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Studies on Controllable Aircraft Rescue System for Passenger Aircrafts using Multi Parachutes and Parafoils

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ABSTRACT:

Loss of lives due to fatal air accidents is an alarming problem faced by the aviation industry. There have been 88 fatal air accidents in the years 2010-2014 according to the IATA safety report. This clearly exhibits the fact that the present safety systems in aircraft are inadequate to save lives during mid-air emergencies. This paper presents a feasible solution to this problem with the use of controllable aircraft rescue system "CARS" involving the use of parachutes and parafoils. Parachutes are placed at the center, nose and tail sections of the aircraft which when deployed during a mid-air emergency to decrease the sink rate, provides stability and much-needed lift to the aircraft. Parafoils are attached to the wings of the aircraft through the fuselage which when deployed provides the much-needed control and enables safe navigation of the aircraft. Floats are provided at the bottom of the fuselage to reduce the force at impact in case of touchdown and also increase the time for which the aircraft can stay afloat in case of water landing. An analysis is performed to determine the size and diameter of parachutes required for aircraft of varying weights. The time of descent of the aircraft with parachutes from various altitudes is also determined. These results are summarized to exhibit the feasibility of the system.

KEYWORDS:

Aircraft stability; Center of gravity; Control; Stability; Parachutes; Parafoils; Aircraft rescue system

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1. Introduction

Aviation experts claim air travel to be one of the safest modes of transportation. Yet, accidents are happening, which makes it difficult to claim that air travel is safe [1]. A Dornier aircraft of the coastguard went missing with a 3-member crew on June 8, 2015, during a routine surveillance mission off the Chennai coast [4]. The coast guard recovered the black box from its crash site located at a depth of 996m and 16.5 nautical miles off the coast of Pichavaram in Cuddalore district [5]. This is the second crash involving a Dornier aircraft preceding the crash off Goa coast killing two of the three crew members [6]. Reducing fatalities is the main aim of any aircraft rescue system. The current system used in small aircraft is the ballistic recovery system [7], which involves the use of a single parachute deployed from the center of the fuselage. The parachute is placed at the rear end of the aircraft and connected with the help of a cable to a handle in the cockpit.

On encountering mid-air emergencies like an aerodynamic stall, a structural failure or mid-air collisions, the parachute is deployed with the help of a solid rocket. The parachute on deployment reduces the sink rate and decelerates the aircraft thus enabling its touchdown. Currently, ballistic recovery systems are working with the National Aeronautics and Space Administration (NASA) to design a new generation of emergency parachutes that could be steered by pilots as they drift to the ground [8]. This system if implemented in a Boeing 747 will require a parachute weighing hundreds of tons. This would result in losing a very large amount of the airlines payload. Moreover, the force of impact at touchdown is equivalent to the force experienced when jumped from a 4-meter tall ledge [9], which can and has caused injuries to passengers. CARS is free of all these drawbacks. Parachutes are placed on the nose, tail, and central fuselage section of the aircraft allowing load distribution and reducing the size of parachutes required.

The parachutes also provide stability and enable deceleration of the aircraft. Parafoils are placed on the rear and are connected to the wings from the fuselage using high strength cables enabling control over the 3 basic movements of the aircraft namely pitch, roll, and yaw. These parafoils are controlled with the help of electric motor arrangement [10]. The high impact at touchdown is reduced in CARS with the help of floats installed below the fuselage and will be deployed as the flight touches down. In the case of water landings, this float will enable the aircraft to stay afloat without sinking for a longer time thus allowing easy evacuation of passengers.

2. Concept

CARS provide stability and control to an aircraft during mid-air emergencies. This is achieved by using 3 parachutes; one placed at the center of gravity (CG) point, one at the nose and another at the tail section of the aircraft. During emergencies, the parachute at the CG point is deployed first followed by the ones at the nose and tail sections. This reduces the sink rate and helps in gaining much-needed lift thus stabilizing the aircraft. Following the deployment of all the parachutes, the parafoils placed at the rear and those attached to either wing are deployed. These mainly simulate the three basic movements of the aircraft namely yaw, roll and pitch. By adjusting the parafoils placed at the rear of the aircraft, the nose pointing (left/right) of the aircraft, i.e., the yaw movement can be controlled. By adjusting the parafoils over the wings, the roll can be controlled. With appropriate electric motor arrangements, the parafoils on the wings can be adjusted such that lift on one wing is increased which initiates a bank and consecutively roll. This operation enables turning of the aircraft. By adjusting the parafoils on the wings and at the rear, pitch movement can also be controlled allowing controlled descent. The block diagram shown in Fig 1 represents the clear understanding of CARS.

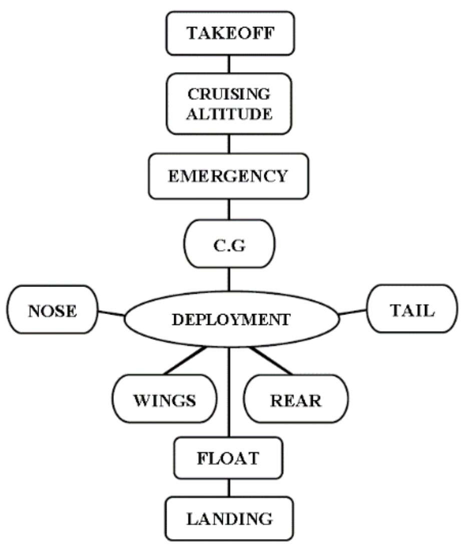

Fig. 1: Block representation of CARS

3. Construction and deployment

CARS makes use of 3 parachutes and 3 parafoils. Parachutes are placed at the CG point, nose and tail sections of the aircraft. Parafoils placed in the fuselage are connected to either wing using high-strength cables. The central parachute is deployed first followed by the chutes at the nose and tail sections. These provide stability and reduce the descent velocity of the aircraft. The parafoils at the wings are mainly used for roll control and those on the rear are used for yaw control. The parachutes and parafoils are interconnected in order to enable easy deployment. The central parachutes are deployed with the help pilot parachute mechanism [11]. On encountering a mid-air emergency, the parachutes and the parafoils are deployed. These are not deployed at a stretch but rather in stages. These stages are as follows:

- 1: Deployment of center parachute: A pilot parachute is used to deploy the center parachute. The pilot chute uses drag force it creates in the main stream to deploy the main chute. The central parachute uses 2 stages for deployment as it enhances stability.
- 2: Deployment of parachutes at nose: On deployment of parachutes at the center, the aircraft has its sink rate reduced and experiences lift. But it is not completely stable. To enhance its stability the parachute at the nose is deployed which improves the stability.
- 3: Deployment of parachutes at the tail: After the parachutes at the center and nose section are deployed, the aircraft attains a certain level of stability. To improve its stability further, the parachute at the tail section is deployed. After this stage, the aircraft attains complete stability.
- 4: Deployment of parafoil on the wings: The parafoil on the left and right wings are deployed at this stage. These are mainly used for control of roll movement thus substituting the function of ailerons.
- 5: Deployment of parafoil at the rear: This parafoil at the rear is deployed finally, which is mainly used for yaw control thus substituting the operation of the rudder. The pitch control is obtained by using the same principle as that of elevators.

4. Working

The parachute deployment is done manually with the help of a button in the cockpit, during mid-air emergencies like mid-air collisions, structural failures or aerodynamic stalls, which has to be pressed by the pilot on doing which the central parachute is deployed first. This deployment system can also be made automated such that it deploys automatically without human intervention based on particular values of altitude. The central parachute placed at the CG point is first deployed using pilot parachute mechanism, which involves the use of a pilot parachute, which brings out the main parachute as shown in Fig. 2. The pilot chute, about a quarter the size of the main chute, is small enough that it can be released at the high speeds without producing large shock forces. The pilot chute then helps to decelerate the fore body while pulling out the main chute so that when the main canopy opens the speed is slowed enough such that shock forces are significantly reduced. The pilot chute uses the drag force it creates in the free airstream to deploy the main chute. The central parachute is a 2 staged parachute with 2 canopies. On deployment of this parachute, the aircraft experiences a decrease in its sink rate and also experiences lift. But the aircraft isn’t completely stable. The parachute at the nose is now deployed to improve the pitch of the aircraft. The parachute at the tail is then deployed to further stabilize the aircraft. This addresses the stability problem.

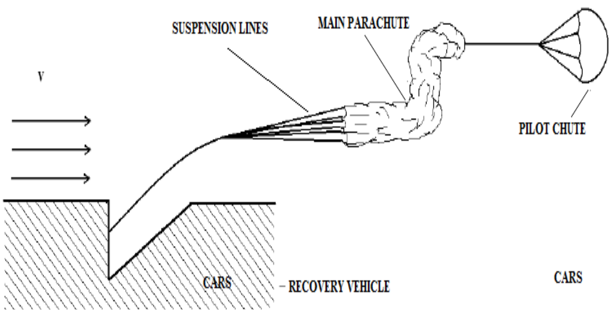

Fig. 2: Pilot chute mechanism

The parafoil attached to the wings from the fuselage is now deployed followed by the parafoil at the rear of the aircraft. The parafoil on the wings is used for roll control. To do this the angle of attack is to be varied in order to increase or decrease lift over the wing. This is done with the help of parafoils by adjusting the toggles of the parafoil. Pulling it down or up will change the airflow over the airfoil thus increasing or decreasing lift and helping roll control. Similarly, the parafoil at the rear will also be adjusted. On pulling the toggle the amount of lift generated is varied thus generating yaw movement. These parafoils are controlled by an electric motor arrangement which controls the toggle movement thus enabling control. All the parachutes and parafoils are interconnected which enables easy deployment of each without the need of any additional deployment mechanism for all except the central parachute.

5. Analysis

This analysis aims at determining the size, diameter of the parachutes required for aircraft of different weights and seating capacity. The descent velocity for their corresponding values and the time taken for a touchdown of the aircraft is also determined [2-3]. The formulae used for the analysis are as follows,

Size of chute - $S = (2 * g * m)/(\rho * c_d * v^2)$

Diameter of chute - $d = \sqrt{(4 * S)/\pi}$

Time - $t = D/v^2$

Where, G - Acceleration due to gravity (9.8m/s), M - Mass of payload (aircraft), Cd - Coefficient of drag (0.75), P - Density of air (1.225kg/m3), S - Size of parachute required, v - Descent velocity of parachute payload system and D - Altitude of the aircraft at deployment stage. The time taken for aircraft to a touchdown for corresponding values of descent velocity from various altitude levels has been determined and given in Table 1. As the descent velocity increases, the time to touch down is decreased.

Table 1: Time taken for touch down vs. Descent velocity

Descent velocity (v) in m/s	Time taken to touchdown from (min) 9200m	6100m	3100m	1500m
3	51	34	18	08
5	30	20	11	05
10	15	10	05	2.5
50	3	02	01	0.5
100	1.5	01	0.5	0.25
300	0.5	.3	0.2	0.1

Fig. 3 shows the time for a descent velocity of 10m/s vs. the altitude of descent. The time taken for descent is maximum for higher altitudes and decreases with respect to altitude. This graph is plotted without weight being taken as a factor. This analysis thus determines the size and diameter of parachute required for aircraft of different weights.

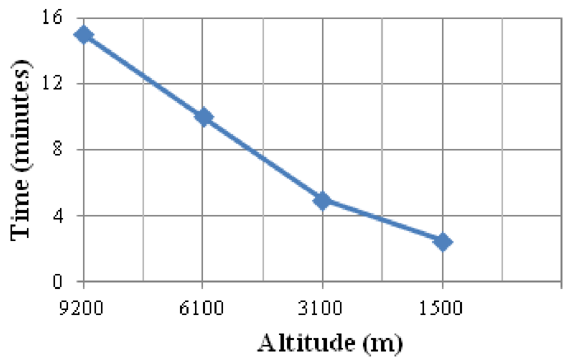

Fig. 3: Time of descent of aircraft at 10m/s from various altitudes

5.1. Airbus A330-203

Based on the specifications of maximum take-off weight – 230 tonnes and maximum operating altitude - 41000ft, the size and diameter of the parachutes required are determined for various values of descent velocity and given in Table 2. The weight of the aircraft is distributed such that 50% of the load is shared by the center, 30% of the load by the nose and 20% of the load by the tail parachutes respectively.

Table 2: Area of parachutes required for Airbus A300-203

Descent velocity v (m/s)	Center shares 50% load $S(m^2)$	d(m)	Nose shares 30% load $S(m^2)$	d(m)	Tail shares 20% load $S(m^2)$	d(m)
3	272592.6	589.3	163555.6	456.4	109037	372.7
5	98133.3	353.6	58880	273.9	39253.3	223.6
10	24533.3	176.8	14720	136.9	9813.3	111.8
50	981.3	35.3	588.8	27.4	392.5	22.4
100	245.3	17.7	147.2	13.7	98.1	11.2
300	27.2	5.9	16.3	4.6	10.9	3.7

5.2. Airbus A320-216

Based on the specifications of maximum take-off weight – 64.5 tonnes and maximum operating altitude - 39000ft, the size and diameter of the parachutes required are determined for various values of descent velocity and given in Table 3. The weight of the aircraft is distributed amongst the parachutes in the same manner as considered for Airbus 330-203.

Table 3: Area of parachutes required for Airbus A320-216

Descent velocity v (m/s)	Center shares 50% load $S(m^2)$	d(m)	Nose shares 30% load $S(m^2)$	d(m)	Tail shares 20% load $S(m^2)$	d(m)
3	76444.4	312.1	30577.8	197.4	45866.7	241.7
5	27520	187.2	11008	118.4	16512	145.03
10	6880	93.6	2752	59.2	4128	72.5
50	275.2	18.7	110.1	11.8	165.12	14.5
100	68.8	9.4	27.5	5.9	41.28	7.2
300	7.6	3.1	3.05	1.9	4.6	2.4

5.3. Bombardier CJ200LR

Based on the specifications of maximum take-off weight – 24.041 tonnes and maximum operating altitude - 12,496ft, the size and diameter of the parachutes required are determined for various values of descent velocity and given in Table 4. The weight of the aircraft is distributed amongst the parachutes in the same manner as considered for Airbus 330-203.

Table 4: Area of parachutes required for Bombardier CRJ200LR

Descent velocity	Center shares 50% load		Nose shares 30% load		Tail shares 20% load	
v (m/s)	S(m^2)	d(m)	S(m^2)	d(m)	S(m^2)	d(m)
3	272592.6	589.3	163555.6	456.4	109037	372.7
5	98133.3	353.6	58880	273.9	39253.3	223.6
10	24533.3	176.8	14720	136.9	9813.3	111.8
50	981.3	35.3	588.8	27.4	392.5	22.4
100	245.3	17.7	147.2	13.7	98.1	11.2
300	27.2	5.9	16.3	4.6	10.9	3.7

6. Case studies

6.1. Structural failure

Japan airlines flight 123 - This is the deadliest single-aircraft accident in history. Japan airlines flight 123, a Boeing 747SR-100, was a scheduled flight from Haneda airport Tokyo to Osaka international airport Itami. This flight crashed on the 12th August 1989 due to in-flight structural failure [11]. The flight had 509 passengers and 12 crew members aboard out of which 4 passengers survived and 520 lives perished.

- Problem: The rear pressure bulkhead tore open due to incorrect repair. Pressurized air rushed out of the cabin blew off the vertical stabilizer from the plane along with all 4 hydraulic lines out. This resulted in the loss of non-functional control surfaces and lack of stabilizing support from vertical stabilizer [12].
- Solution: This deadliest air crash could have been averted using CARS. Japan airlines flight 123 stayed in the air for 32 minutes before it crashed. On encountering structural failure, the parachute at the center could have been deployed followed by the parachutes at the nose, tail sections and the parafoils at the rear and wings. The parachutes at the center, nose, and tail provide stability. The parafoil at the rear substitutes the function of vertical stabilizer for yaw control and the ones on the wings for the roll control thus keeping the aircraft under control and perform a safe landing, which would have saved lives.

6.2. Mid-air collision

Überlinger mid-air collision - this incident was a mid-air collision that happened on 1st July 2002 involving a Bashkinian airlines 2937, a Tupolev-Tu-154M, flying from demanded one international airport, Moscow, Russia carrying 60 passengers and 9 crew members to Barcelona international airport, Barcelona, Spain and DHL cargo flight 611, a Boeing 757-23APF, flying from Bahrain international airport heading to Brussels airport, Brussels, Belgium carrying two crew members. The collision resulted in the loss of lives of all the passengers and crew of both the aircraft [12].

- Problem: This accident was a case of mid-air collision due to communication technology deficiencies [12] that resulted in disaster and loss of lives. The Bashkinian airlines 2973 and DHL flight 611 collided at right angles at a height of 34, 890ft [13]. Bashkinian 2973 exploded and the DHL's vertical stabilizer was sliced completely. The 611 lost 80% of a stabilizer and struggled a 7km before crashing.
- Solution: CARS has the capability to save lives in this case. The 2 crew members of DHL flight could have been saved. Using this system, on the loss of vertical stabilizer, the rear parafoil would have substituted for yaw control and the parachutes from the center, nose and tail section would have provided stability to the aircraft. The parafoil on the wings would have provided control over roll movement thus enabling a controlled descent.

6.3. Aerodynamic stall

Air Asia flight QZ8501 - this was a scheduled international flight from Surabaya's Juanda international airport in Indonesia to Changi international airport, Singapore. This aircraft, an Airbus A320-216, crashed on the 28th of December 2014 into the Java sea claiming the lives of 155 passengers and 7 crew members [13]. The investigation has revealed that the flight crashed due to rudder travel limiter failure and inappropriate pilot response, which resulted in a stall, which was beyond recovery [13].

- Problem: A tiny soldered electrical connection was found to be cracked in 2 of the rudder travel limiter units which resulted in sending 4 warning signals to the pilots. The crew's attempt to fix the problem by resetting the flight management system disengaged the autopilot. Further miscommunication between the crew caused the aircraft to enter a prolonged stall beyond the capability of the flight crew to recover [14].
- Solution: Using CARS, on encountering warnings and realizing that the autopilot has been disengaged and that attempts to fix the problem are failing, the parachutes at the center section and the parafoil at the tail section can be deployed which would enable in decreasing the angle of attack to a healthy value thus enabling stall recovery.

6.4. Pilot error

Air France flight 447 - An Airbus A330-203, was a scheduled passenger flight from Galeão airport, Rio de Janerio, Brazil to Paris Charles de Gaulle, France, which crashed on June 1, 2009, killing 216 passengers and 12 crew members. The investigation revealed the cause of the crash to be due to the incorrect reaction of the crew, which ultimately led the aircraft to an aerodynamic stall from which they never recovered [14]. This accident was the deadliest in the history of Air France [15].

- Problem: The aircraft's pilot tubes were obstructed by ice crystals which resulted in temporary inconsistencies in the measured airspeed. This resulted in the disconnection of the autopilot and a reconfiguration to alternate law. Without the autopilot, the aircraft began to roll right due to turbulence. The pilot reacted by deflecting the side stick to the left. At the same time, the pilot made an abrupt nose up input on the side stick, an unnecessary action. This resulted in the aircraft entering into an aerodynamic stall which the crew never diagnosed and never took any action to recover [15].

- Solution: CARS, on being automated such that it deploys automatically on reaching an altitude, which is considered dangerous, would have saved Air France flight 447. On reaching that particular altitude, the parachutes and parafoils would have been deployed. This would have helped in decreasing the sink rate thus giving a safe touchdown. The floats provided would have helped in keeping the aircraft afloat for long in the Atlantic Ocean thus saving lives.

7. Advantages of CARS

- Load distribution: CARS uses 3 parachutes instead of one which allows load distribution thus enabling its use in larger aircraft as the weight is distributed equally among all parachutes.
- Control: The parafoils placed at the rear and wings enable roll, yaw and pitch control thus allowing control and navigation of the aircraft.
- Sink rate: This system decreases the sink rate thus increasing the time in the air and giving the pilot time to take the next step.
- Cost: CARS uses pilot parachute mechanism to deploy the parachute, which is a cheap method and thus reduces cost.
- Floats: The use of floats placed at the bottom of the fuselage helps in reducing the force at impact and also helps in keeping the aircraft afloat in case of a water landing. The reduced force at impact reduces the injuries caused to passengers due to the high impact force.
- Stability: The use of 3 parachutes increases the stability of the aircraft.
- Weight: The use of 3 parachutes reduces the weight of each parachute and so reduces the weight of the entire system.

8. Conclusion

CARS, when put to effective use, can be used to save the lives of passengers and avert major air accidents. An analysis has been performed to determine the size and diameter of parachutes required for aircraft of different weights. The time of descent of the aircraft with CARS is also determined. This supports the fact that this system can be implemented as an additional safety feature, which can be used in cases of mid-air emergencies. Nature’s fury cannot be controlled by any man-made technology. The same also applies to CARS. Thus, CARS has been proposed as a precautionary system, which is not answerable to nature’s fury.

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