Aircraft Disaster Management in Gujarat Using Geographic Information System

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***Abstract*— Among various disasters, aircraft disaster is considered to be one of the deadliest disaster. Search and Rescue (SAR) operations play a vital role at the time of disaster. Reducing the search area, decreasing the reach time and following the optimal route to reach the crash site are some of the important factors to enable the SAR team to save more lives in the accident area. Using the laws of projectile motion combined with the force due to air drag we can approximately predict the possible area of crash of the aircraft in order to find the wreckage and the approximate time of the plane to reach the ground. Additionally, Geographic Information System (GIS) helps to identify the area of the wreckage, generates a probability map with probable location of the crash, suggest the optimal route to reach the crash site and help to assist the ground crew – for example, district administration, hospitals, police, NGO's etc in the vicinity of the crash site. The scope of the present study is aimed at an aeroplane under cruising experience failure due to structural or engine malfunction. We apply differential equation and formulae to analyze the situation in four different hypothetical cases considering the Gujarat state, India and suggest ways and means for SAR operations.**

***Index Terms*: Air drag, search and rescue operations, Geographic Information Systems, plane crash, Gujarat, India.**

I. Introduction

Across the world, more and more people are taking air travel. This rapid increase is because of 10.5% improvement in fuel efficiency and 56% increase in labour productivity. During the course of 2011, airlines around the world have carried a total of approximately 2.7 billion people. It is an increase of 5.1% compared to 2010. India's strong economic growth has boosted the market in many fold for air travel. Flying became affordable in India. The number of people travelling by air is nearly equal to the number of people travelling by train on a day [1]. There are six to seven million air passengers in the country. This number may raise by tenfold in five years. India has witnessed over 25 percent increase in air traffic in the last two years.

There has been a considerable increase in plane crashes across the world. The recent MH370 plane of Malaysian airlines has astonished the whole world is a classic example in this direction. During 1999-2011, the number of accidents across the world was 2,179 and number of deaths was 17,928.

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Table 1-a, 1-b provide general information about the accidents due to air crashes. This excludes the accidents due to helicopters, fighter planes, balloons etc. Table 1-a shows the number of accidents and number of deaths during 1999-2011 across the world. Table1-b provide date of accidents and number of deaths in India for major accident.

Year	**Deaths**	**Number of accidents**
2011	828	117
2010	1,115	130
2009	1,103	122
2008	884	156
2007	971	147
2006	1,294	166
2005	1,459	185
2004	771	172
2003	1,230	199
2002	1,413	185
2001	4,140	200
2000	1,582	189
1999	1,138	211
Total	17,928	2,179

Table 1-a: Aviation accidents of aircraft capable of carrying more than six passengers (not including helicopters, balloons, or fighter airplanes) across the world

Year	**Deaths**	**Date**
1962	94	Jul 7
1978	213	Jan 1
1982	17	Jun 21
1988	124	Oct 19
1990	92	Feb 14
1991	69	Aug 16
1993	55	Apr 26
1996	349	Nov 12
2000	60	Jul 17
2009	211	Sep 4
2010	158	May 22
Total	1,252	

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Table 1-b: Major Commercial jet aeroplane accidents and deaths in India with dates.

In any type of disaster, search and rescue (SAR) operations play a vital role. Search time and area are the two most important factors for any SAR team. Decreasing the search time and narrowing down the search area increases the chances to rescue the survivors after any aeroplane crash. It an aeroplane at its cruising altitude loses its contact with air traffic controller and is on the verge of an accident, the trajectory path and time taken by the aeroplane to reach the ground can be approximated with the help of projectile formulae combined with force due to air drag. The parameters such as relative velocity with respect to air, altitude at which the airplane is cruising, structural parameters like weight, drag coefficient etc are known. These parameters are readily available with the air traffic controller monitoring the airplane.

The minimum time taken by the plane to reach the ground can be approximately calculated with the projectile motion equation along the airplane direction. The distance covered by the plane in horizontal direction is calculated by substituting the minimum time obtained in the horizontal projectile motion equation. The results include minimum time taken by the plane to reach the ground, minimum and maximum horizontal distance it can travel is calculated by making the following assumptions:

a) all the driving forces (thrust) acting on the airplane at the last known co ordinates are taken as zero, indicating structural and engine failure condition of the plane.

b) since the airplane is in cruising condition the component of velocity along the vertical direction is considered to be zero.

c) change in the density of air and acceleration due to gravity with altitude are neglected and taken to be constant.

d) gliding of the aeroplane not considered.

The results obtained from the formulae are visualised using Geographic Informative System (GIS). GIS enables us to generate probability maps, connects the results such as minimum and maximum horizontal distance obtained from the formulae with real time Earth co-ordinate system. As discussed earlier, it helps find to an optimal route to reach the determined area.

Thus SAR teams can make an effective and efficient search with the ultimate goal of saving the lives in a relatively short period of time. Once the map shows the probable area of crash site, the nearby helping ground crew such as district head quarters, hospitals, police stations, N.G.Os etc can be alerted. This way there will be less wastage of time, narrowing down the time in search efforts.

II. SCOPE OF STUDY

As per the International standards and recommended practices, (1994) an aviation accident is defined as an occurrence of an event associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of travel in the flight until such time all such persons have disembarked. The accident can happen to a person, who may fatally or seriously injured, or the aircraft may sustain damage or experience structural failure or the aircraft may miss or completely inaccessible to the control room.

Between the time a passenger boards the plane and the time he/she disembarks, there are six distinct phases involved by the aeroplane during the air travel. They are described in the following steps

a) Taxi: It is the first and the last stage. In this stage the aircraft reaches the runway, or it parks near to the gate after landing.

b) Take off and initial climb: The aircraft accelerates, lifts off and starts climbing.

c) Climb: The pilot retracts the slats/flaps, and the aircraft climbs until it reaches cruise altitude.

d) Cruise: The aircraft flies at a more or less constant altitude and this is generally the longest phase of the flight.

e) Descent and initial approach: The aircraft descends to get closer to its destination airport. Air traffic control may request the aircraft to loiter for a while and wait till its turn come for the next phase.

f) Final approach and landing: The aircraft, in landing configuration aligned with the runway axis, approaches the runway threshold, then lands and slow down. [10]

In figure 1 all the six phases of the aircraft is presented along with the time duration for each phase for an estimated flight time of 1.5 hours. On board fatalities and fatal accidents for each phase are also presented in terms of relative percentage value. In the same figure, it is interesting to see that there is maximum percentage (21%) of on board fatalities during the cruise stage. The percentage of fatal accidents and onboard fatalities of worldwide commercial jet fleet from 2001 to 2010 are also shown at the bottom [11]

(Source: http://www.boeing.com/news/techissues/pdf/statsum.pdf)

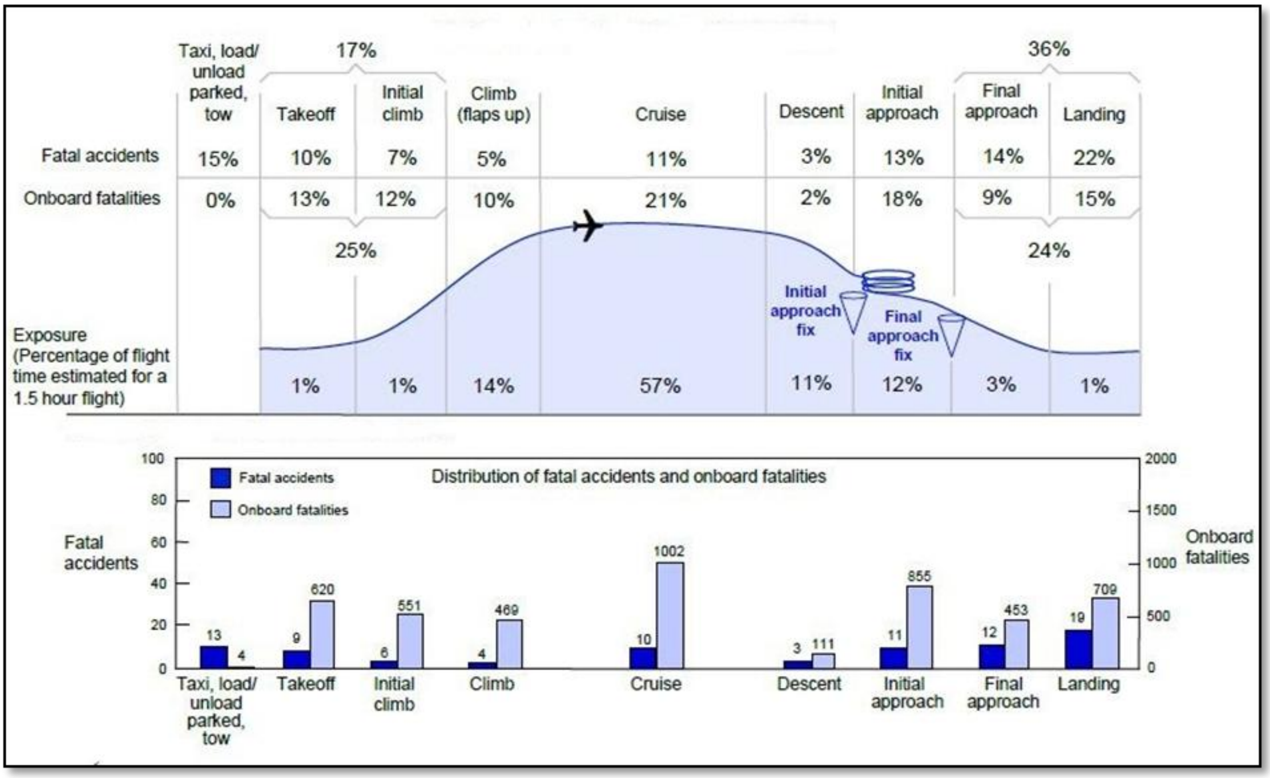

Fig. 1: Percentage of time spent in each phase on an average of 1.5 hours of flight time Fatal accidents and Onboard fatalities during each phase of plane from 2001-2010

Between 2001to 2010 there are 10 major accidents and 1002 onboard fatalities (figure 1) during the aeroplane under cruising phase. There are many reasons for an aircraft accident to occur. This includes fuel tank explosion, mid-air collision, uncontrolled decompression, controlled flight into terrain, engine and structural failures. The present study focuses on the condition where a passenger plane under cruising condition undergoes an engine malfunction or structural failure. Under these conditions the driving force acting on the plane becomes zero and so the trajectory of the plane can be calculated using the laws of projectile motion with and without considering the force due to air drag.

III. STUDY AREA

Our present analysis of events are focused on Gujarat state, India. It lies approximately between longitude 68°04'-74°04' E and latitude 20°01'-24°07' N and is bordered by Rajasthan to the north, Maharashtra to the south, Madhya Pradesh to the east, and the Arabian Sea as well as the Pakistani province of Sindh on the west covering an area of 1,95,984 square kilometres . There are ten airports in Gujarat, one of which is an international airport. Fleet acquisition activities and fleet size of all domestic airlines are around 300 aircrafts per month. Present study enables to find the wreckage area during an airplane disaster at anyplace inside the study area.

IV. CONVENTIONAL METHOD

406 MHz Emergency Location Transmitters (ELT): Emergency Locator Transmitter (ELT) is a compact, self contained radio transmitter carried on board airplanes to facilitate accurate location and timely rescue operation in an event of any distress situation. COSPAS-SARSAT is a worldwide SAR system, initially launched by Canada, France, Russia and the US in 1979. The number of member states of the organization has grown to 42 as on February 2010. This SAR service in India is organized by the Airports Authority of India in collaboration with the Ministry of Defence. The area of responsibility extends over the entire Indian territory as well as airspace over high seas encompassing FIRs of Chennai, Kolkata and Mumbai. In addition to the Armed Forces with Indian Coast Guard, all Central and State Government departments, district administration, civil organizations and other may also use the SAR. [8]

COSPAS-SARSAT, is a search and rescue satellite system that locates the emergency radio beacons transmitting signals at 406 MHz. It finds the location of crash site by transmitting the beacon's signal to its ground control station. This method of tracking an aircraft has many disadvantages as mentioned below

1. SAR response to anonymous beacons and can be delayed 4–6 hours, and in some occasions as much as 12 hours tacking people life at risk.

2. The information transmitted by the beacon is an unique siren tone of 15, 22, or 30 digit serial number called a hex-tone which cannot be recognised until the personnel plane and owner details are known.
3. The transmitting power of the beacons is 0.1 W continuous weak signal. This cannot usually penetrate debris or trees. It is untraceable when stuck in extreme terrain conditions .[11]

The present model gives the location of crash site within a few seconds with accuracy making this system more reliable when compared to the existing conventional SAR method.

V. ESTIMATION OF APPROXIMATE MINIMUM, MAXIMUM DISTANCE AND TIME USING LAWS OF PROJECTILE MOTION

A. Horizontal projectile motion formulae without air drag to calculate maximum distance

Laws of projectile motion are well established. These projectile formulae are generally used to calculate the horizontal distance and time taken by a body when projected from a certain height with a certain velocity. The variation in vertical and horizontal distances with respect to time can be calculated with the help of the formulae given below.

$$y = \frac{1}{2}gt^2 \qquad \text{-----(1)}$$

$$x = vt \qquad \text{------(2)}$$

y=vertical distance (height)
x=horizontal distance (range)
v=Horizontal component of initial velocity
t=time taken to reach the ground
g=acceleration due to gravity

Assumptions such as considering the body to be a point object with unit mass, neglecting resistance due to air will not affect the trajectory of the body when it is of small size, projected with lower velocities. In case of large bodies like aircraft moving with high velocity this assumption will lead to large error while calculating the horizontal distance. Force due to air drag depends upon the size, velocity and geometrical parameters of the body. This need to be taken into consideration to impose the laws of projectile motion on an aircraft. Equation 1 and equation 2 are used to calculate the maximum theoretical horizontal distance the airplane can travel when the plane encounters engine or structural failure.

B. Force due to Air Drag

Air drag refers to forces that act on a solid object in the direction of the relative fluid flow velocity. Drag force always decreases the solid velocity relative to the fluid along the path. The drag equation calculates the force experienced by an object moving through a fluid with relatively large velocity [12]. The force on moving object due to fluid [3] is

$$F_d = 0.5\rho v^2 c_d A \qquad \text{-----(3)}$$

F_d =Force of drag
ρ= Density of fluid
v = Relative velocity
C_d=Drag co-efficient
A=Reference area

C. Differential equation

Since the driving force acting on the aircraft along horizontal direction is assumed to be zero, there will be only a force due to air drag along horizontal direction acting opposite to the relative motion of the aircraft. We derive a differential equation for the projectile motion using the formula F=ma. This includes the forces due to air drag along x and y direction.

$$m\begin{pmatrix} v'_x \\ v'_y \end{pmatrix} = \begin{pmatrix} 0 \\ -gm \end{pmatrix} - \begin{pmatrix} Dv_x{}^2 \\ Dv_y{}^2 \end{pmatrix} \qquad \text{-----(4)}$$

m=mass of the body
v_x= velocity along horizontal direction
v_y= velocity along vertical direction
g= acceleration due to gravity
$D=0.5\rho C_d A$ -----(5)
ρ= Density of air at cruising altitude
v = Relative velocity
C_d=Drag co-efficient

During cruising conditions the velocity along the horizontal direction is taken as =V and along vertical direction it is considered to be zero, =0. Taking these as boundary conditions and integrating the differential equation 4 along horizontal (x direction) and vertical (y direction) directions, the following two equations are obtained

$$Vx = \frac{v}{v\partial t+1} \qquad \textbf{-----(6)}$$

Where,
V_x=velocity along horizontal direction (ms^{-1})
δ=co efficient of air drag per unit mass (m^{-1})
v=Initial Velocity along horizontal direction (ms^{-1})
t= time taken to reach the ground (s)
and

$$Vy = \sqrt{\frac{g}{\partial}} \tanh\left(\sqrt{g}\, t\right) \qquad \text{------(7)}$$

where,
V_y=velocity along vertical direction
g=acceleration due to gravity

D. Vertical distance

Since velocity is the only variable and all other parameters are constants, integrating the velocities with the initial boundary conditions will result in time dependent equations of horizontal and vertical distance. On integrating the equations 6 and equation 7 with respect to tim the following formulae are obtained

$$y = \frac{1}{\partial} ln\left|\text{sech}\left(\sqrt{g\partial}\ t\right)\right| \qquad \text{------(8)}$$

$$x = \frac{1}{\partial} ln|v\partial t + 1| \qquad \text{------(9)}$$

Where,
y=vertical distance (altitude where plane is cruising)
v=initial horizontal velocity at altitude y
x=horizontal distance

It the cruising altitude(y) at the last known co ordinates are known, the minimum time taken by an airoplane can be calculated using equation 8 and the time estimated is substituted in equation 9 to get the minimum horizontal distance the airplane can travel under the specified condition.

E. Trajectory of the aircraft with and without Air drag

Force due to air drag acts against the relative motion between the aircraft and the air medium. The horizontal distance travelled by the plane will be less as compared to the condition it the air drag is neglected. As an example, the trajectory of the aeroplane, cruising at an altitude of 10.7 km with initial speed of 900 kmhr-1 and undergoes an engine failure, is shown in figure 2.

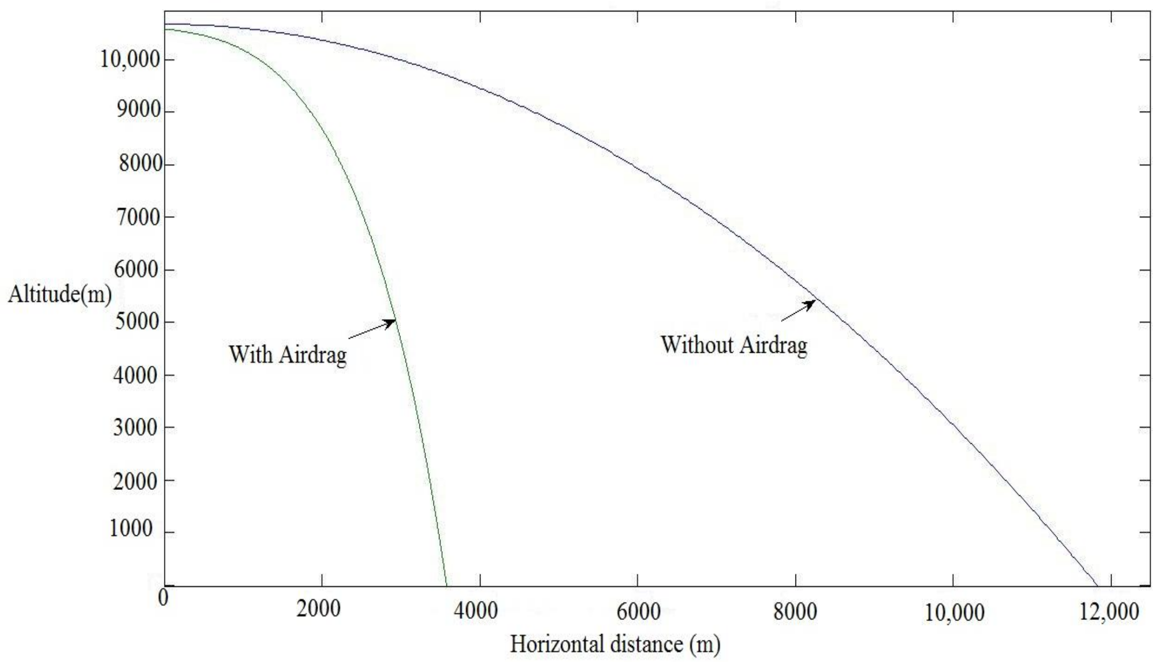

Fig. 2: Trajectory of the aircraft in the presence and absence of air drag with altitude along y axis and horizontal distance along x axis.

The horizontal distance calculated without considering the force due to air drag will give the maximum distance the plane can travel.

The distance between the maximum and minimum limits will probably be the area of finding the accident site. The above two assumptions are reasonably good and can be justified as there will be many unknown parameters of the aircraft failure like fully damaged or partially damaged etc.

VI. METHODOLOGY

The methodology followed in our study consists of the following 3 steps as described and presented as a flow chart in figure 3:

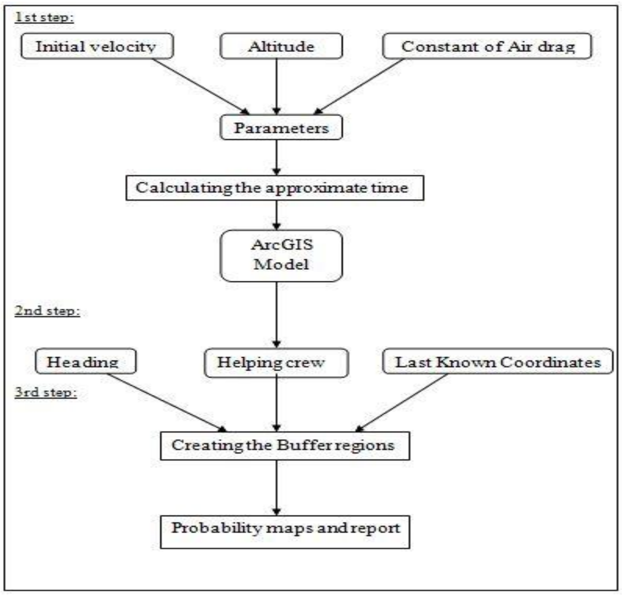

Fig. 3: Flow chart showing the methodology and steps involved in calculating the probable area of the accident site. First step involves calculating the approximate time taken, second and third steps are creating the buffer layers to get probable accident site.

The first step is calculation of approximate time taken by the plane under cruising condition to reach the ground when it undergoes an engine malfunction. The parameters such as cruising altitude of the plane, velocity and constant air drag per unit mass are usually available with the air traffic controller. The maximum and minimum horizontal distance, minimum time required are calculated by substituting the above mentioned parameters in equations 1,8 and 9 respectively.

The second step involves visualising the results obtained by creating the buffer region using GIS technique. A model is created using ArcGIS technique that automatically generates the map that shows the probable area with minimum and maximum distance of crash site as boundaries. The following four parameters are required to create GIS layer to narrow down the possible area of wreckage and to make effective search by SAR teams.

a) Direction of the aircraft
b) Last known coordinates(LKC)
c) Scheduled air route
d) Locations of the helping ground crew such as district head quarters, hospitals, Police stations, N.G.Os etc
e) Road map of the area

All the above parameters can be processed and put into GIS on different layers. These layers are overlapped to get the most probable area for the crash site, helping crew locations and the optimal routes to reach the site. The indicated site will be the most probable area for SAR operations. A report with the details of helping the crew within the vicinity of 100 km from the crash site can easily be generated using GIS.

VII. MODELLING IN ARCGIS:

Modelling in arc GIS is a technique that connects the two dimensional formula with three dimensional coordinate system and generates the desired maps. Equations 2 and 9 are incorporated into ArcGIS and a model is created where parameters such as velocity, LKC, minimum time taken to reach the ground, altitude and constant of air drag per unit mass are the input to the model. The possible area between the minimum and maximum horizontal distance will be generated as the output. Buffer 1 corresponds to approximate minimum distance the airplane can cover calculated from equation 9 and buffer 2 corresponds to maximum horizontal distance calculated from equation 2. The model can be understood from another flow diagram presented in Figure 4.

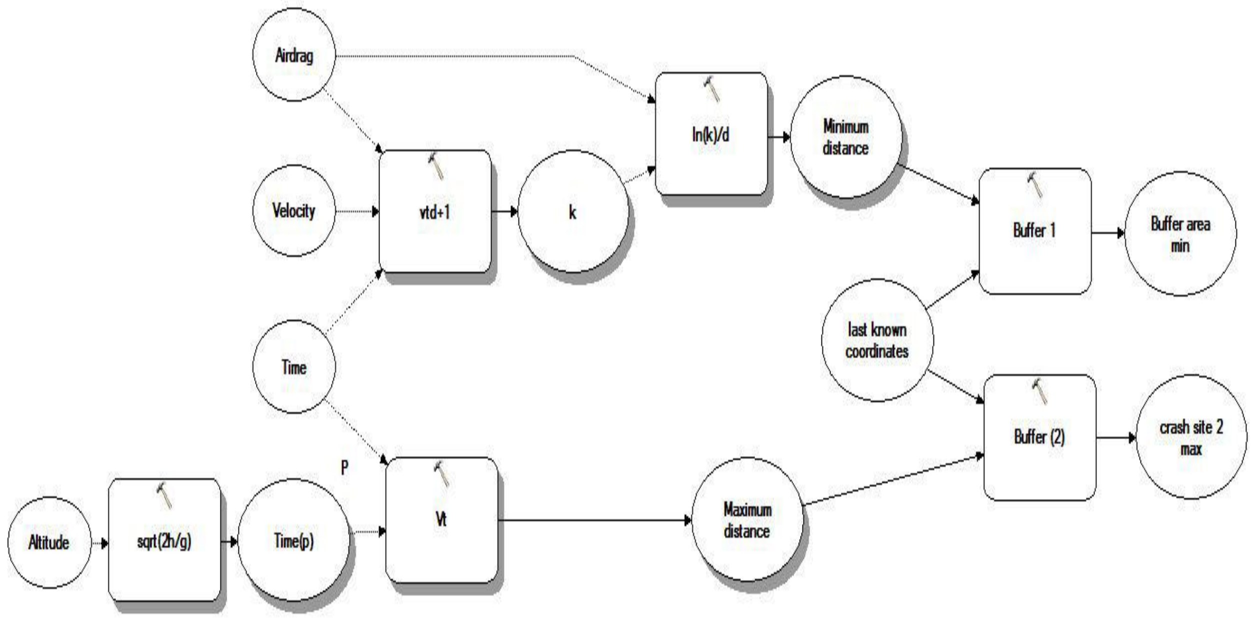

Fig. 4: Model in Arc GIS with air drag, velocity, time and altitude as input parameters and the minimum and maximum horizontal buffer areas will be the output parameters of the maps being generated.

VIII. ANALYSIS

Four different cases of hypothetical plane crash at different locations within the study area (Gujarat State) are considered. The model is analysed by taking general cruise parameters into consideration. Different airlines travelling in the state of Gujarat, their corresponding cruise speed, altitude and the last known coordinates (LKC), [6] are considered for our present study. Table 2-a give the details of different parameters.

Sl. no	**Airlines**	**Departs**	**Arrives**	**Departs**	**Arrival**	**Cruising speed (kmhr-1)**	**Altitude (m)**	**LKC**
1	Indigo 165	Ahmedabad	Delhi	5:00pm	6:25pm	922	10,670	23.4 N 72.9 E
2	Kingfisher 184	Chennai	Ahmedabad	9:05pm	10:55pm	850	10,100	22.4 N 73.1 E
3	Jetkonnect	Porbandar	Mumbai	3:50pm	5:15pm	800	11,000	21.3 N 70.1 E
4	kingfisher IT-4159	Bhuj	Mumbai	1:45pm	3:25 PM	950	9,500	22.4 N 71.0 E

Table 2-a : Four different airlines travelling between two locations, their general cruising velocity, altitudes and the coordinates of last known position can be seen.
(After initiation of this work the Kingfisher flight operations considered in the present study are terminated.)

A. Case Study

In this case, Indigo 165 travelling from Ahmadabad to New Delhi is considered as crashed in Sabarkantha district, fifty three kilometres away from Ahmadabad airport. Last contact with the pilot indicate that, the height of the plane was 10,670 m with a speed of 922 kmhr-1(250ms-1) and the last known coordinates are 23.4N and 72.9E. The air drag constant (D) of the airplane is assumed to be around 0.027804 kgm-1.

Calculating the minimum time required to reach the ground

Laws of projectile motion with force due to air drag is used in order to approximately calculate the time taken by the plane to reach the ground. From the assumed parameters such as cruising altitude and velocity, the minimum time taken can be calculated using the equation 8. In the present case it is estimated around 110 seconds.

Preparation of buffer layers and Reclassification to get a probable map

The estimated minimum time and last known coordinates are incorporated into the arc GIS model and the buffer area between the minimum and maximum horizontal distances are created as shown in figure 5. Here the horizontal distances are taken as radius and circles are drawn with last known co-ordinates of its focal point.

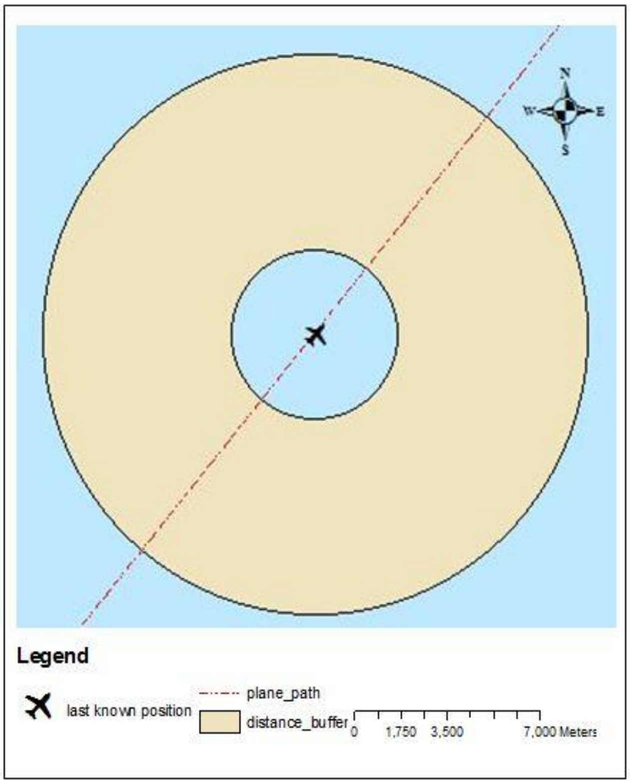

Fig. 5: Indicating the distance buffer between minimum and maximum horizontal distance, last known position, Plane path of Indigo165 airlines.

With heading of the aircraft into account, a sectional buffer region with an angle of about 45^0 with respect to path is created. The intersection of the two buffer layers will give the most probable area of finding the wreckage. The shaded portion showed in figure 6 indicates the probable area of plane crash.

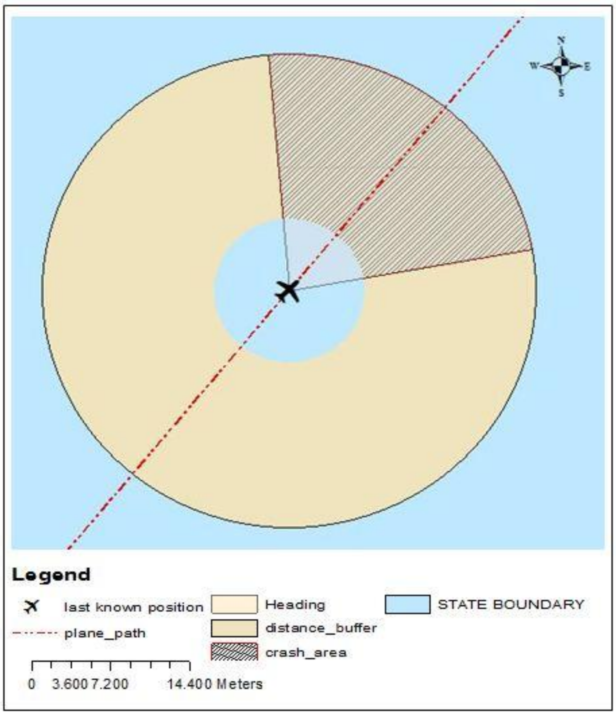

Fig. 6 Map showing distance buffer and heading buffer areas with last known position, plane path, and the overlapping area which indicates the most probable crash location.

Once the maximum probable area of the accident is estimated the next immediate step will be to find the optimal routes to reach the target area. The details of nearby helping ground staff within hundred kilometres radius can be identified using geoprocessing and reporting tools available in arc GIS software.

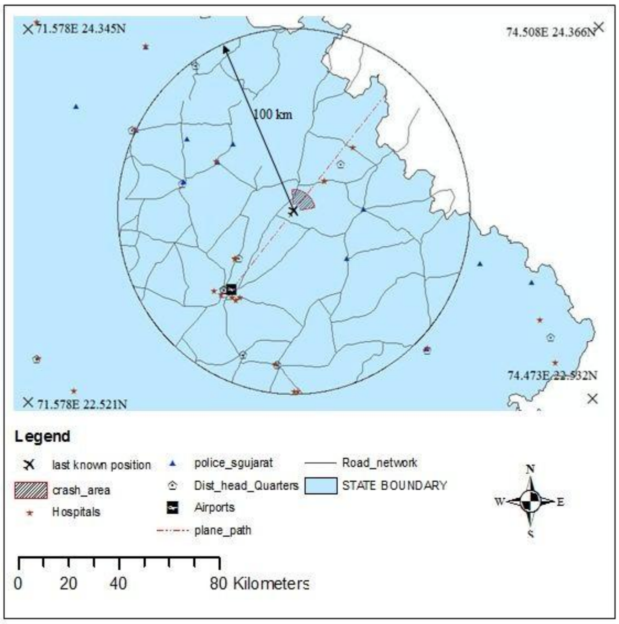

Fig. 7: Details of the helping ground staff such as hospitals, police stations, district headquarters, road routes suggested to them within hundred kilometres from Last Known Coordinates and the latitude & longitudes of the accident site.

According to the map generated (figure 7) there are six district head quarters, seven police stations, fifteen major hospitals within hundred kilometre radius. Details available in the GIS database include the phone numbers and addresses that can be generated as a report. Optimal routes to reach the crash site can also be suggested to the helping crew so that they will not lose time during the operations.

B. *Generalised model*

As shown in table 2-a, the four typical cases are studied. They are planes cruising at different altitudes, velocities and with different constants of air drag between two locations lost the contact with Air Traffic controller at different locations. Variation of the parameters include - the initial velocity, constant of air drag, minimum time taken and the cruising altitude. These are input to the model, from which the buffer regions are generated. Depending on the heading direction of the plane, triangular buffers with roughly ninety degrees angle are created. The buffer layers are then reclassified and probable area of finding the accident site can be generated by intersecting them. A report containing the details of helping the ground staff within hundred kilometre radius can be generated and also optimal routes are suggested to the rescue teams. Figure 8 shows the Last known positions, air routes, probable crash area and nearby helping teams for the cases given in table 2-a. The details showing the minimum time and the distance limit for the four cases are shown in table 2-b.

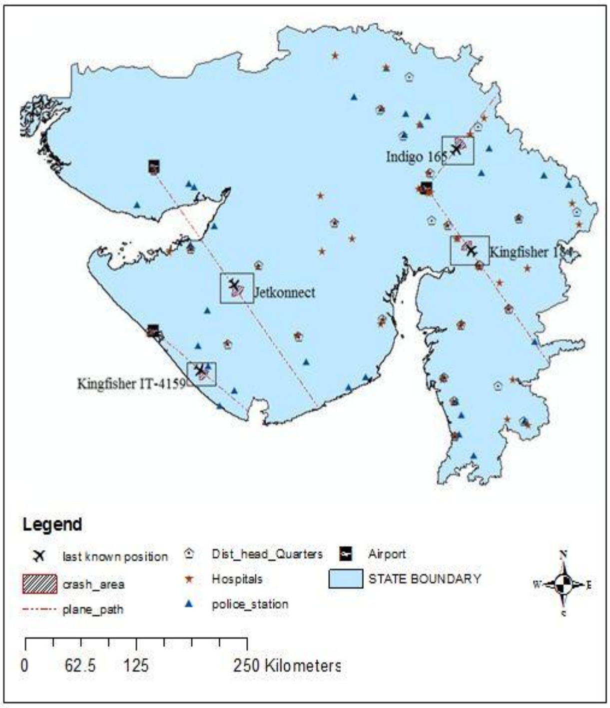

Fig. 8: Probable crash areas of the four cases mentioned in table 2-a, scheduled flight path details of helping ground crew such as hospitals, police stations, district head quarters in Gujarat state, India.

Sl. No	Airlines	Departs	Arrives	Time taken (s)	Horizontal Distance(m)		Accident site location showing latitude and longitudes	
					Min	Max	Min	Max
1	Indigo 165	Ahmedabad	Delhi	110	3,630	11,943	72.95E 23.47N	73.00E 23.53N
2	Kingfisher 184	Chennai	Ahmedabad	105	3,490	10,718	73.07E 22.47N	73.03E 22.52N
3	Jetkonnect	Porbandar	Mumbai	115	3,510	10,526	70.17E 21.24N	70.22E 21.20n
4	kingfisher IT-4159	Bhuj	Mumbai	100	3,547	11,614	70.54E 22.07N	70.58E 22.01N

Table 2-b: Details showing approximate time taken, minimum and maximum distance travelled by four airlines and latitudes and longitudes of the crash area

IX. Conclusions

In this study, the probable location of an accident site is suggested when an aircraft undergoes engine or structural malfunction during the cruise stage. The maximum and minimum limits of horizontal distance are calculated using the laws of projectile motion taking force due to Air drag into account. The probable location of accident site on a maps is generated that helps the SAR ground crew using modelling technique in Arc GIS thereby reducing the search time. Optimal routes to reach the crash site and details of nearby ground crew can be also be found using arc Map.

This analysis enables the search and rescue teams in making effective and efficient search from the probable area. This analysis can also be applied to military aircrafts, private jets if the constant of air drag that depend on the structural factors of the plane and other parameters such as velocity, altitude, last known coordinates are known. Thus it is concluded that our model assists the rescue teams in making effective search by narrowing down the search area and suggesting optimal routes so that more number of lives can be saved in the case of aeroplane disaster.

X. Acknowledgement

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