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SIMULATION OF CIRRUS SR-22 USING BLADE ELEMENT THEORY FOR PROPELLERS

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Abstract: - Blade tracking is the process of determining the positions of the tips of the propeller blades relative to each other (blades rotating in the same plane of rotation). Tracking shows only the relative position of the blades, not their actual path. The blades should all track one another as closely as possible. In aeronautics, a propeller, also called an airscrew, converts rotary motion from an engine or other power source into a swirling slipstream which pushes the propeller forwards or backwards. It comprises a rotating power-driven hub, to which are attached several radial airfoil-section blades such that the whole assembly rotates about a longitudinal axis. The blade pitch may be fixed, manually variable to a few set positions, or of the automatically variable "constant- speed" type.

Keywords: - Blade Theory, Propellers, Cirrus SR-22

1. INTRODUCTION

Aerodynamics, branch of physics that deals with the motion of air and other gaseous fluids and with the forces acting on bodies passing through such a fluid. Aerodynamics seeks, in particular, to explain the principles governing the flight of aircraft, rockets, and missiles. It is also concerned with the design of automobiles, high-speed trains, and ships, as well as with the construction of such structures as bridges and tall buildings to determine their resistance to high winds. Observations of the flight of birds and projectiles stirred speculation among the ancients as to the forces involved and the manner of their interaction. They, however, had no real knowledge of the physical properties of air, nor did they attempt a systematic study of those properties. Most of their ideas reflected a belief that the air provided a sustaining or impelling force. These notions were based to a large degree on the principles of hydrostatics (the study of the pressures of liquids) as they were then understood. Thus, in early times, it was thought that the impelling force of a projectile was associated with forces exerted on the base by the closure of the flow of air around the body. This conception of air as an assisting medium rather than a resisting force persisted for centuries, even though in the 16th century it was recognized that the energy of motion of a projectile was imparted to it by the catapulting device. [1]

Near the end of the 15th century, Leonardo da Vinci observed that air offered resistance to the movement of a solid object and attributed this resistance to compressibility effects. Galileo later established the fact of air resistance experimentally and arrived at the conclusion that the resistance was proportional to the velocity of the object passing through it. In the late 17th century, Christiaan Huygens and Sir Isaac Newton determined that air resistance to the motion of a body was proportional to the square of the velocity. [1]

In order to overcome drag forces, an aircraft must generate thrust. This is accomplished with a motor-driven propeller or a jet engine. When the airplane is in level flight at a constant speed, the force of the thrust is just enough to counteract the aerodynamic drag.

Moving air can also generate forces in a different direction from the flow. The force that keeps an airplane from falling is called lift. Lift is generated by an aircraft wing. The path over a wing's curved top is longer than the path along the flat bottom of the wing. This causes the air to move faster over the top than it does along the bottom. With all other factors being equal, faster moving air has lower pressure than slower moving air, according to Bernoulli's principle, stated by Daniel Bernoulli, one of the most important pioneers in the field of fluid dynamics. This difference is what allows the slower moving air to push up against the bottom of the wing with greater force than the faster moving air is pushing down against the top of the wing. In level flight, this upward force is just enough to counteract the downward force caused by gravity. [2]

Aerodynamic forces are also used to control an aircraft in flight. When the Wright brothers made their first flight in 1903, they needed a way to control their aircraft to climb, descend, bank and turn. They developed what is known as three-axis control for pitch, roll and yaw. Pitch (nose pointing up or down) is controlled by an elevator (the "flaps") on the back or trailing edge of the horizontal stabilizer in the tail section. Roll (tilting left or right) is controlled by ailerons (also flaps) on the trailing edges of the wings near the tips. Yaw (nose pointing left or right) is controlled by the rudder on the trailing edge of the vertical stabilizer in the tail section. These controls employ Newton's Third Law of Motion because they generate force by deflecting the airflow in the opposite direction of the desired movement. This force is also what allows aerobatic planes to fly upside down. [2]

A pilot may also use flaps on the inboard section of the trailing edge of the wing during takeoff and landing. When in the downward position, flaps increase both lift and drag to allow the plane to fly slower without stalling. Some larger aircraft can also extend slats on the front or leading edges of the wings to increase lift at low speeds.

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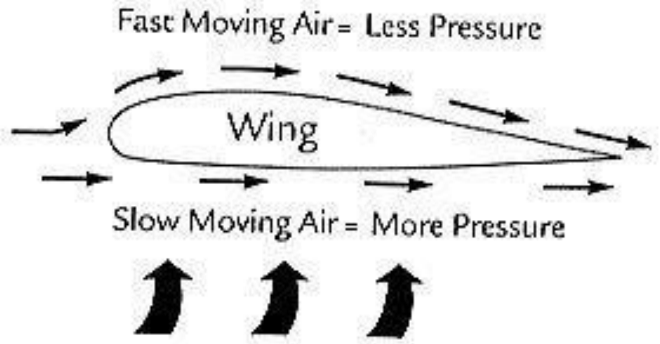

Fig 1 Aerodynamics in Planes

When the smooth airflow over a plane's wing is disrupted and this reduces the amount of lift, a stall can occur. According to the Federal Aviation Administration's Airplane Flying Handbook, "This is caused when the wing exceeds its critical angle of attack. This can occur at any airspeed, in any attitude, with any power setting." Typically, most stalls occur when an aircraft is moving too slowly with the nose at too high of an upward angle. The air no longer flows along the top surface but instead breaks away and forms turbulent swirls on top of the wing. This causes the plane to lose lift and start to fall, sometimes rather abruptly. [3]

Another thing that can happen in an airplane is a spin. The Airplane Flying Handbook defines a spin as "an aggravated stall that results in what is termed 'autorotation' wherein the airplane follows a downward corkscrew path." This usually occurs in a slow turn when the slower inside wing stalls, and the outside wing is still generating lift. "Especially at low altitude, successful spin recovery may be difficult if not impossible in many aircraft," according to Scot Campbell, a doctoral candidate in Aerospace Engineering at the University of Illinois at Urbana-Champaign, and Donald Talleur, an assistant chief flight instructor at the University of Illinois Institute of Aviation, writing in "The Aerodynamics of a Spin," for the Canadian Owners and Pilots Association. One reason for this is the danger of going into a flat spin in which both wings and all of the control surfaces are stalled, and the aircraft falls like a maple tree [4]

2. LITERATURE REVIEW

Peiqing Liu, Zhongzhe Duan, Lichuan Ma and Rong Ma [1] The low density of stratospheric air and small flight speed of airship bring certain difficulty to the aerodynamic design of stratosphere airship propeller. This paper firstly analyzes characteristics of flow around the propeller for an airship in atmospheric environment and the influence of the propeller outlet flow angle to sectional efficiency, then discusses the principle and the method of choice in geometry parameter of the propeller with the equal Re number and the equal stress principle. To specially avoid the appearance of laminar separation bubble (lower the efficiency), authors adopt the airfoil with the low Reynolds Number and high lift in the design and present a three-blade propeller of composite materials with the variable-speed and fixed-pitch according to the design criteria of the airship propeller. The detail specification of the propeller is: the diameter D=6500 mm, propeller actual factor 62.3, maximum width 516 mm, and propeller pith angle 32.80. The paper also evaluates the aerodynamics performance in detail with the strip theory.

H. Tang, G. Chen and P. Liu [2] Airflow disturbance affected aerodynamics of aircraft between damping rings. In order to simulate this disturbance, extra-fluent field of damping rings aircraft was analyzed by Reynolds stress model (LLR-QI) in this paper. Numerical simulations results indicate that spaces between damping rings affected drag coefficient, and keep to test results, to based on improving firing accuracy of the aircraft.

A. Al-Mahadin and E. Papageorgiou [3] The study of unsteady aerodynamics is highly critical due to its important impact on modern aircraft, in particular fighters, hence, modeling methods have been investigated and established. However, conventional methods, such as the least-square and maximum likelihood are not fully capable to predict all the required cases of unsteady aerodynamics at very high angle of attack and with complications from other factors such as severe weather conditions. Therefore, other methods should be investigated using artificial intelligence techniques. It is known that fuzzy logic, as a branch of artificial intelligence, can model unsteady and nonlinear systems in various areas such as control, stability, nonlinear stochastic system and coupled-unstable system. In this paper, the appropriateness of utilizing fuzzy logic to model unsteady aircraft aerodynamics was investigated. It is concluded that fuzzy modeling can reasonably model unsteady aerodynamics if the appropriate aerodynamic inputs, such as angle of attack and pitch rate are used. To establish a reliable model of unsteady aerodynamics using fuzzy model, it is important to utilize experimental data to train and test the FL model. The model can be further validated by comparison with mathematically obtained data.

V. G. Paul, S. Periyasamy and K. Nikam [4] The behavior of the aircraft under oscillations in pitch, roll, yaw and plunge during the flight are crucial for the development of flight control systems and in determining the flight envelope of the aircraft. At present, the prediction of dynamic behavior of the aircrafts are mainly carried out using flight tests. These analysis at the last stage of aircraft development leaves least opportunities to make design changes and are expensive and time consuming. Till date Computational Fluid Dynamics (CFD) is not effectively used in this field due to the huge computational requirements to carry out the required studies and due to the lack of maturity of numerical tools to predict the involved unsteady flow features like highly separated flows. With availability of advance computing capabilities and maturity of CFD solvers, authors have put efforts to use full RANS simulations in carrying out the unsteady forced dynamic motion of the aircraft and compared it with the experimental data. And efforts are put to evaluate the flow physics predicted by CFD. This research paper presents CFD validation of low-speed small amplitude pitch oscillations test data for a Transonic Cruiser (TCR) Aircraft using Metacomp's CFD++ solver. The Stiffness and Damping of the Normal Force and Pitching Moment, estimated by Linear

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Regression Analysis (Least Squares) are in good agreement with the experimental data even in high angle of attacks.

F. Jelenčiak, M. Gerke and I. Masár [5] This article describes a Projection Equivalent Method (PEM) as a new approach for modeling of aircraft. PEM is a method [20] by which it is possible to obtain a mathematical model of the aerodynamic forces and moments acting on the flying machine during flight. For PEM, it is characteristic that in principle it provides an acceptable regression model of aerodynamic forces and moments, which possesses a reasonable and plausible behavior from dynamics viewpoint. The main advantage of the PEM is that it is not necessary to carry out measurements in wind tunnel for identification of model parameters. Plausible dynamic behavior of the model can be achieved by specific correction parameters, which are possible to be determined on the base of experimental data obtained during a flight of the aircraft. In this article, authors present the Projective Equivalent Method, which is applied to an airship. The airship is a special flight system, which is extremely sensitive to the aerodynamic forces impact. Therefore an airship is a suitable object for the comparison of a flight mechanics model providing data calculated by PEM and sensor data from experimental flight.

Liying Yuan, Jiashan Cui, Mingyu Pan and Yongqi Liu[6] For the Characteristics of missile during flights with nonlinear and coupling and dynamicity, a kind of adaptive fuzzy PID hybrid control strategy is designed, which is used to control the missile attitude motion. In order to more accurately reflect changes in the vicinity of the error rate of zero, the use of fuzzy sets detailed rules for the program control method of fuzzy reasoning adaptive fuzzy PID controller missile flight parameters for online self-tuning. Through the simulation results shown that this controller possesses the dynamic response speed, high stability, adaptive anti-jamming ability and good robustness etc.

A. A. Azeez, M. Gadala, N. A. Khudhiri and S. S. Dol [7] This project deals with understanding the various steps involved in performing finite element analysis of computational fluid mechanics systems to enhance the aerodynamics performance of the RC plane for SAE competition. The analysis is conducted for the complete airplane and for the wing optimization. Various modifications are applied to the wing and is analyzed first and then the best cases are applied to the whole airplane. The steps include creating a modeling plan, material selection, geometric modeling, model meshing, applying boundary conditions, and obtaining the required results by solving the models. The software used to conduct the finite element analysis is Workbench. Once the results are obtained, model and result verification are done to validate the data. It is concluded that the airplane-45 degrees winglet has the highest lift force with the minimum drag.

M. Alkhedher and k. Al-Aribe [8] Flight maneuvers can generate nonlinear and unsteady aerodynamic loading. Artificial Neural Networks (ANN) and Adaptive Neuro Fuzzy Logic Inference System (ANFIS) are developed to model and predict aerodynamics coefficient under different values for angle of attack. The system is developed to model the unsteady aerodynamic normal force and the pitch moment coefficients. Based on the extensive analysis of the proposed identification methods, the artificial intelligence models showed low mean square errors in modeling and prediction results.

Z. M. Ali, W. Kuntjoro, W. Wisnoe, R. E. M. Nasir, F. Mohamad and N. F. Reduan [9] This paper discusses the aerodynamics characteristics of Blended Wing Body - Baseline II E2, unmanned aerial vehicle aircraft. A computational method, Computational Fluid Dynamic (CFD) Star CCM+ software has been performed to obtain the aerodynamics characteristic of the BWB. The aerodynamic characteristics prediction of BWB-Baseline II E2 aircraft was obtained through CFD analysis using unstructured mesh and standard one - equation turbulence model, Spalart-Allmaras was selected in the investigations. Lift coefficient (CL), drag coefficient (CD) and moment coefficient (CM) were studied at flight condition of Mach 0.1 (~34 m/s) at different angles of attack, α. The CFD results were compared with the experimental result. The results show the trend of lift curves are similar at the linear region (α = -10° to 7°) but at the higher angle of attack the trends become nonlinear. The drag coefficient for CFD simulations is greater than experimental result and there are differences in pitching moment curves between CFD simulation and experiment data which the experiment data shows a steep curve than simulation.

3. PROPOSED WORK

Actuator disc theory

Each pair is equal and opposite in direction. Nevertheless, they are not usually opposite in position. For straight and level flight the AA is adjusted by the pilot to make the lift equal to the weight, if it is greater the aircraft will climb. If lift is less than weight the aircraft will descend. The engine thrust is adjusted by the throttles to make it equal to the drag, if it is greater the aircraft will increase airspeed - if it is less the aircraft's airspeed will decrease.

Actuator disc theory is the simplest rotor theory possible: the rotor is replaced by a permeable disc carrying an axisymmetric force field. It is more than a century old, with a first analytical result obtained by Froude in 1889. In 1918 Joukowsky published the first rotor performance prediction for a helicopter rotor in hover; in 1920 Betz and Joukowsky published the maximum efficiency of wind turbine rotors. In modern rotor design codes, this momentum theory still forms the basis, be it with many adaptations and engineering add-ons. Best known is the classical theory relating to an actuator disc with thrust acting against the flow but without torque, so without wake swirl. This theory gives the Betz-Joukowsky limit. The results deviate when applied to a flow annulus instead of the entire stream tube, due to the role of the pressure exerted by one annulus to the other. The momentum theory for discs with thrust and torque is relevant for rotors operating with high torque at low rotational speed. For increasing rotational speed, the performance increases from zero to the Betz-Joukowsky limit. In all flow cases, with or without torque, the velocity vector in the meridional plane appears to be constant at the disc. For the performance per annulus and the performance with torque, the deviation from the classical momentum theory is explained by classifying

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force fields as conservative or non-conservative and investigating their impact on energy and momentum balances.

The actuator disk denotes a technique for analyzing rotor performance. In this model, the rotor is represented by a permeable disk that allows the flow to pass through the rotor, at the same time as it is subject to the influence of the surface forces. The 'classical' actuator disk model is based on conservation of mass, momentum, and energy, and constitutes the main ingredient in the 1D momentum theory. Combining it with a blade-element analysis, we end up with the BEM model. In its general form, however, the actuator disk might as well be combined with a numerical solution of the Euler or Navier–Stokes equations.

In a numerical actuator disk model, the Navier–Stokes (or Euler) equations are typically solved by a second-order accurate finite difference/volume scheme, as in a usual CFD computation. However, the geometry of the blades and the viscous flow around the blades are not resolved. Instead, the swept surface of the rotor is replaced by surface forces that act upon the incoming flow. This can either be implemented at a rate corresponding to the period-averaged mechanical work that the rotor extracts from the flow or by using local instantaneous values of tabulated airfoil data.
Blade Element Theory for Propellers

A relatively simple method of predicting the performance of a propeller (as well as fans or windmills) is the use of Blade Element Theory. In this method the propeller is divided into a number of independent sections along the length. At each section a force balance is applied involving 2D section lift and drag with the thrust and torque produced by the section. At the same time a balance of axial and angular momentum is applied. This produces a set of non-linear equations that can be solved by iteration for each blade section. The resulting values of section thrust and torque can be summed to predict the overall performance of the propeller.

The theory does not include secondary effects such as 3-D flow velocities induced on the propeller by the shed tip vortex or radial components of flow induced by angular acceleration due to the rotation of the propeller. In comparison with real propeller results this theory will over-predict thrust and under-predict torque with a resulting increase in theoretical efficiency of 5% to 10% over measured performance. Some of the flow assumptions made also breakdown for extreme conditions when the flow on the blade becomes stalled or there is a significant proportion of the propeller blade in windmilling configuration while other parts are still thrust producing.

The theory has been found very useful for comparative studies such as optimizing blade pitch setting for a given cruise speed or in determining the optimum blade solidity for a propeller. Given the above limitations it is still the best tool available for getting good first order predictions of thrust, torque and efficiency for propellers under a large range of operating conditions.

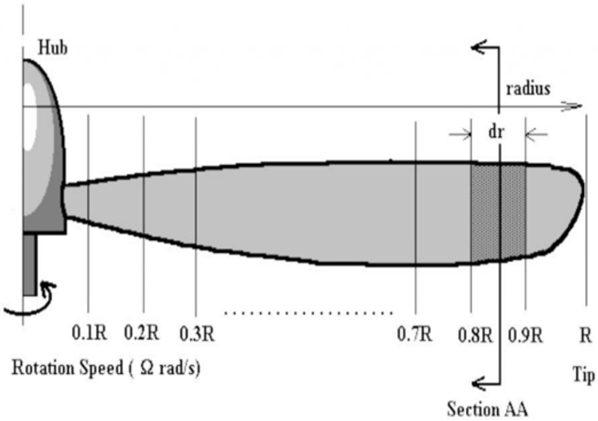

Fig 2 Blade Element Sub-Division

4. IMPLEMENTATION AND RESULTS

In the case of the simulation, we have used Jabiru Light Aircraft Propeller. The following are the dimensions and characteristics which are measured in the labs taking 12 sections of 0.05 m (5cm).

Table 1 Dimensions and Characteristics of Blade

SECTION (m)	Thickness to chord ratio	PITCH (rad)	CHORD LENGTH (m)	THICKNESS (m)
0.150	0.539	0.570	0.106	0.057
0.200	0.514	0.540	0.111	0.057
0.250	0.485	0.506	0.115	0.056
0.300	0.457	0.475	0.118	0.054
0.350	0.427	0.441	0.119	0.051
0.400	0.401	0.413	0.115	0.046
0.450	0.381	0.391	0.105	0.040
0.500	0.349	0.356	0.100	0.035
0.550	0.349	0.356	0.092	0.032
0.600	0.342	0.349	0.082	0.028
0.650	0.345	0.352	0.072	0.025
0.700	0.335	0.342	0.063	0.021

[Data Source : Sample Lab Study]
The total number of blades 2 and diameter of blade is 1.52 m.

Fig 3 Cirrus SR-22

In the process of simulation, we consider that the Jabiru propeller is mounted on the Cirrus SR-22 having characteristics mentionedin Fig 4

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Cirrus SR22 characteristics and performance			
Wing aspect ratio	9.9		
Gross wing area	13.9 m^2		
Max Takeoff Weight	1542 kg		
Takeoff run	314 m		
Rate of climb	427 m/min		
Cruising speed	185 kt = 95.17 $m.s^{-1}$		
Stalling speed (flaps down)	60 kt = 30.87 $m.s^{-1}$		
Takeoff speed	72 kt = 37.04 $m.s^{-1}$		
Climb speed	88 kt = 45.27 $m.s^{-1}$		
Engine Type and performance			
Company	Continental		
Model	IO-550-N		
Power	310 HP= 231kW		
Max RPM	2700		
Flight phase	Takeoff	Climb	Cruise
Altitude	Sea level	6000 ft	12000 ft
Density	1.225 $kg.m^{-3}$	1.024 $kg.m^{-3}$	0.849 $kg.m^{-3}$
Velocity	37.04 $m.s^{-1}$	45.27 $m.s^{-1}$	95.17 $m.s^{-1}$
RPM	2700	2650 (2600 initially)	2680 (2500 initially)
Advance ratio	0.540	0.639	1.49

Fig 4 Cirrus Sr-22 Characteristics

In our MATLAB code for the calculation of the Cruse altitudes and velocities, for the process to obtain the coefficients of lift and drag four our propeller we can make use of XFOIL (reference to MIT website) which offers these coefficients for the specific airfoils and Reynolds numbers.
The engine is a continental Io 550 and it produces two hundred thirty one thousand watts and its max APM is 2700. And finally at cruise the flight altitude is 12000 feet.
The air density is zero point eight nine kilograms per cubic metres. The velocity of flight would just so is ninety five point seventeen metres per second. The OPM is two thousand sixty two thousand six hundred eighty.
Initially at the start of crews two thousand five hundred will take 2500 here and finally the advanced ratio of the propeller at cruising altitude and at this crew's velocity is one point forty nine we will run our Matlab program at cruise altitude and velocities of the Sirius or Cirrus.
So , cruise altitude and velocities of the Sirius assault 20 to equip the Jabiru proper so in order to obtain the coefficients of lift and drag for propeller because we need them of course in our blade element theory calculations to obtain the lift and drag we can use X foil which is a M.I.T. software open source software that is developed where a lot of different shapes of air falls are recorded and the software actually allows to work out a different lift coefficients and coefficients of drags and center of pressures and so on at different Reynolds No.

Test Case for Takeoff

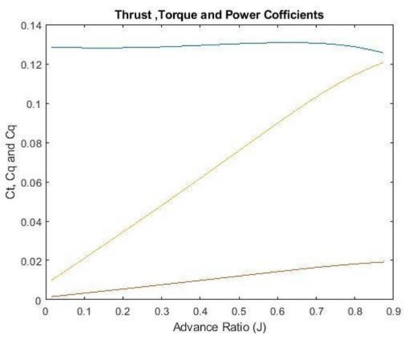

Fig 5 Takeoff Case Thrust, Torque and Power Coefficient Graph

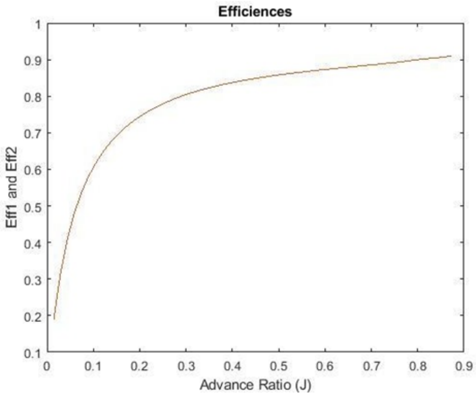

Fig 6 Takeoff Case Efficiencies Graph

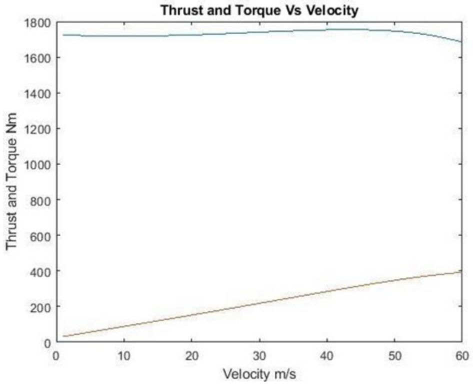

Fig 7 Takeoff Case Trust and Torque Graph

Test Case for Climb

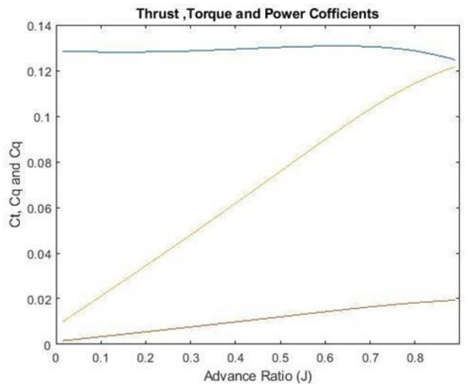

Fig 8 Climb Case Thrust, Torque and Power Coefficient Graph

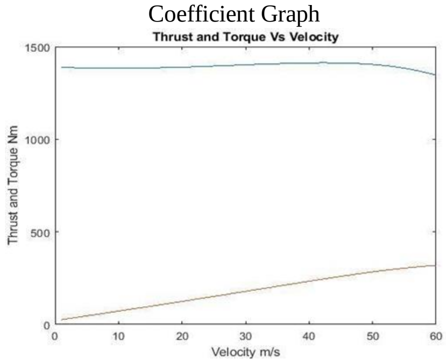

Fig 9 Climb Case Trust and Torque Graph

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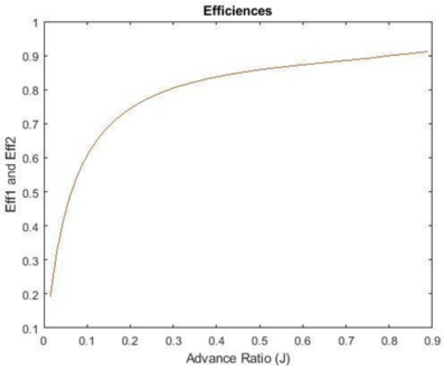

Fig 10 Climb Case Efficiencies Graph

5. CONCLUSION

In our MATLAB code for the calculation of the Cruse altitudes and velocities, for the process to obtain the coefficients of lift and drag four our propeller we can make use of XFOIL (reference to MIT website) which offers these coefficients for the specific airfoils and Reynolds numbers. The engine is a continental Io 550 and it produces two hundred thirty-one thousand watts and its max APM is 2700. And finally at cruise the flight altitude is 12000 feet. So , cruise altitude and velocities of the Sirius assault 20 to equip the Jabiru proper so in order to obtain the coefficients of lift and drag for propeller because we need them of course in our blade element theory calculations to obtain the lift and drag we can use X foil which is a M.I.T. software open source software that is developed where a lot of different shapes of air falls are recorded and the software actually allows to work out a different lift coefficients and coefficients of drags and center of pressures and so on at different Reynolds No. The simulations are conducted using 3 flight modes ,takeoff, climb and cruise and have used Blade Element Theory in MATLAB to design and simulate a propeller in real flight conditions.

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