Speed to Fly

Looking out at the world from 13,000 feet MSL is pleasant, however to get to your goal you must use some of that altitude to cover distance. The 2 major questions you face are how much altitude to use and how fast to fly. The mathematical basis for your choices is the polar of your glider. Simple relationships between speed to fly and lift or sink are shown in the next figures. Mathematical verification follows.

Speed To Fly -- What Does This Phrase Mean ?

There are many speeds which we use to fly safely – Vs, Va, Vne

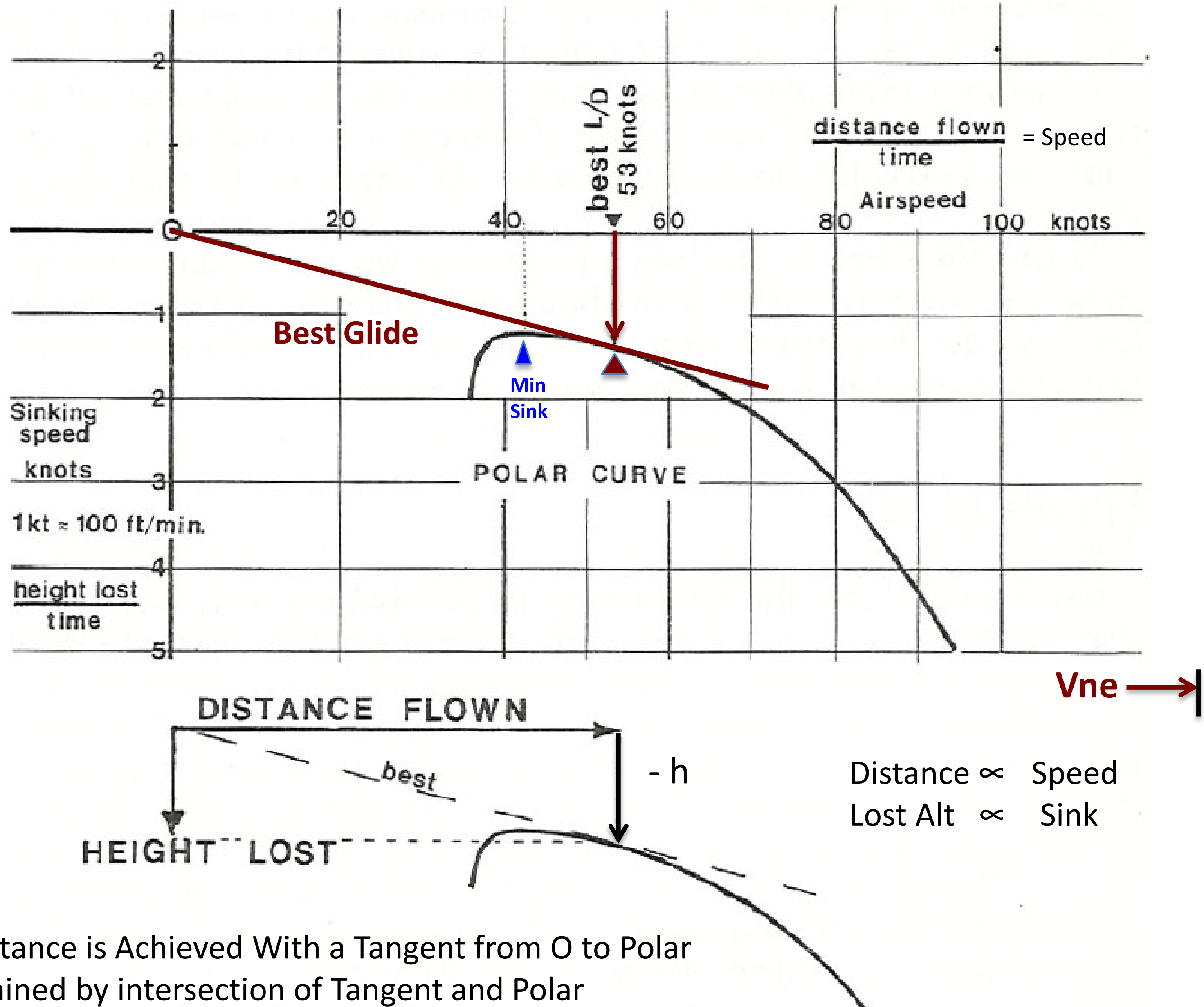
However, the term "Speed to Fly" has a different connotation

The speed a pilot selects to achieve a specific flying goal

- Stay aloft for the longest time (min sink)
- Reaching a certain place on the ground (from the current altitude and position -- gliding for distance)
- Achieving the best speed through the airmass

To select the best speed for a flying goal one needs to understand the polar of one's sailplane

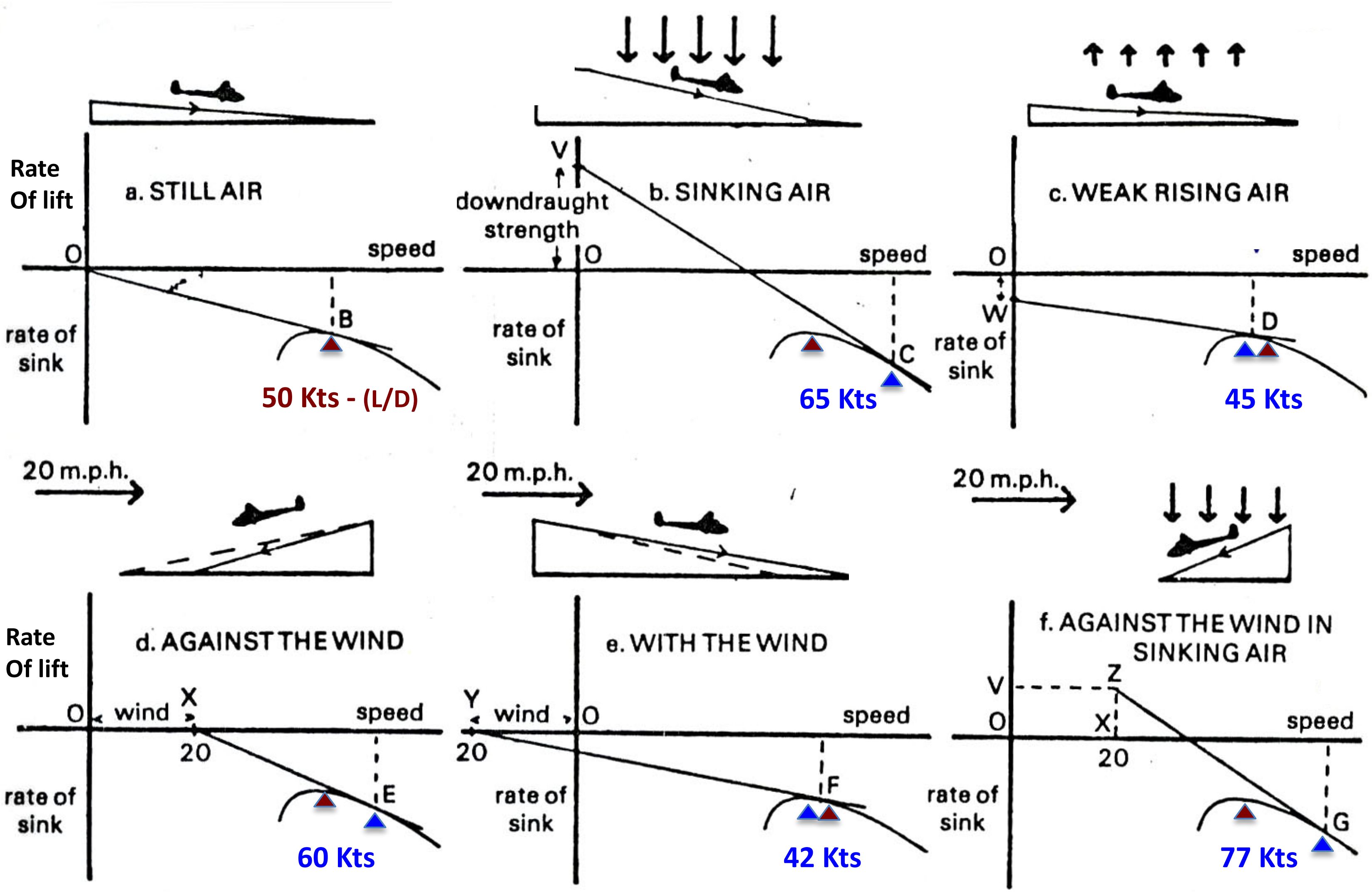
Typical Sailplane Polar



Maximum Distance is Achieved With a Tangent from O to Polar
Speed determined by intersection of Tangent and Polar

From - Piggot

The Sailplane Polar Can Be Used to Find Best Speeds for Distance



118. Determining the speed to fly for maximum distance in various conditions by means of the performance curve.

Speeds are for an ASW-19 - Note the sailplane is flown between ~ 45-80 kts - Rarely is 50 kts (Best L/D) selected

From - Piggot

Derivation of Speed to Fly For Thermal Flight

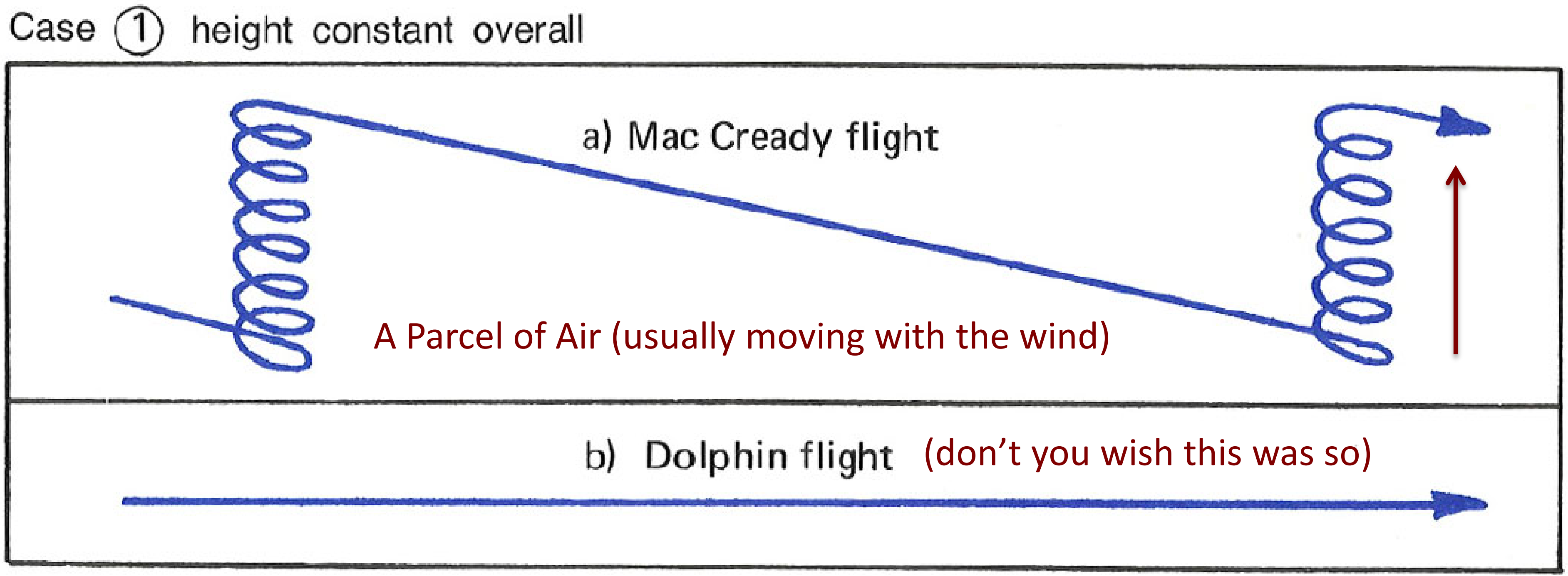
From the previous Figure -- "Speed to Fly" can mean different speeds depending on the context of the flight or the phase of the flight. The usual meanings for cross country flights are:

- Selecting the airspeed that allows one to fly as far as possible over the ground with the existing altitude (taking into account lift, sink and the wind, *i.e.* a headwind or tailwind). As shown, these speeds depend on the polar of the sailplane. (Note that speeds varied from about 45 – 80 kts on the polar used in the previous figures).

- Selecting the airspeed that achieves the highest possible speed between thermals through the airmass. This will maximize overall cross country speed even though the air is moving over the ground (wind). Requires a bit more thought.

MacCready Theory -- In the early 1950's, Paul MacCready proposed that the best speed to fly between thermals is that speed indicated by the polar based on the *expected rate of climb* in the next thermal.

MacCready Theory – Derivation



Assumptions for MacCready Theory

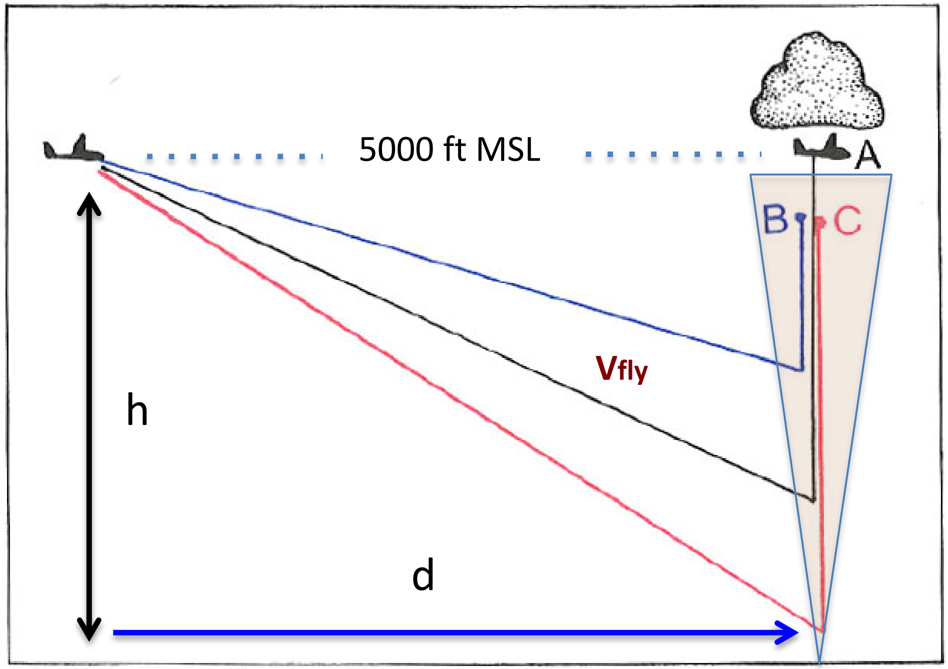
- Flight Through Airmass Ignoring the Wind (No major sink).
- Climb and Glide to the next thermal to achieve distance
- Pilot Knows the Value of Lift in the Next Thermal
- Pilot Actually Achieves This Rate of Climb
- Pilot Makes it to the Next Thermal to Complete the Cycle

From - Reichmann

Speed to Fly- MacCready Theory

Derivation of the Speed to Fly for Cross Country Speed -- Assume a set of equally spaced set of thermals along your course (say - 4 kts and 5 miles apart with cloud bases at 5000 feet MSL) and analyze speeds for a typical flight segment. Thus, one complete segment involves a glide to the next thermal (horizontal distance of "d") and a climb back to 5000 feet MSL (vertical distance of "h") as shown in the figure below.

Principle of optimization



Three possible outcomes

PRINCIPLE OF OPTIMIZATION

The illustration shows that pilot A flies most efficiently, while pilot B loses too much time during his slower glide. Pilot C arrives earlier than A in the thermal, but is so low that he cannot make up the altitude loss in time. But how can we figure the optimum airspeed? This is where the calculated, generally derived cruise speed is handy, as its projective drawing can be transferred directly onto a polar graph. The equation: (#1)

$$V_{cruise} / V_{fly} = \text{Climb}/(\text{Climb} - \text{Sink})$$

Vcruise = speed over segment

Vfly = speed thru air

From - Reichmann

The Calculation

Assumptions

You *know* the strength of the next source of lift (Cl). This will be the *MacCready setting*

You will achieve the rate of climb you expect (predict). *This is a big assumption*.

You can reach the lift from your present altitude and location. *Another assumption*

These assumptions are true for a major segment of the distance flown.

It turns out that the best speed through the airmass is obtained when one spends an *equal amount of time gliding and climbing.*

One very useful aspect of this treatment of the problem is that the equation can be easily related to the polar of the sailplane you are flying (see the next page for an example).

THE "CLASSIC" CROSS-COUNTRY THEORY

DISCUSSED MATHEMATICALLY

Basic quantities:

V = airspeed

Si = sailplane sink speed in straight flight; always negative

Cl = sailplane climb in circling flight

To determine the average cruise speed V_{cruise} we base our computations on a given flight segment including glide and climb and ending at the same altitude as that at which it began.

During the glide the sailplane loses altitude h and covers distance d. Equations:

(1) average cruise speed:

$$V_{cruise} = \frac{d}{t}$$

(2) total flight time t:

$t = t_1 + t_2$ (t_1 = glide time, t_2 = climb time)

(3) altitude lost:

$-h = t_1 \cdot Si$ (Si = sink speed in glide)

(4) altitude gained while climbing:

$h = t_2 \cdot Cl$

(3/4) $t_2 = t_1 \cdot \frac{-Si}{Cl}$

(5) gliding time $t_1 = \frac{d}{V}$

used in equation (3/4):

(6) $t_2 = \frac{d}{V} \cdot \frac{-Si}{Cl}$

partial times used in equation (2):

$$t = \frac{d}{V}\left(1 + \frac{-Si}{Cl}\right) \rightarrow V_{cruise} = \frac{V \cdot Cl}{Cl - Si}$$

This condition holds true for any flown speed V and for any sailplane sink Si (which is the sum of sailplane polar sink Ws and the meteorological airmass movement Wm, either positive or negative).

From - Reichmann

The Equation and the Sailplane Polar

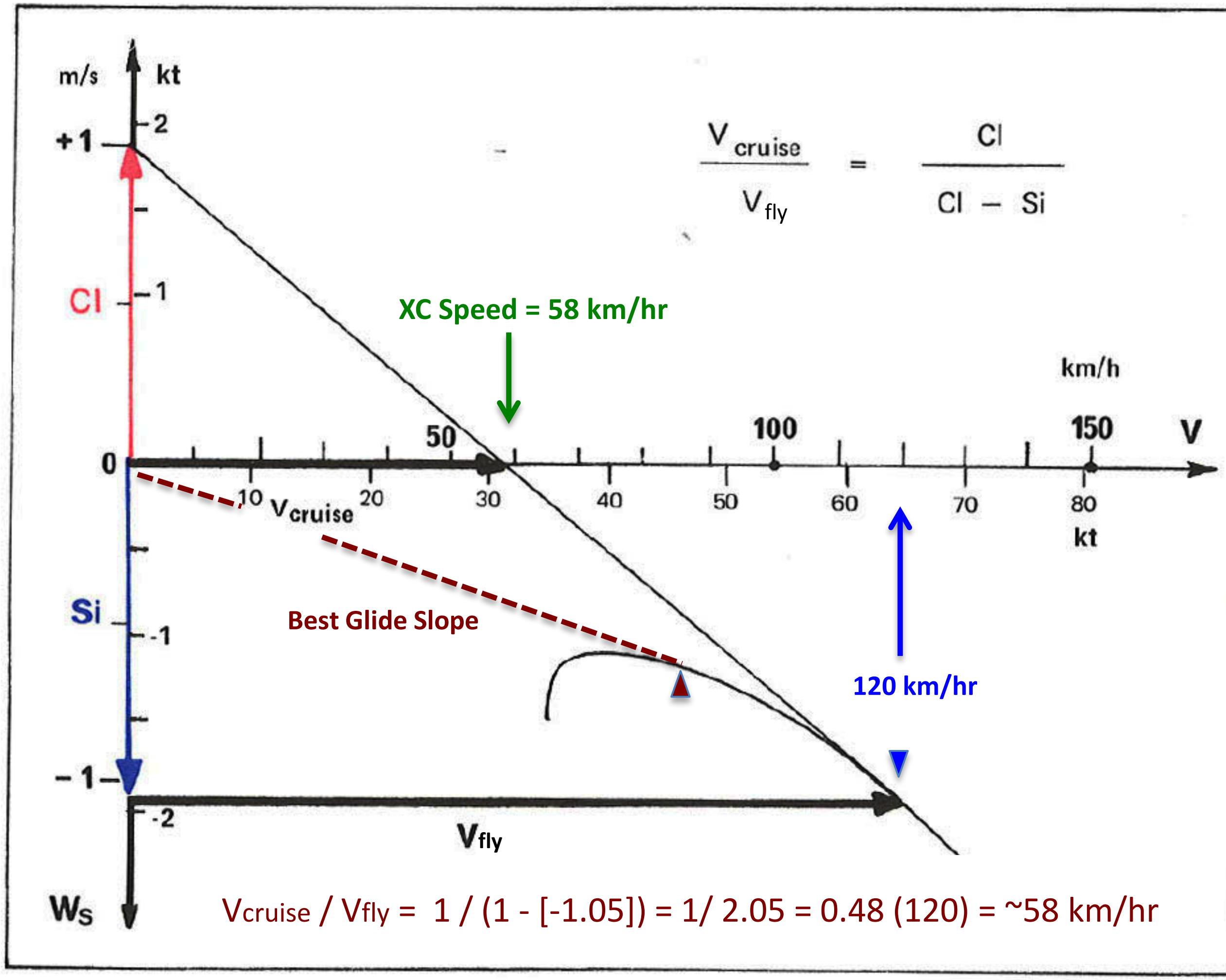
Note how the V_{cruise} and Speed to Fly (V_{fly}) depend on the strength of the lift (Cl).

Also note how the polar of the sailplane determines performance (the slope of the tangent)

Thus - for any expected value of lift on course, there is a defined speed to fly between your position and that thermal.

This is the MacCready Speed (V_{fly})

Graphic Construction of Speed-to-Fly in Still Air (Polar for an ASW-15)

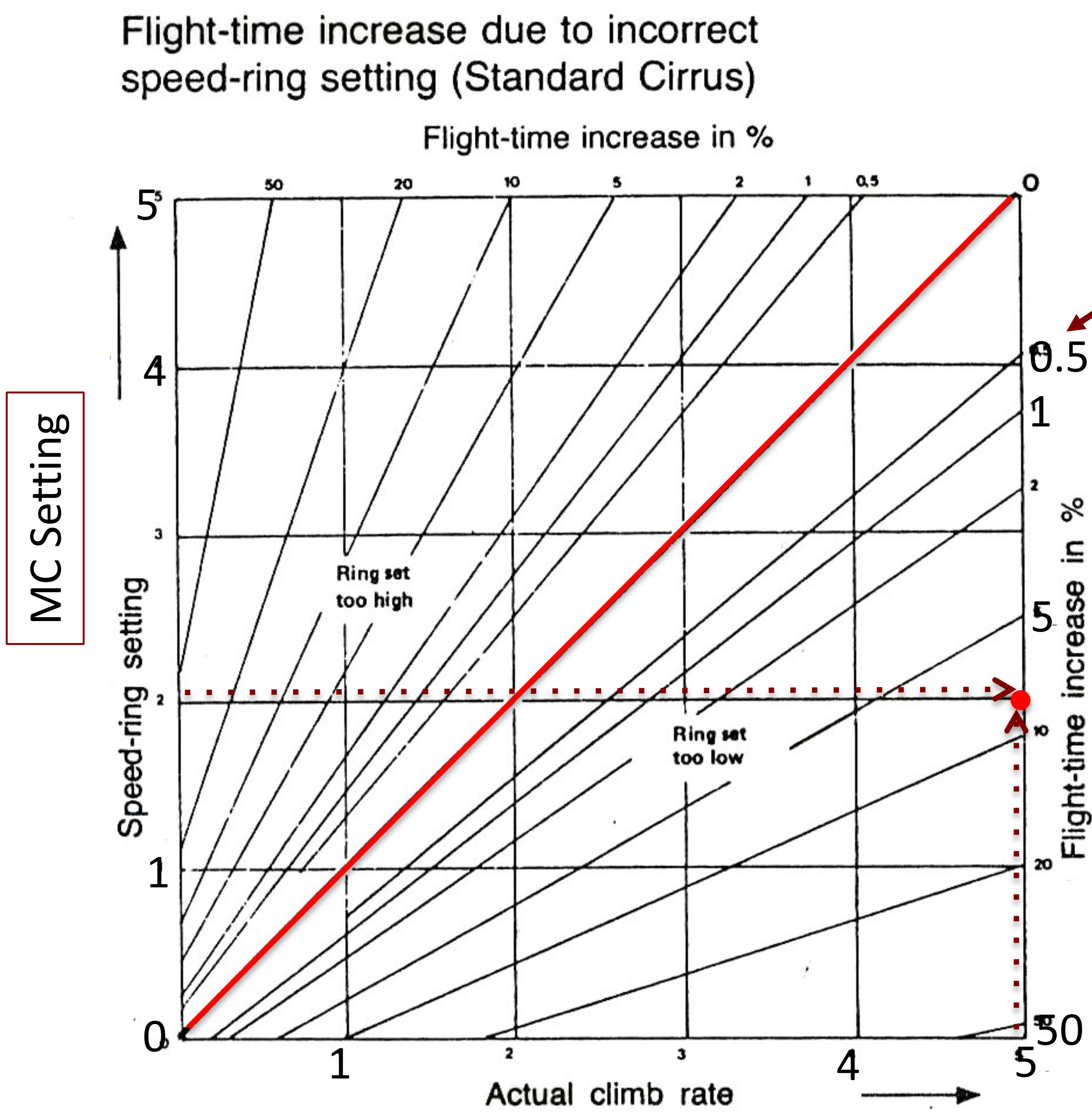


Cl	=	expected climb (1 m/s)
Si	=	sink, here = W_s = polar sink rate of the sailplane (-1.05 m/s)
V_{fly}	=	speed-to-fly (120 km/h)
V_{cruise}	=	cruising speed (58 km/h)

Or - XC speed made good

From - Reichmann

What If I Do Not Fly the MacCready Speed ?



MC set at 4 kts, and get a climb of 5 kts -- yields a 0.5 % increase in flight time

MC set at 2 kts, and get a climb of 5 kts -- yields a 7 % increase in flight time

MC set at 0 kts (best L/D), and get a climb of 5 kts -- -yields a 50% increase in flight time

From - Reichmann

A More Intuitive Way of Looking At It

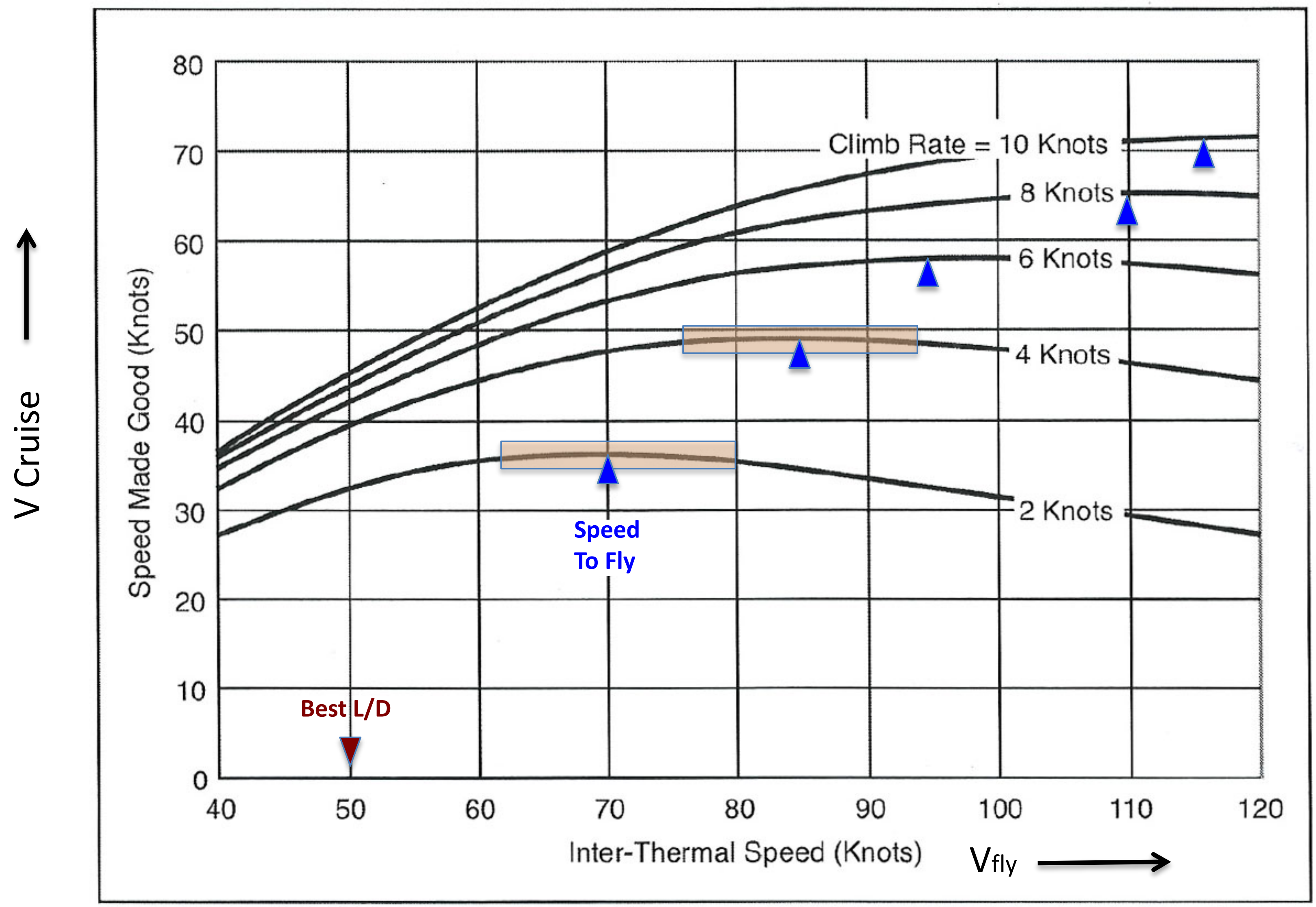


Figure 15.12 – The speed-to-fly for a given climb rate is indicated by the peak of the curve. For example, the speed-to-fly for a 4-knot climb rate is 85 knots. (These curves are for a Duo Discus at 6.2 pounds per square foot wing loading, with a best L/D of 45:1 at 50 knots.)

From - Holtz

Examples of Using MacCready Speeds

In addition to their wonderful GPS navigation features, modern Flight Computers provide a lot of information about speeds to fly and the glide slope to your goal

The data they provide is all based on the polar you have programmed into the computer and MacCready theory

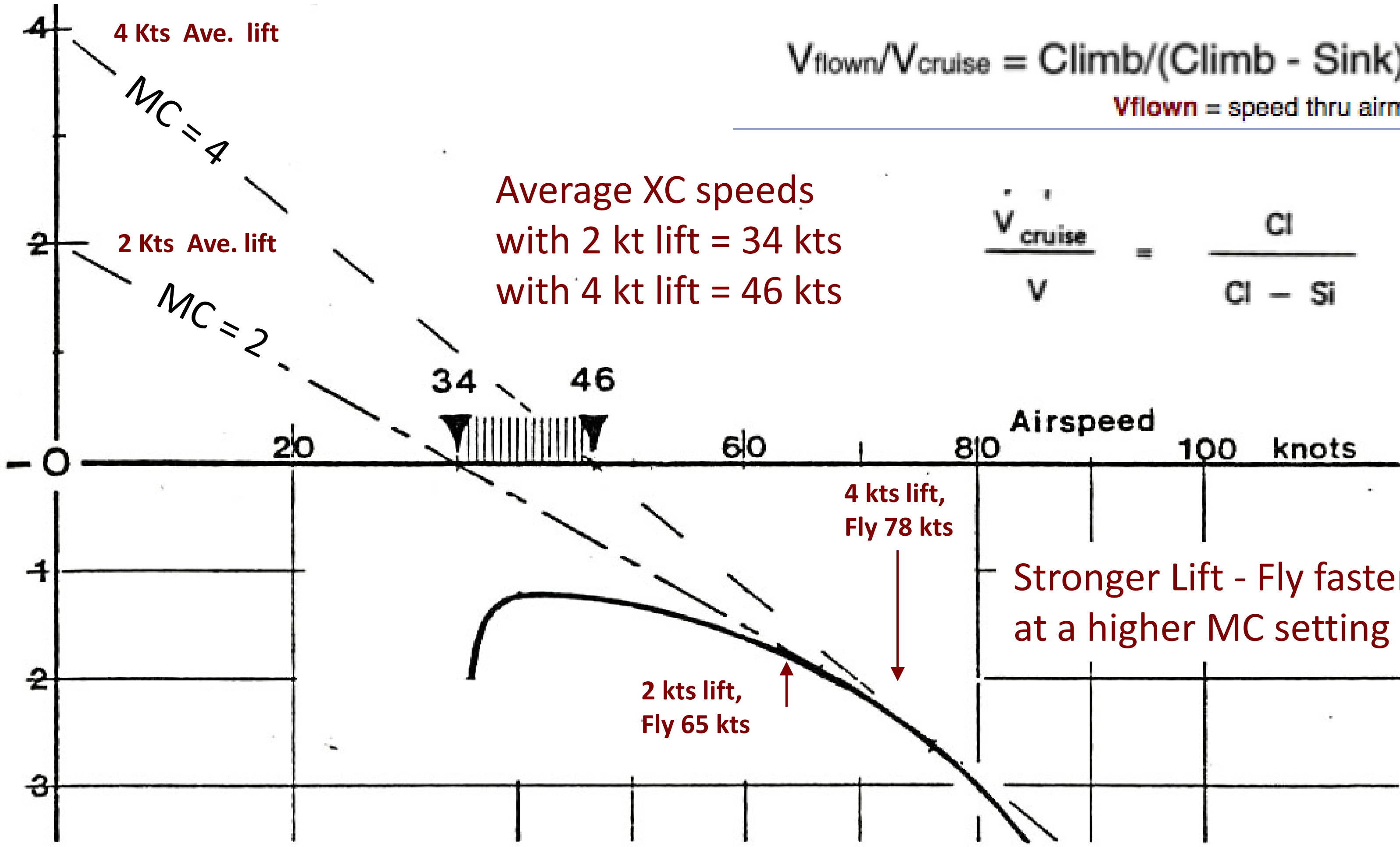
Realize that a higher MC value means that you are to fly faster to the next thermal, but it also means you will fly a higher sink rate as dictated by your polar (because it moves your performance down your polar to the right)

The next few figures provide more explanation

Flight Computer Tells - Speed to Fly From MC Theory

$$V_{flown}/V_{cruise} = Climb/(Climb - Sink)$$

Vflown = speed thru airmass



$$\frac{V_{cruise}}{V} = \frac{Cl}{Cl - Si}$$

112. Increasing the achieved rate of climb from 2 to 4 knots can give an increase in average speed of over 10 knots.

Strict MC theory argues that you spend ½ time cruising and ½ time climbing – If you have programmed MC 4 into your computer, it will tell you to fly faster (78 kts) than if you set MC 2 (65 kts) as shown above

Inter-thermal Speeds

Most experienced XC pilots do not strictly adhere to the speed directions from their flight computer. Constant changes in speed induce losses and can be shown to result in slower XC speeds as compared to flying a single speed that is "about right" for the conditions.

So -- What is the Right Speed ??

The answer obviously depends on the polar of your ship, but for a modern flapped ship the speeds are pretty fast. Look at the MacCready (Mc) speeds for an ASW-27

	Dry ASW 27			
Mc	Speed	Avg	L/D	Ft/mi
0	55	0	48	109
1	65	31	46	116
2	73	44	41	129
3	80	53	36	146
4	87	60	32	163
5	93	65	29	181
7	104	74	24	218
9	114	82	21	254
	Speed Flown	XC Speed	L/D At Speed	Sink Rate

Conditions	Lift		Speed Flown
Strong Conditions	(6-8 kts lift)	-	90 – 100 kts +
Medium Conditions	(4-6 kts lift)	-	80 – 90 kts
Weaker Conditions	(2-4 kts lift)	-	65 – 80 kts
Survival Conditions	(~1 kt lift)	-	50 – 55 kts

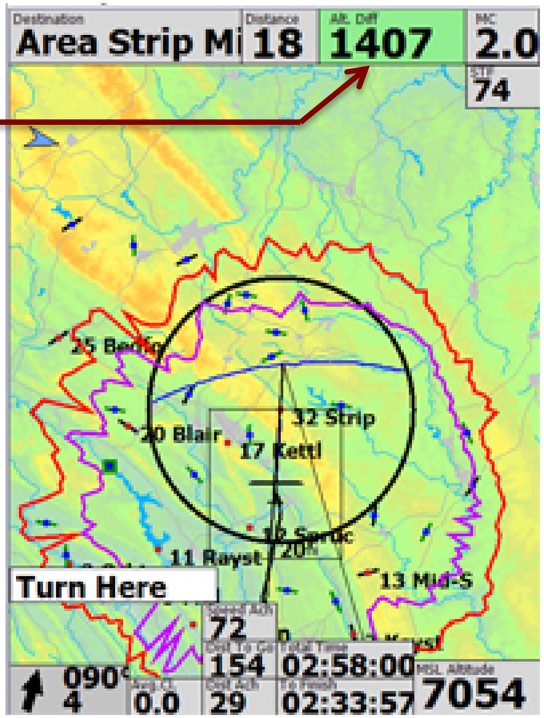
MC Speeds for a Dry and Ballasted ASW-27

Carrying Water Makes a Big Difference Because it Moves the Polar to the Right

	Dry ASW 27				Wet ASW 27			
Mc	Speed	Avg	L/D	Ft/mi	Speed	Avg	L/D	Ft/mi
0	55	0	48	109	67	0	48	112
1	65	31	46	116	79	35	45	117
2	73	44	41	129	89	51	41	127
3	80	53	36	146	97	62	37	141
4	87	60	32	163	105	69	34	156
5	93	65	29	181	113	76	31	170
7	104	74	24	218	127	85	26	201
9	114	82	21	254	139	93	23	230
		XC Speed	L/D At Speed	Sink Rate		XC Speed	L/D At Speed	Sink Rate

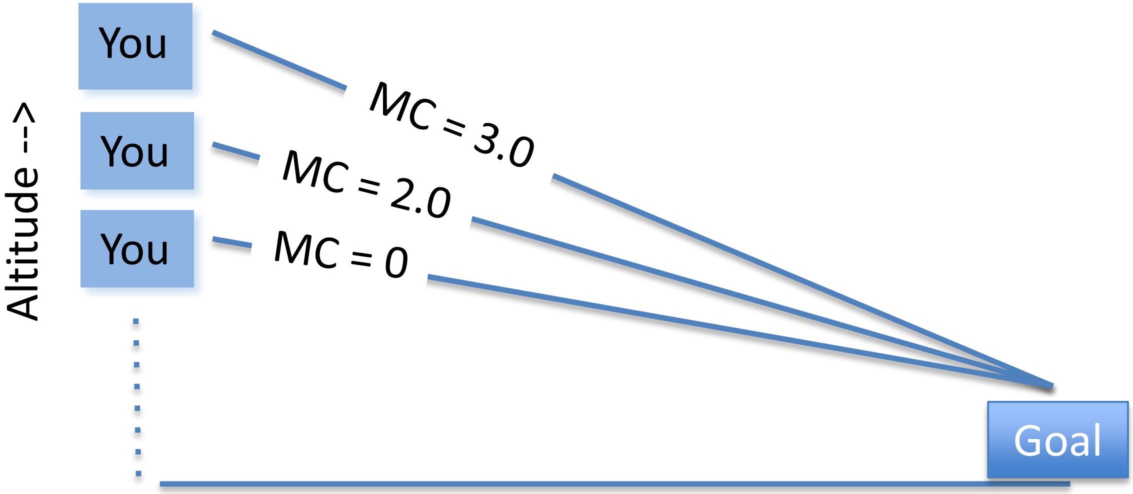
Computers Show the Differential Altitude to a Goal

Other useful data from your flight computer is how much above (or below) you are from the glide slope to your goal. Here a Clear Nav shows you are 1407 feet above glide slope to make a goal (at MacCready 2.0).



The accuracy of this data is critically dependent on having a valid polar for your ship programed into the computer

Your current MacCready setting will change the numerical value of the differential altitude shown. The differential in slope comes from the different speeds (sink rates) dictated by MC theory and your polar.



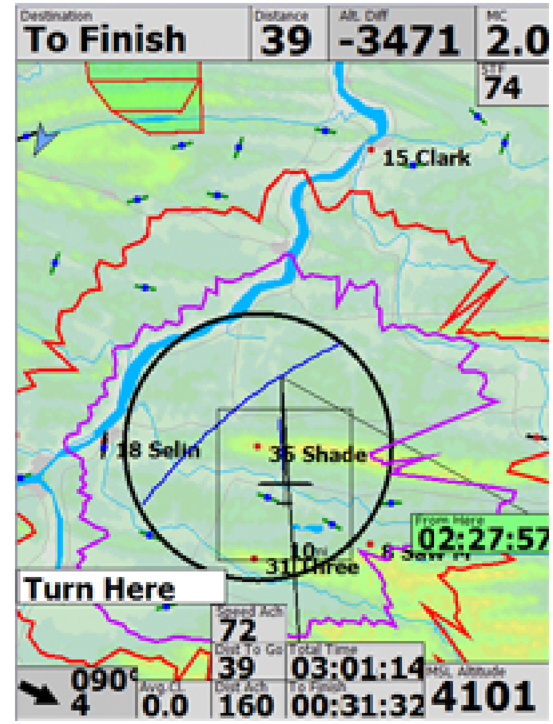
Note especially that a higher MC value dictates a higher average sink rate over the glide. This sink can come from your speed or sinking air (usually a combination of both)

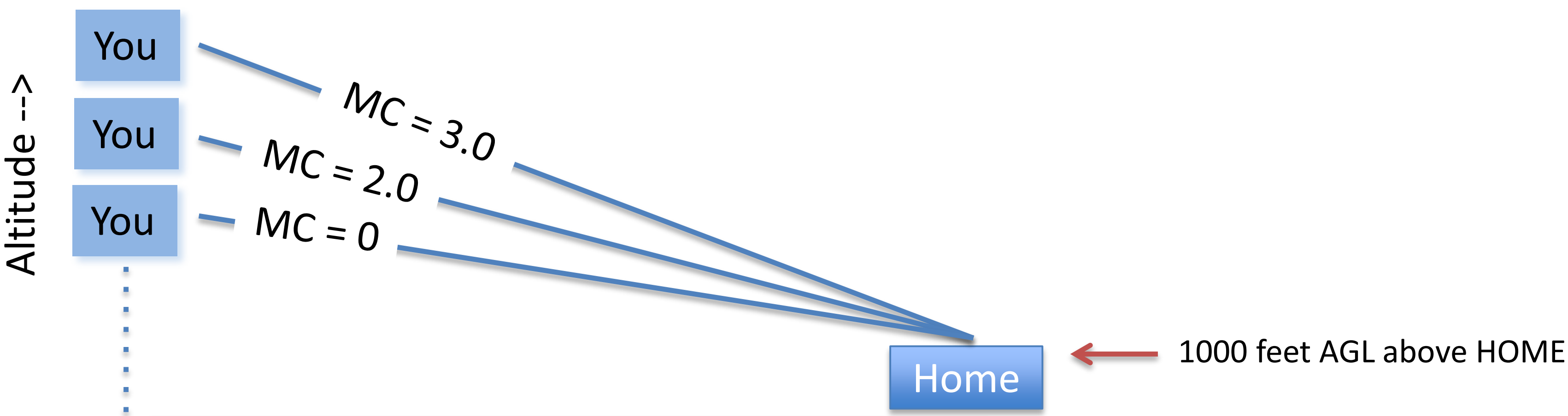
Final Glide to Finish

The Polar and chosen MacCready value are very important in developing your strategy for the final glide to your goal.

At some point on task, your computer will tell you that you have enough altitude to begin your final glide to the finish. The altitude differential displayed to the finish depends on the MC value selected.

Be conservative – Set your MC value for a final glide to about 3. Final glides at MC = 0 rarely work. (The altitude differential shown at MC=0 means your ship is performing exactly to the polar and you will encounter no sink during the glide to the finish – *this is not a likely event*).





END