Introduction to Aircraft Design
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Lecture - 21
Cargo, GA and Military Aircraft, Some additional concept

Hello, let us look at some additional concepts related to cargo, general aviation and military aircraft. A gist of what we are going to cover in this lecture is shown to you in this cover slide.

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We are going to look at flying cars, we are going to look at new general aviation aircraft, and we are going to look at some generations of the fighter aircraft and also looking at exciting maneuverability capabilities of modern military aircraft.

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Let us start with the cargo aircraft. These are the ones as you can see the aircraft with no windows. They are the ones that carry the stuff that you order online mostly. This is the world's largest cargo aircraft. The one with 6 engines, the A225 Maria and this is a concept of the largest cargo aircraft that the US Air Force is going to operate. Notice that it is so large that helicopters can actually take off from within the aircraft and this is how the inside of a cargo aircraft normally looks like.

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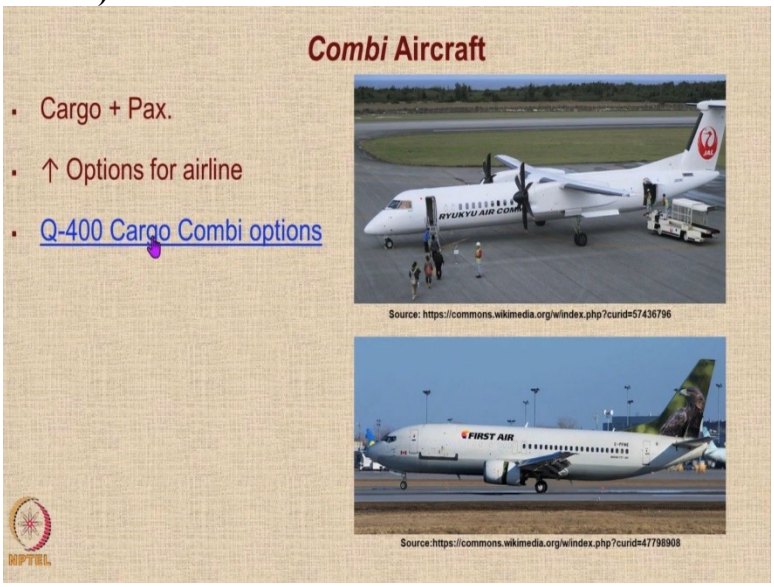

We have discussed about cargo aircraft in the original lecture clips but today we will look at 1 special category called as the combi aircraft. These are aircraft which are a combination of both cargo and passengers. So as you can see on the bottom right of the screen. There is an aircraft

operated by an airline called first air in which the forward half of the aircraft has no windows that means that is the cargo part and the rear half has windows which is the passenger part.

So the front door is the cargo door and the rear door is the passenger door. By operating combi aircraft such as the one shown in the top right. In this case, the seats are in the front and the cargo is behind. You have higher options available for the airline. If it does not have a full cargo load or a full passenger load, it can operate with a mixed bag. This aircraft Q-400 Cargo, it offers several combi options, it is not just 1 combi option. Let us have a look at the various combi.

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And are very famous combi Aircraft Operations are there in what is called as the milk run by Alaska Airlines. I would recommend all of you to go online and search for Alaska Airlines milk run which starts from Seattle and goes right up to Anchorage, the capital of Alaska. And it is a daily run and this is the 1 that supplies the basic groceries, eggs and milk etc. to Alaska. So it is a very interesting case study in air transportation. How an airline operates a daily service which provides groceries to remotely connected communities.

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Let us have a look now at one of the modern general aviation aircraft called as the HONDAJET H-420. This is a very unique aircraft as we will see in a short video clip about the aircraft.

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The Honda jet has become a new benchmark in general aviation aircraft both because of its excellent looks, unique design and also its abilities and performance.

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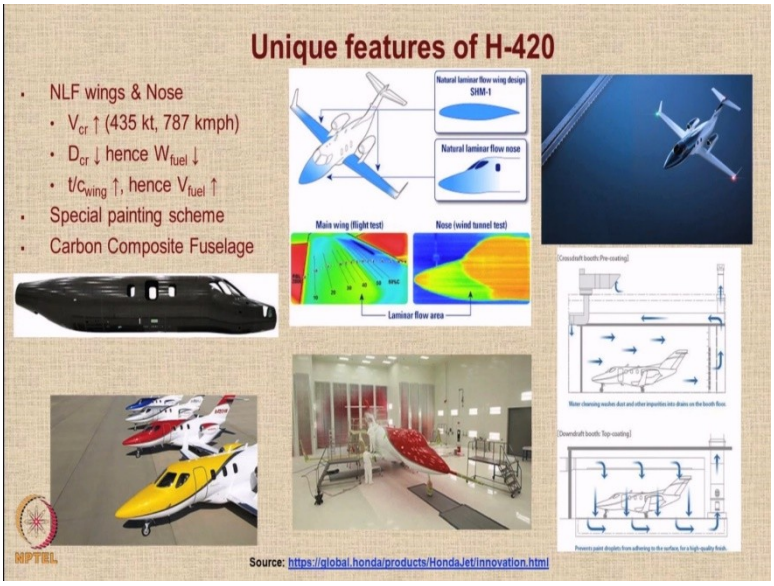

Let us look at some unique features of H-420. First of all the aircraft has been very carefully designed to provide a natural laminar flow in its wings and also in the nose as you can see in this particular figure. The nose portion has been very carefully designed to provide laminar flow to a large extent. In most aircraft you can expect the top the front 5% of the aircraft to have laminar flow but here it is a much larger portion as you can see by this green patch, this is the leading edge and this is the trailing edge.

So, we see that more than half the wing has got laminar flow and almost the entire nose has also laminar flow. So, this reduces the drag. When you use an NLF airfoil you also get a very large chord. So, the benefit of having laminar flow on the wings and the nose is that its cruise speed increases. This aircraft has a very high screw speed of 787 kilometers per hour. Due to the presence of a large area under laminar flow, the total drag decreases and hence the fuel consumption also reduces.

The t/c is quite high. So, therefore there is a larger volume available for the fuel to store. And this aircraft also follows a very special painting scheme as you can see in these 2 sketches. First there is some draft you know you when you paint it, you spray the paint and then you take out all the fumes and then there is a downward draft so that the paint does not get deposited. So, because of that you have such a beautiful color deposition on the aircraft.

And you can see it comes in multiple beautiful colors. So it is a very special painting scheme which is followed. Even structurally, the entire fuselage is carbon composite. So that makes it structurally very efficient, very light weight.

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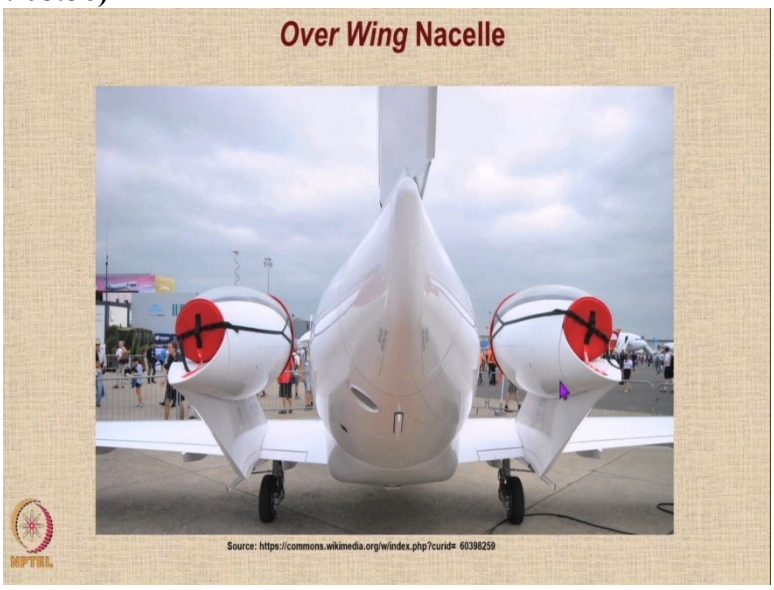

But the most unique feature that stands out in this aircraft is when you look it from the rear. We see that the engines are mounted over the wing. This is one of the very few aircraft available today in which the engines are mounted on the wing but over the wing. So, there are many reasons for this and we have covered some of them in the lecture but I would recommend all of you to go online and read there are several papers available about the design of this aircraft. Their detailed CFD studies were done to establish the angle of these engines.

Notice the engines are slightly angled inside they are not exactly straight. So, there is a reason for all that the height of this particular pylon, the location from the fuselage, the angle etc. all has been very carefully determined to create most aerodynamically optimal design and since the engines are mounted on the rear side they are behind the passenger cabin. So the noise levels are also much lower. And because they are mounted above the wings the accessibility for maintenance also is very high.

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This aircraft is not only very well designed aircraft but also it has 1 several awards and accolades right from 2004 onwards. Here we see the awards which have been won by the aircraft in the first 7 years of existence and then it does not stop here. It continues from 2012 to 2018. So the latest award is the AIAA foundation Award for Excellence from the AIAA in 2018. And in 2012, it won the aircraft design award by AIAA.

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Now, let us move on to some private jets. Now, I hope that very soon, you become so rich and wealthy that you are able to afford your own aircraft. And then that situation arises in your life, do not forget me. Remember that I had told you about the top 10 most expensive private jets in the world. So here I have a menu available to you to purchase your aircraft. On the left and right

of the screen there are photographs of world's top 10 aircraft and you have to look at them in alternate manner.

This is Airbus A380. This is Airbus A340. This is Boeing 747 and this is Boeing 787 etc. So you can choose depending on how much money you can spare. The cheapest in this menu is the Gulfstream G-500 which is here which is just $44 million and the most expensive one $600 million Airbus A380. This is the basic price. And to give you an idea about these aircraft, I have decided to show you a small video clip.

When you become super wealthy, it is important to be able to travel in comfort and style. For those whom first class cabins will not do. There is always the option of buying your own private jet. But even these come in a wide range of prices and sizes from the smaller luxury models to the ornate flying palaces. These are 10 of the most expensive private jets in the world. Number 10, the Gulfstream G500 44 million dollars. The Gulfstream G500 is the company's newest design with the first only being delivered to a customer in September of 2018.

The 91 foot 2 inch long jet has a wingspan of 87 feet and an inch. A cruising speed of around 448 miles per hour and its delivery spec. There is room for 10 people to sleep. The interior is incredibly luxurious and includes 27 inch wide seats, ample headroom to walk around, height adjustable conference tables, and plenty of storage room with a price tag of 44 million dollars. The cabin can be customized to your requirements such as the choice of whether the galley is in the front or the back.

And it comes with high speed internet access that said to be 30 times faster than other planes in its class. As with all private jets, the running cost can significantly increase the total overall price but the G500 has been designed to be as economical as possible. The total annual budget which includes flying for 400 hours is approximately 2.4 million dollars which averages to the cost of 13 and 22 cents per mile.

Number 9, the Embraer lineage 1000E based on the Embraer lineage 190 regional jetliner. The Brazilian company describes the 1000E as an ultra large business jet with a spacious interior big

enough to easily accommodate 19 people. It is just shine of 119 feet long with a wingspan of 94 feet and 3 inches and as a range of 5294 miles at a cruising speed of 543 miles per hour. The interior cabin is split into 5 sections which includes a walk in cargo area to the rear, a master bedroom, a bathroom with a walk in shower and entertainment lounge and a dining area.

And if you happen to have changed from the 53 million dollars asking price. Well there is plenty of further optional extras that can be fitted. And Breyers design chief J. Beaver has overseen lavish redesigns of interiors that are built to a customer's requirements including the Kyoto airship along with skylights and the Hollywood airship which imbues the style and luxury of 1930s Tinsel town.

Number 8, the Gulfstream G650ER 71.5 million dollars. The 71.5 million dollars G650Er is Gulf streams flagship product and as you would expect for the model held in such high regard by the company. It is one of the best you can buy that is specifically designed as a private jet. It is an extended range version of the G650. And can travel a distance of 8600 miles at a cruising speed of 560 miles per hour. It is 99 feet 9 inches long and 99 feet 7 inches wide and has a 2138 cubic foot cabin that can be configured for between 11 to 18 passengers.

The interior is decorated with rich leather, fine wood veneers and handcrafted stonework. It includes our standard audio and high definition TV equipment, a convection oven, a series of 26 inch widescreen televisions and it comes fully equipped with dinnerware and cutlery. So you will be ready to entertain. By using an app on your smartphone, you will be able to control the temperature, lighting, the shades and the windows and entertainment devices while you are on board the wireless network that is connected to 2 multichannel satellite systems.

And ensures that you are kept in contact with the ground. It is cruising altitude is 51,000 feet which keeps it above commercial traffic and weather but the cabin is pressurized to around 4000 feet. So you will hardly feel like you float at all.
Number 7, the Bombardier global 7500 $73 million. The Bombardier global 7500 is according to the company the world's largest and longest range business jet with a range of 8800 miles.

This gives the ability to make a nonstop flight between New York and Australia. Ultimate comfort with 4 customizable living spaces as well as an additional crew resting area. Bombardier offers a range of options when it comes to the setup of the interior with choices of a master suite with a walk in shower, a club suite with 4 ergonomic seats large TV and windows or conference suite with room for 6 to sit and eat an entertainment suite and even a private three person suite. Without buying a larger plane and refitting it for your needs.

This is as luxurious a private jet as is possible to buy.
Number 6, the Boeing 757 $100 million. In 2011, Donald Trump bought a Boeing 757 from Microsoft cofounder Paul Allen and gave it exactly the type of makeover you would expect from Mr. Trump far beyond simply having his name painted on the outside. The interior is what is made this a $100 million purchase. It is powered by a pair of Rolls Royce RB211 turbofan engines and can fly for 16 hours and more than 500 miles an hour.

The refurbishment of the plane that in a commercial setup can carry up to 200 people, now has room for just 43. Some of the features include a bedroom, a dining room, a private guest room and entertainment room and this Jett even has a 24 karat gold bath. Yes, you heard that correct. Every seat has a personal TV screen as well with access to an entertainment system that offers a library of more than 1000 movies and 2500 audio CDs.

There is also gold everywhere including on the seat belts and the family logo is stamped on virtually every object in the cabin.
Number 5, the Airbus ACJ319NEO 101.5 million dollars. The Airbus ACJ319NEO is a new model of jet that completed test flights in early 2019. And the first is currently scheduled for delivery in 2020. Airbus has taken the popular A320NEO and added new engines and extra fuel tanks to extend its range and have partnered with Falco technique to customize the VIP cabin on board.

There is a focus on weight reduction to make this jet as economical to fly as possible. But that does not mean luxury is the second priority. This state of the art cabin is built with all the latest technologies such as low altitude cabin pressure, entertainment facilities, private cabins, a

conference room and permanent connection to the internet through satellites. In trials, it recently completed a 16 hour flight at around 500 miles an hour with a configuration that could seat 162 people.

The first of these 101.5 million dollars jets to be produced is. aviation in Germany. But with 14 on order, it is quite possible there will be 1 on the way to a billionaire near you.
Number 4, the Boeing 787-8 BBJ 324.6 million dollars. The Boeing Dreamliner first went into commercial use in 2011. And it was inevitable that they would release a business version of the jet. Something they did by 2014. The first one was built in collaboration with Kestrel and Green point technologies who spent 2 and a half years designing and installing the custom interior.

The list price of the 787-8 is 224.6 million dollars and the upgrades cost of further 100 hundred million dollars. But as you will see, it was all worth it as they have converted the plane into a 2400 foot luxury flying home. The master suite accessible from the entrance is completely separate from the rest of the cabin and is designed to be an oasis of silence. It has a California king size bed, a huge bathroom with marble sinks, a double size walk in shower and even heated marble floors.

Those with a lot of luggage are catered for as the master suite also comes equipped with its own dressing room, a walk in closet, a refrigerator and a safe. Beyond the private quarters, the jet has an open main lounge designed to feel as spacious as possible and includes 2 decker beds in front of a 55 inch flat screen display. Along with other seats that have their own monitors to the rear of this cabin is a VIP lounge.

And then behind it is the guest cabin with 18 first class reclining seats and a row of Premium Economy seats for the staff. The jet has a range of 11,500 miles. So, you can reach virtually anywhere on Earth.
Number 3, the Boeing 747-8 VIP over 367 million dollars. The 747 is probably the most famous commercial airliner in the world. But for those able to afford it, Boeing also offers a private version of the jet costing 367 million dollars for the base model.

One recent and confidential client instead of spent another 100 million to upgrade the interior powered by 4 General Electric Genx engines. It can fly 9200 miles non-stop at 645 miles an hour and can be customized into virtually any configuration a client would want. The recent craft designed by Green point technologies made use of the 4786 square foot interior to include a state room three large lounges in office and a huge dining room with a table that seats 14 people.

This is also the model that is been announced to be the replacement for air force 1 and that an estimated 660 million dollars will likely become the most expensive private aircraft ever to be constructed. Plans involve making 2 jets resistant to media strikes, nuclear war and terrorist attacks with the ability to deploy flares, jam radars and refuel in midair. On board they will be able to seat about 100 people and all the equipment needed to run the entire country.

Number 2, the Airbus A340-300 350 to 500 million dollar was thought to be the second most expensive private jet in the world is owned by one of Russia's wealthiest billionaires, Alisher Usmanov. Based on an Airbus A340-300, which has a purchase price of 238 million dollars. In extensive refit means this particular jet will have cost in excess of 350 million dollars. Although no one knows quite for sure. At 209 feet long and with 4 engines, it is the biggest private jet in Russia and has a range of 10,300 miles with a cruising speed of 540 miles per hour.

The high costs and high fuel consumption mean that this model is not often used by civilian air fleets. But when you are 1 of the richest people in the world, it is unlikely to matter. Very little is known about the interior of jet though as no images have ever been released. What is known is that it is registered in the Isle of Man with the registration M-IABU, which means I M Alisher Bourkhanovich Usmanov and it is named after his father.

Number 1, the Airbus A380 at over 600 million dollars also known as the flying palace. The most expensive private jet was conceived and ordered by Saudi Arabian Prince Alwaleed bin Talal in 2013 but he apparently sold it to an unknown buyer before even receiving delivery of the plane. It is a fully customized Airbus A380 which is the largest jet that is flown by commercial carriers and costs 400 million dollars from the assembly line refitting the interior of the double decker plane costs at least 200 million dollars.

And could actually have been far more for this expense. The prince installed a concert hall a Turkish bath, a luxury car garage. So we can take his prized vehicles anywhere he goes and the prayer room with computer controlled maps that automatically rotate to face Mecca. There are 5 bedrooms which each have an in suite bathroom, a king size bed and dining area, a meeting room and even a luxury dining room where each of the 14 seats is equipped with foot rests, massages and adjustable supports.

There is also a boardroom and a laid back lounge. But undoubtedly, the most standout feature of this jet is the throne. That is pride and placed in the center. The A380 has a cruising speed of 560 miles per hour and a range of 9200 miles. But you probably will not notice how long your trip is with amenities like this. Well, I feel like I have been in an airport all day. I do not know about you. And if you had a few 100 million dollars to spare, let us know how you would design and decorate your own private jet. If you enjoyed this video, make sure to leave a like and subscribe. As always, I am Mr. Luxury, pip pip, da doodly doo.

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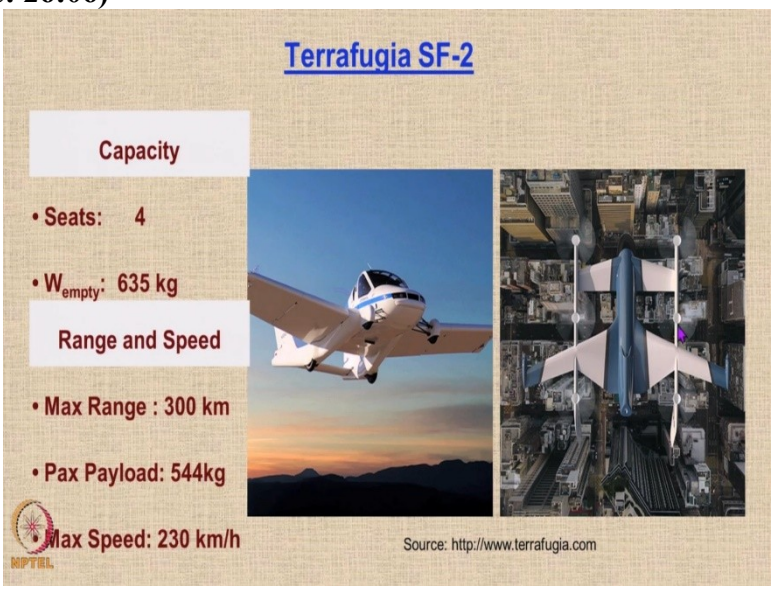

So as I mentioned, when you buy these aircraft for your own personal travel, do remember you saw it first here. All right now, now we look at an interesting concept, something that all of us dream about the flying cars, the cars that can fly in the air, like we have cars that can move on the roads. These are some artist impressions, taken from a very interesting page on Pinterest

called as flying cars. So there are a lot of imaginative and creative ideas have been given by people about flying cars.

But friends, we are very far away from this level of expertise. I will talk today only about 2 personal flying vehicles or personal flying cars which are likely to be available in the near future. The first of these cars available to you is the Terrafugia SF-2. As you can see, it is a very beautiful aircraft and also a very beautiful car both at the same time. And these are its specifications.

It has a capacity of 4 seats including the pilot and pilots and an empty weight of 635 kilograms but you can travel 300 kilometers in 1 fuel charge with a maximum payload of 544 Kg at a maximum speed of 230 kilometers per hour. This is how it will look as an artist's impression in the top view the new version of this car. So there are more and more, newer and newer designs which are being proposed. So, this is a new design which has been proposed. Let us have a look at the video of the whole concept of our Terra future.

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Moving ahead, the next option that is available to us is the Aeromobile. And there are many versions of this. They have reached version 5 I think by now. We will talk about the basic version 4 which was on display. So this is airmobile 4.0. As you can see, it is a car on which wings are mounted on the top backside. Here the capacity is just 2 seats and a total payload of

600 kg. The range is much larger than Terrafugia SF-2. It is 700 kilometers and the maximum speed is a little bit lower of 200 kilometers per hour. So let us have a look at the concept of airmobile 4.

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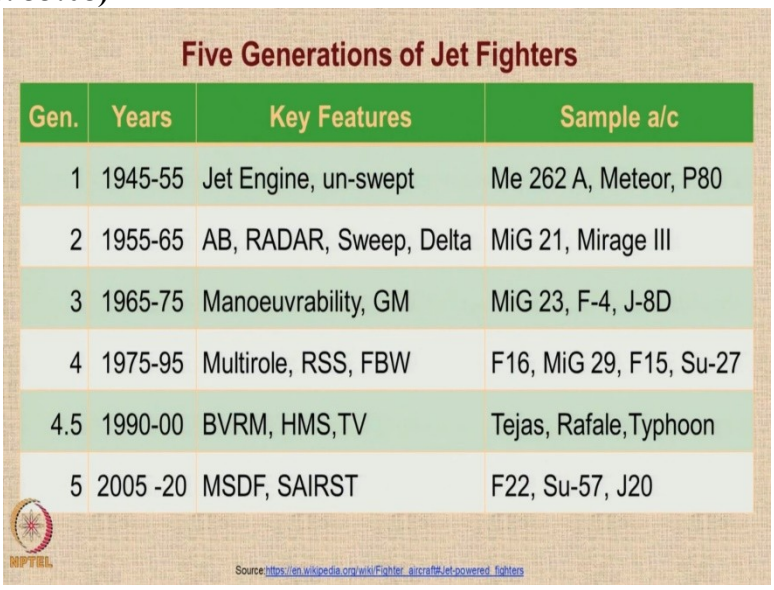

So as you can notice, this is just a concept video. And once again, if you happen to buy any of these cars in the near future, remember where you first saw it. Now let us move to a little bit more exciting and nerve wracking stuff; the military aircraft. We will look at 3 aspects of military aircraft beyond what has been covered in the video clips. We will look at fighter aircraft generations. We will look at some of the key requirements of fighter aircraft.

And then finally, we will end by looking at some interesting aspects of maneuverability and super maneuverability and survivability of military aircraft. Just like any other family, there are 5 generations of jet fighters. In fact, there is now a sixth generation also. The first generation was after the Second World War in the post-World War years 45 to 55. During which the key features of the aircraft were in production of the jet engine on Me 262 A. These were aircraft with the jet engine and they had un-swept wings.

So the 3 aircraft that represent this particular area are the Me 262 A, the Gloster Meteor and P80. The next generation was mid-50s to mid-60s. During this time, features such as the afterburner were incorporated in the engine to make it much more capable. Radar was brought into the

aircraft, sweep was introduced and some aircraft had Delta wings. An example of the aircraft which belong to this family is the MiG 21 which India also has operated very successfully and also Mirage 3 from the French stable.

So we started using military aircraft essentially from the second generation. The next generation was the mid-60s to mid-70s or early 70s in which maneuverability and guided designs. These were some of the key features they have brought into the aircraft technology. In this table belongs MiG 23, MiG 27, F-4 Phantom and from the China J-8D aircraft. Generation 4 was from mid-70s or early 70s to around mid-90s. This is a long period of time.

During this time, the concept of multi role aircraft, the concept of relaxed static stability, fly by wire these concepts were brought into or these features were added into the aircraft. The aircraft in this family are quite few the ones that were many of you know F15 and F16 from the western stable and MiG 29 and Sukhoi 27 they belong to this generation from the Russian stable. After generation 4, there was a generation 4.5 which was from early 90s to around 2000.

Here beyond visual rain missiles, helmet mounted sight and thrust vectoring. These are the features that were brought into the design of the aircraft. So, our own Tejas belongs to this category along with the Rafale and the Eurofighter Typhoon and then we had generation 5 which is the present generation aircraft from 2005 onwards to 2020 approximately. So, here there are features such as multi sensor data fusion and situational awareness due to infrared techniques.

The aircraft in this family and then some stealth also can be considered as brought in this particular category. So, the 3 aircraft, the 3 present day aircraft, the top ranking aircraft of today, the F22 which is now actually very old. F35 is replacing it in many ways. F22, Sukhoi 57 and J20 from the Chinese stable. They belong to the fifth generation of military aircraft. And there is a proposal to look at the sixth generation aircraft which will start from 2025 and go on till something like 2035 etc.

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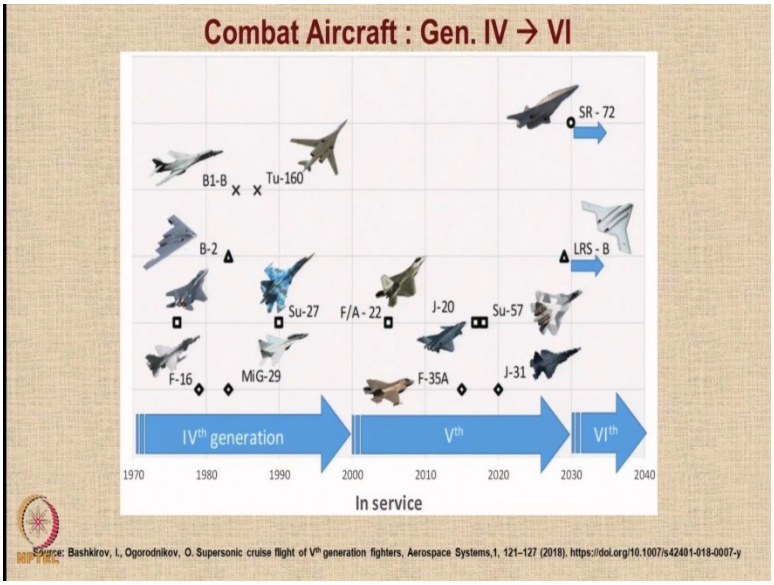

So, here is another look at combat aircraft from generation 4 to generation 6. Generation 4 consists of the aircraft from you know up to around the year 2000, the F16 MiG 29, Sukhoi 27 B-2 etc. They are all fourth generation. Then fifth generation are the ones which are currently in service like the F/A-22, the J20 from China, the F-35A, the J31, Sukhoi 57 and the ones that are going to be brought out from 2030 onwards, the UCAVs unmanned combat Aerial Vehicles etc. SR-72.

These are the ones which are called the sixth generation which is yet to come which is for the future. More details about combat aircraft generation from 4 to 6 are available in this paper which talks about the supersonic cruise flight of the fifth generation fighters.

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Let us look at the typical requirements of combat aircraft. So, at the first level we have requirements on the aerodynamics. The prime requirement today for a military aircraft is to have high Wing loading. So that its acceleration performance and cruise performance is increased. Then, we would like to have range so that you can reach the combat zone and you can cover that zone. We need to have air superiority which means no one else should be able to come into the area under our control and do any Hanky Panky.

We should be able to control an airspace within the limited area and time. So, during that time and during on that area, we should be superior to anybody else. That is the aim of an air superiority aircraft. That is a requirement. Stealth is also a very important requirement where you would like to see the enemy before the enemy sees you. In fact, what you would prefer is if the enemy is just not able to see you. We saw this in the Gulf War.

When the B-2 bombers were able to fly without any fear of being detected because they were and therefore there is a very interesting video which shows how the enemy is you know how the gulf war you know when B-2 used to enter the space you know the people there would fire missiles at random because they do not know where the aircraft is. And then we have the requirements on maneuverability.

The maneuverability requirements could be on climbing performance, they could be on acceleration or could be on turning speed. It could be on many, many parameters. But more maneuverability is a very important requirement. Especially when you are looking at an aircraft that has to get there quickly fight against the enemy and come back.

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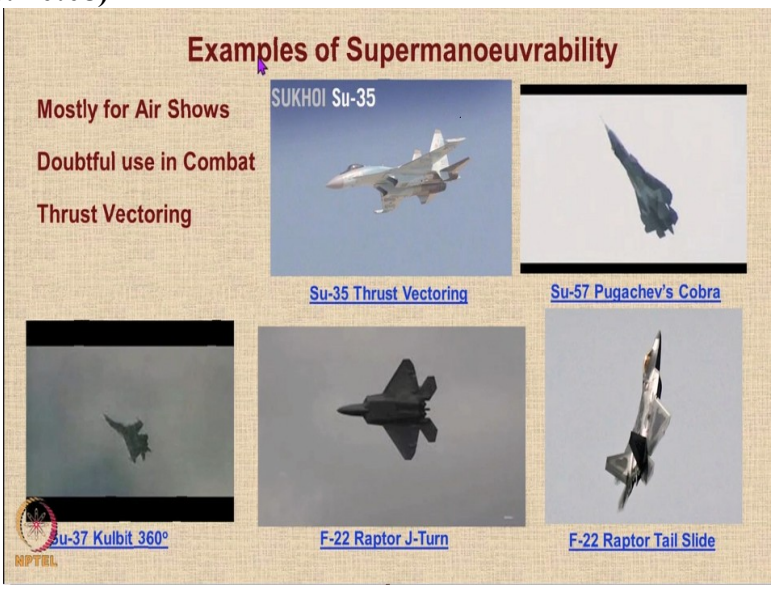

So let us look at some examples of super maneuverability. Maneuverability beyond the normal standards. Mostly this particular demonstration is done in air shows to illustrate the superiority of these aircraft. It is basically mostly it is like a sales presentation or a sales demonstration. There is a huge amount of doubt whether all these super maneuverability, maneuvers or features are really going to be useful in combat.

They might be that is why they have been provided but it is mostly used as an illustration of how maneuverable our aircraft is. And the prime mechanism by which we achieve super maneuverability is thrust vectoring that is a prime mechanism. So let us have a look at some examples of thrust vectoring.

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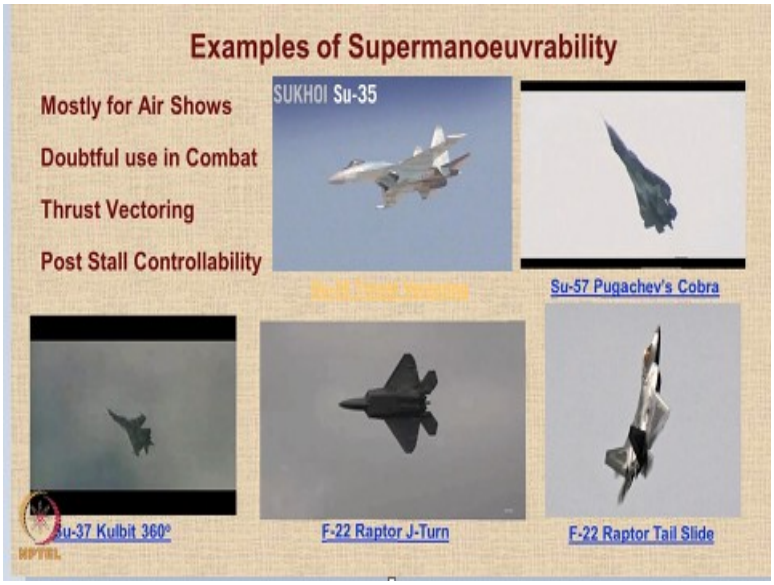

Moving ahead. Apart from thrust vectoring one of the major mechanisms through which we can achieve super maneuverability is to have post stall controllability. So, as you will see in these wonderful maneuvers, the aircraft is going to go beyond the normal stalling regime. And once you have a control in that particular regime only then you are able to do these kinds of stunts or demonstrations.

Let us now look at one of the most famous maneuvers which has made a lot of headlines in aviation air shows which is called as the Pugachev's Cobra. I will show you a small video clip of Pugachev's Cobra as executed by the SU-57 fifth generation aircraft.

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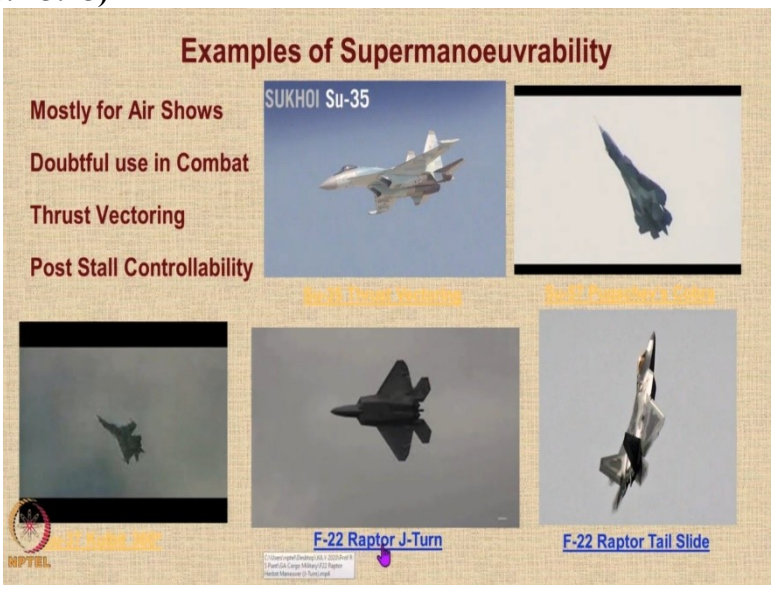

So, the Pugachev's Cobra was actually discovered by you know by luck or by chance by a Yugoslavian pilot and then it was considered to be a very interesting and a very exciting maneuver. So, now let us look at a higher version of the Pugachev's Cobra so called 360 degree kulbit turn. So after the 360 degree kulbit, now let us look at another interesting maneuver, which is the J-turn and this will be shown on F-22 Raptor.

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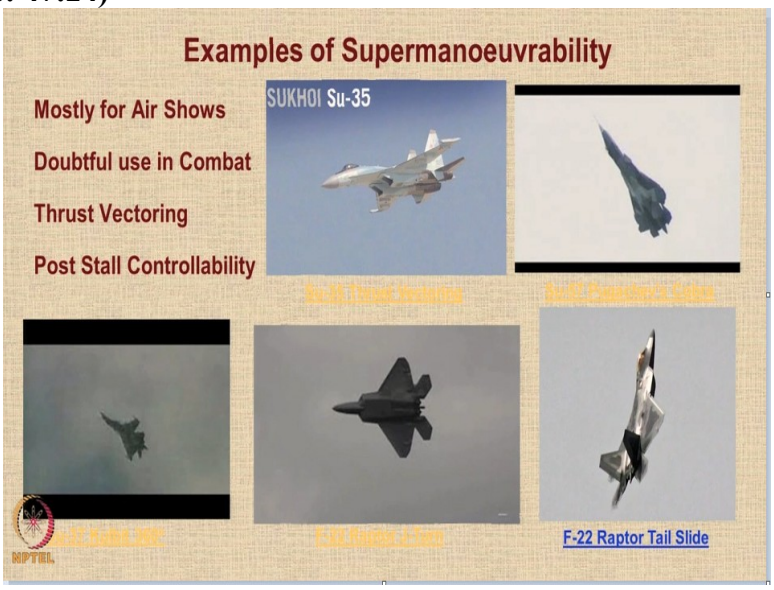

So this was an aircraft from the western stable the F-22. And now, to sum it up, we will look at the maneuver called as a tail slide in which the aircraft goes vertically upwards and then falls down like a stone. That also we will show you on F-22. Raptor.

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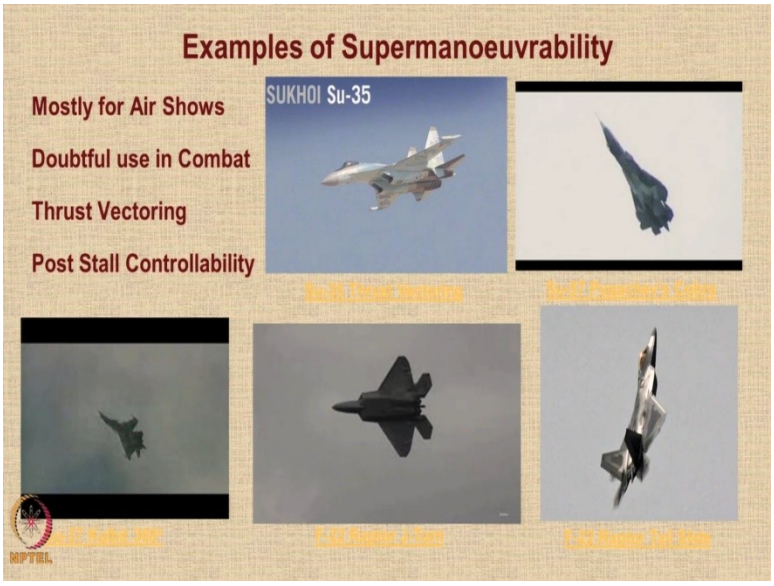

So all this looks very exciting and looks very breathtaking. But in Modern Combat, where we have the beyond visual range missiles in which you have fire and forget weapons. You know, there may not be any need for any of these very super maneuverable capability in the aircraft. So that is why there are questions on whether this kind of maneuverability is really going to be of great use. But still, it does make a very exciting demonstration during the air shows. And also it tries to convince the user to buy the aircraft because of the fantastic ability.

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Moving ahead, let us look at some other requirements for the combat aircraft. From the power plant, we have a requirement of high thrust to weight to ratio, low fuel consumption, infrared signature and smoke reduction. Now, interestingly, earlier when we were students, we were told

that in military aircraft, we never worry about low fuel consumption. But now, because of the changing scenario and because of the economics and operating costs, low fuel consumption is also coming as an important requirement even for combat aircraft.

Of course, not at the cost of performance but with the performance if you can also give low fuel consumption. Great, that is a deadly combination. As far as avionics is concerned, there is a requirement now for very intuitive man machines interfaces and systems. So that the pilot can work seamlessly and carry out all the complex activities in the aircraft. Those days have gone when there would be a separate person in the cockpit to do the avionics or the weapon part.

And there would be only 1, the pilot would only focus on the Airman ship and you know flying but now it is multi role many aircraft are single pilot aircraft. So the pilot has to do everything. So things like the helmet mounted sights, head up display etc. And also various other equipment on the aircraft that allow you to control your weapons, allow you to scan the landscape, multiple targets to be against all this as possible because of advanced avionics.

Armament well, armament is basically the main purpose of carrying of a military aircraft. So, there should be a choice of various types of armament. There should be accuracy of these armaments, large quantity of stores to be able to be carried onboard. So many military aircraft are actually designed around the kind of argument that they are supposed to carry. To be able to keep your Air Force ready, there is a requirement of availability, reliability and maintainability.

So, whether it is peacetime or whether it is during the combat, the system should be able to operate with very high availability rate and it should be easy to repair them. It should not be there for every small thing you have to bring them back to the manufacturer or to the hangars. There should be many possibility of on the field repairs, there should be possibility of line replaceable units which can be replaced at the forward basis and then brought back to the main maintenance Bureau's for further checks and improvements.

And finally, combat aircraft essentially are supposed to go out there do their job but they will always be facing the barrage of enemy fire. So they should be able to survive and you should be

able to maintain functionality even in the face of threats. So this is also a very important requirement. Especially for aircraft which are designed for a mission called as a combat air patrol or close air support.

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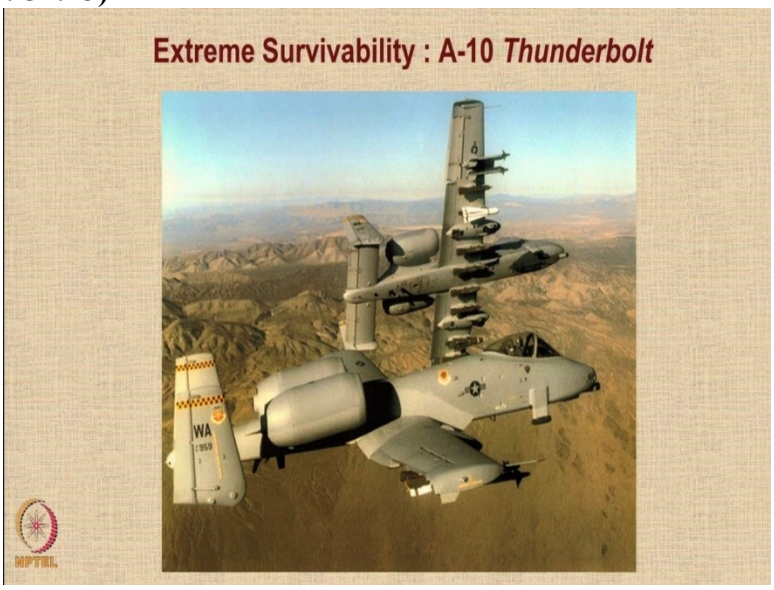

And the big daddy in this particular category is the A-10 Thunderbolt aircraft and aircraft which the US Air Force has been planning to replace for a long time. But it is finding very difficult to get a replacement for this because of its fantastic features. So let us hear about the survivability of Thunderbolt from a member of the design team of A-10 Thunderbolt, you know literally from the horse's mouth. I will play the video for you.

I was invited by the people who actually started the A-10, a wonderful guy named Colonel Avery Kay to join in to head up the technical effort to define the aeroplane. The Air Force called it the concept formulation packet. And I did this completely outside my regular job in the Pentagon which was working for the secretary of defense, we were actually doing something unique in the history of air power and air design.

We were actually designing an aeroplane directly for the mission of supporting ground troops. That was never done before. It is never been done since then. To make an aeroplane do close support, the very first thing is it has to fly close enough to the targets and stay close enough that you can actually detect the kind of camouflage threats that really are dangerous to your own

infantry and your own soldiers. You just need to be in close so you need to be flying under 300 knots.

And if you happen to be lucky enough to catch a target as you see it you need to stay real close as you come around to attack it. So you need an aeroplane that is very maneuverable and operates in the 200 to 300 knot region. That means a large wing. In order to get that good maneuverability need to have beautiful visibility out of the cockpit into the cockpit has to be very narrow. The nose has to slope down.

You have to be able to see over the side. And of course to the rear as you go past the target and to protect yourself. You need to have weapons that will allow you to bring fire in very close to friendlies because their most dangerous threats are the ones that are in closest. I mean weapons that are very accurate and that will not harm your friends even if they are in closest 20 meters that almost exclusively means a powerful cannon or the anything else.

We will fill that job and that is why the A-10 got a 30 millimeter cannon, the most powerful cannon on any aeroplane in the world. At the same time you need to be able to operate under the weather that puts even more premium on maneuverability and slow speed because lots of places in the world, your troops are in trouble and the clouds are 1000 feet or under. Again fast movers 500 not jets, F16, F15, F35, not a prior to operate under 1000 feet.

We also need an aeroplane that when operating in close to these targets and under weather can survive the obvious ground fire that it is going to get. Because if you are going after you know what is attacking you and your friend, they are likely to shoot at you too with rifles, machine guns, small shoulder fired weapons. If you need an aeroplane that can take those kind of hits, there is no way you can do this mission and not get hit.

You need an aeroplane that can take those hits that will protect the pilot. We built in a titanium bathtub about 1200 pounds worth of armor for the pilot, very, very thick front windshield glass to protect them. Even the side glass is bulletproof. So, pilot is protected that is the most

important thing. And the aeroplane has totally redundant controls, you can blow a hole in almost any part of the aeroplane, tear off any single control aileron, rudder, whatever.

And there is another 1, we specified it had to be a second control to take over. And a second mechanical control system not hydraulic or electric that is so easily shot up. They can keep the aeroplane flying and get that pilot home. So we made this aeroplane the most survivable aeroplane ever built even more so an aeroplane in world war 2 that were very conscious of facing enemy fire in the tried to do a lot. We went way further than any aeroplane has ever done.

In requiring the aeroplane to be controllable after damage, have very low incidence of fire explosion, we specified that the fuel could not be anywhere near the engine. Again, that is a tremendous handicap to any fast moving jet because they always wrap the fuel around the engine. So we forced the designers under great complaint from them to put no fuel anywhere near an engine. And that is why you see the configuration of the A-10, we cannot the engine directory outside the fuselage. He put a rifle through a rifle bullet through fuel tank.

It is a you know even if the fuel comes out and burns a bit, you are not going to tear up the engine and blow up the aeroplane. We also specified very important the aeroplane has to be able to fly out of really austere fields, unpaved roads, dirt strips, grass fields, pastures all that because it is so important to be up near the troops. And if you have an aeroplane that can only fly out of 10,000 foot, you are not going to do close support and then even more stringent.

We specified, the aeroplane had to fly out of these conditions, no hangar no nothing just tents and a dirt strip and be able to fly multiple sorties per day. The A-10 actually can fly more than 3 sorties a day under those conditions. Come back hot refuel and rearm. Never turn off the engine, get ammunition on and go out again. Because for your friends when they are under pressure by an overwhelming force they just need air constantly.

They need overhead air and that is the other thing we designed into the aeroplane was not only that you could put out a lot of sorties every day to keep up presence. But every shorty had to have at least 2 hours warrior time over your friendlies. If you come in there with some fast

moving jet and all you have got is 15 or 30 minutes. You are not much help because the enemy is not going to simply stop shooting after 15 minutes. So those were the kind of things that we designed in the A-10 that are quite unique. There is no other aeroplane in the world that has those combination of characteristics.

(Video Ends: 58:50)

I hope you have enjoyed this session and I will be very happy to answer any questions you have using the Moodle or using the bulletin board. Thank you.