Donald R. Crawford was the DG2's second very educational speaker.

Mr. Crawford gave us a presentation on simplified performance estimation of aircraft design. Using design methods based on his book and research of nomograms. The use of nomograms produces accurate performance calculations without computers or mathematical formulas. The secret to his method are simple, he has done all the hard work by designing the entire math and computation into the nomogram sheets of scalar. Something like a slide ruler (anyone have or remember them) of paper for aircraft design. You work with known quantity’s like airspeed, wing load, climb rate, and then determine unknown quantity’s by drawing simple lines and connecting the dots per say.

Mr. Crawford’s book will explain in detail his methods better then I can do in this newsletter. His book has been in my collection for many years and has been very useful and easy to use. It is worth the price of admission. Just for the valuable insight to an easier method of performance estimation. Even in today’s world of powerful home computers this book needs to be on your bookshelf.

The book is unusual in that key aerodynamic relationships are clarified with easy to use and easy to understand nomograms. As a result you can immediately make valid performance calculations for a new design, and see the consequences, or benefits, of changing design features.

"...I have discovered that a screw-shaped device such as this, if it is well made from starched linen, will rise in the air if turned quickly..."

Leonardo Da Vinci - Codice Atlantico
A WHAT!

A nomogram or nomograph is a graphical calculating device, a two-dimensional diagram designed to allow the approximate graphical computation of a function. Like a slide rule, it is a graphical analog computation device; and, like the slide rule, its accuracy is limited by the precision with which physical markings can be drawn, reproduced, viewed, and aligned. Most nomograms are used in applications where an approximate answer is appropriate and useful. Otherwise, the nomogram may be used to check an answer obtained from an exact calculation method.

The slide rule is intended to be a general-purpose device. Nomograms are usually designed to perform a specific calculation, with tables of values effectively built in to the construction of the scales.

A nomogram typically has three scales: two scales represent known values and one scale is the scale where the result is read off. The known scales are placed on the outside; i.e. the result scale is in the center. Each known value of the calculation is marked on the outer scales and a line is drawn between each mark. Where the line and the inside scale intersects is the result. The scale marks include 'tick marks' to indicate exact number locations, and labeled reference values. These scales may be linear, logarithmic or have some more complex relationship. Straight scales are useful for relatively simple calculations, but for more complex calculations, simple or elaborate curved scales may need to be used.

Usage is simple — a taut string or other straight edge is placed so as to contact the two known values on their lines. The required answer is read off another line. This allows calculation of one variable when the other two are known. Additional lines are sometimes added that are simple conversions of one of the other variables.

One common nomogram that defies the above definition is a temperature graph. On this graph, degrees Fahrenheit and degrees Celsius are both indicated. While it is drawn as a single line with two scales, the two different scale markings indicate that there are actually two lines overlapping each other.

Example: Parallel-resistance/thin-lens nomogram

The nomogram below performs the computation

\[ \frac{1}{1/A + 1/B} \]
This nomogram is interesting because it performs a useful nonlinear calculation using only straight-line, equally-graduated scales.

A and B are entered on the horizontal and vertical scales, and the result is read from the diagonal scale. This formula has several uses: for example, it is the parallel-resistance formula in electronics, and the thin-lens equation in optics.

In the example below, the green line demonstrates that parallel resistors of 56 and 33 ohms have a combined resistance of about 21 ohms. It also demonstrates that an object at a distance of 56 cm from a lens whose focal length is 21 cm forms a real image at a distance of about 33 cm.

The Supermarine Spitfire was a single-seat fighter used by the RAF and many Allied countries in World War II.

Produced by Supermarine, the Spitfire was designed by R.J. Mitchell, who continued to refine it until his death in 1937. Elliptical wings gave it a distinctive look and a thin cross-section, making it much faster than contemporary designs. Much loved by its pilots, the Spitfire saw service during the whole of World War II, in all theatres of war, and in many different variants.

More than 20,300 examples of all variants were built, including two-seat trainers, with some Spitfires remaining in service well into the 1950s.

The aircraft was dubbed Spitfire by Sir Robert MacLean, director of Vickers (the parent company of Supermarine) at the time, and on hearing this, Mitchell is reported to have said, "...sort of bloody silly name they would give it." The word dates from Elizabethan times and refers to a particularly fiery, ferocious type of person, usually a woman. The name had previously been used unofficially for Mitchell's earlier F.7/30 Type 224 design.

We come to learn

After Mr. Crawford’s presentation the group started talking about wing span load distribution. This brought up the Spitfire wing layout and why it had an Elliptical wing. I always believed it was due to aerodynamic concerns but this is not the reason. Someone knew the reason but read on to learn why.
Spitfire V loaded weight had crept up to 6,417 lb. and the maximum speed up to 369 mph. The first squadron to fly the Spitfire V was the No. 92 and in March 1942, fifteen Spitfire VBs which had been shipped to Malta on H.M.S. Eagle, became the first Spitfires to serve outside Europe. Spitfires of this Mark were later to serve in the Western Desert and the Pacific and Burma areas.

Supermarine’s Chief Designer, R.J. Mitchell, had won three Schneider Trophy seaplane races with his designs, combining powerful Napier or Rolls Royce engines with minute attention to streamlining. These same qualities are equally useful for a fighter design, and in 1930 Mitchell produced such a plane in response to an Air Ministry specification (F7/30) for a new and modern monoplane fighter.

This first attempt at a fighter resulted in an open-cockpit monoplane with gull-wings and a large fixed spatted undercarriage. The Supermarine Type 224 did not live up to expectations; nor did any of the competing designs which were also deemed failures.

Mitchell immediately turned his attention to an improved design as a private venture, with the backing of Supermarine’s owners Vickers. The new design added gear retraction, an enclosed cockpit, oxygen gear, and the much more powerful newly developed Rolls Royce PV-12 engine, later named the Merlin.

By 1935 the Air Ministry had seen enough advancement in the industry to try the monoplane design again. They eventually rejected the new Supermarine design on the grounds that it did not carry the required eight-gun load, and did not appear to have room to do so.

Spitfire Mk. V Trop Once again Mitchell was able to solve the problem. It has been suggested that by looking at various Heinkel planes he settled on the use of an elliptical platform, which had much more chord to allow for the required eight guns, while still having the low drag of the earlier, simpler wing design. Mitchell’s aerodynamicist, Beverley Shenstone, however, has pointed out that Mitchell’s wing was not directly copied from the Heinkel He 70, as some have claimed; the Spitfire wing was much thinner and had a completely different section. In any event, the elliptical wing was enough to sell the Air Ministry on this new Type 300, which they funded by a new specification, F.10/35, drawn up around the Spitfire.

The prototype first flew on March 5, 1936. Performance was such that the Air Ministry immediately placed an order for 310. At the time it was still being "shaken out" by Vickers test pilots, even before the aircraft had been handed to them for their own flight testing.

A feature of the final Spitfire design that has often been singled out by pilots is its washout feature, which was unusual at the time. The incidence of the wing is +2° at its root and −½° at its tip. This twist means that the wing roots will stall before the tips, reducing the potentially dangerous rolling moment in the stall known as a spin. Many pilots have benefited from this feature in combat when doing tight turns close to the aircraft’s limits because when the wing root stalled it made the control column shudder giving the pilot a warning that he was about to reach the limit of the aircraft’s performance.

The man who developed the Spitfire

Mitchell only lived long enough to see the prototype Spitfire fly. It’s perhaps a tribute to the design that it was capable of infinite development. Mitchell left behind him a team led by his Chief Draughtsman, Joe Smith, who was more than capable of doing the job. In all, there were 24 variants of the Spitfire. As one historian noted: ‘If Mitchell was born to design the Spitfire, Joe Smith was born to defend and develop it.’

Production

To build the Spitfires in the numbers needed a whole new factory was built at Castle Bromwich, near Birmingham as a "shadow" to Supermaine's Southampton factory. Although the project was ultimately led by Lord Nuffield who was an expert in mass construction, the Spitfires was a bit too
complex and Supermarine and Vickers engineers were needed. The site was setup quickly from July 1938 - machinery was being installed 7 months after work started on site.

**Supermarine production**

Supermarine was ill equipped to fulfill the Air Ministry contract to build Spitfires in 1936. The company's reputation rested on hand-building small numbers of specialized aircraft; mass production of warplanes was a different matter. In fact, the Air Ministry came close to canceling the contract: the Spitfire nearly didn't happen. The solution was one of the largest sub-contract schemes ever to take place in British industry.

**Supermarine Spitfire variants**

There were 24 makes of Spitfire and many sub-variants. These covered the Spitfire in development from the Merlin to Griffon engines, the high speed photo-reconnaissance variants and the different wing arrangements.

**Naval version**

There also was a naval version of the Spitfire called the Seafire. It was especially adapted for operation from aircraft carriers: with an arrester hook, folding wings and other specialized equipment. However, like the Spitfire, the Seafire had a narrow undercarriage track, which meant that it was not well suited to deck operations. Due to the addition of heavy carrier equipment, it suffered from an aft centre-of-gravity position that made low-speed control difficult, and its gradual stall characteristics meant that it was difficult to land accurately on the carrier. These characteristics resulted in a very high accident rate for the Seafire.

Compared with other naval fighters, the Seafire II was able to outperform the A6M5 (Zero) at low altitudes when the two types were tested against each other in WW2. Contemporary western carrier aircraft like the F6F Hellcat and the F4U Corsair, however, were considerably more powerful. Late-war Seafire marks equipped with the Griffon engines enjoyed a considerable increase of performance compared to their Merlin-engined predecessors.

The name Seafire was arrived at by collapsing the longer name Sea Spitfire

**Service**

The first Spitfires to shoot down another plane did so in early September 1939. That the downed aircraft were Hawker Hurricanes was unfortunate but the pilots were found not to be blamed.

**Battle of Britain**

The Spitfire is often credited with winning the Battle of Britain. The design was mass produced in Castle Bromwich, Birmingham where there now stands a large metal memorial on Chester Road at Spitfire Roundabout. The aircraft and Mitchell were lauded in the movie The First of the Few, although the film was a dramatization and not factually accurate.

The Spitfire was one of the finest fighters of the war; aviation historians and laymen alike often claim it to be the most aesthetic. It is, however, frequently compared to the Hawker Hurricane, which was used in greater numbers during the critical stage of 1940. The Hurricane's guns were better suited to attacking bombers, but a close pattern of fire and slower speed made the Hurricane vulnerable when attacking the German fighter escorts. It should be noted, however, that in total numbers the Hurricane actually shot down more Luftwaffe aircraft, both fighters and bombers, than the Spitfire. Losses were high among the more numerous Hurricanes, whereas the Spitfire had a greater chance of survival.

Another contemporary, the German Luftwaffe's Messerschmitt Bf 109, was similar in attributes and performance to the Spitfire. Some advantages helped the Spitfires win many dogfights, with maneuverability the attribute most often quoted. Good cockpit visibility was probably a greater factor, as the early Bf 109s had narrow, paneled cockpit windows. Spitfires were assigned the task of taking on the Bf 109Es, while the Hurricanes intercepted bombers whenever possible. Nonetheless, seven of every ten German planes destroyed during the Battle of Britain were shot down by Hurricane pilots.

**Speed and altitude records**

The Spitfire Mk. XI flown by Sqn. Ldr. Martindale, seen was damaged after its flight on 27 April 1944 during which it achieved a true airspeed of 606 mph (975 km/h). Due to the high altitudes necessary for these dives, a fully feathering Rotol propeller was fitted to prevent over speeding.

During the spring of 1944, high-speed diving trials were being performed at Farnborough to investigate the handling of aircraft near the sound barrier. Because it had the highest limiting Mach number of any aircraft at that time, a Spitfire XI was chosen to take part in these trials. It was
during these trials that EN409, flown by Squadron Leader Martindale, reached 606 mph (975 km/h) in a 45-degree dive. Unfortunately the engine/propeller could not cope with this speed and the propeller and reduction gear broke off. Martindale successfully glided the 20 miles (30 km) back to the airfield and landed safely.

**From: Spitfire - A Test Pilot’s Story**

**Arrow Books**

“That any operational aircraft off the production line, cannons sprouting from its wings and warts and all, could readily be controlled at this speed when the early jet aircraft such as Meteors, Vampires, P-80s, etc could not, was certainly extraordinary” — Jeffrey Quill

On 5 February 1952 a Spitfire Mk. 19 of No. 81 Squadron RAF based in Hong Kong achieved probably the highest altitude ever achieved by a Spitfire. The pilot, Flight Lieutenant Ted Powles, was on a routine flight to survey outside air temperature and report on other meteorological conditions at various altitudes in preparation for a proposed new air service through the area. He climbed to 50,000 feet (15,240 m) indicated altitude, with a true altitude of 51,550 feet (15,712 m), which was the highest height ever recorded for a Spitfire. However, the cabin pressure fell below a safe level, and in trying to reduce altitude, he entered an uncontrollable dive which shook the aircraft violently. He eventually regained control somewhere below 3,000 feet (900 m). He landed safely and there was no discernible damage to his aircraft. Evaluation of the recorded flight data suggested that in the dive, he achieved a speed of 690 mph (1110 km/h) or Mach 0.94, which would have been the highest speed ever reached by a propeller-driven aircraft. Today it is generally believed that this speed figure is the result of inherent instrument errors and has to be considered unrealistic.

**Other operators**

A Spitfire from the 303 Kościuszko Squadron, apart from the RAF, Spitfires served with most of the Allied air forces in World War II, especially the Polish Air Force, Czechoslovak Air Force, Royal Canadian Air Force, Royal Australian Air Force, South African Air Force and Royal New Zealand Air Force. It was one of only a few foreign aircraft to see service with the United States Army Air Force. Several European countries also operated Spitfires based in the UK, under the auspices of the RAF, including the Armée de l'Air as part of the Free French air force, the Forces Aériennes Françaises Libres (FAFL). (See Armée de l’Air (Part II.).) In the Swedish Air Force the Spitfire was given the name S31 and it was in use up to 1955 when it was replaced by SAAB J29 Tunnan. [1]


Spitfires played a major role in the Greek Civil War, flown by the RAF and SAAF during 1944 and 1945, and by the Royal Hellenic Air Force from 1946 through the end of the war in 1948.

Spitfires last saw major action during the 1948 Arab-Israeli War, when — in a strange twist — Israeli Spitfires were engaged by both British and Egyptian Spitfires.

Some air forces retained Spitfires in service until well into the 1960s, while some pilots who flew Spitfires in World War II were able to remain in service for decades; for example, Flight Lieutenant “Joe” Kmiecki, a Polish pilot who flew Spitfires during the war, did not retire from the RAF until 1981.

There is evidence that during the war the Germans used captured Spitfires to strafe targets in England.

**Planes remaining in use**

Spitfire at Temora Aviation Museum in Australia

About 50 Spitfires and a few Seafires remain airworthy and many aircraft museums treasure static examples of this graceful yet lethal fighter. The RAF maintains some for flying display and ceremonial purposes in the Battle of Britain Memorial Flight at RAF Coningsby in Lincolnshire.

The Temora Aviation Museum in regional New South Wales, Australia, has an airworthy Supermarine Spitfire Mk VIII, which is flown regularly during the Museum’s flying weekends.

A black-painted Spitfire, which belonged to Israeli pilot and former president Ezer Weizmann, is still in active flight condition. The Black Spitfire is on exhibit in the Israeli Air Force Museum in Hatzerim and used for ceremonial flying display.

**CONTACT! MAGAZINE**

Bob Young spoke about Contact Magazine and how useful it was as an information avenue which is not seen in the other magazines.

This magazine has been great since the first issue, it needs to stay around. You can help by subscribing. I have read every issue and have learned something from every issue, good quality magazine. Below are the Editor’s words on the Magazine.
Reach for Excellence Drives CONTACT!

Today's crop of magazines leaves most of us wanting more. More information that is. Looking back 20 years or more, experimental aviation magazines were full of people like you and me, building things with their own hands, in their garage, basement or hangar. Now when you look in just about any magazine, $60,000 is considered a good price for an experimental aircraft. Mostly what the other magazines are interested in is selling ad space, so you can rest assured that any feature article will be on something that's advertised in the pages of their publication. We like to refer to these types of articles as adicles.

But we have no advertising in our magazine.

CONTACT! Magazine fills your plate with good, solid black and white information. We go out and get the experiences of the people who are at the leading edge of homebuilding. Six issues a year contain in-depth, first-hand technical articles which are easily understood and apply to your current project or future dream design. And we listen to our readers and their interests. It's not easy digging out facts but we are committed.

When CONTACT! Covers a homebuilt design you can be sure that all bases are covered in plain language from assembly techniques, to materials, to design features, to flying qualities. Technical specifications, actual reproductions of plans or manuals, cutaway drawings, exploded views, and photo captions tell the entire story. Short of buying the kit or plans you get the entire picture.

CONTACT! Puts you in touch with the people who are at the forefront of auto power. Not just photos but full details on weight. Dimensions, scale outlines, cooling configurations, and the important performance results. Unlike others CONTACT! Will publish updates on these developments so that you have a good point of reference

CONTACT! Magazine is published and edited by Patrick Panzera (EAA #555743), homebuilder, instrument rated pilot. Professional building designer and certified building inspecto. You can count on factual, detailed, and plainly written. Quality information. CONTACT! Is truly independent. Contains no advertising and won't be found on newsstands. Top quality paper ensures exact photo reproduction.

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The picture Show

At our second meeting we viewed one of the timeless series of video programs by brilliant German aeronautical engineer Dr. Alexander Lippisch, explaining the phenomena of induced drag from program number eight which was arranged in a very intelligible manner.

We witnessed the science of the fabulous smoke tunnel, where lift and drag of wing tip vortices are analyzed. We watched as Prof. Lippisch taught us with wing models and smoke in his own lab.

These programs were produced in 1955 by The University of Iowa, they are still pertinent today! There are thirteen half-hour instructional films.

Video Programs:

1. Preview
2. The Laws of Fluid Motion
3. History of Early Flight
4. Discovery of Dynamic Lift
5. Stability and Control
6. Propulsion
7. Problems of Drag
8. The Induced Drag
9. Different Aircraft
10. High Lift Devices
11. Story of the Vortex
12. Flight in Nature
13. Modern Problems of Flight

The following is what you would find as an explanation on induced drag in an aerodynamics book. There is drag component caused by the generation of lift. Aerodynamicists have named this component the induced drag. This drag occurs because the flow near the wing tips is distorted span wise as a result of the pressure difference from the top to the bottom of
the wing. Swirling vortices are formed at the wing tips, which produce a down wash of air behind the wing which is very strong near the wing tips and decreases toward the wing root. The local angle of attack of the wing is increased by the induced flow of the down wash, giving an additional, downstream-facing, component to the aerodynamic force acting over the entire wing. This additional force is called induced drag because it has been "induced" by the action of the tip vortices. It is also called "drag due to lift" because it only occurs on finite, lifting wings. The magnitude of induced drag depends on the amount of lift being generated by the wing and on the wing geometry. Long, thin (chord wise) wings have low induced drag; short wings with a large chord have high induced drag.

This is how Alexander Martin Lippisch explained induced drag on the video. How do you explain induced drag? Why not use a river with logs and a person crossing the river by stepping on the logs to get across.

As you step on the logs they give way and sink into the water as you push off against them on to the next log.

Since the log you have stepped on is now lower in the water then the next log you must step up hill a little to place your foot on it.

Even if there was no friction or drag produced by someone walking across the logs, there is energy used or work done to go up hill. They are always climbing onto the next log.

Aircraft are supported by air which is being pushed down causing them to climb a little even in cruise. So even if you had a perfect drag free aircraft body (Rutan’s working on it), the aircraft would still have induced drag caused by the work being done. Lift is needed to keep the aircraft up and its climbing as it moves forward (pushing air down) even in level cruise flight.

The aircraft is working in a column of descending air. The column of descending air is caused by the airfoil producing lift. So the aircraft is always doing work. How much work or energy used depends on how fast the logs or air molecules go down. This varies with speed, so does drag. Induced drag is the unavoidable by-product of lift and increases as the angle of attack increases. Remember, the greater the angle of attack, up to a critical angle, the greater the amount of lift developed and the greater the induced drag. Since there are two different ways that lift is produced, there are also two different types of induced drag: dynamic drag (Newtonian) and pressure drag (Bernoulli).

Some water, some logs, a foot and you have a great explanation of induced drag in this video.

So make sure you come to watch the other videos and learn.

Alexander Martin Lippisch

Alexander Martin Lippisch was born on 2 November 1894 in Munich, Germany, the son of Franz and Clara (Commichau) Lippisch. His father was an artist. Alexander was educated at schools in Berlin and Jena, Germany, and was planning to enter art school when the First World War began. He enlisted in Germany’s armed forces in 1915, and served until 1918 as an aerial photographer and map per. In 1943 he was awarded a doctoral degree at the University of Heidelberg.

Lippisch worked for the Dornier Aircraft Company in Friedrichshafen, Germany, as an aerodynamicist from 1918-1922. He was employed as a glider designer for Weltensegler, Inc. in Baden-Baden (1922-1923); as a designer for A. G. Steinmann, Hagen, Westphalia (1923-1925); and in 1925 he joined the staff of the aerodynamics and design department of the Rhon-Rossittengesellschaft, north of Frankfurt. From 1933-1939 he was in Darmstadt as chief of the technical department of the Deutsche Forschungsanstalt fur Segelflug (DFS). DFS sent him to the Messerschmitt Company in 1939, to head a department to develop a rocket fighter (ME-163) for the Air Ministry. From 1943-1945 he served as director of research for the Aeronautical Research Institute in Vienna, Austria.
He came to the United States in January 1946 as a part of the Operation Paper Clip program administered by the United States Department of Defense. He was stationed at Wright Field in Dayton, Ohio, where he stayed until December 1946 when his family joined him. He worked for the Naval Air Materiel Center in Philadelphia, Pennsylvania, from 1946-1950. Lippisch and his family received United States citizenship in 1956.

In 1950 Lippisch accepted employment at Collins Radio Company in Cedar Rapids, Iowa, where he was director of the aeronautical division until 1964. One of his first projects at Collins was the design of a high-speed smoke tunnel. Lippisch's work on smoke tunnel flow visualization led to a thirteen part television series in 1955, entitled The Secret of Flight. The series addressed the amateur viewer, demonstrating the principle of flight through the use of simple models and a smoke wind tunnel. A believer in the importance of a broad education, Lippisch gave many lectures on the significance and the history of flight.

He also worked on remote powered vehicles which led to his concept of the Aerodyne. This wingless aircraft was suspended solely by the thrust of its engines and was capable of vertical takeoff and landing. The Aerodyne project was discontinued in 1960, at which time Lippisch became the director of the hydrodynamic laboratory at Collins.

He designed a high speed boat which performed very well up to a certain speed, but beyond that point the aerodynamic forces lifted the bow too much. This triggered his interest, and he proposed a boat whose hull would lift out of the water by means of short airplane type wings. This idea was utilized in the aerofoil boat, which was a seaplane that flew efficiently near the ground or water surface. It was powered by a conventional aircraft propeller and was capable of flying far from the ground like a regular airplane. The first full scale aerofoil boat was the Collin X-112. It was first flown in 1965.

Lippisch retired from Collins Radio Company in 1964. He underwent lung surgery and upon recovery found himself desiring to continue his work in aircraft design. He consulted for several United States and German companies on the designs of Aerodynes, Aeroskimmers, and Aerofoil boats.

In the mid 1920s a friend sent Lippisch a flying seed of a tropical plant. This seed was essentially an arrow shaped wing, and as others had done before him, Lippisch based his tailless arrow shaped aircraft on this example from nature. A private sponsor saw one of these designs and thought it would be possible to build a large version of this type for use as a transoceanic transport. However, Lippisch felt that the wing near the body should be thicker so that it could be utilized for additional storage. Lippisch decided that this would only be possible by making the wing near the body longer, and this is how he arrived at the delta shaped wing. His first motorized delta wing flew in 1931. Lippisch continued his work with the delta wing during his time as director of the Aviation Research Institute in Vienna, Austria. His team worked on delta wing airplanes that were designed to accommodate a variety of new engines, such as the turbojet and ramjet engines.

Alexander M. Lippisch died 11 February 1976 in Cedar Rapids, Iowa, of a heart and lung ailment. *Induced drag reduction the natural way, maybe!*

As almost everyone must have noticed the wings of all bird have ragged outline to their trailing edges produced by the tips of the feathers but on the other hand since the early days aircraft have always had smooth trailing edges (probably because it looks more efficient!).

When early aerodynamicists were researching bird’s wings it was assumed that the saw tooth trailing edges were basically due to the requirements for the fold of the wings and nothing to do with aerodynamics. Even the oldest fossils of feathered birds show the typical ragged trailing edge. The shape does not appear to have changed much over millions of years. Darwinian Theory would suggest that this feature would change over time or at least this feature would not have remained the same across all bird species if it did not have a very significant purpose. It would appear that there is an advantage in having a feather like trailing edge. Looking closely at each feather, each one is slightly different from the next (just as fingers on a hand are different). It would appear that each feather over time has developed their own particular shape for a very specific purpose and the increase in efficiency must be significant for the system not to have changed over the millennia.

Lift line theory gives a series of vortices produced along the trailing edge. The effect on a wing is that these combine downstream to produce a single large tip vortex. It would appear that the use of the wing feather ends on bird’s trailing edge is to stabilize these vortices and prevent them migrating towards the tip. They appear to act the same as wing fences but in a much more subtle way and for no extra wetted area.

Winglets are used to break up the strength of the tip vortex. *Spillman tips* (see note) were tried to emulate the pectoral tip feathers on birds, but they were neither long enough nor of variable incidence. There was also nothing to limit the span wise flow, so the tip vortex was already fairly powerful before it was trying to be dispersed. Recent aerodynamic developments appear to be to using small vortex generators to...
achieve similar a sort of result of stabilizing the span wise flow.

Looking at bird’s wings. Sea birds with large span have relatively smooth trailing edges inboard and the end of the feather slowly gets more pronounced toward the Tip, with relatively small pectoral feathers. Large land birds on the other hand with their limited available span have much more pronounced trailing edge feathers and large pectoral feathers. These feathers have an advantage in that they are flexible and adjust automatically to the loads imposed so that they are near optimum for all stages of flight. A modern equivalent is the flexible mast and sail on high-speed sailboards. It can also be seen that birds preen their feathers frequently and the trailing edge arrangement of the feathers is important to them.

Tests on wings with stepped trailing edges have at times produced some unexpected reductions in drag, but so far there has been no systematic research on the subject.

The use of a saw tooth trailing edge on a wing should have the effect of reducing the span wise flow thus reducing induced drag and also improving the flow near the stall. An added bonus would also be reduction in wake turbulence and probably less noise.

Since this is basically a vortex system it should be more efficient at higher Reynolds numbers.

Ian Hannay, Fleet, Hants. UK 2005

Who in the group will be the first to try this method on their aircraft?

**Spillman tips** (Tip Sails)
**United States Patent 4272043**

Tip sails are more complicated devices, as shown in the figure below, consisting of several tapered fins (or smaller winglets), placed radially with an axial gap between two elements (Spillman, 1978). They also have the leading edge protuberance similar to the tip tanks.

For best performance it is suggested that the number of vanes be no more than 4, at angles 15-20 deg between 2 vanes; each vane should have a chord no larger than 30 % of the tip tank chord.

**Lift-induced drag**

In aerodynamics, lift-induced drag, or induced drag, is a drag force which occurs whenever a lifting body or a wing of finite span generates lift.

There is no practical wing of infinite span. However, the characteristics of such a wing can be measured on a section of wing spanning the width of a wind tunnel. By definition, the reaction force is resolved into two components. That parallel to the incident airflow is the drag and that normal to the incident airflow is the lift. At practical angles of incidence the lift greatly exceeds the drag.

An airfoil produces lift by generating an area of high pressure on the under surface and an area of low pressure over the upper surface. On a wing of finite span some air 'leaks' around the wingtip from the lower surface towards the upper surface producing a wingtip vortex. The vortices then create a down flow or 'downwash' behind the wing. This modifies the airflow around the wing, relative to that on a wing of infinite span, tilting the total reaction force rearwards. The angular deflection is small and has little effect on the lift as defined above. However, there is an increase in the drag equal to the product of the lift force and the angle through which it is deflected. Since the deflection is itself a function of the lift the additional drag is proportional to the square of the lift. Unlike parasitic drag, induced drag is inversely proportional to the square of the airspeed.

Induced drag can be minimized by increasing a wing span. The effect of the wingtip vortices is

Normally the wingtip vortex is not visible, but it is always there. This picture shows the wingtip vortex of a business jet sending cloud tops into swirls.
greatest near the wing tips. With increased wingspan a lesser portion of the wing is in the most affected region. Increasing span with no other change would increase wing area. In practice, the wing area is kept constant by increasing the aspect ratio rather than the span.

Optimize the span wise load distribution. If the lift is diminished towards the wingtips there is less pressure differential near the wingtips to create wingtip vortices. Minimum induced drag is achieved when the span wise lift distribution is elliptical. The parameter with greatest effect on lift distribution is the wing plan form. Thus, a wing with elliptical plan form would have low induced drag. Few aircraft have this plan form because of manufacturing complications — the most famous example is the World War II Spitfire. Tapered wings with straight leading and trailing edges can approximate to elliptical lift distribution. Typically, straight wings produce between 5–15% more induced drag than an elliptical wing. The lift distribution may also be modified by the use of washout, a span wise twist of the wing to reduce the incidence towards the wingtips, and by changing the airfoil section near the wingtips.

Provide a physical barrier to vortex formation. Such a barrier might take several forms. Some early aircraft had fins mounted on the tips of the tail plane which served as endplates. More recent aircraft have wingtip mounted winglet to oppose the formation of vortices. Wingtip mounted fuel tanks may also provide some benefit.

**Induced drag is calculated as follows:**

\[
D_i = \frac{1}{2} \rho V^2 S C_{Di} = \frac{1}{2} \rho_0 V_e^2 S C_{Di}
\]

where

\[
C_{Di} = \frac{k C_L^2}{\pi A} \quad \text{and} \quad C_L = \frac{1}{2} \rho_0 V_e^2 S
\]

**Thus**

\[
D_i = \frac{k L^2}{\frac{1}{2} \rho_0 V_e^2 S \pi A}
\]

**Where**

- \(A\) is the aspect ratio,
- \(C_{Di}\) is the induced drag coefficient,
- \(C_L\) is the lift coefficient,
- \(D_i\) is the induced drag,
- \(k\) is the factor by which the induced drag exceeds that of a wing of infinite span typically 1.05 to 1.15,
- \(L\) is the lift,
- \(S\) is the gross wing area,
- \(V\) is the true airspeed,
- \(V_e\) is the equivalent airspeed,
- \(\rho\) is the air density and \(\rho_0\) is 1.225 kg/m³, the air density at sea level, ISA conditions.

Induced drag must be added to the parasitic drag to find the total drag. Since induced drag is inversely proportional to the square of the airspeed whereas parasitic drag is proportional to the square of the airspeed, the combined overall drag curve shows a minimum at some airspeed - the minimum drag speed. An aircraft flying at this speed is at its optimal aerodynamic efficiency. The minimum drag speed occurs at the speed where the induced drag is equal to the parasitic drag. This is the speed at which the best gradient of climb, or for unpowered aircraft, minimum gradient of descent, is achieved.

The speed for best endurance i.e. time in the air, is the speed for minimum fuel flow rate. The fuel flow rate is calculated as the product of the drag or power required and the engine specific fuel
consumption. The engine specific fuel consumption will be expressed in units of fuel flow rate per unit of thrust or per unit of power depending on whether the engine generates thrust e.g. a jet engine, or power e.g. a turbo-prop engine.

The speed for best range i.e. distance traveled, occurs at the speed at which a tangent from the origin touches the fuel flow rate curve. The curve of range versus airspeed is normally very flat and it is customary to operate at the speed for 99% best range since this gives about 5% greater speed for only 1% less range.

We have a schedule:

2006 Meeting Schedule
10:00 am
FlaBob Airport
Chapter One Hanger

February  25
March    18
April    15
May      27
June     24
July     15
August   26
September 16
October  28
November 18
December 16

Check this site for any schedule updates and changes.

http://www.eaach1.org/calen.html

What this is and what it is not!

It is important to remember that this newsletter is merely a conduit for information passed among members sharing their experiences. Its established purpose is fellowship and encouragement. It is NOT the intent to give authoritative advice on aircraft construction or design. The Editor and the contributing writers disclaim any liability for accuracy or suitability of information that is shared. You can assume that all or some of the information in each issue is not correct for aircraft design.

This is simply a collection of notes which were taken at the Design Group meeting and placed with other items into a newsletter format. This is very informal, it will continue if you like it, BUT leaving open the option to quit anytime it becomes time consuming. After saying all that, hope fully you will enjoy this news letter. Lots of items will come from the meeting as best as one can interpret what is stated. Many items will come from other sources such as books and internet files (Grabbing from any source to make it useful and a lot will come from the internet to expand what was talked about at the meeting, like the Spitfire and Induced drag material in this issue. (I will take it where I can get it).

Speak out if you were wrongly quoted or something misinterpreted, no harm was implied, only lack of knowledge in understanding and interpreting what was said. This will only be sent by email to anyone whom would like to receive it. How many times a year this will happen is up for grabs at this time.

So with that said. Welcome to the second semi-official newsletter. This is the trial run. This is an effort to reach out and to help connect the design group.

If others would like to contribute articles, stories and materials in the future feel free. The newsletter should provide a way for us to communicate with each other. It is a place for those of us who want to network, connect and share information to do so. Anyone can write anything to whomever about any aircraft or aviation design ideas. With any luck we will learn something from everyone and hopefully someone can learn one thing from us.
Minimizing Induced Drag with Geometric and Aerodynamic Twist on a Wing of Arbitrary Planform

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Project Overview
Dr. Warren F. Phillips has recently developed and published a method for reducing induced drag through spanwise circulation control [1, 2, 3, 4 and 5]. It has been shown that, for an unswept wing of any planform shape, there exists an optimum distribution of geometric and/or aerodynamic twist that will result in the production of induced drag at the same minimum level as that produced by an elliptic wing of the same aspect ratio but with no geometric or aerodynamic twist. Utah State University has filed a patent application for technology based on this discovery. The technology has the potential for reducing induced drag by up to 16 percent, depending on aspect ratio and taper ratio. Since wing twist is very easily implemented, even as a retrofit to existing aircraft, this development has the potential for significant fuel savings. The fuel savings associated with minimizing induced drag is an obvious benefit in both civilian and military applications.

* This paper received an award as the “2003 AIAA Best Paper” awarded by the AIAA Atmospheric Flight Mechanics Technical Committee.
Dr. Phillips has recently developed and published a method for minimizing induced drag through spanwise circulation control. In its simplest form, the method can be used to minimize the induced drag acting on a wing of any planform shape through the implementation of either geometric or aerodynamic twist, which is commonly called washout. To minimize the induced drag, the geometric and/or aerodynamic twist must vary along the span of the wing in a special way that depends on the planform shape of the wing. The total amount of twist required to minimize the induced drag is directly proportional to the lift coefficient developed by the wing,

\[ C_L = \frac{Wn}{\frac{1}{2} \rho V^2 S_w} \]

where \( W \) is gross weight, \( n \) is load factor (normal acceleration, \( g \)), \( \rho \) is air density, \( V \) is airspeed, and \( S_w \) is wing area. With proper twist implementation, a wing of any planform shape can be designed to produce the same minimum induced drag as an elliptic wing of the same aspect ratio, operating at the same lift coefficient. Such twist-optimized wings are much simpler and less costly to manufacture than an elliptic wing. Proper twist implementation can reduce the induced drag acting on a lifting wing by as much as 15 percent. In cruise configuration, the induced drag is typically about 50 percent of the total drag acting on the airplane, and in landing configuration, the induced drag can be as much as 90 percent of the total drag. Thus, implementation of optimum twist can significantly reduce the total drag on an airplane. However, if spanwise circulation control is implemented solely through the use of fixed twist, the wing can only be optimized for one design lift coefficient. This means that, if the airplane is designed to operate over a wide range airspeed and/or gross weight, the implemented twist must be a compromise for the range of lift coefficients that will be encountered during different mission phases.
Implementation of Twisterons to Minimize Induced Drag for a Broad Range of Lift Coefficients

a) Twisteron configuration with no flap deflection and washout set to minimize induced drag at $C_L = 0.6$.

b) Twisteron configuration with 15° flap deflection and washout set to minimize induced drag at $C_L = 1.4$.

To avoid the limitations associated with minimizing induced drag by means of fixed wing twist, it is possible to implement the twist distribution required to minimize induced drag by employing full-span trailing-edge flaps that can be twisted along their length to produce a continuous spanwise variation in zero-lift angle of attack. For a rectangular wing little twist is required in the region near the root. Thus, the geometry shown above can be used to closely approximate the aerodynamic twist needed to minimize induced drag. These control surfaces can also be deflected symmetrically as flaps and/or asymmetrically as ailerons to establish roll control. In the following discussion the twisting control surfaces shown above are referred to as twisterons. The advantage of using twisterons to establish the spanwise circulation control needed to minimize induced drag is that the twist can be varied with the parameters that affect the lift coefficient. This allows us to maintain minimum induced drag over a wide range of operating conditions. The aircraft can be fitted with sensors to determine gross weight, normal acceleration, air density, and airspeed. The sensor outputs can be used in an active feedback control system to maintain minimum induced drag over a wide range of operating conditions. Because most of the parameters that affect the lift coefficient also affect the required elevator deflection, the induced drag can be nearly minimized by properly linking the twisteron deflection to the elevator deflection. Utah State University has filed a United States Patent Application for the twisteron technology.
Utah State University Experimental Aircraft with Operational Twisterons

Utah State University has designed, built, and flown an experimental UAV with operational twisterons. This electric powered aircraft has a wingspan of 10 feet, a gross weight of 35 pounds, a top speed of 100 miles per hour, and was designed for 7-g maneuvers. In the design and development of this aircraft a beneficial side effect of twisteron deflection was discovered. The change in wing circulation that is brought about by twisteron deflection produces a favorable change in the downwash induced on an aft tail, which reduces the elevator deflection needed to trim the aircraft over a wide range of airspeed, gross weight, and normal acceleration. This produces a further reduction in total aircraft drag, beyond that provided directly by the twisterons. For the aircraft shown above, this resulted in a total drag reduction of 20 percent during some mission phases.

References
A newly developed mathematical solution to a well-established theory of lifting wings has led to the development of improved technology that can significantly reduce the drag acting on an aircraft in subsonic flight. This drag reduction is accomplished through twisting of the wing, or some portion of the wing, in a special manner that depends on wing shape and aircraft operating conditions.

Of course, twisting the wing of an aircraft is not new. Only eight years after the first unpowered human flight by Otto Lilienthal in 1891, and more than four years before their first powered flight in 1903, the Wright brothers began experimenting with wing twist as a means of controlling the rolling motion of an aircraft. Many hours of watching birds in flight led Wilbur Wright to conclude that birds “regain their lateral balance when partly overturned by a gust of wind, by a torsion of the tips of the wings.” This was one of the most important discoveries in aviation history.

Less than two decades later, Ludwig Prandtl published the first theory of lifting-wing, which allowed us to mathematically analyze and predict the effects of wing twist. In the 1920s, Hermann Glauert discovered from Prandtl’s theory that twisting the two sides of a wing in a symmetric manner could affect the drag acting on the wing. Under some conditions, however, wing twist was found to reduce the drag, and for other conditions twist would increase it.

The foundation of the recent technology improvement is a new analytical solution to Prandtl’s theory that allows us to predict and maintain the proper distribution and amount of wing twist, which is necessary to minimize an important component of aircraft drag. With the modern sensors and flight computers used on most aircraft today, this new mathematical solution could yield substantial fuel and cost savings.

Using Prandtl’s lifting-line theory, the elliptic wing of the WW II British Spitfire was designed to minimize induced drag, but was very expensive to manufacture. A newly developed solution to Prandtl’s theory has shown that, with proper twist implementation, a wing of any planform shape can be designed to produce the same minimum induced drag as an elliptic wing.

by Warren F. Phillips
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A new solution

A new closed-form solution that includes spanwise variation in wing twist has recently been developed from Prandtl's lifting-line theory (see http://twisteron.usu.edu). This solution shows that the conclusions sometimes reached from the results first published by Glaubert are erroneous. It shows that an unswept wing of any planform shape can be designed with proper twist implementation to produce less induced drag than any tapered wing with no twist. This analytical lifting-line solution has been validated by comparison with CFD results and was found to be in excellent agreement with this modern computational method.

The twist that is required to minimize induced drag on a wing of any planform shape...
can be implemented in several ways. The method most commonly used is called geometric twist. When pure geometric twist is employed, the wing cross section at each location along the wingspan has an airfoil shape that is geometrically similar to that of the root cross section. However, the outboard airfoil sections are rotated relative to the root section. To minimize induced drag on a rectangular wing, the trailing edge of the outboard sections must be rotated upward relative to the inboard sections, to produce a continuously decreasing local angle of attack.

Another method sometimes used to effectively twist a wing is called aerodynamic twist. For a wing with pure aerodynamic twist, the chord line of the airfoil cross section at each location along the span of the wing is exactly parallel with the chord line of the root airfoil section. The effective twist is achieved through a smooth variation in the airfoil section geometry between the root and the tip of the wing. If aerodynamic twist is to be used to minimize induced drag on a rectangular wing, the airfoil section camber must be progressively reduced as the spanwise coordinate moves outboard from the root toward the wingtip.

Either geometric or aerodynamic twist can easily be incorporated in the design of a wing, if the desired twist distribution is fixed and does not change with operating conditions. To minimize induced drag, the geometric and/or aerodynamic twist must vary along the span of the wing in a special way that depends on the planform shape of the wing. However, the amount of wing twist required to minimize induced drag is a strong function of gross weight, altitude, airspeed, and normal acceleration. With proper twist implementation, a wing of any planform shape can be designed to produce the same minimum induced drag as an elliptic wing of the same aspect ratio, operating at the same conditions. Such twist-optimized wings are much simpler and less costly to manufacture than an elliptic wing.

Proper twist implementation can reduce the induced drag acting on a lifting wing by as much as 15%. At the airspeed that results in minimum overall drag, the induced drag is typically about 50% of the total drag, and at much lower airspeeds, the induced drag can dominate the total drag. Thus, implementation of optimum twist can significantly reduce the total drag on an airplane. However, if fixed twist alone is implemented, the wing can be optimized for only one design operating condition. This means that, if the airplane is to operate over a wide range of airspeed, altitude, and/or gross weight, the implemented fixed twist must be a compromise for the range of operating conditions that will be encountered during different mission phases.

Twisterons

To avoid the limitations associated with minimizing induced drag by means of fixed wing twist, it is possible to implement the twist distribution needed to minimize induced drag by using full-span trailing-edge flaps that can be twisted along their length to produce a continuous spanwise variation in wing twist. These control surfaces, called twisterons, can also be deflected symmetrically as flaps and/or asymmetrically as ailerons to generate high lift and provide roll control.
The advantage of using twisterons to establish the wing twist needed to minimize induced drag is that the twist can be varied, to maintain minimum induced drag over a wide range of operating conditions. The aircraft can be fitted with sensors to determine gross weight, normal acceleration, air density, and airspeed. The sensor outputs can be used in an active feedback control system to maintain minimum induced drag as the operating conditions change. Because most of the parameters that affect optimum wing twist also affect the required elevator deflection, the induced drag can be nearly minimized by properly linking the twisteron deflection to the elevator deflection.

Another advantage of using twisterons to minimize the induced drag produced by the main wing of an airplane is a reduction in the up-elevator deflection required to trim the aircraft at low airspeeds. When twisteron deflection is varied with airspeed so as to maintain minimum induced drag, an increasing nose-up pitching moment is produced by the twisting wing as airspeed is reduced and twisteron deflection is increased. This reduces the negative lift on an aft horizontal stabilizer, which is typically required at low airspeeds, and provides additional savings in drag over that realized for the wing alone.

**UAV experiment**

Students at Utah State University have designed, built, and flown an experimental UAV with operational twisterons. Designed for 7-g-maneuvers, this electric-powered aircraft has a wingspan of 10 ft, a gross weight of 35 lb, and a top speed of 100 mph.

During the aircraft’s design and development, another beneficial side effect of twisteron deflection was discovered. The change in the wingtip vortices that is brought about by twisteron deflection produces a change in the downwash induced on an aft stabilizer, which further reduces the elevator deflection needed to trim the aircraft over a wide range of airspeed, gross weight, and normal acceleration. This results in a further reduction in total aircraft drag, beyond that provided directly by the twisterons. For a prototype created by Utah State University, this reduced the total drag by as much as 20% during some mission phases.

**Potential applications**

The Air Force is currently funding a multidisciplinary research program to support development of the next generation of intelligence, surveillance, and reconnaissance (ISR) aircraft, including high-altitude, long-endurance UAVs. Because of endurance requirements (possibly 24-48 hr), these ISR aircraft will require a very high vehicle fuel fraction and must operate efficiently over a wide range of gross weight, altitude, and airspeed. At the maximum-endurance airspeed, induced drag acting on an aircraft is typically more than 50% of the total drag. Thus, future ISR aircraft could benefit significantly from twisting trailing-edge flaps, which could maintain minimum induced drag during all phases of operation.

Perhaps the greatest potential benefit could come from the use of twisterons on transport aircraft. A large jet transport weighing about 750,000 lb will typically burn more than 75 gal of fuel per minute, and half of its total weight can be fuel. In 2004, according to the FAA, U.S. civil aviation aircraft are expected to consume more than 24 billion gal of jet fuel. With consumption of this magnitude, a fuel savings of even a fraction of a percent is very significant. Twisterons have the potential for reducing fuel consumption for a typical transport aircraft by approximately 2.5%.
Design Group 2

Meeting
March 18, 2006
10:00 am
At FlaBob Airport
In Chapter One Hanger

Will Present
Low Aspect Ratio Aircraft Design

With Speakers

Ed Marquart

On Saturday – March 18, 2006- Design Group 2 will have FlaBob’s Master airplane craftsmen Ed Marquart of Maverick, Lancer and the popular Marquart Charger will be a guest speaker.