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# Hybrid Power Supply for Take-off and Landing in Commercial Aircraft

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***Abstract: Hybrid is a viable technology to improve efficiency with respect to its uniqueness. It is the solution to use less fuel in an aircraft and to reduce the economic cost. Because the current state of our fossil fuels makes it unlikely that we will be able to fly an aircraft in the future, hybrid technology was developed to reduce fuel consumption. In this system, the amount of fuel used for takeoff, climb, and cruise can be bypassed using electric engines. The working principle is based on the electric engines and the batteries (lithium-ion). In the present, we have seen a propulsion design that can be used without any hassles and minimizes both the cost and the amount of fuel consumed. Because the Magni650EPU electric motor was the most compatible with the project, it was chosen. The goal was to improve fuel efficiency as well as hybridization.***

***Keywords: Hybrid technology, fossil fuel, electric engine, Magni650EPU, lithium-ion battery.***

## I. INTRODUCTION

Renewable energy replenishes within a certain period without harming the ecosystem. These resources, such as sunlight, wind, rain, tides, waves, biomass, and thermal energy stored in the earth's crust, have the advantage of being available everywhere in one form or another. They are indestructible. And they have negligible impact on the climate or the ecosystem [1].

Increased levels of air pollution are caused by increases in fossil fuel-based road transportation, industrial activity, and electricity generation (as well as open waste burning in many cities). The use of charcoal and firewood for heating and cooking in many underdeveloped nations adds to poor indoor air quality. According to World Health Organization studies, their presence over metropolitan cities causes millions of premature deaths and costs billions of dollars [1].

So, the most critically needed field of renewable energy is transportation vehicle industries, including the aviation and aerospace industries. For example, each time a falcon 9 launches, 147 tons of fossil fuels are used. As a result, all aircraft manufacturers are constantly fighting to develop the most efficient renewable energy to save money on rising fuel prices [1].

When compared to conventional jet engines, electric aero planes are finally finding practical uses after decades of study and development. Electric aero planes excel in the areas of quick response, reduced noise, improved handling in crosswinds, and the capacity to generate differential thrust. Let us look at all the recent advancements in the realm of electric aviation by first understanding the technology that underpins it. All existing electric aircraft, including Alice, the most advanced electric aero plane to date, are propeller driven [2].

The blade motion provides thrust, and in an electric aircraft, the propeller is powered by an electric motor. Axial flux motors are used in all current electric aero planes. Jet engines do not self-start; to start them, we must rotate the main shaft of the engine through an air turbine starter, which then burns the fuel at a rate that speeds up the propeller. Electric aircraft, on the other hand, do not require any assistance to start in the first place [2].

The most crucial factor in achieving a good take-off is high speed. High speed is obtained in propeller aero planes by increasing the pitch of the blades. A larger pitch angle equals more force, but there is a catch: as the pitch increases, the stress on the blades increases as well. This reaction torque will certainly reduce the speed of the propeller in a jet engine based aero plane; as a result, such turbojet engines require a separate governing mechanism to keep the speed constant. On the other hand, the electric motor only depends on the supply frequency during high pitch operation, producing a large thrust force, making the entire take-off operation of an electric aero plane much simpler [2].

Commercial planes are the most popular mode of transportation. Commercial planes, such as cargo flights and private planes, use a lot of fuel on a regular basis. As a result, commercial planes must pay high rates. To cut fuel consumption and make the aircraft more cost-effective, electric engines are installed and powered instead of gasoline engines during take-off, landing, and cruising. Electric engines cannot be used in heavier aircraft like the A380, A350, and others since they require massive batteries. As a result, planes like the ATR 72-600 are better equipped to handle this technology. The electric engines on this aircraft can carry a maximum weight of 23000 kg and do not require many batteries to function.

## II. LITERATURE REVIEW

For decades, the aviation industry has fantasized about the idea of electric aircraft, and now it is finally a reality. Electric aero planes offer numerous benefits in terms of quick reaction, reduced noise, and improved handling. Alice is the most advanced electric aircraft among all the electric aircraft, and it is propeller driven. The propeller provides thrust due to its aero foil action, and axial flux motors are used in all current electric modern aircraft. Axial flux motors provide 30-40% more torque. In electric aircraft, unlike jet engines, there is no need for assistance to start the engine, and we have a prime mover. The simplicity of boosting speed by increasing supply frequency is comparable to that of a jet engine. However, as compared to electric aircraft, jet engine responses are quite slow [2].

The pitch of the blades in turboprop aero planes is increased to achieve high speed. More force equals a greater pitch angle, but, as the pitch increases, so does the stress on the blades. In a jet engine-based aero plane, this reaction torque will obviously limit the speed of the propeller, hence such turbojet engines will require a separate mechanism to keep the speed constant. During high pitch operation period, on the other hand, the electric motor in EA is only dependent on the supply frequency, thus it will automatically take extra power from the source to maintain the speed. A high pitch angle and fast engine speed improve the aircraft's thrust, making the entire take-off smoother [2].

Each magni650 motor incorporates an electric propulsion unit and has a maximum and nominal output of 850kw and 560kw, respectively (EPU). EPU weighs 200kg/400.9lbs and has a shaft power of 850SHP. The magni650 is capable of operating at a maximum altitude of 35000 feet. Its maximum continuous and nominal torques are 3020Nm and 2820Nm, respectively. The output RPM ranges from 1200 to 2300 [4].

A battery pack consisting of 18 modules with 120 cylindrical lithium-ion cells each. The 18650-cell size was chosen because it is based on nickel manganese cobalt compound. Because the cells in each module are so close together, a liquid cooling system with cell-contacting cooling plates was developed to circulate a water glycol mixture between them. Each module produces 120 volts and has a 12-kWh capacity.

These 18 modules were integrated to make a 72 kWh 720-volt battery, giving the entire three-pack propulsion system a total capacity of 216KWh. The YASA 750r motor is powered by this cylindrical lithium-ion cell battery [5].

Hybridization of the propulsion architect enables the development of novel propulsion systems with even greater aerodynamic advantages. The wing's aerodynamic lift properties may be increased because of the improved propulsor arrangement. A variant of this design is an architecture with two electric-driven propellers and a gas turbine on each wing. This hybrid propeller concept improves aircraft lift properties while also lowering weight and expense. With a larger number of engines, the power rating factors for each propulsor can be reduced. Due to rising maintenance expenses, several gas turbine topologies result in greater prices. An architecture with two electric engines does not require a large cost penalty because electric propulsion is predicted to require less maintenance [6].

Block fuel refers to the whole amount of fuel necessary for a trip while it is still on the cover. Trip fuel, taxi fuel, possibility fuel, alternative fuel, last save fuel, and supplemental fuel are all considered while determining the square fuel. The concept of overloading after landing is not considered here.

Execution tables, weather forecasts, actual masses, and air traffic control limits are all considered while computing trip fuel. The possibility fuel, which accounts for 5% of the total square fuel, completes unexpected events such as course modifications. The ultimate saved gasoline is that which has been consumed at a constant speed for approximately 45 minutes. More fuel is injected based on the pilot's evaluation of the situation [7].

Wind is a critical component of fuel use. While employing explicit fuel, the bounds of the wind scenario on that day are considered. In general, the CG of an aero plane adjusts its position in reaction to the wind bearing, affecting fuel usage. Long-distance flights should be taken in twin motor aero planes. At a lower take-off speed of 170kt, fuel consumption is decreased to 58kg, resulting in a 26 percent increase in range. 51kg of gasoline should be set aside if the descent is on a difficult slope. Per voyage, more than 110kg of fuel is lost [8].

The inter turbine temperature reaches 800oC during maximum take-off, although the usual take-off temperature is 765oC. The engine's maximum yield force is 17354Nm, and its highest speed is 1212rpm [9].

The icing speed decision before take-off and landing is dependent on outside air temperature conditions, such as when temperatures are below 5-7 degrees Celsius and visibility is less than 1 mile due to moisture, cloud, rain, or fog, according to the ATR 72-500 speed selection chart. Below the acceleration height, the cloud base will be 1500 feet above ground level. The speed is determined by the weight [13].

For instance, the MTOW is 20 tones, V1/Vr is 105 knots, V2 is 110 knots, and mi. After take-off, the flaps 0-degree speed is 132 kts, and the final approach flaps 30-degree speed is 105 kts, although the speeds change when icing conditions are applied. The V1/Vr is 113 kts, the V2 is 118 kts, and the mi is After take-off, flaps 0 degree will be 157kts, and final approach flaps 30 degree will be 114kts. As a result, as the weight of the aircraft increases, the normal and icing speeds of various variables alter as well [13].

The PW150A engines of the Q400 have twice the power of the PW127M/F engines on the ATR72s, which has a considerable impact on the operational planning of trips with this type. The Q400's basic version's maximum take-off weight (MTOW) is over 28,000kg, while the ATR72-is 500's 22,800kg, making the Q400's MTOW 23 percent greater than the ATR72. The Q400's payload, however, is just 18% higher than the ATR72-at 500's 8625kg. This difference is due to the Q400's higher operational empty weight, which is over 17,600kgs, or 36% more than the ATR72- 500's. Unlike the ATR72, which extensively uses proven lightweight composites in the wing and tail plane, the Q400 has larger (and thus heavier) engines and uses little or no composites in its aircraft structure [14].

The base version of the Q400 has a maximum take-off weight (MTOW) of 28,000kg, compared to 22,800kg for the ATR72-is 500, making the Q400's MTOW 23 percent more than the ATR72. The Q400's payload, on the other hand, is just 18% more than the ATR72-8625kg. 500's This is owing to the Q400's significantly larger operational empty weight, which is approximately 17,600kgs, or 36% more than the ATR72-500. The Q400 features larger (and consequently heavier) engines and employs little or no composites in its aircraft structure, unlike the ATR72, which extensively uses proven lightweight composites in the wing and tail plane [14].

## III. HYBRID PROPULSION SYSTEM

An integration propulsion system combining jet propulsion and electric propulsion is used as the hybrid propulsion approach. This hybrid system will be installed in an ATR 72-600 turboprop plane, which is more suitable for the experiment. The PW127M series engine, having a maximum output of 2,750 SHP, powers the ATR 72-600 [3].

### A. *Propulsion Engine*

The aircraft is powered by a magni650 EPU electric engine. The magni650 electric propulsion unit (EPU) is an axial-flow electric motor that delivers 850 SHP, 640 kW, and 3.000 Nm of torque. A magni650 motor, four MagniDrive 100 controllers, and a closed loop integrated thermal management system are included in each EPU. 640 kW is the maximum amount of power that can be produced. Magni650 EPU has a dry weight of 200 kg (440.9 lbs).Continuous power of 560 kW is the nominal power. The maximum operational height is 35000 feet, and the output RPM ranges from 1,200 to 2,300. DO-160G is a certification for environmental protection. 3.020 Nm maximum constant torque. The maximum operating voltage is 800 volts direct current. Min operational voltage 500Vdc Nominal torque 2,820Nm [4].

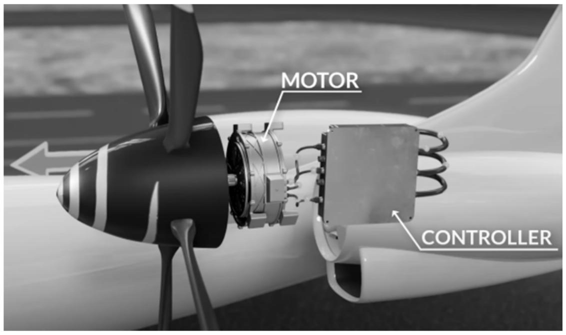


Fig.3.1.1 Magni650 [4]

### B. *Controller*

The MagniDrive 100 is a high-performance, multi-application power electronics package that includes both an inverter and a motor controller. It is designed to be bidirectional, capable of both DC/AC propulsion and AC/DC generating. It can be used on HVDC networks with up to 800 VDC. The magniDrive 100 is a non-pressurized drive that combines outstanding thermal performance, EMI immunity, and lightning protection for metallic and composite constructions. Both analogue throttle input (for retrofits, for example) and Fly-By-Wire controls are supported by the magniDrive 100. (For newly designed aircraft). MagniDrive 100 has CAN x4, RS485, PT1,000, and a pressure sensor. It weighs 12 kg / 26lbs. The output is 170W [4].

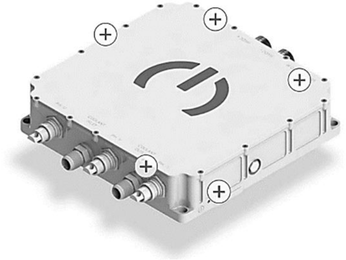


Fig. 3.2.1 magniDrive 100 controllers [4]

### *C. Power management system*

A battery pack made up of 18 modules with 120 cylindrical lithium-ion cells apiece. The common 18650 cell dimension was used, which is based on nickel manganese cobalt chemistry. The cells are tightly packed in each module, so a liquid cooling system with cell contacting cooling plates was created to circulate a water glycol mixture across them [5].

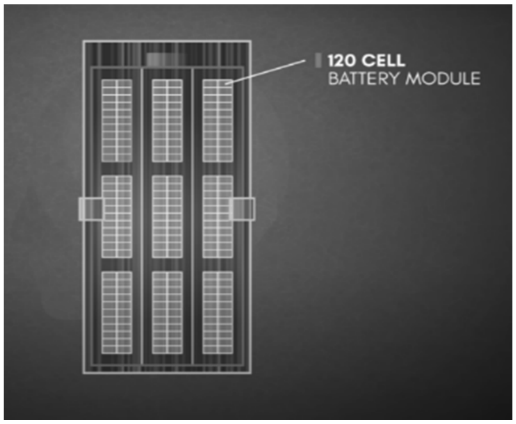


Fig. 3.3.1 Battery compartment contains 18 modules of battery pack [5]

Each module produced 120 volts and had a 12-kWh capacity. When these 18 modules were joined to form a battery pack, they produced a 720-volt battery with a capacity of 72 kWh, giving the entire three-pack propulsion system a total capacity of 216 Kwh [5].

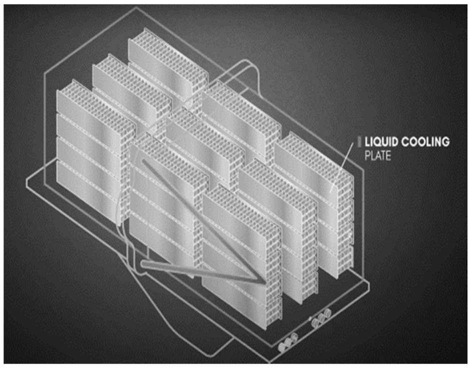


Fig. 3.3.2 Battery Pack with liquid coolant

The 168Wh/kg specific energy of the cell battery pack makes it the highest energy density battery ever used in an electric aircraft. This battery system is anticipated to have a flight range of up to 320 kilometers, or around 200 miles, in cruise conditions. Magni650 requires a maximum power of 650 kW.

Three compartments are fixed in the aircraft to meet the need, each compartment containing 18 modules with a capacity of 216 KWh. As a result, the combination of three compartments has 54 modules with a maximum power capacity of 648 KWh, providing enough power to the electric engine to achieve maximum thrust [5].

## IV. PROPELLER ARCHITECTURE

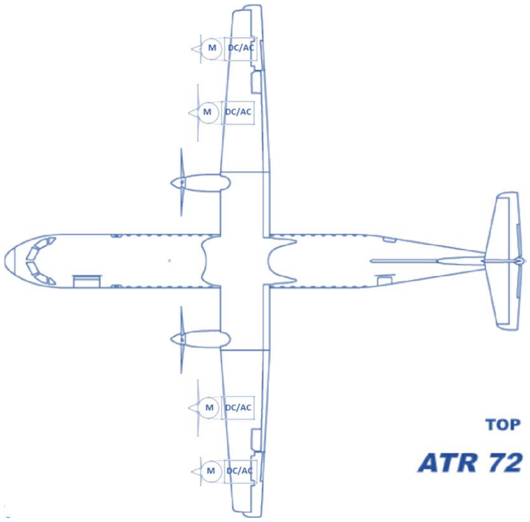


Fig. 4.1 Schematic propeller architecture for ATR 72-600 [3, 6]

In Fig. 3.1 Electric engine magni650 is attached to both sides of the wings in perfect dimension. Four engines were installed weighs 230 kg/engine to attain the maximum take-off power and thrust. Each engine is designed according to the weight ratio and center of gravity of the plane.

A new type of throttle system is installed in the instrumentation cluster of the cockpit to operate the electric engine and thrust is produced as the same way of operating turboprop engine.

To power the single engine 3 compartments of battery module pack are needed. These battery compartments are fixed under the fuselage of the aircraft, distributed according to the weight ration and center of gravity of the airplane. Each battery compartment weighs 97.2 kg.

The airplane is electrically powered by four electric engines, so twelve compartments of battery pack weighs 1550 kg with capacity of 2,593 kWh are fixed and these twelve compartments are equally distributed and fixed in fuselage of the aircraft. Power is transmitted from battery to the electric engine controller by conducting cables.

## V. PROPULSION TECHNIQUE

The propulsion technique of the Hybrid ATR 72-600 is an integration electric engine associated with PW127M engine for various flight performance.

| Factors | ATR 72-600 (kg in approx.) | Hybrid ATR 72-600 (kg in approx.) |
|---|---|---|
| Operational empty weight (OEW) | 13,450 | 16,000 with battery and 4 E-engine |
| Max Payload (at typical in service OEW) | 7,550 | 6,000 |
| Max zero fuel weight | 21,000 | 22,000 |
| Max fuel payload | 5,000 | 3,000 |
| Max take-off weight (MTOW) | 23,000 | 24,000 |

Table. 5.1 Weight Comparison between ATR 72-600 and Hybrid ATR 72-600 [3]

Assume the Hybrid ATR 72-600 flight is scheduling a trip from destination A to B.
Routing from A to B: 300 NM or 555.6 Km.
Payload: 4,500 kg.
Block fuel for 300 NM: 994 kg approx.
Operational weight: 21,494 kg approx.
TOW: 21,500 kg approx.

| Fuel segment | Fuel Weighs in kg approx. |
|---|---|
| Taxi | 35.2 |
| Trip fuel | 913 |
| Contingency fuel | 45.65 |
| Fuel loaded | 994 |

Table. 5.1 Block fuel [7]

### A. *Engines Startup*

Both engines are powered simultaneously. Electrically both engines are powered on and go into a condition check and ready to give thrust. One of PW127M operates in HOTEL mode for cabin power supply and air conditioning. Around 110 kg/hr of fuel is consumed [8].

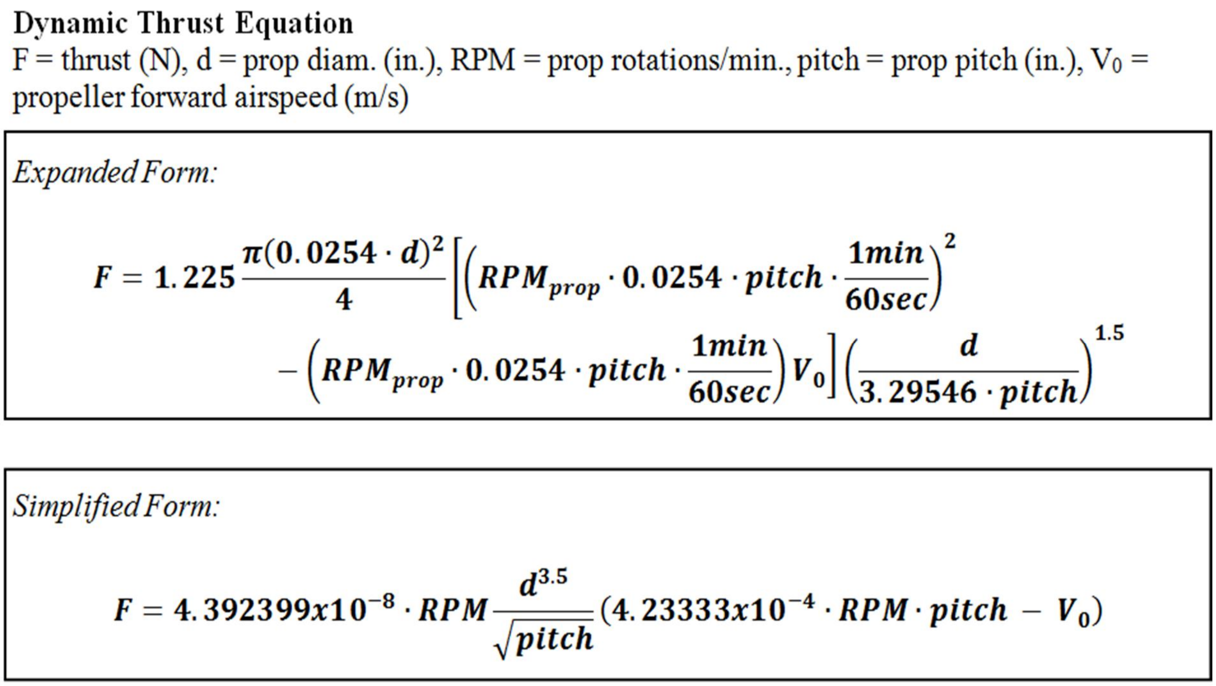
### B. *Taxi*

The aircraft is moved from the ramp to the runway by an electric engine that is throttled up to a specific speed, while the turboprop's shaft is rotated by an electric starter at zero throttle. Assuming the airport has a shorter taxiway, the turboprop consumes approximately 3.55 percent of its block fuel, resulting in a fuel consumption of around 35.2 kg.

#### 1) *Thrust produced by turboprop engine for taxing*

| Parameters | Values in approx. | Units |
|---|---|---|
| Forward speed ( Vtaxing ) | 5.55 | m/s |
| Diameter of the propeller | 154.7244 | Inches |
| RPM | 900 | Rev/min |
| Pitch of the propeller | 14.6 | inches |

Table. 5.2.1. Data to analyze thrust in taxing. [3, 9]



**Dynamic Thrust Equation**

F = thrust (N), d = prop diam. (in.), RPM = prop rotations/min., pitch = prop pitch (in.), $V_0$ = propeller forward airspeed (m/s)

*Expanded Form:*

$$F = 1.225\frac{\pi(0.0254\cdot d)^2}{4}\left[\left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1min}{60sec}\right)^2 - \left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1min}{60sec}\right)V_0\right]\left(\frac{d}{3.29546\cdot pitch}\right)^{1.5}$$

*Simplified Form:*

$$F = 4.392399x10^{-8}\cdot RPM\frac{d^{3.5}}{\sqrt{pitch}}(4.23333x10^{-4}\cdot RPM\cdot pitch - V_0)$$

Fig. 5.2.1 Equation to calculate thrust for propeller engine [10, 11]

Using the equation in fig. 4.2.1 with given parameters in table. 4.2.1, the thrust produced by the turboprop engine for taxing is 594.60lbs.

### *2) Hybrid ATR 72-600*

In Hybrid ATR 72-600, the equal amount of thrust is produced by electric engine for taxing the aircraft where the turboprop remains idle. Using the energy formula (HP=T*V/375) [12] the energy consumed by the electric engines for taxing is 14.70 kW.

## *C. Takeoff:*

### *1) ATR 72-600*

| Parameters PW127F engine | Values in approx. | unit |
|---|---|---|
| Vinitial | 0 | knots |
| V1 | 121 | knots |
| Distance | 1302 | m |
| Rpm | 1212 | Rev/min |
| Pitch | 121.44 | inches |

Table 5.3.1.1 Data to analyze thrust in take-off [8, 13]

### ***2) Applying these conditions in Hybrid ATR 72-600***

The PW127M engine provides 3102.50 pounds of thrust during takeoff. For takeoff, the electric engine delivers 80 percent of the thrust provided by the ATR 72 PW127M engine, which is 2482lbs. PW127M engine provides 20% thrust around 620.5lbs to aid the electric engine in achieving take-off speed. For 20% of the thrust produced by the PW127M engine, approximately 11.2 kg of trip fuel is utilized, while the battery power consumed by the electric engine for take-off is 686.80kw.

## *D. Climb*

| Parameters | Values in approx. | Units |
|---|---|---|
| Vr | 121 | knots |
| Vclimb | 170 | knots |
| Vfl210 | 204 | knots |
| Rpm | 1296 | Rev/min |
| Thrust | 3535.705 | lbs |
| Fuel consumed | 183 | kg |

Table. 5.4.1 Data to analyze climb thrust [8, 9, 10, 13]

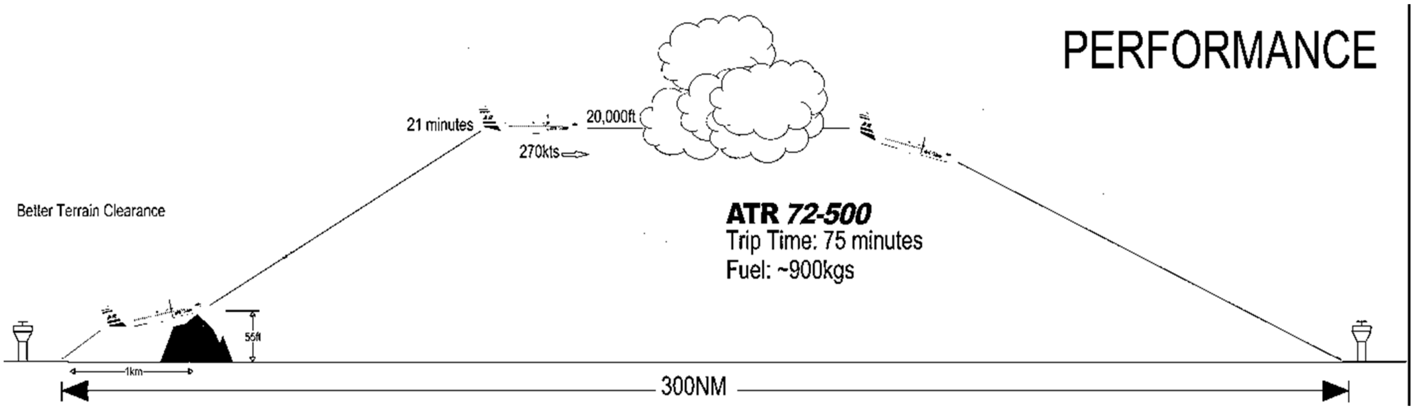


Fig. 5.4.1 ATR 72-600 Performance [14]

### *1) Hybrid ATR 72-600*

The electric engine produces 2828.654lbs of thrust 80% of the time during climb, and the aircraft requires 1100.4kw of energy to produce that thrust. The PW127M engine provides the remaining 20% of thrust (707.141lbs) to help the electric engine reach its maximum speed. The fuel consumed for the climb in the hybrid ATR 72-600 is approximately 55.6 kg.

### *E. Cruise*

With a maximum rpm of 1300, the aircraft can reach a top speed of 510 kilometers per hour. An ATR 72-600 with a fuel flow of 768kg/hr consumes 520 kg of fuel during cruising [3, 8]. During cruise, the propulsion system in the hybrid ATR 72-600 operates in vice-versa, with the PW127M engine producing 80% of thrust and the electric engine providing 20% of thrust to assist with cruise.

| Parameters | The value of PW127 engine in approx. | The value of Magni650 in approx. | Units |
|---|---|---|---|
| Thrust | 2843.2 | 710.8 | lbs |
| Fuel consumed | 424 | - | Kg |
| Power consumed | - | 447.92 | KW |

Table 5.5.1 Thrust and Power calculations

### *F. Descent and Landing*

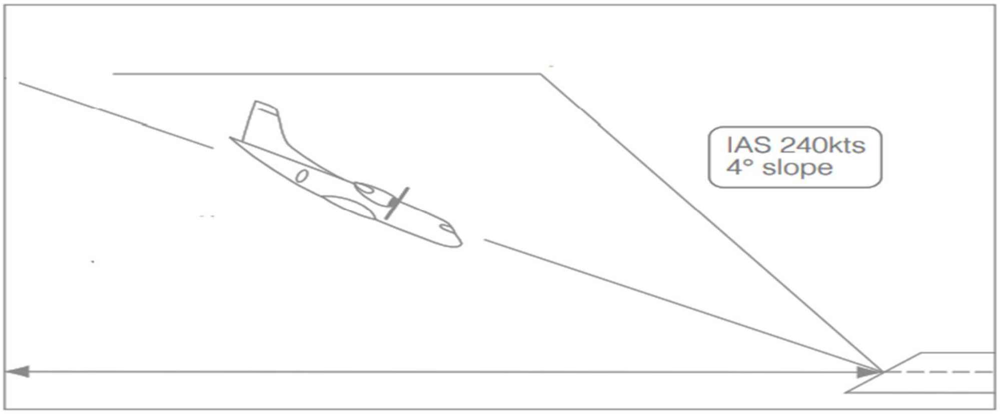


Fig. 5.6.1 Descent of ATR 72-600 [8]

The aircraft descends at a 4-degree slope, which consumes less fuel and requires less thrust. The fall is completed entirely by the PW127M engine at 240kts, consuming 108 kg of fuel and landing at 112KIAS. The electric engine shuts off during descent, assisting the aircraft by reducing thrust [8].

## VI. RESULT

From the above propulsion technique, the fuel consumption of Hybrid ATR 72-600 is calculated using the above data. Taxing, takeoff, climb, cruise, and descent fuel consumption are all computed independently. Takeoff while taxing. The electric engine excels at climbing and cruising, while the PW127M engine excels at descending and landing. For each part, the power consumed by the electric engine is determined.

| Flight Operations | Fuel consumed in ATR 72-600 kg approx. | Fuel consumed in Hybrid ATR 72-600 | Fuel Saved from total trip fuel of 913 kg |
|---|---|---|---|
| Taxing | 35.2 | 35.2 | 0 |
| Take-off | 56.5 | 11.2 | 44.8 |
| Climb | 222 | 55.6 | 166.4 |
| Cruise | 520 | 424 | 106 |
| Descent | 108 | 108 | 0 |
| Trip Fuel | 906.5 | 676 | 230.5 |

Table. 6.1 Fuel consumption in kg

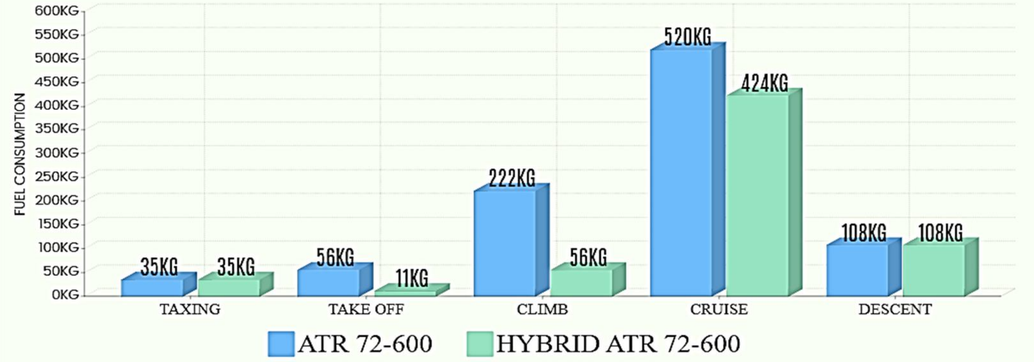
The electric engine consumes 2249.87kW of power. The battery pack has a total capacity of 2572 kWh. After the excursion, 13.5 percent of the battery is left in the vicinity of 350kW.

| Flight Operations | Power consumed by Hybrid ATR72-600 in kW approx. |
|---|---|
| Taxing | 14.70 |
| Take-off | 686.80 |
| Climb | 1100.45 |
| Cruise | 447.92 |
| Descent | 0 |
| landing | 0 |
| Sum | 2249.87 |

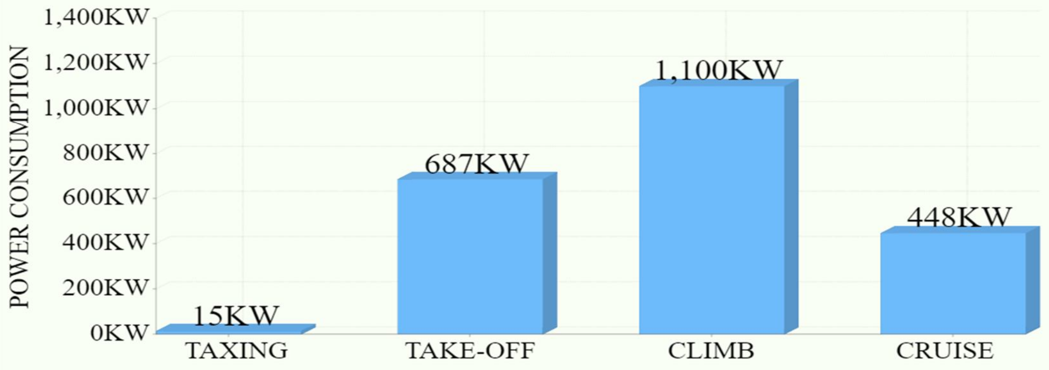
Table. 6.2 Power Consumption in Kw

The current average price of jet fuel in India is approximately 112.9 rupees per liter. The usual ATR 72-600 fuel refill cost is 102,345 rupees for a 300-kilometer journey. Refueling a hybrid aircraft cost only 76,320 rupees, saving 26,000 rupees per trip.
The average cost of one kilowatt-hour of power is 5.43 rupees. It costs up to 14,000 rupees per trip to replenish the Hybrid ATR 72-600 batteries.

## VII. GRAPH



Graph.1 Fuel consumption ATR 72-600 vs Hybrid ATR 72-600



Graph.2 Power Consumption of Hybrid ATR 72-600

## VIII. CONCLUSION

Hybrid technology is a cost-effective technology in which the electric engine plays a critical role in generating sufficient mechanical energy sources while also improving the environment. The estimates that resulted in the paper of Hybrid ATR 72-600 fuel consumption give a lot to society by saving 230.5kg of fuel and 26,000 Indian rupees for a 300NM trip. It also emphasizes the importance of reducing pollution in the environment. In the context of aviation, hybrid ATR 72-600 configurations demonstrate that the technological feasibility of the hybrid approach is mostly dependent on battery performance, whereas fuel reduction in aircraft is solely dependent on fuel. The introduced propulsion approach can be used by an aircraft designer to optimize future hybrid HEA systems.

### *A. Nomenclature*

Abbreviations
EPU – Electric Propulsion Unit
SHP – Shaft Horsepower
KWH – Kilowatt-hour
NM – Nautical Mile
KTS – Knots
KCAS – Knots Calibrated Air Speed
KIAS – knots Indicated Air Speed
RPM – Rotation per Minute
LBS – Pounds
VDC – DC Volts
EMI – Electro Magnetic Interference
Nm - Torque
Vtaxing – Taxing speed of aircraft
Vinitial – Initial speed of aircraft
V1 – Ground speed
VR – Rotational speed of aircraft climb
Vclimb – Climb speed
MTOW – Maximum Take-off Weight

## IX. ACKNOWLEDGEMENT

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