VOLUME I
PERFORMANCE FLIGHT TESTING PHASE

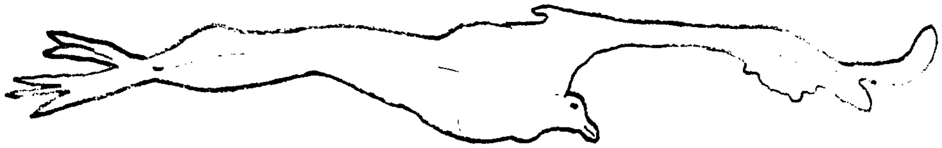
CHAPTER 4
HIGH L/D

JANUARY 1992

USAF TEST PILOT SCHOOL
EDWARDS AIR FORCE BASE, CALIFORNIA

FORWARD

This set of notes was prepared to supplement the lectures in the Introductory Soaring Course at the USAF Test Pilot School. We feel that the new soaring pilot needs a brief look at the long colorful history of soaring in order to appreciate the design refinements and proven techniques that have made soaring the essence of flight. The TPS student is well versed in both aerodynamic theory and flight test techniques. For this reason, a short chapter on the aerodynamics of sailplane performance was included without a more fundamental development of the theory of flight. A brief guide to sailplane operations was written to condense the techniques and procedures of a soaring flight into a convenient reference source. We hope that this text will kindle in the student a genuine interest in soaring, and provide him with a sound base for experiencing this challenging and rewarding endeavor.



PAUL D. TACKABURY
Major USAF

USAF TEST PILOT SCHOOL
Edwards AFB California
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REVISED BY:

JAMES M. PAYNE
Major USAF

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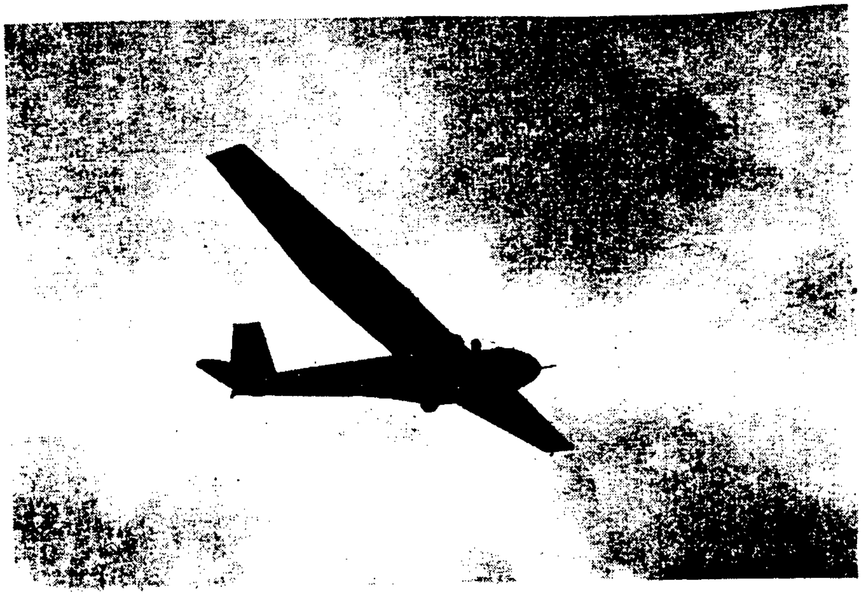


Schweizer 2-33

CHAPTER 1

INTRODUCTION

In 1967, the USAF Test Pilot School inaugurated an introductory soaring program which provided each student with about three hours of sailplane flying. The program was conceived to expose student test pilots and flight test engineers to an additional type of aircraft with flying characteristics unlike any other in the school curriculum. TPS students are regularly flying aircraft whose lift-to-drag ratios (L/D) vary respectively from 2.2:1 (T-38 Low L/D) to 11:1 (A-37). The soaring program completes the higher end of this spectrum with aircraft having an L/D of 36:1 (Grob 103).

The soaring program lends itself effectively to the investigation of nonsteady state stability and control flight testing techniques. This type of testing is presently applied to the T-38 when it is configured to simulate a power limited or powerless aerospace vehicle. Since the motive power of a sailplane is derived solely from gravity, this nonsteady state test method is the only way of determining the stability and control characteristics.

The lifting body and space shuttle concepts dictate a gliding, power-off approach and landing pattern. Consequently, NASA initiated a mandatory soaring program for their lifting body test pilots. Experience gained in the TPS soaring program is likewise expected to benefit and better prepare the school graduate for such a test program. It also is a valuable background for operations where flame-out patterns may be required.

The meteorological state of the atmosphere plays a significant role in soaring flight. The conditions that exist to produce lift are of vital interest to the soaring pilot. Consequently, one of the benefits to be realized from a soaring program is an increased awareness and appreciation of the meteorology of flight.

In summary, the objectives of the soaring program are threefold:

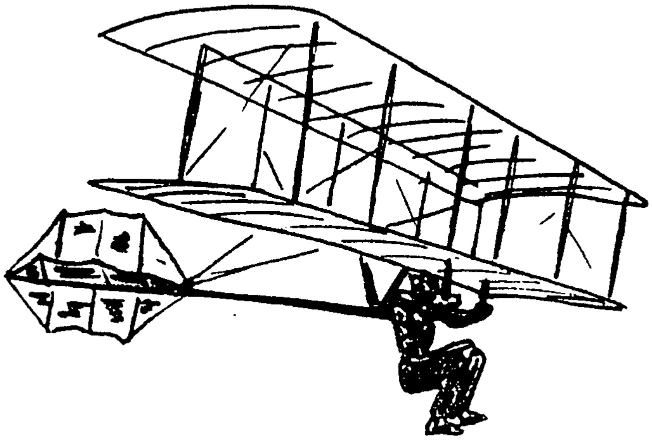
a. To introduce TPS pilots to the realm of powerless flight.

b. To allow the TPS pilot to qualitatively evaluate the performance and stability characteristics of a high L/D aircraft in low subsonic flight under nonsteady state flight conditions.

c. To better prepare the TPS pilot for present and future test programs.

Chapters 2, 3, and 4 have been written to give the student a familiarity with sailplanes, their role in aviation, and their performance and operation. Techniques for flight testing sailplanes have been purposefully omitted since the student is expected to have already learned the basic flight testing techniques. The student is encouraged, however, to extend his knowledge of flight testing to include determining the polar and penetration speed for a sailplane.

CHAPTER 2



HISTORICAL BACKGROUND

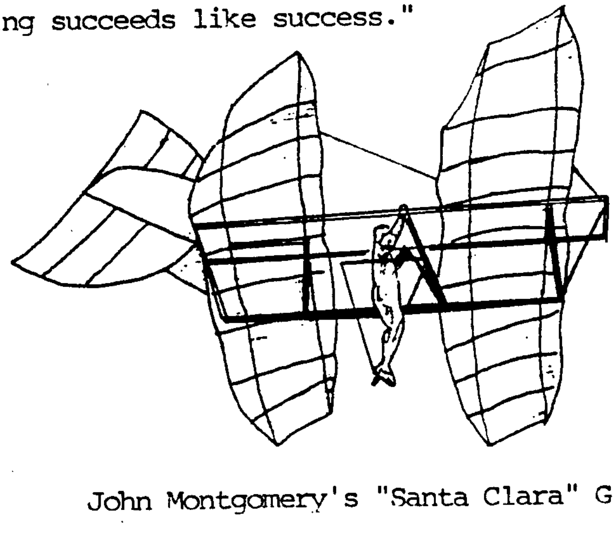
The glider is not a newcomer to aviation--rather it was the cradle of aviation. Men have always had the birds above them as a challenge to fly, in case man couldn't have thought of it without some hints. But, most of the early attempts to fly on bird wings involved flapping them--a terribly inefficient process that was doomed to failure. But, most frustrating of all nature's challenges was the sight of the great soaring birds flying effortlessly without even flapping their wings. So having failed to fly by flapping, and perplexed over the apparent defying of gravity by the soaring birds, man would go back to walking for another hundred years and leave flight to the birds.

For three thousand years, the Chinese have flown kites. But it wasn't until Sir George Cayley (our friend who found that the "hinder part" of a spindle was as much responsible for drag as was the forepart) that it was discovered that a kite could be stabilized in flight without a string if it were properly balanced and fitted with an empennage.

Caley's 1804 Sketch of a Model Glider

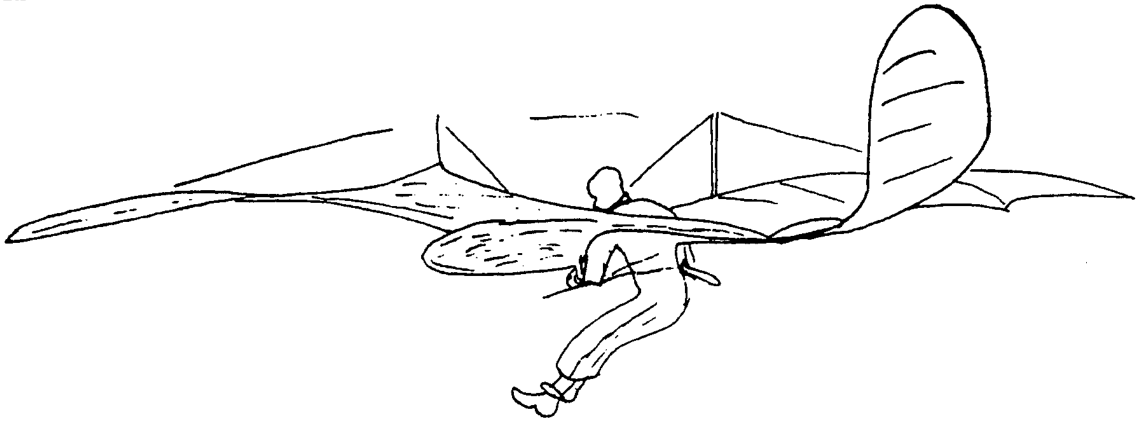
Sir George Cayley said that "if pointed downward in an angle of about 18°, it would proceed uniformly in a right line forever with a velocity of 15 feet per second." By 1850, he was building full sized aircraft, one which carried a boy. Three years later, he built one which has an additional set of wings which could be flapped with oars to regain the height lost in gliding. He called it waftage. But he had a lot yet to learn, and his test pilot bashed it on the first and last flight.

In America between 1880 and 1890, a Californian named John Montgomery set himself to the "adaptation of man to the flight of soaring birds." His wings were the first built with spars and ribs, instead of copying the flimsy structure of bird wings. For control, he put on tail surfaces which included a rudder and elevator. After a few low leaps with his glider, Montgomery was launched from the top of a hill facing an 18 knot sea breeze. The glider was meant to fly--and it did, for 200 yards out in front of the hill. That was in 1884. The great value of his efforts was simply that he had succeeded in flying. "Nothing succeeds like success."



John Montgomery's "Santa Clara" Glider

Then came Otto Lilienthal who investigated wing section and camber, center of pressure movements over the wing, and stability. By 1891, he was gliding down the hills around Berlin on his first wings. His apparatus was called a "hang glider," because the pilot literally put the wings on his shoulders and hung below them while he flew.* Here's an illustration of his monoplane glider.



Lilienthal's Monoplane Hang Glider

Before his death in the crash of his last glider, Lilienthal had logged nearly 2000 flights! A reporter wrote of one of these.

> I have seen innumerable photographs showing Lilienthal in the air, but I had no idea of the perfection to which he had brought his invention. Of everything that I have seen, there is nothing which could make such an impression on the nerves or excite so much admiration and enthusiasm as the terrible and audacious skill of Lilienthal in midair. The sight of a man supported by great white wing, and moving at a great height above you with the speed of a race horse, while the wind produces a peculiar drumming in the bracing cords, makes an unforgettable impression.

Just before the turn of the century, Octave Chanute picked up where Lilienthal left off, realizing that the one difficulty remaining was stability and control. Chanute was an engineer, and through his research, paved the way for the Wright Brothers.

The Wrights tested every theory they could find, and rejected most as unsound. Then in 1900, they built their first glider, designed to fly at 21 mph. At the recommendation of the US Weather Bureau, they set out for

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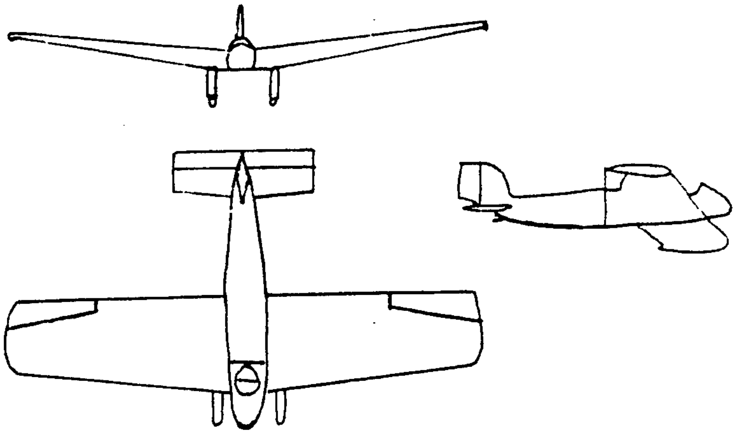
*Hmmm--Sounds familiar doesn't it?

Kitty Hawk, NC to find the wind conditions they had designed for. The glider worked, but only in near gale strength winds for lack of sufficient wing area. The following year, the Wrights returned with a new glider with nearly twice the wing area. It flew slightly better—but disappointed them greatly. With the encouragement of Octave Chanute, they built a third glider with an aspect ratio of 6:1 (AR for the Grob 103 is 17:1!) and flew it in the summer of 1902. With this highly successful glider, they flew over a thousand flights--some in winds over 36 mph! One observer said, "All she needs is a coat of feathers to maker her light, and she'll stay in the air indefinitely."

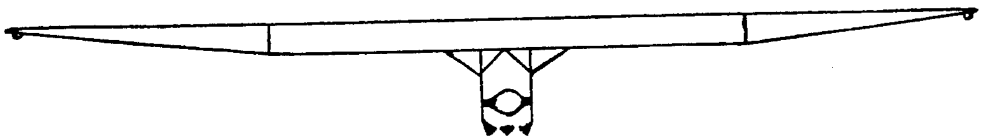
By 1903, the Wrights felt they had learned enough to add an engine, and the airplane was born. The glider all but dropped from history.

Gliding as a sport was born in Germany about 1909 with school boys flying copies of Lilienthal's hang gliders in the Rhon Mountains on the slopes of the Wasserkuppe. Flights of 1000 yards were made in the next few years, just before the First World War. The war ended these gliding experiments, and it was not until 1920 that a group of enthusiasts met again at the Wasserkukppe to build a second generation of hang gliders and compete for distance. By 1920, it was inevitable that the glider would have to look more like the airplanes of the day. And sure enough, a young German engineer named Wolfgang Klemperer brought a modern looking monoplane glider (the Black Devil) to the Wasserkuppe. His first flight lasted 2 1/2 minutes and carried him over a mile.



Blue Mouse

The following year (1921), Klemperer flew his next glider, the "Blue Mouse" for 13 1/2 minutes. But this time he had a rival--an engineer named Arthur Martens who designed what became the prototype of the modern sailplane. He called it the "vampyr"--a rather appropriate name when you see it.

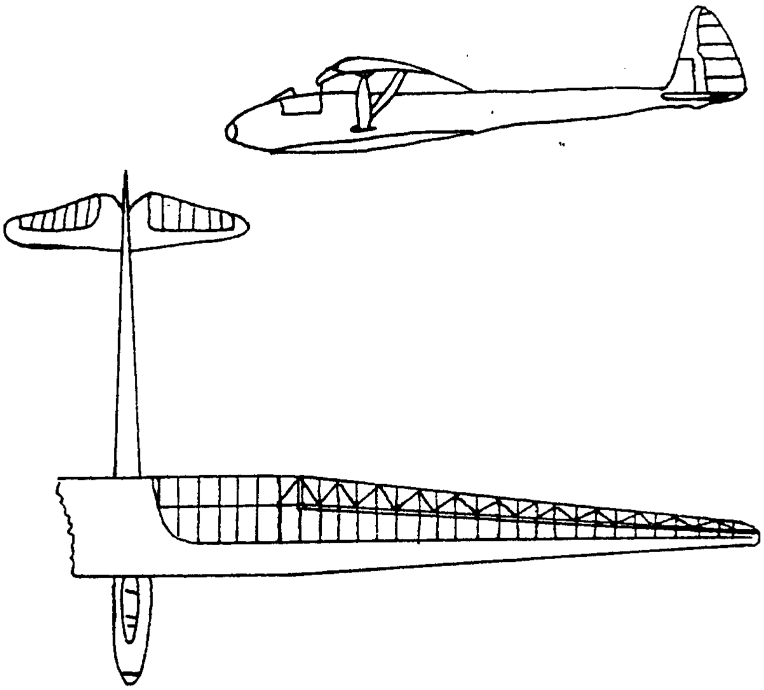


Arthur Martens' "Vampyr"

Martens stayed up for 15 1/2 minutes to capture the world record. But all of these flights were just long glides down into a broad valley. With gliders weighing 200 pounds empty, you can imagine the effort involved in getting one back up to the launch point. Then something happened that changed everything. One of these fliers found that he could soar on the vertical component of wind blowing over the ridges at Hildenstein, landing close to where he was launched for a world's record.

In 1922, Martens flew the Vampyr in ridge lift for over an hour. Within a week, the endurance record was over 3 hours. The endurance record was then pushed up to 14 hours by another German who soared just above the tops of dunes along the sea coast. Ridge soaring for records was beginning to look a lot like flag pole sitting, and the appeal of gliding diminished. There seemed little future for the sport by 1925. The glider was still chained to the hills.

In 1926, another great breakthrough came--a German glider pilot named Max Kegel was slope soaring on the Wasserkuppe when a summer thunderstorm caught him up into its core and dumped him out higher than anyone had ever been before in a glider. He seized the opportunity to set out cross country for a landing 30 miles away. The lesson was learned--there's enough lift in convective air currents to carry a sailplane away from the ridges and up to significant heights. This was the great secret of the soaring birds. In 1928, Robert Kronfeld introduced the technique of circling to stay in thermals--again at the Wasserkuppe. Suddenly, the doors of the world were opened! Glider pilots began gaining 5000 - 6000 feet in strong thermals, then flying from thermal to thermal for cross country records. To get the most out of thermals, Kronfeld had a new glider built in 1929--a beautiful machine even by today's standards.



Kronfeld's "Wien"

With it, he climbed around a towering cumulo nimbus cloud to 10,000 feet, and set off downwind for a world distance record of 85 miles. Gliding had gotten its second wind.

Up until about 1930, gliders had been launched by using a winch or frequently a bungee cord.

Now another great thing happened to gliding--the airplane tow or aero tow. This meant that instead of being launched at just barely traffic pattern altitude, the glider pilot could climb behind the tow plane as high as he wished. Experienced tow pilots proved able to put the glider in good strong thermals consistently.

By 1931, competition swung from duration to distance. Prizes were no longer awarded for duration flights. Distance flying was the thing. Thermals lasted only during the hours of sunshine and then diminished at night. So, there was a practical limit to the time available for covering ground. Glider design shifted from very low cruise speeds to much higher design speeds permitting more miles to be covered while the thermals lasted. By 1935, the distance record stood at 314 miles. The pendulum had swung far the other way. In competition flying, the gliders could not be retrieved from such great distance before the start of the next day's activities, and this created problems which were partly solved by requiring roundrobin flights.

Ridge and thermal soaring had been well worked out by the mid 1930s. And then, the big league was discovered, the mountain wave. A large mountain range was found to disturb the winds in the atmosphere for more than 50,000 feet above it. The mountain acted like a rock in the bed of a fast, shallow stream. It forced the flow above it into a wave which continued for some distance downstream. Often these great waves in the air are marked by characteristic lenticular cloud like the famous Tehachapi Wave.

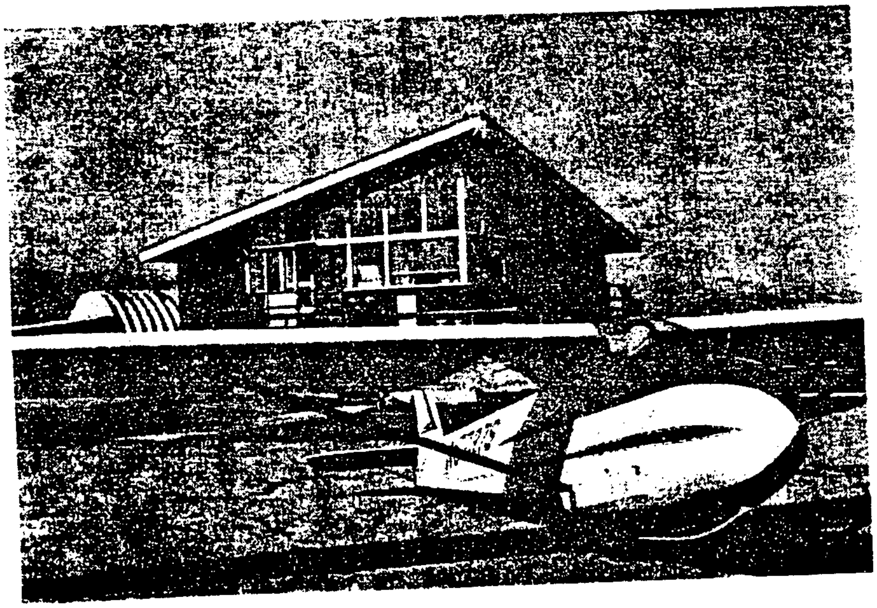
Altitude records soared upward. In 1939, a Luftwaffe captain flew to an unprecedented 21,400 feet. It was time to start thinking about oxygen systems and ultimately pressurization.

Gliding caught on in England--then in America, and continued strong in Europe until World War II brought an abrupt end to the golden years of sport gliding. Gliders were used by all nations in wartime operations, primarily as troop transports. Then after five years of war, the idea of soaring again was irresistible to the prewar glider pilots. But, there were few gliders around to fly. To remedy this, a furniture company in England built a hundred Olympia gliders. The Slingsby Sailplane Company went into operation in England, along with Schweizer in the US. Gradually, sport gliding became a vital part of the aviation picture around the world.

By 1950, the world altitude record stood at 42,000 feet. In 1961, Paul Bikle took a Schweizer 1-23E to 46,267 feet in the vicinity of Koehn Dry Lake, California! He used oxygen, but had no pressurization, as he rode the great Tehachapi Wave to a world altitude record for sailplanes. In April 1983 a California glider pilot flew a Kestrel 19 from Mojave, California to Seminole, Texas to tie the world distance record of 907 statue miles.

The state of the art has progressed to the point that the best Open Class sailplane has a 24.5 meter wing span and a measured best L/D of 60:1.

Competition has always been a strong part of the motivation for soaring. But concurrent with the amassing of impressive world records, glider enthusiasts have built a fine sport which has gained great popularity in recent years. Part of the credit for this broadened popular interest is due to professional soaring organizations, such as the Soaring Society of America. Through their efforts, soaring has been expanded to include not only the purists, but the average citizen as well. Commercial soaring schools are springing up around the world. The sport has come of age.



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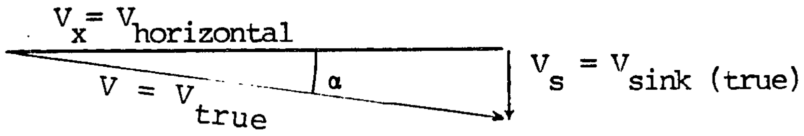
CHAPTER 3

SAILPLANE PERFORMANCE

Sailplane performance is not measured in terms of maximum speed or rate of climb or miles per gallon. Instead, the performance of a sailplane is measured in terms of (1) how slowly it descends vertically through the air, and (2) how flat the angle at which it glides. A moment's thought will convince you that these two qualities are not identical. Referring to the following sketch, you can see that the glide angle is a function of both the sinking speed and the airspeed of the glider.



$$\left.\begin{matrix}\text{Glide}\\\text{Angle}\end{matrix}\right\}\ \gamma = \sin^{-1}\frac{V_{sink}}{V_{true}} = \sin^{-1}\frac{V_s}{V}$$

Instead of glide angle, it is customary to speak of "glide ratio," commonly called the lift-to-drag or "L over D" ratio. (See Appendix)

$$\text{The glide ratio is } \frac{V_{horizontal}}{V_{sink}} = \frac{V_x}{V_s} = \frac{L}{D}$$

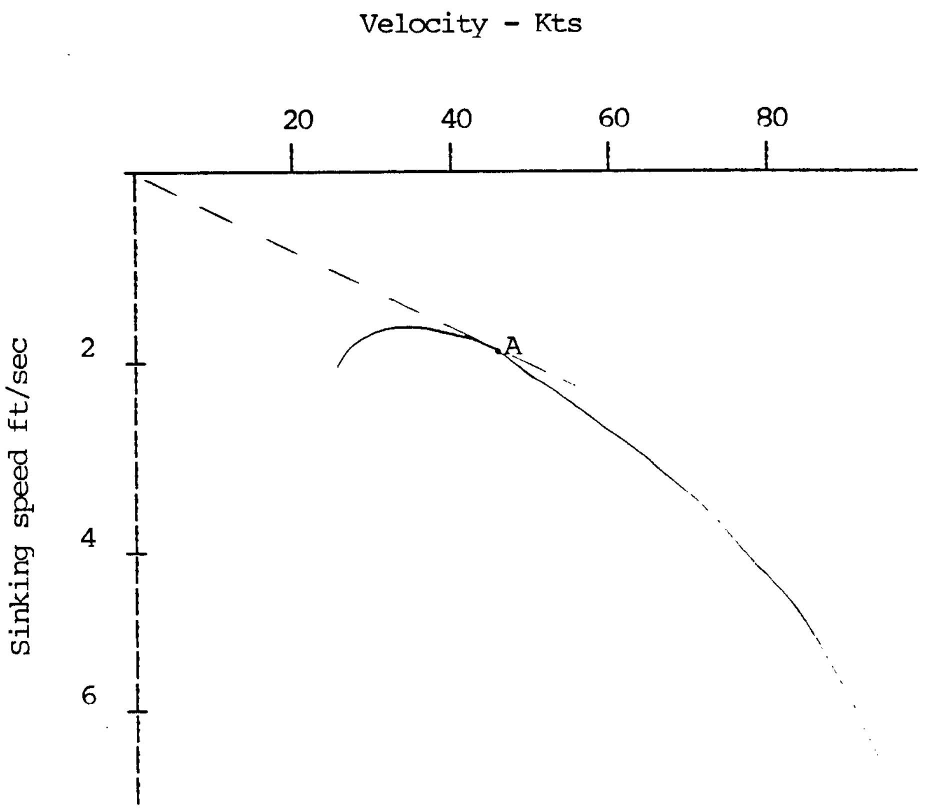
Generally, it isn't convenient to measure horizontal velocity directly, so we substitute the relationship $V_x = V \cos \gamma$ into the glide ratio equation to get the more usable equation.

$$\text{Glide Ratio} = \frac{V \cos \gamma}{V_s}$$

When the glide ratio is greater than 7 to 1, the cosine of γ is between unity and .99. Since the glide ratio of a sailplane is much higher than this, we can simplify the equation to:

$$\text{Glide Ratio} \approx \frac{V}{V_s}$$

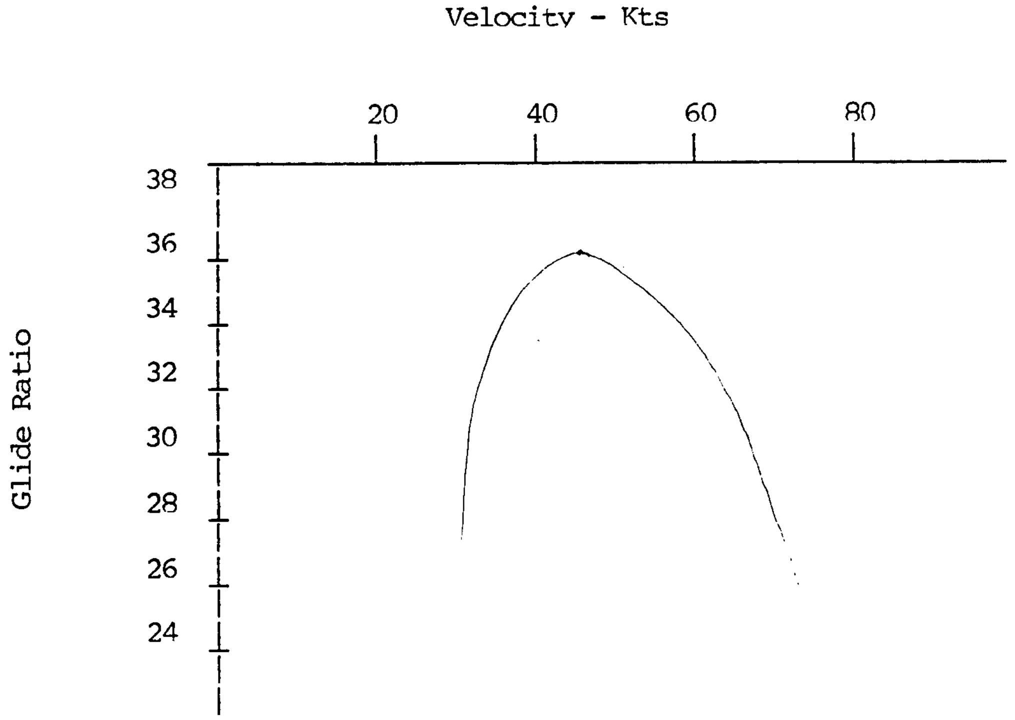
If we plot sinking speed V_s versus airspeed, we have a graph known as the the polar curve. Characteristically, it looks like the following sketch:



POLAR CURVE

Note that at every point on the polar curve there is a corresponding glide ratio $\frac{V}{V_s}$.

For example, the maximum L/D occurs at point (A) where the glide ratio is $\frac{45 \times 1.6889 \text{ ft/sec}}{2.05 \text{ ft/sec}} = 37.0$ if we plot these corresponding values of glide ration versus airspeed, the resulting graph is knows as the the penetration curve. The following curve was derived from the polar curve above.



PENETRATION CURVE

Penetration is a word used by sailplane pilots to describe the capacity of a glider to get from an area of lift, through a region of calm or descending air, with maximum speed for a minimum loss of altitude. Generally speaking, early sailplanes had poor penetration capabilities. They were designed to fly slowly in ridge lift—but not for going places. The latest airplanes today are designed for good penetration, which implies higher speeds.

Now, a close comparison of the polar curve and the penetration curve reveals what may be a surprise to you. Namely, the fact that the minimum sink speed and the best glide speed are not one and the same. In fact, the minimum sink speed is somewhat slower than the speed for the best glide ratio. Let's dip into some of our low speed aerodynamics theory to get some insight into this.

We have seen that $C_D = \underbrace{C_{D_O}}_{\text{Parasite}} + \underbrace{\frac{1}{\pi A_R e} C_L{}^2}_{\text{Induced}}$

and so $D = C_D \frac{1}{2} \rho V^2 S = \left(C_{D_o} + \frac{C_L{}^2}{\pi A_R e} \right) \frac{1}{2} \rho V^2 S$

The motive power of a glider is gravity alone. Now at any given altitude, the glider possesses a given potential energy. In steady flight, it spends this potential energy to overcome the energy dissipated by drag. The rate of energy loss due to drag must equal the rate of loss of potential energy, and therefore:

$$\underbrace{DV}_{\substack{\downarrow \\ \text{energy} \\ \text{dissipated} \\ \text{by drag}}} = \underbrace{W V_s}_{\frac{d}{dt}\text{ (potential energy)}} = W \left| \frac{\Delta h}{\Delta t} \right|$$

where W is the weight of the glider and V_s is the true sinking speed and V is the true airspeed in feet per second.

To retain altitude in level unaccelerated flight, the sailplane must fly in rising air. The wing extracts energy from the rising air in which the glider is flying. We can calculate fairly simply the energy involved from the above relationship, remembering that one horse power equals 550 ft lb of work per second. A good high performance sailplane weighing say 825 pounds loses altitude at only 2 feet per second at its optimum penetration speed. The power required to lift it up again this 2 feet in one second $= \frac{825 \times 2}{550} = 3$ hp. In a strong cumulonimbus cloud, rates of climb on the order of 40 ft/sec are not unusual. The power to lift the sailplane at this speed is $3 + \frac{825 \times 40}{550} = 63$ hp. When you consider how a sailplane, from a wing area of 200 square feet, extracts power of this order from the small area of the atmosphere which it occupies, you get some idea of the vast power contained in a single convection cloud.

Let's use our aerodynamics to find the minimum sink speed. We know that

$$D = \left(C_{D_o} + \frac{C_L{}^2}{\pi A_R e} \right) \frac{1}{2} \rho V^2 s \qquad (1)$$

and we saw that in steady flight,

$$DV = WV_s \qquad (2)$$

Now assuming that lift equals weight, we have

$$C_L = \frac{W}{\frac{1}{2}\rho V^2 S} \qquad (3)$$

Substituting (2) and (3) into equation (1), we get

$$WV_s = DV = \frac{1}{2}\rho V^3 S \left(C_{D_0} + \frac{W^2}{\frac{1}{4}\rho^2 V^4 \ \pi A_R e \ \ S^2} \right) \qquad (4)$$

which simplifies to

$$WV_s = \frac{1}{2} C_{D_0} \rho S V^3 + \frac{W^2}{\frac{1}{2}\pi A_R e \rho S V} \qquad (5)$$

Let's write this equation in terms of equivalent airspeed and equivalent sink speed.

$$V_e = V\sqrt{\sigma} \quad \text{so} \quad V = \sqrt{\frac{\rho_o}{\rho}} \ V_e$$

and the equivalent sink speed is $V_{s_e} = V_s \sqrt{\frac{\rho}{\rho_o}}$

$$\text{So} \quad V_s = V_{s_e} \sqrt{\frac{\rho_o}{\rho}}$$

Substituting these expressions into equation (5) we have

$$WV_{s_e} = \underbrace{\left(\frac{1}{2} C_{D_o} \rho_o S \right)}_{K_1} V_e^{\,3} + \underbrace{\left(\frac{W^2}{\frac{1}{2}\pi A_R e \rho_o S} \right)}_{K_2} \frac{1}{V_e}$$

Note that the quantities in parentheses are simply constants for a particular glider.

Thus $$V_{s_e} = \frac{K_1}{W} V_e^{3} + \frac{K_2}{WV_e}$$

Now the minimum sink speed is found by differentiating V_{s_e} with respect to V_e, and setting this equal to zero.

Hence:

$$\frac{dV_{s_e}}{dV_e} = \frac{3K_1V_e^{2}}{W} - \frac{K_2}{WV_e^{2}} = 0 \quad \text{so} \quad \frac{K_1}{W} V_e^{2} = \frac{K_2}{3WV_e^{2}}$$

Thus $$V_e^{4} = \frac{K_2}{3K_1} \quad \text{and} \quad V_{e_{\substack{\text{min}\\\text{sink}}}} = \sqrt[4]{\frac{K_2}{3K_1}}$$

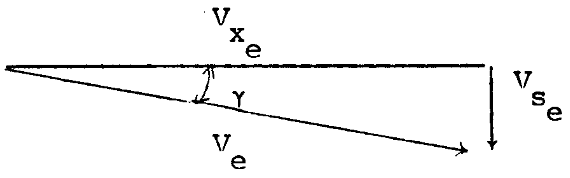
If we put in the values of K_1 and K_2 we get

$$V_{e_{\substack{\text{min}\\\text{sink}}}} = \sqrt[4]{\frac{4}{3\pi A_R e C_{D_o} \rho_o^{2}}} \qquad \sqrt{\frac{W}{S}}$$

Since $\frac{K_1V_e^{2}}{W} = \frac{1}{3} \frac{K_2}{WV_e^{2}}$, the same substitution shows that

$$\underbrace{\frac{1}{2} \rho_o C_{D_o} SV_e^{2}}_{\text{Parasite Drag}} = \underbrace{\frac{1}{3}}_{\frac{1}{3}} \underbrace{\frac{W^2}{\frac{1}{2} \pi A_R e \rho_o SV_e^{2}}}_{\text{Induced Drag}} \quad \text{at minimum sink speed}$$

Now, the BEST GLIDE ANGLE occurs when $\frac{V_{s_e}}{V_e}$ is a minimum.



We saw that $V_{s_e} = \frac{K_1 v_e^3}{W} + \frac{K_2}{WV_e}$

So $\frac{V_{s_e}}{V_e} = \frac{K_1 V_e^2}{W} + \frac{K_2}{WV_e^2}$

Differentiating this with respect to V_e and equating to zero, we find that

$$V_e^4 = \frac{K_2}{K_1} = \frac{4\,W^2}{\pi\, A_R e \rho_o{}^2 S^2\, C_{D_o}}$$

or

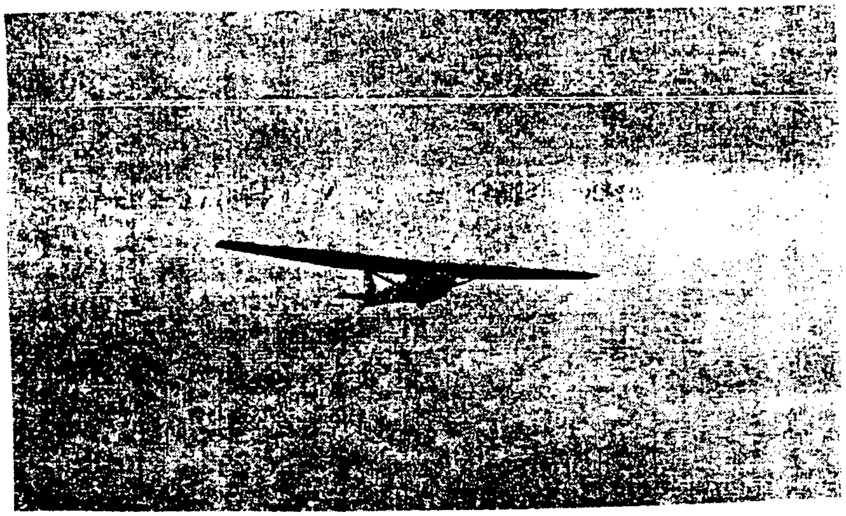
$$V_{e_{\substack{\text{min}\\\text{glide}\\\text{angle}}}} = \sqrt[4]{\frac{4}{\pi\, A_R e \rho_o{}^2 C_{D_o}}}\;\sqrt{\frac{W}{S}}$$

Since at the best glide angle, $K_1\, V_e = \frac{K_2}{V_e^3}$

we have $\underbrace{\frac{1}{2}\, C_{D_o}\, \rho_o S V_e^2} = \underbrace{\frac{W^2}{\frac{1}{2}\pi\, A_R e \rho_o\; S V_e^2}}$

or: Parasite Drag = Induced Drag

We conclude that at the minimum rate of sink, the parasite drag is one third of the induced drag; and that at the best gliding angle (i.e, minimum $\frac{V_s}{V}$) the parasite and induced drag are equal. Looking again at the polar curve, we see the relationship between minimum sinking speed and best gliding angle.



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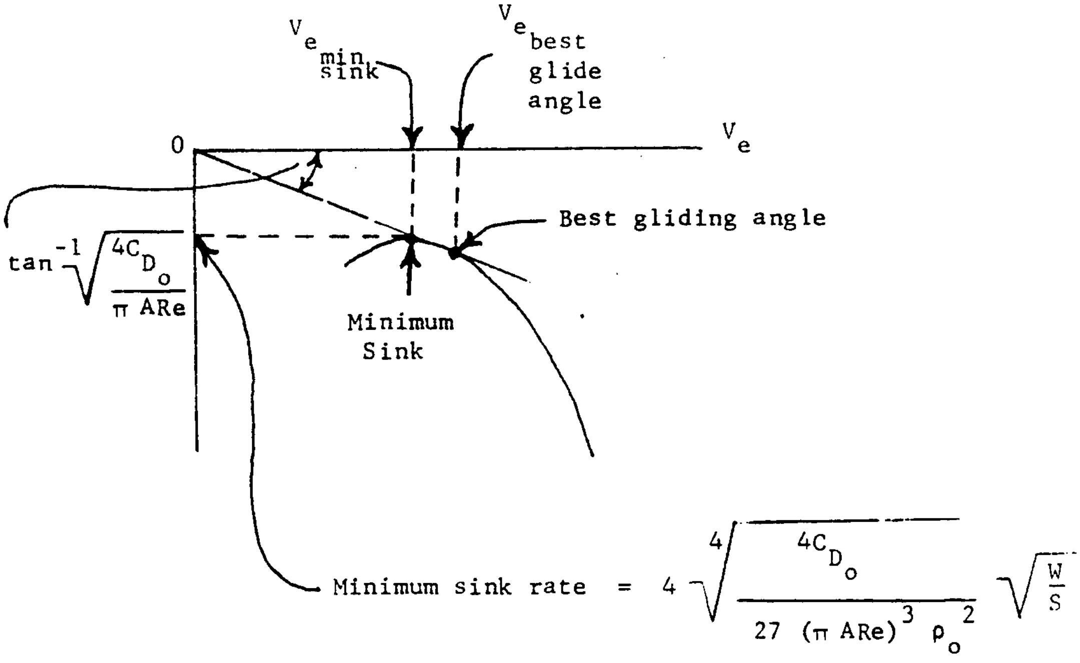
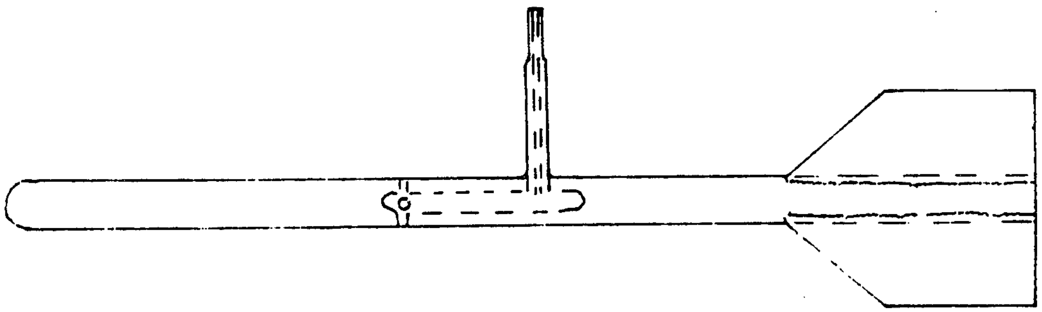


To minimize the sink rate, the glider should have the lowest possible zero-lift drag coefficient, C_{D_o}, and high aspect ratio. Consequently, sailplanes are extremely clean aerodynamically and have very high aspect ratios ranging from 10:1 to 20:1. The upper limit is usually determined by structural considerations, since the weight of the structure becomes prohibitively high as the aspect ratio is increased.

Higher penetration speeds have resulted from the use of low drag laminar airfoils. These, as you recall, are usually very smooth and have their maximum thickness near the mid chord. Rain, ice, and dirt can radically alter the flying characteristics of an airfoil, particularly one which achieves its performance by promoting laminar flow.

From all of this, we conclude that we should fly in lift at the minimum sink speed if gaining altitude is our primary aim. On the other hand, if we are covering distance, as on a cross country flight, we would want to fly at the MacCready "speed to fly" which gives us the best speed. Higher speeds are also useful to carry us through regions of sink.

It should be apparent that one of the most important results of glider flight testing is the polar curve showing sink rate versus airspeed. From this curve, the minimum sink speed and the best glide speed can be determined graphically. The curve is obtained experimentally by measuring sink rates corresponding to different airspeeds. Since vertical speed is not a good flight test instrument, it is customary to time a descent through 500 foot altitude bands, and to average the results. It is important to consider pitot static system corrections before valid flight test data can be obtained. It is common practice to use a trailing cone or bomb to calibrate the pitot static system of a sailplane.



Trailing Static Bomb

CHAPTER 4

SAILPLANE OPERATIONS

This chapter is a collection of procedures and techniques used by most sailplane operations. Liberal reference was made to practices recommended by the Soaring Society of America in their publication, American Soaring Handbook, Volumes 2 and 4. In a few instances, these procedures have been altered to coincide with recommended procedures at the soaring site used by the School.

PREFLIGHT INSPECTION

The glider should be preflighted IAW the appropriate checklist. Sailplanes are designed to be dismantled and trailered. Therefore, special care should be taken to ensure that the structure is rigged properly and that the flight controls are connected.

TAKEOFF

When the sailplane pilot has completed the before takeoff checks and is ready, the crewman will attach the towline to the sailplane. On the first flight of the day, the pilot should pull the tow release to check operation and signal for rehook.

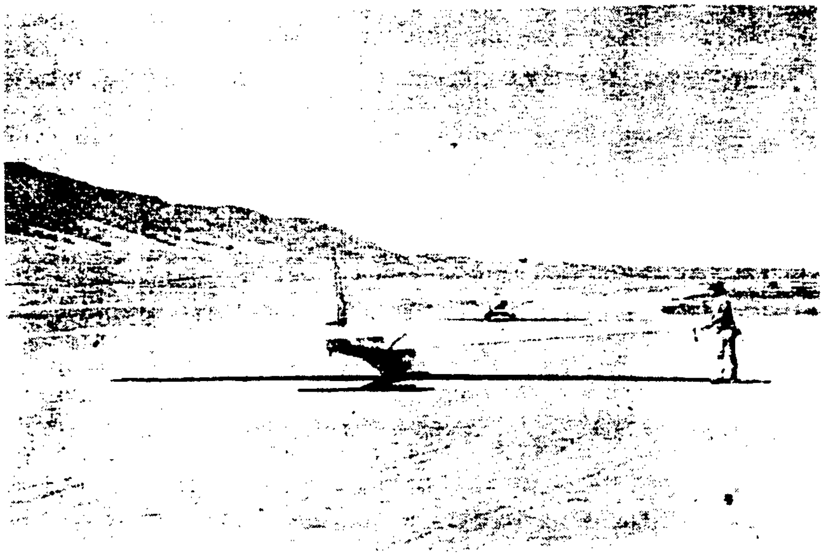
When the sailplane pilot is ready for takeoff, he gives the wing runner a thumbs up. The runner levels the wings. At this signal, the tow pilot will move the tow plane forward until the rope tightens. The crewman will assist the sailplane pilot in checking air and ground traffic, wind conditions, and runway ahead before takeoff. The sailplane pilot is the pilot-in-command, and only he signals for takeoff. This signal is given by fanning the rudder several times. The tow plane pilot will in turn fan his rudder to signal he acknowledges the glider is ready. CAUTION: DO NOT MOVE RUDDER PEDALS AFTER THE WING IS RAISED UNTIL <u>READY</u> <u>FOR</u> <u>TAKEOFF</u>!

The tow pilot will then smoothly apply full power and start his normal takeoff. The sailplane pilot should relieve the weight on the nose or tail skid/wheel as soon as possible with the appropriate elevator input <u>without</u> slamming the nose or tail to the ground. The crewman will run with the wing tip, keeping the wings level until aileron control is obtained by the sailplane pilot.

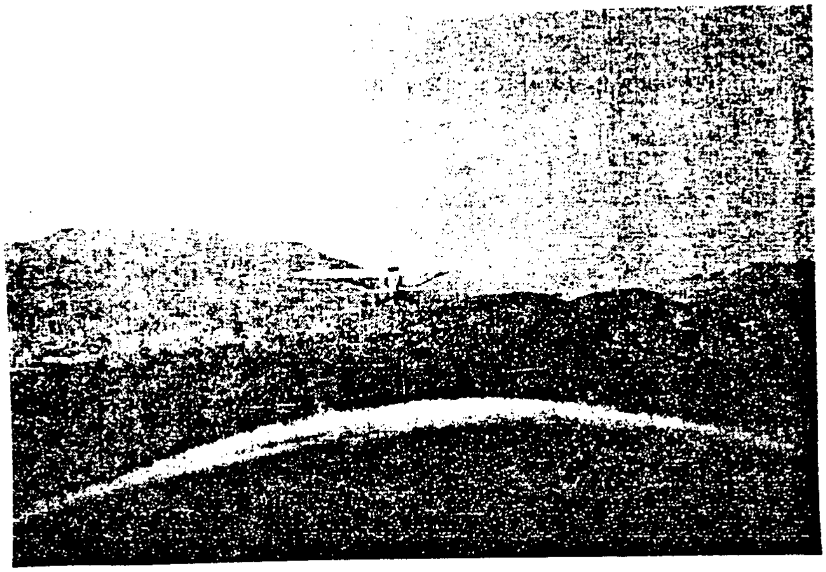
During the ground roll, the sailplane pilot maintains wings level with ailerons and lateral position behind the tow plane with rudder. The sailplane should be allowed to fly itself off. As in formation flying, the pilot should position the sailplane by reference to established position points on the tow plane. Avoid getting too high on takeoff. If the sailplane pilot gets too high, the tow pilot may be forced to release his end of the tow rope and let the sailplane pilot fend for himself.

Often, the sailplane pilot's visibility is restricted by dust and dirt on the initial takeoff. Allow the sailplane to fly off normally. Sufficient visual cues will still be available for making a normal takeoff.

In crosswind conditions, the sailplane, which becomes airborne before the tow aircraft, should be crabbed over the runway in order to maintain a track behind the path of the tow plane. Again, as on a normal takeoff, the sailplane should be properly positioned by aligning the reference points on the tow plane. Once the tow plane is airborne, the tow pilot will establish the drift correction and the sailplane pilot should simply maintain his established position directly behind the tow plane, keeping the towline straight by means of the reference points.



Schweizer 1-26 with Wing Raised to Indicate that the Pilot is Ready for Takeoff



Correct High Tow Position Behind a Piper Super Cub

TOW POSITION

Aero tow requires constant attention. Overcontrolling and overcorrection are the greatest initial problems during tow. Deviations from the correct towing position should be anticipated and prevented, and small control corrections made to hold the desired position.

One technique for towing is to match the tow plane's bank angle and adjust the pitch attitude so the tow plane is approximately on the horizon. This places the sailplane at the same level as the tow plane, clear of tow plane downwash (high tow). This position permits better visibility for both tow and sailplane pilot. Also, the sailplane can be released at any time without danger of the tow rope hitting the sailplane. If the tow plane moves up or down with respect to the desired position, make a small pitch change to keep the tow plane in the same relative position above the sailplane's nose. This results in an asymptotic return to the desired position.

To maintain the correct position in a turn, the sailplane pilot should continue to hold position by using the reference points. All else being equal, a good technique is to delay turning until the point where the towplane started its turn. The nose of the glider will be pointed at the tow ship's outside wingtip, a relationship that will last through the turn. Note that the sailplane and tow plane ideally fly around the arc of a circle. The center of turn and radius are the same for both aircraft. Due to the different speeds of the wingtips when turning, the sailplane always seeks to roll into the turn (i.e., steepen its bank angle). Apply required control inputs to both stick and rudder to compensate for this over banking tendency. When in the correct position, your radius and airspeed are the same as the tow plane's. Therefore, your bank angle must match his to stay in position.

To signal the tow pilot to turn or alter his heading, the sailplane pilot should obtain the maximum possible displacement to the side away from the direction he wishes the tow to turn. This tends to force the nose of the tow plane in the desired direction. This procedure should be used an absolute minimum due to the danger of unwanted acceleration. If the tow plane turns into you during this signal, you will have a huge slack line with which to contend.

If the rope breaks below 200' AGL, land straight ahead, turning only to avoid obstacles. Above 200'AGL, a turn back to a downwind landing can be accomplished safely. Maintain a minimum of best L/D glide speed and turn in the shortest direction. If you are crabbing into a crosswind, the shortest direction will be into the crosswind. Above 500' AGL, you will normally have enough altitude to make a short, modified pattern to land into the wind. A good technique is to practice calling out loud "200 feet" and "500 feet." This reminds you of the zone you are in so that you can react quickly and correctly to a rope break.

DESCENTS

Descents on Tow:

Descents on tow should be made only when absolutely necessary such as lowering ceiling or inability to disconnect. If necessary, the sailplane pilot must recognize the hazard of over running which results when the tow descends with a vertical speed greater than the sinking speed of the sailplane. The sailplane pilot should apply slips or spoilers to produce sufficient drag and sink rate to prevent over running.

DIFFICULTIES ENCOUNTERED ON TOW

1. Waiting too long to correct what appears to be only small deviations. Make smooth and timely corrections when deviations from proper tow position are noted. At all times, the sailplane should be kept aligned with the reference points on the tow plane. The importance of matching the tow plane's bank angle to remain in the correct lateral position behind the sailplane cannot be over emphasized.

2. Too High on Tow. This is the hardest error to correct since the sailplane will tend to overrun the towline when nosed over to return to the correct position. Slack in the towline, if improperly taken out, causes a jerk which either breaks the rope or slingshots the aircraft back to a too high position. To descend from a too high position without obtaining excessive towline slack, the sailplane should be slipped or yawed to one side with rudder. If in a turn, yawing is accomplished by applying outside rudder and steepening the bank slightly. As the rope tightens, make sure your airspeed is adjusted to match the tow plane speed. Trim the sailplane. Not all sailplanes have enough trim power to make stick force zero. The closer you are to the proper trim, the easier it is to maintain proper position.

3. Over Correcting in Recovery to Normal Tow Position. This familiar over controlling error may be avoided by releasing the corrective control pressure when the sailplane starts to respond so that a counter pressure may be applied prior to reaching the correct position. Again, the sailplane pilot

should be entirely dependent upon the tow plane reference points. His line of sight is to the vertical stabilizer and centerline of the tow aircraft. A common error is establishing too great a bank angle to return to proper tow position and then failing to "lead" with the proper controls prior to reaching the proper tow position. USE SMALL BANK ANGLES, MINIMIZE USE OF AILERONS, AND ALWAYS "LEAD" WITH THE DESIRED LATERAL INPUT DUE TO THE SLOW ROLLING RESPONSE OF MOST GLIDERS.

4. Encountering Tow Plane Wake. The wake is a region of turbulence about a wingspan across running behind the tow aircraft. The tip vortices of heavier tow planes are easily identified. This amounts to a region of unpleasant flying, and should normally be avoided. Usually, the easiest correction is to pull up out of the region of disturbed airflow. All sailplanes have the control power to safely fly in the wash.

5. Turbulence. Turbulence has a naturally greater effect on the sailplane than the tow ship because of the sailplane's low wing loading. Maintaining proper tow position in turbulent conditions is best accomplished by keeping the tow plane the proper distance above the top of the instrument panel, thus making asymptotic corrections.

RELEASE FROM TOW

The sailplane pilot should release from the tow plane on a normal taut line. No attempt should be made to relieve some of the towline tension before release. The release knob is pulled and held until the sailplane is free of the towline.

Following the release, the sailplane pilot should make an immediate, but very moderate, right climbing turn to clear the towline and to gain a little more altitude transitioning from tow to gliding speed. The tow plane will turn left and descend.

If the tow plane rocks his wings during the tow portion of the flight, the sailplane must release. This means that the tow pilot has encountered a problem such as engine failure.

Normally, the sailplane releases at a predetermined point or altitude as briefed prior to takeoff. Remember where lift was encountered during the tow, and return to it after release, if desired.

AIR WORK

1. Stall Series. Because of the altitude lost in a stall series, the sequence of stalls should be accomplished in the shortest time without sacrificing precision. Prior to entry, make a couple of clearing turns to look for traffic. The sailplane should be pulled up straight ahead and the pitch attitude held until the stall occurs. The nose is lowered to below the horizon for recovery. When flying airspeed is achieved, return to the normal gliding pitch attitude. The nose is then pulled up into a nose high turn to right (left) and held in this attitude. At stall, the nose is lowered and wings leveled using rudder. Ailerons should not be used while the sailplane is stalled. The adverse yaw is liable to cause a departure/spin. The stall should be repeated with a nose high turn to the left (right). To demonstrate a stall in a turn to final, the sailplane should be placed in a gliding turn at low speed. Back pressure and bank angle should be increased until a stall results. Recovery is again accomplished by relaxing back pressure and rolling out the bank. Finally, an accelerated stall is started from a coordinated steep bank turn. Back pressure is increased until a high speed stall occurs. Relaxing back stick recovers the glide from this stall.

2. Spins. Spins require an altitude of at least 2000' AGL for entry. To enter, stall the sailplane with a pitch attitude of 10° to 20°. At stall, apply full aft stick and full rudder and hold to put the sailplane in a spin and keep it spinning. To recover, apply full opposite rudder and ease the control stick forward to break the stall. The recovery should be started no lower than 1800' AGL so it will be completed by 1500' AGL. The sailplane may not recover from the spin with the control stick held full aft. Be careful not to overspeed or over-g the sailplane during dive recovery. A secondary stall should also be avoided.

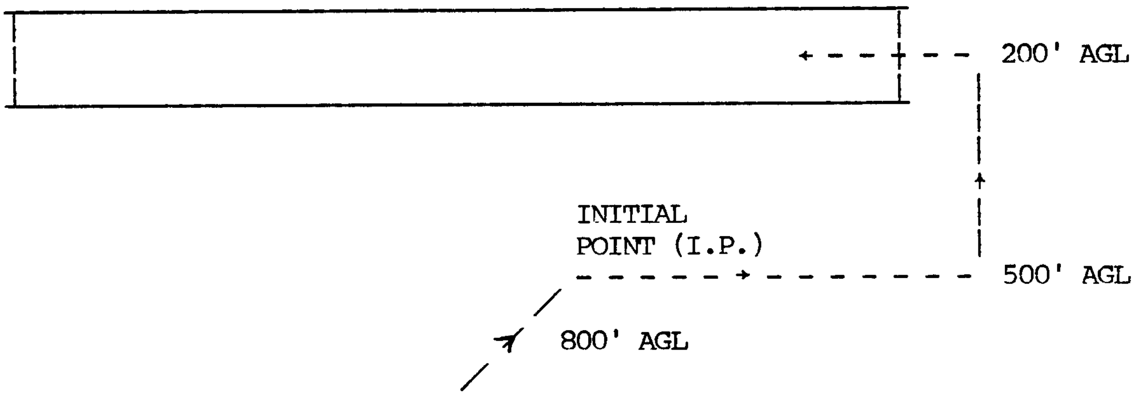
TRAFFIC PATTERNS

1. A smart sailplane pilot is always in gliding range of a suitable landing site. By approximately 1500' AGL, the pilot should be planning his pattern entry so that he is at the entry point on speed and altitude with his before landing checks complete. The TPS standard pattern entry checklist is:

TRAFFIC	Clear well. The entry point area is a high density traffic area.
WINDS	Know what the winds are so you are not surprised by a crosswind.
RUNWAY	In general, land into the wind.
GEAR	Most sailplanes used for training have fixed gear. This is just a good habit.
SPOILERS	Check them so you know that they work.

2. 180° Side Approach. The normal pattern is:

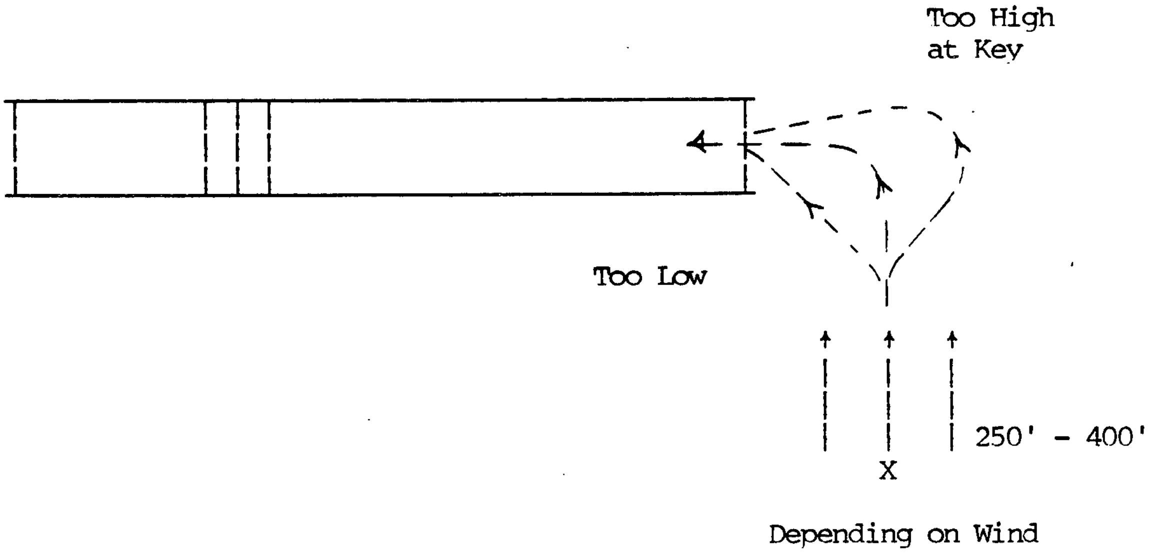
NO WIND



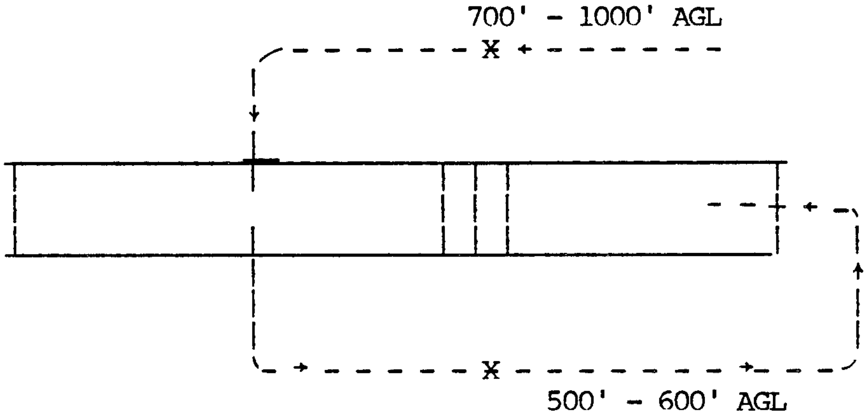
(Field elevation at Fantasy Haven Airport is 4220' MSL.)

NOTE: No soaring is allowed after the Initial Point.

3. <u>90° Side Approach</u>. A useful pattern when it becomes necessary to make a landing from an altitude lower than that required for the 180° side approach is:



4. <u>360° Overhead Approach</u>. A good pattern to use at a strange field if altitude is adequate is:



Flying initial permits the sailplane pilot to observe the wind conditions, field condition, and traffic.

LANDING

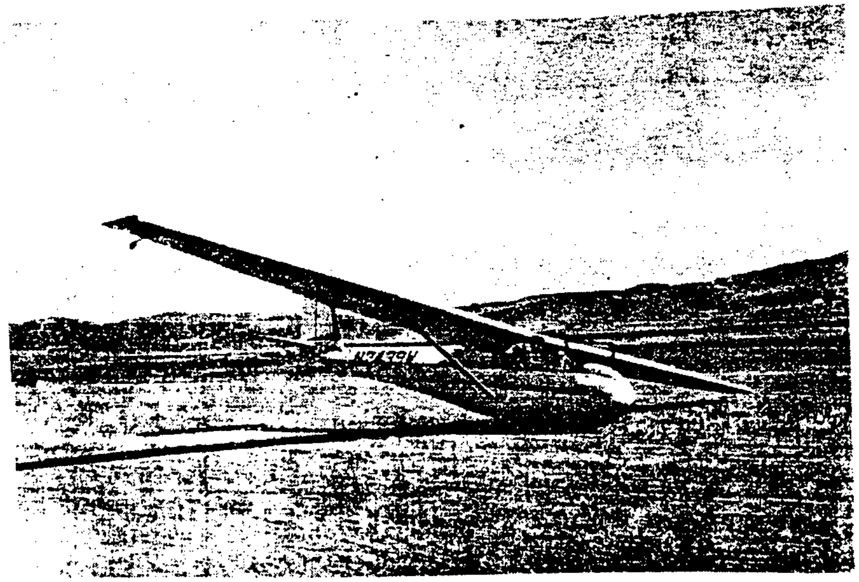
1. Using Spoilers. The proper sailplane approach is close in and high, requiring use of approximately 50% spoilers to maintain the correct glide slope. Although the sailplane can be landed without use of flaps or spoilers by proper adjustment of the base leg to control touchdown point, most pilots prefer to approach slightly high with some altitude as a reserve against sink conditions throughout the pattern. Spoilers should be tested for operation while on downwind or base leg of the pattern so that they can be depended on for adjustment of the approach. One spoiler technique is to use half spoiler on the approach, controlling the glidepath by treating the spoiler handle much as a throttle, by pulling back to steepen the approach or pushing forward to flatten the approach. Another technique is to approach as if to land long without spoilers, and when sure of reaching the touchdown point, applying spoilers. Normal final approach speed is 55 (KIAS/MPH) + 1/2 of headwinds + gust. Spoilers increase the stall speed, drag, and steepen the angle of approach.

2. Using a Forward Slip. A forward slip can be used for altitude correction throughout the pattern. Remember that the airspeed indication is not reliable during the slip maneuver. When recovering from the slip, the sailplane should be flown nose low to prevent an inadvertent stall and to ensure a proper airspeed. If the nose is held too low during the slip, effectiveness is reduced. Using spoilers is normally a better technique for shortening the glide to a landing so all slips should be done with full spoilers out.

Constant airspeed is held on final approach until within approximately 25 feet from the ground. At this point, the sailplane is slowly rounded out and flown onto the ground. The sailplane is not flared or stalled to touchdown as in power aircraft landings. Touchdown should be made at 40-45 KIAS/MPH, but not so high a speed as to cause long float distances. Stalling a sailplane at an altitude of two or more feet will result in a drop-in landing. Since most sailplanes have no shock absorbing landing gear, damage to the aircraft is a strong possibility. In any crosswind, make sure that you do not touchdown with any crab.

AFTER LANDING

Following touchdown, the pilot should ease forward on the stick with enough force to hold the main wheel on the ground, but not so much as to touch any nose wheel/skid. As the speed decreases, rudders and ailerons are used to steer down the runway. If the sailplane has a nose skid, the stick should be held aft at slower speeds to hold the tail down and save wear and tear on the nose skid. The sailplane is "flown" until it comes to a complete stop. Only then should the wing be lowered. The stick should be neutralized to prevent aileron damage as the wing drops to the ground. Ordinarily, the wing nearest the tow plane runway is lowered to the ground. In high crosswinds, however, the glider should be parked with the up-wind wing lowered to the ground to prevent the sailplane's being upset by gusts. It is customary to assist the ground crew in parking the sailplane.



Schweizer 2-33 After Landing

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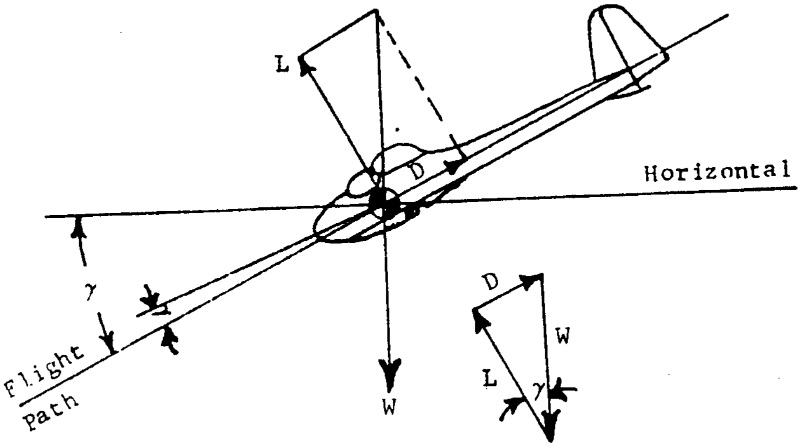
APPENDIX

L/D RATIO

The ratio of lift to drag is a highly significant parameter in sailplane performance. The following discussion shows that the glide ratio of a sailplane is identical to the L/D ratio.

In the following diagram, note that the lift vector is perpendicular to the flight path and the weight vector is perpendicular to the horizontal. By a theorem of plane geometry, the angle included between the lift and weight vectors is identical to the angle included between the flight path and the horizontal. Hence the glide angle, γ, appears as shown in the force triangle.



It can be seen from the vector diagram above that

$$\tan \gamma = \frac{D}{L} = \frac{C_D \, qS}{C_L \, qS} \qquad \frac{C_D}{C_L}$$

The glide angle γ is minimum when the ratio of D to L is minimum, or more commonly, when the ratio of L/D is maximum.

AIRCRAFT DESCRIPTION

Aircraft	Schweizer 2-33	Blanik L-13	Schweizer 1-26A,B,C,D	Grob 103
Gross Weight (lbs)	1040	1040	575	1279
Wing Span (ft)	51	53.75	40	57.4
Wing Span (ft^2)	219.48	206	160	191.5
Wing Loading (lbs/ft^2)	4.73	5.05	3.59	6.68
L/D$_{max}$	23 at 45 (Solo) 23 at 52 (Dual)	28 at 45 KIAS (Solo) 28 at 49 KIAS (Dual)	23 at 45 mph	36 at 51 (Solo) 36 at 57 (Dual)
Min Sink Rate (ft/sec)	2.6 at 36 (Solo) 3.1 at 42 (Dual)	2.5 at 39 (Solo) 2.7 at 44 (Dual)	2.6 at 38 mph	36 at 43 (Solo) 36 at 46 (Dual)
Stall Speed (wings level, 1g)	31 mph (Solo) 34 mph (Dual)	Flaps Up 32 KIAS Flaps Down 30 KIAS	28 mph	36 Kts (Solo) 41 Kts (Dual)
Aspect Ratio	11.85	13.7	10	17.1