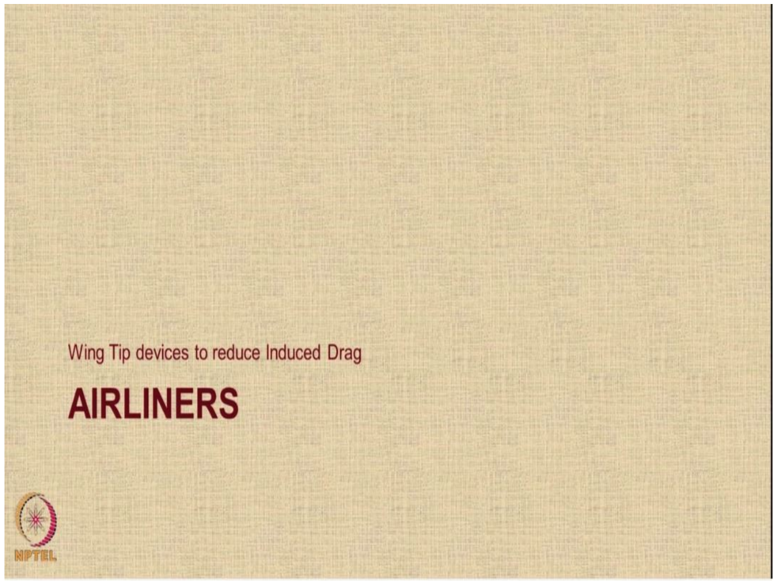
Introduction to Aircraft Design
Prof. Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology, Bombay

Lecture - 17
Airliner and Supersonic Aircraft, Some Additional Concepts

(Refer Slide Time: 00:24)

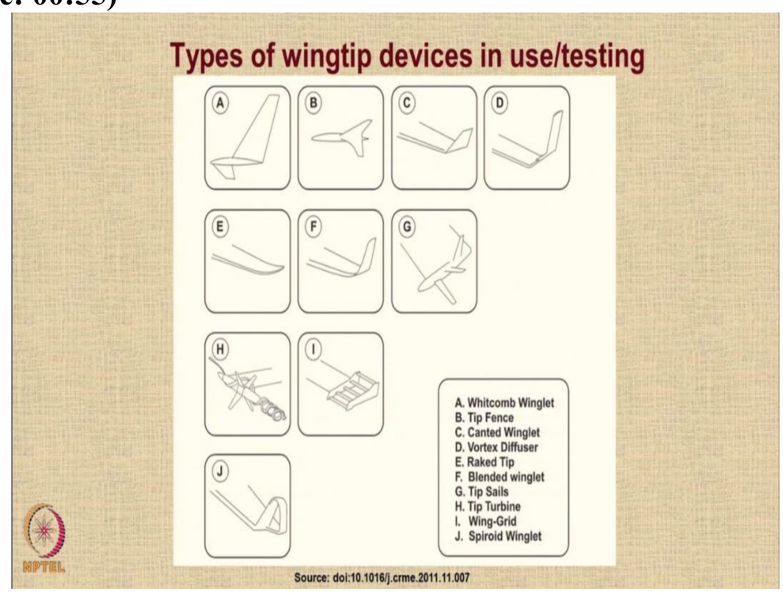
Hello, let us look at some additional concepts related to airliners and supersonic transport aircraft. As you can see on the screen there are several interesting concepts, ranging from spirit winglets to the plans to create laminar flow in supersonic flow, and also some new attempts at supersonic transport or SST aircraft. Let us look at these one by one. We will first look at airliners.

(Refer Slide Time: 00:43)



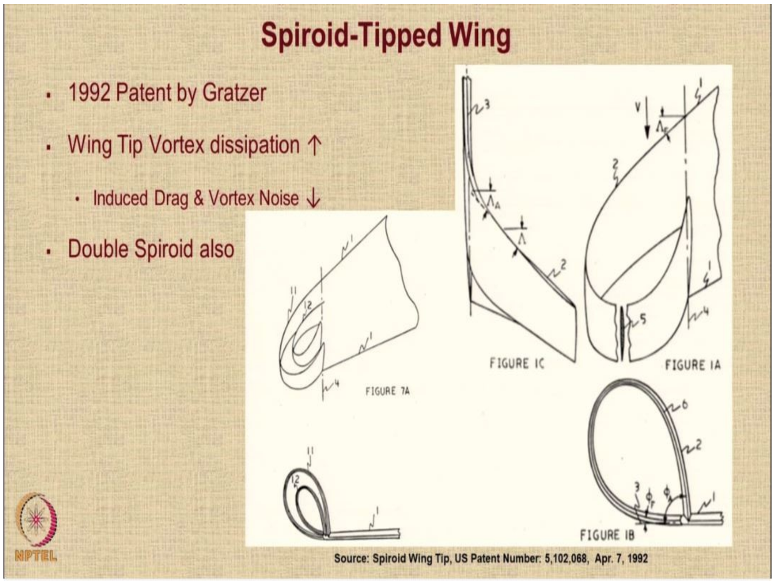
And we look at some wing tip devices which are being considered in airliners to reduce induced drag.

(Refer Slide Time: 00:55)



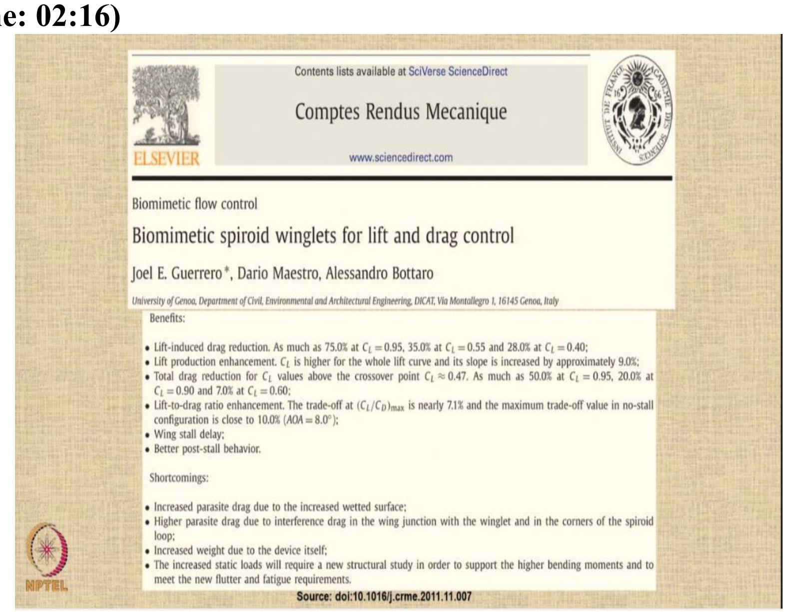
All of us are aware about some standard winglets such as the one seen in the top 4 of this slide, the Whitcomb winglet, the tip fence, the canted winglet and the vortex diffuser, but there are some interesting wingtip devices which are under investigation. And we are going to look today at the last one which is marked as J the Spiroid winglet.

(Refer Slide Time: 01:28)



A Spiroid tipped wing is a very interesting concept which was patented by Gratzer in 1992, this is a US patent and you can see an image which has been taken from the patent document. So, essentially the idea of wing of a Spiroid tip wing or a spiroid winglet is to increase the dissipation of the wingtip vortex and the moment you increase the dissipation, then the induced drag is reduced as well as the vortex noise created by it. There is also a suggestion to use a double spiroid inlet in the same patent. So here instead of 1, there are 2 spiroid configurations mounted at the tip of the wing.

(Refer Slide Time: 02:16)



Contents lists available at SciVerse ScienceDirect

Comptes Rendus Mecanique

www.sciencedirect.com

ELSEVIER

Biomimetic flow control

Biomimetic spiroid winglets for lift and drag control

Joel E. Guerrero*, Dario Maestro, Alessandro Bottaro

University of Genoa, Department of Civil, Environmental and Architectural Engineering, DICAT, Via Montallegro 1, 16145 Genoa, Italy

Benefits:

- Lift-induced drag reduction. As much as 75.0% at $C_L = 0.95$, 35.0% at $C_L = 0.55$ and 28.0% at $C_L = 0.40$;
- Lift production enhancement. C_L is higher for the whole lift curve and its slope is increased by approximately 9.0%;
- Total drag reduction for C_L values above the crossover point $C_L \approx 0.47$. As much as 50.0% at $C_L = 0.95$, 20.0% at $C_L = 0.90$ and 7.0% at $C_L = 0.60$;
- Lift-to-drag ratio enhancement. The trade-off at $(C_L/C_D)_{max}$ is nearly 7.1% and the maximum trade-off value in no-stall configuration is close to 10.0% ($AOA = 8.0°$);
- Wing stall delay;
- Better post-stall behavior.

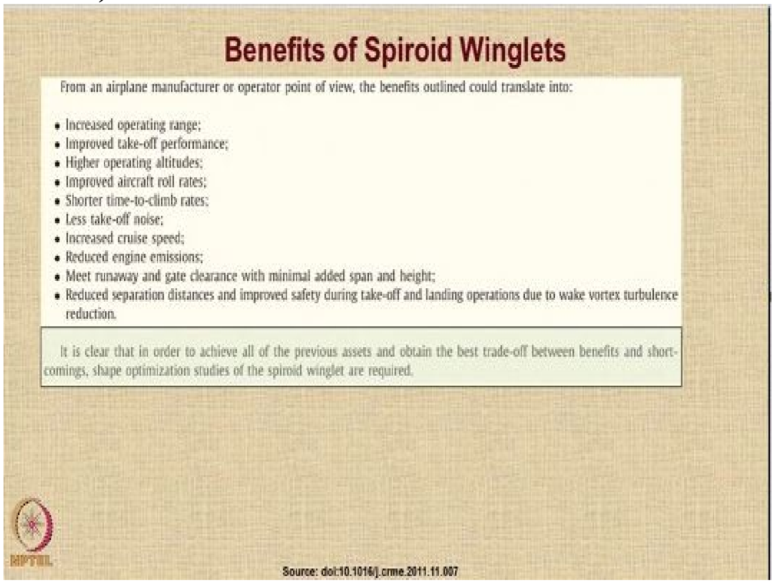
Shortcomings:

- Increased parasite drag due to the increased wetted surface;
- Higher parasite drag due to interference drag in the wing junction with the winglet and in the corners of the spiroid loop;
- Increased weight due to the device itself;
- The increased static loads will require a new structural study in order to support the higher bending moments and to meet the new flutter and fatigue requirements.

Source: doi:10.1016/j.crme.2011.11.007

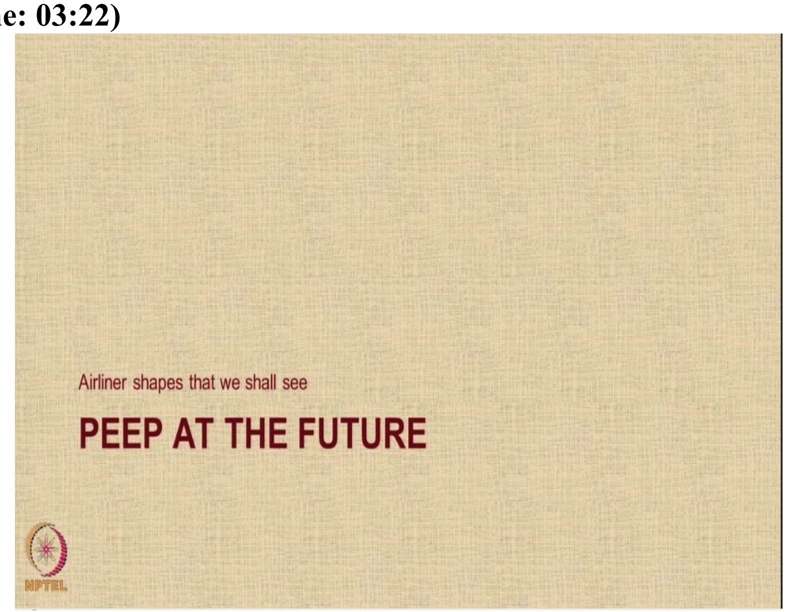
Several studies have been carried out and also are in progress. There is one interesting paper on Biomimetic spiroid winglets for lift and drag controlled by Guerrero at all. So, the basic summary of this paper is that there are certain benefits and certain shortcomings.

(Refer Slide Time: 02:42)



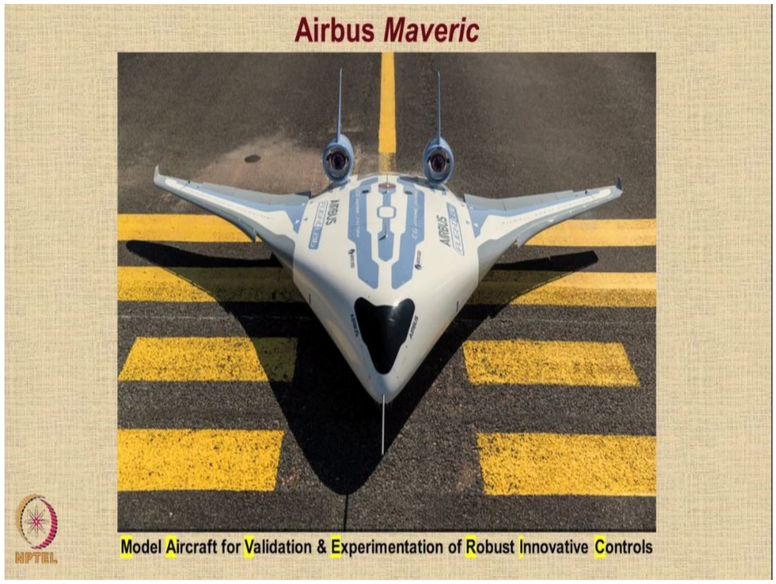
If you focus on the benefits, you can see that there are a large number of improvements in operating range, takeoff performance, operating altitudes, roll rates etc. But there is a very important caveat to it, that to achieve all these benefits, and to obtain the best tradeoff between the benefits and shortcomings, we need to do very careful and detailed shape optimization studies. So this is an open area for research. It has not yet there is no last word in this at the moment. There are many benefits, but there are also several drawbacks.

(Refer Slide Time: 03:22)



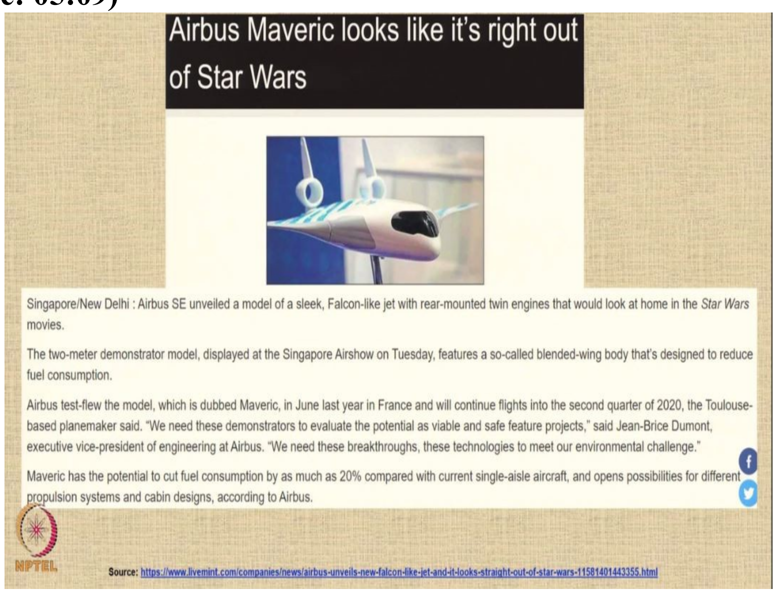
Let us peep at the future and look at some very forward looking shapes that we shall hopefully see in the next few years.

(Refer Slide Time: 03:35)



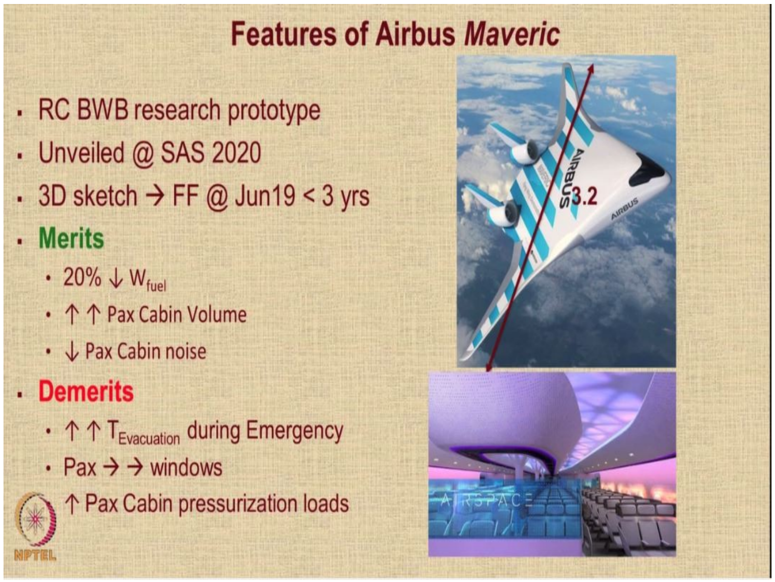
Here is an example of a very interesting concept by the Airbus called as the maveric which stands for model aircraft for validation experimentation of robust innovative controls. So this is the internal project of the company. Let us have a look at a short video.

(Refer Slide Time: 05:09)



So this is a concept that looks right out of Star Wars. And here is a news report that appeared recently in the live mint newspaper. So you can just go through this in front, you can pause the video and you can read this report. So essentially, this is just a test aircraft. It is a very small aircraft.

(Refer Slide Time: 05:31)



So, the current Airbus Maveric is actually remotely controlled blended wing body research prototype, so it is not an aircraft it is just a prototype just 3.2 meters in Wingspan, it was unveiled at the Singapore Air Show in 2020. And it was claimed that from the 3 dimensional sketch to the first flight in June 19, 2019, it took less than 3 years. So, the merits of this configuration are that you will end up with a much lower overall drag which will give you a 20% reduction in the fuel weight and because it is a flattish cabin the blended wing body has a very flat and wide cabin.

The cabin volume available to the passengers is greatly increased. So, you do not feel as if you are flying in very restricted, you know tube like space, you feel as if you are in a theatre with a large number of seats spread across. So, you get much more lateral space. And also because the engines are mounted behind the cabin in a way you have much lower passenger cabin noise. But there are some demerits also, the principal demerit is that in case there is an emergency evacuation required, then the time needed is going to be very, very large.

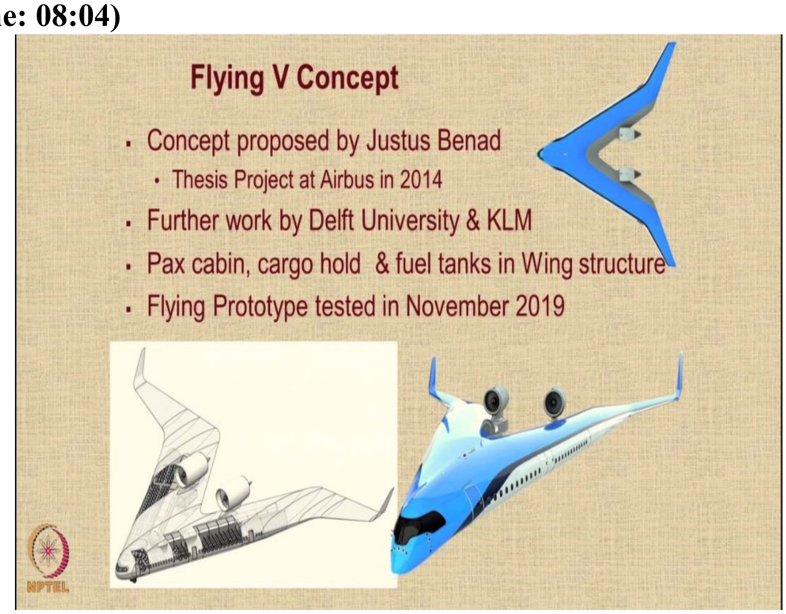
Because the passenger cabin is wide and not so there are not so many doors available and we cannot make too many doors also, there is a limit to how many doors you can make because each door makes the structure slightly weak. Second thing is that the passenger very far away from the windows most passengers they like to be either on an aisle seat, so that they can move up and down the aisle easily to go to the toilets or even just to move around or they want to be near the window so that they can enjoy the scenery and the view outside.

But in a configuration like this, there are going to be very few windows and most people are going to be in the center which may not be really appreciated by the passengers. And secondly, since the passenger cabin does not become elliptical or circular cross section, therefore, there will be much higher loads due to cabin pressurization.

(Refer Slide Time: 07:55)

Another interesting concept is the Flying V concept.

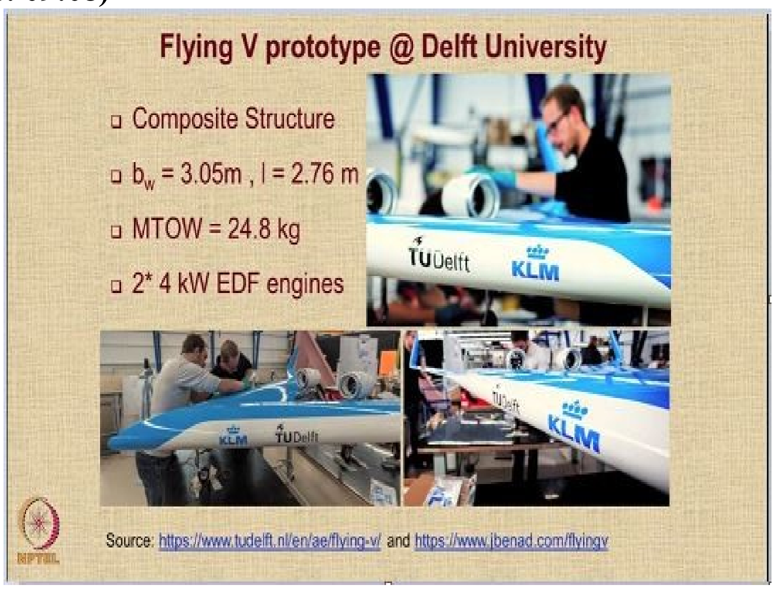
(Refer Slide Time: 08:04)



Which is a concept that has been proposed by Justus Benad as a thesis when he carried out his internship at Airbus in 2014. So, once this study was carried out, this concept was taken up by Delft University in Holland and KLM. Now, in the case of a Flying V concept, the passenger cabin and the cargo hold and the fuel tanks they are all in the wings structure. So, this is the configurational detail of Flying V concept.

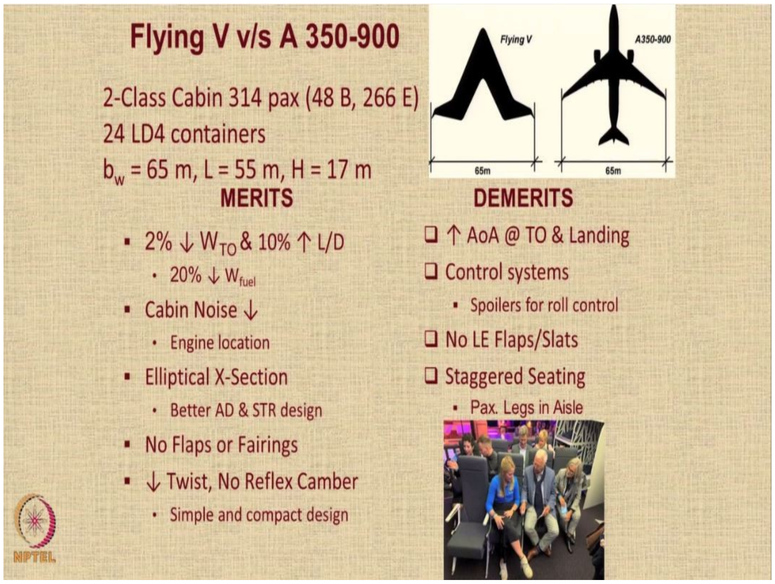
So a prototype of this concept was flight tested in November 2019. And after that work is going on to we are still awaiting any further information on this particular concept. So you can see it is like a flying wing, but it is in a V shape. So with this you can have engines mounted behind so you will have lesser noise in the cabin.

(Refer Slide Time: 09:08)



The Flying V prototype of Delft University has been as I said tested so it is a composite structure which is 3 around 3.05 meters with wingspan and 2.76 meters in length and width just under 25 kgs so it is mount it is powered with 4 with 2 engines each have 4 kilowatt. These are the EDF engines, electrical ducted fans. So here is a close up of the aircraft and another view of the same model at the university. For further information, you can either look at the website of J.Benad who is the inventor of this concept, or the website of the Delft with a page dedicated to the Flying V configuration.

(Refer Slide Time: 10:01)



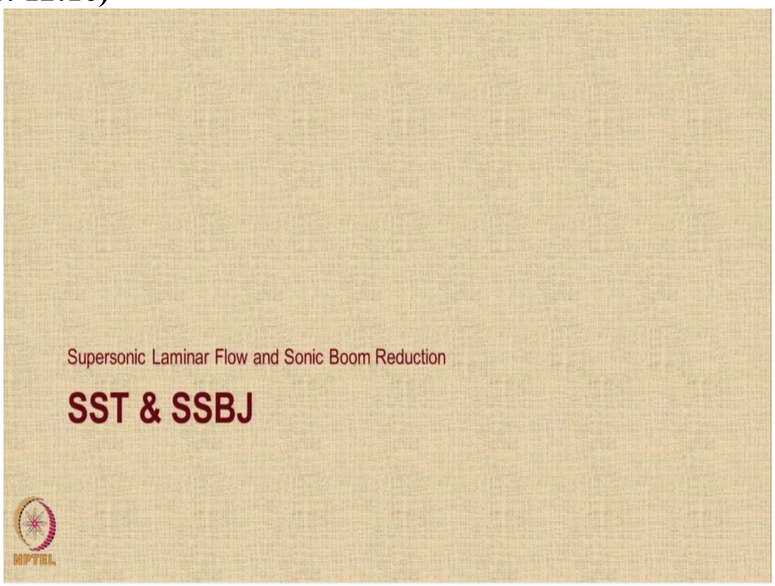
What are the benefits of Flying V versus a standard configuration such as the A 350 900. This is the study that Justus Benad did when he was an intern at Airbus. So, he looked at a 2 class cabin with 114 passengers 48 business class and 266 economy class passengers plus 24 LD4 containers, he kept the wingspan same as that of an A 350-900 for which, he wants to use for a comparison and that airbus that particular configuration is shown along with the equal and Flying V configuration.

So, the study showed that there is a 2% reduction in the takeoff weight and 10% improvement in the L over D because of the flying wing configuration both of these lead to a 20% reduction in the fuel consumed for the mission. The same mission, the cabin noise is lower because of the engine location because the engines are mounted behind the elliptical cross section of the wings are the 2 wings or the 2 fuselages, they give you better aerodynamic and structural design configuration.

There are no flaps or fairings in this configuration and there is much lower twist with no reflex camber. So, it becomes a very simple and compact design. But there are some demerits also the angle of attack at takeoff and landing is much higher. So, that will become very inconvenient for the passengers in the pilots because they will be coming in and taking off at a very steep angle. You need more dedicated and complex control systems like you need spoilers for roll control, there are no leading edge flaps and slats.

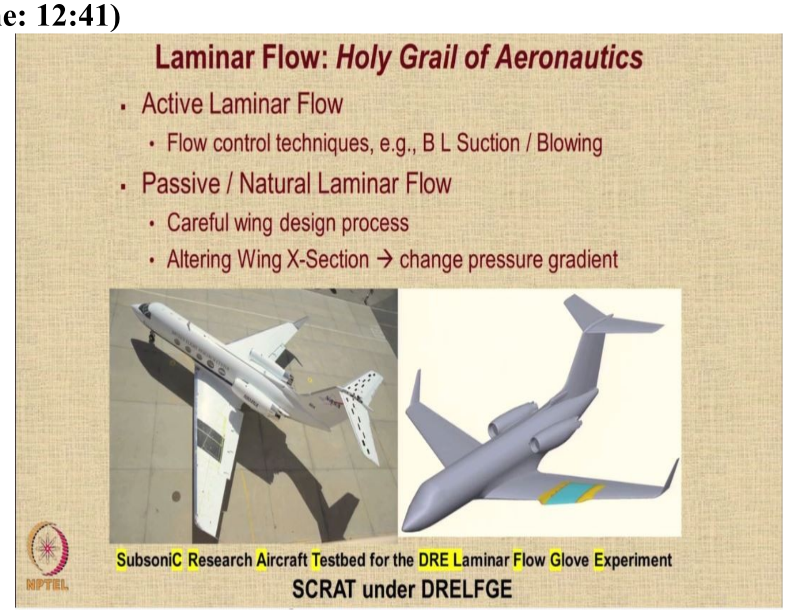
And hence, the aerodynamic efficiency is comparatively lower. Another problem is that the seating has to be staggered and because of that, what happens is that the passenger legs appear in the aisles. So, whenever there is a passenger legs in the aisle passenger do not like it because it will lead to a situation where somebody can trip or you know, they may invade into their privacy.

(Refer Slide Time: 12:16)



Let us look at now some studies related to supersonic transport and supersonic business jets. There are 2 things attempted here one is one aim is to try and create a supersonic laminar flow and to maintain it for a long condition for a long time and also to experiment with techniques with which the sonic boom can be reduced.

(Refer Slide Time: 12:41)

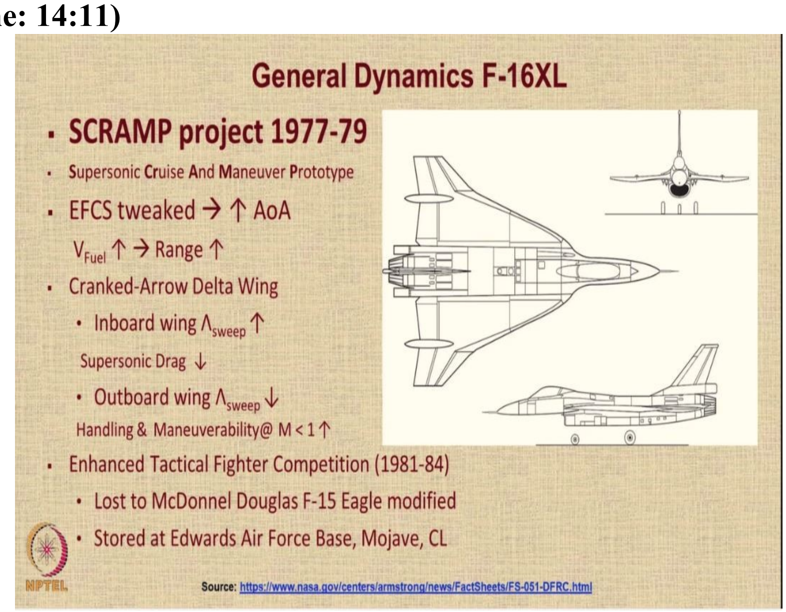


Laminar flow or maintaining laminar flow on an aircraft for a large part of the large fraction of the aircraft surface has been the holy grail of Aeronautics, right from the beginning people have attempted to achieve laminar flow. One way of achieving laminar flow is called as active laminar flow control where we use techniques like boundary layer suction or boundary layer blowing to proactively create laminar flow, but this requires a lot of energy and power.

What people would like to have is passive or natural laminar flow control in which we are not going to use any additional device such as the blower or a suction thing, but we do very careful design of the wing. So, you alter the wing cross section, so, that you can change the pressure gradient and using the changes in the pressure gradient itself you should be able to maintain laminar flow over a large region.

So, one project called as SCRAT under DRELFGE or subsonic research aircraft testbed for the DRE laminar flow glove experiment was carried out in which an aircraft was taken up by NASA Dryden Flight Research Center and on one side on one wing as you can see on the port wing, a small glove was created where a laminar flow area was artificially created and then tested during flight testing.

(Refer Slide Time: 14:11)



Another example of this particular experiment is the General Dynamics F-16XL under the SCRAMP project in 1977 to 79 SCRAMP stands for supersonic cruise and maneuver prototype. So, this is the crank arrow delta wing configuration. So, the electronic flight control system of the F 16 aircraft was tweaked to allow the aircraft to fly at a higher angle of attack. And with this the volume available for the fuel was increased and the range also was increased as a fallout parameter.

As I mentioned, there is a crank arrow delta wing with the double sweep. So, inboard wing has got a very high sweep that you can see at this portion. This is a very high sweep. The aim of this is to reduce the supersonic drag. But you also want to have better handling and maneuverability at low Mach numbers or Mach number less than 1 subsonic part numbers for that we have this particular outboard wing with a lower wing sweep.

So this aircraft took part in the enhanced Tactical Fighter competition conducted by the US Air Force in 1981 to 84. It lost to F 16 Eagle, a modified version of F 16 Eagle, so it was stored in the adverse Air Force Base in Mojave. So, let us have a look at our video

Using a wing originally designed for a supersonic airliner, the company began the supersonic cruise and maneuvering program. The wing was not unlike that of Sweden's drokken fighter, a Delta with a crank arrow or bent leading edge. According to designers that giant aero design gave the aircraft substantial gains in payload and range without sacrificing agility. In 1980, the Air Force and General Dynamics began modifying a few pre-production F 16 into what would become the first F 16 XL all the F 16 e by the Air Force.

The XL name would stick becoming the definitive delta wing by changing the exhale wing required along the fuselage. Over 4 and a half feet were added by lengthening the airframe. Extensive use of composite materials, then new to the aircraft industry gave the exhale more than doubled its original wing area while gaining less than a ton and a half in total weight. Once the modifications were complete, the first XL was ready, having the sub drokkan to familiarize himself with the crank delta wing. Test Pilot Jim McKinney took the XL skyward.

On July the 3rd 1982 initial flight show the designers were right about the potential at the crank terror wing. Joined by the 2 seat belt version in October 1982. The aircraft perform like a job gearing up to 16500 pound bombs cleaned up. The exhales could also be punishing ground attack aircraft. The exhale had over twice the payload capacity of the standard Falcon with almost a 50% increase in range. The bigger wing also meant for a much smoother ride at lower altitude. In 1981, the US Air Force started the advanced Tactical Fighter program.

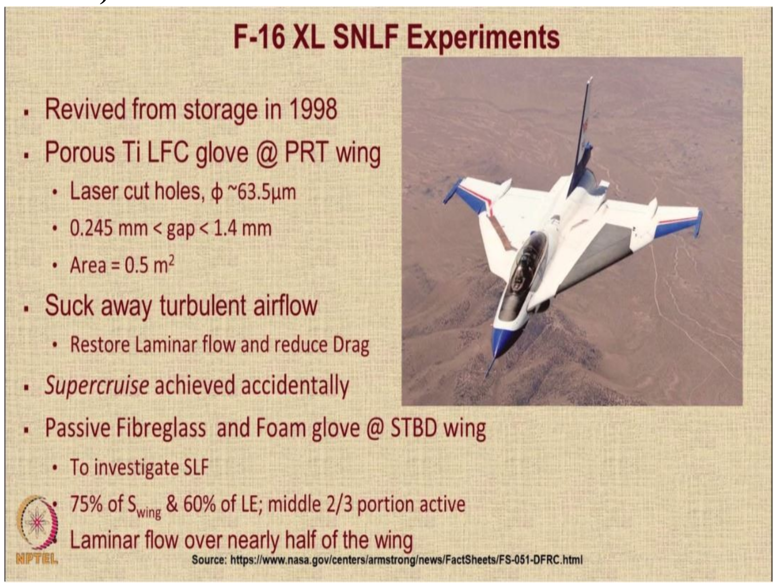
The goal replace the aging F4 Phantom in the road of ground attack. McDonnell Douglas with its modified 2 seats F15 B and General Dynamics with the XL were the main comparatives. During the competition, the exhale had demonstrated an ability to lift a heavy array of weapons. On one mission, the single seater dropped 12500 pound bombs, the equivalent of carrying 2 full sized cars on the wings. The exhales never met one important goal super groups. The ability to fly without the alphabet lit at supersonic speeds.

Zipping over enemy lines without the huge infrared signature of an afterburner was becoming a must in modern warfare. The shutdown between the F15 e and the XL continued through early 1984. Then the Air Force announced their decision. They had chosen the eagle over the XL. Some experts claim that the XL was the better aircraft, but the desire to keep the F15 line open in St. Louis played a role and the design whatever the case, the F15 e came out ahead. After losing the Tactical Fighter competition.

The 2 XL were put in storage first and Edwards and later in Fort Worth. In late 1988, NASA proposed using the XLs for advanced supersonic air flow testing, they took over the aircraft in 1989. They were soon modified to demonstrate the benefits of something called laminar flow. To achieve laminar flow, the turbulent air on the surface of a wing must be removed. The XL was given a special wing mounted fairing filled with millions of microscopic holes each board with a laser beam.

NASA then added a vacuum pump to draw the disturb layer of air inside the wing. This allow the surface air flow to become smooth or laminar, the benefit of laminar flow is less drag. The results of this experiment would dramatic a plane that could not achieve super crews before was suddenly capable of non afterburning supersonic flight. NASA has recently upgraded the original XL in anticipation of follow on testing of these high lift and laminar flow experiments. These programs part of the high speed civilian transport program should keep both of the XLs active with NASA well into the next century.

(Refer Slide Time: 21:23)



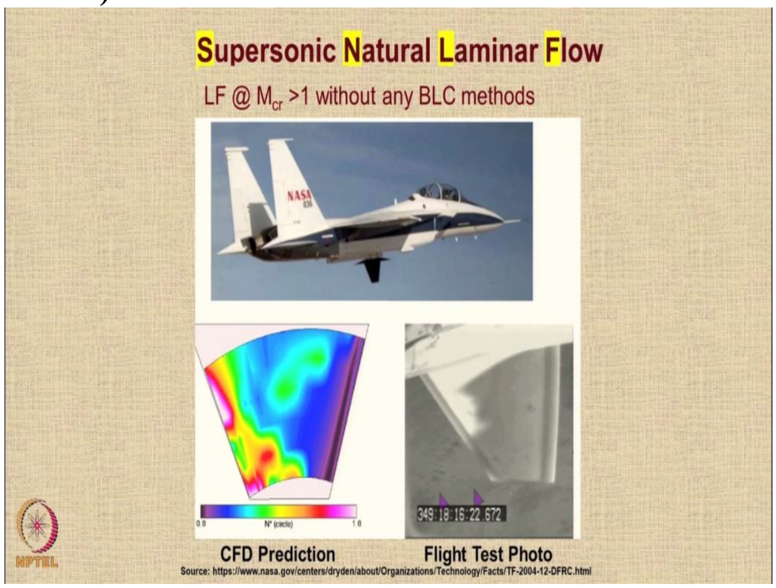
Now, to carry out the supersonic natural laminar flow experiments, this aircraft was actually revived from the storage in 1998. And after revival from storage, it was modified as follows. So, a porous titanium LFC linear flow controlled glove was created in the wing there are laser cut holes of very small diameter 63.5 micro millimeter diameters. So, the gaps between these was maintained as 0.245 mm to 4.4 mm there was a variation of gaps and the area of the glove was about half square meter. So, such a glove was created and inserted on the wing.

So, the aim of this particular glove is to suck away the turbulent airflow this is a active laminar control. So, use you are through these holes, the laser cut holes we are going to suck away the ambient air and restore laminar flow and reduce the drag. Now, it was founded during this experimentation of the aircraft, the aircraft was able to fly supersonic without the need for afterburner this was not something which was planned, this is just something that happened because the drag reduced substantially.

So, therefore, without afterburner the aircraft was able to get the thrust that could create force to make it fly supersonic. So, then passive fiberglass and foam glove was mounted on the starboard wing to investigate the supersonic laminar flow and in that particular wing, it was decided that 75% of the wing and 60% of the leading edge on the middle to third portion will become active.

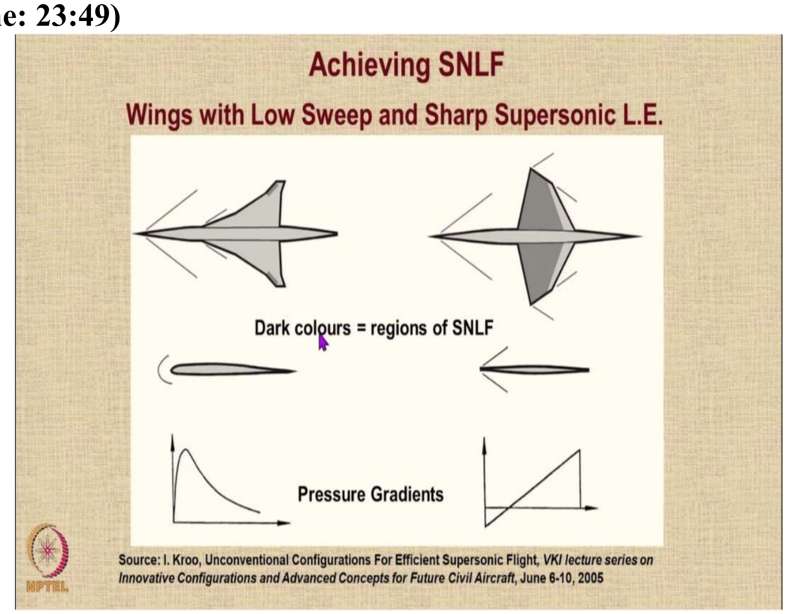
So, during this experiment, it was found that by doing this you could maintain laminar flow or nearly half of the wing.

(Refer Slide Time: 23:20)



So, that is a huge achievement. So, if you look at how supersonic natural laminar flow is created, basically the aim is to create laminar flow at Mach numbers more than 1 without any active boundary layer suction methods. So, NASA has done a season experiments on a small stub mounted below the fuselage and it was this is a CFD prediction and this is the actual flight test information.

(Refer Slide Time: 23:49)



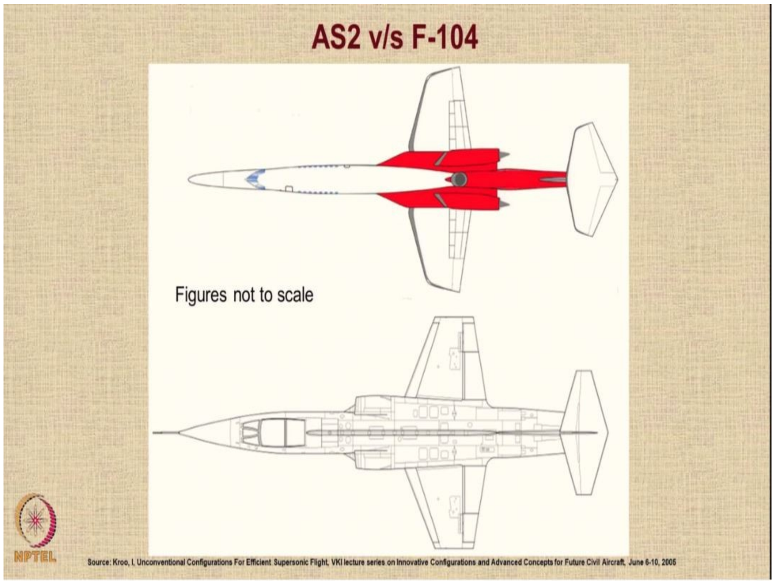
So, how do you achieve supersonic natural laminar flow one mechanism is you use wings with low sweep and sharp subsonic leading edge. So, you can see that this is one possibility, you have low sweep but very sharp leading edge. So, with that sharp leading edge, you get a particular end like this or you could use the conventional approach where it is slowly increased to high value and then comes down slowly.

(Refer Slide Time: 24:20)

Let us look at some supersonic business jets. There is one which is in the pipeline for a long time by a company called Aerion funded by Boeing mostly Aerion AS2 to is a very popular concept not yet seen the light of the day. This is supposed to be a 12 passenger supersonic transport aircraft which would carry around which will fly at Mach number 1.4 up to 8800 kilometers. So, this comes under the category of business jets because 12 passengers is too less to make money in commercial operation program cost is 4 billion dollars.

The unit cost is claimed to be 120 million dollars for aircraft with 4 seats this is a very high cost for an aircraft with can carry many more passengers with more facilities it may cost actually even less than this.

(Refer Slide Time: 25:20)



So, here are some pictures and here is a an indication of how the configuration is similar to that of F-104 star fighter aircraft. We have not done it to scale but we have just enlarge the picture so, that we can keep them definitely one over the other to give you an idea that they are very similar looking with similar sweeps.

Aerion as to supersonic business jet program received a major boost recently when Airbus signed up for a partnership which will help to complete the design of the aircraft and prepare for certification and manufacturing. According to Aerion, the collaboration will support the Mach 1.6 100 plus million dollar 12 passenger as to at least through service century, with final arrangements for series production still to be confirmed. I have always had the confidence that this would make it into service.

It is a question of when not if, but clearly the technological partnership with Airbus is a great step forward and will lead to the commercialization of an Aerion. Airbus is very pleased to be part of this collaboration with Aerion. It is a technology change a knowledge exchange, we are very interested in their sonic laminar flow modeling that they have done and design, we think we could tribute to manufacturing certification, folly techniques.

So it is a total collaboration effort to take this to not only just the business plan, but all through that is writing in the margins. The Aerion AS2 trigent is revised design from the earlier twin engine design and promises to deliver longer range and a larger cabin. The cabin is now comparable to a Gulfstream G 550 in height at 6 feet 2 inches in width at 7 feet 3 inches, the cabin length was expected to be 30 feet long, this new aircraft configuration is really driven by market we did an extensive market refresh.

And we found that width was something that people had a great deal of value in much more so than length. And so you know that led to the new configuration. Also the JTA D although is a wonderful engine. It is old, heavy and noisy. And we clearly need a new core. So we are going back to the engine manufacturers to find the best core that will meet our service marks Aerions is in opening in the market for the supersonic business jet even if the jet may not always be used to its full performance potential.

The jet will cruise at Mach 0.99 in Aerion where supersonic speeds are prohibited, such as the United States. Over water the jet will travel at speeds of Mach 1.4 and 1.6 and crews at speeds of up some Mach 1.2 over populated areas without a sonic boom reaching the ground. I think that the ability to have speed but still the ability to land at normal business airports gives great flexibility and certainly one of the areas that we have found that there has been phenomenal reception is in the Far East where the distances are so vast that it takes forever to get from one place to another and being able to get there and half the time is a great boom.

(Refer Slide Time: 28:45)

Lockheed Martin has also come up with the project in associated with NASA to develop the quiet supersonic technology. This is not going to carry too many passengers. This is a prototype about 96 feet 8 inches long and 29 feet wingspan 14 feet height. So the aim of this project which is funded by NASA is to reduce the intensity of sonic booms and to study the effect of the sonic booms onto the mainland passengers in USA. So this aircraft is going to fly at Mach 1.4.

And it is going to create a sound pressure level of less than per 75 PLdB PL stands for perceived level and dB is the unit for pressure. The max take-off weight of this aircraft, 24,300 pounds. Its empty weight is just below 15,000 pounds, and it can carry 8000 pounds of fuel. But with so much of fuel and so much of empty weight. The air craft can travel only with over 600 payloads for full range so it is not really a very efficient aircraft. But it is very good for experimentation for what it has been built. So let us watch a video of Lockheed Martin experiment in action.

Sonic Boom becomes Sonic thumb. America's top scientists are working on a plane that can fly from LA to the big airport. In just a few hours, Lockheed Martin and NASA partnered up to develop a quiet supersonic plane in the X59. The proposed single pilot craft has a wingspan of 49.5 feet. It is 94 feet long and weighs 32,300 pounds. Total fuel capacity, NASA says the X 59 will be powered by a General Electric f414 engine. This is the same engine used by the FAA218 fighter jets.

The craps hole is designed to abate the noise from shockwaves traditionally associated with Mach Speed travel during that shockwaves come together and create loud Sonic Boom. The Space Agency says the X 59 is decided to separate the shockwaves resulting in much less noise reaching the ground. The aircraft first flight test is scheduled for 2021 buckle up. Canadian engineer designs Mach 24 aircraft antipode Charles Min bardia has done it again.

The engineer just released concept designs for another supersonic aircraft, antipode. The plan has been conceptualized to carry as many as 10 passengers up to 12,430 miles in under an hour, which is speeds as high as 16,000 miles per hour. If you can imagine the world's fastest car clocked in at about 270 miles per hour at 16,000 or Mach 24, which is a little over 18,000 Antipodes estimated to be capable of traveling from London to New York and just 11 minutes of flight that currently takes 8 hours.

Antipode comes on the heels of November 2015 aircraft concept the screamer, which promised to travel at Mach 10 speeds, but was rife with design flaws. Following screamers announcement it was confronted with Sonic Boom and heating issues that would render the concept nonfunctional. Antipode is bombarded his response to screamers flaws. But if you are looking to catch a ride anytime soon, do not hold your breath.

The aircraft is years away from fruition as most of the technology required to make it functional has yet to be developed. But now that the DeLorean might be back in production, you might not even need a Mach 24 aircraft bloodhounds set to break land speed record top 1000 miles per hour. The current land speed record is held by the thrust SSC which broke the sound barrier while traveling at 763 miles per hour in 1997. Now its developers have taken on the challenge to reach 1000 miles per hour with a new car called the Bloodhound SSC.

The 1000 mile per hour car weighs 7.8 tons and measures 13.4 meters long and is designed to tackle the severe aerodynamic challenges. It is carbon fiber and titanium plated bodywork is built to withstand a tremendous amount of pressure 2 computer winglets at the head of the car will help keep the nose grounded to achieve its record breaking speed. The bloodhound is equipped with a V 12 racing engine that powers an ej 200 jet engine and a hybrid rocket engine.

The jet engine typically found in the Euro fighter jet typhoon takes the car to 100 miles per hour in just 5 seconds. When the car reaches 350 miles per hour at around 15 seconds, the rocket is fired, accelerating the car to 1050 miles per hour in another 25 seconds. At its peak speed. The bloodhound would break the land speed record covering 1 mile in just 3.5 seconds. The rocket will then shut off before power brakes.

And parachutes will be deployed to bring the vehicle to a stop to bloodhounds test drive is set to take place in the hack scene pan desert in South Africa in 2016. Sonic Boom from fighter jet caused tremors in New Jersey, while some panicked residents called 911. After feeling the ground shake earlier today, others took to social media to ask what caused the shaking. On Thursday afternoon a series of tremors were felt in parts of the Northeast United States making residents think they were experiencing multiple earthquakes.

The real culprit was a supersonic flight test conducted on 2 fighter jets near the Patuxent River naval airbase in Maryland, which produced a series of sonic booms. A total of 9 sonic booms were reported in 90 minutes from 1:30pm to 3pm. The US Geological Survey center the booms over hemington with tremors felt from South New Jersey to Long Island and the booms were heard as far away as Connecticut.

A temperature inversion which puts warm air higher up in the sky may have caused the sonic boom to be felt over such a large area as sound waves travel farther and warm air. A Navy spokesperson said the supersonic flight tests were conducted almost daily in the area but were rarely felt on land. Supersonic passenger flights will soon be a reality. A new airliner that boasts supersonic speeds is set to revolutionize air travel.

Once it takes flight in 2023 boom technologies planned to supersonic aircraft will have a cruise speed of 1451 miles per hour 2.6 times faster than any other airliner. While a flight from New York to London would typically take 7 hours on a commercial flight, the trip would take a little over 3 hours on a supersonic airliner. The Mach 2.2 aircraft will have 55 seats, each priced at about 5000 US dollars for a round trip ticket.

A one third scale prototype called the XP 1 will begin test flights in 2018 to demonstrate and refine the key technologies required for supersonic travel. Unlike the now retired Concorde and its notoriously loud sonic boom, the boom aircraft will have turbofans where noise reduction and would not be much louder than a normal plane. The company does have some hurdles to face before their project comes to fruition. Supersonic flights are still banned in the US but with federal laws currently set up for renegotiation that could soon change.

That is all thanks for your attention. Is there any questions? Please send it to us on the question forum. Thank you.