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Advances in Aircraft Mechanical Systems and Components

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Abstract: **Aircraft is a complex system of systems. Structural elements are complemented by the Avionics and Mechanical Systems. Avionics would provide the communications, navigation, other control functions and commands. The Mechanical Systems would execute these and provide the power to realize a safe flight starting from takeoff to landing. Each system has its role to play in the successful mission of the aircraft's each flight. Each system will have sub-systems and components to achieve their functional requirements and meeting the reliability, maintainability and safety (RMS) requirements. It is a known fact that many technological advances originate from the Aerospace industry and trickle down to other walks of life. In recent years, the aviation business has entered a major growth period with increased air transportation demand projected for the future. On the other hand, the rising awareness of environmental issues on a global scale necessitates a reduction in substances of concern i.e. decreased greenhouse gas emissions. Furthermore, as the international demand for fuel increases, fuel prices are rising, and the aviation business is urgently requesting better fuel efficiency for economic reasons as well. There is also serious research happening in the area of alternate fuel, fuel cell and all electric aircraft. These needs, currently drive the requirement for newer technology and changes in how aircrafts are made and flown. Thus energy consumption of each system is one area that is scrutinized closely. Going one step ahead the exergy analysis to minimize the entropy generation by these systems and to curtail the endogenous avoidable and exogenous avoidable parts of the exergy destruction occurring in each component are extensively used in Propulsion System and ECS development. Weight reduction is another important aspect in all these systems. Landing Gear System (LGS) weight is generally about 4.0% of the aircraft take-off weight. Developments like equipping composite braces on the main landing gear, electrically actuated Landing Gear are some examples of weight reduction in LGS. Advances in these systems not only aim at improving inflight performance but also look into the energy and fuel saving during ground handling, maintenance and thus reducing life cycle cost. This paper details the technology and the innovations that have gone in to evolving these systems over the years both at system level and component level. The paper also looks into the emerging trends in the design and development of these systems. The trends in developing new configurations, evolving the new systems' architecture, meeting the demanding new requirements at component and system level, using latest software resources for mathematical modeling and simulation, conducting rigorous tests at component and system level at ground and flight test phases and finally meeting the certification requirements are touched upon.**

Index Terms**— Aircraft Mechanical Systems, Environmental Control System, Fuel System, Hydraulic System, Landing Gear System.**

I. INTRODUCTION

Aircraft is nothing but a system of systems. If the structural elements are the skeletal and muscular systems, the mechanical and avionics systems are the other systems of the body like nervous, circulatory, respiratory systems. Avionics would provide the communications, navigation, other control functions and commands. The Mechanical Systems would execute these and provide power to realize a safe flight starting from takeoff to landing. The Mechanical Systems would consist of the Environmental Control System (ECS), Flight Control System (FCS), Fuel System, Hydraulic System (Hyd), Landing Gear System (LGS), Life Support System (LSS), Ice Protection System (IPS), Propulsion System (PS) etc. Depending on the end use of the aircraft, civil or military, the number and complexity of these systems would vary.

The primary function of ECS is to provide all people on board the aircraft with controlled and comfortable atmosphere in terms of amount of fresh air, pressure, temperature, humidity and their rates of change during all phases of flight. The FCS comprises primary control surfaces that are active throughout the duration of the flight and secondary control surfaces which are used in particular flight modes or to obtain certain desired flight characteristics. The LGS must ensure the positive deployment, retraction, and locking of the landing gear, while the thrust reverser actuation, brake actuation, and nose-wheel steering subsystems are responsible for ensuring adequate deceleration and control of the aircraft on the ground. Likewise each system has its role to play in the successful mission of the aircraft. Each system will have sub-systems and components to achieve their functional requirements and meeting the reliability, maintenance and safety (RMS) requirements.

It is a known fact that many technological advances originate from the Aerospace field and trickle down to other walks of life. In recent years, the aviation business has entered a major growth period, becoming a growth industry with increased air transportation demand projected for the future. On the other hand, the rising awareness of environmental issues on a global scale demands a reduction in substances of concern i.e. decreased greenhouse gas emissions. Furthermore, as the international demand for fuel increases, fuel prices are rising, and the aviation business is urgently requesting better fuel efficiency for economic reasons as well. These needs, currently drive the requirement for newer technology and changes in how aircrafts are manufactured and operated. Clean Sky, the joint venture between the European Union and Europe's aviation industry, is working toeards making future aircraft more environmentally friendly. The use of electric power for all non-propulsion requirements on an aircraft will enable power to be used only when it is needed, while getting rid of the hydraulics will not only reduce weight but also reduce pollution because there will no longer be any hydraulic fluid to dispose-off. The no-bleed architecture on the 787 Dreamliner engine, not only improve the efficiency of the engines, it also improves reliability and cuts maintenance costs, Boeing claims. Airbus linked up with Parker Aerospace to explore the possibilities of replacing Auxiliary Power Units (APUs) with fuel cell systems, which could cut fuel consumption by 10-15% on short-haul flights.

Thus energy consumption of each system is one area that is scrutinized closely. Going one step ahead the exergy analysis to minimization of the entropy generation by these systems and to minimize the endogenous avoidable and exogenous avoidable parts of the exergy destruction occurring in each component are extensively used in Propulsion System and ECS development.

Weight reduction is another important aspect in all these systems. LGS weight is generally about 4% of the aircraft take-off weight.

Developments like equipping composite braces on the main landing gear, electrically actuated Landing Gear are some examples of weight reduction in LGS.

Advances in these systems not only aim at the inflight performance but also look into the details of ground handling, maintenance aspects and the life cycle cost etc.

Trends and advances in propulsion system are not discussed in this paper as that is a subject in itself.

II. DRIVERS FOR THE ADVANCES

The advances in the aircraft mechanical systems and their components originate from the following causes:

A. Aircraft functional requirements

Aircraft mission would dictate the type of systems required. For a civil aircraft, the new requirement could be the increased range or increased size. For a military aircraft the new requirement could be a special mission to be performed or a new maneuver to be performed. Or the new requirement could be the result of an aircraft accident investigation. These new requirements in turn could demand an advancement in the existing systems.

Reduction in weight and fuel consumption are always welcome in any aircraft program. The systems' contribution in meeting these goals is possible through innovations and new technologies. It is predicted that there will be an overall improvement of 45% in the fuel efficiency over the next 3 decades, of which 6% is expected from advances and improvements in the aircraft mechanical systems [1].

To satisfy the demanding needs of the Aircraft Manufacturer, the Customer (Airlines), the Users (Passengers) & the Regulatory authorities, new architectures, new systems and higher efficiencies will be examined paying greater attention to highly integrated systems [2].

B. Environmental and other regulations

Newer and stringent environmental norms dictate advances in systems. For example, Clean Sky, the joint venture between the European Union and Europe's aviation industry, is working on making future aircraft more environmentally friendly. Europe's vision for aviation, as presented in the European Commission's report Flight Path 2050, sets very ambitious targets for reducing aircraft emissions. These goals include a reduction of CO_2 emissions by 75%, NO_x by 90%, and noise levels by 65% compared to the year 2000.

C. Optimization of the systems

The optimization at the system level calls for advances right from configuration studies to component development to integration on the aircraft. These optimization studies arise not only from the system performance point of view but also because of the allocations that flow down from the aircraft requirements.

D. New technologies

Finally the new technologies that crop up in materials, manufacturing processes, computer software and analysis tools, testing techniques are all utilized in the design and

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development of the components and the systems for the aircraft. The civil aircraft systems usually embrace the established technologies as the safety and the operational costs are of paramount importance. The Military aircraft on the other hand explore new and advanced technologies to be ahead of the competition.

III. SOLUTIONS AT SYSTEM LEVEL

The advances occurring at system level are discussed in the following paras at various phases of the system life cycle:

A. Configuration Studies

Advances start right from system configuration studies. More-electric and All-electric aircraft are developments in that direction. The latest generation of aircraft use far more electricity than their predecessors. The Airbus A-380 uses 1.2MW of electricity, while the Boeing 787 uses 1.5MW of electricity. The use of electric power for all non-propulsion requirements on an aircraft will enable power to be used only when it is needed, while getting rid of the hydraulics will not only reduce weight but also reduce pollution because there will no longer be any hydraulic fluid to dispose-off. The transition to an electric architecture has drastically reduced Boeing's new 787 Dreamliner's mechanical complexity. Overall the 787 will reduce mechanical systems complexity by more than 50%, compared with a 767 [3]. As things stand, a small proportion of power generated by an aircraft's engines is diverted to central hydraulic pumps and other mechanically driven subsystems, and to the auxiliary power unit (APU) for non-propulsive power [4].

The no-bleed architecture on the 787 Dreamliner engine, not only improve the efficiency of the engines, it also improves reliability and cuts maintenance costs, Boeing claims [5].

Airbus linked up with Parker Aerospace to explore the possibilities of replacing APUs with fuel cell systems, which could cut fuel consumption by 10-15% on short-haul flights.

Decentralization is entering aircraft systems with the development of larger and more complex aircraft [6]. For example the distributed FCS offers advantages like easy design and realization, less weight, improved computational power and growth potential, easy to address obsolescence, less software complexity, improved system safety [5]-[6].

B. Systems' Analysis and Optimization

As the systems are getting complex and are interrelated, Multi-Disciplinary Optimization (MDO) techniques are being employed. System configuration is chosen based on its requirements, which are assigned down from the overall aircraft requirements. System performance calculations and simulations are done along with optimization studies. System weight and power input to the system are the usual optimization parameters. Classical thermodynamic analysis based on energy methods are used for a long time in such optimization. Exergy based analysis is extensively used to minimize the wastage of the useful energy in systems like propulsion and ECS [8].

Virtual build techniques are extensively used at every stage to make sure that the performance targets are achieved. This is to avoid any shortfall that would lead to an expensive iterative design and development cycle that would affect the product cost as well as the project time lines.

Simulation and Computational Fluid Dynamics (CFD) studies are imperative in the design and development of aircraft mechanical systems. Kinematics to check the mechanisms that are employed in these systems, Computer Aided Design (CAD) modelling from basic design to installation studies to maintenance checks have become the norm. Advances are going to be with the use of new Information Technologies (IT) like big data analytics and Internet of Things (IOT).

C. Maintenance

One of the areas that contribute heavily to the life cycle cost of a system is maintenance. With aircraft systems' hardware failures (without considering the propulsion system) causing more than 50% of the accidents there is a need to track and forewarn the failures to enable corrective action to be taken. Integrated Vehicle Health Maintenance (IVHM) with smart sensors and use of big data analytics keeps the aircraft safe and serviceable at all times to maximize their operation. It transforms the system data in to information that supports the operational decisions thereby minimizing the maintenance action/time apart from other benefits. The aim is to increase the system reliability and provide condition based maintenance [9].

D. Ground Movement

Aircraft have to be routed from a gate to a runway and vice versa. The International Civil Aviation Organization engine emissions database (ICAO 2008) states that the engine power setting for taxi/ground idle is 7% of full rated power. Jet engines are not very efficient at low power and speeds, so using an alternative method of propulsion on ground is a good opportunity to save fuel. An aircraft the size of an A320 will probably burn about 200 kg of fuel during taxi from the airport terminal to the end of the runway in a large airport like Paris-Charles de Gaulle. Optimal efficiency in aircraft ground

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maneuvering by incorporating the use of in-wheel electric motor/generators that are capable of producing sufficient power density to effectively maneuver aircraft of any weight on the ground, and provide for safer and more effective braking of the landing gear wheels. New technologies include wheel-mounted electric motors for taxiing that eliminate the need for jet engine-powered maneuvers around the airport aprons and taxiways. For example, in March 2007 Delos Aerospace launched an in-wheel electric motor/generator concept, capable of producing sufficient power density to effectively maneuver aircraft of any weight on the ground [10].

Delta Airlines is partnering with Chorus Motors to build a production electric wheel drive for ground-manoeuvring, for the airline's Boeing 737s.

The development of a new generation of tow-bar less, high-speed aircraft tugs – some of them powered by batteries – has opened the potential for developing these operations further. Electric tugs can be more usefully used for push-back operations. Stockholm Arlanda 2 is the world's first all-electric ramp handling airport terminal. But using these methods will require a radical change to the way airports operate, giving airlines much less control over their ramp operations, slowing down aircraft movements on the ground, with a commensurate loss of flexibility and capacity.

In order to minimize unnecessary engine fuel consumption during this pushback and taxiing, electric taxiing enabling the aircraft to travel autonomously is being researched, and electric systems and mechanisms are being investigated including their structural safety and reliability. Electric taxiing is expected to yield even greater efficiency in the future thanks to fuel cells, and the realization of an on-board fuel cell system is being actively pursued. Once again, electric taxiing is conducted without using the engine. Effective utilization of regenerated power by deceleration and acceleration during electric taxiing is anticipated.

As part of the concept of All-electric aircraft in 2015 Technodinamika Holding Company presented an innovative product for the world market. The system of movement of the aircraft using the electric landing gear wheels for regional and short-haul aircraft. It allows the aircraft to travel throughout the airport without the use of propulsion engines, which reduces fuel consumption by 4%, reduces engine wear and reduces the risk of engine damage from foreign objects while taxiing. In addition, the system allows aircraft to move in reverse without the use of ground equipment, which significantly reduces waiting time and congestion on the ramps and taxiways of the airports.

E. New Technologies

New technologies usually are attempted for the military aircraft. Civil aircraft programs rely on matured technologies. Some of the new technologies that are being attempted are listed below:

1. More Electric Aircraft (MEA) & All Electric Aircraft (AEA)

The approach to move towards having a single power source, which is electrical, on aircraft, compared to the conventional way of having pneumatic, mechanical and hydraulic power sources also resulted in MEA and AEA. This new technology requires changes in the mechanical systems to take advantage of this approach. For example, the ECS needs to be configured in a bleed less configuration. The FCS has to use electro mechanical actuation in place of hydromechanical actuation. For an oil less engine, electromagnetic bearing technology is looked at. B787 uses electric braking [11]. Another example is the electrically actuated Landing Gear, which is discussed in the following para.

2. Electrically actuated Landing Gear

Electrically actuated landing gear system are either dedicated electrical system or a hybrid mix of hydraulic and electrical system. Dedicated electric actuated landing gear system will include electric actuator to actuate the gear and doors. Also axial flux disk motor/generators replace the old friction disk technology, providing increased braking and maneuvering capability to the aircraft wherein there are many engineering benefits to eliminating the heat generated within friction based braking systems [12].

In addition, the electrical actuation landing gear system will require an Emergency actuation system to extend the landing gear in case the electrical system/actuator failure. The emergency system would mostly be of the mechanical type, with a bowden cable operated by the aircrew that would disengage the clutch in the electrical actuator.

Technodinamika Holding, part of the Rostec State Corporation, is developing the newest electric actuators for use on the MC-21 [13]. This electric actuator will be a dual-channel electromechanical system, in which one channel is active, while the second is in hot standby. An integrated monitoring system continuously monitors the performance of the electric actuator and, if the channel fails, the standby channel will be activated.

3. Wireless sensors

With the number of sensors on each system increasing day-by-day, it makes sense to go in for the wireless sensors to reduce the electrical wiring required for these sensors. These

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sensors could be for the functioning and control of the mechanical system on the aircraft or part of IVHM.

IV. NEW MATERIALS

Newer materials that enhance the performance of the components or reduce the weight or improve the reliability of the system always find their way in to the advances in aircraft mechanical systems. Use of composites for components of LG, ECS and Fuel systems is one such example.

Solutions at Component Level

Systems are made of sub-systems and components. Advances in design and development of these components is an area, always cherished by a designer. Some examples of the advances at component level for various systems are listed below:

A. Cold Air Unit (CAU):

CAU is the heart of the ECS. There are a number of variations like turbo-fan, turbo-compressor, turbo-jet, three wheel, four wheel etc. These machines run at a very high speed (75000 rpm) and need to be highly reliable and efficient. Foil/Air bearings are being employed that will not only improve the performance but also the maintainability and life of the unit.

B. Compact Heat Exchangers (CHE):

CHEs used where ever heat transfer is required. Reducing the weight of these units at the same time increasing their efficiencies is the area in which advances are made. New fin materials and configurations are tested to develop the heat transfer characteristics which are subsequently used in designing these units.

C. Landing Gear Components:

Landing gear is a good places for weight reduction. Landing Gear mechanism predominantly composes of structural components manufactured from Steel, Aluminium, Titanium and other heavy metal. There is very little use of composite, except for brake disks and bay doors. As primary structural elements with concentrated loads, conservative design practice has traditionally dictated metal in these components. One area of aircraft design that continues to elude the composites community, however, is the landing gear.

In the late 90's the use of advanced composites in landing gear components were explored. Carbon fiber composite torque links and trailing arm assembly were developed for helicopter landing gear application [14].

For the Boeing 787 landing gear Messier-Dowty achieved a historical milestone, with the first successful take-off and landing of a commercial flight test aircraft equipped with composite braces on the main landing gear [15]–[18].

The use of composite materials, in conjunction with the expanded use of titanium on other major structural components, including the inner cylinder, significantly reduces the weight of the landing gear versus previous generation steel gears. In addition, composites provide higher resistance to corrosion and fatigue than Ultra High Tensile Strength (UHTS) steel parts, contributing to greater in-service reliability and greater time between overhauls.

The upper and lower torque links weigh 0.12 to 0.13kg (0.26 to 0.28 lb), a 30% reduction compared to a baseline aluminium part. The weight of the optimized composite drag brace was 4.7 kg which is a reduction of 39% in comparison to the steel lower drag brace.

Study of alternative fluids for better damping characteristics in the Landing Gear is another example of advances in this system [19].

D. Fuel System Components:

With the search for alternate fuels, there is always a need to develop/modify the fuel components to make them compatible with the new fuel. Secondly to be compatible with the increasing operating temperatures new materials are to be resorted to for the fuel components. There is an opportunity to use new technologies like smart fuel pump and valves [20]. Magnetoresistive sensors are finding application in fuel gauging. Inline Fuel Properties Measurement Unit (FPMU) is another such advancement in fuel gauging.

E. Hydraulic System Components:

The conventional 20.7MPa (3000psi) hydraulic systems are giving way to higher pressure systems. 55.2MPa (8000psi) systems are under development whereas the system pressures are settling into 34.5MPa (5000psi) [21]. Hydraulic system components consequently advance to these higher pressures. For example to conserve the energy, the pump could be a constant pressure variable pump or a load sensing pump with a power matching circuit [22]. The Elctro-Hydrostatic Actuators (EHA) take the advantage of electrical actuation and distributed power supply with improvements in installation and maintenance.

V. CONCLUSIONS

Aircraft Mechanical Systems are very important for the successful mission of any aircraft as they perform the most critical functions in the operation of the aircraft in flight and on ground. With the total number of components for these systems running in thousands in an aircraft, there are opportunities to better these components and systems. To improve the endurance and reliability of the mechanical system it is important to look for continuous improvement. Reducing the weight and operating to greener requirements are some of the drivers towards improvement. As the aircraft systems are complex and are extremely integrated, a holistic approach is taken to transformation. At a system level/component level, during maintenance activities and also during ground handling, changes are envisaged to meet the goal and the drivers. Rethinking is happening at the very basic level to look for solutions to the vexed problems of greener aircraft. At the same time it is imperative that there should be no compromise on the safety and reliability of the systems. Some of the solutions being put forward, in the competitive multi-supplier environment of aircraft manufacturing, are significant. Looking at the seriousness of the players it is beyond doubt that the aircraft industry and operators will achieve the greener goals.

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