The Release of Dropsondes: A Hazard for Commercial Air Traffic?

Reinhold Busen

This paper addresses the question of the probability with which meteorological sondes dropped from aircraft would collide with other aircraft flying at lower levels. Real air traffic data for Germany regarding the total number of aircraft and the fleet composition are used for the calculations. An overall collision probability of about $2.6*10^{-6}$ is estimated for a randomly and uncontrolled dropped sonde to collide with an aircraft, considering peak traffic density. From this probability one collision would statistically be expected out of about 386,000 drops.

In reality the release of dropsondes is supervised by the Air Traffic Control Authorities, reducing the risk to very nearly zero in controlled airspaces. A certain risk will remain for sondes dropped in any airspace without radar surveillance, such as the North Atlantic Flight Corridor. But even this risk could be minimized by specific control procedures.

In all, the risk is much less, about 1/4, of that which currently exists in the case of upsondes released on balloons from the ground. These largely uncontrolled upsondes or radiosondes, as commonly termed, penetrate the airspace levels used by commercial air traffic.

INTRODUCTION

Weather forecasts of any kind require basic meteorological measurements. Horizontally distributed data are available from various sources: the meteorological surface network, instrumented buoys

Reinhold Busen is with DLR, Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Physik der Atmosphäre, Oberpfaffenhofen, D-82234 Weßling, Germany.

drifting on the oceans, aircraft in level flight, or from satellites. Data on the vertical structure of the atmosphere, which is absolutely necessary for any three-dimensional modeling, is only available by transmissions from radiosondes.

For this purpose radiosondes are usually released by a ground station and rise on a balloon as upsondes, continuously transmitting meteorological data on their way through the atmosphere. Most of these ground stations are located on the mainland or on islands, very few sondes are released from ships. A total of about 1,500 radiosondes are released every day worldwide, most of them at 00 UTC and 12 UTC. Geographically, about 90 percent of the ground stations are located north of the equator, concentrated in North America, Europe, and the eastern part of Asia.

An alternative approach is a dropsonde, a special kind of radiosonde. In contrast to upsondes dropsondes are released from an aircraft typically at about 35,000 feet altitude and descend on a parachute with vertical speeds between initially about 20 m/s and about 10 m/s close to the ground. During their falling time of approximately 15 minutes they transmit the vertical profiles of atmospheric parameters such as temperature, pressure, humidity, and wind speed and direction. However, these data are transmitted back to the aircraft or to a communication satellite. As there is no need for a ground station, dropsondes are especially suited for use over inaccessible areas of the world like oceans, deserts, and the polar regions.

Dropsondes have been built since about 1940, first for military applications, but later on increasingly for general weather observation purposes (Trenkle, 1983). Dropsondes received public attention beginning in 1982, when they first were used for observing the intensity of tropical storms, which led to a much better forecast of the development and ground track of hurricanes (Franklin and DeMaria, 1992; Burpee et al., 1996). In these publications the authors rate the efficiency of dropsondes: "The error reductions . . . [using dropsondes] . . . are at least as large as the accumulated improvement in operational forecasts achieved over the last 20-25 years." Lorenz and Emanuel (1998) indicate that well positioned additional data would improve the forecast quality of numerical models, particularly by releasing dropsondes along a flight route adjusted to the actual weather situation. Finally, Skony et al. (1994) demonstrate the quality of data with dropsondes to be equivalent to that of conventional upsondes.

Presently, dropsondes serve for very specific atmospheric investigations, the total production is about 5,000 per year. In the future, however, dropsondes are expected to be used in much larger numbers for getting additional data on the vertical structure of the atmosphere, especially over the Atlantic and Pacific Oceans where the synoptic systems relevant to the European and North American

weather develop. This could be done on a routine basis by commercial airliners crossing the oceans.

Both upsondes and dropsondes mean a potential risk for air traffic at all altitudes due to the possibility of collision between sondes and aircraft. This risk is minimized by specific regulations and procedures regarding the sonde release. The air traffic safety request regarding upsondes is maintained and legally satisfied in the German airspace by announcing every location and start time of regular upsondes in the AIP Germany (Aeronautical Information Publication). Similar regulations are valid for some other European countries. For dropsondes these regulations do not apply, however dropping parachute jumpers or any kind of object from an aircraft needs at least two procedural steps: First a general ATC agreement and a notification in the flight plan, and second an individual ATC clearance for each drop, in close cooperation with the ground controller.

In this paper the possible risk or probability of a dropsonde colliding with an aircraft flying below is estimated for the area of Germany. The next step, assessing the danger to an aircraft of such an impact, is hard to quantify, as only a few experimental impact tests have ever been performed, and these were conducted more than 25 years ago. Data on presently used sondes and their impact on the structure of modern aircraft are completely lacking. However, calculating the probability of a dropsonde colliding with an aircraft, and comparing that with the current experience obtained with upsondes can give an approximate indication of the problem.

The aim of this paper is to introduce the widely unknown possibility of dropping meteorological sondes from aircraft and to inspire some confidence in using them. The most important point outlined in the further content of this paper is, that dropsondes are less dangerous to aircraft than the widely used upsondes, for which no really hazardous accidents related to aircraft are known.

First the method for calculating the collision probability is laid out, followed by a description of the air traffic data base and characteristic features of an airborne dropsonde system. Finally the results of the study and equivalent risks caused by upsondes are discussed.

CALCULATION METHOD

Any aircraft in the air can be hit by a sonde descending on a parachute by means of two different mechanisms:

1. The sonde may hit the upper surface of the aircraft. However, as the aircraft is flying very fast compared to the falling speed of the sonde, the probability of this mechanism is poor and the damage is expected to be minor.

2. Whenever the sonde falls through the airspace in front of an aircraft, the aircraft may hit the sonde. In this case a collision may be more probable and much more dangerous, considering the relation of the aircraft horizontal speed and the sonde vertical speed. For calculating the probability of a collision the vertical extents of both the aircraft and the sonde have to be considered.

One way to estimate the probability of a sonde hitting an aircraft is to run a model that considers the moving aircraft according to the ATC records and simulated drops of sondes including the height-dependent falling speed and the displacement by wind drift. However, tracking an adequate number of sondes to statistically ascertain the presumably low collision probability would need extensive computing resources.

Therefore in this paper a simplified way to obtain about the same result is chosen: In a kind of static approach all aircraft flying over Germany at a certain time are regarded and the total area all of them provide for a possible collision with a dropsonde is calculated. The ratio of this collision area to the total geographical area of Germany, equal to the areal fraction of aircraft coverage, is then a direct measure of the probability for a single sonde randomly dropped over Germany to collide with one of the aircraft. As a basis for these calculations the total number of aircraft and the composition of aircraft types have been provided by DFS (Deutsche Flugsicherung, the German ATC organization).

Of course, aircraft over Germany and elsewhere are distributed at different flight levels and are climbing and descending. However, in the calculations all aircraft are assumed to fly at the same altitude. This simplification does not restrict reality, as the total area of all aircraft stays the same, but the calculation effort is greatly reduced.

Dropsondes normally drift with the prevailing wind, therefore in addition to their general downward motion there is a horizontal displacement. But with all aircraft at one altitude the dropsondes can be considered as just falling vertically, without there being any influence on the final results.

The relevant collision area of any single aircraft type is calculated in the following way (see Figures 1 and 2): The top view and the front view sketches of different types of aircraft can be found in several publications (e.g. Jane's, 1983–1984; DFS, 1996). By taking the relevant measures of the body, the wings and the tail wings the area seen from above can be calculated. The height of the different aircraft components h_i taken from the front view is used to calculate the area in front of the aircraft, which is relevant for a collision whenever a sonde is in that area. The collision time $t_i(Drop)$, i.e. the time interval the falling sonde is in front of the aircraft component i, is calculated as
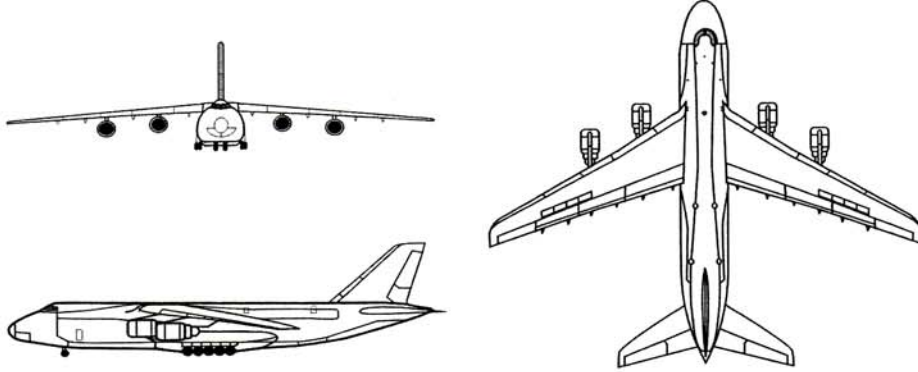
Fig. 1: Example of a typical three view sketch (front, side and top) of an aircraft as found in different aircraft handbooks.
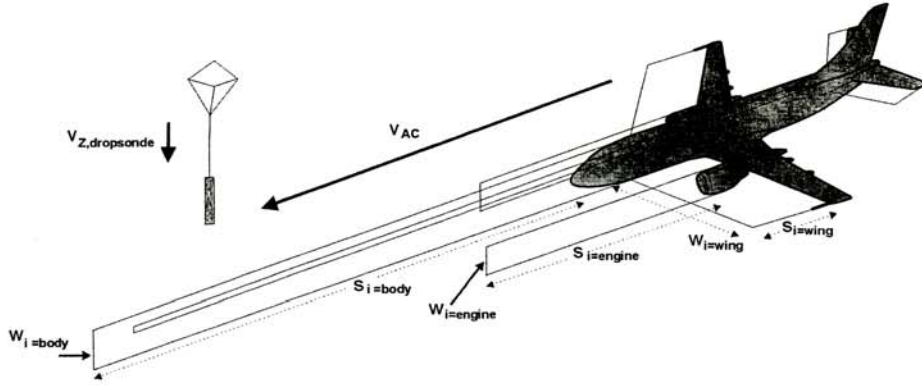
Fig. 2 Illustration of the total collision area. The front collision areas for the different components are about in scale referred to the aircraft size.

$$t_i(Drop) = \frac{h_i + h_D}{v_{z,Dropsonde}} \qquad (1)$$

with $v_{z,Dropsonde}$ = falling speed of the sonde. The term h_D = length of the dropsonde considers the vertical extension of the sonde itself.

During this time interval the aircraft proceeds with speed v_{AC} by a distance

$$s_i = t_i(Drop) \cdot v_{AC} \qquad (2)$$

The collision area F_i in front of component i is then given by

$$F_i = s_i \cdot w_i \qquad (3)$$

with w_i being the horizontal width of the component.

By adding up the top view area and the collision areas of all com-

ponents the total area occupied by the aircraft with respect to a dropsonde collision is obtained. Of course this area strongly depends on the aircraft model, therefore this calculation has to be done for many types of aircraft.

Figure 3 is about in scale, and it can be noticed, that the top view area is only a minor part of the total collision area. The areas in front of the aircraft are determined by the scales of different components: The wings are wide, but have only a limited height, whereas the rudder is very narrow with a large vertical extension. The aircraft body and the engines contribute distinctly, too, due to their large frontal areas.

AIR TRAFFIC DATA BASE

Air traffic data were supplied by the statistical department of DFS. They are based on 1998 flight operations; and the data for July 1998, the busiest month that year, are summarized in Table 1, with the day given in the first column.

The flight activities are separated into flights coming from outside Germany and landing (Entry), those starting in Germany with destinations outside the country (Exit), those crossing Germany without any ground contact (Overflight), and finally domestic flights (Local). They are summed up in the right column. The maximum count in each column is highlighted.
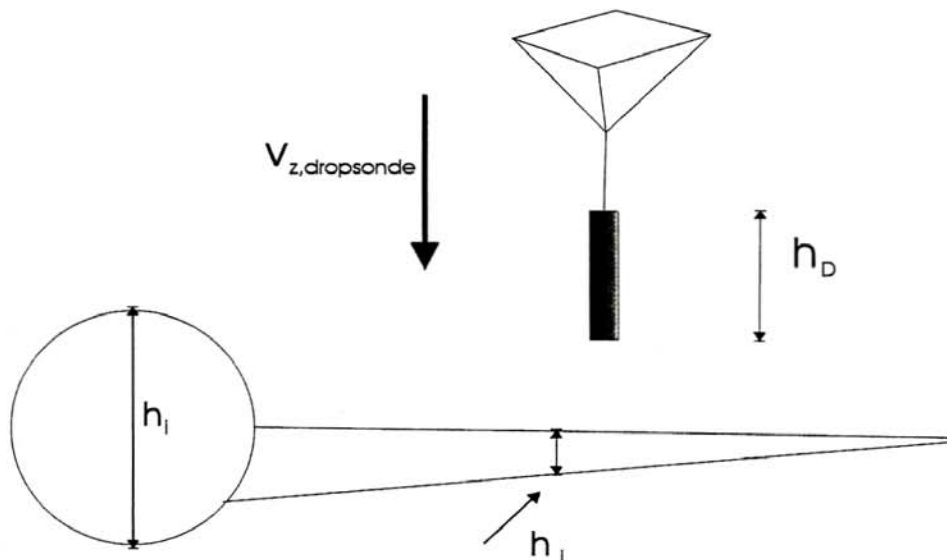
Fig. 3 The collision time interval $t_i(Drop)$ is given by the height of both the dropsonde and the component i and the sonde falling speed $v_{z, Dropsonde}$. For the wings a mean h_i is used, for the dropsonde only the height of the sonde body is considered.

Table 1. Flight Activities in July 1998 Over Germany (with flight plan, IFR rules)

Day	Entry	Exit	Overflight	Local	SUM
1	1,807	1,795	2,118	1,672	7,392
2	1,819	1,835	2,047	1,655	7,356
3	1,851	1,882	2,251	1,566	7,550
4	1,604	1,608	2,102	735	6,049
5	1,596	1,512	2,229	845	6,182
6	1,651	1,652	2,133	1,538	6,974
7	1,776	1,779	2,139	1,696	7,390
8	1,847	1,860	2,183	1,652	7,542
9	1,857	1,862	2,081	1,784	7,584
10	1,920	1,941	2,206	1,597	7,664
11	1,599	1,609	2,083	708	5,999
12	1,622	1,561	2,174	827	6,184
13	1,683	1,662	2,129	1,507	6,981
14	1,732	1,726	2,027	1,524	7,009
15	1,816	1,825	2,104	1,568	7,313
16	1,813	1,822	2,037	1,673	7,345
17	1,896	1,888	2,192	1,503	7,479
18	1,595	1,614	2,042	711	5,962
19	1,631	1,576	2,216	798	6,221
20	1,656	1,659	2,117	1,396	6,828
21	1,726	1,728	2,120	1,485	7,059
22	1,809	1,812	2,186	1,496	7,303
23	1,797	1,790	2,094	1,471	7,152
24	1,863	1,923	2,111	1,432	7,329
25	1,616	1,619	2,108	716	6,059
26	1,637	1,585	2,234	762	6,218
27	1,685	1,635	2,131	1,373	6,824
28	1,764	1,732	2,148	1,498	7,142
29	1,831	1,837	2,116	1,625	7,409
30	1,870	1,843	2,013	1,531	7,257
31	1,891	1,945	2,156	1,371	7,363
CMPL	54,198	54,055	65,714	41,491	215,458

Day:	Day of the month July 1998.
Entry:	Number of international flights arriving in Germany.
Exit:	Number of international flights departing from Germany.
Overflight.	Number of flights without ground contact in Germany.
Local:	Number of domestic flights in Germany.
Sum:	Sum of all flights per day.
CMPL:	Columnar sums, corrected for flights lasting over midnight and being counted in both adjacent days.

The final row (CMPL, for COMPLETE) does not give the columnar sums, but the total number of flight activities. This number is lower, as flights lasting over midnight are counted in both adjacent days, but this overestimate is corrected in the numbers of the last row.

The different categories are about equivalent with slightly higher overflight numbers. Furthermore the weekends can be distinguished from the total sum (last column) and very easily from the local flight density, which is only about half compared with weekdays.

In Table 2 the flight activities of July 10, the day with the maximum number in Table 1, are further split up into hourly intervals (first column). The typical daily course is obvious with distinctly reduced flight activities at night. On the other hand there is no distinct daytime peak, but a broad distribution with about 700 flights per hour between 6:00 and 18:00. Again flights covering two adjacent hours are counted in both hours, but only once in the final row labeled CMPL. The maximum number of 780 for the time interval 15:00 to 16:00 will be used later for the collision probability calculations.

THE DROPSONDE SYSTEM

The dropsonde system presently in use on the hurricane research aircraft of NOAA (National Oceanic and Atmospheric Administra-

Table 2. Flight Activities Over Germany in Hourly Intervals for July 10, 1998 (with flight plan, IFR rules)

Time	Entry	Exit	Overflight	Local	SUM
00:00	9	11	25	10	55
01:00	9	22	27	3	61
02:00	19	25	39	7	90
03:00	45	35	63	11	154
04:00	60	82	68	82	292
05:00	109	163	124	168	564
06:00	157	164	198	210	729
07:00	196	144	152	227	719
08:00	198	166	164	180	708
09:00	172	203	227	159	761
10:00	147	205	235	134	721
11:00	158	182	203	165	708
12:00	175	187	207	160	729
13:00	180	160	193	185	718
14:00	178	154	199	206	737
15:00	199	162	220	199	780
16:00	215	158	171	208	752
17:00	212	161	157	185	715
18:00	194	181	212	163	750
19:00	153	142	170	111	576
20:00	126	92	91	42	351
21:00	59	48	68	29	204
22:00	39	23	81	23	166
23:00	15	7	46	23	91
CMPL	1,920	1,941	2,206	1,597	7,664

Columnar sums in **CMPL** are corrected for event counts in adjacent hours.

tion, U.S.A.) and the US Air Force, as well as on several research aircraft in the U.S.A. and Europe, is the AVAPS system jointly developed by NCAR (National Center for Atmospheric Research, Boulder, CO, U.S.A.), NOAA, and DLR. AVAPS stands for Airborne Vertical Atmospheric Profiling System (Cole, 1997; Hock and Franklin, 1999). The dropsondes are manufactured in license by VAISALA.

The sonde body consists of a fiberboard shell containing the sensors and the electronics. It has to be mechanically strong to withstand the heavy load when being released from the aircraft. A parachute and a cord add up to a total length of about 1.70 meters. However, only the fiberboard shell measuring 40.6 cm in length and 6.98 cm in diameter is considered to be dangerous when colliding with an aircraft. It contains nearly the total mass of the system, which is less than 400 grams anyway.

The sonde descent time is approximately 16 minutes from 14 km altitude, the descent speed is about 17 m/s at 11 km altitude, about 13 m/s at 7 km altitude, and about 10 m/s near the ground. The first two speeds are used in the calculations for high flying jets and lower flying turboprop aircraft, respectively.

RESULTS

In Table 3 the results of the calculations are summarized. The first two columns describe the aircraft type and amount as provided by DFS for July 10, 1998. Thirty-five classes are identified in detail, those remaining are summarized as 'others'. The collision areas are calculated by the method previously stated. Multiplication by the fleet fraction, which is the ratio of the number of a specific aircraft type to the total number of 7,664, leads to a collision area fraction. These area fractions add up to a collision area of 1,184.68 m^2, which is the mean value for one aircraft considering the given aircraft fleet mixture.

In the calculations the following assumptions were made:

1. The unknown mean collision area of the "other" aircraft is assumed to be the same as that of the known aircraft (1,185 m^2). Although these other aircraft amount to only 14.98% of the total fleet, nothing is known about their size; the calculated value is thought to overestimate the true collision area. There might be a few rare wide body or medium range commercial aircraft in that class, but most of them are believed to be small single engine general aviation aircraft flying under IFR conditions.

Table 3. Aircraft Type Distribution and Reuslting Mean Collision Area

ICAO Desig-nator	Amount	Aircraft Type	Total Collision Area [m²]	Fleet Fraction	Collision Area Fraction [m²]
B73B	1,525	Boeing 737-300/400/500	993	0.1990	197.59
A320	846	Airbus A 319/320/321	1,133	0.1104	125.07
MD80	407	MD-80	1,146	0.0531	60.86
ATR	359	ATR 42/72	659	0.0468	30.87
BA46	334	BAC 146-100/200/300	793	0.0436	34.56
B757	324	Boeing 757	1,481	0.0423	62.61
CARJ	297	Canadair Regional Jet	526	0.0388	20.38
B767	206	Boeing 767	1,961	0.0269	52.71
DHC8	188	Dash-8	724	0.0245	17.76
B74B	167	Boeing 747-400	3,712	0.0218	80.89
F50	159	Fokker 50	749	0.0207	15.54
A310	155	Airbus A 310	1,918	0.0202	38.79
A300	146	Airbus A 300	1,947	0.0191	37.09
B73A	143	Boeing 737-100/200	873	0.0187	16.29
B727	100	Boeing 727-100/200	1,221	0.0130	15.93
T154	95	Tupolev Tu-154	1,574	0.0124	19.51
B74A	93	Boeing 747-100/200/300	3,712	0.0121	45.04
B73C	90	Boeing 737-600/700/800	993	0.0117	11.66
F70	81	Fokker 70	839	0.0106	8.87
A340	68	Airbus A 340	2,709	0.0089	24.04
BE20	67	Beech 200, 1300 Super King Air	361	0.0087	3.16
SF34	66	SAAB-Fairchild SF-340	588	0.0086	5.06
DC9	66	Douglas DC-9	911	0.0086	7.85
SB20	65	SAAB 2000	793	0.0085	6.73
MD11	55	MD-11	2,530	0.0072	18.16
C525	54	Cessna 525 Citation Jet	361	0.0070	2.54
C550	52	Cessna 551 Citation 2SP	361	0.0068	2.45
LJ35	48	Gates Learjet 35	361	0.0063	2.26
C130	41	Lockheed C-130	1,694	0.0054	9.06
PA34	40	Piper PA-34 Seneca	361	0.0052	1.88
B777	40	Boeing 777-200/300	3,093	0.0052	16.14
D328	37	Dornier 328	751	0.0048	3.63
F27	34	Fokker F-27 Friendship	776	0.0044	3.44
C160	34	Transall C-160	1,446	0.0044	6.40
TOR	34	Tornado	541	0.0044	2.40
Other	1,148		1,185	0.1498	177.45
SUM	7,664			1.0000	
				Mean collision area [m²]:	**1,184.68**

Amount:	Number of 35 individual aircraft types over Germany on July 10, 1998. The remaining aircraft are summarized as "other". All individual amounts add up to the total number of 7,664 aircraft counted that day (compare Tables 1 and 2).
Collision Area:	Total collision area for each aircraft.
Fleet Fraction:	Ratio of the amount of each specific type to the total number of 7,664 aircraft. All fleet fractions need to add up to 1.000.
Area Fraction:	Product of the collision area and the fleet fraction for each individual aircraft type. All area fractions add up to a mean collision area for one single aircraft representing the actual fleet mixture.

2. The collision area of a Cessna Citation was used for other aircraft of similar size, like the Learjet 35, the Beech 200 and the Piper Seneca.

3. The collision area for the B 747-400 was used for the smaller B 747-100 to 300 aircraft, as no data were available for those types.

To calculate the probability for a randomly dropped sonde to collide with an aircraft, the mean collision area is multiplied by the maximum hourly number of aircraft, which is 780 on July 10, 1998, between 15:00 and 16:00. It is presupposed, that every aircraft keeps in the air for the whole hour, which again is an overestimation. On the other hand this assumption is realistic, as an aircraft crossing Germany in North-South direction would need about one hour (approximate flight time from Hamburg to Munich).

The total collision area covered by aircraft would therefore be

$$F_{Aircraft} = 780 * 1{,}184.68 \ m^2 = 924{,}050.4 \ m^2 = 0.92405 \ km^2. \quad (4)$$

Related to the total area of Germany (356,970 km^2) the fraction of aircraft coverage amounts to

$$\frac{F_{Aircraft}}{F_{Germany}} = \frac{0.92405 \ km^2}{356{,}970 \ km^2} = 2.5886 * 10^{-6}. \quad (5)$$

This is the approximate probability, that a single sonde randomly dropped over Germany would hit an aircraft, or in other words, one of about 386,000 randomly dropped sondes is statistically to be expected to collide with an aircraft.

RELEVANCE FOR RADIOSONDES

Radiosondes or better upsondes in the context of this paper are released from a ground station and ascend on a balloon with typical vertical speeds of about 5 m/s. The upsonde body size and weight is quite comparable to that of a dropsonde. Following the same argumentation and mathematical calculation the probability of it colliding with an aircraft should be even higher, as the increased time interval t_i (up) $\cong 3 * t_i$ *(Drop)* should increase the collision area for each aircraft type by about a factor of three.

Furthermore every upsonde passes the airspace twice, ascending on the balloon and descending on a parachute after the burst of the balloon. The time and the geographical coordinates of the launch are known and published. However, upsondes strongly drift horizontally with the wind. Therefore they may pass the altitude band covered by air traffic some distance away from their launch position. When the balloon finally bursts about 90 minutes after launch, the area the sonde descends is completely unpredictable and random.

The overall collision probability for a single upsonde is therefore estimated to be about $1*10^{-5}$ at the same peak traffic hour situation the dropsonde estimates are based on. As some of these sondes are

released at midnight, when air traffic is reduced, the overall collision probability for upsondes should be somewhat lower. With a minimum of about 30 upsondes released in Germany every day, this means that one collision has to be expected in a time period of about 10 to 12 years.

DISCUSSION

Calculating one single collision probability for the geographical area of Germany by assuming a homogeneous distribution of the aircraft motion is a simplification. The air traffic over Germany and Europe is mostly determined by a network of standard airways the aircraft are aligned like pearls on a string. But these airways have a remarkable width of 10 nautical miles, which broadens the areal distribution.

On the other hand, Germany at its position in Central Europe is highly affected by transits from and to other European countries. This results in an overall much higher traffic density compared to other neighbouring countries.

Both features can be recognized in Figure 4, showing a snapshot of the air traffic over Germany. The southern part is marked by a higher traffic density, whereas the northern and eastern part is distinctly less occupied by air traffic. Therefore the collision probability might depend on the part of Germany the sondes are dropped, with higher values in the central and southern part of Germany and lower values in the areas of little air traffic.

Although these inhomogeneities level out in the mean value for total Germany, they become important for any regional estimate of a collision probability, for example in the vicinity of a major airport.

Another remark concerns the ATC supervision of any dropsonde release. While so far the sondes were treated as randomly dropped, in reality every flight mission with dropsonde release has to be announced to ATC well in advance. During the mission for every single drop the airspace below is checked by the ground controller to avoid any danger for other aircraft. He then gives the final clearance for dropping the sonde.

Following this procedure a collision is very unlikely in a controlled airspace. When transferred to areas without radar surveillance like the North Atlantic air traffic track this study may give hints for the collision probabilities to be expected, but of course it needs to be adjusted to the lower traffic density and the aircraft type distribution of those areas. For example the fleet composition should be distinctly shifted towards wide body aircraft.

Looking at upsondes there is some collision probability left, as they
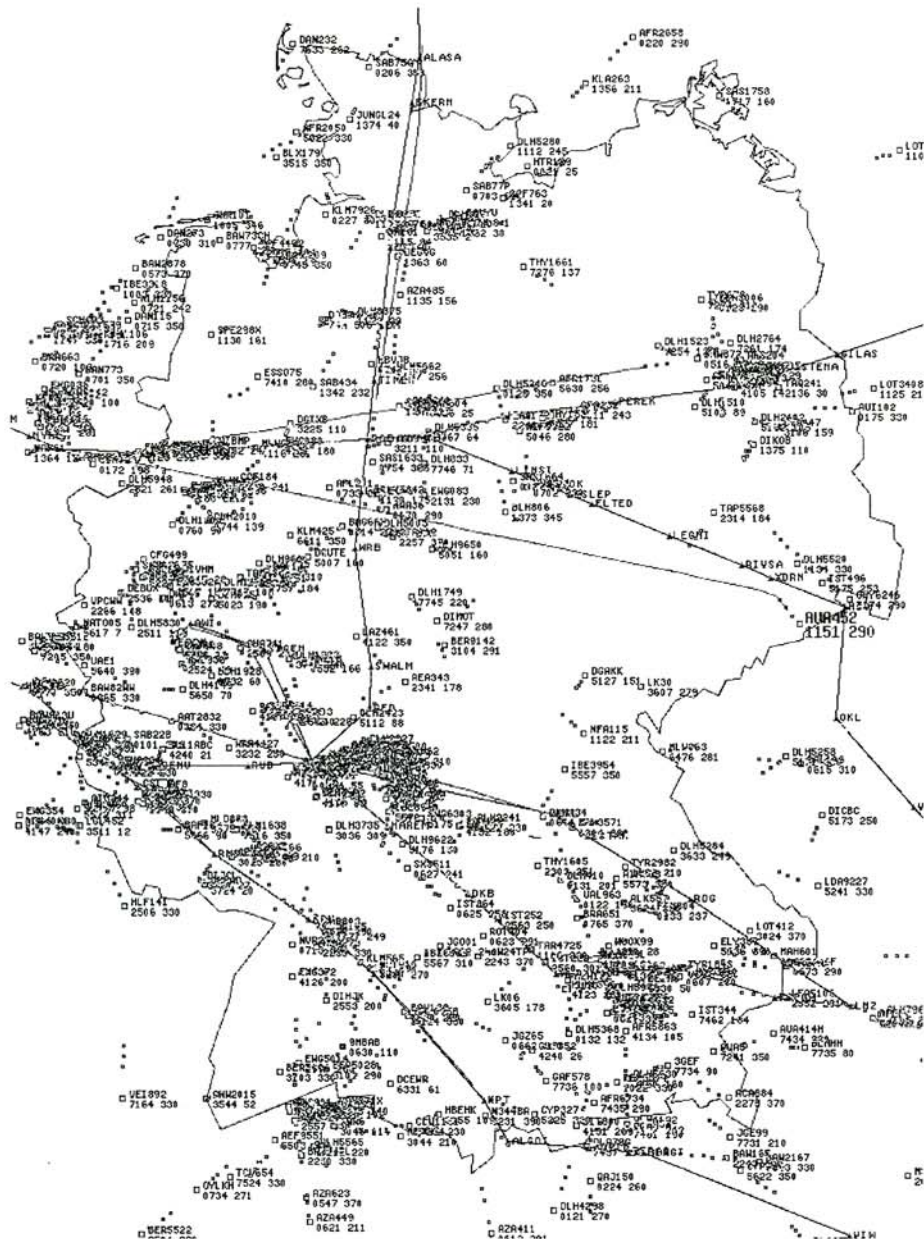
Fig. 4: Snapshot showing the typical air traffic over Germany. Each aircraft is marked with an open square and a label showing the flight ID (upper line) and the transponder code and flight altitude (in hecto feet) below. Distinctly high concentrations are found near airports, e.g. Frankfurt, Munich, Berlin. The straight lines denote flight tracks for some individual aircraft as filed in the flight plans.

are really uncontrolled during most of their flight through the atmosphere. Over Germany an average of about 3 upsondes per year in the proximity of aircraft are observed and reported by pilots (DFS, private communication), but there have been no accidents or dam-

ages so far, resulting from collisions of upsondes and aircraft. However, some sondes may have been destroyed without the pilots perception. In such a case the ground station recognizes a sonde failure and would probably release a second one, if the 'failure' happens during the ascent. During descent the sondes are not tracked anyhow, therefore a 'failure' would not attract any attention.

Another general assumption made in this paper is the effectiveness or danger of any collision to be independent of the sonde type and of the aircraft component hit by it. Upsondes consist of electronic and sensor components packed in a relatively huge styrofoam case for thermal isolation during the long ascent towards the higher and colder regions of the atmosphere. Dropsondes don't need that much insulation, as they quickly descend towards warmer atmospheric layers. But their case has to be stiff to withstand the gravitational shock load they undergo during launch. So a dropsonde case, a fiberboard tube, may cause greater damage when hitting a sensitive component of the aircraft than an upsonde package. Therefore experimental impact tests for this sonde type may become necessary before dropping them in any airspace without radar surveillance.

Unfortunately very little information is available regarding experimental impact tests. A report of the COSPAR working group 6 (Morel, 1970) dealing with "Constant-level balloon impact on aircraft structure" summarizes the following recommendations (extracts):

- *Ingestion tests by a running jet engine were conducted using an electronic package weighing 120 grams. Considering that considerably more stringent specifications are met by jet engines for ingestion of high density objects, like stones, without serious damage, it is concluded that the ingestion of a low density electronic package by the engines will not compromise aircraft operation.*

- *Impact on leading edges: Assuming that all the energy on impact is converted into force (a very conservative estimate), the effect of a light (500 grams) payload section impacting at 600 mph (960 km/h) is a 10 to 20 ton load on the wing. Considering that current commercial jet aircraft have a wing loading capability in excess of 50 tons to withstand engine thrust and landing gear loads, it is concluded that constant level balloons or balloon payloads would not induce an excessive impact load if a reasonable mass (0.5 kg) or lineal density (1 kg per meter) is not exceeded.*

Another statement is found in a working paper of ICAO's Air Navigation Commission (1978). Here unmanned free balloons are classified into three divisions of heavy, medium and light, which are each characterized by total mass and compactness (mass/size ratio). Normal radiosonde balloons and also the dropsondes presently in use fall into the classification of light unmanned free balloons, which are stated not to represent any hazard to aircraft (ICAO, 1978).

However, applying these findings to the upsondes and dropsondes presently in use and to the structural properties of modern aircraft may not be justified. The danger of sonde impacts therefore cannot be quantified within the scope of this paper and would probably need further experimental investigations.

Applying the whole day aircraft fleet mixture or the resulting mean collision area for one aircraft, respectively, to the traffic density data of a single hour may cause minor uncertainties. Of course the fleet composition may be shifted towards larger aircraft by night, whereas the relative importance of small and military aircraft may be more pronounced during daylight. But using the peak traffic hour density should compensate for these differences.

From the points discussed so far it becomes obvious that the study presented here cannot give final numbers, but rather an estimate on the upper bound of the collision probability magnitude, or the danger dropsondes may cause for commercial air traffic. The calculations are based on real numbers and distributions, but of course they represent only a snapshot of the situation. But with upper limits considered for almost every assumption, the probability estimate is believed to represent reality quite well, including some generous safety margins.

So the continued and expanded use of dropsondes appears encouraging for the additional weather data they can provide. At the same time their probability of an impact with another aircraft is estimated to be about 1/4 of that now encountered with currently used upsondes, which appear never to have caused any reported damage. The effects of any impact by either type of sonde appear to be slight, but impact testing is urgently needed, and close cooperation with ATC must be maintained.

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ACRONYMS

AIP	Aeronautical Information Publication
DFS	Deutsche Flugsicherung, the German ATC organization
CMPL	Complete
ICAO	Intrnational Civil Aviation Organization
NOAA	National Oceanic and Atmospheric Administration, U.S.A.

NCAR   National Center for Atmospheric Research, U.S.A.
AVAPS   Airborne Vertical Atmospheric Profiling System
DLR   Institute for Atmospheric Physics

SYMBOLS

F Collision area in front of aircraft component, i
h Height of aircraft component
v Speed
$t_i(Drop)$ time interval the falling sonde is in front of aircraft component, i
s Horizontal distance aircraft moves when it may be hit by sonde
w Horizontal width of aircraft conmponent

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BIOGRAPHY

Reinhold Busen is a research scientist working at the Institute of Atmospheric Physics of DLR (German Aerospace Center). He received both his Diploma in Meteorology (1981) and his Ph.D. (1988) from the University of Frankfurt. Since joining DLR in 1988, he has worked in the field of airborne atmospheric research with specific interest in atmospheric humidity. He has successfully conducted several research projects dealing with the impact of emissions from air traffic on the atmosphere and on climate.

For the past 5 years Dr. Busen has operated a dropsonde system on board the DLR research aircraft to obtain vertical profiles of atmopheric state parameters. In this connexion he became involved in air traffic regulations and air safety needs.