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Air traffic control specialist performance in shared versus traded states

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**AIR TRAFFIC CONTROL SPECIALIST PERFORMANCE IN SHARED VERSUS
TRADED STATES**

A Thesis

Presented to

The Faculty of the Graduate Program in Human Factors and Ergonomics

San Jose State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

by

David Jara

Adviser: Dr. Kevin Corker

August 2002

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APPROVED FOR THE GRADUATE PROGRAM
IN HUMAN FACTORS AND ERGONOMICS

(Dr. Kevin Corker – Thesis Chairperson signs here)

(Dr. Kevin Jordan – Thesis Committee Member signs here)

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APPROVED FOR THE UNIVERSITY

ABSTRACT

AIR TRAFFIC CONTROL SPECIALIST PERFORMANCE IN SHARED VERSUS TRADED STATES

by David Jara

Seventeen Controllers performed in shared and traded supervisory control states. Shared control is the performance of a task by a human operator with the concurrent assistance of automation. Traded control is the process of shifting the handling of a task by either the human operator or automation. In the shared condition, controllers monitored the airspace with the assistance of a conflict probe. In the traded condition, controllers performed a secondary task, in addition to monitoring the traffic with the assistance of the conflict probe. The researcher also manipulated the percentage of planes in free flight, 80% and 100%. Indices included controller workload, separation performance, and secondary task performance. Results indicated that workload was significantly higher in the traded condition, and that there were less separation violations in the shared condition. The participants also performed better on the secondary task in the Traded/100% condition than the Traded 80% condition.

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Introduction

“Speaking mathematically, he [man] is best when doing least” (Birmingham and Taylor, 1954, p. 1752)

The National Airspace System (NAS) is currently undergoing incremental changes in an effort to reduce delays, increase traveler capacity, and reduce operating expenses. This loosening of NAS restrictions will reach a pinnacle with an air space design known as “free flight.” The notion of free flight was formulated by the RTCA (1995, p. 23) as:

A safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through special use airspace, and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity which removes restrictions represents a move towards free flight.

The successful implementation of this concept is dependent upon certain enabling technologies, including conflict probe apparatus, Global Positioning System (GPS), and progressive communication, navigation and surveillance (CNS). The concept of free flight has been the subject of numerous simulation experiments. Summarily, the results range from “could not be refuted” (van Gent, Hoekstra, & Ruigrok, 1998, p. 68) to “should be investigated further” (Cashion, Mackintosh, McGann, & Lozito, 1997, p. 24). To expand upon the latter, the researchers uncovered several suspect areas, including issues related to communications and the controllers’ monitoring function in free flight.

One possible ramification of the concept of free flight is the transformation of the task of the controller from an active controller of aircraft to a monitor of the current air

space situation, with the aide of a conflict probe. The introduction of free flight will undoubtedly change the nature of the controller's task. The demands of maintaining the separation of aircraft are likely to increase workload as the controller attempts to interpret the consequences of aircraft initiating and carrying out maneuvers independent of Air Traffic Controller (ATC) instruction. The ability of controllers to effectively assure the separation while purporting to be passive monitors of the air space situation remains an issue of concern in the aeronautics industry.

The performance of human operators in vigilance tasks has been thoroughly researched (Mackworth, 1948; Dember & Warm, 1979; Davies & Parasuraman, 1982). The literature demonstrates that target detection declines over time (vigilance decrement) and that operators show a tendency to miss targets when the frequency of targets is low. It is unsettling that as the free flight concept is developed, the human operator may be delegated to a task that he/she is not well suited to perform from an empirical perspective. The poor performance of the human operator in monitoring roles makes it imperative that the conflict probe and the operator are conjoined carefully.

Survey of Air Traffic Control

There are three different types of air traffic control: Airport Traffic Control Tower (ATCT), Terminal Radar Control (TRACON), and the Air Route Traffic Control Center (ARTCC) (Wickens, Mavor, & McGee, 1997). The ATCT is responsible for the safe and efficient flow of all traffic operating on the airport surface as well as the airspace immediately surrounding the airport. The ATCT is generally responsible for all the planes within a 4-7 mile radius of the airport and up to 14,500 ft. One of the major

responsibilities of the ATCT is to clear aircraft for departures and arrivals. The ATCT provides specific directions that will ensure the safety of the aircraft while it is in transition from its airspace. The airspace beyond the ATCT is the responsibility of the TRACON. While the ATCT uses mostly the naked eye to maintain the flow of traffic, the TRACON is exclusively a radar environment. In the TRACON, the controllers are responsible for the safe efficient flow of traffic, as well as handing aircraft off to other controllers when the aircraft is leaving their airspace. The TRACON assigns arrival and departure instructions to the aircraft generally between the altitudes of 15,000 and 22,500 ft. The ARTCC was the air space that was simulated in this experiment. The ARTCCs are chiefly concerned with aircraft that are enroute at higher altitudes, although some sectors prepare aircraft for arrival and departure sequencing. The aircraft in the ARTCC are typically travelling at an altitude between 23,000-39,000 ft. A controller may work a sector by himself or herself if the workload is light, but often there will be a team of two controllers that will control an air space. The radar controller is "in charge" and is responsible for the separation of the aircraft and the communications with other sectors. The radar controller will coordinate hand offs with other sectors when the aircraft is about to complete its flight through a sector. The data controller assists that radar controller by completing computer entries and by updating the flight strips. Flight strips contain the pertinent information about a specific flight, including assigned routes and altitudes. The flight's progress is reflected on the strip, as well as any changes to the flight plan. The separation standards used in the ARTCC are usually 2,000 ft vertically and 5 nm laterally. The ARTCC is responsible for aircraft travelling at higher altitudes

across the continental US. Oceanic Air Traffic Controllers are responsible for flights that are traveling over the Pacific and Atlantic. Oceanic controllers have more limited radar equipment and rely upon the reports of pilots to ensure separation. While the today's control system is a safe environment to manage air traffic, researchers in the aeronautics industry are considering concepts and procedures aimed at increasing capacity, such as free flight.

Free Flight Simulations

Endsley, Mogford, Allendoefer, Snyder, and Stein (1997) considered controller performance in the free flight environment. The controllers performed in four conditions with increasing levels of free flight. In the condition that allowed pilots the most freedom to self-separate, seven operational errors were identified, compared to six in the other three conditions combined. Workload results were mixed, with Air Traffic Workload Input Technique (ATWIT) (a 5 min. probe of workload embedded in the task) measures yielding no significant results, while NASA TLX (a post-run measure) scores increased with higher levels of free flight. Communication times showed no significant effects of increasing levels of free flight, but expert observers warned that pertinent information was not shared with pilots as free flight increased. Controllers also showed decreased situational awareness as free flight levels evolved.

Cashion, Mackintosh, McGann, and Lozito (1997) performed an air-ground integration study manipulating traffic density and angle of conflict. In comparison with the above simulation, controller workload increased with traffic density as measured by self-report questionnaires. The researchers also found that controllers were slow to

identify obtuse angle conflicts in high-density situations, as compared to acute angle conflicts, which were identified faster. It is interesting that these conflict angles had an inverse effect on pilots, who found obtuse angles easier to resolve than acute angles. In a related ground side study, Fleming, Lane, and Corker (1999) found that workload increased as the percentage of aircraft that were engaged in free flight increased from 20% to 80%. It was also found that the duration of controller communication increased as levels of free flight increased.

It is important to note that in all of these studies, aircraft intent information was not presented on the controller's display, nor was there a ground conflict probe, a technology that will broadcast potential conflicts to pilots and controllers. The lack of aircraft intent information and a ground conflict probe may have been responsible for the apparent distress experienced by controllers in these free flight simulations, since subjective reports indicated that these tools would be desirable. Hilburn, Bakker, Pekela, and Parasuraman (1997) conducted a ground-side simulation study and found that overall free flight actually reduced workload, as compared to a direct control condition, especially in high traffic scenarios. When intent information was provided verbally by pseudo-pilots in the low traffic density condition, workload decreased. However, intent information had no effect on performance in the high traffic density condition. Intent information also had no effect on Short Term Collision Avoidance Alert (STCA) reaction times. Communication times increased when the pilots shared intent information.

The study conducted by Hilburn, Bakker, Pekela, and Parasuraman (1997) is distinguished from the others with two major inclusions: Military controllers and a

STCA. Hilburn and Parasuraman (1997) state that military controllers are more accustomed to free flight control due to the freedom granted to military aircraft, are more comfortable with advanced displays, and summarily, are habituated to unstable traffic control. Secondly, the STCA may have influenced the behavior and subsequent workload rating of the controllers. It is easy to imagine a controller recording low workload scores when cognizant of the fact that regardless of his long-term performance throughout a scenario, a controller can easily avoid an imminent conflict utilizing the services of the STCA.

Galster, Duley, Masalonis, and Parasuraman (1998) performed a free flight study in which traffic densities and the presence or absence of self-separating aircraft was varied. The controllers were asked to state which two aircraft would collide and the nearest waypoint to the loss of separation. The researchers embedded a secondary task, flight strip updates, in an attempt to estimate workload. Results indicated that subjective workload estimates increased significantly with traffic density, but were not affected by the addition of conflicting aircraft. Additionally, secondary task performance significantly deteriorated as traffic levels increased. In moderate traffic, the controllers missed 10% of the conflicts. In the high traffic density condition, 50% of the conflicts were omitted. In conflicts that were detected, controllers verbalized the loss of separation 196 s in advance in the moderate traffic and 145 s in advance in high traffic. It was also shown that it was difficult for controllers to notice the self-separating maneuvers of pilots. Controllers missed 70% of self-separating maneuvers in the moderate traffic and 85% in the high traffic.

Metzger and Parasuraman (1999) performed a simulation study manipulating traffic densities and locus of control: active or passive. Passive control consisted of the controller detecting the conflict, but refraining from providing a resolution strategy. In the active control locus, controllers provided resolution strategies. The primary task was accompanied by electronic flight strips, which served as a secondary task and a measure of workload. The results of the study indicated that there were no detection differences between active and passive control; however, controllers detected conflicts earlier in the active locus and when traffic density was moderate. It took controllers twice as long to detect conflicts in the passive, high-density condition as compared to the active, high-density condition. The secondary task results showed that controllers omitted more waypoints in the high-density condition and that waypoints were updated earlier in the moderate condition as compared to the high. Marginally significant results were found for earlier updates of the waypoints in the passive locus. Subjective NASA-TLX measures indicated a high workload in the peak condition, but yielded no significant results for locus of control.

Metzger, Galster, and Parasuraman (1999) showed that a conflict alerting system may not have the anticipated beneficial effect on workload and controller performance in free flight. The researchers manipulated a 5 min. "look ahead" conflict probe and traffic levels in the free flight environment. The alerting mechanism appeared to have assisted the controllers, since there were 40% more self-separation maneuvers and conflicts were realized approximately 60 s earlier with the aid of an alerting mechanism. However, a sizable proportion of events went unrecognized. Specifically, in high traffic densities,

50% of self-separating maneuvers and 20% of separation violations were missed with the assistance of the conflict alerting mechanism. The conflict probe showed promising results in moderate traffic, where self-separation maneuvers were anticipated 50 s beforehand. However, conflicts were not attended to until 23 s to 53 s after the alert in both moderate and high traffic. Workload measures were affected by traffic density, which increased as traffic increased. The presence of the alerting mechanism did not affect workload. The researchers concluded that the controllers were apprehensive about the performance of the aid, and that training and alert timing will be very important in the implementation of a conflict probe in free flight.

The researchers report some conflicting evidence of the impact of free flight on air traffic controllers. There is a lack of consensus regarding the impact of free flight on controller workload (Endsley, et al., 1997; Cashion, et al., 1997; Hilburn, et al., 1997) as well as the effect of conflict probes on controller performance in free flight (Metzger, et al., 1999). This lack of consensus fuels the necessity of subsequent research to identify the optimal relationship between automated conflict detection sub-systems and human sub-systems. Wiener and Curry (1980) established four criteria to be considered when evaluating whether a human operator monitors a system or maintains active control.

1. Is the operator a better failure detector when acting as a passive or active controller?
2. Is there a lag in performance when transitioning from passive to active controller?

Does the automation cause the controller to become complacent or easily distracted?

3. Should the automation inform the controller of system changes that it is initiating?

4. How does the reliability of the automation affect controller conflict detection performance?

Supervisory Control

The coupling of a human and an automated system to monitor and control a process has been dubbed supervisory control (Sheridan, 1970). Supervisory control represents a human operator periodically receiving and inputting data from/to a computer that itself closes an independent control loop through effectors and sensors to the defined process (Sheridan, 1992). More generally, supervisory control is the continual exchange of data between the human and the computer. In the air traffic control realm, the free flight controller will be linked with an automated ground conflict probe, constituting a supervisory control system (Hilburn, Bakker, Pekela, & Parasuraman, 1997).

Supervisory control has been explored in many other domains, but has yet to be explored in free flight air traffic control.

Sheridan (1970) constructed a theoretical model to describe the sampling strategies of an operator engaged in a monitoring task. He defined y as a control variable that could be manipulated in order to inflate a value function V of a network's input x , and output z . In air traffic management, y would represent any action of the controller that would be taken to increase V , the reward for taking evasive action. x represents the displays input to the human operator, such as the position and altitude of aircraft targets on a display. z represents the result of taking action, such as separating aircraft, which would affect V , the reward for taking such action. By defining these variables, a predictive equation can be established for a given situation that dictates how often a

supervisor should sample a system in order to attain an optimal reward (V). Figure 1 presents a pictorial description of this sampling process. Sheridan's theory represents the tradeoff of sampling, since a cost may accrue from manipulating y , separated from the cost of sampling x . It is recommended that the controller sample x more often than manipulating y , since the new z may represent a greater cost.

Sheridan (1992) has developed a quantitative model of a supervisory control task called Open Loop Action Theory (OLAT). OLAT serves as a mathematical model of how long a supervisor can go without sampling the system. The theory purports that uncertainty increases if the operator does not actively engage in the process. However, there is a boundary that at some point the controller will initiate action (effort) to reduce uncertainty. The controller essentially seeks to optimize information, seeking minimum effort according to the criterion established. The cost of sampling is losing points on the secondary task and transitioning to a control role. A vector equation can be established based on factors that warrant operator intervention. Figure 2 represents the relationship between reward and the cost of intervening, or sampling, in OLAT.

Rouse (1977) investigated supervisory control by employing a queuing-theory application to model whether a continuous control task should be assigned to a human or computer. The allocation criterion was to minimize service time under cost constraints, such as false alarms, missed events, and human-computer speed mismatches. Results indicated that human-computer mismatches degraded efficiency more than limited computer speed. Rouse emphasizes the benefits of this approach to the allocation of responsibility between human and computers. He states that if the computer is capable of

performing each task equally as well as a human, then the computer should execute the process. However, it is more likely that the human will be capable of performing the tasks but will be temporally restrained or operating under resource constraints.

In a related experiment, Chu and Rouse (1979) allowed a computer to execute tasks that waited in a queue for a certain amount of time in a flight simulation. Computer assistance was found to improve subsystem performance and reduce workload scores. Moray, Sanderson, Shiff, Jackson, Kennedy, and Ting (1982) had an operator attend to four independent control loops. The operator could either monitor the systems and control them manually or leave them to automatic control. The aim was to keep all systems within the criteria established. Results indicated that operators' strategies were divided between automatic and manual control regardless of increasing temporal demands. An adaptive allocation of tasks may prove to reduce workload (Hancock & Chignell, 1989). An adaptive allocation provides a flexible framework in which the human and computer can assume control of a task at optimal times. Hypothetically, an operator could control a task during moderate workload sessions, then switch the task to the computer when workload reached exceedingly high levels. The operator could then regain control when workload reached more manageable levels.

Lee and Moray (1992) simulated the automatic and manual control of an orange juice pasteurization plant. The purpose of the experiment was to analyze human monitoring behavior in relation to system faults. The results indicated that operators who sampled the system frequently while strategizing control actions performed better. Operators who showed poor performance observed the system less frequently and

seemed to perform more random control actions. It was also found that operators who performed poorly focused on a subset of system parameters rather than the entire state of the system. These results indicate that individual differences may supercede automation design and the information presented, highlighting the importance of training in a supervisory control monitoring task.

Kaber and Riley (1999) used a secondary task to gauge the effect of automation on workload. The researchers manipulated whether the allocation of tasks between the human operator and the computer was mandated or suggested. The provision of a suggestion or mandate for either manual or automatic control was based on baseline workload estimations. It was found that the mandated group performed better under manual control than the suggestion group. The researchers contend that this was due to reduced stress levels and increased operator confidence. The mandated group also performed better on the secondary task, indicating a reduced workload. In the suggestion group, operators were more aware of automation suggestions than manual ones. This was interpreted to be problematic because the operators may be underestimating the out-of-the-loop performance issue.

Shared and Traded Supervisory Control

Sheridan (1992) has reduced the range of the supervisory control relationship between human operators and computers to traded and shared control. He defines these concepts according to how much of the task is completed by the human and how much is allocated to the computer. Sharing control means that the human and the computer control different aspects of the process concurrently. Traded control is the discrete

handling of a task by either the human or the computer independent of the other. Shared control can be illustrated with the common practice of television channel surfing. This process is a closed control loop between the human operator and the television. The operator activates the appropriate buttons on the remote control while the television displays the appropriate channels. The human concurrently operates the viewing process, sharing control with the remote and the television. Remaining within the current entertainment example, the pre-recording of a television program serves as an example of traded control. Initially, the human is in control as he/she programs the VCR to record the appropriate program. However, the recording process is entirely executed without the assistance of the human operator. Thus, control is traded between the human and the VCR.

Summary

This simulation experiment incorporated shared and traded control procedures to explore free flight air traffic management. In one condition, control was shared between the human operator and the conflict probe. The Air Traffic Control Specialist and the conflict probe concurrently monitored air traffic development to detect and resolve conflicts. In the traded condition, the Specialist and the conflict probe will alternate control. The Specialist was occupied with a secondary task in the traded condition, but could sample the traffic display at any time in an effort to detect and resolve conflicts. The conflict probe operated throughout this condition, alerting the air traffic control specialist to any pending conflicts. The experimenter also manipulated the percentage of planes in free flight, 80% and 100%. Thus, the experiment consisted of a 2

(shared/traded control) x 2 (80% aircraft in free flight/100% aircraft in free flight) within subjects design.

Either the shared or traded control procedures may be demonstrated to be superior by exhibiting decreased workload and minimal separation violations. There is no projection, a priori, as to which mode of control will be preferred. Shared and traded hypotheses were neutral because previous research involved tasks unrelated to air traffic management (Rouse, 1977; Chu & Rouse, 1979 ; Moray et al.,1982; Hancock & Chignell, 1989). In light of this, the current study was mostly exploratory. It is unknown if workload and performance levels will positively correlate with increased free flight levels, due to conflicting findings discussed previously (Hilburn, et al., 1997; Fleming, et al., 1999). The Fleming, et al., 1999 study involved aircraft in a 20% and 80% free flight environment. It is difficult to draw conclusions from this study because the 100% free flight condition does not consider the impact of mixed equipage. The 100% condition was included to see if there is a ceiling affect for the percentage of planes in free flight, possibly because of the lack of mixed equipage.

Method

Participants

Seventeen active air traffic controllers from Oakland (ZOA) Air Traffic Control Center participated in this study. Most of the controllers were from the domestic enroute environment. Four of the controllers were from the TRACON environment and had no experience controlling domestic enroute traffic. The investigator concluded that the domestic enroute environment and the TRACON environment were similar to an extent

that justified the inclusion of TRACON specialists. One of the participants was a retired domestic enroute specialist with 8 years of experience. The average number of years of experience for the participants was 13.82 ($SD = 5.46$). The average age of the specialists was 39.76 ($SD = 6.81$).

Materials

CTAS. Two Sun Workstations were used in the experiment. One workstation showed traffic and was equipped with the Center TRACON Automation System (CTAS). CTAS is an automated decision support tool for both center and terminal controllers that assists in strategic planning and presents the operator with clearance advisories (Sanford, Harwood, Nowlin, Bergeron, Heinrichs, Wells, & Hart, 1993). The traffic displayed represented a generic domestic enroute sector that was not particular to any facility. The CTAS display is shown in Figure 3 with traffic patterns typical of this experiment. The CTAS display is similar to a current display, with an adjustable view range, aircraft symbols, waypoints, sector boundaries, jet routes, and data blocks. Figure 4 depicts some of these objects. The data block contains new information, including flight ID number, and aircraft type. CTAS was designed to improve the flow of traffic in the NAS with the introduction of new tools such as the Traffic Management Advisor (TMA), Descent Advisor (DA), and the Final Approach Spacing Tool (FAST).

CTAS Conflict Probe. The conflict probe was the only tool in the CTAS array that was of interest in this study. The conflict probe surveys overflights, arrivals, and departures in the Federal Aviation Administration (FAA) host computer every 12 s to check for conflicts (McNally, Engelland, Bach, Chan, Brasil, Gong, Frey, & Vincent,

2001). The conflict probe calculates trajectory and route information based on 4D (time, altitude, and x,y position). The probe displays a list of conflicting aircraft that appears in the upper right hand corner of the screen. The probe was customized so that the conflict pairs appeared in the list when the aircraft violated a separation threshold based on 7 min, 5 NM laterally, and 1000-ft vertically. The list showed the conflicting pairs, whether the aircraft were climbing, descending, or level, time until separation violation, and the closest point of approach, including lateral and vertical distance. An example of conflicting pairs in the conflict probe box is shown in Figure 5.

PAS. The other Sun workstation was equipped with PAS (Pseudo Aircraft Systems) software, which was used to generate the traffic that appeared on the air traffic specialists' CTAS display. PAS provides a high fidelity representation of aircraft performance that can be easily modified. It also presents the current trajectory state information of the aircraft. The pseudo pilot worked with the PAS software to make any altitude, speed, or heading changes that the specialist requested.

Multitask. The specialist was also presented with a secondary task called Multitask (Kaber & Riley, 1999) on a PC desktop computer. Multitask is a Microsoft Visual Basic software program that depicts squares converging on the center of the screen from random directions. The Air Traffic Control Specialists' task was to collapse the squares by mouse clicking on them before they reached the center of the screen. An expiration occurs if the block reaches the center of the screen. Figure 6 depicts a sample screen from the Multitask program. Multitask recorded the number of expirations every 15 s. The blocks took about 17 s to reach the center of the screen. The Specialists had to

click the blocks before they reached the center of the screen to avoid expirations. There were about 3 blocks that appeared on the screen every 10 s.

Communications Equipment. The specialists' were given headsets with microphones to communicate with aircraft. No foot pedal was provided.

Dependent Variables

Secondary Task. The number of expirations on Multitask were measured every 15 s.

Separation Violations. Separation violations of 1000 ft. vertically and 5 nm laterally were recorded.

Maneuver Initiation. The time that a Specialist initiated a maneuver was recorded. The maneuver time was calculated as a function of the time remaining to collision for the planned conflicts, and when the maneuver was initiated in relation to the conflict probe alert

Closest Point of Approach (CPA). The point at which the conflicting pairs were closest to each other was calculated in nm.

Workload. Workload was measured with the NASA-TLX questionnaire after every scenario (Hart & Staveland, 1988). The questionnaire consists of 6 subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration level. The questionnaire has been empirically validated and has been found to be reliable. See appendix C for the NASA-TLX questionnaire.

Design and Procedure

Prior to any data collection, the researcher briefed the participants about the nature of the task. All participants completed an informed consent form. Following the briefing, the Air Traffic Control Specialists completed 4 practice sessions, representing the 4 different scenarios. Following the practice session, the counterbalanced experiment began. Each scenario was 25 min. in length, with 3 scripted conflicts. Each conflict was approximately 5 min. apart. One of the conflicts in each scenario served as a decoy and was not considered in the data analysis. The decoy served to keep the controller engaged in the task early on, although the traffic was not fully developed when this conflict occurred. Each participant performed in every condition, consisting of 4 scenarios. The variables manipulated were percentage of planes in free flight (80%, 100%) and locus of control (shared, traded). The conflict probe was available to the Specialists in all scenarios. Specialists in the shared condition actively monitored the traffic with no Multitask. They were solely responsible for identifying and separating the three scripted conflicts, as well as any other situations that may be potential conflicts. In the traded condition, the Air Traffic Control Specialists were requested to attend to Multitask as much as possible, although they had final responsibility for the safety of the airspace. Thus, the Specialists switched between the Multitask display and the traffic display. A pseudo-pilot served as a confederate of the experimenter. The role of the pseudo-pilot was to play the role of the intruder and any other aircraft that the Specialist decided to query. The intruder was any aircraft that the Air Traffic Control Specialist wanted to contact in an effort to resolve a conflict. The Specialists completed the NASA-TLX

workload questionnaire and a post run questionnaire after each scenario. Upon the completion of all 4 scenarios, the Specialists were administered a debrief questionnaire (see Appendix B). The confidentiality of the participants' identity and results were ensured. Figure 7 represents the experimental design matrix.

Results

The dependent variables for the experiment were workload, number of expirations on Multitask, number of separation violations, time of maneuver, Closest Point of Approach (CPA), as well as questionnaire data. These variables were selected based on the research literature and to allow an analysis of the Air Traffic Control Specialists' behavior in relation to the conflict probe. A 2 (levels of free flight) x 2 (supervisory control mode) within subjects analysis of variance was performed on each of these dependent measures, with the exception of the number of separation violations. The low number of observed frequencies in each cell disqualified these data from being analyzed with inferential statistics. Each analysis will be discussed in turn. To restate the hypothesis under investigation, the supervisory control procedure (traded or shared) that was supported would exhibit decreased workload and minimal separation violations. Statistically this would be indicated by a main effect of supervisory control mode. It is unknown if the dependent variables will be affected by increased free flight levels, due to conflicting findings discussed previously (Hilburn, Bakker, Pekela, & Parasuraman, 1997; Fleming, Lane, & Corker, 1999). Statistically this would be indicated by a main effect of percentage of aircraft in free flight.

The NASA-TLX scores were analyzed and yielded a significant interaction. The means and standard deviations for the workload scores are presented in Table 1. The NASA-TLX scores were analyzed with an ANOVA and yielded significant findings for type of Control. The Traded/80% showed the highest workload score. The Traded Condition was rated as significantly more work than the shared condition, $F(1, 16) = 70.70, p < .00$. Table 2 presents the F table for the NASA-TLX. There was no significant result found for the percentage of planes in free flight, $F(1, 16) = 1.86, p > .19$. An ANOVA was also run on the interaction between the percentage of aircraft in free flight and the type of control. The results were significant, $F(1, 16) = 24.68, p < .00$. A larger percentage of planes in free flight caused an increase of workload in the shared condition, while in the traded condition a larger percentage of planes in free flight caused a decrease in workload. Figure 8 presents the interaction effect in graph format. The Confidence intervals at 95% were calculated on the NASA-TLX workload scores. For Shared/80% $\underline{M} = 163.24 \pm 22.00$. For Shared/100% $\underline{M} = 204.12 \pm 19.96$. For Traded/80% $\underline{M} = 349.12 \pm 23.74$. For Traded/100% $\underline{M} = 280.88 \pm 22.46$. The standard error bars in relation to the means are presented in Figure 9.

To further analyze this interaction in the NASA-TLX scores, a simple main effects ANOVA was administered on the data. The means and standard deviations collapsed across each level of the independent variables are displayed in Table 3. For the type of control at 80% of the planes in free flight, a significant effect was found, $F(1, 16) = 71.63, p < .001$. Table 4 presents the F table for the type of control at 80% and 100% of the planes in free flight. For the type of control at 100% of the planes in free flight, a

significant effect was found, $F(1, 16) = 23.89, p < .001$. For the percentage of planes in free flight at the traded condition, a significant effect was found, $F(1, 16) = 14.30, p < .001$. Table 5 presents the F table for the percentage of planes in free flight at the traded and shared condition. For the percentage of planes in free flight at the shared condition, a significant effect was found, $F(1, 16) = 14.34, p < .001$.

The multitask data were analyzed to see if there was a difference in performance on Multitask between the 80 and 100 percent condition. The Multitask data presented a similar finding to the NASA-TLX scores. The Traded/80% condition ($M = 11.15$ and $SD = 11.02$) as higher than the Traded/100% condition ($M = 4.55$ and $SD = 4.49$). This was a significant result $F(1, 16) = 7.65, p < .01$. The F table for the Multitask scores is displayed in Table 6. The Confidence intervals at 95% were calculated on the Multitask scores. For Traded/80% $M = 11.15 \pm 2.67$. For Traded/100% $M = 4.55 \pm 1.09$. The standard error bars in relation to the means are presented in Figure 10.

Table 7 shows the observed frequency of separation violations based on scenario type in a contingency table. The Traded/80% condition showed the most separation violations, with 5. The Traded/100% condition had 2, and in each of the Shared conditions there was 1.

The time of the cancellation of the free flight pair in relation to when to probe alerted the Air Traffic Control Specialist to the conflict was calculated. The means and standard deviations of when the Specialist intervened in relation to the conflict probe are presented in Table 8. A within subjects ANOVA was performed on the data and yielded no significant result for type of control, $F(1, 16) = .03, p > .87$, the percentage of planes

in free flight, $F(1, 16) = .07$, $p > .80$, or the interaction. The F tables for control type, the percentage of planes in free flight, and the interaction are presented in Tables 9. The Confidence intervals at 95% were calculated on the cancellation times in relation to the conflict probe. For Shared/80% $\bar{M} = 15 \text{ s} \pm 16 \text{ s}$. For Shared/100% $\bar{M} = 24 \text{ s} \pm 17 \text{ s}$. For Traded/80% $\bar{M} = 24 \text{ s} \pm 15 \text{ s}$. For Traded/100% $\bar{M} = 20 \text{ s} \pm 20 \text{ s}$.

The CPA data was calculated to see if there was a difference between the type of control and the percentage of planes in free flight. The means and standard deviations of the CPA data are presented in Table 10. A within subjects ANOVA was performed on the data and yielded no significant result for type of control, $F(1, 16) = 3.04$, $p > .101$, the percentage of planes in free flight, $F(1, 16) = .21$, $p > .66$, or the interaction. The F tables for control type, the percentage of planes in free flight, and the interaction are presented in Table 11. The Confidence intervals at 95% were calculated on the CPA data. For Shared/80% $\bar{M} = 5.15 \text{ nm} \pm 1.02 \text{ nm}$. For Shared/100% $\bar{M} = 4.05 \text{ nm} \pm .88 \text{ nm}$. For Traded/80% $\bar{M} = 4.90 \text{ nm} \pm 1.03 \text{ nm}$. For Traded/100% $\bar{M} = 4.65 \pm 1.01 \text{ nm}$.

Another measure related to time was collected, the difference between the time of the anticipated collision between a conflict pair, and the time of the cancellation by the Specialist. Table 12 shows the means and standard deviations of the cancellation times as a function of scenario type. A within subjects ANOVA was performed on the data and yielded no significant result for type of control, $F(1, 16) = .03$, $p > .87$, the percentage of planes in free flight, $F(1, 16) = .01$, $p > .91$, or the interaction. The F tables for control type, the percentage of planes in free flight, and the interaction are presented in Table 13. The Confidence intervals at 95% were calculated on the cancellation times in relation to

the Time of Collision. For Shared/80% $\underline{M} = 6:44 \pm 16$ s. For Shared/100% $\underline{M} = 6:41 \pm 19$ s. For Traded/80% $\underline{M} = 6:41 \pm 17$ s. For Traded/100% $\underline{M} = 6:40 \pm 26$ s.

Items 6 through 11 on the post simulation questionnaire data were analyzed. This questionnaire can be found in Appendix B. The means and standard deviations for item 6 are presented in Table 14. Item 6 asks "Overall, how much time did you feel you spent monitoring traffic in this scenario?" The Specialists reported that they spent most of their time monitoring the display in the shared condition. An ANOVA was administered on the data and yielded a significant effect for type of control, $F(1, 16) = 12.99, p < .00$, but not for the percentage of plans in free flight, $F(1, 16) = 0.00, p > 1.00$ or the interaction. The F table for item 6 can be found in Table 15. The Confidence intervals at 95% were calculated on item 6 on the post simulation questionnaire and are presented in Figure 11. For Shared/80% $\underline{M} = 4.59 \pm 0.32$. For Shared/100% $\underline{M} = 4.94 \pm 0.23$. For Traded/80% $\underline{M} = 3.76 \pm 0.25$. For Traded/100% $\underline{M} = 3.41 \pm 0.31$.

The means and standard deviations for item 7 are presented in Table 16. Item 7 asks "Overall, how much time pressure did you experience after an alert in this scenario?" The Specialists reported experiencing more time pressure after an alert in the traded condition. An ANOVA was administered on the data and yielded a significant effect for type of control, $F(1, 16) = 6.23, p < .02$, but not for the percentage of aircraft in free flight, $F(1, 16) = 0.00, p > 1.00$ or the interaction. The F table for item 7 can be found in Table 17. The Confidence intervals at 95% were calculated on item 7 on the post simulation questionnaire and are presented in Figure 12. For Shared/80% $\underline{M} = 1.94$

± 0.28 . For Shared/100% $\underline{M} = 2.29 \pm 0.27$. For Traded/80% $\underline{M} = 2.88 \pm 0.31$. For Traded/100% $\underline{M} = 2.53 \pm 0.27$.

The means and standard deviations for item 8 are presented in Table 18. Item 8 asks "Did the secondary task negatively affect the separation of aircraft in this scenario?" The Specialists reported that the secondary task had a moderate negative effect on the separation of aircraft in the traded condition, $F(1, 16) = .18, p > .68$, but no significant effects were found for percentage. The F table for item 8 can be found in Table 19. The Confidence intervals at 95% were calculated on item 8 on the post simulation questionnaire and are presented in Figure 13. For Traded/80% $\underline{M} = 4.41 \pm 0.43$. For Traded/100% $\underline{M} = 4.18 \pm 0.44$.

The means and standard deviations for item 9 are presented in Table 20. Item 9 asks "Overall, how much workload did you experience in this scenario?" The Specialists reported experiencing more workload in the traded condition. An ANOVA was administered on the data and yielded a significant effect for type of control, $F(1, 16) = 39.81, p < .00$, but not for the percentage of aircraft in free flight, $F(1, 16) = 1.42, p > .25$. The F table for item 9 can be found in Table 21. A significant interaction was also found between the percentage of planes in free flight and the type of control for item 9, $F(1, 16) = 10.01, p < .00$. Figure 14 depicts the interaction, which is similar to the NASA-TLX interaction depicted in Figure 8. Both of these interactions show a higher overall workload in the traded condition, with workload increasing with the percentage of planes in free flight in the shared condition and workload decreasing as the percentage of planes in free flight increases in the traded condition. The Confidence intervals at 95%

were calculated on item 9 on the post simulation questionnaire and are presented in Figure 15. For Shared/80% $\bar{M} = 2.47 \pm 0.23$. For Shared/100% $\bar{M} = 2.94 \pm 0.25$. For Traded/80% $\bar{M} = 4.53 \pm 0.30$. For Traded/100% $\bar{M} = 3.71 \pm 0.32$. The means and standard deviations collapsed across each level of the independent variables for item 9 are displayed in Table 22.

The means and standard deviations for item 10 are presented in Table 23. Item 10 asks "Compared to current ops how safe did you feel this scenario was?" The Specialists reported experiencing a higher safety level in the shared condition. An ANOVA was administered on the data and yielded a significant effect for type of control, $F(1, 16) = 21.47, p < .00$, but not for the percentage of aircraft in free flight, $F(1, 16) = .01, p > .90$, or the interaction. The F table for item 10 can be found in Table 24. The Confidence intervals at 95% were calculated on item 10 on the post simulation questionnaire and are presented in Figure 16. For Shared/80% $\bar{M} = 2.41 \pm 0.38$. For Shared/100% $\bar{M} = 2.47 \pm 0.29$. For Traded/80% $\bar{M} = 4.00 \pm 0.36$. For Traded/100% $\bar{M} = 3.88 \pm 0.35$.

The means and standard deviations for item 11 are presented in Table 25. Item 11 asks "What level of situational awareness did you maintain throughout this scenario?" The Specialists reported maintaining a higher level of situational awareness in the shared condition. An ANOVA was administered on the data and yielded a significant effect for type of control, $F(1, 16) = 21.85, p < .00$, but not for the percentage of aircraft in free flight, $F(1, 16) = .22, p > .64$ or the interaction. The F table for item 11 can be found in Table 26. The Confidence intervals at 95% were calculated on item 11 on the post simulation questionnaire and are presented in Figure 17. For Shared/80% $\bar{M} = 4.88 \pm$

0.19. For Shared/100% $\underline{M} = 5.06 \pm 0.26$. For Traded/80% $\underline{M} = 4.00 \pm 0.33$. For Traded/100% $\underline{M} = 3.65 \pm 0.28$.

Discussion

The Specialists in this experiment showed a subjective preference for the shared condition. The Traded control condition showed a significantly higher subjective workload rating via the NASA-TLX than the shared control condition. The high frequency (5) of separation violations in the Traded/80 condition corroborates with the workload data. The highest workload ratings, both on the NASA-TLX and item 9, the workload item on the post simulation questionnaire, were associated with the Traded/80% condition. The post simulation questionnaire also indicated that the Specialists felt more time pressure after an alert and higher overall workload in the traded condition. In the shared condition, the Specialists reported higher safety and situational awareness levels.

Parasuraman, Molloy, and Singh (1993) performed an experiment exploring the propensity of human operators to become complacent in the presence of automation. Complacency was described by Billings, Lauber, Funkhouser, Lyman, and Huff (1981) as "self-satisfaction which may result in non-vigilance based on an unjustified assumption of satisfactory system state" (p. 23). Parasuraman, Molloy, and Singh examined the performance of general participants in an automated task. They found that when there was a manual-tracking task along with the automated task, participants were less likely to detect faults in the automated task when the reliability of the automation was constant. When the reliability of the automation was variable, the operators detected

more faults. In another experiment, the manual tracking task was eliminated and the reliability of the automation had no impact on fault detection, which was performed very well. This lends credence to the idea that operators place more confidence in the automation than it deserves when there is another task to complete. This suggests that system designers should be careful when assuming that operators can handle more tasks because of increased levels of automation, as is often the case.

The significant results found from workload as a function of type of control and the prevalence of separation violations in the Traded/80% condition can also be explained by the context in which the Specialist was operating. Hollnagel (1993) provided a fitting theoretical framework for discussion of these results and adds a dimension to the Sheridan model. Hollnagel proposed that the context in which the operator is immersed determines the control actions taken. The cognition of the operator is also affected by the context under which he/she is operating. The types of control that Hollnagel proposes are as follows:

Scrambled Control A seemingly chaotic control mode in which the operator has very little knowledge of the situation unfolding. Actions taken appear to be random or based on impulsive decisions. This mode may be resorted to in an emergency situation or when there is little time to deliberate over a decision.

Opportunistic Control Action is taken based on information that is presently available, but lacks the input of more abstract concepts and goals.

Tactical Control The tactical control mode introduces some level of forethought and planning.

Strategic Control The level of control that involves the most abstraction and inclusion of goals and principles are used to guide the long-term process. The operator has a well-developed model, which allows for predictions of the system observed.

Based on the theory above, it may be stated that in the traded control mode the Specialists were operating in a scrambled or opportunistic control mode. Subjective reports indicated that the Specialists would be prone to relying solely on the conflict probe to identify conflicting aircraft in the traded condition. In the shared condition, the Specialists had an opportunity to operate in a more strategic control mode. The Specialists were able to compare the maneuvers they initiated with other aircraft that were not involved in the immediate conflict. The whole air space could be considered rather than solely focusing on the pending conflict. Functioning from a strategic control mode allowed the Specialists to create an immediate solution that would not be detrimental to the long-term process.

Although the workload data did show a main effect for type of control, with traded indicating a significantly higher workload, there was no main effect for the percentage of aircraft in free flight. This finding contrasts with Fleming's, et al., (1999) study, which revealed an increase in workload correlated with increasing free flight levels. In Fleming's, et al. experiment, the percentage of aircraft in free flight varied between 20% and 80%. This finding may indicate that there is a ceiling effect for the percentage of planes in free flight on workload. The interaction found can be explained by a simple effect at 80% and 100% when shared only. The essence of the interaction is that the effect of the percentage of planes in free flight is inverse to the effect of the

supervisory control condition. This may be explained by the fact that when the Specialists are forced to extend their capabilities, as in the traded control condition, there is a threshold where the Specialist is forced to "give up." This may not be a negative phenomena. If all of the planes are in free flight, and are expected to separate themselves for the most part, one can assume that the Specialist would be more prone to sit back and let the aircraft separate themselves, paying little attention to the scope. Most of the resources of the Specialist could be used to collapse blocks on Multitask. In the Shared Condition, the Specialist has no other task to attend to. The Specialist probably could not help but to intensely monitor the situation in the Shared/100% condition. It is possible that the Specialist perceived problems or potential problems in the Shared/100% condition because he/she had the time to scrutinize the display. The unpredictability of the traffic probably drove the workload up. The Shared 80% condition allowed for more predictability, hence the lower workload.

Although vigilance decrement has been shown to be a problem when humans are placed in a relatively passive role to monitor an automated process (Parasuraman, 1987), this effect was not found in this experiment. Based on the reduced number of separation violations in the shared condition, it appears that there was no complacency effect observed in the shared condition. The Specialists would have had an opportunity to pay less attention in the shared condition, which could have resulted in conflicts. In general, this theory may only apply to more lengthy temporal processes. The data from this experiment seem to indicate that the traded control condition pushed the Specialists into a more reactive stance, which made them uncomfortable and perform poorly. In light of

these findings, I suggest that future considerations of free flight should reduce the responsibility of the controllers in direct proportion to the input that they are allowed to contribute.

Another theory that may describe the present results is Wicken's (1992) Multiple Resource Theory which asserts that cognitive resources are separated into distinct regions with specific processing stages (responding versus perception and central processing, processing codes (verbal versus spatial), and perceptual modalities (auditory versus visual). Wickens showed that tasks with the same pool of resources interfere and that tasks associated with different pools of resources do not interfere. The Multiple Resource Theory predicts that to the extent that two tasks demand separate rather than common resources on any of the three dimensions, two events will occur: Time-sharing will be more efficient and difficulty insensitivity will be observed. Difficulty insensitivity is characterized by changes in the difficulty of one task being less likely to influence performance of the other.

Based on the Multiple Resource Theory, it may be postulated that the secondary task was similar to the air traffic control task to the extent that they shared the same resources and interfered with one another. Wickens would theorize that if the secondary task was more unrelated, such as an arithmetic problem, there might not have been higher workload ratings and increased separation violations in the traded condition. This may explain why air traffic controllers have a relatively low failure rate in actual operations, despite the multitasking that occurs at air traffic control centers. The tasks that controllers concurrently engage in are unrelated, thus reducing cognitive interference,

which allows them to perform multiple tasks very well. For example, the marking of flight progress strips is largely cognitively incongruent with watching the traffic display, according to the Multiple Resource Theory. The marking of the flight progress strips is more of a verbal activity, while monitoring the display consists mostly of spatial faculties.

From the perspective of shared and traded supervisory control (Sheridan, 1992), it may be observed that in the traded condition, the human operator waited too long before seizing control back from the computer in this experiment. The human and the computer concurrently sharing a task load characterize shared control. The computer may extend the capabilities of the human, or vice versa. In traded control, the burden of control is more discretely placed on either the operator or the machine, and taken back by either one at some later point in time. Based on the results, it can be said that the Specialists utilized poor timing strategy in when they would take control back from the computer and temporarily give up on the secondary task in the traded condition. The operators paid the price for maximizing their attention on the secondary task with poor performance on the primary task, the safety of the aircraft. Traded control can be an effective means of coupling the human and the machine, so long as neither allows one to carry on operations past a reasonable limit, and it is clear which task is allocated to whom. Shared control proved to be more effective in this experiment, but if the task is too menial or more suited to the strengths of the machine, it may be considered a waste to include the human in some shared control tasks.

Each of these theories contributes to explaining the observed behavior from some perspective. Further research is needed to determine which of these theoretical frameworks provide a full description. With the increase in usage that the NAS is facing in the near future, it is inevitable that there will be changes made to the current system. Designers of the future NAS should be careful to study the inherent strengths and weaknesses of the human operator versus the strengths and weaknesses of the automation. While it may be impossible to totally remove human error from the operation of a complex system, it is a reasonable pursuit to eradicate the potential to blame the system designer for a human mishap. Rather than increased capacity being the sole change agent in modernizing the NAS, designers should be careful to examine the effects of an automated system on its human partner. All too often an automated system with advanced technical specifications and functions that appears to be both glamorous and promising, later proves to be the catalyst for disaster, due to a poor coupling with the human operator. It is the objective of the author and others who devise like studies to avoid these often-painful travails in the future NAS.

References

- Billings, C. E., Lauber, J. K., Funkhouser, H., Lyman, G., & Huff, E. M. (1976). NASA Aviation Safety Reporting System (Tech. Rep. TM-X-3445). Moffett Field, CA: NASA Ames Research Center.
- Birmingham, H. P. & Taylor, F. V. (1954). A human engineering approach to the design of man-operated continuous control systems (report no. 433). Washington DC: U.S. Naval Research Laboratory.
- Cashion, P., Mackintosh, M., McGann, A., & Lozito, S. (1997). A study of commercial flight crew self-separation. Proceedings of the 16th AIAA/IEEE Digital Avionics Systems Conference, 2 6.3-19-6.3-25. New Jersey: Institute of Electrical and Electronic Engineers.
- Chu, Y. Y., & Rouse, W. B. (1979). Adaptive allocation of decision making responsibility between human and computer in multi-task situations. IEEE Transactions on Systems, Man, and Cybernetics, SMC-9, 12, 769-788.
- Couloris, G. J., & Dorsky, S. (1995). Advanced air transportation technologies (AATT) potential benefits analysis. Technical Report Prepared for NASA Ames Research Center, Moffett Field, CA.
- Davies, D. R., & Parasuraman, R. (1982). The Psychology of Vigilance. London: Academic Press.
- Dember, W. N., & Warm, J. S. (1979). Psychology of Perception, Second Edition. New York: Holt, Rinehart and Winston.
- Endsley, M. R., Mogford, R. H., Allendoefer, K. R., Snyder, M. D., & Stein, E. (1997). Effect of free flight conditions on controller performance, workload, and situational awareness. FAA technical report.
- Fleming, K. J. Lane and K. Corker (1999). Measuring Controller Reactions to Free Flight in a Complex Transition Sector. Journal of Air Traffic Control, (Oct-Dec), 9-20.
- Galster, S. M., Duley, J. A., Masalonis, A. J., & Parasurman, R. (1998). Effects of self-separation on controller conflict detection performance and workload in mature free flight. In Proceedings of the Third Automation Technology and Human Performance Conference. Norfolk, VA.
- Hancock, P. A., & Chignell, M. H. (1989). Intelligent interfaces. Amsterdam: Elsevier.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In Hancock, P. A., & Meshkati, N. (Eds.), Human mental workload (pp. 239-250). Amsterdam: North Holland Press.

Hilburn, B. G., Bakker, M. W. P., Pekela, W. D., & Parasuraman, R. (1997). The effect of free flight on air traffic controller mental workload, monitoring, and system performance. Proceedings of the 10th International CEAS Conference on Free Flight. 20-21, October. Amsterdam, The Netherlands: Confederation of European Aerospace Societies.

Hilburn, B., & Parasuraman, R. (1997). Military Controllers Provide an Especially Appropriate Population for Evaluation of Free Flight and Other Advanced ATM Concepts. Poster Presented at the CEAS 10th European Aerospace Conference on Free Flight. 20-21, October. Amsterdam, The Netherlands: Confederation of European Aerospace Societies.

Hollnagel, E. (1993). The Context of Control. Duxbury Press.

Kaber, D. B., & Riley, J. M. (1998). Adaptive automation of a dynamic control task based on workload assessment through a secondary monitoring task. In Scerbo, C. W., & Mouloua, M. (Eds.), Automation technology and human performance: Current research and trends (pp. 129-133). Mahwah, NJ: Lawrence Erlbaum Associates.

Lee, J. D., & Moray, N. (1992). Operators monitoring patterns and fault recovery in the supervisory control of a semi-automatic process. In Proceedings of the Human Factors Society 36th Annual Meeting.

Mackworth, N. H. (1948). The breakdown of vigilance during prolonged visual search. Quarterly Journal of Experimental Psychology, 1, 6-21.

McNally, D., Engelland, S., Bach, R., Chan, W., Brasil, C., Gong, C., Frey, J., & Vincent, D. Operational evaluation of the direct-to controller tool. In Proceedings of the 4th USA/Europe Air Traffic Management R&D Seminar, Santa Fe, NM.

Metzger, U., Galster, S. M., Parasuraman, R. (1999). Effects of a conflict detection aid and traffic density on controller mental workload and performance in an ATC task simulating free flight. (1999). In Proceedings of the Tenth International Symposium on Aviation Psychology, Columbus, OH.

Metzger, U. & Parasuraman, R. (1999). Free flight and the air traffic controller: Active control versus passive monitoring. In Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting, Santa Monica, CA.

Moray, N., Sanderson, P., Shiff, B., Jackson, R., Kenedy, S., and Ting, L. (1982). A model and experiment for the allocation of man and computer in supervisory control. In Proceedings of IEEE International Conference on Cybernetics and Society, 354-358.

Parasuraman, R. (1987). Human-computer monitoring. Human Factors, 29, 695-706.

Parasuraman, R., Molloy, R., & Singh, I. (1993). Performance Consequences of automation-induced "complacency." The International Journal of Aviation Psychology, 3(1), 1-23.

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. Human Factors, 39(2), 230-253.

Quinn, C., & J. E. Robinson III. (2000). A human factors evaluation of active final approach spacing tool concepts. In Proceedings of the 3rd USA/Europe Air Traffic Management R&D Seminar, Napoli, Italy, June 13-16.

Rouse, W. B. (1977). Human-computer interaction in multitask situations. IEEE Transactions on Systems, Man, and Cybernetics, 7, 384-392.

RTCA. (1995). Final report of RTCA task force three free flight implementation. Washington DC: RTCA.

Sanford, B. D., Harwood, K., Nowlin, S., Bergeron, Heinrichs, H., Wells, G., and Hart, M. (1993). Center/TRACON automation system: Development and evaluation in the field. In Proceedings of the 38th Annual Air Traffic Control Association Conference Proceedings, October.

Sanford, B. D., N. Smith, K. K. Lee, and S. M. Green. (1999). Decision-aiding automation for the en-route controller: A human factors field evaluation, Tenth International Symposium on Aviation Psychology.

Sheridan, T. B. (1970). On how often the supervisor should sample. IEEE Transactions on Systems Science and Cybernetics, 6, 140-145.

Sheridan, T. B. (1992). Telerobotics, automation, and human supervisory control. Cambridge: The MIT Press.

van Gent, R. N. H. W., Hoekstra, J. M., & Ruigrok, R. C. J. (1998). Free flight with airborne separation assurance. Proceedings From the Conference on Human-Computer Interaction in Aeronautics, 63-69. Montreal, Quebec: l Ecole Polytechnique Montreal.

Wickens, C. D. (1992). Engineering psychology and human performance. New York: Harper Collins.

Wickens, C. D., Mavor, A. S., & McGee, J. P. (1997). Flight to the future: Human factors in air traffic control. Washington, D. C.: National Academy Press.

Wiener, E. L. & Curry, R. E. (1980). Flight deck automation: Promises and problems. Ergonomics, 23(10), 995-1011.

Appendix A. Tables and Figures

Figure 1. Theoretical Model of the Sampling Strategies of an Operator Engaged in a Monitoring Task.

Note. Sheridan (1970) constructed a theoretical model to describe the sampling strategies of an operator engaged in a monitoring task. He defined y as a control variable that could be manipulated in order to inflate a value function V of a network's input x , and output z . In air traffic management, y would represent any action of the controller that would be taken to increase V , the reward for taking evasive action. x represents the displays input to the human operator, such as the position and altitude of aircraft targets on a display. z represents the result of taking action, such as separating aircraft, which would affect V , the reward for taking such action. By defining these variables, a predictive equation can be established for a given situation that dictates how often a supervisor should sample a system in order to attain an optimal reward (V). Figure 1 presents a pictorial description of this sampling process. Sheridan's theory represents the tradeoff of sampling, since a cost may accrue from manipulating y , separated from the cost of sampling x . It is recommended that the controller sample x more often than manipulating y , since the new z may represent a greater cost.

Figure 2. Open Loop Action Theory (OLAT).

Note. Sheridan (1992) has developed a quantitative model of a supervisory control task called Open Loop Action Theory (OLAT). OLAT serves as a mathematical model of how long a supervisor can go without sampling the system. The theory purports that uncertainty increases if the operator does not actively engage in the process. However, there is a boundary that at some point the controller will initiate action (effort) to reduce uncertainty. The controller essentially seeks to optimize information, seeking minimum effort according to the criterion established. The cost of sampling is losing points on the secondary task and transitioning to a control role. A vector equation can be established based on factors that warrant operator intervention.

Figure 3. The CTAS Display.

Note. A typical traffic pattern that was used in the scenarios. The conflict probe appears in the upper right. The lines indicate the paths of conflicting traffic.

Figure 4. Data Tag, Aircraft Symbol, Histories, Jet Route, and Sector Boundary.

Note. This figure depicts some of the information that was available to the Specialist. The data tag provides speed and altitude information for the aircraft. The history lines show the flights' previous path. The waypoints are used for navigation purposes. Jet routes are commonly traversed paths of flight that are optimized for efficiency. The sector boundary defines the space that the Air Traffic Control Specialist is responsible for.

Figure 5. Conflict Probe.

ACTIVE: 0-20 MIN : 5 NM - 2000/2000 FT			
CONF 40	DAI 104		
CONF 40	DAI 105		

Note. This picture depicts the conflict probe list box. The top line shows how far the probe looks out from the point of impact in minutes as well as the lateral and vertical separation standard. The “Show” feature allows the specialist to graphically display the conflicting paths by clicking the box. The “Conflict Pairs” column shows the air craft that are conflicting. Clicking the box next to the pairs will remove them from the list. The “Time” column indicates minutes until impact, or the closest point of approach. The “FI” column indicates how far the air craft are separated in vertically in feet and the “Nm” column indicates how far the air craft are separated laterally in nautical miles.

Figure 6. Multitask.

Note. Multitask was used for the secondary task. The blocks converged towards the center of the screen at random speeds. The goal of the specialist was to collapse the blocks before they reached the center of the screen. The number of blocks that reached the center of the screen were known as expirations, and were counted every 15 s.

Figure 7. Experimental Design Matrix.

Supervisory Control	Percentage of Aircraft in Free Flight	
	80%	100%
Shared	S/80%	S/100%
Traded	T/80%	T/100%

Table 1

Means and Standard Deviations of NASA-TLX Scores

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	163.24	90.71
Shared Control / 100%	204.12	82.30
Traded Control / 80%	349.12	97.87
Traded Control / 100%	280.88	92.59

Note. M = mean and SD = standard deviation.

Table 2

Analysis of Variance for NASA-TLX Scores as a Function of Type of Control (A),
Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	293179.78	1	293179.78	70.70	.001
S/A	66351.47	16	4146.97		
B	3179.78	1	3179.78	1.86	.19
S/B	27326.47	16	1707.90		
C	50603.31	1	50603.31	24.68	.001
S/C	32802.94	16	2050.18		
Total	473443.75	51			

Note. S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Figure 8. The Interaction Effect for the NASA-TLX Based on the ANOVA.

Figure 9. Means and Standard Error Bars for the NASA-TLX at 95% Confidence Intervals.

Table 3

The NASA-TLX Means and Standard Deviations Collapsed Across Each Level of the Independent Variables

<u>Scenario Type</u>	<u>M</u>	<u>SD</u>
<u>Type of Control</u>		
Shared Control	183.68	87.77
Traded Control	315.00	100.00
<u>Percentage</u>		
80%	256.18	132.41
100%	242.50	94.65

Note. M = Mean and SD = standard deviation.

Table 4

Simple Main Effects ANOVA on the NASA-TLX for the Type of Control at 80% of Planes in Free Flight (A) and 100% of Planes in Free Flight (B)

Source	SS	df	MS	F	p
A	293694.12	1	293694.12	71.63	.001
S/A	65605.88	16	4100.37		
B	50088.97	1	50088.97	23.89	.001
S/B	33548.53	16	2096.78		
Total	442937.50	34			

Note. S/A and S/B indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Table 5

Simple Main Effects ANOVA on the NASA-TLX for the Percentage of Planes in Free Flight at the Traded Condition (A) and the Shared Condition (B)

Source	SS	df	MS	F	p
A	39576.47	1	39576.47	14.30	.001
S/A	44273.53	16	2767.10		
B	14206.62	1	14206.62	14.34	.001
S/B	15855.88	16	990.99		
Total	113912.50	34			

Note. S/A and S/B indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Table 6

Analysis of Variance for Multitask

Source	SS	df	MS	F	p
A	369.47	1	369.47	7.65	.01
S/A	773.18	16	48.32		
Total	1142.65	17			

Note. S/A indicates within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level. This was a one-way ANOVA, since the secondary task was unique to the traded condition.

Figure 10. Means and Standard Error Bars for Multitask at 95% Confidence Intervals.

Table 7

Observed Frequency of Separation Violations by Scenario Type

Scenario Type	Separation Violations
Shared Control / 80%	1
Shared Control / 100%	1
Traded Control / 80%	5
Traded Control / 100%	2

Note. The total number of conflicts was 34 for each condition.

Table 8

Means and Standard Deviations of Time Between the CTAS Alert and the Intervention in Minutes and Seconds

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	0:15	1:33
Shared Control / 100%	0:24	1:41
Traded Control / 80%	0:24	1:28
Traded Control / 100%	0:20	1:58

Note. M = Mean and SD = standard deviation. These scores were calculated by measuring the difference between when the conflict pair appeared in the conflict probe box and when the air traffic control specialist issued instructions to resolve the conflict.

Table 9

Analysis of Variance for Cancellation Time in Relation to the Conflict Probe as a Function of Type of Control (A), Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	207.53	1	207.53	.03	.87
S/A	120258.97	16	7516.19		
B	222.62	1	222.62	.07	.80
S/B	52105.38	16	3256.59		
C	1410.62	1	1410.62	.29	.60
S/C	78812.88	16	4925.81		
Total	253018.00	51			

Note. S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level. These scores were calculated by measuring the difference between when the conflict pair appeared in the conflict probe box and when the air traffic control specialist issued instructions to resolve the conflict.

Table 10

Means and Standard Deviations of Closest Point of Approach (CPA) Data in Nautical Miles a Function of Scenario Type

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	5.15	5.95
Shared Control / 100%	4.05	5.11
Traded Control / 80%	4.90	6.02
Traded Control / 100%	4.65	5.91

Note. M = mean and SD = standard deviation. The CPA is calculated by determining the distance at which the conflicting air craft pair were closest to each other.

Table 11

Analysis of Variance for the CPA as a Function of Type of Control (A), Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	15.24	1	15.24	3.04	.101
S/A	80.28	16	5.02		
B	1.02	1	1.02	.21	.66
S/B	79.33	16	4.96		
C	6.22	1	6.22	.30	.59
S/C	332.02	16	20.75		
Total	514.11	51			

Note. S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level. The CPA is calculated by determining the distance at which the conflicting air craft pair were closest to each other.

Table 12

Means and Standard Deviations of Cancellation Times in Minutes and Seconds as a Function of Scenario Type

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	6:44	1:01
Shared Control / 100%	6:41	1:49
Traded Control / 80%	6:41	1:38
Traded Control / 100%	6:40	2:29

Note. M = mean and SD = standard deviation. The cancellation times were determined by subtracting the time of cancellation from the point of impact.

Table 13

Analysis of Variance for Cancellation time in Relation to the Time of Collision as a Function of Type of Control (A), Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	312.03	1	312.03	.03	.87
S/A	176914.47	16	11057.15		
B	92.24	1	92.24	.01	.91
S/B	101729.76	16	6358.11		
C	38.12	1	38.12	.00	.95
S/C	130350.88	16	8146.93		
Total	490437.50	51			

Note. The cancellation times were determined by subtracting the time of cancellation from the point of impact. S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Table 14

Means and Standard Deviations for Item 6 on the Post Simulation Questionnaire

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	4.59	1.33
Shared Control / 100%	4.94	.97
Traded Control / 80%	3.76	1.03
Traded Control / 100%	3.41	1.28

Note. Item 6 asks “Overall, how much time did you feel you spent monitoring traffic in this scenario?” M = mean and SD = standard deviation.

Table 15

Analysis of Variance for Item 6 on the Post Simulation Questionnaire for Type of Control (A), Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	23.53	1	23.53	12.99	.001
S/A	28.97	16	1.81		
B	0.00	1	0.00	0.00	1.00
S/B	15.50	16	.97		
C	2.12	1	2.12	2.98	.103
S/C	11.38	16	.71		
Total	81.50	51			

Note. Item 6 asks “Overall, how much time did you feel you spent monitoring traffic in this scenario?” S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Figure 11. Means and Standard Error Bars with 95% Confidence Intervals for Item 6 on the Post Simulation Questionnaire.

Note. Item 6 asks “Overall, how much time did you feel you spent monitoring traffic in this scenario?”

Table 16

Means and Standard Deviations for Item 7 on the Post Simulation Questionnaire

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	1.94	1.14
Shared Control / 100%	2.29	1.10
Traded Control / 80%	2.88	1.27
Traded Control / 100%	2.53	1.12

Note. M = mean and SD = standard deviation. Item 7 asks “Overall, how much time pressure did you experience after an alert in this scenario?”

Table 17

Analysis of Variance for Item 7 on the Post Simulation Questionnaire for Type of Control (A), the Percentage of planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	5.88	1	5.88	6.23	.001
S/A	15.12	16	0.94		
B	0.00	1	0.00	0.00	1.00
S/B	14.00	16	0.88		
C	2.12	1	2.12	3.11	.10
S/C	10.88	16	0.68		
Total	48.00	51			

Note. Item 7 asks “Overall, how much time pressure did you experience after an alert in this scenario?” S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Figure 12. Means and Standard Error Bars with 95% Confidence Intervals for Item 7 on the Post Simulation Questionnaire.

Table 18

Means and Standard Deviations for Item 8 on the Post Simulation Questionnaire

Scenario Type	<u>M</u>	<u>SD</u>
Traded Control / 80%	4.41	1.77
Traded Control / 100%	4.18	1.81

Note. M = mean and SD = standard deviation. Item 8 asks “Did the secondary task negatively affect the separation of aircraft in this scenario?”

Table 19

Analysis of Variance for Item 8 on the Post Simulation Questionnaire

Source	SS	df	MS	F	p
A	0.47	1	0.47	0.18	.68
S/A	42.53	16	2.66		
Total	43.00	17			

Note. Item 8 asks “Did the secondary task negatively affect the separation of aircraft in this scenario?” S/A indicates within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level. A one-way ANOVA was administered on this item because it was unique to the traded condition.

Figure 13. Means and Standard Error Bars With 95% Confidence Intervals for Item 8 on the Post Simulation Questionnaire.

Table 20

Means and Standard Deviations for Item 9 on the Post Simulation Questionnaire

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	2.47	0.94
Shared Control / 100%	2.94	1.02
Traded Control / 80%	4.53	1.23
Traded Control / 100%	3.71	1.31

Note. M = Mean and SD = standard deviation. Item 9 asks "Overall, how much workload did you experience in this scenario?"

Table 21

Analysis of Variance for Item 9 on the Post Simulation Questionnaire for Type of Control (A), Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	33.88	1	33.88	39.81	.001
S/A	13.62	16	0.85		
B	0.53	1	0.53	1.42	.25
S/B	5.97	16	0.37		
C	7.12	1	7.12	10.01	.006
S/C	11.38	16	0.71		
Total	72.50	51			

Note. Item 9 asks “Overall, how much workload did you experience in this scenario?”

S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Figure 14. The Interaction Effect on the ANOVA for Item 9 on the Post Simulation Questionnaire.

Note. Item 9 asks “Overall, how much workload did you experience in this scenario?”

Figure 15. Means and Standard Error Bars With 95% Confidence Intervals for Item 9 on the Post Simulation Questionnaire.

Note. Item 9 asks “Overall, how much workload did you experience in this scenario?”

Table 22

The Means and Standard Deviations Collapsed Across Each Level of the Independent Variables for Item 9

Scenario Type	<u>M</u>	<u>SD</u>
<u>Type of Control</u>		
Shared Control	2.71	1.00
Traded Control	4.12	1.32
<u>Percentage</u>		
80%	3.50	1.50
100%	3.32	1.22

Note. M = mean and SD = standard deviation. Item 9 asks “Overall, how much workload did you experience in this scenario?”

Table 23

Means and Standard Deviations for Item 10 on the Post Simulation Questionnaire

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	2.41	1.58
Shared Control / 100%	2.47	1.17
Traded Control / 80%	4.00	1.50
Traded Control / 100%	3.88	1.45

Note. M = mean and SD = standard deviation. Item 10 asks “Compared to current ops how safe did you feel this scenario was?”

Table 24

Analysis of Variance for Item 10 on the Post Simulation Questionnaire for Type of Control (A), Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	38.25	1	38.25	21.47	.001
S/A	28.50	16	1.78		
B	0.01	1	0.01	0.01	.91
S/B	16.74	16	1.05		
C	0.13	1	0.13	0.32	.58
S/C	6.62	16	0.41		
Total	90.25	51			

Note. Item 10 asks “Compared to current ops how safe did you feel this scenario was?”

S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Figure 16. The Means and Standard Error Bars With 95% Confidence Intervals for Item 10 on the Post Simulation Questionnaire.

Note. Item 10 asks “Compared to current ops how safe did you feel this scenario was?”

Table 25

Means and Standard Deviations for Item 11 on the Post Simulation Questionnaire

Scenario Type	<u>M</u>	<u>SD</u>
Shared Control / 80%	4.88	0.78
Shared Control / 100%	5.05	1.09
Traded Control / 80%	4.00	1.37
Traded Control / 100%	3.65	1.17

Note. M = mean and SD = standard deviation. Item 11 asks “What level of situational awareness did you maintain throughout this scenario?”

Table 26

Analysis of Variance for Item 11 on the Post Simulation Questionnaire for Type of Control (A), the Percentage of Planes in Free Flight (B), and the Interaction (C)

Source	SS	df	MS	F	p
A	22.37	1	22.37	21.85	.001
S/A	16.38	16	1.02		
A	0.13	1	0.13	0.22	.65
S/B	9.62	16	0.60		
C	1.19	1	1.19	1.31	.27
S/C	14.59	16	0.91		
Total	64.28	51			

Note. Item 11 asks “What level of situational awareness did you maintain throughout this scenario?” S/A, S/B, and S/C indicate within groups sources. SS = Sums of Squares. Df = degrees of freedom. MS = means squared. F = F score and p = probability level.

Figure 17. Means and Standard Error Bars With 95% Confidence Intervals for Item 11 on the Post Simulation Questionnaire.

Appendix B. Post Simulation Questionnaire

DATE:**SCENARIO:****SUBJECT#**

Please consider the following questions while considering the last scenario

1. How would you rate the difficulty of this scenario?

1	2	3	4	5	6
Not very					Very
Difficult					Difficult

Please explain any factors that contributed.

2. Overall, how useful was the display in helping you to separate your aircraft from other aircraft in this scenario?

1	2	3	4	5	6
Not Very					Very
Useful					useful

Please explain any factors that contributed.

3. Overall, how useful was the alerting system in warning you about potential conflicts in this scenario?

1	2	3	4	5	6
Not Very					Very
Useful					useful

Please explain any factors that contributed.

4. How easy was it to detect potential conflicts prior to the alert in this scenario?

1	2	3	4	5	6
Not very					Very
Easy					easy

Please explain any factors that contributed.

5. Did the alerting system provide a far enough look ahead in this scenario (7 min.) ?

1	2	3	4	5	6
Not enough					Plenty of
time					time

Please explain any factors that contributed.

What is optimal amount of time _____

6. Overall, how much time did you feel you spent monitoring traffic in this scenario?

1	2	3	4	5	6
Not a lot of					A lot of
Time					time

Please explain any factors that contributed.

7. Overall, how much time pressure did you experience after an alert in this scenario?

1	2	3	4	5	6
Not a lot of Pressure					A lot of Time

Please explain any factors that contributed.

8. Did the secondary task negatively affect the separation of aircraft in this scenario?

1	2	3	4	5	6
No					Definitely

Please explain any factors that contributed.

9. Overall, how much workload did you experience in this scenario?

1	2	3	4	5	6
Not a lot of Workload					A lot of Workload

Please explain any factors that contributed to difficulty.

10. Compared to current ops how safe did you feel this scenario was?

1	2	3	4	5	6
Very Safe					Not Very Safe

Please explain any factors that contributed to safety level.

11. What level of situational awareness did you maintain throughout this scenario?

1
Low

2

3

4

5

6
High

Please explain any factors that contributed to situational awareness.

Appendix C. NASA-TLX Questionnaire

Mental Demand

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Low High

Physical Demand

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Low High

Temporal Demand

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Low High

Performance

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Low High

Effort

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Low High

Frustration

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Low High

Appendix D. Debrief Questionnaire

Date:

Participant Number:

Total Years as Controller:

Years as Domestic Enroute Controller:

Years as Oceanic Controller:

Age:

Please circle the number that best reflects your answer to the following question.

How effective was the briefing and the training for your understanding of the task?

1	2	3	4	5	6
Not very					Very
Effective					Effective

Please explain any factors that contributed.

Please answer the following questions. Write on the back if you need more space.

How were the pseudo pilot communications?

Would you recommend a better phraseology in free flight between pilots and controllers?

Do you think that the secondary task negatively affected your performance and safety of the aircraft?

Did having some of the aircraft under your positive control (X) affect your performance on the secondary task and controlling traffic?

Was there a specific strategy that you used on the secondary task?

Were there any colors on the secondary task that were more difficult to collapse?

Was there any information missing on the display that you would like to have available?

How realistic do you think the scenarios were given the assumptions of the experiment?

Are there any future research issues pertaining to free flight that you would recommend NASA to pursue?

General comments and suggested improvements: