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Conceptual Design of Super-Scooper Fire-fighting Aircraft with Virtual Reality System

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Abstract
At present, aerial fire-fighting through helicopters and small aircrafts with water dumping method has been broadly engaged all over the world, but the crucial issue faced is the limited quantity of water can only be uplifted and sprayed over the wide areas in large forest fires. Also, the time span of aerial fire-fighting is mainly bounded to daytime operations. But moreover, aircrafts can drop huge amount of water compared to helicopters. The sole aim of this paper is to eradicate the problems faced during aerial fire-fighting. This paper discusses about the existing fire -fighting aircraft, our proposed design philosophy, conceptual design, designing of scooping mechanism, propulsion system selection and placement and finally conclusions. Various aircrafts have been employed over the past years for fire -fighting. As per the recent forest reports of the Forest Survey of India 2021, the actual forest cover of India is 21.71% of the geographic area. Only approx. 40 million hectares of forests are well stocked (crown density above 40%). Moreover, the main critical issue is that this resource has to meet needs and demands of a population of 1400 million people and almost 600 million cattles. This is the reason due to which the forests of the nation are therefore, under tremendous pressure. One of the main causes of degradation and declining of forest is unwanted forest fires over wide areas. Thus, India is in immense need of fire fighters to protect its forest areas since the flora and fauna of India is one of the richest of the world.

Keywords: *Aerial fire-fighting, design philosophy, forest fires, conceptual design, forest reports etc.*

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I. INTRODUCTION

Aerial Firefighting is extinguishing of a fire or particularly quelling of a forest fire. Wildfire quelling is a span of ground & air firefighting mission used to quell wildfires, i.e., it's a distinct endeavour from Firefighting efforts in confined townified urban or city territory.

Working with especially designed aerial firefighting aircraft, brushfire firefighting crews on-board multi operational aircraft set up battlefront and extinguish flake to protect natural resources and endangered wildlife. Also, phlogiston reduction labels the region of crowded city areas intersecting with forest areas.

This paper discusses the main significance of using aircraft for fire fighting purposes over helicopters along with the incorporation of virtual reality system. It is designed in such a way that it can solve the problem of multiple reloading of water/fire retardant due to huge storing capacity (5000 gallons)..As a result of this feature, the forest fire can be easily controlled within the stipulated time and reduce the losses of natural resources and wildlives.

II. Literature Review

In a conceptual design like this, it does not even make sense to start designing an aircraft from scratch and do everything on your own. So, we considered and took some of the already existing designs of aircraft that are close enough to requirements and modifications are made to those designs in order to solve today's problem faced during air attack.

So, the comparative study between 3 different Amphibious Fire-fighting Aircraft is done by only considering their characteristics & performance are given below:

2.1.Beriev Be-200

The Beriev Be-200 is a amphibious aircraft designed and manufactured by the Beriev Aircraft Company for several purpose. Introduced as being designed for fire-fighting, search and rescue, cargo transport, and passenger transportation, it has a volume of 12,000 liters (3,200 US gal) of water, or up to 72 passengers.

The basic configuration of the Be-200 amphibious aircraft is intended for fighting the forest fires using water or flake douse agent. A unique character of the Be-200 aircraft, in comparison to other aircraft, is that it has fully pressurized fuselage, which helps to execute many operations. The aircraft is powered by two, over fuselage, pylon-mounted Progress D-436TP powerplant. The D-436TP is a specific "maritime" anti-corrosion model of the D-436 three shaft turbofan powerplant, designed particularly for the Be-200 aircraft, by Ivchenko Progress ZMKB and made by Motor Sich in Ukraine. These are mounted above the wing-root pods on the undercarriage fairings to avoid water spraying into the engines during aircraft maneuvering.

The Be-200 in amphibious water drop fire-fighter arrangement defeat fires by deploying water contained in eight ferric aluminum alloy water tanks, lies below the cabin floor in the center fuselage portion. Four retractable water scoops, two forward and two aft of the fuselage steps, can be used to scoop a total of 12 tonnes of water in 14 seconds. Alternatively, the tanks can be filled from a lake, river or reservoir on the ground. The water tanks can be dispatched quickly for liftng cargo. Water can be discharged simultaneously up to eight drops or all at a time. The aircraft also lift six auxiliary tanks for flake extinguishing chemical agents, with a gross capacity of 1.2 m^3. The aircraft can discharge its water from tanks within 0.8 to 1.0 seconds during flying above the minimum drop speed of 220 km/h in fire zone.

2.2. Canadair CL-215

The Canadair CL-215 is a two engine, high-wing utility amphibious aircraft. It features a unique fuselage design for an amphibian, which is designed to lodge for the missions needs of various roles that the aircraft was developed to carryout. The CL-215 can be used as an aerial firefighting platform, in which capacity it is used as a water tanker; it has been claimed to be the first aircraft designed to bears the severe aerodynamic and hydrodynamic loads caused by such usage. Other than fire extinguishing role, the CL-215 was designed for use in other sector, such as a search and rescue operation, passenger transport, and cargo; for this purpose, the cabin can be configured in many ways, including a flexible combined alignment. Under typical missions, these applications would tack the aircraft's aptness to land and takeoff from the water, the body having been designed to enable its use upon the open seas.

The CL-215 was designed to perform deftly in the airborne fire extinguishing role. The appliance is designed around conventional best concepts and careful design. The aircraft's fuselage can store a pair of 1,400 liters (300 imp gal) water tanks of which large bottom-facing doors forms their downward; these open to quickly dispatch water over a fire zone. These doors are normally hydraulically operated and electrically controlled, but it also can be operated manually at emergency; the water can be discharged simultaneously, individually, or in sequence at the pilot's selection to make tank empty. Both tanks are placed directly upon the aircraft's center of gravity so that admit and discharge of tanks has minimal impact upon the aircraft's flying characteristics. Water can be rapidly drained into these water tanks during the aircraft is moving on water's surface via purpose-built rotatory aluminum scoops; if it collides, these scoops have been designed to fade away from the aircraft without ruining the fuselage. To avoid the tanks from becoming overfilled, overflow ducts are installed at the top of the tanks, which removes excess water through the sides of the fuselage.

2.3.Canadair CL-415

The Canadair CL-415 is an amphibious aircraft designed & manufactured first by Canadair and modified by Bombardier and Viking Aircraft. It is based on the Canadair CL-215 and is designed especially for aerial firefighting; it can execute many other missions, like search, rescue and utility transport.

The CL-415 has an advanced cockpit, aerodynamics upliftment and changes to the water discharging system as well, creating a modern firefighting amphibious aircraft to employ in detecting and extinguishing wild fires. Compared to the CL-215, the CL-415 has payload capacity and speed, yielding improved productivity and overall performance. Due to the boosted power of its two Pratt & Whitney Canada PW123AF turboprop engines, each capable of producing up to 1,775 kW of thrust, these are placed closer to the fuselage in comparison to the CL-215's installation. While this relocating would typically decrease lateral stability on its own, this is concluded via the addition of an inverted fixed leading-edge slat forward of the righthand horizontal stabilizer. Furthermore, winglets have been installed to this model to improve directional stability.

The CL-415 can drawn up to 6,140 liters (1,620 US gal) of water from a nearby water reservoir, mix it with a chemical foam if needed and discharge it on a fire. The CL-415 was specially designed to transport or to deliver large quantities of extinguisher or water in quick response to fires. This is stored within large tanks which are located mostly below the cabin floor within the body, although a header tank above this level is fitted on both sides of the fuselage. Anti- corrosive materials, predominantly treated aluminum are used to build for aircraft reliability and longevity which facilitates its use in salt water too.

The aircraft can also takeoff partial loads in limited areas, and can turn while scooping if necessary. Management of the water discharging system is operated through water status panel on the flight instrumentation, from direct control of the pilots. There is a manually-operated emergency dump lever is also present, bypassing this system in emergency if it fails.

2.4 Water Scooping Challenge:

- ✓ The main design challenge that requires enormous emphasis while designing the scooping technique in fire-fighting aircraft is its short period of scooping time with huge responsibility of scooping large amount of water and storing it in the tank by suction mechanism through powerful pump.
- ✓ The various important parameters that need special attention are appropriate size of scooper and its diameter along with its material selection so as to avoid corrosion.
- ✓ Highly efficient pump, proper design and arrangement for water dropping doors.
- ✓ The pilots should be provided with the prior detailed information regarding the nearby water resources along with the its depth and length for which aerial supervision should be done which is quite challenging.
- ✓ The scooper is to be designed such that it can scoop water from any muddy and polluted water resources containing undesired items which gets filtered and stuck at the inlet of the scooper and later on removed easily.

III. Our Design Philosophy

3.1 FIRE-FIGHTING AIRCRAFT — CHARACTERISTICS REQUIRED

The paramount characteristics of fire-fighting aircraft are as follows:

- ✓ a storage capacity of at least 5000 gallons of water is the minimum for immediate effect;
- ✓ the water/ fire retarding agent should be dropped at a confined pattern
- ✓ three hopper filling systems are required, i.e., a ground- based system, an onboard system and an in-flight system to refill from a water surface;
- ✓ (d)Proper pilot view, mainly ahead and down- wards;
- ✓ wing span needs to be small to decreases the possible effects of vertical turbulent gusts over the flammable area;
- ✓ must have capability to land and takeoff from uneven or unprepared landing fields, leading to the need for aircraft to have a high lift coefficient, a strong undercarriage and large diameter, low pressure tyres.

3.2 Design Philosophy:

This portion explains the design approach we considered and employed. Design objectives are also decided upon after rigorously studying current scenarios as a baseline for decision making.

3.2.1.Design Approach

Systems engineering and design approach was adopted by our team towards this problem since a systemic approach can obtain a solution in which all external systems and their relations are considered in design. Systems design dictates the need to take every manufacturer requirement into account so we aimed to pay attention to **People**, **Profit** and **Planet** aspects of design all together.

Fig: Three main Aspects of design

Considering all of these three parts into account is translated into measuring the impact of decisions on each aspect. Organizations responsible for fire suppression are governmental which means they have limited budgets from taxpayers' money that should be spend effectively and efficiently. They also represent the people and must reduce the risks to safety of citizens and firefighters. Furthermore, the process of fire suppression should be accelerated especially in early phases of fire during the initial attack. Hence, the design must address the **three P's** with an emphasis on Planet since the other two essentially depend on it.

3.2.2Design Objectives

In this section, major design objectives are derived by detailed examination. The reader should bear in mind that all of design objectives are different aspects of sustainability.

a) Design to value

"The sole motive for the design should balance minimizing time to establish a fire line with reducing total ownership cost."

The aforementioned design objective employs an effective tool which concisely expresses the whole idea of DTV (Design to Value), Cost as an Independent Variable (CAIV). This initiative is usually concerned with budgeted programs. This implies that between the three types of constraints on design which are Time, Cost and Quality (TCQ), cost is a fixed and limited parameter amongst all and the rest are to be compromised considering they must satisfy their bottom-line which are the defined measures of effectiveness, performance and suitability.

b) Reliability (Effectiveness)

"Reduce time to establish a fire line …"

"Achieve drop precision adequate to build a fire line of retardant."

"This aircraft should have the ability to function as a water and fire-retardant dispersing aircraft while maintaining a quick turn-around time."

c)Safety

"Wildfire fighting has been extremely dangerous over the past decades."

The impact of uncertainty and risks in wildfire fighting environment are significant. Hence, safety management is of utmost importance. This also can be deduced considering the history of accidents and fatalities; 1.6 accidents and incidents per year and 1.5 fatalities per year. In summary, there have been accidents in 70% of years. Therefore, the implementation of Safety Management is completely necessary. High risk hazards and primary causes for most frequent mishaps are to be addressed and mitigations should be considered in design.

IV. Conceptual Design

4.1. Sensing

Sensing is the act of gathering information (Visual, Thermal, Communications, etc.…) from the environment. This topic describes how the aircraft benefits from Virtual Reality System and embedded cameras to have a precise sensing so it can drop on its own. The table below summarizes the necessary description and placement of the instruments to achieve the sensing requirements

4.2. Prediction of fire behavior

In order to determine the location of the drop, two Infrared cameras are implemented in the nose of the aircraft to map the fire. Hence, with the help of the geological data of the terrain and wind speed and direction, the fire behavior can be predicted by a computer and the optimal location of drop can be realized.

Infrared Cameras	Two installed in the nose making it possible to sweep the ground and pass the visibility pattern of cockpit. one in the middle and two in the aft part, for integration with VR System and fire prediction system
Wind meter	Wind speed and direction is required for of fire rate and direction of spread.
Operational load monitoring system	This system will measure the amount of load experienced by the aircraft in each direction, this will be particularly useful during drop while integrated with the system health monitoring and contingency management system.
Heat sensors	Senses the temperature profile of the fire.
Precise altitude meter	Precise altitude meter is essential for drop in low-level environment.
Weather radar, Radar, GPS, TCAS, Radio	Standard flight instruments necessary for accurate sensing that provide communication with ground and air crew, detection of danger and mid-air collision avoidance and navigation

Table: Sensing Instruments

4.3. Virtual Reality System

The aircraft must be able to drop on its own without the need for a lead plane, presence of an observer will be required in the cockpit who can monitor the fire data. Unfortunately, extra windows cannot be installed in the cockpit as this will greatly increase fatigue. So, for the observer to have an effective view of the fire area, five cameras are embedded in the skin of aircraft providing visual to a Virtual Reality (VR) helmet that is worn by observer(pilot). The virtual reality helmet system of F-35 has proven to be fully operational. So, it is reasonable to assume that the technology can be implemented in our conceptual designed aircraft. The VR system implemented in F-35 has additional capabilities such as 360° view, integration with systems and sensors, night vision, precision tracking of friendly aircraft maneuvering in the area which can also assist firefighting missions. The initial version of this system should be simple enough to provide situational awareness for the observer. Minimum instruments needed for conducting these operations have been described in table above. This system can be advanced further to provide visual for pilot and night vision for night time operations.

V. Design of Scooping Mechanism

5.1. Drop System Design

Drop system is vital part of firefighting mission. From the mission design requirements of drop system is: 5000gallons of water capacity/ fire retardant, slushing resistant, capable of particular in-flow and out-flow retardant rate, capable of separate drops, easy to inspect and detachability **5.2. System Drop Type Selection**
There are several drop systems types, three of them that qualified to be options for decision making are shown in Table below with their pros and cons:

Type	Pros	Cons
3-spherical Containers	✓ No slushing problem.	✓ Problem in manufacturing ✓ Higher cost. ✓ 3 containers will cause more cost. ✓ Cg travel issue with 3 containers.
One trapezoidal container	✓ less manufacturing cost than spherical	✓ has slushing problem. ✓ less precision than spherical.
One cylindrical container	✓ less manufacturing cost then spherical. ✓ more slushing resistance than trapezoidal.	

Table: Pros and cons of each drop system

5.2.3. Conclusion

The final decision has led us to choose one cylindrical container for drop system after going through the pros and cons of various drop system.

5.2.4.Tank Characteristics

In order to find the best geometrical features of the container, two constraints were dominant:

- ✓ Volume needed for retardant, which must be 5000 gallons.
- ✓ A good finesse ratio for the container in order to have a proper finesse ratio for the aircraft.

Checking the suggested values in reference for similar airplanes, the final geometry of the container is shown in Table below:

Length (ft.)	Diameter (ft.)	Fineness ratio
8.5	2.5	3.4

Three entries are designed at the bottom of the container for loading and reloading. With this configuration the container can be loaded with engines on. The middle entry is also used for drop. The container must be pressurized so the drop operation will be more precise and there will be no splashing. Two circular rings with small holes are designed in order to avoid slushing in the container. Two hollow circular rings are also put for further resistance to slushing. The height of the container with all its systems is as high as a normal human body so that eye inspection could be done after each flight. Also, on each side about 1.5 feet is dedicated to let the inspector to walk beside the container and do the inspection. The thickness of the skin of the container is enough to tolerate the pressure that is exerted for drop precision. At the bottom of the container, there are three stands in order to hold the container. The container is built on a surface that allows it to be carried easily and it will be fixed to the bottom of the fuselage by bolts and nuts. So, if any problem occurred during the service, the container could be disconnected and be replaced with a new one in a few minutes.

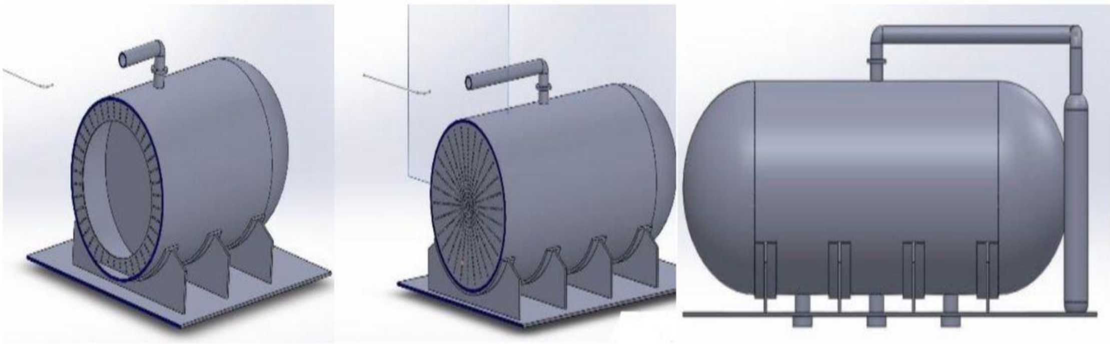

Fig: Three view diagram of tank

VI. Propulsion System Selection and Placement

6.1. Engine Type Selection

Here, the selection of the type of engine is desired (between turbofan and turboprop). To do so, a list of pros and cons has been used.

	Turbofan	Turboprop
Pros	✓ has more propulsive efficiency in higher altitudes than turboprop. ✓ can support high subsonic and even supersonic speeds. ✓ has more Thrust/Weight ratio (Specific Thrust) than turboprop. ✓ can go to higher altitudes than turboprop	✓ better propulsive efficiency in lower altitudes. ✓ better SFC than turbofan. ✓ cheaper than turbofan.
Cons	✓ more expensive than turboprop. ✓ more SFC than turboprop. ✓ more time needed for throttle response than turboprop	✓ needs propellers. ✓ less maintainable than turbofan due to external propeller. ✓ cannot exceed the 360-380 knots max speed. ✓ cannot exceed 27000 ft. altitude. ✓ Propeller torque will endanger stability. ✓ more vibration and a longer shaft with a propeller attached on it will increase Fatigue than turbofan.

Table: Turboprop Vs. Turbofan Pros and Cons

6.2.Engine Placement

In this section the selection of where to put the engine is desired (between Under the wing and Podded beside the fuselage) to do so a table of pros and cons and expert choice has been used. There were more possible options for engine placement like (on the wing, in the wing, …) but after some research, it was obvious that these placement options are not suitable for this purpose so they were eliminated before the final decision between the 2 remaining options (Under the wing, Podded beside the rear fuselage).

	Under the wing (UTD)	Podded beside the rear fuselage (PBTRF)
Pros	✓ Improves the overall aerodynamic efficiency of the wing. ✓ more accessible therefore maintainable than PBTRF. ✓ Good behavior in high AoA's (good for stall). ✓ is prone to pitch up.	✓ will put the exhaust gas directly on horizontal tail (FHQ). ✓ Positive role in Aircraft Longitudinal Stability. ✓ leads to more bending moment which will result in lightening the weight of the whole aircraft.
Cons	✓ makes the wing more complex. ✓ needs a larger Vertical tail and Rudder than PBTRF. ✓ Danger in fire emergency situations in engine.	✓ increase the temperature in the rear fuselage by up to 5 degrees. ✓ makes the Fuselage more complex. ✓ bad for deep stall - will impose a T-tail. ✓ will put the exhaust gas directly on horizontal tail (fatigue).

Table: Position of the Engine Relative to the Wing Pros and Cons

And with the following pros and cons for both of the engine types (Turbofan and Turboprop) it is qualitatively concluded that **turbofan** is better suited for our mission and also with the following pros and cons for both of the engine placement, it is qualitatively concluded that **Under -the wing** option is better suited for our mission.

6.3.Engine Selection

The thrust to weight ratio required for the operation was used to select the turbofan engine that meets the requirements that has been set earlier in the performance sizing.

6.4.Pratt and Whittney 1000G Engine Family

This is the most suitable engine for the fire-fighting mission because the engine:

- ✓ Is 15-16% more fuel efficient than previous versions like IAE V2500 → can save up to $1200000 per aircraft per year.
- ✓ Will cut the carbon emissions by 3600 tons per aircraft per year.
- ✓ Produces 50% less NOx.
- ✓ Produces 75% less noise (increased operations within curfews).
- ✓ Will eventually save more than 20% in total operation cost.
- ✓ Is truly scalable depending on the required thrust 15000 lb. to 40000 lb. thrust.

PW 1200G Series

These series range from 15000-17000 lb. of thrust and are suitable for mission.

Engine	**PW1200G**
Thrust (lb.)	15-17k
Fuel Burn (vs. current engines)	12-15%
Noise (vs. stage 4)	15dB
Emissions-NOx	50%
Fan Diameter (inches)	56
Stage Count	1-G-2-8-2-3
Entry into service	2017

Table: Selected engine performance characteristics

6.5.Derived Characteristics

- ✓ The weight of 81 inches' diameter engine (PW1100G) is 6300 lb.
- ✓ Bypass ratio 9:1.
- ✓ Current Engine SFC's are about 0.35 (V2500) the older version of this engine (similar applications) so it can be derived that this engines SFC ranges between 0.3 to 0.31.

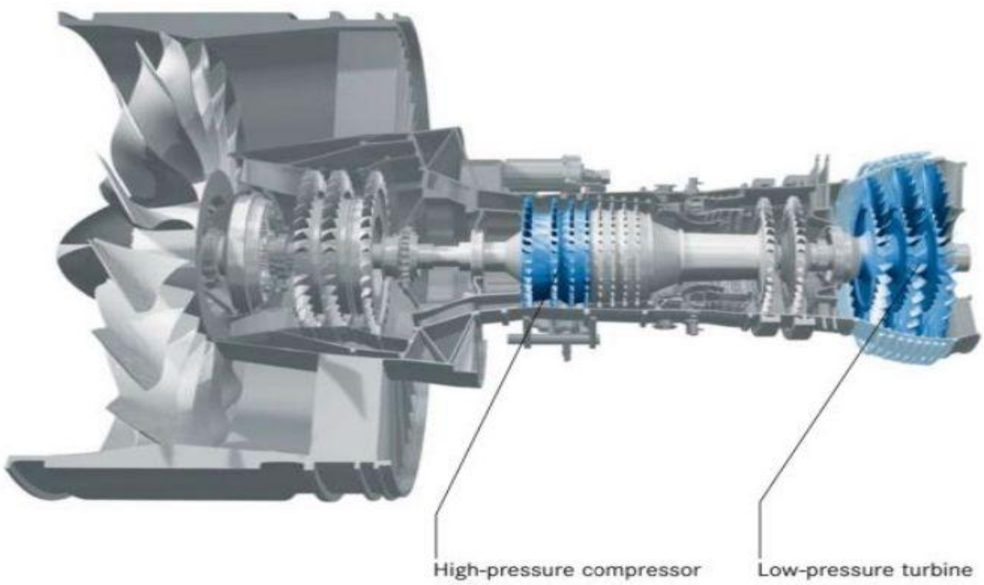

Fig: Engine Cutaway (Source: MTU Aero Engines)

VII. Conclusion

It was observed that the aircraft can carry out the primary mission of ire attack in the most cost-effective and time-efficient manner for a 200km range of operation as per our design requirement. It is being designed in such a way that it will have effective observation capabilities and be agile in gusty and hostile environments such as wildfires in such a way additional aircraft in area for coordination and leading airtankers are no longer needed and the result is saving on expenditures. Thus, the proposed idea of incorporating virtual reality system in this fire fighting aircraft assists tremendously during fire -fighting missions.

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