Determinants of Conflict Risk Judgments in Air Traffic Control

Stéphanie Stankovic

Esa Rantanen

Nicolas Ponomarenko

Shayne Loft

DETERMINANTS OF CONFLICT RISK JUDGMENTS IN AIR TRAFFIC CONTROL

Stéphanie Stankovic
The University of Queensland
Brisbane, Australia
Esa Rantanen
Rochester Institute of Technology
Rochester, NY, USA
Nicolas Ponomarenko
French Civil Aviation Authority
Toulouse, France
Shayne Loft
The University of Western Australia
Perth, Australia

The aim of the study was to identify the determinants of conflict risk judgments in air traffic control. Fourteen expert controllers made conflict risk judgments about air traffic situations in which three variables (conflict geometry, time of closest point of approach or TCPA, and vertical separation between aircraft) were manipulated. The results indicate that conflict geometry, TCPA, and the vertical separation between aircraft significantly influenced judgments of conflict risk. In addition, there was a significant interaction between these three variables. Risk perception was largest under conditions where aircraft were on the same headings, with short TCPA, and no minimum vertical separation. The study was successful in determining what factors of air traffic scenarios increased subjective risk judgments in air traffic control.

Understanding how experts make risk judgments in safety critical work contexts is a major issue in cognitive ergonomics. One prototypical example of an applied work context where individuals are required to make risk judgments under conditions of uncertainty and time pressure is in air traffic control (ATC; Loft, Sanderson, Neal, & Mooij, 2007). Air traffic controllers make judgments about the future relative positions of aircraft in order to assess whether they will lose minimum separation. In approach control, aircraft are in conflict if they are projected to violate both lateral (3 nautical miles) and vertical (1,000 feet) separation simultaneously.

Several theoretical accounts of how controllers make conflict judgments have recently been published (Loft, Bolland, Humphreys & Neal, under review; Rantanen and Nunes, 2005; Stankovic, Raufaste, & Averty, 2008). The Stankovic et al. (2008) model uses three horizontal distance metrics to predict controllers' judgments of conflict risk for pairs of converging aircraft; the distance between the crossing point of the aircraft pair trajectories and the closest aircraft to that point (Dt_0), the distance between the two aircraft when they are horizontally closest (Dt_h), and the horizontal distance between the two aircraft when their growing vertical distance reaches 1,000 feet (Dt_v). The Stankovic et al. model could account for up to 50% of the variance in expert controller risk judgments. However, a significant limitation of the Stankovic et al. study was that it presented aircraft pairs with limited sets of geometry features.

In addition to aircraft converging on common intersection points (crossing headings), pairs of aircraft in ATC often follow each other on the same flight path (same headings), or travel toward each other on the same flight path (opposite headings). In the current study we examine this more representative set of conflict pairs. In addition, we present aircraft pairs that are descending through the altitudes of each other. Judgment of conflict status when aircraft are converging both vertically and horizontally can be challenging due to the difficulty of trajectory estimation in the vertical plane (Boag, Neal, loft & Halford, 2006). The changing difference in altitudes between two aircraft is not directly visually perceptible, but has to be deduced from the numerical altitude readouts in aircraft data blocks, and the estimation of vertical separation at some point in the future is a result of combining these altitude calculations with estimation of groundspeed and future lateral separation. In the current study we examined the relationship between vertical separation and conflict risk judgment by varying the minimum vertical separation of aircraft whilst keeping the minimum distance of lateral separation constant. Finally, we examined the effect of time to closest point of approach (TCPA). We expressed TCPA as the time in minutes for the aircraft to reach minimum horizontal separation. In summary, the study reported here examined the effect of conflict geometry, TCPA and vertical separation on conflict risk judgments.

Predictions

The purpose of the present study was to identifying the factors that determine conflict risk judgments. Our first hypothesis concerned the effect of conflict geometry. For all three conflict geometries (same headings, opposite headings and crossing headings) controllers need to extrapolate the minimum horizontal and vertical separation between aircraft. A simple heuristic used to achieve these separation assessments may consist of mentally moving the two aircraft velocity vectors along the horizontal plane and inferring the time when they will come closest on that plane. Then, the aircraft positions at this point (which can be roughly associated with the crossing point between the aircraft trajectories) have to be maintained mentally in order to estimate the horizontal and vertical separation between them (Stankovic et al., 2008). Conflict geometries should influence the ability to apply such heuristic. In the case of same headings, minimum horizontal and vertical separation extrapolations are particularly difficult. The crossing point between the two aircraft is difficult to estimate in this situation especially because of the lack of perceptual cues of aircraft positions at each side from the crossing point. In the crossing or opposite heading scenarios, controllers' horizontal and vertical separation predictions are facilitated by the presence of these perceptual cues. Thus, controllers may be more uncertain about the future relative positions of same heading aircraft. Increased controllers uncertainty of the future relative positions of aircraft is associated with increased probability that controllers label situations conflicts (Loft et al., under review). We expected to obtain higher conflict risk judgments in same heading situations than in opposite and crossing heading conditions.

In the model proposed by Stankovic et al. (2008), two horizontal distances, minimum horizontal separation *(Dt_h)* and the horizontal distance between the two aircraft when their growing vertical distance reaches 1,000 feet *(Dt_v)*, both significantly predicted conflict risk judgments. It has been demonstrated by numerous studies that controllers are more likely to consider aircraft to be in conflict as minimum horizontal separation decreases (e.g., Stankovic et al., 2008). Thus, we fixed minimum horizontal separation at the conventional threshold of 3 nautical miles used in approach control. By the fixing minimum horizontal separation we were able to more precisely examine the influence of minimum vertical distance. We defined Dt_v as the minimum vertical distance between aircraft when lateral separation was 3 nm. Loft et al. (under review) found experts always interned to vertical problems when lateral separation was constant at 0 nm, even when minimum vertical separation was up to 4,000ft. This is not consistent with the finding of Stankovic et al. (2008) where Dt_v significantly predicted variation in controller risk judgments. However, it is noteworthy that Loft et al. (under review) used a dichotomous rating scale (intervene vs. not intervene). In comparison, Stankovic et al. (2008) investigated risk judgments about conflict by using an 8-point scale. This rating scale should be more sensitive to detecting differences in controllers' perceptions of conflict status with changes in minimum vertical separation. We expected to find differences in risk judgments as function of vertical distance, controllers judging situations as riskier as vertical separation decrease.

We coded Dt_0 in time (as advised by a subject matter expert) to express our TCPA variable. We expected to replicate the results obtained by Stankovic et al. (2008), with conflict risk judgments increasing as time to crossing point increased.

Method

Participants

Fourteen air traffic controllers (12 men and 2 women) from the Toulouse-Blagnac airport volunteered to take part in the experiment. Their ages ranged from 25 to 59 years ($M = 43.29$, $SD = 10.94$). Their average length of experience as an air traffic controller ranged from 2 to 37 years ($M = 20.36$, $SD = 10.13$). Their experience length since sector certification ranged from 0 to 34 years ($M = 10$, $SD = 9.96$).

Variables

The three independent variables were manipulated across 36 static scenarios. These variables are the time to point of closet approach (TCPA), the geometry of conflict, and the vertical separation between aircraft at the moment of the crossing point (VS). Values of TCPA correspond to the time given in minutes that the aircraft would take to reach the crossing point and took the values of 3 or 6 minutes. Geometry of conflict corresponds to the relative headings of the two aircraft. Three conflict geometries were manipulated: (1) situations were a faster aircraft followed a slower aircraft (same headings), (2) aircraft heading directly toward each other on the same flight path (opposite headings), and (3) aircraft converging at 90-degree angle on a common intersection point (crossing headings). The vertical separation variable corresponds to the minimum vertical separation between two aircraft computed at the moment when the aircraft reached their minimum lateral separation of 3 nm. These values of vertical separation were 0, 2,000 or 4,000 feet. The horizontal distance computed at the moment of the crossing point was fixed at 3 nm which corresponds to the conventional minimal separation used in French approach control. Two versions of each of the 18 scenarios were presented. The scenarios were chosen from historical flight data observed from the Toulouse-Blagnac airport.

Each participant was presented the 36 experimental trials in a random order. The main dependent variable was the conflict risk judgment, provided on a 12 points scale from no risk at the far left (1) to extreme risk at the far right (12).

Materials and Procedure

The experiment lasted about 25 minutes. Each experimental situation was displayed on a white sheet of paper. In each situation a pair of aircraft converged toward the same point: one was cruising in altitude and the other one was descending. In all cases the aircraft pair reached their minimum horizontal (3nm) and vertical (0, 2000, or 4000ft) distances of separation in 3 or 6 minutes. A 3 nm scale marker was presented on this display, and the rate of descent (V_z) was set at 1,000 feet per minute. Each aircraft had a data block that displayed its speed in knots, its current flight level (altitude in hundreds of feet), a sign "=" for the cruising aircraft or a down arrow followed by a cleared level for the descending aircraft. In each situation, the aircraft was descending through the level of the cruising aircraft. Two-minute velocity vectors were displayed for the aircraft. Participants were instructed to judge the risk of conflict for each pair of aircraft. Three other judgments were also requested relating to strategies used to ensure separation between two aircraft, but these results are beyond the scope of this paper.

Results and Discussion

A conflict geometry × TCPA × vertical separation (3 × 2 × 3) within-subjects ANOVA was conducted, with conflict risk judgments as the dependent variable. The values for small, medium and large effect sizes are .10, .25 and .40 respectively (Cohen, 1988). Tukey post hoc comparisons were conducted to follow up significant omnibus effects.

Descriptive statistics are given in Table 1. As predicted, geometry of conflict had a significant effect on conflict risk judgment, $F(2, 13) = 5.18$, $p = .013$, $\eta_p^2 = 0.28$. Post hoc tests showed that controllers indicated higher conflict risk assessments for same heading air traffic scenarios ($M = 8.17$, SE

= 0.47) than either opposite heading (*M* = 6.95, *SE* = 0.65) (*p* = .04) or crossing heading (*M* = 6.77, *SE* = 0.66) (*p* = .018) scenarios. There was no significant difference between the opposite heading and crossing heading conditions.

Vertical separation had also a significant effect on conflict risk judgment, $F(2, 13) = 14{,}33$, $p < .001$, $\eta_p^2 = 0.52$. Post hoc tests showed that controllers indicated higher conflict risk assessments when the vertical separation between aircraft was 0 feet (*M* = 9.14, *SE* = 0.36) compared to when it was 2,000 feet (*M* = 6.96, *SE* = 0.72) (*p* = .006) or 4,000 feet (*M* = 5.79, *SE* = 0.77) ($p < .001$). There was no significant difference between the 2,000 feet and 4,000 feet minimum vertical separation conditions. Thus, in contrast to the findings of Loft et al. (under review), controllers conflict status judgments were sensitive to the minimum vertical separation between aircraft. Controllers were making calculations regarding the future vertical separation between aircraft when making conflict decisions.

Finally, TCPA had a significant effect on risk judgments, $F(1, 13) = 7.90$, $p = .015$, $\eta_p^2 = 0.38$. The situation was judged more risky when aircraft were at 3 minutes from the crossing point (*M* = 7.66, *SE* = 0.51) compared to when they were at 6 minutes from this point (*M* = 6.93, *SE* = 0.58) (*p* = .015). In contrast to the findings of Stankovic et al. we found that conflict risk judgments increasing as time to crossing point decreased. This result is more compatible with the interpretation that situations in which TCPA has high values simply offer more time before a clear decision about conflict needs to be made.

Table 1. *Means of judgments of conflict risk as a function of conflict geometry, TCPA, and minimum vertical separation.*

Geometry	TCPA	Vertical Separation	Means	SE
Same Headings	3 min	0 ft	10.00	0.46
		2000 ft	9.43	0.46
		4000 ft	8.54	0.70
	6 min	0 ft	8.57	0.52
		2000 ft	6.46	0.78
		4000 ft	6.04	0.92
Opposite Headings	3 min	0 ft	9.46	0.61
		2000 ft	6.57	1.02
		4000 ft	4.68	0.91
	6 min	0 ft	9.04	0.56
		2000 ft	7.04	0.97
		4000 ft	4.89	1.03
Crossing Headings	3 min	0 ft	9.54	0.57
		2000 ft	5.71	1.02
		4000 ft	5.04	1.04
	6 min	0 ft	8.21	0.86
		2000 ft	6.57	0.91
		4000 ft	5.57	0.87

The main effects were qualified by a 3-way interaction between conflict geometry, TCPA and vertical separation variables on conflict risk judgments $F(2, 13) = 7.73$, $p =. 038$, $\eta_p^2 = 0.17$ (Figure 1). As indicated in Figure 1, TCPA only had an effect on conflict risk judgments for same heading aircraft geometries, and not for opposite or crossing heading geometries. The increase in risk judgments with increased vertical separation was reasonably consistent across the three conflict geometry types when TCPA was 6min. In comparison, the pattern of increase in risk judgments with increased vertical separation when TCPA was 3 min was less for same headings geometries than opposite or crossing heading geometries. Risk judgments for TCPA 3 min problems were higher for same heading geometries than the other geometries when vertical separation was 2,000 ft or 4,000 ft (at 0 ft they were similar).

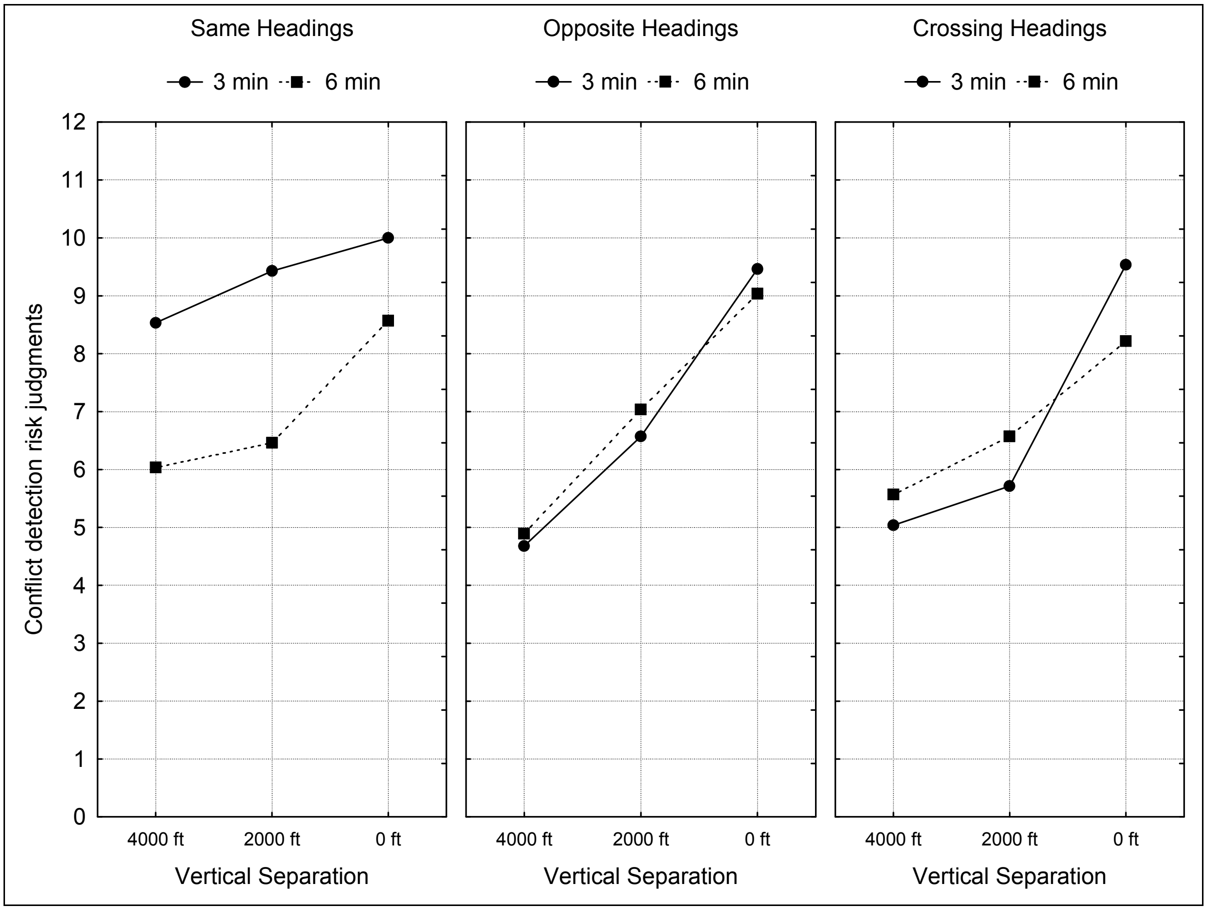

Figure 1. Conflict detection judgments as function of conflict geometry, TCPA and vertical separation.

Conclusion

The study was to examine the effect of three factors on judgments of conflict risk; conflict geometry, minimum vertical separation and time of closest point of approach (TCPA). Controllers judged air traffic situations more risky with decreased vertical separation, when aircraft was traveling on the same heading as other aircraft, and when TCPA was short. To our knowledge, this is the first demonstration in the literature that the respective headings of aircraft can influence controller's perceptions of conflict risk. The paper extends the work of Loft (under review) by demonstrating that vertical separation can indeed affect conflict status judgments. The effect of TCPA is compatible with the fact that controllers are sensitive to the time available to perform various control tasks (Loft et al., 2007; Wickens, Mavor, & McGee, 1997; Payne, Bettman, & Johnson, 1993).

The study is limited by the fact that the air traffic situations presented to controllers were static. At the same time, we see no reason why these patterns of effects would not be replicated using a dynamic simulation (e.g., 5 sec update rate) (Boag et al., 2006). In addition, the air traffic scenarios themselves had sound validity to the extent that they were selected by subject matter experts at Toulouse-Blagnac airport. In conclusion, the study was successful in determining what factors of air traffic scenarios may increase subjective judgments of conflict risk made by air traffic controllers.

References

Boag, C., Neal, A., Loft, S., & Halford, G. (2006). An analysis of relational complexity in an air traffic control conflict detection task. *Ergonomics, 14*, 1508-1526.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Loft, S., Bolland, S., Humphreys, M. S., & Neal, A. (under review). A theory and model of conflict detection in air traffic control: Incorporating environmental constraints. Manuscript under review at *Journal of Experimental Psychology: Applied.*

Loft, S., Sanderson, P., Neal, A., & Mooij, M. (2007). Modeling and predicting mental workload in en route air traffic control: Critical review and broader implications. *Human Factors, 49,* 376-399.

Payne, J. W., Bettman, J. R., & Johnson, E. J. (1993). *The Adaptive Decision Maker*. Cambridge: Cambridge University Press.

Rantanen, E. M., & Nunes, A. (2005). Hierarchical conflict detection in air traffic control. *International Journal of Aviation Psychology,15*, 339–362.

Stankovic, S., Raufaste, E., & Averty, P. (2008). Determinants of Conflict Detection: A Model of Risk Judgments in Air Traffic Control. *Human Factors, 50*, 121-134.

StatSoft (2005). Statistica (Version 7.1) [Computer software]. Maisons-Alfort, France: Author. (www.statsoft.fr)

Wickens, C. D., Mavor, A. S., & McGee, J. P. (1997). *Flight to the Future: Human Factors in Air Traffic Control*. Washington, D.C.: National Academy Press.