Introduction to Aircraft Design
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Lecture – 74
Fighter aircraft life cycle cost estimation model

Hello, today we will look at a model developed for estimating the lifecycle cost of a fighter aircraft and this model has been developed essentially based on the experience gained in India by the development of the Light Combat Aircraft *Tejas*.

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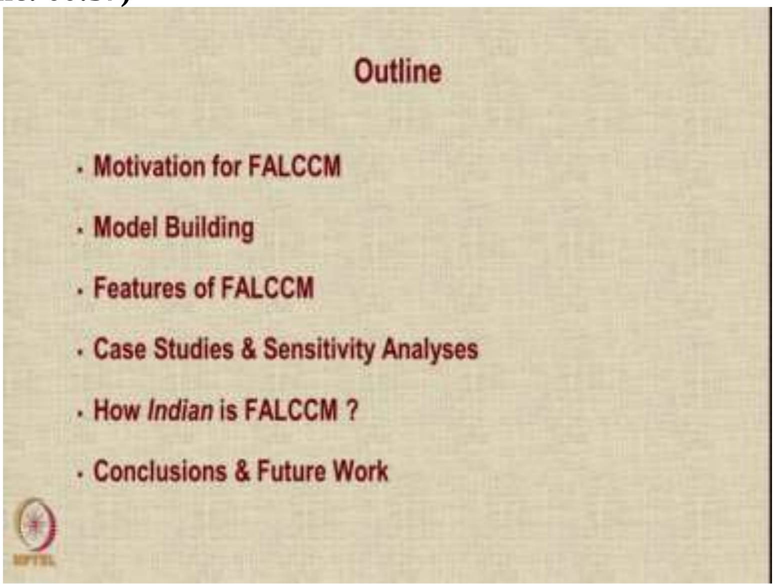

I will give you an outline of today's presentation. First, we will discuss what is the motivation for developing this model called FALCCM. We look at the steps that are followed in building the model. We will highlight the special features of FALCCM then present to you a few case studies and analysis of the sensitivities of certain FALCCM parameters. We want to address the question how Indian is FALCCM because, as I mentioned, it was a model developed based on the experience gained in developing of the Light Combat Aircraft.

And also, we will look at the conclusions of this particular work and highlight some areas in which future work is possible to further improve and upgrade this model.

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Just a quick recap about aircraft lifecycle cost you already know because I hope you have seen the videos regarding the lecture on aircraft cost and LCC essentially LCC is over the life cost of the aircraft which starting from its inception through design and development till its development and flyaway then after it goes in service, there is support and investment then there would be operational and support during its entire life of operation. This is the largest component of the LCC usually at the end of the life there is a disposal.

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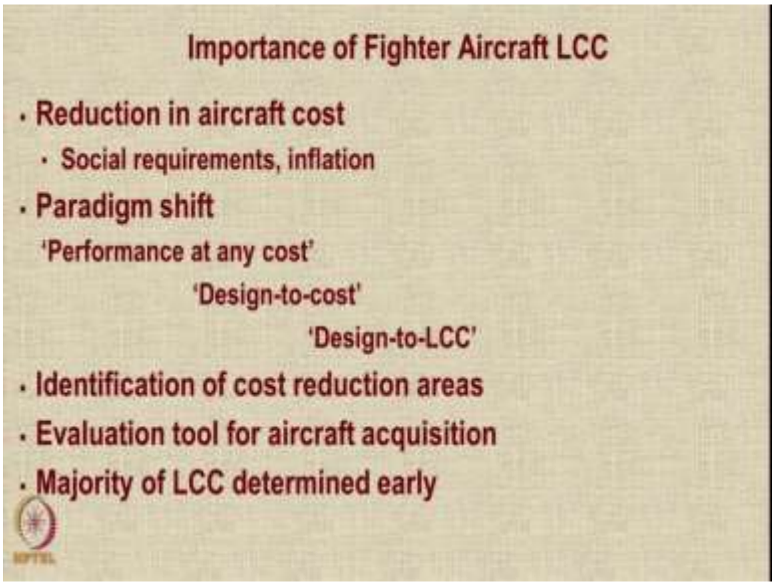

Now, why it is important to look at LCC for any aircraft and especially. So, in the case of fighter aircraft is to see how we can reduce the cost. The costs have to be reduced because of social requirements. No one can afford to have a very expensive aircraft and the inflation is hitting all of us very badly. There has been a paradigm shift in the way aircraft are designed earlier we were looking at performance at any cost.

This was the design paradigm for let us say the Wright flyer or so, many aircraft we are which were designed to do something for the first time achieve performance at any cost slowly when the technology of aircraft matured, there was a paradigm called is design to cost that means there is a fixed cost given a priority and we are told as a design team that you do whatever best you can, but design so that the cost is not exceeded.

But now the paradigm is there is a particular lifecycle cost which is specified and we have to design the aircraft to meet that lifecycle cost. The other benefit of having a lifecycle cost model is to identify the areas in which costs can be reduced. And this particular tool can also become a tool for acquisition of aircraft. So, if there are let us say few competing bidders who are trying to bid an aircraft for supply, then this a model like this can also be used to evaluate various aircraft and to find out which of them is going to end up with a larger lifecycle cost.

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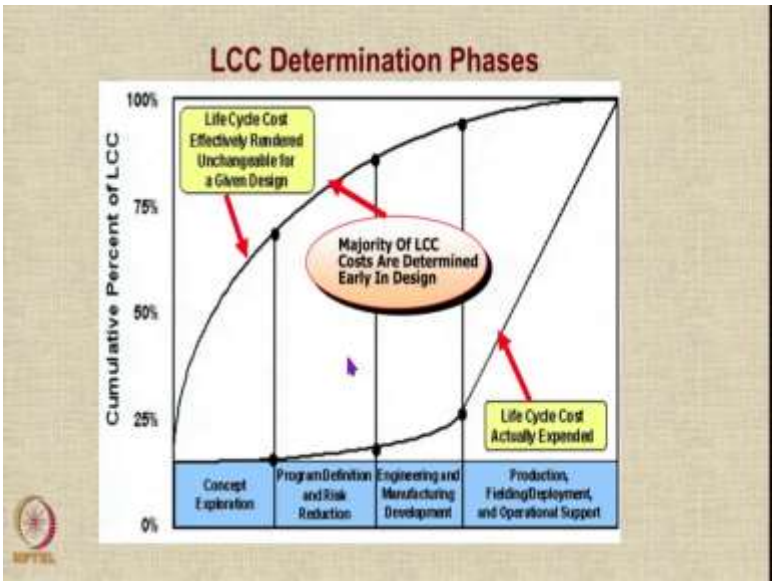

Also, we have to keep in mind that majority of the lifecycle cost actually gets determined very early. As we can see that this particular line shows you how much of the lifecycle cost has actually been expended as we produce as we proceed further in the design from concept exploration or the conceptual design to program definition that is production engineering, manufacturing, development and production and deployment.

So, right up to the conceptual exploration cost you know the percentage of the cost already spent is actually very, very small, whereas nearly, nearly 60 to 70% of the cost is locked in because of the design choices we have made. As we go further you more and more money gets spent the steepest amount of monies, the steepest rise you see is when it goes into production, field development and operational costs.

But at that time, you can see that the amount of the lifecycle cost so by this time, 3/4 or more of the lifecycle costs are already decided where only a small amount of money is spent and hence, a model like this is very useful.

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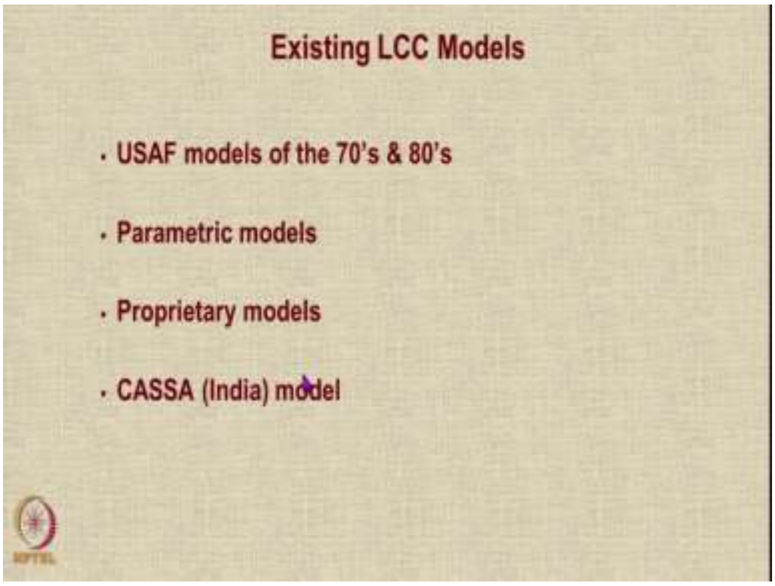

Let us look at what are the existing LCC models. So, US Air Force has models developed in 80s, 70s and 80s. Very old now, there are some parametric models available. There are some proprietary models available with companies who do not want to share them, or they will charge in India, the DRDO labs CASSA in Bengaluru, they had developed a model for cost estimation and it is called as a CASSA model.

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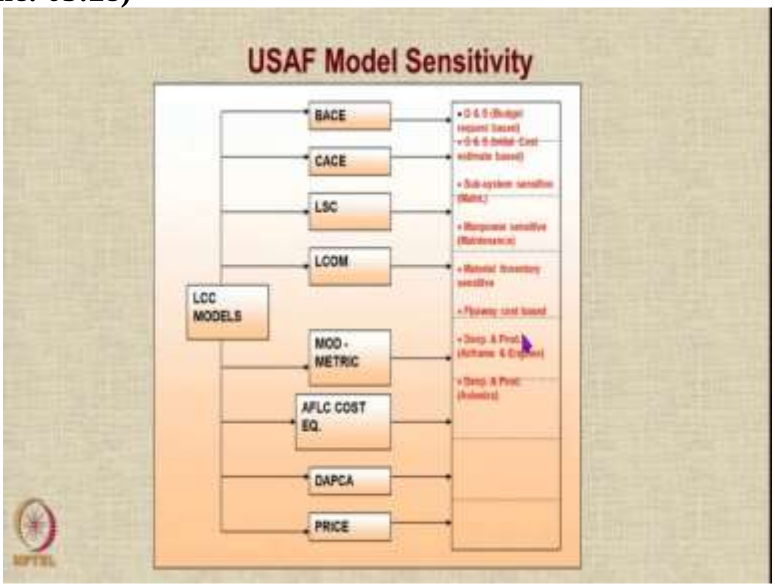

So, what we did is we first studied the various LCC models available by the US Air Force in which all these terms of the lifecycle cost are investigated. There are model like BACE and CACE and LSC, LCOM, etc. And then there is a famous DAPCA model which we have also used in our tutorials, one for Boeing 787-8 and the other for the Global Hawk aircraft. And then there is one called price. All these models were studied, and their good features and limitations were identified.

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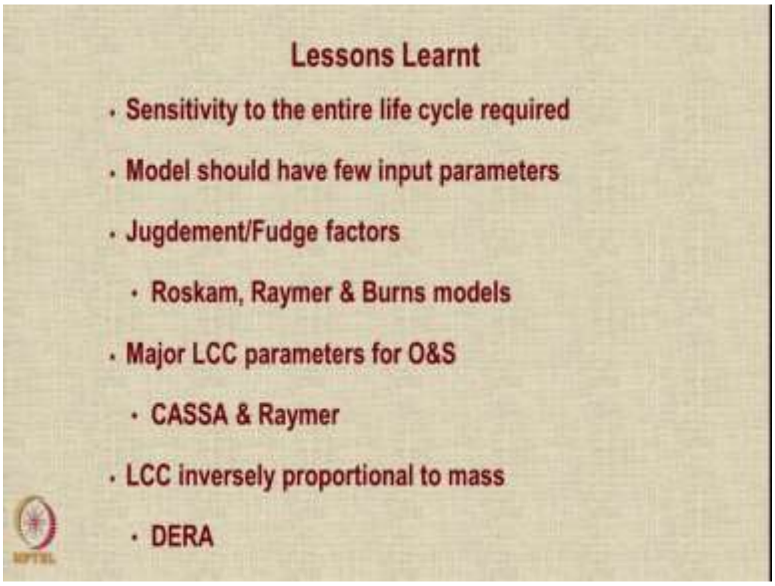

So, what were the lessons learned, the lessons that were learned is that we do not want a cost model that is sensitive only to a few elements of the lifecycle, we want it to be for all then there should not be too many input parameters to play with because otherwise you will not be able to make even a proper start there should be some scope for judgment or fudge factors because every country every operational scenario has differences.

So therefore, certain cost terms are higher or lower in certain operating scenarios, we should be able to upscale or downscale the costs based on our judgement and fudge factors. Even the models by Roskam and Raymer and burns they all have some fudge factors, there is a material fudge factor, there is a fudge factor for the hours that are needed, So, similarly, the major LCC parameters for the operational and support costs have to be included.

CASSA and Raymer have developed models for this and finally, we have also seen during our study that LCC is inversely proportional to mass. So lighter the aircraft better is the LCC this particular thing is also established by a model called DERA.

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What was the motivation for developing this new model FALCCM when there are so many models available, first thing is we need parametric model? So, if you look at trees in the parametric models, which are available the data is statistical and that is pre 1970 the relationships are derived historically. And they produce very broad based cost estimates which are of questionable validity and their relevance may not be there in all scenarios.

Then there are some proprietary models as I mentioned the costs are prohibitive to use them. And then even if you wish to buy a proprietary model, you to spend a lot of money in getting it customized to your requirements and we have no control in the developmental process of these models, they are developed based on some other requirements and we just have to be we are forced to basically just use them the CASSA model, which has been developed indigenously in India by DRDO lab.

It focuses mainly on the acquisition cost and does not have the at that time at least when we worked on it, it did not have any great contribution or assessment of the other costs other than the acquisition costs and it needed a large number of input parameters. So, based on all these studies, there was a need to develop a new model which we call it as FALCCM.

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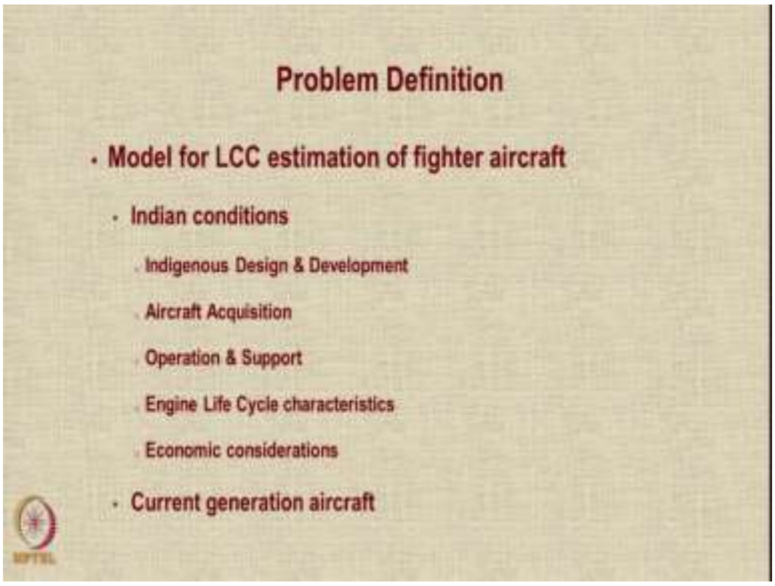

So, what we want is we want a model for LCC estimation of fighter aircraft which is applicable for mostly Indian conditions. It should be able to model indigenous design and development process very carefully and draw numbers and information from our experience of the LCA project. It should talk about accurate acquisition and help us arrive at the estimates it should help us to get an handle over the operational and support cost.

We should be able to incorporate engine lifecycle cost characteristics in that we should be able to put in some economic considerations and it should be able to be applied for current generation aircraft and not only to the old aircraft.

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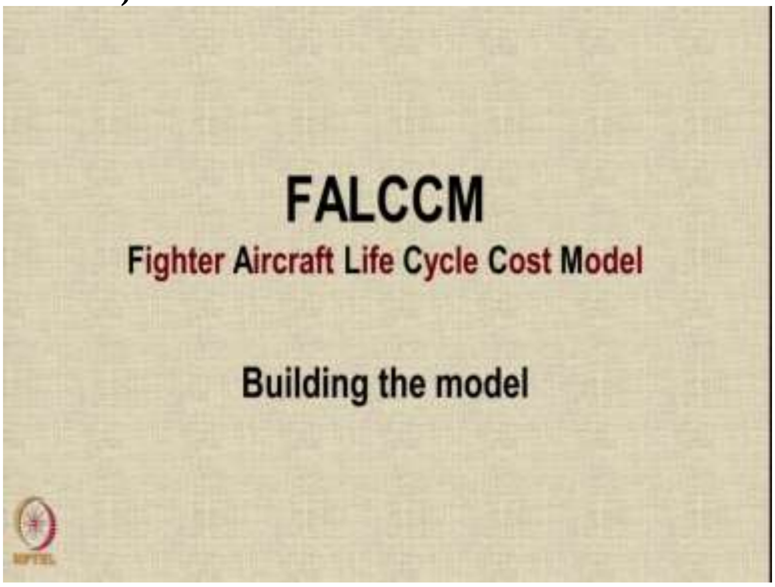

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So, with that, I present to you details of FALCCM the fighter aircraft lifecycle cost model FALCCM. Let us start with how the model was built. So to build this model, we had some cost elements. So the first important cost element is the development cost we call it as D then we have flyaway cost. Then we have support investment cost and engine operation and support cost after operation and support cost.

And then we have introduced a new element for midlife upgrade cost. This is Missing in many of the models, this is a small feature of FALCCM which is kind of unique. And in the end, we have some model for the disposable cost for the disposal costs.

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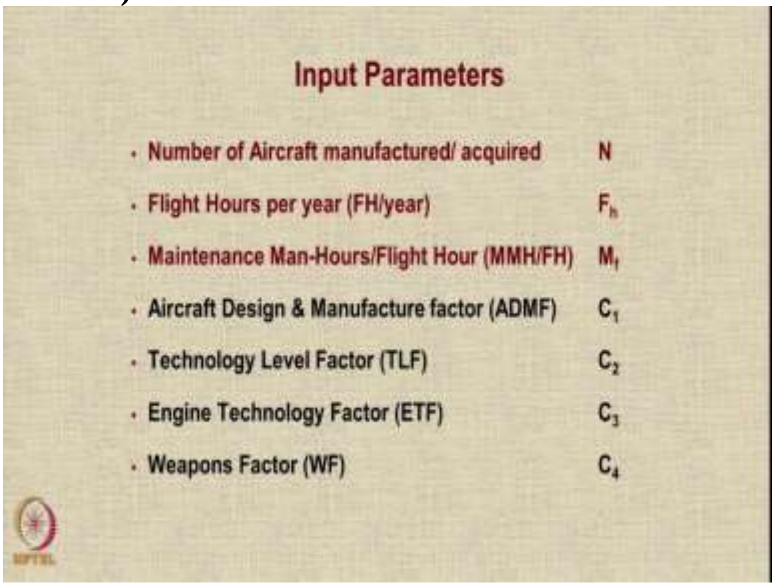

So, let us see how the input parameters work. So, what we have to give is we have to give these numbers to this model we have to give the number of aircraft which are to be acquired if we are purchasing or to be manufactured, we have to give how many flight hours per year we expect to use this aircraft this comes from the data from the user agency, which is in India the Indian Air Force.

We also need to have a target for what is our maintenance man hours per flight hour that we expect to have on this particular aircraft, then there are certain factors there is one factor called as ADMF, which is the aircraft design and manufacture factor. So, it is these are basically complexity factors. So, the model increases or decreases cost of certain elements based on the numerical value of these complexity factors.

So, one is how complex the aircraft is and what is the manufacturers current status that comes under C_1, then you have technology level factor TLF. So, TLF or C_2 takes care of what kind of technology is being used in this particular aircraft, is it current level technology is it very far reaching technology or is it medium level technology. So, some assessment has to be made regarding the level of technology, because that will strongly affect the cost.

Then there is a factor to take care of the engine technology as I mentioned, there was a need to have a model where the engine related parameters can be given not exactly the numerical values, but some idea about the engine technology level. So, here to C_3 we can supply the engine tech level technology level, then there is a weapons factor because most of the military aircraft carry very, very expensive and very complicated weapons and they are becoming more and more sophisticated as we go.

So, each new weapon which gets integrated in the aircraft brings with it a lot of cost in design, in development and in testing and evaluation and approvals. So, therefore, depending on how complex the weapons are, are supposed to be in this aircraft and depending on the technology level of the weapons, we introduce a factor called C_4 weapons factor WF.

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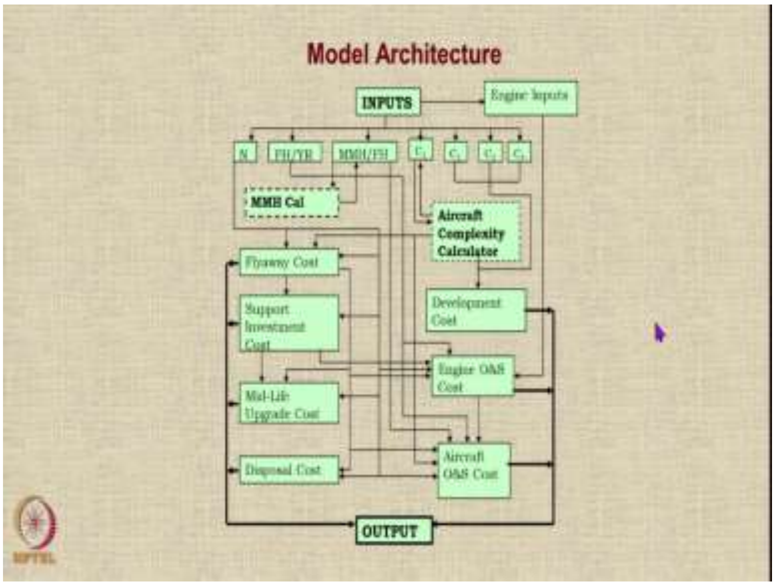

So, you can see that there are some inputs and then there are some outputs. So, we have to see now, how all these things work in one shot.

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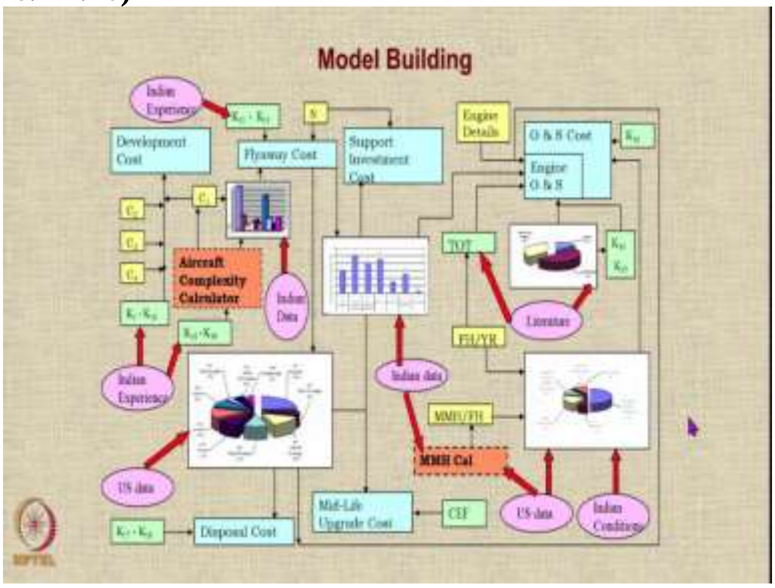

So, in the model, we first look at development costs, flyaway cost, support, investment cost operations and support costs, engine operation support as a part of it, mid-life upgrade and disposal, these are the elements that we need. Ultimately, these are the outputs that we need these outputs get affected by certain parameters complexity factors like C_1, C_2, C_3, C_4, which I told you the weapons factor.

The aircraft manufacturers and design factor technology level factor etc and engine level factor, then the N number of aircraft affects parameters like the flyaway cost etc and the engine details are required to look at the engine O & S costs, then we need flight hours by the year and managed by FH for bringing in the maintenance cost parameters. So, these parameters then are given as input. So, these are the input parameters. Now, these input parameters this is how they relate to each other.

So, for example, the credibility factor C_1 C_2 C_3 C_4 they go into the development cost module and there is something called as the aircraft complexity calculator with that calculator you can get the value of the parameter C_1 that calculator also is going to be affected or affecting the flyaway cost and the flyaway cost also affects the disposal cost. Similarly, there is a MMH calculator which helps you to arrive at an estimate for MMH by FH that calculator gives you this number.

So, there are these calculators which have been created to help look at the effect of certain operational parameters on the complexity factor C_1 and image MMH by a factor etc. So, the flyaway cost that comes out we give a breakup and this breakup is then used. So, the calculations of these models they give us all these. So, some of the breakups that you see here are the breakups which are used from existing information and they then become very useful.

Then, there are various constants K_1 to K_{10}, which takes care of the development cost, then there is 11 to 13 for flyaway cost. And then 14 and 15 are there for the engine operations support cost 16 for the O and S cost and 17 to 18 for the disposal costs. So, these constants they come essentially from the environment in which this model is being applied and then there is also a cost estimating factor which come into play.

Now, you can see that the models these numbers and these models are greatly influenced by data from various scenarios. So, the Indian conditions in the Indian data they normally, so, Indian experience directly affects K_1 to K_{10} and 10 and into K_{39}. Similarly, the US data affects the MMH by MMH calculator and also the Indian data, so, some past knowledge from other countries and some of our own knowledge. So, this is how the whole information is built up.

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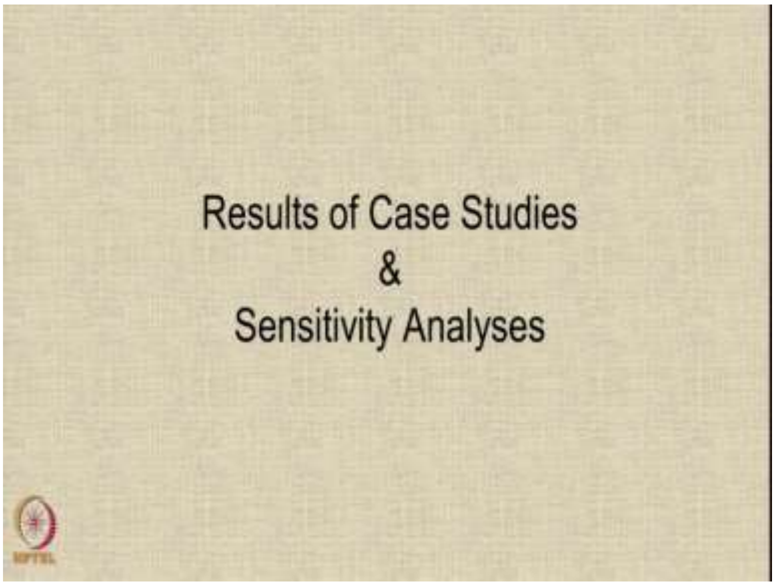

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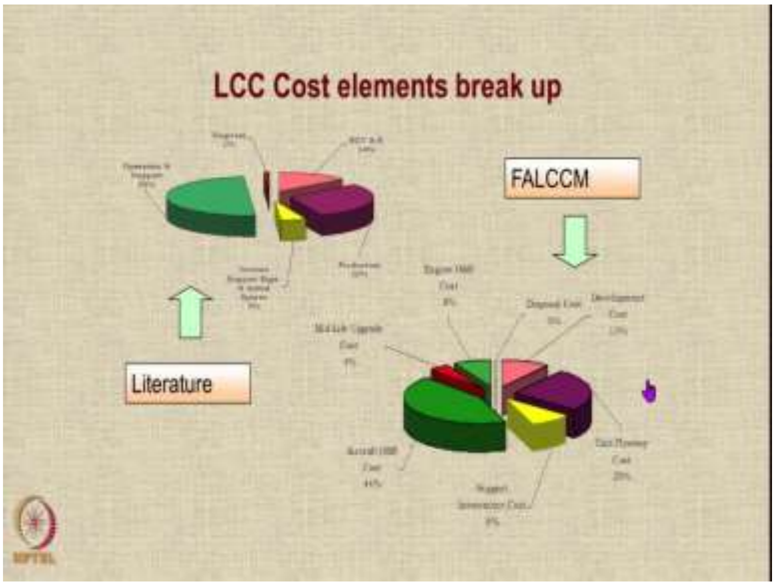

Let us look at the results of case studies and sensitivity analysis just to demonstrate, so, you can see that this is the model in literature which gives you the cost breakup of various items. And roughly the same kind of cost breakup for various cost terms is given also by the FALCCM. So, FALCCM is similar to the models available in literature.

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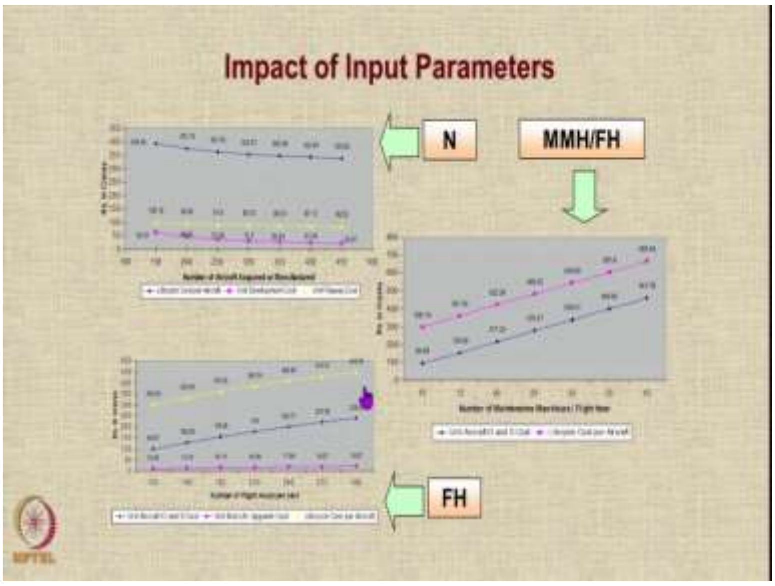

Then, this particular graph shows you the effect of the you know the y axis is the cost in crore rupees and the X axis is the number of aircraft acquired or manufactured. So, the black line here is lifecycle cost per aircraft. This particular crimson or purple line is the line which corresponds to the cost of unit development cost and the unit flyaway cost which is varying from 100 to you know 86 crores, this is for the flyaway cost.

Similarly, this graph shows the effect of number of aircraft produced how it brings down the costs. This graph shows the effect on the flight hours and will usually utilize in of the aircraft how does it affect the costs various costs. So, we see for example, that the unit development cost does not change much. Whereas, there is a huge change in the blue line which is the operational support cost and it goes from 99.97 or 100 crores to 239 crores it is like a huge change because of the number of flight hours per year are varying from 120 to 300.

Similarly, the effect of MMH by FH can be seen as a linear variation here, here on the y axis we have the cost in crores on the x axis, we have the number of MMH by FH. So, if there are as low as 10, you get a very low cost, but if they become 40, it becomes very high cost in fact, it is doubling. So, the this particular line the lifecycle cost for aircraft increases from 300 to 666 if the number of maintenance man hours per flight hours is becoming 4 times more.

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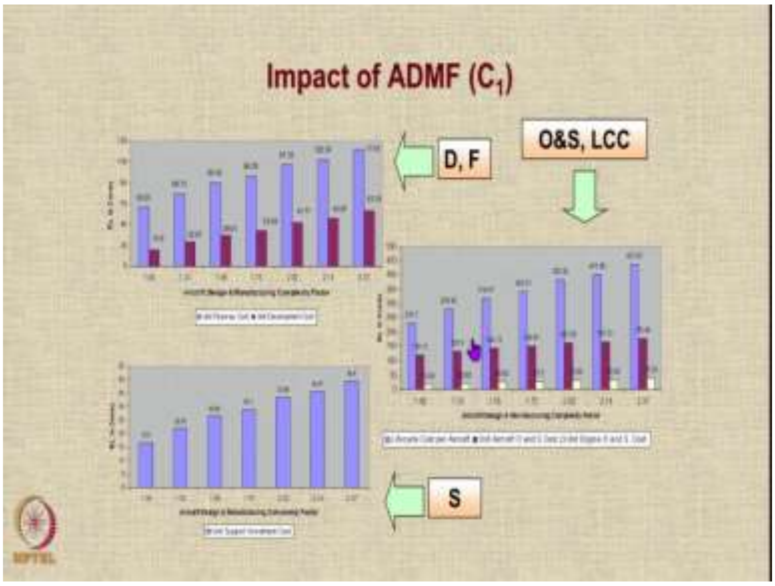

Similarly, we want to look at the effect of various factors like ADMF aircraft design and manufacturing manufacturer factor C_1. Similarly, how it affects the how these factors how does this factor affect. So, the factor is varying from 1 to 2.3 and you can see that it is greatly affecting the unit flyaway cost in blue color and the unit development cost in the dark brown, purple color similarly, if you look at S the factor that affects.

So, this is the aircraft design and manufacturing capacity sector that varies from 1 to 2.37 in this figure and you can see how the support investment cost increases from 13 to 39 crores similarly, operational support and LCC costs.

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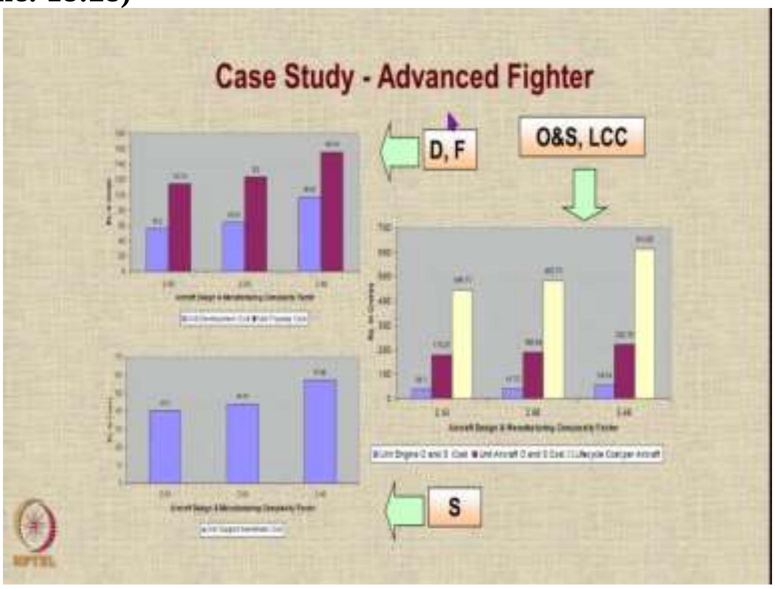

So, this model allows you to look at the variation in the costs based on all these the change in all these parameters. We did a case study for an advanced fighter aircraft and we got these kinds of trends.

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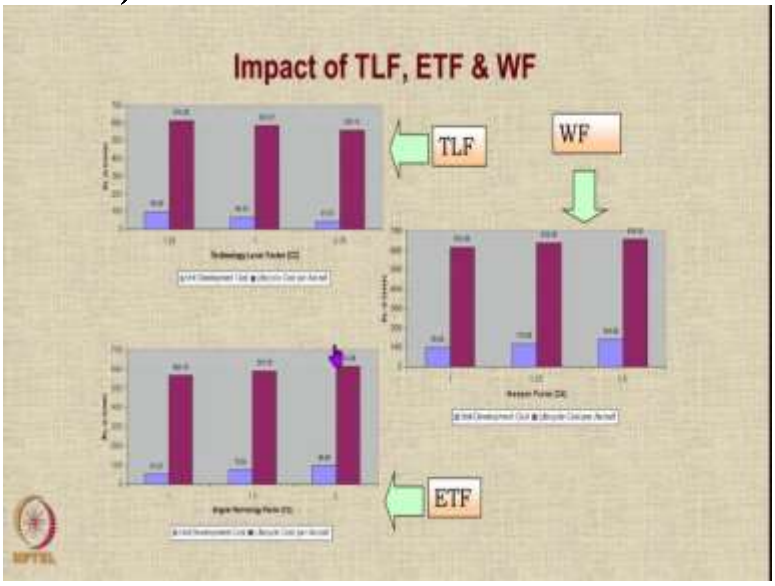

And then we also looked at the impact of factors like the technology level engine technology factor in the weapons factor how they affect the cost. So, weapon factors, for example, affects quite a lot from 1 to 1.5, you can see that the unit development cost changes from 96 to 140. But the cost lifecycle cost is only 614 to 758. Not really a very big change here, but reasonably big change here in the development cost.

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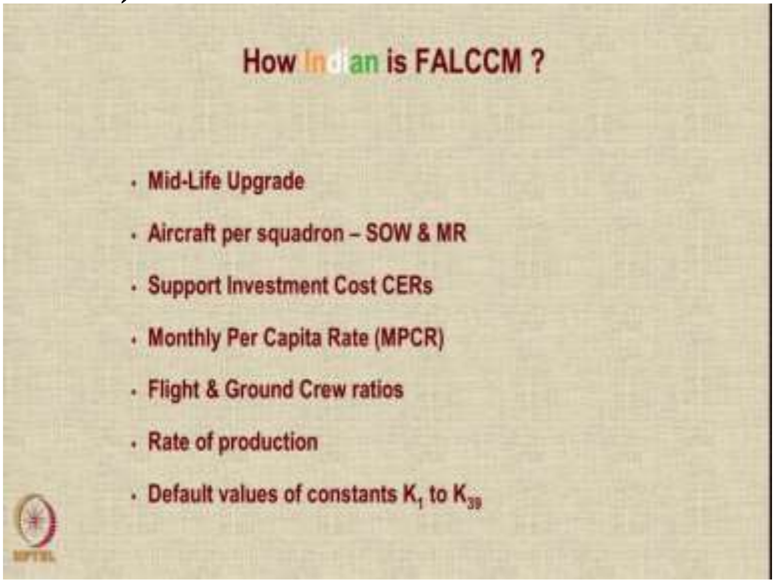

Now, the question that somebody may ask is, how Indian is FALCCM? So, first thing is, as I mentioned, it gives you a method to bring in a mid-life upgrade cost estimation or to incorporate mid-life upgrade in the cost LCC estimation, which is a very common feature in our country. In our country, we actually always go for mid-life upgrades. We do not have the ability or the luxury to discard aircraft and buy new ones very soon.

Then, the number of aircraft per squadron that is applicable in India was taken from the user agency. There were some CERs who are the cost estimator relationship developed for support investment costs based on the data available from the Indian Air Force, the monthly per capita rate MPCR. This information also was used flight and ground crew ratios applicable in the country were also considered.

The rate of production that we normally follow was also included. And some default values of the constants K_1 to K_{39}, which customize the model for a particular operating conditions, their default values were obtained based on an interaction and discussion with the user agency. So, this is how we have brought in lot of Indian elements or India related information in FALCCM.

But it can be customized to any other agency also any other country also, we just have to get the right values of these parameters with an interaction with the various agencies, we can actually get these numbers and we can hence develop the model applicable to that particular scenario.

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The conclusion possible improvements. What we found is that MMH by FH and FH per year are the key parameters because they greatly affect the largest component which is the operations and support cost, the aircraft design and manufacture factor, causative factor impacts on all costs elements mainly development and flyaway cost. So, this is a very important parameter. And the effect of technology level engine technology factor and weapons factor was limited, it does affect but only the development cost, it does not really affect too much the other cost elements.

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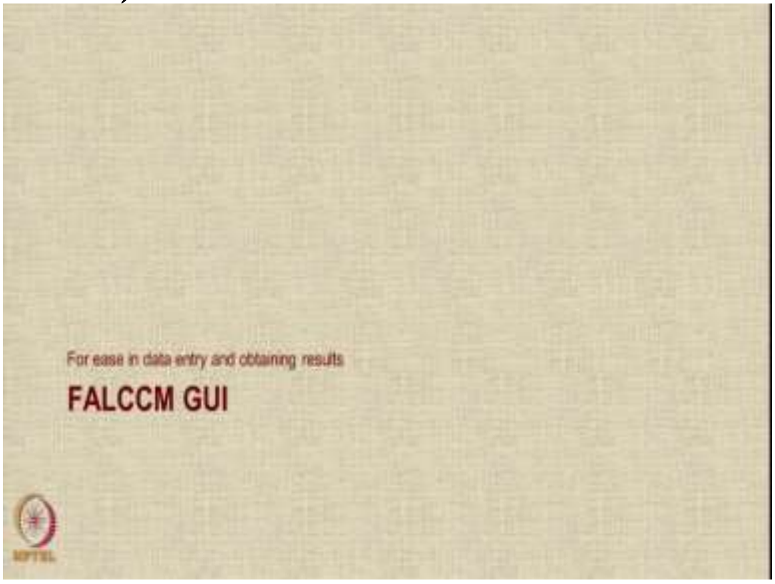

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Now, to make things very easy or to make it easy to use FALCCM graphical user interface was also developed. So, I will just show you a few shots of this graphical user interface, this is the MMH calculator. So, what you do is you for various elements of the aircraft like airframe crew station, landing gear, flight control, power plant engine APU there is a baseline value for these parameters.

And then based on the scenario in which you are operating based on your own peculiarities, you can scale this number up and down to get the MMH value. So, many of these parameters are available and then you can so, the baseline MMH by FH is 15, but it can be altered by using the MMH calculator. This is a very useful tool to arrive at the likely value of MMH by FH in your case similarly, depending on the features of the aircraft.

For example, is it supersonic does it have increased radius of operation does it have increased maneuverability, does it have thrust vectoring does it have reduced signature does it have twin engine does it have lower vulnerability with that you can bring in complexity factors and with the complexity factors, the costs can also be accordingly adjusted. Similarly, here is the output screen.

So, there are all these tabs which allow you to include the information and then finally, you get the numerical value of development cost, flyaway cost support, investment cost and all the cost terms and then you can just also plot the information then you can also investigate various scenarios, like you say increase so much percentage for a particular feature reduce for so and so feature and then you can re compute the cast.

So, there are some constants which can be reset. And finally, we have also incorporated a small graphing facility, where the results that you obtain can be actually graphed and you can obtain plots that illustrate the output. So, it becomes easy for you to share, you do not have to take this material in Excel or some other software and then again plot it you can plot it right there inside the FALCCM grapher itself.

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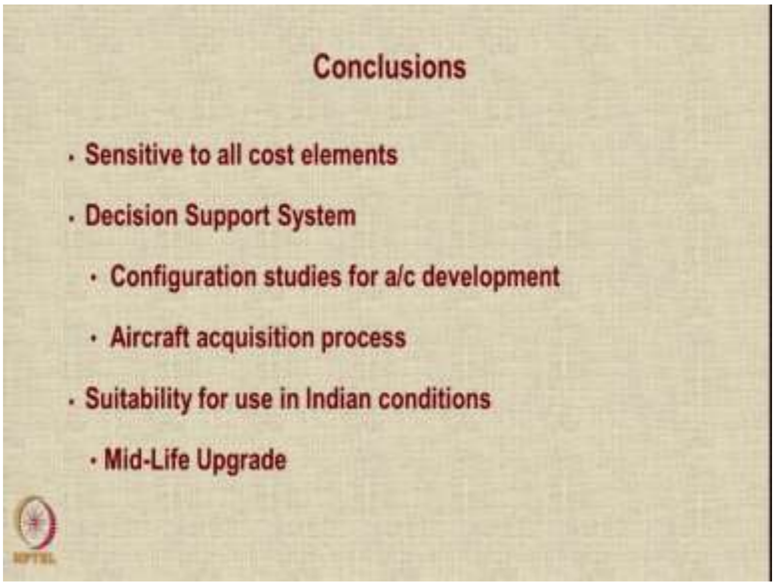

So, to conclude, we have a model, which is sensitive to all cost elements of the lifecycle. This model can be used as a decision support system either you can use it for configuration studies for new aircraft development or you can use it in the aircraft acquisition process as a comparator of various proposals received. We have taken conscious efforts to make the models suitable for use in Indian conditions. And as a for example, we have incorporated a model for midlife upgrade.

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But as always, there is room for improvement, what are the improvements, this in this particular model was developed around 15 years ago. So, of course, there has to be updated information. Now, the life cycle the LCA aircraft has that they just has already seen quite a few hours of operation. So there we have now some data which has been gathered over the times. So obviously, this model can be quickly updated using the aircraft maintenance and cost data.

Then, you can do a more detailed modeling of the technology level factors and engine technology factors on the weapon factors. We saw that they are not showing up too much in the final analysis in the presence condition, but maybe because we have not been able to model it very finely and correctly. And also we would like to be able to interface this particular model with multi display design optimization studies related to aircraft fare new variables. And constraints could be brought in. So, this can become an integrated part in a large design exercise.

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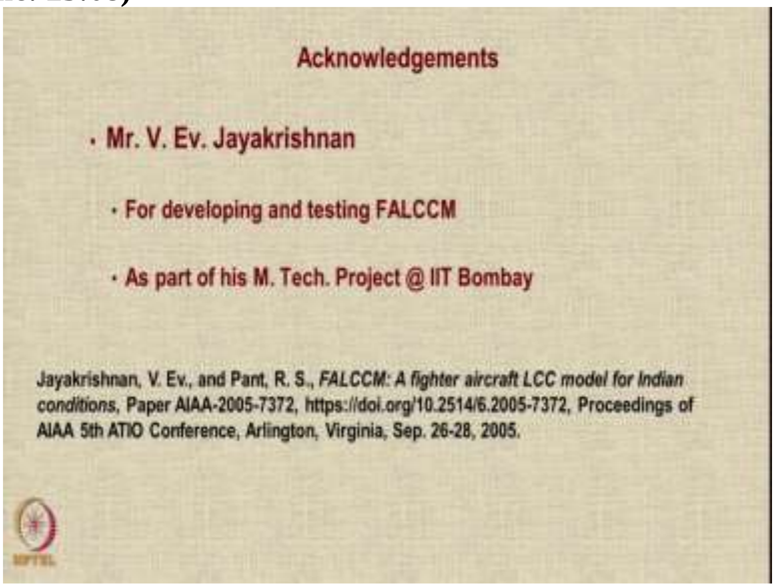

Where overall objective is to minimize, before I stop, I would like to acknowledge the model was developed by Mr. V.E Jayakrishnan. So, I would like to thank him for developing and testing this particular model, and he was done as part of his MTech project at IIT Bombay. And if you are interested to get more information about this particular model, or if you are interested to get to the grips of the model, I would recommend you to look at this paper which is openly available.

It is a paper published in the proceedings of the fifth aviation technology integration and operations conference held in Arlington, Virginia, USA in September 2005. It is available under this DOI so this particular link if you click on this link, you should be able to obtain and if anybody has a problem in obtaining this paper, I will be very happy to share just send me an email and I will be happy to share the material with you. Thank you so much. And I look forward to associate with the some of you to improve this particular model. Thanks.