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SERIOUS VULTURE-HITS TO AIRCRAFT OVER THE WORLD

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Abstract

Between 1955 and 1999 more than 33 aircraft (27 military and other civil) were written off due to collisions with vultures, which had also caused loss of 21 lives in 11 of these aircrashes. These accidents had occurred in seven countries across the continents of Asia, Africa, Europe and North America. Seven species of vultures were responsible for these air accidents. India had lost about 70 million US Dollars every year between 1980 and 1994 due to vulture strikes (Satheesan 1994, 1996, 1998, 1999a). In other countries also writing off fighter aircraft had brought financial loss to the tune of 10 to 17 million US Dollars per accident. Of the 30 accidents where the altitude for collision of aircraft with vultures is known, 50% occurred below 200m and none above 1200m, and almost all of them outside aerodromes. This paper suggests ecologically sound and practical measures to contain vulture menace to aircraft from the Indian experience. Mass killing of vultures may lead to an ecological disaster, which will prove more costly than what vulture-aircraft-strikes could bring about. A very important suggestion is also made as to how amendments to Section 9A of the Indian Aircraft Act 1934 and Rule 81B of the Indian Aircraft Rules 1937 can be made in order to combat the threat of vultures to civil and military aircraft over the world.

Key Words: Vulture-hits to aircraft, Aircrashes, Loss of life, Financial loss, Altitude for collision, Measures to contain vulture menace, Mass killing, Ecological disaster, Amendments to Section 9A of Indian Aircraft Act 1934 Rule 81B of Indian Aircraft Rules 1937.

Introduction

In modern aviation bird strikes undoubtedly are a nightmare the world over. The collision of airplanes with birds (77 identified species), bats (three identified species) and even larger mammals such as deer and antelope in India, is a result of man's short-sightedness in dealing with nature (Satheesan 1992 a, b, c & d). Since the first recorded air crash due to bird-hit in 1912, our generation has started paying dearly for the mistakes of the past (Satheesan 1996). Between 1955 and 1999 more than 33 aircraft (27 military and other civil) were written off due to collisions with vultures, which had also caused loss of 21 lives in 11 of these air crashes. Seven species of vultures were responsible for these air accidents occurring in seven countries across the continents of Asia, Africa, Europe and North America. India had suffered huge financial losses every year between 1980 and 1994 due to vulture-strikes (Satheesan 1994, 1996, 1998, 1999a & c). In other countries also, writing off fighter aircraft due to vulture-hits had brought about unimaginable financial loss. The details of serious vulture hits, which had occurred world wide, their impact on aircraft and man as well as methods of containing vulture menace are discussed in this paper.

Observations

An analysis of 40 serious vulture-aircraft collisions that had occurred over the world revealed that more than 33 aircraft (27 military and other civil) and 21 human lives were lost in 11 of these air accidents as shown in Table 1 and Annex 1. These accidents occurred in India, United States of America, Kenya, Ethiopia, Tanzania, Spain and Pakistan between 1955 to 1999.

Financial loss due to vulture hits

Huge financial losses to aviation due to vulture hits are recorded in countries where vulture menace to aircraft exists. Indian aviation used to lose about US$ 70 million (one aircraft lost and several damaged) every year between 1980 and 1994. Other countries such as the USA and Spain have lost between US$ 10 to 17 million per accident caused by vulture strikes.

Species of vultures involved in accidents

In India all air crashes were caused by a single species namely the White-backed Vulture ***Pseudogyps bengalensis*** even though two other species namely the Long-billed Griffon ***Gyps indicus*** and the Egyptian Vulture ***Neophron percnopterus*** had also collided with aircraft. In the United States the Turkey Vulture ***Cathartes aura*** and the Black Vulture ***Coragyps atratus*** had brought about the air accidents. The African White-backed Vulture ***Pseudogyps africanus***, the White-headed Vulture ***Trigonoceps occipitalis*** and the Ruppell's Griffon ***Gyps rueppelli*** brought down aircrafts in Kenya. In

Serial. No.	Country	Period From – To	No. of Air Accidents	Species involved	Damage/Injury
1	India	1980 – 94	15	Indian White-backed Vulture	Pilot killed in 2 cases, Financial loss about US$ 70 million per year
2	USA	1969 – 94	10 (12)	Turkey Vulture (7 cases), Black Vulture (2 cases), Not Known (3 cases)	Pilot killed in one case. Financial loss of US $ 10 million or more per aircraft written off.
3	Kenya	1955 – 99	3 (4)	Ruppell's Griffon (1case), White-headed Vulture (1 case), African White-backed Vulture (1 case)	11 persons in 3 air crashes, fuel of 90,00 lbs. Dumped before effecting precautionary landing in the fourth case.
4	Ethiopia	1976	1	Not known	Killed both the occupants
5	Tanzania	1959	1	Eurasian Griffon	Pilot killed
6	Spain	1986-87	2	Eurasian Griffon (both the cases)	3 people killed, Financial loss of about US $ 27 million (both added up)
7	Pakistan	1962	1(2)	Not known	Co-pilot killed in one case

Table 1. Serious vulture-aircraft hits over the world

Tanzania and Spain Eurasian Griffon ***Gyps fulvus*** was responsible for air crashes. In Ethiopia and Pakistan the species of vulture were not identified. In Pakistan it could be the White-backed Vulture or a Griffon.

Why do vultures come in the flightpath of aircraft at all altitudes outside aerodromes?

Vultures, 22 species occurring over the globe, are generally communally feeding scavenging raptors. The White-backed vulture and the griffons in India do not have any fixed habitat in non-breeding season, as availability of carcasses is the main restricting factor for their distribution. They have a very

large foraging area. They can feed on a carnivore kill in a Protected Area one day and then fly 150-200 km within two or three days to feed at an urban carcass dump. Vultures depend upon thermals for soaring. From one thermal, after attaining a desired altitude, they glide to catch up with another thermal and thus perform cross-country flight. Vultures soaring in large flocks create a live barrier for aircraft in the sky. The habit of communal soaring, heavy body (1.5 - 12 Kg) and poor reflexes make these birds highly dangerous to aircraft flight safety.

A Ruppell's Griffon collided on 29 November 1973 with a commercial aircraft at an altitude of 37,000 feet (11,280 m) over Abidjan, Ivory Coast, Africa (Laybourne 1974). Temperatures at these heights are around -50°C level and oxygen almost non-existent. Sail plane pilots are recommended to use oxygen cylinders over 12000 feet (3660 m), though birds can breath in this rarefied atmosphere better than humans do. Highflying birds such as griffons and long-distance migrants, even turkey vultures, buzzards, ospreys, geese, terns and cranes may occasionally go very high into the upper levels of the troposphere and find "jet streams" there (Mundy ***et al.*** 1992). These are very strong winds above 30,000 feet (9,150 m) at velocities of more than 100 knots, and in "ribbon-like concentrations". It is possible that some birds know of these and use them for "joy rides". Possibly the Ruppell's Griffon that had hit aircraft at 37,000 feet over Abidjan in 1973 was on a "joy ride" in "jet streams". Air temperatures decline 7.5°C per Km in altitude. Temperature in rising air of thermals decline still faster at about 10°C per Km. Over the equator at 4 Km altitude temperature is at freezing point and at the level of "jet streams" it will be -33°C and colder.

Vulture hits at various altitudes and flight phases of aircraft

An analysis of thirty-eight accidents where the flight phases at which vulture collisions had occurred were known, 21 of them were at cruise and four at descent (see Table 2). Of the 30 accidents where the altitude for collision of aircraft with vultures is known, 50% occurred below 200m and none above 1200m, and almost all of them outside aerodromes. Transport aircraft (both civil and military) suffered less due to vulture hits compared to fighter jets. Fighter jets were more vulnerable during low level cruise (15 cases) because of the high flight speeds during exercises or action in Bombing Ranges.

Indian situation of vulture menace

In India, there are eight species of the Old World vultures, namely the Red-headed or King, Cinereous or European Black, White-rumped or White-backed, Egyptian or Indian Scavenger and Bearded Vultures as well as the Long-billed, Fulvous and Himalayan Griffons. Vultures depend mainly on large mammals for food. They devour large chunks of meat. They get food from carnivore kills in forested areas and flayed carcasses and meat at

primitive slaughter houses, carcass dumps, carcass processing centres and bone mills (Ali & Grubh 1984, Prakash 1989, Satheesan 1990a, 1999a & ***in***

Air-Craft Type	Takeoff Run	Climb	Low Level Cruise	High Level Cruise	Descent	Approach	Landing Roll	NK	Total
Transport	0	5	2	3	0	1	1	2	14
Fighter	0	4	15	1	4	2	0	0	26
Total	0	9	17	4	4	3	1	2	40

Table 2. Vulture hits at various flight phases of aircraft

press 1, Mundy ***et al.*** 1992). They come to the rescue of man to dispose of carcasses when animals die during natural calamities such as floods, storm, drought and war. They also feed on smaller mammals such as cat, dog or larger rodents at times. An army of 200 vultures can reduce a large buffalo carcass to bare skeleton within twenty minutes. Their efficiency in cleaning carcasses is utilized by villagers who collect hide and bones for industry all over India.

There has been a steady decline in the populations of vultures since 1990 all over India, first noticed in 1992 in Delhi (personal observation), which became more evident after 1995 and more serious after 1997. The species that suffered the greatest decline is the White-backed vulture followed by the Long-billed and Eurasian Griffons as well as the Red-headed and Egyptian Vultures. There are several causes of the decline of vulture populations in India but the main cause is persecution by man including trapping, shooting, killing, eating and poisoning (deliberate and incidental). Paucity of food because of modernization of primitive slaughterhouses and closing down of innumerable carcass dumps, especially in cities and towns as well as rural areas with civil and military airfields nearby also reduced the vulture populations. Shortage of food supply in some areas and harassment from the society at large may be the major reason for the fast disappearance of vultures. They tend to disappear from areas where safety is not assured even if food in the form carcasses is available (Satheesan 1999a 1999b).
In the Delhi-Agra-Bharatpur triangle an unimaginably large population of 20,000 vultures occurring in an area of about 10,000 sq Km slided to 150 individuals in decade of persecution (see Table 3).

Disappearance of vultures creates another nightmare
In areas where vultures used to perform the carcass disposal faithfully, no substitution can be found. In Prakasham and Guntur, two coastal districts of

Andhra Pradesh State in South India, vultures had disappeared one and a half to two decades ago because the Bandolu (Banda) community living there

Area	Year	Approximate numbers of birds (maximum)		
		White-backed Vulture	Egyptian Vulture	Other Vulture Species
Delhi-Ghaziabad-Hapur-Dhauj	1990	10,000	3,700	150
Bharatpur-Agra	1990	5,000	1,000	50
Delhi-Agra-Bharatpur	1999	50	90	10

Table 3. Approximate populations of vultures in Agra-Bharatpur-Delhi Area.

used to trap these birds for consumption. During the cyclonic storm that struck coastal Andhra Pradesh in 1990 no vulture was available to appropriate innumerable livestock killed by the storm in this area. During the Super Cyclone that hit the coastal Orissa on 29 October 1999, no vulture was seen to feed on the three hundred thousand live stock carcasses strewn around the coastal belt. Vultures prevent outbreak and spread of infectious diseases such as anthrax, foot and mouth disease and rabies.

Discussion and inferences

The following inferences can be drawn from the analysis of observations:

1. Vultures are a menace to aircraft in several countries including Indian, United States, Kenya, Ehiopia, Tanzania, Spain and Pakistan where several aircraft and human lives were lost over the years.
2. Vulture-hits to aircraft occurred generally outside the aerodrome and mainly at cruise phase of flight and also at descent, climb and approach but between altitudes of 60 and 1200 meters
3. Military aircraft is more vulnerable to vulture-hits during high speed exercises at low levels
4. The White-backed vultures and the griffons have a very large foraging area (may be even more than 10,000 square kilometers as was the case of Delhi-Agra-Bharatpur Triangle in India) and they fed anywhere in the area because of the availablity of regular carcass dumps and other feeding grounds (including carnivore kills in Protected Areas).
5. Denying food to vultures (carcasses) in an area 100 km in radius of a civil aerodrome and 200 km in radius of a military airfield or a bombing range or low-level high-speed exercise zone can reduce the population of vultures from the Indian experience.
6. Airport bird controllers do not want to be held responsible for bird-hit caused aircraft accidents. Killing birds by shooting has been and is a

practice at civil and military aerodromes world over. A research report by Dr Richard Dolbeer (IBSC Proceedings, Slovakia, 1998) has mentioned that between 1991 and 1997 two to five sharp shooters employed at JFK International Airport USA have killed 52,235 gulls (of which 47,601 were Laughing Gulls and 4,634 other species) in 6369 person-hours of shooting (Dolbeer 1998). In India also birds, especially kites and vultures, were killed to prevent bird strikes. Probably now also the system continues in some airports with heavy traffic and high bird concentration. Killing scavenging birds, and also birds in general, in an area will create an "ecological vacuum", to fill which more birds will come if the attraction for them persists in the area. If one goes on killing all the newly arrived birds also, a sizable population of the birds of the larger area will be wiped out over a period of time. This may be one of the contributory factors for the decline of scavenging birds such as vultures and kites near aerodromes in India. Bird controllers at airports are advised to kill birds only in an emergency or as a last resort; but in reality when panic strikes the aerodrome staff (when bird concentration increases over the runway and aircraft is about to take off or land) it may become the first resort. We cannot blame the aviation authorities if they had killed a few birds including vultures because they have an airport operator liability and a responsibility towards the country. It is the duty of the society to help the aviation authorities to solve the bird strike problem.

7. Mass killing of vultures is not the solution to vulture menace to aircraft. This method is shortsighted because extinction or total wipe out of these indispensable scavengers is possible through sustained persecution over a period of time. A large chunk of the vulture population in India was wiped out because of various reasons including killing, trapping, poisoning and predation in the feeding sites (Satheesan ***in press*** 1 & 2). Their communal foraging and feeding as well as exclusive scavenging speeded up their "near decimation" as large number of birds died eating poison-baited carcasses laid out by traditional people around protected areas who want to avenge livestock-marauding carnivores or cattle-lifters who want to take away the hides and bones of stray cattle or poachers who want to trade in parts of wild animals. When some birds die at one site, more birds fly in to fill the "ecological vacuum" as long as the food source exists. This is applicable to all scavenging birds (Satheesan 1999a, b & c, ***in press*** 1). Exclusive scavengers such as the White-backed vulture and the griffons are all the more vulnerable and likely to be easily wiped out compared to the other scavenging raptors such as Egyptian vultures which are versatile in their feeding habits (Satheesan 1989 a, b & c).

8. Small populations of vultures exist in Protected Areas and countrysides in India. We can reinforce them to optimum levels for the better health of the environment We should set up "vulture restaurants" or feeding

stations in natural habitats such as forested areas and inside protected areas much away (at least 200 km) from airfields (Satheesan 1996, 1999a, ***in press*** 1).

9. Ornithologists feel that the airport and civic authorities do not maintain the minimum standards of cleanliness in and around airports nor do they have an efficient garbage disposal system (Blokpoel 1976, Ali & Grubh 1984, Satheesan 1992a, 1992d, 1994, 1996). They think that airsafety measures are never too costly compared to the financial loss and loss of life due to an accident. Killing of birds is not necessary but some deterrents for scaring the birds from aerodrome area are required to give birds the message that runway and neighbourhood is no longer safe for them as a habitat. Even before the construction of an airport is planned the Government authorities should commission an expert to carry out an environmental assessment survey of the area to prevent an environmental catastrophe through a wrong decision. Urban planning should be such that a growing town or city does not envelop the aerodrome over the years. When professional and responsible experts (need not be organization) in bird strike prevention are available in the country there is no room for any compromise formula. As the problem of bird-strikes is a result of society's ills, the solution has to be found out working in the grass-root level bringing awareness to all sections of society. Essentially bird-strike-prevention has to be through joint airport environmental management (Satheesan 1998c, 1998d, 1999c).

Recommendations

1. Provide excellent practical training to the staff and officers (not classroom teaching alone).
2. Economic costs of ecological destruction should be taught to flight safety staff and officers so that manipulation of natural habitat does not recoil.
3. Employ bird scientists (ornithologists) on the pay roll of ground and flight safety department of aerodromes and also at senior administrative levels.
4. A national level organization, planning and execution for bird control at aerodromes are important because prevention is always better than cure.
5. Section 9A of the Indian Aircraft Act 1934 and Rule 81B of the Indian Aircraft Rules 1937 prohibits slaughtering and flaying of animals, depositing of rubbish and other polluted or obnoxious matter in the vicinity of aerodrome: "No person shall slaughter or flay any animal or deposit or drop any rubbish, filth, garbage or any other polluted or obnoxious matter which attracts or is likely to attract vultures or other

birds and animals within a radius of ten kilometers from the aerodrome reference point except in accordance with and subject to the terms and conditions of a permission in writing issued by the Director-General or a Deputy Director-General or any other officer authorized by the Central Government in this behalf". But this rule can be amended to increase the area of the sterile zone from 10 km radius to 100 km in the case of a civil aerodrome and 200 km in the case of a military airfield or a Bombing Range or low-level high-speed exercise zone of fighter aircraft. Slaughtering in a primitive way, illegal slaughtering and flaying, carcass dumping as well as processing should be totally banned in this sterile zone. At the same a modern abattoir or a modern carcass processing center can exist, but only outside 10 km radius as stated in the existing Aircraft Rule.

Conclusion

We should not wait for a catastrophe to act. Zero bird-strike rate is an achievable target (Satheesan 1999). Killing of birds is not at all necessary to save aircraft. Bird-aircraft-strike-prevention has to be a people's programme with active indispensable participation of all sections of society. Human actions such as destroying other species and striving for luxuries at the cost of their basic needs, instead of showing stewardship towards them, is too demeaning and may finish the Web of Life. As scavenging raptors occurring in urban areas do conflict with urban life styles, aircraft flight safety, powerlines and other utility structures, it is necessary to limit their distribution to countrysides, Protected Areas and forests. This can be done only by restricting the food available and controlling the indiscriminate dumping of animal refuse and carcasses in urban areas. If the population of scavenging raptors declines abysmally, it is advisable to set up feeding stations in Protected Areas and countrysides but far away from aerodromes and power installations to avoid collisions. A feeding station like this can be exploited by not only raptors but also other scavenging birds such as storks, crows and ravens. The main point is that scavenging raptors have to be conserved by active management of their populations not only to avoid disasters such as collisions with aircraft and powerlines but also to prevent wipe out of these scavengers themselves and total breakdown of the network of ecosystems as well as to protect ecological and economic security of the planet.

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Annex 1. Serious vulture-aircraft hits over the world

Sl. No	Date	Country/ Aircraft	Airport/ Place	Flight Phase	Altitude (m)	Vulture Species	Damage/ Injury
1	?/?/55	Kenya Cessna	Aberdare Mountains	NK	NK	NK	Aircraft crashed killing the only occupant
2	10/01/59	Tanzania	Serengeti	NK	NK	Griffon Vulture	Aircraft Crashed
3	15/07/62	Pakistan Douglass DC-3	Lahore	Cruise	NK	NK-10 Kg	Bird penetrated windscreen, Co-pilot killed
4	?/?/69	USA T-37 B	NK	Climb	364	Vulture	Penetrated Windscreen, Aircraft written off
5	?/?/70	USA T-37	NK	Climb	606	Turkey Vulture	Penetrated Windshield, Aircraft Crashed
6	?/?/70	USA Se A-7 B	SE Navy	Climb	91	Vulture?	Bird hit Radome & Fuselage, Aircraft written off
7	?/?/71	USA RF-4-C	NK	Cruise-low level	152	Black Vulture	Bird Penetrated Windshield, Pilot ejected but Aircraft Returned to Base
8	?/?/71	USA F-111	NK	Cruise-low level	152	Turkey Vulture	Bird Penetrated Windscreen, Aircraft Crashed
9	30/08/76	Ethiopia Saab MF- J 15	Nr. Awassa	Climb	61	NK	Aircraft crashed vertically killing both the occupants
10	21/10/80	India Helicopter	North India	Enroute	NK	WBV	Helicopter crashed
11	23/10/80	India Fighter Jet	North India	Level	100	WBV	Aircraft crashed, Bird hit Port Wing
12	06/08/81	Kenya Cessna 402	Musiara aerodrome Maasi-Mara	Cruise	NK	Ruppell's Griffon 7.5 Kg	Bird penetrated windshield, Aircraft Crashed & Pilot killed
13	08/11/83	India Fighter Jet	Northwest India	Descent	750	WBV	Bird hit cockpit, canopy & engine Aircraft crashed, Incapacitated pilot killed
14	13/02/85	India Fighter Jet	Northeast India	Level	NK	WBV	Bird hit Engine-1, Aircraft Crashed
15	08/10/86	Spain F-16 A	Bardenas Range	Cruise-low level	NK	Griffon Vulture	Bird hit Fuselage, Engine failure after bird ingestion, Aircraft Crashed
16	16/10/86	India Fighter Jet	North India	Climb	1000	WBV	Bird hit Engine –1, Aircraft Crashed
17	20/10/86	USA F-4 E	GAVR 106 II rt.	Cruise-low level	NK	Black Vulture	Bird hit Fuselage, Aircraft written off

18	20/05/87	Spain F-4E	Bardenas Reales Range	Cruise-High level	606	Griffon 20 lbs	Bird penetrated Windscreen, Aircrash, Pilot & weapon operator killed, Damage cost- US $ 17,000,000/=
19	04/06/87	India Fighter Jet	Western India	Level	150	WBV	Bird hit Radome & Engne-1, Aircraft Crashed
20	30/10/87	India Fighter Jet	Northwest India	Descent	130	WBV	Bird hit Nose & Engine-1, Aircrash, Crops damaged
21	09/11/87	India Fighter Jet	Northwest India	Circuit	400	WBV	Bird hit Radome & Engine-1, Aircraft Crashed
22	04/01/89	USA F16-A	Okeech / Avon Range, Florida	Cruise - Low level	194	Turkey Vulture 4--5 Kg	Bird pernetrated windscreen, Pilot ejected , Aircrash, Damage Cost- $ 10,000,000/=
23	25/05/89	India	Delhi	Climb	1200	NK	Pressure Bulk Head and Radar
24	10/08/89	India	Delhi	Final Approach	758	WBV	Engine shutdown, captain's panel of windshield hit
25	10/11/89	India Fighter Jet	Northwest India	Initial Climb	50	WBV	Bird hit Radome, Windshield & Engine-1, Aircraft Crashed
26	23/11/89	India Fighter Jet	North India	Final Approach	350	WBV	Aircraft Crashed
27	01/03/90	India Fighter Jet	North India	Level	700	WBV	Bird hit Engine-1, Aircraft Crashed
28	21/04/90	USA Harrier TAV-8	SC Beaufort Navy	Cruise-low level	NK	Vulture	Bird hit Fuselage, Aircraft written off
29	02/12/90	Pakistan Bac 125	Karachi	Approach	606	NK	Engine Shutdown, Two Fan Blades separated, others bent
30	18/04/91	USA F-16 A	AS Ft. Smith	Cruise-Low level	91	Turkey Vulture	Bird hit Fuselage, Aircraft written off
31	26-12-91	Kenya Piper PA 31 Navajo	Musiara aerodrome Maasi-Mara	Cruise-low level	76	White-headed Vulture 5.4 Kg	The DC3's collapsed landing gear over-ran the runway. The PA31 flew over the site at good speed. Aircraft burnt
32	27/12/91	Kenya Piper PA 31 Navajo	Musiara Airfield Maasi- Mara Game Park	Landing roll	0	NK	Aircrash killed all 9 occupants, Wind Screen Smashed
33	28/05/92	USA F-18 A	Florida Gainesville	Cruise-low level	61	Turkey Vulture	Bird penetrated windscreen, Aircraft written off

34	03/09/92	USA T-38 A	Texas Abilene-N	Cruise-Low level	500	Turkey Vulture	Bird Penetrated Windscreen, hit Pilot's head and killed him, Aircraft returned to base
35	09/10/92	India Fighter Jet	Northwest India	Level	450	WBV	Bird hit Radome & Engine-1, Aircraft Crashed
36	21/04/93	India Fighter Jet	Northwest India	Descent	500	WBV	Bird hit Engine-1, Aircraft Crashed
37	27/01/94	India Fighter Jet	North India	Climb	170	WBV	Aircraft Crashed
38	19/04/94	India Fighter Jet	South India	Level	100	WBV	Bird hit Windshield, Aircraft Crashed
39	?/07/94	USA F-16	Texas Eagle Pass	Cruise-Low level	NK	Turkey Vulture	Aircraft written off
40	24/02/99	Kenya	Jomo Kenyatta International Airport, Nairobi	Initial Climb	242	African White-backed Vulture 17 lbs	Precautionary Landing, dumping 90,000 lbs fuel, damaged engine, 3 fractured fan blades

Source: Arrington 1994, Richardson 1994, 1996 & Thorpe 1994, 1996, 1998