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Air Traffic Controller and Flight Crew Conduct of a No-Closer-Than Spacing Task utilizing a Cockpit Display of Traffic Information

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"Human Factors Human-in-the-Loop (HITL) Simulation on ADS-B in Cockpit Display of Traffic Information (CDTI) Assisted Pilot Procedure Application – Simulation Results Report"

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Abstract

In order to examine a new concept called Cockpit Display of Traffic Information (CDTI) Assisted Pilot Procedure (CAPP), a Human-In-The-loop (HITL) simulation was conducted for both air traffic controllers and flight crews. In CAPP, the flight crew's task was to make spacing judgments and manage speed using information provided on the traffic displays to stay at or outside of a spacing value issued by the controller. The general purpose of the simulation was to determine the feasibility and operational acceptability of CAPP. Overall, the results support the hypotheses of controller and pilot acceptability of, and ability to conduct, CAPP.

Executive Summary

A Human-In-The-loop (HITL) simulation involving air traffic controllers and flight crews was conducted to examine a new Automatic Dependent Surveillance-Broadcast (ADS-B) Aircraft Surveillance Application (ASA) called Cockpit Display of Traffic Information (CDTI) Assisted Pilot Procedure (CAPP). The purpose of the simulation was to determine CAPP feasibility and operational acceptability from the perspective of the following topics: cloud ceilings, spacing between aircraft, benefits, transition to another ASA, roles and responsibilities, workload, displays, and communications. The CAPP concept examined in the simulation was that most recently defined in ADS-B standards bodies (additional implementations may be possible).

The main objective of CAPP is to begin a spacing reduction in arriving aircraft during the transition from Instrument Meteorological Conditions (IMC) to visual separation operations, such as CDTI Assisted Visual Separation (CAVS), where further spacing reductions are expected. CAPP includes new display elements, procedures, and communications. CAPP involves a controller issuing an instruction to the flight crew of a CAPP aircraft to use their traffic display information to space from a Traffic To Follow (TTF) during final approach operations. The instruction includes the call sign of the TTF and a No Closer Than (NCT) distance value. The NCT distance is expected to be close to, but not less than, the applicable separation standard (as the controller remains responsible for separation). The flight crew's task is to make spacing judgments and manage speed using information provided on the traffic displays to stay at or outside of the spacing value issued by the controller while achieving their desired spacing. The flight crew task is supported by an advisory level alert for the NCT value. When conducting CAPP, the flight crew is expected to continue an Out-The-Window (OTW) visual scan for the TTF and for reaching visual conditions. When the sighting occurs, it is reported to the controller so a transition to visual separation can occur.

Eleven controllers and eleven flight crews conducted CAPP under four conditions examining the independent variables of cloud ceiling (3300 and 1800 feet [ft]) and NCT value (3.2 and 3.5 Nautical Miles [NM]). The participants also conducted CAPP in four other events that examined additional outstanding questions: a CAPP aircraft overtake, no transition from CAPP to CAVS, CAPP with pilot separation responsibility, and extra flight crew actions to transition from CAPP to CAVS.

Overall, the results support the hypotheses of CAPP being feasible and acceptable to controllers and pilots under both ceiling and NCT value conditions. The results also support the hypotheses related to the pilot's ability to conduct CAPP and remain at or outside the NCT value, as well as the controller's ability to detect spacing / separation issues during CAPP. The 3300 ft ceiling was generally found to be more acceptable to pilots and controllers. The NCT value appeared to be less of a factor for pilots, but the 3.2 NM NCT value appears to better approximate the spacing desired by the controller. The 3.2 NCT value may be sufficient for ceilings that allow for additional closure after a transition into CAVS / visual separation operations.

The displays and communications used in the simulation were reported as providing the necessary information for CAPP.

Controllers were generally more positive than pilots about the concept due to reduced workload, having more time available to monitor non-CAPP aircraft, and additional support for

the spacing task during approach. Pilots reported increased traffic awareness but also increased workload.

Both pilots and controllers had questions about separation responsibilities. From a controller perspective, their positive questionnaire responses suggest they may be willing to retain separation responsibility (as done in this simulation). However, it appears the controllers prefer to have the flight crew be issued separation responsibility during CAPP. From a flight crew perspective, it appears that while some pilots may prefer the controller maintains separation responsibility, a majority would be willing to accept it and the transfer is desirable.

Based on the results, CAPP appears to have benefits and is worth pursuing when there is a transition to CAVS / visual separation. Without this transition, not enough data was available to draw final conclusions on the benefits of conducting CAPP. With the transition to CAVS, pilots used the NCT value as a goal (versus a distance to remain far away from) and set in an even lower spacing for the CAVS operation. The lowest ceiling examined in the simulation gave little time to gain the benefit of additional closure during CAVS. Therefore, the exact ceilings under which CAPP is most beneficial should continue to be examined. The separation responsibilities of the controller and flight crew should also continue to be examined since greater benefits, and a more acceptable and desirable implementation, may be possible. Regardless of separation responsibilities, controllers will continue to have a key role in the successful implementation of CAPP. A wide initial spacing within the CAPP pair is unlikely to be reduced significantly by the pilots. Tighter initial spacing will result in reduced spacing at the threshold, and potentially reduced variability, while retaining the ability of pilots to “fine tune” their spacing.

The recommendations and results of this simulation are intended to be used by the FAA, European Organisation for Civil Aviation Equipment (EUROCAE), and RTCA in developing CAPP conceptual and technical standards. The technical sponsors of this research in FAA’s Office of Aviation Safety (AVS), who develop the regulatory and guidance material for ASAs, are also expected to use the recommendations and results in the development of Advisory Circulars (ACs) and Technical Standard Orders (TSOs) based on the international standards.

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1 Introduction

Prior to the introduction of a new operation into the NAS, questions often exist that can be addressed through Human-in-the-loop (HITL) simulations. A new concept termed Cockpit Display of Traffic Information (CDTI) Assisted Pilot Procedure (CAPP) has been proposed by an industry group called the Automatic Dependent Surveillance-Broadcast (ADS-B) In Aviation Rulemaking Committee (ARC) (ADS-B In ARC, 2012b). The concept is similar to other Aircraft Surveillance Applications (ASAs) enabled by ADS-B but also has notable differences that require examination.

The main objective of CAPP is to set up the CAPP aircraft for a transition to visual separation operations where there is expected to be a further reduction in the spacing between aircraft. Reduced controller workload is expected to be an additional benefit.

The basic concept of CAPP involves a controller issuing an instruction for the flight crew to use their traffic information to space from another aircraft during final approach operations. The instruction includes the Third Party Call Sign (TPCS) of the Traffic To Follow (TTF) and a No-Closer-Than (NCT) distance value. The NCT distance is expected to be close to, but not less than, the applicable separation standard, as the controller is responsible for separation. The flight crew selects a spacing value, at or outside the NCT value they are comfortable with as a target value. The flight crew's task is to make spacing judgments and manage speed via the traffic displays to stay at or outside of (no-closer-than) the spacing value issued by ATC. The flight crew task is supported by the two alerts specified for Visual Meteorological Conditions (VMC) CDTI Assisted Visual Separation (CAVS) to single runways. The flight crew is expected to continue an Out-The-Window (OTW) visual scan for the TTF and visual conditions when conducting CAPP. When the sighting occurs, it should be reported to the controller so a transition to visual separation can occur.

CAPP was developed from a similar operation called CAVS, where the flight crew uses a traffic display to space from another aircraft during approach and other operations. In CAVS, the traffic display is used for the visual separation task when the TTF is not in sight OTW. CAVS has been explored in the past when the spacing aircraft is in both Instrument Meteorological Conditions (IMC) and VMC.

While CAPP was developed from CAVS, it is also similar to another ASA called Interval Management (IM). In IM, the pilot receives speeds to fly generated by on-board equipment. Flying those speeds allows the aircraft to achieve a specific interval assigned by the controller (future definitions may also allow for a NCT capability). The operation can be conducted in IMC and the controller maintains separation responsibility.

While CAPP has similarities to both CAVS and IM, it is not exactly the same as either. After CAPP was proposed by the ADS-B In ARC, it entered the standards development process in RTCA and European Organisation for Civil Aviation Equipment (EUROCAE). However, conceptual level questions had to be addressed prior to having those technical standards developed. This HITL simulation is being conducted to address some of those questions. The main questions are related to the operational acceptability of the concept and its information requirements for both controllers and pilots.

This document presents the background, evolution, simulation plan, findings of the CAPP HITL, and recommendations. The document has six main sections, including this one. *Section 2 – Background* introduces the CAPP concept and provides a review of past literature. *Section 3 – Methods* describes how the simulation was conducted. *Section 4—Results* provides the results of the data collection, including the statistical analyses. *Section 5—Discussion* integrates the findings into an overarching discussion. *Section 6—Recommendations and Considerations* details the recommended use of the results.

2 Background

2.1 ADS-B

ADS-B equipment on an aircraft (or surface vehicle) broadcasts position and velocity information, as well as other data such as call sign and weight category. ADS-B uses self-initiated, one-way broadcast messaging that can be received by other aircraft or ground receivers (RTCA and EUROCAE, 2011b; Civil Aviation Safety Authority, 2004) (Figure 2-1). A transmitting system on the aircraft gathers the necessary data from other on-board systems (e.g., navigation system) then generates and transmits the messages. On an individual aircraft basis, ADS-B avionics can be either “broadcast only” (i.e., ADS-B-out) or “broadcast and receive” (i.e., ADS-B in). With an ADS-B in system, a CDTI uses the received and processed messages to display the traffic picture to the flight crew (RTCA and EUROCAE, 2014a).

The ADS-B information can be used by the aircraft for flight deck-based applications (i.e., ASAs), or it can be used by receivers on the ground for applications such as Air Traffic Control (ATC) separation services. A final rule has been published by the Federal Aviation Administration (FAA) stating that ADS-B out is required on aircraft operating in several classes of airspace (similar to airspace that require transponders) by 2020. Europe has a similar mandate with a similar timeframe.

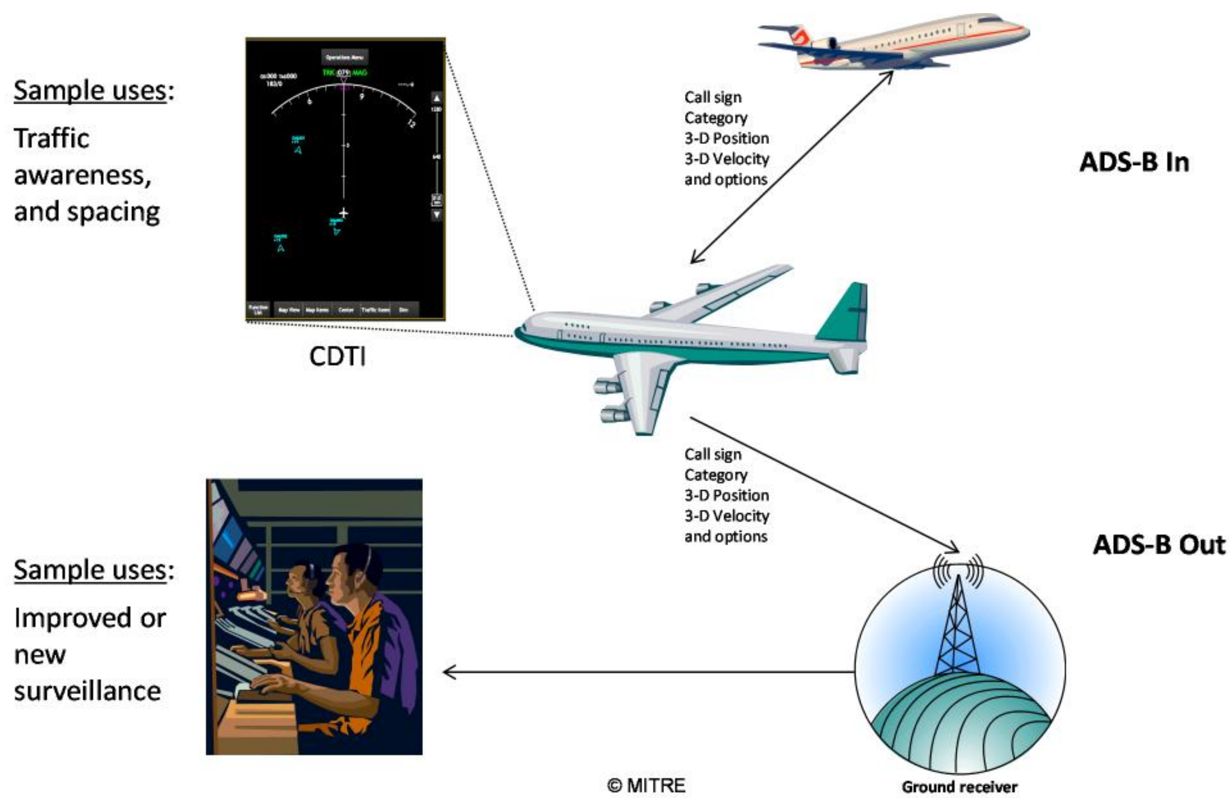

Figure 2-1. ADS-B Overview

2.2 ASAs

The idea of displaying traffic information to pilots has its roots in the 1940s and 1960s. Initial concepts consisted of sending ground-based radar information with map overlays of traffic to the flight deck via television transmissions (Radio Corporation of America, 1946; Hall, 1947; FAA, 1966). Studies on the potential uses of a CDTI continued through the 1970s and 1980s mainly at the Massachusetts Institute of Technology (MIT) and National Aeronautics and Space Administration (NASA) (e.g., Connelly, 1977; Abbott and Moen, 1981; Hart and Loomis, 1980). The expected benefits of this technology included, for example, increased safety, increased capacity, and reduced radio frequency congestion.

In the late 1970s, NASA Ames conducted nine studies to examine potential CDTI display elements including: information content of aircraft future and past track, display background elements, map orientation and scale, and update rate. Several applications were proposed early in the research (e.g., Ace, 1981); however, much of the work in the 1980s was done by NASA Langley on in-trail following, spacing, and merging applications (e.g., Abbott and Moen, 1981; Williams and Wells, 1986). In addition to the in-trail following work, some other studies in the early 1980s focused on collision avoidance with pilot maneuver choice (e.g., Smith and Ellis, 1982; Smith, Ellis, and Lee, 1984).

After a series of high-profile mid-air collisions (e.g., a 1986 collision over Cerritos, California), the FAA developed and mandated an airborne collision avoidance system called Traffic alert and Collision Avoidance System (TCAS). TCAS I includes a traffic display with Traffic Advisories (TAs) to assist in traffic awareness and visual acquisition for collision avoidance. TCAS II includes TAs and an Resolution Advisory (RA) feature, which provides a coordinated vertical maneuver between two aircraft on a collision course. In the mid-1990s, TCAS I and II were mandated for certain aircraft operating in the United States (US).

Once TCAS was in place, several studies and efforts were initiated to exploit the traffic display and to reap its additional benefits (e.g., Hollister and Sorensen, 1990; Mundra and Buck, 1990). Although several applications were proposed, only an oceanic in-trail climb / descent procedure was approved for flight trials (Cieplak and Swensson, 1997). The procedure, however, never went beyond the trial phase (but it was the foundation for another ASA developed in later activities [In-Trail Procedure in Oceanic Airspace in Steinleitner, 2004]).

Following on the early studies and implementation of TCAS, RTCA developed standards for the CDTI and an associated link (ADS-B) with additional capabilities over TCAS (e.g., RTCA, 2002; RTCA, 2003). Additionally, operational applications for the use of CDTI were proposed. Over 70 potential ASAs are described at a high level in RTCA, 2002.

ASAs can be implemented for basic traffic awareness or to space from another aircraft (with or without a transfer of separation responsibility to the flight crew for a particular aircraft). If there is a transfer of separation responsibility, "the controller delegates separation responsibility and transfers the corresponding separation tasks to the flight crew, who ensures the applicable airborne separation minima are met. The separation responsibility delegated to the flight crew is limited to designated aircraft, specified by a new clearance, and is limited in time, space, and scope…" (FAA / EUROCONTROL Cooperative Research and Development, 2001, p.2).

After mainly US development of ADS-B in application standards, an international body called the Requirements Focus Group (RFG) (supported by European Organisation for the Safety of Air Navigation (EUROCONTROL), FAA, RTCA, and EUROCAE) was formed in 2003 to develop the operational and technical requirements for an initial implementation package called Package 1. It mainly consisted of situation awareness applications (Steinleitner, 2004). The RFG completed its activities in 2011. During the time the RFG was conducting its work, an international body called Action Plan 23 (AP23) started (in 2006) to identify the next set of ASAs after Package 1. As part of that work, an international survey on potential ASAs was conducted in 2007 as a web-based survey. Approximately 25 individuals / organizations provided 100 submissions. Not all 100 submissions were for unique ASAs and several shared strong commonalities. Therefore, the submissions were combined to form specific ASAs that utilized specific elements. In 2008, that list of ASAs was used within the FAA to start writing a document called the Application Integrated Work Plan (AIWP) (FAA, 2009). The AIWP was intended to be a coordination document with the aviation community to gain agreement on high level operational concepts and priorities for ASAs. It describes ASAs and their associated maturities, benefits, costs, and enablers.

After several years of development activities in RTCA and EUROCAE, a set of initial ASAs had Minimum Operational Performance Standards (MOPS) defined in RTCA and EUROCAE (2011a). The ASAs in that document included Enhanced Visual Acquisition, Basic Airborne Situation Awareness, Basic Surface Situation Awareness, Enhanced Visual Separation on Approach (VSA), and the In-Trail Procedure in Oceanic Airspace. These applications were expected to be the first to be implemented. A revision to that document added the Traffic Situation Awareness with Alerts as well as CAVS applications (RTCA and EUROCAE, 2014a). MOPS for another application, IM, are currently under development in RTCA and EUROCAE and planned for publication in 2015.

Several of the ASAs that were part of this history of work have similarities to CAPP. The next section reviews current day operations related to CAPP. After that, specific ASAs and their relationship to CAPP will be discussed. See Section 2.6.4 for a summary of the relationship between CAPP and other ASAs.

2.3 Pilot Spacing Operations during Current Day Approaches

Visual approaches are often conducted in the US to achieve the operational efficiency that results when pilots are able to accept visual separation[1] from other aircraft. To conduct visual approaches, the weather conditions at the field must be at least VMC (ceiling at or above 1000 feet [ft] and visibility 3 Nautical Miles [NM] or greater). Additionally, in order for ATC to vector for the approach, the reported ceiling at the airport of intended landing must be at least 500 ft above the minimum vectoring altitude / minimum Instrument Flight Rules (IFR) altitude.

Visual separation can be applied during visual approaches. It can be used to separate two aircraft in terminal areas either by the tower controller by looking OTW, who sees both of the aircraft involved, or by the flight crew who sees the other aircraft involved. If the flight crew accepts a clearance by ATC to maintain visual separation, it must:

1 Note that ICAO uses the term “own separation” instead of “visual separation.”

- Maintain constant visual surveillance with the TTF
- Maneuver the aircraft as necessary to avoid the TTF or to maintain in-trail separation
- Avoid wake
- Not pass the TTF until it is no longer a factor (traffic is no longer a factor when, during the approach phase, the other aircraft is in the landing phase of flight or executes a missed approach)
- Promptly notify ATC "if visual contact with the other aircraft is lost or cannot be maintained or if the pilot cannot accept the responsibility for the separation for any reason" (FAA, 2014b sections 4-4-14 and 5-5-12).

When visual separation is to be used, a traffic advisory is issued by ATC to the flight crew. The flight crew then visually searches for the traffic and, when sighted, reports it in sight. The search for aircraft in a dense traffic environment, during reduced visibility, or at night can be challenging (FAA, 1983; Popp, 1995; Stassen, 1998). The flight crew may have difficulty visually identifying aircraft and may even identify the wrong aircraft as the traffic of concern. When pilots have difficulty acquiring the traffic OTW based on the ATC traffic advisory, multiple advisories, with the concomitant increase in controller and pilot workload, may be issued before the traffic is finally detected. After reporting the aircraft in sight, the flight crew is assigned responsibility for maintaining visual separation and a visual approach clearance can be issued with an instruction to follow the TTF. Thereafter, the flight crew is responsible for maintaining visual separation from the TTF to the runway, while ATC continues to provide separation from all other aircraft.

While maintaining visual separation, the flight crew must adjust spacing as necessary to maintain a safe separation interval; typically by adjusting speed but sometimes with lateral maneuvers. Pilots must detect and respond to unexpected decelerations by TTF requiring the pilot to adjust speed, reconfigure the aircraft, and in extreme cases perform a go-around (if the flight crew judges the separation to be unsafe) (Keller and Leiden, 2002). In challenging visibility environments, the flight crew may lose sight of the TTF, which requires ATC to intervene and establish another form of separation.

The information available on a CDTI through ASAs may also allow the flight crew to make more accurate spacing judgments and enhance the flight crew's ability to keep the TTF in sight OTW during challenging visual conditions. Display features such as closure rate, speed and distance information, as well as a range ring with a spacing alert, could improve pilots' understanding of TTF behavior (Connelly, 1972; Abbott, Moen, Person, Keyser, Yenni, Garren, 1980). In an early assessment of a rudimentary TCAS traffic display this level of information was believed to be a requirement to support an in-trail following procedure (Hollister and Sorensen, 1990). Finally, when losing sight of the aircraft, Imrich (1971) noted the CDTI should assist in traffic awareness when transitioning in and out of clouds, at night, or during visual illusions. This was confirmed during an operational evaluation / flight test of a CDTI capability in which flight crews reported the CDTI helped in maintaining an awareness of the exact position of traffic when flying instrument approaches with visibility less than 5 NM, and when the TTF transitioned in and out of cloud layers (Battiste, Ashford, and Olmos, 2000).

An ASA called VSA has been developed and implemented to support pilot traffic situation awareness when conducting visual separation. The CDTI can only be used for traffic awareness and if the TTF is lost OTW, the flight crew must inform the controller. This ASA is available in Airbus aircraft and was found to be beneficial by UPS in its Boeing implementation (FAA, 2005).

2.4 Pilot Spacing Operations during the CAVS ASA

After the basic ADS-B situation awareness concept of VSA was developed, an ASA called CAVS (also known as / named CDTI Enhanced Flight Rules [CEFR] or CDTI Enabled Delegated Separation [CEDS]) took the next logical step.

The operational concept for CAVS is to use the information available from the CDTI for traffic identification and separation monitoring (as with VSA), but continuing when the TTF can no longer be seen OTW. In this operation, the operational definition of "visual separation" is expanded to include the use of the CDTI to substitute for OTW visual contact when maintaining visual separation. This extends the flexibility of visual operations to conditions of reduced visibility (e.g., haze), difficult sighting and tracking conditions (e.g., clear nights), or IMC based on the information provided to the flight crew via the CDTI. Requirements for the conduct of the approach or other operation would be unchanged except for pilot use of the CDTI for visual separation.

While conducting CAVS, pilots use the CDTI in a manner that is functionally equivalent to using similar information derived from scanning the OTW visual scene while performing visual separation. For example, flight crews following another aircraft while maintaining OTW visual separation are expected to detect closure on the TTF by changes in the apparent size of the target and to adjust ownship speed or path so as to maintain a safe interval. The CDTI provides analogous information in the form of traffic position, range, ground speed, and Differential Ground Speed (DGS). Changes in distance or speed, therefore, are directly observable on the CDTI in the form of both graphical relative distance and alphanumeric information. Use of the CDTI should make it possible to detect such changes well before they would be apparent using visual cues alone, thus improving pilot traffic awareness.

The flight crew uses the CDTI in CAVS to allow for the natural compression to occur during final approach and to "fine-tune" their spacing (Connelly, 1977). Allowing for natural closure to occur and only conducting speed reductions when necessary were found to be beneficial when using the CDTI during current visual approach operations (Olmos, Mundra, Cieplak, Domino, Stassen, 1998). It was also found to be beneficial in research where flight crews were following on-board system generated speed commands for approach spacing during instrument approaches (Bone, Helleberg, and Domino, 2003).

CAVS operations should be mostly transparent to the controller as they are based on current day visual separation operations. Controllers continue to maintain control of the arrival flow to the airport, just as they do today when utilizing visual separation. Pilots should not try to "second guess" controller decisions based on the limited view of traffic they have on the CDTI. The conduct of CAVS is intended to be a collaborative use of traffic information in which both pilots and controllers are more effectively able to perform their historic roles and responsibilities in the context of visual separation. Connelly (1972) summarizes the pilot / ATC relationship: "Employment of the [CDTI] by no means implies ATC by committee or a freewheeling, laissez-faire operation. Traffic flow would still be organized and monitored from the ground...the [CDTI] will be used by the pilot primarily to...fine-tune spacing in trail...In other words, the [CDTI] would be used to enhance the performance of the pilot in carrying out the objectives of the ATC system" (p. 20-21).

The CAVS concept can be applied during visual and instrument approaches (as well as other operations) while the CAVS aircraft is in either VMC or IMC. During VMC and visual approaches, the CDTI is used for the visual separation task and requirements for visual approaches remain unchanged. CAVS could also be used during instrument approaches when the CAVS aircraft is either in VMC or IMC but the airport still has at least VMC. The CDTI is still used for the visual separation task and requirements for the instrument approaches remain unchanged. Several simulations have explored CAVS. The following two sections will review CAVS simulations on operations most relevant to CAPP: IMC CAVS to single runways and VMC CAVS to single runways.

2.4.1 Initial IMC and VMC CAVS to Single Runways Simulations

A series of four medium fidelity cockpit simulations (Bone, Domino, Helleberg, and Oswald, 2003; Bone, Helleberg, Domino, and Johnson, 2003a, 2003b, 2003c), with 46 participant pilots and controller support, were conducted at MITRE Center for Advanced Aviation System Development (CAASD) to examine several aspects of the CAVS application and its associated flight deck procedures. There were two primary goals of the research. The first was to objectively measure the pilot's ability to safely maintain separation from TTF using the CDTI in varying visibility conditions. The second goal was to measure the pilot's subjective comfort level and willingness to perform display-based separation across varying visibility conditions. The simulations were based on a FAA and industry developed concept and through input from the FAA and industry on the simulation design and goals. The experimental goals and conditions are summarized below and results are reported in the context of the open topic areas discussed in Section 2.8.

All simulations were conducted during simulated independent parallel approach operations and had simulated traffic inbound to the parallel runway. This traffic was visible on the CDTI but pilots had no spacing or separation tasks associated with the traffic inbound to the other runway. All simulations were flown with the autopilot coupled and all, except the third, were flown with the autothrottles engaged.

The first simulation (Bone, Domino, et al., 2003) was a basic examination of whether pilots would judge CAVS to be a viable concept and whether additional development was warranted. The purpose of this initial simulation was to test whether CAVS was viable under normal and one non-normal condition and to test the requirement for a minimum spacing value. It examined IMC CAVS to single runways. The simulation was a two by three by three factorial design with one between-subjects (spacing instruction) and two within-subjects (cloud layer thickness and initial spacing on final) variables. For the spacing instruction, one group was told to use their own judgment to determine spacing behind TTF (in the same manner as they do today when maintaining visual separation). The other group was instructed to do the same but to maintain no less than 2.5 NM spacing while conducing CAVS. This value was selected to match the current minimum authorized radar separation applied by ATC at approved runways when certain conditions can be established (FAA, 2014e). If the TTF was in sight OTW, the 2.5 NM minimum spacing requirement did not apply. Pilots in this group were also instructed to start a missed approach and contact controllers if at any time the 2.5 NM spacing limit was violated unless visual contact OTW with TTF had been established. Ownship and all TTFs were in the large weight category, so it was assumed that wake turbulence avoidance issues would be judged not significant.

The second simulation (Bone, Helleberg, et al., 2003a) continued the examination of IMC CAVS to single runways. It was a two by two factorial design with two within-subjects independent variables (CDTI size and location). Each trial began with ownship and TTF (large, Boeing 757, or heavy) in VMC on top of an overcast cloud layer. A single cloud layer thickness was used since the results from simulation one indicated the time spent on the CDTI for separation had no effect on pilots' willingness to perform the CAVS procedure. Furthermore, the thickness allowed for the visual acquisition of traffic above and below the cloud layer and a reasonable length for the final approach segment. The purpose of this simulation was to examine different display sizes and the impact of pilot consideration of wake on their selection of spacing.

Based on feedback received and issues raised (mainly the recovery from wake if encountered) related to IMC CAVS to single runways, it was determined that VMC CAVS to single runways was a more reasonable initial implementation to explore in the next simulation. Therefore, the third simulation (Bone, Helleberg, et al., 2003c) examined VMC CAVS to single runways. The purpose of this simulation was to examine higher workload conditions and test the VMC CAVS to single runways concept. Two speed control conditions were examined: manual (throttle lever input) and autothrottle (Mode Control Panel [MCP] input) in a within-subjects design. The manual speed control condition was expected to produce higher workload. Each trial began with ownship and TTF in clear conditions on top of a haze layer. A haze layer allowed for the visual acquisition of traffic above the layer and assured the loss of the aircraft from the visual OTW scene during the final approach segment.

The forth simulation (Bone, Helleberg, et al., 2003b) continued to examine VMC CAVS to single runways. The purpose of the simulation was to examine a non-normal condition (selected target degrade), a spacing cue, and to continue to test the CAVS concept during visual approach operations. This simulation also examined the interactions between pilots in a two crew member environment by having participants act in both the Pilot Flying (PF) and Pilot Monitoring (PM) positions. It used two independent variables (Variable Range Ring [VRR] and a selected target degrade event) in a within-subjects design. Two VRR conditions were examined: VRR present and VRR not present. The VRR present condition was expected to provide additional spacing cues and thereby aid the flight crew in remaining outside a desired spacing (see Section 2.4.3.1 for a description of a VRR). The weather conditions were clear night with a thin haze layer and nominal winds.

2.4.2 Follow-on IMC CAVS to Single Runway Simulations

After the initial research, MITRE CAASD conducted internal research to determine how the concept of using a CDTI for visual separation could be expanded to achieve additional benefits. After discussions with controllers from several US ATC facilities, Mundra et al. (2008) proposed several such applications under the umbrella name of IMC CAVS. IMC CAVS to single runways is the operation most relevant to CAPP, so it will be the only application that is reviewed.

The proposed concept for IMC CAVS to single runways in this follow-on work is very similar to that examined in the first two IMC CAVS to single runways simulations (i.e., Bone, Domino, et al., 2003; Bone, Helleberg, , et al., 2003a). As part of the follow-on work, the researchers planned to try to address past issues (mainly the recovery from wake if encountered). Therefore, consideration was given to the need for new operational or display requirements. Mundra et al. (2008) proposed using the VMC CAVS to single runways capabilities (proposed at the time) for the spacing task and proposed considering new wake display elements on the CDTI to assist in wake avoidance.

Two simulations were conducted to examine IMC CAVS to single runways. The first is reported in Mundra, Domino, Helleberg, and Smith (2009). This simulation examined the concept and new wake elements. It also added some new communications. The pilots were not given a specific spacing to achieve or to avoid. The ceiling for the simulation was 1500 ft Above Ground Level (AGL) and the visibility was 3 NM. The CDTI included two new display elements for wake: a vertical situation display showing the vertical relationship between TTF and ownship as well as a TTF glidepath reference cue on the Primary Flight Display (PFD). These elements were developed based on an on-line survey querying pilots on wake turbulence concerns and avoidance techniques.

The second and final simulation on IMC CAVS to single runways was reported in Domino, Tuomey, Mundra, and Smith (2010). The communications, operations, and CDTI features are very similar to / the same as those described in Mundra et al. (2009). One difference is the CDTI was a multi-application display that was modified for CAPP (further described in Stassen, Penhallegon, and Weitz, 2010; Estes, Penhallegon, and Stassen, 2010). The second simulation had different weather conditions: a ceiling of 1100 ft AGL and visibility of 4 NM. The simulation also added an additional communication.

2.4.3 VMC CAVS to Single Runways Requirements

Based on the early simulations and related development activities, the initial implementation of CAVS was determined to be VMC CAVS to single runways. It requires the flight crew to establish visual OTW contact with TTF, then correlate that traffic with the corresponding CDTI traffic symbol before using the CDTI information to maintain separation. If visual contact is subsequently lost, the CDTI is used to monitor and maintain separation. VMC CAVS to single runways is expected to allow for continued visual approach operations as ceilings approach the minimum vectoring altitude + 500 ft based the information provided by the CDTI.

VMC CAVS to single runways has moved beyond simulation and development and has been fielded by UPS and American Airlines, and has MOPS developed (RTCA and EUROCAE, 2014a). The next sections will review the flight deck and ground requirements for VMC CAVS to single runways.

2.4.3.1 Flight Deck

Based on the pilot results from the simulations, it was expected that the key required information for VMC CAVS to single runways includes: TPCS, TTF weight category (e.g., light, large, high vortex large, heavy), TTF ground speed (in 1 kt increments), TTF range relative to ownship (to the nearest 0.1 NM), and DGS (in 1 kt increments). The need for an alert was explored but no conclusion was made as to whether or not it was a requirement.

Bone, Helleberg et al. (2003b) also examined a CDTI feature that provided a visual and aural range alerting function in the form of a VRR, which is a means of depicting range information to the flight crew. Such a feature may prove useful as a visual cue on the CDTI for a desired spacing and to alert the flight crew as to when spacing has reduced below a set number (Society of Automotive Engineers [SAE], 1999). It may also draw crew attention to the CDTI and minimize crew monitoring / dwell time on the display (during a busy phase of flight) when approaching a minimum desired spacing (Laughery and Wogalter, 1997; FAA, 2003; Wickens and Hollands, 2000).

The VRR utilized in the simulation was a patented option on the Garmin Aviation Technologies AT2000 CDTI. The VRR was adjustable by the flight crew in 1-mile increments when a greater than 10-mile CDTI range was selected and in tenth of a mile increments when a 10-mile or less CDTI range was selected. When set to a specified distance, the VRR provided a visible cue as to the TTF present position in relation to the VRR value. The implementation used in the simulation included both visual and aural range alerting. When range to the selected TTF became less than the VRR distance, an aural "target range" annunciation sounded and a yellow visual "TGT RANGE" annunciation appeared at the bottom-center of the CDTI. The aural alert sounded only once and the visual alert remained until the range to the TTF exceeded the VRR distance; i.e., once the alert was no longer valid (Laughery and Wogalter, 1997). The aural alert had the redundant visual alert and provided specific information on the nature of the situation by annunciating the phrase "target range" instead of just sounding a tone (Laughery and Wogalter, 1997; FAA, 2003; Wickens, Gordon, and Liu, 1998). The alerts did not include maneuvering instructions since any actions based on the alert were at the pilot's discretion. Pilots were briefed on the ATC mandatory radar separation criteria (including wake turbulence applications) and were informed that once they knew the weight category of the aircraft to follow and time permitted, they were to set the VRR to these separation criteria (including wake turbulence applications) as a reference. Flight crews were briefed that the VRR alerting was advisory in nature, and they should use their judgment as to the appropriate action based on the given situation.

Based on data from the simulations and other activities, RTCA and EUROCAE developed MOPS for VMC CAVS to single runways. Beyond the basic CDTI requirements, CAVS is required to have additional capabilities per RTCA and EUROCAE (2014a, 2014b). The following bullets highlight the key requirements and sub-requirements most relevant to the simulation. They also include related discussion topics. For full details on all requirements, a review of both documents is recommended.

- Designation of a TTF
- For the designated aircraft, the display / presentation of:
  - TPCS
  - DGS
    - When the CAVS aircraft is in-trail of the TTF
    - Must distinguish between a positive DGS and a negative DGS
  - Ownship and the designated aircraft ground speed
  - Traffic range (i.e., horizontal range between the CAPP aircraft and TTF)
  - Range indication advisory level alert (visual depiction)
    - Triggered when the traffic range is below the value set by flight crew to provide the flight crew range awareness information that may require a subsequent response
  - Minimum range caution level alert
    - Triggered when the CAVS aircraft is less than 1.4 NM from the TTF and the CDTI can no longer be used as the sole means of traffic information for CAVS.

The DGS and traffic range must be displayed in the primary field of view when VMC CAVS to single runways is active. All of the requirements were those examined and utilized, to some degree, in the simulations. The only exception is a minimum range caution level alert.

2.4.3.2 Ground

Based on the simulations, additional infrastructure and display information may not be necessary. CAVS mainly benefits from controller knowledge of the aircraft and flight crew capability to perform CAVS. The Safety and Performance Requirements (SPR) for CAVS (RTCA and EUROCAE, 2014b) does not require the display of whether or not an aircraft is capable of CAVS. However, it does note that the information would likely allow for the most optimal use of CAVS.

2.5 IM

IM is another ASA related to CAPP. IM is intended to create operational benefits through management of intervals between aircraft in various domains (e.g., arrival, departure, en route). IM is comprised of both Ground-based IM (GIM) and Flight deck-based IM (FIM) components. GIM supports the controller in determining which aircraft are capable of acting as participants. Depending on the operation, GIM can also help determine the sequence of aircraft, the desired spacing goal, and monitor IM progress. The flight deck component has the displays necessary for the flight crew to enter the IM clearance information, conduct IM, and monitor conformance with the IM clearance.

IM has been explored internationally in simulations (e.g., Hebraud, Hoffman, Papin et al., 2004; Barmore, Abbott, and Capron, 2005; Mercer, Callatin, Lee, Prevot, and Palmer, 2005; Bone, Penhallegon, and Stassen, 2008b), has initial standards developed (e.g., RTCA and EUROCAE, 2011c), has been field tested (e.g., FAA, 2001; Lohr, Oseguera-Lohr, Abbott, Capron, and Howell, 2005) and fielded (e.g., Penhallegon and Bone, 2015). The US and Europe are also currently funding development of international MOPS for IM and the US is developing plans for a full field implementation in the post-2020 timeframe. Additionally, IM was prioritized as one of the highest ASAs for accelerated development by a committee comprised of the US aviation industry (ADS-B In ARC, 2011).

The following paragraphs describe a sample IM operation in the arrival environment. The conduct of IM in other environments is very similar.

An IM arrival operation typically starts in the en route airspace once the controller has used ground automation (e.g., Traffic Management Advisor [TMA], Time-Base Flow Management [TBFM]) to sequence and schedule aircraft. At the appropriate point, the en route GIM automation displays to the controller an aircraft pair (i.e., an IM aircraft and a TTF) that is capable of conducting IM, as well as the desired spacing goal. The controller then decides whether or not to initiate IM on a capable aircraft based on sector traffic, knowledge of ADS-B surveillance range requirements, arrival flow sequence, and the spacing requirement for a given IM pair. The controller uses this information to provide the initiation information to the flight crew in the form of a clearance (FAA, 2011). The IM clearance can contain several elements: the IM clearance type, Assigned Spacing Goal (ASG) type, special points, TTF TPCS, and TTF Intended Flight Path Information (IFPI) (RTCA and EUROCAE, 2011c). The key elements related to the CAPP concept are the TTF TPCS and two types of ASGs. The two types of ASGs that have been in the standards work are the precise value for the flight crew to achieve and maintain and the at-or-greater than (very similar to the same as a NCT) value for the flight crew to remain outside of. While both types of ASGs have existed in the standards work, very few HITL simulations have examined the at-or-greater value (one known effort is reported in Penhallegon, Mendolia, Bone, Orrell, and Stassen [2011]).

Once the IM clearance is provided to the flight crew, it is entered into the flight deck IM equipment which then checks the information is appropriate for the operation and the TTF is in ADS-B surveillance range. If the TTF is not in ADS-B surveillance range, IM cannot start. Once the TTF is in range, is on the expected trajectory, and meets the necessary performance requirements, IM is initiated and the FIM equipment provides an IM speed for the flight crew to fly. Situation awareness information is available to assist the flight crew in monitoring the progression of the spacing operation. IM information can be provided on a CDTI, although guidance information could be provided on other displays as well.

With the presentation of each new IM speed, the flight crew ensures it is feasible for the aircraft's current configuration and environmental conditions. The crew is expected to follow the IM speeds in a timely manner consistent with other flight deck duties unless conditions prevent it (e.g., safety, operational, flight deck IM equipment, or regulatory issues). If unable, the flight crew stops following the IM speeds and contacts ATC to convey they are unable to conduct IM. The controller then terminates IM or provides a new IM clearance, if possible and desirable.

Similarly, if the controller becomes aware of any conditions that prevent continued IM, such as a safety or an operational issue, the controller will contact the flight crew and terminate IM. If no issues arise for either ATC or the flight crew causing a suspension or termination, the flight crew continues following the IM speeds and the controller continues monitoring the operation until the aircraft reaches the planned termination point. At this point, the flight crew discontinues flying IM speeds and terminates IM. Throughout the IM operation, the controller remains responsible for separation between the IM aircraft and the TTF as well as all other aircraft.

When IM operations are in effect, not all aircraft are required to conduct IM. Aircraft not capable of conducting IM can receive speed advisories from the controller that may be proposed by ground automation.

IM when conducted during final approach has similarities to IMC CAVS to single runways. Two major differences are that with IM the flight crew does not have separation responsibility for the TTF and with IM the flight crew receives flight deck generated speeds for the spacing task.

2.6 CAPP

2.6.1 Development Background

The CAPP concept originated in a US aviation industry group called the ADS-B In ARC that was chartered by the FAA in 2010. The ARC was tasked by the FAA to provide recommendations on how to proceed with ADS-B in applications (i.e., ASAs) while remaining compatible with ADS-B out requirements. The ARC used the previously mentioned FAA AIWP report to conduct its activities and to provide recommendations on the ASAs (FAA, 2009, 2010). The original ARC letter and report to the FAA included the CAPP-related concepts of CAVS (and implementations using the term CEDS) in addition to IM and other ASAs (ADS-B In ARC, 2011). Amongst other recommendations, the ARC made a recommendation to the FAA to focus funding on flight deck and ground technical and operational requirements material for a selected set of ten applications. IMC and VMC CAVS to single runway related ASAs were in the top five. The ARC reported the top five applications provided 77% of the (ARC-calculated) total benefits[2].

The ARC made several CAPP-related recommendations even though CAPP was not defined yet. For example, the ARC recommended the FAA examine auxiliary display locations such as a retrofit Electronic Flight Bag (EFB) location and an ADS-B Guidance Display (AGD). The ARC also recommended the FAA / ATC retains separation responsibility. However, CAVS was stated as an exception to that recommendation. Finally, the ARC recommended that additional work be done to “better [understand] the roles for both pilots and air traffic controllers and a change to separation standards” (ADS-B In ARC, 2011, p. 26).

In separate, follow-on recommendations to the FAA, the ARC recommended the FAA examine the new concept termed CAPP. The ARC recommended the FAA pursue CAVS and CAPP (and IM [spacing]) as part of the “five key ADS-B in applications with the greatest potential to positively affect the ADS-B In business case” (ADS-B In ARC, 2012b, p. v). CAPP had not been proposed as a concept in previous work such as the AIWP or material produced by AP23. Therefore as part of this follow-on effort, the ARC produced a 2-page document that described the proposed CAPP concept (ADS-B In ARC, 2012a). That document was a preliminary description of CAPP in

[2] The ARC also recommended the FAA continue refining the benefits estimates based on a limited return on investment without considering additional benefits the ARC expected the ASAs to provide.

both an approach and departure environment. The approach concept described was very similar, in part, to IMC CAVS to single runways with the exception that the controllers maintain separation responsibility during CAPP. The document describes a transition into VMC CAVS to single runways when the conditions permit.

This preliminary description developed by the ARC was reviewed with the ARC and other key stakeholders (e.g., researchers supporting / working for EUROCONTROL and the FAA). Based on those discussions, RTCA Special Committee (SC)-186 and EUROCAE Working Group (WG)-51 developed an initial version of a CAPP OSED so that standards work could begin (RTCA and EUROCAE, 2013a). That document was commented on within the standards bodies. The comments were gathered and were adjudicated when possible. If a resolution could not be determined, the topic was kept open. Resolved comments were incorporated into a new version of the CAPP Operational Service and Environment Description (OSED) (RTCA and EUROCAE, 2013b). Whereas the first version covered both an approach and departure environment, the second version was scoped to only the approach environment. The revision was also released for comment in the standards bodies. Eighteen individuals from the ADS-B community provided approximately 260 comments. The resolved comments were considered when specifying the concept for this stimulation while the outstanding comments / issues were considered for exploration in this simulation. The outstanding topic areas are reviewed in Section 2.6.5.

The CAPP concept is also represented in FAA NextGen material as a “relative spacing ‘No Closer Than’ increment” in the Separation Management portfolio – Relative Spacing Using Traffic Display operational increment (FAA, 2014d). The goal of the operational increment is to maintain visual separation and approach runway throughput when otherwise impossible.

2.6.2 Procedures

As described in RTCA and EUROCAE (2013b), the basic concept of CAPP involves a controller issuing an instruction for the flight crew to use their traffic information to space from another aircraft during final approach operations. The main objective of CAPP is to set up the CAPP aircraft for a transition to visual separation operations where there is expected to be a further reduction in the spacing between aircraft. Reduced controller workload is expected to be an additional benefit.

CAPP can be conducted during single stream visual or instrument approaches in IMC or VMC during IFR. Both aircraft in the operation must be established on final approach or the TTF must be on final approach and the CAPP aircraft must be on an intercept to final. To conduct CAPP, the controller issues an instruction for CAPP with a NCT distance and the TTF TPCS. The NCT value is expected to be close to, but not less than, the applicable separation standard. The flight crew’s task is to make spacing judgments and manage speed via the traffic displays to stay at or outside of (no-closer-than) the spacing value issued by ATC. The flight crew task is supported by the two alerts specified for VMC CAVS to single runways. The flight crew is expected to continue an OTW visual scan for the TTF when conducting CAPP. When the sighting occurs, it should be reported to ATC so a transition to visual separation can occur.

The CAPP flight deck equipment is expected to be the same as the VMC CAVS to single runways tools as described in RTCA and EUROCAE (2014a, 2014b). The CAPP equipment does not include the provision of on-board generated speed guidance nor does it include a specific, precise interval for the flight crew to achieve (as with IM as described in RTCA and EUROCAE, 2011c). The anticipated ground requirements include an indication of which aircraft are capable of performing CAPP and an indication of which aircraft are actively performing CAPP (FAA, 2014a).

CAPP is expected to transition into visual separation and visual approach operations[3] such as VMC CAVS to single runways (Figure 2-2). The controller maintains separation responsibility until there is a transition to visual separation. The NCT value is not a value the flight crew needs to fly up to and maintain. Instead, it is defined as a limit to not breach. However, to achieve the expected benefits, the flight crew is expected to allow for the natural compression that occurs on final approach and to end up close to the NCT value prior to the transition to visual separation. Getting close to the NCT value allows for a further closure, and the associated benefits, during the application of visual separation.

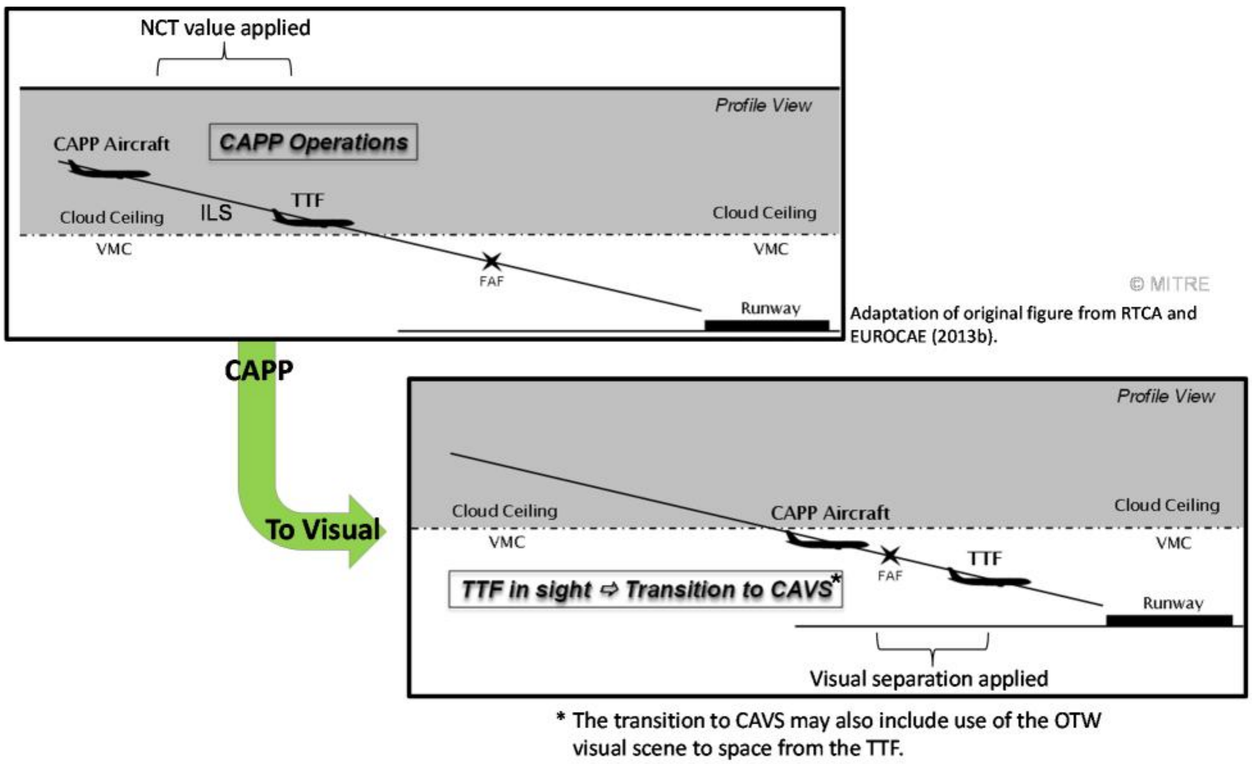

Figure 2-2. CAPP to visual separation / CAVS transition

Figure 2-3 shows the relationship between CAPP and VMC CAVS to single runways spacing and the two associated alerts. The range indication advisory alert indicates the horizontal range to the TTF will fall below a value selected by the flight crew. With VMC CAVS to single runways, the advisory is triggered at (not prior to) the value. The minimum range caution alert indicates the CDTI can no longer be used without OTW visual contact.

[3] However, CAPP does not require a transition into these operations. The concept allows for it to continue during the instrument approach until termination around the FAF.

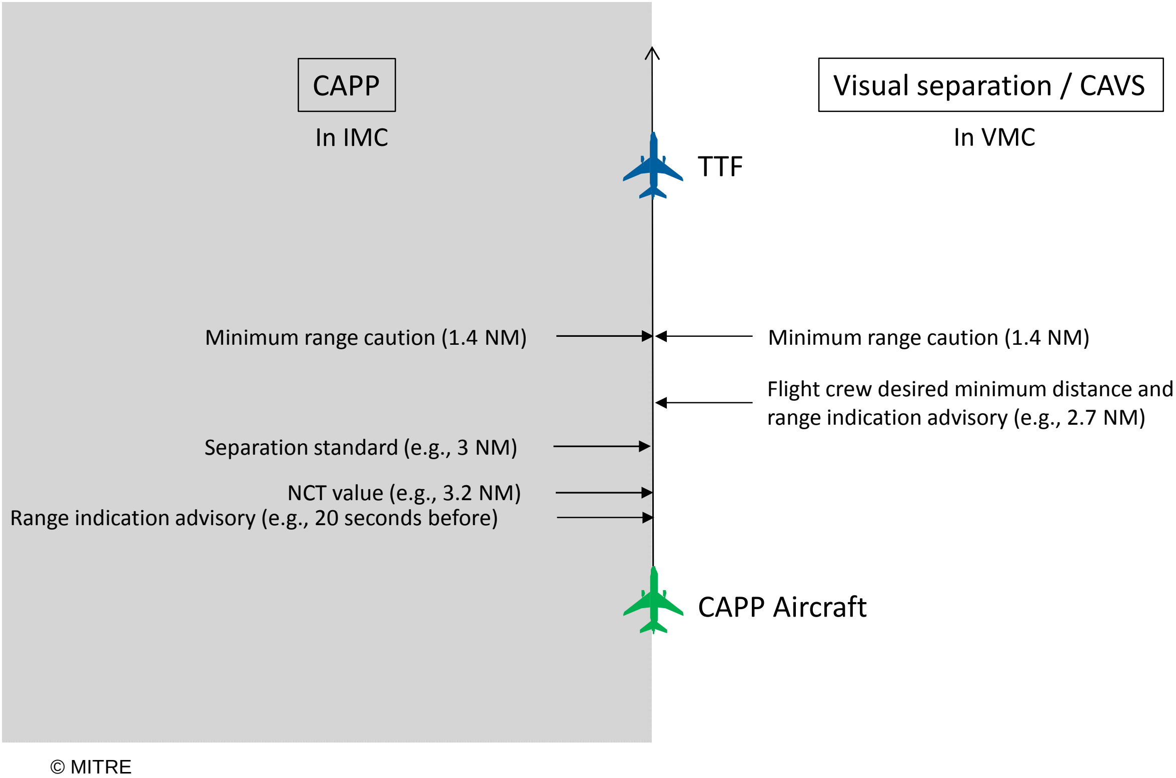

Figure 2-3. CAPP versus CAVS spacing and alerting

2.6.3 Communications

While RTCA and EUROCAE (2013b) do not provide specific phraseology for CAPP, the TTF TPCS and the NCT value are noted as communication requirements. The document provides a sample scenario with sample communications. While they are not specific phraseology requirements, they were expected to be reasonable enough to include in the sample scenario. Those communications include a traffic advisory followed by the CAPP instruction and a report of visually sighting the TTF. The following bullets provide sample communications for a CAPP aircraft (Delta 357) and a TTF (United 123).

- Controller traffic advisory on downwind – "Delta 357, traffic is United 123, 11 o'clock, 7 miles, 4000 feet, inbound on localizer. Report identified."
  - Flight crew reply – "Looking for traffic Delta 357."
- Traffic identification by flight crew – "Philadelphia Approach, Delta 357, United 123 identified."
  - Controller "expect" CAPP communication – "Delta 357, roger. Expect no closer than from that traffic."
- Controller CAPP instruction and report request – "Delta 357, maintain no closer than 3.2 miles from United 123. Report traffic in sight."
  - Flight crew readback – "Maintain no closer than 3.2 miles from United 123. Report traffic in sight. Delta 357."

- Flight crew traffic sighting – “Philadelphia Approach, Delta 357, traffic in sight.”
    - Controller visual separation instruction – “Delta 357, roger. Maintain visual separation from that traffic.”

2.6.4 CAPP Relationship to Other ASAs

As has been noted, CAPP is similar to other ASAs reviewed in this Background section. Table 2-1 provides a summary of the relationship between CAPP and the other ASAs from the perspective of several key aspects. As shown, CAPP utilizes CDTI tools without speed guidance and is mainly expected to be conducted in IMC during instrument approaches when the controller is responsible for separation. Each of the other ASAs have similarities to CAPP, but each contain a unique combination of the aspects. While each is slightly different, the similarities provide insight into CAPP operations.

Table 2-1. CAPP Relationship to Other ASAs

		ASA				
		VSA	VMC CAVS to Single Runway	IMC CAVS to Single Runway	IM	CAPP
CDTI Tools	Basic (e.g., DGS and distance)	✓	✓	✓		✓
	Advanced (e.g., Speed Guidance)				✓	
Separation Responsibility for TTF	Controller				✓	✓
	Flight Crew	✓	✓	✓		
Ownship Weather Requirements	VMC	✓	✓		Op	Op
	IMC			✓	✓	✓
Approach Type	Visual	✓	✓		Op	Op
	Instrument			✓	✓	✓
Individual Determining the Spacing Goal	Controller				✓	NCT
	Flight Crew	✓	✓	✓		✓*

Op – Optional implementation
* With a controller limit

2.6.5 Open Questions

The following sections provide the key, open issues / topics that were captured during the CAPP concept development process described in Section 2.6.1.

2.6.5.1 Concept Acceptability and Operational Suitability

2.6.5.1.1 General Acceptability

- Is the concept acceptable to both pilots and controllers?
- Will mixed CAPP equipage result in issues for controllers?
  - Note: Mixed equipage means some aircraft are able / equipped to perform CAPP and some aircraft are unable / unequipped to perform CAPP.

2.6.5.1.2 Benefits

- Does CAPP result in reduced controller workload as compared to IMC instrument approaches without CAPP?
- Does CAPP prove useful in the set-up to visual separation operations?
- Does CAPP have any operational value if there is no transition to visual separation operations?
- How does aircraft spacing during CAPP operations compare with non-CAPP spacing during instrument approaches in IMC?

2.6.5.1.3 Spacing and NCT Value Acceptability

- What is a reasonable value or range of values for the NCT variable?
  - What is "close" enough such that a reasonable transition can occur to visual separation?
  - What is "far" enough to allow the controller to ensure the flight crew does not get too close to the separation standard?
- Can the controller reasonably determine the NCT value?
- How close does the flight crew get to the NCT value prior to transitioning out of CAPP?
- Can the controller and flight crew detect unexpected behaviors like aggressive decelerations of the TTF or spacing issues?
- How is CAPP terminated when there is a breakout of the TTF?

2.6.5.1.4 Ceiling

- Is there a point where the ceiling is too low to transition to visual separation operations and further close the spacing (to achieve the intended benefit)?
- Is there a reasonable / necessary amount of time needed for the conduct of CAPP prior to transitioning to visual separation?

2.6.5.1.5 Transition

- Is there a smooth transition into visual separation operations?
  - Is the point of transition into visual separation obvious?
  - Does the transition need to be explicitly conveyed in a communication?
- Does the flight crew remain on the instrument approach or transition to a visual approach?
- If there is no transition into visual separation operations, is the controller more likely to want to continue or cancel CAPP?
  - May be related to where the controllers set the NCT value and then how close flight crews get to the NCT value

2.6.5.1.6 Roles and Responsibilities

- Are flight crew and controller roles and responsibilities during CAPP acceptable?

2.6.5.2 Human Factors

Human factors issues are represented in many of the other topic areas. While not specifically called out as a key open topic in the concept development process to date, topics such as workload and situation awareness are typically issues of concern and are expected to be addressed in development activities.

2.6.5.3 Displays

- How well does the transition to visual separation work with the NCT “range indication” advisory level alert? Does this alert need to be inhibited at some point?
- What should the NCT “range indication” alert be set to? Is there a default value?
- What is the flight crew action after the NCT “range indication” is triggered?
- Do the avionics need to provide a separate CAVS capability or can the same capability be used for both CAPP and CAVS?
- Can CAPP be performed using the CAVS display elements?
  - Is there a benefit to providing the flight crew any additional display elements?

No questions were specifically identified for the minimum range caution alert.

2.6.5.4 Communications

- What are the necessary communications for initiation and termination?
  - Is there a separate traffic advisory or just a CAPP instruction?
- What is the necessary new phraseology?
  - Besides TPCS and NCT value, is “Traffic identified” necessary?
- When should the communications occur?

- o Are the necessary communications for CAPP acceptable during a high workload environment?

2.7 Study Purpose and Design

Based on these open questions and no prior research on CAPP, the FAA determined that a HITL simulation on CAPP would be worthwhile prior to developing MOPS requirements. From that point, preliminary simulation ideas were proposed by the authors of this document and the FAA project manager and technical sponsors. Those ideas were vetted with key stakeholders in the FAA and industry through discussions and a simulation plan review telecon in March 2014. With this input, the plan was updated and the simulation was executed.

The general purpose of the simulation was to determine CAPP feasibility and operational acceptability to both flight crews and controllers. The results of the simulation were intended to:

- Support the validation of the concept and claimed operational value
- Determine information and communication needs, and the associated procedures for flight crews and controllers, including those related to flight deck alerting and TPCS use
- Define the transition out of CAPP into other ADS-B in concepts (e.g., VMC CAVS to single runways) using a multi-purpose CDTI
- Support the next steps of CAPP development in the standards community.

The key topics to address were the general acceptability of the concept, the impact on flight crew and controller workload, and the question of whether CAPP is possible using the CAVS flight deck functionality. In discussions of the simulation plan and the literature review, the broad topics areas of the concept acceptability and operational suitability (including the sub-topics of general, ceiling, and NCT acceptability, benefits, spacing, transition, as well as roles and responsibilities), human factors, displays, and communications were considered for examination in the simulation.

It was determined that several of the open questions could be addressed in the simulation through the data collection efforts. Two general topics were determined to be the most important and comprise the independent variables: 1) the acceptable ceilings and 2) the acceptable NCT values. Both have an impact on the concept from an acceptability and benefits perspective.

The cloud ceilings and NCT values were planned to be examined under nominal conditions. However, since it is important to understand off-nominal events, two additional events were added. The first off-nominal condition added was a CAPP aircraft overtake condition where the pilot goes inside the NCT value and continues toward the separation standard. It is an issue for both flight crews and controllers. Since this was a possible occurrence in real world operations, it was desirable to examine pilot and controller behavior during this event. The second off-nominal condition added was the inability to transition out of CAPP into CAVS. Again, this is an issue for both flight crews and controllers.

Finally, two other events were added to examine specific areas of concern. An issue that came up in discussions was the number of actions required by the flight crew to transition from CAPP into CAVS. It was recognized that this transition occurs at a very busy time for the flight crew. Therefore, it was desirable to examine how many CDTI actions were acceptable to the flight crew for this transition. The final topic was the spacing and separation responsibilities of pilots and controllers during CAPP.

The following section provides the research topics areas to be address in the simulation in the context of past literature.

2.8 Research Topic Areas

In order to gain an initial understanding of the issues involved with introducing CAPP into field operations, a HITL simulation was designed (described in Section 3) to address selected key questions. Topics of interest were identified and data was collected with respect to the four primary areas.

- CAPP concept acceptability and operational suitability
- Human factors
- Displays
- Communications.

The following sections address each topic area and discuss the relevant literature results. The section closes with the experimental hypotheses based on the literature review and open questions related to CAPP.

2.8.1 Concept acceptability and operational suitability

2.8.1.1 Spacing

To achieve the intended benefits from CAPP, controllers will need to set aircraft up on final approach at a reasonable spacing and speed that allows for compression to a final beneficial spacing. After being set-up, pilots are expected to allow for the compression and time decelerations to achieve the desired spacing. During CAPP, they will be expected to close to somewhere near the NCT value so that additional compression can occur during VMC CAVS to single runways where the final spacing will occur.

From a flight crew perspective, the spacing task during CAPP is very similar to that done during IMC CAVS to single runways. The pilot is determining the spacing to achieve, but with CAPP, there is a NCT limit. CAPP can be compared to the past work from the perspective of the spacing achieved, closure, use of a NCT value, and the detection of spacing issues.

In the first simulation on IMC CAVS to single runways, Bone, Domino, et al. (2003) examined three different initial set-up spacings (3.5, 4.0 and 4.5 NM). There were differences in final mean spacing when spacing in IMC without the TTF in sight (i.e., when conducting CAVS) and VMC with the TTF in sight based on initial spacing. When aircraft started at 3.5 NM, the final spacing between aircraft was lower than when aircraft started at 4.5 NM. There were no differences in mean final spacing when aircraft were set up at 4.0 versus 3.5 NM. Similarly, Bone, Helleberg, et al. (2003a) reported that when spacing in IMC without the TTF in sight (i.e., when conducting IMC CAVS to single runways) separation decreased as initial spacing decreased for both Boeing 757 and heavy aircraft (but not for large). Similar trends were seen for final spacing between aircraft after exiting IMC. In the two simulations examining VMC CAVS to single runways (Bone, Helleberg, et al., 2003b, 2003c), very similar trends were seen. Final spacing between ownship and the TTF decreased as initial spacing decreased when following all aircraft types (large, Boeing 757, and heavy aircraft).

In addition to final spacing, closure rate was examined in the final three simulations (Bone, Helleberg, et al., 2003a, 2003b, 2003c). In those simulations, pilots were able to use the information available on the CDTI to allow for higher DGS when spacing between aircraft was greater and lower DGS when spacing between aircraft was reduced. This data indicates the pilots are appropriately using the CDTI information for the spacing task.

When examining whether a NCT instruction (not less than 2.5 NM when TTF was not in view) had an impact on the final mean spacing in CAVS, no differences were found by Bone, Domino, et al. 2003. Mean final spacing when the TTF was not in sight for the group who was given the instruction and the group that was not given the instruction was approximately 2.9 NM. However, the NCT instruction did have an effect on the distribution of spacing values. Pooled variance in final spacing across all approaches among the 2.5 NM spacing group was significantly less than the variance for the no instruction group.

There is also the question about whether pilots can detect spacing issues when conducting CAPP. Spacing data in Bone, Domino, et al. (2003) indicated pilots had no difficulty with anomalous speed behavior of the TTF and were able to detect and respond appropriately to aggressive slow-downs solely by reference to the CDTI without visual or aural alerts. There were no go-arounds or missed approaches from a failure to detect this situation.

For controllers, these CAVS simulation results indicate that controllers will continue to have a key role in the successful implementation of CAVS procedures and that large initial spacing intervals are unlikely to be reduced significantly by the pilots. Tighter initial spacing or an instruction to maintain a certain speed or greater will result in reduced spacing at the threshold, and may reduce variability, while retaining the ability of pilots to “fine tune” their spacing.

CAPP should be examined to determine whether the differences from CAVS yields different spacing behavior results.

2.8.1.2 Use of a NCT Value

The NCT value utilized in CAPP has an impact on how close the pilots can ultimately get to the separation standard and how comfortable the controller is allowing the pilot to get that close while still remaining responsible for separation.

When examining a NCT instruction (not less than 2.5 NM when TTF was not in view), Bone, Domino, et al. (2003) noted that no pilot in the spacing instruction group violated the 2.5 NM spacing restriction during the period of time that TTF was not in view, even under conditions of rapid, unannounced deceleration of the TTF and no CDTI distance alerting.

Very few HITL simulations have examined pilots conducting a NCT task when the controller remains responsible for separation. Most previous IM simulations used a precise interval for the flight crew to achieve when the controller was responsible (e.g., Bone, Penhallegon, and Stassen, 2008b; Barmore et al. 2005; Aligne, Grimaud, Hoffman, Rognin, and Zeghal, 2003). One known IM effort that used a NCT-like capability in a departure environment with pilot participants is reported in Penhallegon et al. (2011). However, the NCT capability was different from CAPP in that the flight crew did not have any actions until the system determined the IM aircraft would be at or inside the NCT value by the specified point. If the system determined this was going to occur, IM speeds were provided for the flight crew to fly. It was also different in that if the system determined the spacing was going to be at or lower than the NCT value, it would provide IM speeds to achieve the NCT value. In this simulation, pilots indicated a preference for the NCT operation over a precise operation.

For controllers, the NCT value has an impact on their level of monitoring and potentially the number of interventions. It is desirable to set a NCT values that is close enough to the separation standard to ensure the expected CAPP benefits, yet far enough from the separation standard to not overly concern the controller about the potential for the aircraft to get too close to the separation standard (potentially leading to queries / unnecessary communications or breakouts).

2.8.1.3 Ceiling Acceptability

The operational value of CAPP depends on the cloud ceiling altitude. Higher ceilings may allow for visual operations (e.g., VMC CAVS to single runways) without the need for CAPP. Lower ceilings may not allow for a transition out of CAPP to leverage the CAVS benefits. Additionally, the operational acceptability of CAPP may depend on the amount of time spent spacing when in the cloud layer. Therefore, cloud layer and ceiling results from the CAVS studies are discussed next.

Several ceilings have been examined in CAVS work. Bone, Domino, et al. (2003) reported a simulation where pilots conducted IMC CAVS to single runways. Pilots were initially in visual conditions, then entered in IMC layer, and then transitioned out of the layer. The pilots experienced three cloud thicknesses (500, 2000, and 4000 ft) with ceiling at 2400 +/-200 ft AGL and good visibility below. All pilots agreed the three thickness levels experienced were acceptable and the majority agreed that a thicker layer would be acceptable for CAVS. The different cloud thicknesses did not have an impact on the final spacing between aircraft.

Bone, Helleberg, et al. (2003a) reported a simulation where pilots conducted IMC CAVS to single runways. It was very similar to Bone, Domino, et al. (2003) except the cloud thickness was a constant at 1500 ft. The ceiling started at 3500 +/-200 ft and ended at 2000 +/-200 ft Mean Sea Level (MSL) (1500 ft AGL). All pilots agreed they would routinely perform CAVS in the IMCs experienced.

Mundra et al. (2009) examined IMC CAVS to single runways with a 1500 ft AGL ceiling and Domino et al. (2010) examined the same operation with an 1100 ft AGL ceiling. Pilots reported the conditions were acceptable for both simulations.

While flight crews in the CAVS simulations found the ceilings to be acceptable, they did not have to transition into another ASA. In CAPP, the acceptability of the ceiling may be affected by the transition to VMC CAVS to single runways.

2.8.1.4 Roles and Responsibilities

In CAPP, the controller assigns the flight crew a spacing task while maintaining separation responsibility. As has been reviewed already, CAVS has a transfer of separation responsibility while the pilot is conducting a spacing task. Pilots found this operation acceptable in simulations (e.g., Bone, Helleberg, et al. 2003b; Domino et al., 2010). In the majority of IM simulations, the pilot conducted a spacing task while the controller maintained separation responsibility (RTCA and EUROCAE, 2011c). Having the pilots conduct an IM spacing task on final approach while the controller maintains separation responsibility has been found to be generally acceptable to controllers (e.g., Aligne et al. 2003) including under abnormal situations (Boursier et al., 2006). Pilots have also found it to be generally acceptable (e.g., Hebraud, Hoffman, Pene et al., 2004).

Prinzel et al. (2012) was one of the few studies found that directly examined the differences between pilots spacing with and without separation responsibility. The authors examined this subject area with IM and a synthetic / enhanced vision system. The authors found pilots spacing with separation responsibility reported better situation awareness for the TTF and lower workload. When there was a spacing issue with the TTF, pilots reported better awareness of the TTF when they were responsible for separation versus not being responsible. Pilots reported being more “in-the-loop” when responsible for separation because of the closer proximity to the TTF and having the task of separation responsibility. When pilots did not have separation responsibility, they were further away from the TTF and waited for the controller to respond to a separation issue (when they should have reported a spacing issue). However, there were no reported differences for spacing precision, acceptability, efficiency, or safety of the operation regardless of whether the pilot or controller was responsible for separation from the TTF.

When examining the impact of varying levels of separation responsibilities on pilots, Vu et al. (2012) also found that pilots had better situation awareness when they had separation responsibility.

Rognin, Grimaud, Hoffman, and Zeghal (2002) examined ATC issues associated with the delegation of spacing tasks. The authors highlighted concerns to consider such as either reduced or increased monitoring by the controller and the potential for the controller to have difficulty recovering if there is a separation issue. The authors also pointed out benefits of the delegation of a spacing task such as the pilot providing additional monitoring of the spacing interval and being another loop of control. The authors also stated the delegation of the spacing task may also increase the time available to the controller for other tasks.

2.8.1.5 Benefits

As stated previously, the main objective of CAPP is to set up aircraft for a transition to visual separation operations such that there can be a further reduction in the spacing between aircraft. Therefore, pilots would be expected to allow for compression on final approach during CAPP down somewhere close to the NCT value and then allow for additional compression down to a lower spacing they are comfortable with during VMC CAVS to single runways. The benefits potentially realized from CAPP are related to the benefits of CAVS operations. Therefore, the past work on CAVS is reviewed next.

Visual operations allow for reduced distance flown and reduced spacing between aircraft based on pilots applying visual separation and achieving spacing below radar separation standards. FAA (2014c) shows that visual operations (as compared to instrument operations) result in higher throughput at 30 core US airports (in various runway configurations). Mundra et al. (2009) examined Los Angeles International Airport (KLAX) operations and found a mean spacing reduction of approximately 0.4 to 1.2 NM when the TTF crossed the threshold (of the common runway) when the facility is able to conduct visual operations. These results validated findings in an older study (Haines, 1978). That study showed a minimum spacing reduction of approximately 0.6 to 1.1 NM when the lead aircraft crossed the threshold when the facilities were able to conduct visual operations. Mundra et al. (2008) also show several major airports (KATL, KBOS, KCLT, KDFW, KEWR, KJFK, KLAX, KLGA, KORD, and KSDF) where the arrival rate could be increased on the order of six aircraft per hour during visual operations. This could be achieved if the minimum spacing realized during visual operations is 2 NM behind large and small aircraft and if spacing during visual operations could be reduced below wake separations standards (as is done in current day visual separation operations). The authors state that 2 NM is likely a practical lower limit for spacing between the aircraft as the TTF crosses the runway threshold to ensure that TTF has time to clear the runway.

The benefits of IMC CAVS to single runways is expected to deliver aircraft at similar spacing to that seen during current day visual separation operations without CAVS. Mundra et al. (2009) reported on the spacing realized in a simulation when IMC CAVS to single runways. The spacing from the TTF realized in this simulation was slightly higher for CAVS when compared to a baseline visual condition but the authors hypothesize that pilots are able to provide spacing with CAVS that is similar to that achieved in current day visual operations (and less than operations without visual operations).

Domino et al. (2010) found a mean spacing of 2.5 NM as the TTF crossed the threshold (of the common runway) for an IMC CAVS to single runways operation during which pilots were free to select their own spacing as they do during visual separation operations. This was a reduction of 0.65 NM from an Instrument Landing System (ILS) baseline condition (without the application of visual operations). The authors reported that if these results are indicative of what could be expected in the field, there could be an increase of approximately six arrivals per hour with two arrival runways in operation at the simulated airport of KLAX. Based on this body of work, it appears the actual spacing realized under CAVS is likely very similar to that seen during current day visual separation operations and is beneficial. If there is a desire to reach the 2 NM minimum to achieve additional benefits, guidance to pilots about the goals of the operation may need to change slightly (e.g., they may need to be provided a target spacing).

Based on the CAVS activities, it appears that IMC CAVS to single runways is able to provide spacing between aircraft that is similar to current day visual operations. To examine the benefits case for CAPP then, it is necessary to examine whether or not the flight crew closes to the NCT value during CAPP, and then closes further during VMC CAVS to single runways.

2.8.2 Human Factors

2.8.2.1 Workload

When introducing a new task, it is desirable to ensure there is spare capacity for other tasks and that workload is not so high the pilot becomes overloaded and performance starts suffering.

For the flight crew, several past research activities are relevant to the workload impact of CAPP. Bone, Domino, et al. (2003) reported on a simulation where pilots conducted IMC CAVS to single runways with and without a NCT value, as well as under varying cloud layer thicknesses. Pilots reported completing all cockpit tasks and that they had light to moderate workload. In Bone, Helleberg et al. (2003a), pilots also conducted IMC CAVS to single runways, but without a NCT value. Pilots reported workload as low and reported completing all cockpit tasks.

Bone, Helleberg, et al. (2003c) and Bone, Helleberg, et al. (2003b) reported on simulations where pilots conducted VMC CAVS to single runways. Pilots generally reported low workload that was similar to that experienced during visual approaches without CAVS, including under the higher workload condition of manual throttle control. In the two follow-on simulations examining IMC CAVS to single runways, workload was found acceptable (Mundra et al., 2009; Domino et al., 2010).

Controller workload is affected by factors such as the number of aircraft controlled, sector flight time, aircraft performance differentials, sector area, and the number of transitioning aircraft (National Research Council, 1997). During normal operations, controllers try to predict the point at which the situation is approaching their personal limits and their workload will become unacceptably high. When a traffic situation becomes unmanageable, controllers my take actions, such as task shedding, to reduce their workload.

Since CAPP shifts workload involved in aircraft speed control and spacing to the flight crew, it should reduce controller workload through a reduction in the number of required instructions and a reduction in the amount of communications.

The closest ASA where pilots conduct a spacing task and the controller is responsible for separation is IM. Having the pilots conduct an IM spacing task on final approach while the controller maintains separation responsibility has been found to have acceptable workload for controllers (e.g., Aligne et al. 2003) including under abnormal situations (Boursier et al. 2006). Pilots have also found it to be generally acceptable although with an increase in the mental demand aspect of workload (e.g., Hebraud, Hoffman, Pene et al., 2004) or similar to operations without IM (e.g., Bone et al. 2008b).

2.8.2.2 Situation / Traffic Awareness

Endsley (1999) defines three levels of situation awareness:

- Level I – Perception of elements in the environment (e.g., aircraft location, aircraft call sign, and aircraft ground speed)
- Level II – Comprehension of the current situation (e.g., current aircraft spacing)
- Level III – Projection of future status (e.g., future aircraft spacing).

For pilots, understanding ownship position and it in relation to dynamic traffic is an important task. Building a traffic picture not only allows pilots to know the position of surrounding traffic, it allows them to anticipate and project future events and is the basis from which decisions and maneuvers are made. Therefore, the traffic picture must consist of the most up-to-date information possible.

Pilots without a CDTI currently try to build these levels of awareness, in part, from party line communications between pilots and ATC. The CDTI has been proposed as a useful tool for flight crews when building the traffic picture and understanding how ownship fits into that picture (e.g., Stassen, 1998; Imrich, 1971; Verstynen, 1980).

An early study of a CDTI-based spacing task included several appropriate tests ("stop action quizzes") of situation awareness (Howell, 1972), and found that pilots are selective in assimilating information about particular aircraft. The target aircraft received the most attention and the CDTI helped with attaining traffic awareness of that aircraft. Results indicated that information reported on the closest aircraft was frequently better than information reported on the furthest aircraft. It was therefore stated the CDTI can allow the pilots to ignore more remote targets, which could be seen as a benefit. It may be acceptable for flight crews to know less about the more remote aircraft and to concentrate on the target aircraft of concern (while the controller continues to handle separation issues and TCAS provides alerting when necessary).

Howell (1972) also reported that 100% of the pilots agreed that "Awareness of other traffic during an approach to a major airport in [IMC]…is useful for planning the approach and analyzing irregularities." None said it was "unnecessary…" or that it "satisfies only natural curiosity." Pilots reported the CDTI helps situation awareness either "quite a bit" or "tremendously." With respect to cockpit duties, ninety-five percent (95%) of the pilots said the CDTI allowed them to plan ahead.

Pilots in the CAVS work showed acceptable traffic awareness evidenced by the closure rate / DGS data mentioned previously (Bone, Helleberg, et al., 2003a, 2003b, 2003c). In those simulations, pilots were able to use the information available on the CDTI to allow for higher DGS when spacing between aircraft was greater and lower DGS when spacing between aircraft was reduced. Additionally, Bone, Domino, Helleberg, and Oswald (2003) reported that pilots did not have difficulty with anomalous speed behavior of TTF and were able to detect and respond appropriately using solely the CDTI when conducting IMC CAVS to single runways.

In IM evaluations, pilots reported a better understanding of the situation (Hebraud, Hoffman, Papin et al., 2004) and the ability to anticipate (Hebraud, Hoffman, Pene et al., 2004) with IM. However, Hebraud, Hoffman, Pene et al. (2004) did report that one pilot thought that situation awareness could be worse due to a focus on the target aircraft and neglect of other duties. In Bone et al. (2008a, 2008b), pilots reported improved and acceptable situation awareness under normal and non-normal scenarios.

At a minimum, CAPP should not degrade the pilot's traffic situation awareness as the flight crew is actively engaged in the operation through the requirement to fly the CAPP instruction. Therefore, the traffic situation awareness on the TTF / relevant traffic is expected to be good.

For controllers, the task of remaining cognizant of current and evolving conditions, i.e., maintaining situation awareness, is fundamental. The controller must maintain a three-dimensional mental image of the traffic he or she is controlling as well as the surrounding environment. This image must include "altitude, airspeed, heading, call sign, type of aircraft, open communications, weather, runway configuration / condition, current traffic 'picture', future traffic 'picture', immediate and potential conflicts" (Garland, Stein, and Muller, 1999). The loss of situation awareness can cause problems such as slower detection, slower responses, more incorrect responses, and deskilling (if long term). For controllers, a reduction in situation awareness can increase the chances for a loss of separation (Endsley, Mogford, Allendoerfer, Snyder, and Stein, 1997).

Any new procedures must ensure that controller situation awareness is not degraded. "The human controller relies greatly on a detailed mental picture of the air traffic, which active task performance and manipulation of data help to sustain." (Hopkin, 1999. p. 504-5). Traffic can quickly become unmanageable once a controller loses situational awareness, forcing the controller to change from being proactive to reactive (Lee, Mercer, Smith, and Palmer, 2005). Endsley et al. (1997) found that when aircraft are in a free flight environment there is a greater loss of situation awareness as pilots are given greater degrees of freedom. Previous research has shown that controllers tend to lose their effectiveness if they are not actively involved with the control of traffic. "Means et al. (1988)…demonstrated that controllers' memory for flight data is a function of the level of control exercised…flight information of 'hot' aircraft, which required extensive control instructions, was significantly better than memory for flight information for 'cold' aircraft" (Garland, et al., 1999).

During the conduct of IM, controllers have shown acceptable situation awareness when pilots conduct a spacing task while the controller maintains separation responsibility. For example, Penhallegon and Bone (2009) found controllers showed acceptable traffic awareness including under abnormal situations during IM operations in the en route descent.

It is possible that CAPP may affect controller situation awareness. CAPP places controllers in a situation where they are less actively involved in aircraft speed control for CAPP aircraft. The impact of this on controller performance, monitoring, and the ability to intervene must be examined. The impact will be examined in the simulation by examining whether controllers are able to maintain situation awareness while aircraft are conducting CAPP, or whether they lose situation awareness and are not able to detect developing spacing issues.

2.8.2.3 Head Down and Scan Time

For pilots, concepts that require the use of an additional display will likely increase head down time and add to the instrument scan. In these cases, head down time should not increase to an unacceptable level. Bone, Domino, et al. (2003) reported a simulation where pilots conducted IMC CAVS to single runways with a CDTI on the Navigation Display (ND). Pilots reported reasonable head down time. Bone, Helleberg, et al. (2003a) reported a simulation where pilots conducted IMC CAVS to single runways. Pilots reported more challenges integrating the CDTI into their scan when it was hosted on an auxiliary display (versus the ND).

Bone, Helleberg et al. (2003b, 2003c) reported simulations where pilots conducted VMC CAVS to single runways with the CDTI in an auxiliary display location. Pilots reported increased head down time over visual approaches without CAVS and more challenges integrating the CDTI into their scan when it was hosted on an auxiliary display.

The impact of the two separate flight deck displays, the location of those displays, and the impact on pilot's scan need to be examined for CAPP.

IM is the closest operation where pilots are conducting a spacing task and the controller is responsible for separation. Previous IM studies have indicated that monitoring of aircraft under flight deck spacing operations (IM) was increased for non-spacing aircraft (Mercer et al. 2005; Boursier, et al. 2006), but reduced for aircraft that had been sequenced and were maintaining their spacing (Aligne et al., 2003). Previous simulation results also indicate that controllers are able to intervene on non-normal situations such as the lead inappropriately converging on its TTF (Boursier et al., 2006; Bone et al., 2007). These studies showed the events were detected through normal radar monitoring and were sufficiently resolved. Although the controllers in Bone, Penhallegon, Stassen, Simons, and Desenti (2007) reported some questions about knowing when to intervene, all reported they were likely to detect and intervene in a developing spacing problem before it became a separation issue and did so in the scenarios presented.

2.8.3 Displays

The information displayed to the flight crew and the controllers is critical to the proper execution of CAPP. CAPP displays must include the necessary information to conduct the operation and must not contain any conflicting or hazardously misleading information.

For the flight deck, there have been several experiments conducted on similar concepts. Bone, Domino, et al. (2003) reported a simulation where pilots conducted IMC CAVS to single runways. The CDTI was hosted on the ND. Bone, Helleberg, et al. (2003a) reported a simulation where pilots conducted CAVS during instrument approaches that was very similar to Bone, Domino, et al. (2003). The CDTI was hosted on the ND in some conditions and an auxiliary display in other conditions. Bone, Helleberg, et al. (2003b, 2003c) reported on simulations where pilots conducted VMC CAVS to single runway. The CDTI was hosted on an auxiliary display. For all simulations, pilots reported they were comfortable using the CDTI for separation when traffic was and was not visible OTW. The majority of pilots reported being more confident using the CDTI, as compared to OTW cues, to establish appropriate spacing behind a TTF during approach. Pilots reported the closure to the final spacing occurred at a comfortable and appropriate rate. All pilots reported having the necessary display elements (traffic position, ground speed, flight identification, and weight category as well as range and DGS relative to ownship. A graphical, static closure cue was also provided). Pilots appeared to find the numeric range to the TTF and DGS most useful relative to the other elements. Pilots reported that minimum distance alerting should be a required feature.

In follow-on research on CAVS during instrument approaches, Mundra et al. (2009) examined the same display elements and added wake avoidance features on the CDTI. Pilots reported being willing to accept separation responsibility during CAVS with the display features available. When providing feedback on the CDTI elements, several high ranking elements (e.g., numeric range to traffic, traffic ground speed, and numeric closure rate) were the same elements that were ranking highly in the past CAVS simulations. The new wake cues were ranked at the bottom and relatively low compared to all other CDTI elements. However, the pilots still reported them as useful. The authors suggest further research into whether such wake elements should be minimum requirements or "nice-to-have."

Domino et al. (2010) also examined CAVS during instrument approaches with a multi-function CDTI hosted on the ND with a new closure cue. Wake tools such as those in in Mundra et al. (2009) were used but only for demonstration purposes and no data other than workload was reported on the features. Pilots reported the display supported the task and allowed them to select the appropriate closure rate. Pilots also reported being as confident using the CDTI information as the OTW information for the spacing task.

Bone, Helleberg, et al. (2003b) also examined a CDTI that provided a visual and aural range alerting function in the form of a VRR, as mentioned in Section 2.4.3.1. Objective data indicated that closure rates and the final spacing between aircraft were not significantly different regardless of whether the VRR was present or not. Additionally, since the VRR range setting was one piece of information from which to base spacing decisions and to which adherence was not mandatory, the pilots' reaction to the VRR aural and visual alert was often minimal. On the occasions they did respond, it was to immediately do one or more of the following: increase the flap setting, lower the landing gear, or reduce the airspeed. Pilot responses indicated that it was acceptable to set the VRR to the ATC mandatory radar separation criteria (including wake turbulence applications) but were mixed as to whether it would be desirable to set the VRR to another number. Pilots agreed the VRR spacing alert should be considered advisory in nature. In actual operations, it may be desirable to allow each flight crew to set the desired range of the VRR based on the particular conditions for that approach. Some pilots reported the setting of the VRR was the most difficult manipulation of the CDTI (setting the VRR required pushing a button to select the feature, pushing buttons to select the desired value, and pushing a button to enter the selected value).

Overall, pilot opinions were mixed in Bone, Helleberg, et al. (2003b) as to whether either the textual or aural alerts were necessary. Pilots found the aural and textual visual alert acceptable but preferred the aural. In Domino et al. (2010), pilots did not have an alert when conducting IMC CAVS for single runway approaches but several pilots stated a desire for a spacing alert to indicate reaching a specific range or closure rate from the TTF.

One of the main questions for the CAPP pilot displays is whether or not the CAVS display elements currently defined in RTCA and EUROCAE (2014a, 2014b) are sufficient for CAPP. Past research on similar concepts appears to indicate that it should be possible. The additional wake tools used in Mundra et al. (2009) and Domino et al. (2010) when operating in instrument conditions are not expected to be necessary because CAPP will not be conducted inside the separation standards (including the wake limitations).

It also needs to be determined whether pilots will find the AGD and CDTI combination acceptable for CAPP, including the CDTI being hosted on an auxiliary display. In four CAVS simulations (Bone, Domino, et al., 2003; Bone, Helleberg, et al, 2003a, 2003b, 2003c), pilots preferred a CDTI in the primary field of view but found a CDTI located in the throttle quadrant forward console area (the same location typically used in some weather radar installations) to be an acceptable implementation, especially when that was the only implementation they experienced during the simulation. An AGD was not used in those simulations, nor was one used in Mundra et al. (2009) or Domino et al. (2010). An AGD has been used in IM simulations (e.g., Bone et al. 2008b) and is one of the displays implemented by UPS and American Airlines for CAVS and IM.

For controllers, the SPR for CAVS does not require the indication of whether or not an aircraft is capable of CAVS (RTCA and EUROCAE, 2014b). However, it does note the information would likely allow for the most optimal use of CAVS. The CAPP OSED recommends the controller be provided information to determine whether or not an aircraft is capable of CAPP (RTCA and EUROCAE, 2013b). If such information was not available to the controller, the document suggests the flight crew would have to request CAPP. The anticipated ground requirements stated in FAA (2014a) include an indication of which aircraft are capable of performing CAPP and an indication of which aircraft are actively performing CAPP.

2.8.4 Communications

CAPP will require the introduction of new procedures, including phraseology and communications between the pilot and controller. Past simulations have examined the necessary phraseology and communications for similar concepts.

In the initial four CAVS simulations, there was an attempt to stick with current phraseology as much as possible. Traffic was identified with current day traffic advisories. However, TPCS could be added as an optional element to allow for the use of the TPCS on the CDTI to more easily identify the TTF. In Bone, Domino et al. (2003) and Bone, Helleberg, et al. (2003a), pilots replied that use of TPCS is beneficial but some reported the potential confusion when hearing ownship flight identification over the common frequency. In the follow-on two VMC CAVS to single runways (i.e., Bone, Helleberg, et al., 2003c, 2003b), pilots replied that use of TPCS is beneficial. However in Bone, Helleberg, et al. (2003b), pilot opinions were varied on the actual use.

In addition to the use of TPCS, there needed to be a communication to authorize CAVS. In Bone, Domino, et al. (2003), the phrase “own separation” was used. Questions were not specifically asked on the use of the term “own separation.” However, development activities outside of the simulation led to the choice to not change current phraseology, thereby allowing the use of current visual separation phraseology to include the use of the CDTI. Controllers preferred use of current phraseology because the operation was the same whether or not the pilot was using the CDTI to space from traffic. Therefore, in the follow-on three CAVS simulations (Bone, Helleberg et al., 2003a, 2003b, 2003c), the phrase “visual separation” was used to authorize the use of the CDTI when the TTF was not in sight OTW. There were few to no pilot reports of issues with the use of “visual separation.”

As noted previously, there were two follow-on simulations that examined IMC CAVS to single runways. The communications changed from the previous CAVS simulations and current day phraseology. In the first, Mundra et al. (2009) used communications that were similar to those originally proposed for CAPP (and shown in the sample scenario in RTCA and EUROCAE, 2013a). The first communication was a traffic advisory including the TPCS when the CAVS aircraft and TTF were on base. The pilot used the information to find the TTF on the CDTI and then reported the traffic “identified” (a new term to indicate identification of the TTF on the CDTI). The second communication was to “maintain CAVS separation” (a new phrase to authorize CAVS) and a clearance for a transition to and for the ILS. The second and final simulation on IMC CAVS to single runways was reported in Domino et al. (2010). For the communications, this simulation added another communication between the first and second one noted for Mundra et al. (2009). This additional communication from the controller told the flight crew to “expect [CAVS] reference that traffic” with a dogleg vector to join final. The authors of both reports did not report there were any issues with the utilized communications.

As can be seen, CAPP communications have several simulations from which to develop the phraseology and communications requirements. It also had sample communications in the sample scenario (RTCA and EUROCAE, 2013a). The exact communications necessary need to be defined. The communications will need to be brief as the communications load in the CAPP environment can be high. Additionally, the instruction needs to avoid confusion related to TPCS. Using TPCSs to talk about (rather than talking to) other aircraft on the same frequency introduces a potential for confusion for controllers and pilots. The FAA identified TPCS as a topic to address and initiated an activity to examine the topic (see Bone, et al., [2013] for further details). This simulation will use the results from that on-going activity and continue to provide data to the effort.

2.8.5 Hypotheses

Based on the past work and open CAPP questions, four specific hypotheses to address were defined:

- Controllers will be able to detect spacing / separation issues during CAPP.
- Pilots will be able to remain at or outside the NCT value during CAPP.
- Controllers will find CAPP acceptable under different cloud ceilings and NCT values.
- Pilots will find CAPP acceptable under different cloud ceilings and NCT values.

In addition to these four specific hypotheses, other open topics / questions will be addressed in the remaining sections.

3 Method

The simulation methodology described in this section was reviewed in the spring of 2014 with key research and ADS-B stakeholders in the FAA and aviation industry. Reviews of the simulation plan allowed key stakeholders to provide feedback that could be incorporated in the final simulation design. After incorporating inputs from meetings and demonstrations, dry run testing was executed with internal and external participants. Suggestions for changes from all the development activities were incorporated as adjudicated with the key stakeholders prior to data collection activities.

3.1 Simulation Environment

The simulation was conducted in the MITRE CAASD Integration Demonstration and Experimentation for Aeronautics (IDEA) Laboratory. As mentioned previously, this simulation was the first HITL examination of CAPP. However, the simulation utilized controller, flight crew, and pseudo-pilot workstations from past ADS-B simulations that were modified as necessary for CAPP. The following sections describe the utilized capabilities.

3.1.1 Controller Workstation

The terminal workstation had a representative 2K display that hosted a Standard Terminal Automation Replacement System (STARS) interface that was very similar to the currently fielded STARS system. However, the workstation had a (non-STARS) QWERTY keyboard and mouse. Some keys were programmed to serve as special function keys. The STARS workstation software consisted of a Terminal Controller Workstation display (Figure 3-1), and contained the vast majority of basic STARS functionality. This functionality was defined and validated as sufficient for the simulation by controller subject matter experts.

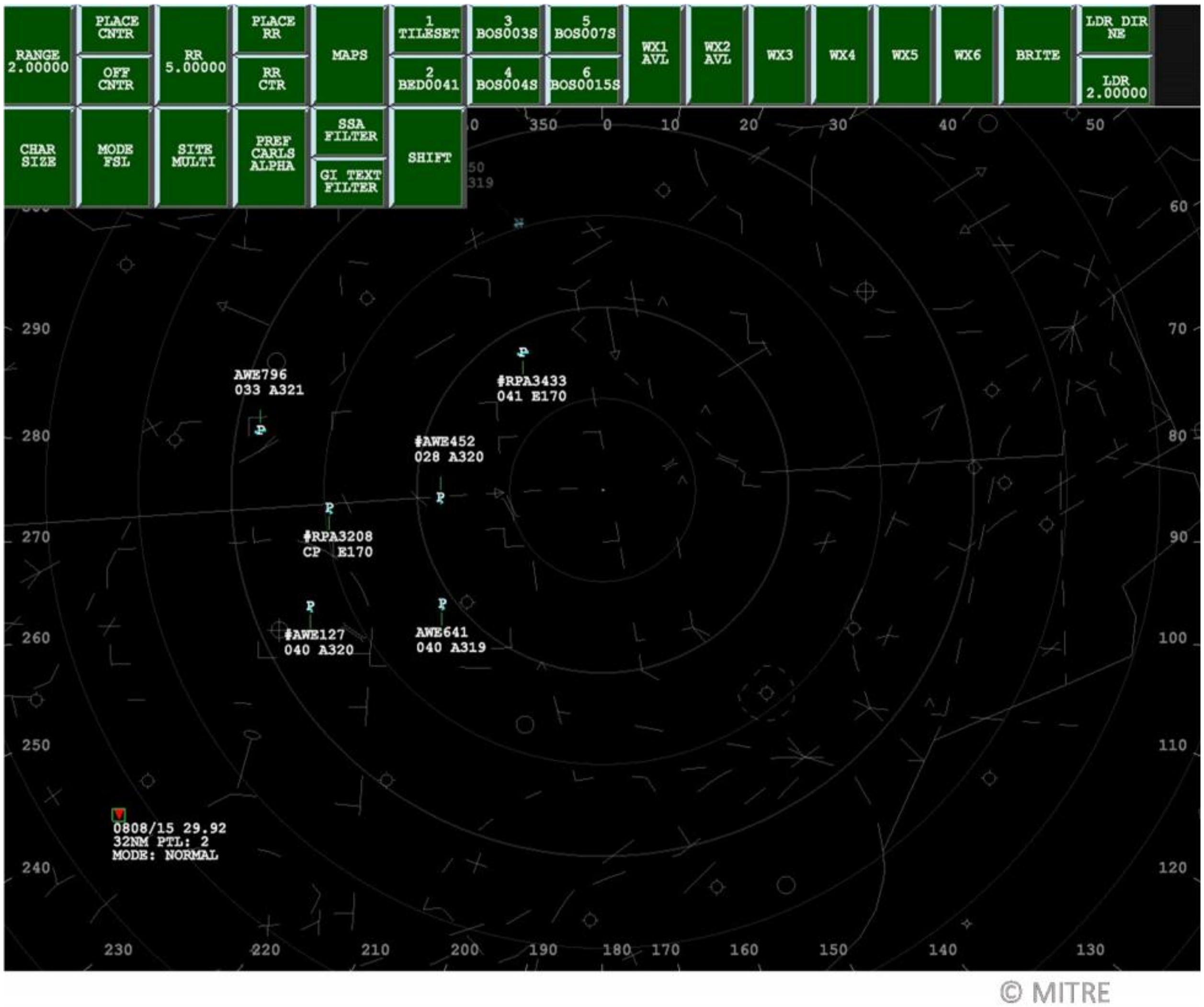

Figure 3-1. STARS Interface

In the simulation, two CAPP indications were used. One was simply entering "CP" into the scratchpad once an aircraft was actively performing CAPP. The "CP" timeshared the field with the aircraft altitude. The other indication was the use of a hash character (#) to indicate when an aircraft was capable as acting as a CAPP aircraft. This hash character was shown to the left of the aircraft identification. This is the same field as currently used for other ADS-B surveillance indications. Both of the CAPP indications are shown in Figure 3-2.

The implementation utilized in the simulation is not the final or necessarily recommended design. It was notional for the simulation, but believed to be a reasonable potential implementation.

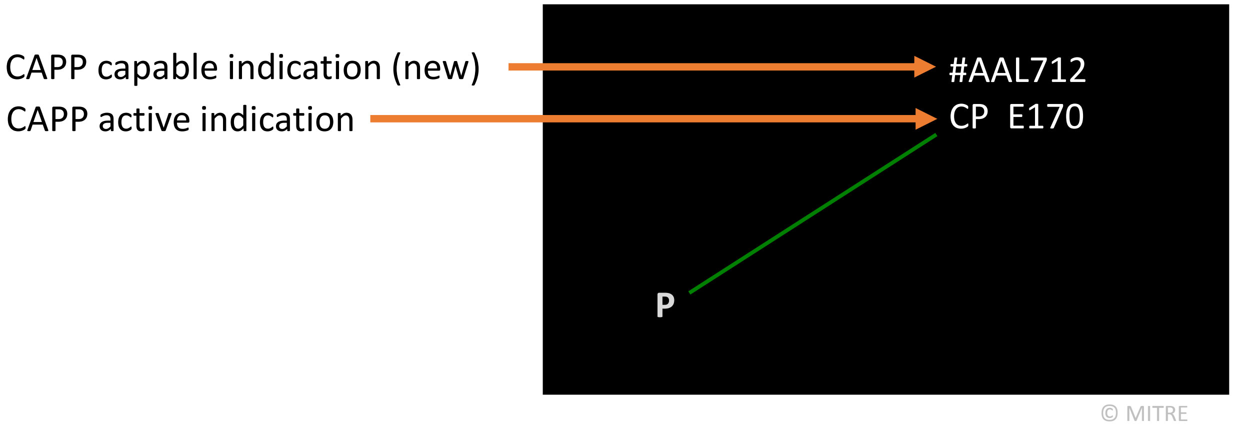

Figure 3-2. CAPP Indications in Aircraft Data Block

3.1.2 Flight Deck Workstation

3.1.2.1 Flight Deck

The flight deck simulator consisted of a standard Boeing 777 flight deck layout as shown in Figure 3-3. The equipment included standard elements such as a MCP, two radio management panels, Engine-Indicating and Crew-Alerting System (EICAS), a Flight Management System (FMS) with Control and Display Unit (CDU) interfaces, dual PFDs, and dual NDs. The simulator also included a 180-degree OTW visual capability. New traffic display components were added to accommodate CAPP (i.e., elements on the CDTI and AGD). The locations of the CDTI and AGD are shown in Figure 3-4. The utilized CDTI and AGD elements were based on requirements for CAVS as CAPP was expected to utilize the same features (as reflected in a previous draft of RTCA and EUROCAE, 2014a, 2014b). The following sections review the CAPP displays in detail.

Figure 3-3. Boeing 777 Flight Deck Simulator

Figure 3-4. CDTI and AGD Location in Flight Deck Simulator

3.1.2.2 CDTI

The flight deck simulator was equipped with two CDTIs that were hosted on auxiliary displays: one at the captain's eleven o'clock position and the other located at the First Officer's (FO's) one o'clock position. The CDTI provided basic traffic information to the flight deck, and was used to set up CAPP and perform CAPP operations. It was designed to allow for the integration, control, and operation of multiple ASAs in a seamless manner. The overall design philosophy is described in Stassen et al. (2010) and Estes et al. (2010). The original CDTI design described in those papers was updated in order to meet the requirements of the current simulation and to bring it in line with the standards current at the time of simulation development (RTCA and EUROCAE, 2011a and a draft of RTCA and EUROCAE, 2014b). This included adding a setup tab in the options menu that allowed for the entry of the required information for CAPP and the transition to CAVS. The setup tab had options for the TTF TPCS, the CAPP NCT value, and the CAVS minimum distance value. The TTF TPCS field could be auto-populated if the pilot selected an aircraft. The CAPP NCT value, and the CAVS minimum distance were not auto-populated so pilot entry was required. The CDTI with the setup information entered is shown in Figure 3-5.

Figure 3-5. CDTI during CAPP Setup

After the appropriate information (i.e., TTF TPCS, CAVS NCT value, and CAVS minimum distance value) was entered, the PM pushed the “Confirm Arm” button so the flight crew could coordinate on the entered information. Once the coordination occurred, the system could be armed by pushing the “Arm” button. Once armed and after the initiation performance requirements were met, CAPP was enabled and the equipment provided the CAPP information. Figure 3-6 shows the CDTI with CAPP active and Figure 3-7 shows an inset from the CDTI that highlights the CAPP features. These features, and those on the AGD (reviewed in the next section) were used by the flight crew to fly CAPP and then transition into CAVS. The features (as discussed in section 2.4.3) were implemented as required by RTCA and EUROCAE (2014a, 2014b). The feature to distinguish between a positive and negative DGS is not specifically defined in RTCA and EUROCAE (2014a). However, it does note the potential for confusion if not done properly and recommends a graphical indication of the sign. The authors / researchers agreed with this concern and decided not to use a “+” and “-” indication as they can be confusing (depending on the location of the symbol and the surrounding information). To help avoid confusion in this simulation, a static graphical cue was used to meet the requirement as shown in Figure 3-7. A “> <” symbol indicated the CAPP aircraft was closing on the TTF, while a “< >” symbol indicated the CAPP aircraft was pulling away from the TTF (these symbols were also used in Domino et al., 2010). A circle was placed around the TTF symbol on the CDTI to visually depict the NCT value. The TTF TPCS as well as range and closure related information (i.e., TTF ground speed, DGS, and range) were provided. The CDTI also depicted text associated with the alerts described in Section 3.1.2.4.

Figure 3-6. CDTI when CAPP Engaged

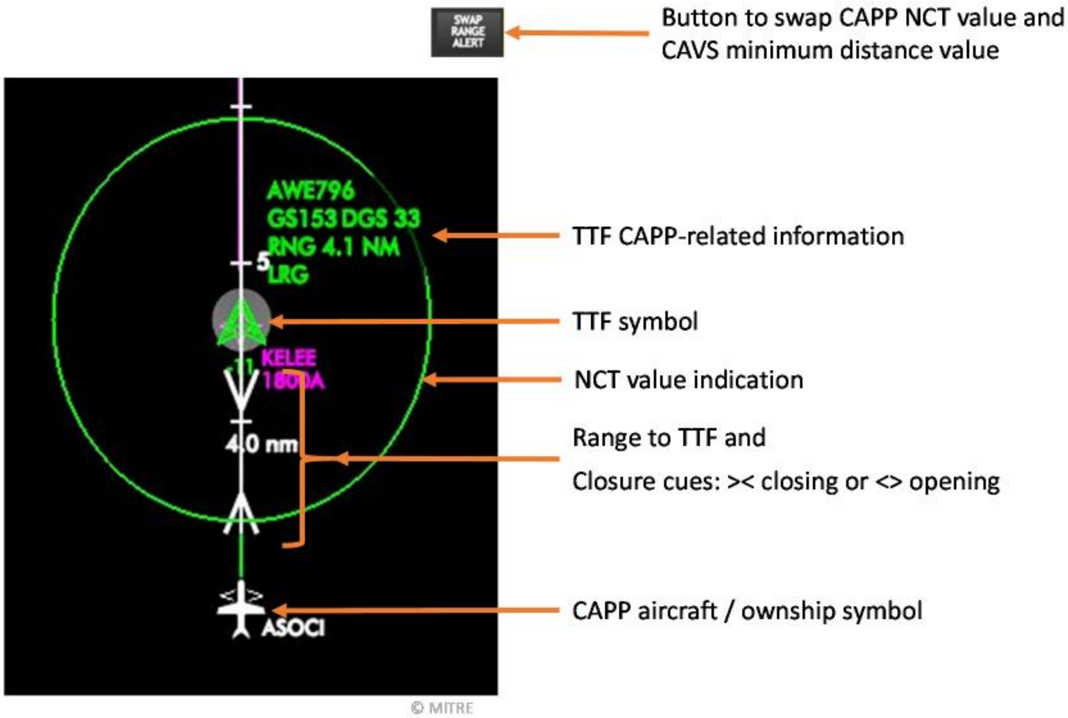

Figure 3-7. CDTI Inset Showing CAPP Display Elements

When it was appropriate to transition to CAVS, the flight crew pushed the "SWAP RANGE ALERT" button to swap the CAPP NCT value for the CAVS minimum distance value. CAVS was then flown until the point where final decelerations for landing were required (around the Final Approach Fix [FAF]). When the TTF landed, the display information was removed, the target aircraft remained selected though the symbol changed to brown, and the message "TRAFFIC LANDED [*TTF TPCS*]" was provided (Figure 3-8).

Figure 3-8. CDTI when TTF has Landed

3.1.2.3 AGD

The AGD provided key CAPP information. It was located between the left ND and the EICAS display as shown in Figure 3-4. Five pieces of information were provided to the crew via the AGD when CAPP was active: TTF TPCS, DGS value, closure cues, range to TTF, and NCT value. The same information was provided for CAVS. As with the CDTI, the AGD was used in previous ADS-B simulations (e.g., Bone, Penhallegon, and Stassen, 2008); however, it was modified here to provide the CAPP information. It is also similar to that planned to be used by American Airlines in their implementation of CAVS (Huber, 2013, July 4). The AGD and the associated information are shown in Figure 3-9. The fields at the top of the AGD were applicable to other ASAs but not CAPP or CAVS. The AGD also had a field to provide alert flags. The next section will review the alerts and the displayed information.

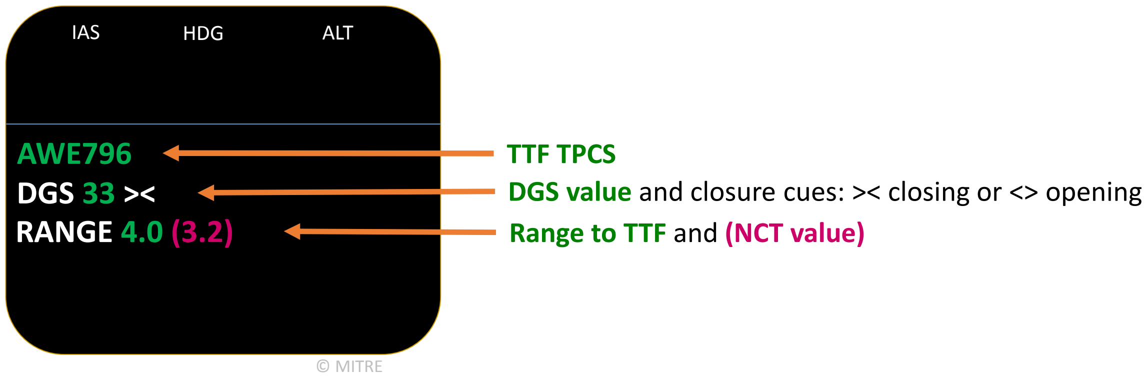

Figure 3-9. AGD and the Associated Information

3.1.2.4 Alerts Presented on the CDTI and AGD

Once CAPP was active, two alerts (as reviewed in Section 2.4.3.1) were possible based on the requirements for CAVS (as reflected in a draft of RTCA and EUROCAE, 2014a and 2014b). The first alert was the range indication advisory level alert which was defined by RTCA and EUROCAE (2014a) to be triggered when the traffic range was below the CAVS minimum distance set by the flight crew. This alert was intended to provide the flight crew range awareness information that may require a subsequent response. When discussing the use of this alert for CAPP, the authors and developers thought it would be undesirable to alert when falling below the CAPP NCT value. After debate and coordination with the FAA, it was decided that triggering the alert at a reasonable time threshold before the NCT value was preferred and acceptable for the simulation. After some research and testing, the alert was set to trigger 20 seconds (sec) prior to reaching the CAPP NCT value. Additionally, the alert was triggered when it was determined the NCT value had been reached and the alert had not been triggered at 20 sec (e.g., due high DGS and missing surveillance information with the algorithm initiating an alert at a 1 Hertz rate). When the alert was triggered, the following display changes occurred (shown in Figure 3-10).

- On the AGD:
    - A white advisory ("ADV") flag was depicted.
    - A white box was placed around the CAPP fields.
    - The TTF TPCS, DGS value, and range value changed from green to white.
- On the CDTI:
    - The TTF designated aircraft symbol and data block changed from green to white.
    - The message "TRAFFIC RANGE [*TTF TPCS*]" was depicted in white.
    - The NCT value, NCT value indication, and target symbol pulsed.

While the alerting 20 seconds prior to the NCT value did not conform to the current CAVS standards, the same scheme was used for the CAVS range indication advisory for consistency across the applications.

Figure 3-10. Flight Deck Displays during Range Indication Advisory Alert

The other alert was the minimum range caution level alert. It was set to trigger when the CAPP aircraft was less than 1.4 NM from the TTF based on RTCA and EUROCAE (2014a). At this point, the CDTI could no longer be used as the sole means of traffic information for CAPP or CAVS. Therefore CAPP or CAVS had to be terminated unless another means of spacing or separating from the TTF could be utilized. When the alert was triggered, the following display changes occurred (shown in Figure 3-11).

- On the AGD:
  - A yellow caution ("CAU") flag was depicted.
  - A yellow box was placed around the CAPP fields.
  - The TTF TPCS, DGS value field, and range value field changed in color from white (assuming a range indication advisory had been triggered) to yellow.
  - The DGS value and range value changed from numbers to "XX".
- On the CDTI:
  - The TTF designated aircraft symbol changed from white (assuming a range indication advisory had been triggered) to yellow and the outline changed to a yellow circle.
  - The TTF designated aircraft data block changed from white (assuming a range indication advisory had been triggered) to yellow.
  - The message "TRAFFIC PROXIMITY [*TTF TPCS*]" was depicted in yellow.
  - "SUSPENDED" was placed over the CAPP operations tab.
- An aural "Traffic proximity" alert was also provided.

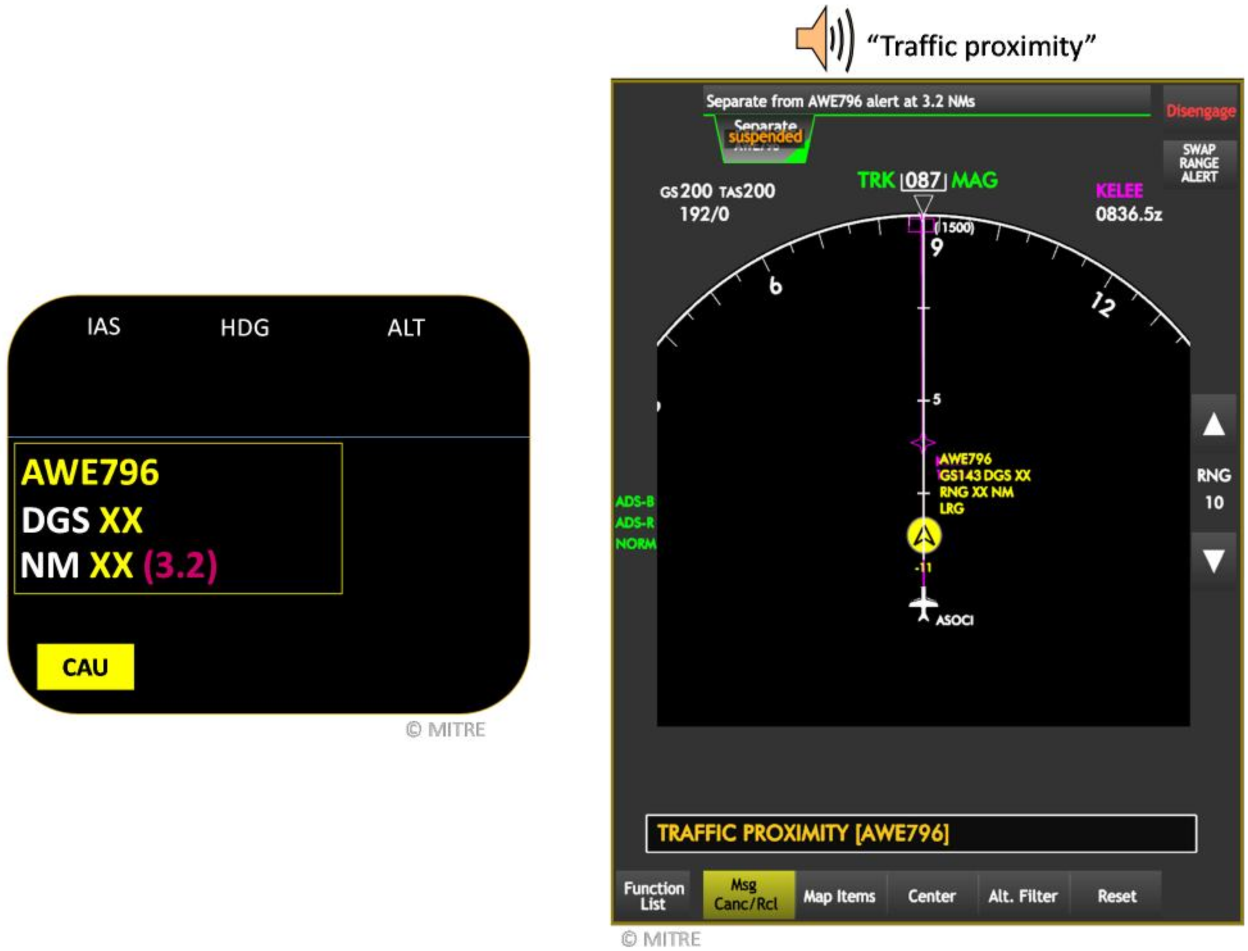

Figure 3-11. Flight Deck Displays during Minimum Range Caution Alert

3.1.3 Pseudo-Pilot Workstation

Pseudo-pilots act as "pilots" for all (some CAPP capable and some not CAPP capable) aircraft other than the participant flight crew's aircraft. This allowed the controller to interact normally with the traffic. It also allowed aircraft to maneuver based on ATC instructions, which is reflected on both the controller and flight crew displays. The pseudo-pilots used an interface termed Simpilot which allowed users to control multiple simulated aircraft simultaneously. It provided basic information about the aircraft (e.g., aircraft call sign, type) and allowed the user to control various aspects of the aircraft (e.g., heading, airspeed, altitude, route, communications frequency) and respond to controller instructions by entering commands. The pseudo-pilots were able to initiate CAPP according to the instruction from the controller. The interface was adapted specifically for this simulation to provide specific indications to the pseudo-pilots when a range indication advisory alert was triggered so they could report "unable CAPP." The pseudo-pilots were also provided indications when they reached visual conditions where they were to report that transition to the controller so they could transition to CAVS. A capability was also added that changed the CAPP NCT value to the CAVS minimum distance value. Finally, a capability was added that mimicked expected pilot spacing behavior and speed adjustments (for further details on this capability, see Section 3.1.5).The interface is shown in Figure 3-12.

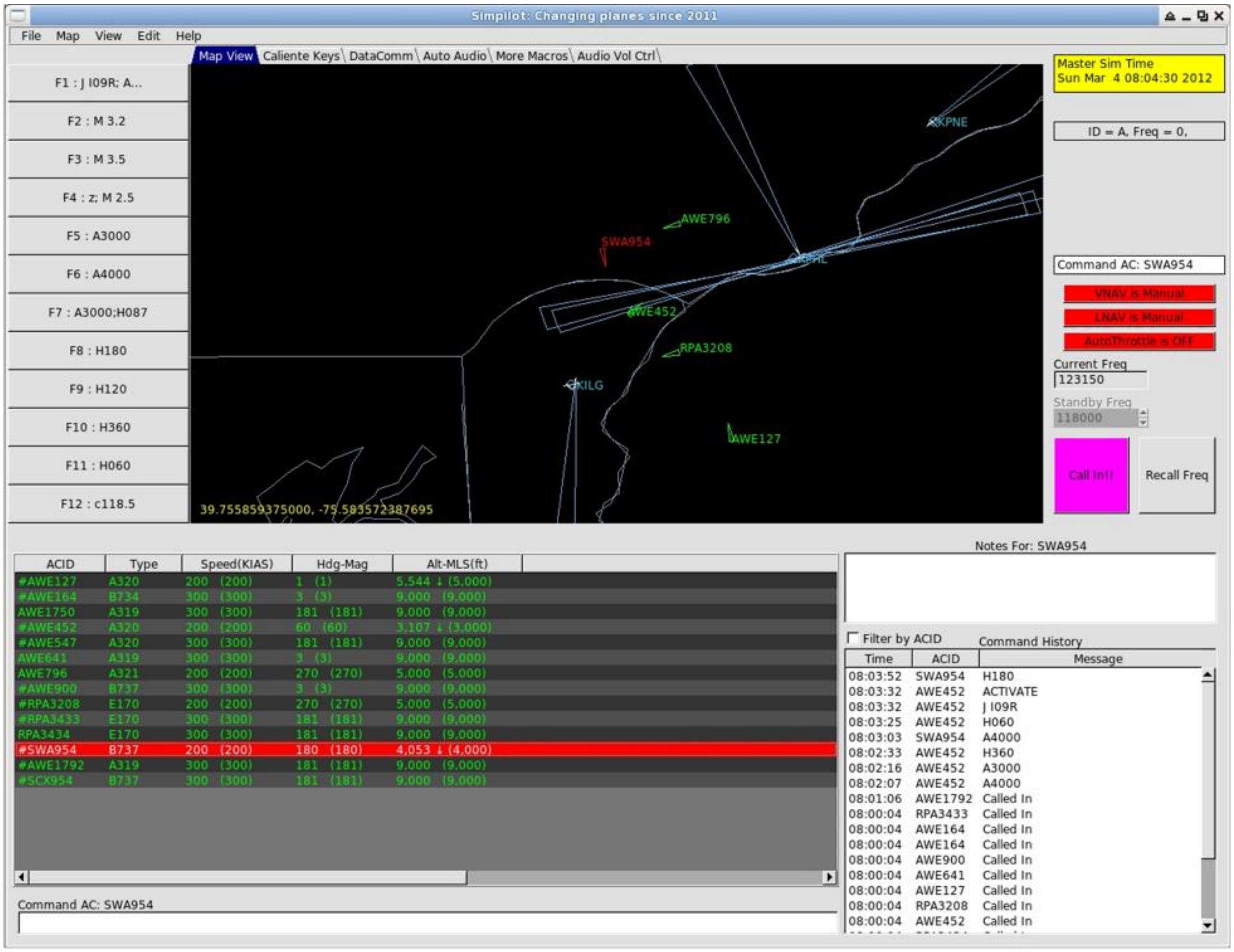

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Figure 3-12. Simpilot / Pseudo-Pilot Interface

3.1.4 Airspace

The simulation airspace modeled for this simulation was based on Philadelphia International Airport (KPHL). The KPHL environment was chosen based on American Airlines interest in and existing flight deck equipage for CAVS. It was also chosen based on the availability of an environmental database to use in the simulation. KPHL also happened to be one of the top five airports the ADS-B In ARC recommended for prioritized implementation of ASAs (ADS-B In ARC, 2011). However, the traffic flows simulated were based on a generic traffic pattern with a downwind segment followed by vectoring to the final approach course. Therefore, the airspace modeled was not specific to one particular facility (i.e., KPHL). Existing KPHL waypoints were used to allow aircraft to enter a north and a south traffic pattern for the ILS approach to Runway 9 Right (Figure 3-13 and Figure 3-14). The weather conditions within the airspace were approximately 8 NM of visibility and the ceiling was either 1800 or 3300 ft, depending on the particular scenario. The winds were calm at all altitudes.

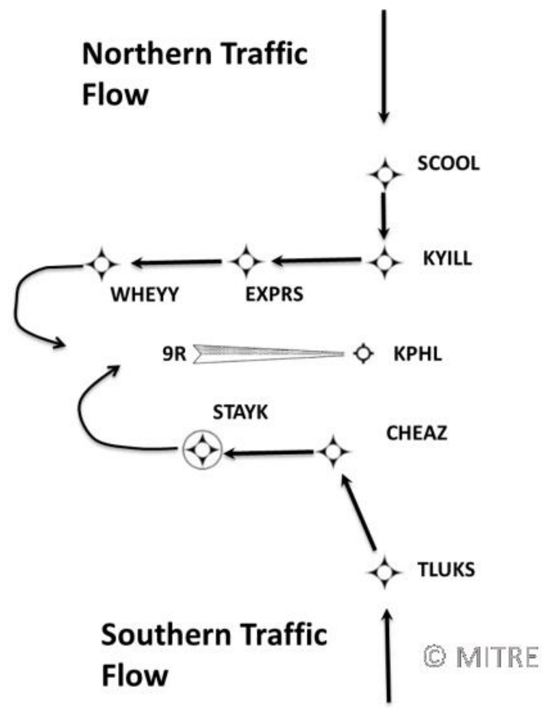

Figure 3-13. Arrival and Traffic Pattern for the ILS to Runway 9 Right

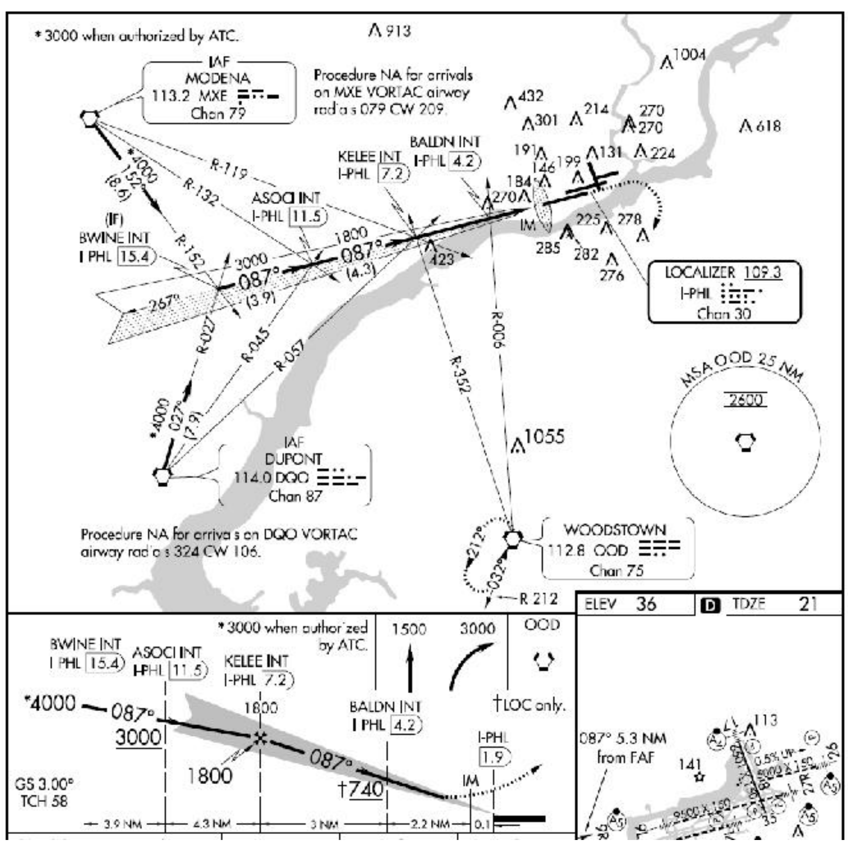

Figure 3-14. KPHL ILS to Runway 9 Right

Controllers were told to manage the aircraft as necessary and vector them on to final approach at points specified a priori based on the two ceiling conditions: 10 NM for the 1800 ft ceiling and 15 NM for the 3300 ft ceiling (see Section 3.4 for additional details). Traffic arrived via both the north and south flows for each scenario. The participant aircraft flight crew alternated between flying either the north or the south flow and started each run outside the final controller's airspace. This was done to allow the flight crew time to get acclimated to the new position and aircraft state prior to checking in with the controller and being given the first instruction.

3.1.5 Traffic

Traffic for the simulation included the participant aircraft along with other aircraft arriving on either the north or south flow for the ILS approach to Runway 9 Right (as shown previously in Figure 3-13). Attempts were made to develop traffic flows that were medium to high density and kept the controller at a high but reasonable workload. The higher workload environment was desirable to encourage the controller to utilize CAPP and achieve a final spacing within aircraft pairs that approximated those seen in visual approach and visual separation conditions. The density of the flow was modified several times prior to data collection based on controller subject matter expert inputs prior to selecting the final density. It was found that approximately 7 NM within aircraft pairs on the two flows allowed for a reasonably high density of traffic without overloading the controller or creating an overly extended final approach segment. Equivalent traffic levels were used through the entire simulation to avoid workload differences between scenarios, with only changes to aircraft call signs, slight variations to the aircraft types (e.g., Boeing 737 instead of an Airbus A320) and timing of flows between scenarios to avoid the same communication and task patterns.

At the start of a scenario, traffic started arriving from the two flows and gradually built to the full density of traffic that lasted until the data collection was complete for the scenario and the scenario was terminated by one of the researchers (at the point where the participant aircraft was handed off to the tower controller). When the traffic was at full density, approximately ten aircraft were managed by the controller at any given moment. A total of approximately 30 aircraft were accepted at handoff and 21 were vectored to final during each scenario.

All aircraft flying in the simulation were ADS-B out and capable of as acting as a TTF. There was a mixture of aircraft that were capable as acting as a CAPP aircraft (70%) and aircraft that were not capable as acting as CAPP aircraft (30%). This CAPP capability split was chosen after debate with key stakeholders and was believed to represent a reasonable number of aircraft such that the controller would choose to run CAPP operations. However, it was believed to be reasonably short of 100% equipage which may be unrealistic (at least in the near term) and may be easier to manage based on not having to deal with the difficulties of mixed equipage. The participant aircraft was always CAPP capable.

Pseudo-piloted aircraft were all large aircraft, but varied by type. Types included: Airbus A319, Airbus A320, Airbus A321, Boeing 717-200, Boeing 737-400, Boeing B737-700, Boeing 737-800, Embraer E-170, Embraer E-190, and McDonnell Douglas MD88. Pseudo-piloted aircraft also varied in their final approach speeds between 130 to 150 knots (kts) with an average speed of

138 kts. Pseudo-piloted aircraft that performed CAPP varied their speed to conform to the CAPP instruction. Expected pilot spacing behavior and speed adjustments were mimicked using a distance based spacing algorithm (similar to an IM implementation, e.g., Bone et al. 2008b) except the aircraft were only allowed to decelerate (based on expected pilot behavior). The algorithm utilized the CAPP NCT value issued by the controller and entered by the pseudo-pilot. A slight buffer was added based on the assumption that pilots would not fly right up to the exact CAPP NCT value. Some variability to that buffer was added based on expectations of different pilot spacing buffer choices (0.1 to 0.3 NM at an evenly distributed interval). CAVS worked similarly only the alert value was 2.5 NM from the TTF (plus the same spacing buffer and variability). The spacing achieved by the participant aircraft flight crew was at their discretion.

3.2 Participants

One controller and two pilots were scheduled for each one day session. Participant controllers were coordinated through the FAA and National Air Traffic Controllers Association (NATCA) standard procedures which involved submitting a request with specific requirements, followed by approvals, and finally identification of participants. Controllers were compensated for their participation through standard FAA processes. Controllers were required to have experience actively controlling traffic as a Terminal Radar Approach Control (TRACON) Final Controller using Common Automated Radar Terminal System (CARTS) or STARS. A total of 11 controllers acted as TRACON Final Controllers in the study and were from a variety of TRACONs (i.e., Boston, Cleveland, Dallas-Fort Worth, Denver, Detroit, Gateway, Indianapolis, Memphis, Minneapolis, Oklahoma City, and Tampa). The tower controller and feeder controller positions were not staffed. Controllers had an average experience of 20 years (with a minimum of 4.5 years and a maximum of 33 years) actively controlling air traffic.

Flight crews were recruited through the MITRE CAASD pilot database and CAPP / ADS-B interested parties. The MITRE CAASD database consists of a list of approximately 250 pilots who have expressed interest in participating in MITRE CAASD simulations through a variety of recruiting activities. Some pilots may have supported a past MITRE CAASD simulation and some may have not. They may live in the local MITRE CAASD area or remotely. They may also have varying levels of experience. A request for participation was developed and distributed to members of the MITRE CAASD database. The same request was set to internal distribution lists of airlines and unions (e.g., Air Line Pilots Association [ALPA], Jet Blue, United, UPS, and US Airways [now American Airlines]) that expressed an interest in supporting CAPP research activities through various industry activities. The request stated that each pilot was required to be an Air Transport Pilot (ATP), have at least 100 hours of Federal Aviation Regulation Part 121 “glass cockpit” experience, be qualified in turbojet aircraft with auto throttles, and have operated an aircraft using their ATP rating within the last 12 months. Pilots were told they would be compensated for their participation. Additionally, pilots not local to MITRE CAASD were told they could be provided accommodations at a local hotel for one or two nights depending on the distance traveled.

It was desirable to have both pilots be from the same airline and to have a pairing of a Captain and a FO for each simulation day. However, prior to recruiting, it was determined the impact of not meeting either of these conditions was minimal. Therefore, they were determined to be goals but not requirements.

A total of 22 pilots (acting as 11 flight crews) were recruited and participated in the study. Twelve of the pilots were qualified as Captains and 10 were FOs. Their estimated average total flight hours was 11,836 hours (with a minimum of 4100 hours and a maximum of 22,000 hours). The pilots were currently flying a variety of aircraft types (e.g., Airbus A320, McDonnell Douglas MD-11, Boeing 737-800, Boeing 757, Boeing 777-200, Bombardier CRJ, and Embraer EMB-145). During the simulation, one pilot acted as the PF, and one pilot acted as the PM. The roles were not switched during the simulation.

MITRE CAASD staff members acted in two pseudo-pilot positions for each simulation day. The authors served as observers for both the flight crew and air traffic controllers.

3.3 CAPP Operations

The CAPP operations conducted in the simulation were as described in Section 2.6.2. This section points out some specific topics where changes, or specific implementation decisions, were made for this simulation.

3.3.1 Procedures

The controller was instructed to manage aircraft and sector operations as normal for his facility. The controller was asked to conduct CAPP and follow CAPP procedures and phraseology for any aircraft that were CAPP capable. The controller was told that if he ever needed to terminate CAPP, he should do so using the instruction, "Terminate CAPP." The controller was told that it was unnecessary to terminate (or not initiate) CAPP just because the aircraft were believed to be "too far" apart for CAPP to be beneficial. The controller was also asked to allow the aircraft to conduct CAVS once visual conditions were reported. Finally, the controller was asked to hand off all aircraft to the tower controller around the FAF. This is common at some facilities but less common at other facilities. Handing off around the FAF gave a consistent hand off point and allowed the controller to see CAPP operations for as long as reasonably possible.

Pilots were told they would be assigned the role of PF or PM and would remain in that role throughout the simulation. They were told to follow normal cockpit procedures and if there were differences in airline policies they should agree on an approach during training. They were also asked to fly the flight deck simulator as if it were a large category aircraft (versus a heavy). This was done based on expectations of having a larger pool of large category aircraft pilots and to allow for the spacing realized when a large aircraft spaces behind another large aircraft.

Pilots were briefed that the expectation for CAPP is they use the traffic information to close to a self-determined value not inside the NCT value with the anticipation to close further when conducting CAVS. They were instructed to enter the NCT value given by the controller and a self-determined value for the CAVS minimum distance advisory alert upon receiving the CAPP instruction from the controller. They were told they could use the traffic information to fly up to but not inside the NCT value. They were told if the NCT range indication advisory was triggered, they should take action to avoid reaching NCT value or, if unable, contact the controller and report "Unable CAPP." They were also told to contact the controller and report "Unable CAPP" if they reached or went inside the NCT, though they did not need to tell the controller when the NCT range indication advisory was triggered if they could remain outside the NCT value.

If there were no issues associated with the NCT value, pilots were told to report visual conditions / traffic in sight[4], and once instructed by the controller, to conduct CAVS by swapping the CAPP NCT value for the CAVS minimum distance value. In all approaches but one, this required one CDTI input. At that point, the pilots could use any combination of the OTW visual scene and display traffic information to close to a desired spacing from the TTF. They were informed that flying CAVS was very similar to flying CAPP except they were now responsible for separation and no longer had the NCT value limitation. They were told to contact the tower controller (flight deck observer in this simulation) when instructed by the controller and to be stabilized by 1000 ft.

While not specifically stated in RTCA and EUROCAE (2013b), the controller was told that he should monitor for spacing and separation issues, as with current day operations, and should not try to determine the exact aircraft position relative to the NCT value. The task of monitoring the NCT value, and the aircraft spacing from it, was a task for the pilots.

While the specifics for real world implementations still need to be determined, the controller was asked to not issue speed instructions to CAPP aircraft unless he needed to terminate CAPP. This allowed the pilots to conduct CAPP without potentially contradictory speeds from the controller. Actual field operations may allow the controller to issue a speed to an aircraft performing CAPP.

3.3.2 Communications

The sample communications in the CAPP OSED were described in Section 2.6.3. This section will describe the specific communications used in this simulation.

During the dry runs leading up to the simulation, the communication procedures used in the draft CAPP OSED sample scenario were used (RTCA and EUROCAE, 2013b). After utilizing this set of interactions, dry run participants reported that it required too much communication. The concern of the amount of communications was also pointed out in comments received on the draft CAPP OSED (RTCA and EUROCAE, 2013b). Therefore, the authors decided to truncate the communications as much as possible. The final CAPP communications did not include a traffic identification element prior to the CAPP instruction. It did include a truncated CAPP instruction. The final communication decided on for the simulation had fewer words and an implicit request to report the traffic in sight, as shown below.

- Controller CAPP instruction used in this simulation – “American 456, CAPP 3.2 miles behind United 123.”

This new communication methodology was found much more acceptable in subsequent discussions and dry runs.

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[4] While RTCA and EUROCAE (2014b) require initial visual acquisition of the TTF and the correlation of that with the CDTI, this was not believed to be necessary in this simulation because the flight crew had already been following this aircraft for several miles and had confirmed that was the TTF through the use of TPCS in the ATC CAPP instruction.

The controllers were asked to issue the CAPP instruction when the CAPP aircraft was on an intercept to final or established on final (and when the TTF was already established on final) per RTCA and EUROCAE (2013b). They were allowed to issue it either in conjunction with or separate from the approach clearance. If it was issued separate from the ILS approach clearance, they were not told whether it needed to be before or after the ILS approach clearance. The following shows a sample of the CAPP instruction in conjunction with the ILS approach clearance.

- Controller CAPP instruction in conjunction with the ILS approach clearance – “Brickyard 4126, CAPP 3.5 miles behind JetBlue 56, you’re five from ASOCI maintain 3000 until established on the localizer, cleared ILS 9 right approach.”

Flight crews were told to report visual conditions and the traffic in sight with the following phraseology.

- Pilot report of visual conditions / TTF in sight – “Philly Approach, American 456, traffic in sight.”

3.4 Experimental Design

Two independent variables were used: cloud ceiling level and NCT value. The cloud ceiling contained two levels: 1800 and 3300 ft. The NCT value also contained two levels: 0.2 and 0.5 NM outside the separation standard (3.0 NM was the separation standard used in this simulation). The selection of the levels for each variable is described below.

The cloud ceilings were chosen to determine the highest and lowest reasonable altitudes to transition out of CAPP into CAVS and still achieve the intended benefits for CAPP. It was first desirable to determine the highest reasonable altitude to transition out of CAPP into CAVS and still achieve the intended benefits for CAPP. The 3330 ft ceiling was chosen based on the belief that any higher altitudes may allow for visual operations (e.g., CAVS) without the need for CAPP.

In addition to examining a highest reasonable altitude, it was also desirable to determine the lowest reasonable altitude to transition out of CAPP into CAVS and still achieve the intended benefits for CAPP. The original concept description stated that CAPP is to be used when VMC exists but the conditions are not practical for visual operations (ADS-B In ARC, 2012a). In discussions leading up to the simulation with key stakeholders, concerns were expressed about 1000 ft not providing sufficient time to exit CAPP and transition to visual separation / approach operations and further close the spacing from the TTF. Therefore, an 1800 ft ceiling was chosen because it was still later in the approach but still may allow for some additional closure. When the aircraft exited the 1800 ft ceiling, they were on an approximately 6 NM final. When the aircraft exited the 3300 ft ceiling, they were on an approximately 11 NM final. Both ceilings had different point where the controller was told to have aircraft intercept final: 10 NM for the 1800 ft ceiling and 15 NM for the 3300 ft ceiling. The two different intercept points were intended to achieve some level of consistency across controllers and to allow for similar times for conducting CAPP prior to exiting the cloud layer (i.e., approximately 4 NM). See Table 3-1 for the ceiling conditions and related distances.

Table 3-1. Ceiling Conditions and Related Distances

Ceiling (ft)	Desired Intercept to Final (NM from Runway)	Transition to Visual (Approximate NM from Runway)	Approximate Distance Conducting CAPP (NM)
1800	10	6	4
3300	15	11	4

For the NCT independent variable, the 0.2 and 0.5 NM outside the separation standard values were chosen to determine the minimum closest and furthest distances possible from the separation standard and still achieve the intended benefits for CAPP. It was recognized that in real world operations, the NCT value would be determined by the controller and may not be a set value. However, it was necessary to set some values so the topic could be examined in the simulation. It was necessary to find a range of NCT values that were close enough to the separation standard to ensure the expected CAPP benefits, yet far enough from the separation standard to not overly concern the controller about the potential for the aircraft to get too close to the separation standard (potentially leading to queries / unnecessary communications or breakouts). Based on discussions with the key stakeholders and subject matter experts, two values were chosen: 0.2 and 0.5 NM from the separation standard. The 0.2 NM value was believed to be very close to the minimum the controller would find acceptable. The 0.5 NM value was believed to be about as far as aircraft should be to the separation standard to prevent a reduction on throughput and was believed to be reasonable enough to allow for the flight crew to further close the spacing from the TTF during visual separation operations. It should be noted the NCT values have interdependencies with the ceilings. A tighter NCT value may be acceptable for lower ceiling / when on a shorter final than for a higher ceiling / when on a longer final.

Table 3-2 summarizes the independent variables and levels.

Table 3-2. Independent Variables

Ceiling (ft)	NCT Value (NM above Separation Standard)
1800	0.2
	0.5
3300	0.2
	0.5

Four core scenarios examining the independent variables were presented to the pilots and controllers. Each scenario was approximately 40 minutes long and the controller managed traffic for the full scenario. The flight crew was able to fly one arrival and approach to landing and then be repositioned as a new aircraft outside of the final controller's airspace to fly the arrival and approach a second time within the same scenario (Table 3-3). The participant aircraft flight crew was given sufficient time to get acclimated to the new position and aircraft state prior to checking in with and then being given the first instruction by the controller. Each participant experienced the same set of data collection scenarios (in a repeated measures design). The order of the scenarios was counter balanced across participant groups.

Table 3-3. Pilot and Controller Runs by Independent Variable Scenario

Scenario	1		2		3		4	
Ceiling (ft)	1800				3300			
NCT (NM outside Separation Standard)	0.2		0.5		0.2		0.5	
Controller Run	1		2		3		4	
Pilot Run	1	2	1	2	1	2	1	2

Besides the four scenarios examining the independent variables, four extra events were examined:

- CAPP aircraft overtake
  - For the participant controller – Pseudo-pilot aircraft aggressively decelerates and goes inside the NCT value without informing the controller.
  - For the participant pilots – TTF for participant pilot aircraft aggressively decelerates without (confederate) controller intervention.
- No transition from CAPP to CAVS
- CAPP with pilot separation responsibility
- Extra flight crew actions to swap the CAPP NCT value for the CAVS minimum distance.

Three of these events (CAPP aircraft overtake for the participant controller, no transition from CAPP to CAVS, and CAPP with pilot separation responsibility) were examined in a fifth scenario with both the participant controller and pilots. The other two events were conducted by the pseudo-pilots and a confederate controller. The participant controller was not involved.

The specific events and reasons for examining them were noted in Section 2.7, and are described in greater detail next. These events were always run as the last set. The conditions for all extra events were an 1800 ft ceiling and a 3.2 NM NCT value (when applicable).

The first event in the fifth scenario was only for the participant controller. The participant pilots were not involved, even though they were flying in the scenario. This event was achieved by a pseudo-pilot who aggressively accelerated a CAPP aircraft and decelerated a TTF. The pseudo-pilot did not report the CAPP aircraft getting inside the NCT value. The goal was to see if the controller detected this event. If the controller detected the event and the CAPP aircraft was inside the NCT value, the pseudo-pilot was told to react as if the flight crew accidently went inside the NCT value and to help the controller resolve the situation. If the controller detected the event and the CAPP aircraft was not inside the NCT value, the pseudo-pilot was told to report the spacing status to the controller. This event was sometimes triggered with different pairs in the scenario since there was limited time to create the closure situation.

The second event in the fifth scenario included both participant controller and pilots and examined the situation where the participant aircraft could not transition out of CAPP. The pilot participants were told not to report the transition to visual conditions or the traffic in sight and to continue with CAPP until around the FAF (which is the normal termination point should a transition not occur). This event was intended to support the examination of topics related to not transitioning from CAPP to CAVS.

The final event in the fifth scenario also included both the participant controller and pilots. In this event, the controller did not issue a CAPP instruction but instead instructed the flight crew to maintain separation from the TTF using the instruction "Maintain separation from [*TTF TPCS*]." This event was intended to support the examination of topics related to separation responsibility.

After the fifth scenario, the two extra participant pilot event runs were conducted. As mentioned previously, the participant controller was not involved. In order to keep the runs as brief as possible, the participant aircraft was started on an intercept to final approach. The first run was conducted only if the participant pilots had not seen the range indication advisory level alert and the conditions that required reporting to the controller "Unable CAPP." The condition was created by the pseudo-pilot decelerating the TTF for the participant aircraft. The confederate controller allowed the situation to evolve until the point where the pilot participants reported an issue. The controller was told to intervene normally once the pilot participants reported the issue. This event was intended to support the examination of topics related to pilots detecting and reacting to going inside the NCT value.

The final extra participant pilots only run examined additional CDTI actions to transition out of CAPP into CAVS. This event was intended to support the examination of whether more CDTI actions were acceptable. The CDTI interface changed slightly to enable this examination through the removal of the "SWAP RANGE ALERT" button. Without this feature, the PM was required to enter the operations menu and conduct six actions (versus one) to swap the CAPP NCT value and the CAVS minimum distance value.

3.5 Simulation Procedure

The day started with greeting the controller and pilot participants and having each complete a consent form and demographics questionnaire. This was followed by a joint introductory briefing. The briefing provided background on the research, ADS-B, as well as the CAPP concept and its origins. The briefing then provided details on pilot and controller roles and responsibilities, the interfaces each would be using, and the communications procedures (Section 3.3 details the briefed procedures and communications). Based on past research (e.g., Bone, Penhallegon, Benson, and Orrell, 2013; Cardosi, personal communication, October 4, 2014), it was felt that both pilots and controllers benefit from understanding the information available and utilized by their counterpart. Therefore, overviews of the displays and the associated information were provided in this joint briefing. Finally, the flight crew was given basic information about closure and distances that can be expected during normal operations on final approach.

At the conclusion of the introductory briefing, the controller was brought to the IDEA lab and was allowed to familiarize himself with the STARS workstation, set up the displays according to his preferences, and ask any questions. The controller was briefed on the basic display features, information new for CAPP, and the KPHL airspace. The controller was then given a "cheat sheet" with key information on it such as the ceiling and final intercept points, CAPP communications, and CAPP procedures.

At the same time, the flight crew was brought to the flight deck simulator for familiarization and training on the various interfaces and procedures they would encounter during the data collection scenarios. The flight crew first conducted an approach without CAPP or a CDTI to become familiar with the flight deck simulator. They then conducted a practice CAPP approach where they were taught how to interact with and utilize the CDTI and AGD for CAPP and CAVS. The controller was able to observe this practice run in order to gain a better understanding of the flight deck CAPP activities.

Once the individual training sessions were complete, a training scenario was run for both the participant pilots and the controller. The conditions included a 2800 ft ceiling, a 15 NM final intercept target, and a 3.2 NM NCT value. The controller conducted the scenario giving numerous aircraft CAPP instructions. Each was reminded to enter "CP" into the scratchpad for all aircraft conducting CAPP during this training session, but were informed they did not have to use it in the data collection runs if they felt it was unnecessary. Pilots performed three runs within this training scenario. The first two runs were CAPP training runs and the final was a baseline condition where they flew an ILS in IMC with a transition to visual separation. The CDTI was not available. After the final run, participants were shown the post-scenario questionnaire and were given the opportunity to review it prior to having to complete it for data collection. Pilots and the controller completed the task load index (TLX) for the ILS baseline condition and the baseline and CAPP TLX pairwise comparisons. Training lasted approximately 130 minutes.

Once all training was completed, the data collection scenarios were conducted. Each core scenario lasted approximately 40 minutes and post-scenario questionnaires were given after each scenario. Prior to executing each scenario, pilots and the controller were informed of the specific conditions for the current scenario. Pilots were informed of their call sign for the run via a Post-It note (Sun Country was always used as the company name but the flight number changed for each approach). The controller was asked to have aircraft intercept final at approximately a 10 NM final for the 1800 ft condition and a 15 NM final for the 3300 ft condition. The controller was told they could extend the final if necessary for spacing on final.

At the conclusion of the final data collection runs, participants were provided with a final questionnaire encompassing the entire simulation. Once they completed the final questionnaire, the controller and pilots were brought together for a short, informal debrief before they were released.

3.6 Data Collection

Four methods of subjective data collection were used for this simulation: questionnaires, system recorded data, observation, and final debriefs. Five types of questionnaires were used, including:

1. **Demographics** – Upon arrival, participants were asked to fill out a demographics questionnaire. This addressed participants' experience. Controllers and pilots had separate questionnaires (Appendix A).

2. **NASA TLX Pairwise Comparison** – This form consists of a pairwise comparison of each NASA TLX subscale. Pilots and controllers were trained how to complete the forms per NASA (1986). There were a total of 15 comparisons and the objective of this section was to select which subscale per comparison was a greater contributor to workload. Pilots and controllers completed this portion two times: after the baseline scenario and after the first CAPP scenario. The data from this section was used to weight each subscale for the overall NASA TLX workload calculation (weight baseline data and CAPP scenario data separately) (Appendix B).
3. **Post- Scenario** – After each scenario, participants were asked to fill out a questionnaire based on the scenario just experienced. All Post-Scenario questionnaires included workload measures (Bedford Workload Rating Scale and TLX) along with additional rating scale and yes / no questions. Pilot participants completed a Post-Scenario questionnaire after each run during a scenario (two runs per scenario) and controllers completed this questionnaire after each scenario. Post-Scenario questionnaires exist for the four scenarios examining the independent variable and the extra events. Controllers and pilots had separate questionnaires (Appendix C).
4. **Post-Simulation** – After the completion of the simulation, participants were asked to complete the final questionnaire covering all the scenarios experienced. The questionnaire included a series of rating-scale and yes / no questions. Controllers and pilots had separate questionnaires (Appendix D).
5. **Debrief** – Open ended questions in a discussion format were used after all the scenarios and events were completed.

In these questionnaires, participants were asked to provide subjective feedback on areas such as the overall CAPP concept, workload, situation awareness, head down / scan time, displays, communications, and simulation realism.

Data for objective metrics was automatically recorded by the simulation platform or by the observers and included:

- Flight deck speed changes (frequency, magnitude, and direction)
- Spacing and DGS within aircraft pair
- Pilot and controller interactions with displays (e.g., pilot TTF selection and data entry)
- Type and frequency of alert events
- Frequency of pilot and controller initiated go-arounds / breakouts and terminations
- Frequency of missed CAPP opportunities and lack of transition to visual separation
- Frequency of controller changes to NCT value
- Communications issues (e.g., deviations from defined phraseology).

4 Results

The majority of results are based on the four independent variable conditions. Result related to the extra events (e.g., CAPP aircraft overtake) will be noted. Pilot results are shown as pseudo-pilot, participant pilot, or combined pilot data. Generally, the pilot data is combined to provide detail of the controller's experience on the overall set of aircraft. However, participant pilot data is reported separately when a distinction is made between the behavior of the participants (who operated the aircraft according to their own desires during the CAPP and CAVS operation) versus the behavior of the pseudo-pilot aircraft (which behaved as designed by the authors / researchers based on expected pilots behavior during the CAPP and CAVS operation, as described in Section 3.1.5). Note the different pilot roles in the simulation are abbreviated as "PsP" for pseudo-pilots and "PaP" for participant pilots only when necessary for brevity in tables or figures.

This section starts with a description of the analytical method. It then presents results for the conduct of the full approach (CAPP and CAVS) by key points in the approach. Finally, results are presented that are more broadly applicable (e.g., display use).

4.1 Analysis Methods

4.1.1 Subjective

The subjective results are based on responses to the statements from both the post-scenario and post-simulation questionnaires and the informal debrief. The post-simulation questionnaires comprise most of the data so in these cases the source will not be noted. Any data from the post-scenario questionnaires or the informal debrief will be noted. As a reminder, controller results are based on 11 responses while pilot results are based on 44 responses (if the 22 pilots conducted two runs within a scenario as they did in the four core scenarios) or 22 responses (if they only conducted one run as they did for an extra event). A series of Independent Samples t-tests were used to determine if pilot position (i.e., PF and PM) had any effect on subjective response[5].These tests were conducted for the continuous scaled statements for all scenarios. No significant differences were found, therefore all pilot participant (i.e., PF and PM) data was combined.

While some questions in the questionnaires were yes / no with an opportunity for open-ended comments, most response-scale items were statements with a scale allowing near infinite options but with 100 hash marks (without numeric labels) with an opportunity for open-ended comments. The scale was anchored on the left with the label "Strongly Disagree" and on the right with the label "Strongly Agree" (Figure 4-1).

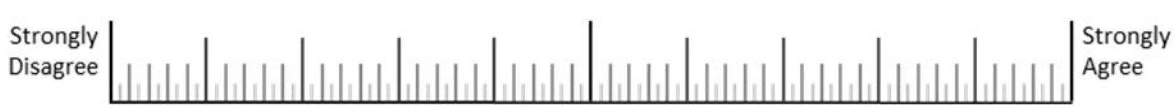

Figure 4-1. 100-Point Agreement Scale

[5] These tests are not related to hypothesis tests and only serve as a check to combine results from both positions.

Most of the items were presented as a statement, and participants were asked to rate their level of agreement. Participants were told to draw a straight line anywhere on the scale, including between the lines and right on the end points. During data reduction, responses were rounded to the nearest single digit between 0 and 100. In the presentation of the results, any responses below the midpoint (i.e., lower than 50) on the scale will be considered on the "disagree" side while any responses above the midpoint (i.e., higher than 50) on the scale will be considered on the "agree" side. Any responses at the midpoint (i.e., equal to 50) will be considered "neutral" (Figure 4-2).

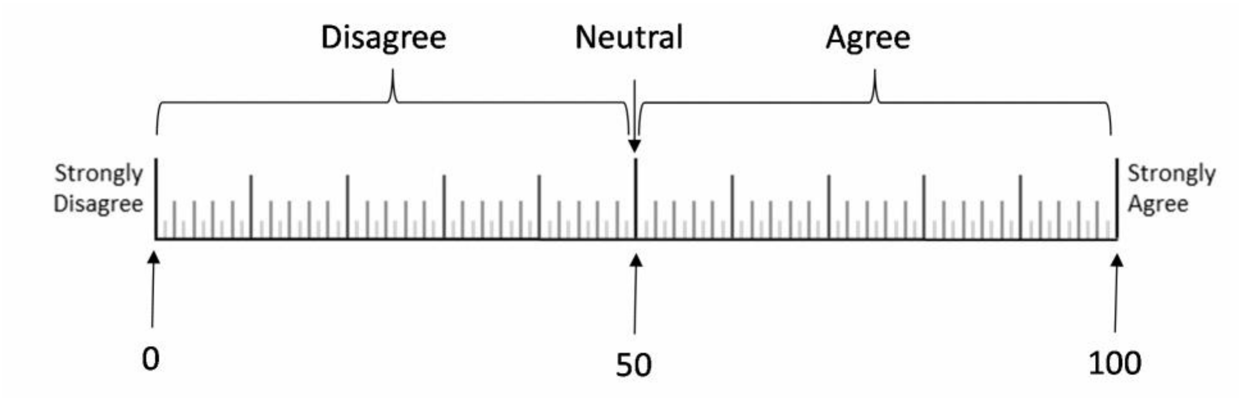

Figure 4-2. 100-Point Agreement Scale Agreement Rating Breakdown

When presenting results on the 100-point agreement scale, the following terminology / methodology will be used to describe the levels of agreement.

- The majority (# responses / total #; %) of [controllers / pilots] [agreed / disagreed].
  - Low variability, e.g., Standard Deviation (SD) of less than 25.0
- A slight majority (# responses / total #; %) of the [controllers / pilots] [agreed / disagreed].
  - Low variability, e.g., SD of less than 25.0
  - "Majority" is slightly above 50%
- [Controller / Pilot] responses were variable but the majority (# responses / total #; %) [agreed / disagreed].
  - Responses have a SD of greater than 25.0 but distribution is relatively skewed.
- [Controller / Pilot] responses were variable.
  - Responses have a SD of greater than 25.0 and the distribution is relatively flat across the scale.

To summarize a series of related statements, figures like that shown in Figure 4-3 are utilized. The figures show the scale and the disagreement and agreement sides. "Smiling" or "frowning" faces are shown on scale where the replies to the statements have a positive or negative meaning. The statement is shown to the left of the graph. The statement shown is directly quoted from the questionnaire. If the same statement was used for both controllers and pilots, the statement is only shown once. When the controller and pilot statements were slightly different, brackets are used and the controller text is presented before the "/" and the pilot text is presented after, e.g., "The spacing [being achieved by the CAPP aircraft / I achieved] was acceptable."

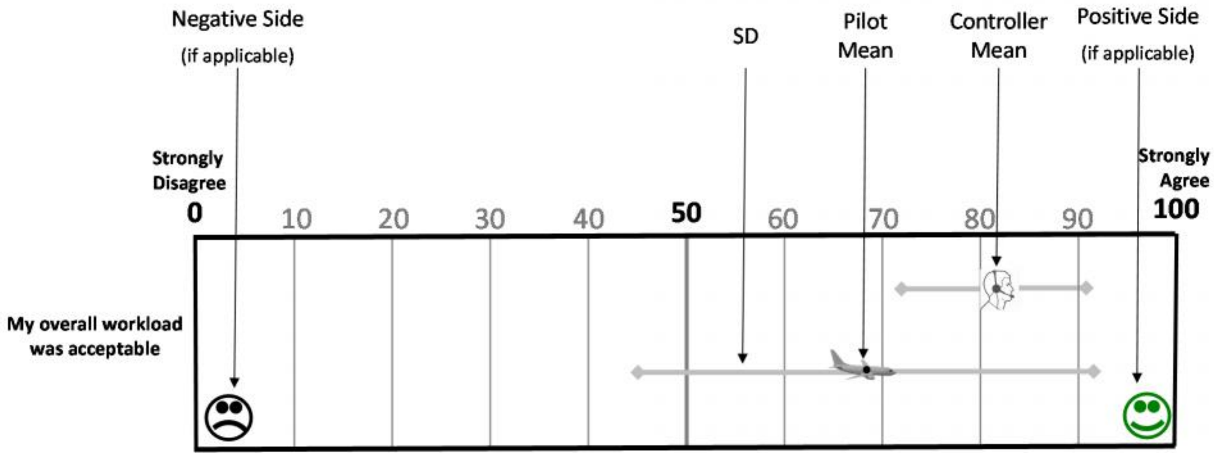

Figure 4-3. Sample Summary Figure

The means (M) and SDs are shown on the figures. The means are shown by points and the SDs are shown by the bars. Symbols are also used to indicate the responding party and the particular condition the reply relates to. See Figure 4-4 for details on the symbols and their use.

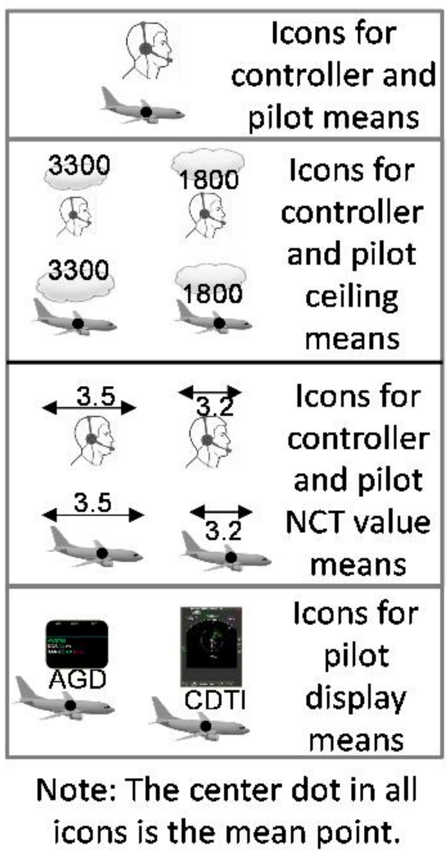

Figure 4-4. Symbols Used in the Summary Figures and Their Meaning

A limited number of questions were on a seven point scale along with an opportunity for open-ended comments. Figure 4-5 shows an example of the seven point scale used in the questionnaires.

Greatly *Increases*	*Increases*	Somewhat *Increases*	No Effect	Somewhat *Reduces*	*Reduces*	Greatly *Reduces*

Figure 4-5.Sample Seven Point Scale

Two workload measures were used in the simulation. The NASA TLX "pencil and paper" version was used in the post-scenario questionnaires and the pairwise comparison weighting tool was used for both a baseline and CAPP conditions. The pairwise comparison weightings were used to reduce between-rater variability. The TLX ratings on a per scenario basis were used to compare workload ratings across the various conditions (NASA, 1986). The Bedford Workload Rating Scale was also used (Roscoe, 1984).

4.1.2 Objective

Data for the objective results were recorded by the simulation platform and included those noted in Section 3.6. Most data is reported by the phase of the operation while the communication data is reported as a separate section. Due to simulation issues the objective data does not include the first day of data collection.

4.1.2.1 Approach Phases

Objective data related to the spacing within the aircraft pair was calculated prior to CAPP, during CAPP (first phase of the approach) and after the transition to visual conditions and CAVS (second phase of the approach). The initial phase / CAPP is shown in Figure 4-6. CAPP started after the CAPP instruction was accepted and the CAPP system was engaged. At this point the CAPP aircraft was in the traffic pattern, and likely on a dogleg to final or on final. CAPP continued during the approach and ended when the CAPP aircraft exited the cloud layer (i.e., 1800 or 3300 ft). Objective data reported during CAPP includes spacing and speed data at initiation, during conduct, and at the end (normal or early termination). Data is also reported on alerting events.

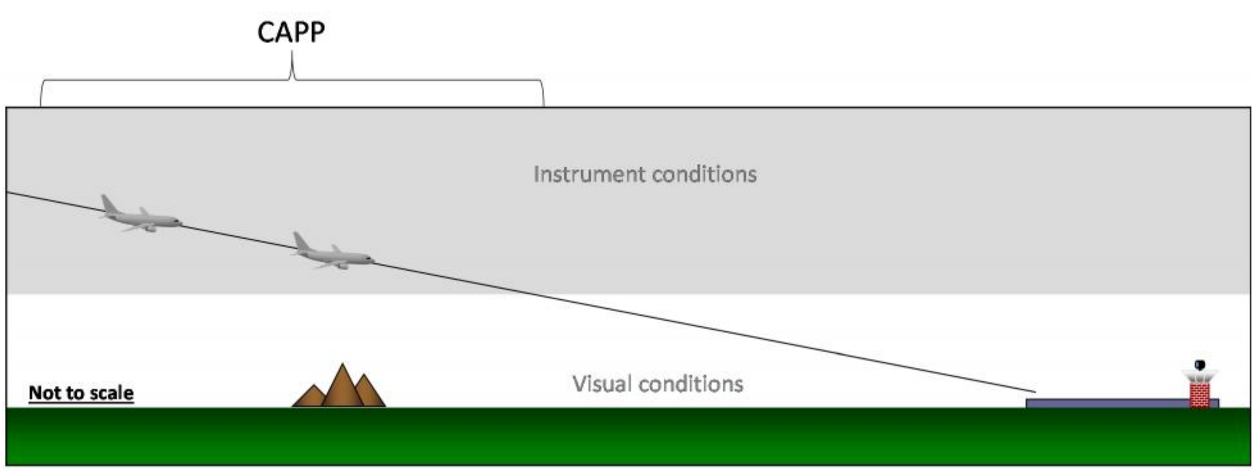

Figure 4-6. Profile View of the CAPP Phase of the Approach

The next phase started when the CAPP aircraft exited the ceiling (i.e., 1800 or 3300 ft) and ended when the TTF crossed the threshold (Figure 4-7). During this phase, the participant aircraft was in visual conditions and should have transitioned to CAVS. Objective data reported during CAVS includes spacing and speed data during conduct and at the end.

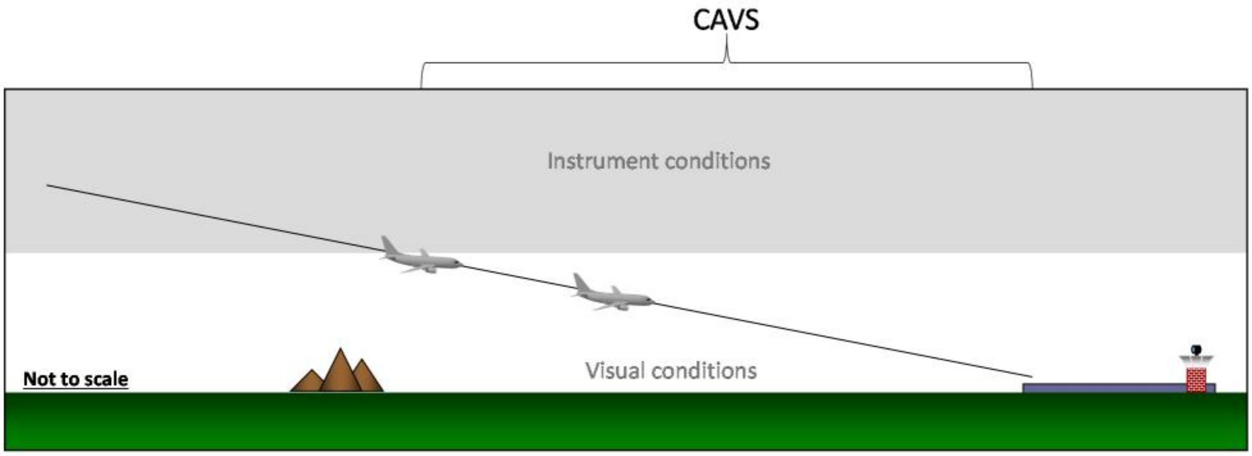

Figure 4-7. Profile View of the CAVS Phase of the Approach

Table 4-1 provides the total number of aircraft in the objective data across the conditions. Five outliers were removed based on the criteria of the CAPP initiation distance being greater than three SDs from the mean. Table 4-2 shows the same events divided by participant and pseudo-pilots. As can be seen, the total numbers decrease across the columns. The reduction is due to things such as not all aircraft being equipped for CAPP, CAPP not being initiated, CAPP or CAVS having to terminate, and CAPP not ending prior to the scenario ending.

Table 4-1. Sample Size per Objective Data Category by Condition

	Pre-CAPP	CAPP			CAVS
Condition	Localizer Capture	CAPP Initiation	CAPP Alerts	CAPP End	CAVS END
1800 / 3.2	202	116	23	103	100
1800 / 3.5	229	159	40	95	94
3300 / 3.2	196	126	5	118	115
3300 / 3.5	225	153	11	138	124

Table 4-2. Sample Size Divided by Participant and Pseudo-Pilot Aircraft per Objective Data Category by Condition

	Pre-CAPP		CAPP						CAVS	
	Localizer Capture		CAPP Initiation		CAPP Alerts		CAPP End		CAVS End	
Condition	PsP	PaP	PsP	PaP	PsP	PaP	PsP	PaP	PsP	PaP
1800 / 3.2	182	20	98	18	19	4	86	17	84	16
1800 / 3.5	209	20	140	19	35	5	76	19	76	18
3300 / 3.2	176	20	108	18	5	0	101	17	99	16
3300 / 3.5	206	19	135	18	10	1	120	18	106	18

While the data in Table 4-1 and Table 4-2 include data for pseudo-pilots and participant pilots, other data for only participant pilots is reported when related to the set-up for CAPP and when CAPP and CAVS are in progress. As mentioned previously, participant data for the first day is not included for this set of objective data due to simulation issues.

Objective data for spacing parameters was divided into “tight” initial spacing and “wide” initial spacing in the CAPP pair. The breakdown of the data was conducted because experimental control of the initial spacing of aircraft was difficult when having both controller and pilot participants. The tight condition was used to get a better understanding of the potential benefits of CAPP and to get a better understanding of pilot behavior when placed closer to the NCT value. The tight conditions are those expected at busy facilities where CAPP is actually expected to be used. The wide values are also included to provide the full picture of the way operations evolved over the course of the simulation and to accurately reflected actual initial spacings. The wide data is provided for reference only while the tight spacing data is expected to be more representative of the potential benefits. The threshold between tight and wide conditions were derived from discussions with controller subject matter experts. The experts provided a value for each ceiling / target final-approach-intercept-point that would be expected to be used for spacing between aircraft when joining the final approach course when traffic demand is moderately high. Based on those discussions, the threshold was set at the following:

- 1800 ft ceiling with the 10 NM final intercept target
    - Tight: Less than 4.5 NM
    - Wide: 4.5 NM or greater
- 3300 ft ceiling with the 15 NM final intercept target
    - Tight: Less than 5.0 NM
    - Wide: 5.0 NM or greater.

4.1.2.2 Communications

Controller and pilot communications were captured with audio recording and then transcribed. Communications events were also captured during controller observations. The CAPP instruction was analyzed for both pilot and controller issues, which CAPP instruction element the issue was related to, and how the issue was ultimately resolved.

When examining the CAPP instruction communications of the controller, all communications from the controller to pilots (pseudo-pilots and participant pilots) were examined. The issues were placed into one of the following topic areas.

- Deviation from defined phraseology
    - Lack of the use of the specified phraseology (Note: the exclusion of the term “miles” was not counted as an error)
- Stumble / slip
    - Error or partial word that is corrected.
- CAPP instruction with error
    - An error that is not corrected within the same transmission.
- CAPP instruction for non-CAPP capable
    - An instruction given to an aircraft that was not CAPP capable.
- CAPP confirmation request
    - A request to confirm whether a CAPP aircraft was already given an instruction and was actively conducting CAPP.
- CAPP instruction given when controller could not recall if already given
    - The issuance of what is believed to potentially be a second (repeat) instruction, when it in fact is not.
- Re-issue to aircraft already conducting CAPP
    - The issuance of a second (repeat) instruction when a CAPP aircraft has already been given an instruction and is actively conducting CAPP.

When examining the CAPP instruction communications from the pilots, only communications from the participant pilots were examined. The pilot issues were placed into one of the following topic areas.

- Non-response
  - A lack of a response to the CAPP instruction
- Readback error
  - An error in one of the CAPP instruction elements
- Data missing from read back
  - A lack of a full read back of all the CAPP elements
- Request for full repeat
  - A request to the controller for a complete repeat of the CAPP instruction.
- Request for clarification
  - A read back with a request to the controller for a clarification of some or all of the CAPP instruction.
- Stumble / slip
  - Error or partial word that is corrected.
- Deviation from defined phraseology
  - As opposed to controllers, this was only noted for the participant pilots when they deviated from the phraseology used by the controller (whether or not the phraseology used by the controller was correct / as defined or incorrect / not as defined).

For both controllers and pilots, the CAPP instruction issue was then attributed to one of the following CAPP instruction elements.

- "CAPP" term
- First Party Call Sign (FPCS)
- TPCS
- NCT value
- "behind" term.

The resolution to the issue was attributed to one of the following categories.

- Self-corrected within the same transmission
  - An error made or word stumble that is quickly corrected within the same transmission.
- Corrected by other party
  - An error that occurred in a transmission by one party and then was noted and corrected in the follow-on communication of the second party.
- Corrected by initiator in follow-on communication
  - An error that occurred in a transmission by one party and then was noted and corrected in a follow-on communication by the same party.
- Not corrected
  - An error that was not corrected by either party.

Due to simulation issues, the recorded audio data and the associated transcripts are missing data from the first two days of data collection as well as some data from day 9 scenario 1 and day 11 scenario 4. However, some of this missing data is captured elsewhere such as in the controller observations. Any missing data beyond those mentioned here will be noted in the subsequent sections. Additionally, any data used to fill in any missed recorded audio data will be noted. The total number of CAPP instructions that were issued included more than just those possible with CAPP capable aircraft. For example, instructions could be issued to aircraft already conducting CAPP and to aircraft not capable of CAPP.

4.1.3 Statistical Method

This section presents the general approach to the statistical methods as well as the high level results of Multivariate Analysis of Variance (MANOVA) tests. Statistical results on a per-topic basis will be reported in the appropriate sections.

The nature of statistical inferences is to validate conclusions based on data collected that represents a subset of a population and more importantly, determining whether an effect (experimentally driven) is real in nature. General criterion for making statistical inferences and testing for statistical significance is executed by selecting a criterion (i.e., alpha, α) for statistical significance that is appropriate for the research being conducted. Alpha (α) is conventionally set at 0.05 or 5% chance of a committing a Type I error. An increase in α increases the probability of committing a Type II error (β). Given the exploratory nature of the concept, an α of 0.05 was, a priori, considered too conservative. Therefore, 0.1 ($\alpha = 0.1$) was applied to all statistical tests. Since five total tests were conducted, the $\alpha = 0.1$ was further adjusted for experiment-wise error using a Bonferroni Correction. The adjusted α for determining statistical significance is $\alpha = .02$ for all tests. Follow-up tests are adjusted further based on $\alpha = .02$ divided by the number of follow-up tests needed.

4.1.3.1 MANOVA and Analysis of Variance (ANOVA) Tests

Repeated measures MANOVA tests were planned to protect against Type I error for similar questions that could be grouped based on measuring the same concept and utilizing the same rating scale structure. Two MANOVAs were conducted: one for pilot post-scenario questionnaire data and the other for controller post-scenario questionnaire data. The authors selected the following key post-scenario statements to address the four experimental hypotheses.

- Pilot Post-Scenario Questionnaire
  - During CAPP, I was able to remain outside the no-closer-than value from the traffic I was following.
  - CAPP was operationally acceptable.
- Controller Post-Scenario Questionnaire
  - For Aircraft Performing CAPP - I was confident that the spacing being achieved by the flight crews would remain outside my separation responsibility. (1)
  - For Aircraft Performing CAPP - I was able to detect when spacing / separation issues were developing. (2)
  - CAPP was operationally acceptable. (3)

Prior to statistical analysis, a series of Pearson Correlations were conducted for all dependent variables specific to the associative hypotheses measuring the CAPP concept for pilot and controller statements. The general assumption for MANOVAs is for there to be some level correlation between dependent measures (not too low or high), specifically within a range from 0.3 to 0.7 (Mayers, 2013). All correlations for both pilot ($r = 0.657$) and controller (1 and 2, $r = 0.527$; 1 and 3, $r = 0.669$; 2 and 3, $r = 0.408$) post-scenario questionnaire were in an acceptable range to run both MANOVAs. The overall results of these tests are reported in the following two sections. Any statistically significant results will be presented in the appropriate sections.

Three Repeated Measures ANOVAs were conducted on: 1) participant pilot workload, 2) controller workload, and 3) final aircraft pair spacing at CAVS end. The statistical results of these tests will be presented in the appropriate sections.

4.1.3.2 Pilot Post-Scenario MANOVA

Using Wilks's (λ) statistic, there was a significant effect for ceiling on pilots' perception of: 1) their ability to remain outside the NCT during CAPP and 2) operational acceptability, $\lambda = 0.751$, $F(2, 31) = 5.15$, $p = 0.012$. Using an adjusted Bonferoni Correction of $p = .01$, separate univariate ANOVAs on the outcome variables reveal significant effects on pilots' perception of their ability to remain outside the NCT during CAPP, $F(1, 32) = 8.23$, $p = 0.007$ and operational acceptability, $F(1, 32) = 7.84$, $p = 0.008$. Although all average responses were on the positive side of the scale, pilots had a statistically more positive response to both statements in the 3300 ft ceiling scenarios compared to the 1800 ft ceiling scenarios. No effect was found for the NCT values nor was there an effect for the interaction.

4.1.3.3 Controller Post-Scenario MANOVA

Controller Repeated Measures MANOVA did not reveal a significant omnibus statistic (Wilks' λ) indicating there are no statistical differences for the three controller questions.

4.2 Approach Conduct (CAPP and CAVS)

4.2.1 Pre-CAPP

4.2.1.1 Localizer Intercept

Controllers were instructed to have CAPP aircraft intercept the final approach course at two distances from threshold based on cloud ceiling height: 10 NM for the 1800 ft ceiling and 15 NM for the 3300 ft ceiling. As mentioned previously, the different intercepts to final were to achieve some level of consistency across controllers and to allow for similar times to conduct CAPP prior to exiting the cloud layer.

Localizer capture distances were measured when the aircraft track was within 5° of the final approach course. Figure 4-8 shows the distribution of localizer intercept points measured as distance from threshold. Table 4-3 shows the means and SDs. On average, aircraft were vectored to intercept the final approach course close to that expected. However, the 1800 ft and 3.5 NM condition had an average intercept distance three miles greater than the target distance. It is unclear why this occurred. As can be seen over all the conditions, the traffic did require some increases in the final approach course intercept distance.

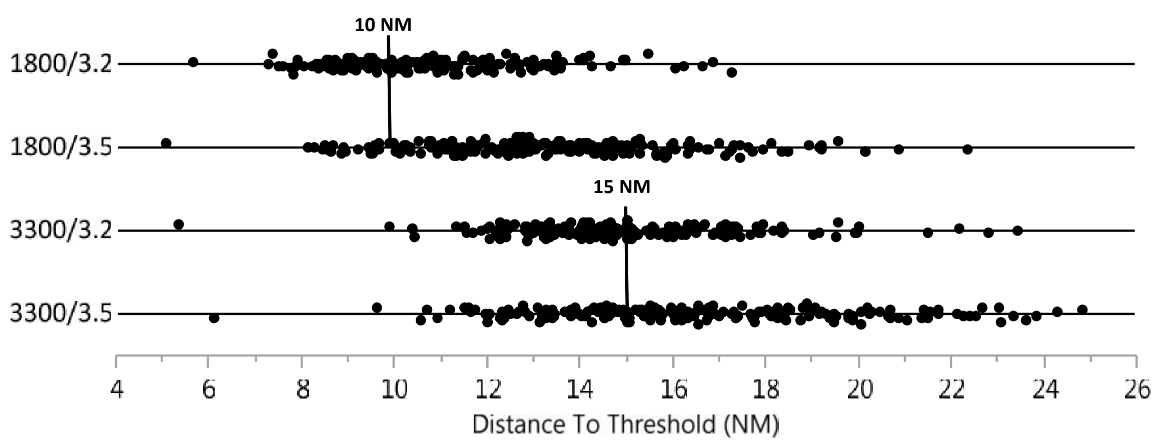

Figure 4-8. Distance to Threshold during Localizer Intercept

Table 4-3. Distance to Threshold during Localizer Intercept by Condition

Condition	Target Distance (NM)	Mean Distance (NM)	SD (NM)
1800 / 3.2	10	10.7	2.0
1800 / 3.5	10	13.1	2.7
3300 / 3.2	15	14.9	2.3
3300 / 3.5	15	16.3	3.1

Figure 4-9 and Table 4-4 show the ground speeds of aircraft at localizer intercept. The mean speeds across the scenarios were as expected at approximately 200 kts.

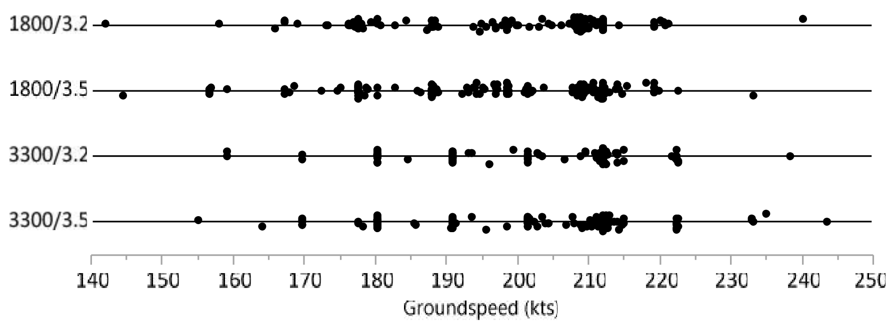

Figure 4-9. Groundspeed during Localizer Intercept

Table 4-4. Ground Speed during Localizer Intercept by Condition

Condition	Mean (kts)	SD (kts)
1800 / 3.2	201.7	14.2
1800 / 3.5	199.8	15.3
3300 / 3.2	205.8	12.9
3300 / 3.5	204.3	14.3

4.2.1.2 CAPP Initiation

Each condition had approximately 70% of the aircraft that were CAPP capable. The majority (10/11; 91%) of controllers reported that this was a reasonable number of aircraft. The controller that reported "no" did not comment. For the CAPP capable aircraft, Table 4-5 and Figure 4-10 show the total number of CAPP opportunities, initiations, and missed opportunities, based on the controller observations. The data only includes CAPP capable aircraft that had a potential TTF (i.e., this data does not include CAPP capable aircraft that were the first aircraft at the beginning of the scenario without an aircraft ahead of it). The data includes all qualifying aircraft regardless of the distance between the pair because controllers were asked to run CAPP as often as possible, regardless of initial spacing. The data also includes aircraft that got a CAPP instruction but were not able to finish the CAPP operation due to the scenario ending after the participant aircraft completed CAPP.

As can be seen across all scenarios, the majority of the time (96%) CAPP was initiated.

Table 4-5. CAPP Initiations by Condition

Condition	Total Opportunities	Initiations	Missed Opportunities
1800 / 3.2	147	137 (93%)	10 (7%)
1800 / 3.5	189	183 (97%)	6 (3%)
3300 / 3.2	147	140 (95%)	7 (5%)
3300 / 3.5	178	172 (97%)	6 (3%)
All	661	632 (96%)	29 (4%)

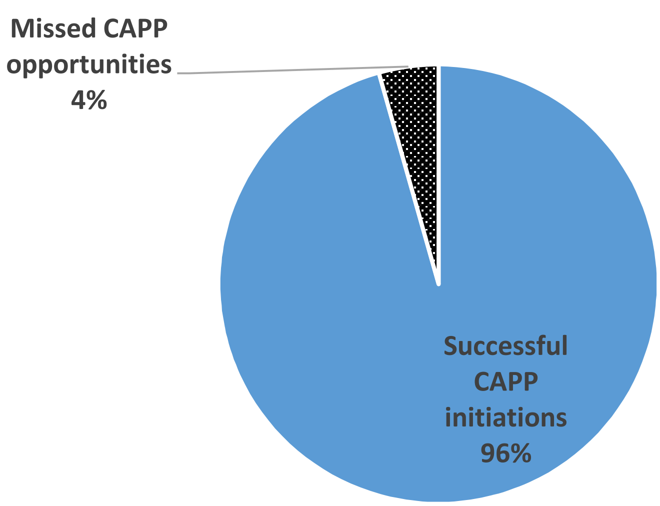

Figure 4-10. Missed and Successful CAPP Initiations

When examining the limited number of times CAPP was not initiated, it was often (16/29; 55% of the cases) unclear why it was not initiated (Figure 4-11). In some cases, however, the controller made a statement about why CAPP was not initiated. The reasons for not initiating are shown in Figure 4-11. While the controllers were told they could still initiate CAPP with larger distances between the aircraft, controllers chose not to do so in 28% (8/29) of the cases. There were also three cases (10%) when the controller believed the aircraft were too close to initiate CAPP. Finally, there were two cases (7%) where the controller incorrectly thought that CAPP had been initiated when it actually had not.

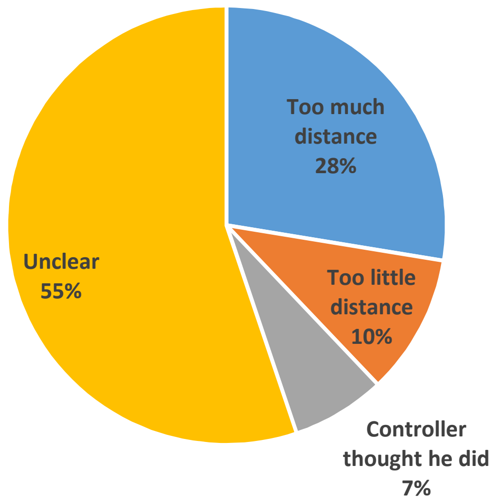

Figure 4-11. Reasons for Missed CAPP Initiation Opportunities

After receiving the CAPP instruction, participant and pseudo-pilots initiated CAPP. CAPP initiation is defined as the point where the CAPP operation is armed (which is very quickly [i.e., less than a second] followed by the system engaging). Participant pilot CAPP arming was done via the "Arm" button select on the CDTI. Pseudo-pilot arming was done by entering a command in the pseudo-pilot interface. Initiation in this section only includes correct participant and pseudo-pilot CAPP execution. Pseudo-pilot errors during CAPP initiation (e.g., incorrect TTF call sign entry) were removed from the analysis. There were no entry errors on the participant pilot side.

CAPP initiation usually took place prior to localizer capture (Table 4-6). The vast majority of aircraft were on a dogleg / intercept to final when CAPP was initiated (Table 4-7). There were fewer instances of CAPP initiation on final and base with even fewer cases on downwind. Some of the outliers (i.e., "Other") for both north and south downwinds were due to the controller vectoring aircraft through the localizer.

Table 4-6. Distance to Threshold for Participant and Pseudo-Pilot CAPP Aircraft at CAPP Initiation by Condition

Condition	Mean* (Localizer Capture) (NM)	Mean (CAPP Initiation) (NM)
1800 / 3.2	11.0	12.8
1800 / 3.5	13.2	14.6
3300 / 3.2	14.9	16.7
3300 / 3.5	16.5	18.4

* Localizer capture means are for CAPP-initiated aircraft only

Table 4-7. Traffic Pattern Position for Participant and Pseudo-Pilot CAPP Aircraft during CAPP Initiation

	Traffic Pattern Position					
	Downwind	Base	Between Base and 30^0 Intercept	30^0 Intercept	Final	Other
N size (%)	2 (0.4)	38 (7)	240 (43)	195 (35)	71 (13)	11 (2)

Controllers were responsible for making judgments about what spacing to use between aircraft pairs when vectoring them to final. Based on the objective spacing data, controllers issued and pilots initiated the CAPP operation with an average of 4.8 NM (SD= 1.0) spacing within pairs with a noticeable range of dispersion (Figure 4-12). A total of 554[6] CAPP operations were initiated.

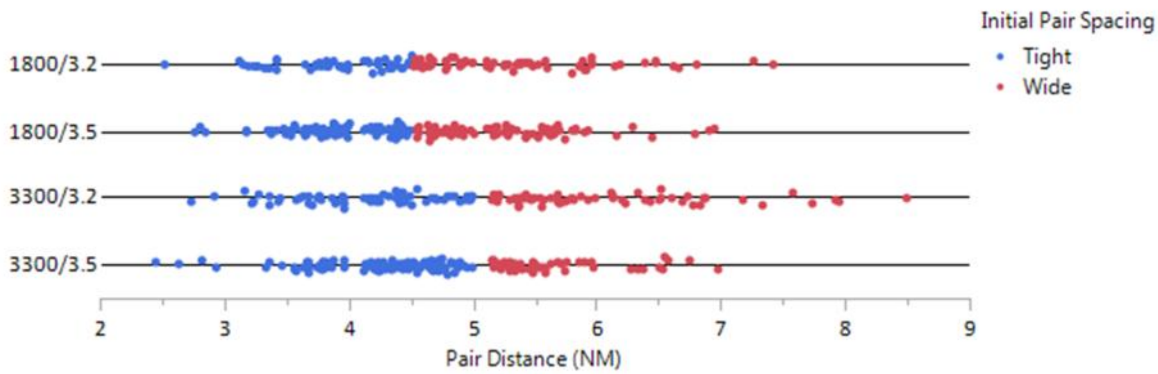

Figure 4-12. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAPP Initiation

Of the 554, 303 (55%) were initiated with tight spacing. The remainder, 251 (45%) were initiated with wide spacing. Aircraft that were paired with tight spacing averaged 4.1 NM (SD = 0.5) across all scenarios. Aircraft paired with wide spacing averaged 5.6 NM (SD = 0.7) across all scenarios. See Table 4-8 and Table 4-9 for an overview of CAPP initiation pair spacing distances. As expected, spacings for the 3300 ft conditions are greater than the spacings for the 1800 ft conditions since the aircraft are further out on the final approach course.

[6] Based on the objective data that excluded the first day of data collection as noted in Section 4.1.2.

Table 4-8. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAPP Initiation by Condition

Condition	Overall Spacing		Tight Spacing		Wide Spacing	
	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)
1800 / 3.2	4.7	1.0	3.9	0.5	5.4	0.7
1800 / 3.5	4.6	0.8	3.9	0.4	5.2	0.6
3300 / 3.2	5.1	1.2	4.2	0.6	6.1	0.8
3300 / 3.5	4.7	0.8	4.3	0.5	5.7	0.5

Table 4-9. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAPP Initiation by Independent Variable

Independent Variables	Overall Spacing		Tight Spacing		Wide Spacing	
	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)
1800	4.6	0.9	3.9	0.4	5.3	0.6
3300	4.9	1.0	4.2	0.5	5.9	0.7
3.2	4.9	1.1	4.0	0.5	5.7	0.8
3.5	4.6	0.8	4.1	0.5	5.4	0.6

DGS during CAPP initiation was higher for the 1800 ft ceiling scenarios compared to the 3300 ft ceiling scenarios (Table 4-10). As noted previously, all conditions had similar ground speeds on average at localizer intercept. Therefore, the DGS differences are likely due to speeds being more similar on extended final approach (i.e., in the 3300 ft conditions).

Table 4-10. Participant and Pseudo-Pilot CAPP Aircraft Pair DGS at CAPP Initiation by Condition

Condition	Mean (Total) (kts)*	SD (Total) (kts)
1800 / 3.2	15.1	22.5
1800 / 3.5	10.7	20.6
3300 / 3.2	4.1	11.1
3300 / 3.5	2.9	15.8

* All values are CAPP aircraft convergence.

The data in the remainder of this section is based on participant pilots only and is related to interactions with the CDTI. CAPP set-up is defined as the time from when the PM selected the "Operations Menu" on the CDTI (after receiving the CAPP instruction), entered the necessary information, coordinated on the information, and pushed the "Arm" button.

After selecting the operations menu, all participant pilots correctly entered the assigned 3.2 NM or 3.5 NM NCT value and there were no entry errors. All pilots used a CAVS minimum distance that was less than CAPP NCT value. The majority of pilot participants used 2.5 NM as the CAVS minimum distance (Table 4-11).

Table 4-11. Participant Pilot CAVS Minimum Distance Entry Values by Condition

Condition	2.0 NM (%)	2.5 NM (%)	2.7 NM (%)	2.8 NM (%)	3.0 NM (%)	Average (NM)
1800 / 3.2	5	53	0	32	10	2.6
1800 / 3.5	0	53	5	32	10	2.7
3300 / 3.2	11	50	0	22	17	2.6
3300 / 3.5	6	50	6	22	16	2.6

After entering all the necessary information and selecting the “Confirm Arm” button, pilots coordinated on the information. On average, crew coordination took 7.3 sec across all conditions. The average for each nominal scenario was relatively uniform (Table 4-12).

Table 4-12. Participant Pilot Crew Coordination Time by Condition

Condition	Mean (sec)	SD (sec)
1800 / 3.2	7.8	7.4
1800 / 3.5	5.7	3.9
3300 / 3.2	7.4	7.9
3300 / 3.5	7.1	3.7

After crew coordination, the system was armed. The CAPP set up process from start to finish took, on average, 44 sec. Set-up times ranged from 13 to 329 sec (Figure 4-13). The set up time for the 3300 ft ceiling scenarios took on average 13 sec longer than the 1800 ft ceiling scenarios (Table 4-13). Most pilot participants were fairly consistent with the amount of CAPP set-up time to setup the operation. However, three crews (1, 7, and 10) were noticeably more dispersed (Figure 4-14). Only crew 1 was noted in the observer notes as having some issues using the CDTI to set up CAPP. The largest two outliers were around 15 NM from the threshold in the 3300 ft ceiling conditions and from different crews. Nothing unusual was mentioned from the observer notes to help provide context to these outliers. Additionally, participants rated workload as low in both cases.

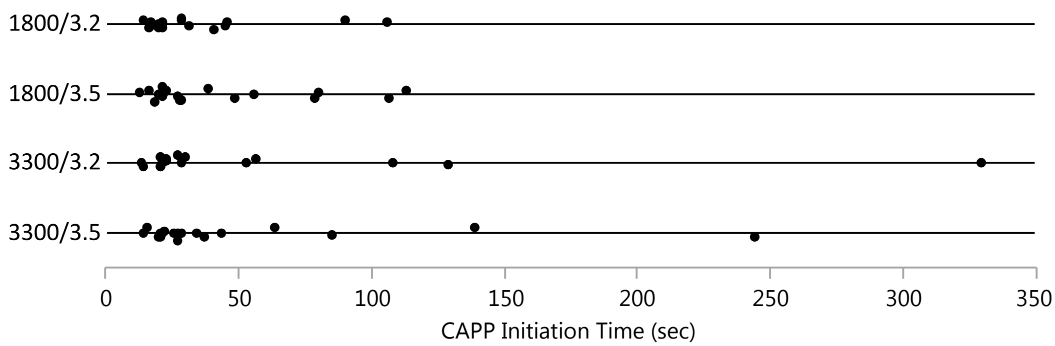

Figure 4-13. Participant Pilot CAPP Set-Up Time Distribution

Table 4-13. Participant Pilot CAPP Set-Up Time by Condition

Condition	Mean (sec)	SD (sec)
1800 / 3.2	33.7	25.4
1800 / 3.5	41.2	31.1
3300 / 3.2	53.4	75.9
3300 / 3.5	49.5	57.4

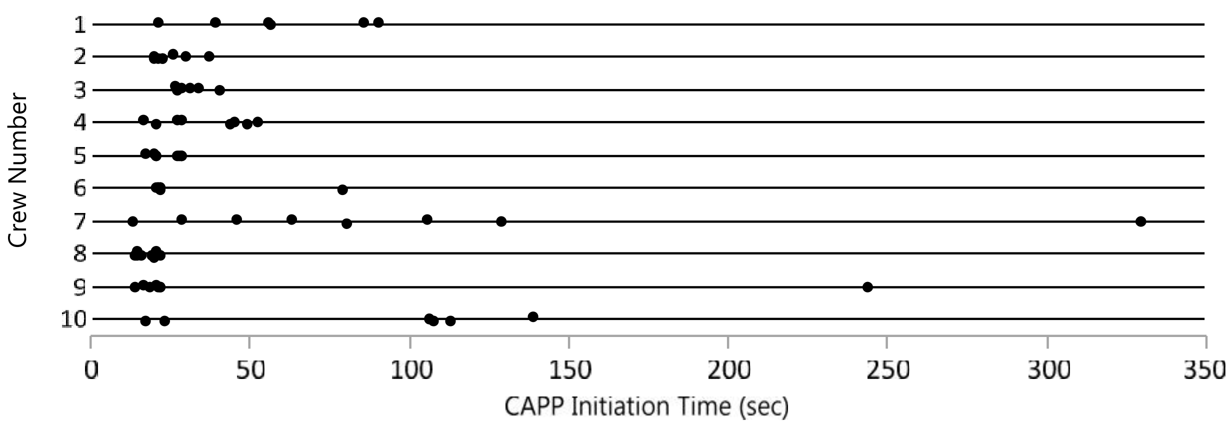

Figure 4-14. CAPP Set-Up Time Distribution by Participant Pilots

4.2.2 CAPP

During CAPP, participant pilots were responsible for making spacing decisions based on the CDTI and adjusting speed to achieve a desired spacing from the TTF. The number of participant pilot speed changes made were recorded. Speed changes are defined as either a speed increase or decrease resulting in a change in the MCP speed of five kts or greater for more than five sec.

Twice as many speed changes were made in 1800 ft ceiling conditions as compared to the 3300 ft ceiling conditions (Table 4-14)[7]. This is to be expected since aircraft were likely making speed

[7] Although frequency counts are used in the "Max Changes" column, a Descriptive Mean (DM) is also shown since the mean is an easier method of interpreting a measure of central tendency.

changes to react to the TTF slowing to its final approach speed. The number of speed changes for the NCT values are very similar. In a few cases, pilot participants made several speed changes, as reflected in the maximum number of speed changes column in Table 4-14.

Table 4-14. Frequency of Participant Pilot Speed Changes during CAPP by Condition and Independent Variable

Condition	Desc. Mean	SD	Max Changes		Independent Variables	Desc. Mean	SD	Max Changes
1800 / 3.2	2.7	1.8	7		**1800**	2.7	1.7	7
1800 / 3.5	2.6	1.7	6		**3300**	1.2	1.3	5
3300 / 3.2	1.4	1.4	5		**3.2**	2.1	1.7	7
3300 / 3.5	0.9	1.1	3		**3.5**	1.8	1.7	6

Whether pilots increased speed during CAPP was also of interest. Speed increases are defined as a change in MCP speed of five kts or greater for more than five sec. Table 4-15 shows the speed increases per condition. Participant pilots made less than one speed increase per condition on average. However, five (50% of which the objective data was available) of the participant pilots increased speed more than once. A similar number of speed increases were made for both ceiling conditions. However, more speed increases were made for the 3.2 NM conditions as compared to the 3.5 NM conditions. This may have occurred to allow for additional closure to the lower NCT value.

Table 4-15. Frequency of Participant Pilot Speed Increases during CAPP by Condition and Independent Variable

Condition	Sum	Desc. Mean		Independent Variables	Sum	Desc. Mean
1800 / 3.2	7	0.4		**1800**	13	0.4
1800 / 3.5	6	0.3		**3300**	15	0.4
3300 / 3.2	10	0.6		**3.2**	17	0.5
3300 / 3.5	5	0.3		**3.5**	11	0.3

The average magnitude of both speed increases and decreases during CAPP were noticeably greater in the 1800 ft ceiling conditions compared to the 3300 ft ceiling conditions (Table 4-16). This is to be expected since aircraft were likely making speed reductions to react to the TTF slowing to its final approach speed. The NCT values appear to be very similar.

Table 4-16. Magnitude of Participant Pilot Speed Changes during CAPP by Condition and Independent Variable

Condition	Mean (kts)	SD (kts)		Independent Variables	Mean (kts)	SD (kts)
1800 / 3.2	22.2	14.4		1800	20.8	15.2
1800 / 3.5	19.6	16.3		3300	7.7	10.2
3300 / 3.2	10.0	9.6		3.2	15.9	13.5
3300 / 3.5	5.3	10.4		3.5	12.7	15.4

Pilots were asked if they were able to remain outside the NCT value when conducting CAPP. The majority (19/22; 86%) of pilots agreed (M=74.8; SD=19.8). The majority (19/22; 86%) of pilots agreed they were able to detect developing spacing issues (M=78.6; SD=24.6). All pilots agreed their traffic awareness was acceptable (M=86.7; SD=13.9). See Figure 4-15 for the results.

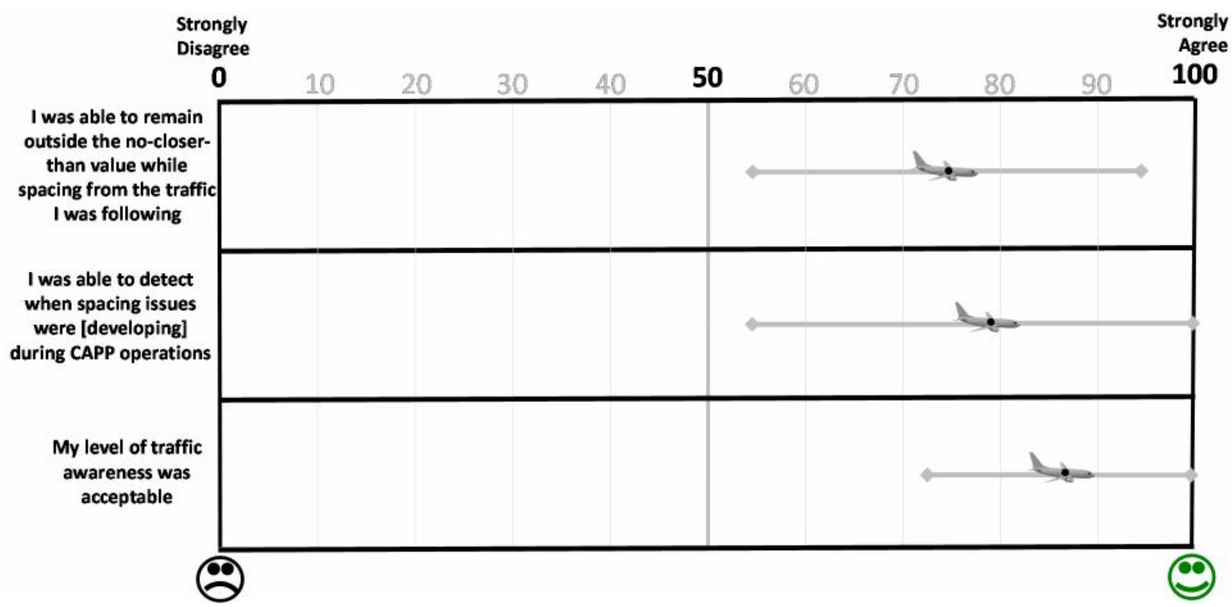

Figure 4-15. Summary of Pilot Responses to Spacing Statements

In the post-scenario, pilots were also asked if they were able to remain outside the NCT value. As reported in Section 4.1.3.2, the Repeated Measures MANOVA revealed statistically significant results for only the ceiling. Pilots found the ability to remain outside the NCT value more acceptable under the 3300 ft ceiling than under the 1800 ft ceiling. Figure 4-16 depicts the results.

- 1800 ft and 3.2 NM
  - Pilot responses were variable but the majority (36/44; 82%) agreed (M=73.9; SD=35.8).
- 1800 ft and 3.5 NM
  - Pilot responses were variable but the majority (35/44; 80%) agreed (M=78.3; SD=28.7).
- 3300 ft and 3.2 NM
  - The majority (38/41; 93%; Missing 3 values) of pilots agreed (M=87.8; SD=20.6).
- 3300 ft and 3.5 NM
  - The majority (36/38; 95%; Missing 6 values) of pilots agreed (M=88.4; SD=19.8).

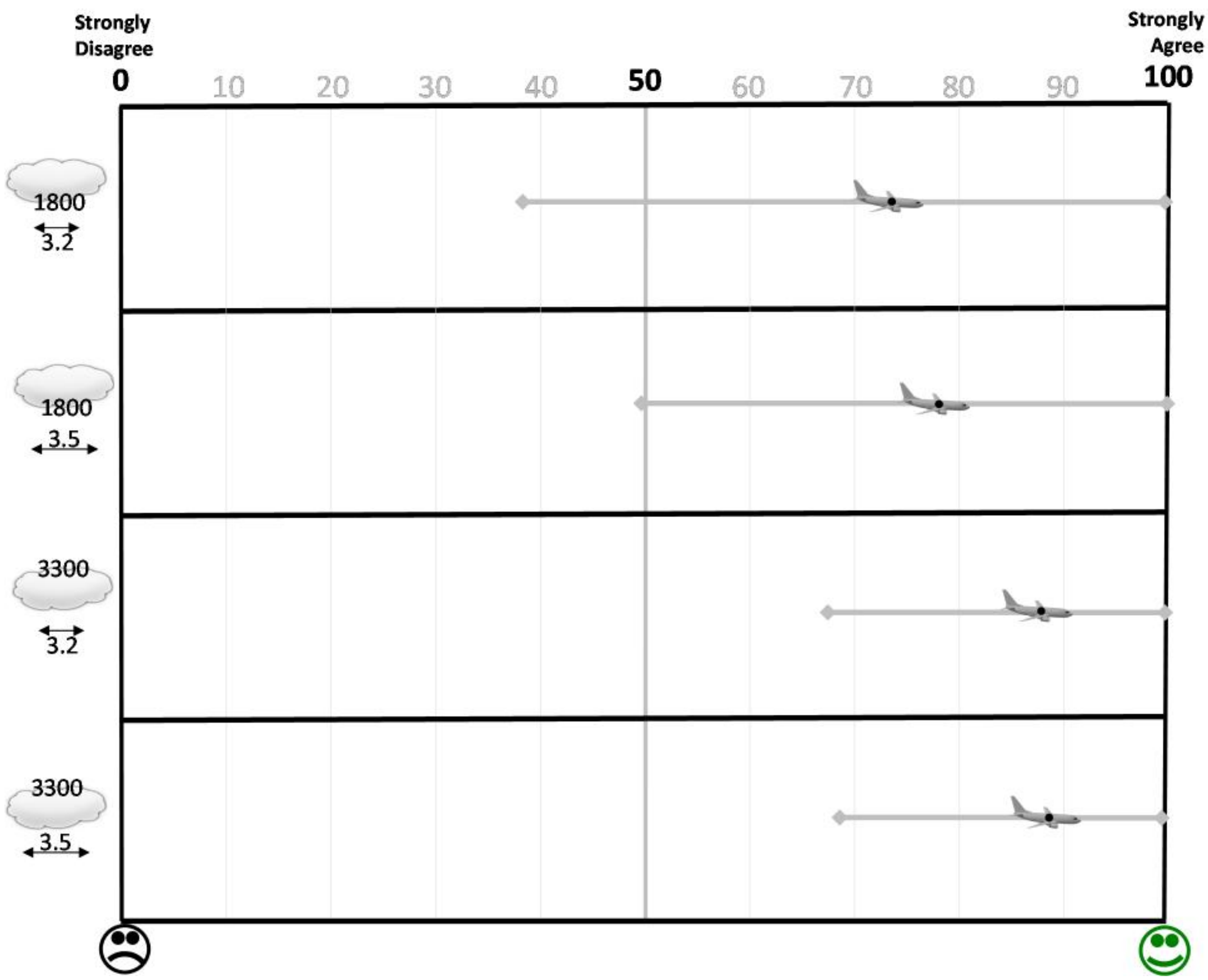

Figure 4-16. Pilot Responses to Post-Scenario Statement "I was able to remain outside the no-closer-than value from the traffic I was following"

Controllers were asked if they were confident the spacing being achieved by the CAPP aircraft would remain outside their separation requirements. Controller responses were variable but the majority (8/11; 73%) agreed (M=62.7; SD=26.6). Controllers were asked how aircraft conducting CAPP affected their monitoring of CAPP aircraft for both NCT values. For the 3.2 NM condition, controller responses were about evenly split between an increase or reduction (DM=3.8 [of 7.0]; SD=1.8). For the 3.5 NM condition, controller responses were variable but the majority (8/11; 73%) reported a reduction (DM=4.8 [of 7.0]; SD=1.7) (Figure 4-17).

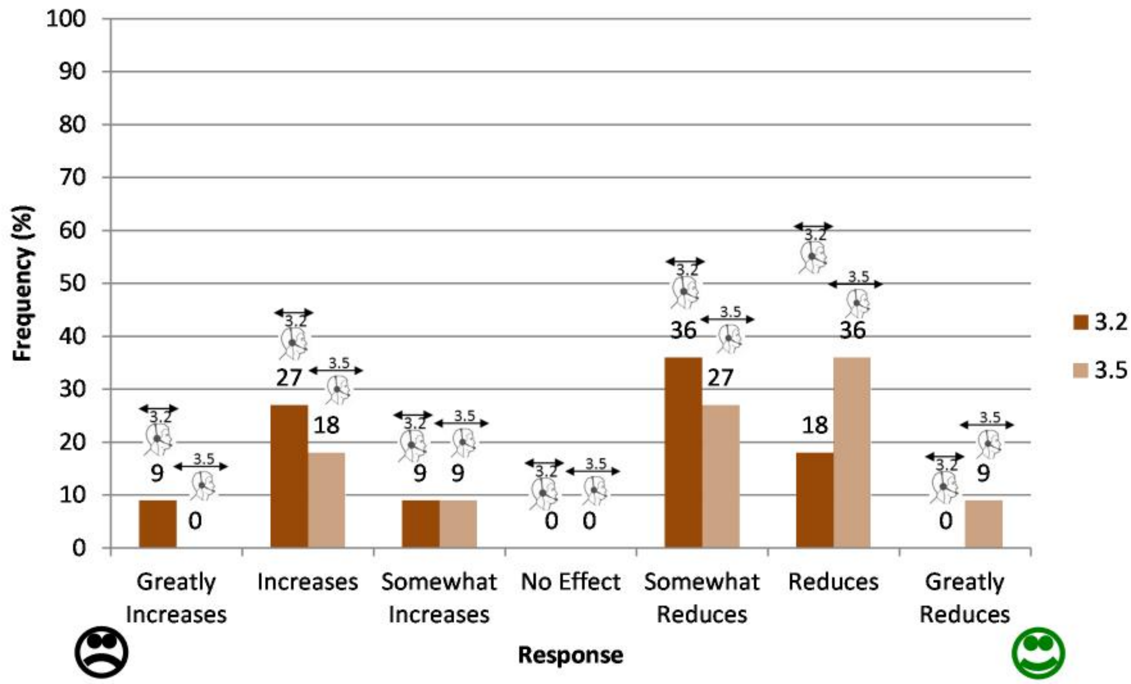

Figure 4-17. Controller Responses to "How did aircraft conducting CAPP [affect] your monitoring of CAPP traffic?"

In the post-scenario questionnaire, controllers were also asked if they were confident the spacing being achieved by the CAPP aircraft would remain outside their separation requirements. The majority of controllers agreed for all conditions. The 3300 ft and 3.2 NM condition appears to be rated the most favorably for CAPP aircraft remaining outside controller separation requirements. However, as reported in 4.1.3.3 the Repeated Measures MANOVA did not reveal statistically significant results. Responses are shown below and Figure 4-18 depicts the results.

- 1800 ft and 3.2 NM
  - o The majority (10/11; 91%) of controllers agreed (M=75.9; SD=19.5).
- 1800 ft and 3.5 NM
  - o The majority (9/11; 82%) of controllers agreed (M=74.9; SD=19.7).
- 3300 ft and 3.2 NM
  - o All (11/11; 100%) of controllers agreed (M=85.8; SD=13.4).
- 3300 ft and 3.5 NM
  - o The majority (10/11; 91%) of controllers agreed (M=81.6; SD=16.5).

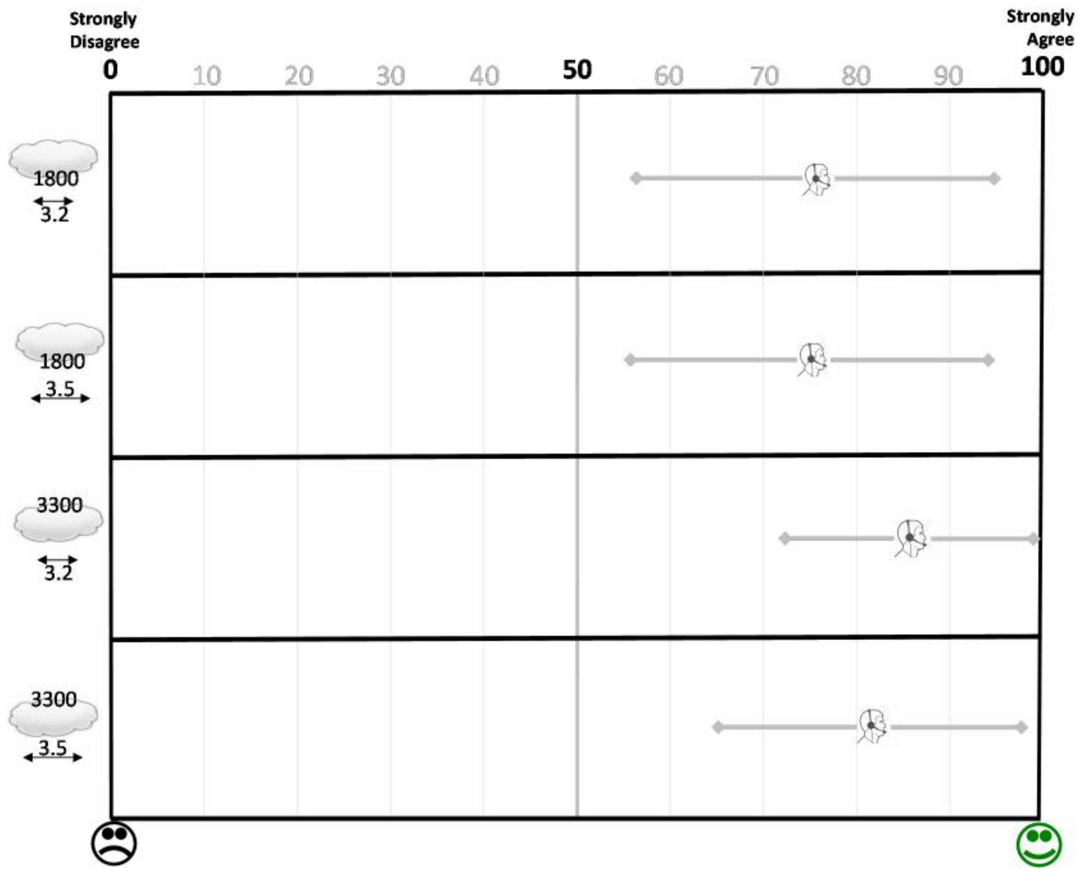

Figure 4-18. Controller Responses to Post-Scenario Statement "I was confident that the spacing being achieved by the flight crews would remain outside my separation responsibility" for CAPP Aircraft

Controllers were asked how aircraft conducting CAPP affected their monitoring of non-CAPP aircraft for both NCT values. For the 3.2 NM condition, the majority (10/11; 91%) of controller responses indicated no effect (4/11; 36%) or an increase (6/11; 55%). Only one controller reported a reduction (DM=3.4 [of 7.0]; SD=1.2). For the 3.5 NM condition, the majority (10/11; 91%) of controller responses were for no effect (5/11; 45%) or an increase (5/11; 45%). Only one controller reported a reduction (DM=3.5 [of 7.0]; SD=0.9). CAPP does not appear to have a negative impact on the monitoring of non-CAPP aircraft. It may allow controllers to attend to other tasks such as the monitoring of non-CAPP aircraft. See Figure 4-19 for the responses.

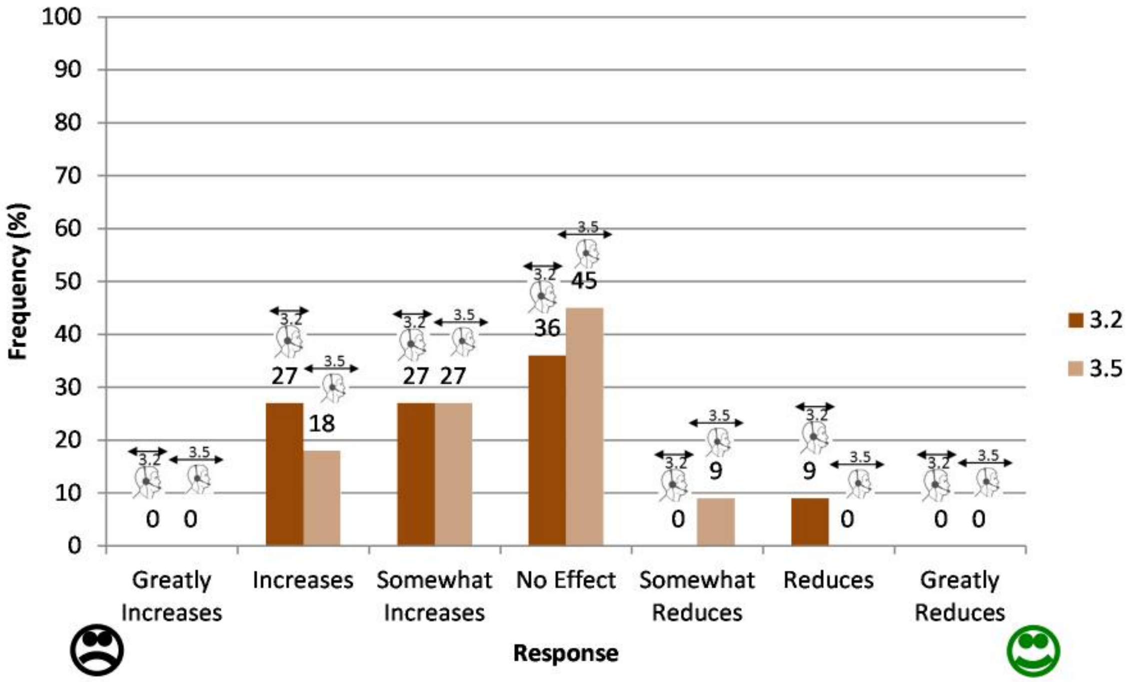

Figure 4-19. Controller Responses to “How did aircraft conducting CAPP [affect] your monitoring of non-CAPP traffic?”

Controllers were also asked whether they could detect developing spacing / separation issues for both NCT values. For the 3.2 NM condition, controller responses were variable but the majority (8/11; 73%) agreed (M=62.4; SD=25.7). For the 3.5 NM condition, all controllers agreed (M=74.0; SD=17.4). Controllers were also asked whether they knew when to intervene on CAPP aircraft for both NCT values. For the 3.2 NCT value, the majority (8/11; 73%) of the controllers agreed (M=61.5; SD=22.5) and for the 3.5 NCT value, the majority (8/11; 73%) of the controllers agreed (M=68.2; SD=22.4). The 3.2 NM conditions may be more challenging for controllers when monitoring for spacing issues and interventions.

When asked whether the necessary monitoring was acceptable, the majority (8/11; 73%) of the controllers agreed (M=70.8; SD=16.1). All the controllers agreed when asked if their traffic awareness was acceptable (M=78.2; SD=11.0). See Figure 4-20 for the results.

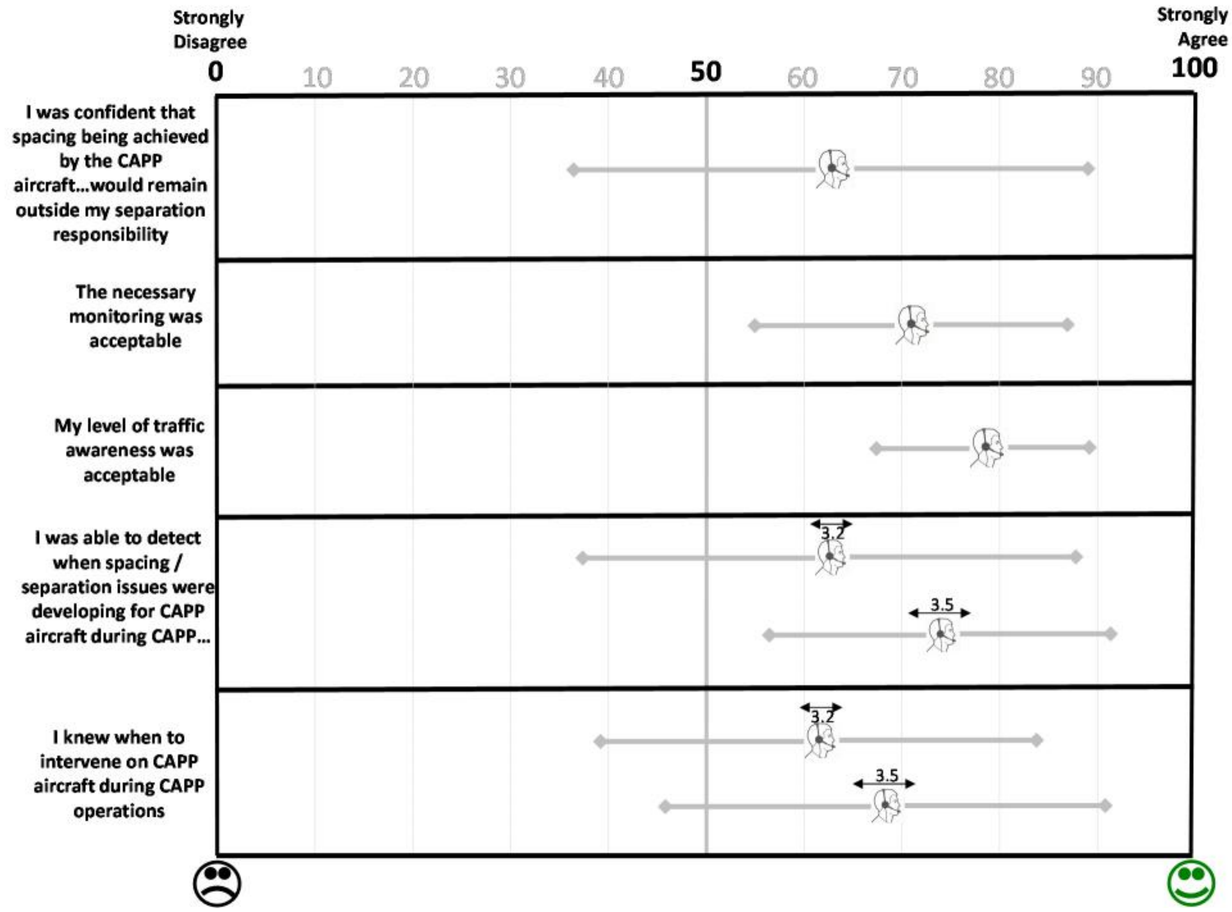

Figure 4-20. Summary of Controller Monitoring Statements

In the post scenario questionnaire, controllers were also asked if they were able to detect when spacing / separation issues were developing. For both CAPP and non-CAPP aircraft, the majority to all the controllers agreed and the means were very similar to each other across conditions. As reported in Section 4.1.3.3, the Repeated Measures MANOVA did not reveal statistically significant results. The 3.2 NM conditions do not appear to be more challenging than the 3.5 NM conditions, as appeared possible based on the post-simulation results for the same statement. Responses are shown next and Figure 4-21 depicts the results.

- CAPP aircraft
  - 1800 ft and 3.2 NM
    - All (11/11; 100%) of controllers agreed (M=81.6; SD=13.4).
  - 1800 ft and 3.5 NM
    - The majority (10/11; 91%) of controllers agreed (M=76.1; SD=21.5).
  - 3300 ft and 3.2 NM
    - All (11/11; 100%) of controllers agreed (M=83.4; SD=14.6).
  - 3300 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=78.7; SD=18.9).

- Non-CAPP aircraft
    - 1800 ft and 3.2 NM
        - All (11/11; 100%) of controllers agreed (M=86.2; SD=10.2).
    - 1800 ft and 3.5 NM
        - All (11/11; 100%) of controllers agreed (M=81.1; SD=13.9).
    - 3300 ft and 3.2 NM
        - All (11/11; 100%) of controllers agreed (M=83.1; SD=12.7).
    - 3300 ft and 3.5 NM
        - All (11/11; 100%) of controllers agreed (M=83.9; SD=11.5).

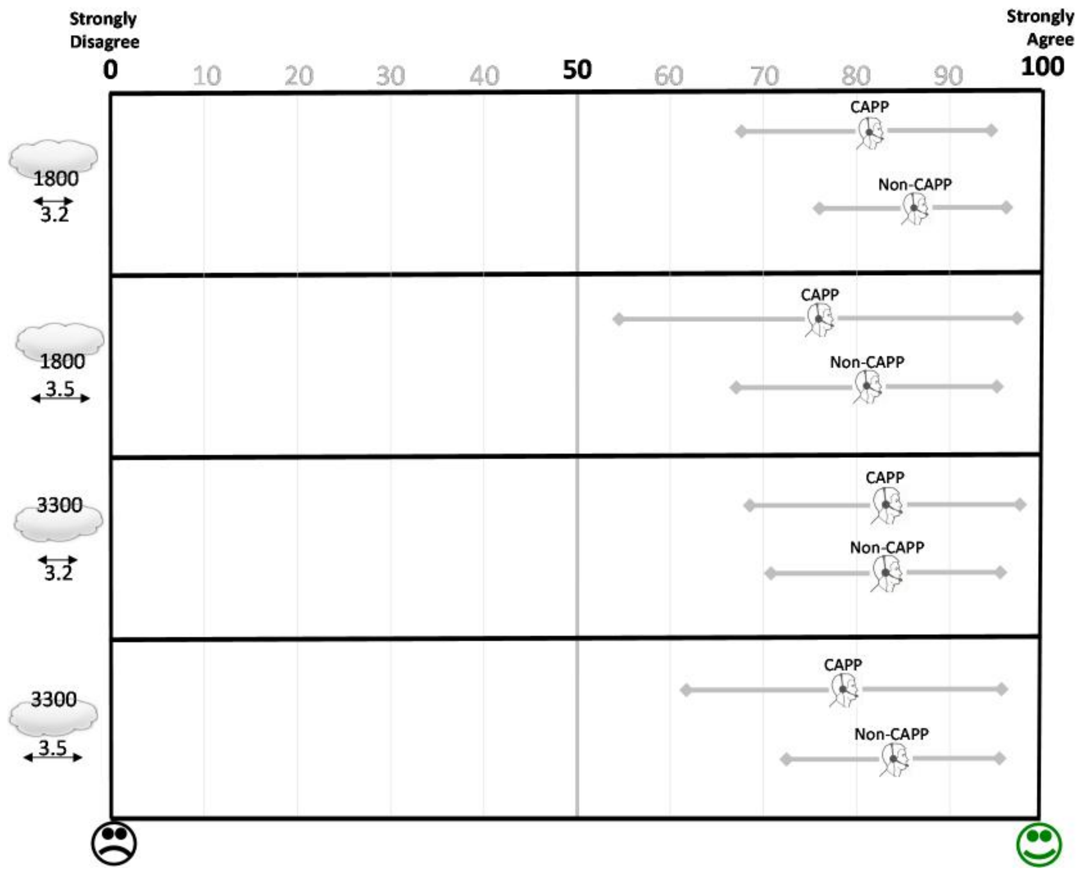

Figure 4-21. Controller Responses to Post-Scenario Statement "I was able to detect when spacing / separation issues were developing"

Controllers were also asked in the post scenario questionnaire if they knew when to intervene. For CAPP aircraft, the majority of the controllers agreed for all conditions except the 1800 ft and 3.5 NM condition where responses were variable. For CAPP aircraft, both the ceiling and NCT value appeared to play a role. The 3300 ft condition ratings were more favorable than the 1800 ft condition ratings and the 3.2 NM NCT value ratings appear more favorable than the 3.5 NCT value rating. The 3300 ft and 3.2 NM condition appears to be the most favorable for controllers knowing when to intervene. For the non-CAPP aircraft, the ratings were all positive and very similar to each other, except potentially between the 1800 ft and 3.2 NM and 1800 ft and 3.5 NM conditions. Responses are shown next and Figure 4-22 depicts the results.

- CAPP aircraft
  - 1800 ft and 3.2 NM
    - The majority (9/11; 82%) of controllers agreed (M=71.7; SD=17.2).
  - 1800 ft and 3.5 NM
    - Controller responses were variable (M=62.5; SD=30.1).
  - 3300 ft and 3.2 NM
    - The majority (10/11; 91%) of the controllers agreed (M=83.9; SD=15.8).
    - 3300 ft and 3.5 NM
      - The majority (7/11; 64%) of controllers agreed (M=75.1; SD=21.7).
- Non-CAPP aircraft
  - 1800 ft and 3.2 NM
    - The majority (10/11; 91%) of controllers agreed (M=87.3; SD=14.8).
  - 1800 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=73.4; SD=24.6).
  - 3300 ft and 3.2 NM
    - All (11/11; 100%) of the controllers agreed (M=86.3; SD=12.2).
  - 3300 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=80.5; SD=17.2).

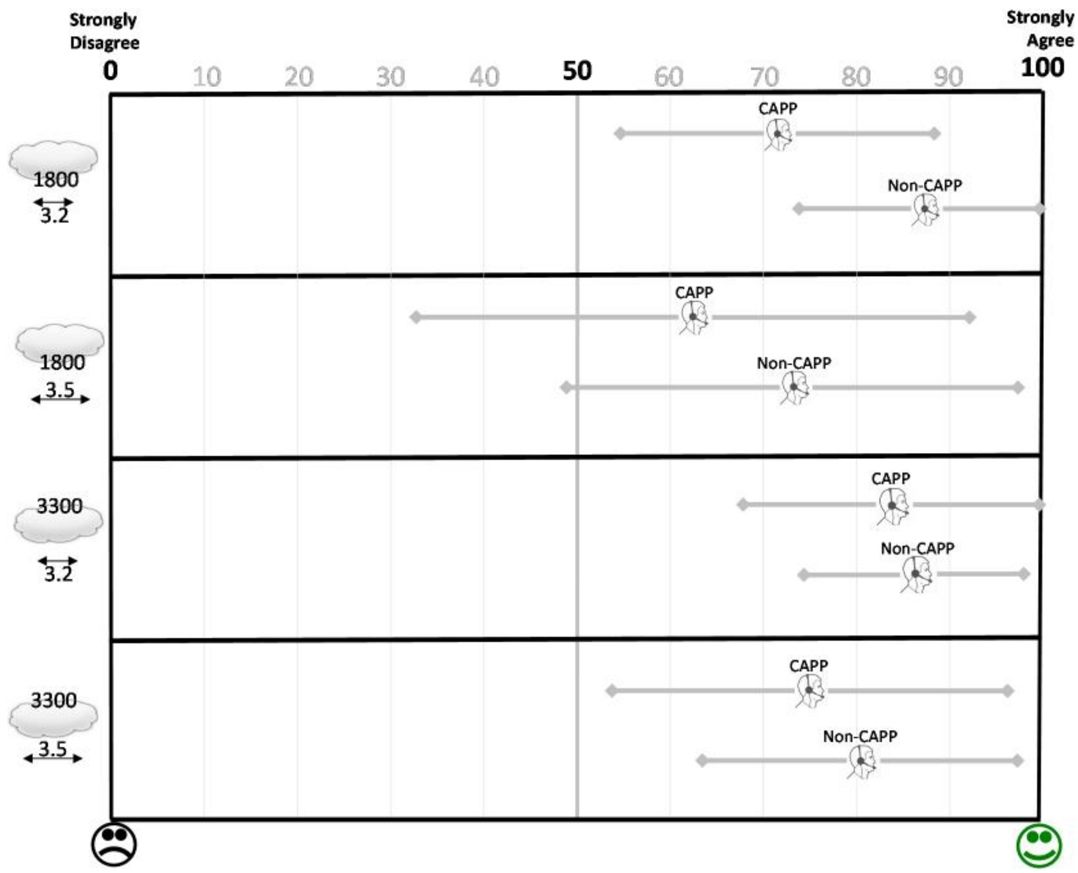

Figure 4-22. Controller Responses to Post-Scenario Statement "I knew when to intervene on aircraft"

Controllers and pilots were asked if the spacing achieved during CAPP operations was acceptable for the two NCT values. For controllers and pilots, both values appear to have similar acceptability. However, pilots appear to find both more acceptable than controllers. The following bullets provide the responses.

3.2 NM

- The majority (8/11; 73%) of the controllers agreed (M=68.8; SD=22.2).
- The majority (21/22; 95%) of pilots agreed (M=82.3; SD=16.3).

3.5 NM

- The majority (10/11; 91%) of controllers agreed. One was neutral (M=69.3; SD=15.3).
- The majority (21/22; 95%) of pilots agreed. One was neutral (M=82.5; SD=15.6).

Controllers and pilots were also asked whether they would be comfortable with closer spacing. All replies were variable.

3.2 NM

- o Controller responses were variable (M=52.2; SD=29.1).
- o Pilot responses were variable (M=58.5; SD=32.1).

3.5 NM

- o A slight majority (6/11; 55%) of the controllers agreed (M=68.4; SD=24.1).
- o Pilot responses were variable (M=65.6; SD=28.6).

See Figure 4-23 for a summary of these statements.

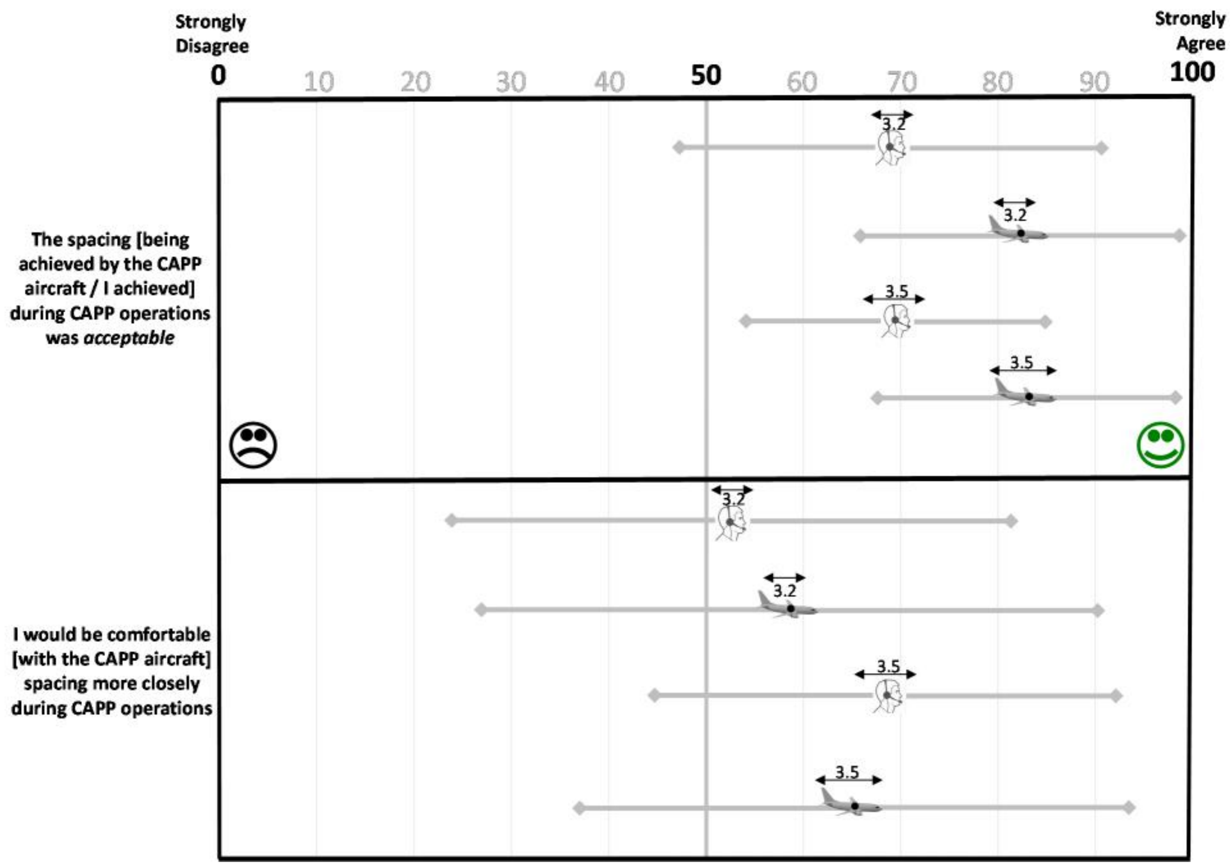

Figure 4-23. Summary of Controller and Pilot Responses to Statements about the NCT Value Acceptability

In the post-scenario questionnaire, controllers were also asked whether the spacing being achieved by the aircraft was acceptable for both CAPP and non-CAPP aircraft. All means were on the agree side of the scale. For CAPP aircraft, the 3300 ft and 3.2 NM condition appears to be rated most acceptable for the spacing being achieved. The non-CAPP aircraft had a similar, but not as strong trend. The other three conditions were rated similarly. When comparing CAPP aircraft and non-CAPP aircraft, the ratings were very similar across all conditions. Figure 4-24 depicts the results.

- CAPP aircraft
  - 1800 ft and 3.2 NM
    - The majority (10/11; 91%) of controllers agreed (M=76.6; SD=16.8).
  - 1800 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=72.7; SD=18.0).
  - 3300 ft and 3.2 NM
    - All (11/11; 100%) of controllers agreed (M=86.7; SD=13.2).
  - 3300 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=74.3; SD=26.3).
- Non-CAPP aircraft
  - 1800 ft and 3.2 NM
    - The majority (9/11; 82%) of controllers agreed (M=74.9; SD=15.4).
  - 1800 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=71.1; SD=17.0).
  - 3300 ft and 3.2 NM
    - The majority (10/11; 91%) of controllers agreed (M=80.5; SD=20.0).
  - 3300 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=73.1; SD=25.1).

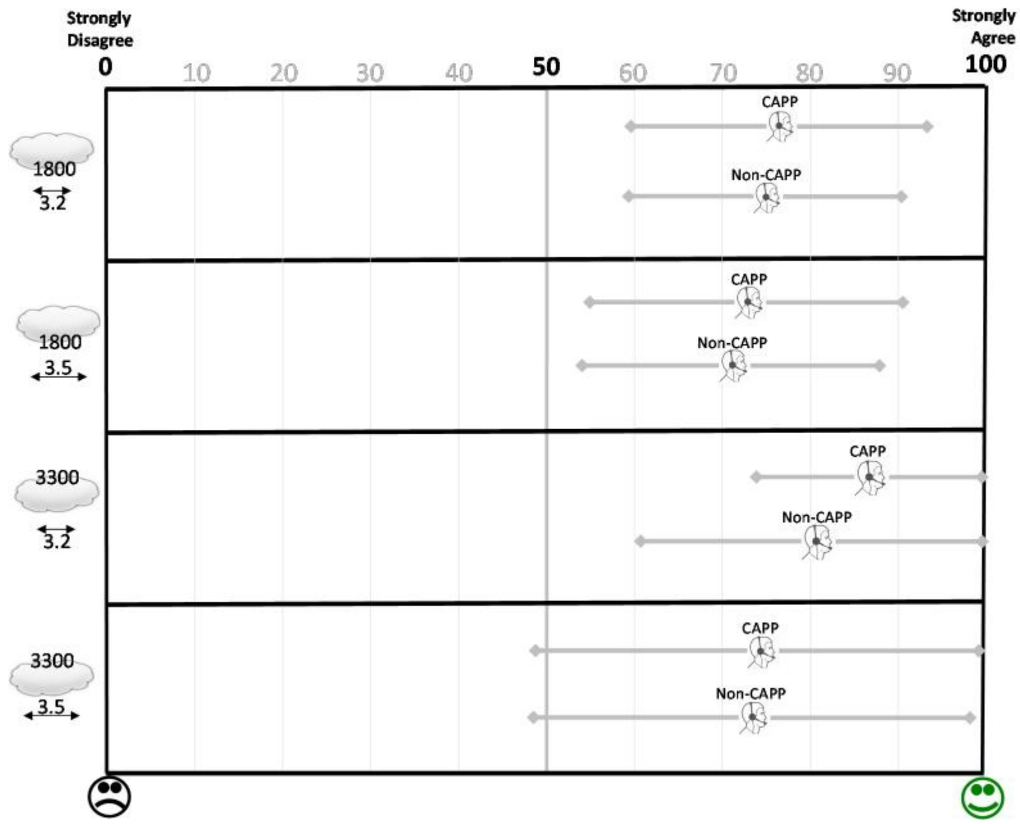

Figure 4-24. Controller Responses to Post-Scenario Statement "The spacing being achieved by aircraft was acceptable"

Controllers were asked if the pilots were achieving the spacing the controller desired for the two NCT values. For 3.2 NM, the majority (9/11; 82%) of controllers agreed (M=72.3; SD=22.9). For 3.5 NM, controller responses were variable but the majority (8/11; 73%) agreed (M=64.1; SD=27.7). The spacing achieved with the 3.2 NM NCT value appears to better approximate the spacing desired by the controller. While they did not get the opportunity to do so in the simulation, controllers were asked if they would be able to determine an appropriate NCT value. The majority (10/11; 91%) of controllers agreed and one was neutral (M=84.3; SD=16.9). See Figure 4-25 for a summary of these statements.

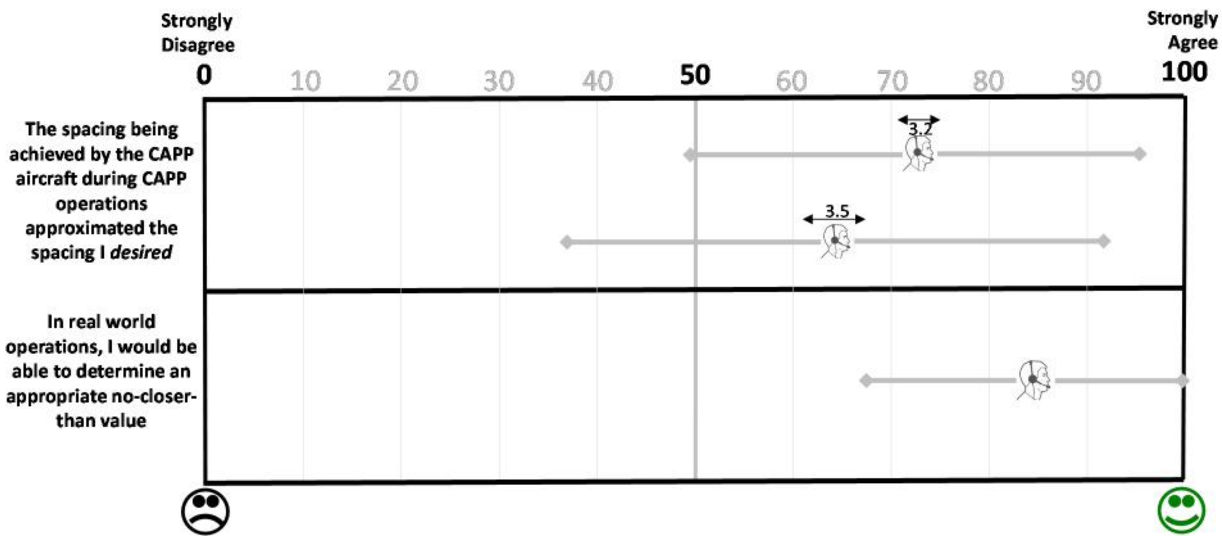

Figure 4-25. Summary of Controller Responses to Statements about the NCT Value Determination

4.2.2.1 CAPP Alerts

All alert events during CAPP were recorded. There were 0 CAPP minimum range caution level alerts. However, there were CAPP range indication advisory alerts, which were triggered off the NCT value (see Section 3.1.2.4 for a review of the CAPP alerts). Overall, 14% (79/554) of CAPP operations resulted in a CAPP range indication advisory alert. The pair distances when the alerts were triggered are shown in Figure 4-26.

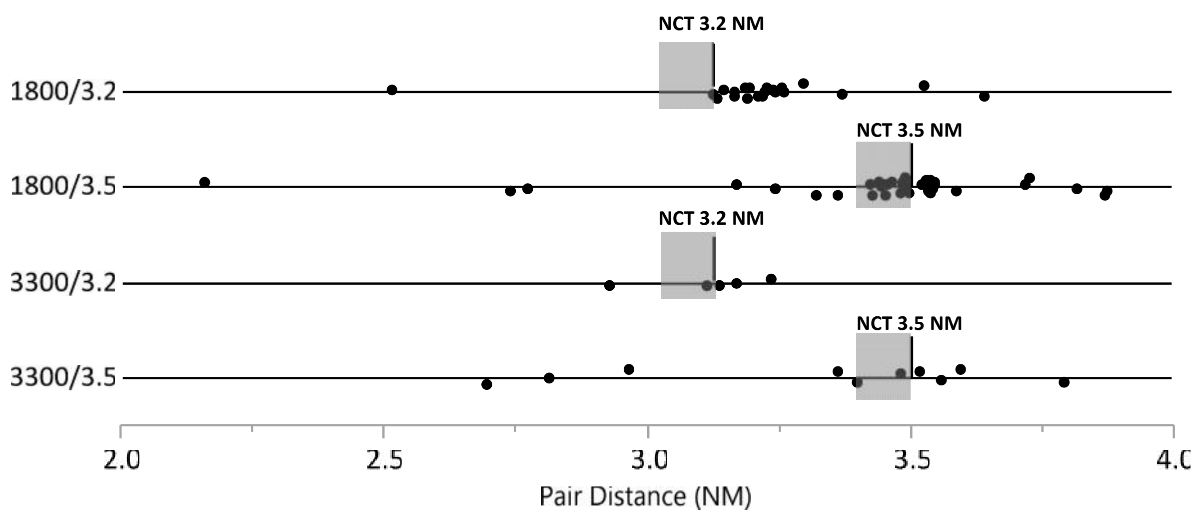

Figure 4-26. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAPP Range Indication Advisory Alert

The CAPP range indication advisory alerts generally occurred after starting CAPP outside the NCT value then encroaching on the NCT value. On 16 occasions however, the alert occurred immediately after pilots initiated the operation and was a result of the controller initiating

CAPP when the aircraft was already inside the NCT value. This may have happened for a few reasons: 1) the controller may not have realized the CAPP aircraft was inside the NCT value, 2) the controller realized the CAPP aircraft was inside the NCT value but initiated anyway, or 3) the aircraft may have been outside the NCT value when the controller set up the operations but the aircraft got inside the NCT value once the equipment was set up. The pilots may not have checked to see if they were inside the NCT value at initiation (nor were they required to).

The other alerting events (n=25) shown slightly inside the NCT value (gray shading in Figure 4-26) were due to the algorithm triggering an alert just below the NCT value (based on reasons described in Section 3.1.2.4). The greater the DGS, the further the TTF got inside the NCT value before the next update rate. The TTF never exceeded 0.1 NM inside the NCT for any of the alerts.

Participant pilots did not always report to the controller when they reached the NCT value. Many of the observer comments related to this indicate participant pilots got inside the NCT value, albeit barely, but did not report it to the controller (despite being trained to do so). However, it should also be noted that for all participant pilot CAPP range indication advisory alerts, only during two alerts did pilots stay inside the NCT value. For all other alerts, participant pilots were able to stay at or outside the NCT value. The two that remained inside did not explain why they did so.

Table 4-17 shows the number of range indication advisory alerts per successful CAPP operations / initiations. The 3300 ft ceiling condition had many fewer CAPP alerts (6%) as compared to the 1800 ft ceiling condition (23%). The higher number of alerts under the 1800 ft conditions is likely due to the fact that the majority of the compression has already occurred and the spacing between the aircraft is at about the closest point on the approach. The 3300 ft conditions are likely similar because, as stated and repeated, the aircraft are still further away from the NCT value based on being further out on final. There was not a notable dichotomy for either NCT values which generated a similar percentage of CAPP range indication advisory alerts.

Table 4-17. Participant and Pseudo-Pilot CAPP Aircraft CAPP Range Indication Advisory Alerts by Condition and Independent Variable

Condition	PsP	PaP	Total		Independent Variables	Total
1800 / 3.2	19 (19%)	4 (22%)	23 (20%)		1800	63 (23%)
1800 / 3.5	35 (25%)	5 (26%)	40 (25%)		3300	16 (6%)
3300 / 3.2	5 (5%)	0 (0%)	5 (4%)		3.2	28 (11%)
3300 / 3.5	10 (7%)	1 (6%)	11 (7%)		3.5	51 (16%)

There was a similar composition of ceiling and NCT results for DGS when a CAPP range indication advisory alert occurred (Table 4-18 and Table 4-19). Like the percentage of CAPP alerts, DGS was generally higher for the 1800 ft ceiling conditions compared with the 3300 ft ceiling conditions.

Table 4-18. Participant and Pseudo-Pilot CAPP Aircraft DGS at CAPP Range Indication Advisory Alert by Condition

Condition	Mean (Total) (kts)*	SD (Total) (kts)
1800 / 3.2	16.8	17.4
1800 / 3.5	25.5	20.5
3300 / 3.2	2.3	1.3
3300 / 3.5	7.9	12.3

* All values are CAPP aircraft convergence.

Table 4-19. Participant and Pseudo-Pilot CAPP Aircraft DGS at CAPP Range Indication Advisory Alert by Independent Variable

Independent Variables	Mean (kts)	SD (kts)
1800	22.4	19.8
3300	6.1	10.3
3.2	14.1	16.6
3.5	22.0	20.3

4.2.2.2 CAPP Terminations

The number of CAPP terminations and the associated reasons were captured in the controller observation data (Figure 4-27). Some of the CAPP operations that were initiated were terminated by the controller either based on their own concerns or by the pilot reporting unable (Table 4-20 and Table 4-21). As can be seen, a higher percentage of terminations occurred under the 1800 ft ceiling condition as compared to the 3300 ft condition. This may be expected as the aircraft are closer to the NCT value under the 1800 ft / lower ceiling condition. The NCT values do not appear to have an impact on terminations. Of the terminations, ten were in situations where the CAPP aircraft was set-up inside the NCT value.

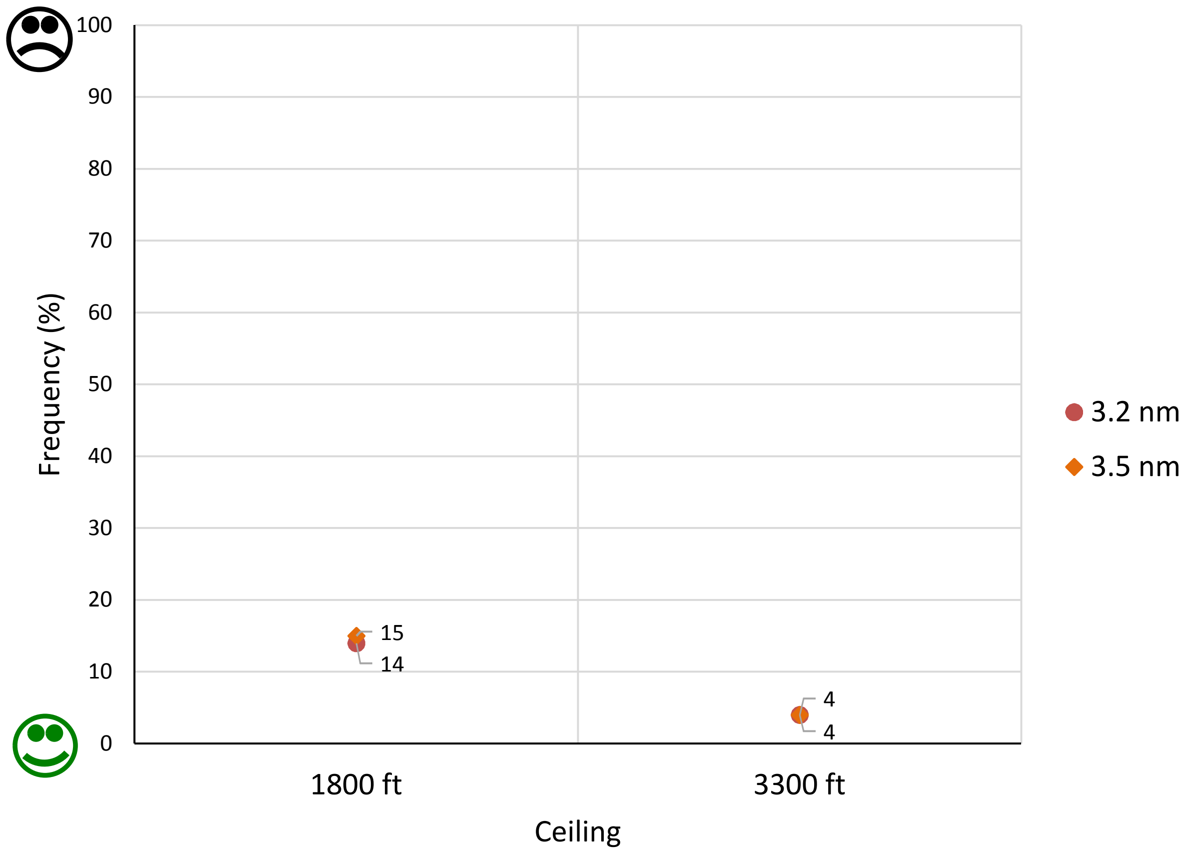

Figure 4-27. CAPP Terminations by Condition

Table 4-20. Participant and Pseudo-Pilot CAPP Aircraft CAPP Terminations by Condition

Condition	CAPP Initiations	Controller Initiated Terminations	Pilot Initiated Terminations	All Terminations
1800 / 3.2	**137**	3 (2%)	15 (11%)	18 (14%)
1800 / 3.5	**183**	4 (2%)	24 (13%)	28 (15%)
3300 / 3.2	**140**	1 (1%)	5 (4 %)	6 (4%)
3300 / 3.5	**172**	3 (2%)	4 (2%)	7 (4%)
All	**632**	11 (2%)	48 (8%)	59 (9%)

Table 4-21. Participant and Pseudo-Pilot CAPP Aircraft CAPP Terminations by Independent Variable

Independent variable	CAPP Initiations	Controller Initiated Terminations	Pilot Initiated Terminations	All Terminations
1800	**320**	7 (2%)	39 (12%)	46 (15%)
3300	**312**	4 (1%)	9 (3%)	13 (4%)
3.2	**277**	4 (1%)	20 (7%)	24 (9%)
3.5	**355**	7 (2%)	28 (8%)	35 (10%)

After termination, the majority (81%) of aircraft were kept in the traffic flow when the termination was initiated by either the controller or pilot (Table 4-22). Only a small percentage (8%) of the terminations were immediately broken out (0.8% [5/632] of the overall CAPP initiations). A limited number of termination reasons are unknown because the audio data was not available to verify the action taken by the controller.

Table 4-22. Action Taken by Controller after Termination

	Controller Initiated Termination	Pilot Initiated Termination	All Terminations
Total	**11**	**48**	**59**
Aircraft kept in flow	6 (55%)	42 (88%)	48 (81%)
Aircraft kept in flow but later broke out	0	2 (4%)	2 (3%)
Aircraft kept in flow and asked if TTF is in sight	0	1 (2%)	1 (2%)
Aircraft broke out	3 (27%)	2 (4%)	5 (8%)
Unknown	2 (18%)	1 (2%)	3 (5%)

When asked if the termination procedures were clear, all controllers agreed (M=79.4; SD=18.0). Pilot responses were variable, but the majority (14/22; 64%) agreed (M=66.1; SD=28.5). Figure 4-28 depicts the results.

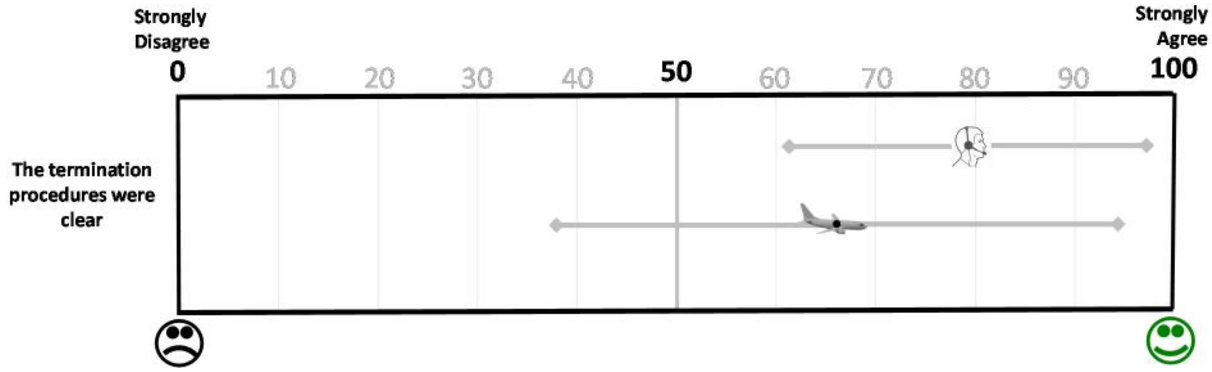

Figure 4-28. Summary of Responses to CAPP Termination Statement

In addition to the CAPP-induced terminations, there were 11 situations where aircraft not performing CAPP were broken out of the traffic flow when on final approach (approximately 5% of all [2238] aircraft that joined the final approach course but did not conduct CAPP). Table 4-23 and Table 4-24 show these results. The number of non-CAPP breakouts were similar across the conditions except for the 1800 ft and 3.5 NM condition. Additionally, the 1800 ft ceiling had almost twice as many non-CAPP breakouts as the 3300 ft ceiling. The 3.5 NM condition also had almost twice as many non-CAPP breakouts as the 3.2 NM condition. In contrast to the 5% breakouts for non-CAPP aircraft, the percentage of CAPP breakouts was 0.8% (5/632) as reported previously.

Table 4-23. Non-CAPP Terminations by Condition

Condition	Non-CAPP Breakout Opportunities	Non-CAPP Induced Breakouts
1800 / 3.2	**70**	2 (3%)
1800 / 3.5	**55**	6 (11%)
3300 / 3.2	**63**	1 (2%)
3300 / 3.5	**63**	2 (3%)
All	**251**	11 (4%)

[8] From controller observations.

Table 4-24. Non-CAPP Terminations by Independent Variable

Independent Variable	Non-CAPP Breakout Opportunities	Non-CAPP Induced Breakouts
1800	**125**	9 (7%)
3300	**126**	4 (3%)
3.2	**133**	5 (4%)
3.5	**118**	8 (7%)

Two CAPP terminations were intentionally designed into extra scenarios to test controller and pilot behavior (that were not included in the results above). Both controllers and pilots experienced conditions where the TTF decelerated to a sufficient degree to cause a termination of CAPP. The termination conditions were triggered by the pseudo-pilot. The controller and pilot conditions were independent of each other. In the controller case, the controller had to terminate. In the pilot case, the pilots had to report “unable” so the controller could terminate the operation (see Section 3.4 for additional details on the events).

In the post-simulation questionnaire, controllers were asked about the full scenario, of which the termination event was only one event in numerous other CAPP operations. Controllers did not appear to report any significant issues with the termination. All (10/10; Missing 1 value) controllers detected the situation. It should be noted the overtake occurred very quickly as the pseudo-pilot aggressively accelerated the CAPP aircraft and aggressively decelerated the TTF to make the overtake an issue in the limited time available on final. It should also be noted that some controllers also saw situations that required terminations in scenarios prior to this one that were not nearly as aggressive, even if not by design. Those situations were also managed by the controllers.

The pilots flew the one termination event and then completed the post-scenario questionnaire. All pilots detected the situation and reported it to the controller for resolution. The pilots Bedford Workload Rating Scale had a relatively high mean (M=4.1; SD=2.5) (Figure 4-29). Ten pilot responses (10/18; 56%; Missing 4 values) indicated the “workload [was] satisfactory without reduction,” i.e., a rating between one and three. Six pilot replies (33%) indicated that “workload [was not] satisfactory without reduction,” i.e., a rating between four and six. Two pilot replies indicated the task was impossible, but did not comment. A rating this strong indicates the situation was particularly challenging and the task being “impossible” was the task of conducting CAPP, (versus the task of flying the aircraft) as all pilots continued successfully flying the aircraft after reporting the condition to the controller. The majority (15/17; 88%; Missing 5 values) of the pilot responses indicated the AGD and CDTI included the necessary information for the termination event. Two (12%) pilots replied “no.” One reported wanting additional information to anticipate the TTF approach speed. Pilot responses were variable but the majority (11/17; 65%; Missing 5 values) did not find CAPP operations acceptable in this situation (M=43.4; SD=35.6) (Figure 4-30). This might be expected since the overtake condition occurred unusually quickly and the confederate controller was told to not intervene on this pilot detection event. Overall, it generally appears the pilots had the necessary information for the termination event but that it was still a challenging situation.

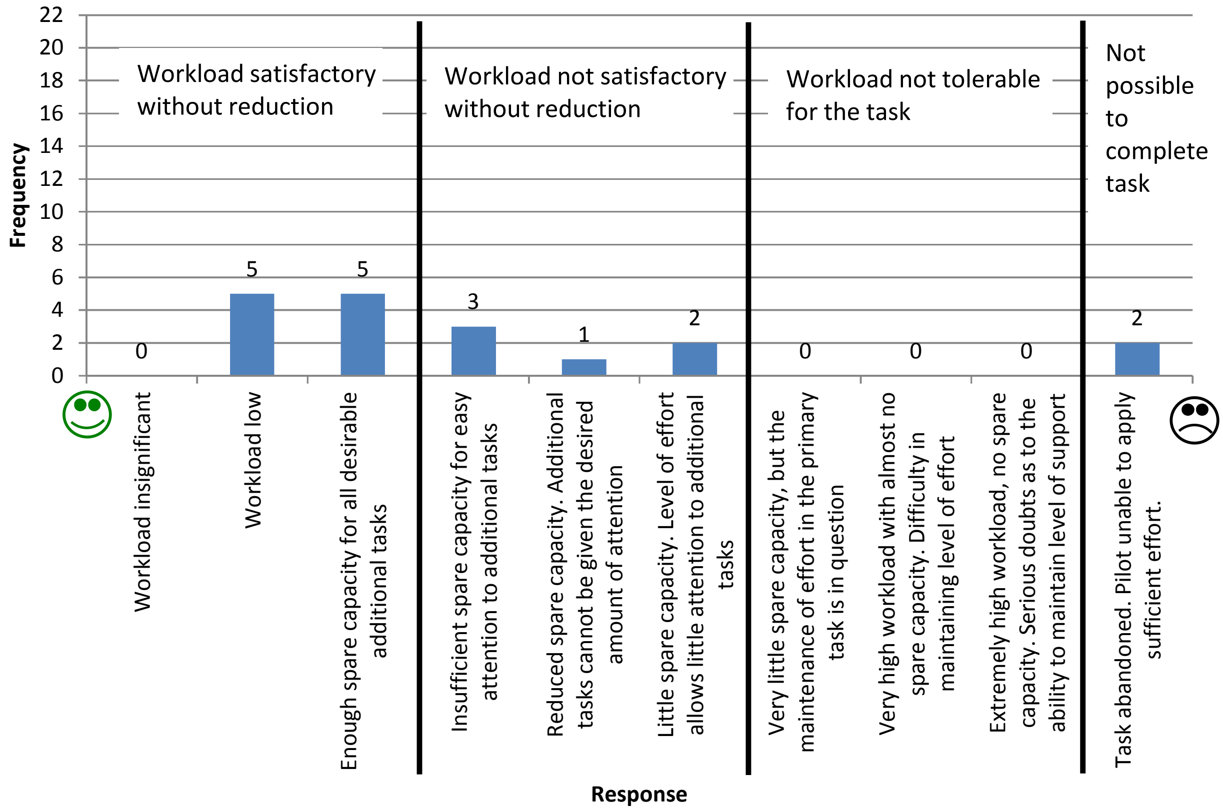

Figure 4-29. Pilot Responses to the Bedford Workload Rating Scale for CAPP Termination due to Overtake on TTF

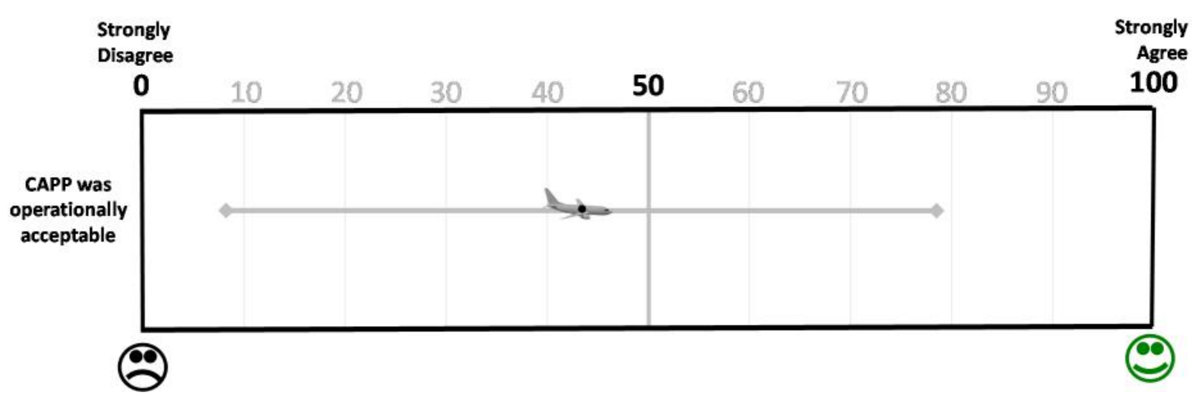

Figure 4-30. Pilot Responses to Post-Scenario Statement on CAPP Termination

4.2.2.3 CAPP End

CAPP end is defined as the point where the CAPP aircraft reached visual conditions and was able to conduct CAVS. The spacing within the CAPP pair is shown in Table 4-25, Table 4-26, and Figure 4-31. Only participant pilot data is included in these conditions.

Table 4-25. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAPP End by Condition

Condition	Overall Spacing		Tight Spacing		Wide Spacing	
	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)
1800 / 3.2	3.9	0.7	3.5	0.2	4.1	0.7
1800 / 3.5	3.9	0.5	3.8	0.3	4.0	0.6
3300 / 3.2	4.9	1.1	4.2	0.6	5.8	1.0
3300 / 3.5	4.5	0.7	4.3	0.5	5.1	0.7

Table 4-26. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAPP End by Independent Variable

Independent Variable	Overall Spacing		Tight Spacing		Wide Spacing	
	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)
1800	3.9	0.6	3.6	0.3	4.1	0.7
3300	4.7	0.9	4.2	0.5	5.5	0.9
3.2	4.4	1.1	3.9	0.6	4.9	1.2
3.5	4.3	0.7	4.1	0.5	4.5	0.8

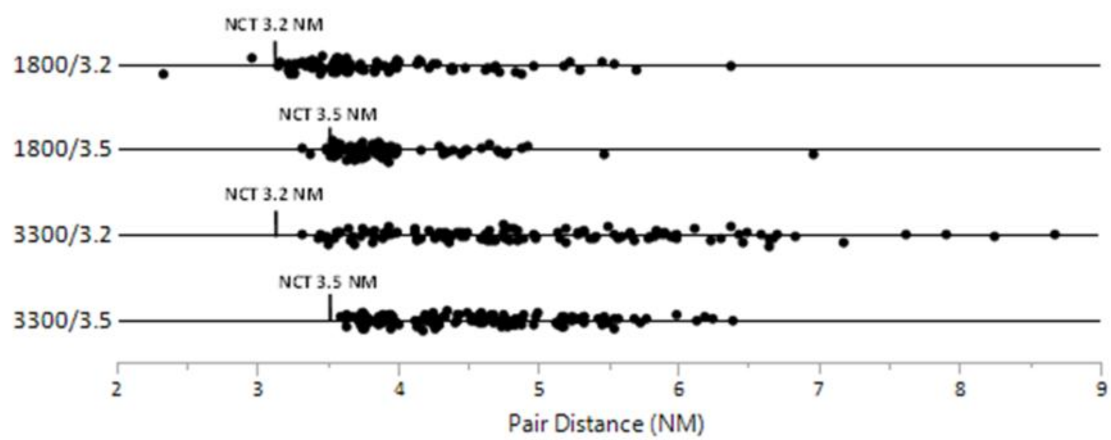

Figure 4-31. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAPP End

The spacing is noticeably closer and less variable for the 1800 ft ceiling conditions compared to the 3300 ft ceiling conditions, as would be expected since aircraft are closer to the runway and would be expected to be closer based on normal compression as the TTF decelerates to its final approach speed. The NCT values have similar means. As can be seen in Figure 4-31, the vast majority of the conditions are outside the separation standard. Some aircraft were inside the NCT value at CAPP end. A CAPP range indication advisory alert was triggered on the flight deck, but the participant pilots had not informed the controller. The controller also did not intervene in the situation, nor would they need to because the aircraft was outside the separation standard.

Only one condition is clearly inside both the NCT value and the separation standard. For this particular case, the participant flight crew had been spaced widely at initiation and had closed aggressively on the TTF. They received a CAPP range indication advisory alert but did not report it to the controller. They did, however, actively attempt to fix the spacing by making speed changes and even making an S-turn on final. Unfortunately, the latter half of the scenario (where this event occurred) does not have the audio data. Therefore, the controller actions cannot be described. It is possible that prior to the spacing issue the controller had transferred the participant aircraft to the tower (against simulation directions) and the scenario had ended from a controller perspective. The controller observations did not include any notes about a separation issue.

4.2.3 Transition

Participant and pseudo-pilots were responsible for reporting “traffic in sight” or reaching visual conditions to the controller once visual conditions were reached (the transition point). On many occasions, both pilot participant and pseudo-pilots were not prompt in reporting traffic in sight either due to workload or forgetfulness. It also appeared confusing, at times, for the participant pilots. They were authorized to conduct CAVS without having the traffic in sight OTW so some appeared confused whether they should report traffic in sight or not. Participant pilots sometimes just reported reaching visual conditions and not the traffic in sight. Participant pilots may have also swapped the CAPP NCT value for the CAVS minimum distance and were conducting CAVS but initially forgot to inform the controller. This also likely occurred for pseudo-pilots.

Transitions out of CAPP into CAVS were recorded in the controller observation data. Table 4-27 shows all CAPP operations for all aircraft that were not terminated or unfinished before the end of the scenario and whether there was a report from the pilot to the controller of a transition into visual operations. As can be seen in Figure 4-32 and Table 4-28, a higher percentage of reports occurred under the 3300 ft conditions as compared to the 1800 ft conditions. The NCT values do not appear to have an impact on whether the pilots report a transition to visual conditions.

Table 4-27. Report of Transition to Visual Operations for Participant and Pseudo-Pilot CAPP Aircraft by Condition

Condition	Fully Executed CAPP Operations	Report of Transition to Visual Operations	No Report of Transition to Visual Operations
1800 / 3.2	**96**	62 (65%)	34 (35%)
1800 / 3.5	**118**	72 (61%)	46 (39%)
3300 / 3.2	**116**	100 (86%)	16 (14%)
3300 / 3.5	**125**	111 (89%)	1 (11%)
All	**455**	345 (76%)	110 (24%)

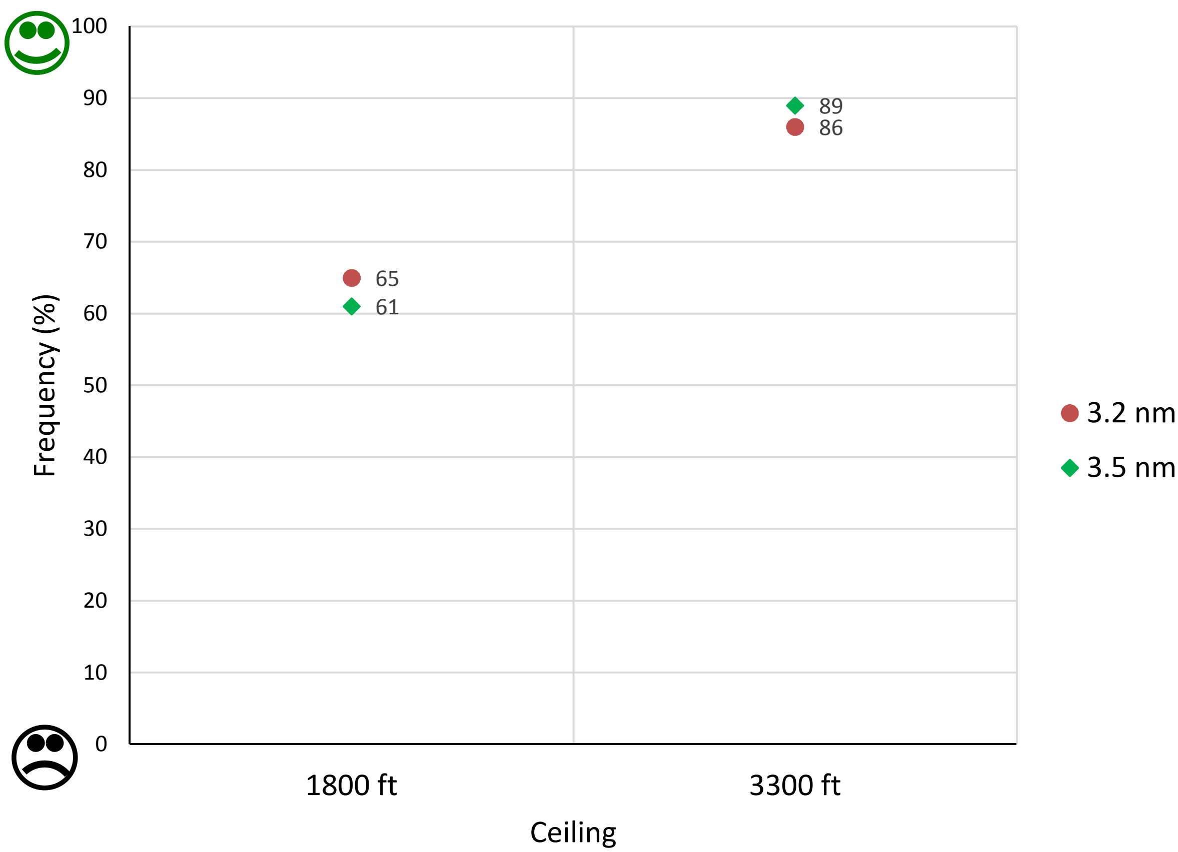

Figure 4-32. Report of Transitions to Visual Operations by Participant and Pseudo-Pilot CAPP Aircraft

Table 4-28. Report of Transitions to Visual Operations for Participant and Pseudo-Pilot CAPP Aircraft by Independent Variable

Condition	Fully Executed CAPP Operations	Report of Transition to Visual Operations	No Report of Transition to Visual Operations
1800	**214**	134 (63%)	80 (37%)
3300	**241**	211 (88%)	30 (12%)
3.2	**212**	162 (76%)	50 (24%)
3.5	**243**	183 (75%)	60 (25%)

Regardless of whether the transition to visual conditions was reported, data was also captured on whether pilots swapped the CAPP NCT value for the CAVS minimum distance when actually in visual conditions. Table 4-29 shows those results (data from the reported transition set is excluded when pseudo-pilots had issues with properly swapping the values). As can be seen, 59% (255 of 4339) of participant and pseudo-pilot CAPP aircraft that transitioned into visual conditions took the action to swap the CAPP NCT value for the CAVS minimum distance. At this point, the participant pilots were able to perform CAVS and close to their CAVS minimum distance or other distance as desired. It should be noted that some aircraft may have transitioned into visual conditions and not swapped the two values but still conducted CAVS with the equipment remaining in the CAPP configuration. As with the reporting of the transition to visual conditions, a higher percentage of swaps occurred under the 3300 ft conditions as compared to the 1800 ft conditions.

[9] As a reminder, this data does not include the data from the first day due to simulation issues.

Table 4-29. Transitions to Visual Conditions and Swapping of the CAPP NCT Value for the CAVS Minimum Distance for Participant and Pseudo-Pilot CAPP Aircraft by Condition

Condition	Transitions to Visual Conditions	Swap of CAPP NCT value for CAVS minimum distance when in Visual Conditions	No Swap of CAPP NCT value for CAVS minimum distance when in Visual Conditions
1800 / 3.2	**100**	44 (44%)	56 (56%)
1800 / 3.5	**94**	48 (51%)	46 (49%)
3300 / 3.2	**115**	79 (69%)	36 (31%)
3300 / 3.5	**124**	84 (68%)	40 (32%)
All	**433**	**255** (59%)	**178** (41%)

The time from the transition to visual conditions to the participant pilot swapping of the CAPP NCT value for the CAVS minimum distance was recorded (Table 4-30 and Table 4-31). In the 1800 ft ceiling conditions, participant pilots took less time than in the 3300 ft ceiling conditions. Participant pilots also chose not to, or forgot, to swap values more often in the 1800 ft ceiling conditions compared to the 3300 ft ceiling conditions. This may be due to the proximity of the CAPP aircraft to the FAF and other competing priorities (e.g., transitioning to a landing configuration).

Table 4-30. Time from the Transition to Visual Conditions to the Participant Pilot Swapping of the CAPP NCT Value for the CAVS Minimum Distance by Condition

Condition	SWAP conducted (%)	Time to Select SWAP	
		Mean (sec)	SD (sec)
1800 / 3.2	47	16.4	10.1
1800 / 3.5	58	17.3	7.9
3300 / 3.2	78	38.7	21.2
3300 / 3.5	90	38.2	20.1

Table 4-31. Time from the Transition to Visual Conditions to the Participant Pilot Swapping of the CAPP NCT Value for the CAVS Minimum Distance by Independent Variable

Independent Variable	SWAP conducted (%)	Time to Select SWAP	
		Mean (sec)	SD (sec)
1800	50	16.9	8.7
3300	75	38.4	20.3
3.2	58	30.0	20.7
3.5	68	29.7	19.2

Participants were asked if the transition was acceptable. The majority (9/11; 82%) of the controllers agreed (M=70.8; SD=20.4) and the majority (20/22; 91%) of pilots agreed (M=83.9; SD=14.7). Participants were also asked whether it was acceptable when the transition was not possible. Controller responses were variable (M=56.6; SD=28.3). The majority (16/21; 76%; Missing 1 value) of pilots agreed (M=69.6; SD=23.6). See Figure 4-33 for a summary.

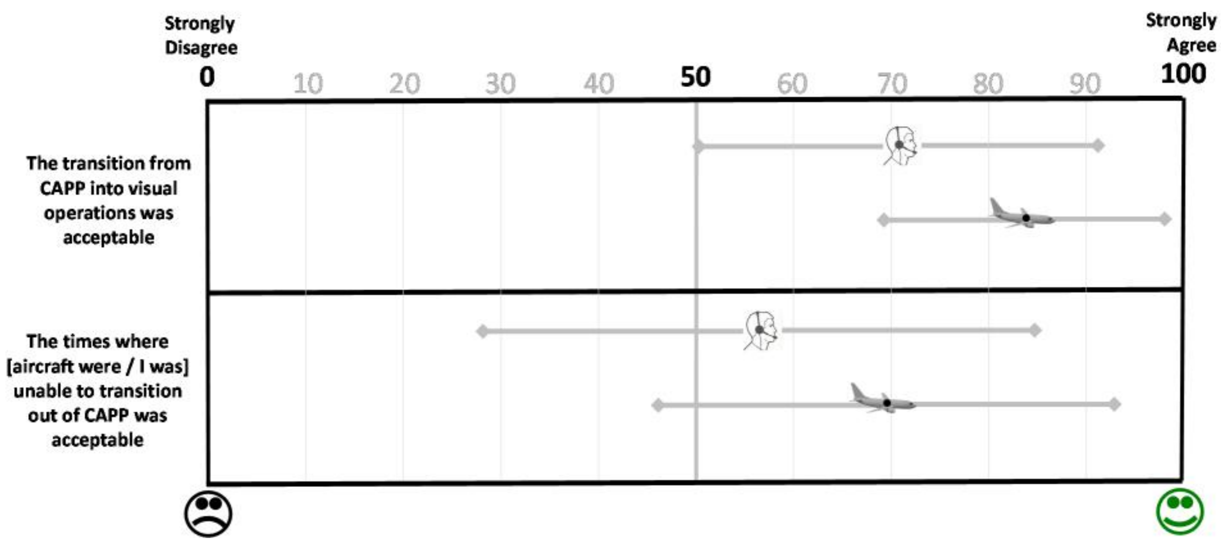

Figure 4-33. Summary of Responses to Statements on the CAPP to CAVS Transition

In the post-scenario questionnaire, controllers and pilots were also asked whether the transition from CAPP into visual operations was acceptable. The controller results are shown next. The responses for the 3300 ft conditions were rated more acceptable than the 1800 ft conditions for the transition. The NCT values appeared to have less of an impact.

- 1800 ft and 3.2 NM
    - A slight majority (6/11; 55%) of controllers agreed (M=59.1; SD=24.6).
- 1800 ft and 3.5 NM
    - Controller responses were variable (M=58.6; SD=28.1).
- 3300 ft and 3.2 NM
    - The majority (9/11; 82%) of controllers agreed (M=80.9; SD=20.1).
- 3300 ft and 3.5 NM
    - The majority (8/11; 73%) of controllers agreed (M=76.3; SD=21.4).

The pilot results for the post-scenario questionnaire are shown next. As can be seen, the pilots generally found all the conditions more favorable for the transition than did controllers. The 1800 ft and 3.2 NM condition appears to be the least favorable for the transition from CAPP to visual conditions. Figure 4-34 depicts the results.

- 1800 ft and 3.2 NM
    - Pilot responses were variable but the majority (36/43; 84%; Missing 1 value) agreed (M=77.5; SD=31.4).
- 1800 ft and 3.5 NM
    - The majority (40/43; 93%; Missing 1 value) of pilots agreed (M=84.7; SD=18.7).
- 3300 ft and 3.2 NM
    - The majority (38/40; 95%; Missing 4 values) of pilots agreed (M=86.5; SD=23.1).
- 3300 ft and 3.5 NM
    - The majority (37/38; 97%; Missing 6 values) of pilots agreed (M=89.4; SD=15.1).

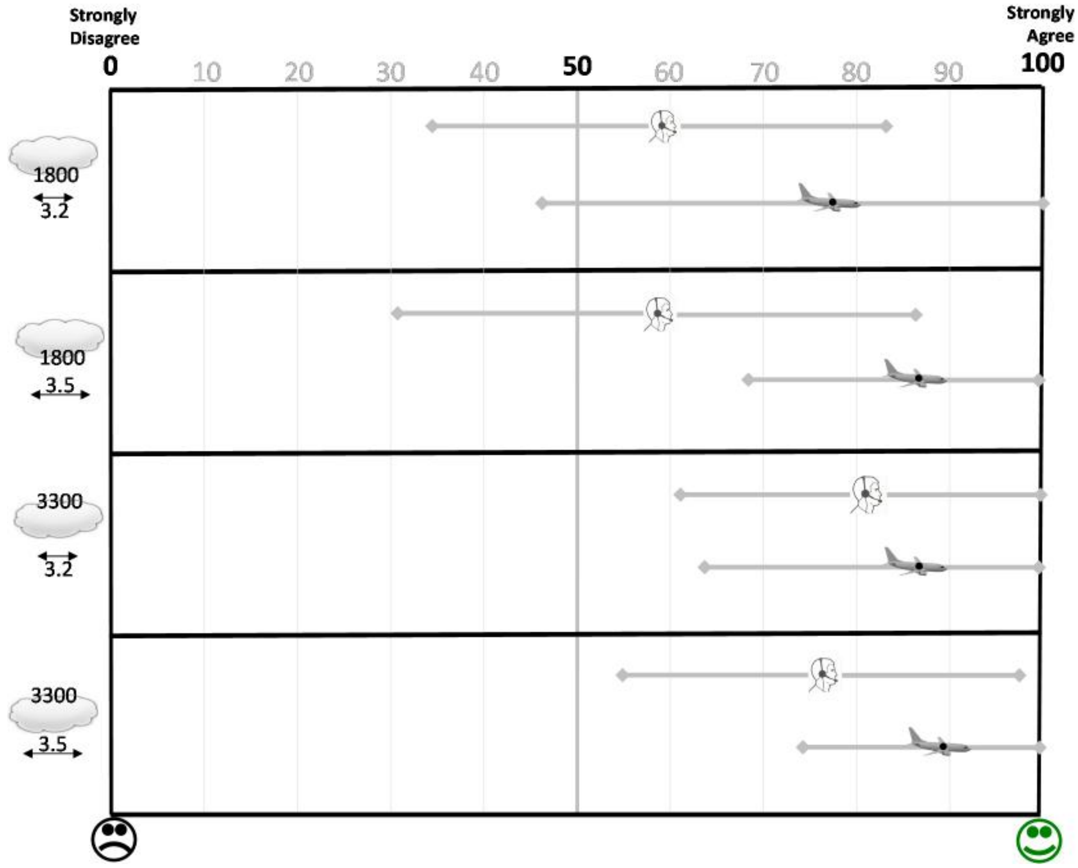

Figure 4-34. Controller and Pilot Responses to Post-Scenario Statement "The transition from CAPP into visual operations was acceptable"

In the majority of the scenarios, operations successfully transitioned into CAVS, as expected. One extra event was designed to have the flight crew conduct CAPP until final decelerations for landing, without a transition into CAVS. There were no breakouts for participant pilot aircraft in this scenario. In the post-simulation questionnaire, controllers were asked about the full scenario, of which the no-transition-event was only one event of numerous other CAPP operations. Controllers did not appear to report any specific issues with the lack of transition. It should be noted that controllers also saw this event occur in other scenarios prior to this one, though it was not by design.

Pilots flew the one non-transition event and the competed then post-scenario questionnaire. In the Bedford Workload Rating Scale, the majority (17/22; 77%) of pilots reported the "workload [was] satisfactory without reduction," i.e., a rating between one and three (M=2.9; SD=1.2). However, five pilot replies (23%) indicated that "workload [was not] satisfactory without reduction," i.e., a rating between four and six (Figure 4-35). While the pilot participants were told not to report the transition to visual and to continue CAPP until around the FAF, several pilots (13/21; 62%; Missing 1 value) reported they transitioned. This may indicate a confusion between the CAPP and CAVS transition versus an IMC and VMC transition, or simply that the transition out of CAPP to the final stages of landing was considered the transition. Also in the post-scenario questionnaire, pilots were asked whether CAPP was operationally acceptable.

Pilot responses were variable but the majority (16/22; 72%) agreed (M=71.1; SD=29.8). See Figure 4-36. In summary, the event where there was not a transition into CAVS appeared to have relatively reasonable pilot workload, and it appeared to be acceptable to the pilots.

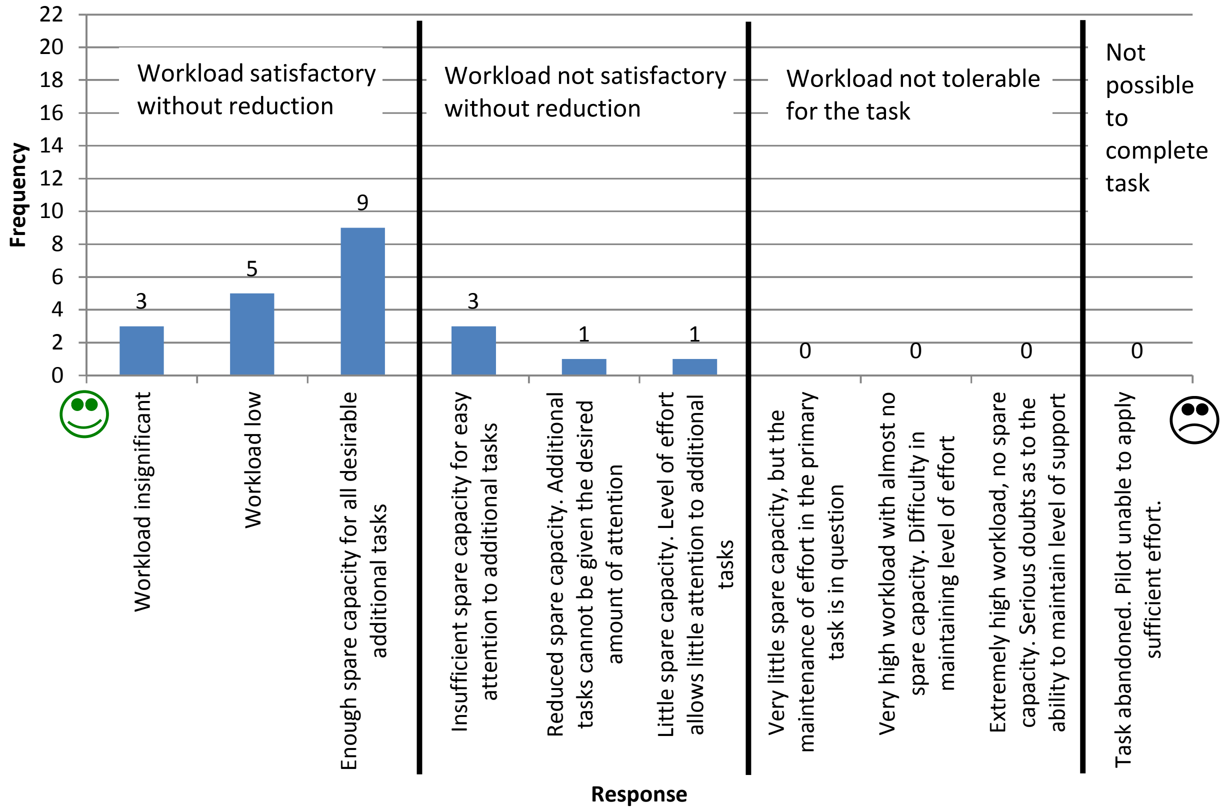

Figure 4-35. Pilot Responses to the Bedford Workload Rating Scale when there was No Transition from CAPP to CAVS

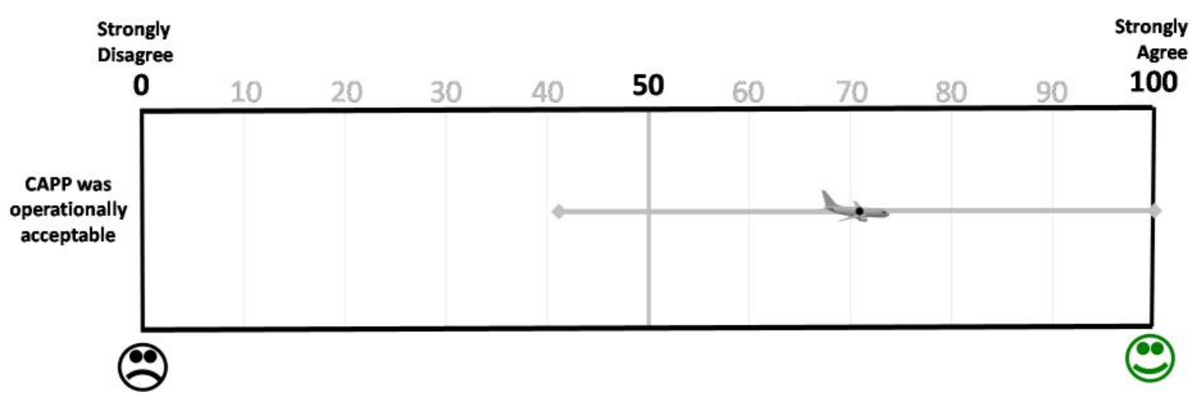

Figure 4-36. Pilot Responses to Post-Scenario Statement when there was No Transition from CAPP to CAVS

4.2.4 CAVS

In the demographic questionnaire, pilots were asked how they currently space behind another aircraft. The question was: "When you are flying your aircraft using visual separation to follow another aircraft to the same runway (under normal conditions), do you have a personal **typical** and **minimum** spacing that you are willing to achieve behind another aircraft?" (Missing 1 value). Figure 4-37 shows the result for pilots who fly large aircraft. The most common typical distances are 3 and 5 NM. The most common minimum distance is 3 NM. The minimum distance for the majority (10/14; 71%) of the pilots is at or below the separation standard of 3.0 NM. Figure 4-38 shows results for pilots who fly 757 and heavy aircraft. The most common typical distances are 3, 4, and 5 NM. The most common minimum distance is 3 NM. The minimum distance for the slight majority (4/7; 57%) of the pilots is at or below the separation standard of 3.0 NM.

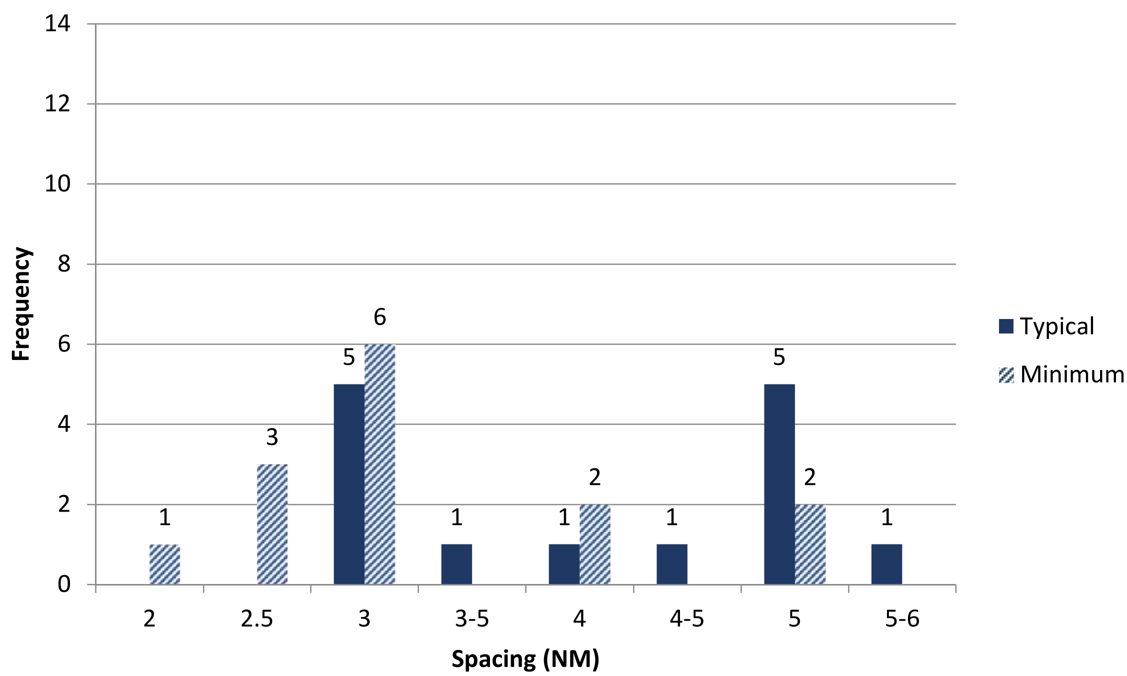

Figure 4-37. Typical and Minimum Spacing Achieved behind A TTF during Visual Separation for Participant Pilots Flying Large Aircraft

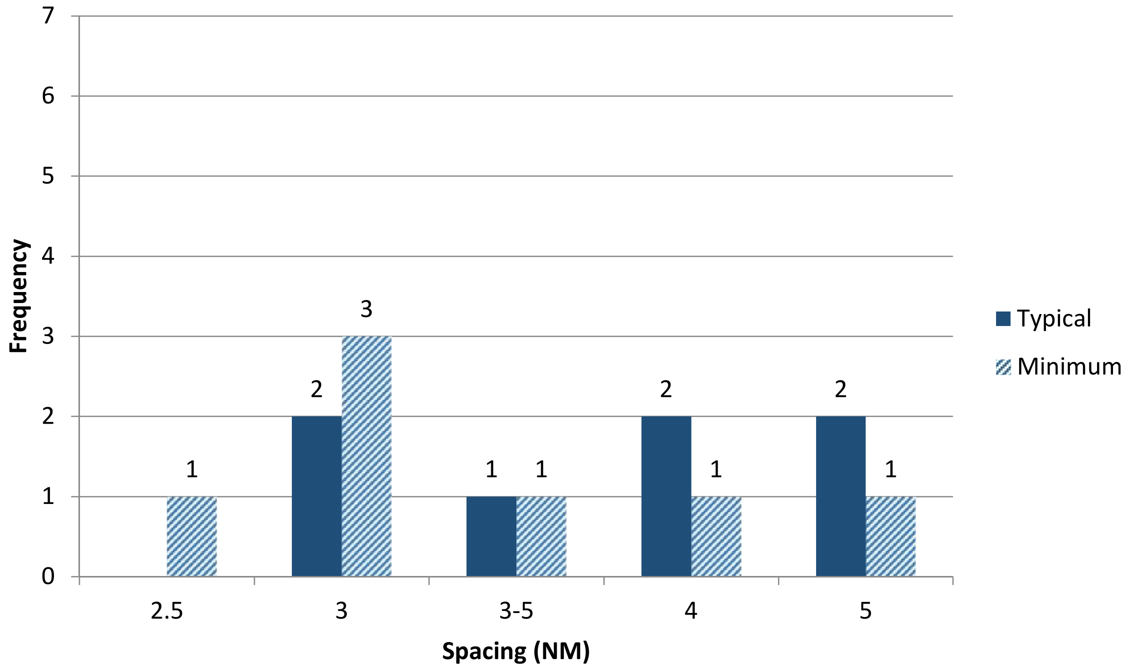

Figure 4-38. Typical and Minimum Spacing Achieved behind A TTF during Visual Separation for Participant Pilots Flying 757 and Heavy Aircraft

In the post-scenario questionnaire, pilots were asked what their desired spacing was behind the TTF during CAVS. The PF replies are shown in Figure 4-39. As can be seen for CAVS, the majority (81/82; 99%; Missing 6 values) of values chosen by the PF were below the CAPP NCT value and at or less than the separation standard of 3.0 NM.

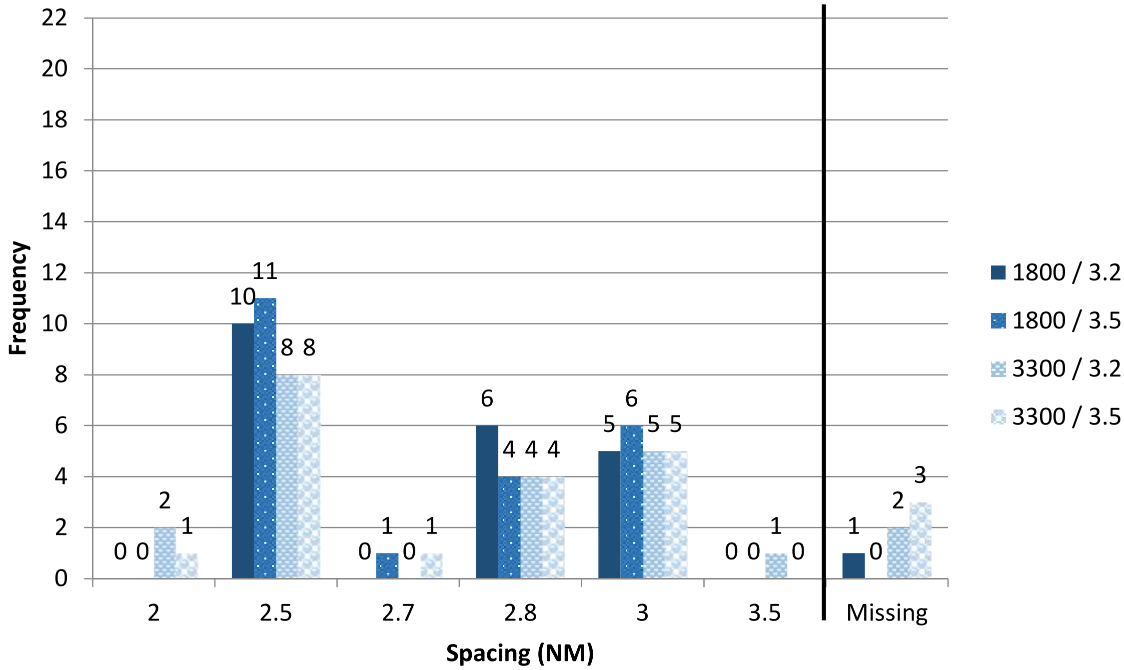

Figure 4-39. PF Replies to "What was your desired spacing from the [TTF for visual separation / CAVS]?"

The number of times participant pilots made a speed change during CAVS was also recorded (Table 4-32). Speed changes are defined as either a speed increase or a decrease resulting in a change in the MCP speed of five kts or greater for more than five sec. When comparing average number of speed changes between ceiling and NCT independent variables separately, the 3300 ft ceiling had on average about two more speed changes compared to the 1800 ft ceiling. Both NCT values, however, were much more similar. This is to be expected since aircraft were likely making speed changes to react to the TTF slowing to its final approach speed. When looking across the full approach (CAPP and CAVS combined), both ceiling conditions had a similar average number of speed changes (slightly over 3 speed changes).

Table 4-32. Participant Pilot Speed Changes during CAVS by Condition and Independent Variable

Condition	Desc Mean	SD	Max Changes (freq)		Independent Variables	Mean	SD
1800 / 3.2	0.3	0.5	2		**1800**	0.4	0.6
1800 / 3.5	0.4	0.6	2		**3300**	2.2	1.1
3300 / 3.2	1.9	1.1	4		**3.2**	1.2	1.2
3300 / 3.5	2.4	1.2	4		**3.5**	1.4	1.4

The average magnitude of speed changes was also noticeably greater in the 3300 ft ceiling scenarios compared to the 1800 ft ceiling scenarios (Table 4-33). Again, this is a likely outcome as the speed differential is likely highest as the TTF flight crew decelerates to its final approach speed while the CAPP aircraft is holding speed and closing, as expected. Both NCT values were similar.

Table 4-33. Magnitude of Participant Pilot Speed Changes during CAVS by Condition

Condition	Mean (kts)	SD (kts)		Independent Variables	Mean (kts)	SD (kts)
1800 / 3.2	8.4	14.5		1800	9.3	14.7
1800 / 3.5	9.9	15.2		3300	28.3	18.2
3300 / 3.2	31.4	20.8		3.2	21.0	21.4
3300 / 3.5	25.4	15.3		3.5	17.7	16.9

Participant pilots increased speed far less often in CAVS compared to CAPP. There were only two speed increases total, both occurring in the 3300 ft and 3.5 NM condition.

4.2.4.1 CAVS End

CAVS end is defined as the point when the TTF lands. As mentioned in Section 4.2.1.2, the majority of pilot participants used CAVS minimum distance values of 2.5 and 2.8 NM. In all cases, it was a value less than the CAPP NCT value. Therefore, the expectation is that final spacing on average would be less than that seen at CAPP end.

Pair distances for aircraft that swapped the CAPP NCT value for the CAVS minimum distance are shown in Table 4-34 and Table 4-35. Distance values were dispersed between 2 NM and 5.5 NM (Figure 4-40).

Table 4-34. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAVS End by Condition

Condition	Overall Spacing		Tight Spacing		Wide Spacing	
	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)
1800 / 3.2	3.6	0.6	3.3	0.3	3.8	0.6
1800 / 3.5	3.7	0.4	3.7	0.2	3.7	0.4
3300 / 3.2	3.5	0.8	3.0	0.5	4.0	0.7
3300 / 3.5	3.4	0.6	3.3	0.5	3.7	0.6

Table 4-35. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAVS End by Independent Variable

Independent Variables	Overall Spacing		Tight Spacing		Wide Spacing	
	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)	Mean (NM)	SD (NM)
1800	3.6	0.5	3.5	0.4	3.7	0.5
3300	3.4	0.7	3.2	0.5	3.8	0.7
3.2	3.5	0.7	3.1	0.5	3.9	0.7
3.5	3.5	0.5	3.4	0.5	3.7	0.5

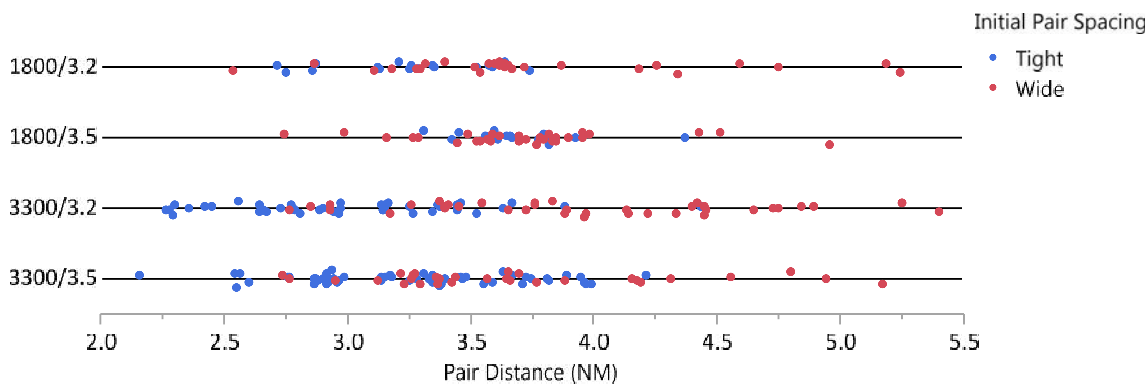

Figure 4-40. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at CAVS End

A Factorial Repeated Measures ANOVA was conducted to measure the tight pair spacing aircraft only when the TTF landed across the ceiling and NCT independent variables (with only aircraft that took the action to swap the CAPP NCT value for the CAVS minimum distance). A significant main effect was found for ceiling, $F(1, 16) = 20.93$, $p = 0.0001$. A significant main effect was found for NCT, $F(1,16) = 9.906$, $p = 0.006$. There was no significant interaction, $F(1,16) = 4.388$, $p = 0.052$. For the significant ceiling main effect, the 3300 ft conditions had a significantly tighter pair spacing ($M = 3.4$; $SD = 0.7$) compared to the 1800 ft conditions ($M = 3.7$; $SD = 0.6$). This is logical because the higher ceiling allowed for more closure during CAVS operations to the desired CAVS target distance. For the significant NCT main effect, the 3.2 NCT value had significantly closer spacing at CAVS end ($M = 3.5$; $SD = 0.7$) compared to the 3.5 NCT value ($M = 3.6$; $SD = 0.6$).

When calculating the additional distance closure made during CAVS, there was a noticeable difference across both ceiling levels. Additional closure was measured by subtracting the CAPP end pair distance with the CAVS end pair distance. The 3300 ft ceiling conditions had a higher closure compared to the 1800 ft ceiling conditions, as would be expected based on the time available to actively space during CAVS (Table 4-36 and Table 4-37). The 3.2 NM NCT conditions had similar closure distances to the 3.5 NM NCT conditions.

Table 4-36. Participant and Pseudo-Pilot CAPP Aircraft Closure Distance from CAVS Start to CAVS End by Condition

Condition	Mean (Total) (NM)	SD (Total) (NM)
1800 / 3.2	0.2	0.4
1800 / 3.5	0.1	0.4
3300 / 3.2	1.1	0.5
3300 / 3.5	1.0	0.5

Table 4-37. Participant and Pseudo-Pilot CAPP Aircraft Closure from CAVS Start to CAVS End by Independent Variable

Independent Variable	Mean (Total) (NM)	SD (Total) (NM)
1800	0.2	0.4
3300	1.1	0.5
3.2	0.9	0.6
3.5	0.8	0.6

4.2.5 Full Approach

Table 4-38 and Figure 4-41 show the distances for the CAPP operations at the key points along the approach for the tightly spaced aircraft pairs. When looking across the full approach (i.e., CAPP initiation to CAVS end), there was minimal closure for the 1800 ft and 3.5 NM condition and more closure for the 1800 ft and 3.2 NM condition. There were similar closures for the 3300 ft conditions but the 3300 ft and 3.2 NM condition ended up closer. Both 3.2 NM conditions ended up closer than the 3.5 NM conditions. When looking at CAPP initiation to CAPP end, little closure occurs in the 3300 ft conditions. This is likely due to the minimal speed difference expected between the CAPP aircraft and TTF. Finally, when examining CAPP end to CAVS end, little closure occurred for the 1800 ft conditions. This is likely due to less time for closure and the need for the CAPP aircraft to decelerate to its final approach speed. More closure occurred for the 3300 ft conditions based on more time in CAVS and time before the CAPP aircraft had to decelerate to its final approach speed.

Table 4-38. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance for Tight Initial Spacing at Key Points across Full Approach by Condition

Condition	CAPP Initiation Mean (NM)	CAPP Initiation SD (NM)	CAPP End Mean (NM)	CAPP End SD (NM)	CAVS End Mean (NM)	CAVS End SD (NM)
1800 / 3.2	3.9	0.5	3.5	0.2	3.3	0.3
1800 / 3.5	3.9	0.4	3.8	0.3	3.7	0.2
3300 / 3.2	4.2	0.6	4.2	0.6	3.0	0.5
3300 / 3.5	4.3	0.5	4.3	0.5	3.3	0.5

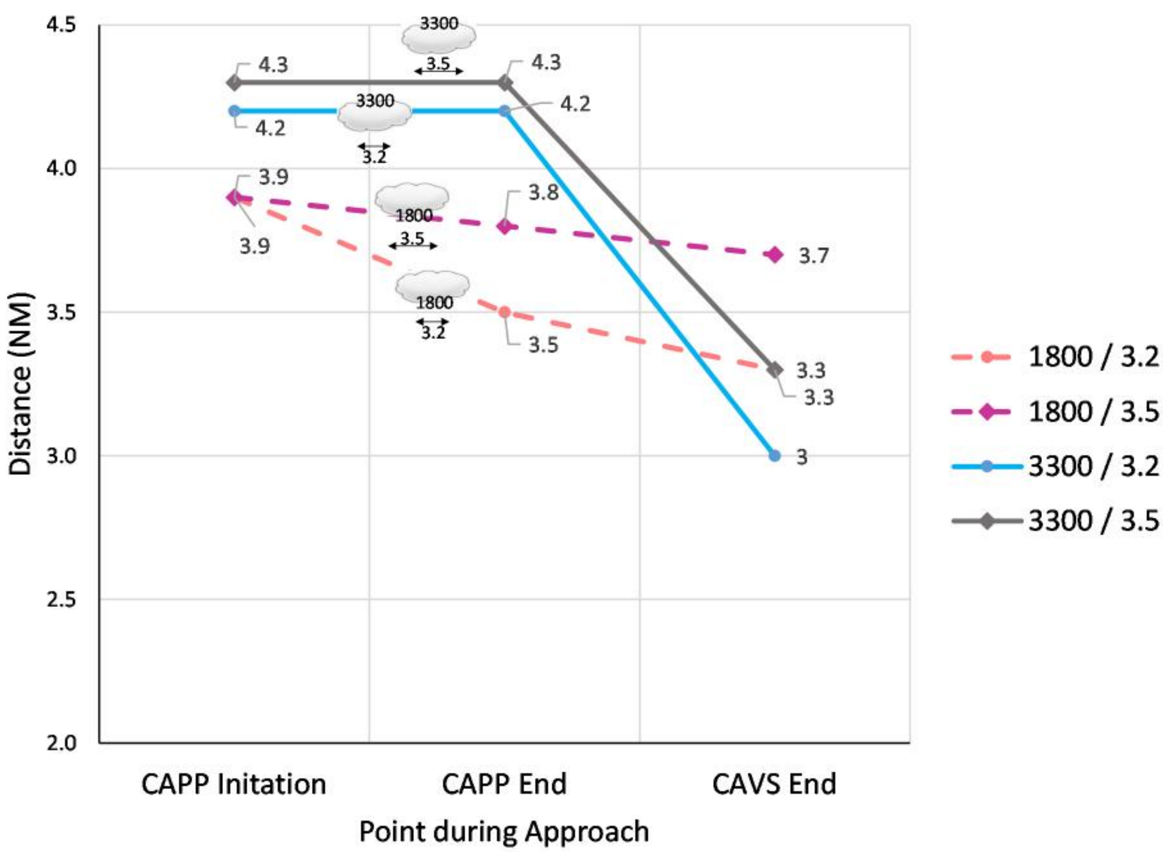

Figure 4-41. Participant and Pseudo-Pilot CAPP Aircraft Pair Distance at Key Points across Full Approach

4.3 General Acceptability

Controllers and pilots were asked whether CAPP is operationally acceptable for each of the four variables. The following bullets show the results for the controllers. While the majority agreed to all conditions, the 3300 ft ceiling appears to be more acceptable than the 1800 ft ceiling and 3.5 NM appears to be more acceptable than 3.2 NM.

- Ceiling
  - 1800 ft
    - Controller responses were variable but the majority (7/11; 64%) agreed (M=71.4; SD=30.8).
  - 3300 ft
    - All controllers agreed (M=88.6; SD=11.0).
- NCT value
  - 3.2 NM
    - Controller responses were variable but the majority (8/11; 73%) agreed (M=65.8; SD=30.6).
  - 3.5 NM
    - All controllers agreed (M=83.7; SD=13.4).

The pilot responses are shown next. While the majority agreed to all conditions, the ceiling conditions appear very similar while the 3.5 NM appears to be slightly more acceptable than 3.2 NM.

- Ceiling
  - 1800 ft
    - Pilot responses were variable but the majority (18/22; 82%) agreed (M=75.5; SD=25.2).
  - 3300 ft
    - Pilot responses were variable but the majority (19/22; 86%) agreed. (M=79.0; SD=26.8).
- NCT value
  - 3.2 NM
    - Pilot responses were variable but the majority (18/22; 82%) agreed (M=71.5; SD=26.8).
  - 3.5 NM
    - Pilot responses were variable but the majority (18/22; 82%) agreed (M=80.3; SD=28.3).

See Figure 4-42 for a summary of these statements.

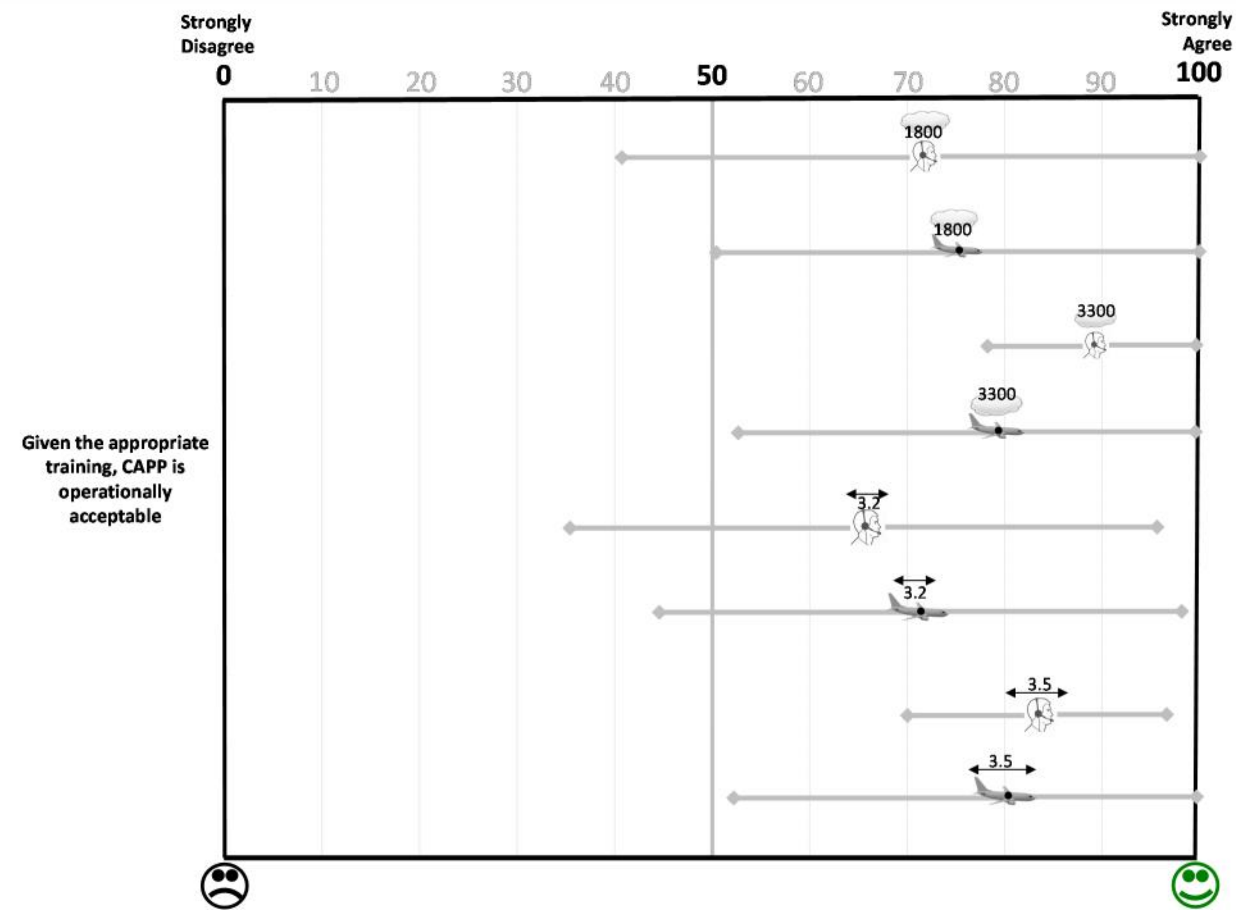

Figure 4-42. Summary of Controller and Pilot Responses to General Acceptability Statements

In the post-scenario questionnaire, controllers and pilots were also asked whether CAPP is operationally acceptable based on the condition just experienced (rather than by each variable as was asked in the previously reported statement from the post-simulation questionnaire). The controller results are shown first. While the majority of the controllers agreed, the responses for the 3300 ft conditions appear more acceptable than the 1800 ft conditions. The NCT values appeared to have less of an impact. However, as reported in 4.1.3.3 the Repeated Measures MANOVA did not reveal statistically significant results.

- 1800 ft and 3.2 NM
  - The majority (8/11; 73%) of controllers agreed (M=74.3; SD=20.6).
- 1800 ft and 3.5 NM
  - The majority (8/11; 73%) of controllers agreed (M=76.6; SD=20.7).
- 3300 ft and 3.2 NM
  - The majority (9/11; 82%) of controllers agreed (M=83.6; SD=18.9).
- 3300 ft and 3.5 NM
  - The majority (10/11; 91%) of controllers agreed (M=81.7; SD=18.0).

The pilot results for the post-scenario questionnaire are shown below. While the majority of pilots agreed, the responses for the 1800 ft and 3.2 NM condition appear to be the least acceptable. However, as reported in Section 4.1.3.2, the Repeated Measures MANOVA revealed statistically significant results for only the ceiling. Pilots found the 3300 ft ceiling more acceptable than the 1800 ft ceiling. Figure 4-43 depicts the post-scenario results.

- 1800 ft and 3.2 NM
  - Pilot responses were variable but the majority (33/44; 75%) agreed (M=71.5; SD=31.5).
- 1800 ft and 3.5 NM
  - Pilot responses were variable but the majority (36/43; 84%; Missing 1 value) agreed (M=79.0; SD=25.6).
- 3300 ft and 3.2 NM
  - Pilot responses were variable but the majority (36/40; 90%; Missing 4 values) agreed (M=81.1; SD=27.6).
- 3300 ft and 3.5 NM
  - The majority (35/38; 92%; Missing 6 values) of pilots agreed (M=83.5; SD=20.9).

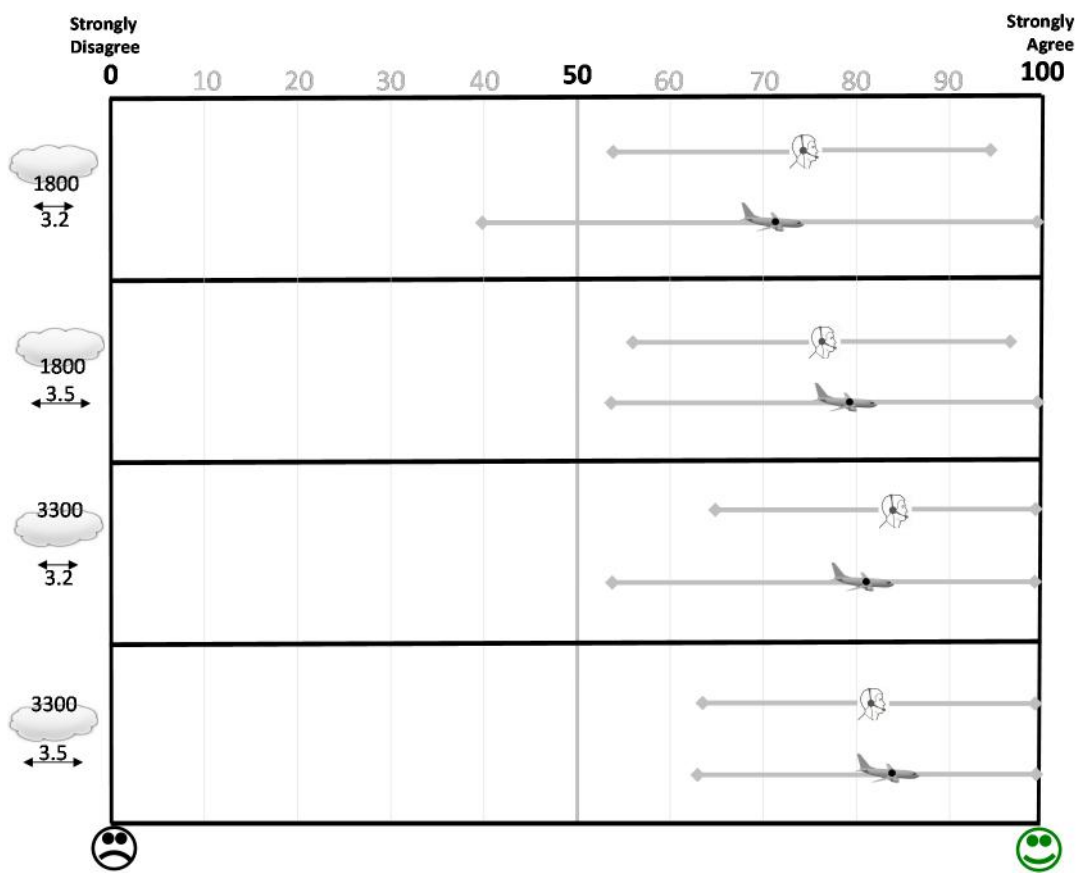

Figure 4-43. Controller and Pilot Responses to Post-Scenario Statement "CAPP was operationally acceptable"

4.4 Ceiling Acceptability

Controllers and pilots were asked about the acceptability of the 1800 and 3300 ft ceilings experienced in the simulation as well as lower and higher ceilings. The following bullets provide the responses. Controllers appear to find the 3300 ft ceiling more acceptable than the 1800 ft ceiling. Pilots appear to find both ceilings to be similarly acceptable but showed a potential preference for the 3300 ft ceiling. Both pilots and controllers appear to question the acceptability of a lower ceiling, while a higher ceiling appears to be potentially more acceptable.

1800 ft

- Controller responses were variable (M=52.8; SD=34.0).
- The majority (17/22; 77%) of pilots agreed (M=73.8, SD=22.9).

3300 ft

- The majority (10/11; 91%) of controllers agreed. One was neutral (M=81.6; SD=14.9).
- The majority (20/22; 91%) of pilots agreed. Two were neutral (M=82.1, SD=16.1).

Lower (i.e., below 1800 ft)

- Controller responses were variable (M=47.9; SD=35.4).
- Pilot responses were evenly split: 10 (45%) disagreed, 2 (9%) were neutral, and 10 (45%) agreed (M=54.9; SD=30.2).

Higher (i.e., above 3300 ft)

- Controller responses were variable but the majority (8/11; 73%) agreed (M=71.4; SD=36.2).
- The majority (16/22; 73%) of pilots agreed (M=74.5; SD=24.9).

See Figure 4-44 for a summary of these statements.

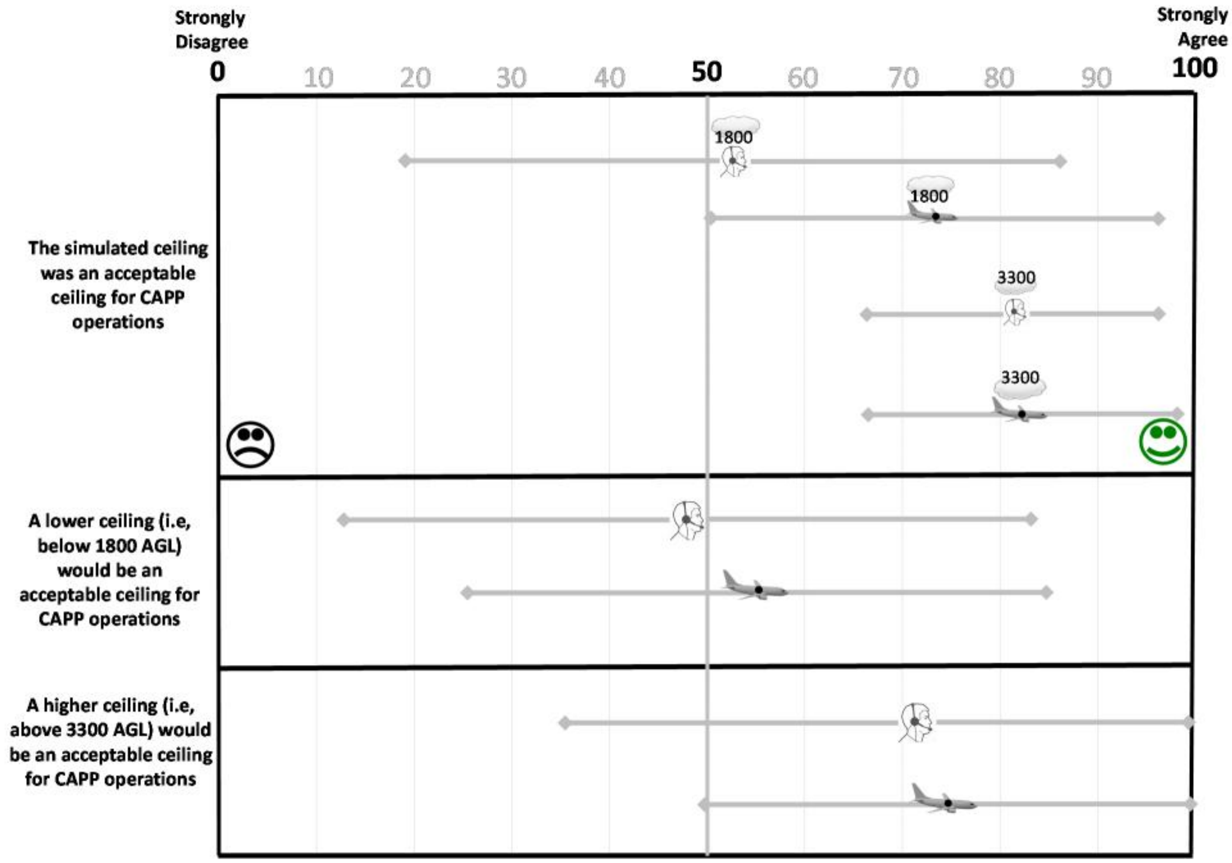

Figure 4-44. Summary of Controller and Pilot Responses on Ceiling Statements

4.5 Benefits

Pilots and controllers were asked whether CAPP is desirable. The majority (9/11; 82%) of controllers agreed. Two (18%) were neutral (M=78.7, SD=17.0). Pilot responses were variable but the majority (14/22; 64%) agreed (M=61.6; SD=26.7). Controllers appear to find it more desirable. In the post-scenario questionnaire, controllers and pilots were also asked whether CAPP was operationally desirable. The majority of the controllers agreed, but the responses for the 3300 ft conditions appear to be more desirable and less variable than the 1800 ft conditions. The NCT values appeared to have less of an impact. The most desirable condition appears to be the 3300 ft and 3.2 NM condition.

- 1800 ft and 3.2 NM
    - Controller responses were variable but the majority (8/11; 73%) agreed (M=72.0; SD=29.4).
- 1800 ft and 3.5 NM
    - Controller responses were variable but the majority (8/11; 73%) agreed (M=71.7; SD=27.3).
- 3300 ft and 3.2 NM
    - The majority (9/11; 82%) of controllers agreed (M=83.6; SD=18.6).
- 3300 ft and 3.5 NM
    - The majority (9/11; 82%) of controllers agreed (M=79.5; SD=20.1).

The pilot results for the post-scenario questionnaire are shown next. While the majority of the pilots agreed, the responses had large variability. All conditions appear very similar. Figure 4-45 depicts the results

- 1800 ft and 3.2 NM
    - Pilot responses were variable but the majority (30/43; 70%; Missing 1 value) agreed (M=64.1; SD=31.5).
- 1800 ft and 3.5 NM
    - Pilot responses were variable but the majority (29/43; 67%; Missing 1 value) agreed (M=69.6; SD=28.0).
- 3300 ft and 3.2 NM
    - Pilot responses were variable but the majority (28/40; 70%; Missing 4 values) agreed (M=68.4; SD=32.8).
- 3300 ft and 3.5 NM
    - Pilot responses were variable but the majority (28/38; 74%; Missing 1 value) agreed (M=72.3; SD=28.3).

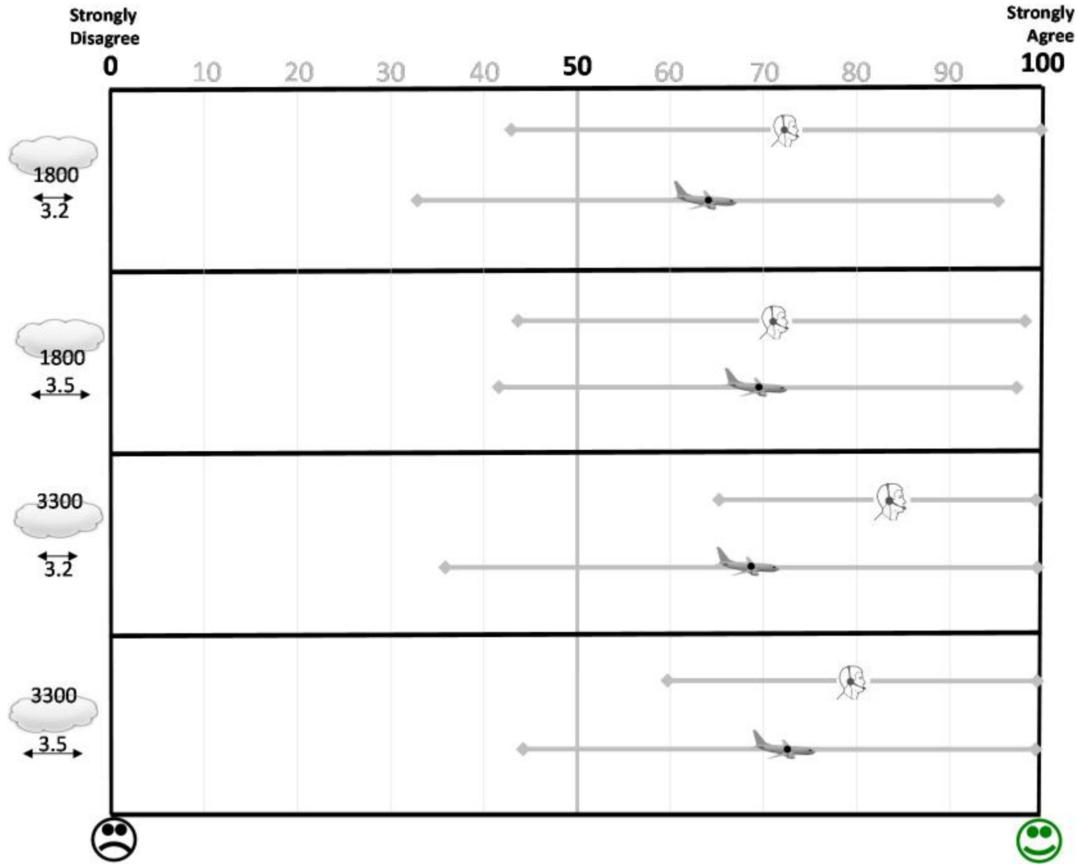

Figure 4-45. Controller and Pilot Responses to Post-Scenario Statement "CAPP was operationally desirable"

Based on the main goal of CAPP being a transition to CAVS / visual operations, controllers and pilots were asked whether CAPP was useful as a transition to visual separation. The majority (8/11; 73%) of controllers agreed (M=73.0; SD=20.1). Pilot responses were variable but the majority (16/22; 73%) agreed (M=65.3; SD=29.1). Controllers and pilots were also asked about the utility of CAPP with and without a transition to visual separation operations. When asked if CAPP is only useful when there is a transition to visual separation operations, controller responses were variable but the majority (8/11; 73%) disagreed (M=35.6; SD=26.7). For pilots, the majority (15/22; 68%) disagreed (M=40.0; SD=20.1). When asked if CAPP is only useful when there is **no** transition to visual separation operations, the majority (8/11; 73%) of controllers disagreed (M=27.3; SD=24.3). Pilot responses were variable but the majority (15/22; 68%) also disagreed (M=40.8; SD=28.3). In summary, CAPP appears useful to controllers and pilots with and without a transition to visual operations. However, pilot opinions appear more varied than controller opinions. See Figure 4-46 for a summary of these statements.

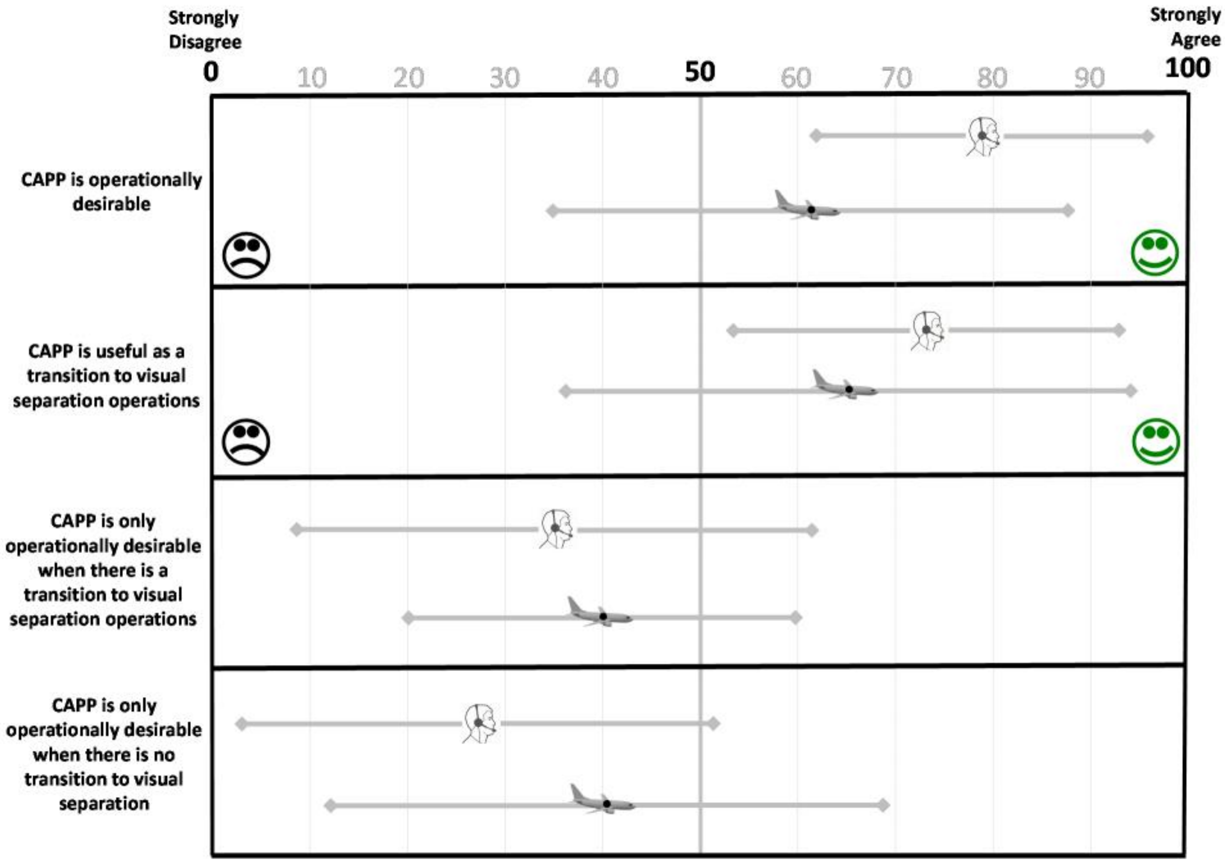

Figure 4-46. Summary of Controller and Pilot Responses to Benefits Statements

Controllers and pilots were asked about the advantages of CAPP. The most common controller responses of the 14 total reply topics were the following:

- Reduced / more precise spacing between aircraft / increased efficiency (5/14; 29%)
- Support for the controller in the spacing / separation task / added safety (4/14; 29%)
- Reduced controller workload (3/14; 21%).

The most common pilot responses of the 24 total reply topics were the following.

- Increased situation awareness / traffic awareness (17/24; 71%)
- Increased efficiency / tighter spacing (5/24; 21%).

Controllers and pilots were also asked about the disadvantages of CAPP. The most common controller responses of the 11 total reply topics were the following.

- Issues / difficulties resolving issues when pilots report “unable CAPP” (3/11; 27%)
- Expected pilot variability in spacing, including excess spacing (2/11; 18%)
- Not knowing what pilots will do but still being responsible for separation (2/11; 18%).

The most common pilot responses of the 24 total reply topics were the following.

- Head down time / scan / monitoring of displays (7/24; 29%)
- Pilot workload (6/24; 25%)
- Spacing and separation responsibilities (5/24; 21%).

In order to start to understand the potential CAPP spacing benefits, participant pilot spacing behavior during the four CAPP independent variable conditions can be compared to the baseline and extra events (e.g., no transition from CAPP to CAVS and CAPP with pilot separation responsibility) (Table 4-39). However, drawing conclusions is difficult due to the low sample sizes. In the no-transition event, only one participant pilot aircraft was in the tight spacing category so any comparison to CAPP with a transition is challenging. For the CAVS with pilot separation responsibility event, only two participant pilot aircraft were in the tight spacing category. The baseline condition (i.e., ILS followed by visual separation without a CDTI) had five participant pilot aircraft in the tight spacing category. While the numbers are relatively low, the trends are very similar to that seen in the combined pilot data in Section 4.2.5.

The wide data is provided for reference only while the tight spacing data is expected to be more representative of the potential benefits. When examining the tight spacing pairs, the CAPP with pilot separation responsibility event had the lowest spacing and the 1800 ft and 3.5 NM condition had the highest spacing. The other conditions (including the baseline) were very similar. The no transition from CAPP to CAVS event only had one aircraft in the tight spacing category and the ones in the wide spacing pairs were similar to the 1800 ft and 3.5 NM condition. While the data should be interpreted with caution, the CAPP aircraft appears to be able to get closer to the TTF with a lower NCT value and / or more time for visual separation.

Table 4-39. Final Overall Spacing for Participant Pilot Aircraft Initially Spaced Tightly

Scenario and Operation Type		Tight		Wide	
		Mean (NM)	SD (NM)	Mean (NM)	SD (NM)
CAPP to CAVS	1800 / 3.2	2.8 (n=2)	0.1	3.7 (n=12)	0.8
	1800 / 3.5	3.6 (n=5)	0.1	3.7 (n=11)	0.6
	3300 / 3.2	2.9 (n=8)	0.4	4.4 (n=9)	1.9
	3300 / 3.5	2.8 (n=6)	0.4	3.4 (n=10)	0.6
Other	No Transition from CAPP to CAVS (1800 / 3.2)	-- (n=1)	--	3.5 (n=9)	0.6
	CAPP with Pilot Separation Responsibility (1800 / na)	2.3 (n=2)	0.6	3.3 (n=8)	0.5
	ILS followed by visual separation with no CDTI (2800 / na)	2.8 (n=5)	0.4	5.3 (n=5)	1.1

4.6 Roles and Responsibilities

Controllers and pilots were asked if their roles and responsibilities were clear during CAPP. The majority (10/11; 91%) of the controllers agreed (M=75.6; SD=24.2) and the majority (18/22; 82%) of pilots agreed (M=77.7; SD=24.6).

Pilots and controllers were also asked about potential changes in separation responsibilities. When asked if the controller should maintain separation responsibility, controller responses were variable but the majority (7/11; 64%) disagreed (M=33.9; SD=27.5). Pilot responses were variable but the majority (15/22; 68%) agreed (M=67.9; SD=26.6). When controllers were asked whether it was acceptable to be responsible for separation during CAPP, controller responses were variable (M=38.4; SD=29.6). When asked if the flight crew should be issued separation responsibility during CAPP, the majority (8/11; 73%) of the controllers agreed (M=79.0; SD=23.7). Pilot responses were variable but the majority (14/22; 64%) agreed (M=65.6; SD=27.5). When asked if they would be willing to issue the flight crew separation responsibility for the TTF during CAPP, the majority (10/11; 91%) of the controllers agreed (M=84.4; SD=22.6). When asked if they would be willing to accept separation responsibility for the TTF during CAPP, pilot responses were variable but the majority (17/22; 77%) of pilots agreed. However, the five pilots that disagreed had responses of 20 or less. (M=62.6; SD=30.0). See Figure 4-47 for a summary of these statements.

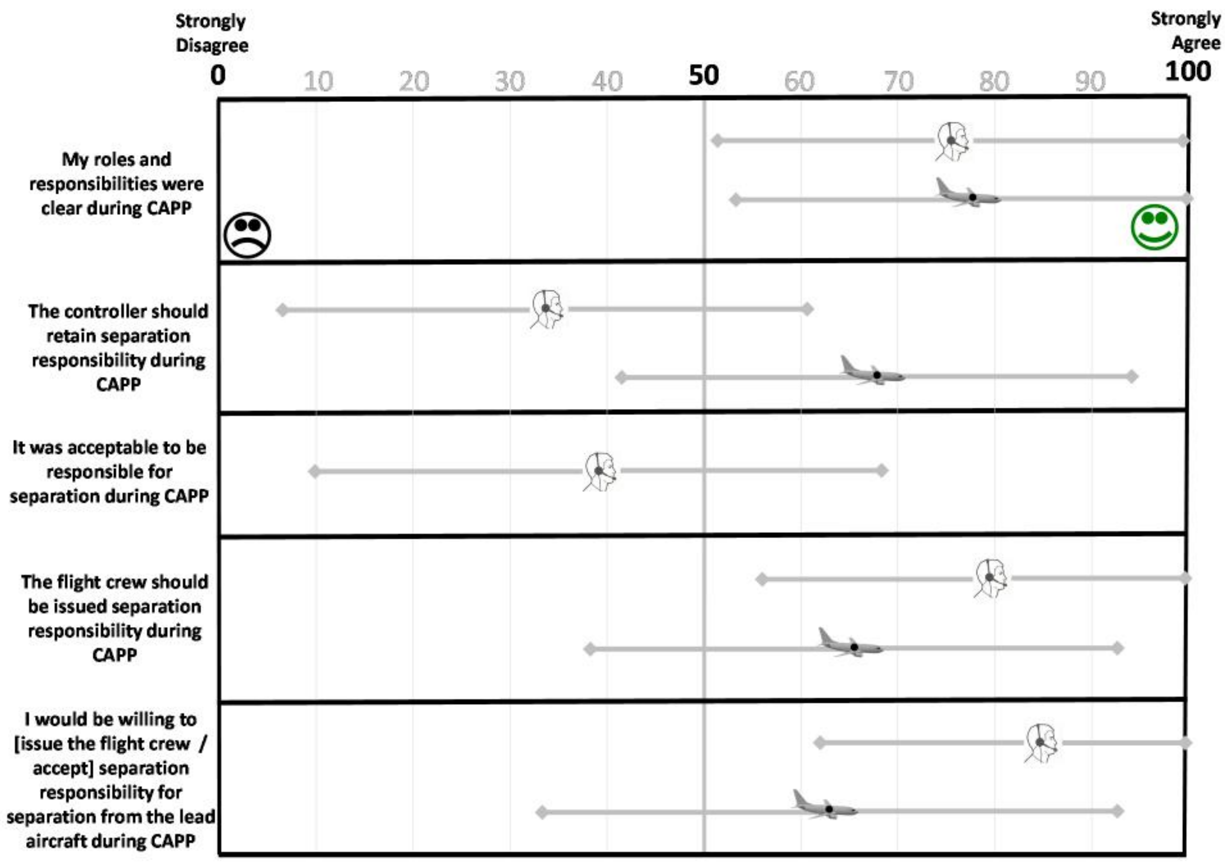

Figure 4-47. Summary of Controller and Pilot Roles and Responsibility Statements

In the majority of the scenarios, pilots conducted CAPP and the controller was responsible for separation. One extra event was designed to have the flight crew conduct CAPP-like operations while having separation responsibility (similar to IMC CAVS to single runways). The pilots flew the one separation responsibility event and then competed the post-scenario questionnaire.

There were no breakouts for participant pilot aircraft in this scenario. The pilots Bedford Workload Rating Scale had a mode of 3 (M=2.5; SD=1.1). The majority of pilots (19/22; 86%) reported the "workload [was] satisfactory without reduction," i.e., a rating between one and three. Three pilot replies (14%) indicated that workload was not "satisfactory without reduction," i.e., a rating between four and six (Figure 4-48).

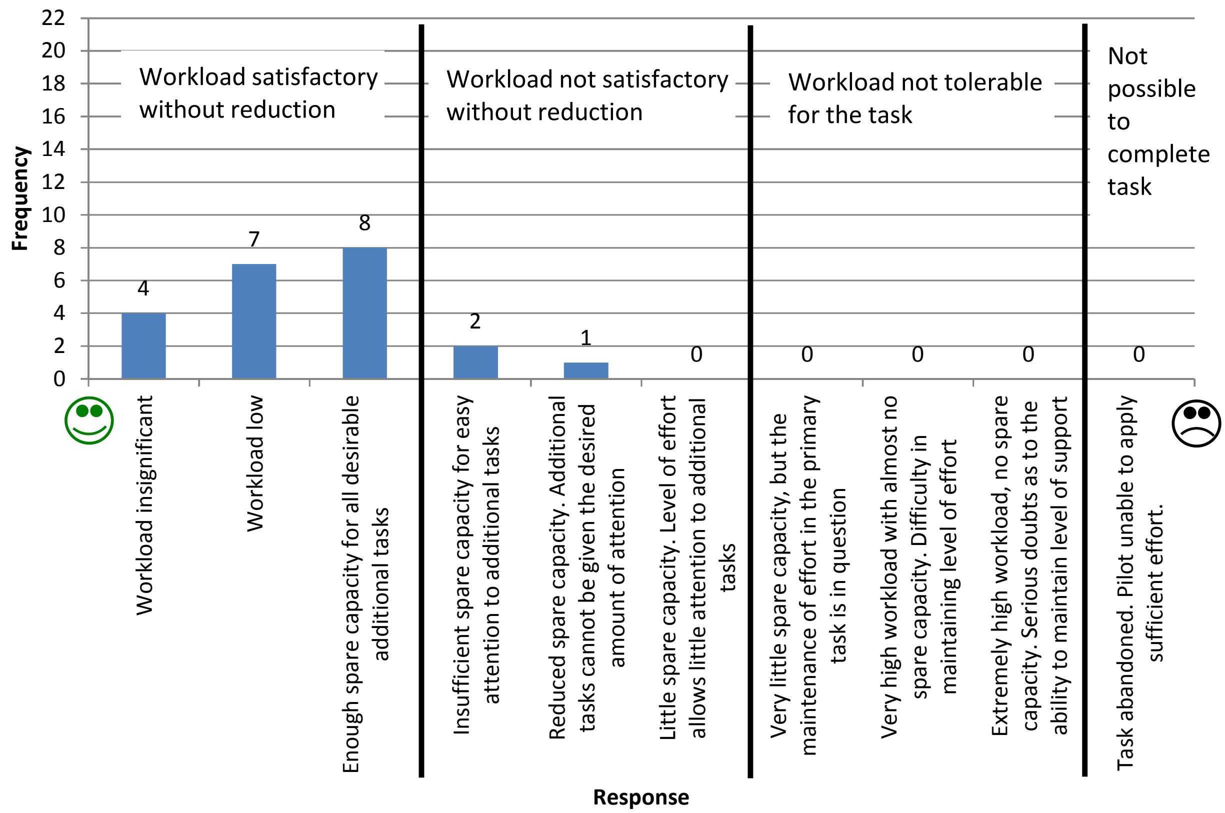

Figure 4-48. Pilot Responses to the Bedford Workload Rating Scale when having Separation Responsibility during CAPP-like Operations

Pilots were asked in the post-scenario questionnaire to report their desired spacing from the TTF. For the operation, the majority (16/22; 73%) of pilots chose at or between 3.0 and 2.5. The remainder (6/22; 27%) chose the CAPP values of 3.2 or 3.5. Controllers and pilots were asked in the post-scenario questionnaire whether pilots having separation responsibility during CAPP-like operations was operationally desirable. Controller responses were variable (M=57.6; SD=31.3). The majority of pilots (18/22; 82%) reported that it was desirable (M=75.6; SD=24.6).

Controllers and pilots were asked in the post-scenario questionnaire whether pilots having separation responsibility during CAPP-like operations was operationally acceptable. The majority (8/11; 73%) of controllers reported that it was acceptable (M=67.9; SD=21.5). The majority of pilots (19/22; 86%) reported that it was acceptable (M=79.2; SD=24.8). Finally, the majority (8/11; 73%) of controllers reported that spacing being achieved by pilots having separation responsibility was acceptable (M=70.3; SD=21.2). See Figure 4-49 for a summary of these statements.

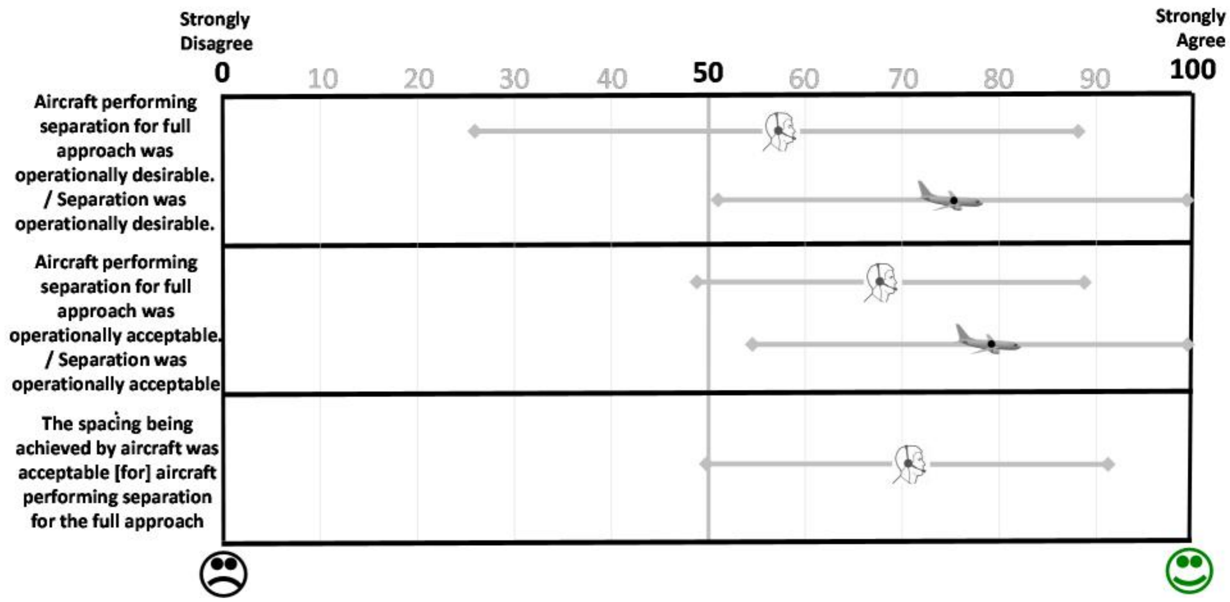

Figure 4-49. Controller and Pilot Responses to Post-Scenario Statements related to Pilots having Separation Responsibility during CAPP-like Operations

4.7 Workload

This section includes the results for all workload questions including those reviewed in detail in previous sections.

In the post-scenario questionnaire, controllers and pilots were asked to rate their workload on the Bedford Workload Rating Scale. The controller results are below. See Figure 4-50. All scenarios appear very similar and workload appears to be acceptable to controllers.

- 1800 ft and 3.2 NM
    - The majority (9/11; 82%) of controller responses indicated the "workload [was] satisfactory without reduction," i.e., a rating between one and three. Two (18%) replies indicated that workload was not "satisfactory without reduction," i.e., a rating between four and six (M=3.0; SD=1.0).
- 1800 ft and 3.5 NM
    - The majority (8/11; 72%) of controller responses indicated the "workload [was] satisfactory without reduction." Three (28%) replies indicated that workload was not "satisfactory without reduction," i.e., a rating between four and six (M=3.0; SD=0.9).
- 3300 ft and 3.2 NM
    - The majority (9/11; 82%) of controller responses indicated the "workload [was] satisfactory without reduction." Two (18%) replies indicated that workload was not "satisfactory without reduction," i.e., a rating between four and six (M=2.8; SD=0.8).
- 3300 ft and 3.5 NM
    - The majority (10/11; 91%) of controller responses indicated the "workload [was] satisfactory without reduction." One (9%) reply indicated that workload was not "satisfactory without reduction," i.e., a rating between four and six (M=2.9; SD=0.5).

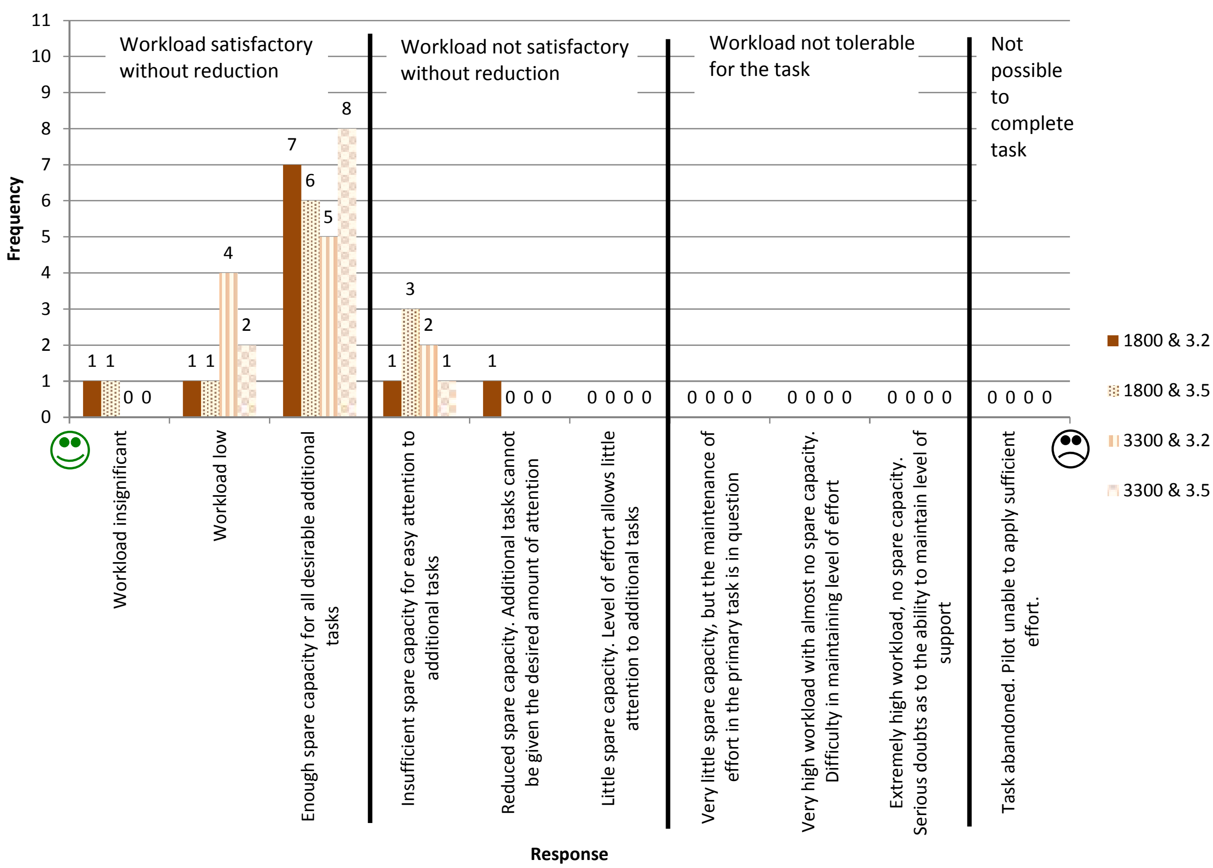

Figure 4-50. Controller Responses to the Bedford Workload Rating Scale per Condition

The pilot results are below and in Figure 4-51. Overall, the majority of the pilots found workload acceptable but some reported very challenging workload conditions. Some reported very high workload conditions, including “workload not tolerable for the task” and “not possible to complete the task.”

- 1800 ft and 3.2 NM
  - The majority (32/44; 73%) of pilot responses indicated the “workload [was] satisfactory without reduction,” i.e., a rating between one and three. Nine (20%) pilot replies indicated that workload was not “satisfactory without reduction,” i.e., a rating between four and six. Two (5%) pilot replies indicated that workload was not “tolerable for the task,” i.e., a rating between seven and nine. One (2%) pilot reply indicated the task was impossible (M=3.1; SD=1.9).
- 1800 ft and 3.5 NM
  - The majority (34/44; 77%) of pilot responses indicated the “workload [was] satisfactory without reduction.” Eight (18%) pilot replies indicated that workload was not “satisfactory without reduction,” i.e., a rating between four and six. Two (5%) pilot replies indicated that workload was not “tolerable for the task,” i.e., a rating between seven and nine (M=2.8; SD=1.4).
- 3300 ft and 3.2 NM
  - The majority (38/42; 86%; Missing 2 values) of pilot responses indicated the “workload [was] satisfactory without reduction,” i.e., a rating between one and three. Two (5%) pilot replies indicated that workload was not “satisfactory without reduction.” One (2%) pilot reply indicated that workload was not “tolerable for the task,” i.e., a rating between seven and nine. One (2%) pilot reply indicated the task was impossible (M=2.7; SD=1.8).
- 3300 ft and 3.5 NM
  - The majority (35/38; 92%; Missing 6 values) of pilot responses indicated the “workload [was] satisfactory without reduction.” Three (8%) pilot replies indicated that workload was not “satisfactory without reduction,” i.e., a rating between four and six (M=2.5; SD=1.1).

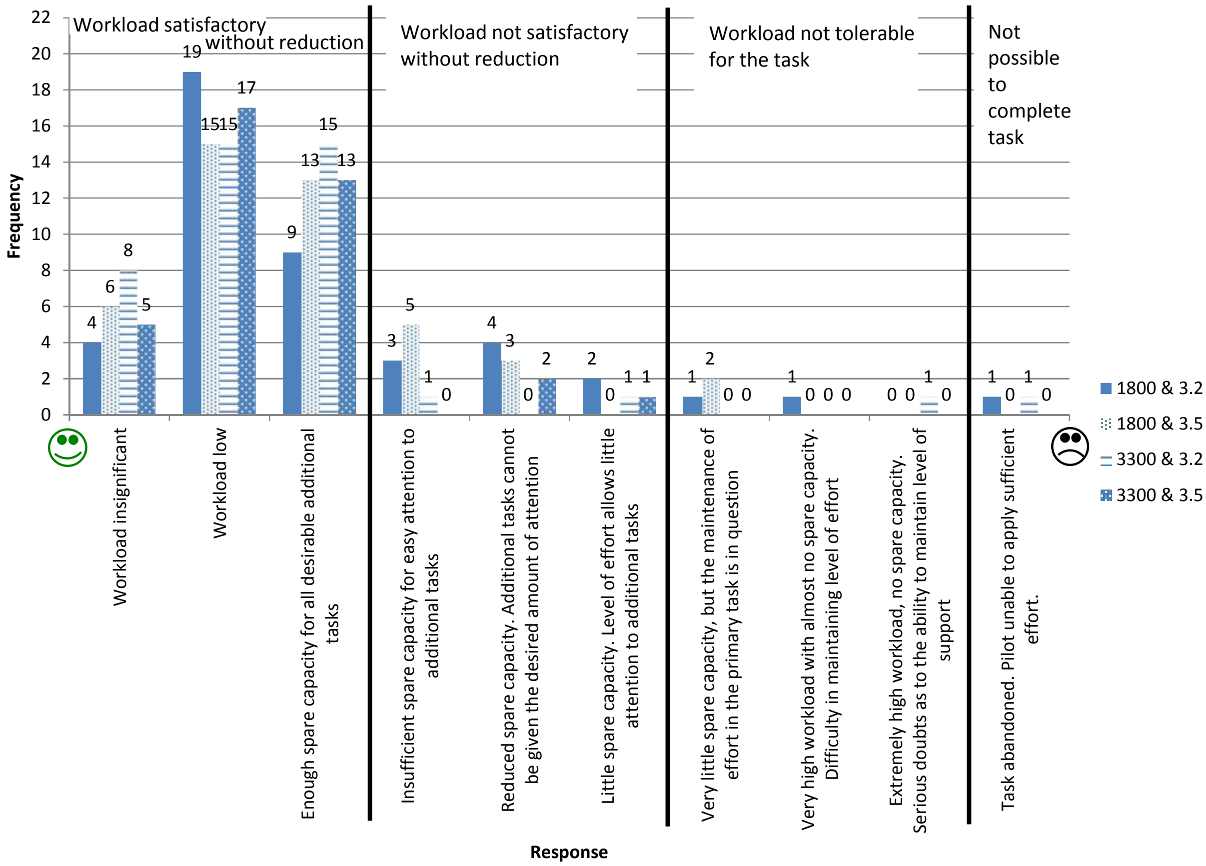

Figure 4-51. Pilot Responses to the Bedford Workload Rating Scale per Condition

As noted previously, ratings in the seven to ten range indicate the situation was particularly challenging, but the task being "not tolerable" or "impossible" was the task of conducting CAPP (versus the task of flying the aircraft) as all pilots continued successfully flying the aircraft after reporting the condition to the controller.

See Figure 4-52 for both the pilot and controller replies for each of the conditions as well as the extra events. Across all the conditions and events, the workload appears very similar with the exception of the CAPP aircraft overtake event, which appeared to be the most workload intensive event for the pilots.

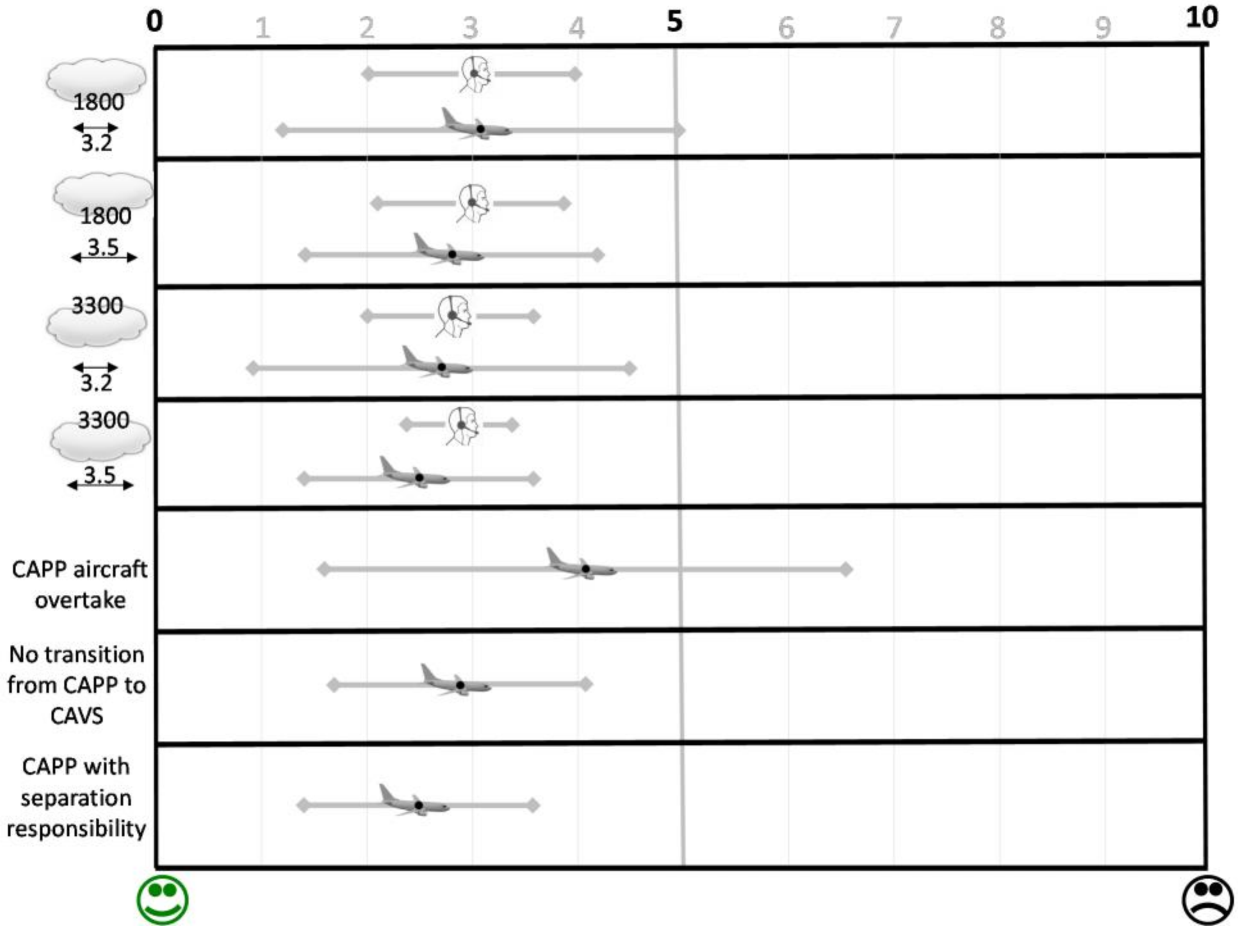

Figure 4-52. Controller and Pilot Response Means to the Bedford Workload Rating Scale per Condition and Event

In addition to the Bedford Workload Rating Scale, participants were also asked to complete the TLX (Table 4-40, Table 4-41, and Figure 4-53). Pilot responses showed lower workload on average than did controller responses for the TLX measure. For controllers, a Factorial Repeated Measures ANOVA was used to test controller workload as reported in the TLX measure. No significant main effects were found for either ceiling or NCT and there was no significant interaction. A Factorial Repeated Measures ANOVA was used to test participant pilot workload as reported in the TLX measure. A significant main effect (Greenhouse-Geisser) was found for ceiling, $F(1, 37) = 8.75$, $p = 0.005$. A significant main effect for NCT and the interaction were not found. Contrasts revealed the 1800 ft conditions had significantly higher workload compared to the 3300 ft conditions, $F(1, 37) = 8.75$, $p = 0.005$, $r = .43$, although all scores were on the low workload side of the scale.

Table 4-40. Controller Workload Ratings on TLX scale by Condition and Independent Variable

Condition	Mean	SD		Independent Variable	Mean	SD
1800 / 3.2	36.0	11.6		1800	37.8	13.3
1800 / 3.5	39.7	14.6		3300	32.4	14.7
3300 / 3.2	30.7	15.0		3.2	33.3	13.6
3300 / 3.5	34.2	14.5		3.5	37.0	14.7

Table 4-41. Pilot Workload Ratings on TLX scale by Condition and Independent Variable

Condition	Mean	SD		Independent Variable	Mean	SD
1800 / 3.2	30.1	22.8		1800	25.5	21.4
1800 / 3.5	27.6	21.1		3300	22.8	20.9
3300 / 3.2	23.5	23.2		3.2	26.8	21.2
3300 / 3.5	22.2	20.2		3.5	24.9	20.8

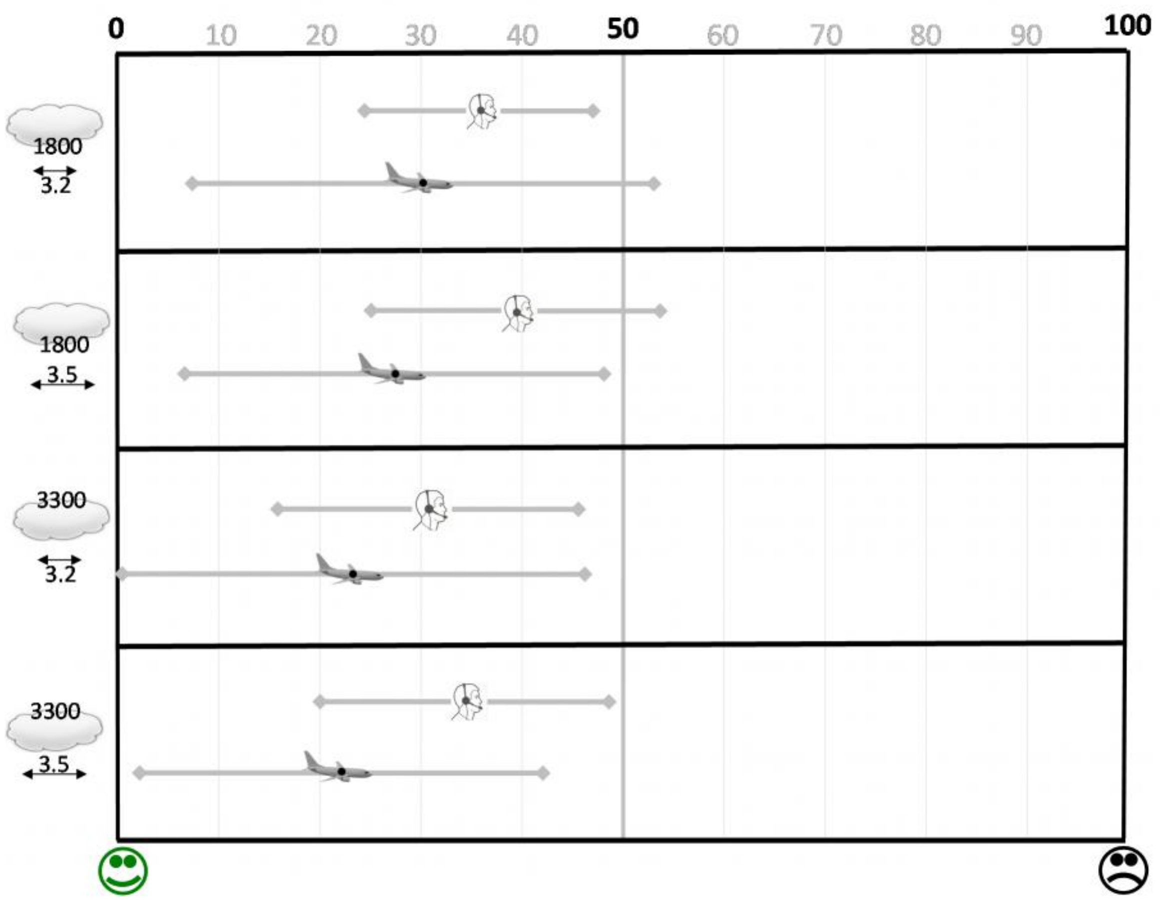

Figure 4-53. Controller and Pilot Responses to the TLX per Condition

Controllers and pilots were asked how the workload of CAPP compares to similar conditions without CAPP. The majority (8/11; 73%) of the controllers reported a reduction (DM=4.9 [of 7.0]; SD=1.5) while the majority (17/22; 77%) of the pilots reported an increase (DM=2.7 [of 7.0]; SD=1.5). See Figure 4-54.

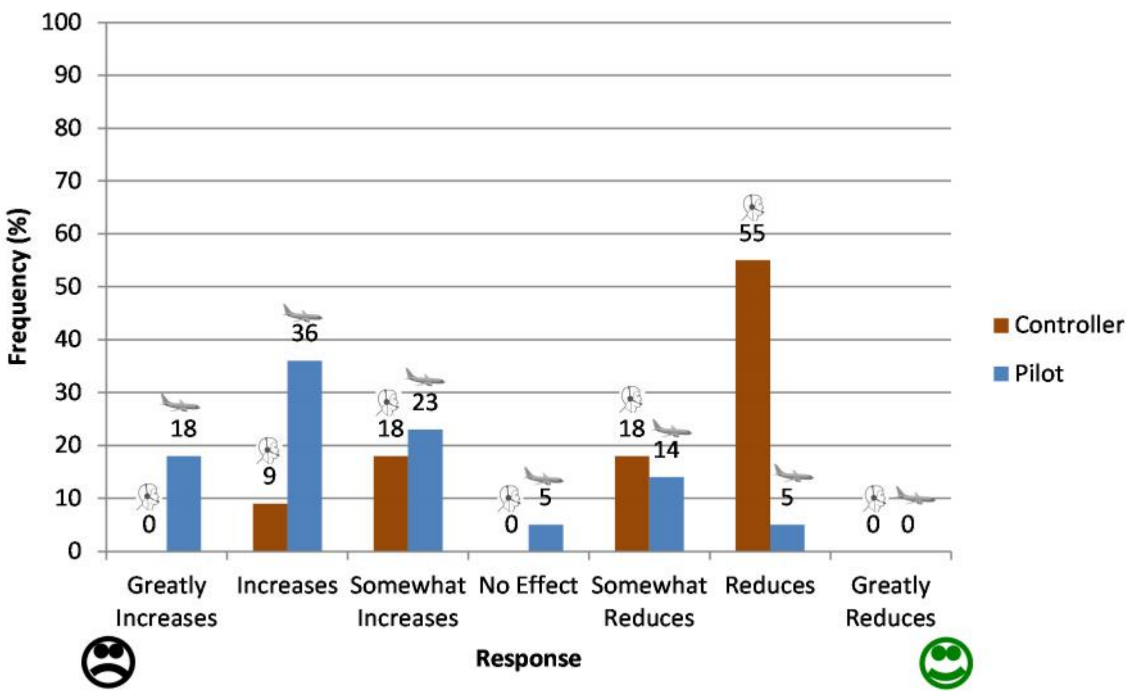

Figure 4-54. Controller and Pilot Responses to "How would you rate the overall effect of CAPP on your workload, as compared to [controlling / operating a] similar aircraft under similar conditions?"

When asked if the overall workload was acceptable, all controllers agreed (M=81.6; SD=9.3). Pilot responses were variable but the majority (17/22; 77%) agreed (M=69.3; SD=27.7). See Figure 4-55 for a summary. Overall, controllers generally reported a reduced and acceptable workload. Pilots generally reported increased but acceptable workload. However, some pilots reported challenging workload conditions.

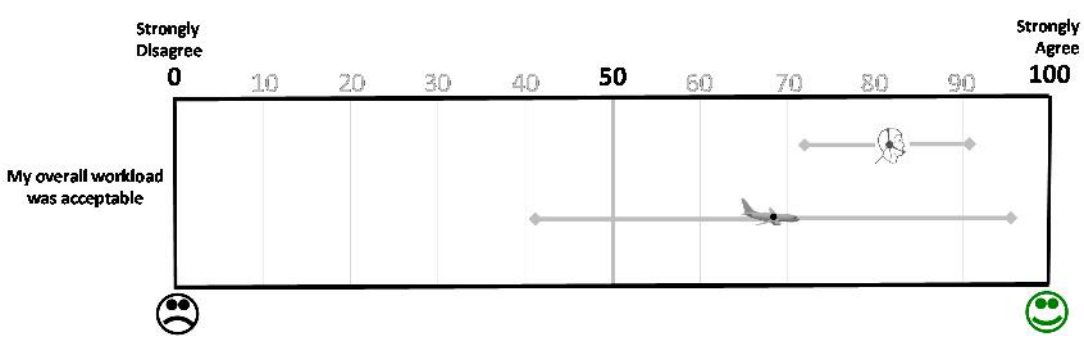

Figure 4-55. Summary of Pilot Scan Statement for Workload

4.8 Displays

4.8.1 Controller

Controllers were asked about the display capabilities for CAPP. All controllers agreed that placing a symbol before the aircraft call sign is an acceptable means to indicate CAPP capable aircraft (M=82.6; SD=11.4). When asked if differentiating CAPP aircraft by entering "CP" in the scratchpad was necessary, controller responses were variable but the majority (8/11; 73%) agreed (M=65.1; SD=27.6). See Figure 4-56 for a summary of these statements.

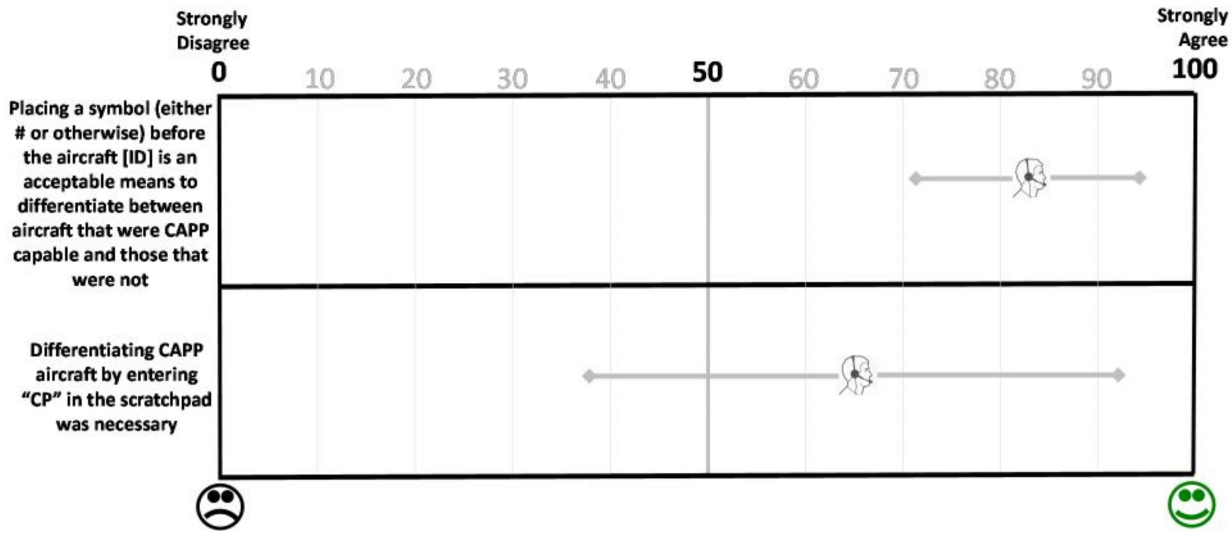

Figure 4-56. Summary of Controller Display Statements

4.8.2 Flight Crew

Pilots were asked to estimate the amount of time using the CDTI and AGD for CAPP. As can be seen in Figure 4-57, the PFs spend the majority of their time on the AGD while the PMs spent the majority of their time on the CDTI.

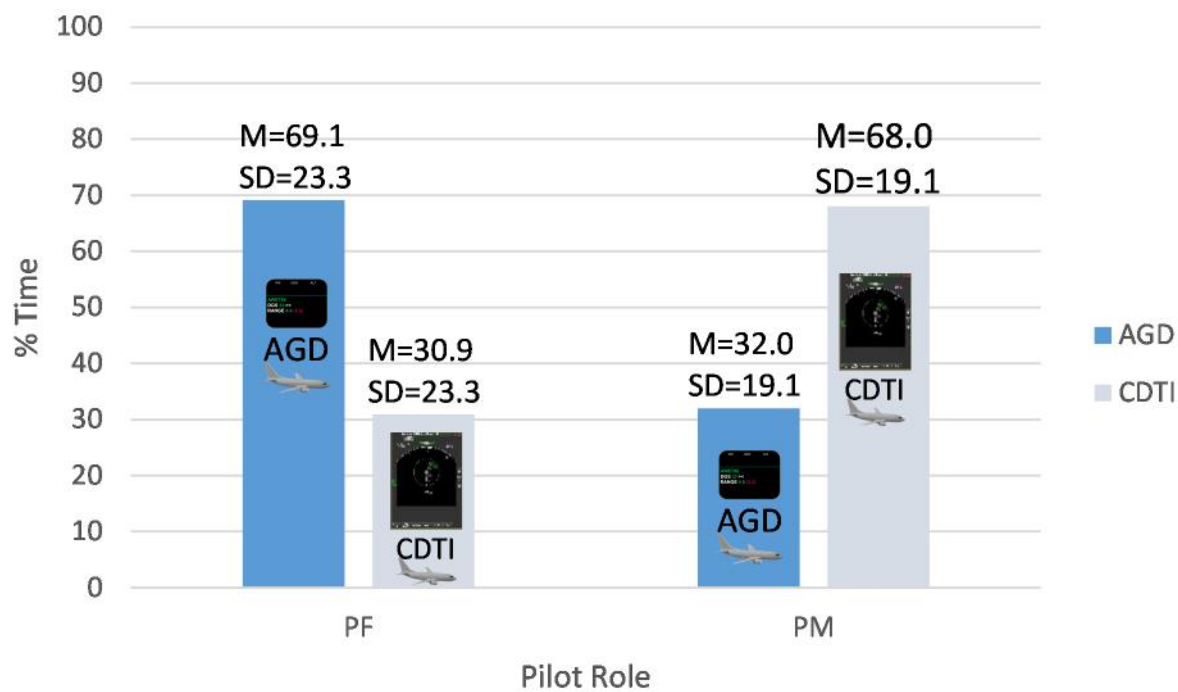

Figure 4-57. Pilot Responses to "Considering total time on the CAPP displays, estimate the total percentage of time using each display (total should equal 100)"

Pilots were asked how difficult it was to integrate the two displays into their normal scan (Figure 4-58). For the AGD, pilot responses were variable (DM=4.5 [of 7.0]; SD=1.8). For the CDTI, pilot responses were variable but the majority (17/22; 77%) reported "borderline" or were on the easy side of the scale (DM=4.5 [of 7.0]; SD=1.7).

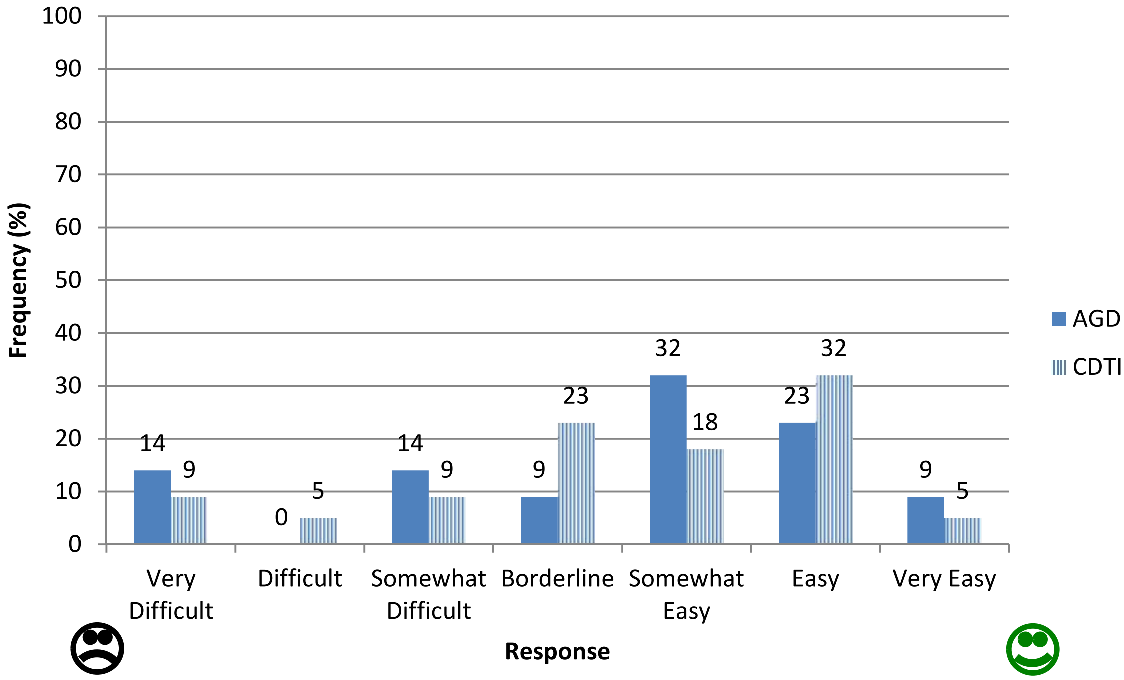

Figure 4-58. Pilot Responses to "How difficult was it to integrate the displays into your normal instrument scan?"

Pilots were asked if the necessary scan time was acceptable. Responses were variable but the majority (15/22; 68%) agreed (M=65.0; SD=28.6). When asked if the level of head down time was acceptable, pilot responses were variable (M=47.6; SD=29.5). See Figure 4-59 for a summary.

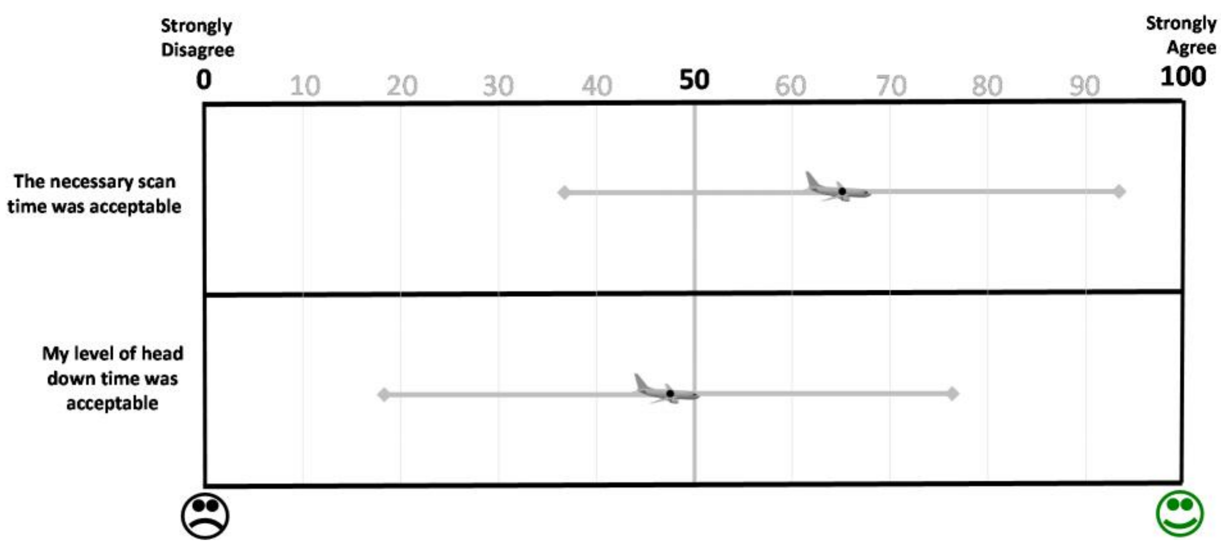

Figure 4-59. Summary of Pilot Scan Statements

Pilots were asked if they would be willing to perform CAPP with the displays used in the simulation. Responses were variable but the majority (18/22; 82%) agreed (M=72.6; SD=30.1). However, two of the pilots (in the same crew) that disagreed provided a 0 response (without comment). Other comments on the displays indicated that one of these pilots wanted a recommended speed and the other seemed to want all the information on the ND. Pilots were asked whether they were comfortable using the displays both when the TTF was not and was visible OTW. The majority (21/22; 95%) of pilots agreed when the aircraft was not visible (M=82.4; SD=21.7) and the majority (21/22; 95%) of pilots agreed when the aircraft was visible (M=85.0; SD=20.2). For both statements, the one pilot that provided a low disagreement rating was one of the same pilots that provided a 0 response to the willingness to use the displays. See Figure 4-60 for a summary of these statements.

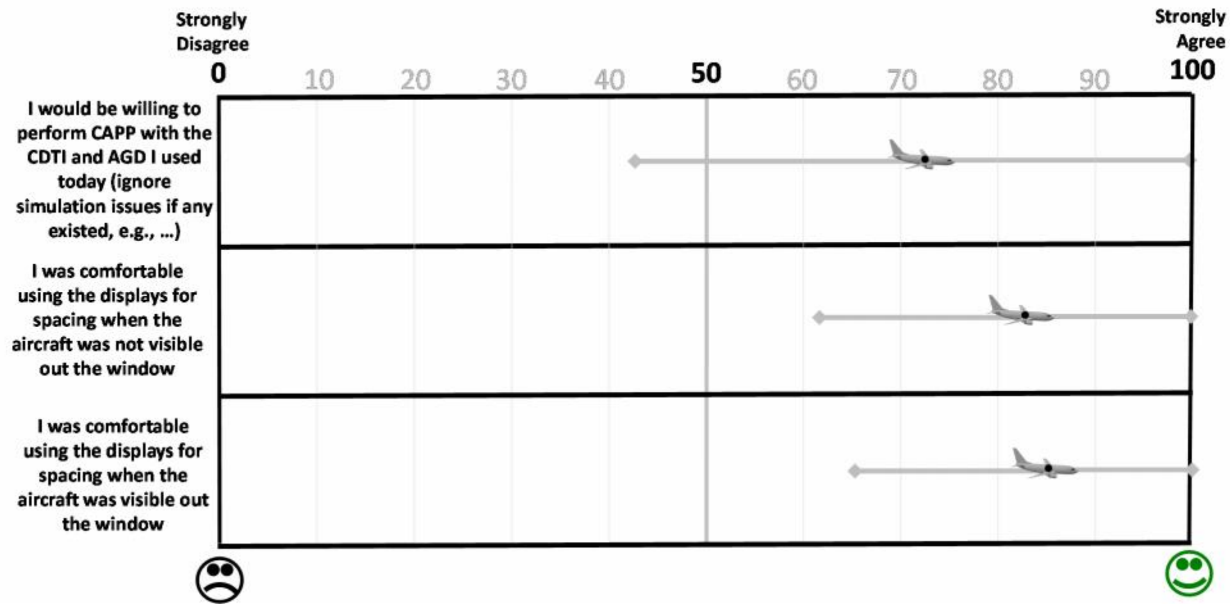

Figure 4-60. Summary of Pilot Overall Display Statements

Pilots were also asked about the display elements. When asked if the DGS is useful, all pilots agreed (M=91.9; SD=10.6). The majority (19/22; 86%) of pilots also agreed that DGS is a minimum requirement (M=83.5; SD=27.2). When asked if the range to the TTF is useful, all pilots agreed (M=92.6; SD=5.9). The majority (20/22; 91%) of pilots agreed that range is a minimum requirement (M=81.5; SD=23.7). When asked if the graphical closure cue (i.e., ><) is useful, pilot responses were variable but the majority (16/22; 73%) agreed (M=66.7; SD=30.6). Pilot responses were evenly split as to whether the graphical closure cue is a minimum requirement: 9 (41%) disagreed, 4 (18%) were neutral, and 9 (41%) agreed. See Figure 4-61 for a summary of these statements. The majority (19/22; 86%) of pilots replied “yes” when asked whether both displays included all the necessary information for CAPP. Of those that replied “no” one wanted “visual trend information”, one wanted a “glideslope” on the AGD, the final one wanted “cueing when target aircraft changes significantly.”

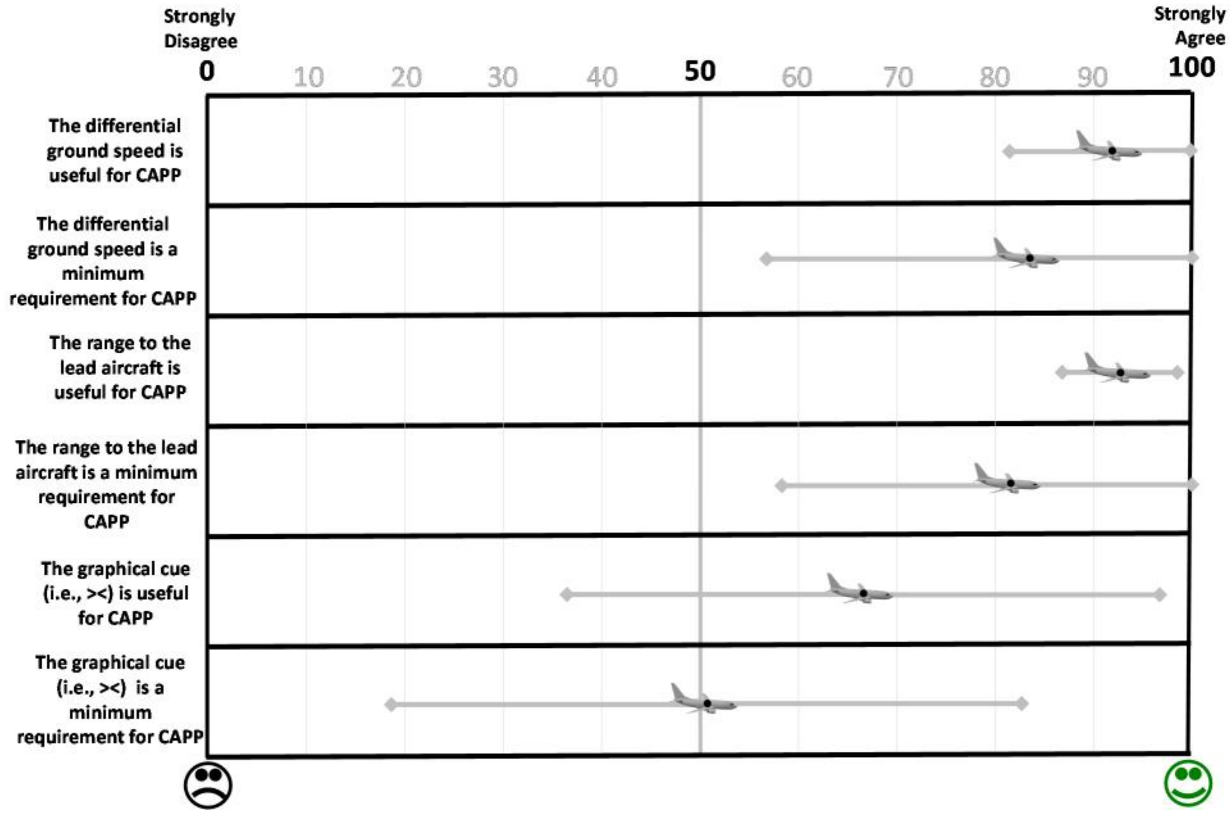

Figure 4-61. Summary of Pilot Utilized Display Element Statements

Besides being asked about the display elements the pilots had available, they were asked if the display of a distance-from-NCT-value would be useful. Pilot responses were variable (M=58.6; SD=27.7). Pilot responses were also variable about whether it could be a requirement (M=57.0; SD=32.6). See Figure 4-62 for a summary of these statements. Overall, pilots seemed willing to use the displays both with and without the TTF in sight OTW and reported the necessary display elements were available.

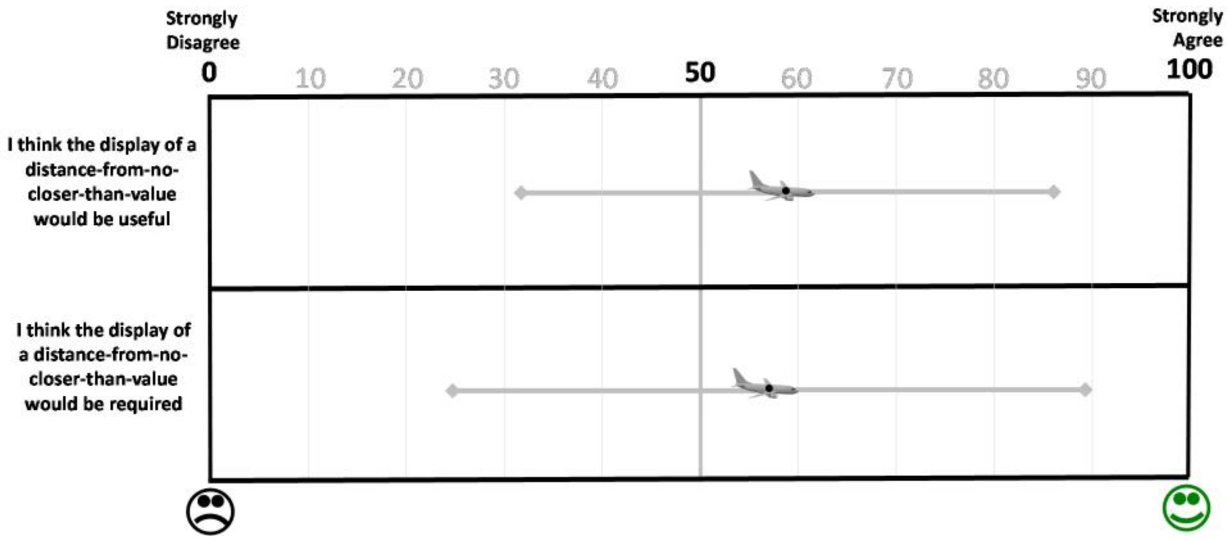

Figure 4-62. Summary of Pilot Potential New Display Element Statements

In the majority of the scenarios when it was appropriate for the flight crew to transition to CAVS, the PM pushed one button to swap the CAPP NCT value for the CAVS minimum distance value (as described in Section 3.1.2.2). Pilots were asked in the post-scenario questionnaire about the acceptability of this display interaction. The results were similar across conditions. Pilots found the interaction acceptable.

- 1800 ft and 3.2 NM
  - The majority (37/41; 90%; Missing 3 values) of pilots agreed (M=81.4; SD=20.0).
- 1800 ft and 3.5 NM
  - The majority (38/44; 86%) of pilots agreed (M=80.4; SD=21.1).
- 3300 ft and 3.2 NM
  - The majority (35/38; 92%; Missing 6 values) of pilots agreed (M=82.8; SD=24.6).
- 3300 ft and 3.5 NM
  - The majority (32/36; 89%; Missing 8 values) of pilots agreed (M=83.4; SD=19.9).

An extra event did not have this one button option so the flight crew was required to enter the operations menu and conduct six actions (versus one) to swap the CAPP NCT value for the CAVS minimum distance value. The time required to swap the values is shown in Table 4-42. The extra actions took much longer than the one button push swap, as would be expected.

Table 4-42. Time from Transition to Visual Conditions to the Participant Pilot Swapping of the CAPP NCT Value for the CAVS Minimum Distance by Condition

Condition	SWAP conducted (%)	Time to Select SWAP	
		Mean (sec)	SD (sec)
1800 / 3.2	47	16.4	10.1
1800 / 3.5	58	17.3	7.9
3300 / 3.2	78	38.7	21.2
3300 / 3.5	90	38.2	20.1
Extra Actions to Swap CAPP NCT value for CAVS minimum distance	90	59.6	36.0

In the post-scenario questionnaire, the pilots were asked about the acceptability of performing these additional actions. Pilot responses were variable (M=62.9; SD=33.9. Missing 1 value). Figure 4-63 depicts the results for all conditions. As can be seen, the greater number of CDTI actions to transition to CAVS appeared much less favorable.

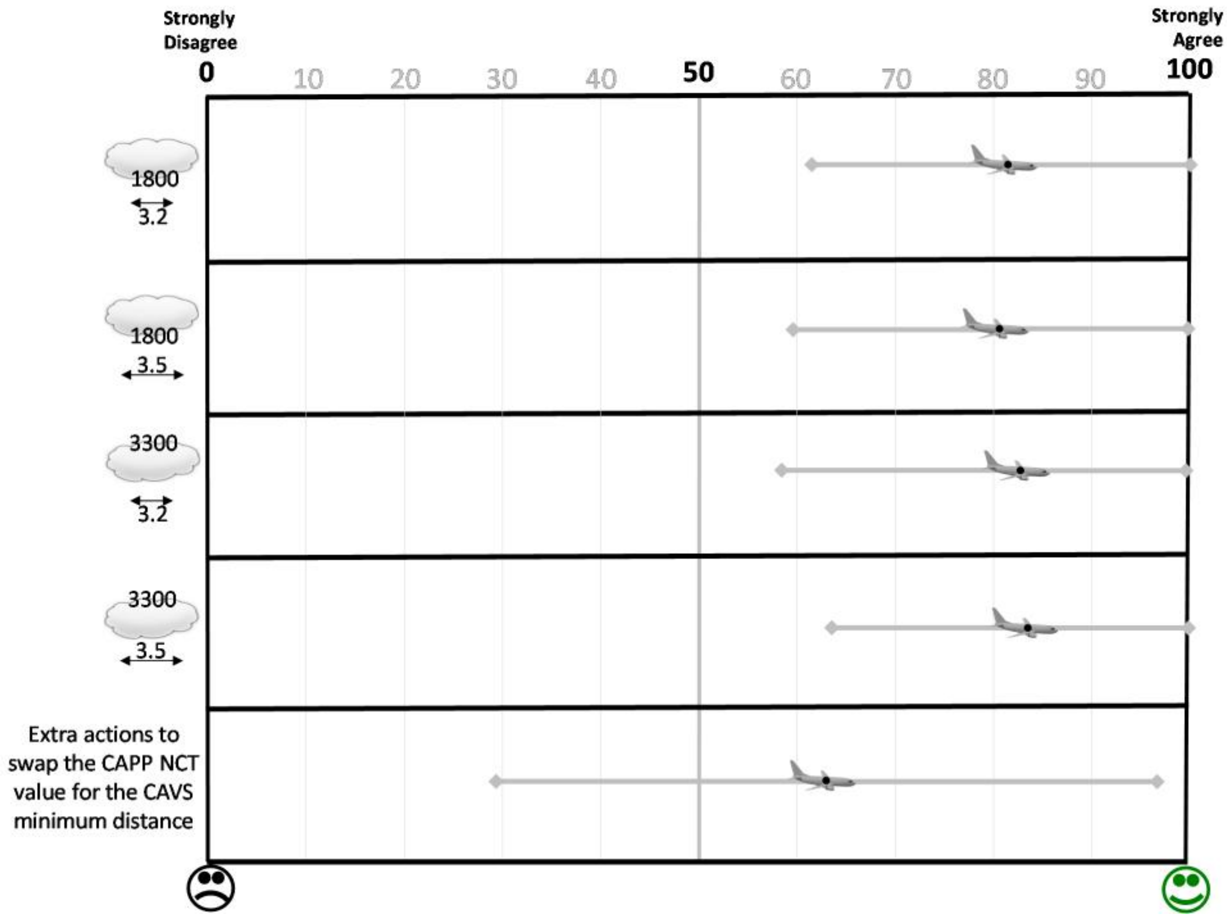

Figure 4-63. Pilot Responses to Statements Related to the Acceptability of the Number of CDTI Actions to Transition from CAPP into CAVS

4.9 Communications

When asked if the CAPP instruction was acceptable, the majority (10/11; 91%) of the controllers agreed (M=78.6; SD=14.4). One (9%) was neutral. Pilot responses were variable but the majority (16/22; 73%) agreed (M=71.5; SD=28.3). At least two of the pilot disagree ratings were due to combining the CAPP instruction with the ILS clearance. One controller also stated the combining of the CAPP instruction with the ILS clearance "is a lot to say all at once." As will be shown later in this section, only two controllers used this combination on a regular basis.

Pilots were asked if the point where the CAPP instruction was issued was acceptable. Pilot responses were variable (M=55.1; SD=36.8). Thirteen (59%) pilots agreed and nine (41%) pilots disagreed. Of the seven that disagreed and provided comments, five (71%) suggested that it should come earlier while the other two (29%) had issue with combining the CAPP instruction and the ILS clearance (as noted above). Overall it appears the CAPP instruction is acceptable to both controllers and pilots, but the combination of the CAPP instruction with the ILS clearance can make communications challenging. Additionally, some pilots want the CAPP instruction earlier.

Because a separate traffic advisory had been part of the initial CAPP communication (as described in Section 2.6.3), pilots and controllers were asked if a separate traffic advisory communication was a necessary prior to the CAPP instruction. Controller responses were variable but the majority (8/11; 73%) disagreed (M=32.2; SD=30.0). Pilot responses were evenly split: 10 (45%) disagreed, 2 (9%) were neutral, and 10 (45%) agreed (M=50.1; SD=32.1). See Figure 4-64 for a summary.

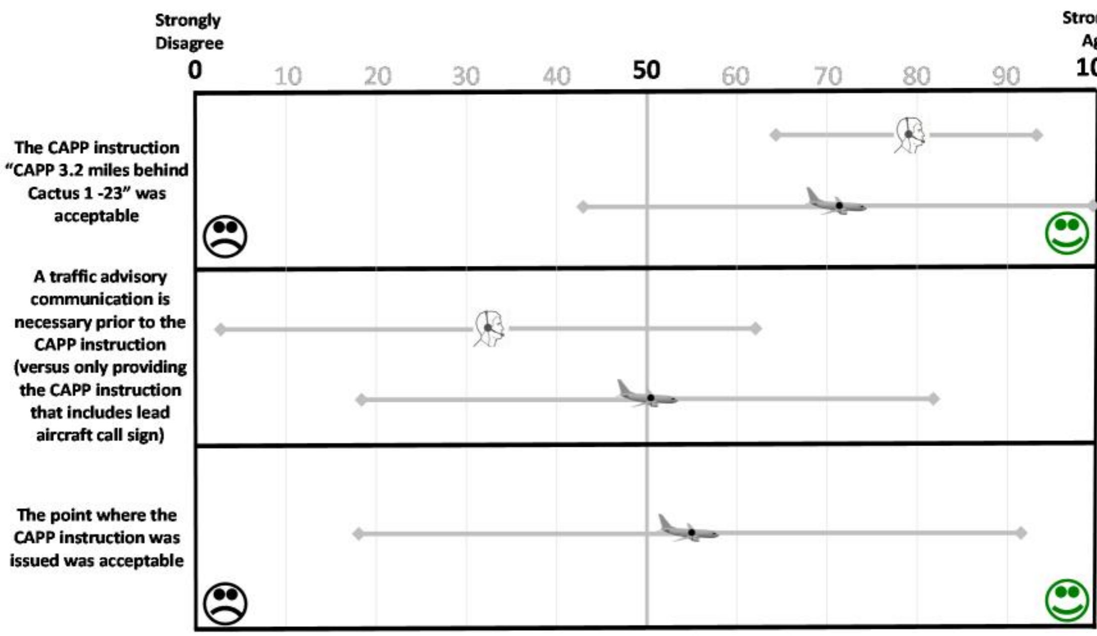

Figure 4-64. Summary of Responses to Statements on the CAPP Instruction

Participants were asked whether the use of TPCS in the CAPP instruction was acceptable. The majority of controllers (9/11; 82%) agreed (M=71.8; SD=20.5) and the majority (19/22; 86%) of the pilots agreed (M=74.6; SD=21.6). When pilots were asked whether they experienced any confusion about whether they were being talk to (as a first party aircraft) or about (as a third party aircraft), the majority (19/22; 86%) of pilots disagreed (M=29.1; SD=22.2). See Figure 4-65 for a summary.

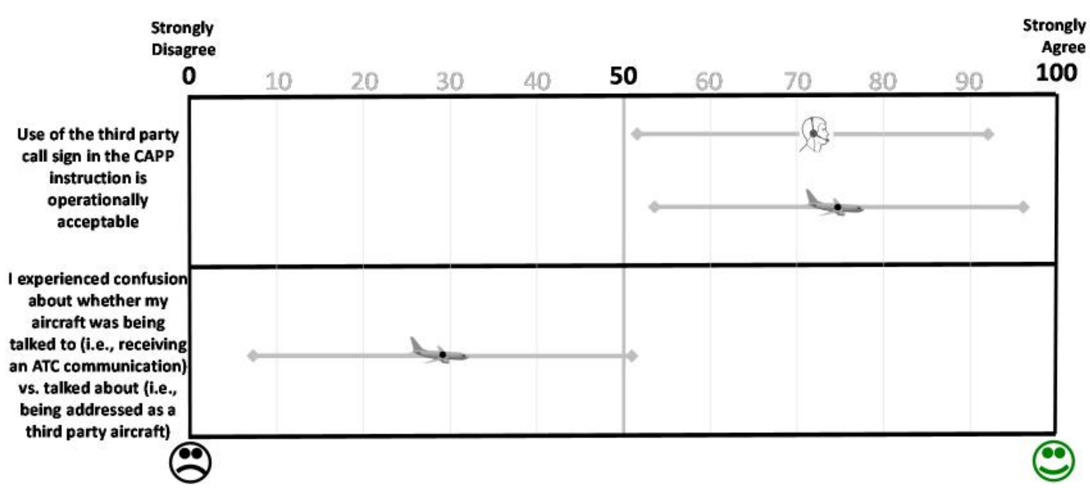

Figure 4-65. Summary of Responses to Statements on the use of TPCS in the CAPP Instruction

Data reported in the remainder of this section is mainly derived from the transcripts from the audio recordings (for additional details on the communications analysis method, see Section 0). However, since some data was not available in the audio recordings, data from controller observations is also included. The data that was available in the audio recordings is the main source of data described further in the following sections. When the data from the controller observations is used, it is noted as such.

In the available controller observation data (data was not available for scenario 1 on day 1), CAPP instructions were issued to CAPP capable aircraft 620 times (ignoring the accidental issuance of a CAPP instruction to a non-CAPP capable aircraft). In the available audio data, the controllers issued 523 CAPP instructions in the four conditions. Of the 523, some were issued when an aircraft was not CAPP capable and some were issued when aircraft were already performing CAPP.

Of the 523 issued CAPP instructions, 511 were not re-issued CAPP instructions, already provided instruction, or issued instructions to non-CAPP aircraft. Of those 511, the breakdown of how the CAPP instruction was issued is shown in Table 4-43. The table shows the majority (82%) of the CAPP instructions were issued without additional communications in the transmission. A small percentage of CAPP instructions were combined with the localizer intercept (1%) or a vector (3%). The CAPP instruction was combined with the ILS clearance in 14% of the cases. The majority (89%) of the CAPP-instruction-and-ILS-clearance combinations came from two controllers; one had 69% (49/71) and the other had 20% (14/71). The remainder was spread across the remaining controllers.

Table 4-43. CAPP Instruction and its Relationship to other Communications in Same Transmission by Condition

Condition	CAPP Instruction Alone	CAPP Instruction with ILS Clearance	CAPP Instruction with Localizer Intercept	CAPP Instruction with Vector	Total
1800 / 3.2	93 (89%)	11 (10%)	1 (1%)	0	**105**
1800 / 3.5	114 (78%)	26 (18%)	3 (2%)	4 (3%)	**147**
3300 / 3.2	96 (83%)	15 (13%)	1 (1%)	4 (3%)	**116**
3300 / 3.5	117 (82%)	19 (13%)	1 (1%)	6 (4%)	**143**
All	420 (82%)	71 (14%)	6 (1%)	14 (3%)	**511**

When the controller observation data is included, the trends are similar. The CAPP instruction was issued alone 71% (443/620) of the time and in combination with the ILS clearance 29% (177/620) of the time.

4.9.1 Controller Issues

The controller CAPP instruction communication issues broken down by condition and independent variable are shown in Table 4-44, Figure 4-66, and Table 4-45. As can be seen, each condition and independent variable had approximately one-quarter of the CAPP instructions with some form of issue. The 1800 ft conditions appeared, for unknown reasons, to have slightly more communication errors than the 3300 ft conditions. The 3.5 NM conditions appeared, for unknown reasons, to have slightly more communication errors than the 3.2 NM conditions. The 1800 ft and 3.5 NM condition appears, for unknown reasons, to be the most different from the 3300 ft and 3.2 NM condition.

Table 4-44. Controller CAPP Instruction Issues Relative to Number of CAPP Instructions Issued by Condition

	Condition				
Issue	**1800 / 3.2**	**1800 / 3.5**	**3300 / 3.2**	**3300 / 3.5**	**All**
Total - Issued Instructions	**104**	**151**	**120**	**148**	**523**
Deviation from Defined Phraseology	13 (13%)	29 (19%)	9 (8%)	16 (11%)	67 (13%)
Stumble / Slip	12 (12%)	7 (5%)	6 (5%)	10 (7%)	35 (7%)
CAPP Instruction with Error	1 (2%)	6 (4%)	4 (4%)	4 (3%)	15 (3%)
CAPP Instruction for Non-CAPP Capable	0	3 (2%)	1 (1%)	3 (2%)	7 (1%)
CAPP Confirmation Request	0	0	0	1 (1%)	1 (<1%)
CAPP Instruction given when Controller Could Not Recall if Already Given	0	0	0	1 (1%)	1 (<1%)
Re-Issue to Aircraft Already Conducting CAPP	0	1 (1%)	2 (2%)	1 (1%)	4 (1%)
Total	**26 (25%)**	**46 (30%)**	**22 (18%)**	**36 (24%)**	**130 (25%)**

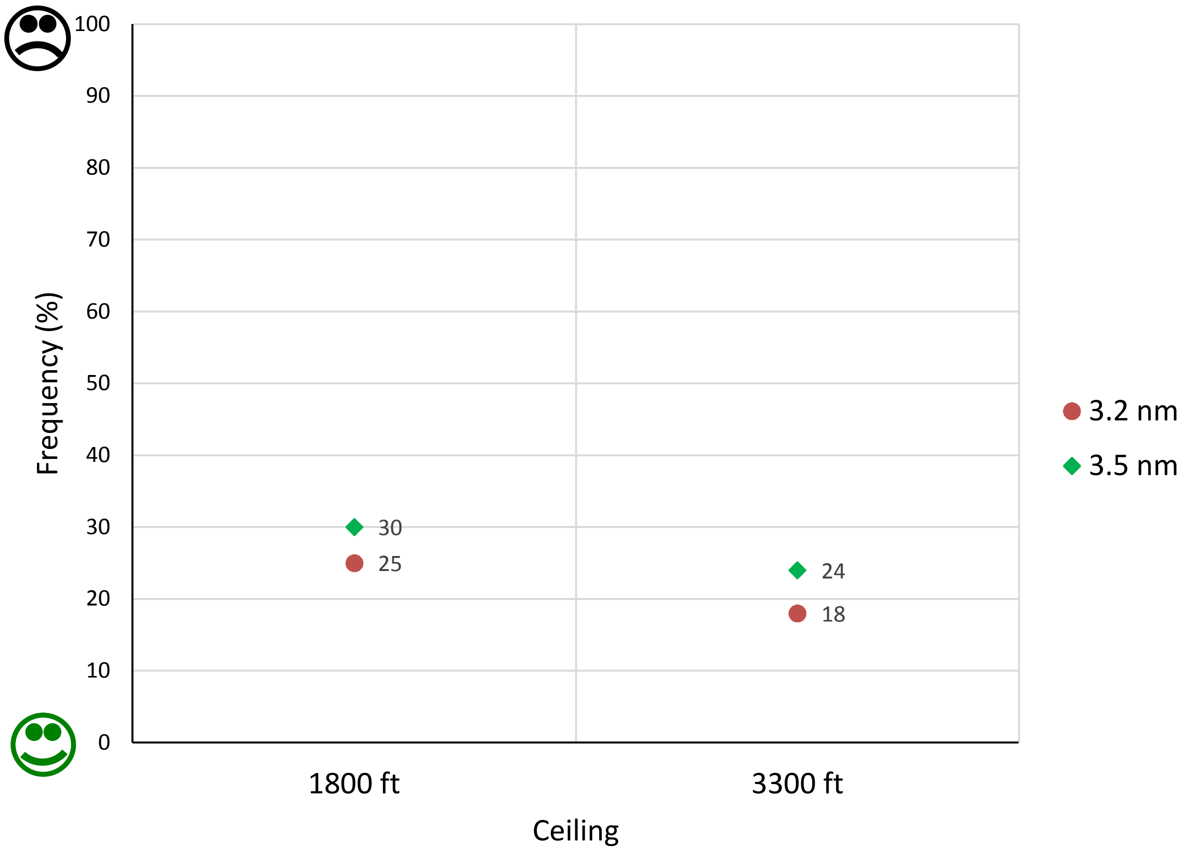

Figure 4-66. Controller CAPP Instruction Issues

Table 4-45. Controller CAPP Instruction Communication Issues Relative to Number of CAPP Instructions Issued by Independent Variable

	Independent Variable			
Issue	**1800**	**3300**	**3.2**	**3.5**
Issued CAPP Instructions	**255**	**268**	**224**	**299**
Deviations from Defined Phraseology	42 (16%)	26 (10%)	23 (10%)	45 (15%)
Stumble / Slip	19 (7%)	16 (6%)	18 (8%)	17 (6%)
CAPP Instruction with Error	7 (3%)	8 (3%)	5 (2%)	10 (3%)
CAPP Instruction for Non-CAPP Capable	3 (1%)	4 (1%)	1 (<1%)	6 (2%)
CAPP Confirmation Request	0	1 (<1%)	0	1 (<1%)
CAPP Instruction given when Controller Could Not Recall if Already Given	0	1 (<1%)	0	1 (<1%)
Re-Issue to Aircraft Already Conducting CAPP	1 (<1%)	3 (1%)	2 (<1%)	2 (<1%)
Total	**72 (28%)**	**59 (22%)**	**49 (22%)**	**82 (27%)**

Table 4-46 shows the issues broken down relative to each other. The majority (115/130; 88%) of the issues were minor and were deviations from defined phraseology, stumble / slips, and minor issues related to the issuance of the CAPP instruction. The remainder of the issues (15/130; 12%) were errors in the CAPP instruction.

Table 4-46. Controller CAPP Instruction Communication Issues Relative to Each Other

	Issues
Total	**130**
Deviations from Defined Phraseology	67 (52%)
Stumble / Slip	35 (27%)
CAPP Instruction with Error	15 (12%)
CAPP Instruction for Non-CAPP Capable	7 (5%)
CAPP Confirmation Request	1 (1%)
CAPP Instruction given when Controller Could Not Recall if Already Given	1 (1%)
Re-Issue to Aircraft Already Conducting CAPP	4 (3%)

The most frequent issue that occurred was a deviation from the defined phraseology that occurred in 67 cases (52%). As noted previously in Section 0, the exclusion of the term “miles” was not counted as an error. The majority of the time controllers used the defined phraseology. All deviations from the defined phraseology were related to the “behind” term. The majority of all deviations (82%; 55/67) were from one controller for unclear reasons. The controller used nothing in the place of “behind” for the majority of the cases (87%; 48/55). The remainder of the times he substituted new words (i.e., “with,” “off,” “from,” “on”). The controller did not report any communication issues in the post-scenario or post-simulation questionnaires. The next most frequent deviation (12%; 8/67) were from one controller who used “following” instead of “behind” in the 1800 ft and 3.5 NM condition for unknown reasons. The remainder (7%; 5/67) were committed by a third controller when “from” was used instead of “behind”. None of the other CAPP instruction elements (i.e., “CAPP” term, FPCS, TPCS, or NCT value) had issues. All controller deviations went uncorrected by either the pilot or the controller, as would be expected for deviations from the term “behind,” and no follow-on communication were present.

The next most common communication issue was a minor stumble / slip that occurred in 35 cases (27%). Table 4-47 shows the majority of the stumble / slips were related to the call sign of either the first or third party aircraft. All stumbles / slips were quickly self-corrected within the same communication transmission (by definition) and no follow-on communication were present.

Table 4-47. CAPP Instruction Stumble / Slip Element Frequency

CAPP Instruction Element	Cases
"CAPP" Term	3
FPCS	10
TPCS	13
NCT Value	9
"Behind" Term	0

The CAPP instruction had errors in 15 cases (12%). Table 4-48 shows the majority of the CAPP instructions with errors were related to the call sign of either the first or third party aircraft. All the first party call sign issues were resolved. The FPCS errors were all corrected by the pilots in the read back. All the TPCS issues were resolved. Four of the five (80%) were corrected by the pilots in the read back. The last one (20%) was corrected by the controller in a follow-on transmission. For the six issues related to the NCT value: two (33%) were corrected by the pilots in the read back, one (17%) was corrected by the controller in a follow-on transmission, and three (50%) were not corrected.

Table 4-48. CAPP Instruction with Error Element Frequency

CAPP Instruction Element	Cases
"CAPP" Term	0
FPCS	4
TPCS	5
NCT Value	6
"Behind" Term	0

In seven cases (5%), controllers attempted to issue a CAPP instruction to aircraft that were not CAPP capable. All cases were resolved by either the pilot or the controller. Three of the cases (43%) were quickly self-corrected by the controllers prior to the pilot reply. Three of the cases (43%) were corrected by the pilots in the read back. The final case (14%) was corrected by the controller in a follow-on transmission.

In one case (1%), a controller asked an aircraft that was conducting CAPP to confirm CAPP was being conducted. In 4 cases (3%), a controller unintentionally re-issued the same CAPP instruction to an aircraft that was already conducting CAPP. Finally, in 1 case (1%), a controller issued a CAPP instruction to an aircraft when the controller was not sure whether the CAPP instruction had been previously issued (it had not). Overall, the vast majority of ATC communication errors were minor. Errors related to FPCS or TPCS in the CAPP instruction were all corrected and resolved.

4.9.2 Participant Pilot Issues

Table 4-49 and Table 4-50 show the total number of CAPP instruction communication issues for the participant pilots. Most conditions had approximately 19% of the CAPP instruction communications with some form of issue (the 3300 ft and 3.2 NM condition had fewer). Table 4-51 shows the issues broken down relative to each other.

Table 4-49. Participant Pilot CAPP Instruction Issues Relative to Number of CAPP Instructions Issued by Condition

	Condition				
Issue	**1800 / 3.2**	**1800 / 3.5**	**3300 / 3.2**	**3300 / 3.5**	**All**
Total - Received Instructions	**17**	**18**	**17**	**17**	**69**
Deviation from Defined Phraseology	0 --	0 --	0 --	0 --	0 --
Stumble / Slip	2 (12%)	1 (6%)	0 --	1 (6%)	4 (6%)
Non-Response	0 --	0 --	0 --	0 --	0 --
Readback Error	0 --	1 (6%)	0 --	2 (12%)	3 (4%)
Data Missing from Readback	1 (6%)	0 --	0 --	0 --	1 (1%)
Request for Full Repeat	0 --	0 --	1 (6%)	0 --	1 (1%)
Request for Clarification	0 --	1 (6%)	0 --	1 (6%)	2 (3%)
Total	**3 (18%)**	**3 (16%)**	**1 (6%)**	**4 (24%)**	**11 (16%)**

Table 4-50. Participant Pilot CAPP Instruction Issues Relative to Number of CAPP Instructions Issued by Independent Variable

	Independent Variable			
Issue	**1800**	**3300**	**3.2**	**3.5**
Total - Received Instructions	**35**	**34**	**34**	**35**
Deviation from Defined Phraseology	0 --	0 --	0 --	0 --
Stumble / Slip	3 (9%)	1 (3%)	2 (6%)	2 (6%)
Non-Response	0 --	0 --	0 --	0 --
Readback Error	1 (3%)	2 (6%)	0 --	3 (9%)
Data Missing from Readback	1 (3%)	0 --	1 (3%)	0 --
Request for Full Repeat	0 --	1 (3%)	1 (3%)	0 --
Request for Clarification	1 (3%)	1 (3%)	0 --	2 (6%)
Total	**6 (17%)**	**5 (15%)**	**4 (12%)**	**7 (20%)**

Table 4-51. Participant Pilot CAPP Instruction Communication Issues Relative to Each Other

	Issues
Total	**11**
Deviation from Defined Phraseology	0 --
Stumble / Slip	4 (36%)
Non-Response	0 --
Readback Error	3 (27%)
Data Missing from Readback	1 (9%)
Request for Full Repeat	1 (9%)
Request for Clarification	2 (18%)

The pilots responded to all CAPP instructions and had no deviations from the phraseology used by the controller (note: the controller could have used the wrong phraseology, but the pilot read back the phraseology the controller used). All but one case (99%) that needed correction was corrected.

The largest number of issues (4/11; 36%) occurred in the stumble / slip category. All stumbles / slips were quickly corrected within the same transmission (by definition) and no follow-on communications were present. Two (50%) were related to the TPCS, one (25%) to the term "behind" and the final (25%) was an incorrect order of the instruction elements.

Of the three cases (27%) that included a read back error, two cases (67%) were related to the NCT value and both were corrected by the controller in a follow-on transmission. The other read back error was a wrong read back of the TPCS (i.e., "154" instead of "1154") and was not corrected by the controller. The pilots did not correct their readback error either. However, the operation was conducted as expected by both participants since CDTI data indicates the correct aircraft was selected and that only the readback was in error.

In the case (1%) where data was missing from the read back, the pilot did not include the term "behind" and the TPCS. The controller corrected it and provided the information in a follow-on transmission. There was one request for a full repeat that was provided by the controller in a follow-on transmission. Similarly, in one of the two requests for clarification, the pilot read back the full CAPP instruction but asked for and received a confirmation. The other request for clarification was on the TPCS and was provided by the controller. The number of issues are low so the data should be considered cautiously. Overall, one-third of the issues were minor. The most significant readback error was a wrong TPCS that was not corrected by either party. However, since the correct TTF was selected and the operation was conducted as expected, no issues evolved that required later correction.

It was also of interest to determine whether there were any TPCS issues for the participant pilots. Over the course of the simulation, a CAPP instruction was issued 48 times to another aircraft, but with the participant aircraft's call sign (i.e., TPCS). Of the 48 times, there were zero instances of participant pilot confusion on the communication frequency (e.g., asking "was that for us?" or mistakenly executing an instruction for another aircraft).

4.9.3 Overall Communication Issues

Table 4-52 shows the breakdown of all 141 CAPP instruction communications with controller or participant pilot issues. Note the majority (90%) of errors shown in Table 4-53 occurred when the CAPP instruction was issued without other clearances / instructions as would be expected since the CAPP instruction was most often (82% of the time) issued alone. The CAPP instruction was issued along with the ILS clearance in 14% of the CAPP operations but only 4% of the issues were associated with those communications.

Table 4-52. Total CAPP Instruction Communication Issues by Condition

Condition	Total Controller Issues	Total Pilot Issues	Total Issues
1800 / 3.2	26	3	**29**
1800 / 3.5	46	3	**49**
3300 / 3.2	22	1	**23**
3300 / 3.5	36	4	**40**
All	130	11	**141**

Table 4-53. CAPP Instruction Communication Issues as Related to Transmission Content

	All
Total	141
CAPP Instruction Alone	127 (90%)
CAPP Instruction with ILS Clearance	6 (4%)
CAPP Instruction with Localizer Intercept	4 (3%)
CAPP Instruction with Vector	4 (3%)

Table 4-54 shows how often the CAPP instructions were issued with additional communications in the transmission and the relationship to communication issues. The table shows the number of times the CAPP instruction communication was issued and when issues occurred. There may be more than one issue associated with each time the particular CAPP instruction was issued. For unknown reasons, the CAPP instruction with a localizer intercept had the largest percentage (67%) of issues. This instruction has more information than the CAPP instruction alone but less than the CAPP instruction with the ILS clearance (which had a much smaller percentage [8%]). It should be noted that even though the CAPP instruction with the ILS clearance had the lowest percentage, it was noted as a challenging communication for some of the pilots who experienced it and at least one of the controllers who tried using it (as mentioned previously in this section).

Table 4-54. Relationship between Issues and CAPP Instruction Communication

	Issues	Times Utilized	Issues in Comm Exchange when Utilized
Total	141	511	28%
CAPP Instruction Alone	127	420	30%
CAPP Instruction with ILS Clearance	6	71	8%
CAPP Instruction with Localizer Intercept	4	6	67%
CAPP Instruction with Vector	4	14	29%

4.10 Simulation

Participants were asked whether the simulation environment was an effective context for evaluating CAPP. The majority (10/11; 91%) of the controllers agreed (M=85.5, SD=15.0). One was neutral. The neutral controller commented on the pseudo-pilot aircraft behavior (e.g., higher than normal turn rates). The majority (20/22; 91%) of pilots also agreed (M=85.4, SD=16.6). Participants were also asked if they received an adequate amount of training. All (11/11; 100%) of the controllers reported getting an adequate amount of training. The majority (19/22; 86%) of pilots reported getting an adequate amount of training. See Figure 4-67 for a summary of these statements.

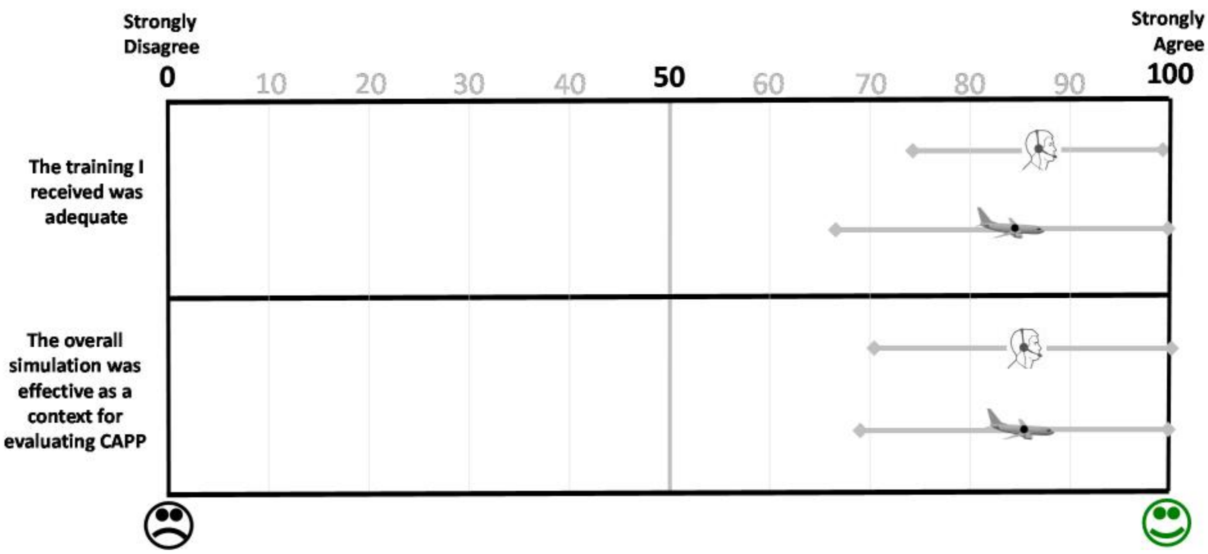

Figure 4-67. Summary of Controller and Pilot Responses to Simulation Statements

5 Discussion

The following sections provide interpretation of the results and draw conclusions. Results from the full set of data (i.e., post-scenario questionnaires, post-simulation questionnaires, and objective data) are integrated. Material related to the general conduct of the full approach (CAPP and CAVS) is covered first followed by broader topic areas and then any extra events not already covered.

When the term “pilot” is used, it refers to the participant pilots. When data is based on pseudo-pilots, it is noted as such. When subjective results are discussed, they are only based on participant pilot data. However, some objective results combine participant and pseudo-pilot data. Additionally, the majority of the results are based on the four conditions examining the independent variables and the associated levels (i.e., ceiling [1800 and 3300 ft] and NCT value [3.2 and 3.5 NM]). Any results associated with the extra events (i.e., CAPP aircraft overtake; no transition from CAPP to CAVS; CAPP with pilot separation responsibility; or extra action to swap the CAPP NCT value for the CAVS minimum distance) will be noted as such.

Overall, the results support the hypotheses of CAPP being feasible and acceptable to controllers and pilots under both ceiling and NCT value conditions. The results also support the hypotheses related to the pilot’s ability to conduct CAPP and remain at or outside the NCT value as well as the controller’s ability to detect spacing / separation issues during CAPP. The displays and communications utilized in the simulation were reported as providing the necessary information for CAPP.

The 3300 ft ceiling was generally found to be more acceptable than the 1800 ft ceiling to pilots and controllers. The NCT value appeared to be less of a factor for pilots, but the 3.2 NM NCT value appeared to better approximate the spacing desired by the controller. Controllers were generally more positive about the concept due to reduced workload and additional support for the spacing task during approach. Pilots reported increased traffic awareness but also increased workload. Finally, both pilot and controller questionnaire replies raised questions about the appropriate separation responsibilities.

5.1 Approach Conduct (CAPP and CAVS)

5.1.1 Initiation

To initiate CAPP, controllers needed to know which aircraft were capable (70% were capable in the simulation). All controllers agreed that placing a symbol next to the aircraft identification on the surveillance display was an acceptable means to differentiate between aircraft that were capable of CAPP and those that were not. Once CAPP was initiated, controllers were asked to enter “CP” into the scratchpad if they thought it was useful to differentiate between aircraft actively conducting CAPP and those capable but not actively conducting CAPP. While there was some variability, the majority of the controllers reported that entering “CP” into the scratchpad was necessary. This data indicates the expected ground requirements in FAA (2014a) are those necessary and sufficient for the controller.

CAPP was initiated the vast majority of the time with little difference across conditions. Controllers provided the CAPP instruction most often when the CAPP aircraft was on an intercept to the final approach course (as instructed and specified in RTCA and EUROCAE [2013b]). The majority of the time the controller issued the CAPP instruction alone and in those cases the controllers and pilots found it acceptable. However, there were instances where the controllers issued the CAPP instruction with another instruction (i.e., ILS clearance, localizer intercept or a vector). For unknown (and possibly random) reasons, the combination of the CAPP instruction and a localizer intercept instruction had the most communication errors percentage-wise. While some pilots and at least one controller reported the CAPP instruction combined with the ILS clearance was a challenging communication, the fewest communication errors occurred in this combination. However, this combination was not used by the majority of controllers and is not one the authors can recommend based on its complexity.

Controllers issued the CAPP instruction (e.g., "American 456, CAPP 3.2 miles behind United 123) the majority (97%) of the time with no issues or only minor issues (i.e., using a different term than "behind" or errors corrected within the same transmission). When looking at the controller issues that were not minor (3% of all CAPP instructions), the problem was with an error in an element of the CAPP instruction. When the NCT value was the error, half of the errors went uncorrected. While undesirable, this does not pose a safety issue because the NCT value is outside the separation standard. The error was likely just an issue with remembering which NCT value was applicable for the current scenario. The CAPP instruction also had controller errors for the FPCS and TPCS. All FPCS errors and the majority of the TPCS errors were corrected by the pilots in the readback. This indicated the pilots had a good understanding of the traffic picture during CAPP and were aware of instructions intended for them based on the information provided in the CAPP instruction and the set-up geometry (i.e., it was highly likely the aircraft just ahead of them on final was the aircraft they were intended to follow). The remainder of the TPCS issues were corrected by the controller.

Sixteen percent of all the participant pilot CAPP instruction readbacks had issues. The largest number of issues were minor (i.e., issues corrected within the same transmission). When looking at the pilot issues that were not minor, errors in reading back an element of the CAPP instruction was the largest category (3 cases). Two cases were reading back the wrong NCT value, which were both corrected by the controller. The final case was the incorrect readback of the TPCS (the first number was not included), which was not corrected. However, the operation was conducted as expected since the correct aircraft was actually selected by the flight crew and CAPP was performed off of the correct aircraft. This indicates the readback was a slip in speaking (and not in intent).

Also of interest for the CAPP instruction is any confusion related to TPCS. Using TPCSs to talk about (rather than talking to) other aircraft on the same frequency introduces a potential for confusion for controllers and pilots. The FAA identified TPCS as a topic to address and initiated an activity to examine the topic (see Bone et al., 2013 for further details). This simulation used the results from that on-going activity to choose the TPCS option and provides data to the overall effort. Over the course of the simulation, there were zero instances of participant pilot confusion on the communication frequency (e.g., asking "was that for us?" or executing an instruction for another aircraft). The results should be interpreted cautiously since the airline name used for ownship in the simulation was not the airline name for vast majority of the pilots, which may have had an influence on this outcome. However, the results are consistent with other research specifically examining TPCS (e.g., Bone et al., 2013). The majority of pilots also reported not being confused when TPCS was used.

Effort went into keeping the CAPP instruction concise yet understandable. The NCT concept and the request to report visual conditions were implied in the communication and not explicitly stated. Additionally, a separate traffic identification communication was not included (as in RTCA and EUROCAE, 2013b; Mundra et al., 2009; Domino et al., 2010). It appears the instruction worked well based on the limited number of errors, the correction of the vast majority of errors, and the limited number of pilot repeat requests. Additionally, some controllers found it possible to combine the CAPP instruction with other instructions, including the information-rich ILS clearance. However, as noted previously, some pilots noted the combination of the CAPP instruction and the ILS instruction was challenging.

The point at which the CAPP instruction was issued was limited in the simulation (to the initiation point of on a dogleg to final or on final), and some pilots reported wanting the CAPP instruction earlier than when they received it. In real world operations, there will likely not be a limit as to where the CAPP instruction can be issued, so controllers will be able to choose an operationally logical point for themselves and pilots. If the CAPP instruction is issued earlier, a traffic advisory communication may become more important. About half of the pilots thought it may have been useful even under the conditions experienced in the simulation and may consider it more useful when the TTF is not relatively obvious based on the set up geometry.

After accepting the CAPP instruction, participant pilots appropriately entered the NCT values as instructed by the controllers. All pilots entered a CAVS minimum distance that was less than the CAPP NCT value and less than or equal to the 3.0 NM separation standard. The majority of the time 2.5 or 2.8 NM was entered for the CAVS minimum distance value. When asked what their target value was, 2.5 and 2.8 NM were reported most often and all but one were less than or equal to the 3.0 NM separation standard. The CAPP set-up process (i.e., TTF selection, NCT value entry, CAVS minimum distance value entry, and crew coordination) took, on average, 44 seconds. The set-up times under the 3300 ft conditions were longer than those under the 1800 ft conditions. However, it seemed to have little impact and may simply be a reflection of the additional time available on a longer final approach course intercept.

The spacing at CAPP initiation within the CAPP pair was, on average, approximately 5 NM. However, the dispersion led to a decision to bin the objective data for spacing parameters into “tight” initial spacing and “wide” initial spacing in the CAPP pair. As mentioned previously, the breakdown was utilized due to lack experimental control with both pilot and controller subjects and to examine CAPP under the conditions where it is most often expected to be utilized (i.e., busy facilities where tight spacing is the norm).

5.1.2 Conduct and Transition

Once the information was entered into the flight deck systems, CAPP started. The spacing results reviewed in this section is for the CAPP pairs with tight spacing.

During the CAPP portion of the approach for both participant and pseudo-pilot aircraft, minimal closure occurred, on average, for the 3300 ft conditions. The closure for the 3300 ft conditions happened in the CAVS portion of the approach, which was also the portion of the approach when the TTF was decelerating to its final approach speed and the highest DSG is expected to occur. The average closure across the full approach for the 3300 ft conditions was approximately 1 NM. The final spacings were below the NCT values, but at or above the 3.0 NM separation standard.

In the 1800 ft conditions, less closure occurred across the full approach. In the 1800 ft and 3.5 NM condition, aircraft were already close to the 3.5 NM NCT value at set-up and only closed 0.2 NM on average. In the 1800 ft and 3.2 NM condition, closure occurred across both the CAPP and CAVS portion of the approach (again where the DGS is expected to be largest). However, CAPP aircraft only closed 0.6 NM across the full approach. The final average spacing under both 1800 ft conditions for the CAPP pairs was greater than the NCT values (and at or above the 3.0 NM separation standard).

When examining participant-pilot-only CAPP aircraft pairs with tight spacing, the numbers are relatively low but similar trends in spacing were seen. However, the participant-pilot-only data has final average spacing values below the 3.0 NM separation standard and similar to those expected for CAVS / visual separation. Overall, the CAPP aircraft appeared to be able to get closer to the TTF in the final phases of the approach with a lower NCT value and / or more time for visual separation (i.e., a higher ceiling).

Over the course of the full approach (CAPP and CAVS), all conditions had a similar average number of speed changes made by the participant pilots (slightly over 3 speed changes). The majority of speed changes were speed decreases. However, some speed increases did occur. The majority of speed increases occurred during CAPP (when the CAPP aircraft was further out on the approach). The speed change magnitudes were greatest during CAPP for the 1800 ft conditions, which was likely due to decelerating as the TTF decelerates to its final approach speed. During CAVS, the magnitude of speed changes was greatest during the 3300 ft conditions, again, likely due to decelerating as the TTF decelerated to its final approach speed. In other words, the larger magnitude of speed changes was more likely driven by the TTF deceleration to its final approach speed versus something specifically related to the CAPP or CAVS operation. The CAPP aircraft had to adjust for the deceleration of the TTF during CAPP for the 1800 ft condition and during CAVS for the 3300 ft condition because of the difference in the distances from the threshold for the two ceilings (i.e., the same distance from the threshold occurs later in the approach / during CAVS in the 3300 ft conditions.)

During the conduct of CAPP, the majority of pilots reported they were able to remain outside the NCT for all conditions and statistical tests indicate they reported being better able to remain outside the NCT values under the 3300 ft conditions than the 1800 ft conditions (the NCT values did not show a significant difference). Pilots reported they were able to detect developing spacing issues. All pilots agreed their traffic awareness was acceptable.

When asked about their ability to manage CAPP operations, the majority of controllers agreed they were confident the spacing being achieved by the CAPP aircraft would remain outside their separation responsibility for all conditions and the statistical test did not reveal any differences between conditions. Similarly, the majority of controllers agreed they could detect developing spacing / separation issues for CAPP aircraft under all conditions and the statistical test did not reveal any differences between conditions. The majority of controllers also reported they knew when to intervene on CAPP aircraft under all conditions. Additionally, controllers did not intervene unnecessarily when pilots were performing CAPP, were outside the NCT value, and had no developing spacing issues.

Based on the number of aircraft conducting CAPP (70%) in the simulation, CAPP did not have a negative impact on the monitoring of non-CAPP aircraft. In fact, the majority of controllers either reported no impact or an ability to be freed up to increase monitoring of non-CAPP aircraft. Overall, the majority of controllers reported the necessary scan time and their traffic awareness was acceptable.

Even though it was set for them in the simulation, the majority of controllers agreed that in actual operations they would be able to determine the appropriate NCT value. The majority of controllers and pilots agreed the spacing being achieved during both NCT values was acceptable. Controller and pilot responses were variable when asked whether they would be more comfortable with a closer than 3.2 NM NCT value. Prior to going any closer than 3.2 NM, it should be considered whether a closer NCT value is needed since the intent is to transition into CAVS / visual separation operations. Going closer than 3.2 NM may also create more issues for controllers related to knowing when to intervene when they are still responsible for separation. The 3.2 NCT value may be sufficient for ceilings allowing for additional closure after a transition into CAVS / visual separation operations. Obviously, an appropriate NCT value is driven by the aircraft pairing and the spacing desired by the controller at the point of transition to visual operations / CAVS. In other words, a higher NCT is acceptable for higher ceilings.

When asked whether the spacing being achieved by the CAPP aircraft was desired, the majority of the controllers agreed for both NCT values but were slightly more variable for the 3.5 NM conditions. This possibly indicates a controller desire for the pilots to reduce spacing as close as possible to the separation standard.

CAPP either ended in a transition to visual operations / CAVS or in an abnormal termination. Controllers could terminate CAPP if they felt there was a spacing or separation issue developing. Flight crews were instructed to report “unable CAPP” if there were unable to remain outside the NCT value. The CAPP range indication advisory alert was intended to inform the flight crew when encroaching on the NCT value and was triggered 20 seconds prior to reaching the NCT value[10]. Flight crews were told that when the NCT range indication advisory was triggered, they should take action to avoid reaching NCT value or, if unable, to contact the controller. The CAPP range indication advisory alert was triggered in 14% of the CAPP operations. The 3300 ft ceiling condition had many fewer CAPP alerts as compared to the 1800 ft ceiling condition. The higher number of alerts under the 1800 ft conditions was likely due to the fact that the majority of the compression had already occurred and the spacing between the aircraft was at about the closest point on the approach.

At CAPP initiation, there were cases (4% out of the 14%) where the controllers initiated the operation when the CAPP aircraft was already inside the NCT value. This may have happened for at least three reasons: 1) the controller may not have realized the CAPP aircraft was inside the NCT value, 2) the controller realized the CAPP aircraft was inside the NCT value but initiated

[10] If conditions were encountered that prevented the triggering of the alert at 20 sec, the alert was triggered when it was determined the NCT value had been reached.

anyway, or 3) the aircraft may have been outside the NCT value when the controller set up the operations but the aircraft got inside the NCT value once the equipment was set up. The pilots may not have checked to see if they were inside the NCT value at initiation (nor were they required to). Initiating CAPP inside the NCT value does not create a safety issue but could lead to unnecessary workload and communications.

The other cases (10% out of the 14%) were where the CAPP operation was initiated outside the NCT value but CAPP aircraft encroached on the NCT value. The majority of the participant pilots were able to remain at or outside the NCT value after the alert was triggered. However, there were two cases when the pilots remained inside the NCT value but did not report it to the controller. Pilots may have made a judgment call that reporting the situation to the controller was unnecessary based on the conditions at the time or may have been waiting for the controller to intervene. Such a result would be consistent with Prinzel et al. (2012), who found that when pilots did not have separation responsibility during a spacing task (as compared to when they did), they waited for the controller to respond to a separation issue (when they should have reported a spacing issue).

There were zero minimum range caution level alerts over the course of the approach (i.e., none under either CAPP or CAVS).

CAPP abnormal terminations occurred more often in the 1800 ft conditions, as would be expected since the aircraft are closer to the NCT value when the controller is still responsible for separation (i.e., there has not been a transition to CAVS / visual separation). Both NCT values had a similar number of terminations. A majority of all terminations across the conditions were initiated by the flight crew. After termination, the majority of the time, the controller did not break the aircraft out, but kept it on the approach. This occurred more often when the pilot initiated the termination. Only a limited number of aircraft were broken out of the approach immediately or later in the approach. Additionally, there were approximately five times fewer breakouts of aircraft conducting CAPP than there were aircraft not conducting CAPP. This indicates CAPP can help prevent breakouts during approach.

When asked if the abnormal termination procedures were clear, all controllers agreed they were. However, controllers did report difficulty resolving issues when pilots reported “unable CAPP.” The pilot responses were variable, but the majority agreed the termination procedures were clear. The variability may be related to the question of what to do and when (regardless of training) if the controller is still responsible for separation.

Participant and pseudo-pilots were responsible for reporting “traffic in sight” or reaching visual conditions to the controller once visual conditions were reached (the transition point). Participant and pseudo-pilots reported the transition to visual conditions the vast majority of the time for the 3300 ft conditions, but only slightly more than half of the time for the 1800 ft conditions. On many occasions, both participant pilots and pseudo-pilots were not prompt in reporting traffic in sight either due to workload or forgetfulness. The participant pilots appeared sometimes confused about whether they should report traffic in sight or not since they were authorized to conduct CAVS without the traffic in sight OTW. Participant pilots sometimes just reported reaching visual conditions. This caused the controller to be confused at times about whether the traffic was actually in sight and visual separation could be issued.

This indicates that in training for CAPP, it should be made clear that having the aircraft on the CDTI for CAVS allows the pilot to report the traffic in sight while it is not in sight OTW. This may become more obvious once pilots normally conduct CAVS.

After getting cleared for CAVS, participant and pseudo-pilots were expected to swap the CAPP NCT value for the CAVS minimum distance. Regardless of whether the transition to visual conditions were reported, data was captured on whether or not pilots performed the swap, and how long it took, when actually in visual conditions. Participant pilots conducted the swap the vast majority of the time for the 3300 ft conditions, but only about half of the time for the 1800 ft conditions. In the 1800 ft conditions, participant pilots may have chosen not to or forgot to swap values. When the swap was conducted in the 1800 ft ceiling conditions, participant pilots took about half of the time seen in the 3300 ft conditions. These results may be a reflection of the proximity of the CAPP aircraft to the FAF, the expectation of little additional closure, and other competing priorities (e.g., transitioning to a landing configuration).

When asked if the transition from CAPP to CAVS was acceptable, controllers and pilots generally agreed it was. Pilots appeared to find the transition more acceptable than the controllers for both ceiling conditions. Controllers appeared to find the 3300 ft conditions more acceptable than the 1800 ft conditions for the transition. Part of the issue for the controllers with the 1800 ft conditions may have been the transition occurred close to or after the point where some facilities have already transferred aircraft to the tower controller.

Both pilots and controllers appeared to question the acceptability of a lower ceiling, while a higher ceiling appears to be potentially more acceptable. However, controller replies had variability for the higher ceilings. Some of the variability of the controller replies for higher ceilings may be due to questioning the benefits of CAPP when visual operations (e.g., CAVS) could be conducted without the need for CAPP. Lower ceilings may not have sufficient time to exit CAPP and transition to CAVS / visual separation and further close the spacing from the TTF.

When asked if the CAPP operation was acceptable, controllers generally agreed it was. Statistical tests on the post-scenario results did not reveal a difference among the conditions. However, trends in the post-simulation and post-scenario indicate the 3300 ft conditions may be more acceptable. When pilots were asked if the CAPP operation was acceptable, responses were variable but the majority agreed that it was acceptable and statistical tests indicate they found the 3300 ft conditions more acceptable than the 1800 ft conditions.

When asked about workload during the approach, the majority of controllers reported acceptable and similar workload across the conditions. Statistical tests did not reveal any differences across the conditions. The majority of controllers reported the workload associated with CAPP was reduced compared to similar non-CAPP conditions. All controllers agreed the workload was acceptable. For pilots, the majority found workload acceptable but some did report very challenging workload conditions. Some even reported the “task” was impossible to complete. A rating this strong indicates the situation was particularly challenging and the task being “impossible” was the task of conducting CAPP (versus the task of flying the aircraft) as all pilots continued successfully flying the aircraft after reporting the condition to the controller. The workload rating experienced during CAPP in this simulation were higher than those reported in the past for IMC CAVS to single runways (e.g., Bone, Helleberg, et al., 2003a). For the TLX, statistical tests on the pilot replies found the 1800 ft conditions to require more workload than the 3300 ft conditions. The majority of pilots reported the workload associated with CAPP was increased compared to similar non-CAPP conditions. While pilot responses were variable and some responses were very high, the majority agreed that workload was acceptable.

5.2 Flight Deck Displays

Flight crews had two displays associated with CAPP: the AGD and the CDTI. The design of the CDTI attempted to keep necessary actions to a minimum. For example, the PM was able to select the TTF on the CDTI which auto-populated the TTF TPCS field. After that was completed, only the CAPP NCT value and the CAVS minimum distance value needed to be entered (there were no default values for either one).

When asked to estimate the amount of time spent using either display, the PFs reported referencing the AGD more often while the PM reported referencing the CDTI more often. Such results may be expected since the PF is looking mainly at the key information necessary to conduct the task (which is mainly available through the AGD). Additionally, the PM is mainly reviewing and interacting with the CDTI for set-up, the swap of the CAPP NCT value and the CAVS minimum distance value, as well as general traffic monitoring.

All pilots reported the DGS and range to the TTF were useful and the majority agreed that both were minimum requirements. When asked whether the graphical closure cue (i.e., ><) was useful, the majority agreed but were split as to whether it was a minimum requirement. Pilot responses were varied when asked whether a distance-from-NCT-value would be useful. Overall, the majority of pilots reported that both displays contained the necessary information for CAPP conduct and termination.

The pilot responses were variable for questions related to display integration into the normal scan and the level of head-down time. Additionally, the most often pilot cited disadvantage of CAPP was the head down time / scan / monitoring of displays. While there was some variability in the pilot replies, the majority agreed the necessary scan time was acceptable. The majority of pilots also reported they were comfortable using the displays both when the TTF was and was not visible OTW. When asked if they would perform CAPP with the displays used in the simulation, the majority agreed they would. Such difficulties integrating auxiliary displays into the scan, yet still showing general acceptability, has been seen in past simulations on VMC and IMC CAVS to single runways (Bone, Domino, et al., 2003; Bone, Helleberg, et al, 2003a, 2003b, 2003c).

As reported previously, the transition from CAPP to CAVS was found acceptable when only requiring one button push to swap the CAPP NCT value for the CAVS minimum distance value (as described in Section 3.1.2.2). At this point, the equipment automatically transitioned from CAPP to CAVS operations based on that single action. The pilots did not need to perform several actions to stop one ASA (CAPP) and then start another ASA (CAVS). A design that allows such an easy transition between the ASAs is highly desirable, especially when in a high workload phase of flight. An extra event examined in the simulation required the flight crew to enter the operations menu and conduct six actions (versus one) to perform the swap and transition to

CAVS. The extra actions took about four times longer than the one button push swap. Pilots found the extra actions less favorable and were variable when reporting on the acceptability.

Overall, it appears the pilots had the necessary display information as specified for CAVS in RTCA and EUROCAE (2014a, 2014b). The graphical static closure cue could possibly be improved. While the feature to distinguish between a positive and negative DGS is not specifically defined in RTCA and EUROCAE (2014a), it does note the potential for confusion if not done properly and recommends a graphical indication of the sign. The authors / researchers agreed with this concern and decided not to use a "+" and "-" indication. Consideration should be given to providing some type of dynamic graphical closure cue. However, this feature may not be a minimum requirement.

5.3 Benefits

The main goal of CAPP is to support the transition into CAVS / visual separation. The majority of controllers found CAPP to be useful for this transition while the majority of the pilots agreed (though with some variability). Controllers and pilots also seemed to find benefit to CAPP even without a transition to CAVS / visual separation.

Reduced controller workload is also expected to be a benefit of CAPP. When asked if CAPP is desirable, the majority of the controllers agreed. However, the responses for the 3300 ft conditions appear to be more desirable and less variable than the 1800 ft conditions. Controllers reported the advantages of CAPP as better spacing between aircraft, additional support for the spacing / separation task, and reduced workload. This aligns with Rognin et al. (2002) who point out the benefits of the delegation of the spacing task through increased time available for the controller for other tasks and the support of the pilot in monitoring of the spacing interval and being another loop of control.

The pilot responses were variable but the majority agreed when asked if CAPP is desirable for both the 1800 and 3300 ft conditions. Pilots reported the benefits of increased traffic awareness and better spacing between aircraft.

In order to start to understand the potential CAPP spacing benefits, participant pilot spacing behavior during the conditions examining the independent variable conditions can be compared to the baseline (ILS followed by visual separation without a CDTI) and no transition from CAPP to CAVS event. Drawing conclusions is difficult due to the low sample sizes. However, while the numbers are relatively low in the participant pilot data, the trends are very similar to that seen in the combined participant and pseudo-pilot data in Section 4.2.5. When examining the final spacing at the end of the approach for participant pilot CAPP aircraft pairs that had tight initial spacing, the 1800 ft and 3.5 NM condition had the highest spacing (greater than the NCT value by 0.1 NM and greater than the 3.0 NM separation standard). The other conditions (including the baseline) were very similar and were below the NCT value and the 3.0 NM separation standard. The no transition from CAPP to CAVS event only had one aircraft in the tight spacing category and the ones in the wide spacing pairs were similar to the 1800 ft and 3.5 NM condition. While the data should be interpreted with caution, the CAPP aircraft appeared to be able to get closer to the TTF with a lower NCT value and / or more time for CAVS / visual separation. This expectation was supported by the statistical test conducted on both participant and pseudo-pilot CAPP aircraft that had tight initial spacing that revealed closer end spacings over the course of the approach for the 3300 ft conditions as compared to the 1800 ft conditions and for the 3.2 NM conditions as compared to the 3.5 NM conditions.

As with previous CAVS simulations (e.g., Bone, Helleberg, et al., 2003c) and in order for CAPP aircraft pairs to achieve the desired final spacing, controllers will continue to have a key role in the successful implementation of CAPP. A large initial spacing within the CAPP pair is unlikely to be reduced significantly by the pilots. Tighter initial spacing will result in reduced spacing at the threshold, and may reduce variability, while retaining the ability of pilots to “fine tune” their spacing. As with Bone, Domino, et al. (2003), the NCT value was not only a NCT value for the flight crew to avoid going inside of, it became a goal for the pilots. Therefore, setting this value provided some additional support to the controller in monitoring the spacing but also provided the flight crew a spacing goal.

5.4 Extra Events

5.4.1 No Transition from CAPP to CAVS

In the majority of the scenarios, operations successfully transitioned into CAVS as expected. One extra event was designed to have the flight crew conduct CAPP until final decelerations for landing without a transition into CAVS. There were no breakouts for participant pilot aircraft in this event and controllers did not appear to report any specific issues. While the pilot participants were told not to report the transition to visual and to continue CAPP until around the FAF, a majority of pilots reported they transitioned. This may indicate a confusion between CAPP and CAVS transition versus an IMC and VMC transition or simply the transition out of CAPP to the final stages of landing was considered the transition. The event appeared to have relatively reasonable (and very similar to the independent variable conditions) pilot workload, and to be acceptable to the majority of pilots and controllers. However, not enough data was available to draw reasonable conclusions on the benefits of conducting CAPP without a transition to CAVS.

5.4.2 CAPP Aircraft Overtake

In order to trigger CAPP terminations, two CAPP aircraft overtake events were intentionally designed to test controller and pilot behavior. Both controllers and pilots experienced conditions where the TTF decelerated to a sufficient degree to cause a termination of CAPP. Some controllers also saw terminations occur prior to this one, even if not by design, simply based on issues that arose during normal CAPP operations.

All controllers detected situations requiring termination and kept the majority of the aircraft on the approach. Controllers did not appear to report any significant issues with the terminations. The ability of controllers to intervene was seen in previous simulations where controllers were able to intervene on non-normal situations such as the lead inappropriately converging on its TTF (Boursier et al., 2006; Bone et al., 2007). These studies showed the events were detected through normal monitoring and were sufficiently resolved. Although the controllers in Bone, et al. (2007) reported some questions about knowing when to intervene, all reported they were likely to detect and intervene in a developing spacing problem before it became a separation issue and did so in the scenarios presented.

All pilots detected the overtake situation and reported it to the controller for resolution. These results are similar to past CAVS simulations where the pilot had separation responsibility (e.g., Bone, Domino, et al., 2003) and IM simulations where the controller had separation responsibility (e.g., Bone et al., 2008a). The majority of the pilots indicated the AGD and CDTI included the necessary information for the termination event. This was the highest workload event reported by the pilots. While there was variability, the majority of pilots did not find CAPP acceptable in this situation, as might be expected since the overtake condition occurred unusually quickly and the confederate controller was told to not intervene on this pilot detection event. Overall, it generally appears the pilots had the necessary information for the termination event, but that it was a challenging situation when the overtake was so aggressive. A less aggressive overtake may be less challenging, but possibly more difficult to detect (though the CAPP range indication advisory alert should help if the situation progresses to that point).

Overall, the controllers appeared to be able to detect and deal with an overtake situation that was becoming a spacing / separation issue. While pilots reported high workload and unacceptability of the situation, such an aggressive deceleration is expected to be rare in the real world environment. In the real world, the controller would be expected to detect such a situation, potentially intervening prior to the flight crew receiving the alert, and intervening if a spacing / separation issue developed.

5.4.3 CAPP with Pilot Separation Responsibility

The majority of controllers and pilots reported their roles and responsibilities were clear during CAPP in the conditions examining the independent variable conditions where the controller retained separation responsibility. However, there were some replies that questioned roles and responsibilities. Prior to the simulation, the question of roles and responsibilities were known based on the CAPP concept having origins in IMC CAVS to single runways (where the pilot has separation responsibility) and questions that came up in CAPP concept development. Additionally, the ADS-B In ARC recommended that additional work be done to “better [understand] the roles for both pilots and air traffic controllers and a change to separation standards” (ADS-B In ARC, 2011, p. 26). Therefore, one extra event was designed to have the flight crew conduct CAPP-like operations while having separation responsibility and questions were asked about separation responsibilities.

When asked if the controller should maintain separation responsibility, controller responses were variable but the majority disagreed. Controller responses were also variable when asked whether it was acceptable to be responsible for separation during CAPP. Additionally, two controllers reported one of the disadvantages of CAPP as being responsible for separation and not knowing how the pilot would behave. The majority agreed the flight crew should be issued separation responsibility and reported they would be willing to issue the flight crew separation responsibility. The majority of controllers also reported the spacing being achieved by pilots when having separation responsibility in the extra event was acceptable. From a controller perspective, their positive replies to many other questionnaire statements indicate they may be willing to retain separation responsibility (as done in this simulation). However, it appears the controllers prefer to have the flight crew be issued separation responsibility during CAPP.

When pilots were asked if the controller should maintain separation responsibility, replies were variable but the majority agreed. However, pilot responses were variable but the majority agreed the flight crew should be issued separation responsibility. Pilot responses were variable but the majority also agreed they would be willing to accept separation responsibility. After conducting the CAPP with pilot separation responsibility event, the majority of pilots reported it was acceptable and desirable. From a flight crew perspective, it appears while some pilots may prefer the controller maintains separation responsibility, a majority would be willing to accept it and that it is desirable to do so.

When examining the benefits of conducting CAPP with pilot separation responsibility, the spacing was closer for this event than was the spacing for the conditions examining the independent variables (where the controller retained separation responsibility) as well as the baseline condition. While the number of events were low, this result aligns with past work by Mundra et al. (2009) and Domino et al. (2010).

Overall, the CAPP with pilot separation responsibility event appeared to have relatively reasonable (and very similar to the independent variable conditions) pilot workload, and appeared to be acceptable to the majority of pilots and controllers. Additionally, the spacing within the aircraft pair was closer than when there was not a transfer, and there were no breakouts for participant pilot aircraft in this event. A transfer of separation responsibility to the flight deck may remove some of the variability of pilot responses when asked about the desirability of CAPP and would align with past work that found such a transfer was acceptable to pilots with acceptable workload (Bone, Domino, et al., 2003; Domino et al., 2010; Prinzel et al., 2012). It may also affect the acceptability of conducting the operation to lower ceilings (such as those reported in Mundra et al., 2009). Finally, it may remove any difficulties or confusion when transitioning from CAPP to CAVS, as this would consolidate the two operations into one.

6 Recommendations and Considerations

Based on the simulation results, the following are recommendations and considerations for the FAA as well as for RTCA and EUROCAE in determining next steps for CAPP development. Where necessary, follow-on sub-bullet justifications are provided.

6.1 Concept

- When CAVS operations follow CAPP, remove the current operational requirement to correlate a TTF sited OTW with the CDTI prior to initiating the CAVS operation.
    - While RTCA and EUROCAE (2014b) requires initial visual acquisition OTW of the TTF and the correlation of that with the CDTI, this was not believed to be necessary in this simulation. The flight crew had already been following this aircraft for several miles and had confirmed that was the TTF through the use of TPCS in the controller CAPP instruction. Additionally, it is highly likely the controller would have detected any issues with wrong TTF identification by the point of the transition to CAVS.
- When CAVS operations follow CAPP, allow the flight crew to report the TTF in sight when reaching visual conditions based on having the TTF on the CDTI.
    - While RTCA and EUROCAE (2014b) requires initial visual acquisition of the TTF OTW, that may not be possible when CAVS follows CAPP and led to some confusion by both controllers and pilots. Removal of this requirement would make the transition clearer.
- Make it clear in flight crew operational training material what the required action is when a CAPP range indication advisory alert has been triggered and then the CAPP aircraft goes inside the NCT value (i.e., take action to get outside the NCT value and contact the controller).
    - A small number of pilots in the simulation went inside the NCT value and stayed there without contacting the controller. Making the actions very clear and the reasons for those actions may help overcome this issue.

6.2 Benefits

- Continue to examine the exact ceilings under which CAPP is beneficial and determine the extensibility to the NAS. Consider in this analysis the benefits of CAPP operations with and without a transfer of separation responsibility to the flight deck, if both are found to be acceptable.
    - The cloud ceilings utilized in the simulation were chosen to determine the highest and lowest reasonable altitudes to transition out of CAPP into CAVS and still achieve the intended benefits for CAPP. The lowest ceiling examined in the simulation gave little time to gain the benefit of additional closure during CAVS. Ceilings higher than 1800 ft will allow for additional closure to a more desirable final spacing. A ceiling much higher than the 3300 ft one examined may allow for visual operations (e.g.,

CAVS) without the need for CAPP. However, the highest reasonable ceiling may be facility dependent.

- Consider whether IM can achieve the intended goal of CAPP (to support the transition to visual separation operations such as CAVS) more accurately with a precise spacing goal. In examining this topic, thought should be given to how the transition from IM (when receiving IM speeds) to CAVS (not getting speeds) should occur.
    - While pilots in this simulation used the NCT value as a goal, IM may allow the flight crew to more accurately, and with reduced variance, achieve a precise goal of the controller prior to transitioning to CAVS. However, a more complex set of avionics would be required and those avionics may not be available as quickly as CAPP equipment could be.

6.3 Roles and Responsibilities

- Consider starting deployment / the operational use of CAPP with no transfer of separation responsibility to the flight crew. After learning from and gaining benefits where possible under that implementation, consider a transfer of separation responsibility to the flight crew (in the context of a clearly defined concept with clear roles and responsibilities) to gain greater benefits, and to achieve a more acceptable and desirable implementation.
    - Concerns have been expressed about a transfer of separation responsibility in the ADS-B In ARC. Both pilots and controllers in this simulation had questions about separation responsibilities. From a controller perspective, their positive replies to many questionnaire statements indicate they may be willing to retain separation responsibility (as done in this simulation). However, it appears the controllers prefer to have the flight crew be issued separation responsibility during CAPP. From a flight crew perspective, it appears that while some pilots may prefer the controller maintains separation responsibility, a majority would be willing to accept it and that it is desirable to do so.
- Consider the work done in this report as input to the ARC recommendation that additional work be done to "better [understand] the roles for both pilots and air traffic controllers and a change to separation standards" (ADS-B In ARC, 2011, p. 26).

6.4 Displays

- Accept the controller feedback provided in the simulation as validation the controller display requirements in FAA (2014a) are sufficient for CAPP.
- Accept the pilot feedback provided in the simulation as validation the CAVS requirements in RTCA and EUROCAE (2014a) are sufficient for CAPP (see the following bullets for additional recommendations related to the requirements).

- As recommended in RTCA and EUROCAE (2014a), discourage the use of "+" and "-" to indicate convergence or divergence between the CAPP aircraft and TTF. Consider recommending a dynamic graphical closure cue instead.
    - The feature to distinguish between a positive and negative DGS is not specifically defined in RTCA and EUROCAE (2014a). However, it does note the potential for confusion if not done properly and recommends a graphical indication of the sign. The authors / researchers agreed with this concern and decided not to use a "+" and "-" indication as they can be confusing (depending on the location of the symbol and the surrounding information). To help avoid confusion in this simulation, a static graphical cue was used to meet the requirement. However, some pilots reported wanting dynamic information.
- Consider changing or clarifying the requirement in RTCA and EUROCAE (2014a) to allow for the CAVS and CAPP range indication advisory alert to be triggered earlier than when the horizontal distance to the [TTF] is less than the CAVS minimum distance so the alerting scheme for CAVS and CAPP are the same.
    - After debate and coordination with the FAA during simulation definition, it was decided that triggering the range indication advisory alert at a reasonable time threshold before the NCT value was preferred and acceptable for both CAPP and CAVS during the simulation.
- Consider standards requirements to keep display interactions to a minimum for the transition between CAPP and CAVS (and potentially between other ASAs that occur at a high workload period).
    - The design of the CDTI in the simulation attempted to keep necessary actions to a minimum. For example, the PM was able to select the TTF on the CDTI which auto-populated the TTF TPCS field. After that was completed, only the CAPP NCT value and the CAVS minimum distance value needed to be entered (there were no default values for either one). Additionally, there was only one button push necessary to swap the CAPP NCT value for the CAVS minimum distance value. At this point, the equipment automatically transitioning from CAPP to CAVS operations based on that button push. The pilots did not need to perform several actions to stop one ASA (CAPP) and then start another ASA (CAVS). The transition from CAPP to CAVS was found acceptable when only requiring one button push while the event where extra actions were required took much longer and was found to be less acceptable.

6.5 Communications

- Consider keeping a CAPP instruction as concise as possible and as similar as possible to that used in the simulation.
    - o During the dry runs leading up to the simulation, the communication procedures used in the draft CAPP OSED sample scenario were used (RTCA and EUROCAE, 2013b). After utilizing this set of interactions, dry run participants reported that it required too much communication. The concern of the amount of communications was also pointed out in comments received on the draft CAPP OSED. Therefore, the authors decided to truncate the communications as much as possible (see Section 3.3.2 for further details). Those used in the simulation appeared to work well.
- Consider the pilot and controller feedback as continued validation for the TPCS format utilized (telephonic / conventional, e.g., “United”).
    - o The results are consistent with other research specifically examining TPCS (e.g., Bone et al., 2013). The majority of pilots reported not being confused when TPCS was used and there were zero instances of participant pilot confusion on the communication frequency (e.g., asking “was that for us?” or executing an instruction for another aircraft).

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Appendix A Demographics Forms

A.1 Controller Demographics Form

Please complete the following background questionnaire. Your identity will be kept confidential and will not be included in any of the material that will be produced as a result of this study.

1. How many years of experience do you have actively controlling air traffic? ___ Years

2. How many months out of the past 12 have you actively controlled air traffic? __ Months

3. Age: ____Years

4. Gender (circle one) Male Female

5. At which facility do you now (or did you last) work?

6. At what other types of facilities have you worked? (circle all that apply)

Tower TRACON Center Other_________________________

7. What is your current position?______________________

8. Have you ever worked at a final approach control position? (circle one) **YES** **NO**

   If yes, approximately how many months / years? __________________________

   If yes, which facility? __________________________

9. What other positions have you held within the FAA (e.g., TMC, airspace operations, etc.)? _________________________

10. Have you ever been a controller at Philadelphia International Airport (PHL)? (circle one) **YES** **NO**

If yes, approximately how many months / years:_____________________________

11. Do you have any experience (such as demos or simulations) with concepts where pilots use cockpit tools to space from other aircraft? (circle one) **YES** **NO**

    If yes, please describe your previous experience:______________________

12. Can we follow up with you after the simulation if we have any questions on the data you provided? (circle one) **YES** **NO**

A.2 Pilot Demographics Form

Please complete the following background questionnaire. Your identity will be kept confidential and will not be included in any of the material that will be produced as a result of this study.

1. Airline Affiliation(s): ________________

2. Age: ______Years

3. Gender (circle one) **Male** **Female**

4. Estimated total flight hours: _____________

5. Aircraft Type Ratings: ______________________________

6. Current aircraft flying:_________________________________

7. Current aircraft qualification position (circle one) **Captain** **First Officer** **Flight Engineer**

8. Have you ever operated at Philadelphia International Airport (PHL)? (circle one) **YES** **NO**

   If yes, approximately how many times: _____________________________

9. When you are flying your aircraft using visual separation to follow another aircraft to the same runway (under normal conditions), do you have a personal **typical** and **minimum** spacing that you are willing to achieve behind another aircraft? (enter one value per cell)

Aircraft Type	**Typical Spacing (miles)**	**Minimum Spacing (miles)**
Large		
B757		
Heavy (e.g., B777)		

Comments:

10. When you are flying your aircraft using visual separation to follow another aircraft to the same runway (under normal conditions), what factors affect the spacing you use? (provide factors)

    Factors:____

11. Do you have any experience (such as demos or simulations) with concepts where pilots use cockpit tools to space from other aircraft? (circle one) **YES** **NO**

    If yes, describe: ____

12. Have you ever participated in other MITRE flightdeck simulations? (circle one) **YES** **NO**

    If yes, which one(s)? _______________________________________

13. Can we follow up with you after the simulation if we have any questions on the data you provided? (circle one) **YES** **NO**

Appendix B NASA TLX Pairwise Comparison

Circle the Scale Title that represents the more important contributor to workload for the scenario you just performed.

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand
Frustration or Effort	Performance or Mental Demand
Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand
Frustration or Mental Demand	

Appendix C Post Scenario Questionnaires

C.1 Controller Post Scenario Questionnaire

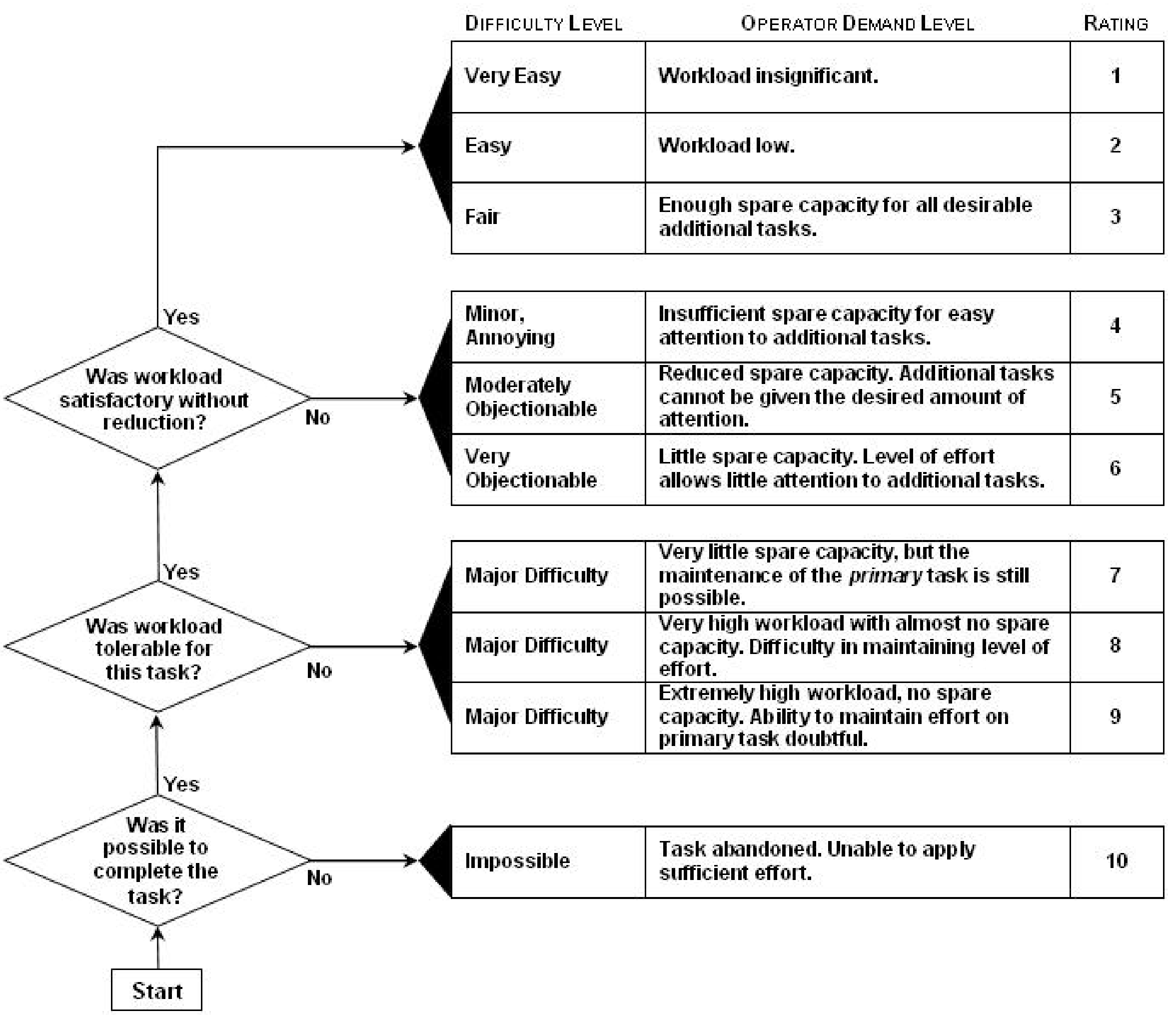
CAPP POST SCENARIO ATC QUESTIONNAIRE

__Instructions__: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. Using the chart below, how would you rate your *average* level of workload?

(a) Working up from the bottom, answer each yes/no question.
(b) Select the numerical rating that best reflects your experience.



2. Using the scales below, indicate the most appropriate workload rating (draw a line on each scale)

Mental Demand *How mentally demanding was the task?*

Very Low Very High

Physical Demand *How physically demanding was the task?*

Very Low Very High

Temporal Demand *How hurried or rushed was the pace of the task?*

Very Low Very High

Performance *How successful were you in accomplishing what you were asked to do?*

Perfect Failure

Effort *How hard did you have to work to accomplish your level of performance?*

Very Low Very High

Frustration *How insecure, discouraged, irritated, stressed, and annoyed were you?*

Very Low Very High

Concept

3. I was confident that the spacing being achieved by the flight crews would remain outside my separation responsibility. (draw a line on each scale)

    Aircraft performing CAPP:

    Strongly Disagree — Strongly Agree

    Aircraft never performing CAPP:

    Strongly Disagree — Strongly Agree

   Comments:

4. The spacing being achieved by aircraft was acceptable. (draw a line on each scale)

    Aircraft performing CAPP:

    Strongly Disagree — Strongly Agree

    Aircraft never performing CAPP:

    Strongly Disagree — Strongly Agree

   Comments:

5. I was able to detect when spacing / separation issues were developing. (draw a line on each scale)

    Aircraft performing CAPP:

    Strongly Disagree — Strongly Agree

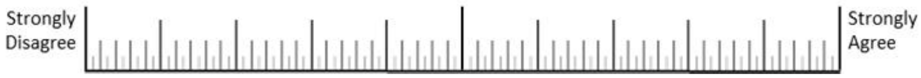
    Aircraft never performing CAPP:

    Strongly Disagree — Strongly Agree

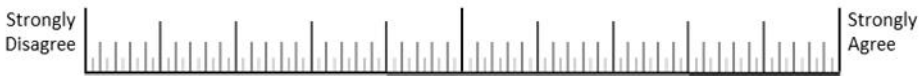
   Comments:

6. I knew when to intervene on aircraft. (draw a line on each scale)

Aircraft performing CAPP:



Aircraft never performing CAPP:



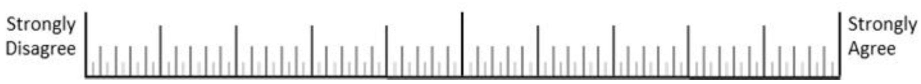
Comments:

7. Did you ever hesitate to intervene on aircraft? (circle one per row)

Aircraft performing CAPP	Yes	No
Aircraft never performing CAPP	Yes	No

If yes, why? What was the impact?

8. The transition from CAPP into visual operations was acceptable. (draw a line on scale)



Comments:

9. Were there any times when an aircraft could not transition into visual separation?

Yes	No

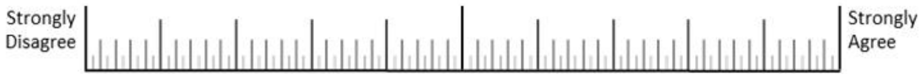
If yes, why? What was the impact?

10. Were there any breakouts / go-arounds / missed approaches? (circle one)

CAPP	Yes	No
Visual Separation / CAVS	Yes	No

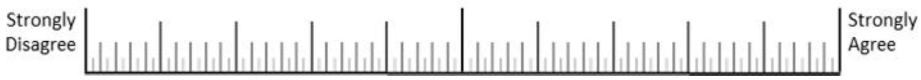
If yes, why? What was the impact?

11. CAPP was operationally *desirable*. (draw a line on scale)



Comments:

12. CAPP was operationally *acceptable*. (draw a line on scale)



Comments:

Communications

13. Did you experience any CAPP-related communication difficulties? (circle one)

Yes	No

If yes, explain:

Displays

14. Did you experience any CAPP-related display difficulties? (circle one)

Yes	No

If yes, explain:

Overall

15. Did you have any other CAPP-related difficulties with this particular run? (circle one)

Yes	No

If yes, explain:

16. If you have any other comments about this run, please provide them.

C.2 Controller Post Extra Scenario Questionnaire

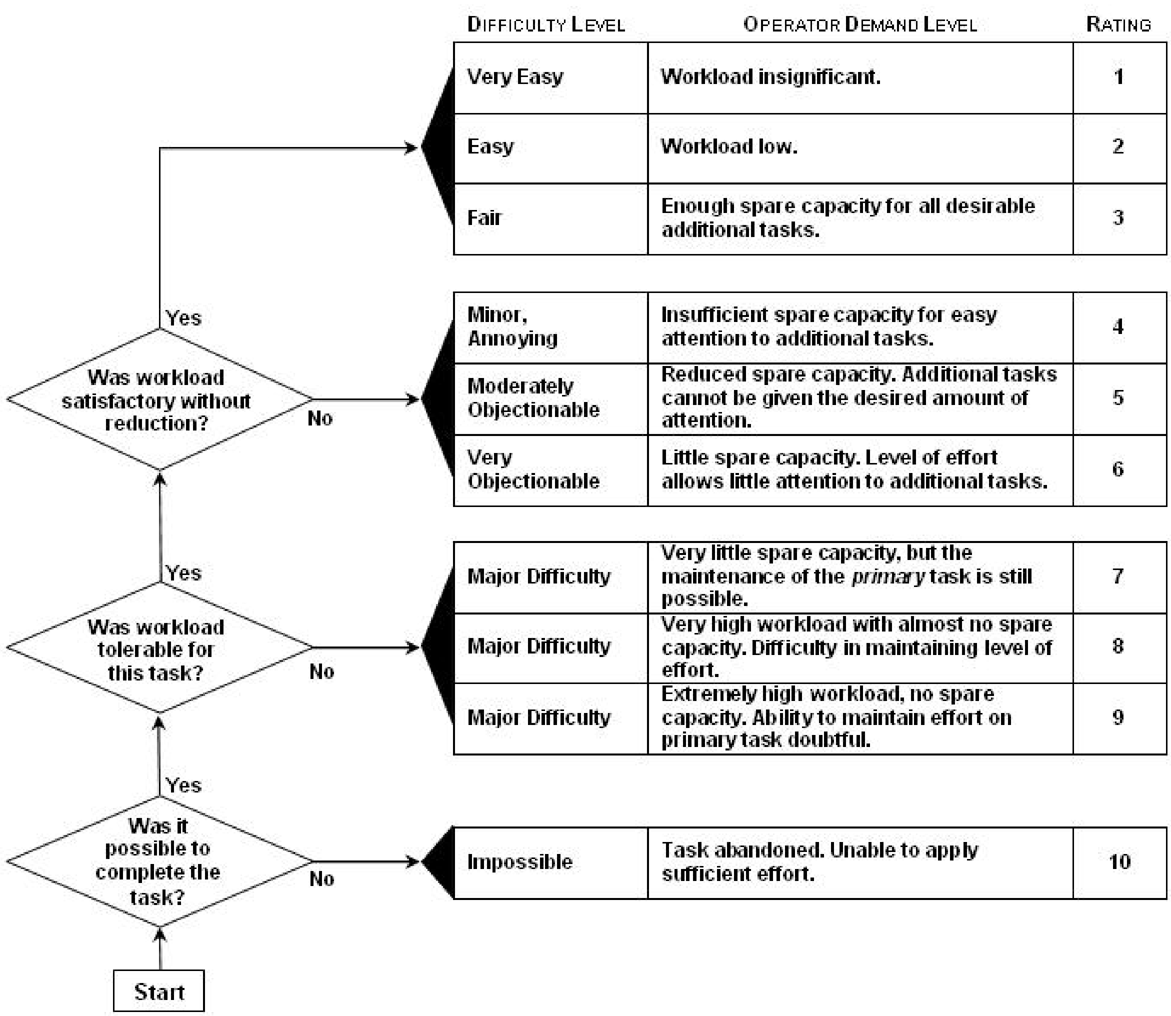
CAPP POST EXTRA SCENARIO ATC QUESTIONNAIRE

Instructions: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. Using the chart below, how would you rate your *average* level of workload?

(a) Working up from the bottom, answer each yes/no question.
(b) Select the numerical rating that best reflects your experience.



2. Using the scales below, indicate the most appropriate workload rating (draw a line on each scale)

Mental Demand *How mentally demanding was the task?*

Very Low Very High

Physical Demand *How physically demanding was the task?*

Very Low Very High

Temporal Demand *How hurried or rushed was the pace of the task?*

Very Low Very High

Performance *How successful were you in accomplishing what you were asked to do?*

Perfect Failure

Effort *How hard did you have to work to accomplish your level of performance?*

Very Low Very High

Frustration *How insecure, discouraged, irritated, stressed, and annoyed were you?*

Very Low Very High

Concept

3. I was confident that the spacing being achieved by the flight crews would remain outside my separation responsibility. (draw a line on each scale)

   Aircraft performing CAPP:

   Strongly Disagree — Strongly Agree

   Aircraft not performing CAPP:

   Strongly Disagree — Strongly Agree

   Comments:

4. The spacing being achieved by aircraft was acceptable. (draw a line on each scale)

   Aircraft performing CAPP:

   Strongly Disagree — Strongly Agree

   Aircraft never performing CAPP:

   Strongly Disagree — Strongly Agree

   Aircraft performing separation for full approach:

   Strongly Disagree — Strongly Agree

   Comments:

5. I was able to detect when spacing / separation issues were developing. (draw a line on each scale)

Aircraft performing CAPP:

Strongly Disagree — Strongly Agree

Aircraft never performing CAPP:

Strongly Disagree — Strongly Agree

Aircraft performing separation for full approach:

Strongly Disagree — Strongly Agree

Comments:

6. I knew when to intervene on aircraft. (draw a line on each scale)

Aircraft performing CAPP:

Strongly Disagree — Strongly Agree

Aircraft never performing CAPP:

Strongly Disagree — Strongly Agree

Aircraft performing separation for full approach:

Strongly Disagree — Strongly Agree

Comments:

7. Did you ever hesitate to intervene on aircraft? (circle one per row)

Aircraft performing CAPP	Yes	No
Aircraft never performing CAPP	Yes	No
Aircraft performing separation for full approach	Yes	No

If yes, why? What was the impact?

8. The transition from CAPP into visual operations was acceptable. (draw a line on scale)

Strongly Disagree ———————————————— Strongly Agree

Comments:

9. Were there any times when an aircraft could not transition into visual separation?

Yes	No

If yes, why? What was the impact?

10. Were there any breakouts / go-arounds / missed approaches? (circle one)

Aircraft performing CAPP	Yes	No
Aircraft never performing CAPP	Yes	No

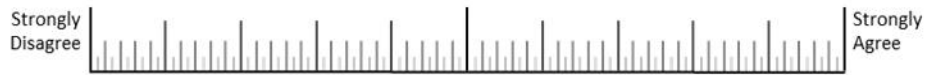
If yes, why? What was the impact?

11. CAPP was operationally *desirable*. (draw a line on scale)

Strongly Disagree ———————————————— Strongly Agree

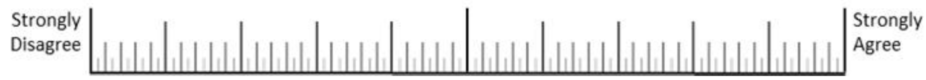
Comments:

12. Aircraft performing separation for full approach was operationally *desirable*. (draw a line on scale)



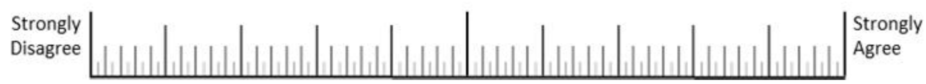
Comments:

13. CAPP was operationally *acceptable*. (draw a line on scale)



Comments:

14. Aircraft performing separation for full approach was operationally *acceptable*. (draw a line on scale)



Comments:

Communications

15. Did you experience any communication difficulties? (circle one)

Yes	No

If yes, explain:

Displays

16. Did you experience any display difficulties? (circle one)

Yes	No

If yes, explain:

Overall

17. Did you have any other difficulties with this particular run? (circle one)

Yes	No

If yes, explain:

18. If you have any other comments about this run, please provide them.

C.3 Pilot Baseline Post Run Questionnaire

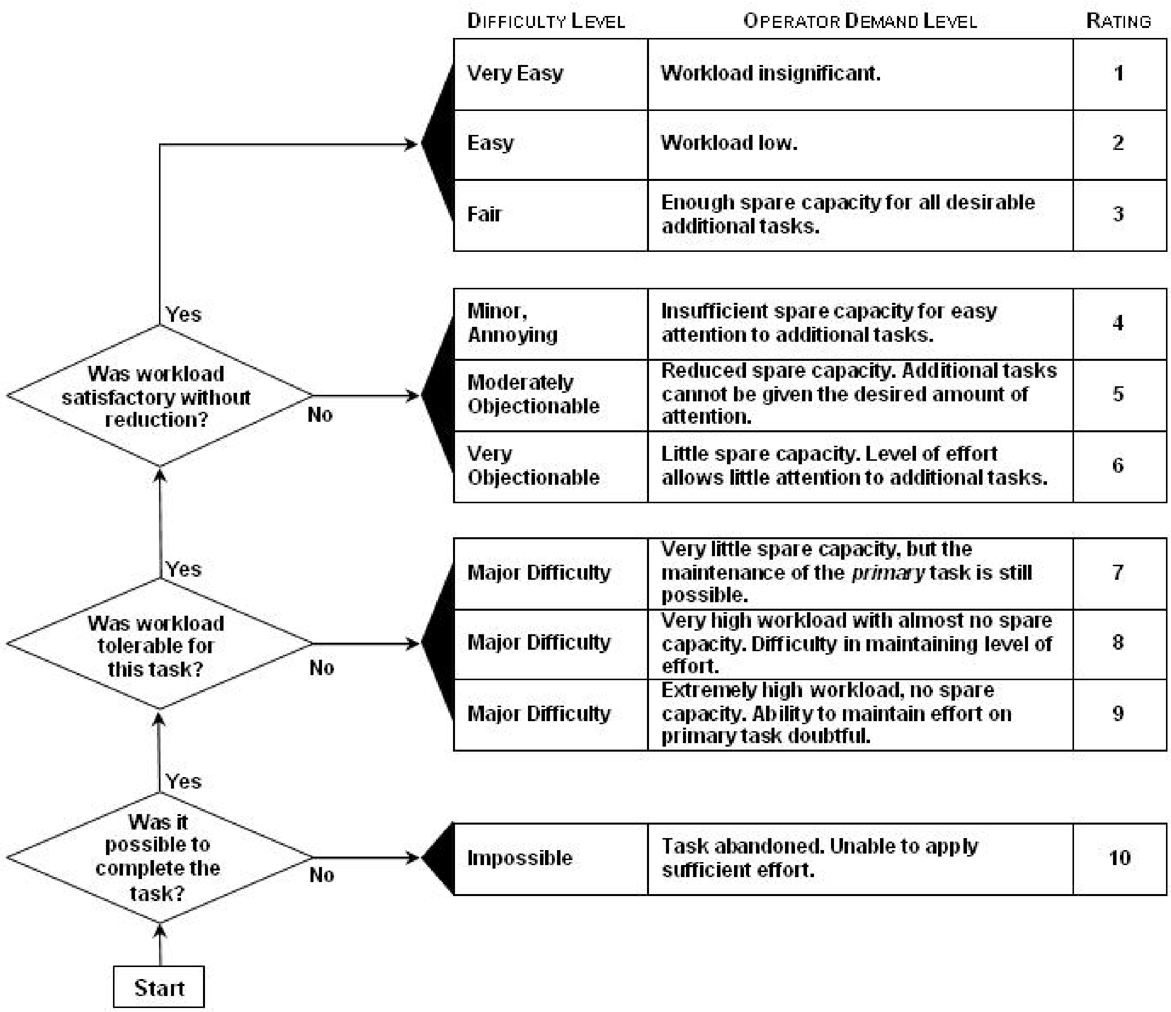
CAPP BASELINE POST RUN <u>PILOT</u> QUESTIONNAIRE

<u>Instructions</u>: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. Using the chart below, how would you rate your *average* level of workload?

(a) Working up from the bottom, answer each yes/no question.
(b) Select the numerical rating that best reflects your experience.



2. Using the scales below, indicate the most appropriate workload rating (draw a line at the appropriate location on each)

Mental Demand *How mentally demanding was the task?*

Very Low Very High

Physical Demand *How physically demanding was the task?*

Very Low Very High

Temporal Demand *How hurried or rushed was the pace of the task?*

Very Low Very High

Performance *How successful were you in accomplishing what you were asked to do?*

Perfect Failure

Effort *How hard did you have to work to accomplish your level of performance?*

Very Low Very High

Frustration *How insecure, discouraged, irritated, stressed, and annoyed were you?*

Very Low Very High

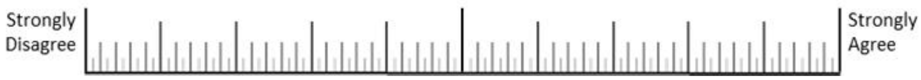
Concept

3. What was your desired spacing from the lead aircraft? (enter one value per row)

Operation	Target spacing interval
Visual Separation	

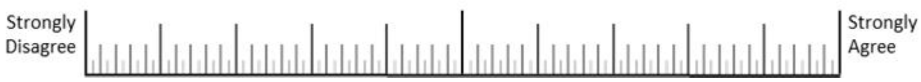
Comments:

4. I achieved my desired spacing during visual separation. (draw a line on each scale)



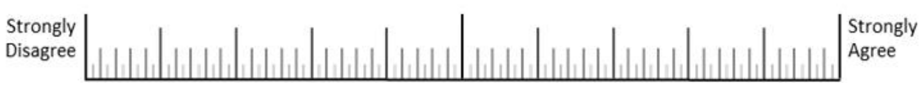
Comments:

5. I was able to remain outside my desired spacing from the traffic I was following during visual separation. (draw a line on the scale)



Comments:

6. The transition from the ILS into visual operations was acceptable. (draw a line on the scale)

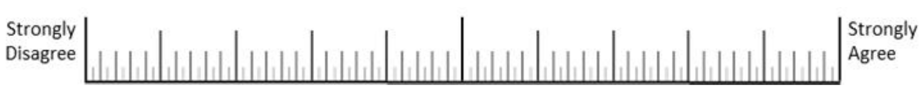


Comments:

7. Were there any breakouts / go-arounds / missed approaches? (circle one) Yes / No

If yes, why? What was the impact?

8. The ILS approach was operationally acceptable. (draw a line on the scale)



Comments:

Communications

9. Did you experience any communication difficulties? (circle one)

Yes	No

If yes, explain:

Overall

10. Did you have any difficulties with this particular run? (circle one)

Yes	No

If yes, explain:

11. If you have any other comments about this run, please provide them.

C.4 Pilot Post Run Questionnaire

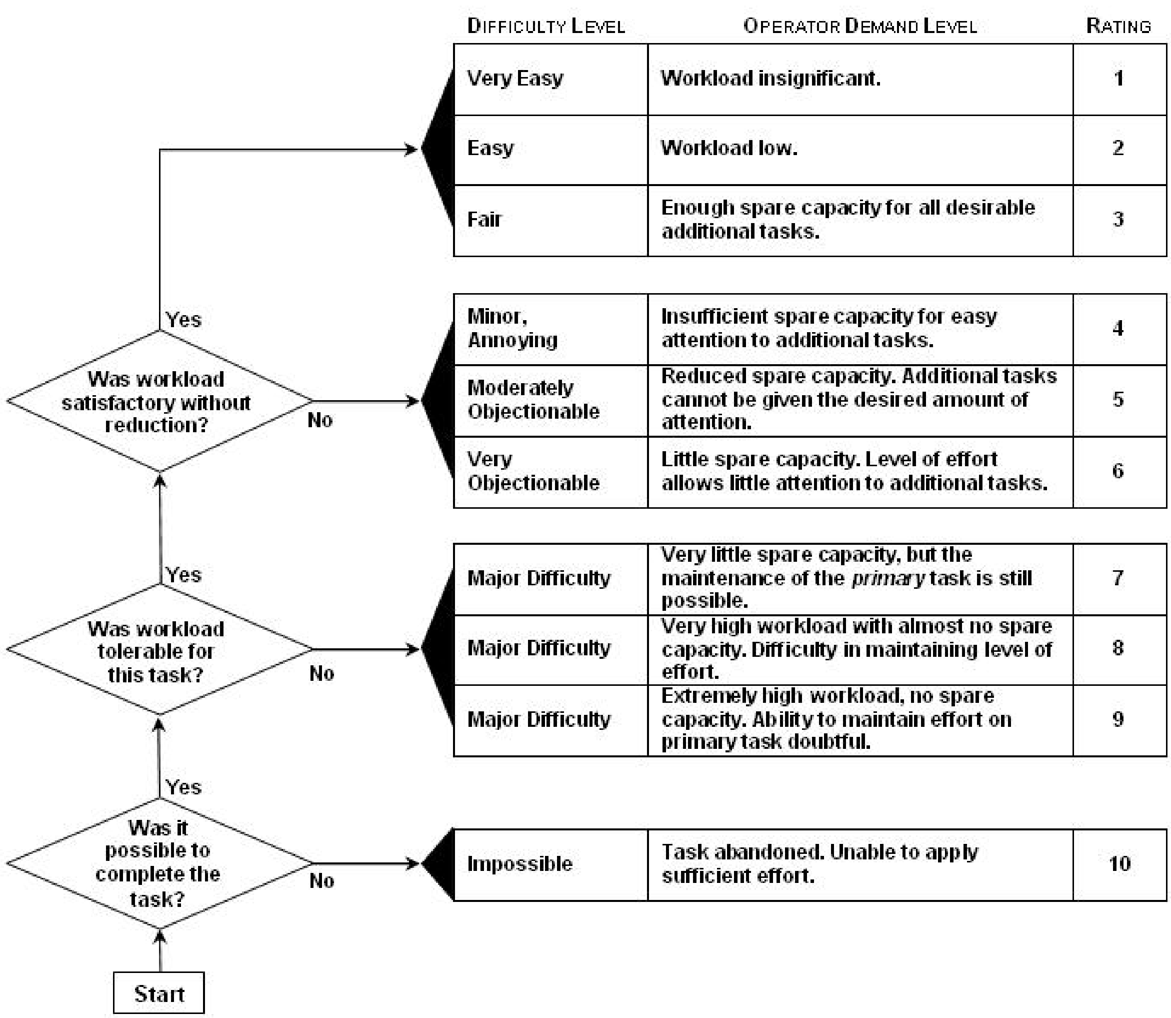
CAPP POST SCENARIO <u>PILOT</u> QUESTIONNAIRE

<u>Instructions</u>: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. Using the chart below, how would you rate your *average* level of workload?

(a) Working up from the bottom, answer each yes/no question.
(b) Select the numerical rating that best reflects your experience.



2. Using the scales below, indicate the most appropriate workload rating (draw a line on each scale)

Mental Demand *How mentally demanding was the task?*

Very Low Very High

Physical Demand *How physically demanding was the task?*

Very Low Very High

Temporal Demand *How hurried or rushed was the pace of the task?*

Very Low Very High

Performance *How successful were you in accomplishing what you were asked to do?*

Perfect Failure

Effort *How hard did you have to work to accomplish your level of performance?*

Very Low Very High

Frustration *How insecure, discouraged, irritated, stressed, and annoyed were you?*

Very Low Very High

Concept

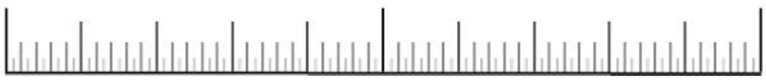
3. What was your desired spacing from the lead aircraft? (enter one value per row)

Operation	Target spacing interval
CAPP	
Visual Separation / CAVS	

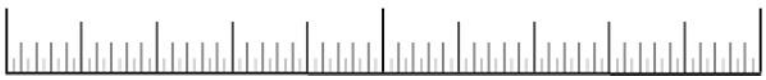
Comments:

4. I achieved my desired spacing. (draw a line on each scale)

For CAPP:

Strongly Disagree  Strongly Agree

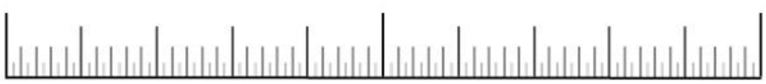
For visual separation / CAVS:

Strongly Disagree  Strongly Agree

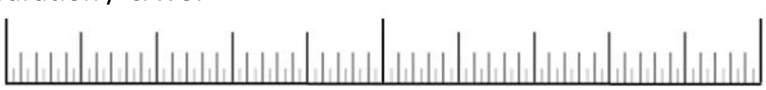
Comments:

5. I was able to remain outside the no-closer-than value from the traffic I was following. (draw a line on each scale)

For CAPP:

Strongly Disagree  Strongly Agree

For visual separation / CAVS:

Strongly Disagree  Strongly Agree

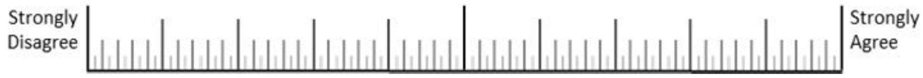
Comments:

6. Were you able to transition out of CAPP?

Yes	No

If no, why? What was the impact?

7. The transition from CAPP into visual operations was acceptable. (draw a line on the scale)



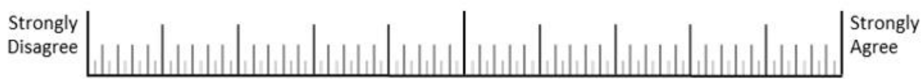
Comments:

8. Were there any breakouts / go-arounds / missed approaches? (circle one)

CAPP	Yes	No
Visual Separation / CAVS	Yes	No

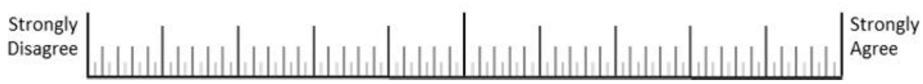
If yes, why? What was the impact?

9. CAPP was operationally *desirable*. (draw a line on the scale)



Comments:

10. CAPP was operationally *acceptable*. (draw a line on the scale)



Comments:

Communications

11. Did you experience any CAPP-related communication difficulties? (circle one)

Yes	No

If yes, explain:

Displays

12. Did you experience any CAPP-related display difficulties? (circle one)

Yes	No

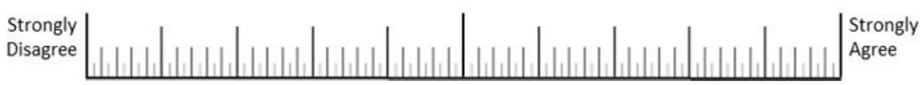
If yes, explain:

13. Did both the AGD and CDTI implementations include all the information necessary for you to make informed and accurate spacing decisions? (circle one)

Yes	No

If no, describe any instances where you would have liked more information, and the form in which the additional information would have been most useful.

14. The number of actions required to change the CAPP no-closer-than value to a CAVS no-closer-than value was acceptable. (draw a line on the scale)



Comments:

15. Were any alerts triggered? (circle one)

Yes	No

If yes, describe what occurred and your actions:

Overall

16. Did you have any CAPP-related difficulties with this particular run? (circle one)

Yes	No

If yes, explain:

17. If you have any other comments about this run, please provide them.

C.5 Pilot Post Separation Run Questionnaire

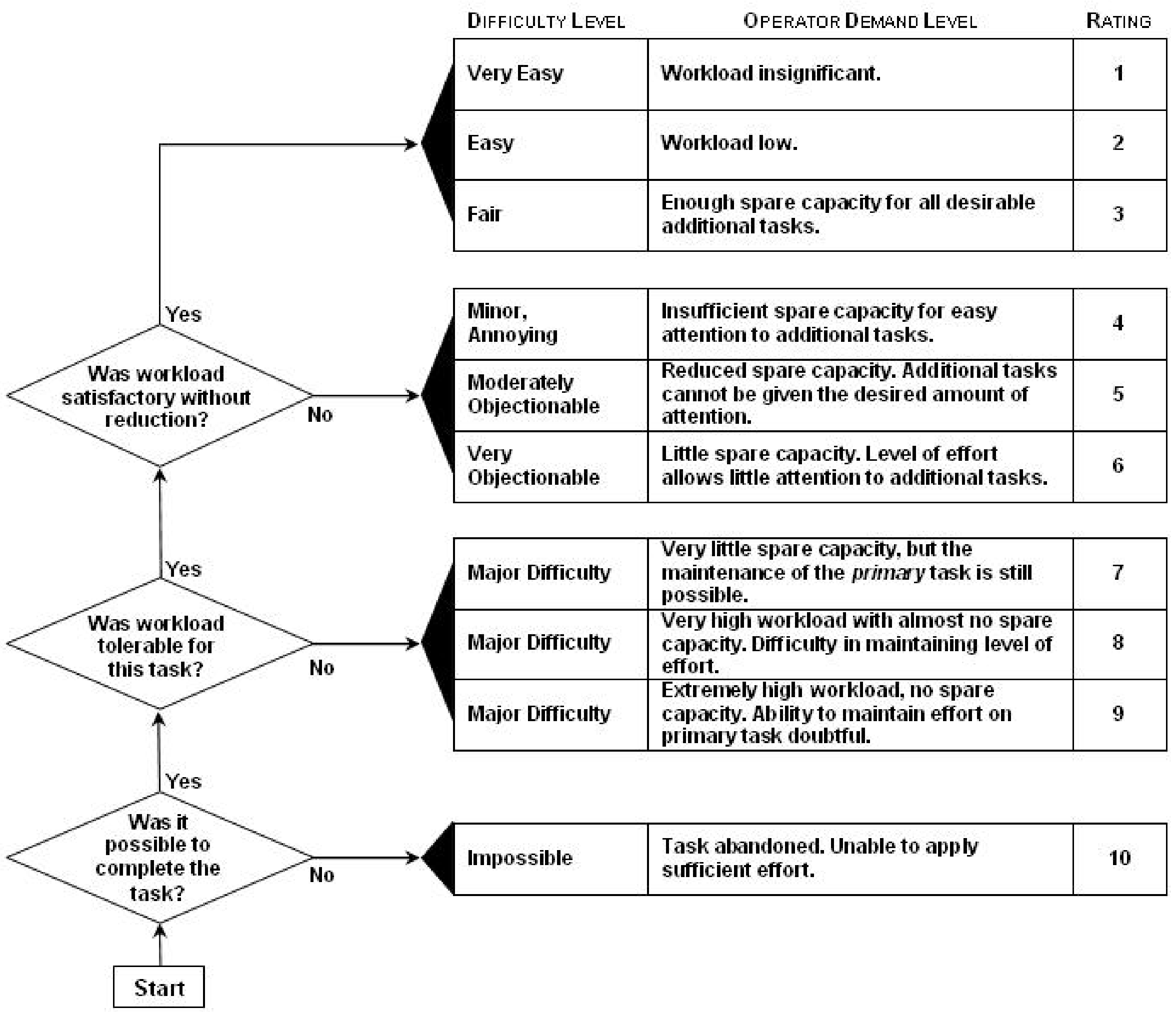
CAPP SEPARATION RUN POST RUN PILOT QUESTIONNAIRE

Instructions: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. Using the chart below, how would you rate your *average* level of workload?

(a) Working up from the bottom, answer each yes/no question.
(b) Select the numerical rating that best reflects your experience.



2. Using the scales below, indicate the most appropriate workload rating (draw a line on each scale)

<u>Mental Demand</u> *How mentally demanding was the task?*

Very Low Very High

<u>Physical Demand</u> *How physically demanding was the task?*

Very Low Very High

<u>Temporal Demand</u> *How hurried or rushed was the pace of the task?*

Very Low Very High

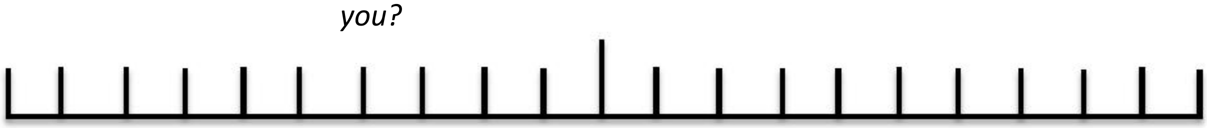
<u>Performance</u> *How successful were you in accomplishing what you were asked to do?*

Perfect Failure

<u>Effort</u> *How hard did you have to work to accomplish your level of performance?*

Very Low Very High

<u>Frustration</u> *How insecure, discouraged, irritated, stressed, and annoyed were you?*



Very Low Very High

Concept

3. What was your desired spacing from the lead aircraft? (enter one value per row)

Operation	Target spacing interval
Separation	

Comments:

4. I achieved my desired spacing. (draw a line on each scale)

For separation:

Strongly Disagree — Strongly Agree

Comments:

5. I was able to remain outside the no-closer-than value from the traffic I was following. (draw a line on each scale)

For separation:

Strongly Disagree — Strongly Agree

Comments:

6. Were there any breakouts / go-arounds / missed approaches? (circle one)

Separation	Yes	No

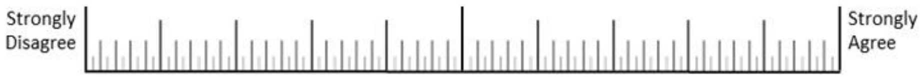
If yes, why? What was the impact?

7. Separation was operationally *desirable*. (draw a line on the scale)

Strongly Disagree — Strongly Agree

Comments:

8. Separation was operationally *acceptable*. (draw a line on the scale)



Comments:

Communications

9. Did you experience any communication difficulties? (circle one)

Yes	No

If yes, explain:

Displays

10. Did you experience any display difficulties? (circle one)

Yes	No

If yes, explain:

11. Did both the AGD and CDTI implementations include all the information necessary for you to make informed and accurate spacing decisions? (circle one)

Yes	No

If no, describe any instances where you would have liked more information, and the form in which the additional information would have been most useful.

12. Were any alerts triggered? (circle one)

Yes	No

If yes, describe what occurred and your actions:

Overall

13. Did you have any difficulties with this particular run? (circle one)

Yes	No

If yes, explain:

14. If you have any other comments about this run, please provide them.

Appendix D Post Simulation Questionnaires

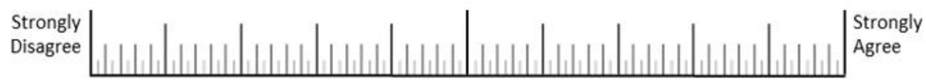
D.1 Controller Post Simulation Questionnaire

<u>Instructions</u>: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider all scenarios when answering*. If you have any questions, please ask the experimenter.

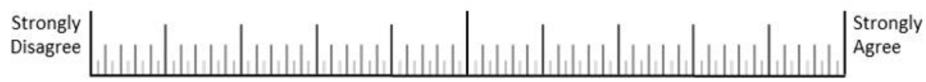
CAPP Concept

1. The acceptability of CAPP was affected by the cloud ceiling. (draw a line on each scale).

   1800 ft:

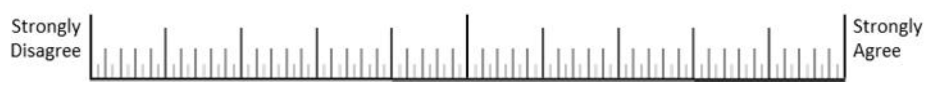
   3300 ft:

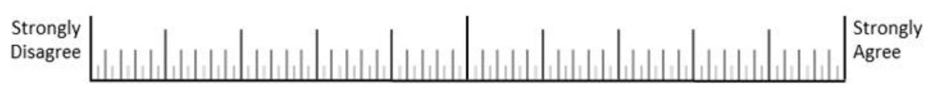
   Comments:

2. The acceptability of CAPP was affected by the no-closer-than value (i.e., 0.2 versus 0.5 nm from the separation standard). (draw a line on each scale)

   3.2 nm:

   3.5 nm:

   Comments:

3. CAPP is operationally desirable. (draw a line on the scale)

Strongly Disagree | Strongly Agree

Comments:

4. CAPP is useful as a transition to visual separation operations. (draw a line on the scale)

Strongly Disagree | Strongly Agree

Comments:

5. CAPP is only operationally desirable when there is a transition to visual separation operations. (draw a line on the scale)

Strongly Disagree | Strongly Agree

Comments:

6. CAPP is only operationally desirable when there is **no** transition to visual separation. (draw a line on the scale)

Strongly Disagree | Strongly Agree

Comments:

7. The simulated ceiling was an acceptable ceiling for CAPP operations. (draw a line on each scale)

   1800 ft:

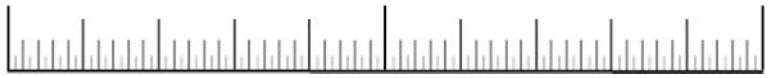
   Strongly Disagree | Strongly Agree

   3300 ft:

   Strongly Disagree | Strongly Agree

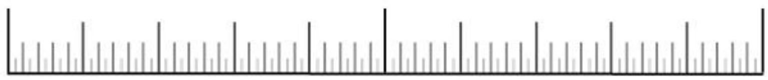
Comments:

8. A lower ceiling (i.e., below 1800 AGL) would be an acceptable ceiling for CAPP operations. (draw a line on the scale)

Strongly Disagree  Strongly Agree

Comments:

9. A higher ceiling (i.e., above 3300 AGL) would be an acceptable ceiling for CAPP operations. (draw a line on the scale)

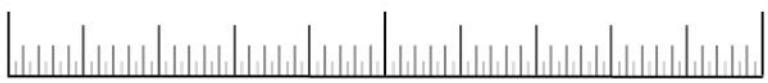
Strongly Disagree  Strongly Agree

Comments:

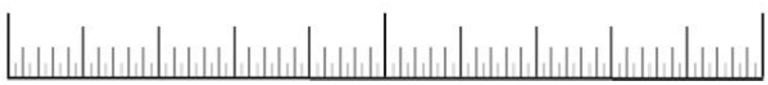
10. Given the appropriate training, CAPP is operationally acceptable. (draw a line on each scale)

Ceiling

1800 ft:

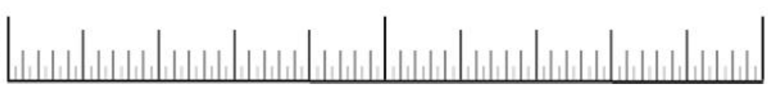
Strongly Disagree  Strongly Agree

3300 ft:

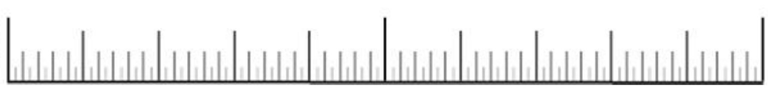
Strongly Disagree  Strongly Agree

No-closer-than value

3.2 nm:

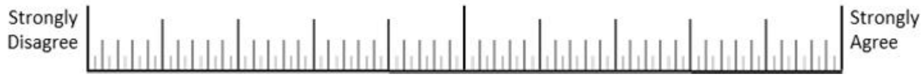
Strongly Disagree  Strongly Agree

3.5 nm:

Strongly Disagree  Strongly Agree

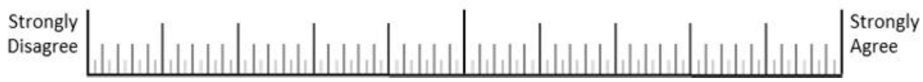
Comments:

11. In real world operations, I would be able to determine an appropriate no-closer-than value. (draw a line on the scale)



Comments:

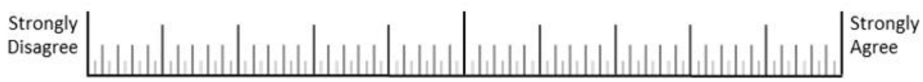
12. I was confident that the spacing being achieved by the CAPP aircraft during CAPP operations would remain outside my separation responsibility. (draw a line on the scale)



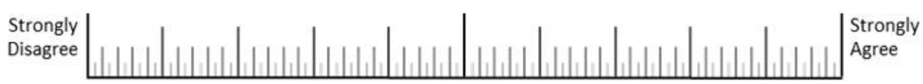
Comments:

13. It was clear that the speed changes made by the CAPP aircraft during CAPP operations were driving towards the goal of appropriate spacing. (draw a line on each scale)

3.2 nm:



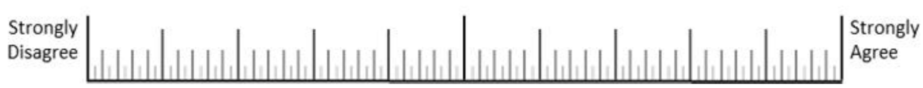
3.5 nm:



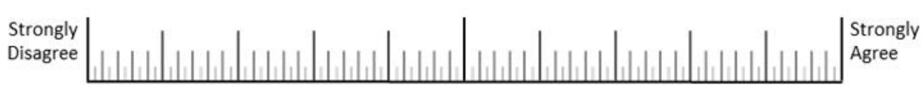
Comments:

14. The spacing being achieved by the CAPP aircraft during CAPP operations approximated the spacing I *desired*. (draw a line on each scale)

3.2 nm:



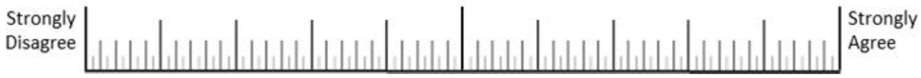
3.5 nm:



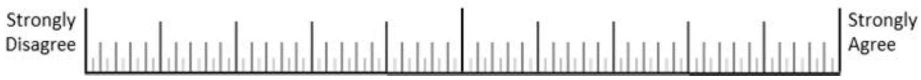
Comments:

15. The spacing being achieved by the CAPP aircraft during CAPP operations was *acceptable*. (draw a line on each scale)

3.2 nm:



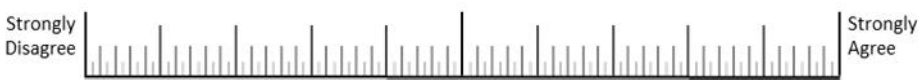
3.5 nm:



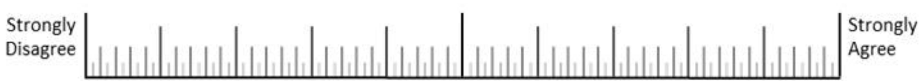
Comments:

16. I would be comfortable with the CAPP aircraft spacing more closely during CAPP operations. (draw a line on each scale)

3.2 nm:



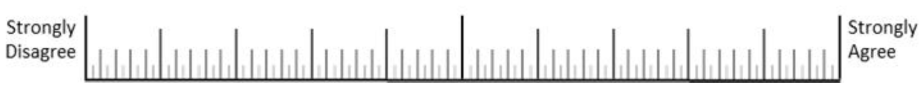
3.5 nm:



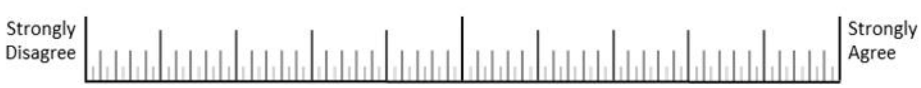
Comments:

17. I was able to detect when spacing / separation issues were developing for CAPP aircraft during CAPP operations. (draw a line on each scale)

3.2 nm:



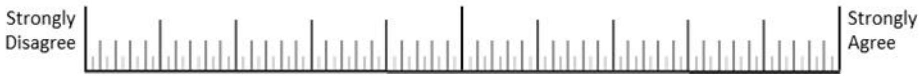
3.5 nm:



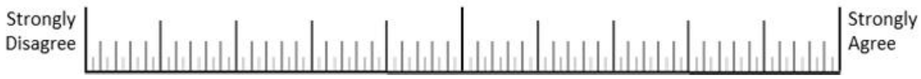
Comments:

18. I knew when to intervene on CAPP aircraft during CAPP operations. (draw a line on each scale)

3.2 nm:



3.5 nm:



Comments:

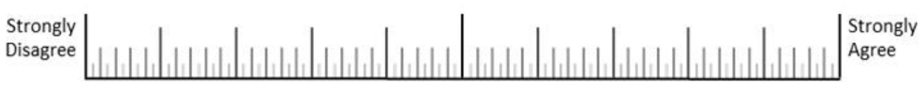
19. Did you ever hesitate to intervene on a CAPP aircraft during CAPP operations? (circle one per row)

0.2 nm	Yes	No

0.5 nm	Yes	No

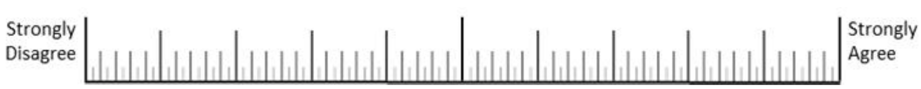
If yes, describe why and the impact:

20. The transition from CAPP into visual operations was acceptable. (draw a line on the scale)



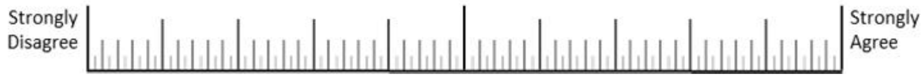
Comments:

21. The times where aircraft were unable to transition out of CAPP was acceptable. (draw a line on the scale)



Comments:

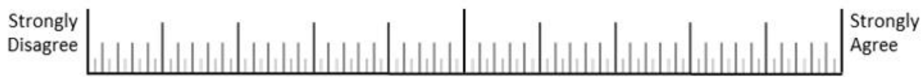
22. The termination procedures were clear. (draw a line on the scale)



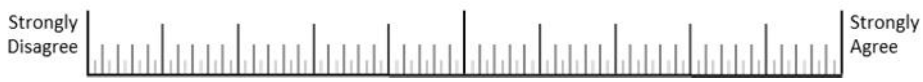
Comments:

23. I was confident that the CAPP traffic I was handing off would be accepted with minimal problems. (draw a line on each scale)

3.2 nm:



3.5 nm:



Comments:

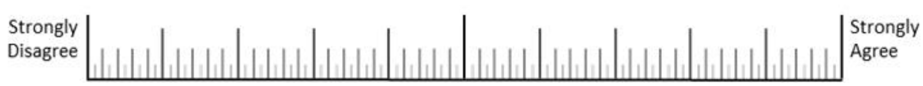
24. There was a reasonable number of aircraft that were able to perform CAPP. (circle one)

Yes	No

What percentage would be reasonable? (This simulation had about 70% CAPP equipped)
________%

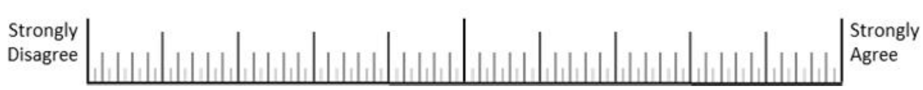
Explain:

25. My roles and responsibilities were clear during CAPP. (draw a line on the scale)



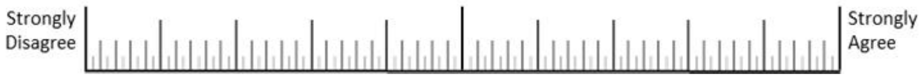
Comments:

26. While performing CAPP, all tasks were completed successfully. (draw a line on the scale)



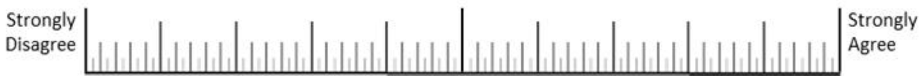
Comments:

27. The flight crew should be issued separation responsibility during CAPP. (draw a line on the scale)



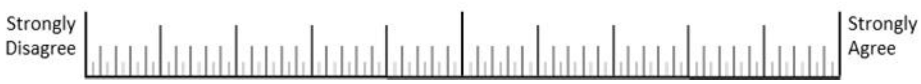
Comments:

28. I would be willing to issue the flight crew separation responsibility for separation from the lead aircraft during CAPP. (draw a line on the scale)



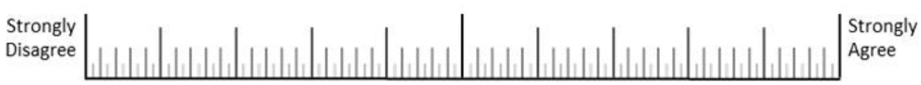
Comments:

29. The controller should retain separation responsibility during CAPP. (draw a line on the scale)



Comments:

    a. It was acceptable to be responsible for separation during CAPP. (draw a line on the scale)



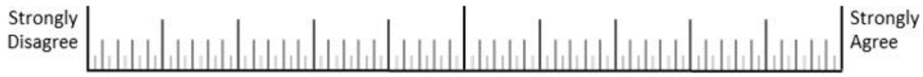
Comments:

30. How would you rate the overall effect of CAPP on your workload, as compared to controlling similar aircraft under similar conditions? (draw a line on the scale)

Greatly *Increases*	*Increases*	Somewhat *Increases*	No Effect	Somewhat *Reduces*	*Reduces*	Greatly *Reduces*

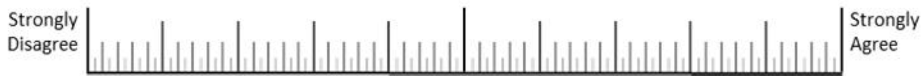
Comments:

31. My overall workload was acceptable. (draw a line on the scale)



Comments:

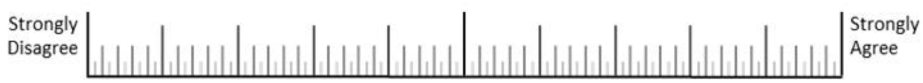
32. My level of traffic awareness was acceptable. (draw a line on the scale)



Comments:

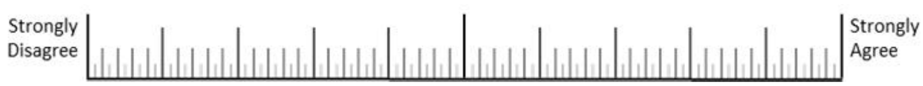
Communications

33. The CAPP instruction “CAPP 3.2 miles behind Cactus 1 -23” was acceptable. (draw a line on the scale)



Comments:

34. A traffic advisory communication is necessary prior to the CAPP instruction (versus only providing the CAPP instruction that includes lead aircraft call sign). (draw a line on the scale)



Comments:

35. Did you have any issues during communications when third party call sign was used? (circle one)

Yes	No

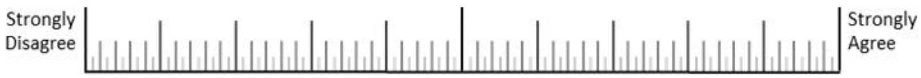
If yes, describe:

36. The flight crew has only the 3 letter identifier of the traffic on their traffic display. If the flight crew had difficulty decoding the airline name, would it be acceptable to issue the three letter identifier to the flight crew? [e.g., Brickyard / RPA] (circle one)

Yes	No

Comments:

37. Use of the third party call sign in the CAPP instruction is operationally acceptable. (draw a line on the scale)



Comments:

Display

38. How did aircraft conducting CAPP effect your monitoring of CAPP traffic? (circle one per row)

3.2 nm	Greatly *Increases*	*Increases*	Somewhat *Increases*	No Effect	Somewhat *Reduces*	*Reduces*	Greatly *Reduces*

3.5 nm	Greatly *Increases*	*Increases*	Somewhat *Increases*	No Effect	Somewhat *Reduces*	*Reduces*	Greatly *Reduces*

Comments:

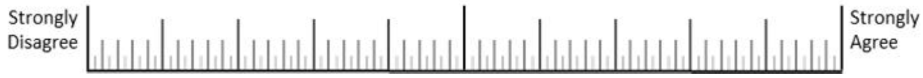
39. How did aircraft conducting CAPP effect your monitoring of non-CAPP traffic? (circle one per row)

3.2 nm	Greatly *Increases*	*Increases*	Somewhat *Increases*	No Effect	Somewhat *Reduces*	*Reduces*	Greatly *Reduces*

3.5 nm	Greatly *Increases*	*Increases*	Somewhat *Increases*	No Effect	Somewhat *Reduces*	*Reduces*	Greatly *Reduces*

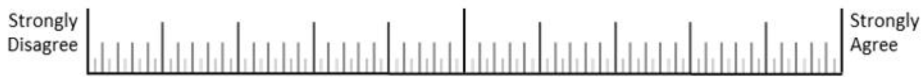
Comments:

40. The necessary monitoring was acceptable. (draw a line on the scale)



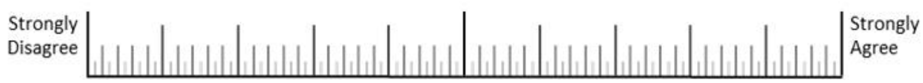
Comments:

41. The # symbol was an acceptable symbol to differentiate between aircraft that were CAPP capable and those that were not. (draw a line on the scale)



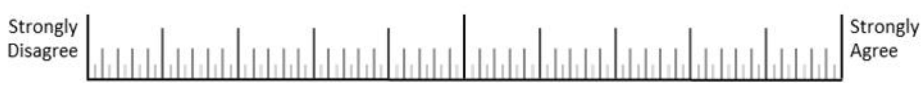
Comments:

42. Placing a symbol (either # or otherwise) before the aircraft identification is an acceptable means to differentiate between aircraft that were CAPP capable and those that were not. (draw a line on the scale)



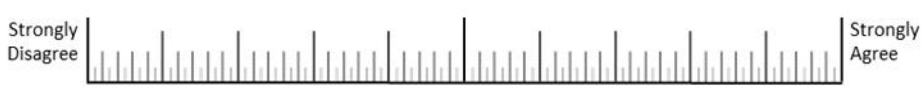
Comments:

43. Differentiating CAPP aircraft by entering “CP” in the scratchpad was necessary. (draw a line on the scale)



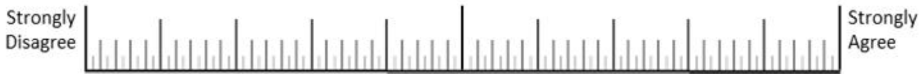
Comments:

44. I was able to detect a difference in spacing on my display when the pilot was flying the 0.2 nm NCT versus the 0.5 nm NCT (if there were any). (draw a line on the scale)



Comments:

45. It was necessary to detect a difference in spacing on my display when the pilot was flying the 0.2 nm NCT versus the 0.5 nm NCT. (draw a line on the scale)



Comments:

Overall

46. What advantages / disadvantages do you see with CAPP?

Advantages
Disadvantages

47. What was the most difficult situation to deal with when aircraft were conducting CAPP?

48. What was the easiest situation to deal with when aircraft were conducting CAPP?

49. What problems, issues, or concerns do you have with CAPP?

50. How could CAPP be improved?

51. If you have any other comments about anything else in the simulation, please provide them:

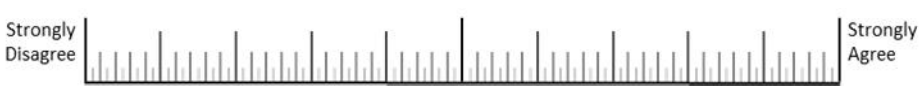
Simulation

52. How did the simulated traffic load compare to similar conditions? Simulation traffic was… (circle one)

Much *Heavier*	*Heavier*	Somewhat heavier	About the same	Somewhat lighter	Lighter	Much Lighter

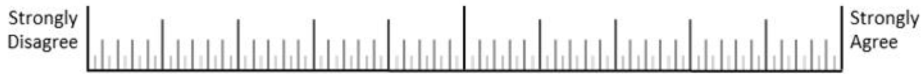
Comments:

53. The training I received was adequate.



Comments:

54. The overall simulation was effective as a context for evaluating CAPP.



Comments:

55. Was there anything about the simulation that artificially affected using it as a context for evaluating? (circle one)

Yes	No	Don't Know

If yes, explain:

D.2 Pilot Post Simulation Questionnaire

Instructions: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider all scenarios when answering*. If you have any questions, please ask the experimenter.

CAPP Concept

1. The acceptability of CAPP was affected by the cloud ceiling. (draw a line on each scale)

   1800 ft:

   Strongly Disagree — Strongly Agree

   3300 ft:

   Strongly Disagree — Strongly Agree

   Comments:

2. The acceptability of CAPP was affected by the no-closer-than value (i.e., 0.2 versus 0.5 nm from the separation standard). (draw a line on each scale)

   3.2 nm:

   Strongly Disagree — Strongly Agree

   3.5 nm:

   Strongly Disagree — Strongly Agree

   Comments:

3. CAPP is operationally desirable. (draw a line on the scale)

   Strongly Disagree — Strongly Agree

   Comments:

4. CAPP is useful as a transition to visual separation operations. (draw a line on the scale)

Strongly Disagree ... Strongly Agree

Comments:

5. CAPP is only operationally desirable when there is a transition to visual separation operations. (draw a line on the scale)

Strongly Disagree ... Strongly Agree

Comments:

6. CAPP is only operationally desirable when there is **no** transition to visual separation. (draw a line on the scale)

Strongly Disagree ... Strongly Agree

Comments:

7. The simulated ceiling was an acceptable ceiling for CAPP operations. (draw a line on each scale)

   1800 ft:

   Strongly Disagree ... Strongly Agree

   3300 ft:

   Strongly Disagree ... Strongly Agree

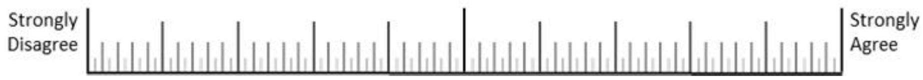
Comments:

8. A lower ceiling (i.e., below 1800 AGL) would be an acceptable ceiling for CAPP operations. (draw a line on the scale)

Strongly Disagree ... Strongly Agree

Comments:

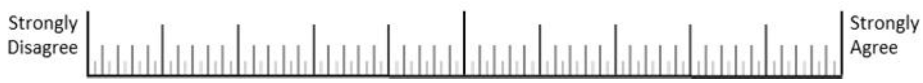
9. A higher ceiling (i.e., above 3300 AGL) would be an acceptable ceiling for CAPP operations. (draw a line on the scale)



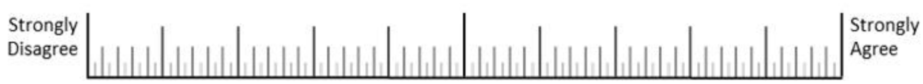
Comments:

10. The spacing I achieved during CAPP operations was *acceptable*. (draw a line on each scale)

3.2 nm:



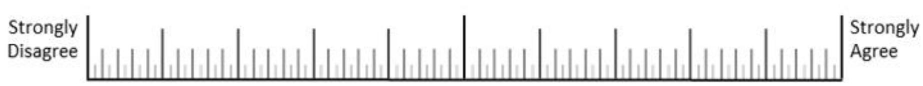
3.5 nm:



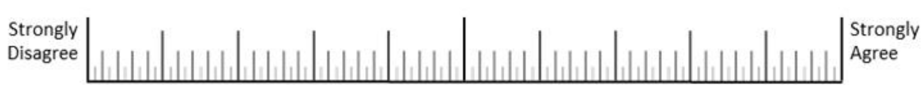
Comments:

11. I would be comfortable spacing more closely during CAPP operations. (draw a line on each scale)

3.2 nm:



3.5 nm:

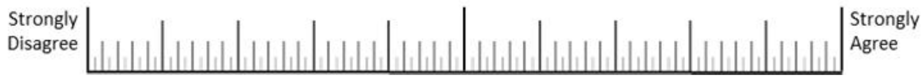


Comments:

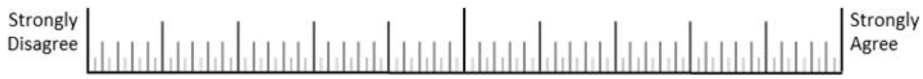
12. Given the appropriate training, CAPP is operationally acceptable. (draw a line on each scale)

Ceiling

1800 ft:

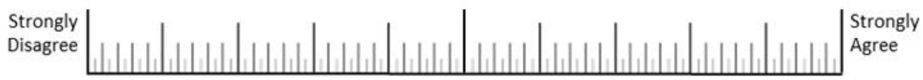


3300 ft:

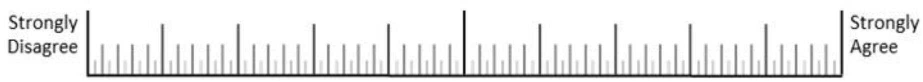


No-closer-than value

3.2 nm:

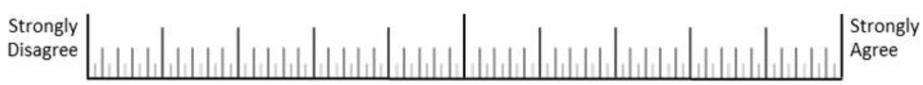


3.5 nm:



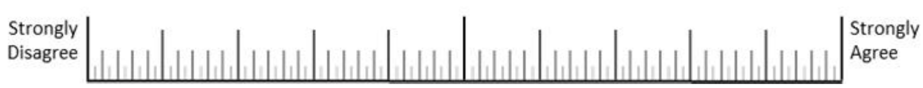
Comments:

13. The transition from CAPP into visual operations was acceptable. (draw a line on the scale)



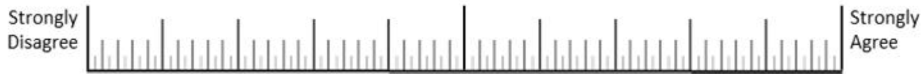
Comments:

14. The times where I was unable to transition out of CAPP was acceptable.



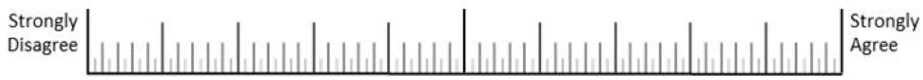
Comments:

15. The termination procedures were clear. (draw a line on the scale)



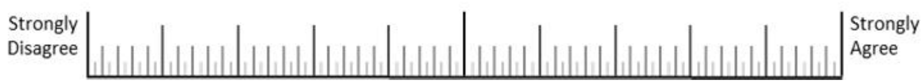
Comments:

16. My roles and responsibilities were clear during CAPP. (draw a line on the scale)



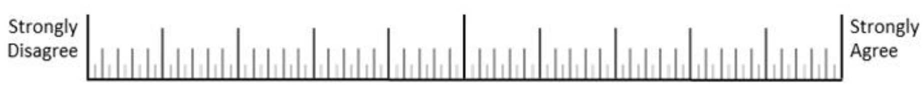
Comments:

17. While performing CAPP, all tasks were completed successfully. (draw a line on the scale)



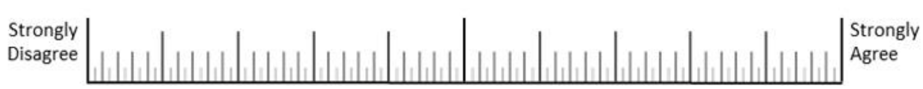
Comments:

18. The flight crew should be issued separation responsibility during CAPP. (draw a line on the scale)



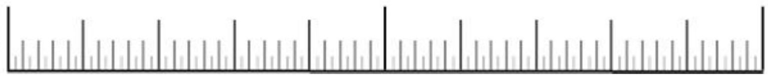
Comments:

19. I would be willing to accept separation responsibility for separation from the lead aircraft during CAPP. (draw a line on the scale)



Comments:

20. The controller should retain separation responsibility during CAPP. (draw a line on the scale)

Strongly Disagree  Strongly Agree

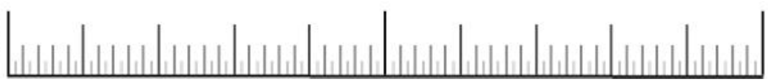
Comments:

21. How would you rate the overall effect of CAPP on your workload, as compared to operating a similar aircraft under similar conditions? (circle one)

Greatly *Increases*	*Increases*	Somewhat *Increases*	No Effect	Somewhat *Reduces*	*Reduces*	Greatly *Reduces*

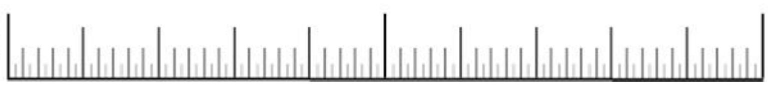
Comments:

22. My overall workload was acceptable. (draw a line on the scale)

Strongly Disagree  Strongly Agree

Comments:

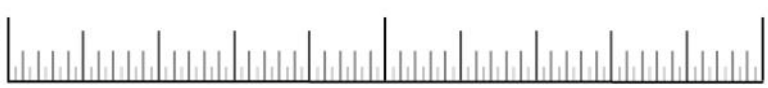
23. My level of traffic awareness was acceptable. (draw a line on the scale)

Strongly Disagree  Strongly Agree

Comments:

Communications

24. The CAPP instruction "CAPP 3.2 miles behind Cactus 1 -23" was acceptable. (draw a line on the scale)

Strongly Disagree  Strongly Agree

Comments:

25. The point where the CAPP instruction was issued was acceptable. (draw a line on the scale)

Strongly Disagree — Strongly Agree

Comments:

26. “A traffic advisory communication is necessary prior to the CAPP instruction (versus only providing the CAPP instruction that includes lead aircraft call sign). (draw a line on the scale)

Strongly Disagree — Strongly Agree

Comments:

27. I experienced confusion about whether my aircraft was being talked to (i.e., receiving an ATC communication) vs. talked about (i.e., being addressed as a third party aircraft). (draw a line on the scale)

Strongly Disagree — Strongly Agree

Comments:

28. Do you believe you would get used to being talked about (i.e., being addressed as a third party aircraft) and not just to (i.e., receiving an ATC communication)?

Yes	No	Don’t Know

Would that experience reduce any concerns? (circle one)

Yes	No	Don’t Know

Comments:

29. Did you have any issues during communications when third party call sign was used? (circle one)

Yes	No

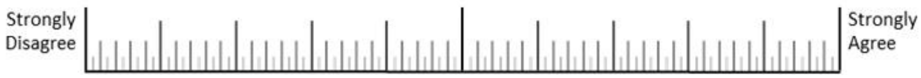
If yes, describe:

30. Did you have any issues during display interactions related to third party call sign? (circle one)

Yes	No

If yes, describe:

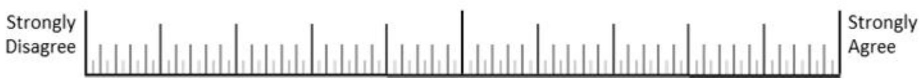
31. Use of the third party call sign in the CAPP instruction is operationally acceptable. (draw a line on the scale)



Comments:

Display

32. I was able to perform CAPP by primarily focusing on the information on the AGD and occasionally referencing the EFB CDTI. (draw a line on the scale)



Comments:

33. Considering total time on the CAPP displays, estimate the total percentage of time using each display (total should equal 100). (enter a value for each display)

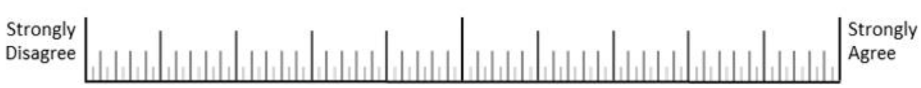
Display	Percentage Use
AGD	

CDTI	

Total	100%

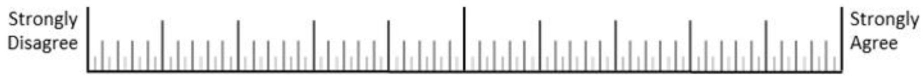
Comments:

34. I was able to remain outside the no-closer-than value while spacing from the traffic I was following. (draw a line on the scale)



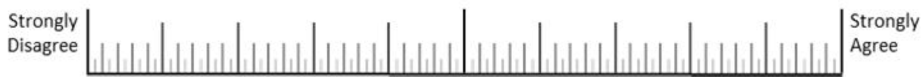
Comments:

35. I was able to detect when spacing issues were developing aircraft during CAPP operations. (draw a line on each scale)



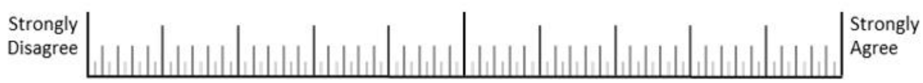
Comments:

36. The differential ground speed is useful for CAPP. (draw a line on the scale)



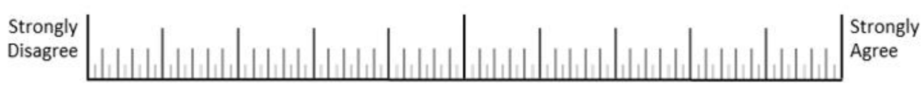
Comments:

37. The differential ground speed is a minimum requirement for CAPP. (draw a line on the scale)



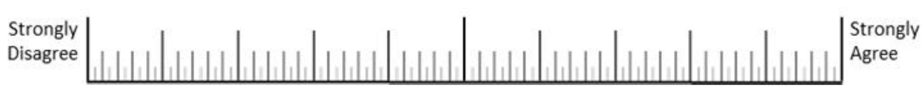
Comments:

38. The range to the lead aircraft is useful for CAPP. (draw a line on the scale)



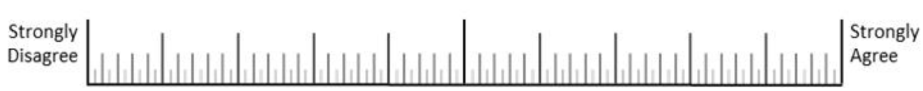
Comments:

39. The range to the lead aircraft is a minimum requirement for CAPP. (draw a line on the scale)



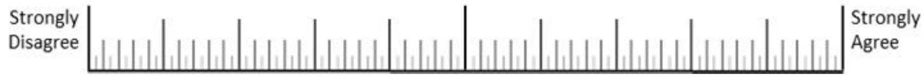
Comments:

40. The graphical cue (i.e., ><) is useful for CAPP. (draw a line on the scale)



Comments:

41. The graphical cue (i.e., ><) is a minimum requirement for CAPP. (draw a line on the scale)



Comments:

42. Did the combination of both the AGD and CDTI implementations include all the information necessary for you to make informed and accurate spacing decisions? (circle one)

Yes	No

If no, describe any instances where you would have liked more information, and the form in which the additional information would have been most useful.

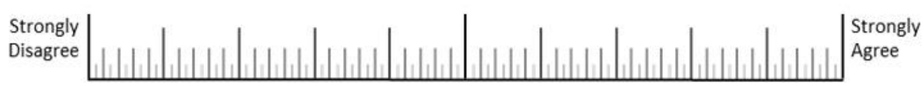
43. Did you find any elements on the displays to be confusing or misleading? (circle one per row)

AGD	Yes	No

CDTI	Yes	No

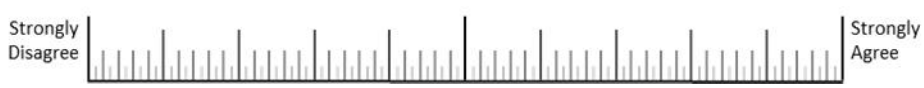
If yes, describe:

44. I think the display of a distance-from-no-closer-than-value would be useful. (draw a line on the scale)



Comments:

45. I think the display of a distance-from-no-closer-than-value would be required. (draw a line on the scale)



Comments:

46. Did you need additional information on the AGD or CDTI to conduct CAPP? (circle one per row)

AGD	Yes	No

CDTI	Yes	No

If yes, describe:

47. Did you have any issues with the two separate displays? (circle one per row)

AGD	Yes	No

CDTI	Yes	No

If yes, describe:

48. I would be willing to perform CAPP with the CDTI and AGD I used today (ignore simulation issues if any existed, e.g., readability of text on the displays). (draw a line on the scale)

Strongly Disagree | Strongly Agree

Comments:

49. I was comfortable using the displays for spacing when the aircraft was not visible out the window. (draw a line on the scale)

Strongly Disagree | Strongly Agree

Comments:

50. I was comfortable using the displays for spacing when the aircraft was visible out the window. (draw a line on the scale)

Strongly Disagree | Strongly Agree

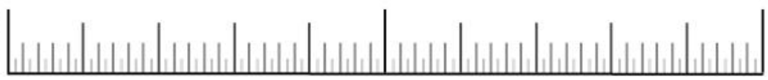
Comments:

51. How difficult was it to integrate the displays into your normal instrument scan? (circle one per row)

AGD	Very difficult	Difficult	Somewhat difficult	Borderline	Somewhat Easy	Easy	Very easy
-------------							
CDTI	Very difficult	Difficult	Somewhat difficult	Borderline	Somewhat Easy	Easy	Very easy

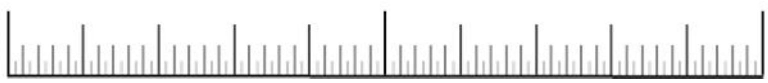
Comments:

52. The necessary scan time was acceptable. (draw a line on the scale)

Strongly Disagree  Strongly Agree

Comments:

53. My level of head down time was acceptable. (draw a line on the scale)

Strongly Disagree  Strongly Agree

Comments:

Overall

54. What advantages / disadvantages do you see with CAPP?

Advantages
Disadvantages

55. What was the most difficult situation to deal with when aircraft were conducting CAPP?

56. What was the easiest situation to deal with when aircraft were conducting CAPP?

57. What problems, issues, or concerns do you have with CAPP?

58. How could CAPP be improved?

59. If you have any other comments about anything else in the simulation, please provide them:

Simulation

60. The training I received was adequate.

Strongly Disagree — Strongly Agree

Comments:

61. The overall simulation was effective as a context for evaluating CAPP.

Strongly Disagree — Strongly Agree

Comments:

62. Was there anything about the simulation that artificially affected using it as a context for evaluating? (circle one)

Yes	No	Don't Know

If yes, explain:

Appendix E Acronyms and Abbreviations

ADS-B	Automatic Dependent Surveillance-Broadcast
ADV	Advisory
AGL	Above Ground Level
AIWP	Application Integrated Work Plan
AGD	ADS-B Guidance Display
ALPA	Air Line Pilots Association
ANOVA	Analysis of variance
ARC	Aviation Rulemaking Committee
AP23	Action Plan 23
ASA	Aircraft Surveillance Application
ASG	Assigned Spacing Goal
ATC	Air Traffic Control
ATP	Air Transport Pilot
CAASD	Center for Advanced Aviation System Development
CAPP	CDTI Assisted Pilot Procedure
CARTS	Common Automated Radar Terminal System
CAU	Caution
CAVS	CDTI Assisted Visual Separation
CDTI	Cockpit Display of Traffic Information
CDU	Control and Display Unit
CEDS	CDTI Enabled Delegated Separation
CEFR	CDTI Enhanced Flight Rules
CP	CAPP capable
DGS	Differential Ground Speed
DM	Descriptive Mean
EFB	Electronic Flight Bag
EICAS	Engine-Indicating and Crew-Alerting System
EUROCAE	European Organisation for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration

FAF	Final Approach Fix
FIM	Flight deck Interval Management
FMS	Flight Management System
FO	First Officer
FPCS	First Party Call Sign
ft	feet (/foot)
GIM	Ground Interval Management
HITL	Human-In-The-Loop
IDEA	Integration Demonstration and Experimentation for Aeronautics
IFPI	Intended Flight Path Information
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IM	Interval Management
IMC	Instrument Meteorological Conditions
KLAX	Los Angeles International Airport
KPHL	Philadelphia International Airport
kts	Knots
M	Mean
MANOVA	Multivariate Analysis of Variance
MCP	Mode Control Panel
MIT	Massachusetts Institute of Technology
MOPS	Minimum Operational Performance Standards
MITRE	MITRE
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NCT	No Closer Than
ND	Navigation Display
NM	Nautical Mile
OSED	Operational Service and Environment Description
OTW	Out-The-Window

PaP	Participant Pilot
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring
PsP	Pseudo-Pilot
RA	Resolution Advisory
RFG	Requirements Focus Group
RTCA	RTCA
SAE	Society of Automotive Engineers
SC	Special Committee
SD	Standard Deviation
sec	seconds
SPR	Safety and Performance Requirements
STARS	Standard Terminal Automation Replacement System
TA	Traffic Advisory
TBFM	Time-Based Flow Management
TCAS	Traffic alert and Collision Avoidance System
TGT	Target
TLX	Task load index
TMA	Traffic Management Advisor
TPCS	Third Party Call Sign
TRACON	Terminal Radar Approach Control
TTF	Traffic To Follow
UPS	UPS
US	United States
VMC	Visual Meteorological Conditions
VRR	Variable Range Ring
VSA	Enhanced Visual Separation on Approach
WG	Working Group

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