airfoils : RC sailplane glide polar



4.4 Influence of sailplane construction parameters on the minimum sinking speed VYMIN.

A way to explore the computer model of the flying RC sailplane is to vary one of the sailplane construction parameters (for instance the wing span) while leaving the others constant and to observe performance characteristics (for instance the minimum sinking speed). As base of the following figures, we have taken the RC sailplane ASW 17 (see Annex 2) with an airfoil Quabeck HQ 1.5-9. Calculation results show 3 categories of curves:

- -The parameter has important influence on the minimum sinking speed. The curve doesn't show a minimum. (Fig. 32)
- -The parameter influences the minimum sinking speed and a minimum of the minimum sinking speed curves is shown. (Fig. 33)
- -The influence of the parameter on the minimum sinking speed is very small. (see Fig. 34) The influence of the elevators moment arm (not plotted) was found to be, for TH between 2 and 5 times the mean wing chord, zero.

All these graphs may give us hints to construct RC sailplanes with lower sinking speed. These investigations are a first step in optimization, which will be treated in a separate paper.

Fig. 32 One-parameter variation vs. min. sinking speed VYMIN

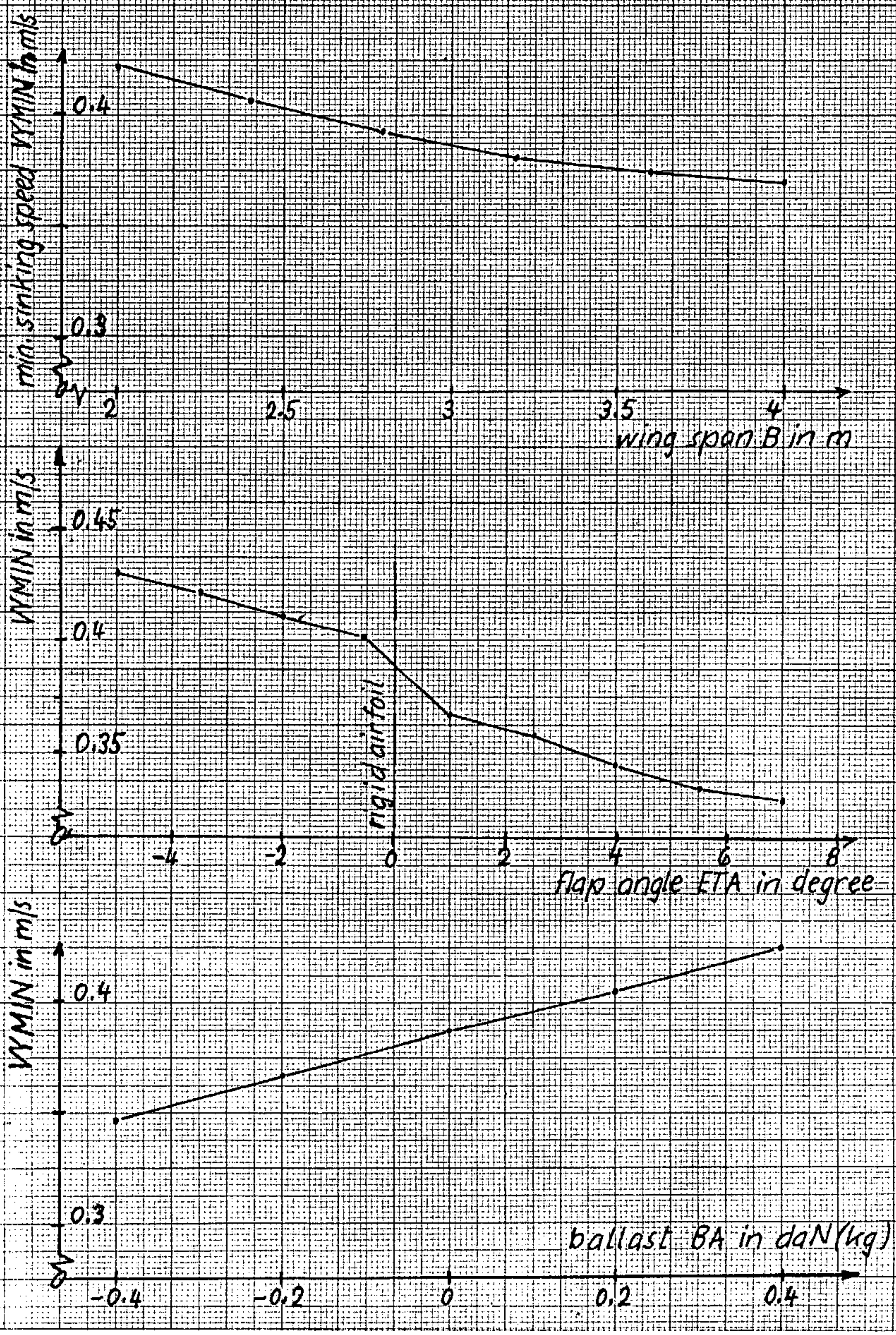


Fig. 33 One-parameter variation vs. min sinking speed VYMIN

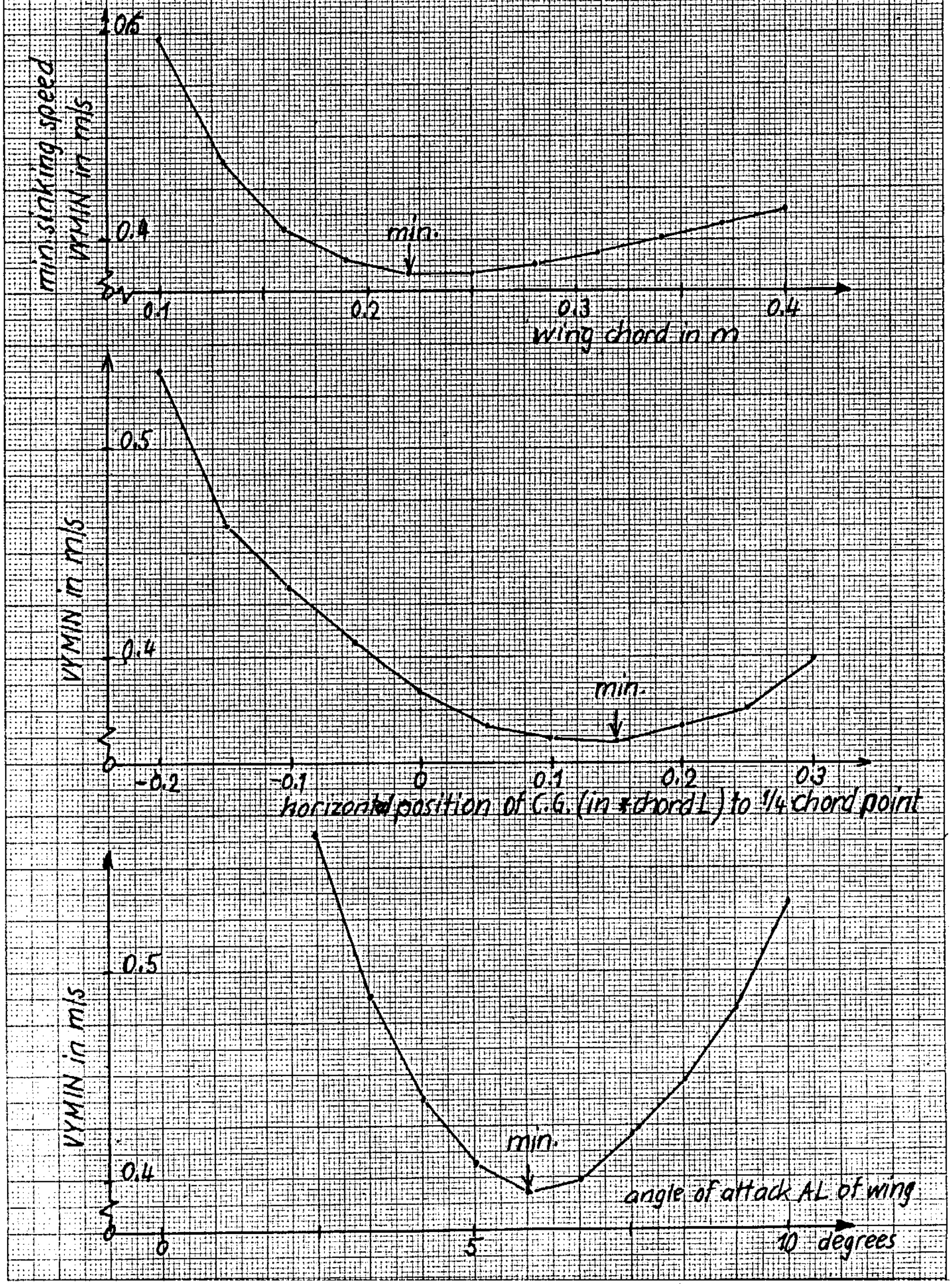
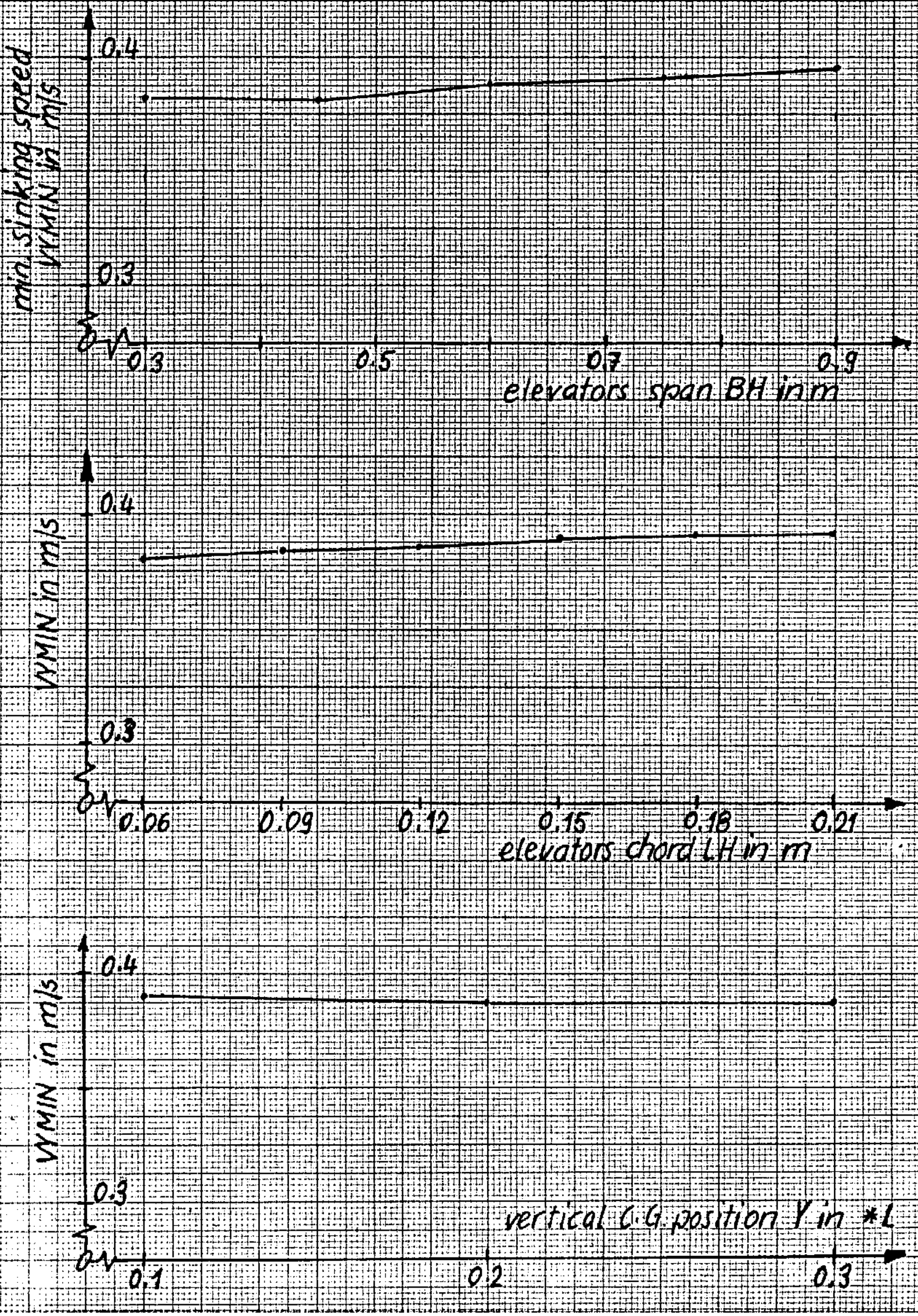


Fig.34 One-parameter variation vs. min. sinking speed VYMIN



4.5 Comparison on 4 RC sailplanes

Four types of existing (and flying) sailplanes (Fig. 35,37,39, 40) were chosen for comparison with respect to

-longitudinal dihedral EWD (Fig. 41)
-elevators moments (Fig. 42)
- " restoring moments (Fig. 43)
-sailplane glide polars (Fig. 44)

We shouldn't forget in this comparison our friends, the birds. You, dear reader, may add a "bird curve" to the glide polars; for data see for example lit. (3).

Longitudinal control behavior (longitudinal dihedral, Fig.41)

The Milan- curve shows, at an angle of attack AL of 2 - 4 degr. a nearly horizontal slope. This corresponds with longitudinal control problems experienced in practice.

Elevators moments (Fig. 42)

Small elevators moments (with respect to sailplane C.G.) with all angles of attack AL are advantageous. (see curves "Schwarzer Rab" and "RC federleicht")

Elevators restoring moments (Fig. 43)

Negative important restoring moments produce a high amount of longitudinal static stability. The plane "Schwarzer Rab" has, at an angle of attack of 7 degrees, an instability. The best amount of stability should be tested with the flying sailplane.

Sailplane glide polars (Fig. 44)

These curves show performance values (horizontal and sinking speeds, glide ratios) of the 4 sailplanes. The "RC federleicht" plane has the best sinking speed but a low flight speed (horizontal speed) and not a very high glide ratio. The difference of sinking speed between the"ASW 17"and "Milan" was demonstated in many flight tests. (parallel flights)

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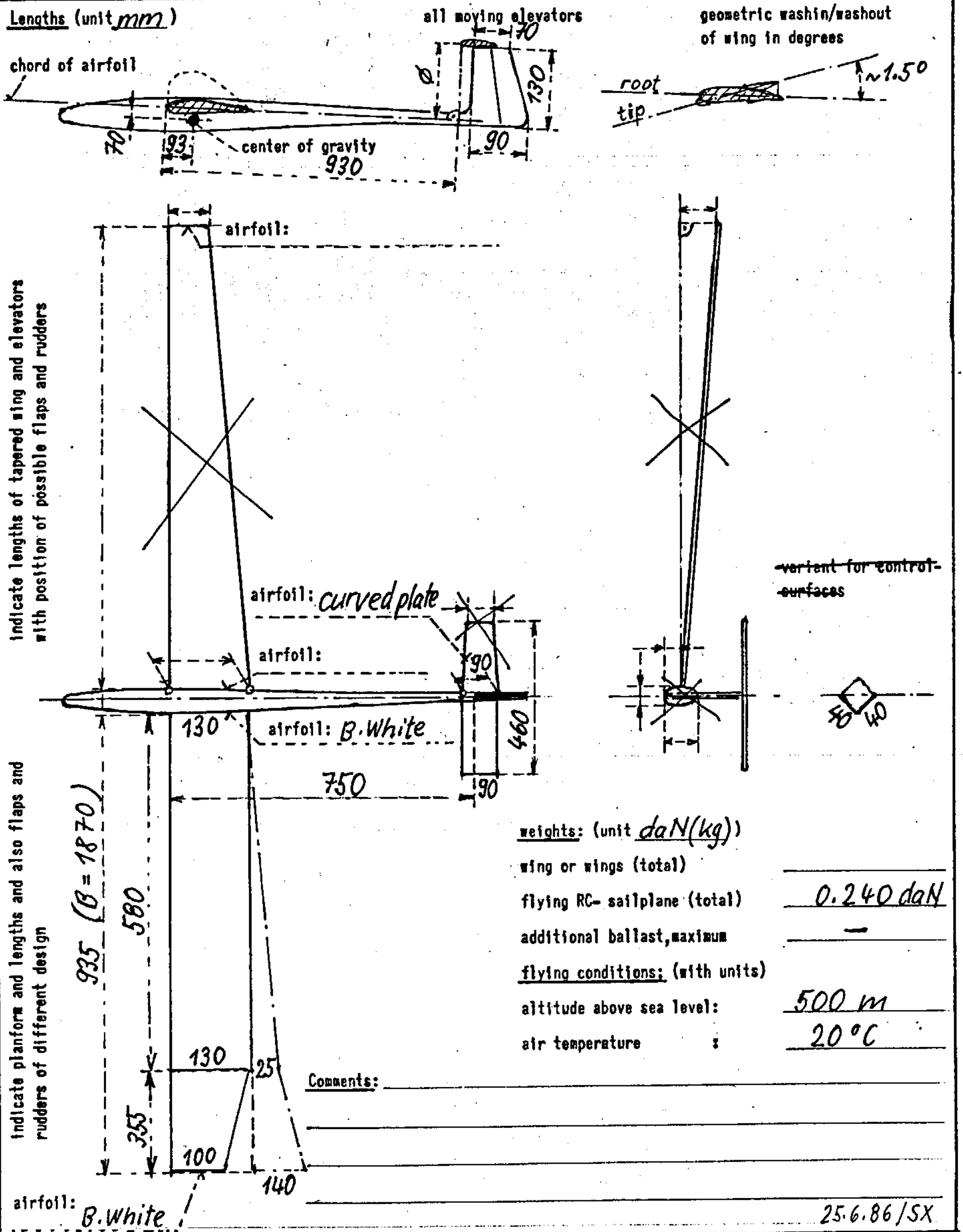
NAME OF RC- SAILPLANE : RC-federleicht (feather Light) DATE : 4.4.86 F35

NAME, ADDRESS, PHONE-NR OF DESIGNER AND/~~OR~~ PILOT : Wolfgang Heide,
(see journal "Flug + Modelltechnik" 4/1986 and next page)

Lengths (unit mm)



weights: (unit daN(kg))

wing or wings (total)

flying RC- sailplane (total) 0.240 daN

additional ballast, maximum —

flying conditions: (with units)

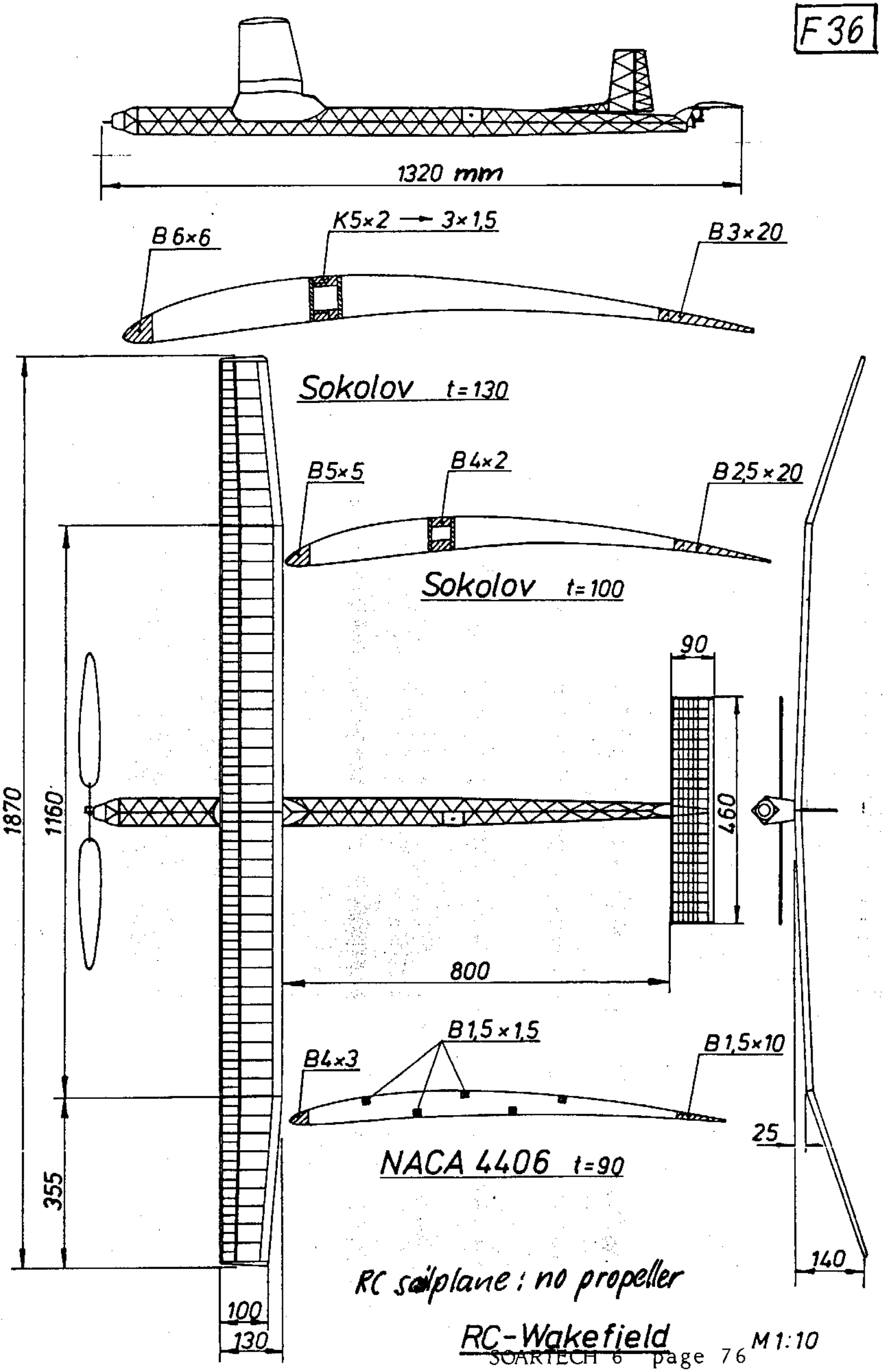
altitude above sea level: 500 m

air temperature : 20°C

Comments:

25.6.86/SX

F 36



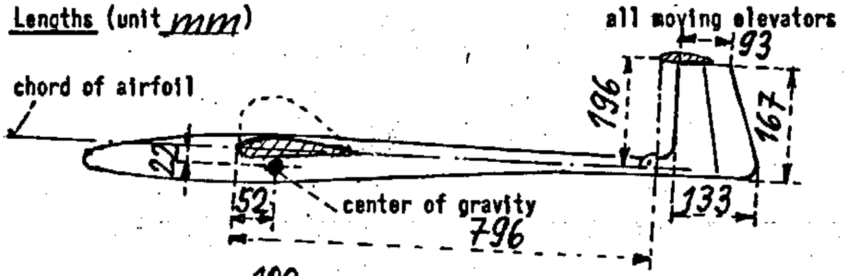
RC sailplane : no propeller

RC-Wakefield M 1:10

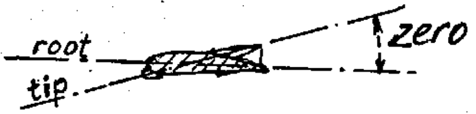
NAME OF RC- SAILPLANE : Schwarzer Rab (Black raven) DATE : 16.3.86 **F 37**

NAME, ADDRESS, PHONE-NR OF DESIGNER AND/OR PILOT : Michael Wohlfahrt (see Journal " Flug + modelltechnik" 3/1983 and next page)

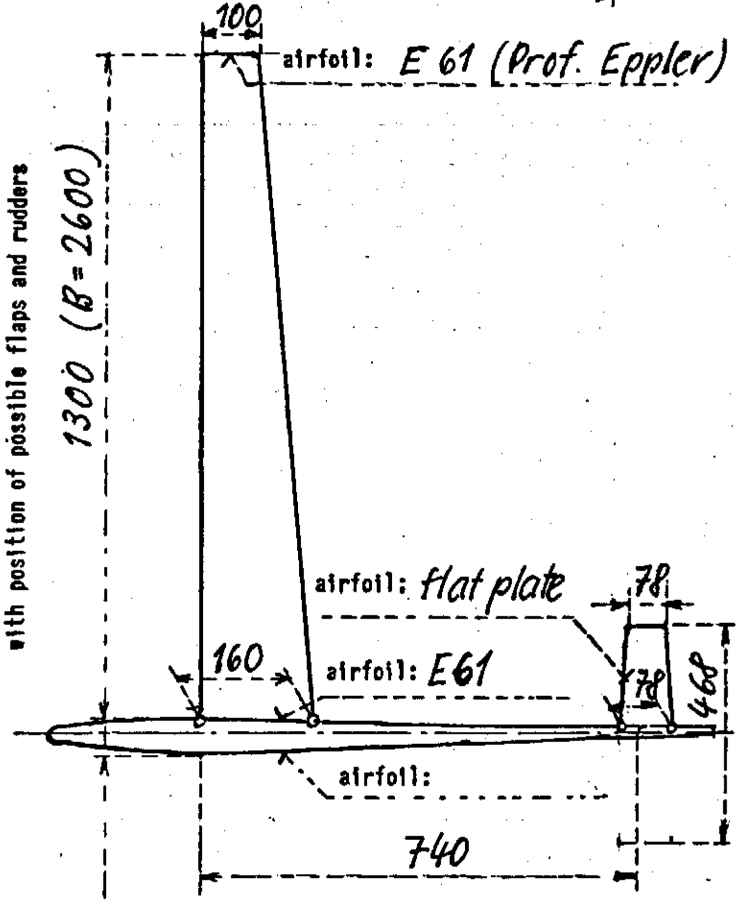
Lengths (unit mm)

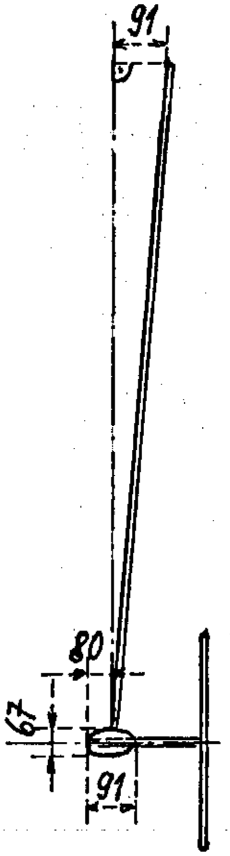


geometric washin/washout of wing in degrees



indicate lengths of tapered wing and elevators with position of possible flaps and rudders





~~variant for control-surfaces~~

weights: (unit daN(kg))

wing or wings (total) 0,470

flying RC- sailplane (total) 0,900 daN

additional ballast, maximum —

flying conditions: (with units)

altitude above sea level: 500 m

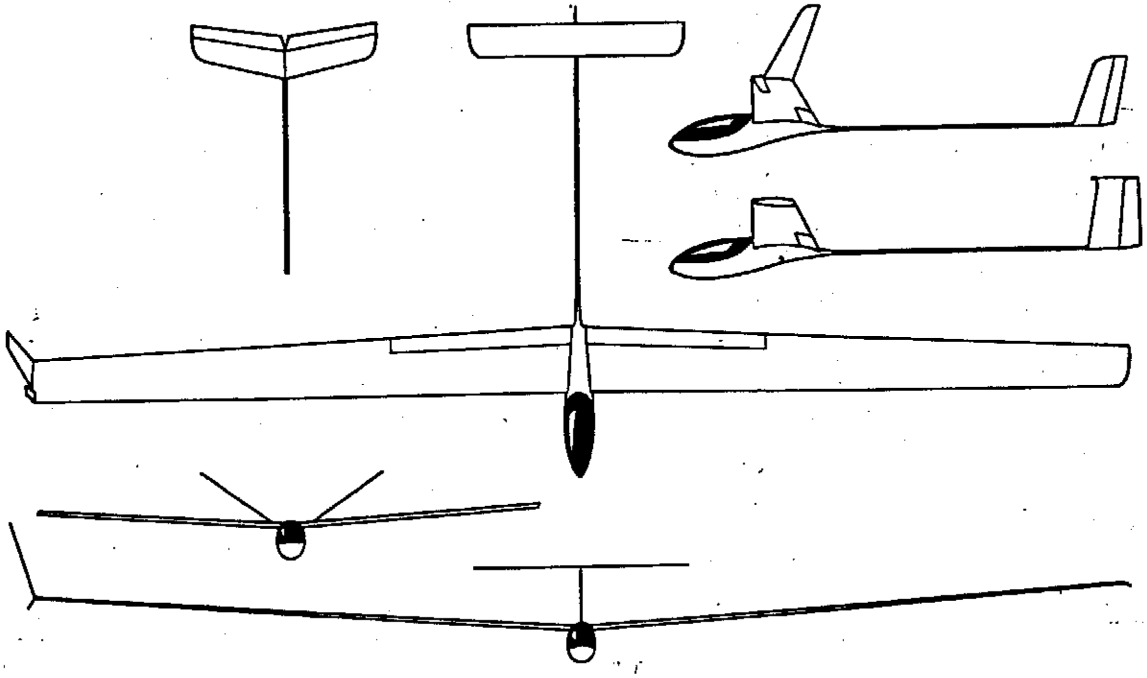
air temperature : 20 °C

indicate planform and lengths and also flaps and rudders of different design

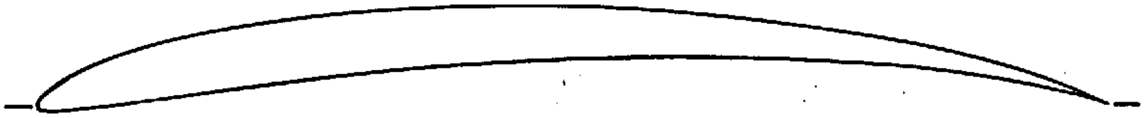
airfoil:

Comments:

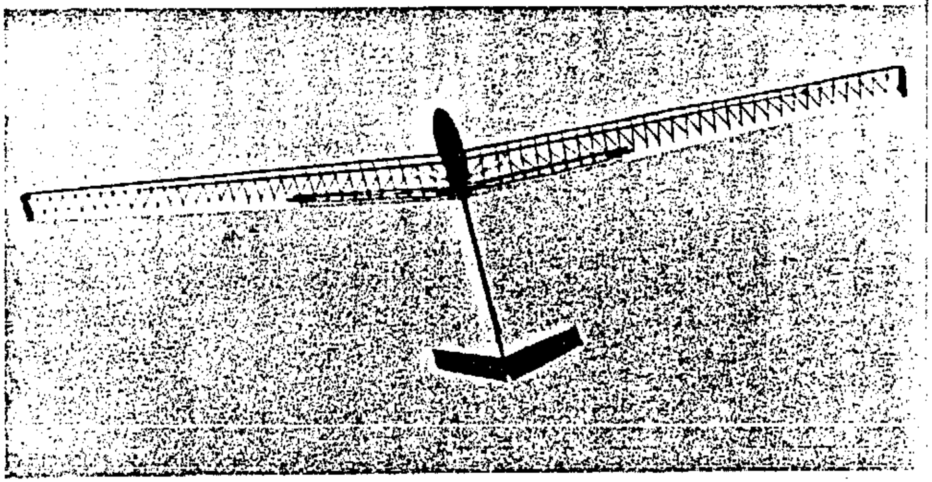
25.6.86 / SX



Die Variationen des Schwarzen Rab', in Skizzen dargestellt



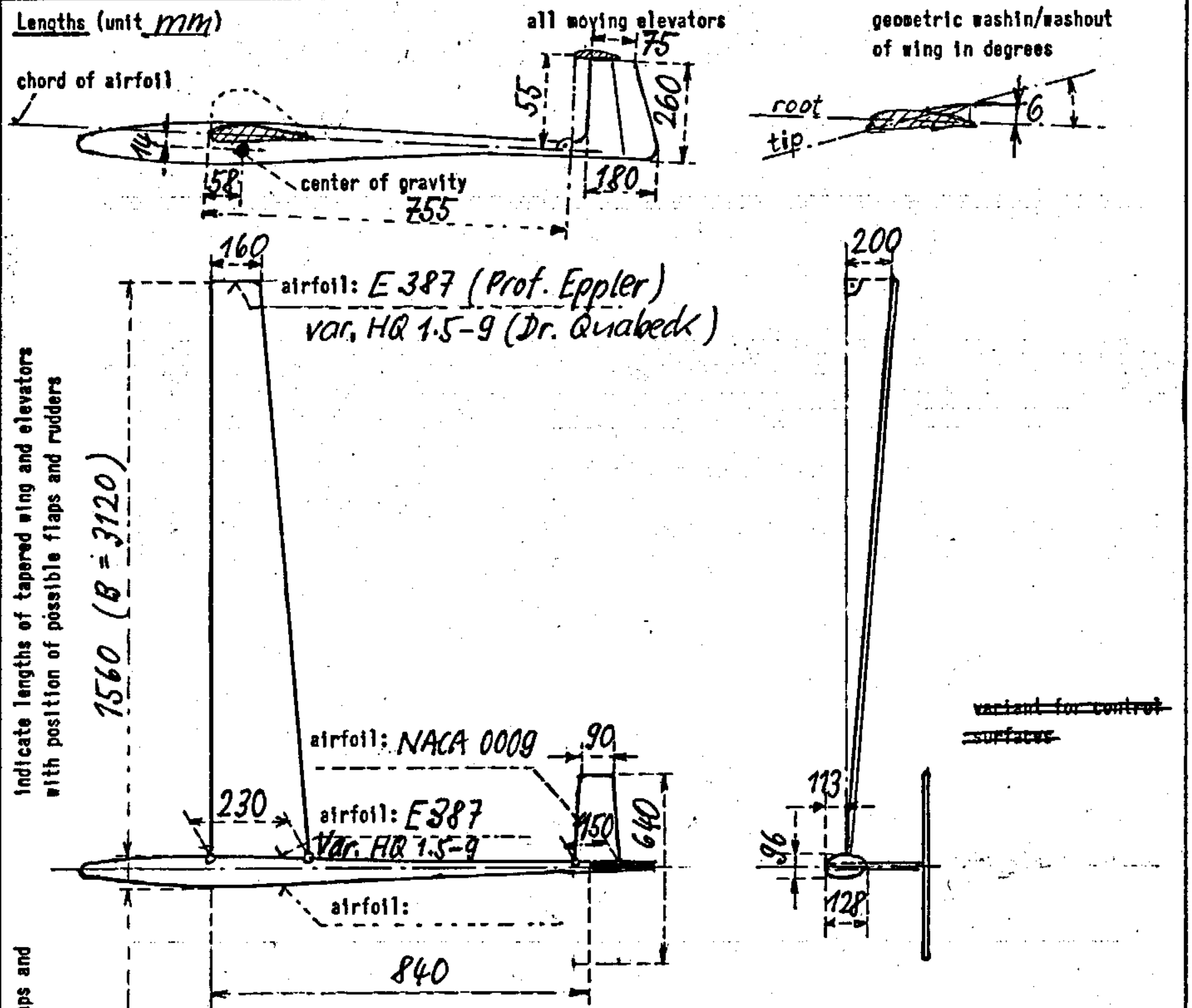
Das Flügelprofil E 61, von Prof. Eppler auf ein möglichst minimales Sinken berechnet



Der Schwarze Rab' mit dem V-Leitwerk und in Version mit T-Leitwerk und Winglets

NAME OF RC- SAILPLANE : ASW 17 (Carrera kit) DATE : 16.3.86 F 39

NAME, ADDRESS, PHONE-NR OF ~~DESIGNER AND/OR~~ PILOT : A. Saxer, Münchenbuchsee (Switzerland)



weights: (unit daN (kg))

wing or wings (total) ____

flying RC- sailplane (total) 1.890 daN

additional ballast, maximum —

flying conditions: (with units)

altitude above sea level: 500 m

air temperature : 20 °C

indicate planform and lengths and also flaps and rudders of different design

Comments:

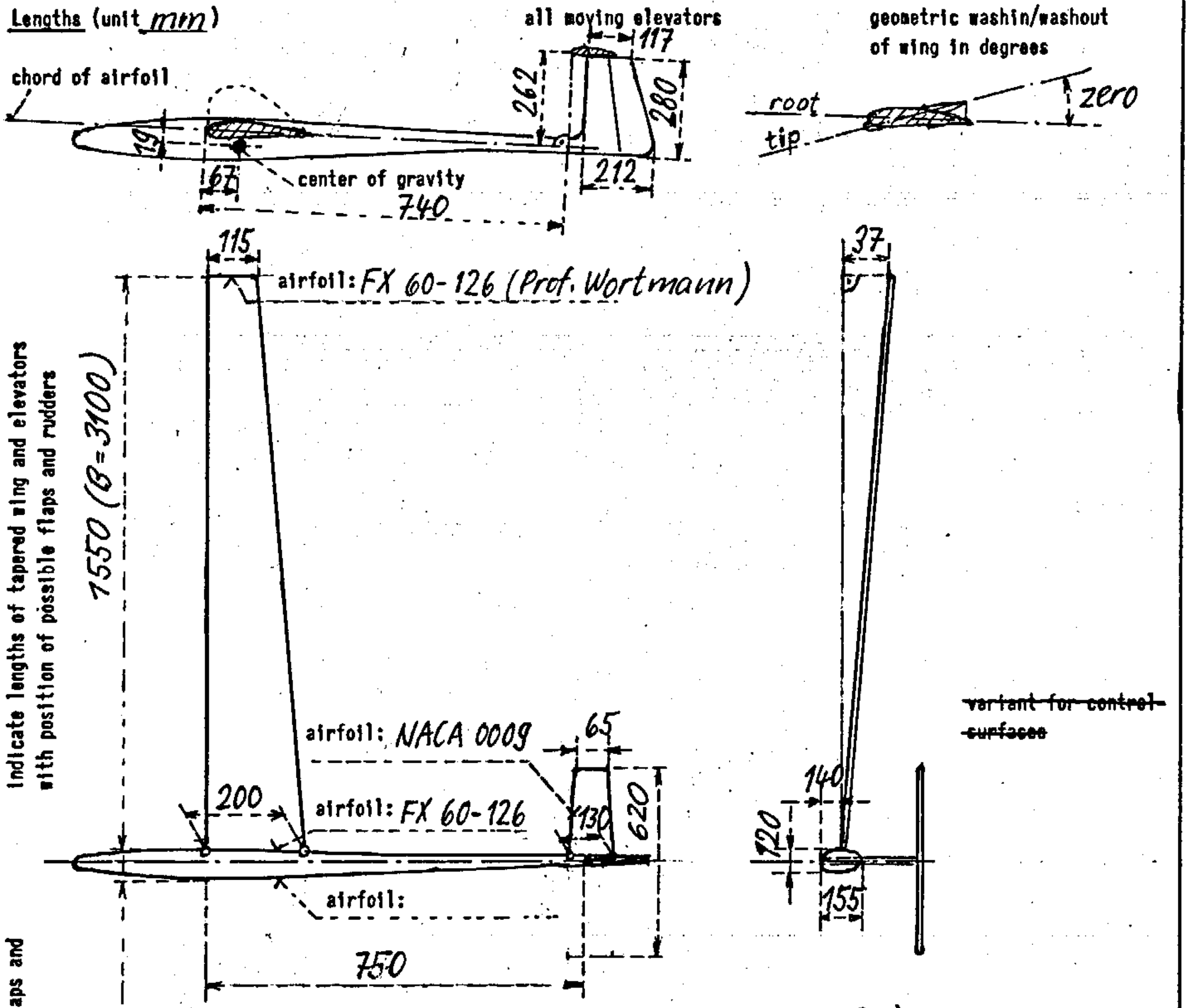
airfoil:

25.6.86/SX

NAME OF RC- SAILPLANE : Milan DATE : 28.12.85 F 40

NAME, ADDRESS, PHONE-NR OF DESIGNER : Bruno Meuwli, Fribourg (Switzerland)
pilot: Erwin Gerber, Münsingen (Switzerland)

Lengths (unit mm)



weights: (unit daN (kg))

wing or wings (total)

flying RC- sailplane (total) 3.100 daN

additional ballast, maximum —

flying conditions: (with units)

altitude above sea level: 500 m

air temperature : 20°C

Indicate planform and lengths and also flaps and rudders of different design

airfoil:

Comments:

25.6.86/SX

Fig. 41 Comparison of 4 RC sailplanes: Longitudinal dihedral

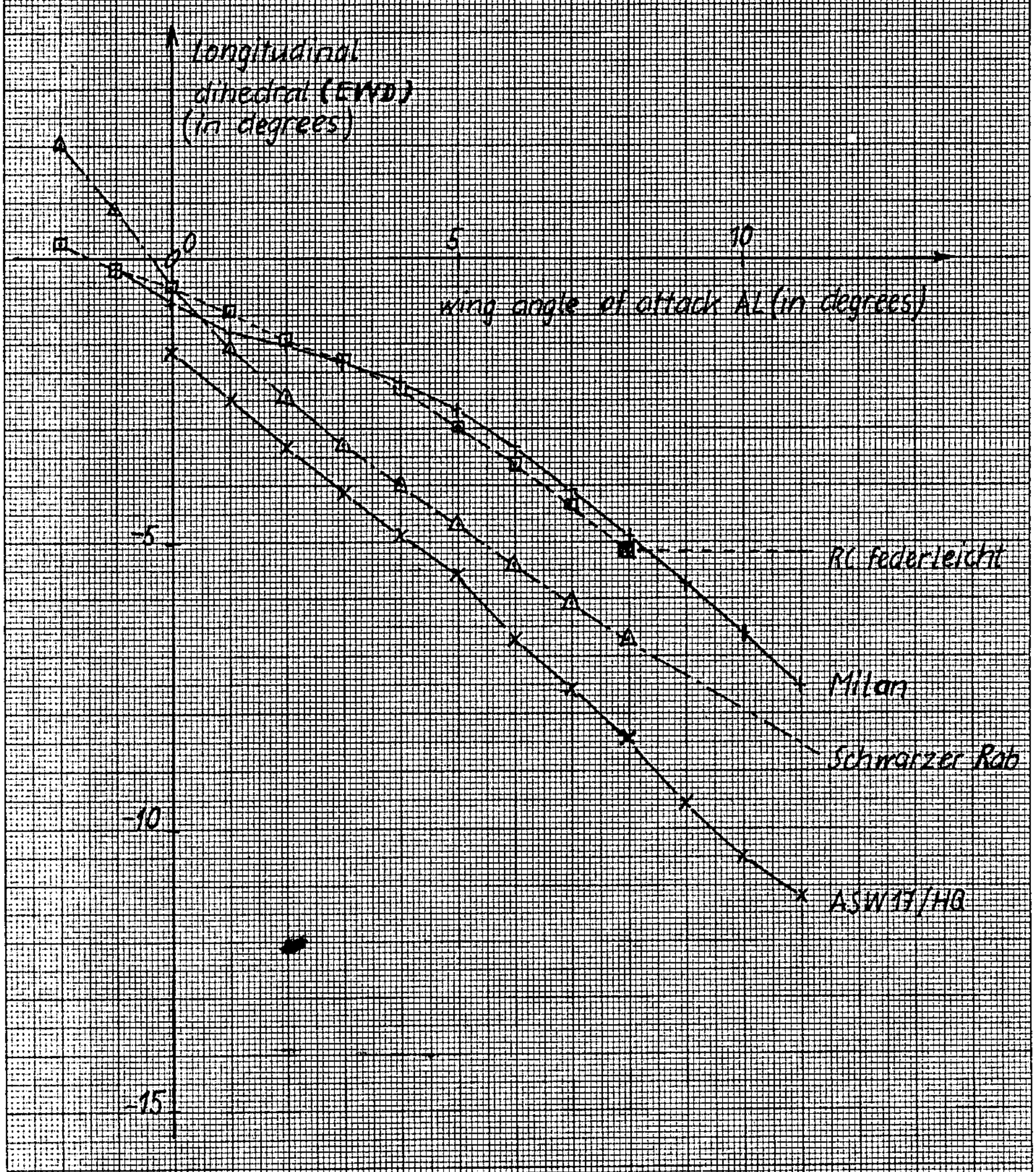


Fig. 42 Comparison of 4 RC sailplanes : elevators moments

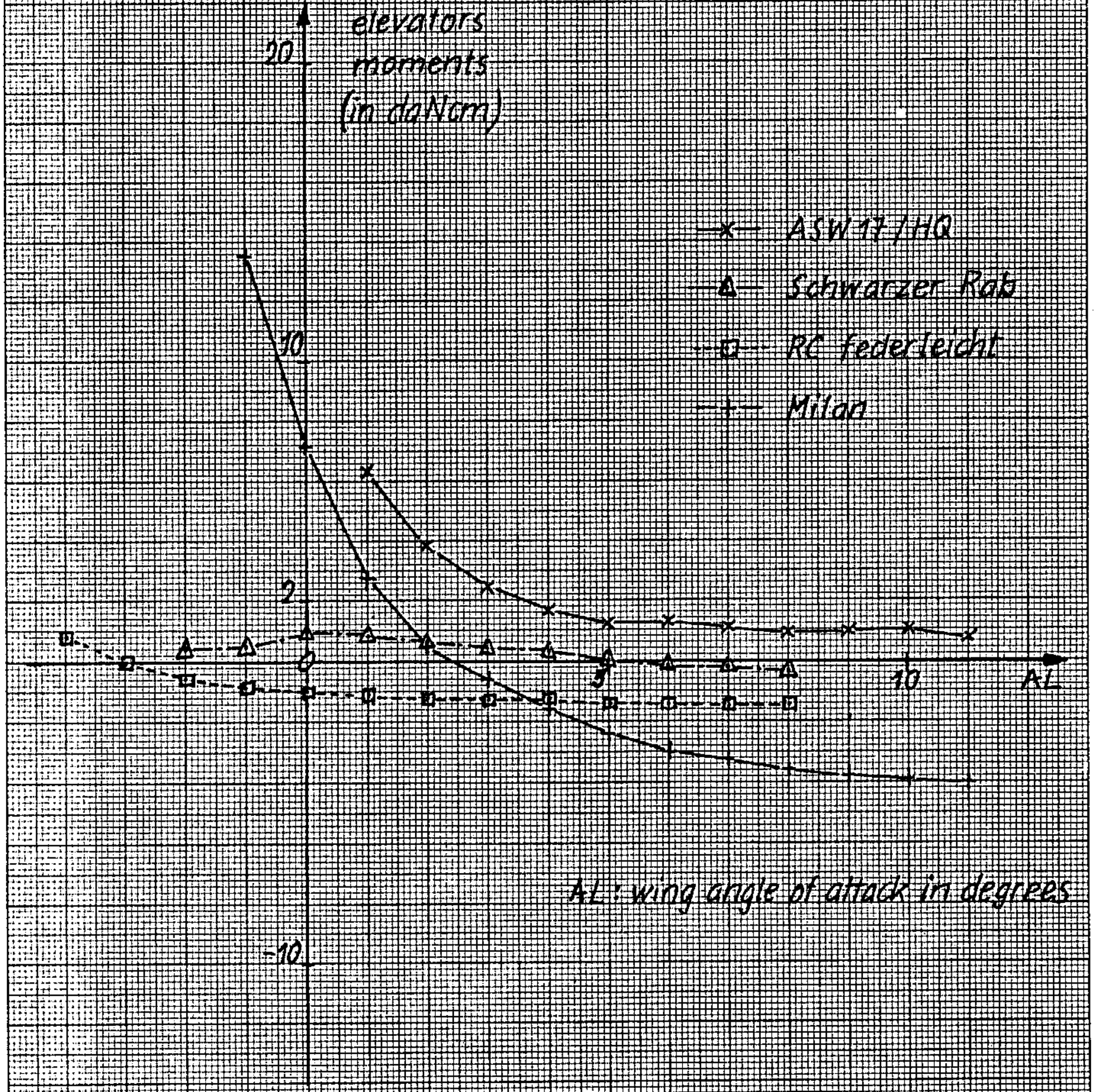


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Fig. 43 Comparison of 4 RC sailplanes: restoring moments MSD/Q

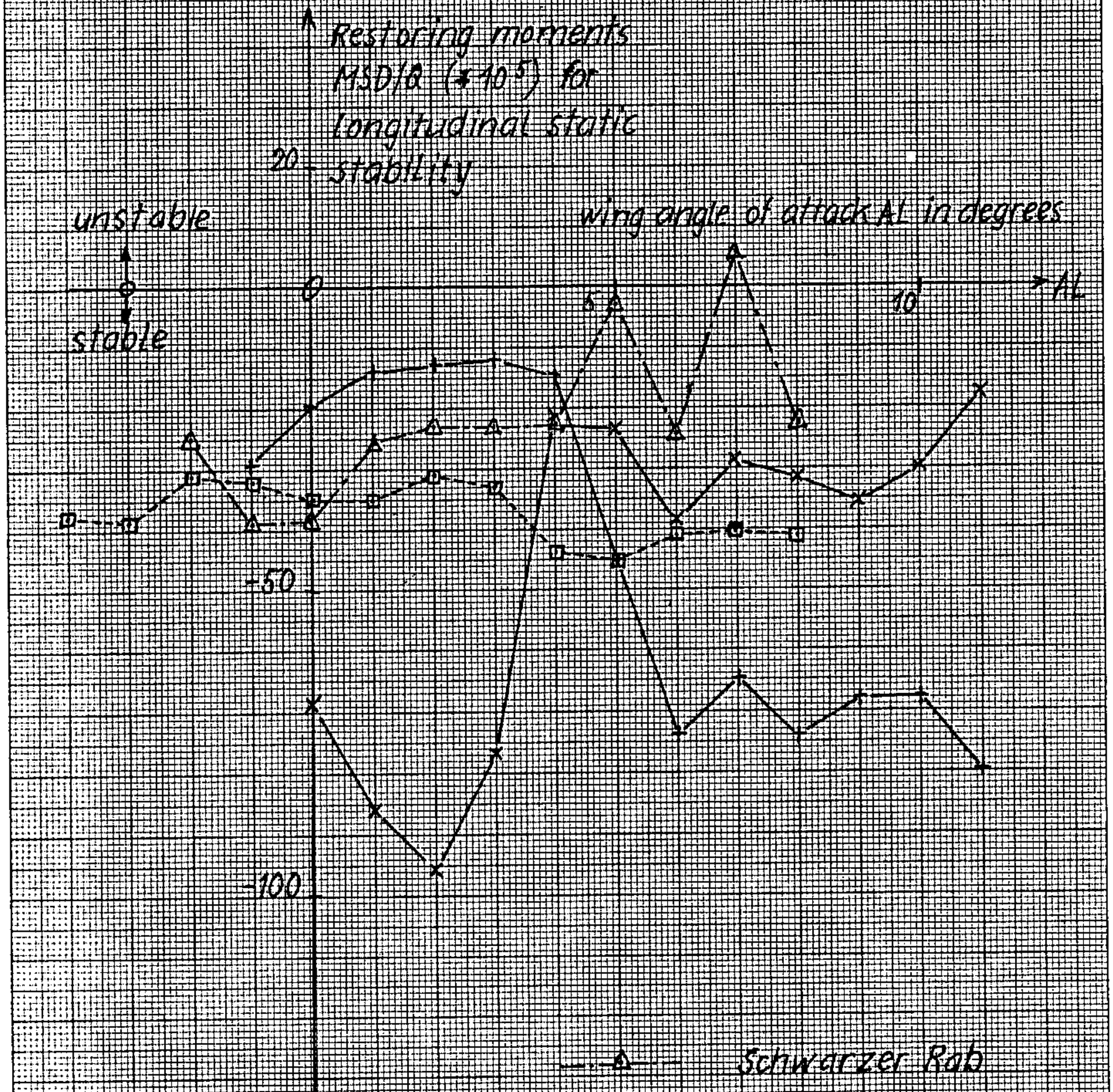
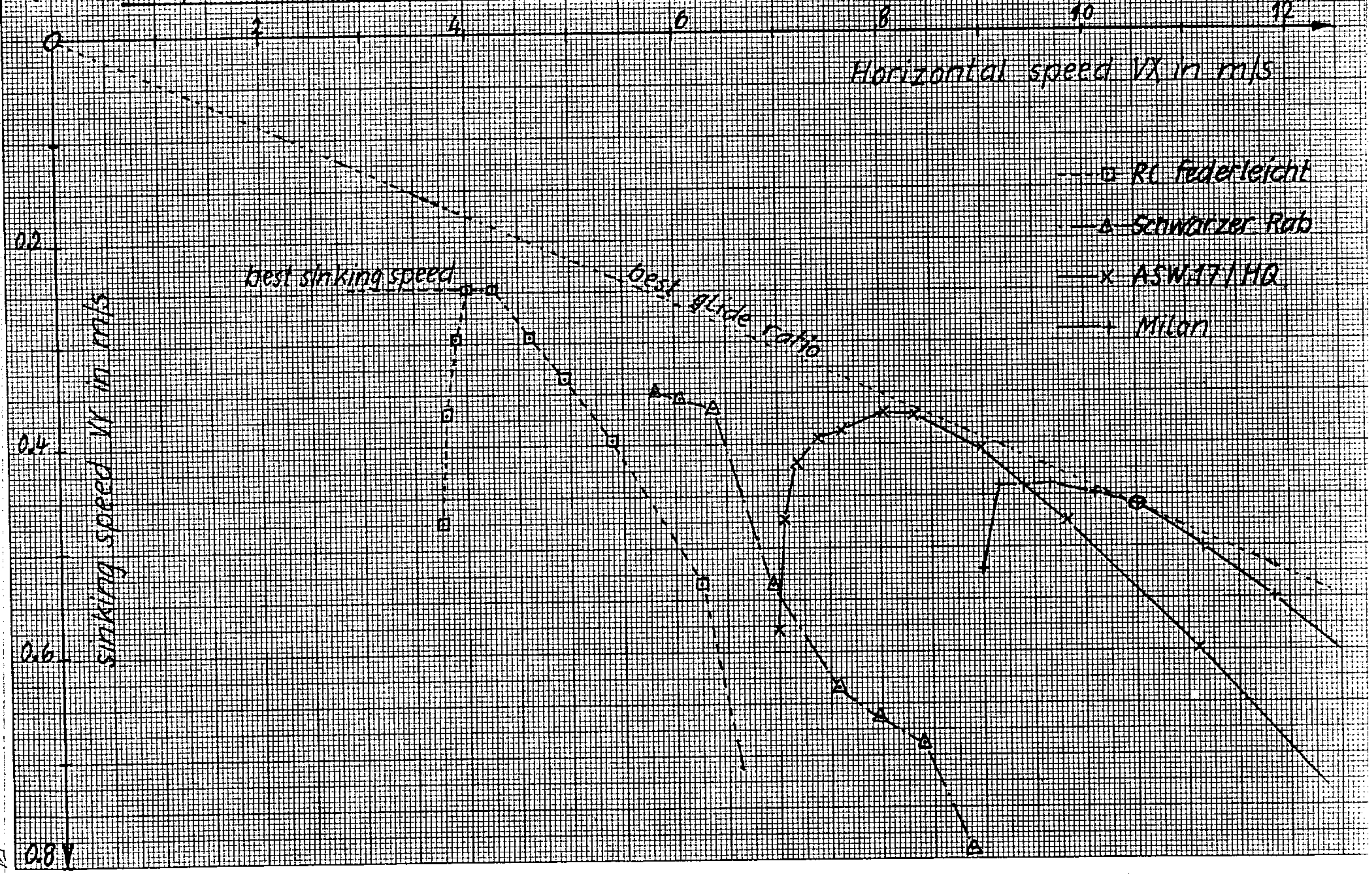


Fig. 44 Comparison of 4 RC sailplanes: sailplane glide polars



ANNEX 1 : Symbols, Units and Description

A	daN	lifting force of wing
AL(PHA)	degree	angle of attack of wing (of infinite span)
ALO	"	zero lift angle of attack
ALA	"	downwash angle (influence of wing on elevators)
ALD	"	angle of rotation (longitudinal stability)
ALH	"	angle of attack of elevators (of infinite span)
ALI	"	induced angle of attack of wing
ALIH	"	" " " " " elevators
ALT	"	total angle of attack of wing
ALTH	"	" " " " " elevators
AT	daN	total lifting forces of wing and elevators
B	m	wing span
BA	daN	ballast (in addition to sailplane weight)
BH	m	span of elevators
BL	m	fin span
BR	m	maximum width of fuselage
CA	-	lift coefficient of wing airfoil
CAH	-	" " " elevators airfoil
C.G.	-	center of gravity of sailplane
CM	-	moment coefficient of wing
CMH	-	" " " elevators
CW	-	drag or total drag coefficient
CWT	-	total drag coeffient of wing
DL	kps/m^2	atmospheric density
EPS	degree	angle of glide
ETA	"	angle of flaps (of wing)
ETAH	"	" " " (of elevators)
EWD	"	longitudinal dihedral or decalage
FF	-	wing shape (rectangular, trapezoidal or combined)
G	-	glide ratio
GF	-	sailplane weight function
GM	daN	sailplane weight
HH	* L	elevators moment arm perpendicular to wing chord
HR	m	height of fuselage
K1	s/m	performance factor 1 (for thermal flying)
K2	-	" " 2 (for F3B flying)

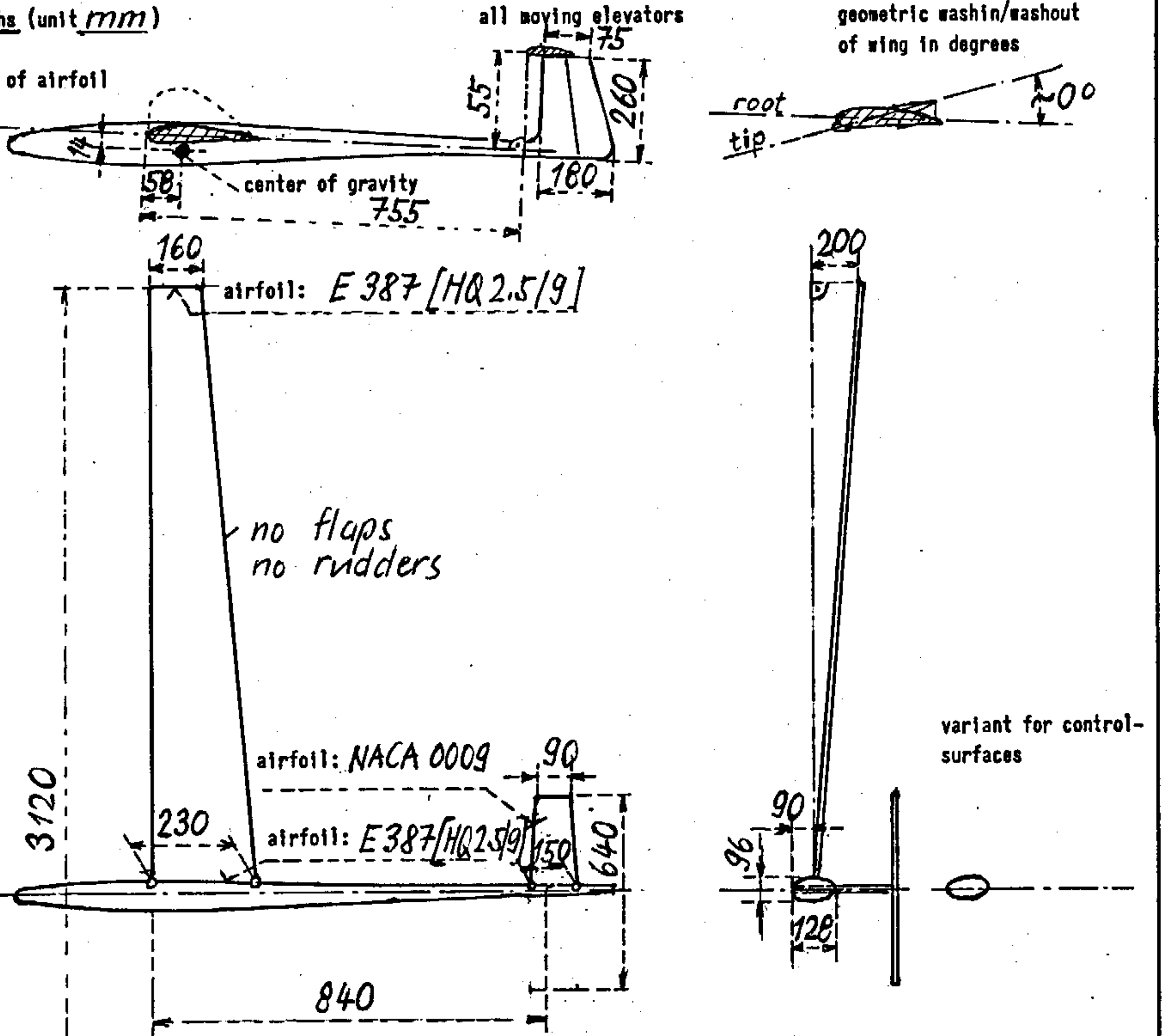
ANNEX 1 : Symbols, Units and Description

L	m	mean wing chord
LH	m	" elevators chord
LL	m	" fin chord
MAH	mdaN	moment for elevators lift with respect of C.G.
MF	mdaN	longitudinal moment of wing (L/4 point)
MFS	mdaN	" " " " (C.G. of sailplane)
MH	mdaN	" " " tailplane (L/4 point)
MHS	mdaN	" " " " (C.G. of sailplane)
MSD/Q	m^3	reduced restoring moment for longitudinal stability
NR	-	wing airfoil number
NRH	-	elevators airfoil number
P	daN/m^3	air pressure
Q	daN/m^2	dynamic or aerodynamic pressure
RE	-	wing Reynolds number
S	* L	distance from L/4 to C.G. in wing chord direction
STEIG.(MSD/Q)	m^3/deg	slope of reduced restoring moment curve (stability)
T	deg.Celsius	air temperature
TH	* L	elevators moment arm in wing chord direction
V	m/s	flight or gliding speed
VX	m/s	horizontal component of flight speed
VY	m/s	sinking speed
W	daN	total drag force of wing
WH	daN	" " " " elevators
WL	daN	" " " " fin
WR	daN	drag force of fuselage and fillet wing-fuselage
WT	daN	total drag force of sailplane
Y	* L	distance L/4 - C.G perpendicular wing chord direction

NAME OF RC- SAILPLANE : ASW 17 / Carrera (kit) DATE : 26th June 86

NAME, ADDRESS, PHONE-NR OF DESIGNER AND/OR PILOT : A. Saxer, Lindenweg 29, CH-3053
Münchenbuchsee SWITZERLAND

Lengths (unit mm)



Indicate lengths of tapered wing and elevators
with position of possible flaps and rudders

Indicate planform and lengths and also flaps and
rudders of different design

weights: (unit daN)

wing or wings (total) 0.750 daN

flying RC- sailplane (total) 1.890 daN

additional ballast, maximum 0.0

flying conditions: (with units)

altitude above sea level: 420 metres

air temperature : 20° Celsius

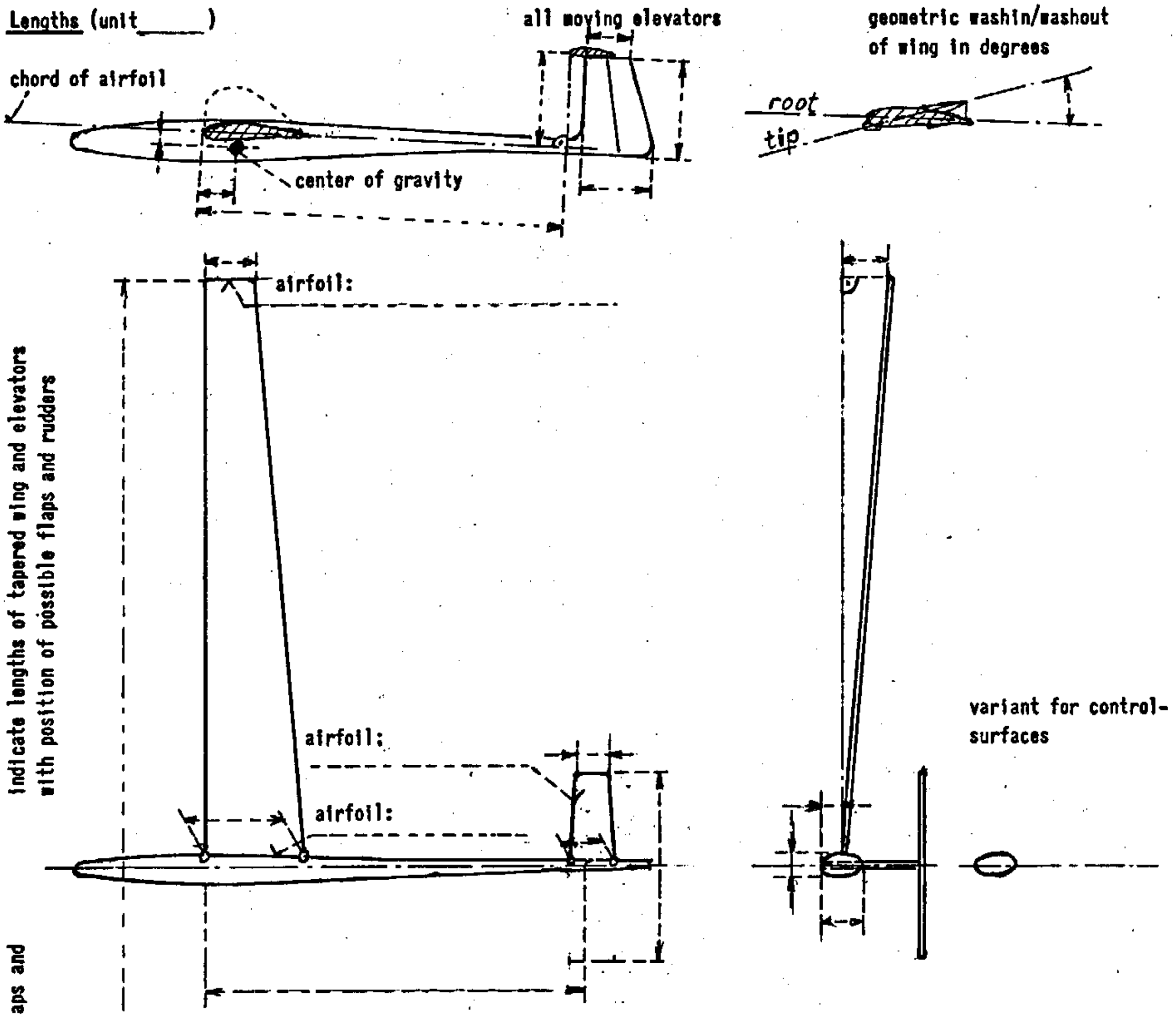
Comments:

25.6.86/SX

NAME OF RC- SAILPLANE : ______________________ DATE : __________

NAME, ADDRESS, PHONE-NR OF DESIGNER AND/OR PILOT : ______________________

Lengths (unit_____)



weights: (unit __________)

wing or wings (total) __________

flying RC- sailplane (total) __________

additional ballast, maximum __________

flying conditions: (with units)

altitude above sea level: __________

air temperature : __________

Comments: ______________________

25.6.86/SX

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(2) Bertermann D.: Konstruktion von RC- Segelflugmodellen. Verlag fuer Technik und Handwerk, Baden-Baden.*1983, ISBN 3-88180-105-7
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(3) Hartman F. A.: Locomotor mechanisms of birds. Smithsonian Miscellaneous Collections Vol. 143, Nr.1. City of Washington. Published by The Smithsonian Institution, Publication 4460 (1961)

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PERSONAL NOTES

The cronicle of this contribution begins with discussions of the longitudinal moments on an ISF (International RC Sailplane Forum) annual meeting in Switzerland.

The author wishes to thank to Bruno Saxer for his laborious computer programming and to Gerda Saxer for her front page drawing. This paper would never have been started and completed without the advice and encouragement of Herk Stokely.

Aerodynamic Formulas with comments (in German) may be requested from the Editor of SOARTECH. Readers desiring analysis of his/her sailplane may send a completed data sheet (in this contribution) to the author to execute the calculations.

Everybody is invited to make suggestions and critical remarks on the subjects treated in this paper. (in SOARTECH or to the author) There is still a big gap to create and play with mathematical models on RC sailplanes. (see for example fig.1 for possible ideas)

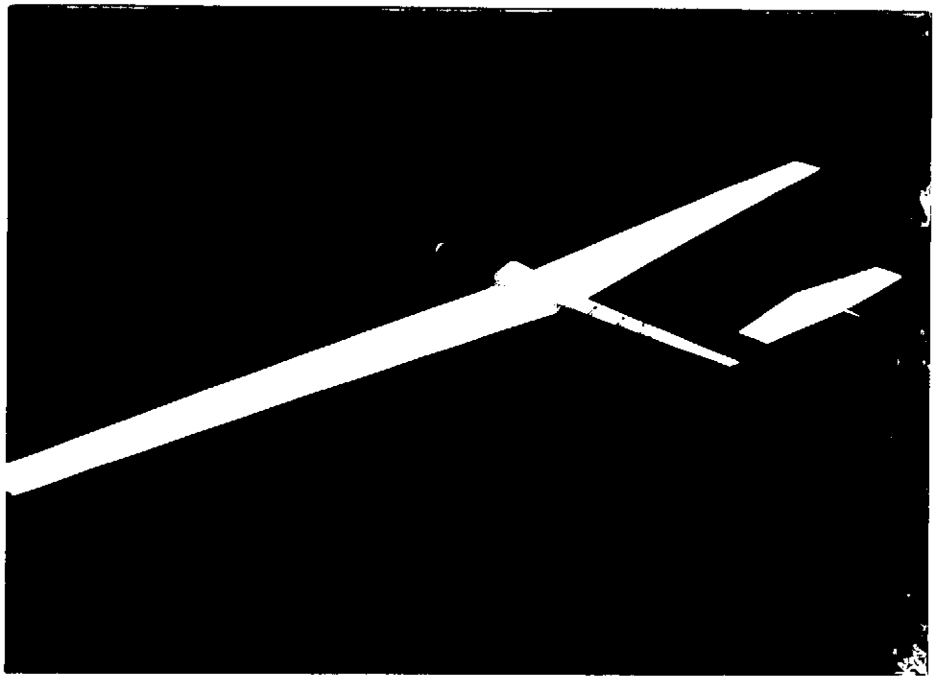
Please address any feedback to the author to the following address:

Armin Saxer, Lindenweg 29, CH-3053 Muenchenbuchsee SWITZERLAND

NEW AIRFOIL DEVELOPMENTS

Like Armin Saxer, Rolf Girsberger has been a constant supporter and contributor to Soartech. He is also one of the folks behind the ISF seminars in Europe. This paper provides data on several families of the airfoils which he has developed. Like Michael Selig, Mr. Girsberger has developed his airfoils with the help of the Eppler - Sommers programs. The airfoils in the RG series are being accepted and used with success by European F3B sailplane designers. One of the most notable is the Telescoping wing "TELE-F" developed by Ralf Decker and Dieter Pfefferkorn. At least one production F3B model (the Austrian Geitner "Mini-Starbird") has now incorporated one of these airfoils as well.

This paper, which I mentioned in Soartech #5, was originally presented to an ISF seminar. It provides methods for modifying both the thickness and camber of his airfoils to more precisely meet the needs of designers. Correspond with Mr. Girsberger at Ehrendingerstr. 29, CH-5400 Ennetbaden, Switzerland.



Airfoil families 12A, 14A, and 15A

Presented at the ISF-Seminar 1985, Brugg-Windisch, Switzerland
(Translated from German)

Rolf Girsberger, Ennetbaden, Switzerland

1. Introduction

The designers of R/C sailplanes often ask for airfoils with thickness and/or camber a little bit different from the original values. These modified airfoils are intended to meet the requirements of e.g. particular wing construction methods, limited size for servos or a special design of wing tips. The airfoil families 12A, 14A, and 15A give more freedom to the designer by preserving the favourable properties of the original airfoils 12, 14, and 15 /1/.

2. Method of creating families of airfoils

The original airfoils were analysed following the NACA-method, see /2/. A mean line and a thickness distribution (i.e. a symmetrical airfoil) were computed for each base airfoil. The airfoils are characterised by:

a)	thickness ratio, fraction or % of chord	d/l
b)	location of maximum thickness, fraction or % of chord	x_d/l
c)	camber ratio, fraction or % of chord	f/l
d)	location of maximum camber, fraction or % of chord	x_f/l
e)	shape of thickness distribution	
f)	shape of mean line.	

The method of combining mean line with thickness distribution and the corresponding notations are shown in figure 1. The thickness distribution is given by the coordinates x, y_t and the mean line is given by the coordinates x, y_c.

All respective datas for airfoils 12A, 14A, and 15A are listed in table 1. For example the base airfoil 15A has a thickness ratio of 8.9% ($d/l=0.089327$) with location of maximum thickness at 31.4% ($x_d/l=0.314183$) and a camber ratio of 1.8% ($f/l= 0.017969$) with location of maximum camber at 39.4% ($x_f/l= 0.393759$).

A particular airfoil of a family is generated by thickening or thinning the thickness distribution and by raising or reducing the camber of the mean line proportionally to the required value. The coordinates are computed from the following formulae.

We first calculate Δx and Δy from:

$$\Delta X = \frac{d/l}{(d/l)_{base}} \cdot y_t \cdot \sin \alpha^*$$

$$\Delta y = \frac{d/l}{(d/l)_{base}} \cdot y_t \cdot \cos \alpha^*$$

where the angle α^* corresponds to:

camber unchanged: $\alpha^* = \alpha_c$

camber changed: $\alpha^* = \arctan\left[\frac{f/l}{(f/l)_{base}} \cdot \tan \alpha_c\right]$

$$\approx \frac{f/l}{(f/l)_{base}} \cdot \alpha_c$$

The coordinates now are calculated from:

upper surface	$X_o = X - \Delta X$ $y_o = \frac{f/l}{(f/l)_{base}} \cdot y_c + \Delta y$
lower surface	$X_u = X + \Delta X$ $y_u = \frac{f/l}{(f/l)_{base}} \cdot y_c - \Delta y$

The airfoils are denominated in such a manner that the camber and thickness in percent of chord are added to the number of the airfoil. For example airfoil 15A-2.5/9.5 has a camber ratio of 2.5% and a thickness ratio of 9.5%.

3. Effects of changes in thickness and camber on the airfoil characteristics

An important question concerns the aerodynamic properties of the airfoil family in comparison to the original airfoils. Computations with the Eppler program /3/ confirm that the shape of the theoretical section characteristics as calculated for the original airfoils /1/ is preserved if thickness and camber are only slightly altered. The following approximate values for the effect on the aerodynamic properties can be given:

a) Effect of change in thickness

- An increase in thickness ratio of 1% (e.g. from 9% to 10%) raises the minimal (theoretical) drag coefficient by $c_d \approx 0.0003$. The opposite is true for a reduction of thickness ratio. Therefore, the drag of an 11% thick airfoil is approx. $c_d \approx 0.0009$ higher than the drag of a 8% thick airfoil. This simple rule has been confirmed for the present airfoil families within the range from 8% to 13% thickness.
- Thick airfoils normally have a higher critical Reynolds number than thin airfoils. The upper limit for F3B models is estimated 11% to 12% (some thicker airfoils of different design are claimed to perform quite good). For larger sailplanes it might be a little bit more.
- The nose of thicker airfoils than the original is blunter and the nose of thinner airfoils is sharper. This affects the lower edge of the laminar drag bucket only slightly within the range from 8.5% to 12% thickness.

b) Effect of change in camber

- An increase in camber raises the absolute value of the moment coefficient c_{mo} and the zero lift angle α_o. Again the opposite holds for a reduction in camber. Both are changed in direct proportion to the camber ratio. They can be converted to a different camber by:

$$c_{mo} = \frac{f/l}{(f/l)_{base}} \cdot c_{mo\,base}$$

$$\alpha_o = \frac{f/l}{(f/l)_{base}} \cdot \alpha_{o\,base}$$

- An increase in camber moves the lift-drag curve to higher lift coefficient and vice versa. The increment in lift may be computed from:

$$\Delta c_l = 0.11 \cdot (\alpha_o - \alpha_{o\,base}) \qquad (\alpha_o \text{ in degrees})$$

- Camber ratios from approximately 1.5% to 3% are reasonable for the families 12A, 14A and 15A.

Thickness distribution and mean line are proper characteristics of an airfoil family. Therefore it is not recommended to combine thickness distribution and mean line of the different airfoil families.

4. Examples

1.) Airfoil 12A-1.8/9.0

For use in F3B models airfoil 15 shall be replaced by airfoil 12A with identical camber and thickness namely d/1=0.090 and f/1=0.018 (rounded). The coordinates are given in table 2. Figure 2 shows the corresponding section caracteristics calculated with the Eppler program. The drag coefficient in the high speed range is expected to fall ca. 5% below the drag of airfoil 15 /1/.

2.) Airfoil 15A-2.5/13.0

This airfoil is intended for large sailplanes (span of 4 m and more). The coordinates are given in table 2 and the section characteristics are shown in figure 3.

Remark: The values of α_o and c_{mo} given in table 1 differ by a negligible amount from the respective values for the original airfoils, see /1/.

Literature:

/1/ R. Girsberger — New airfoils for R/C gliders
Soartech no. 5, 1986
(Translated from German)

/2/ I.H. Abbott/A.E. v.Doenhoff — Theory of Wing Sections
Dover Publications Inc., New York,
page 112

/3/ R. Eppler/D. Somers — A Computer Program for the Design and Analysis of Low-Speed Airfoils
NASA TM 80210

PROFIL NR. 12A

I	X	Y_t	Y_c	α_c [°]
1	1.000000	0.000000	0.000000	-5.579993
2	0.996628	0.000191	0.000330	-5.598968
3	0.986926	0.000942	0.001275	-5.454482
4	0.971705	0.002379	0.002641	-4.728190
5	0.951461	0.004323	0.004131	-3.700784
6	0.926268	0.006686	0.005565	-2.863754
7	0.896336	0.009545	0.006902	-2.252564
8	0.862125	0.012916	0.008095	-1.726575
9	0.824097	0.016742	0.009091	-1.259547
10	0.782717	0.020923	0.009872	-0.886893
11	0.738474	0.025324	0.010448	-0.601637
12	0.691807	0.029742	0.010893	-0.533924
13	0.643139	0.033825	0.011428	-0.778213
14	0.593208	0.037312	0.012185	-0.941532
15	0.542661	0.040230	0.013009	-0.894089
16	0.491979	0.042621	0.013746	-0.749729
17	0.441676	0.044456	0.014320	-0.534551
18	0.392246	0.045701	0.014676	-0.268545
19	0.344171	0.046315	0.014777	0.045287
20	0.297905	0.046267	0.014600	0.404528
21	0.253866	0.045529	0.014133	0.805200
22	0.212444	0.044088	0.013383	1.248748
23	0.173980	0.041938	0.012366	1.730766
24	0.138781	0.039091	0.011118	2.250595
25	0.107121	0.035573	0.009681	2.814418
26	0.079224	0.031428	0.008115	3.410024
27	0.055311	0.026722	0.006485	4.091101
28	0.035494	0.021520	0.004877	4.749371
29	0.020069	0.016001	0.003303	6.005511
30	0.008443	0.010003	0.002145	5.299144
31	0.002271	0.004915	0.000583	12.775229
32	0.000000	0.000000	0.000000	12.069278

$\alpha_0 = 2.15°$ $C_{mo} = -0.0512$

$d/l = 0.092754$
$x_d/l = 0.323953$
$f/l = 0.014778$
$x_f/l = 0.350534$

PROFIL NR. 14A

I	X	Y_t	Y_c	α_c [°]
1	1.000000	0.000000	0.000000	-4.645868
2	0.996657	0.000185	0.000272	-4.656094
3	0.987002	0.000914	0.001052	-4.527160
4	0.971776	0.002312	0.002190	-3.973661
5	0.951456	0.004203	0.003465	-3.211956
6	0.926159	0.006490	0.004737	-2.586164
7	0.896125	0.009228	0.005974	-2.133278
8	0.861805	0.012420	0.007137	-1.742055
9	0.823647	0.015985	0.008195	-1.435764
10	0.782110	0.019805	0.009162	-1.251668
11	0.737630	0.023653	0.010138	-1.303430
12	0.690747	0.027253	0.011274	-1.466355
13	0.642138	0.030523	0.012518	-1.435506
14	0.592331	0.033496	0.013710	-1.284304
15	0.541830	0.036135	0.014766	-1.090758
16	0.491185	0.038381	0.015631	-0.840990
17	0.440909	0.040179	0.016253	-0.554545
18	0.391514	0.041475	0.016599	-0.224216
19	0.343477	0.042216	0.016641	0.141846
20	0.297262	0.042362	0.016367	0.551807
21	0.253279	0.041875	0.015772	0.996667
22	0.211921	0.040734	0.014872	1.483854
23	0.173531	0.038923	0.013689	2.007166
24	0.138421	0.036448	0.012265	2.570411
25	0.106869	0.033325	0.010646	3.185855
26	0.079103	0.029587	0.008894	3.852036
27	0.055341	0.025287	0.007070	4.635556
28	0.035648	0.020476	0.005263	5.395996
29	0.020312	0.015318	0.003509	6.800697
30	0.008755	0.009698	0.002129	6.380572
31	0.002366	0.004717	0.000599	12.940685
32	0.000001	0.000000	0.000000	12.338034

$\alpha_0 = 2.02°$ $C_{mo} = -0.0454$

$d/l = 0.084760$
$x_d/l = 0.309210$
$f/l = 0.016661$
$x_f/l = 0.361275$

PROFIL NR. 15A

I	X	Y_t	Y_c	α_c [°]
1	1.000000	0.000000	0.000000	-6.505747
2	0.996695	0.000170	0.000377	-6.530591
3	0.987164	0.000835	0.001465	-6.408744
4	0.972166	0.002106	0.003064	-5.688336
5	0.952171	0.003821	0.004870	-4.652286
6	0.927258	0.005902	0.006698	-3.801269
7	0.897635	0.008417	0.008505	-3.184291
8	0.863751	0.011381	0.010232	-2.638627
9	0.826063	0.014747	0.011807	-2.133336
10	0.785038	0.018448	0.013180	-1.681960
11	0.741168	0.022384	0.014320	-1.275375
12	0.694954	0.026435	0.015218	-0.931193
13	0.646897	0.030451	0.015889	-0.659998
14	0.597459	0.034234	0.016404	-0.556032
15	0.547148	0.037518	0.016905	-0.603498
16	0.496654	0.040153	0.017425	-0.536562
17	0.446543	0.042187	0.017812	-0.313626
18	0.397260	0.043632	0.017966	-0.023756
19	0.349280	0.044450	0.017851	0.322838
20	0.303054	0.044620	0.017435	0.721935
21	0.258995	0.044113	0.016709	1.167138
22	0.217489	0.042918	0.015678	1.661286
23	0.178876	0.041026	0.014363	2.196021
24	0.143469	0.038451	0.012799	2.779718
25	0.111535	0.035211	0.011037	3.408899
26	0.083313	0.031355	0.009134	4.101140
27	0.058987	0.026927	0.007172	4.842413
28	0.038801	0.022044	0.005194	5.835028
29	0.022646	0.016699	0.003354	6.592000
30	0.011040	0.011303	0.001574	8.924052
31	0.003049	0.005538	0.000374	7.679281
32	0.000000	0.000000	0.000000	8.401024

$\alpha_0 = 2.63°$ $C_{mo} = -0.0660$

$d/l = 0.089273$
$x_d/l = 0.314183$
$f/l = 0.017969$
$x_f/l = 0.393759$

30.10.85/RG.

Table 1

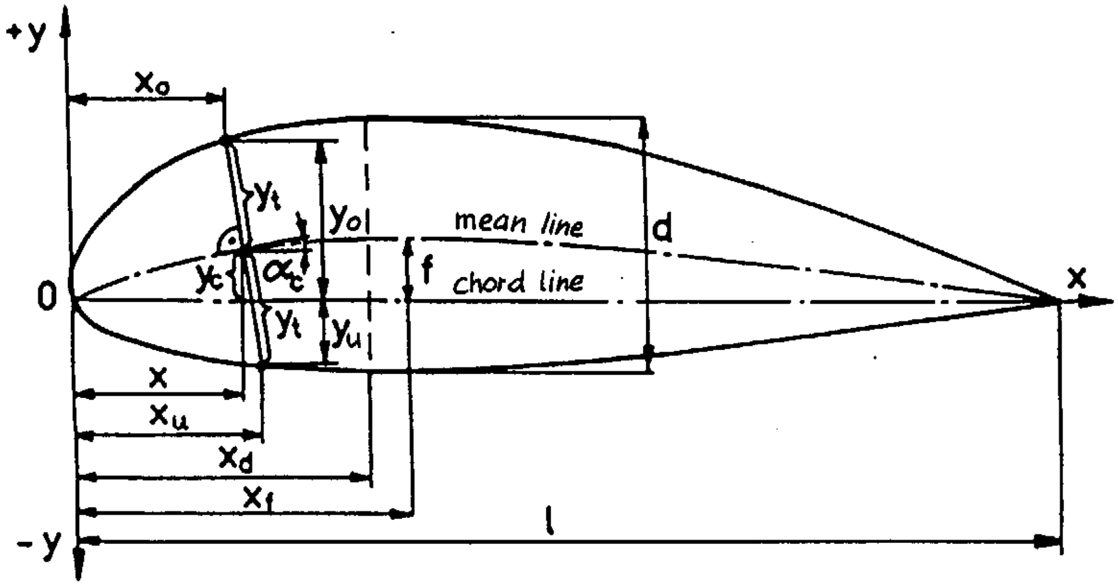
Profil 12A-1.8/9.0

N	X	Y
0	100.000	0.0
1	99.665	0.059
2	98.703	0.246
3	97.194	0.551
4	95.179	0.921
5	92.666	1.325
6	89.678	1.766
7	86.258	2.238
8	82.453	2.731
9	78.310	3.232
10	73.879	3.730
11	69.213	4.212
12	64.368	4.674
13	59.393	5.104
14	54.340	5.487
15	49.264	5.809
16	44.217	6.058
17	39.250	6.222
18	34.613	6.294
19	29.752	6.267
20	25.311	6.138
21	21.131	5.906
22	17.248	5.573
23	13.697	5.143
24	10.506	4.625
25	7.702	4.030
26	5.306	3.373
27	3.339	2.671
28	1.810	1.942
29	0.735	1.226
30	0.100	0.531
31	0.0	0.0
32	0.354	-0.389
33	0.953	-0.703
34	2.204	-1.138
35	3.760	-1.484
36	5.756	-1.793
37	8.143	-2.053
38	10.918	-2.266
39	14.059	-2.434
40	17.548	-2.560
41	21.358	-2.646
42	25.462	-2.696
43	29.829	-2.711
44	34.421	-2.694
45	39.199	-2.647
46	44.119	-2.569
47	49.132	-2.461
48	54.192	-2.318
49	59.248	-2.135
50	64.260	-1.890
51	69.148	-1.559
52	73.816	-1.184
53	78.233	-0.827
54	82.366	-0.517
55	86.166	-0.266
56	89.589	-0.084
57	92.587	0.030
58	95.113	0.085
59	97.147	0.092
60	98.682	0.064
61	99.661	0.022
62	100.000	0.0

Profil 15A-2.5/13.0

N	X	Y
0	100.000	0.0
1	99.673	0.077
2	98.735	0.324
3	97.259	0.730
4	95.280	1.230
5	92.805	1.788
6	89.858	2.405
7	86.481	3.077
8	82.717	3.787
9	78.613	4.518
10	74.218	5.250
11	69.582	5.966
12	64.761	6.644
13	59.813	7.267
14	54.795	7.815
15	49.742	8.271
16	44.701	8.621
17	39.730	8.853
18	34.877	8.956
19	30.191	8.922
20	25.717	8.746
21	21.497	8.426
22	17.569	7.964
23	13.969	7.367
24	10.730	6.646
25	7.878	5.814
26	5.440	4.892
27	3.428	3.901
28	1.879	2.868
29	0.753	1.827
30	0.156	0.845
31	0.0	0.0
32	0.454	-0.741
33	1.455	-1.389
34	2.651	-1.934
35	4.332	-2.455
36	6.358	-2.896
37	8.875	-3.273
38	11.577	-3.574
39	14.724	-3.806
40	18.206	-3.967
41	22.001	-4.063
42	26.081	-4.096
43	30.419	-4.071
44	34.979	-3.989
45	39.722	-3.854
46	44.607	-3.665
47	49.589	-3.422
48	54.635	-3.111
49	59.679	-2.702
50	64.619	-2.223
51	69.408	-1.731
52	74.016	-1.266
53	78.394	-0.850
54	82.495	-0.502
55	86.269	-0.230
56	89.669	-0.039
57	92.647	0.076
58	95.154	0.125
59	97.174	0.122
60	98.698	0.084
61	99.666	0.028
62	100.000	0.0

<u>Table 2</u>



d : maximum thickness
f : maximum camber, maximum ordinate of mean line
l : chord length
x : abscissa of point on mean line or on thickness distribution
x_o : abscissa of point on upper surface
x_u : abscissa of point on lower surface
x_d : abscissa of maximum thickness
x_f : abscissa of maximum camber
y_c : ordinate of point on mean line
y_t : ordinate of point on thickness distribution
y_o : ordinate of point on upper surface
y_u : ordinate of point on lower surface
α_c : angle of mean line

Note: These symbols differ from those given in /2/

Fig. 1: Notations

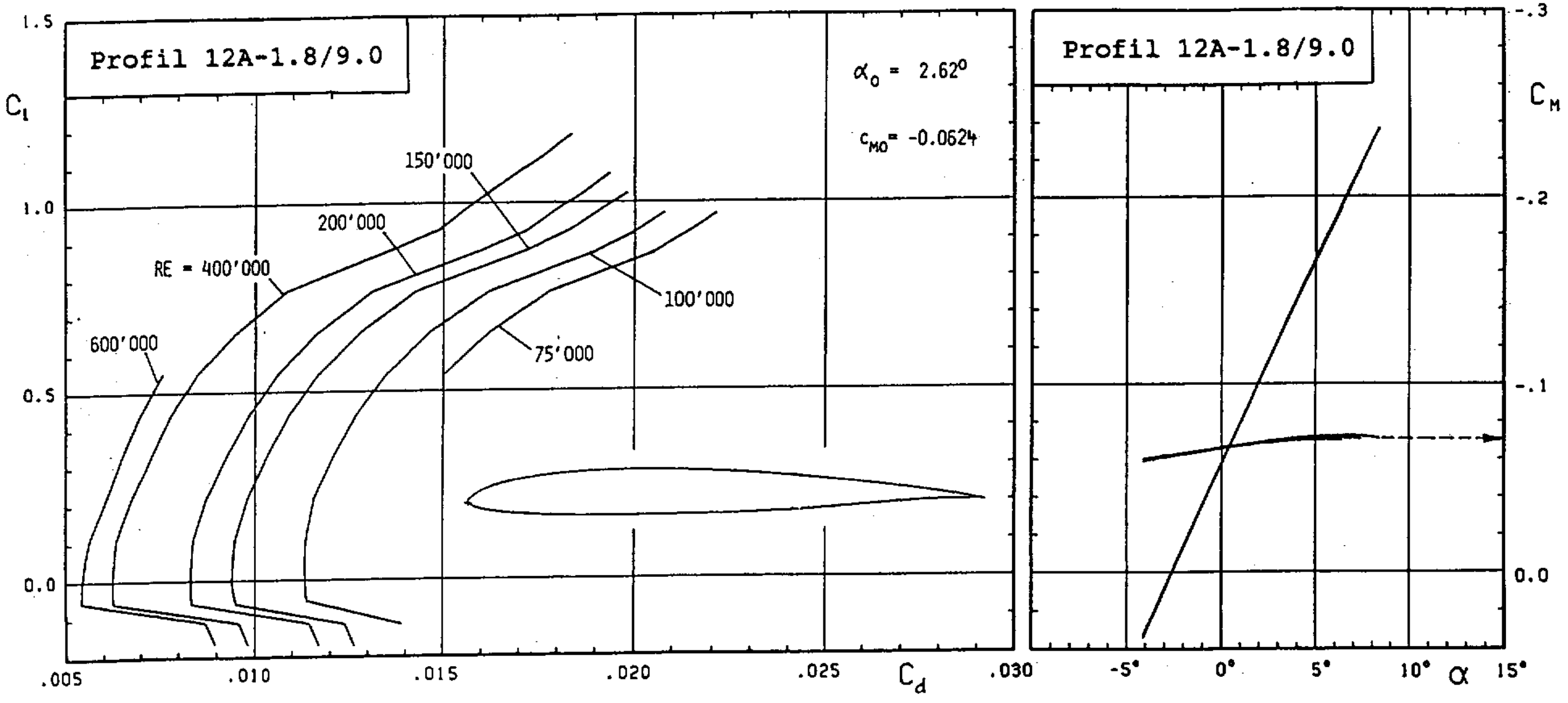
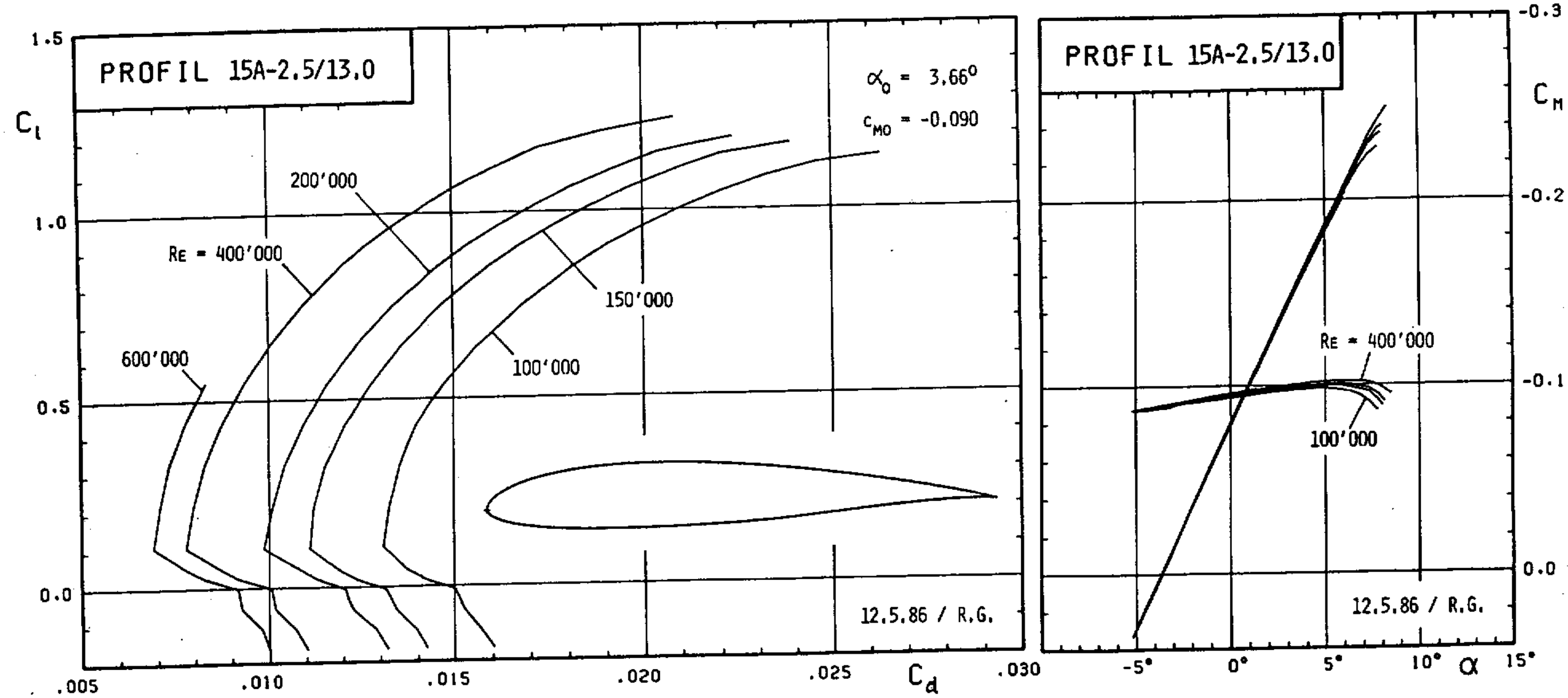


Fig. 2: Section characteristics of airfoil 12A-1.8/9.0



<u>Fig. 3:</u> Section characteristics of airfoil 15A-2.5/13.0

EQUILIBRIUM, STABILITY, AND THE LOAD ON YOUR TAIL

In his performance paper, Armin Saxer devotes a significant section to analyzing the longitudinal behavior of the RC sailplane. This is a tricky area which is often poorly understood. If you want to work through a complete exposition of all of the factors involved, this paper by David Fraser covers the whole territory: Flying wings, canards, lifting stabilizers, and most of the mathematical relations that go with them. You may find some of the comments and conclusions controversial, eg: "any configuration can be made stable ....", "a flying wing cannot use flaps ....", or "I ignored the downwash .....". Although this is often a area where any discussion leads to controversy, the content of David's paper represents solid basic engineering analysis: an excellent source of all of the basic knowledge you need to begin to understand this complex subject.

You may wonder if this David Fraser is the brother of Bob Fraser who gave us the translation of Althaus in Soartech 5. No, in fact he is the same man. I have a friend at work named Bob Fraser and did a mental mixup. David is responsible for both contributions. Correspond with David at Fraser-Volpe Corp, 1025 Thomas Dr., Warminster Industrial Park, Warminster Pa. 18974.

EQUILIBRIUM, STABILITY AND THE LOAD ON YOUR TAIL

November, 1985

As a frequent flier of one of the largest clubs in the nation, the Valley Forge Signal Seekers, I am often asked questions about trimming an airplane that suggest there are quite a few modellers out there who have never had the opportunity to properly understand the forces acting on an airplane. Many, I suspect, have had it incorrectly explained by others who also don't understand the subject. As a result the myths tend to propogate until they become so widely believed that they are taken for the truth.

Aerodynamics is not a simple subject, and because you can't stop the airplane to actually feel the forces acting on it, it's not really surprizing that a lot of erronious opinions and bogus "facts" are circulated. Most of you who are reading this are relatively more interested in the details of the aerodynamics than the average flier, but there is still a lot of misunderstanding about airplane stability, even among the so-called experts. What I want to do in this article is to explain the title topics mathematically, with worked examples, so you can be on firm footing in your understanding of the subject.

Now I don't want any of you to believe what's written here simply because it's in print. I want you to be able to convince yourself that it's true. In the process you may have to deal with some long-held, but nonetheless wrong beliefs. Deal with them. Sort them out. It's well worth the reward. If you find concepts that are new to you, get a book on high school mechanics and learn the concepts. Not only will you be learning something new - a reward in itself - but you will be able to apply the knowledge to making your airplanes fly better, and that's what it's all about anyway, isn't it?

As I said, this is a mathematical article, and I make no apology for it. I'll make it as simple as I can, but aerodynamics is, at heart, a mathematical discipline, and to attempt to explain it without math is like trying to explain a sunset to a blind man. Specifically, you will need to know high school algebra, and understand the idea of a derivative. You should also have some grounding in statics, a branch of mechanics.

Nothing I say here will be new - it's all in any of the standard texts on aerodynamics (see the bibliography) but I have reduced it to the essentials. I will take many things for granted because space is limited. If this causes you a problem, keep going anyway; hopefully the point will be resolved further along.

Here is what we are going to do:

1. We will review the basic concepts of moment, equilibrium and stability. Since these terms will be used a lot, it is important that we have a clear idea of exactly what we're talking about. I will assume that everyone is familiar with the basic characteristics of a wing, that is, we know that lift is proportional to angle of attack up to the stall, and that camber produces a pitching moment that is independent of the lift if measured at the aerodynamic center (AC) of the wing.

2. We will discuss the airplane configuration and the conditions that must be satisfied for trimmed, stable flight.

3. We will derive the equilibrium and stability equations, and show that they apply to all configurations of airplanes. And we will examine several examples so you can see the practical effects.

Finally - and this will occur thruout the discussion - we will critically examine the more common fallacies, show why they are wrong, and what the real situation is.

I'll take it for granted that everyone has a pretty good idea of what a force is - let me just remind you that all forces have two properties: magnitude (size) and direction. Gravity produces a force on your body whose magnitude is your weight, and whose direction is down. The air produces a force on your car whose magnitude is called wind resistance, and whose direction is always downwind. And so on.

A moment, otherwise known as a torque or a couple, is a force acting at a distance, where the direction of the force is perpendicular to the line joining the force with the measurement point, see figure 1. A moment is always the product of the force and the distance, such as foot-pounds or newton-meters, and produces a turning motion about the measurement point. Moments or torques are found everywhere: the hands of a clock are turned by moments (no pun intended), as are the wheels of cars and bicycles. If you suspend an airplane at any point other than its center of gravity, gravity will produce a moment about the suspension point that will cause it to turn. In fact the definition of the c.g. is that point on the airplane where the sum of all the moments due to gravity is zero. It is <u>not</u> the point where the <u>mass</u> is equally distributed in every direction, it is the point where <u>the moments</u> are equally distributed. Look at figure 2 and you will see that there are 2 pounds to the left of the c.g. and only 1/2 pound to the right. However because the 2 pound mass is closer than the 1/2 pound, its moment is identical (but opposite in sign) to that produced by the 1/2 pound.

Equilibrium is defined as the condition of any system where stated variables are either zero or constant. For example, let's consider a car travelling on a straight road at a steady speed. If we take direction and speed to be the stated variables, the car is in equilibrium, since both variables are constant. If, however, we were to choose weight and distance from a starting point to be the variables, the car is not in equilibrium, since fuel is being burned, thereby changing the weight, and the distance is continually changing. The only way to bring the system into equilibrium in the second case is to stop the car and shut off the engine.

We are free to choose any variables we like in talking about equilibrium, but it's usually wise to make sure we all understand what they are. In the case of our airplane the variables will be airspeed, three rotations (pitch, roll and yaw), angle of attack (alpha) and lift co-efficient (Cl). We will require the airspeed, alpha and Cl to be constant, and the rotations to be zero. This is nothing more than stating that the airplane is in steady, altho not necessarily level flight.

In order for such an airplane to be in equilibrium there are two general conditions that must be fulfilled. First: the sum of all forces acting on the airplane must be zero. This does not mean that all forces are zero, but that if there are forces in one direction there must be other forces in the opposite direction of exactly the same amount. For an airplane in level flight and in equilibrium, the lift must equal the weight, and the thrust must equal the drag. If the airplane is coming straight down, the thrust plus the weight must equal the drag, and the lift must be zero.

Second: the sum of all moments must be zero; see figure 3. This follows from our condition that the rotations must be zero. If there were some net moment acting on the airplane it would turn, and that would violate our requirement for equilibrium. As with forces, this does not mean that there are no moments, but that if one moment tends to rotate the airplane, say, nose up, there must be another moment tending to rotate it nose down by exactly the same amount.

Note that it doesn't matter what point you use in converting forces into moments provided you include and use the same point for all of them, (fig. 4). The advantage to using the c.g. is that the moment produced by the weight is always zero and therefore dosen't need to be carried in the equations. If a moment is already given as such, as, for example, about an aerodynamic center, it is simply added to the sum of the other moments no matter where the lifting surface may be.

To summarize; equilibrium requires both the sum of forces and the sum of moments to be zero.

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Before we define stability, let's examine some systems in equilibrium and see what happens to them when they are disturbed, i.e. when they are forced away from equilibrium. To use the example of the car again, let's assume that there is a rise in the road and that the driver does nothing to the accelerator. The car will, of course, slow down, but it will regain its original speed as soon as the road levels out again. In other words, as soon as the disturbance is removed the system regains its original equilibrium.

Now consider the pendulum shown in figure 5. If its mass is positioned exactly at the top of the arc, it will stay there. This is a true equilibrium. However any disturbance which overcomes the friction in the pivot will allow gravity to move the mass away from equilibrium and the final rest position will be at the bottom of the arc, i.e. the original equilibrium position will never be regained. If we now disturb the pendulum from the bottom point it will eventually settle at the same point again, i.e. it will regain the second equilibrium position.

In this case we have two equilibrium positions, but clearly they are not equal. It is the difference between these that illustrates the difference between equilibrium and stability - equilibrium means that the state variables (speed, position, etc.) are zero or constant; stability means that when an equilibrium system is disturbed it tends to regain the original equilibrium when the disturbance is removed. The pendulum also shows it is possible to have equilibrium with or without stability. In the case of an airplane, it may be possible to trim it, (equilibrium) but still have it virtually uncontrollable because it's not stable.

Altho the definition just given for stability is accurate, it is inconvenient. It we wanted to measure stability using this definition we would have to find an equilibrium, disturb it, and then watch to see what happens. This is, of course, possible, and in fact is done in all flight tests, but what we want to do here is to mathematically model the airplane and compute the equilibrium and stability before flying it. There are some relatively simple (and some not-so-simple) mathematical techniques that do this, and what we must do now is convert this definition of stability into a set of equations.

In order to put this in terms that we all are interested in, let's go straight to the airplane. Let's assume we have found an equilibrium position - which we usually call "trimmed flight" - and that we suddenly encounter a upwards gust of wind. The immediate effect will be an increase in angle of attack, (alpha) and, assuming the wings are not near the stall, a proportionate increase in Cl. See figure 6.

Now it is intuitively obvious that the change in alpha produced by the gust should produce moments that tend to rotate the airplane so alpha returns to the pre-gust value, i.e. towards the original equilibrium.

Put simply: an increase in alpha must produce a decrease in pitch. (If the moments were such as to increase pitch, it should be clear that this increase would further aggrivate the original disturbance, and the airplane would rapidly upset.) So if we can write an equation that will relate the total moment acting on the airplane to either the angle of attack or Cl we will have a tool that allows us to study stability. And when we have found the equation, we must arrange the location of the c.g. and the lifting surfaces so a negative effect (pitch-down) is produced by a positive cause (increased alpha.)

Clearly it is impossible for an increase in alpha to produce a decrease in the lift. In other words we have no control over the direction of the forces produced by the increase in alpha. Besides, we want the airplane to rotate, and rotations are produced by moments rather than simple forces. Given these two facts it should be clear that we need to first define all the moments acting on the airplane and then to see how these vary as either alpha or Cl is changed. Since our starting point is equilibrium, the initial sum of moments is zero.

We will make the assumption that the aircraft has at most, two lifting surfaces, but we will make no assumptions as to the relative sizes of these two wings. This means that the equations developed will be valid for all conventional, tandem wing, canard and flying wing aircraft. We will start by investigating equilibrium first, because there are some surprises here, and then we will move on to stability where there are more surprizes. Take particular note of the sign conventions, especially that weight is negative.

Equilibrium (Refer to figure 7.)

Sum of Forces: $L1 + L2 + W = 0$ . . . (1)
Sum of moments: $M1 + M2 + L1*X1 + L2*X2 = 0$ . . . (2)
Also: $X2 = X1 - X12$ . . . (3)

M1 and M2 are the moments produced by the wings independently of the lift - they are an effect due to camber. It is assumed both X1 and X2 are measured from the c.g. to the aerodynamic center of the wings. Up, forward and clockwise are positive. As drawn, L1, L2 and X1 are positive, W and X2 are negative. X12 is defined as positive. Depending on camber, M1 and M2 can be positive, negative or zero. We also assume that M1, M2, W, X1 and X2 are known.

The first thing we can do is find an equation that will give us the lift on each wing. (I will frequently call both lifting surfaces "wings", even tho the smaller one is normally called the horizontal stabilizer. On the canard configuration, the forward wing is frequently called the canard.)

Substituting (1) into (2) and collecting terms:

$$M1 + M2 + (-W - L2)*X1 + L2*X2 = 0$$

$$L2*(X2 - X1) = -M1 - M2 + X1*W$$

and, using (3): $$L2 = (M1 + M2 - W*X1)/X12 \qquad . . . (4)$$

Knowing L2, we use equation (1) to find L1. We could also have solved for L1 first, and then used (1) to find L2. Remembering that this equation is valid for *any* equilibrium condition and *any* configuration, let's look at some examples with real numbers.

1. Conventional airplane, c.g. at the wing AC (X1 = 0), and both airfoils symmetrical; M1 = M2 = 0. Quite typical of a pattern plane.

L2 =(0 + 0 - 0*W)/X12 = 0. In other words the forward wing carries the entire load and the lift on the tail is zero as long as the ship is in equilibrium. Surprizing? Don't go away, it gets better.

2. As for 1, but with the c.g. 1 inch aft of the wing AC (we'll assume that X12 = 30 inches and the weight is 6 lb.)

L2 = (0 + 0 - 1*(-6))/30 = 0.2 lb. or 3.2 oz. Note that the sign is positive which means the lift of the tail is up. For *any* equilibrium at *any* speed.

3. Same thing, but with the c.g. 1 inch ahead of the wing AC.

L2 = (0 + 0 - (-1)*(-6))/30 = -0.2 lb., or 3.2 oz. down. Also at any speed. In these three cases the lift on the forward wing is 6 lb., 5.8 lb. and 6.2 lb. respectively.

Some of you probably don't believe what you just read. You will point out that I ignored the downwash, the decalage or whatever. And of course you are right - I did ignore them. The exact angles of the lifting surfaces and the downwash are unimportant here, just the lifts actually developed. Obviously we must adjust the angles so these lifts are available, but if you want to know what the lift needs to be at trim, you can forget them. Others of you will point out that you "know" the lift on the tail of a conventional airplane must be down. Well, to quote Mark Twain: "It's not what people *don't* know that's the problem, it's what they *do* know that just ain't *so.*" Cases 1 & 2 are perfectly real airplanes any of us could build and fly, and yet in both cases the lift on the tail is not down.

Let's continue to look at the implications of this equilibrium equation for airplanes that have at least one cambered wing.

4. As above, but with M1 negative. Remember that the moment of any

wing M = (p/2)*VV*A*c*Cm, where p is the density of the air, V is the velocity, A is the wing area, c is the mean chord and Cm is a co-efficient that makes the numbers come out right (really!) Cm is fixed for a given wing and can be found in the literature for the wing. If we assume a sailplane with V = 30 fps, A = 900 sq in. (6.25 sq ft.) c = 0.8 ft., and Cm = -0.05, (the Sagitta) the total moment of the wing is:

M1 = 0.0012*30*30*6.25*0.8*(-0.05) = -0.27 lb-ft.

To be consistent we change 30 in. to 2.5 ft. and putting the c.g. at the wing AC:

L2 = (-.27 + 0 -0*(-6))/2.5 = -0.108 lb. or 1.73 oz. down. Note that this value is valid only at 30 fps., and as the speed increases the load on the tail will increase as the square of the speed.

5. Same as 4, but with the c.g. 1 inch aft of the wing AC. First let's re-arrange equation (4) as follows:

L2 = (p/2)*VV*A*C*Cm/X12 - X1*W/X12 . . . (5)

Note that the second term is independent of speed and the first term varies as the square of speed. We know from cases 2 and 4 that the second term produces an upload on the tail while the first produces a continuously increasing download. Each term and the total lift on the tail are graphed in figure 8. As you can see, the load is up at low speed, goes thru zero at about 41 fps and is a download above that speed. The numbers are real, the equations are real, and if you still don't believe it, now's the time to figure out where you went wrong.

Before going further, it's helpful to find an equation for L1, the lift of the forward wing. Not too surprizingly this has the same form as that for L2, but with the signs changed:

L1 =(-(M1 + M2) + X2*W)/X12 . . . (6)

Unlike the rear wing, the forward wing always carries an upload as long as (M1 + M2) is negative. I.e.

L1 = (-(-) + (-)*(-))/(+), which is always positive.

6. The canard. Let's take case 4, interchange the wings and move the c.g. to 4 inches forward of the rear wing's AC. Intuitively we know that L2 will be about the same as the weight, and therefore L1 is the interesting lift.

L1 = (-(0.0012)*VV*6.25*0.8*(-0.05))/2.5 + (-0.333)*(-6)/2.5

or: L1 = 0.00012*VV + 0.8 lb. This is graphed in figure 9.

Some interesting things emerge from a comparison of the loads on the smaller wings for the two configurations. For example: the load on the canard's "tail" is 3.6 times the load on the conventional tail at 70 fps (48 mph). This in turn means that the canard will have more induced drag unless the forward surface has a higher aspect ratio, and full size canards almost all do have a higher aspect ratio than the tails on conventional configurations - they need it just to break even. Secondly, because the canard's tail is always developing substantial lift, it usually has a highly cambered and difficult to manufacture airfoil. Thirdly, as you lower flaps on the canard's wing, which greatly increases its aerodynamic moment, the canard has to develop even more lift to compensate. On the conventional tail, any upwards lift on the tail is <u>reduced</u> when flaps are lowered and usually becomes negative, but at a much lower amount than the canard's.

7. The flying wing. For this configuration M2 and L2 are zero. Equations 1 and 2 reduce to:

$$L1 + W = 0 \qquad . \; . \; . \; (1a)$$

$$M1 + L1*X1 = 0 \qquad . \; . \; . \; (2a)$$

$$\text{so:} \qquad M1 = -L1*X1 = W*X1 \qquad . \; . \; . \; (7)$$

We will see later on that on a flying wing the c.g. must be ahead of the wing AC, making X1 negative. Since W is always negative, this means that flying wings must have a positive aerodynamic moment, which is the opposite of the usual (and desirable) case. The immediate implication is that a flying wing cannot use flaps, because they would result in a negative moment, making the airplane umtrimmable. Flying wings have many restrictions, and I won't dwell on them here.

Now that we have explored the conditions necessary to trim the airplane (bring it into equilibrium) we must look at the how our trimmed airplane reacts to disturbances, in other words, stability.

As I said earlier we must first take equation (2) and find how the total moment depends on Cl or alpha (see appendix 1). Then we must discover a way to make a positive change in Cl produce a negative (pitch-down) moment.

$$M1 + M2 + L1*X1 + L2*X2 = Mt \qquad . \; . \; . \; (2s)$$

where Mt is the total moment on the airplane, and is zero at trim.

First we expand the equation, letting Q = (p/2)*VV.

$$Mt = Q*A1*c1*Cm1 + Q*A2*c2*Cm2 + Q*A1*Cl1*X1 + Q*A2*Cl2*X2 \quad .\ .\ (8)$$

The first two terms are independent of the lift co-efficients (which follows from the definition of an AC.) so their derivatives with respect to Cl are zero. In the last two terms, Q, both areas and both lengths are independent of Cl. We may therefore rewrite (8) as:

$$Mt = K3 + K4 + K1*Cl1 + K2*Cl2 \qquad .\ .\ .\ (9)$$

where the definitions of the K's are obvious.

The remaining problem before taking the derivative is to find an expression for Cl2 in terms of Cl1, or vice versa. Because conventional configuration airplanes far outnumber any other, the usual practice is to find Cl2 in terms of Cl1. And this brings us to the subject of interference, that is, the effect one wing has on the other.

All wings leave wakes, which means that the air behind the wing is disturbed compared to the air well in front of the wing. The disturbance can be approximated quite reasonably by making two modifications to the fourth term: first the velocity will be lower for the second wing. The exact amount depends on the configuration, but is typically about 5% for a conventional configuration, less for a canard. Second: the first wing produces a downwash proportional to its lift co-efficient, the effect of which is to reduce the slope of Cl2 vs alpha. The reduction can be quite significant, possibly as much as 50%, but more likely about 20% (see ref 1, p 224). The upshot is that we can modify (9) to read:

$$Mt = K3 + K4 + K1*Cl1 + K2*E*Cl1 \qquad .\ .\ .\ (10)$$

where E is sometimes called the "tail efficiency".

Differentiating and expanding:

$$\begin{aligned} dMt/dCl &= K1 + K2*E \\ &= Q*(X1*A1 + E*X2*A2) \\ \text{using(3):}\qquad &= Q*(X1*A1 + E*A2*(X1 - X12)) \\ &= Q*(X1*(A1 + E*A2) - E*A2*X12) \qquad .\ .\ .\ (11) \end{aligned}$$

Now Mt is a moment and therefore we can write it as:

$$Mt = Q*At*Xt*Cmt$$

If we now identify At as the total weighted area of the wings, At = A1 + E*A2, and set Xt = X12, we have, using (11):

$$\frac{dMt}{dCl} = \frac{dCmt}{dCl} * Q*(A1 + E*A2)*X12 = Q*(A1 + E*A2)*X12*\left| \frac{X1}{X12} - \frac{E*A2}{(A1 + E*A2)} \right|$$

Eliminating common terms and re-arranging:

$$\frac{dCmt}{dCl} = \frac{X1}{X12} - \frac{1}{(A1/E*A2 + 1)} \quad . . . \quad (12)$$

Equation (12) is the stability equation for any pair of wings, given the assumptions stated as we went along.

As we said earlier, the requirement for stability is that an increase in Cl must result is a decrease in the total moment, or, what is the same thing, in Cmt. In other words dCmt/dCl must be negative. It is clear that the second term is always negative, but the first term can be positive, negative or zero, depending on c.g. location. If we set the derivative = zero, we can find the c.g. location where we have neutral stability, that is, the X1 where the airplane makes no pitch response to a disturbance in Cl.

$$X1 = Xn = \frac{X12}{(A1/E*A2 +1)} \quad . . . \quad (13)$$

Xn is the "neutral point" of the airplane and represents the furthest aft position of the c.g. that will not make the airplane unstable.

There are many interesting properties of these equations, some of them due to terms they do <u>not</u> include. Like the trim equation, there are no terms involving any of the airplane's angles (incidence, decalage). Downwash shows up only as an efficiency factor applied to the rear wing. Weight is missing, as is airfoil moment, which, altho they are in the trim equations, have no effect on stability. You will also note that the lifts of the wings do not appear in either equation, which means that they are irrelevant for stability. If this really causes you a problem see the appendix at the end.

While we realize that the c.g. should be no further aft than the neutral point, the exact amount of stability is largely a question of personal preference, at least in models. In full size civilian aircraft the stability is controlled by regulation and is always significant, but in military aircraft and models the stability is usually relatively low. This results is a more responsive airplane, altho you have to stay ahead of it little more. Let's take some examples:

1. Standard configuration, weighted area of the tail = 10% of the wing:

Xn = X12/((1/0.1) + 1) = X12/11 = 9.1% of X12

Assuming X12 = 30 inches, the neutral point is 2 3/4 in. aft of the wing AC.

2. Canard, same areas and size as 1:

Xn = 30/((.1/1) + 1) = 27 1/4 in. aft of the forward wing, or 2 3/4 in. forward of the main wing.

3. Tandem wing, equal <u>weighted</u> areas (A1 = EA2):

Xn = X12/2 i.e. the neutral point is midway between the wings, which is what one would intuitively expect.

4. Flying wing. Here we must slightly rearrange the equation to avoid dividing by zero:

Xn = X12*E*A2/(A1 + E*A2), and let A2 go to zero.

Xn = 0, in other words the c.g. must not be further aft than the AC of the wing, as was stated earlier.

One of the interesting outcomes of the neutral point equation is that it clearly shows <u>any</u> configuration can be made stable simply by properly locating the c.g., no matter what the relative sizes of the wings. Indeed in a conventional model airplane there is rarely any justification for a large horizontal stabilizer unless we are restricted as to the c.g. location, which we almost never are. Yet I frequently hear modellers talking about enlarging the tail to make the airplane more stable. It will, of course, provided the added weight doesn't move the c.g. a proportionate amount rearward; however it's much simpler to relocate the c.g. To prove this point to doubting Thomases, I fly a Sagitta XC with a tailplane area just 2/3 the area on the plans with absolutely no problems whatever. Assuming we can adjust the c.g., the horizontal stabilizer can be substantially smaller than commonly believed.

As those of you who are familiar with the standard texts will have observed, contrary to the practice of those texts, I have chosen to base the Mt and Cmt on the total weighted area of the wings and the separation of their aerodynamic centers. As a result there is no "tail volume ratio" in my equations and the actual numbers that my equations produce for dCmt/dCl will be different by the ratio of the mean aerodynamic chord to X12. The advantage of doing it this way is that the equations are very simple, they give the neutral point as a dimension, rather than a percent of the forward wing's mean chord, and they have no built in bias towards conventional configurations. However they are neither more nor less valid than any other set of equations derived from the same starting point and based on the same assumptions.

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You will also notice I have only hinted at whether the requirements of trim and stability are better satisfied by one configuration or another. It's now time to look at that in a little more detail.

Let's look at the flying wing first, since it's the simplest case of the three. As we saw above, this configuration must have a wing that has a net positive moment. If we remember that virtually all full size aircraft use flaps to achieve a wider speed range, and that the flying wing can't use flaps, or any other device that produces a negative moment, we see that this type must either have a larger wing to achieve the same landing speed, which sacrifices high speed performance, or else it must land faster, which requires stronger and heavier landing gear as well as increased runway lengths.

There is another more serious problem that follows from (12). If we re-arrange it we have:

dCmt/dCl = X1/X12 - (E*A2)/(A1 + E*A2), which reduces to:

dCmt/dCl = X1/X12 by letting A2 go to zero.

X12 represents the distance between the wings in a two-winged airplane, but what does it represent in a flying wing? Rather than derive it, I'll simply state that it ends up as a distance that is the order of the wing chord. Now clearly if X12 is small, any change in X1 must also be small to stay in the same range of stability. But since X1 is the location of the c.g. this is simply another way of saying that the range of the c.g. in a flying wing is much more limited than in a two-winged aircraft. No great problem for models, but a real handicap for full size planes. "Ladies and gentlemen, unless you all move to the center of the airplane we won't be able to take off!"

There is a third problem that has to do with more complex stability problems than we have considered here, but the effect is simple to state: the airplane's pitch oscillations are relatively fast and poorly damped. This varies from annoying to dangerous, depending on the exact specifics.

In short, despite its tantalizing simplicity, the flying wing is not a great airplane from the standpoint of equilibrium and stability.

As many people know, the Wrights' first airplane was a canard. It is less well known that it was unstable and very difficult to control. For many years the canard was ignored, but the recent resurrection of the configuration due to Burt Rutan has demonstrated that it is perfectly possible to design one that performs well.

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Nonetheless there are some difficulties that are unique to the canard and we will take a look at a couple of them.

1. The area of the tail on a conventional airplane is determined essentially by the requirements of stability, not those of equilibrium. This follows from the fact that it is possible to adjust the c.g. so the stabilizer's lift is zero, and even with normal variations of the c.g. it will still be very small. In a conventional airplane, therefore, we have one variable, area, answering to only one requirement, stability.

In the canard the forward wing supports a substantial amount of the total weight of the vehicle, and therefore must have a certain minimum area just to obtain equilibrium. And like the conventional type, it needs a certain area for stability. Unfortunately if we are not careful we will find the area we want for trim is considerably more than we would like for stability - it would move the neutral point too far forward. We must compromise, and while this is certainly possible, it is something we don't have to do in a conventional configuration. The compromise usually takes the form of a very highly cambered canard with a high aspect ratio working at high lift co-efficients. On the conventional tail, as we all know, the airfoil can be anything including a simple slab, because it's typically working at Cl's of about 0.1.

2. Because the best place for a rudder is as far aft of the c.g. as possible, the usual place for it on a canard is at the ends of the main wing. That means there must be two of them (which must be linked), and their loads must be carried thru the wing structure. Even then, the wings must usually be swept back to get the rudders sufficiently far aft, and that complicates the spar design. On the up side, the rudders act as tip plates and tend to reduce the induced drag.

Finally let's look at a few of the problems with a conventional layout.

The assumption that I made earlier about the effect of the forward wing on the tail is open to considerable modification at very high angles of attack, i.e. near the stall. If the stabilizer is enveloped by the wake of a partially stalled wing it can result is a lot of bobbing around for the airplane. This is why many airplanes have the tailplane mounted on top of the rudder - to guarantee it will never be in the wing's turbulence.

If the conventional airplane is a tractor rather than a pusher, the stabilizer is directly in the propeller wake. That can cause large pitch changes when power is applied. For reasons we didn't discuss here the propeller also causes a decrease in the stability, which requires either an increase in the size of the stabilizer or mounting it on top of the rudder again.

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Finally the conventional configuration, at least in single engine piston types, uses the fuselage aft of the wing esentially to support the tail. In other words there is a lot of metal out there that is used only to satisfy the requirements of equilibrium and stability.

Because models have many fewer restraints than full-size airplanes we can play more with the various types. Except for sailplanes, efficiency and low landing speed are relatively unimportant, and we can usually adjust the c.g. to anywhere we want and leave it there. We don't really have to worry if the ride is lousy because no-one's in the plane to feel it. Consequently modellers are really freer to build unusual types than full-size designers. But none of us - full-size or modeller - can ignore the basic equilibrium and stability rules discussed here unless we like destroying airplanes or building unflyable models.

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Note: The symbols in Etkin's book can be confusing. Be careful.

Appendix 1:

The derivative can be taken with respect to either Cl or alpha because the equation relating lift-coefficient to angle of attack is assumed to be linear, which means the derivatives will differ only by a constant. The usual convention is to use Cl, altho if the analysis is extended to include non-linear effects such as the stall, alpha is preferrable. Here I have used the Cl of the forward wing.

Appendix 2:

There is a persistent myth concerning the nature of the load on the tail of a conventional aircraft. It is stated by several authors (Brad Powers, Andy Lennon, et al.) that the load on the tail must be down for stable, trimmed flight. The usual justification goes as follows: The neutral point of an aircraft is akin to the aerodynamic center of a lifting surface, and we can therefore consider the total lift of the vehicle as acting there. (True.) Since the c.g. is always ahead of the NP, there is a nose-down couple produced between the c.g. and the lift at the NP. (Also true.) Therefore the tail must produce a nose-up moment to balance the nose-down one, and that means the lift on the tail must be down. (False.)

The argument is false because it ignores the forward wing's contribution to the total moment. We can look at this in two ways:

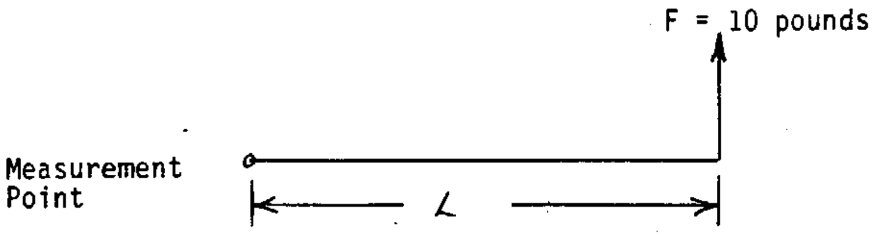
1. There are two things that occur at a NP, just as at a wing AC. These are the total lift, and the total moment. The aerodynamic moment at the NP of any airplane is produced by both wings, not just the tail, (see equation 2 and figure 7). Since any force acting at a distance produces a moment, it is false to assume that only the tail supplies the moment necessary to balance the c.g.-NP couple. The wing, which lies ahead of the NP, will also supply a moment, and it will always be nose-up. What the moment is that the tail must supply (and therefore whether its lift is up or down) depends entirely on the specifics of the airplane's dimensions, and on the Cm of the wing. In this case the use of the name "horizontal stabilizer" is confusing, stability is provided by the combination of the wings, not just one.

2. The equations simply don't support the argument, and I have given examples that demonstrate that. Please note that it's not just my equations that show the error of the argument, all the standard texts' equations also do the same thing.

There is no question that many airplanes, if not most, have a down-load on the tail during a significant part of their flight envelope. But neither stability nor trim considerations require that this be the case with all conventional airplanes, as the myth states.

Another way to look at this is as follows:

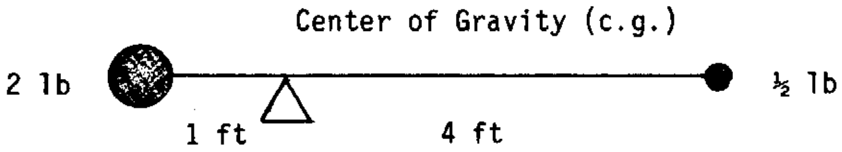
Consider a conventional airplane with a total area of 10, and 90% of it in the front wing. If the argument is true, than the load on the rear wing must be down. Now reduce the front wing's area by 10% and add it to the tail. Same total area, but more in the tail. Keep repeating this process until the areas of the wings have reversed, i.e. the front wing is now 1/9th the rear wing. In the process you went progressively from a conventional configuration thru a tandem wing to a canard. Now you know that the lift of both wings on a canard must be up, and the argument says the lift on the rear wing of the (conventional) starting point must be down. Where, pray tell, did the two "musts" meet, and how did they interchange? In the middle, at the equal area tandem wing? If so, why bother with the rear wing at that point since, apparently it's lift must be zero?! Obviously this is ridiculous, and the reason is the argument is wrong.



L = 5 feet

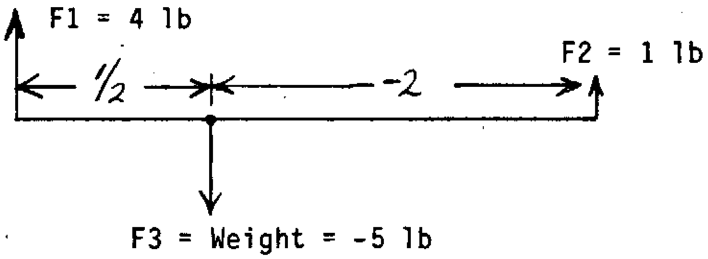
Torque = Moment = Force * Distance
= 10 * 5
= 50 lb-ft (or ft-lb)

FIGURE 1



2 lb * 1 ft = 2 = ½ lb * 4 ft

FIGURE 2

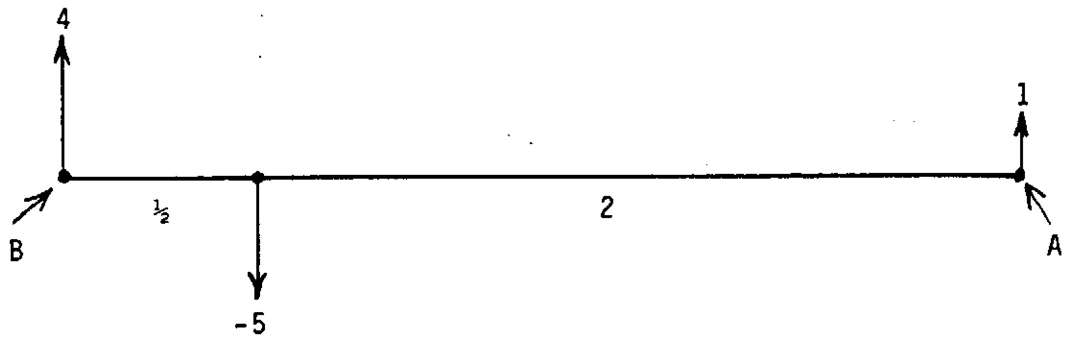


Moment 1 = 4 * ½ = 2
Moment 2 = 1 * -2 = -2
Moment 3 = -5 * 0 = 0
Sum = 0

Force 1 = 4
Force 2 = 1
Force 3 = -5
Sum = 0

THE EQUILIBRIUM SYSTEM

FIGURE 3



Moments taken about A

4 * 2.5 = 10
1 * 0 = 0
-5 * 2 =-10
Sum = 0

Moments taken about B

4 * 0 = 0
1 * -2.5= -2.5
-5 * -0.5= 2.5
Sum = 0

FIGURE 4

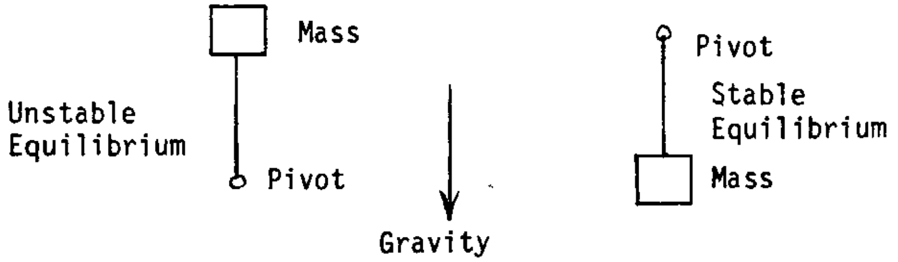


FIGURE 5

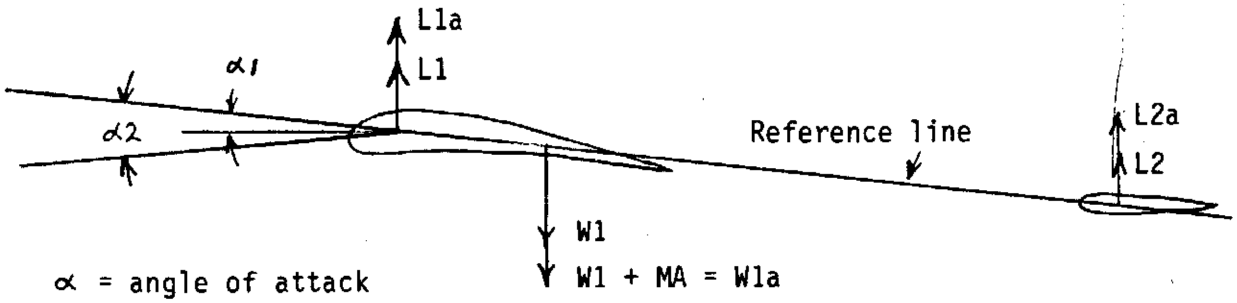
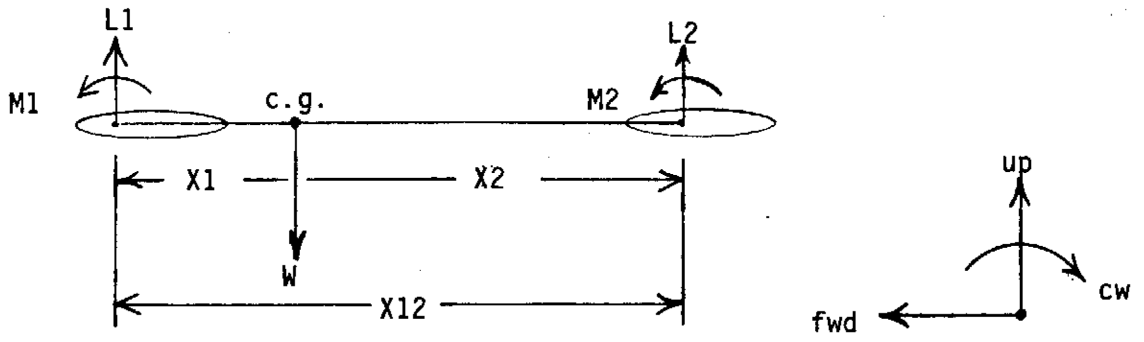
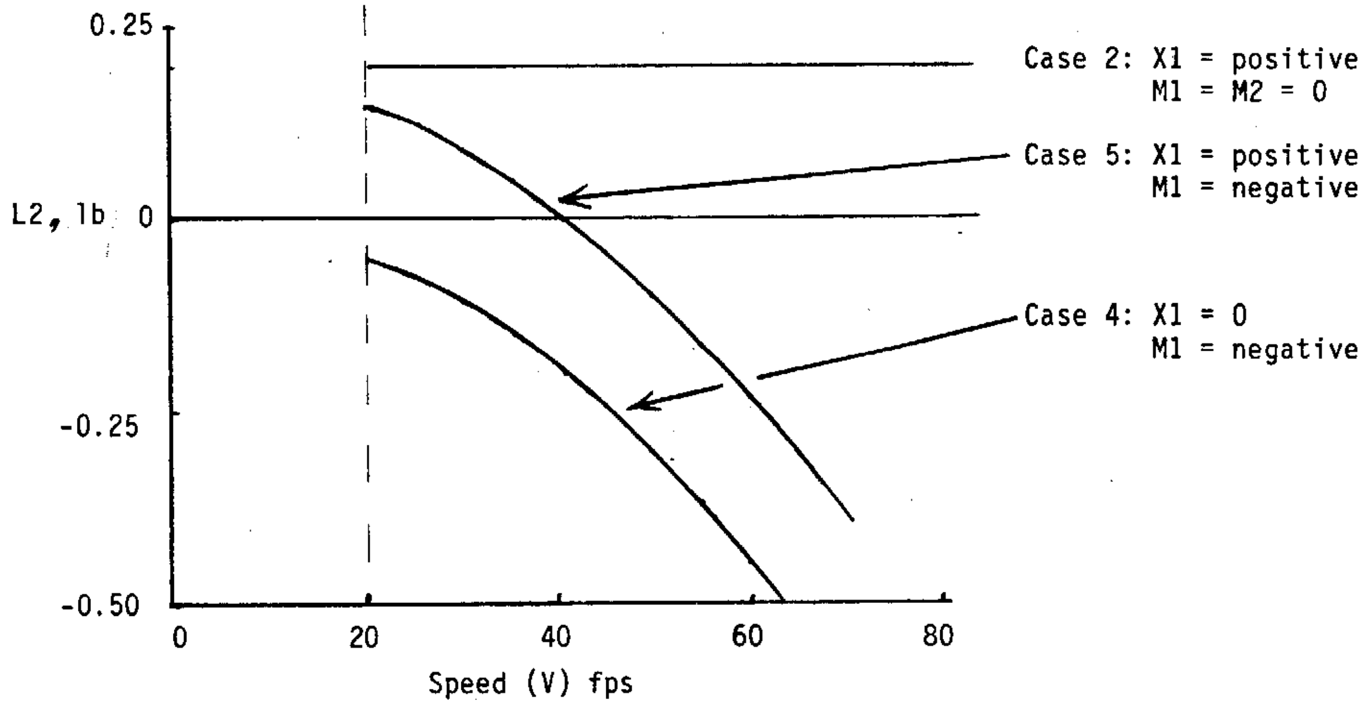


FIGURE 6



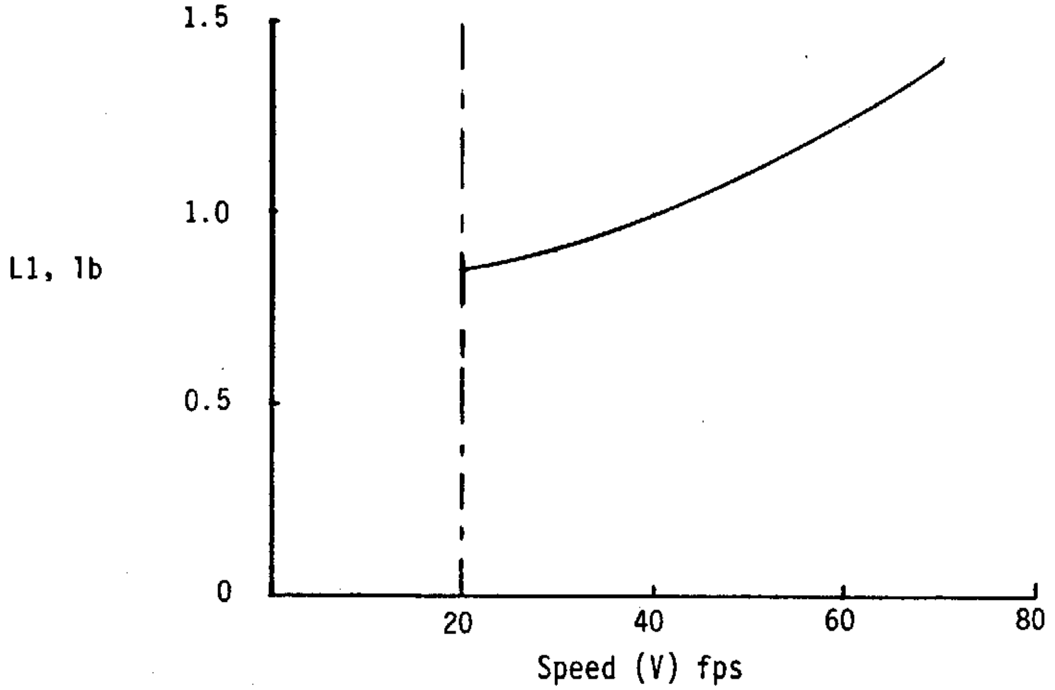
Positive Conventions

FIGURE 7



CONVENTIONAL CONFIGURATION

FIGURE 8

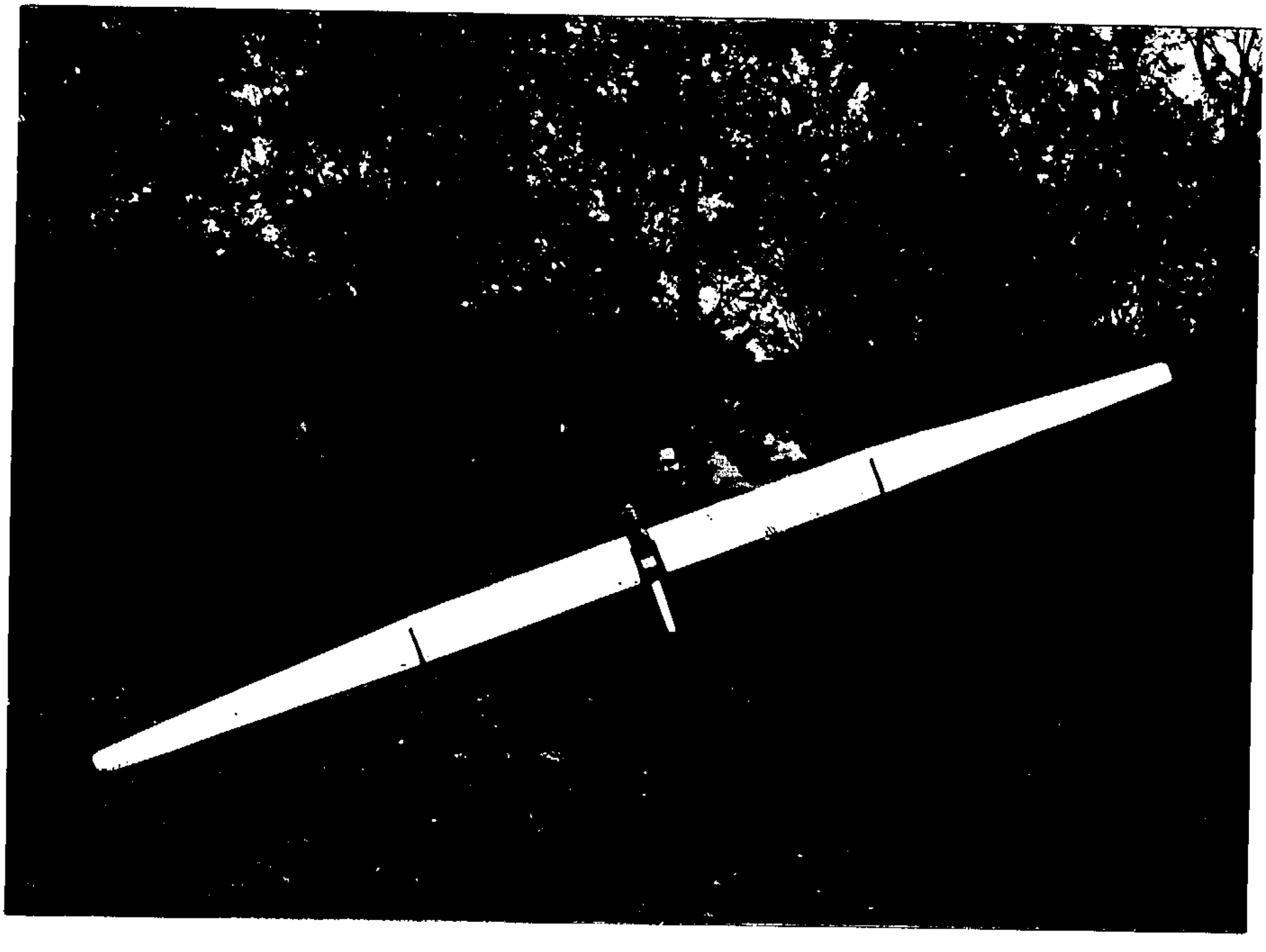


CANARD CONFIGURATION

FIGURE 9

THE FRICTION AND PRESSURE DRAG OF AIRFOILS

In this paper, Hewitt Phillips provides a fascinating analysis of the mechanisms of drag production on airfoils at low Reynolds Number. Although the article is highly technical, the analysis and conclusions are both very interesting. I think that it´s especially interesting to note where on the surface of the airfoil the different kinds of drag are generated. It´s also startling to note, that the laminar portion of the flow may be generating more of the drag than the turbulent portion under some conditions. Correspond with Hewitt at 310 Manteo Ave., Hampton, Va. 23661.



The Friction Drag and Pressure Drag of Airfoils

by Hewitt Phillips

Summary

The friction drag, pressure drag, and distribution of friction drag on the surface are calculated for two airfoils using the Eppler program. These calculations are made for a wide range of angle of attack at a Reynolds number of 100,000. The results show that the friction drag contributed by the laminar region of the boundary layer at moderate angles of attack usually exceeds that contributed by the turbulent region. The friction drag of the airfoil does not change greatly with increasing angle of attack, whereas the pressure drag increases progressively. A discussion is given of some design considerations of the airfoils studied. These design considerations involve sources of drag not fully analysed in the theory.

Introduction

In 1743, the French mathematician Jean D'Alembert proved that a body such as an airfoil moving through an ideal, non-viscous fluid should experience no drag. This result puzzled scientists for over 150 years, because airfoils were known to have drag in practice, yet air is a fluid of very low viscosity which was believed to approach the mathematical concept of a non-viscous fluid very closely.

The correct explanation of the drag of airfoils was first given by the German scientist Ludwig Prandtl in a famous paper in 1904, in which he introduced the concept of the boundary layer. Prandtl showed that the drag of an airfoil was composed of friction drag, the effect of forces tangential to the surface, and pressure drag, the effect of forces normal to the surface. Both of these sources of drag result from the presence of the boundary layer, a thin layer of air dragged along with the airfoil near its surface.

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Despite the availability of the explanation given by Prandtl, very few attempts have been made to determine the relative magnitudes of friction drag and pressure drag. Experimental drag measurements, whether by direct measurement of force or by wake surveys, give the total of the friction and pressure drags. measurement of the individual drag components with sufficient accuracy is extremely difficult. Even the calculation of the drag components was extremely tedious before the advent of high-speed computers, and was rarely attempted. At present, however, the availability of sophisticated airfoil design programs such as the Eppler program makes it possible to calculate the relative values of friction drag and pressure drag along with the other characteristics of the airfoil.

The purpose of this paper is to present some recent results on the relative magnitudes of friction drag and pressure drag on two airfoils of interest for radio-controlled gliders. In the process of presenting these results, it is hoped to convey a better appreciation of the factors that influence airfoil design. The paper does not attempt to select a particular airfoil as superior in some application. In fact, the main results of the paper may be considered somewhat acedemic, and not directly related to the problem of airfoil selection.

The distribution of friction drag on the surface is calculated for two airfoils over a wide range of angle of attack at a Reynolds number of 100,000. The relative values of friction drag and pressure drag are then presented. Some discussion is given of factors neglected in the theory which tend to result in underestimation of the drag.

Method of Analysis

The results presented in this paper were calculated with the Eppler program. For a complete description of this program, the reader is referred to the report of Reference 1. The program enables calculation of the pressure distribution on the airfoil in inviscid flow (that is, without a boundary layer). Then, this pressure distribution is used to calculate the development of the boundary layer on the upper and lower surfaces. The boundary layer calculation gives the variation of friction drag along the surfaces of the airfoil. If the component of friction drag in the free-stream direction is plotted as a function of the chordwise distance, the area under this curve gives the total friction drag acting on a surface. In addition, the momentum loss in the boundary layer at the trailing edge may be analysed to give the total drag of the airfoil. The pressure drag may then be obtained as the difference between the total drag and the friction drag.

The Eppler program has been extended in a later report (reference 2) to allow a second iteration on the effect of the boundary layer. That is, following the first calculation, the pressure distribution is recalculated based on the streamlines as displaced by the presence of the boundary layer. This option of the program is not used in the present report, because the effects have been found to be small and because of the considerably greater calculation time required.

Although the Eppler program as given in reference 1 gives a printout of the total drag of an airfoil, it does not give the friction drag in a form that is immediately useful in calculating total friction drag. The program presents values of friction drag as a function of the distance along the surface, starting at the trailing edge, moving forward along the top surface, and then back to the trailing edge along the lower surface. In order to obtain the plots of friction drag as a function of chordwise distance, it is necessary to reorder the values of friction drag as calculated. For this purpose, the program was modified to store the desired quantities on a tape. Then, a second program was written, using this tape as input data, to produce plots of friction drag as a function of chordwise position, and to integrate these curves to obtain the total friction drag on the upper and lower surfaces.

Symbols

v	local velocity on airfoil
V_∞	free-stream velocity
x	chordwise distance from leading edge
c	airfoil chord
α	angle of attack with respect to the angle for zero lift
L	lift per unit span
D	drag per unit span
C_L	section lift coefficient, $L/\frac{\rho}{2}V_\infty^2 c$
C_D	section drag coefficient, $D/\frac{\rho}{2}V_\infty^2 c$
R	Reynolds number, $\frac{\rho V_\infty c}{\mu}$
ρ	air density
μ	air viscosity
CDF	component of local friction drag coefficient in free-stream direction, based on free-stream velocity, $F\|\sin(\alpha-\beta)\|/\frac{\rho}{2}V_\infty^2$
F	local friction drag per unit area
β	angle of inner normal to airfoil surface

3

Description of Airfoils

The airfoils used as examples are the Eppler 214 and the Selig 2091. Drawings of the airfoils and velocity distributions over a range of values of angle of attack are shown in figures 1 and 2. Angle of attack used throughout this report is the angle above that for zero lift. These velocity distributions exhibit some features common to all airfoils. The velocity goes to zero at a point near the leading edge, called the stagnation point. Then, on the upper surface, it increases to values considerably larger than the free-stream value, and subsequently decreases to a value slightly less than the free-stream value at the trailing edge. On the lower surface, the velocity also increases, but at the higher angles of attack, it may remain below free-stream velocity until it comes to the same value at the trailing edge as that on the upper surface. By Bernoulli's principle, when the velocity increases, the pressure decreases, and vice versa. With increasing angle of attack, the pressure is reduced to low values near the leading edge on the upper surface, and subsequently increases toward the trailing edge. The increment of velocity due to angle of attack, which results in the fanning out of the curves near the leading edge, is nearly the same for all airfoils. The designer's job, therefore, is to create an airfoil shape with a basic pressure distribution at zero lift which, when combined with the incremental pressure distribution due to angle of attack, gives a favorable distribution of pressure at some design condition or range of conditions.

The behavior of the boundary layer is influenced primarily by the pressure distribution, not by the airfoil shape directly. Whenever the boundary layer is forced to flow into an increasing pressure gradient, it slows down and may separate. Ideally, the airfoil should provide a decreasing (or favorable) gradient all the way to the trailing edge, but, as mentioned previously, this condition is impossible to meet on the upper surface because the flow must return from a higher value to near free-stream velocity at the trailing edge. The main difference between airfoils is the manner in which this velocity decrease takes place.

In the case of the E-214 airfoil (figure 1), the velocity decreases very gradually on the upper surface to a point near the trailing edge, then decreases abruptly in the last few percent of the airfoil chord. This design is intended to delay separation on the upper surface to as high an angle of attack as possible, thereby providing lower drag at high lift and a high stall angle.

In the case of the Se-2091 airfoil(figure 2), the velocity decreases more smoothly, avoiding the sudden drop near the trailing edge at the expense of a steeper average slope. The type of pressure distribution near the forward part of the airfoil is intended to reduce the size of the separation bubble, which marks the end of the laminar boundary layer and the transition to a turbulent boundary layer. By encouraging the formation of a smaller separation bubble, this airfoil design is intended to avoid large drag increases at the lower Reynold's numbers due to the separation bubble. These drag increases have been shown to occur in wind-tunnel measurements, but are not predicted by the Eppler program. A more complete discussion of the design considerations for this airfoil is given in reference 3.

Results

The lift-drag polars given by the Eppler program for the two airfoils at a Reynolds number of 100,000 are shown in figure 3.* At this value of Reynolds number, the calculated values of drag may be expected to be low, but wind-tunnel data are not available for these particular airfoils. The curves are of interest, however, in correlating with the friction and pressure drag data to be presented.

The locations of boundary-layer transition on the upper and lower surfaces for both airfoils, and the location of the separation point of the turbulent boundary layer on the upper surface, are shown in figure 4. In the familiar computer-generated plot produced by the Eppler program, these data are presented on the same axes, but they have been replotted on separate axes so that the data for the two airfoils may be compared.

The variation of friction drag coefficient along the upper and lower surfaces of the two airfoils at angles of attack of 4°,8°, and 14° are shown in figure 5. Actually the quantity plotted is the component of friction drag coefficient in the free-stream direction, based on free-stream velocity. Thus, the area under each curve gives the total friction-drag coefficient for that condition.

Values of friction-drag coefficient for each surface, the total friction-drag coefficient, and the total drag coefficient for the airfoil, are presented for the E-214 airfoil in figure 6 and for the Se-2091 airfoil in figure 7. Since the total drag is the sum of the friction drag and pressure drag, the pressure drag is the difference between the plotted values of total drag and friction drag.

In the printout of the Eppler program, separate values of total drag coefficient are given for the upper and lower surfaces, based on computed momentum loss in the boundary layers on the upper and lower surfaces at the trailing edge. These values are added to give the total drag coefficient of the airfoil. These values should not be interpreted as the correct values for the separate surfaces, however, because even in inviscid flow, which would produce no boundary layers, a pressure drag would exist on the lower surface aft of the stagnation point, offset by an equal and opposite thrust contributed by the area starting at the stagnation point and continuing around the upper surface to the trailing edge. The thrust exists because of the large negative pressure around the sharply curved leading edge of the airfoil, producing what is called "leading-edge suction". These increments of pressure force cancel when added, so that the total drag given by the Eppler program is correct. The reasons for presenting the separate upper- and lower-surface values in the Eppler program are that they are computed separately from the boundary-layer calculations on the upper and lower surfaces, and that their sum gives the total drag correctly.

Discussion of Results

The difference between the predicted lift-drag polars of the two airfoils may be explained with the aid of the data on transition and separation points given in figure 4. Both airfoils have about the same useful range of lift coefficient. The Se-2091 airfoil, at angles of attack greater than 4°, has a favorable pressure gradient on the lower surface, resulting in complete laminar flow on this surface. As a result, the minimum drag is slightly less than that of the E-214, which has lower-surface

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* A Reynolds number of 100,000 corresponds to an airspeed of about 16 ft/sec with a one foot chord, or 32 ft/sec with a 6 inch chord.

transition around 0.5c. As the angle of attack increases, however, the more rearward transition point of the E-214 on the upper surface has a predominant effect, resulting in lower drag at a given value of lift coefficient. This more rearward transition location results from the more gentle adverse pressure gradient on the upper surface of the E-214. In the higher range of angles of attack, the separation point on the upper surface of the Se-2091 moves forward, whereas that of the E-214 stays aft in the region of abrupt pressure recovery. As a result, the lift of the Se-2091 is reduced, resulting in a lower maximum lift coefficient.

The distributions of friction drag shown in figure 5 give further insight into the calculated boundary-layer development of the two airfoils. An explanation of the assumptions made in the Eppler program is required to interpret these results. The boundary layer is assumed to start as a laminar layer at the stagnation point, using for a short distance the exact theoretical solution for a stagnation-point flow. Then the development of the laminar layer as influenced by the airfoil pressure distribution is calculated step by step. The friction at the surface is proportional to the gradient of velocity with distance away from the surface. Near the nose, then, where the boundary layer is thin, the surface friction is greatest. As the boundary layer thickens, the surface friction decreases. When the boundary layer encounters an adverse pressure gradient, the velocity gradient at the surface may approach zero and then reverse. At this point, in practice, a laminar separation bubble occurs, and the flow reattaches as a turbulent boundary layer. In the Eppler program, transition is assumed to occur instantaneously at the point of laminar separation. From this point, the step-by-step solution using the turbulent boundary-layer equations is continued until the velocity gradient at the surface again falls to zero, where turbulent separation occurs. In practice, this procedure gives excellent results at higher values of Reynolds number (greater than about 400,000). At a Reynolds number of 100,000, the laminar separation bubble can be expected to occupy an appreciable fraction of the chord. Under these conditions, the theoretical calculations are expected to be somewhat in error. The inability to account for the separation bubble is the main deficiency in the boundary-layer calculations made by the Eppler program. The calculations of the growth of the laminar and turbulent boundary layers themselves is based on semi-empirical theory which has been shown by numerous comparisons with experiment to be accurate.

The data of figure 5 shows the region of laminar flow starting at the leading edge, with the drag coefficient dropping to zero at the transition point; then the drag increasing again in the turbulent region. A surprising result is the relatively high drag contributed by the laminar region. Most available data, based on full-scale aircraft, indicate that the drag provided by the laminar region should be only a small fraction of the drag produced by the turbulent region. At a value of Reynolds number of 100,000, however, the turbulent drag coefficient is only 2 or 3 times the laminar value at the same distance from the leading edge. On the airfoil, the laminar region is near the leading edge, where the boundary layer is thin. As a result, the drag contributed by the laminar region actually exceeds that contributed by the turbulent region.

A good comparison of the drag coefficients of the laminar and turbulent boundary layers at comparable distances from the leading edge is given by the curve shown in figure 5 for the lower surface of the Se-2091 airfoil at angles of attack of 2° and 4°. At 2°, the boundary layer on the lower surface is almost fully turbulent, whereas at 4°, it is almost fully laminar. The drag coefficient in the turbulent layer is seen to be 2 or 3 times that in the laminar layer. As a result, a laminar boundary layer on an airfoil at low Reynolds number does reduce the friction drag, though the gains are not as great as on full-scale aircraft.

At an angle of attack of 14°, the boundary layers of both airfoils on the upper surface are fully turbulent, and on the lower surface fully laminar. The approach to the separation region on the upper surface results in a low value of friction drag. The more extensive separation on the Se-2091 airfoil is apparent.

In figures 6 and 7, the integrated values of friction drag coefficients and the total drag coefficients for the two airfoils are compared. In order to appreciate these results, it should be recalled that the pressure drag in ideal, non-viscous flow is zero. Any pressure drag shown on figures 6 and 7 therefore results from the presence of the boundary layer.

From figures 6 and 7, the total friction drag is seen to be fairly constant as the angle of attack changes, whereas the pressure drag increases rapidly with increasing angle of attack. These results do not seem to be greatly different for the two airfoils. In fact, similar studies made for much higher (full-scale) Reynolds numbers and for a variety of airfoils all show similar results. In the past, very few studies have been made of the relative values of friction drag and pressure drag. One such study (reference 4) made in 1937 by the same method as the present report, but using laborious hand calculations, concluded that the pressure drag for a 14 percent thick airfoil was about 0,13 of the total, but these studies were for an airfoil operating at a lift coefficient of 0.17. The general impression seems to be held, however, that the pressure drag is usually less than the friction drag. the results of figures 6 and 7 show that the pressure drag increases rapidly at the higher angles of attack, and may be as much as 65 to 70 percent of the total at the stall.

The distribution of pressure drag on the airfoil cannot be determined by the present method, though previous wind-tunnel studies have shown that it originates partly from a loss of "leading-edge suction" and partly from a reduction of positive pressure near the rear of the airfoil. Accurate determination of the pressure drag by integration of the drag component of the surface pressure is very difficult, however, because the lift forces are so much larger than the drag forces. Very accurate values of the slope of the airfoil surface at each pressure location would be required to determine the pressure drag accurately by this method.

Because of the importance of the pressure drag, the conclusion might be reached that an airfoil design should be sought which reduces the pressure drag. When it is realized, however, that all the pressure drag comes from the outward displacement of the streamlines by the thickness of the boundary layer, the pressure drag is seen to be inseparably linked to the boundary layer. Most previous airfoil development has been based on attempts to obtain a thinner boundary layer by extending the region of laminar flow, preventing separation, etc. These methods are therefore basically correct, though their main result may be to reduce pressure drag rather than friction drag. One way to reduce pressure drag is to remove the boundary layer by suction, but this method requires expenditure of power that is not available in a glider.

A concluding statement may be made concerning the sources of error in the theoretical analysis. As mentioned previously, the program does not take into account the separation bubble which occurs following laminar separation. This bubble, at low values of Reynolds number, entrains additional air into the boundary layer, which, according to the discussion given previously, should increase the pressure drag. Also, the region of turbulent separation near the trailing edge causes thickening of the boundary layer. The resulting increase in pressure drag is not accounted for in the program. It is not surprising, therefore, that at low values of Reynolds number, wind-tunnel measurements show higher drag than predicted by the program. The Se-2091 airfoil is designed specifically to reduce losses due to the separation bubble, whereas the E-214 airfoil is designed to reduce the turbulent separation at the trailing edge. The comparison of the merits of the two airfoils, then, depends on factors not considered in the theory. A more advanced theory that takes into account these complex phenomena would be required to make a valid comparison of these airfoils.

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Conclusions

From an analytical study of two airfoils at a Reynolds number of 100,000, the following conclusions have been reached:

1. At moderate angles of attack, where the transition from laminar to turbulent flow occurs near the midpoint of the airfoil, the friction drag contributed by the laminar region usually exceeds that contributed by the turbulent region. This result, which is opposite from that expected on full-scale aircraft, occurs because the laminar layer is near the leading edge where the boundary layer is thinner, and because the drags of the laminar and turbulent boundary layers are not so different at a Reynolds number of 100,000 as at full-scale Reynolds numbers.

2. The friction drag is relatively insensitive to angle of attack, whereas the pressure drag increases rapidly with increasing angle of attack, and reaches a value of about 0.65 to 0.70 of the total drag of the airfoil near the stall.

3. An accurate comparison of the drag characteristics of the airfoils studied would require consideration of the drag contributed by laminar separation bubbles and by separated flow near the trailing edge. Neither of these sources of drag is included in the theoretical analysis.

9

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4. Squire, H.P. and Young, A.D. The Calculation of the Profile Drag of Aerofoils. British R&M No. 1838, Nov. 18, 1937.

FIGURE CAPTIONS

Figure 1.- Inviscid velocity distributions on the Eppler 214 airfoil at angles of attack from -4° to 20° in increments of 2°.

Figure 2.- Inviscid velocity distributions on the Selig 2091 airfoil at angles of attack from 2° to 14° in increments of 2°.

Figure 3.- Lift-drag polars for the E-214 and Se-2091 airfoils at a Reynolds number of 100,000.

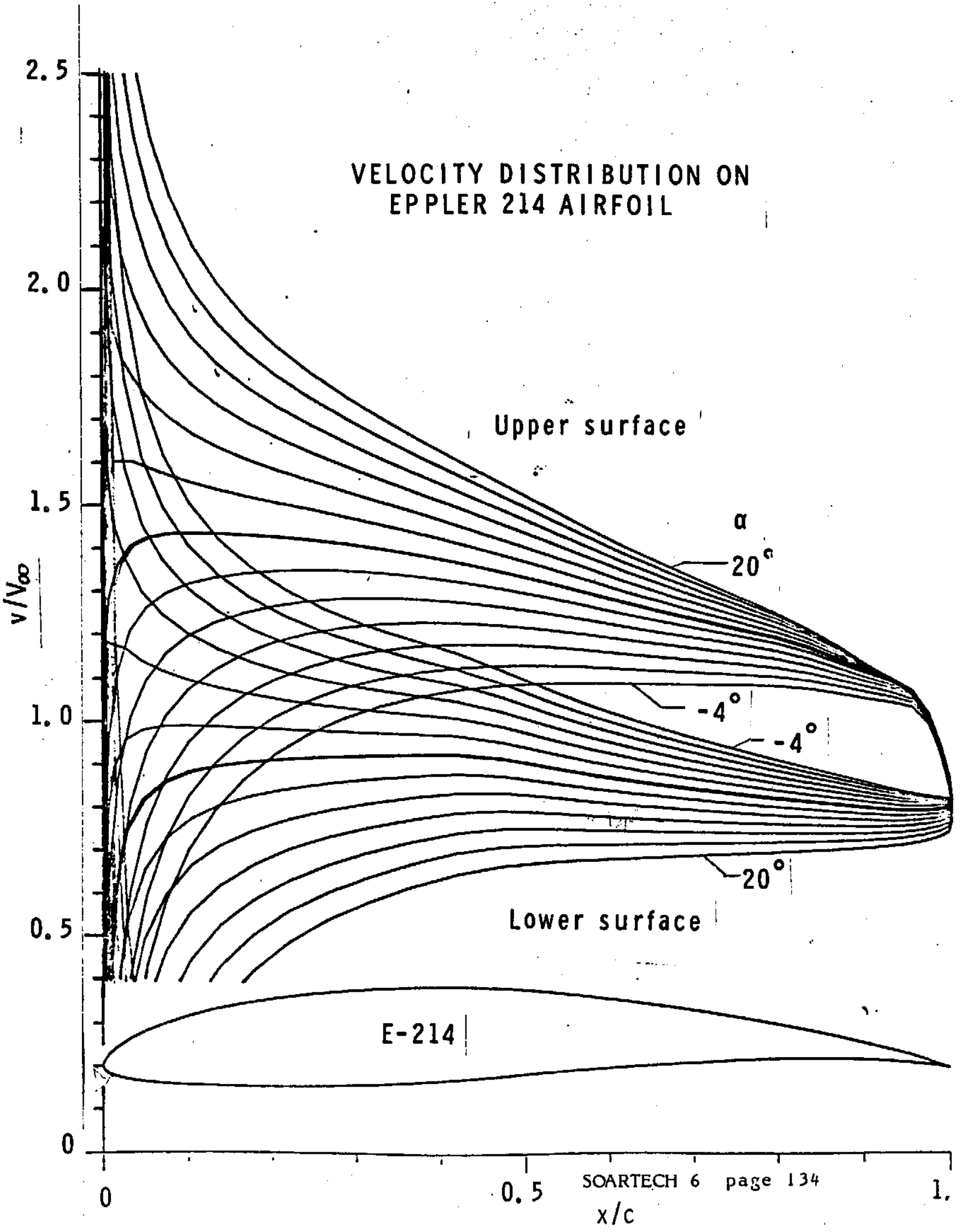
Figure 4.- Locations of transition on the upper and lower surfaces and separation on the upper surface for the E-214 and Se-2091 airfoils at a Reynolds number of 100,000.

Figure 5.- Distributions of CDF, the component of friction drag coefficient in the free-stream direction, along the upper and lower surfaces of the E-214 and Se-2091 airfoils at angles of attack of 4°, 8°, and 14°, R = 100,000.

Figure 6.- Variation with angle of attack of the coefficients of total drag, pressure drag, total friction drag, and friction drag on the upper and lower surfaces, E-214 airfoil, R = 100,000.

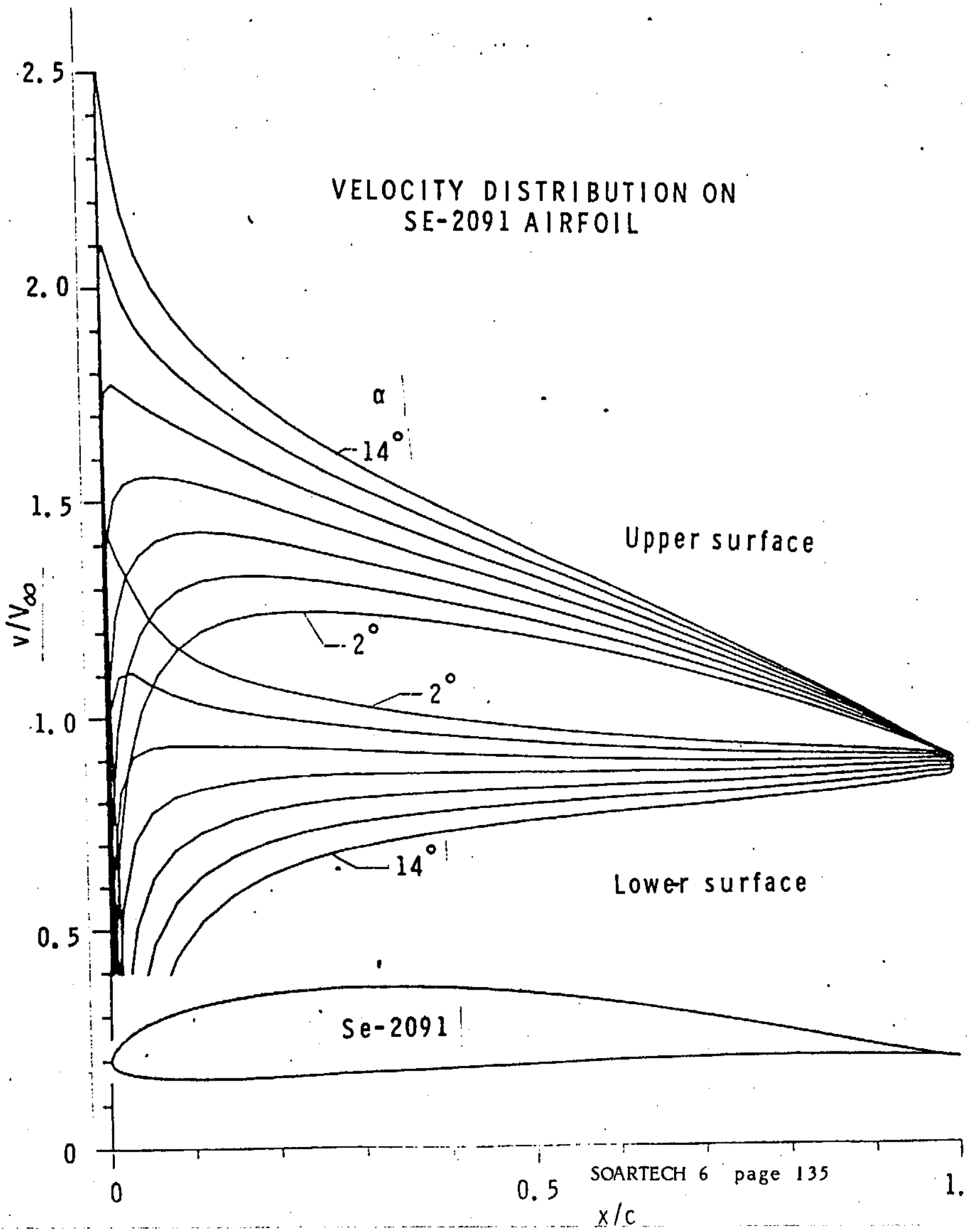
Figure 7.- Variation with angle of attack of the coefficients of total drag, pressure drag, total friction drag, and friction drag on the upper and lower surfaces, Se-2091 airfoil, R = 100,000.

FIGURE NUMBER 1



VELOCITY DISTRIBUTION ON EPPLER 214 AIRFOIL

FIGURE NUMBER 2



VELOCITY DISTRIBUTION ON SE-2091 AIRFOIL

FIGURE NUMBER 3

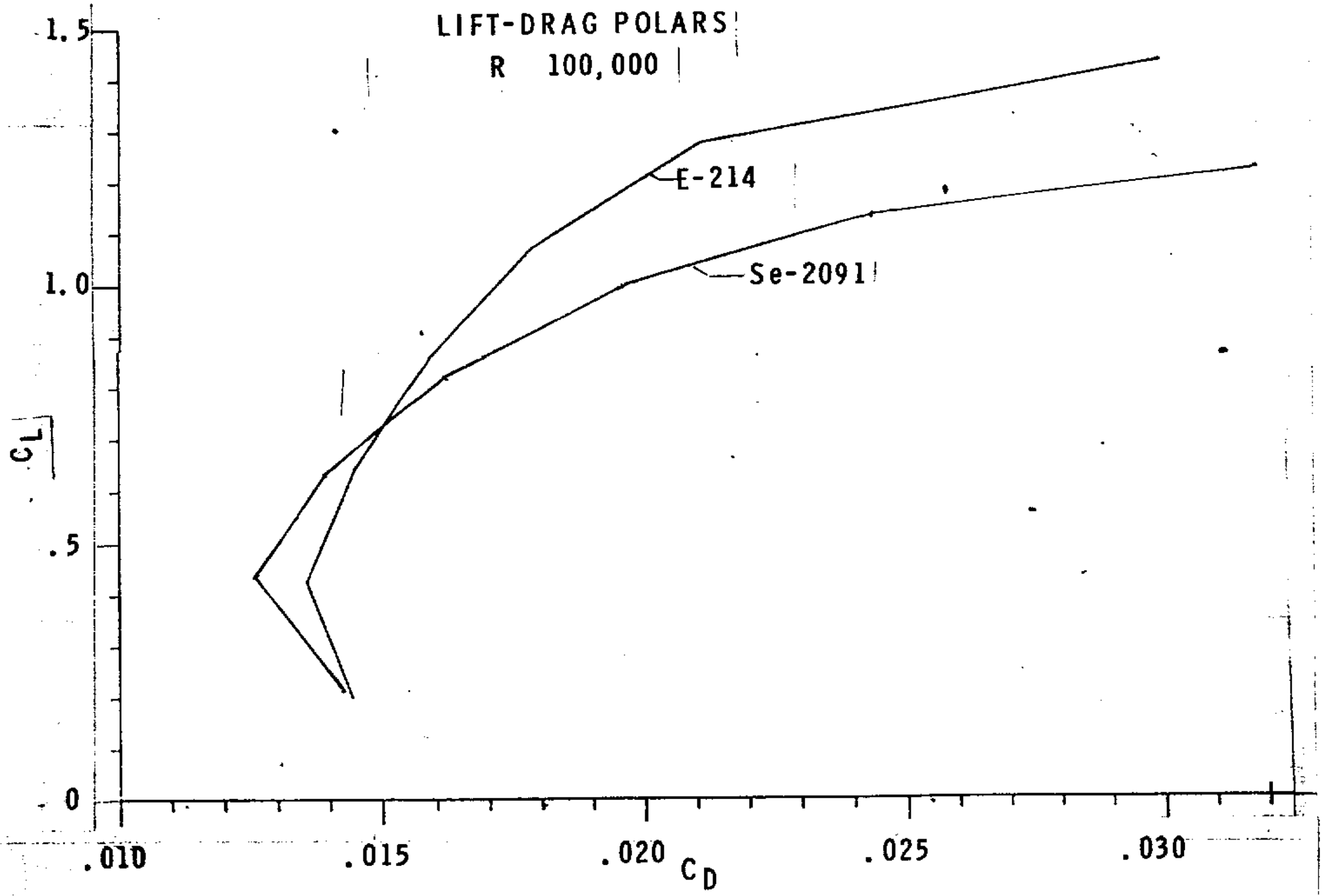


FIGURE NUMBER 4

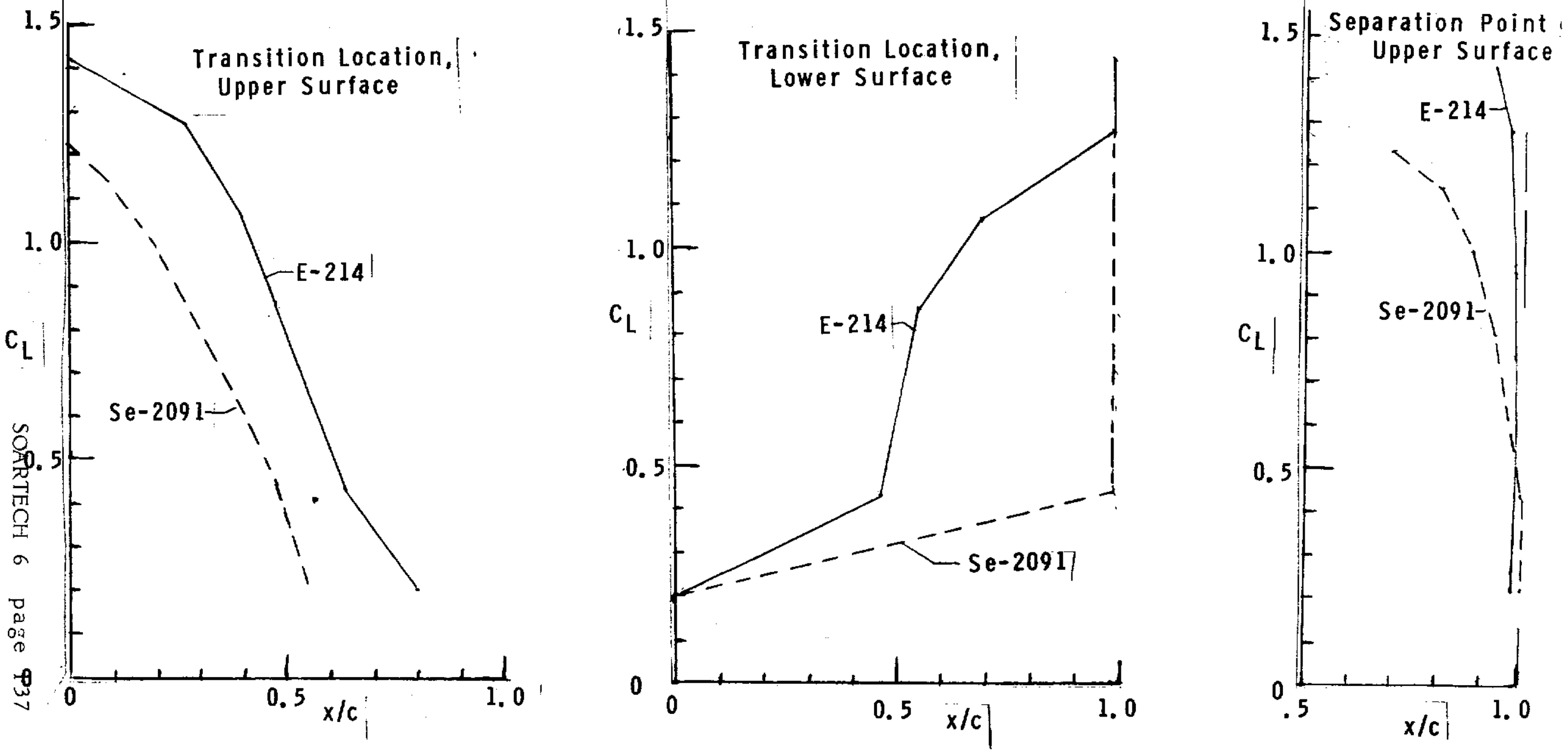


FIGURE NUMBER 5

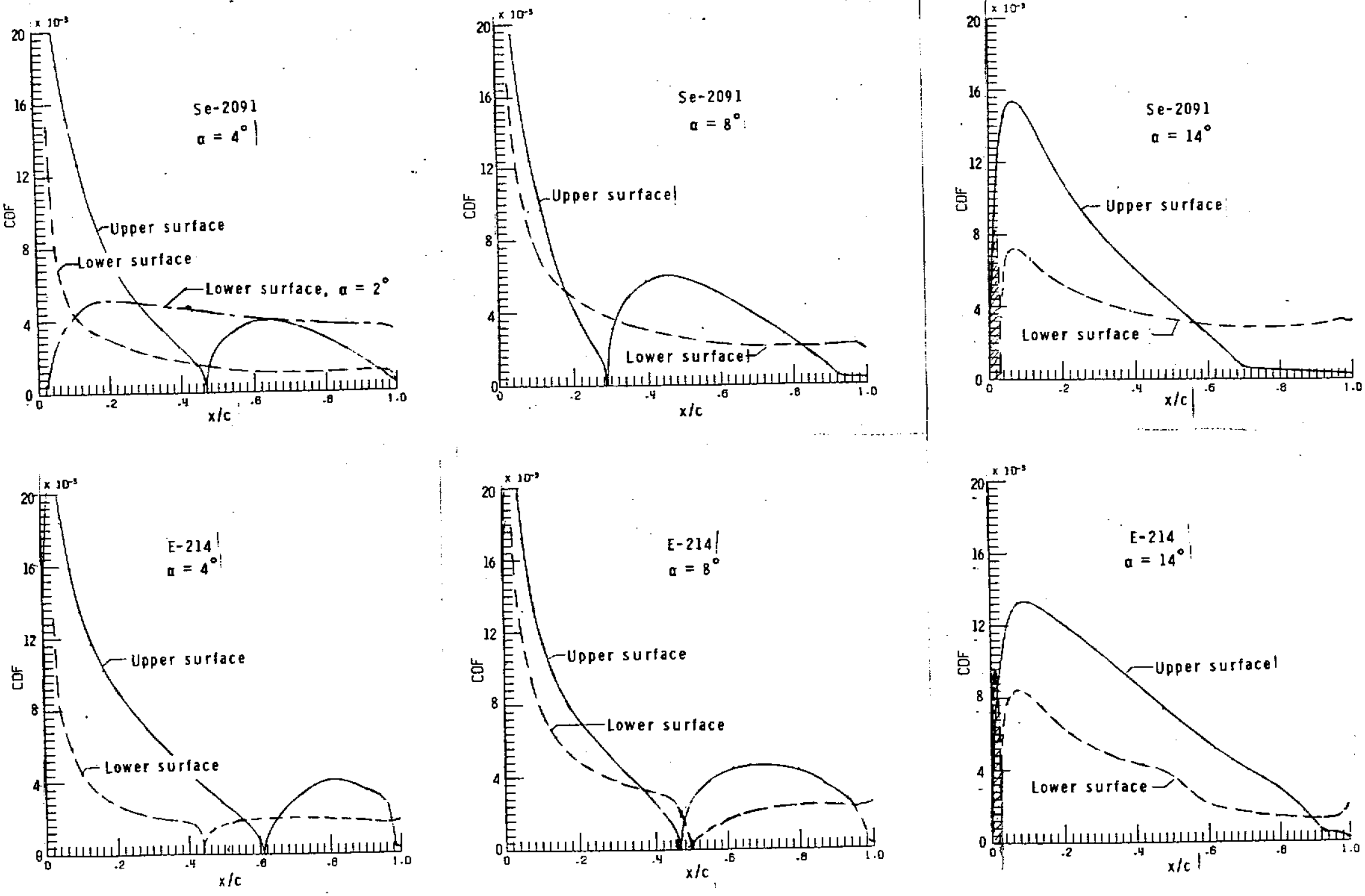


FIGURE NUMBER 6

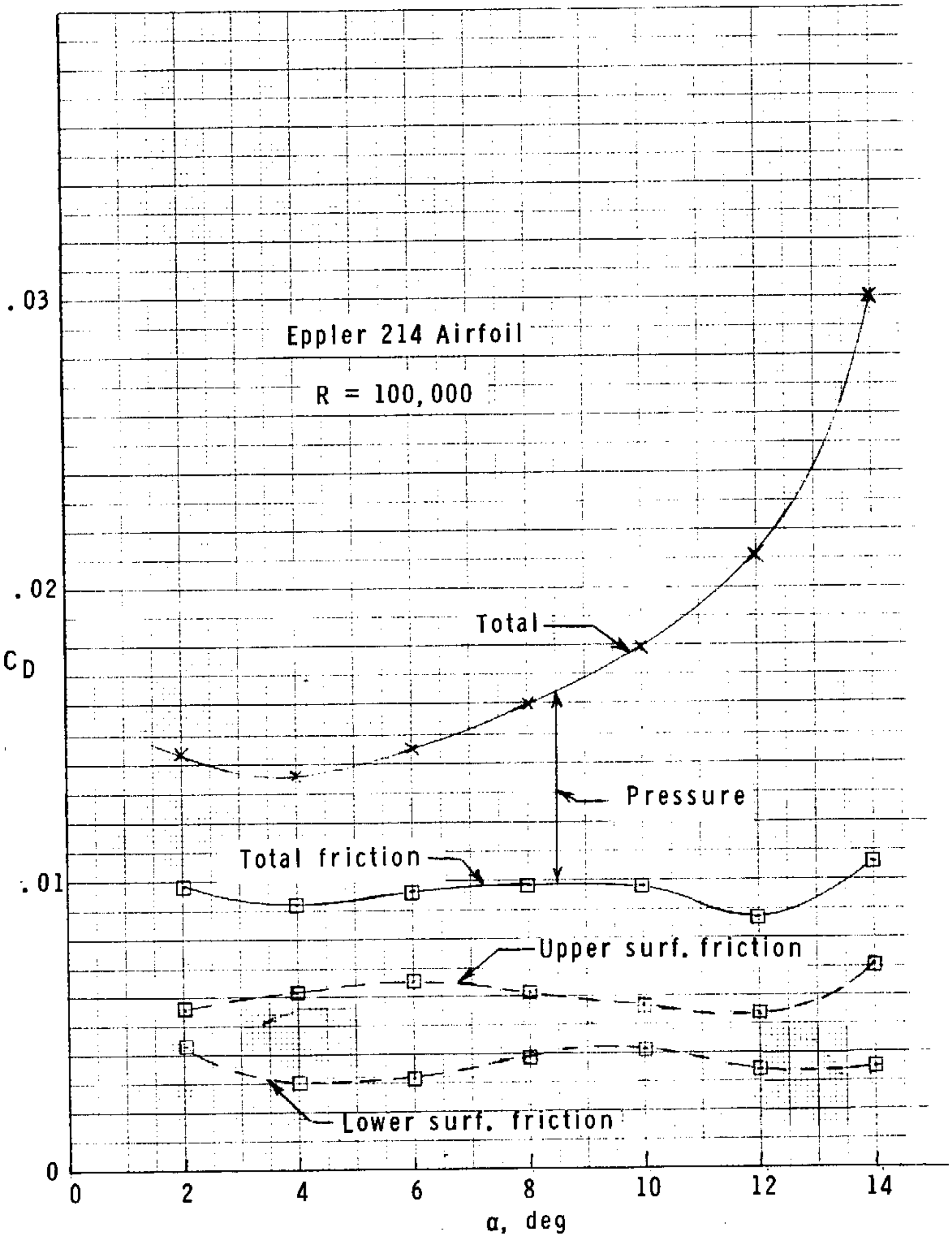
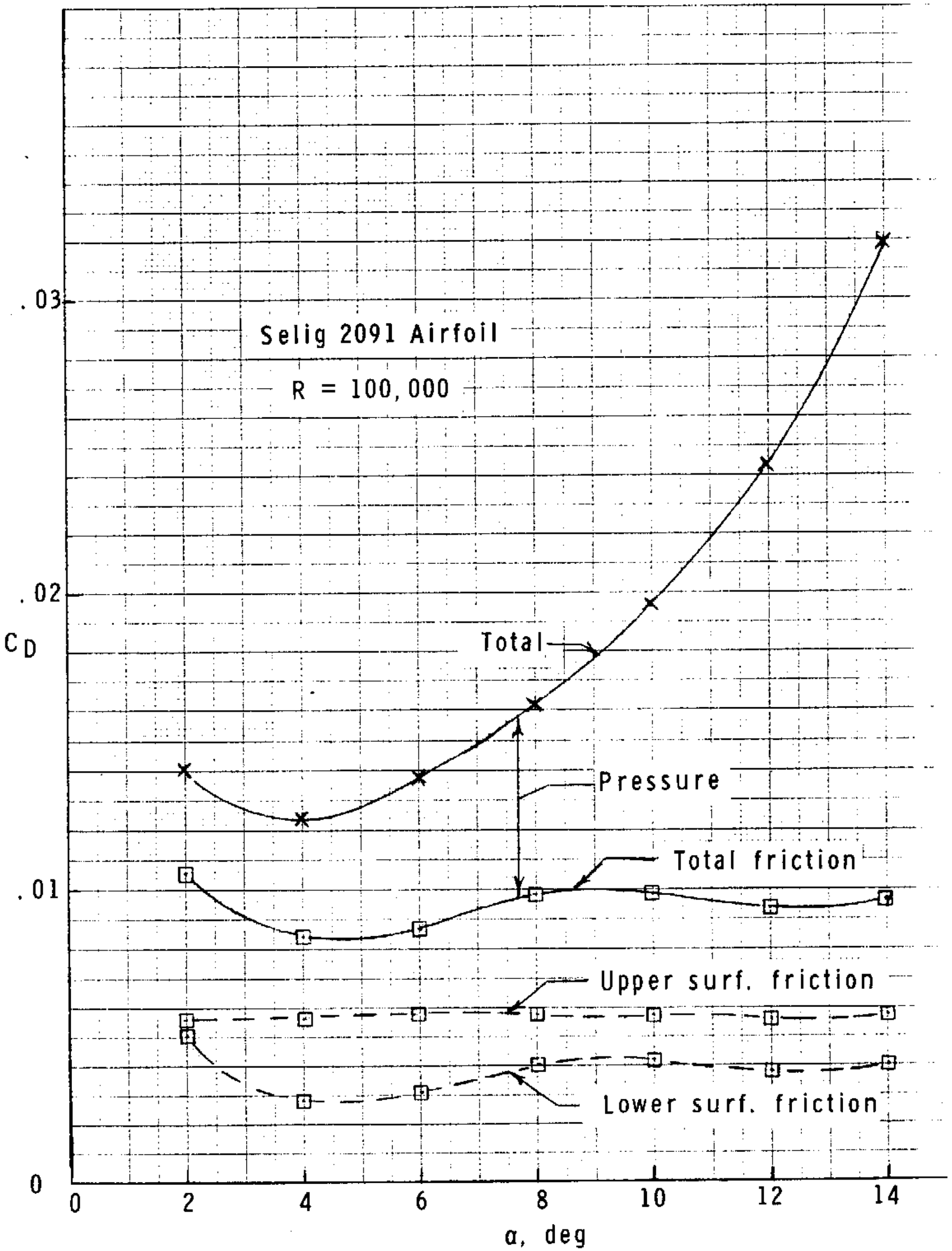


FIGURE NUMBER 7



ESTIMATING THE WEIGHT OF A NEW DESIGN

Professor W.M.J.Schlösser of the Technische Hogeschool Eindhoven in the Netherlands has done several interesting items for SOARTECH. In Soartech 5 he authored a valuable algorithm for estimating the weight of a new R.C. sailplane design. In that publication, I offered to publish a program to do the estimations if someone would develop it and send it to me. Here, Max Chernoff offers a BASIC program which performs the necessary functions and mathematical relationships which will allow the estimation of the weight for sailplanes which are still in the conceptual stage. It allows you to explore different structural methods for the new model and determine the range of practical weights that can be achieved with them.

If weight is important to your design concept, you´ll even be able to tell what structural concept will give you the best chance to finish the model within your weight target. Max says that this program isn´t elegant, but it gets the job done. He has added what he calls a "scale factor" which doesn´t appear in Prof. Schlösser´s paper. This allows you to adjust the Aspect ratio of the model. Prof. Schlösser´s algorithm established both aspect ratio and wing area automatically based on span. If you set the "scale factor" equal to one, the calculation will be as Prof Schlösser intended. By making it either loarger or smaller than one, the aspect ratio will change (as will the results). Max Chernoff´s address is 16506 Forest Lake Dr., Tampa, Fl. 33624.

```
10 REM PREDICTION OF WINGLOADING BY MAX CHERNOFF
20 INPUT "ENTER SPAN IN INCHES";SINCH
30 S=SINCH/39.37
32 LPRINT "-----------------------------------------"
40 LPRINT "SPAN= ";SINCH;" IN INCHES"
42 INPUT "ENTER SCALE FACTOR FOR AREA";SF
44 LPRINT "SCALE FACTOR FOR AREA = ";SF
50 A=.135*S^1.284
55 A=A*SF
60 LAM=7.41*S^.176/SF
62 AREA=A*39.37^2
64 LPRINT "WING AREA IN SQ. IN. =";AREA
66 LPRINT "ASPECT RATIO=";SINCH*SINCH/AREA
110 GVR=13.15*A^1.333
120 GVS=19.95*A^1.301
130 GSR=1.34*A^1.333
140 GSS=2.14*A^1.301
150 GRH=11.51*A^1.472/SF
160 GRK=13.77*A^1.393/SF
170 GBH=1.8+3.5*A
180 GBL=1!+2.2*A
190 INPUT "WING OF RIBS AND SPARS ? (Y OR N)";A$
200 IF A$="N" THEN GOTO 230
210 LPRINT "WING OF RIBS AND SPARS"
220 GV=GVR
225 GOTO 250
230 LPRINT "WING OF STYROFOAM CORE"
240 GV=GVS
250 INPUT "STAB OF RIBS AND SPARS ? (Y OR N)";A$
260 IF A$="N" THEN GOTO 300
270 LPRINT "STAB OF RIBS AND SPARS"
280 GS=GSR
290 GOTO 320
300 LPRINT "STAB OF STYROFOAM CORE"
310 GS=GSS
320 INPUT "FUSELAGE OF BUILTUP WOOD ? (Y OR N)";A$
330 IF A$="N" THEN GOTO 370
340 LPRINT "FUSELAGE OF BUILTUP WOOD"
350 GR=GRH
360 GOTO 390
370 LPRINT "FIBERGLASS FUSELAGE"
380 GR=GRK
390 INPUT "HEAVY RADIO CONTROL COMPONENTS ? (Y OR N)";A$
400 IF A$="N" THEN GOTO 440
410 LPRINT "HEAVY RADIO CONTROL SYSTEM"
420 GB=GBH
430 GOTO 460
440 LPRINT "LIGHT RADIO CONTROL SYSTEM"
450 GB=GBL
460 G=GV+GS+GR+GB
470 B=G/A
480 CONG=16!/4.44822
490 CONB=CONG*(.3048*.3048)
500 GT=GT*CONG
```

```
510 GK=GK*CONG
520 BT=BT*CONB
530 BK=BK*CONB
540 G=G*CONG
550 B=B*CONB
620 LPRINT "COMBINATION OF COMPONENT FUNCTIONS"
630 LPRINT "WEIGHT (OZ) = ";G
640  LPRINT "WINGLOADING (OZ/SQ.FT.) = ";B
650 INPUT "TRY ANOTHER ? (Y OR N)";A$
660 IF A$="Y" THEN GOTO 20
670 CLS
680 END
```

SAMPLE OF PROGRAM OUTPUT:

```
------------------------------------------------
SPAN=  120  IN INCHES
SCALE FACTOR FOR AREA =  1
WING AREA IN SQ. IN. = 875.2677
ASPECT RATIO= 16.45211
WING OF RIBS AND SPARS
STAB OF RIBS AND SPARS
FUSELAGE OF BUILTUP WOOD
LIGHT RADIO CONTROL SYSTEM
COMBINATION OF COMPONENT FUNCTIONS
WEIGHT (OZ) =  50.24822
WINGLOADING (OZ/SQ.FT.) =  8.266858
------------------------------------------------
SPAN=  120  IN INCHES
SCALE FACTOR FOR AREA =  1
WING AREA IN SQ. IN. = 875.2677
ASPECT RATIO= 16.45211
WING OF STYROFOAM CORE
STAB OF STYROFOAM CORE
FIBERGLASS FUSELAGE
HEAVY RADIO CONTROL SYSTEM
COMBINATION OF COMPONENT FUNCTIONS
WEIGHT (OZ) =  73.70403
WINGLOADING (OZ/SQ.FT.) =  12.12582
------------------------------------------------
SPAN=  120  IN INCHES
SCALE FACTOR FOR AREA =  .9
WING AREA IN SQ. IN. = 787.7409
ASPECT RATIO= 18.28012
WING OF STYROFOAM CORE
STAB OF STYROFOAM CORE
FIBERGLASS FUSELAGE
HEAVY RADIO CONTROL SYSTEM
COMBINATION OF COMPONENT FUNCTIONS
WEIGHT (OZ) =  67.24778
WINGLOADING (OZ/SQ.FT.) =  12.29293
```

NEW DEVELOPMENTS IN AIRFOIL PLOTTING

I´ve not been able to get over the incredible usefulness of Chuck Anderson´s home computer airfoil plotting program. Although his newest developments aren´t ready for general issue yet, they are very interesting,and I´d like to share them with you. Consider this a preview of coming attractions.

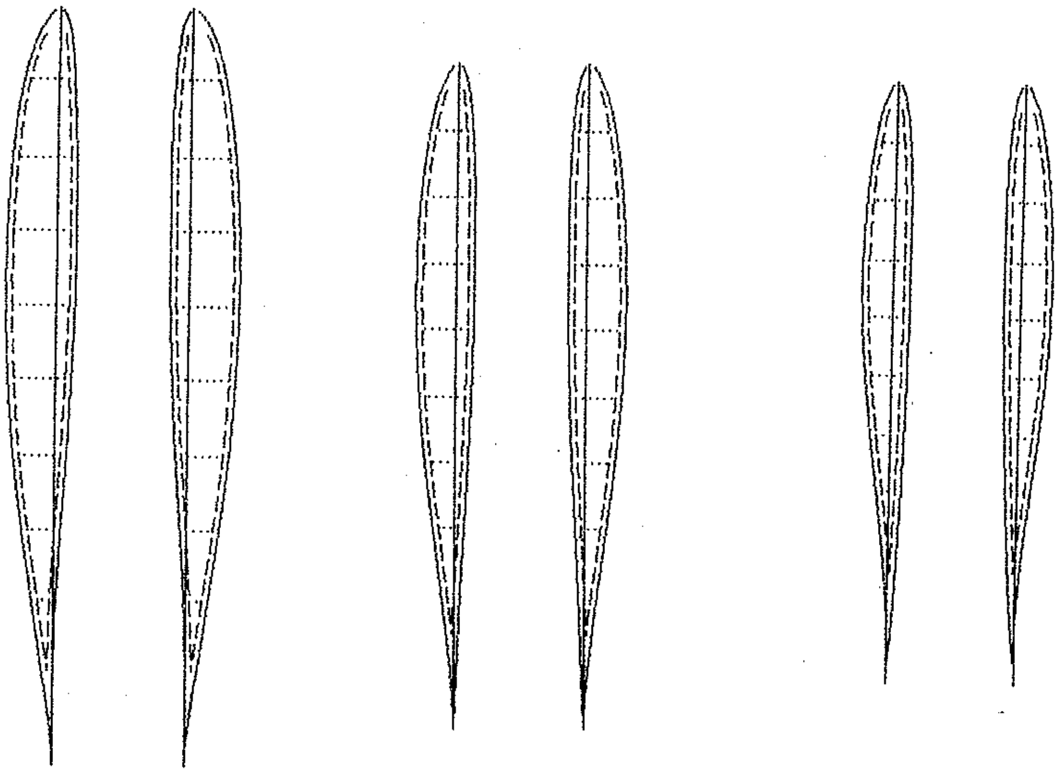
Chuck´s programs can be purchased at very low cost. They run on the Commodore 64, IBM PC/XT/AT and clones, and the Apple Macintosh; and many popular printers are supported. Be sure to tell Chuck which computer and printer you have if you contact him about the programs.

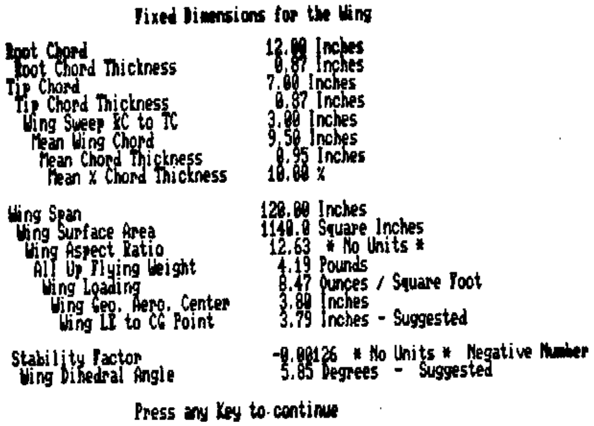
The original feature of his program was the ability to plot model wing ribs. The basic plotting program allows you to plot any of about 50 airfoils whose data are supplied with the program. You can plot any chord length (so long as the airfoil doesn´t get more than about 4 inches thick), plot any skin thickness, and put vertical bars on the plot at customer selected chord stations. (This is excellent for making foam cutting templates, or locating spars and leading & trailing edges.) The latest version of the program that I have also contains a utility program that allows you to convert any airfoil ordinates (even Eppler type), to the standard US type. It also allows you to create any Quabeck airfoil´s ordinates, any of a couple of types of NACA airfoil series, and it also allows you to combine the top surface of any airfoil with the bottom surface of any other. After exercising all of this creativity, you then use the plotting program to plot them.

So much for the program as it existed in the past. Now, there are some new developments on the horizon. The first is a new Mirror Plot Option in the program. This allows you to choose to plot two ribs of each size side by side at the same time. Very nice if you´re building a set of wings, you get a new template for each rib. The next new feature coming sometime in the future is the ability to plot a whole wing set of ribs. This program feature allows you to input the root chord, the tip chord, and the number of ribs you wish. It then patiently plots each intermediate rib at the proper length (with the mirror plot if desired). If you also want the airfoil to change from root to tip that too is an option. You could, for example, you could enter a wing with an Eppler 214 root section with a 12 inch chord, a tip with a 6 inch chord and a quabeck 2.5/9 airfoil, and 28 ribs with 1/16 sheeting thickness, and just sit back and watch them plot out. It´s interesting to watch the airfoil slowly transform from one to the other as the plot marches out the wing. If the wing has two sections of different taper, you would have to do that in two runs - no problem.

These features aren´t completely debugged at this writing, and I don´t know when Chuck will issue them, but because I´ve been helping with the programs, I can run all of these features now. In fact, Mark Kummerow wrote asking with help to build a 200 inch version of Gene Dees flying wing "Icarosaur". Using the modified version of Chuck´s program, I was able to plot 102 wing ribs (51 per side) for Mark which transformed from a 18 inch thickened Eppler 174 root to a symmetrical Quabeck tip of 10 inch chord. It took a while, but by running the program in a compiled form, the main limitation was printer speed. It´ll be fascinating to see Mark´s finished "Super Icarosaur". Look for it at the Toledo trade show in 87.

The final preview of Chuck´s program is it´s transformation to a complete wing design system (still in development). With this version, you will put in the various wing parameters I´ve mentioned, and then add to that the number and dimensions of the spars, and the dimensions of the leading and trailing edges that you´ll be using in the wing. This program will then plot all of the ribs for you with the skins, spars, and webbing all plotted in. When will these be ready? Write to Chuck and tell him how interested you are. His address again is PO Box 305, Tullahoma, Tn. 37388. It may be ready for the Commodore 64 now. The MSDOS and Macintosh versions will come later.





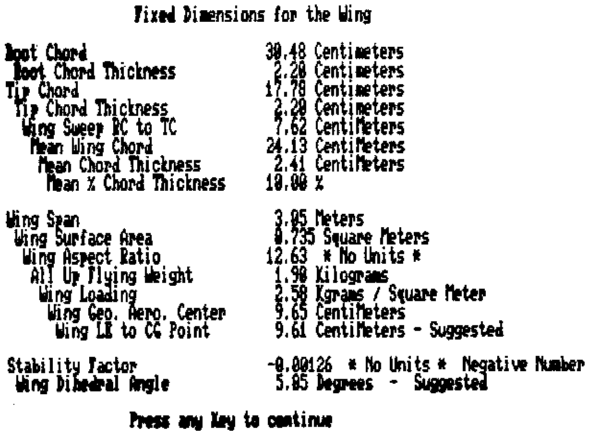
```
           Fixed Dimensions for the Wing

Root Chord                     12.00 Inches
 Root Chord Thickness           0.87 Inches
Tip Chord                       7.00 Inches
 Tip Chord Thickness            0.87 Inches
  Wing Sweep RC to TC           3.00 Inches
   Mean Wing Chord              9.50 Inches
    Mean Chord Thickness        0.95 Inches
     Mean % Chord Thickness    10.00 %

Wing Span                     120.00 Inches
 Wing Surface Area            1140.0 Square Inches
  Wing Aspect Ratio            12.63  * No Units *
   All Up Flying Weight         4.19 Pounds
    Wing Loading                8.47 Ounces / Square Foot
     Wing Geo. Aero. Center     3.80 Inches
      Wing LE to CG Point       3.79 Inches - Suggested

Stability Factor               -0.00126  * No Units *  Negative Number
 Wing Dihedral Angle            5.85 Degrees  -  Suggested

           Press any Key to continue
```



```
           Fixed Dimensions for the Wing

Root Chord                     30.48 Centimeters
 Root Chord Thickness           2.20 Centimeters
Tip Chord                      17.78 Centimeters
 Tip Chord Thickness            2.20 Centimeters
  Wing Sweep RC to TC           7.62 CentiMeters
   Mean Wing Chord             24.13 CentiMeters
    Mean Chord Thickness        2.41 CentiMeters
     Mean % Chord Thickness    10.00 %

Wing Span                       3.05 Meters
 Wing Surface Area              0.735 Square Meters
  Wing Aspect Ratio            12.63  * No Units *
   All Up Flying Weight         1.90 Kilograms
    Wing Loading                2.58 Kgrams / Square Meter
     Wing Geo. Aero. Center     9.65 CentiMeters
      Wing LE to CG Point       9.61 CentiMeters - Suggested

Stability Factor               -0.00126  * No Units *  Negative Number
 Wing Dihedral Angle            5.85 Degrees  -  Suggested

           Press any Key to continue
```

PERFORMANCE IN PASCAL

This paper by Ed Karns is very much self explanatory, so there's no need for an introduction. If you wish to get the program, (it runs on IBM or IBM clones) send to Ed for it, or send me a formatted 5 1/4 disk with a prestamped and addressed mailer and I'll make you a copy. If you should have Turbo Pascal running on some other kind of computer, let me know what the details are; there is some possibility I can get the source programs on your disk for you to recompile. Sorry I can't help with Apple or Commodore disks. This is a fascinating program with several startling features (such as the ability to instantly switch all dimensions and data between English and Metric units) and excellent screen displays (though it doesn't use graphics). You may contact Ed at the Departure Co., 16 Jess Ave., Petaluma, Ca. 94952.

```
Foil = Clark  Y        *    R# =    91345   V = 12.45 MPH    18.19  Feet/Sec
 CL    VX     VY     L/D  !  CL    VX    VY     L/D  !  CL    VX    VY    L/D
0.00 0.00   226.660.00     0.42 32.79  1.89  17.32    0.84 23.19  1.26  18.43
0.02 132.50 57.21 2.32     0.44 32.03  1.83  17.46    0.86 22.92  1.26  18.22
0.04 101.80 25.38 4.01     0.46 31.33  1.76  17.76    0.88 22.66  1.26  18.01
0.06 84.88  15.40 5.51     0.48 30.68  1.70  18.03    0.90 22.40  1.26  17.81
0.08 74.15  10.73 6.91     0.50 30.06  1.64  18.28    0.92 22.15  1.26  17.60
0.10 66.63  8.09  8.23     0.52 29.48  1.59  18.50    0.94 21.92  1.26  17.40
0.12 60.99  6.42  9.50     0.54 28.93  1.55  18.69    0.96 21.69  1.26  17.21
0.14 56.57  5.21  10.87    0.56 28.41  1.51  18.86    0.98 21.46  1.26  16.98
0.16 52.99  4.34  12.22    0.58 27.91  1.47  19.00    1.00 21.24  1.27  16.76
0.18 50.00  3.69  13.56    0.60 27.44  1.44  19.12    1.02 21.03  1.27  16.54
0.20 47.47  3.19  14.89    0.62 27.00  1.40  19.22    1.04 20.83  1.28  16.33
0.22 45.29  2.79  16.21    0.64 26.57  1.38  19.31    1.06 20.63  1.28  16.13
0.24 43.38  2.48  17.51    0.66 26.17  1.36  19.27    1.08 20.44  1.28  15.92
0.26 41.69  2.22  18.79    0.68 25.78  1.34  19.23    1.10 20.25  1.29  15.73
0.28 40.18  2.00  20.05    0.70 25.41  1.33  19.17    1.12 20.06  1.31  15.28
0.30 38.77  2.45  15.79    0.72 25.05  1.31  19.11    1.14 19.88  1.34  14.86
0.32 37.55  2.32  16.15    0.74 24.71  1.30  19.03    1.16 19.70  1.41  14.01
0.34 36.43  2.21  16.46    0.76 24.38  1.29  18.94    1.18 19.53  1.41  13.86
0.36 35.41  2.12  16.73    0.78 24.07  1.28  18.85    1.20 19.36  1.47  13.18
0.38 34.47  2.03  16.97    0.80 23.77  1.27  18.75    1.22 18.21  5.13  3.55
0.40 33.60  1.96  17.16    0.82 23.47  1.26  18.65    1.24*16.32**7.93**2.06
  Press any Key to continue              Wing Drag C  0.602        90.1 %
```

A Design Analysis Computer Program for Small Airframes in Pascal

By Ed Karns August 1986 Revised December 1986

The computer program described below will work for any small airframe, powered scale, control line, what have you, not just R/C gliders.

About three years ago my good friend Rolf suggested I take a look at his recently acquired copy of SoarTech #2. I had no idea such a fascinating publication existed. Here under one cover were articles about some of my favorite pass times, building and flying R/C gliders and playing with computer programs. Of greatest interest was Armin Saxer´s article on using the Hewlett Packard HP-41 calculator to run quite elaborate routines to optimize an airframe design. Since we are both familiar with programming and micro computers, the challenge appeared to be to convert Mr. Saxer´s program (at least in part) over to the more popular micro machines. The advantages would be obvious, faster execution speed, increased storage space for data, added features, better information display, etc., etc.

WHICH LANGUAGE ?

Well, Rolf favored BASIC in a big way and I was ready to go along because it was currently the most popular computer language. However, we decided to write down all the things we wanted our program to do and try to fit the language to the problem at hand rather than be prejudicial about it. The list ran into many pages of possibilities and it became evident that either Pascal or C (because of their superior file handling ability, easier readability, structurability (!) and modularity) would be "quite the better choice for the chore". Since neither of us wanted C (its a cludge language) for just this one project. That left Pascal. After we began writing the first version of the program we were introduced to Turbo Pascal (from Borland International) and were smitten with its speed and the quality of its editor. Later we were happy to discover we were not the only ones to favor Turbo for a given job. According to recent estimates more than 500,000 copies of Turbo are floating around and it is giving BASIC (all makes and models) a run for the title, most popular. Since Turbo Pascal is compatible with many other versions of Pascal, the source code generated for it can be transferred to well over 70% of the world´s computers ! This leaves HP-41 language in the dust and shows that, at least for now, we have made a good choice. Time will tell if it is the best choice.

THE FIRST VERSION

The thrust of Mr. Saxer´s program is to take airfoil data and the rough dimensions of a given design and have the HP calculator repeatedly try minor variations on the dimensions until an optimum set for a given criteria is found. At first blush this would seem like the proper approach and it may yet prove to be a good procedure to add to a future version of our program. However, as the code began to build we discovered a problem. Because of the recursive nature of the optimizing algorythm (it calls its own procedures from within those same procedures) and memory intensive code, among other things, this first attempt left virtually no room for all the other features we wanted in the final program. In addition, neither we, nor anybody we knew, wanted to build a computer generated design that fulfilled just one, single criteria. We all wanted designs that were multifunction, we wanted the designs to soar and speed and have nice stalls and easy landing characteristics, etc. We are not knocking optimizing algorythms (logic + outline + intent + ? = algorythm). Optimizing can be incredibly valuable. But who would want to build and fly a bullet with tiny, stubby wings in a slope race, even though the computer reports that this design is best for speed. The computer doesn´t care that the design can´t make the turns and requires a gale force wind for lift. To compute properly the kind of compromise decisions required to optimize for, say, the slope race glider problem, actually border on the limits of mankind´s most exotic computers in combination with some future algorythm set into an artificial intelligence language (able to learn from its mistakes) rather than the equipment available to the independent modeler or engineer. It may be that some day a future version of this very program running on a "glorioski" future computer will answer the optimum slope racer problem.

After some soul searching and discussion we grudgingly agreed to scrap the first attempt and build a more original program using as many of Mr. Saxer´s good ideas as we could. Although an airframe designer may use our program to repeatedly compare different variations against the known performance of an existing design, the real world calls for a compromise of designs rather than striving for the construction of a computer generated optimum. Sorry fellows, this just goes to show that this is still more black art and white magic than exact science. Then again, I know many who will actually be relieved and happy to hear this. We have left the door open for others to extend this program toward the ideal (including optimizing) and maybe some day we will reach that goal (see below).

We were able to build a program that calculated surface areas, aspect ratios and wing loadings, flight speeds and even gave many valuable hints for design improvements. It had a separate editor program that built tables of airfoil data used in producing a pretty nifty flight simulation report. Rolf and I were quite proud of our work and let it stand at that. We were happy with it, it worked, it helped us both to better understand what made glue and balsa "fly so good".

Then a new version of the Turbo Pascal compiler came out. This served as stimuli to review the program and see about improvements. We both realized there were lots of features we wanted to add to the older version, so, once more into the breach.

ONWARD AND UPWARD

In this, the new, improved version we have been able to include the airfoil editor into the main program. While we were at it, we added a menu shell so that all the program options could be easily reviewed and selected. We also added features that make valid building suggestions about dihedral angles, etc. and reported bubble separation and stall points in the simulation, etc. Many of these new features are from suggestions made by other programs appearing in articles in both Soar Tech #1 & #2 by Armin Saxer, Chuck Anderson, the Schlössers, and Martin Simons.

Rather than try to write an instruction manual or operations guide, we have found that most operators of the program will learn how to run it by treating the program as a puzzle to be worked out, rather than a chore to be learned. With this in mind, below is an overview and brief description of the simulation report screen. Otherwise, the new comer will be left to his/her own devices with respect to program operation. Bear in mind that the program is not "bullet proof" and inappropriate entries (like entering a letter where a number is expected) will make it "bomb".

THE PROGRAM IN USE

The main menu selections include :

- changing airfoils for simulation with a given airframe.
- adding or editing the airfoil data for up to 45 airfoils.
- changing wing span and chord(s) and more.
- changing tail plane dimensions, both vertical and horizontal.
- changing air temperature and pressure, and converting metric to British units (& vise versa).
- changing all the dimensions back to the defaults (an F3B ship)

The display selections include reports of wing and tail area and loading, aspect ratios, suggested dihedral angles used in the flight simulation. The fixed dimension results are all recalculated each time any dimension is changed. A hard copy report has been added and it fills two pages completely, including the simulation.

THE FLIGHT SIMULATION

The program begins with a given R/C glider airframe, an F3B class ship, 2.74 meter span, with a reasonable, 1.9 kilo weight (mass), mid position wing and standard tail configuration. The operator can change wing and tail plane shapes (span, chord, sweep, airfoil thickness, etc.) and review the different flight speed and stall reports. He/she can modify the flying environment (temp. and pressure) to the extreme (Death Valley, Mount Everest, Jupiter, Venus ??). Some operators have gotten some real entertainment from playing with the extreme variations as well as enlightenment about a particular real world design.

The flight simulation will report the full range of Lift versus Drag ratios (L/D), coefficients of Drag (CD), Reynolds Numbers and horizontal and vertical velocities for a range of coefficients of Lift (CL) from 0.0 to 1.28 for just the wing or for the whole airframe. When the calculated results begin to reach erroneous conclusions, the stall point appears. This can happen with certain airfoils of undersized wings or overweight airframes at unexpectedly high air speeds. Stalls in high speed turns can be simulated by simply increasing the weight (mass). For a four G turn, quadruple the weight (mass). Observe the changing stall point.

The flight simulation report is a built-up table of numbers beginning at maximum speed, maximum Reynolds number, 0.0 horizontal speed, your basic vertical dive to terminal velocity (coefficient of lift, CL = 0.0). (The program makes more than 45 calculations for each report set, or over 3000 program calculation steps in a complete simulation !) The very first report set of numbers may not be quite correct, depending. Since all these calculations have to have a starting point, some beginning information is given that may not be a true reflection of reality for the design under consideration. The second set of calculated results (at CL = 0.02) is much closer to the truth because the computer has had a chance to run through the first round of calculations using closer-to-valid airfoil data points rather than start-up-given program data points. The same applies to the very last generated set of results. This time, the computer is forced to stop its calculations with invalid information (CD = 1.000). This is acceptable for most cases as very few designs will try to fly at CL´s as high as 1.30 (a high angle of attack), most will stall long before this point is reached.

As each set of results is calculated, the values for Reynolds number, speed, drag coefficient (either for the wing or total drag) are updated. As CL increases, CD can increase or stabilize or even decrease (as it does at bubble separation). The program "remembers" previous values for CD, as well as vertical and horizontal velocity and L/D, and compares the latest values. If there is a change in increase or decrease, the value´s display intensity is changed (from bright to dim or vise versa). It is these "phase" changes that are reported by the changes in display intensity. A quick comparison also looks for out-of-bounds values (like dramatic changes in the L/D) and signals a stall. Those with PClones and some other computers can use control S to interrupt the display output and examine the changing values.

It is not important to understand how the program goes about its business, but it is kind of neat (and, maybe, useful) to observe those "phase" transitions. For those with the programmers yen, the source code is usually included on the distribution disk along with another program that will make a fresh, clean airfoil data file. Warning : DO NOT run this file (re)creation program unless you want to loose all the stuff in the original airfoil file ! It will be overwritten.

WHAT WE WANT TO DO NEXT

About Christmas of ´84 we discussed the possibility of actually marketing the program commercially. Well, simply put, we concluded that there are just not enough modeler/engineers with computers/money to warrant the advertising-expense/support-grief, let alone produce a profit. What to do with this reasonably valuable program (?) Answer = give it away ! About this time the idea of shareware and freeware began to prove itself as a way to make valuable software available at reasonable cost. We wanted to go one step further with the freeware idea.

We do not think the program has reached its full potential. We think that other programmers, modelers and/or engineers will use the program and discover that they wish it had an added feature or three. Well, we want this feedback to change the program. We would like to see the program become somewhat "organic" and grow in size and power and become more and more useful. So, here is how it maybe should work.

1) Feel free to pass copies of the program around to friends and at club meetings. The wider the dispersion, the better. If you run across an older version of the program, replace it with the latest available. (Be careful NOT to erase or replace someone´s data file, AIRFOIL.DAT).

2) If you discover an interesting way in which computers can be used to improve airframe design, no matter how complex or esoteric, or simple for that matter, send it to us or let us know about it and we will try to make it a part of a future version of the program. Suggestions received so far include adding graphics (we´re working on it), working with and calculating CL/CD data graphs for custom airfoils (maybe, some day) and others.

3) If you can write in Pascal (or any other computer language) and can produce working source code that will fit into the program, send it to us and we will try to add it to a future version so that all can benefit. Source code in some other languages may end up being converted to Pascal. Herk Stokely found a couple of bugs in an earlier version and we promptly corrected them. He also suggested the wing only / total airframe option which we have added. We have been trying to get him to add some of his own touches of code as well.

4) If you suspect that your current version is out of date, find a way to update it. We have recently learned that there is an older version of the program on CompuServe, in the Model Builder´s SIG section. By the time you read this it will (hopefully) be updated. If you find that the program is useful, meaningful and valuable and wish to see the idea furthered, then send us $10.00 and we will send the very latest version on disk along with all the most current documentation.

Once again, the idea is to have the program expand over the years, a joint effort of many modelers and engineers, so that it may one day give us the kind of advice that will help produce some fantastic and fascinating future small airframes. Who knows where it will lead us.

Lots of Lift

LONGITUDINAL STABILITY

With all of the data on stability in this issue, I thought it might be interesting to end with this simple little paper on the calculation of longitudinal stability. Ernie Currington has sent me several cameo gems which I'll pass along in upcoming issues of Soartech. Correspond with Ernie at 12 Caribou Crescent, Kirkland, Quebec H9J 2H8, Canada.

CALCULATION OF THE NEUTRAL POINT (N_o) FOR R/C SAILPLANES

GENERAL. ANALYSIS OF THE SOURCES LISTED BELOW HAS LED TO THE FOLLOWING FIRST ORDER METHOD FOR CALCULATING N_o

METHOD

$$N_o = \left[.36 - .11\lambda \right] - \left[\frac{3.333\, N_F B_F^2}{S_\omega \bar{\bar{C}}} \right] + \left[.32 + \frac{AR}{55} \right] K_T \bar{V}_H$$

WHERE
N_o = NEUTRAL POINT / $\bar{\bar{C}}$
$\bar{\bar{C}}$ = MEAN AERODYNAMIC CHORD - IN
λ = EQUIVALENT STRAIGHT TAPER RATIO
N_F = DISTANCE - NOSE TO $.25\bar{\bar{C}}$ - IN
B_F = MAX FUSE WIDTH - IN
S_ω = WING AREA - IN^2
AR = WING ASPECT RATIO
$\bar{V}_H$ = HORIZONTAL TAIL VOL COEFF' $= \frac{S_H}{S_\omega} \cdot \frac{L_T}{\bar{\bar{C}}}$
S_H = HORIZONTAL TAIL AREA - IN^2
L_T = $.25\,\bar{\bar{C}}_{WING}$ TO $.25\,\bar{\bar{C}}_{H.TAIL}$ - IN
L_F = FUSE LENGTH - IN
K_T = TAIL 'EFFICIENCY
= .9 TEE-TAIL, .85 MID TAIL, .8 LOW TAIL

LIMITATIONS

λ BETWEEN .5 & 1.0
AR BETWEEN 10 & 15
L_F/B_F GREATER THAN 16

EXAMPLE	DEKKER 1983	FLAMINGO (J. BEDFORD)	SAGITTA XC (J. BEDFORD)
N_o	.415	.461	.425
$CG/\bar{\bar{C}}$	.300	.350	.310
∴ STATIC MARGIN	.115	.111	.115

2/2

SOURCES

- THANKS TO
  - ALAN STANDING (AERODYNAMICS - CANADAIR) FOR COMMENTS
  - JOE BEDFORD FOR PLANS & LETTING ME MEASURE HIS AIRPLANE
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- CALCULATION OF M.A.C & POSITION - CURRINGTON 1985
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- COLLEGE NOTES

E. G. CURRINGTON