#### Calculating the Benefits of Dynamic Soaring

#### By Taras Kiceniuk

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The average climb or sink rate of a dynamiic soaring glider is calculated at different speeds. This average vertical speed is a useful measure of a glider's energy exchange with the atmosphere; although in dynamic soaring, a glider often gets much energy in a kinetic form, as extra forward speed. Figures are presented here showing graphs of equivalent average vertical speed calculated at increasing g forces in a dynamic soaring cycle. The calculations are done with a spreadsheet under various simplified atmospheric conditions. The air conditions used here can be viewed as a single dynamic cycle or as a repeating cycle of air motion made up of uniform air blocks. As used here a cycle has two air block types, which have two types of vertical motion; for example--we can assume the glider encounters a 100 foot long block of air rising at 5 foot per second followed by a 100 foot long block of air sinking at 2 Vs., then the two blocks repeat with another 5 Vs rising section again, and so on.

Each figure is for a given set of air conditions. All the graphs shown here are for the same glider performance, a 40:1 L:D ratio, with a one g best L:D speed of 100 feet/second. Eight cases of dynamic soaring technique are presented in columns across each graph. The different cases employ different degrees of varying g force. The first column case is steady one g flight; the other columns use increasing g fluctuation. All the techniques used here have one g of net upward lift. For added clarity, lines of equal speed connect the different column cases. In these calculations, we assume that the glider's speed does not change significantly during a dynamic soaring cycle. The benefits of dynamic soaring can be seen in the graphs by faster forward speeds and larger climb rates.

#### Structure of the figures

The top of each figure shows the glider characteristics used in that sheet of calculations. Below this glider specification box are the assumed air conditions. Then comes a graph showing the glider's calculated performance (presented as average vertical speed) with different dynamic soaring techniques. Average vertical speed is used to represent the glider's net power situation while the glider employs different g force profiles. Lines connect data points of various approximately uniform forward speeds. Directly under the graph are shown the cyclic g forces employed in the different cases. At the bottom of the figure are the cyclic changes in vertical glider speed and the cyclic changes in the angle of the glider's path. (Path angle is similar to pitch angle when one deducts the glider's angle of attack.) The forward speed of the glider is taken to be approximately constant throughout each dynamic soaring

#### cycle. Description of the figures

The first figure is for continuous 5 foot per second updraft. The best performance at all speeds is found in the first column case, which is constant I g flight. This tells us that in uniform air, smooth flight is best and there is no benefit to tying dynamic soaring. The fastest level running speed with no net climb or descent is 150 Vs, it is found in Case I by interpolation between the speed lines marked with triangles and with squares.

Figure 2 is mixed updrafts and stationary air. The horizontal sizes of the air mass blocks are both taken to be 200 feet. 200 feet of 5 Vs updraft is followed by 200 feet of still air. Here the best average climb rate is found in Case 3 at a speed oflOOfeet/second. This climb rate is about 1.5 f/s, which compares favorably to zero in Case 1, smooth I g flight. Case 3 uses a pull up of 2 gs in the updraft and 0 g in the still air. Fastest level running speed is 135 Vs with a Case 3 g force profile.

Figure 3 is turbulence with no net vertical flow, equal size up and downdrafts of 5 Vs strength. With no net up flow, this figure shows pure dynamic soaring. Here the best climb rate is found in Case 6 at a forward speed of 140 Vs. The fastest level running speed of about 173 Vs is found in Case 7. The g forces in Case 7 are +4 g and -2 g. This speed is faster than the level speed in Figure 1, which flies a constant 5 Vs updraft. The comparison with Figure I shows how with dynamic soaring a mixture of updraft and downdrafts can be a stronger source of energy than pure updraft alone.

In Figure 4 the downdraft is twice as strong as the updraft, 10 Vs versus 5 Vs. Despite the net down flow of 2.5 f/s, the increased wind shear gives dynamic soaring a big jump in speeds and energy- note the changes in graph scale. The best climb of 6 Vs is attained at a speed of 180 Vs 'in Case 5. The fastest level running speed is 250 Us 'in Case 8, with g forces of +8 g and -6 g.

Figure 5 is for mixed sink and still air-- 20 Vs downdrafts alternating with blocks of air at rest. Here there are some more graph scale changes. The best climb of about 9 Vs is produced at a speed of 270 Vs in Case 6, which uses plus 8.5 g and minus 6.5 g The fastest level running speed shown is about 320 Vs in Case 8. It is remarkable that a glider can fly so fast using only the energy from sinking air.

Figure 6 is for turbulence of mixed 20 Vs updraft and 20 Vs downdraft. The best rate of climb is 135 f1s at a speed of 390 Vs (Case 4). The fastest horizontal running speed is off the graph- more than 650 feet/second. The associated g forces are over +36 g and -34 g. With such high g maneuvering the effects of the one g force of gravity are relatively small and the glider's flight path can be quite inclined for short periods of time. These energy calculations are considered to be valid when the wind shear is approximately cross- wise to the glider's flight path, this includes vertical wind variation as well as side to side. Fore-aft wind variation is difficult for a glider to utilize to any large extent.

Figure 7 makes a comparison with Figure 2; in Figure 7 the updraft blocks are twice as strong, but twice as far

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apart. The case I performance is the same in figures 2 and 7, but the stronger gusts in 7 can give better dynamic soaring results.

Figure 8 shows the problem that occurs when the air blocks are too big. The graph looks the same as 'in Figure 3, but looking at the chart below the graph we can see that \*in many of the higher g cases the +- change in path angel exceeds 30 degrees and the assumptions used in the calculations are no longer accurate. The two simplif~dng assumptions used here are that the glider's speed does not change much throughout a dynamic soaring cycle and that the wind shear is approximately perpendicular to the glider's flight path.

#### Conclusions

The benefits of dynamic soaring can be very great if turbulence or wind shear is present in the atmosphere. A mixture of updraft and downdraft can be a much stronger source of glider energy than just updraft alone. This is particularly true as the updrafts become stronger. Large g forces can be beneficial in even moderate strength dynamic soaring conditions. To get all the energy from an updraft rising at twice a glider's normal sinking speed, the glider can pull four gs while flying at twice its normal best L:D speed. High g loads and turbulence scale may both limit dynamic soaring possibilities. Atmospheric flow variations are best for dynamic soaring when within a certain size range. If the air blocks are too large the required changes in aircraft path angle become too large and the speed changes also. The high frequency limit may come from the wing's size and from the rate of lift force change possible on the wing. In dynamic soaring the high gs and aerodynamic forces can extract much more energy from the atmosphere than can a gravity-limited glider flying at one g. If we can find consistent airways containing enough wMid shear and can tolerate the high g forces used, then dynamic soaring technique can enable very long and fast flights.

Simplified Two Air Block System at Different Speeds and Gee Loads

Glider Specif	fications:								
All U Fastest Glid	Best L:D = Speed of Weight = er Speed = Increment=	800 180	to one feet/second lbs feet/second feet/second		Indu	ced Drag = tion Drag = 70	10	lbs lbs. feet/sec	
Air Condition	ns:	Smooth L	.ift						
	Air Block 1					Air Block 2			
p Air Motion =	5	feet/second	d	Upward A	ir Motion =	5	feet/second		
Hrz, Size =	200	feet	ł	Horizontal B	lock Size =		feet		
G Load C1 =	1	x 32 f/s/s		Gee Load	Case #1 =	1	x 32 f/s/s		
G increment =	0.5	x 32 f/s/s	]						
	Glider Av	verage Ve	rtical Spee	d in Differ	ent Dyna	mic Gee F	orce Case	es	
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Case #	1	2	3	4	5	6	7	8	
Gee, Block 1	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	
Gee, Block 2	1.00	0.50	0.00	-0.50	-1.00	-1.50	-2.00	-2.50	
Speed	Change i	in Vertica	l Velocity, f	/s and +	Path A	ngle Char	ige, deg.		
100	0	32	64	271					f/:
	0	9	18						d
120	0	27	53 13	80 18	· · · ·				f/. d
140	0	6 23	13 46 <sup>-</sup>	<u>18</u> 69	91	114			f/
140	0	5	40 9	14	18	22			d
160	0	20	40	60	80	100	120	140	f/
	0	4	7	11	14	17	21	24	d
180	0	18	36	53	71	89	107	124	f/
		3	6	8	11	14	17	19	de
	0	3	0	0		17		10	

Figure 1. Loss of performance produced by varying gee force when soaring uniform lift. At lower speeds the glider wing can stall and not make a high gee data point.

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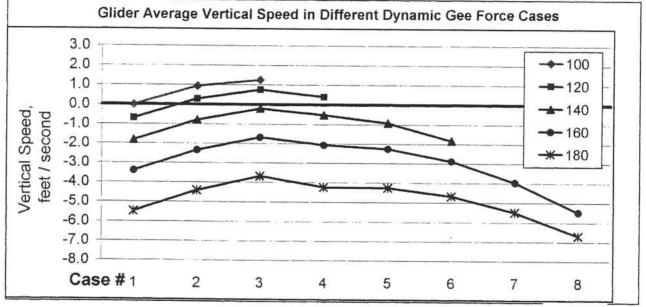
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Simplified Two Air Block System at Different Speeds and Gee Loads

Glider Specifications:	and the second sec					
Best L:D =	40	to one	Drag @ B	Best L:D s	speed & 1 g	iee
@ Speed of	100	feet/second	Induc	ed Drag =	= 10	lbs
All Up Weight =	800	lbs	Fricti	on Drag =	= 10	lbs.
Fastest Glider Speed =	180	feet/second	Stall Speed +&- G=	70	100	feet/sec
Speed Increment=	20	feet/second	Neg G drag factor=	1.25	ratio	

	AIL BIOCK	. 1	F	Air Block	2
Up Air Motion =	5	feet/second	Upward Air Motion =	0	feet/second
Hrz, Size =	200	feet	Horizontal Block Size =	200	feet
G Load C1 =	1	x 32 f/s/s	Gee Load Case #1 =	1	x 32 f/s/s

G increment = 0.5 x 32 f/s/s



		Gee Forc	es in the	Different (	Cases				
Case #	1	2	3	4	5	6	7	8	
Gee, Block 1	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	
Gee, Block 2	1.00	0.50	0.00	-0.50	-1.00	-1.50	-2.00	-2.50	
Speed	Change ir	n Vertical	Velocity,	f/s and ·	+ - Path A	ngle Chan	ae, dea,		
100	0	32	64						f/s
	0	9	18						deg
120	0	27	53	80					f/s
	0	6 ·	13	18	122				deg
140	0	23	46	69	91	114			f/s
	0	5	9	14	18	22			deg.
160	0	20	40	60	80	100	120	140	f/s
	0	4	7	11	14	17	21	24	deg.
180	0	18	36	53	71	89	107	124	f/s
	0	3	6	8	11	14	17	19	deg.

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#### Dynamic Soaring of Patchy Lift Net Up Flow 2.5 f/s Figure 2.

Wind Shear 5 f/s

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	Up Weight =		lbs			tion Drag :		lbs.	
	der Speed =		feet/second	Stall Spe	ed +&- G=	70	100	feet/sec	
Speed	Increment=	: 20	feet/second	Neg G d	rag factor=	1.25	ratio		
ir Conditio	ns:	Turbulen	ce Equal	Up and De	owndrafts				
	Air Block	1				Air Block	2		
Air Motion =	5	feet/secon	d	Upward A	ir Motion =	-5	feet/secon	d	
Hrz, Size =		feet	F		lock Size =	200	feet		
G Load C1 =	1	x 32 f/s/s		Gee Load	Case #1 =	1	x 32 f/s/s		
G increment =		x 32 f/s/s							
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ee, Block 1	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	
ee, Block 2	1.00	0.50	0.00	-0.50	-1.00	-1.50	-2.00	-2.50	
peed	Change		I Velocity, f/	's and +	Path Ar	ngle Cha	nge, deg.		
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20	0	9	18				***		
20	0	27 6	53 13	80 18					
40	0	23	46	69	91	114			25 m 25
1997))	0	5	9	14	18	22			
	0	20	40	60	80	100	120	140	
60	0								
60	0	4	7	11	14	17	21	24	
60 80			7 36 6	<u>11</u> 53 8	14 71 11	17 89 14	21 107 17	24 124 19	

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#### Figure 3. Equal Strength Mixed Updrafts and Downdrafts Wind shear 10 f/s

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Simplified Two Air Block System at Different Speeds and Gee Loads

5 -10 **Glider Specifications:** Drag @ Best L:D speed & 1 gee Best L:D = 40 to one @ Speed of 100 feet/second Induced Drag = 10 lbs All Up Weight = 800 lbs Friction Drag = 10 lbs. Fastest Glider Speed = 260 100 feet/sec feet/second Stall Speed +&- G= 70 Speed Increment= 40 1.25 feet/second Neg G drag factor= ratio Air Conditions: Net Downflow-- Downdrafts Stronger than Ups Air Block 1 Air Block 2 Up Air Motion = 5 feet/second Upward Air Motion = -10 feet/second Hrz. Size = 200 feet Horizontal Block Size = 200 feet G Load C1 = 1 x 32 f/s/s Gee Load Case #1 = x 32 f/s/s 1 G increment = x 32 f/s/s 1 Glider Average Vertical Speed in Different Dynamic Gee Force Cases 10.0 5.0 0.0 **/ertical Speed** feet / second -5.0 -10.0 -100-15.0 -140 -20.0 180 220 -25.0 **★**260 -30.0 Case #1 2 3 4 5 6 7 8 Gee Forces in the Different Cases

Case #	1	2	3	4	5	6	7	8	
Gee, Block 1	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	
Gee, Block 2	1.00	0.00	-1.00	-2.00	-3.00	-4.00	-5.00	-6.00	
Speed	Change i	n Vertical	Velocity,	f/s and	+ - Path Ar	ngle Chan	ige, deg.		
100	0	64		-	8 <b></b> 8				f/s
	0	18							deg.
140	0	46	91		N <del>917</del> 81	199	((66.)		f/s
	0	9	18		<del></del> )(				deg.
180	0	36	71	107	142		1.55		f/s
	0	6	11	17	22		3 <del>75</del> 3		deg.
220	0	29	58	87	116	145	1.55		f/s
	0	4	8	11	15	18			deg.
260	0	25	49	74	98	123	148	172	f/s
	0	3	5	8	11	13	16	18	deg.

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Dynamic Soaring in Net Down Flow. The updrafts are the same as the previou Figure 4. figure, the downdrafts twice as strong. Net Down Flow 2.5 f/s.

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Simplified Two Air Block System at Different Speeds and Gee Loads

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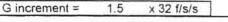
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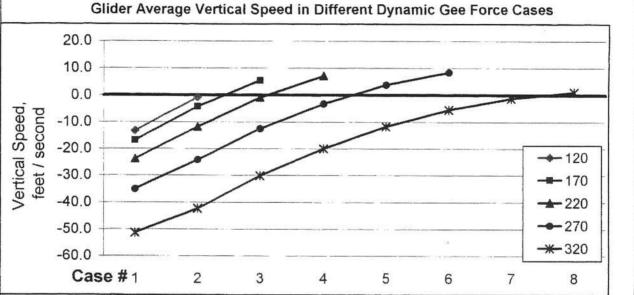
Glider Specifications:					VARA NA ALE SURVEY	
Best L:D =	40	to one	Drag @ B	est L:D s	speed & 1 g	ee
@ Speed of	100	feet/second	Induce	ed Drag =	= 10	lbs
All Up Weight =	800	lbs	Frictio	on Drag =	= 10	lbs.
Fastest Glider Speed =	320	feet/second	Stall Speed +&- G=	70	100	feet/sec
Speed Increment=	50	feet/second	Neg G drag factor=	1.25	ratio	

#### Air Conditions:

Downdrafts Mixed with Still Air

	Air Block	1	م	ir Block	2
Up Air Motion =	0	feet/second	Upward Air Motion =	-20	feet/second
Hrz, Size =	200	feet	Horizontal Block Size =	200	feet
G Load C1 =	1	x 32 f/s/s	Gee Load Case #1 =	1	x 32 f/s/s





#### Gee Forces in the Different Cases Case # 1 2 3 4 5 6 7 8 Gee, Block 1 1.00 2.50 4.00 5.50 7.00 8.50 10.00 11.50 Gee, Block 2 1.00 -0.50 -2.00 -3.50 -5.00 -6.50 -8.00 -9.50 Speed Change in Vertical Velocity, f/s and + - Path Angle Change, deg 120 0 80 -------f/s 0 18 \_\_\_ deg. --------..... 170 0 56 113 -----------f/s ----0 9 18 ------------deg 220 0 44 87 131 -------f/s ---0 6 11 17 ----225 --deg. ---270 0 36 71 107 142 178 -----f/s 0 4 8 15 11 18 \_\_\_ deg. 320 0 30 60 90 120 150 180 210 f/s 0 3 5

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deg.

Downdrafts and Still Air--Figure 5.

Wind Shear 20 f/s Net Down Flow 10 f/s

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Simplified Two Air Block System at Different Speeds and Gee Loads 20 -20

Glider Speci	fications:								
All L Fastest Glie	Best L:D = @ Speed of Jp Weight = der Speed = Increment=	100 800 650	to one feet/second lbs feet/second feet/second		Induc	Best L:D s ced Drag = ion Drag = 70 1.25		e Ibs Ibs. feet/sec	
Air Conditio		Strong Tu	rbulence						
an oonanto			Buloneo			Air Die ek 0			
Jp Air Motion =	Air Block 1 20	feet/second		I Inward A	Air Motion =	Air Block 2 -20	feet/second	4	
Hrz, Size =		feet			lock Size =	200	feet	-	
G Load C1 =		x 32 f/s/s			I Case #1 =	1	x 32 f/s/s		
G increment =	5	x 32 f/s/s							-
	Glider Av	verage Ver	tical Spee	d in Diffe	rent Dynar	nic Gee	Force Cas	es	
200	)								
150	S 16								-
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50	)	/		~	<u> </u>				-
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-350 -400									
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Gee, Block 1	1.00	6.00	11.00	16.00	21.00	26.00	31.00	36.00	
Gee, Block 2	1.00	-4.00	-9.00	-14.00	-19.00	-24.00	-29.00	-34.00	
Speed	Change i	in Vertical	Velocity, 1	/s and -	+ - Path Ar	ngle Cha	nge, deg.		
130	0								f/s
260	0	123							de f/s
260	0	123							de
390	0	82	164	246					f/s
F0476476	0	6	12	18					de
	0	62	123	185	246	308			f/s
520	0	3	7	10	13	16			de
		10	98	148	197	246	295	345	f/s
	0	49							0004/0
520 650	0	49 2	4	6	9	11	13	15	de

Figure 6.

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Stronger Atmospheric Turbulence No Net Vertical Flow 40 f/s Wind Shear

Simplified Two Air Block System at Different Speeds and Gee Loads

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Glider Speci								
All L Fastest Glic	Best L:D = @ Speed of Jp Weight = der Speed =	40 f 100 800 180	to'one feet/second lbs feet/second		Induc Frict ed +&- G=	ed Drag = ion Drag = 70	= 10 I 100 f	bs bs. eet/sec
Speed	Increment=	20	feet/second	Neg G d	rag factor=	1.25	ratio	
Air Conditio	ns:	Patchy Li	ift Stronge	er Patches	, Farther A	part		
	Air Block '	1				Air Block 2	2	
Jp Air Motion =	10	feet/secon			ir Motion =	0	feet/second	
Hrz, Size = G Load C1 =	200 1	feet x 32 f/s/s		Horizontal B Gee Load	lock Size = Case #1 =	600 1	feet x 32 f/s/s	
G increment =	0.5	x 32 f/s/s	]					-
	Glider Av	verage Ve	rtical Spee	d in Diffe	ent Dynan	nic Gee	Force Case	S
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140 0 23 46 69 91. 114 137  f/s   0 5 9 14 18 22 26  deg   160 0 20 40 60 80 100 120 140 f/s   0 4 7 11 14 17 21 24 deg   180 0 18 36 53 71 89 107 124 f/s	120	0	27	53	80					the state of the s
0 5 9 14 18 22 26  deg   160 0 20 40 60 80 100 120 140 f/s   0 4 7 11 14 17 21 24 deg   180 0 18 36 53 71 89 107 124 f/s		0	6	13	18				227	deg.
160 0 20 40 60 80 100 120 140 f/s   0 4 7 11 14 17 21 24 deg   180 0 18 36 53 71 89 107 124 f/s	140	0	23	46	69	91.	114	137		f/s
0 4 7 11 14 17 21 24 deg   180 0 18 36 53 71 89 107 124 f/s		0	5	9	14	18	22	26		deg.
<b>180</b> 0 18 36 53 71 89 107 124 f/s	160	0	20	40	60	80	100	120	140	f/s
		0	4	7	11	14	17	21	24	deg.
0 3 6 8 11 14 17 19 deg	180	0	18	36	53	71	89	107	124	f/s
		0	3	6	8	11	14	17	19	deg.

# Figure 7.Patchy Lift with Stronger More Separated UpdraftsNet Up Flow 2.5 f/sWind Shear 10 f/s

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Simplified Two Air Block System at Different Speeds and Gee Loads

Clider Speci	ficationa							
Glider Speci								
	Best L:D =		to one				speed & 1 ge	e
	@ Speed of		feet/second	1		ced Drag =		lbs
	Up Weight =		lbs	n and analysis		tion Drag :		lbs.
	der Speed =		feet/second		eed +&- G=	70	100	feet/sec
Speed	Increment=	20	feet/second	Neg G	drag factor=	1.25	ratio	
Air Conditio	ns:	Turbulen	ce Lower	Frequenc	у			
	Air Block 1	1				Air Block	2	
Up Air Motion =	5	feet/secon	d	Upward ,	Air Motion =	-5	feet/secon	d
Hrz, Size =		feet		Horizontal E	Block Size =	600	feet	
G Load C1 =	1	x 32 f/s/s		Gee Load	d Case #1 =	1	x 32 f/s/s	
G increment =	0.5	x 32 f/s/s	7					
	Glider Av	verage Ve	rtical Spee	d in Diffe	rent Dynar	nic Gee	Force Cas	es
3.0	Τ	and a closed to constrain the second second	allowed . It shall with a				- (14 million 17 million	
2.0	+							
1.0								
. 0.0		4					17.0	
	1	X		~			*	
00 -1.0	-	///	/~			×		
d 0 -2.0		/ /						_
-3.0	~	/_/	/					
0.4- et /	/	1	*					
Vertical Speed feet / second -2.0 -2.0 -2.0 -2.0	<b>K</b>							
> -6.0		×						
		/					160	
-7.0	/	/					<del>- <b>ж</b>-</del> 180	• • • • • • • • • • • • • • • • • • •
-8.0	<b>X</b>	988 SLITTING		Malaine - 10 alleidire - 11 alleidire		ni ini menini i i menini		
Ca	se # 1	2	3	4	5	6	7	8
		Gee Ford	ces in the [	Different (	Cases	4.5-Xamilan (54 - 55 - 56 - 56 - 56 - 56 - 56 - 56 -		<u> </u>
Case #	1	2	3	4	5	6	7	8
Gee, Block 1	1.00	1.50	2.00	2.50	3.00	3,50	4.00	4 50

Gee, Block 1	1.00	1.50	2.00	2.50	2.00	2.50	4.00	1.50	-
Gee, Block 2	1.00	0.50	0.00	2.50 -0.50	3.00 -1.00	3.50 -1.50	4.00 -2.00	4.50 -2.50	
Speed	Change i	in Vertical	Velocity,	f/s and	+ - Path	Angle Char	nae, dea.		
100	0	96	192						f/s
	0	26	>30 deg.						deg
120	0	80	160	240		( <del>1</del> ))			f/s
	0	18	>30 deg.	>30 deg.					deg
140	0	69	137	206	274	343			f/s
	0	14	26	>30 deg.	>30 deg.	>30 deg.			deg
160	0	60	120	180	240	300	360	420	f/s
	0	11	21	>30 deg.	>30 deg.	>30 deg.	>30 deg.	>30 deg.	deg.
180	0	53	107	160	213	267	320	373	f/s
	0	8	17	24	>30 deg.	>30 deg.	>30 deg.	>30 deg.	deg.

Taras K August 2002

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Figure 8. Problems can arise with path angles when air blocks become too large.

TECHNICAL SOARING