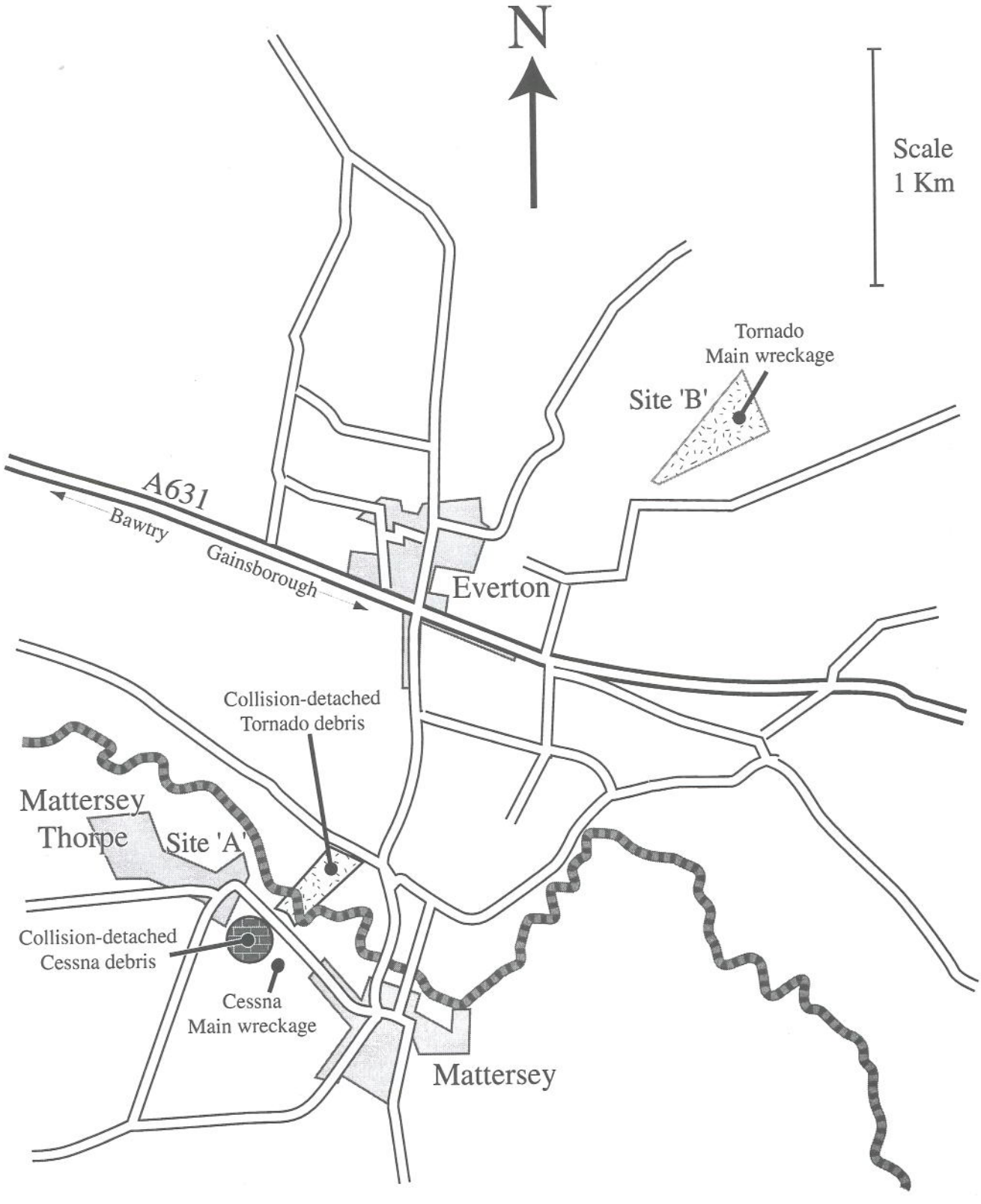
Extract from Audio Track on Tornado ADR

Time to Impact (seconds)	Crew Member	Crew Conversation
-48	Student	Look Outside
-46	Student	We got eighty - eighty miles to go - so we can do an Ops check
-42	Instructor	Good
-40	Student	OK - Fuel I got three thousand and (one) hundred and twenty - the front (burning) three hundred (????)
-32	Student	Sequence is normal
-31	Student	Temperature nineteen and er - nineteen - both
-23	Student	Instruments - my engine instruments are checking good
-21	Student	ADI is erected
-20	Student	One zero zero five give me four hundred and fifty
-16	Student	And I got on the rad- altimeter six hundred and fifteen
-12	Instructor	OK - ECS is still blowing
-10	Instructor	In the back
-8	Instructor	We got voltmeters in the green - pulsing
-6	Instructor	SAHR and IN headings look pretty reasonable
-4		The rest of the kit is good
-2	Student	OK - Er - And I got Cabin Alt-
0		Impact

( ) brackets denote uncertain or unknown word

Map of collision area and wreckage scatter



Executive summary of DERA 'See and Avoid' study

This report describes the development of a mathematical model representing the salient characteristics of activity in the UKLFS. Data were collected from a wide variety of sources in order to characterise the total amount of civil and military activity, its temporal variation and its spatial distribution. The model reproduces representative topographical and regulatory characteristics of the UKLFS in a simulated area about one sixth of the total size. Predictions were made of the annual collision rates assuming no effect of the see and avoid principle. These were compared with observed rates of confliction as reported to the Joint Airprox Working Group. A satisfactory level of agreement was found. Civil-military conflictions were slightly underestimated. The main reason appears to be greater tendency to report such conflictions than those between like types.

The salient effects of aircraft characteristics, environmental factors, and psychological processes were represented in a model which allowed the residual collision rates taking account of the see and avoid principle to be estimated. The estimates are in reasonable agreement with the historical record. Visual lookout is assessed as generally more than 99% effective in resolving conflictions. Existing conspicuity measures are effective. Worthwhile reductions in the collision rate could be obtained using collision warning systems, high power lamp assemblies, and black paint schemes.

Estimation of Detectability of Each Aircraft Involved in the collision

1. Resume of events: On 21 January 1999 an Italian pilot was to fly his first low level sortie in the Tornado. An RAF flying instructor occupied the rear seat. Shortly after take off the aircraft was on a heading of 41°, at 435 kt, between 600 and 700 feet agl. It struck a Cessna 152 circling near the village of Mattersey. Both aircraft were destroyed. The RAF pilot, the Italian pilot and the pilot and passenger in the Cessna were all killed. The visibility was 10 km, and there was no significant cloud.

2. Discussion: The principal factors in the causation of this accident concern visual look out and aircraft conspicuity. Taking into account the weather conditions, time of year, time of day, latitude, the geometry of the collision, and the characteristics of the aircraft, it is possible to estimate the detectability of each aircraft from the point of view of the other. Three viewpoints need to be considered: The RAF pilot's, the Italian pilot's, and that from the Cessna.

3. The view from the Cessna: Eyewitness evidence suggests that the Cessna was in a sustained left turn at the time of impact, and had, in fact, completed more than one orbit. It is highly likely that the attention of both the pilot and the passenger was focused on the point on the ground around which they were orbiting. The Tornado would also have been obscured much of the time by parts of the airframe. Figure 1 illustrates the intrinsic detectability of the Tornado during the last 25s before impact. It shows the cumulative probability of detection assuming no obscuration and a reasonably broad scan (180° by 30°). Throughout this period the Tornado would have been more than 40° from the sun; glare would not have had much influence on its detectability. Assuming the Cessna was in a 30° banked turn at about 90 kt, and was on a heading of about 80° at impact, the Tornado would have been unobscured between about 20s and 14s from impact (I-20 to I-14s). On this basis, a diligently scanning pilot could have had about a one in five chance of detecting the confliction.

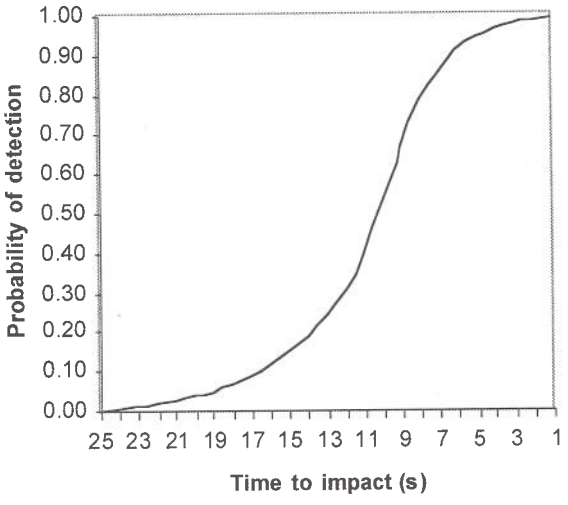


Figure 1:
Intrinsic conspicuity of the Tornado

4. The view from the Tornado (rear seat): Of all the people involved in the collision the RAF pilot was probably the best prepared to maintain a good visual look out in terms of his training, airmanship, and workload. Unfortunately, he did not have an unobstructed view in the forward sector, and had no opportunity to detect the confliction.

5. The view from the Tornado (front seat): Figure 2 shows the cumulative probability of detecting the Cessna given an unobscured view. These estimates take account of the transmissivity of the canopy and the head up display (HUD) combiner glass, but it is not known whether the pilot in the front seat was using his clear or dark visor, so two curves are shown. Again, a reasonably broad scan is assumed (180° by 30°). With a clear visor, the cumulative probability of detection passes 0.5 at about I-8.5s. Using the dark visor introduces a delay of about 2s. On this basis the Cessna was, in principle, reasonably detectable, but this assessment takes no account of clutter in the HUD.

6. From the viewpoint of the pilot in the front seat the Cessna was positioned within the HUD frame throughout the last 25s before impact. It is unlikely that it made any significant change in height, so it would have been close to the HUD horizon bar making lateral translations of a few degrees until the last few seconds, when it would have increased in apparent size dramatically. The effective apparent size of the Cessna would not have been significantly greater than the thickness of the horizon bar (2mrad) until some eleven seconds from impact. Complete or partial obscuration by the HUD symbology was a significant possibility until about I-7s. Even without obscuration, the effect of the HUD symbology would have been to reduce the probability of detection.

7. Most research on visual search in cluttered fields deals with factors such as the effects of non-target density and the discriminability of targets from non-targets, and, as such, does not cast much light on the problem of detecting unexpected targets in the background of an informative, virtual image. There is some evidence (eg Reference A) suggesting that, even though the virtual image and the real background may be at the same optical distance, attention may be confined to one at a time. Thus, the HUD symbology forms a *Gestalt* separate from that of the world beyond, so that, particularly when detailed, numerical information is being extracted from it, cues in the background are less likely to be noticed. The magnitude of this effect (which has been called cognitive tunnelling) cannot be estimated with any confidence, but it is likely to be more potent for unexpected events. It is possible that it had a particular influence on events at a critical moment. The identification of that moment is possible by reference to the cockpit voice recording (CVR) and airborne data recording (ADR).

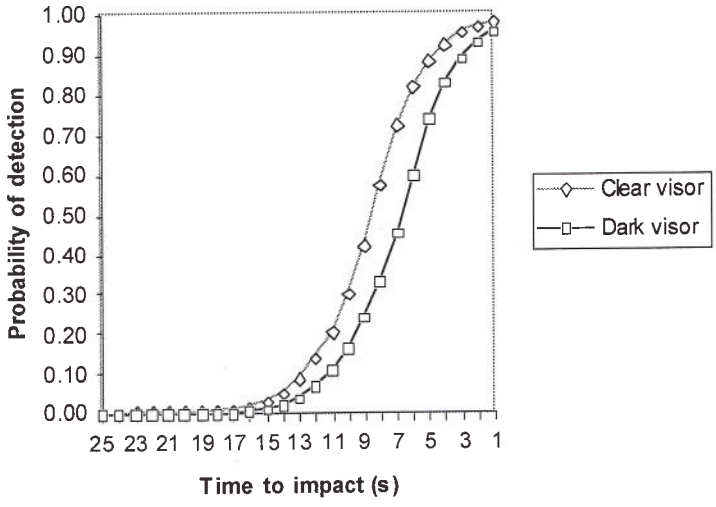


Figure 2:
Intrinsic conspicuity of the Cessna

8. The CVR reveals that during the 30s before impact the Italian pilot was engaged in a routine check procedure. For most of that time his focus would have been on displays within the cockpit. The checks were carried out in a slow, deliberate manner. It is difficult to believe that he was able to give more than scant attention to visual look out. However, he did make a small adjustment in heading during this period (Figure 3), possibly by reference to the HUD. Figure 3 suggests that he would have interrogated a heading reference at about I-15s, to initiate the manoeuvre, and again at I-7s, to complete it. During the first interrogation the Cessna would have been more or less head on, and presented a small, difficult target. Even if he used the HUD at this point, the probability of his detecting the confliction would have been negligible (even without the effects of clutter). At I-7s, however, the Cessna would have been quite detectable, and a line of sight centred on heading information at the bottom of the HUD would, in theory, have been close enough for the stimulus to register. That it did not is clear from the fact that the Italian pilot went on to check displays on the right-hand console. The effects of clutter and cognitive tunnelling offer an explanation for this failure. Equally, it is not possible to dismiss the possibility that he used a head down display at the critical moment, particularly bearing in mind that the transfer to head up references imposes a significant delay as the line of sight and accommodation of the eyes are changed.

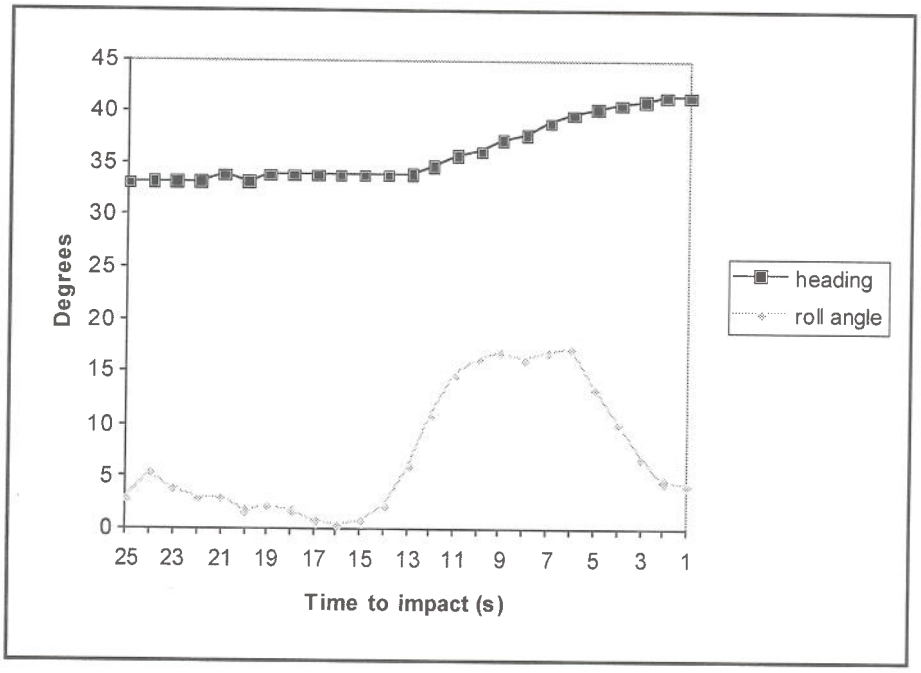


Figure 3:
Tornado roll angle and heading

9. Even allowing that the RAF pilot could make no contribution to look out in the forward sector, and that those aboard the Cessna were probably pre-occupied with ground references at the critical time, the see-and-avoid principle could well have prevented this accident. That it did not can be attributed, in part at least, to the Italian pilot's preoccupation with within-cockpit checks for a substantial period. This fact calls into question the advisability of requiring trainees to perform such checks before they have had a chance to adapt to low level flying, particularly in the case of trainees, like this pilot, whose previous experience is largely confined to less threatening environments.

10. Conclusions: The nature of the Cessna's final manoeuvre presented those on board with only a limited opportunity for detecting the Tornado, and it is likely that their attention was confined to ground references during the critical period.

11. Only the pilot in the front seat of the Tornado had any opportunity to detect the confliction. In principle, in the conditions prevailing, a diligent scan would have had a moderate probability of revealing the threat in time to allow avoiding action to be taken. This principle was undermined by the pilot's attention to a routine check procedure. His lack of experience, and the nature of his previous flying experience probably contributed to this error. It is possible that the effects of clutter in the HUD reduced the probability of detection at a critical moment.

12. Remedies: Whether or not high intensity strobe lights were operating on these aircraft had no bearing on the outcome. High powered lamp assemblies on the Tornado would have enhanced its conspicuity, but to no avail if the Cessna occupants' attention was elsewhere. If

the Cessna had been operating a transponder, and the Tornado had had a collision warning system, it is virtually certain that the collision would have been avoided. It is in exactly this circumstance, when the see and avoid principle is compromised by workload or inexperience, and the conflicting aircraft is marginally detectable that a collision warning system becomes most valuable.

References:

A. Wickens, C. D. and Long, J. (1995). Object versus spaced-based models of visual attention: Implications for the use of head-up displays. Journal of Experimental Psychology: Applied, 1, 179-183.

Relevant regulations

The Rules of the Air Regulations (1996) are set out in Statutory Instrument No 1393 of 1996. The following paragraphs include extracts from the Rules, as that are considered to be relevant to this investigation:

Low Flying

5 (1) Subject to the provisions of paragraphs (2) and (3):

(a) An aircraft other than a helicopter shall not fly over any congested area of a city, town or settlement below:

(i) such height as would enable the aircraft to alight clear of the area and without danger to persons or property on the surface in the event of failure of a power unit….; or

(ii) a height of 1500 feet above the highest fixed object within 600 metres of the aircraft:

whichever is the higher.

.....

(e) An aircraft shall not fly closer than 500 feet to any person, vessel, vehicle or structure."

Rules for avoiding aerial collisions

17 (1) General

(a) Notwithstanding that the flight is being made with air traffic control clearance it shall remain the duty of the instructor of an aircraft to take all possible measures to ensure that his aircraft does not collide with any other aircraft.

(2) Converging

(b) (i)..... when two aircraft are converging in the air at approximately the same altitude, the aircraft which has the other on its right shall give way:

(3) Approaching head on

When two aircraft are approaching head on or approximately so in the air and there is danger of a collision, each shall alter its course to the right.

(4) Overtaking

(a)..... an aircraft which is being overtaken in the air shall have the right of way and the overtaking aircraft, whether climbing, descending or in horizontal flight, shall keep out of the way of the other aircraft by altering course to the right and shall not cease to keep out of the way of the other aircraft until that other aircraft has been passed and is clear, notwithstanding any change in the relative positions of the two aircraft."

Air Navigation (No.2) Order 1995

SCHEDULE 8

Flight crew of aircraft – Licences and Ratings

PART A – LICENCES

1 AEROPLANE PILOTS

Private Pilot's Licence (Aeroplanes)

Minimum age -17 years
No maximum period of validity
Privileges:

(1) .....the holder of the licence shall be entitled to fly as pilot in command or co pilot of an aeroplane of any of the types specified or otherwise falling within the aircraft rating included in the licence:

(2) (a) He shall not fly such an aeroplane for the purpose of public transport or aerial work save as herein provided":

The schedule allows a PPL holder to conduct aerial work related to flying instruction (if his licence includes a flying instructor's rating), towing a glider or the dropping of persons by parachute.

"He shall not receive any remuneration for his services as a pilot on a flight save that if his licence includes a flying instructor's rating.....he may receive remuneration for the giving of such instruction or the conducting of such flying tests"

Extract from Air Navigation Order

Public transport and aerial work

119 (1) (a) Subject to the provisions of this article, aerial work means any purpose (other than public transport) for which an aircraft is flown if valuable consideration is given or promised in respect of the flight or the purpose of the flight.

(b) If the only such valuable consideration consists of remuneration for the services of the pilot the flight shall he deemed to be a private flight for the purposes of Part III of this Order.

(2) Subject to the provisions of this article, an aircraft in flight shall for the purposes of this Order be deemed to fly for the purposes of public transport:

(a) if valuable consideration is given or promised for the carriage of passengers or cargo in the aircraft on that flight;

(b) if any passengers or cargo are carried gratuitously in the aircraft on that flight by an air transport undertaking, not being persons in the employment of the undertaking (including, in the case of a body corporate, its directors and, in the case of the Authority, the members of the Authority), persons with the authority of the Authority either making any inspection or witnessing any training, practice or test for the purposes of this Order, or cargo intended to be used by any such passengers as aforesaid, or by the undertaking; or

(c) for the purposes of Part III of this Order (other than articles 14(2) and 15(2) thereof), if valuable consideration is given or promised for the primary purpose of conferring on a particular person the right to fly the aircraft on that flight (not being a single-seat aircraft of which the maximum weight authorised does not exceed 910 kg) otherwise than under a hire-purchase or conditional sale agreement.

(3) (a) Notwithstanding that an aircraft may be flying for the purpose of public transport by reason of sub-paragraph (2)(c), it shall not be deemed to be flying for the purpose of the public transport of passengers unless valuable consideration is given for the carriage of those passengers.

(b) A glider shall not be deemed to fly for the purpose of public transport for the purposes of Part III of this Order by virtue of

paragraph (2)(c) if the valuable consideration given or promised for the primary purpose of conferring on a particular person the right to fly the glider on that flight is given or promised by a member of a flying club and the glider is owned or operated by that flying club:

(c) Notwithstanding the giving or promising of valuable consideration specified in subparagraph (2)(c) in respect of the flight or the purpose of the flight it shall:

(i) subject to sub-paragraph (ii) below, for all purposes other than Part III of this Order; and

(ii) for the purposes of articles 14(2) and 15(2) of this Order; he deemed to be a private flight.

(4) Where under a transaction effected by or on behalf of a member of an association of persons on the one hand and the association of persons or any member thereof on the other hand, a person is carried in, or is given the right to fly, an aircraft in such circumstances that valuable consideration would be given or promised if the transaction were effected otherwise than aforesaid, valuable consideration shall, for the purposes of this Order, be deemed to have been given or promised, notwithstanding any rule of law as to such transactions.

(5) (a) For the purposes of paragraph (2)(a), there shall be disregarded any valuable consideration given or promised in respect of a flight or the purpose of a flight by one company to another company which is:

(i) its holding company;

(ii) its subsidiary; or

(iii) another subsidiary of the same holding company

(b) For the purposes of this article 'holding company' and 'subsidiary' have the meanings respectively specified in Section 736 of the Companies Act 1985[(a)]

(6) (a) A flight shall, for the purposes of Part Iv of this Order, be deemed to be a private flight if:

(i) the flight is:

(aa) wholly or principally for the purpose of taking part in an aircraft race contest or exhibition of flying;

(bb) for the purpose of positioning the aircraft for such a flight as is specified in sub-paragraph (aa) hereof and is made with the intention of carrying out such a flight; or

(cc) for the purpose of returning after such a flight as is specified in subparagraph (aa) hereof to a place at which the aircraft is usually based;

(ii) the only valuable consideration in respect of the flight or the purpose of the flight other than:

(aa) valuable consideration specified at paragraph (2)(c); or

(bb) in the case of an aircraft owned in accordance with paragraph (10)(a), valuable consideration which falls within paragraph (10)(0);

is either:

(cc) that given or promised to the owner or operator of an aircraft taking part in such a race, contest or exhibition of flying and such valuable consideration does not exceed the direct costs of the flight and a contribution to the annual costs of the aircraft which contribution shall bear no greater proportion to the total annual costs of the aircraft than the duration of the flight bears to the annual flying hours of the aircraft; or

(dd) one or more prizes awarded to the pilot in command of an aircraft taking part in an aircraft race or contest to a value which shall not exceed £500 in respect of any one race or contest except with the permission in writing of the Authority granted to the organiser of the race or contest which permission may be granted subject to such conditions as the Authority thinks fit;

or falls within both sub-paragraphs (cc) and (dd).

(b) Any prize falling within paragraph (6)(a)(ii)(dd) shall be deemed for the purposes of this Order not to constitute remuneration for services as a pilot.

(7) (a) Subject to paragraph (b), a flight shall be deemed to be a private flight

if the onlv valuable consideration given or promised in respect of the flight or the purpose of the flight other than:

(i) valuable consideration specified at paragraph (2)(c); or

(ii) in the case of an aircraft owned in accordance with paragraph (l0)(a), valuable consideration which falls within paragraph (l0)(0);

is given or promised to a registered charity which is not the operator of the aircraft and the flight is made with the permission in writing of the Authority and in accordance with any conditions therein specified.

(b) If valuable consideration specified at paragraph (2)(c) is given or promised the provisions of that paragraph shall apply to the flight.

(8) Subject to paragraph (0),a flight shall be deemed to be a private flight if:

(i) the only valuable consideration given or promised in respect of the flight or the purpose of the flight other than:

(aa) valuable consideration specified at paragraph (2)(c); or

(bb) in the case of an aircraft owned in accordance with paragraph (10)(a), valuable consideration which falls within paragraph (10)(0);

is a contribution to the direct costs of the flight otherwise payable by the pilot in command; and

(ii) (aa) no more than 4 persons (including the pilot) are carried on such a flight;

(bb) the proportion which such contribution bears to the total direct costs of the flight shall not exceed the proportion which the number of persons carried on the flight (excluding the pilot) bears to the number of persons carried on the flight (including the pilot); and

(cc) no information concerning the flight shall have been published or advertised prior to the commencement of the flight other than, in the case of an aircraft operated by a flying club, advertising whollv within the premises of such a flying club in which case all the persons carried on such a flight who are aged 18 years or over shall be members of that flying club:

(dd) no person acting as a pilot on such a flight shall be employed as a pilot by or be a party to a contract for the provision of services as a

pilot with the operator of the aircraft being flown on the flight.

(b) If valuable consideration specified at paragraph (2)(c) is given or promised the provisions of that paragraph shall apply to the flight.

(9) (a) Subject to paragraph (0), a flight shall be deemed to be a private flight if the only valuable consideration given or promised in respect of the flight or the purpose of the flight other than:

(i) valuable consideration specified at paragraph (2)(c); or

(ii) in the case of an aircraft owned in accordance with paragraph (10)(a), valuable consideration which falls within paragraph (l0)(0);

is the payment of the whole or part of the direct costs otherwise payable by the pilot in command by or on behalf of the employer of the pilot in command, or by or on behalf of a body corporate of which the pilot in command is a director, provided that neither the pilot in command nor any other person who is carried is legally obliged, whether under a contract or otherwise, to be carried.

(0) If valuable consideration specified at paragraph (2)(c) is given or promised the provisions of that sub-paragraph shall apply to the flight.

(10) A flight shall be deemed to be a private flight if:

(a) the aircraft is owned:

(i) jointly by persons (each of whom is a natural person) who each hold not less than a 5% beneficial share and:

(aa) the aircraft is registered in the names of all the joint owners; or

(bb) the aircraft is registered in the name or names of one or more of the joint owners as trustee or trustees for all the joint owners and written notice has been given to the Authority of the names of all the persons beneficially entitled to a share in the aircraft; or

(ii) by a company in the name of which the aircraft is registered and the registered shareholders of which (each of whom is a natural person) each hold not less than 5% of the shares in that company; and

(b) the only valuable consideration given or promised in respect of the flight or the purpose of the flight is either:

(i) in respect of and is no greater than the direct costs of the flight and is given or promised by one or more of the joint owners of the aircraft or registered shareholders of the company which owns the aircraft; or

(ii) in respect of the annual costs and given by one or more of such joint owners or shareholders (as aforesaid);

or falls within both sub-paragraphs (i) and (ii).

(11) A flight in respect of which valuable consideration has been given or promised for the carriage of passengers and which is for the purpose of:

(a) the dropping of persons by parachute and which is made under and in accordance with the terms of a written permission granted by the Authority pursuant to article 49 of this Order;

(b) positioning the aircraft for such a flight as is specified in sub-paragraph (a) hereof and which is made with the intention of carrying out such a flight and on which no person is carried who it is not intended shall be carried on such a flight and who may be carried on such a flight in accordance with the terms of a written permission granted by the Authority pursuant to article 49 of this Order or

(c) returning after such a flight as is specified in sub-paragraph (a) hereof to the place at which the persons carried on such a flight are usually based and on which flight no persons are carried other than persons carried on the flight specified in subparagraph (a);

Relative Attitudes at Impact