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*Ref. to C. E. Jackson*

A WIND TUNNEL INVESTIGATION OF THE  
KASPER VORTEX CONCEPT\*

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Abstract

A model of the Kasper vortex lift wing was constructed and tested in a small scale wind tunnel in an effort to verify the inventor's high lift and low drag predictions. Not one of the vortex configurations tested performed as well as a conventional clean airfoil. Flow visualization studies using tufts indicated fundamental differences from Kasper's predictions, including both the direction of vorticity and the number of vortices present. The model from a former wind tunnel investigation was obtained in order to confirm the promising results reported. Retesting, however, showed drastically inferior performance to that originally published. This investigation, though not matching full scale Reynolds numbers, indicates that significant vortex lift cannot be obtained without some means of external energy addition.

Nomenclature

- AR Aspect ratio,  $b^2/S$
- b Wing span
- c Airfoil chord
- $C_D$  Coefficient of drag,  $drag/qS$
- $C_{D_0}$  Equivalent parasite drag coefficient
- $C_L$  Coefficient of lift,  $lift/qS$
- $C_{L_2}$  Sectional lift coefficient
- $C_{\mu}$  Coefficient of blowing,  $thrust/qS$
- e Span efficiency factor
- $L'$  Lift per unit span
- L/D Lift over drag ratio
- q Free stream dynamic pressure,  $1/2 \rho v_{\infty}^2$
- Re Reynolds number
- S Wing area
- $v_{\infty}$  Free stream velocity
- $\rho$  Air density
- $\Gamma$  Circulation strength

I. Introduction

Today's high speed commercial jet aircraft have made air travel the most preferred mode of long distance transportation. Helicopter technology with its vertical landing and take-off capability has found a multitude of profitable applications in special purpose short haul work. But our present day mastery of aeronautics has little to offer to satisfy the great need for long range and high speed transport type aircraft with a V-STOL capability. Some have attempted tilting rotor schemes, others have tried vectored thrust and augmentation. Still others are working on blown flap systems or supersonic helicopter rotors. So far none of these schemes has fulfilled the goals of payload, range, speed, operating cost, take-off distance and safety to an extent where the new market's demands can be met. Recently, a new phenomenon has allegedly been discovered which, the discoverer claims, may lead to a superior method of meeting the V-STOL transport challenge. The discoverer is Mr. Witold A. Kasper, the new phenomenon is what he calls Vortex Augmented Lift or simply "Vortex Lift."

Mr. Kasper, a former national glider champion of Poland, is now a retired Boeing engineer who had specialized in high lift landing devices. By 1966 Kasper and two associates had completed the BKB-1 tailless glider with the goal of improving stability and control at low speeds over conventional gliders. During test flights (1) Kasper investigated the stall characteristics of his glider. He found the stall began at 40 mph and with a sink rate of 600 fpm; at full up elevon deflection, he found no loss of control. Kasper wondered if he had reached a fully stalled condition, so prior to the next flight he adjusted his linkage to increase the up deflection of the elevons. During the next flight he began his stall as before, at 40 mph the sink rate went from 200 fpm to 600 fpm as before. As he pulled the stick back further an amazing thing happened. The speed dropped to 20 mph, the angle of attack indicator showed 35 degrees and the sink rate had dropped to only 100 feet per minute - half the minimum sink rate in normal flight! The airplane was also completely stable and control response was as good as in normal flight. The lift coefficient required for such performance is 3.15 and the L/D is 17.6.

If these results are accurate, then obviously some new phenomenon is operating on Mr. Kasper's glider. Kasper proposes that a tornado like vortex forms horizontally over the upper surface of his wing, drastically increasing the circulation about

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the airfoil which both increases the lift and reduces the drag. He suggests it may be possible to further enhance this effect by deploying special flaps (Protected by U.S. Patent No. 3,831,885) which control feeding of the vortices and vortex shedding as shown in figure 1. He also suggests the use of blowing to energize the vortex and create super circulation.

KASPER  
POWERED  
PROTOTYPE

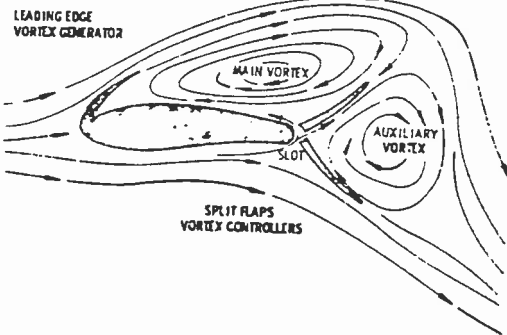
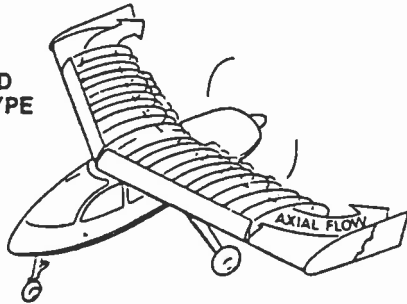


Figure 1. Kasper vortex augmented wing and airfoil section

So far no one has independently verified Mr. Kasper's performance with flight tests, and aerodynamic theory does not seem to be able to confirm or deny this alleged phenomenon. Subsequent flights of the sailplane showed high vortex lift performance somewhat sporadically. The possibility of occasional aid from local atmospheric lift should not be ruled out.

Several other pilots have flown the BKB-1 glider, and while performance was not always confirmed, another characteristic was always confirmed; the glider has a stable mode of flight at very high angles of attack which is not accompanied by any shuddering or oscillation. Several aerodynamicists are convinced that little or no vortex shedding occurs and that a stable vortex pattern exists.

During past discussions between Mr. Kasper and the author the need for careful experimental work became painfully clear. However, as a result of informal wind tunnel testing on a 0.1 scale model of his BKB-1 sailplane at NASA Langley in 1973, a brief account of which is included in

reference 2, Mr. Kasper warns that significant performance may not be obtainable with small scale models. He explains that when simulating full scale Reynolds numbers at many times full scale velocity, the flow pattern is altered so that little lift is obtained, while at low Reynolds numbers, viscosity losses impede the vortex flow. Wind tunnel tests of Kasper's airfoil have also been conducted at the State University of Wichita (3) and by Saab Scania in Sweden (4,5). Wichita obtained poor results. Saab also obtained poor performance until blowing with external air was introduced. These results will be discussed in more detail toward the end of this paper.

Most recently, a two page article (6) appeared in Soaring Magazine which showed promising results from a small scale wind tunnel test of an airfoil using Kasper flaps without blowing. The test was conducted as a class project by Daniel Walton, at that time a graduating senior at the Northridge campus of the University of California. Walton obtained a maximum lift coefficient of 3.0 but an L/D of only 1.5. Walton's lift curve slope was twice the value expected for a model of his aspect ratio and airfoil thickness. Walton's model was later shipped to Seattle for retesting by the author. These results will be discussed later in this paper.

Upon discussing Walton's results with Mr. Kasper, he proposed four modifications of Walton's test to improve the performance. They were, 1) sweep the wing 13 degrees, 2) remove the trailing edge flaps near the tip plates, 3) thin down the airfoil, 4) run the tunnel at lower speed. The purposes of the above four modifications, according to Kasper, are as follows: 1) to give the axial core flow of the vortex a sense of direction, 2) to provide an escape for the axial flow at low angles of attack (Kasper supposed this may smooth out Walton's lift curve, avoiding the stall), 3) to lower the drag, and 4) to satisfy the condition that the production and maintenance of external vortices requires low airspeed. By incorporating these changes, it was hoped to increase the strength of the vortices, thereby increasing the maximum lift coefficient past 3.0 and decreasing the drag so as to yield a sizeable L/D.

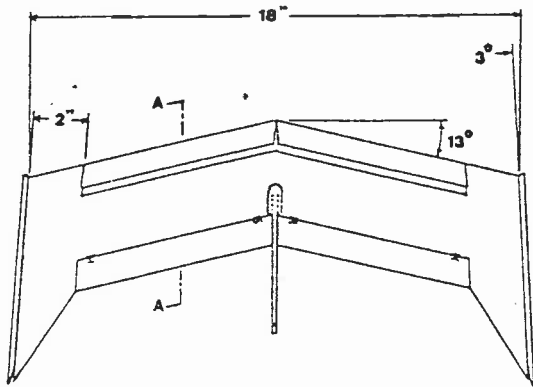
At this point the author decided to build a model similar to Walton's and incorporate exactly the suggestions of Mr. Kasper. The final drawings of the wind tunnel model were submitted to Kasper for approval before construction began. Testing commenced in January of 1975 during the author's sophomore year at the University of Washington. The model closely resembles Kasper's full scale prototype airplane which crashed on takeoff May 28, 1974 due to admitted pilot error (2). The aircraft is presently being rebuilt.

## II. Experimental Setup and Procedure

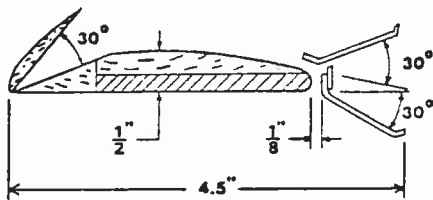
### a. Model Characteristics

Figure 2 shows the geometry of the University of Washington Kasper wing model with the first flap configuration. The model was built over a 3/16 inch aluminum base plate. The upper and front surfaces are mahogany, the rear flaps are 1/16 inch aluminum sheet. The surfaces were finished with four coats of sanding sealer, then two coats of

flat black spray paint. The model was refinished with two brushed coats of gloss black paint prior to run number eight. The end plates are 1/4 inch plexiglass. A Clark Y section was chosen for the clean airfoil. Both front and rear flaps are 25% chord. The flaps are built at fixed angles but may be easily interchanged with flaps built at other angles. Subsequent configurations also used 1/16 sheet aluminum flaps. Fairings and scoops were mahogany or balsa wood. Wind tunnel "clax" was used for filling surface imperfections and slot gaps.



WING AREA 0.61 SQ. FT.  
ASPECT RATIO 3.8



SECTION A-A

Figure 2. Scale drawing of U of W Kasper wing model

b. Wind Tunnel Description

All testing was done using the venturi wind tunnel at the University of Washington. Figure 3 shows a side view of the tunnel. The test section is hexagonal in cross section with 36 inches between opposing corners. The clean section dynamic pressure range of the tunnel is from 0 to 14 psf. The tunnel turbulence factor is 2.85.

The tunnel uses a three component beam balance which measures lift, drag and pitching moment. The model is mounted on three strut supports as seen in figure 4. Pitching from 0 to 90 degrees angle of attack is accomplished by means of two separately used pitching arms which connect the model to the

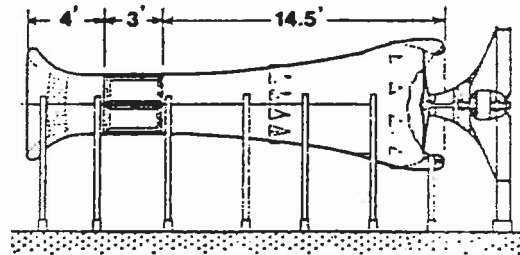


Figure 3. Side view of the U of W venturi wind tunnel

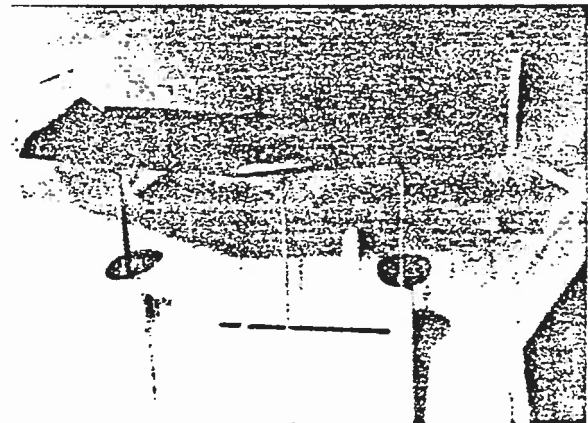


Figure 4. Kasper model mounted in venturi tunnel

tunnel pitch strut. One arm is for 0 to 45 degrees and one for 45 to 90 degrees angle of attack.

c. Data Reduction

Lift and drag forces were reduced in the usual manner to obtain coefficients by dividing the forces by wing area and dynamic pressure. No wind tunnel wall corrections, blockage corrections or fork tares were applied in data reduction. These corrections are of the order of a few percent of the measured forces.

d. Testing Procedure

Angle of attack was calibrated using a pendulum inclinometer. Angles were measured with respect to the wing flat bottom surface. The dynamic pressure calibration was verified by using an independent pitot-static probe and U-tube manometer. Balance accuracy was verified using known standard masses. All surface imperfections were filled with

wind tunnel clax, and the entire model was wiped clean before each run.

#### IV. Discussion of Results

Each configuration was tested at up to four different airspeeds to check for Reynolds number dependence. The four dynamic pressures used were 0.49, 1.94, 4.40, and 10.52 psf. These speeds correspond to Reynolds numbers of 50,000, 100,000, 150,000, and 232,000. The given Reynolds numbers are not corrected for the tunnel turbulence factor.

During the last half of the test program each configuration was tufted in an effort to visualize the flow field. The tufting method used was somewhat unconventional because there was a need to obtain information about the flow far from the surface of the model. Long tufts often several inches in length were taped to the trailing edges of all flaps. Short tufts were also taped to the model surfaces in the normal fashion. In addition, a tuft wand was inserted through the ceiling of the tunnel which allowed probing of any particular area of interest. The flow was in general very turbulent and somewhat unsteady so that the flow field presented itself clearly only after it was observed closely for several minutes at various angles of attack. For this reason it was deemed that instead of taking multitudes of photographs, careful sketches drawn of the flow during testing would be a more efficient means of recording the data.

#### III. Experimental Results

The performance of all configurations tested is summarized in table 1. The geometry of each configuration is followed by the values of maximum lift coefficient and maximum lift over drag ratio obtained for each run. Note that not one of the configurations even begins to approach a  $C_{L_{max}}$  of 3.15 as claimed for Kasper's BKB-1 sailplane. The table indicates a very slight improvement with increasing Reynolds number. However, the magnitude of the improvement is seen to be negligible. Runs 1-9 show a slight improvement in performance with a gloss over flat finish. Again the magnitude of the improvement is negligible.

The performance of all configurations is plotted in figure 5 at a Reynolds number of 150,000. By far the best performance is seen to be that of the clean airfoil (Config. 11) with no flaps. The characteristics are completely conventional.

Highlighting the vortex flap data, figure 5a shows the performance is only slightly affected by substantial alterations of rear flap geometry. The dominant variable affecting performance is seen to obstruction of the rear slots as shown in figure 5b. Note the performance increase not with the augmenting scoop but with a closed slot. The three configurations which fall into a distinctly higher performance level are grouped together in figure 5c. All had one or more of the rear flap slots closed. Figure 5d shows a very slight improvement with the enlarged lower slot gap of configuration 6. Configuration 12, with only a front flap is seen to perform quite similarly to the configurations with rear flaps and open slots except that it has the lowest drag.

Figure 5 shows that most of the flap configurations stall at about 30 degrees angle of attack but not one of them attains the  $C_{L_{max}}$  of the clean wing.

#### a. Rationale For Configuration Selection

Before analyzing the numerical data in detail, let us examine the reasoning leading from one configuration to the next. Referring back to table 1, configuration No. 1 was first chosen because at that time Mr. Kasper believed this was the optimum configuration. The model was originally painted flat black to improve contrast for flow visualization techniques. The performance of configuration 1 was disappointing. In order to determine if surface finish was of importance, the model received a polished finish (renamed configuration 2) prior to run 8. The polished finish negligibly improved performance.

These results were discussed with Mr. Kasper. He proposed that a strong vortex may have formed with both rough and smooth surfaces, but had been blown behind the airfoil so that its effect on the lift of the model were minimal. He suggested the upper rear flap be raised in an attempt to contain the vortex over the wing.

Configuration 3 was designed to contain the vortex as suggested. However, testing showed no improvement over the basic configuration. No flow visualization had yet been performed. Configuration 3 was judged to be ineffective in containing the vortex above the wing.

Configuration 4 attempted, by means of a triangular scoop, to get more forward momentum into the main vortex so as to keep it in front of the rear flap. The reduction in performance was unexpected.

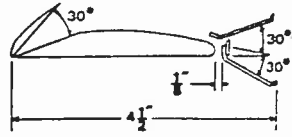
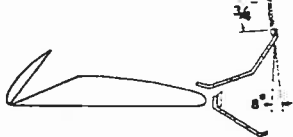
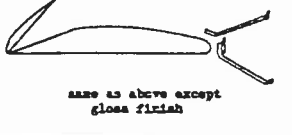
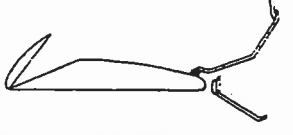
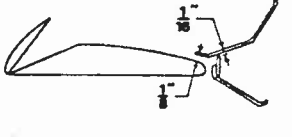
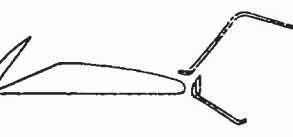
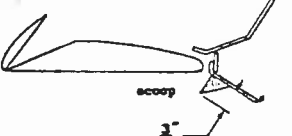
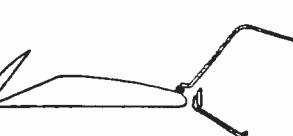
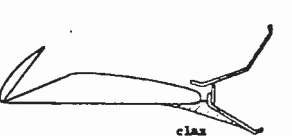
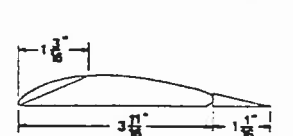
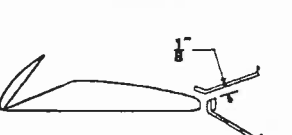

In testing configuration 5, it was thought if increasing the flow through the slot impaired the performance, then perhaps decreasing the flow through the slot would improve performance. This hypothesis proved true.

By this time it was evident that this test had become an exercise in stabbing in the dark. With no mathematical theory and relying on force data alone, one simply could not anticipate the effects of alterations of configuration. Mr. Kasper urged the use of long lightweight tufts as a "flashlight in the darkness".

The use of tufts indeed proved to be a very useful diagnostic tool. As outlined earlier, tuft results were recorded by making careful sketches as the tufts were observed over several minutes. A tuft wand was used to help fill in the picture. Figure 6a shows that for configuration 3, a clockwise vortex of unknown strength was in fact contained by the upper rear flap. What was destroying the lift was the counter-clockwise vortex behind the wing.

Beginning with configuration 6 priority was changed from obtaining a strong forward vortex to reversing the direction of the rear vortex to yield clockwise, or positive circulation. Increasing the rear slot width did not alter tuft results and only negligibly improved the performance. A small improvement was obtained with the extended flap of configuration 7, but the counter-clockwise rotation of the rear vortex persisted.

Table 1. Summary of experimental results

Config. No.	Configuration (Drawn to Scale)	Run	Re/1000	C <sub>L</sub> max	L/D max	Config. No.	Configuration (Drawn to Scale)	Run	Re/1000	C <sub>L</sub> max	L/D max
1		1	50	0.86	1.97	7		27	100	1.15	2.15
		2	100	1.03	1.76			28	150	1.11	2.16
		3	150	1.00	1.81			29	232	1.07	2.13
		4	232	0.94	-						
		5	100	0.99	1.84						
		6	150	1.03	1.78						
		7	232	0.97	1.86						
2		8	50	1.07	1.92	8		30	100	1.23	2.82
		9	100	1.03	1.82			31	150	1.19	2.93
		10	vary	-	-			32	232	1.14	2.95
3		11	50	0.92	1.57	9		33	100	1.15	2.43
		12	100	1.03	1.81			34	150	1.11	2.43
		13	150	1.00	1.87			35	232	1.07	2.09
		14	232	1.00	1.90						
4		15	50	0.77	1.45	10		36	100	1.23	4.07
		16	100	0.85	1.42			37	150	1.18	3.87
		17	150	0.86	1.49			38	232	1.14	4.14
		18	232	0.86	1.60						
5		19	50	1.15	2.88	11		39	50	1.17	8.91
		20	100	1.30	3.21			40	100	1.14	9.56
		21	150	1.28	3.48			41	150	1.11	10.60
		22	232	1.27	3.48			42	232	1.07	10.12
6		23	50	0.92	1.74	12		43	150	1.11	2.18
		24	100	1.07	1.81			44	232	1.07	2.28
		25	150	1.05	1.88						
		26	232	1.04	1.88						

By closing the slot between the upper rear flap and the wing in configuration 7 (renamed configuration 8), it was hoped that the additional flow through the rear exit slot would force clockwise circulation in the rear vortex. The performance was somewhat improved but the tuft indications were at first unclear. After a lengthy session of meticulous probing with the tuft wand, the flow field was deduced to be that sketched in figure 6b. Only one of the three new vortices formed was clockwise. This revealed the geometry of configuration 8 to be all wrong.

Configuration 9 was designed to effectively contain the forward vortex and at the same time induce a clockwise circulation in a single rear vortex. Figure 6c shows that although a clockwise

rear vortex was achieved, an even larger and unexpected counter-clockwise vortex was induced behind the wing again cancelling any possible gains.

Configuration 10 showed somewhat improved performance once more due to closing the rear flap slot but the flow pattern was essentially that of configuration 9 except more pronounced. Configuration 11 was the clean Clark Y airfoil, providing a baseline for comparison.

Configuration 12 was tested to determine the effect of the leading edge flap alone. Again, two opposing vortices formed as shown in figure 6d. The flow pattern is strikingly similar to that of configurations 1-7. The performance was virtually the same as all earlier configurations with open

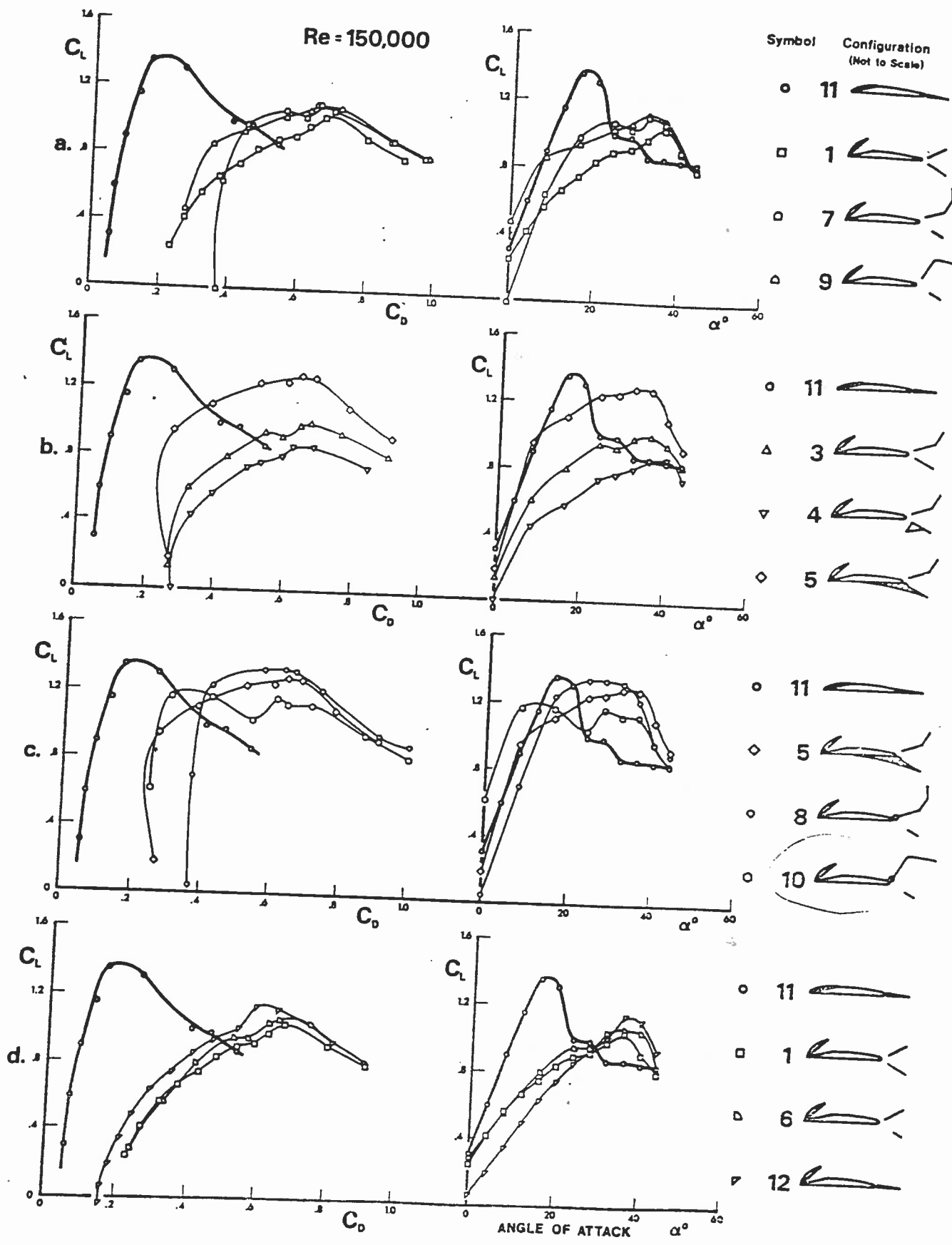


Figure 5. Kasper wing model performance

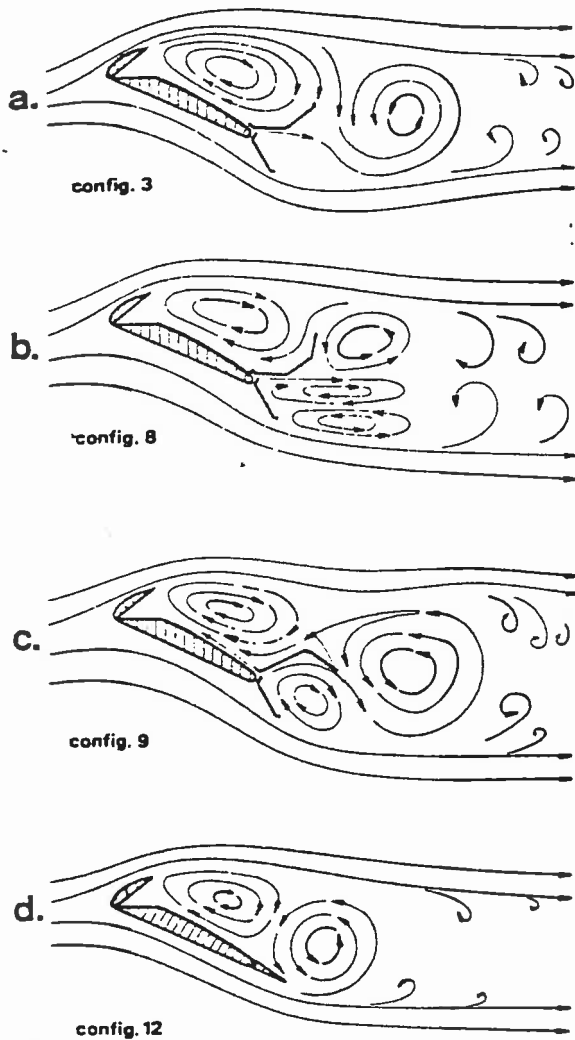


Figure 6. Flow visualization results with the U of W wing

rear slots. This seems to indicate that the net effect of the rear flaps with open slots was merely to alter the position of the basic vortex pair formed over the wing at high angles of attack, and to contribute more wetted area for skin friction drag. With closed slots, the lower rear flap was better able to operate as a standard unslotted flap, and thereby improve performance.

b. What Could be Learned by Analytical Methods?

Ten years ago, a purely analytical attempt at solving three dimensional separated flow problems such as the Kasper vortex lift concept would have been quite unfeasible. Much progress has since been made through the use of numerical methods and large computers so that the state of the art today allows aerodynamicists to tackle problems such as reattachment after separation and stall prediction for both two and three dimensional wings. By using

predominantly potential flow methods, the pressure distribution over highly swept delta wings with leading edge vortex separation can be accurately predicted. (7) The boundary conditions for the Kasper concept are likely to be somewhat similar.

In carrying out an analytical investigation of this concept, a great deal of simplification results if only one external vortex is used. This leaves two distinct questions to be addressed. First, what are the necessary conditions to stop the external vortex from shedding away? Second, having achieved a stable vortex, can a unique solution be found for the rear reattachment point (which may occur on a free surface) so that a pressure distribution on the airfoil can be obtained?

The apparent requirement of wing sweep, and the Swedish tests (4) both indicate vortex stability to be sensitive to three dimensional characteristics. But by using appropriate trailing edge blowing or suction, for example, a two dimensional solution might be made stable. This would allow a relatively low cost two dimensional program to be utilized.

For non externally energized flow, this concept is likely to depend on three dimensional factors for its very existence, so that a full analysis requires a three dimensional program. The necessary spanwise core flow for stability would be found as a result of finding a steady state solution. Sweepback would probably be required to initiate a spanwise flow component. A three dimensional analysis could be very costly and would probably not be warranted until an experiment undisputably demonstrates high performance.

An interesting calculation can be performed to find the sectional lift coefficient produced by the Kasper wing if some geometric characteristics are arbitrarily specified using reasonable guesses. Referring to figure 7, let us again deal with two external vortices whose strengths are labeled  $\Gamma_2$  and  $\Gamma_3$ . Let an integration path for  $\Gamma_2$ , such as shown in the figure, be specified to be of length  $3/2c$ , and let the velocity in the direction of the path have an average magnitude of  $V_\infty$ . The circulation,  $\Gamma_2$ , is now specified to be  $3/2 V_\infty c$ . Let  $\Gamma_3$  equal  $\Gamma_2$ . If  $\Gamma_1$  produces a  $C_L$  on the airfoil of 1.0, which is a typical value for a stalled section, then  $\Gamma_1$  is easily shown to be  $1/2 V_\infty c$  by using the standard equations  $L' = \frac{1}{2} \rho V_\infty^2 C_L c$  and

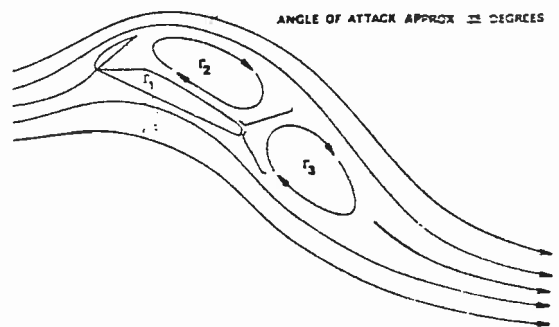


Figure 7. Idealized flow field with vortex lift

$L' = \rho V \Gamma$ . The symbols for these equations have been defined in the nomenclature. The final  $C_L$  produced by summing the contributions from  $\Gamma_1$ ,  $\Gamma_2$  and  $\Gamma_3$  is 7.0. This  $C_L$  is about twice the  $C_{L_{max}}$  obtainable with today's triple slotted flap systems. This calculation ignores much of the important physics of the problem, but gives a reasonable upper bound on the performance which may be expected.

c. Data interpretation and evaluation

The results from the vortex flaps configurations as seen in figure 5 show improved performance when the slot feeding the main vortex is closed. This is contrary to the expectations of Mr. Kasper, who predicted that the increased strength of circulation of the vortices would more than offset the loss of downward momentum. Apparently, net circulation was not significantly improved, while the effectiveness of the lower rear flap was diminished.

As stated earlier, the performance of the clean airfoil is quite conventional. The wing stalls at 16 degrees angle of attack, attaining a  $C_{L_{max}}$  of 1.35 and a maximum L/D of 10.0. Figure 6 shows that most of the flapped configurations stall at roughly twice the angle of attack of the clean airfoil, however the  $C_{L_{max}}$  is not as high. High angles of attack themselves are no advantage, since this causes passenger discomfort during landing and takeoff. The drag of all flapped configurations is prohibitively high, with the best performance being that of configuration number 10 at a Reynolds number of 232,000, giving a maximum L/D of 4.14 at a  $C_L$  of 1.2. Recall that Kasper claims an L/D of

17.6 at a  $C_L$  of 3.15 for his sailplane. By accounting for the difference in induced drag due to aspect ratio between the BKB-1 glider and the University of Washington model of the powered airplane, wind tunnel results should show an L/D of 5.1 at a  $C_L$  of 3.15, in order to substantiate Kasper's claims. Reynolds number effects may reduce the L/D to about 3 or 4.

It is interesting to compare the BKB glider performance with a prediction based on an induced drag polar. Using the BKB aspect ratio of 9.5, assuming a  $C_{D_0}$  of 0.01, and assuming  $e$ , the span efficiency factor to be 1.0, we use  $C_D = C_{D_0} + C_L^2/\pi A e$ . At a  $C_L$  of 3.15 the  $C_D$  is 0.34, therefore the L/D equals 9.2. Mr. Kasper claims to obtain an L/D of 17.6 at the same  $C_L$ .

Results from this wind tunnel study show neither high lift coefficients nor any reduction in induced drag from the use of vortex methods. However a question remains which must be answered. Why did Daniel Walton (6) obtain a  $C_{L_{max}}$  of nearly 3.0 with his model of the Kasper airfoil?

The author contacted Mr. Walton and obtained his gracious cooperation in shipping his model to Seattle for retesting in the venturi wind tunnel. Figure 8 shows the large difference between configuration 10 of the University of Washington wing and Walton's published results. An even more startling difference occurred between the author's retesting of the Walton model and Walton's original results. Walton's model was retested at the same Reynolds number and in the identical configuration as in his published article (6). The maximum lift

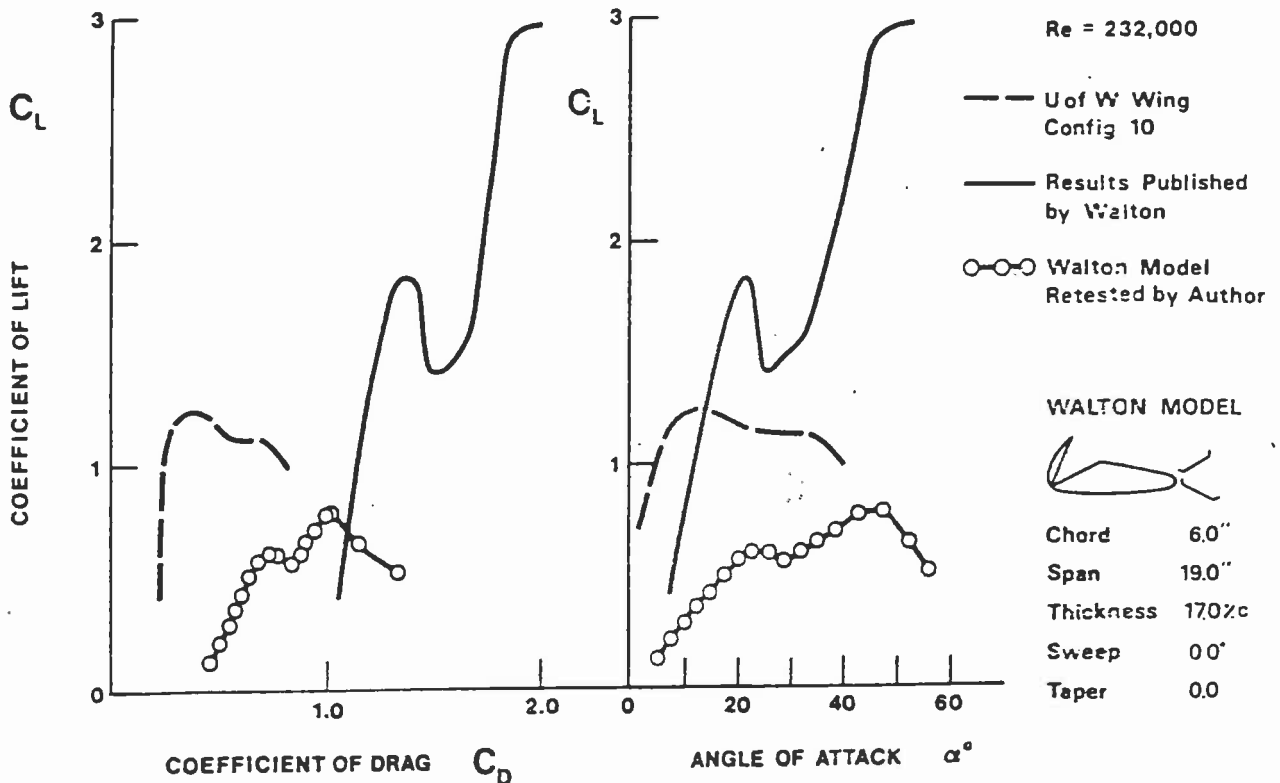


Figure 8. Performance comparison of U of W wing, results published by Walton, and retesting of Walton model

coefficient produced by Walton's model was only 0.8, about one fourth of that originally published. Figure 8 shows somewhat similar characteristics between the two tests of Walton's model, only the magnitudes of the data are significantly different. The reasons for this large discrepancy are not yet clear. The venturi tunnel balance and dynamic pressure indicator were carefully recalibrated and found to have been accurate. Daniel Walton is at the time of this writing recalibrating the Northridge wind tunnel. About 1/3 of the discrepancy was explained when blockage and wall corrections were applied to both tests. However 2/3 of the discrepancy remains unexplained awaiting a recalibration of the Northridge tunnel. The cross-sectional area of the venturi wind tunnel is 1.5 times that of the rectangular Northridge tunnel which is 28 inches wide by 20 inches high. Even if we assume that no errors were made in the Northridge test, improved vortex performance due to tunnel walls is of no use for free flying aircraft.

Though a study of the effect of variation of flap angles was not conducted on the University of Washington wing, such a study was made by the author using Walton's model, which has a built-in capability for that purpose. This testing did not yield any worthwhile gain in performance.

Walton's original vortex airfoil data had been the only promising wind tunnel results known

to date in which no excessive blowing was used. But by using blowing, researchers at Saab Scania (4) have obtained significant amounts of super circulation, producing high lift coefficients. Blowing is measured in terms of  $C_\mu$ , defined as thrust/qS, where q and S are dynamic pressure and wing area. Figure 9 shows very promising gains in performance when a modest amount of blowing was applied. Without blowing, the performance of the Saab model is almost identical to that of the University of Washington wing. An attractive feature of Saab's method of introducing blowing is simplicity. For each wing half, blown air exits spanwise from a single nozzle protruding a short distance out from the side of the fuselage, located at the exact core of the single vortex. The Saab report also shows significant improvement with Reynolds number, where at constant  $C_\mu$  of 0.4, the three  $C_{Lmax}$ 's corresponding to Reynolds numbers 50,000, 100,000 and 150,000 were 2.65, 3.15 and 4.45.

Figure 10 compares the Saab results (adjusted to an aspect ratio of 7.28) with results from recent NASA full scale wind tunnel tests (8) of a four engine STOL transport using upper surface blowing and boundary layer control. Even at very low Reynolds number the Saab vortex airfoil compares very well with state of the art high lift technology. The higher induced drag of the NASA

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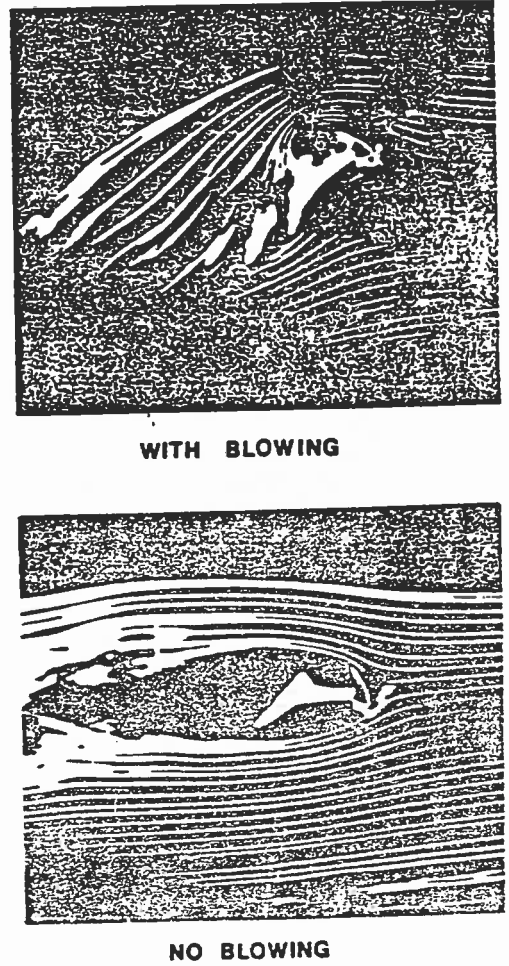
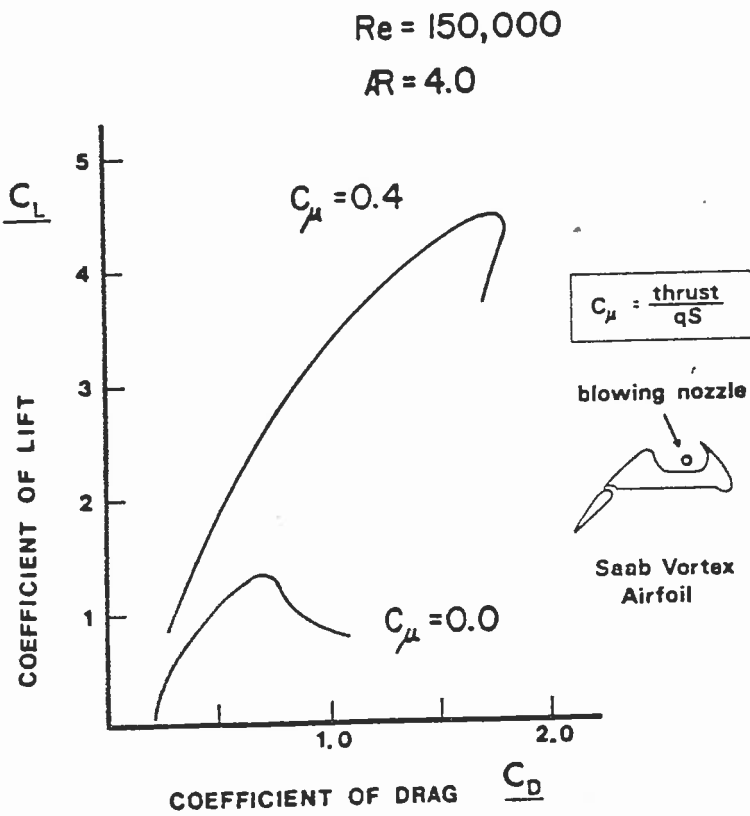


Figure 9. Saab vortex lift performance with and without blowing

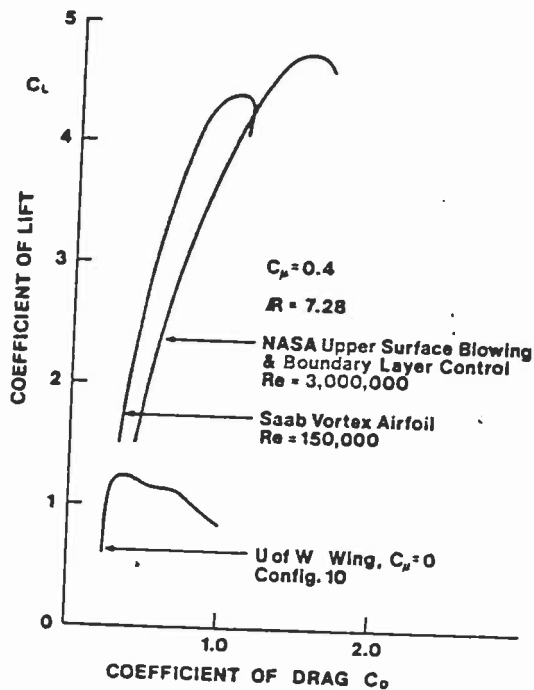


Figure 10. Comparison of Saab vortex lift performance with and without blowing

wing is caused by concentrated regions of lift near engine nacelles causing a lower span efficiency factor than that of the vortex wing, which has a more elliptical lift distribution.

#### V. Conclusions

Based on the results presented in this paper, the author feels justified in concluding that no promising vortex lift performance can be obtained at Reynolds numbers below 250,000 without the use of external blowing.

It is possible, though doubtful, that a critical Reynolds number exists above which respectable performance can be obtained without applying blowing to vortex lift. The simplest, most direct method to determine if this is true is to carefully flight test Kasper's remaining glider, the BEKAS N, for which he claims even better vortex lift performance than that of the BKB-1.

Vortex lift has been shown to be quite responsive to blowing, and at full scale Reynolds numbers it may be possible to out-perform the more conventional jet flap techniques presently being developed. A new Swedish airforce contract has recently been awarded to Saab Scania for a larger scale investigation of blown vortex lift. These results should be carefully reviewed when and if they become available. Further wind tunnel research along these lines may yet develop this concept to the point where an efficient STOL transport aircraft is not only feasible but profitable.

#### References

1. Cox, Jack, "The Revolutionary Kasper Wing," *Soaring*, Vol. 37, No. 12, December, 1973, pp. 20-23.
2. Sunderland, L. D., "What Happened to the Kasper Wing?" *Sport Aviation*, Vol. 25, No. 1, January 1976, pp. 30-35.
3. Gleason, Mark E., "A Preliminary Wind Tunnel Investigation of a Vortex Augmented Wing," Master's Thesis, State University of Wichita, 1972.
4. Claréus, Ulf, and Westesson, Rolf A., "FÖRSÖK MED VIRVELLYFT," Institutionen för Flygteknik SAAB-SCANIA, 1973.
5. Ridder, KTH, Ingelman-Sundberg FFA, Loyd LiH, Westesson, Claréus, "Virvellyft. Kommentarer till några preliminära vindtunnelprov.," SAAB-SCANIA, 1974-03-01.
6. Walton, Daniel, "A Brief Wind Tunnel Test of the Kasper Airfoil," *Soaring*, Vol. 38, No. 11, November 1974, pp. 26-27.
7. Weber, J. A., Brune, G. W., Johnson, F. T., Lu, P. and Rubbert, P. E., "Three-Dimensional Solution of Flows over Wings with Leading-Edge Vortex Separation," *AIAA Journal*, Vol. 14, No. 4, April 1976, pp. 519-525.
8. Aoyagi, Falarski and Koenig, "Wind Tunnel Investigation of a Large-Scale Upper Surface Blown-Flap Model Having Four Engines," NASA TM X-62, 419, N75-32016.