ASSESSMENT OF FLIGHT CREW ACCEPTANCE OF AUTOMATED RESOLUTION SUGGESTIONS AND MANUAL RESOLUTION TOOLS

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Abstract

The air side part-task study was an initial assessment of flight crew responses to ground side automation derived conflict resolutions. The study was designed to assess pilots' acceptability of different types of conflict resolutions provided by the automation (vertical and horizontal) at different ranges (near and far) from ownship. Data from the study shows that conflict resolutions created either by the automation or by flight crews were safe; all resolutions maintain a separation distance greater than 5 nm. Crews rated ~30% of automated resolution as problematic and reported that they would seek ATC input. However, when allowed to modify automated resolutions with flight deck route planning tools crews only wanted to consult with ATC on ~ 8% of resolutions. Finally, crews reported that the decision to accept, reject or modify an automated resolution is a complex and situation dependent decision. When close to TOD they generally preferred to descend, but when 500 nm or more from TOD they generally preferred to climb.

1 Introduction

The capacity of the current U.S. air traffic control system is fundamentally limited, or capped, by the controller workload associated with monitoring and separation; and by sector saturation, such as that in the northeast corridors of the U.S. and between major city pairs like Chicago and New York. The workload cap stands in contrast to a predicted increase in demand for air transportation, which would require a system that can handle much higher traffic densities. The increased demand will require air traffic management in the US to move from the current and traditional Air Traffic Management (ATM) architecture, where ground based controllers manage traffic flows while eliminating traffic conflicts, to a next generation ATM environment where traffic separation and flow management may be distributed between ATM users, providers and automation. To accomplish this transition, operator roles and responsibilities, along with information requirements, must evolve.

In this discussion of the required systems changes, ATM researchers and designers have paid significant attention to the design and development of the ground system's architecture. However, they have paid much less attention to the other distributed components, such as the flight deck and its role in the conflict resolution decision process. This approach is in stark contrast with the latest Joint Planning and Development Office (JPDO) concept of operations v2.0 (con-ops) which envisions the flight crew playing a major role in trajectory based operations and separation management (JPDO, 2007) [1]. The JPDO con-ops suggest that flights crews could support trajectory-based operations (TBO) and separation management (SM) by means of limited delegations of separation management; or, with the aid of automation, or by operating without ATC support in unmanaged airspace.

The con-ops also suggest that ground and/or air-based systems be developed to provide auto-resolution suggestions to solve traffic conflicts. In response to this particular concept, researchers at the NASA Ames Research Center (ARC) are exploring advanced conflict detection and auto-resolution systems which would detect projected conflicts and then generate and uplink conflict resolutions (flight plan modifications), substantially replacing functions now performed by air traffic controllers (ATCs).

1.1 Auto-resolution algorithms

Researchers at NASA Ames have been developing ground side automation in response to the expected changes in the future ATM system, e.g., Center TRACON Automation System (CTAS) Traffic Management Advisor (TMA), and Direct-to, McNally, 2002 [2]. In response to the expected changes in roles and responsibilities advanced decision support technology, including an auto-resolution capability is being developed (Erzberger 2006)[3] . Additionally, in response to the JPDO and the need for concepts of operation which specify how these advanced technologies will be deployed, Erzberger identified two concepts of operations where an automatic trajectory server (ATS) could interact directly with data-link equipped flight decks, or be accessible to the controllers through a trial planning tool built into their workstation. In either case, the pilots or the controllers are expected to review resolution suggestions based on known traffic management or flight deck constraints before implementation. In the case of the flight deck, the ATS would uplink a proposed resolution which would be reviewed by the crew who could accept, reject or modify the suggested resolution. Controllers, on the other hand could request a resolution suggestion from ATS using their trial planning tool. After receiving the suggested resolution from ATS they could use their trial planning tool to modify the resolution as needed to meet their traffic management constraints, they could also reject the resolution and request a different resolution. In either concept Erzberger suggests that auto-resolutions will be approved or at least evaluated by the users and providers in the system prior to implementation/execution.

Based on the requirement to have pilots and controllers evaluate auto-resolutions prior to implementation and our continuing effort to improve the resolution algorithms, researchers in the human automation division at Ames conducted a Ground-side and Air–side evaluation of the auto-resolutions provided by ATS.

2. Ground and Air side part-task

2.1 Ground Side Study

To start to address the changing roles and responsibilities for the ATSP and flight decks in the future national airspace system, an air and ground part-task study on the use and acceptability of automated conflict resolutions presented as suggestions to pilots and controllers is being conducted. In both part-task studies the pilots' and controllers' only task is to resolve traffic conflicts in traffic densities up to 3X current day traffic levels. For a full description of the ground part-task, see Prevot (2008)[4].

2.2 Air Side Study

This paper will focus on the air-side study, where pilots were presented a 3D display of traffic within 120 NM of ownship and a single or multi aircraft traffic conflict. Next, they received a suggested resolution which they executed and then were asked to rate the resolution on a five point scale from excellent to unsatisfactory. In a similar scenario, pilots were asked to resolve traffic conflicts with a manual route assessment tool (RAT) and then also asked to rate the resolution on the same scale. The RAT and rating scale will be described in detail later in the paper. After rating each scenario the pilots were asked to verbally report their reason for each individual rating.

3.0 Method

3.1 Subjects

12 commercial glass transport pilots were paid participants in the study. Their flight hours range from 1000 to 13,000+ with an approximate mean of 6000 hours.

3.2 Design

The design of the air side study was a within subjects design. The study presented 3 resolution aiding conditions (1- manual resolution, 2-automation suggest only, and 3 – auto suggestions with manual resolution tool), by 2 time to loss of separation ((LOS) – near 6.5 minutes and far 10.5 minutes).

24 unique conflict situations and auto-resolutions, ~ 10.5 minutes before LOS, were selected from the ground side auto-resolution trials (see Prevot, 2008). In each air side conflict situation the ownship aircraft was selected to be the one chosen by the ATS to resolve the conflict situation. The ATS systems used a number of factors in computing the auto-resolution and determining which aircraft should execute the resolution maneuver (See Erzberger, 2004)[5].

The original 24 conflict situations were allowed to progress down to 6.5 minutes to LOS to create the near time to LOS trials. The 48 conflict and resolution trials were counterbalanced and presented in blocks of 16 trials for each resolution condition. The

Fig 1. CSD, conflict alerting, and uplinked path.

resolution trials were combined and presented to the pilot as recommended resolutions by the ground automation.

3.3 Procedure

Pilots were first given initial training on how to use the cockpit situation display (CSD) for visualization of conflict situations, and how to enter their ratings. This training was followed by 16 conflict situations where automated resolutions were provided. During each trial the pilots were responsible for resolving the conflict situation presented during a 2 minute trial. Each trial was concluded with the pilot selecting the execute button on the RAT or the trial timing out after 90 seconds. After executing the resolution they rated the resolution for acceptability and provided a verbal report for why that rating was given. The automation only block of trials was followed by additional training on the CSD and RAT, see Figure 1. Pilots then flew the remaining counterbalanced trials, either manual (no resolution suggestions) or interactive (resolution suggestions with RAT), in blocks of 16 trials each. Each trial was followed by acceptability ratings and verbal reports of why a resolution was selected, as in the automation only trials. For a complete description of the flight deck CSD and RAT, see Granada, 2005[6]. Note: The traffic density metric is based on current "map alert" values for the selected sectors (ZKC – 50 and ZID 91) in the NAS.

3.4 Dependent measures

A variety of measures were collected and analyzed: resolution safety - failed resolutions, minimum separation distances; resolution efficiency - distance and/or time added to the path length, number of maneuvers, and number of conflicts. Additionally, subjective resolution acceptability and concept acceptability rating and verbal justification for ratings and resolution choices were collected. The ratings were presented in a table format with the letters A-E and the labels in bold below: Acceptability (individual conflict resolutions and operating concept) Ratings.

- **Unacceptable - ATC coordination required.** *You believe the resolution was unacceptable and would reject it because it compromises safety of flight or you are unable to comply. ATC coordination is required to find a new resolution.*
- **Poor - ATC coordination sought.** *You believe the resolution is poor and would definitely seek ATC coordination because a new resolution is highly desired.*
- **Marginal - ATC coordination probably sought.** *You believe the resolution is marginal and would probably seek ATC coordination because a better resolution is possible.*
- **Good - ATC coordination probably not sought.** *You believe that the resolution is good, although there might be a better one. You would probably not seek ATC coordination.*
- **Excellent - ATC coordination unnecessary.** *You believe that the resolution is excellent and would not seek ATC coordination.*

4.0 Results

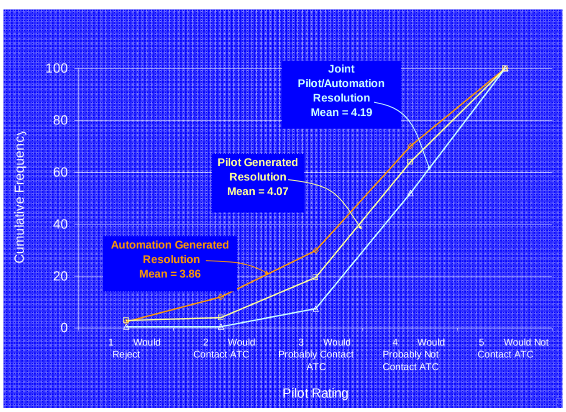

Fig 2. Cumulative frequency of pilot acceptability ratings by resolution conditions.

Figure 2 shows the distributions of pilot ratings of acceptability for automation only, interactive suggestions, and manual conflict resolution conditions. As the cumulative ratings show, pilots rated the auto-resolutions suggestions as problematic and would probably contact ATC about 30% of the times. While they rated the resolutions that they created problematic 20% of the times and in the interactive condition where they had both resolution suggestions and the RAT problematic only 8% of the times, this difference was significant, $p < 0.05$). As these data suggest even with automation resolution suggestions and flight deck tools, pilots feel the need to consult ATC about some conflict situations and their resolutions. The relationship between pilots and ATC about safe and efficient operations has been developed over many years and probably will continue as we move to add automation to what has traditionally been a manual ATC function.

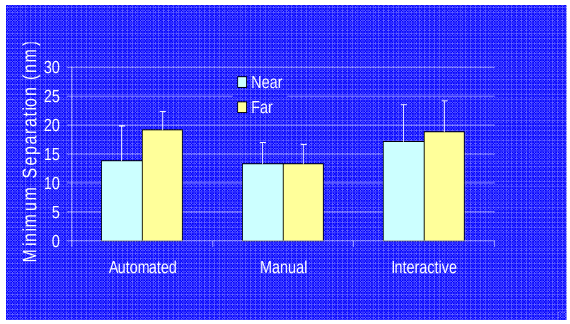

Fig 3. Minimum separation distance from the intruder as a function of resolution conditions.

As Figure 3 shows, pilots' minimum separation distance in all conditions remained well beyond the 5 NM minimum separation distances, thus all resolutions were safe. However, the figure shows that pilots in the manual condition for both near and far conflicts situations created the most efficient resolutions. Resolution suggestions in the automation only near condition were almost as efficient. Resolutions of pilots in the interactive (near and far) conditions and automation suggestions far condition were the least efficient. These results suggest that pilots with on board tools can create efficient resolutions but may sacrifice some efficiency and accept slightly less efficient resolutions provided quickly by automation.

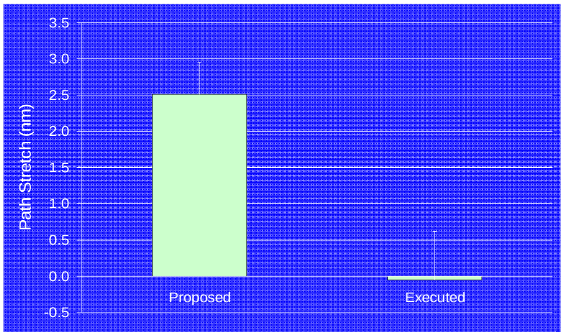

Fig 4. Mean horizontal path stretch for automation only (proposed) vs. Executed (manual and interactive executed) resolutions.

As Figures 4 and 5 show, the majority of path stretches were quite small and some were negative. Although, the automation did not suggest a resolution direct to a down stream fix, pilots using on-board tools in the manual and interactive conditions used this technique to shorten their path; thus, the difference in the mean horizontal path length between the automation only (2.5 NM) and the manual and interactive (-.05).

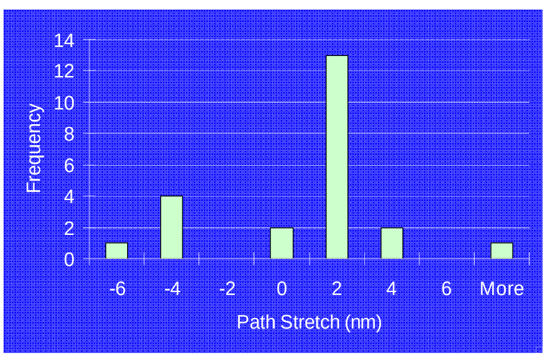

Fig 5. Magnitude and frequency of path stretches for all executed resolutions.

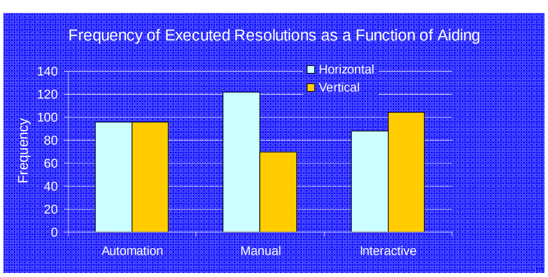

Fig 6. Frequency of resolution by conditions.

Figure 6 shows that for the automation condition pilots executed horizontal and vertical resolutions with equal frequency, as expected since we balanced the number of horizontal and vertical resolutions presented. In the interactive condition, they again started with a balanced number of suggestions. However, with access to the on-board resolution tool we see a slight preference for horizontal resolution, and when they only have the on-board manual resolution tool, a stronger preference for vertical resolution. These data did not aid us in determining the pilots' true preferences given our experimental scenarios. However, pilot questionnaire data presented later suggest that the preference to move horizontally or vertically is not a binary decision and is much more complex and situation dependent.

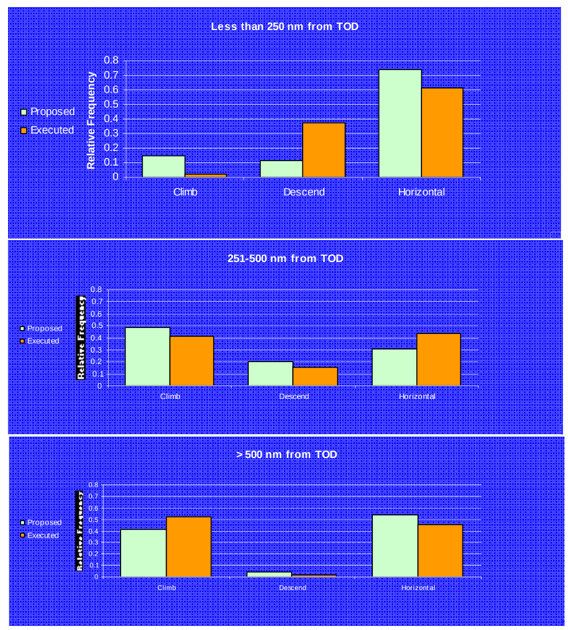

Fig 7. Resolution preference as a function of distance from top of descent.

Table 1. Pilots' comments on why they selected and executed different maneuver relative to their proximity to TOD - < 250, 251-500 and > 500 NM.

Suggested	Executed	<250 from TOD: Comment
Climb	Descent	The reason I chose to go down instead of up is because I'm close to the TOD point and it didn't make sense to climb

		that close to TOD. So, I went down instead.
Descent	Descent	That's what I would have done, the same thing they did given my proximity to the airport and they look like that would keep us clear of all conflicts.
Horizontal	Descent	I believe being so close to the TOD a descent would work better than the ATC resolution.
Horizontal	Horizontal	Simple heading, less effort, less energy. Better for everybody.
Climb	Climb	I got my climb. Always acceptable in most cases. Even mildly close in the modern aircraft climbs so quickly that a climb, unless you are within a few minutes of TOD probably if you're more than 30 minutes away from TOD, it's ok to climb in my opinion

Table 2. Distance to TOD 251-500 NM.

Climb	Horizontal	I'd rather have a simple horizontal deviation than climb because we're getting close to the airport.
Descent	Climb	Well, going that far down this far from destination airport… I'd rather take a 4000 ft climb and that's what we did. Again, assuming that there was no turbulence or other factors involved, it's pretty close to service ceiling for that weight, so that's what we did. I don't think it would be acceptable to go down that far from the airport. That's why we went up higher.
Descent	Descent	I didn’t like the automated route. So, I tried going left and right, but I didn't know if I had time, so I went ahead and accepted the automated route.
Descent	Horizontal	I just wanted to stay at altitude, obviously. Stay at altitude longer. We're 300 miles from TOD. No point in going down when it's just a 10 degree turn, less than 10.
Horizontal	Horizontal	Selection was good. Just took us about 20 degrees off course then back. It shouldn't be a problem.

Table 3. Distance to TOD > 500 NM.

Climb	Climb	It did what I thought it would do before. Just so far away. The ceiling is 40, so climb up.
Horizontal	Climb	Ok. I didn't take the automated because I was able to take my favorite choice of climbing. This is

		based on the aircraft being fully capable of 40,000. So I'm happy with that and I could have used the turn, of course. It wasn't that bad.
Horizontal	Climb	Again, that far out a climb makes sense rather than going off course. Would probably have wanted a climb to save fuel. 800 miles away.

As Figure 8 shows, pilots were most comfortable with auto-resolutions when both pilots and ATC reviewed resolutions prior to implementation. They were least comfortable when auto-resolutions were not assessed by either pilots or ATC. They were somewhat more comfortable when resolutions were assessed by either pilots or ATC, but when given the choice between their reviews or ATCs they were more comfortable when ATC assessed the resolution. Pilots, as in today's NAS, are comfortable with resolutions from ATC.

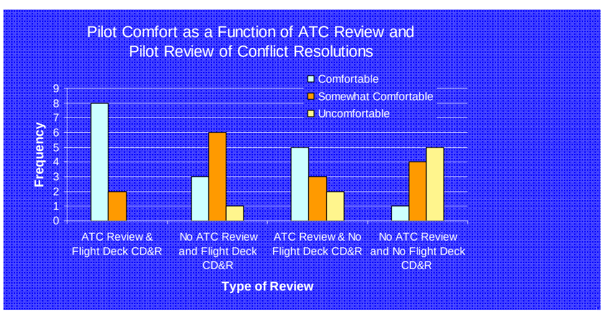

Fig 8. Post-session rating of pilot comfort-level with automation resolutions.

5.0 Conclusions

In summary, pilots reported they were likely to seek input from ATC on 30% of the automated resolutions provided to them. When allowed to use flight deck tools to request and modify auto-resolutions the need to consult ATC dropped to 8% of the time. Pilots showed a strong preference for horizontal resolutions in the manual resolution condition, but when an equal number of vertical and horizontal resolution suggestions were provided there was not a strong preference for either. In trials where pilots had access to flight deck tools their executed resolutions were safe, and more efficient than those provided by the automation.

The choice of vertical or horizontal while seeming binary was not. While pilots did not seem to have a preference for left or right horizontal maneuvers, there was a clear preference for when to execute climb of descent based on their proximity to TOD. Table 1-3 shows that when 200 nm or less from TOD, almost all pilots preferred to descend and when greater than 500 nm to TOD they generally preferred to climb. The auto-resolution algorithms currently do not take these preferences into account, but clearly these distinctions would make the resolution suggestions more acceptable.

Finally, the initial results from this study should be viewed as a first attempt to expose auto-resolution suggestions to flight crews and to get their feedback and the criteria that they normally consider when requesting or accepting a flight route change. So their reasons for rating a proposed change as acceptable or unacceptable will be very useful feedback to the designers of any auto-resolution system or to the designers of Next Gen automation. Additionally, flight crews created and executed safe and efficient route changes using their flight deck resolution automation, and used their RAT to modify unacceptable or inefficient proposed route changes.

6.0 References

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