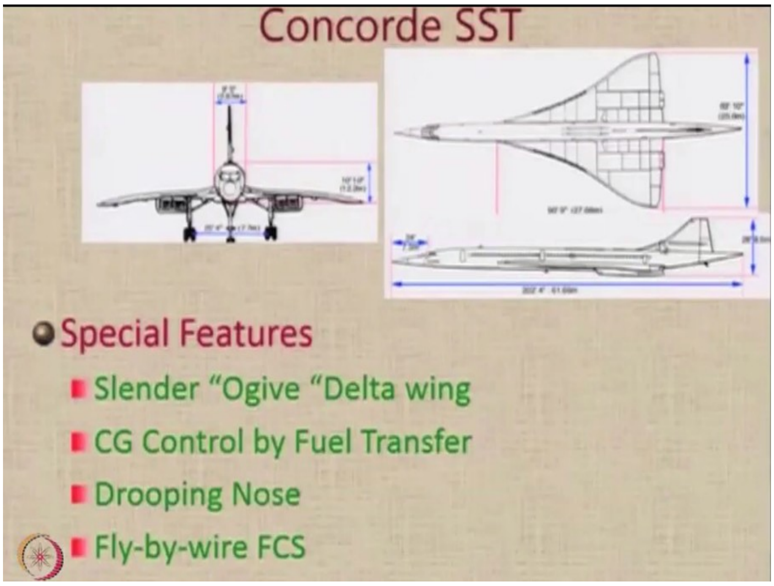
LIntroduction to Aircraft Design
Prof. Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology - Bombay

Lecture – 16
Supersonic Transport Aircraft

Let us now look at supersonic transport aircraft. Well there are not many choices available here. If we look at history, the only two aircraft which have seen supersonic flight with passengers, the one is the Concorde and the other one is the Concordski or TU-154M from the Russian stable.

(Refer Slide Time: 00:41)

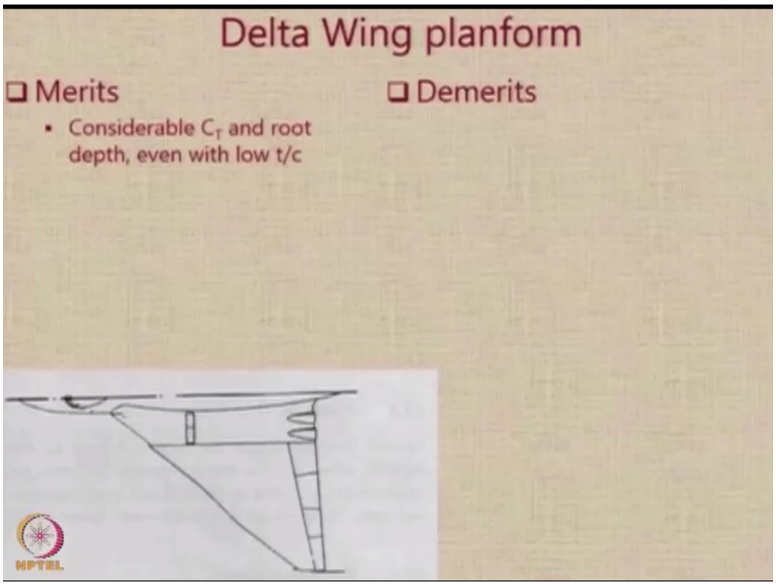


Let us look at some design features of the Concorde supersonic transport or SST as it is called. First of all the wing of the aircraft itself is a very special one. It is a very slender wing with a very low aspect ratio because that is suitable for supersonic flight and the shape is called as the ogive delta. So this shape is called as the ogive delta okay. It is not a pure delta, it is not like a triangle, but it is like a curved shape for a triangle.

This was the first aircraft in which the center of gravity adjustment or control was achieved by transporting fuel within the various fuel tanks. This kind of CG control is needed because when the aircraft transitions from subsonic flight to supersonic flight, we know that there is going to be a change in the location of the center of pressure, it will move backwards and hence there is a huge amount of change in the pitching moment which is created and this has to be adjusted by changing the center of gravity of the aircraft.

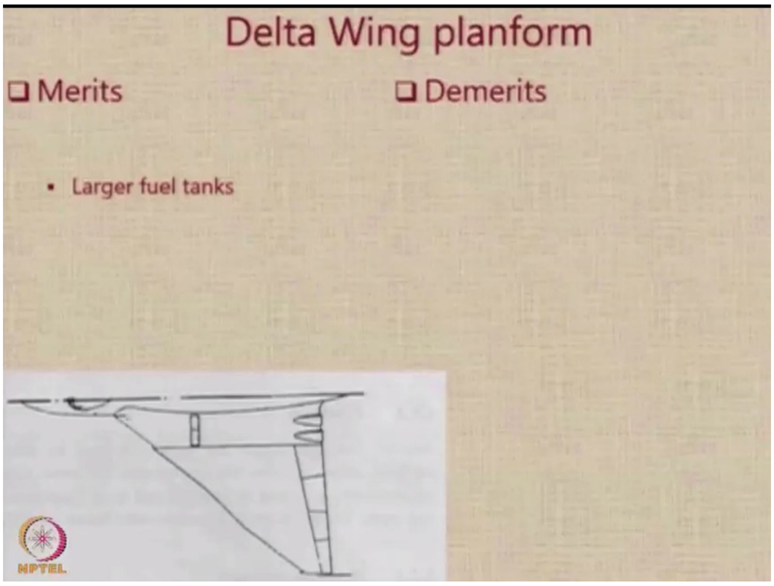
In Concorde, it is achieved by transferring the fuel between various tanks. This also had a drooping nose to meet the special requirements which are prevalent when you operate an aircraft both in subsonic as well as in supersonic flight and it was also the first aircraft to have a fly-by-wire flight control system, but please note this was not a digital system. This was actually an analog fly-by-wire control system but the first aircraft to have this feature.

(Refer Slide Time: 02:35)



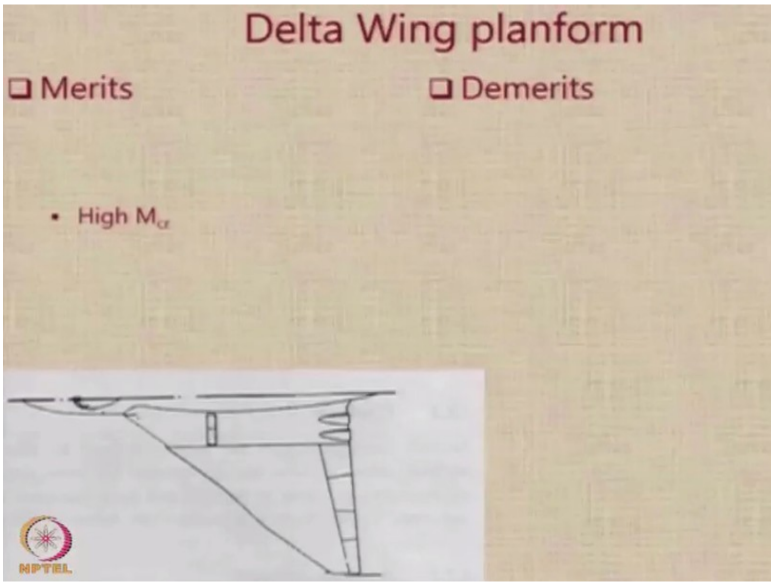
A delta wing planform which is used on Concorde has several merits and demerits. You can see a sketch, this is a typical delta wing planform. This is not that of the Concorde, it is just an example to show you how a delta wing typically looks like. First of all, a delta wing can give you a very large value of root chord even with a lower value of thickness to chord ratio t by c which is needed for supersonic flight. So even with a very thin wing you can get a very large tip chord and a root depth.

(Refer Slide Time: 03:17)



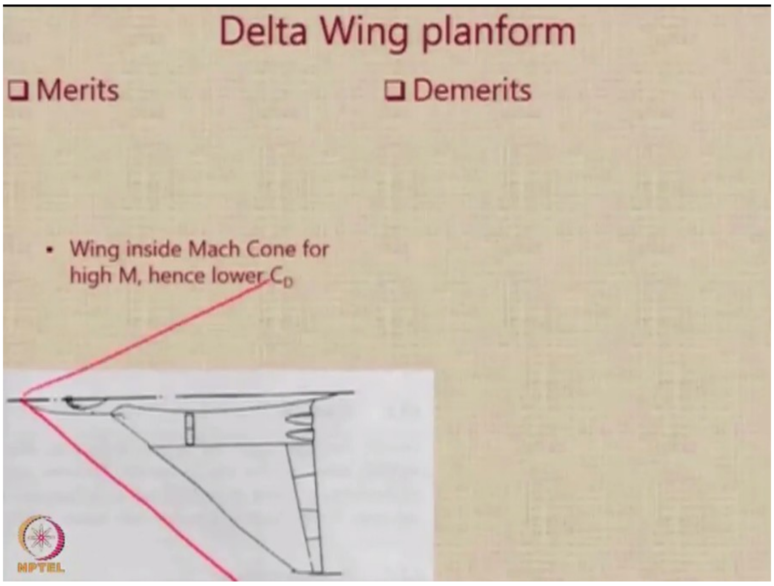
The volume available for the fuel tanks becomes very large because of the t by c because of the volume available.

(Refer Slide Time: 03:28)



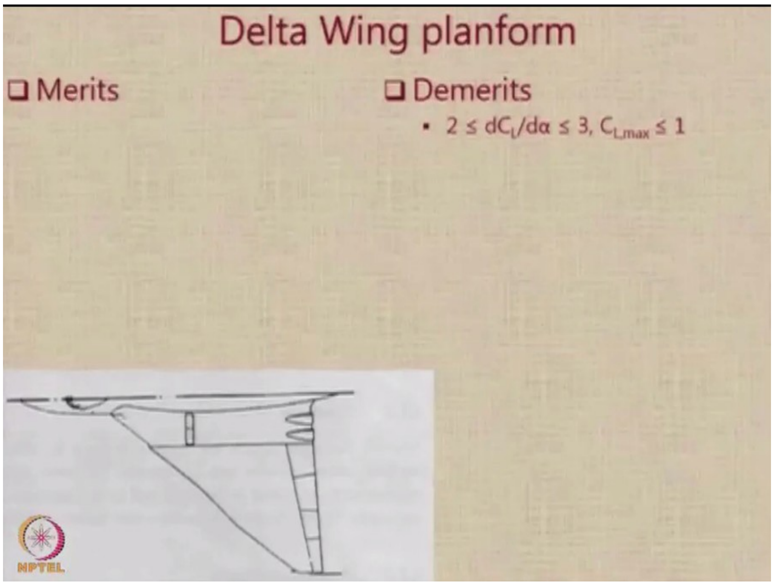
The aircraft has a very high critical Mach number so it can fly to much higher Mach numbers without necessarily facing the drag divergence.

(Refer Slide Time: 03:42)



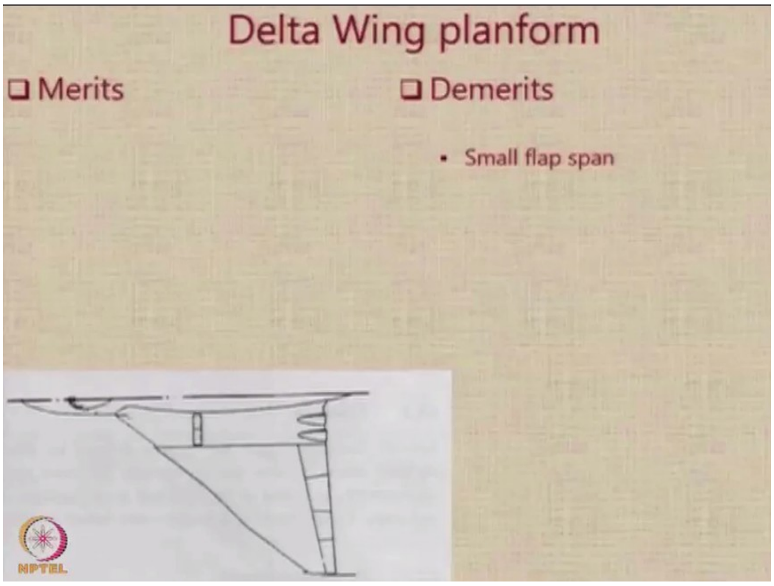
The wing remains inside the Mach cone for high Mach number and therefore the drag is reduced. So at high speeds there will be a shock wave created and the angle of the shock wave will be a function of the free stream Mach number. By providing a delta wing configuration, the leading edge is highly swept. It allows the leading edge to remain completely inside the Mach cone.

(Refer Slide Time: 04:07)



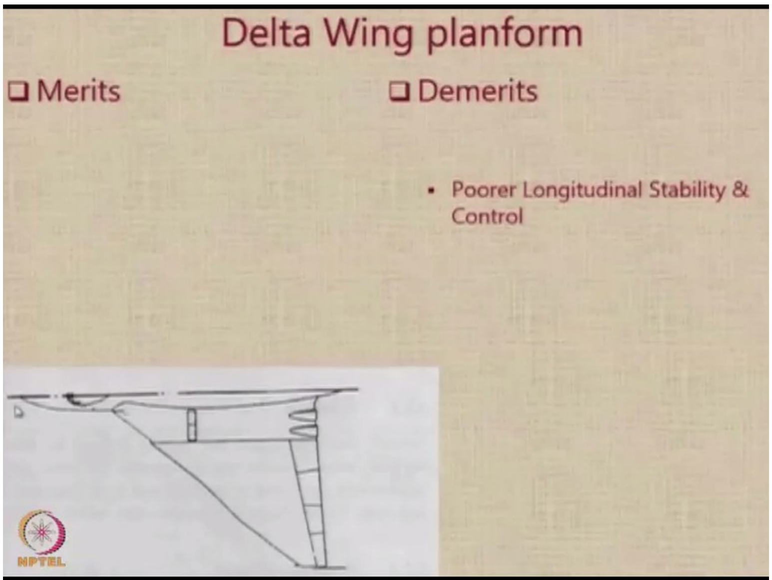
There are a few demerits. The first demerit is that the lift curve slope of a delta wing is generally much lower nearly you know very low as compared to a conventional aircraft. The lift curve slope can become as low as between 2 and 3 and the Cl max that you will get will also be much lower, it is generally less than 1.

(Refer Slide Time: 04:37)



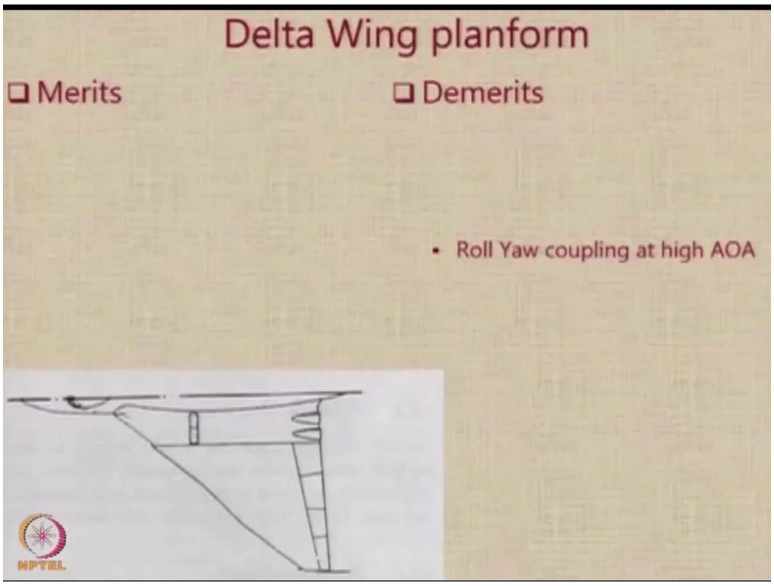
Because the delta wing for a given area would have a smaller wing span, therefore the span available for mounting the flaps reduces, so you have a smaller flap span.

(Refer Slide Time: 04:47)



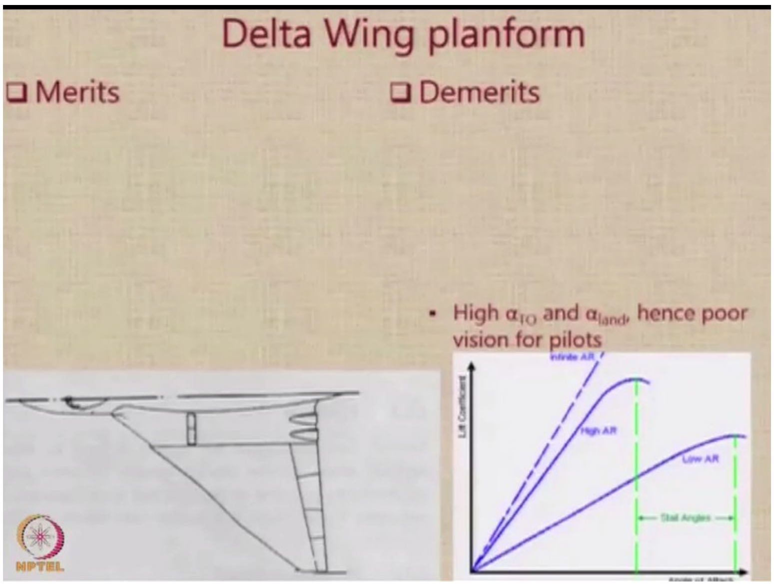
One of the biggest problems with this planform is its poor longitudinal stability and control because the tail arm is less, the wing is much farther behind, so the tail arm available for the stability is much lower.

(Refer Slide Time: 05:06)



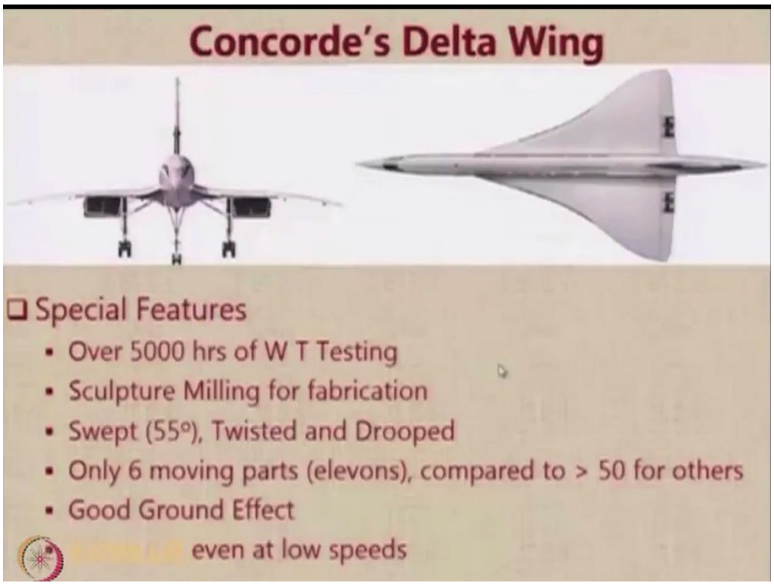
Then you have a roll yaw coupling at high angle of attack which is the cause of many accidents and many instances in aircraft with delta wings. The aspect ratio of the wing tends to be low for a given area because the wingspan is less and low aspect ratio we know leads to higher induced drag plus the wing also becomes heavier.

(Refer Slide Time: 05:34)



One of the most serious problems that you encounter in a delta wing is that the angle of attack at takeoff which is the angle of attack at which you have approximately the maximum lift and the one at landing both these angles they tend to be very high, so therefore you get a very poor vision for the pilots and that is the reason why the designers of Concorde had to go for a drooping nose to allow the pilot’s better visibility when the aircraft is coming into approach for landing at a very high angle.

(Refer Slide Time: 06:09)



Concorde's delta wing also has got some very interesting features. It was designed after about 5000 hours of wind tunnel testing and the shape of the wing is such that it had to be chemically milled, it is called as sculpture milling where you literally draw, you literally create the wing out of a block of material. It is a swept wing with leading edge sweep of 55 degrees, twisted and drooped to control the lift distribution over the wing.

One of the good features of this wing is there are only 6 moving parts called as the elevons as compared to more than 50 moving parts on other contemporary aircraft and it has a very good ground effect which allows it to have a better takeoff performance and it gives you vortex lift even at low speeds. Let us have a look at what is meant by vortex lift because this is a speciality of the lift distribution or the lift generation mechanism of a delta wing.

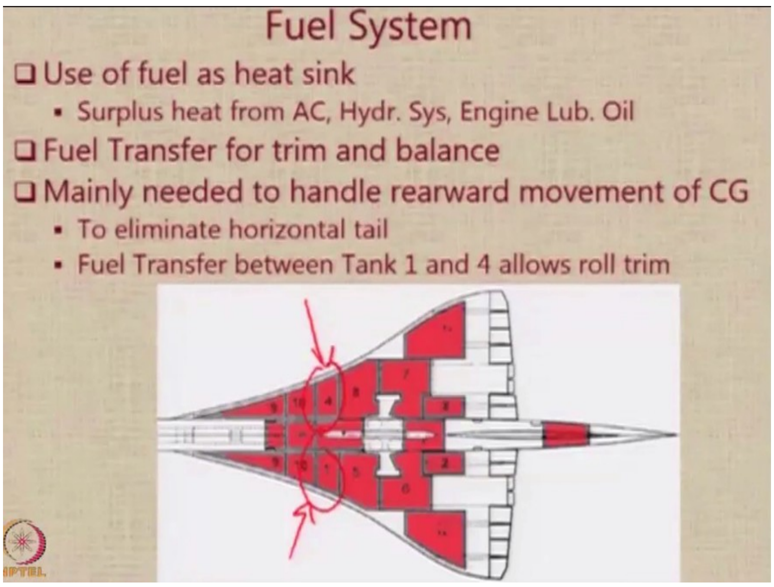
Here we see a delta wing which has got this very special vortex pattern, two vortices which are attached. You can see the vertices are dancing as the wing is rolling okay. So these vertices remain attached to the leading edge and they are the ones that give you a non-linear lift on a delta wing.

(Refer Slide Time: 07:52)

Let us have another closer look at the vortex lift on Concorde and also discuss the problem regarding the high angle of attack. You can see a video of a Concorde approaching for landing. You can notice that the nose was bent down. The nose is drooping downwards and here you see the curling of the vortex. As the as the wing touches the ground you saw that there was a curling of the vortex.

See the nose is deflected downwards because the aircraft comes at such a high angle at landing that the visibility of the piolet will be very bad unless you bring the nose down. So the nose is drooped. Look at the extremely slender nose landing gear and as the aircraft comes into land as it touches down you can see a huge vortex rolling up on the wing.

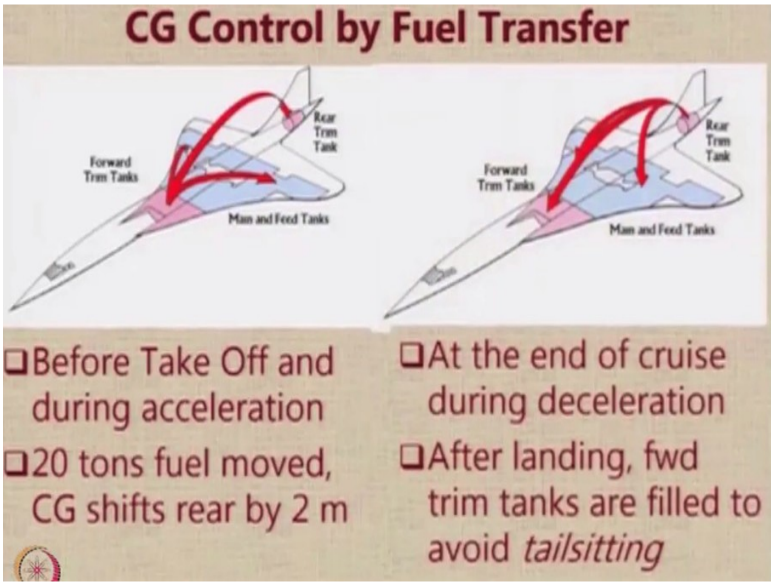
(Refer Slide Time: 08:55)



The fuel system of the aircraft as I mentioned is very interesting. First of all because of aerodynamic heating when you fly at such a high Mach number, there is going to be a lot of temperature issues on the structure. So the fuel is used as a heat sink. So the surplus heat from the air conditioning system, hydraulic system and the engine lubricating oil, this heat is absorbed by passing fuel over these systems through heat exchanger.

The fuel transfer for treatment balance has already been discussed. The purpose of this is to eliminate the need for a horizontal tail and when you transfer fuel between tank number 4 and tank number 1, these two tanks then you can also create a slight rolling imbalance which can be used to trim the aircraft in roll if needed. The aircraft has 10 different fuel tanks and fuel is transferred as we can see.

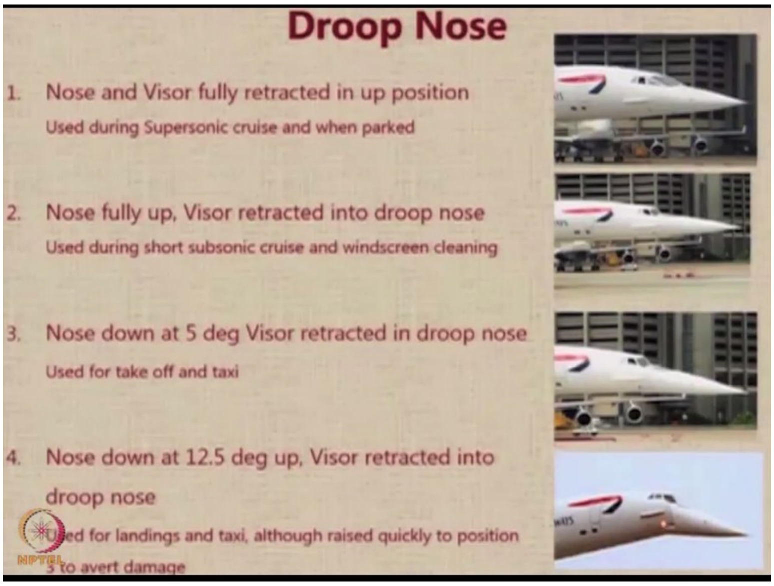
(Refer Slide Time: 10:04)



So we have a rear trim tank below the tail in the fuselage and we have a forward trim tank and then we have the main and the feed tanks in between. So before takeoff and during acceleration, we would like to have, so the fuel is moved, around 20 tons of fuel is moved so the CG moves behind by about 2 meters, but at the end of the cruise and during deceleration okay we would like to go for nose down.

During this case, the fuel is transferred forward and after landing the fuel from the rear trim tank is filled in the forward trim tank to ensure that the center of gravity remains ahead and we avoid a problem of tailsitting in which the tail of the aircraft hits the ground due to CG imbalance.

(Refer Slide Time: 11:06)



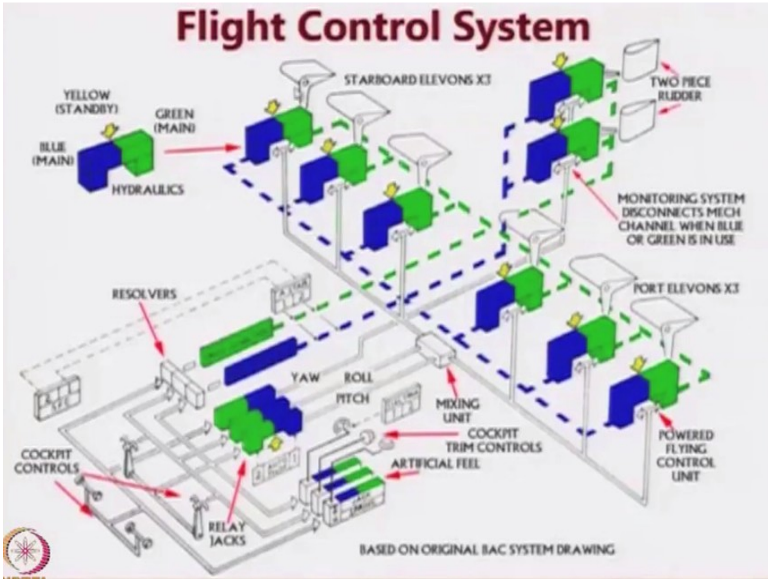
Let us now look at the droop nose of the Concorde and its various positions. There are 4 positions for the droop nose. The first position is position number 1 in which the nose and the visor are fully retracted in that position. The visor is basically a pane of glass that actually sits over the canopy as you will see. This configuration is used during supersonic cruise and when the aircraft is parked so that there is least amount of chance that birds and other rodents, etc. can go and occupy the area.

The second position is the nose fully up but the visor retracted in the droop nose. So now you can see that the canopy is fully exposed and the visor is inside the droop nose. This position is used during short subsonic cruise and when you want to clean the windscreen. So when the visor is up the windscreen is not reachable. So here it is done when you want to clean the windscreen and when to do a short subsonic cruise, for example when you do a low speed fly past.

The next position number 3 is when the nose is down by 5 degrees and the visor is fully retracted in the droop nose. This particular position is used during takeoff and taxi when the aircraft needs better visibility but not very large. When you come into land the nose is down by 12 and a half degrees and the visor is retracted into the droop nose completely. This one is used for landing and taxi, although after the work is over it is quickly retracted back to position number 3 to avoid any damage to the nose.

So we can see the Concorde designers came up with a very complex and cumbersome method to handle the problem of vision during the various phases of flight. In modern day aircraft, one might be able to address this problem by fitting reliable cameras. There is talk also about synthetic vision nowadays, but during the time when Concorde was designed in the early 60s, we did not have such technology and hence they had to go for this droop nose. This particular facility led to a very complex system and there were many issues regarding its maintenance and also the weight.

(Refer Slide Time: 13:53)



Finally, let us look at the flight control system, the first aircraft to have a digital fly-by-wire control system. You can notice here that there are 3 different color schemes here You have the green and the blue system, so there are 2 hydraulic systems green and blue and then you have the yellow which is the standby. So, there are 2 main hydraulic systems with a third as standby.

So the two main ones are called as the blue system and the green system which is powering almost every control. A 2 piece rudder, the 3+3, 6 part elevons okay, but the standby system is going to power only a few of these elements and it ensures that the aircraft can be flown even when both the main channels, the green and the blue, are not working. Thank you for your attention.