Forum

High Speed Craft and Colregs – A Proposal

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Pike has pointed out the increasing risk of collision resulting from the expansion of the fast commercial vessel fleet and has made some proposals for alleviating the problems. This paper points out some difficulties with Pike's proposals and suggests, instead, a simpler modification of the philosophical basis of the COLREGS which would equally alleviate the greater risks of collision introduced by higher speed craft.

1. INTRODUCTION. In a recent paper,[1] Pike pointed out the problems presented by the increasing number of fast commercial vessels. Ships capable of 50 knots and more are already on the drawing board, he said, whilst 40 knot vessels of 140 m length are already operational. Pike asserted that the increasing number and higher capability of these existing and projected vessels exposes potential weaknesses and inadequacies in the COLREGS.[2] The Regulations currently assume that vessels, having observed each other visually or by radar, have time to assess the risk of collision, determine appropriate action and manoeuvre to avoid collision. However, in the case of high speed vessels, the time from likely first contact to the point of collision is sufficiently short that this process has become difficult to sustain. When the give-way vessel is the slower vessel it is increasingly likely that, by the time she has determined that a collision risk exists, it is already too late for her to avoid a collision or very close encounter by her own action alone. Of course the Regulations specify that, in such a situation, the stand-on vessel *shall take such action as will best aid to avoid a collision*, but the stand-on vessel may only do so when she is close enough to be convinced that the give-way vessel cannot avoid a collision by her own actions alone – is it necessary or desirable to compel the high speed vessel to come this close? Pike suggests that, in practice, masters of high speed vessels will do their best to manoeuvre early and in such a way that they avoid situations in which risk of collision exists. But as larger and less manoeuvrable high speed craft (HSC) are built, and become more common, this policy will be increasingly difficult to maintain. As a result of his analysis, Pike outlined a number of changes to the COLREGS which he believed would reduce the risks and problems he had identified.

Mills,[3] commenting on Pike's paper, argued that the existing COLREGS could be interpreted in ways which would allow high speed craft to navigate safely. In particular the safe speed rule (rule 6) does, in appropriate circumstances, compel HSC to reduce speed when in the vicinity of other craft, and, under the existing Regulations, all vessels are permitted, at sufficient distance, to alter course at will to avoid collision risks arising. Mills does suggest that, in constricted and busy waters, a system of Marine Traffic Control may be desirable in order to allow fast vessels to operate to maximum benefit whilst keeping the risk of collision acceptably low. Mills sees such a system as an extension of the principle of Traffic Separation Schemes already provided for in the COLREGS.

Pike[4] subsequently expanded on his earlier contribution. He repeated and extended his list of possible changes which could alleviate the problem. They may be summarised as:

(a) high speed vessels should reduce speed to, say, 30 kt whenever a danger looms,
(b) the COLREGS should require high speed vessels to give way early or to reduce speed if inter-vessel range has reduced below some threshold,
(c) harbour authorities, who might, in the light of (b), be tempted to ban small craft from areas where they might impede high speed commercial traffic, should not yield to that temptation,
(d) the COLREGS should specify a special identification signal to be shown by high speed vessels,
(e) high speed ferry routes should be marked on charts,
(f) small craft should carry brighter lights and radar transponders to make themselves more visible,
(g) the importance of visual lookout should be reinforced perhaps even to the extent of separating the visual and electronic watch functions and outlawing one man bridge operation on high speed vessels.

As a result of the work of Pike and others, including papers at two recent conferences, Cockcroft[5] summarised the basic problem, that of crossing encounters between craft of widely differing speeds, and discussed the possibility of HSC carrying special identifying lights. He noted the problems of defining exactly what constitutes a high speed craft. He also reported that, whilst there is a general agreement amongst mariners that the problem of high speed vessels should be brought to the attention of the International Maritime Organisation, there is a lack of consensus about whether, and in what way, the COLREGS should be altered to take account of the problems. In conclusion, Cockcroft, on behalf of the Institute, invited comments from all interested parties.

It is also worth mentioning here that the problems to which Pike refers are not completely new, having existed in slightly different form for nearly forty years with respect to hovercraft. Hardwick[6] identified the problem in terms of the large disparities of speed and said that the normal practice of seamen had become for small fast craft to keep out of the way of slower, less manoeuvrable craft. The COLREGS were not modified to account for hovercraft other than to introduce a special light to be carried by hovercraft when operating in non-displacement mode. On the other hand, hovercraft have never become very common. Their necessary operational limitations in terms of sea state and their commercial economics have confined them to relatively short-range operations on well-defined routes, mostly in reasonably sheltered waters. The contrast therefore with the current situation is that Pike anticipates (and the author concurs with Pike's assessment) that high speed displacement craft will, in the next few years, become very much more commonplace.

The purpose of this paper is to suggest an alternative approach to the modification of the COLREGS to take account of the problems introduced by the operation of high speed vessels.

2. SOME PROBLEMS WITH PIKE'S RECOMMENDATIONS. Several of Pike's recommendations suggest that HSC should, in one way or another, be differentiated from other craft and that the COLREGS should specify different duties or responsibilities for such craft. For instance high speed craft, he suggests, should be required to reduce speed below some threshold (30 knots is mentioned) as soon as a collision risk is noted, they

should be required to take early action to keep out of the way of other craft, they should be required to take avoiding action in all collision risk situations (i.e. they never 'stand on') and they should carry special identifying lights. All of these changes would require that all sea-going craft could be clearly and unambiguously divided into two categories, high speed craft and the rest (not-high-speed craft?). Pike admits there is no easy solution to this problem though, in several places, he uses the speed of 30 knots as illustrative of the divide between high speed and not high speed.

In the author's view, however, the choice of a single arbitrary speed can never really be satisfactory. If 30 knots is the dividing speed, then a craft travelling at 31 knots will be compelled to behave differently from a craft travelling at 29 knots. It is very important that all craft can quickly recognise any vessel for what it is so that they know their own responsibilities and what to expect of the vessel concerned. For any definition of high speed involving a sharp cut-off speed there will inevitably be doubt about vessels travelling in a range of speeds near the cut-off. It may be argued that such doubt would be eliminated by the carriage of a special light or other signal. Whilst that might seem to settle the difficulty, it must be remembered that the recognition of any special light or daymark at sea in adverse conditions is always problematical. Vital minutes can pass whilst an Officer of the Watch peers through binoculars through mist, haze or spray at a distant vessel continuously disappearing and reappearing as large waves elevate and depress his height of eye. Even if the problem of instant recognition of a high speed craft can be put aside, the idea that a vessel travelling at 31 knots poses a danger which requires different collision avoidance procedures from one travelling at 29 knots is highly questionable.

Cockcroft refers to the 1994 *International Code of Safety for HIgh Speed Craft* for a definition (a craft capable of a maximum speed in metres per second equal to or exceeding 3·7 times the one sixth power of the displacement) but points out that this formula is unsatisfactory for vessels of 500 tonnes or less. But a definition of HSC which uses a sharp cut-off speed which is different for different craft is even more unsatisfactory and potentially more confusing to other vessels than one which uses a single speed for all craft.

A further difficulty with a definition of HSC on the basis of its maximum speed capability is the question 'When is a high speed craft not a high speed craft?' Should high speed craft travelling below the cut-off speed be required to conform to the rules for high speed craft or those for not-high-speed craft? At first sight it would seem obvious that they should behave as not-high-speed craft. But a HSC remains capable of high speed even when operating at lower speeds. There will be situations in which the most seamanlike solution will be to avert a risk of collision by increasing speed. If the HSC crosses the defining speed boundary during such a manoeuvre, which set of rules does it obey? Or should the rules forbid a HSC operating at low speed to increase speed unless there are no other vessels near by?

All these difficulties are effectively the result of trying to differentiate vessels into two categories and give the different categories different responsibilities. It seems to the author that it is largely in order to avoid such difficulties that Mills and others argue that the existing COLREGS can already be interpreted in such a way as to allow the masters of high speed craft to avoid risk of collision by early manoeuvre and that therefore the COLREGS need no modification. But Cockcroft comments on this approach too. He suggests that if a high speed craft takes action when in fact it is the other vessel which is required to keep out of the way and a collision ensues the lawyers acting on behalf of the other vessel will argue strongly that the high speed craft was not acting properly within the COLREGS. Such a case will be difficult to refute.

3. THE PRINCIPLES OF THE COLLISION REGULATIONS. It has been pointed out previously that the COLREGS are, in fact, a set of rules which implement, however imperfectly, an underlying philosophy. Oudet[7] for instance identifies the principle that vessels 'drive on the right' as part of that philosophy. From this principle can be derived the rules for head-on meetings and for crossing situations. On the other hand, the rules for overtaking vessels in open waters derive from a different principle, effectively that a vessel should not be forced to deviate from its current course and speed by the actions of another faster vessel approaching from behind – effectively a 'no pushing and shoving' principle. These principles are not stated explicitly in the COLREGS, but recognising that they exist and identifying their form is helpful both to trainees learning and trying to make sense of the rules, and to those who wish to argue for amendments.

The current COLREGS implement this underlying philosophy in a way which is consistent and satisfactory provided the speeds of all vessels do not differ too greatly. In a crossing situation, the vessel which has the other on its starboard side normally alters course to starboard so that the two vessels pass port to port as they would if 'driving' on the right of the road. Of course, the COLREGS do not mandate exactly that course of action, instead they constrain the seaman more indirectly so that altering to starboard is normally the most sensible option open to him.

The potential problems of such a manoeuvre when the speeds of the two craft vary greatly can be seen by reference to Fig. 1. Vessel S, travelling at 10 knots, first observes

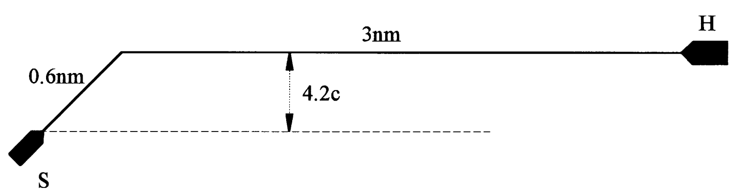

Fig. 1. A crossing encounter between vessels of widely disparate speeds

vessel H, travelling at 50 knots, at a range of 6 miles, a not unreasonable assumption for a small fishing vessel with bridge height-of-eye 4 metres. Taking bearings on H, the master of S determines that a risk of collision exists when H is at a range of 3 miles (3·6 minutes later). S turns to starboard onto a course parallel to H's. If S can turn instantly the passing range will be 4·2 cables. In reality, of course, S has a finite radius of turn which will reduce the passing range still further. In this example, the angle of intersection between the original courses of the two vessels has been taken as 45°. If the angle were more acute the passing range would be reduced still further as it would also if S's speed were yet slower or H's faster. Nor has the finite size of either vessel been taken into account. A large, fast catamaran vessel has a significant beam which will also reduce the passing range. The fundamental difficulty is that, in a crossing encounter when the give-way vessel is the slower vessel, and there is a large disparity of speed between the two vessels, the passing range which the give way vessel can create by its own action alone may be relatively small.

4. THE CALVERT COLLISION AVOIDANCE RULES. Nearly forty years ago, Calvert[8] pointed out that the most effective way to avoid collisions both at sea and in the air lay in a particular set of manoeuvres which are effectively prevented by the current COLREGS. In a crossing encounter, the Calvert system of manoeuvres would require both vessels to alter course to starboard. Hollingdale[9] provided a more formal

mathematical justification for Calvert's work, and a lengthy and fascinating debate following in this *Journal* (Wylie,[10,15] Planty,[11] Morrel,[12,16] Calvert[13,14,17,18] and others). In one contribution Calvert[13] pointed out that his proposals were, he believed, just a logical consequence of the principle which was already inherent in the COLREGS.

The conclusion of the debate might be summarised thus; the seamen accepted the correctness of the theoretical work (which was restricted to encounters between two craft) but were unwilling to accept any need to modify the COLREGS on that basis. One of the reasons for that unwillingness was the perception, on the part of the seamen, that the rules proposed by Calvert were extremely prescriptive, giving not only a direction but also a magnitude for the course change in any encounter. Seamen felt that to accept such a system would restrict their freedom to act in accordance with the *common practices of seamen* particularly where more complex encounters involving several vessels occurred. Further, there would be a temptation to rely on a literal application of the prescriptive rules where good seamanship might demand a deviation therefrom. What seamen desire is a definition of responsibility and the freedom to act appropriately to discharge that responsibility. The COLREGS are a tried and tested formula which provides both that definition and that freedom. As a mathematician, the author appreciates the logic of the Calvert proposals but as a seaman, albeit a part-time one of relatively limited experience, he can also appreciate and sympathise with the misgivings of the seamen.

5. THE CALVERT RULES AND HIGH SPEED CRAFT. Despite their previous unpopularity and their rejection by seamen, the author believes that the Calvert[8] rules indicate the way ahead for a minimal amendment of the COLREGS which would regularise the practice of high speed vessels in manoeuvring to avoid the risk of collision and meet the concerns of Pike and others about the risks introduced by high speed craft.

Firstly, the philosophy of the proposed change must be outlined. The existing principle in the crossing encounter is that the vessel which sees the other to starboard gives way. Usually she does this by altering course to starboard. The other vessel is required to keep her course and speed. The change proposed by the author is to relax this latter requirement, but only to the extent of allowing the vessel which under current rules is the stand-on vessel to alter course to starboard if it is safe to do so and she so desires. The effect of this would be that, in a crossing encounter, the current stand-on vessel would be free to increase the eventual CPA by her own action instead of having to accept that CPA (provided no collision is likely) resulting from the action of the give-way vessel.

The proposed change would not weaken the current requirement on the give-way vessel to keep out of the way nor, since it is permissive but not mandatory, would it entitle the give-way vessel to expect the stand-on vessel to make any particular manoeuvre. It would, however, entitle a stand-on vessel which anticipated that the CPA resulting from the action of the give-way vessel alone would be too small for comfort, to manoeuvre to increase it. Under the current rule 17(a)(ii) the stand-on vessel is already permitted to manoeuvre as soon as it becomes apparent to her that the give-way vessel is not taking appropriate action. The change would allow the stand-on vessel to take action even when the give-way vessel was manoeuvring appropriately.

Is the manoeuvre which the proposed change permits safe? Normally, in a crossing encounter, the give-way vessel will alter course to starboard. The work of Calvert and Hollingdale demonstrates that, in this case, an alteration to starboard by what is currently the stand-on vessel can only increase the eventual CPA. If the give-way vessel, for good reason, elects to adopt any other course of action, the stand-on vessel is not required to do other than stand on as provided by the current regulations. So the proposed permitted manoeuvre is already known to be safe.

The advantage of the proposed change is that, in a crossing encounter between two vessels of disparate speed where the current rules require the faster vessel to stand on, the change would allow the faster vessel to make a manoeuvre which would increase the eventual CPA. This would effectively regularise what is, by all accounts, already the practice of high speed vessels. Cockcroft[5] describes an interpretation of the current COLREGS adopted by some to justify the current practice. When vessels are at a range of 4 or 5 miles, even if they are on a collision course, there is no risk of collision so rules 15–17 do not yet apply and both vessels are free to manoeuvre as they wish. At a lesser range (the rules, of course, make no specification as to what range) a risk of collision exists and the vessels are constrained by the rules. At shorter ranges yet, rule 17(a)(ii) and rule 17(b) apply and the stand-on vessel may manoeuvre in whatever way avoids a collision. Thus, as far as the stand-on vessel is concerned, she may manoeuvre in whatever way she believes desirable (and in accord with good seamanship) provided she does it early enough or late enough. 'Early' and 'late', in this context, are not defined by the rules and, in practice, would be subject to interpretation by the courts subsequent to a collision. Cockcroft mentions the likelihood that, under the current rules, when a stand-on vessel manoeuvres early using the above justification and there is subsequently a collision, the lawyers for the give-way vessel would certainly argue that the manoeuvre was not in accord with the COLREGS. The advantage of the proposed change would be to eliminate the middle period during which the stand-on vessel is required to stand on and instead allow her the discretion to make a particular course change which, in normal circumstances, is bound to increase the margin of safety. In abnormal circumstances, the stand-on vessel is under no obligation to do other than stand on as under the existing rules.

It might be argued that the proposed change would increase the uncertainty during an encounter. Currently, the give-way vessel can rely on the stand-on vessel to maintain course and speed; under the amended rules the give-way vessel would be uncertain as to the actions of the current stand-on vessel. But, as already noted, the permitted action of the stand-on vessel is certain only to contribute to a safe outcome. Under current regulations a give-way vessel which unconditionally relies on the stand-on vessel to maintain course and speed is behaving in an unseamanlike manner. Although in the vast majority of circumstances, the stand-on vessel will do just that, there are circumstances which can force a stand-on vessel to change course or speed regardless (for example, change of direction of a narrow channel, encounter with a third vessel, man overboard) so the give-way vessel must always continue to observe and consider the possibility that the stand-on vessel will manoeuvre despite its obligations under the rules. The proposed change would, therefore, not unduly complicate the task of the give-way vessel, which must always anticipate the possibility of manoeuvre by the stand-on vessel. Instead, in difficult circumstances, it would simplify the task of the give-way vessel by providing a convention about the likely action which can be anticipated.

It must be made clear that the proposal is that the relaxation of the requirement to stand on should apply to all vessels, not just to high speed vessels. In this way the necessity to distinguish, on some more or less arbitrary basis, between some vessels, the high speed vessels, and the remainder is eliminated. The integrity of the COLREGS is maintained so that all vessels (at least all power-driven ones) are treated alike. Of course, the expectation is that it is the high speed vessels which will most frequently take advantage of the new freedom, but all vessels would be entitled to so do.

6. CONCLUSION. The author proposes that the problems which have been identified by Pike and others arising when high speed craft come into proximity with slower vessels may be alleviated by a relaxation of the current requirement for one of

the two vessels in a crossing encounter to maintain course and speed. The proposed change would give that vessel instead the discretion, but not the requirement, to alter course to starboard provided such action is safe. Pike, Mills and Cockcroft have pointed out that it is already increasingly the practice of high speed vessels to alter course at an early stage, even when they are in a position which would eventually require them to stand on, so that a risk of collision does not arise. The suggested change would regularise that practice and allow a manoeuvre, which is normally the one desired, to be made at a somewhat later stage in the encounter. As such it would, in the author's opinion, increase the margin of safety which can be achieved in such encounters. Plant[19] commented that it is important that *the regulations conform as closely as possible to what mariners regard as established and best practices*. Given the perceived desire of masters of high speed vessels to avoid close quarters situations and the risk of collision, the suggested change seems to allow the COLREGS to conform in that way.

The author has not so far suggested any detailed changes to the COLREGS; rather the proposed change is outlined at a philosophical level. It is felt important that seamen should consider the proposal as a basic philosophical one before looking at the details of its implementation. If others feel that the idea has merit and may be desirable, then the details of its implementation can be considered. If the idea can, for good reason, be rejected on a philosophical basis then such detailed discussion would be nugatory.

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Fast Craft and the COLREGS

A. T. C. Millns

I understand that The Netherlands are pressing the IMO to change the COLREGS so that high speed craft (HSC) have the obligation of keeping out of the way of other vessels.

There is an IMO definition of high speed craft which was adopted by resolution MSC 36(63) in May 1995.[1] It is the *International Code of Safety for High Speed Craft*. It covers vessels on international routes but does not cover, for instance, warships, troopships, fishing and pleasure craft. However, for the purpose of the COLREGS, I am sure that this definition should be widened and then incorporated.

I agree with many of the points in Mr R. D. Pike's article printed in this *Journal* in May 1997.[2]

Southampton and Dalian Universities invited me to the IMO Conference held in Dalian in September 1996, to present my paper on *Inshore Conflicts*, *Fast Ships*, *and Regulations*.[4]

I am both a retired Senior Navigating Officer with many years' experience in the liner trade to the Far East and Africa, and a yachtsman. My ships were the *Fast Craft* of the period designed for constant speeds of up to 25 kt in order to maintain schedules to the minute on the mail ships to and from South Africa. I have been a yachtsman since the late 1940s, with experience of yachts from 12 to 100 ft.

When meeting other fast ships, which occurred regularly in the Channel, such as one of the *Old Queens* working up to some 30 kt after leaving Cherbourg bound for New York, there was no hazard. It was rather an enjoyable event for our own passengers on their final night at sea from South Africa, to be part of the spectacle of very large vessels being lit (albeit briefly) for the occasion at 2300 hrs.

I am convinced that the danger lies at the meeting point of two or more vessels of *widely differing speeds or characteristics*. This conviction is strengthened by my visit to the Amethyst Bridge Simulator at HMS *Dryad* to which Lieutenant Commander H. Cook RN kindly invited me in July 1998[7].

This is an ongoing saga. The fast ships of yesteryear, dhows, frigates and clippers were each overtaken in their turn by the next generation of vessel. The evolution of steam propulsion and the independent manoeuvrability it provided resulted in the basic rule that *steam should give way to sail*. We are now in a natural progression from the Greyhounds of the Atlantic to the fast vessel of a different type and scope. They in their turn require control and direction, since conventional vessels of whatever size from dinghy to large tanker would be unable to manoeuvre out of the way of one of the new generation of HSC, because of the former's lack of speed/response characteristic. It must be appreciated that this generation of HSC are already attaining speeds of 40–50 knots for commercial and leisure vessels and 60 knots in the case of military vessels.

In the simulator at HMS *Dryad*, 'Amethyst' changed from a frigate, to a container ship then to a VLCC and back again! This is very realistic. We were in deep water with a HSC or hovercraft crossing from starboard to port; thus Amethyst was always the give-way vessel. Amethyst's OOW picked up the stand-on vessel six points on the starboard bow at seven miles – about the limit of visibility of the 'flashing light'. Wind force four was used, since above that strength the HSC started to become obscured by spray and its aspect unclear. The OOW appraised the situation and went 'Hard a Starboard' with the engine set at full speed. Basically, the manoeuvre requires a ninety-degree turn to be successful; this is caused by the speed differential of the vessels.

(a) As a frigate, Amethyst manoeuvred with adequate sea room.

(b) As a container ship (37,636t), Amethyst manoeuvred well provided that the OOW/Master is the type who has very strong nerves. Any slight hiccup – line squall, vessel ahead manoeuvring to enter the separation lane, fishing boats, RFA fuelling etc, and I feel that he would book himself a place in court. I would thus not recommend it, especially as at one stage the HSC disappeared below the flare of our bow before emerging the other side!

Continuing as a container ship, we had to reduce speed to 12 kts, so as not to arrive ahead of schedule. At this speed Amethyst was unable to respond adequately to the COLREGS, to keep out of the way of a crossing vessel.

(c) As a fully laden VLCC (254,000t) Amethyst's response was sluggish – unfortunately we then experienced a rudder fault and had to display our 'Not under Command Signal' to avoid disaster.

(d) Amethyst then rejoined the 'Fleet' as a frigate, refuelled at sea and manoeuvered to her station with ease.

I cannot find a record of any tests having taken place by HSC operators or by any Regulatory Authority. I find this to be surprising. Further tests can be verified and set up and I am sure that Lt Commander Cook would be pleased to do so, for the relevant Authority. (There is a small fee per morning or afternoon session – a small price to pay for safety.)

With the arrival of HSS ferries, several yachting friends have expressed their fears to me concerning their vulnerability. There is no way in which they could begin to respond to these 40–50 knot vessels. Although these HSS are employed on regular routes and their operation can be anticipated, at the time of actual danger, vessels of widely differing speeds or characteristics have no margin in which to obey the current COLREGS.

High speed military and leisure craft need also to be considered, since the commander/helmsman's visibility is very considerably reduced both ahead and astern by flying spray etc. Because of their low profile, it may not be possible for other vessels to detect them in good time either visually or by radar. Whilst their actual speed may be less than that of one of the new breed of HSS ferries, their speed is relative to their size, and the damage that they can do is considerable. (An example for illustration only – a radio-controlled 1-metre-long model managed to ram and sink a Mirror dinghy!). I have been advised of instances on the Riviera and Sydney Harbour where they have struck another pleasure craft and *planed up* into its cockpit killing its occupants. The most recent to come to my attention was the death of six aboard a 31 ft cruiser which was sliced in two by a 45 ft speed boat, capable of speeds of up to 80 mph.[5] A recent TV travel programme showed the presenter being taken across Long Beach Harbour in a wing vessel at 100 mph.[6] I am sure that there are many similar occurrences.

It is possible to set an arbitrary speed 'x' to define a high speed craft. But if this is done, as sure as eggs are eggs, at the time of any incident the craft will have been travelling at 'x–y' knots. I am sure that the only beneficiaries for any set speed would be those in the legal profession who could argue the matter in their chambers/courts.

My own recommendation would be for a calculated speed to be set, which will cater for the vessel's size. Since the IMO have already started out on this route, I believe that their formula should be applied to all craft used or capable of being used on the water (except for vessels propelled by sail or seaplanes landing or taking off).

A high speed craft is a craft capable of a maximum speed in metres per second (m/s) equal to or exceeding $3{\cdot}7\ V\,0{\cdot}1667$, where V = displacement corresponding to the design waterline (m3).

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Once a vessel is designated a high speed craft the actual speed of the vessel at any given point would not be relevant. Once designated a high speed craft, that definition would remain. It should then be bound to keep clear of all other craft. However, if risk of collision arises between two or more such designated HSC, then they should respond to one another as if they were normal powerdriven vessels. As well as the navigation lights for a power-driven vessel, they should exhibit an all round flashing yellow light visible for 6 miles.

We have the results of the 'Collision Decisions' questionnaire reported by Captain A. N. Cockcroft FNI in *Seaways* July 1998.[8]

We know that simulator results indicate a real risk, and I am sure that revision of the COLREGS in respect of High Speed Craft is more than due. To rely on these vessels keeping out of the way, without legislation, is surely courting disaster.

The present HSS Ferries are but the tip of the iceberg in a new form of sea travel. It is now imperative that the COLREGS should be updated sooner rather than later.

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KEY WORDS

1. High Speed Craft. 2. Safety. 3. Colregs.

Aircraft Collision Risks at the Start of the 21st Century

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1. INTRODUCTION. Much has been written on the subject of aircraft collision risk and avoidance over the past 50 years. As a particularly interested aviator (a military and civilian pilot for the last 32 years), with a limited memory for the mathematics I studied at school, I have read several of these treatises with interest. I do, however, feel that the advent of modern, accurate navigation systems has changed the distribution of collision causes radically. We should be concentrating, not on the risks of aircraft *accidentally* flying into each others' paths, but on the risks of them *deliberately* doing so.

That statement requires explanation, of course. There is a risk of one pilot deliberately and *willingly* putting his aircraft in the path of another (a terrorist or suicide for example), but the risk is considerably less than that of a pilot who does it *unwillingly*, but equally deliberately.

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2. CAUSES OF COLLISIONS. Accidents such as air-to-air collisions are classified according to 'cause groups'. These cause groups include:[1]

(i) *Human factors*, including medical factors, and aircrew, ATC and servicing errors.
(ii) *Technical faults*, including system failure and metal fatigue.
(iii) *Operational and natural risks*, including birdstrikes and weather factors.

Human factors are the most likely cause of a mid-air collision. Over decades, blame has regularly been apportioned to some individual whether in the air or on the ground because he or she has made an error while being responsible for the safe navigation of one or both of the aircraft involved, or in preparing the standards for safe flight. Bad weather can be forecast and in a perfect world avoided or, in more practical terms, prepared for. Mechanical and electrical systems can go wrong, but ATC and pilots are trained to check them and take corrective action if needed. The human is the weak link in any chain of events leading to a mid-air collision.

Rules are designed to ensure that collisions only happen when aircraft are where they should not be, because of either wrong information or wrong interpretation of that information. Safety separation standards are laid down as a result of mathematical calculations, and provided the aircraft stick to the laid-down separation, the odds of collisions, or even airmisses, are infinitesimal. Nonetheless, the actual number of collisions and the number of airmisses and airprox hazards reported each year proves it is not enough to set out these separations – they are not adhered to!

The human factors cause group is split into aircrew error, ATC error, servicing error, and medical factors. Medical factors cause several incidents every year, and the occasional accident, but are unlikely to be the cause of mid-air collisions. Servicing error may well cause equipment malfunction; in the case of ATC radars or computers, altimeters, and aircraft navigation systems, they can cause collisions. However, modern aircraft carry duplicated or triplicated navigation equipment, and the flight-deck instruments are also duplicated. Nevertheless, errors in installation or servicing of navigation or ATC equipment are a perpetual danger, and can indeed lead to an aircraft being in the wrong place.

ATC errors have been a recent cause of many airmisses and a few collisions. The modern controller is generally working to saturation, and overwork and stress lead to errors which cannot be entirely eliminated. However, I should like to consider these factors in the same manner as the stress on a pilot when considering the causes of collisions. Although the position of the man under stress is different, the effect is similar.

3. THE DELIBERATE AND WILLING COLLISION. Previous collision avoidance studies have concentrated on the likelihood of an aircraft straying from its intended flight path either horizontally or vertically into the path of another. As navigation instruments and equipment become more accurate, it was decided that separation standards could be reduced for the same or reduced likelihood of that straying. Witness the Reduced Vertical Separation Minima (RVSM) being introduced on the North Atlantic, and the Basic Area Navigation Standards (B-RNAV), soon to be applied in much of Europe and to be replaced by even more sophisticated equipment in the future. It has become obvious that Air Data Computers (ADC) with sophisticated sensors, and navigation computers using satellite navigation systems and Loran to update inertial navigation platforms, permit the pilot to position his aircraft in 3 dimensions to a previously undreamed-of standard. Random errors in horizontal and vertical position are being whittled down, and the chances of straying accidentally into the flight path of another aircraft are being constantly reduced.

Unfortunately, the improved standards of position keeping contain in them the seeds of major catastrophe. For many years, airmisses and airprox occurrences (where pilots or ATC consider that a collision risk was present) have shown that even the earlier standards of separation are irrelevant if humans do not apply them because of error. In fact, the errors can be said to have saved many collisions from happening because, had they not been present, the aircraft would have been in exactly the same part of the sky. Now that more accurate height and position keeping is available, more collisions such as the one between the Saudia 747 and the Kazakh Il-76 over India in 1996, and the collision between the Tu-154 and C-141 off the west coast of Africa in 1997, are likely.

Let me illustrate this by the example of two aircraft going to the same horizontal position at the same time. If one pilot (A) is told to fly at 31 000 feet and another (B) to fly at 33 000 feet, provided they obey the clearance, no collision should occur. However, there is a chance of one pilot either mis-hearing or mis-interpreting his clearance or his altimeter. If pilot A decides to fly at 33 000 feet, there is obviously a collision risk. Several years ago, the accuracy of the pressure instruments used by the pilots was such that the chances of either pilot being at exactly 33 000 feet was small. The navigation instruments were also inaccurate, and the chances of either pilot being over the expected position was also small. An airmiss was probable, a collision actually unlikely. However, the accurate instruments now available reduce the chances of the pilots being away from their cleared altitudes and positions considerably. The consequence of mis-interpreted clearance is now much more likely to be a collision.

4. MATHEMATICAL CALCULATION. Navigation and flight instrument errors tend to be published at the 95 percent level; that is to say that the aircraft should be within such and such a distance from its intended position for 95 percent of the time (twice the standard deviation of a gaussian distribution). Ten years ago, using VOR/DME navigation, the expected errors in horizontal position were ± 1 nautical mile (1852 metres, say 2000). The errors of altimeters vary with altitude; I consider that collisions are more likely during climb, hold or approach than cruise at high level, and shall take altimeter errors as published[2] for a servo altimeter at 20000 feet as an average figure for my calculations. At that altitude, a servo altimeter should have been within ± 100 feet (30 metres) for 95 percent of the time.

If an airliner (the most catastrophic case for collision consequences), is taken to be represented by a box 50 metres long by 50 metres wide and 10 metres high, then a collision between two aircraft would occur if any part of one box touched the box of the other. We can simulate that by considering one aircraft as a point source, and the other as a box of twice the dimensions, and consider the likelihood of that point intruding on the larger box of 100 metres by 100 metres by 20 metres.

The most dangerous collision, and the one which allows pilots almost no time to avoid visually, is that between two aircraft approaching each other from the front quadrant, effectively head on. I shall consider the case of this head-on collision, and ignore for calculation purposes the less dangerous overtaking situation. Collisions between aircraft crossing at near right angles are also quite possible but, for the moment, I wish to ignore these also, because I am concerned with the *relative* increase in danger rather than the actual numbers. I can then consider that the chances of collision are given by the likelihood of a moving point entering the fixed aircraft box from the front, i.e. a rectangle of 100 metres horizontally and 20 metres vertically.

The actual chances of that happening depend on gaussian distributions whose standard deviations are 1000 metres horizontally and 15 metres vertically from the intended position (half the distance of the 95 percent errors). We can see that if the point arrives within the horizontal coordinates of the rectangle, it is quite likely to collide; in fact the chances of it being outside the vertical coordinates of the rectangle are only 50 percent. The chances of missing horizontally are much better, 99·6 percent, so the total likelihood of collision is only 0·2 percent, a theoretical assumption confirmed by the relatively large numbers of reported airmisses compared with actual collisions.

Unfortunately, with modern equipment we now have the potential for accuracies of less than $\pm$50 feet (15 metres) vertically, and 300 metres horizontally using raw GPS with Selective Availability. That means, first, that if the point arrives within the horizontal coordinates of the rectangle, it is more than 80 percent likely to be also within the vertical coordinates, and secondly that the chances of arriving within the horizontal coordinates are 26 percent. There is now a 22 percent likelihood of the aircraft actually colliding, as against the likelihood of only 0·2 percent of a few years ago. The danger of misinterpreted clearances has jumped by a factor of 100, and Differential GPS is expected to reduce horizontal errors to 3 metres, raising the future probability of a collision to 80 percent if both aircraft are planning to be in the same place at the same time.

5. ASSISTANCE FOR PILOTS. Fortunately, assistance for collision avoidance is available in the form of Airborne Collision Avoidance Systems (ACAS, called TCAS by the Americans), which are now being installed worldwide in most commercial aircraft after the Delhi collision. Such instruments warn the pilot of potential conflictions with traffic similarly equipped, in sufficient time for him to take avoiding action if he sees the confliction. More modern equipment (ACAS II) actually gives the pilot avoidance instructions which can be followed even if the pilot cannot see the other aircraft. Has the cure been found before the disease has become common?

Unfortunately, I believe that, despite the obvious benefits of the ACAS installation, it is a palliative not a cure. Humans will continue to err, and as we have seen, any such error will effectively guarantee a collision if another aircraft is flying a reciprocal route at the error altitude. ACAS will be absolutely vital in such a case to provide separation and thereby protection from collision. Unfortunately, history shows that when automatic systems take over the responsibility from humans, as in the case of navigation systems, the human tends to rely on the automatics more and more. (Witness the Korean airliner straying into Soviet airspace and being shot down, reputedly because the crew fed in the wrong co-ordinates and *did not notice they were wrong*.) Already airline crews spend little time scanning the sky visually for possible collisions, because they are usually in controlled airspace and separated from others by ATC clearances. They also know that the chances of seeing an aircraft on an actual collision course in time to avoid it are negligible anyway.[3] (Cockpit design, I must admit, plays its part here.) Fewer eyes are in the cockpit, and each crew member has more work to do on routine matters, therefore stress shows as a factor.

No automatic system is 100 percent reliable, although I am at present unable to find figures for the reliability of ACAS. At present, most of the ACAS faults have been fail-safe, i.e. the pilot is warned unnecessarily. However, a system which failed to give the necessary warning, or whose warning was missed or ignored during a period of high cockpit workload, would allow the collision to occur with the previously calculated chance. Whatever success and serviceability rate manufacturers may find for ACAS, coupled with the calculated future collision chance of 80 percent, will become the actual chance of a collision in the event of a human error of a mis-heard, mis-transmitted, or misunderstood clearance. We are therefore in the situation when effectively the only chance of avoiding collisions in the event of a misunderstood clearance is the ACAS. It may be worth mentioning here that UK Civil Aviation Authority target level of safety is 5×10^{-9} fatal accidents per flying hour.[4]

6. THE UNASSISTED PILOTS. I have hitherto only considered collisions between

two aircraft equipped with ACAS, which effectively means two public transport aircraft. Many commercial and private, not to mention military, aircraft, will not be equipped with ACAS until well into the next decade if at all. Even Mode C (altitude reporting) transponders, the minimum equipment to indicate on the transport aircraft's ACAS, will not be in every aircraft. However, the availability and price of satellite navigation systems have attracted pilots and owners to fit them much earlier than they have fitted ACAS. This means that there are even now many aircraft flying with the ability to keep their horizontal position as accurately as an airliner, but unable to warn an airliner of their presence. ACAS will provide no protection from them.

7. A SOLUTION. I have already stated that a modern aircraft is 95 percent likely to be within 300 metres of its horizontal position using raw GPS information. I have shown that no real safe vertical separation exists, so the aim must be to move the colliding aircraft away from each other horizontally. Already, many aircrew are recommending that the safest way to avoid collisions is to fly off-set tracks. Such an idea is a logical application of the visual navigation safety rule that, when following a line feature, the aircraft should keep the feature on its left. This, I believe, must be the solution, although again it is far from being a cure. A navigation system that allows accuracies of $\pm 0{\cdot}2$ nm on 95 percent of occasions, would ensure that if all aircraft followed the line feature of the route centreline on the right of it by 0·2 nm, the chances of head-on collision would be reduced by a factor of 20, and if separation of 0·5 nm were laid down, the chances would be lessened by a further factor of 50. No wonder such a solution finds favour with many experienced captains. I calculate that the actual risk of collision *subsequent to a human error* ***and*** *an ACAS error* would be less than 0·01 percent.

An aircraft with no ACAS, nor a modern navigation system, would be effectively as likely to be at the new position of the airliner as it would be on the centreline. There would actually be a marginal improvement in safety from collision with it, but that would still only be a risk of 0·2 percent. An accurately navigated aircraft without an Air Data Computer (I doubt if an aircraft without Mode C would spend the money on a ADC) would have the same horizontal accuracy standard as the airliner. The risk of collision in such a case, without offsetting the route, would be 13 percent (50 percent $\times$ 26 percent). The risk of collision if the airliner were to fly an offset track, even if the unequipped aircraft did not, would again be reduced to 0·01 percent.

8. IMPROVEMENTS AFTER R-NAV IMPLEMENTATION. The intended implementation of area navigation systems is designed to reduce the reliance on published routes such as airways. The facility to fly direct tracks between departure and destination airfields is only one feature of the system, and this might be thought to reduce the chances of collision. Unfortunately, the main reason for R-NAV implementation is to increase the numbers of aircraft which can use the same airspace safely (if they do not make errors). Since traffic will still be flying between the most popular airfields, the direct tracks will become *de-facto* airways, in the same way that paths between market towns became roads in the middle ages. I believe that any short-term alleviation in collision risk brought about by R-NAV will soon be lost.

9. CONCLUSION. If human errors cause aircraft to arrive at the same intended point in the sky (a risk which, I admit, I have been unable to quantify with my limited information available), I have shown that they are now very likely to hit each other. ACAS can provide protection, but in the event of a failure of the ACAS or its interpretation, that risk would return at its very high level.

A modern navigation computer can guide an aircraft anywhere in the world. It can surely be programmed to route the aircraft along a flight path offset by 0·5 nm to starboard from the centreline of the planned route at all times until the final approach fix, giving vastly increased safety. Even the infinitesimal chances of collision with a serviceable ACAS installation would be considerably reduced, for minimal cost. I therefore recommend that all public transport aircraft capable of accurate navigation plan to fly all Air Traffic Service Routes (and any planned direct tracks) offset by 0·5 nm to starboard in order to reduce the risk of collision caused by human error.

REFERENCES

[1] *AP 3207 – RAF Manual of Flight Safety*.

[2] *AP 3456 – RAF Manual of Flying (Volume D – Aircraft Instruments & Instrument Systems)*.

[3] *Human Factors for Pilots*. Dr Roger G. Green, Helen Muir, Melanie James, David Gradwell, Roger L. Green.

[4] *Aeronautical Information Circulars*. UK Civil Aviation Authority.

KEY WORDS

1. Air navigation. 2. Safety. 3. Human factors.

Note *from* Editor

I have included this paper in *Forum* as both I, and a referee, consider some of the statements made rather controversial. I hope it leads to further papers and a lively debate.