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Abstract

This paper describes a usability study of proposed cockpit interfaces to support Airborne Precision Spacing (APS) operations for aircraft performing dependent parallel approaches (DPA). NASA has proposed an airborne system called Pair Dependent Speed (PDS) which uses their Airborne Spacing for Terminal Arrival Routes (ASTAR) algorithm to manage spacing intervals. Interface elements were designed to facilitate the input of APS-DPA spacing parameters to ASTAR, and to convey PDS system information to the crew deemed necessary and/or helpful to conduct the operation, including: target speed, guidance mode, target aircraft depiction, and spacing trend indication. In the study, subject pilots observed recorded simulations using the proposed interface elements in which the ownship managed assigned spacing intervals from two other arriving aircraft. Simulations were recorded using the Aircraft Simulation for Traffic Operations Research (ASTOR) platform, a medium-fidelity simulator based on a modern Boeing commercial glass cockpit. Various combinations of the interface elements were presented to subject pilots, and feedback was collected via structured questionnaires. The results of subject pilot evaluations show that the proposed design elements were acceptable, and that preferable combinations exist within this set of elements. The results also point to potential improvements to be considered for implementation in future experiments.

2 Abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast
AFDS	Autopilot Flight Director System
ALT	Altitude
APS	Airborne Precision Spacing
AOC	Airline Operations Center
APPR	Approach
ASTAR	Airborne Spacing for Terminal Arrival Routes
ASTOR	Aircraft Simulation for Traffic Operations Research
ARINC429	Aeronautical Radio, Incorporated 429 data bus
ATC	Air Traffic Control
ATOL	Air Traffic Operations Laboratory
ATSP	Air Traffic Service Provider
CDA	Continuous Descent Arrival
CDTI	Cockpit Display of Traffic Information
CPDLC	Controller Pilot Datalink Clearance
ConOps	Concept of Operation
DEV	Deviation
DPA	Dependent Parallel Approaches
EFB	Electronic Flight Bag
EICAS	Engine Instrument and Crew Alerting System
EXEC	Execute
FAA	Federal Aviation Administration
FMA	Flight Mode Annunciator
FMC	Flight Management Computer
FNL	PDS Final Mode
HITL	Human-in-the-Loop
ID	Aircraft Identification
MCDU	Multifunction Control and Display Unit
MCP	Mode Control Panel
MFD	Multifunction Display
MIN	Minimum
MOD	Modified
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NAVAID	Navigation Aid
NCT	No Closer Than
ND	Navigation Display

NG	Next Generation
NM	Nautical Miles
PAIR	PDS Paired Mode
PFD	Primary Flight Display
PDS	Pair Dependent Speed
PRI	Primary Spacing Aircraft, also known as Active Spacing Aircraft
PTH	Path
REFAC	Reference Aircraft, also known as Target Aircraft
RTA	Required Time of Arrival
RWY	Runway
SEC	Seconds
SPD	Speed
STA	Scheduled Time of Arrival
TOD	Top of Descent
VNAV	Vertical Navigation

3 Introduction

Airborne Precision Spacing (APS) is an operational concept where the control of the aircraft's speed is delegated by the air traffic service provider (ATSP) to the flight crew in order to precisely achieve an assigned inter-aircraft spacing. The concept allows the flight crew to make minor speed adjustments based on cues from an on-board system while flying a continous descent arrival (CDA). The concept is intended to address both capacity and efficiency issues facing the air transportation system by enabling the merging of efficient trajectories by a variety of aircraft into a precisely-spaced arrival stream in the terminal area.

Airborne systems that could be used for generating the speed commands have been under development for more than 10 years[1][2][3]. Fast-time simulations and human-in-the-loop (HITL) studies have been conducted during that period which have verified the effectiveness of the algorithms in achieving precise inter-aircraft spacing in the terminal environment[4][5]. The current NASA instantiation of this algorithm is called Airborne Spacing for Terminal Arrival Routes (ASTAR), and the airborne system is called Pair Dependent Speed (PDS).

As the development of airborne spacing systems progresses, so also does research into the procedures and human interfaces required to conduct spacing operations. EuroControl has already proposed flight deck user requirements for airborne spacing[6]. The HITL studies already mentioned also sought to determine if the procedures and cockpit interfaces proposed for conducting APS operations were acceptable. A recent human-in-the-loop (HITL) experiment conducted at NASA Langley's Air Traffic Operations Laboratory (ATOL) applied a prototype PDS system and associated procedures to the conduct of paired CDA profiles to a single runway. The results of this study showed that the procedures and interfaces used for airborne spacing can achieve the desired results with little negative performance impact over conventional CDAs[5].

NASA has been working to extend the APS concept to support dependent parallel approaches (DPA), where the runways are close enough together that spacing must be managed between aircraft arriving on both runways[7]. This requires a redesign of the way the crew will interface with the aircraft, including the traffic display, speed guidance display, data entry and crew notifications. The focus of the study described in this report was to design, test, and refine crew interface concepts for APS-DPA operations. Two crew interface systems were investigated: a system with the interfaces fully integrated with the standard cockpit displays, and a system with the application and interfaces hosted on an Electronic Flight Bag (EFB)[1].

For this study, two interface concepts were designed, one suitable for a typical modern glass cockpit and the other for an EFB, and included means for inputting spacing control parameters, the display of PDS-commanded speed and PDS mode, the display of target aircraft and spacing trend indication. NASA's Aircraft Simulation for Traffic Operations Research (ASTOR) was utilized as a platform on which to implement and display these concepts for the study. The study sought to maximize the insight gained from the pilot evaluations by developing alternative versions of the interfaces such that pilots could make comparisons and express preferences for either individual design elements or combinations of the elements.

This report describes the conceptual design of the proposed APS interfaces for the fully integrated system, the methodology used for the conduct of the experiment, and the results of the pilot evaluations. The EFB interface concepts are also described herein, but were not intended to be part of the usability study (see Appendix C: Electronic Flight Bag Interface Concepts for APS-DPA). Final conclusions and recommendations are made based on analysis of the pilot evaluation data.

4 Fully Integrated APS Interface Concepts

The goal for the fully integrated version of the APS-DPA interface was to develop interfaces to allow pilots to perform the following functions:

1. manage voice or datalink reception of spacing clearances;
2. initialize PDS with spacing clearance parameters;
3. verify validity of spacing clearance parameters before executing;
4. engage PDS target speed to the autopilot while also flying CDA profile;

[1] An EFB (FAA's Advisory Circular - AC120-76A[10]), is an electronic display system in addition to the standard cockpit displays that displays a variety of aviation data, automates basic calculations (e.g., performance data, fuel calculations, etc.), and/or presents various graphical information to help flight crews perform flight management tasks more easily and efficiently.

5. monitor progress of APS-DPA, including:
    a. PDS target speed;
    b. PDS operation mode;
    c. Target aircraft position and information;
    d. Spacing deviation and trend information; and
    e. Off-nominal indications.
6. disengage PDS from autopilot and/or cancel spacing clearance.

Concepts were developed which would modify the operation of several typical glass cockpit displays, interfaces, and their underlying control software. These concepts were implemented in a special ASTOR software build created for the study to support simulations, and included modifications to the following:

- Engine Instrument & Crew Alerting System/Multifunction Display (EICAS/MFD);
- Mode Control Panel (MCP);
- Multifunction Control and Display Unit (MCDU);
- Primary Flight Display (PFD); and
- Navigation Display (ND).

The focus of the study was to obtain pilot evaluations for the design elements developed for the PFD and the ND. The modifications made to the EICAS/MFD, MCP and MCDU were necessary to integrate the APS-DPA functionality and enhance the realism of the spacing scenarios presented on the ASTOR, but were not the focus of pilot evaluations. Implementation details of the EICAS/MFD, MCP and MCDU concepts are discussed in Appendix B: Supplemental Design Concepts for Fully Integrated Implementation.

4.1 APS Interface Concepts for Primary Flight Display

The PFD typically displays tactical information to the crew. Alternative design concepts were proposed to use the PFD to present the PDS-commanded target speed and annunciation of the active PDS guidance mode.

4.1.1 PDS Target Speed Indication

During spacing operations, ASTAR calculates a target speed (also referred to as PDS target speed) to be met by the aircraft in order to achieve the spacing interval. Two different concepts for displaying the PDS target speed were implemented for evaluation in this study, shown in Figure 4-1.

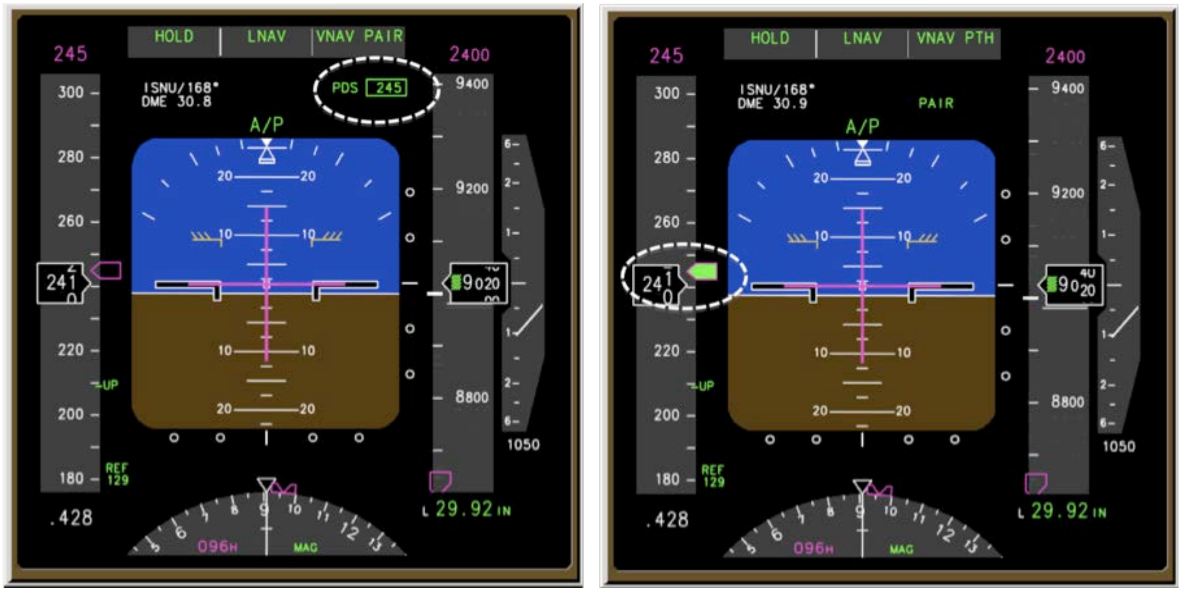

Figure 4-1: PDS Target Speed Concepts: Text (Left); Speed Bug (Right).

In the first concept, the PDS target speed appeared as a textual indication in a dedicated area of the upper right corner of the PFD. The PDS target speed text appeared in white until PDS was engaged to the autopilot, when the text changed to green. Changes to PDS target speed were highlighted for 10 seconds by a flashing box surrounding the text. This concept was identical to the implementation of PDS target speed in the preceding APS HITL study.

This concept was considered acceptable by subject pilots participating in the previous experiment who were tasked with manually entering the PDS target speed into the MCP speed window. However, the concept had not yet been applied to the conduct of APS-DPA operations, nor had it been used in a fully integrated, autopilot-flown profile.

In the second concept, the PDS target speed was indicated by a filled green “speed bug” on the speed tape of the PFD. The green bug appeared when PDS was providing valid speed guidance, regardless of the state of autopilot engagement. When the PDS target speed was engaged to the autopilot, the implementation caused the green bug and the normal commanded-speed bug (magenta) to coincide. The green bug was displayed all the way to touchdown unless PDS was terminated.

It was thought that a graphical PDS target speed indicator provided a more visual, contrasting alternative to the textual display. By juxtaposing the PDS target speed bug and the normal autopilot commanded speed bug such that neither could be obscured, the pilot could quickly determine whether the two coincided or diverged. In autothrottle mode, this allowed the pilot to anticipate speed changes from PDS; if manual speed intervention were used (which was not part of this study) the pilot could adjust the commanded speed until the indicators coincided.

4.1.2 PDS Mode Annunciation

During an APS operation, PDS speed guidance transitions through several different modes of operation. Beyond ADS-B range of the target aircraft, the Required Time of Arrival (RTA, formerly referred to in the APS concept as STA for Scheduled Time of Arrival) mode drives the target speed. The Paired mode is active once all of the data is available to begin spacing relative to the target aircraft. The Final mode indicates PDS speed guidance has transitioned to a stabilized final approach speed. Two other modes were defined in the ConOps; PDS Profile mode (speed guidance without interval management) and PDS Speed Reversion mode (off-nominal conditions suspending ASTAR guidance). Neither were implemented for this study, but concepts were proposed for their display. Two different concepts were implemented for the display of PDS mode annunciation, shown in Figure 4-2.

Figure 4-2: PDS Mode Annunciation Concepts: Text (Left); FMA (Right).

In the first concept, the PDS mode appeared as a textual indication in a dedicated area of the upper right corner of the PFD. The PDS mode text appeared in white until PDS was engaged to the autopilot, when the text changed to green. Changes to PDS mode were highlighted for 10 seconds by a flashing (white or green) box surrounding the text. This concept was identical to the implementation of PDS target speed in the preceding APS HITL study.

This concept was considered acceptable by subject pilots participating in the previous experiment, however, it had not yet been applied to the conduct of APS-DPA operations, nor had it been used in a fully integrated, autopilot-flown profile.

In the second concept, PDS mode annunciation was integrated into the Flight Mode Annunciator (FMA) of the PFD. The FMA is used to annunciate autoflight settings and modes of the autopilot. To indicate PDS autoflight modes, the pitch mode segment of the FMA was divided into four (4) quadrants, as shown in Figure 4-3. The leftmost upper and lower quadrants of the pitch mode segment displayed the vertical autopilot mode currently selected and armed, as normal. The modified right upper and lower quadrants of the pitch mode segment displayed the active and armed PDS modes, respectively.

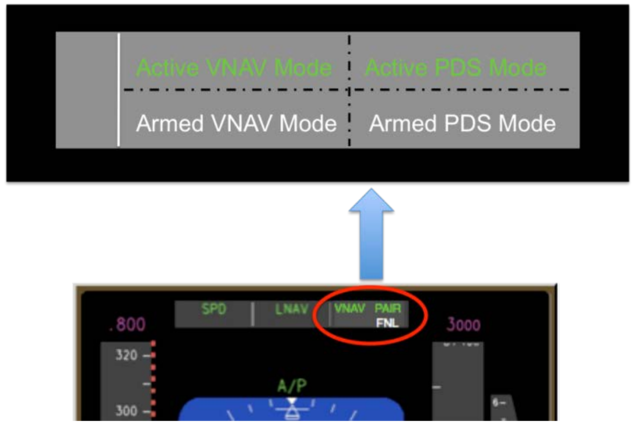

Figure 4-3: FMA Pitch Segment Modified to Display PDS Modes

It was thought that annunciating PDS mode with other autopilot modes in the FMA was more consistent with an integrated approach than the ad hoc presentation of the first concept. (The integration of PDS guidance to the autopilot is also discussed in Appendix B: Supplemental Design Concepts for Fully Integrated Implementation.) Table 4-1 shows several examples of the concept implementation during typical phases of an APS-DPA operation. The following conventions established for FMA annunciation of existing modes permitted enhancements to the PDS mode display not implemented in the first concept. For example, display of the next PDS mode in sequence was implemented on the line reserved for armed modes on the FMA. Further, a convention exists to display degraded autopilot modes on the FMA, and it could be applied to off-nominal PDS conditions, such as PDS Speed Reversion mode. (An example of this concept is also shown, but was not implemented in ASTOR.)

Table 4-1: PDS Mode Annunciation Examples; FMA.

PDS FMA Example	Description	FMA Pitch Mode Depiction
PDS RTA Mode Engaged	When PDS mode changes, green box appears for 10 seconds; Pair mode armed	VNAV STA PAIR
PDS Pair Mode Engaged	PDS Final mode armed; G/S armed	VNAV PAIR G/S FNL
PDS Final Mode Engaged	VNAV disengaged; G/S engaged	G/S FNL
PDS Mode Degraded	PDS off-nominal condition (Speed Reversion mode)	VNAV PAIR

4.2 APS Interface Concepts for the Navigation Display

The ND presents strategic information to the crew, so this design concept used the ND to present the “big picture” of the APS-DPA operation. Concepts were developed for depicting one or two target aircraft involved in the spacing operation. Concepts were also developed for depicting the spacing deviation output from PDS in the form of a trend indicator, which might be used as a strategic tool for monitoring the operation’s progress.

4.2.1 Target Aircraft Depiction

The concepts for displaying target aircraft relied on existing or proposed standards for Cockpit Display of Traffic Information (CDTI) symbols. Both DO-317 (Minimum Operational Performance Standards for Aircraft Surveillance Applications System) [8] and a draft symbol set appendix for DO-289 (Aircraft Surveillance Applications Minimum Aviations System Performance Standards) [9] were used as references. The standards impart specific meanings to CDTI symbols and colors, which were applied to the paradigm of an on-board application supporting the APS-DPA operation.

Two similar concepts were proposed, shown in Figure 4-4. For both concepts, the standard CDTI symbol for depicting ADS-B targets was a chevron, and in particular, a green chevron with a shape-hugging border indicated that the target was coupled to an on-board application (in this case, PDS). For both concepts, ND conventions for displaying CDTI symbols were implemented, such that the aircraft ID of the target aircraft was displayed, subject to pilot control. Further, if the ND range selector put the CDTI symbol(s) out of range, convention dictated that a half-symbol for the symbol appeared on the outer range ring of the ND at the appropriate bearing.

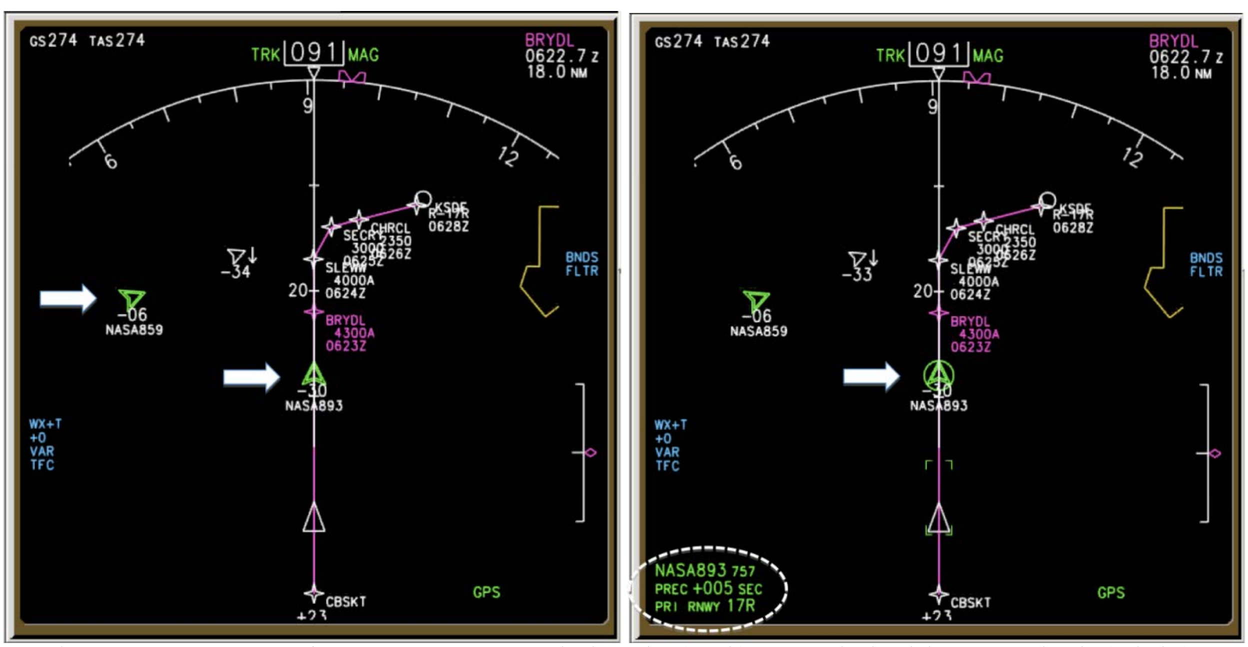

Figure 4-4: Target A/C Concepts: Coupled Only (Left); Coupled with Data Block (Right).

The first concept displayed the target aircraft as the green “double” chevrons. No distinction was made between the two target aircraft other than their associated IDs, i.e., which aircraft was the precision or “no closer than” (NCT) target, or which aircraft was the active spacing target. This was a basic concept for displaying the target aircraft with a minimum of clutter on the ND. It was thought that pilots wishing to distinguish between precision and NCT targets could derive this by correlating the aircraft ID and the original spacing clearance parameters on the PDS main menu page of the MCDU. Similarly, the active spacing aircraft ID was depicted (in magenta) on the same MCDU page, see the implementation detail in Appendix B: Supplemental Design Concepts for Fully Integrated Implementation”.

The second concept interpreted the standards further to make a distinction between the two spacing targets by adding a green “selected” circle around the active spacing target. This enabled another enhancement in the form of a data block associated with the selected target. The data block always appeared in the lower left portion of the ND and contained information associated with the selected target aircraft, including the aircraft ID, aircraft type, spacing interval type, spacing deviation and landing runway. This concept was thought to provide significantly more information about the target aircraft, at the expense of additional ND clutter. The justification for displaying the additional information was to conveniently present strategic information on the progress of the spacing operation that would otherwise only be available through the PDS menu pages in the MCDU. (The MCDU has several other uses, and use of the data block could avoid interrupting them to look for spacing information.)

Note that while the first concept could be considered to be a selectable subset of the second, the ability to select ND views was not available in the study’s scenario presentation, so the concepts were presented separately.

4.2.2 Trend Indication

Trend indication is potentially useful strategic information during phases of APS when PDS is managing the spacing interval. The trend indicator concept proposed synthesizing PDS outputs to depict the aircraft’s position relative to spacing limits. A spacing operation can be conducted within recoverable limits of spacing deviation from the specified spacing interval. Beyond these limits, the deviation is termed excessive and the spacing interval can no longer be achieved without also exceeding programmed PDS limits. The spacing deviation (in seconds) from nominal was displayed on the MCDU’s PDS main menu page (and also on certain target aircraft depictions) but the maximum limits of deviation were not displayed. Two different concepts were developed for integrating both pieces of information into a trend indicator, shown in Figure 4-5.

Figure 4-5: Trend Indicator Concepts: Conformance Box (Left); Deviation Scale (Right).

In the first concept, the excessive spacing deviation limits were used to draw pictorial "conformance box" brackets around the ownship symbol on the ND. The box was positioned around the nose of the ownship symbol relative to the spacing deviation from nominal. Positive spacing deviations shifted the box so that the forward brackets moved away from the nose of the ownship; negative spacing deviations shifted the forward brackets towards the nose of the ownship. There was no center position depicted; as long as the nose of ownship remained within the conformance box, the spacing deviation was within recoverable limits.

The conformance box boundaries were range-based (time-based deviation limits from PDS converted to distance), thus the size of the depicted conformance box varied in accordance with the ND range selector. It was thought that this concept offered an intuitive, scan-friendly option for viewing the trend information because it was aligned with the ownship and the course line.

The second concept proposed a deviation indicator presentation in the lower left corner of the ND. The deviation outputs from PDS were synthesized to display the aircraft's spacing deviation relative to the excessive spacing limits with a green pointer on a fixed scale. A positive spacing deviation moved the pointer up the scale, and a negative spacing deviation moved the pointer down. (A modification to this concept is discussed in Section 6.5.) Unlike the first concept, the size of the scale remained constant, therefore the sensitivity increased as the PDS limits decreased and vice-versa. Like the first concept, there was no zero deviation center indicator. It was thought that this design concept would seem familiar to current commercial pilots, and therefore be met with some acceptance, because a similar Vertical Navigation (VNAV) deviation scale is depicted in the lower right corner of the ND to indicate altitude deviations relative to the profile being flown.

5 Methodology

5.1 Experiment Objectives

The primary objective of the experiment was to evaluate the usability and acceptability of the interfaces designed to support APS-DPA operations. It was hypothesized that pilots would find all versions of the interfaces presented to be both usable and acceptable, and that insight would be gained from analyzing the questionnaire responses by subject pilots in the following areas of interest:

- importance of the proposed interface to the conduct of the operation;
- usability of proposed interfaces;
- preferences in the proposed display interfaces;
- preferences in combinations of the proposed interfaces;
- design anomalies; and
- suggestions for improvement.

Since this was a study in which no interaction with the recorded scenario was possible, there was no attempt to evaluate subjective workload, procedures, or performance.

5.2 Dependent Measures

The dependent variables for the study consisted of subject pilot evaluations of the interface design elements, collected via structured questionnaires administered after individual test runs and also after the complete session. The questionnaires were designed to gather the following types of information.

- Usability: Were the design elements understandable? Were they intuitive, user-friendly?
- Usefulness: Were the design elements needed or not? After seeing them, if they were subsequently removed, would the subject pilot miss any of them? Did they impact the situation awareness of the APS-DPA operation?
- Acceptability: Did the design elements make the subject pilot feel more comfortable about the APS-DPA operation? Was the subject pilot confident about the status of the operation?
- Improvements: Assuming the proposed concepts were useful, what could be done to enhance the effectiveness, appearance or other aspects of the design elements?

5.3 Experiment Scenario Design

The concept for the experiment was to present the proposed interface concepts in a manner best suited to obtaining subject pilot evaluations on their acceptability and usability. The ASTOR platform was chosen for its ability to realistically represent the proposed APS interfaces as they would appear on modern Boeing commercial glass cockpit displays. Custom ASTOR software was developed to implement the APS interface concepts, and modified spacing scenarios from the previous ATOL APS experiment were used to run simulations with the ASTOR software and generate recordings of a simulated spacing operation from the cockpit perspective of the simulated aircraft.

Although this approach required more effort than traditional storyboarding techniques for presenting new display concepts, it was deemed to have several advantages. First, the recorded spacing scenario offered a continuous, full-motion representation of the interface concepts as they appeared during the spacing operation, enhancing the realism and affording the subject pilots an opportunity to evaluate the interfaces appearance at any point in the scenario. Second, the ASTOR programming modifications were reusable for future ATOL demonstrations and/or experiments at the completion of this study. A key feature of the ASTOR modifications was the ability to control the APS interface design elements via a configuration file, such that any combination of the design elements could be selectively enabled for a particular simulation. This feature allows these elements to be quickly modified to evaluate their usability in future spacing scenarios.

The traffic scenario for the recorded simulation utilized models which match CDA operations at the Louisville Standiford Airport (SDF). An existing traffic scenario which merged two east-bound streams into a single CDA to Runway 17R was modified to separate the streams and simulate dependent parallel approach operations to Runway 17R and Runway 17L. A list of simulated test conditions is included below. Simulated winds were set to zero (no wind) to enhance the repeatability of the scenarios from run to run.

- Winds: No wind, all altitudes
- Aircraft type: Heavy, two-engine, narrow-body transport aircraft
- ASTOR Build: OpTech_ASTAR10_2010SEP16
- ASTAR version: 10

The scenario consisted of six aircraft (ID = NASA xxx), each assigned to fly one of the two published CDAs: 1) the SEA BISCUIT ONE (CBSKT1) ARRIVAL to Runway 17R, and 2) the CALKS ONE (CALKS1) ARRIVAL to Runway 17L. The lead aircraft in the CALKS ONE arrival stream was NASA 907, which autonomously flew the CDA to Runway 17L with a Required Time of Arrival (RTA) but without an assigned spacing interval. The lead aircraft in the SEA BISCUIT ONE arrival stream was NASA 893, which autonomously flew the CDA to Runway 17R with a RTA and without an assigned spacing interval. The remaining aircraft in the scenario autonomously flew the CDAs and spacing interval assignments specified in Table 5-1. See Figure 5-1 for a pictorial diagram of the spacing scenario which shows the spacing intervals for the ASTOR station (NASA 995) used as the ownship in the experiment presentation.

Table 5-1: Spacing Scenario Clearance Parameters.

Aircraft ID	CDA	Runway	RTA	Precision Interval	Target Aircraft	NCT Interval	Target Aircraft
NASA 907	CALKS1	17L	06:24:13Z				
NASA 859	CALKS1	17L	06:26:52Z	180 sec	NASA 907		
NASA 917	CALKS1	17L	06:32:53Z	140 sec	NASA 893		
NASA 893	CBSKT1	17R	06:25:32Z				
NASA 995	CBSKT1	17R	06:28:16Z	165 sec	NASA 893	90 sec	NASA 859

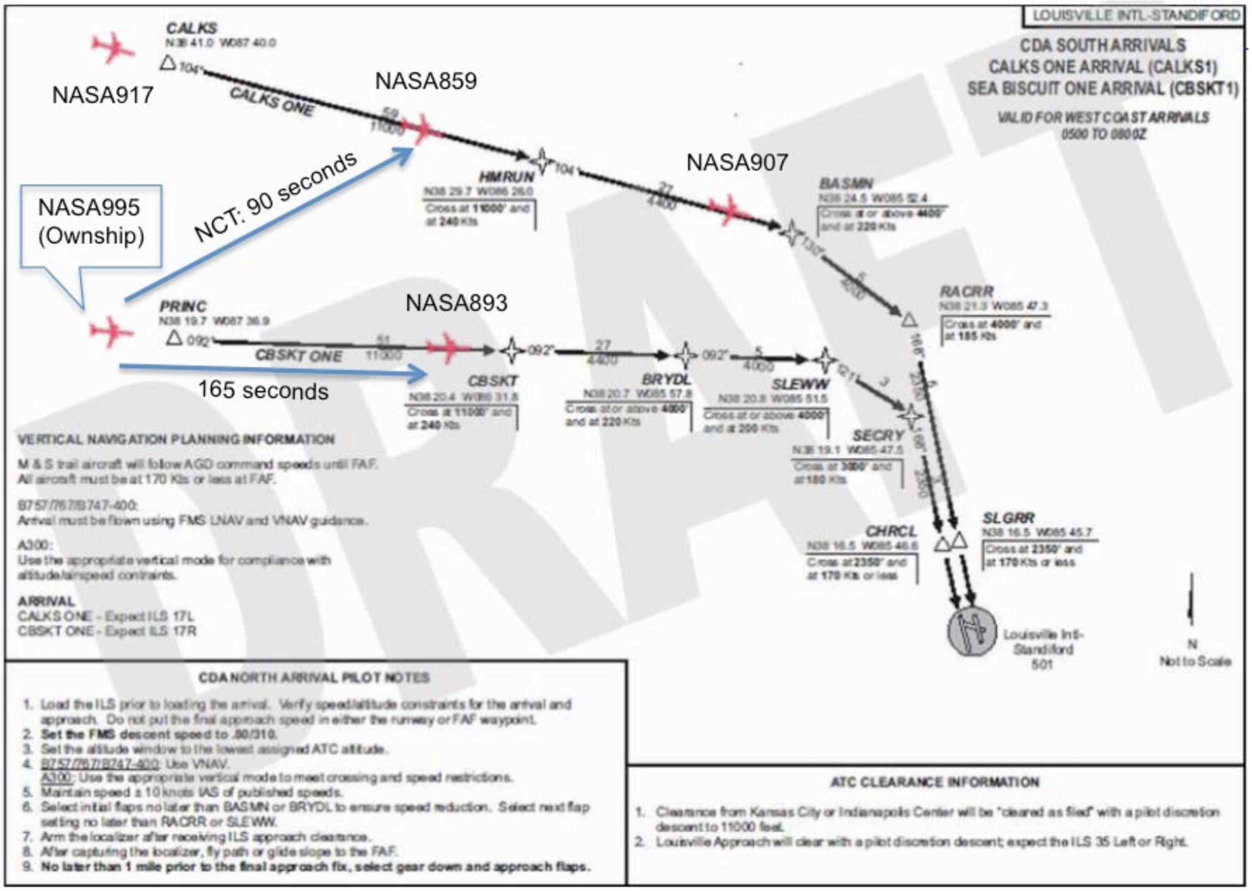

Figure 5-1: Spacing Scenario Diagram.

The intrinsic recording facilities of ASTOR were utilized to capture data necessary for playback of the multi-aircraft spacing scenarios for the usability study presentations. This facility enabled a portable demonstration displaying multiple aircraft while using only one ASTOR station. The use of a recorded simulation file ensured that the simulated scenario would appear identically for each presentation. The simulations were recorded in a laboratory similar to the ATOL, equipped with several ASTORs and a scenario traffic generator. The experimental software build used for the simulations allowed the ASTOR to: 1) simulate reception of a spacing clearance via datalink; 2) parse the clearance and load the spacing parameters to the MCDU PDS menu pages (Appendix B: Supplemental Design Concepts for Fully Integrated Implementation); and 3) execute the spacing instructions by autonomously flying the PDS target speed. After the scenario was run to completion, the recorded file from the ASTOR representing NASA 995 was saved for playback during the experiment sessions.

The procedure for recording the experimental scenario was to start the simulation with all ASTOR stations (aircraft) at a point prior to top of descent (TOD). Aircraft then received spacing clearances via datalink, also before TOD. The test operator visited each ASTOR station to manually load the received clearance parameters to ASTAR via the MCDU PDS menu pages. The verified clearance was then executed and the autopilot was manually engaged by selecting the “PDS” engage function on the MCP. The manual nature of serially starting all six of the

ASTOR stations led to minor timing variations in the eight (8) recorded scenarios, but these variations were largely damped out as the scenario progressed.

In order to program the ASTOR representing NASA 995 with the NCT spacing interval necessary to simulate APS-DPA, the test operator manually entered the NCT interval parameters via the MCDU PDS menu interface. Again, this was done prior to the TOD for NASA 995. Once the initial clearance was modified with the NCT interval, the test operator manually executed the clearance via the MCDU.

5.4 Experimental Protocol

An experiment session consisted of several presentations displayed on a workstation consisting of a computer monitor and a mouse. The associated computer was programmed with the ASTOR software, which simulated the operation of a modern commercial Boeing glass cockpit. Before the ASTOR software was started, the subject pilot was given a pre-experiment briefing on APS-DPA concepts and the proposed design concepts that were to be evaluated.

The bulk of the session consisted of nine runs, each of which presented the subject pilot with a recorded spacing scenario replayed on the ASTOR platform. The experimental runs each simulated an APS-DPA spacing operation in which the ownship (NASA 995) was assigned both a precision interval and an NCT interval. Played back at normal speed, the recorded simulations would have lasted approximately twenty-four (24) minutes from TOD to touchdown. However, the ASTOR playback facility allowed the speed of playback to be varied by the test operator. This facility was used to fast-forward the playback through periods of relative inactivity, and each run was shortened to approximately five to seven minutes.

During the first familiarization run (R0), the subject pilot was asked to interact with the ASTOR by using the mouse to enter a typical spacing clearance into the MCDU pages specifically designed for this exercise. In the remaining runs (R1-R8), the subject pilots were asked to only observe the presentation as the spacing scenario progressed.

A post-run questionnaire was administered to capture the subject pilot's evaluation of the design elements presented. After all of the test runs were completed, a final questionnaire was administered in which overall impressions of the test were captured.

In an ideal experiment, only one independent variable would change per run in order to best associate its interrelation to the dependent variables. This approach was considered both impractical and unnecessary for this usability study, as it would have taxed the desired 2-3 hour time limit for the experiment, and it was believed the grouping of certain design elements would not significantly compromise the subjective data obtained. See Table 5-2 for a description of test runs, detailing the design elements which were grouped for each run. The runs were given a run number so they could be correlated to the post-run questionnaire data. Although the test runs were numbered, the run order was randomized for each test session to prevent unintended bias introduced by a set order.

Table 5-2: Test Run Matrix Showing Display Options Enabled

Run	PDS Target Speed Option	PDS Mode Option	Target Aircraft Option	Trend Indicator Option
R1	Text	Text	Coupled Only	None
R2	Text	FMA	Coupled Only	None
R3	Speed Bug	Text	Coupled Only	None
R4	Speed Bug	FMA	Coupled Only	None
R5	Text	Text	Coupled Only	Conformance Box
R6	Text	Text	Coupled Only	Deviation Scale
R7	Text	Text	Coupled w/Data	Conformance Box
R8	Text	Text	Coupled w/Data	Deviation Scale

Run R0: This run was part of every experiment in order to introduce the subject pilot to the MCDU PDS menu pages added to monitor and control the spacing operation, and also familiarize the subject pilot with the specific spacing clearance(s) which were part of the recorded scenario. The subject pilot was given specific tasks to accomplish in these menu pages, which included:

- Identifying the spacing aircraft and intervals;
- Identifying the landing runway(s) for the spacing aircraft;
- Determining whether the clearance can be accepted (i.e., ASTAR algorithm is providing speed guidance);
- Modifying a spacing parameter as requested by the investigator;
- Executing the spacing clearance.

Runs R1-R4: These runs were made holding design elements for target aircraft and trend indication constant, while varying the combinations for displaying PDS target speed and PDS mode, as shown in Table 5-2.

Runs R5-R8: These runs were made holding design elements for PDS target speed and PDS mode constant, while varying the combinations for displaying target aircraft and trend indication, as shown in Table 5-2.

5.5 Subject Pilots

The subject pilots for this study were either current or former commercial airline pilots with experience in one or more of the following aircraft: 1) Boeing 777; 2) Boeing 737 NG (Next Gen); 3) Boeing 767-400; and 4) Boeing 747-400. The ASTOR platform's representation of a modern Boeing glass cockpit was sufficiently familiar to all subject pilots to require no additional training other than a briefing on the new APS interfaces, and the experimental scenarios and procedures.

Volunteers were solicited by contacting the Airline Operations Centers (AOCs) for United Airlines at the Chicago (ORD) and Dulles (IAD) airports. These pilots were tested in-domicile.

Additional local pilots were solicited for dry-run experiments held at or near the Contractor's office in Hampton, VA. These pilots had the same experience as listed above, and flew (or had recently flown) for Airtran Airlines, American Airlines, and Southwest Airlines. All subject pilots received a small stipend for participating.

6 Results and Discussion

The following is a discussion of the experiment objectives and dependent measures obtained from analysis of the subject pilot responses to the test questionnaires. The full text of the questionnaires, as well as a complete set of results for the questionnaires, is shown in Appendix A: Tabulated Experimental Results.

6.1 Subject Pilot Ratings for Usability of Proposed Interfaces

The post-run questionnaires asked subject pilots to rate their ability to identify specific information presented in the spacing scenario, using a scale of 6 "very easy to identify" to 1 "not able to identify at all". If it was believed the information was missing from a particular run, the subject pilot was asked to answer "Not Applicable" ("N/A"), which was interpreted as missing data. These data were correlated with the elements presented in that run (see Figure 6-1) to determine the rating for a particular design element option (for example, text vs. green bug option for PDS target speed.) Since the test run matrix was not balanced (some design options were shown more frequently than others), the sample size (N) for each element option is noted in the following results analysis.

The post-run questionnaire also asked subject pilots to rate the helpfulness of each design element in understanding the spacing operation, using a scale of 5 "very helpful" to 1 "not helpful". These data were correlated with the elements presented in that run as above.

For PDS target speed, the text option was presented to subject pilots in runs R1, R2, R5, R6, R7 and R8; the speed bug option was presented in runs R3 and R4. After each run, subject pilots were asked to rate their ability to identify 1) current PDS target speed and 2) changes to PDS target speed. The pertinent data collected from this question is summarized in Table 10-2 and Table 10-3. As shown in Figure 6-1, the average ratings for the text option were 5.40 (SD= 0.65, N=150) and 5.03 (SD=0.87, N=150), respectively. The average rating for the green speed bug were 5.22 (SD=0.92, N=50) and 5.00 (SD=1.06, N=50), respectively. In response to the helpfulness question (see Table 10-20), the average rating was 4.22 (SD=0.66, N=147[2]) for the

[2] The missing response(s) were due to an internet connection drop while the questionnaire was being administered.

text option, and 4.08 (SD=0.99, N=49[2]) for the green speed bug. This indicates subject pilots had a high degree of confidence in the usability of either design option, with the text option rating slightly higher for all categories.

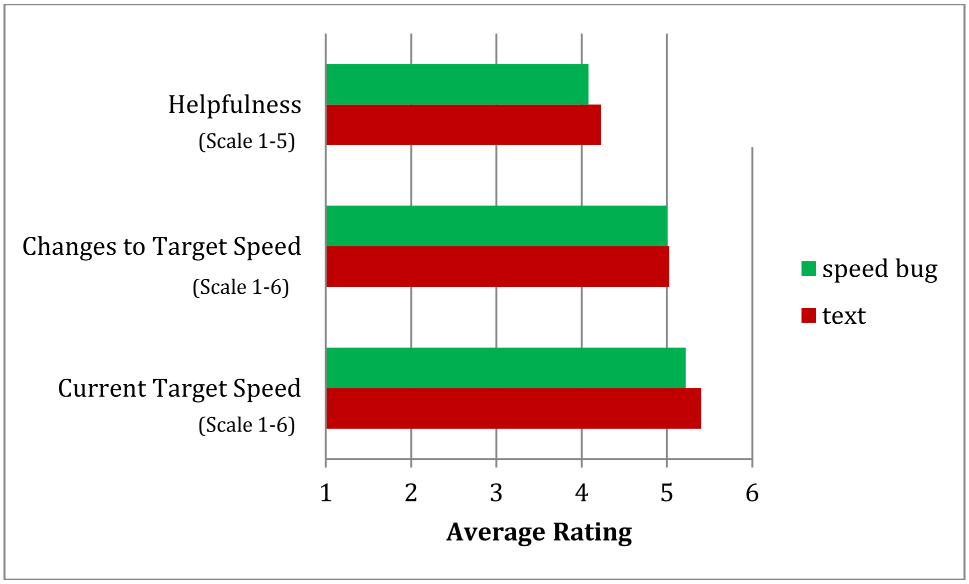

Figure 6-1: PDS Target Speed Option Average Ratings.

For PDS mode, the text option was presented to subject pilots in runs R1, R3, R5, R6, R7 and R8; the FMA option was presented in runs R2 and R4. After each run, subject pilots were asked to rate their ability to identify 1) current PDS mode and 2) changes to PDS mode. The pertinent data collected from this question is summarized in Table 10-4 and Table 10-5. As shown in Figure 6-2, the average ratings for the text option were 5.17 (SD= 0.77, N=150) and 4.83 (SD=0.88, N=149[2]), respectively. The average ratings for the FMA option were 5.16 (SD=1.07, N=50) and 4.96 (SD=1.08, N=50), respectively. Subject pilots were also asked to rate their ability to identify the next PDS mode in sequence. In this case, only the FMA option provided this information, so subject pilots should have responded with "N/A" for the runs with the text option. A significant number of subject pilots did not respond with "N/A" (many responded instead with "not able to identify"), indicating some confusion regarding the instructions. The pertinent data collected from this question is summarized in Table 10-6. The average rating to this question was 3.23 (SD=2.03, N=120) for the text option, and 4.85 (SD=1.43, N=46) for the FMA option. If the N/A responses are converted to "not able to identify", the average rating becomes 2.78 (SD=2.02, N=150) for the text option. Both of these results are significantly lower than for the FMA option. These data indicate subject pilots had a high degree of confidence in their ability to identify PDS mode and mode changes for either design option, and a higher degree of confidence in their ability to identify the next mode in sequence for the FMA option. In response to the helpfulness question (see Table 10-21), the design alternatives were rated equally high, with average ratings of 4.00 for each alternative.

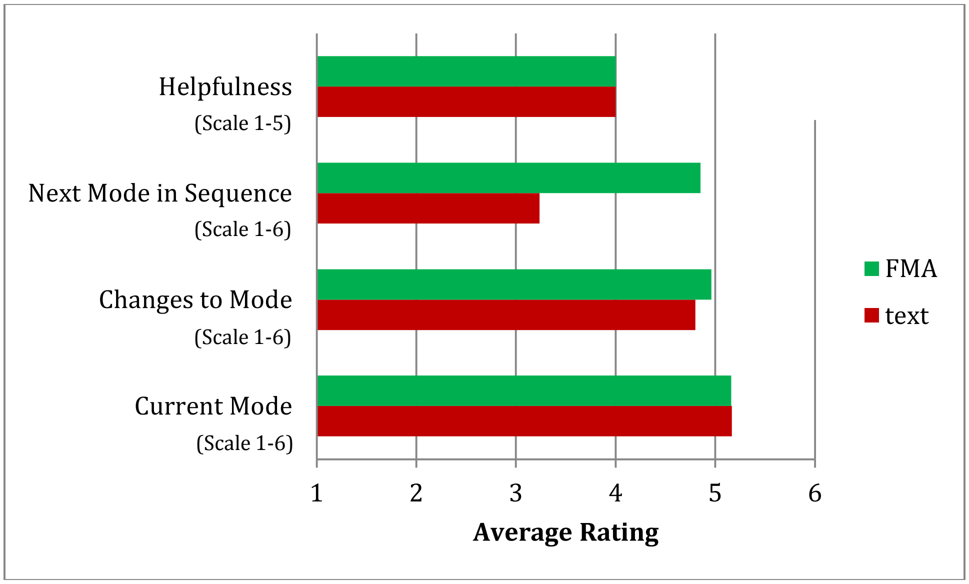

Figure 6-2: PDS Mode Annunciation Option Average Ratings.

For target aircraft depiction, the "coupled only" option was presented to subject pilots in runs R1, R2, R3, R4, R5, and R6; the "coupled with data block" option was presented in runs R7 and R8. Subject pilots were asked to rate their ability to identify several characteristics of the target aircraft. Some of these characteristics were only identifiable in the data block, so subject pilots should have responded with "N/A" for the runs where the information was not present. The lack of "N/A" responses led to the hypothesis that subject pilots may have identified some of this information from the MCDU, which was "parked" on the PDS main menu page during the recorded scenarios. (In support of this hypothesis, several subject pilots responded correctly for target aircraft characteristics available ONLY from the data block and not the MCDU page. For instance, assigned runway and aircraft type together received fifty-six of the fifty-seven "N/A" responses in the "coupled only" runs, indicating that most subject pilots correctly responded that the information was missing.) This menu page would have allowed the subject pilot to determine the active spacing aircraft, spacing interval type and spacing deviation without the need for the data block. This may have skewed the intended results of the questions about these characteristics. The pertinent data collected from this question is summarized in Table 10-7 through Table 10-18, and Table 10-22. The average ratings for rating the usability of target aircraft characteristics and the overall helpfulness of the design alternatives are shown pictorially in Figure 6-3. The average ratings consistently favor the "coupled with data block" option over the "coupled only" option, indicating that subject pilot's found characteristic(s) of the former more useful and helpful. The perceived importance of these characteristics is discussed in the next section.

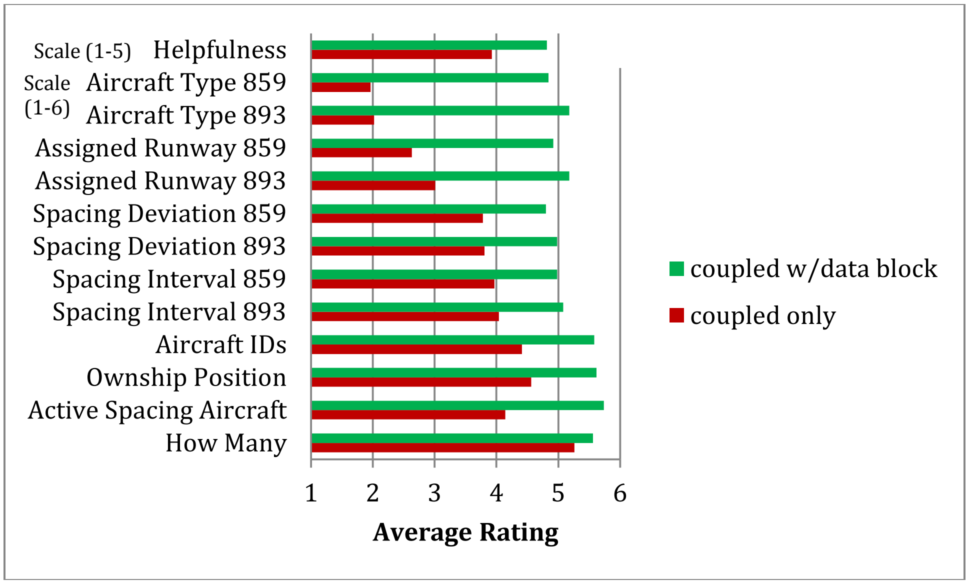

Figure 6-3: Target Aircraft Depiction Option Average Ratings.

For the trend indicator, the "conformance box" option was presented to subject pilots in runs R5 and R7, the "deviation scale" option was presented in runs R6 and R8, and there was no trend indicator displayed on runs R1, R2, R3, and R4. After each run, subject pilots were asked to rate their ability to determine and understand the aircraft's progress towards achieving the assigned spacing goal. The pertinent data collected from this question is summarized in Table 10-19. As shown in Figure 6-4, the average rating for the conformance box option was 4.84 (SD=0.61, N=50). The average rating for the deviation scale option was 4.84 (SD=0.76, N=50). The average rating for no trend indication was 4.18 (SD=0.75, N=100). The results indicate a slight enhancement in the subject pilot's ability to judge the aircraft's spacing progress with either trend indicator. The benign nature of the recorded spacing scenario did not cause significant deviations to be displayed by either trend indicator, possibly diminishing the perception of its potential usefulness (see comments in Section 6.3.4). In response to the helpfulness question (see Table 10-23), the average ratings indicate a modest preference for the conformance box option (3.98, SD=1.19, N=49[2]) vs. the deviation scale option (3.48, SD=1.22, N=48[2]).

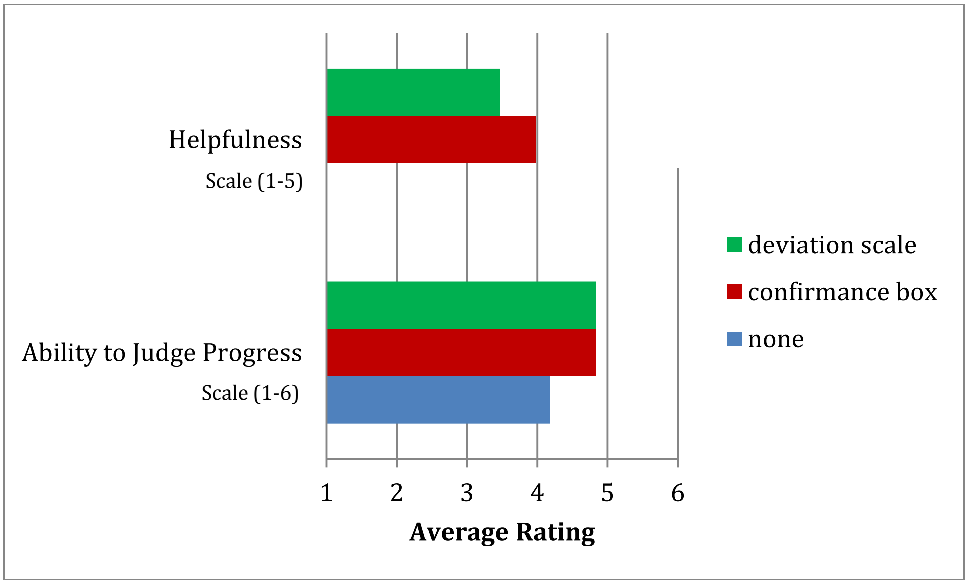

Figure 6-4: Trend Indicator Option Average Ratings.

6.2 Subject Pilot Ratings of Interface Importance to APS-DPA Operations

An evaluation of the relative importance of the information conveyed by the design elements was obtained via the final questionnaire. The data was analyzed to verify that each element category was considered useful, and to further determine which characteristics of each element was considered the most useful. This data indicates that subject pilots considered all of the element categories to be important, but not equally important.

Subject pilots were asked to rate the importance of each of the four categories of design elements (i.e., PDS target speed indicator, PDS mode, target aircraft depiction and trend indicator). The pertinent data collected from this question is summarized in Table 10-27. Using a scale of 5 "very important" to 1 "not important", the responses in rank order were:

1. PDS target speed indicator (average rating = 4.92, SD = 0.27, N=25);
2. Target aircraft depiction (average rating = 4.72, SD = 0.60, N=25),;
3. PDS mode annunciation (average rating = 4.36, SD = 0.89, N=25);
4. Trend indicator (average rating = 4.12, SD = 1.18, N=25).

For each design element category, subject pilots were asked to rate the importance of several characteristics of that element. For example, relative to PDS target speed, they were asked to rate the importance of being able to determine both the current target speed, and changes to the target speed, using a scale of 5 "very important" to 1 "not important". The results shed light on which element characteristics were most valued, and provide a context for the element preferences discussed later.

For the PDS target speed indicator (see Table 10-28), it is clear that both of the element characteristics were considered very important; subject pilots responded that detecting speed changes (average rating = 4.80) was almost as important as displaying the PDS-commanded speed (average rating = 4.92).

For the target aircraft depiction (see Table 10-29), it is interesting to note that out of eight listed characteristics, the three most important (ownship relative position, active spacing aircraft and number of target aircraft) were shown without the use of the data block. While both of the target aircraft design alternatives were able to depict the ownship relative position and number of spacing targets, only one of the alternatives ("coupled with data block") was implemented to also indicate the active spacing aircraft with a selected circle. This one highly valued characteristic may be a large contributor to the significant preference for this design alternative discussed later. The rank ordering of the five remaining characteristics (spacing deviation, aircraft ID, assigned runway, aircraft type, spacing interval type) indicate the information within the data block implementation that subject pilots found most useful.

For the PDS mode annunciation (see Table 10-30), it is interesting to note that two characteristics, current mode (average rating = 4.24) and changes to mode (average rating = 4.20) were rated significantly higher than the ability to determine the next mode in sequence (average rating = 3.44). While both of the PDS mode design alternatives were able to show current mode and changes to mode, only the FMA design alternative was able to show the next PDS mode in sequence. This characteristic was still considered important, and may have been a contributor to the preference for the FMA design option (see Section 6.3.2.)

6.3 Subject Pilot Interface Preferences

The final questionnaire asked subject pilots to indicate a preference for individual design elements in each of four categories; PDS target speed; PDS mode annunciation, target aircraft depiction and trend indicator. Subject pilots were given a choice of both design options in each category, or "None" to indicate no option was preferred. They were also asked to consider whether their preference changed when the elements were considered in combination rather than individually. (only one subject pilot answered in the affirmative). The results are summarized in Table 10-31 through Table 10-35.

6.3.1 PDS Target Speed

Subject pilot responses were almost evenly split on which of the two PDS target speed display options was preferred, with thirteen (52%) preferring the green speed bug option and twelve (48%) preferring the textual speed indication. This result confirms the hypothesis that both options were usable and acceptable, and echoes the usability ratings discussed previously. A pilot who favored the green speed bug commented "…best presented as a speed bug for instant comparison with actual speed." A pilot who preferred the text option said, "I prefer the text version of PS (sic) target speed because I can always find it. Rapid changes to the bug display can cause it to disappear."

6.3.2 PDS Mode Annunciation

Subject pilot responses slightly favored the FMA integration option of PDS mode display, with fifteen (60%) preferring the FMA option and ten (40%) preferring the textual mode indication. This result is again similar to the usability and helpfulness ratings discussed previously, where both options were rated almost equally useful. A pilot who preferred the FMA option commented, "Most aircrews are trained to be very diligent on FMA observation, mode changes, and correct presentation for desired flight mode. So basically this would be in normal aircrew scan/procedures…" A pilot who preferred the text option said, "…I think it will enhance understanding and avoid confusion by keeping the PDS modes in the text box and separate from the VNAV mode annunciators. I know at this airline that pilot understanding of the available VNAV modes and their annunciations is a bit of a weak point. By adding more to that portion of the FMA annunciations the confusion may increase."

6.3.3 Target Aircraft Depiction

Subject pilot responses were overwhelmingly in favor of the "coupled with data block" option, with twenty-four (96%) preferring this option and one (4%) preferring the "coupled only" option. In examining the ratings on target aircraft characteristics discussed previously, this result can largely be attributed to one characteristic of the preferred option, which was the selected circle drawn around the active spacing aircraft. This is echoed in comments such as, "I want to know which aircraft is controlling my speed...the circle is a BIG HELP", and, "I prefer the circle with a minimal data block adjacent to the aircraft depiction to include A/C number, type, and runway assignment until Final mode where the info on the ND should no longer be depicted.". The one subject pilot who preferred the "coupled only" option offered, "I like the circle around it, but this is not needed info in most cases."

6.3.4 Trend Indication

Subject pilot responses were in favor of the conformance box trend indicator display option, with seventeen (68%) preferring this option, five (20%) preferring the deviation scale option, and three (12%) preferring no trend indicator. Usability ratings for these options were equal, and the helpfulness rating slightly favored the conformance box. Written comments were helpful in understanding the more dramatic preferences expressed in this result. Several comments were made calling the conformance box "intuitive", while an equal number of comments labeled the deviation scale "confusing", largely for its similarity to the VNAV path indicator on the opposite side of the ND. One commenter said, "My preference is Conformance Box over Deviation Scale. Deviation Scale looks too much like VDEV (sic) scale and could be confused. Conformance Box is also along track and easy to interpret." Of the pilots preferring the deviation scale, one commented, "…prefer the side deviation indicator, as changes more evident. Probably due to constant scale presentation." Of the three pilots who preferred no trend indication, comments included "…provides information I have no control over…", "…slightly useful but not necessary…", and "…tough to judge because the deviations were so minor".

6.3.5 Other Preference Considerations

The one subject pilot who changed preferences when considering the design elements in combination rather than individually responded with an individual preference for the FMA option of PDS mode annunciation, but preferred the text option when considered in combination. The motivation appeared to be based on ambivalence for the PDS mode annunciation options, coupled with a preference to keep both PDS target speed and mode displays together on the PFD.

6.4 Subject Pilot Preferences for Combinations of Interfaces

In the post-run questionnaire, subject pilots evaluated the presentation of each spacing scenario's design elements for their overall understandability, the level of confidence they provided, and for their intuitiveness and user-friendliness. This data was analyzed to determine if the results coincided with the individual usability ratings and preferences for the design element options, and to see if further insights could be gained about the effectiveness of element combinations.

Understandability, confidence and intuitiveness were rated using a scale of 5 "very understandable, confident, intuitive" to 1 "not understandable, not confident, not intuitive". The data collected for these questions is shown in Table 10-24 through Table 10-26. A summary of these results is also shown in Table 6-1, which facilitates a direct comparison of the average rating per run for each question, along with an overall rank order of each run's average rating. The "Combined Rating" column of this table combines the weighted responses for each question's responses from Table 10-24 through Table 10-26 into a single average rating. The runs are rank-ordered from top to bottom according to the combined rating. The design elements presented during each run are displayed as icons for reference.

The results indicate a consistent rank ordering of each run's average rating from top to bottom. It should be noted that the runs were presented in a different order for each subject pilot, so this is likely not the result of a bias introduced by the order of presentation. Also, since these were post-run evaluations, it was not a post-experiment determination of the subject pilot's preferred combination of elements. Both the average ratings and the combined ratings show that runs which displayed either of the trend indicator options (R5, R6, R7, and R8) scored consistently higher than those without a trend indicator (R1, R2, R3, and R4). Further, of the runs which displayed a trend indicator, those displaying the "coupled with data block" option of target aircraft display scored highest for both the mean responses and the combined rating (R7 and R8).

The results seem to indicate that the design elements presented on the ND drove the rating criteria of understandability, confidence and intuitiveness. Subject pilots may have interpreted these criteria as primarily strategic in nature, and rated based on the element combination's ability to provide the "big picture". A contributing factor may have been that the design element categories which garnered the highest individual preference scores (target aircraft and trend display) preempted consideration of the other categories (PDS target speed and PDS mode), for which preferences were not as clearly delineated. Another possibility is that subject pilots may have adopted a preferred set of design elements during the pre-experiment briefing, and answered the post-run evaluations accordingly.

Table 6-1: Combined Design Element Preferences.

Run	Comb. Rating	Elements	Understandability Rating (1-6)	Understandability Rank	Intuitiveness Rating (1-5)	Intuitiveness Rank	Confidence Rating (1-5)	Confidence Rank
R7	4.61	PDS .800 PDS PAIR	5.16	2	4.38	1	4.28	1
R8	4.56	PDS .800 PDS PAIR	5.28	1	4.2	2	4.2	2
R5	4.17	PDS .800 PDS PAIR	4.8	3	3.92	3	3.8	3
R6	4.01	PDS .800 PDS PAIR	4.64	4	3.61	4	3.76	4
R4	3.92	PAIR FNL	4.52	5	3.6	5	3.64	5
R3	3.88	PDS PAIR	4.48	6	3.54	6	3.6	7
R2	3.77	PDS .800 PAIR FNL	4.32	8	3.4	7	3.6	6
R1	3.69	PDS .800 PDS PAIR	4.32	7	3.36	8	3.4	8

Design Elements Options Key:

PDS Target Speed	PDS .800 Text	Speed Bug
PDS Mode	PDS PAIR Text	PAIR FNL FMA
Target Aircraft	Coupled Only	Coupled w/ Data Block
Trend Indicator	Conformance Box	Deviation Scale

6.5 Suggested Improvements by Subject Pilots

6.5.1 PDS Target Speed Interface

Several written comments suggested that a combination of the green speed bug and textual modes would be better, and that both options of PDS target speed display could be useful, depending on the instrument scan pattern demanded by a particular phase of flight. A mockup of one subject pilot's suggestion for the combination of the two options is shown in Figure 6-5, in which the textual presentation of PDS target speed ha been relocated to the area above the speed tape, juxtaposing it with the commanded speed text. This concept facilitates easy comparison of the two speeds.

It was also suggested by some that, while generally important during APS-DPA operations, PDS target speed (as well as other PDS design elements) may be an unnecessary distraction during final approach, when spacing deviations are no longer being countered by PDS target speed.

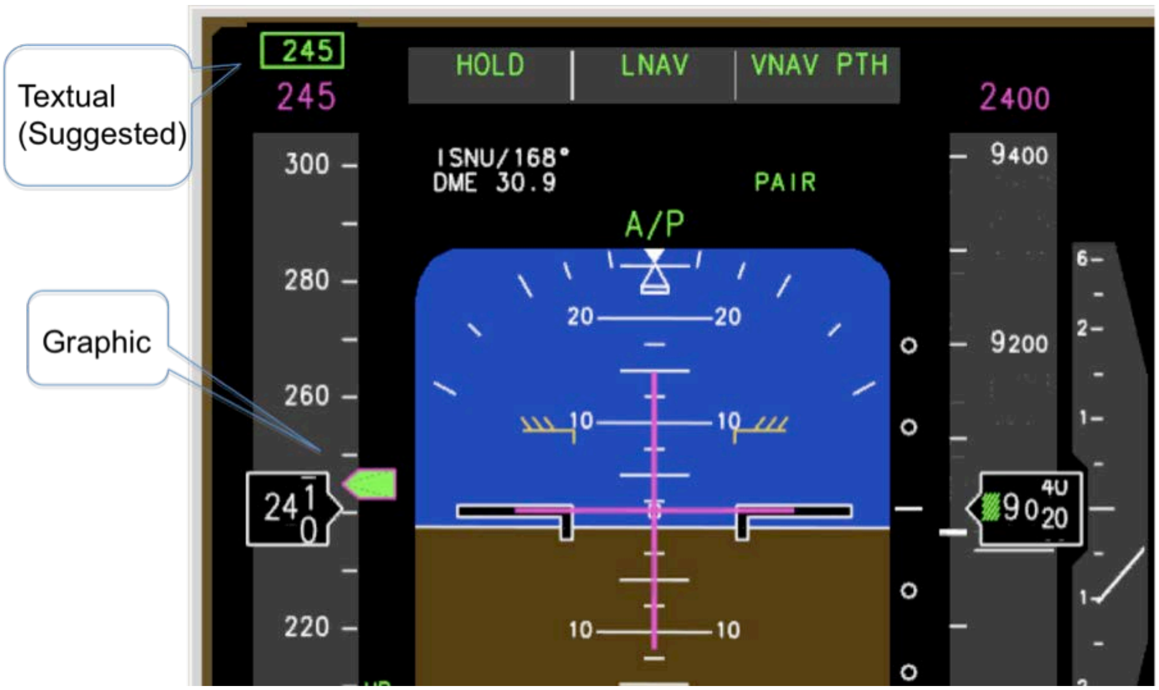

Figure 6-5: Suggested Concept for PDS Target Speed Display.

6.5.2 PDS Mode Annunciation

Several subject pilots commented that the addition of the PDS information to the FMA was “confusing”. Some implementation anomalies in the ASTOR depiction of this option may have contributed to the confusion (see Appendix E: ASTOR Implementation Issues). However, several subject pilots commented that the FMA information is vital to understanding the operation of modern Boeing automation, and therefore this was the rightful place for PDS mode annunciation. In retrospect, it may have been less confusing if, as some suggested, the PDS annunciation were added by introducing a new segment to the FMA. This would have had the advantage of not changing the pilot’s understanding of any existing segment, and would have isolated any additional training to that required for the new PDS segment.

6.5.3 Target Aircraft Depiction

In examining the comments made, it is clear that the identification of the active spacing aircraft with a select circle was perceived as enhancing the situation awareness during the spacing operation. There were several suggested improvements to enhancing the awareness of the active spacing aircraft in the event of a change of active aircraft. These suggestions included:

1) “blinking” of the circle, 2) changing the color of the circle, and 3) changing the text color of the ID of the active spacing aircraft to magenta.

Several comments were made regarding the efficacy of the data block. Comments supporting the data block information were offset by comments recommending: 1) less information in the data block, 2) allowing the data block to be selectively turned on or off, and, 3) automatically turning the data block off on final approach to eliminate it as a distraction. It was also noted that the data block as implemented could conflict with the display of Navigation Aid (NAVAID) information, which is selected via the EFIS control panel.

6.5.4 Trend Indication

Several comments were made about the deviation scale option of the trend indicator being confusing. Most cited the scales similarity to the VNAV deviation scale on the opposite side of the ND, which would also be displayed while flying a CDA profile. No suggestions for improvement were made by the commenters, but the essence of the comments were used to propose a mockup of an alternative deviation scale shown in Figure 6-6. In this concept, the scale pointer indicating the relative spacing deviation from nominal has been replaced with a small, green ownship-like triangle indicator. The original sense of the scale has been reversed, such that negative deviations are up or forward on the scale, and positive deviations are down or aft, improving the scale’s appearance as a longitudinal deviation indicator.

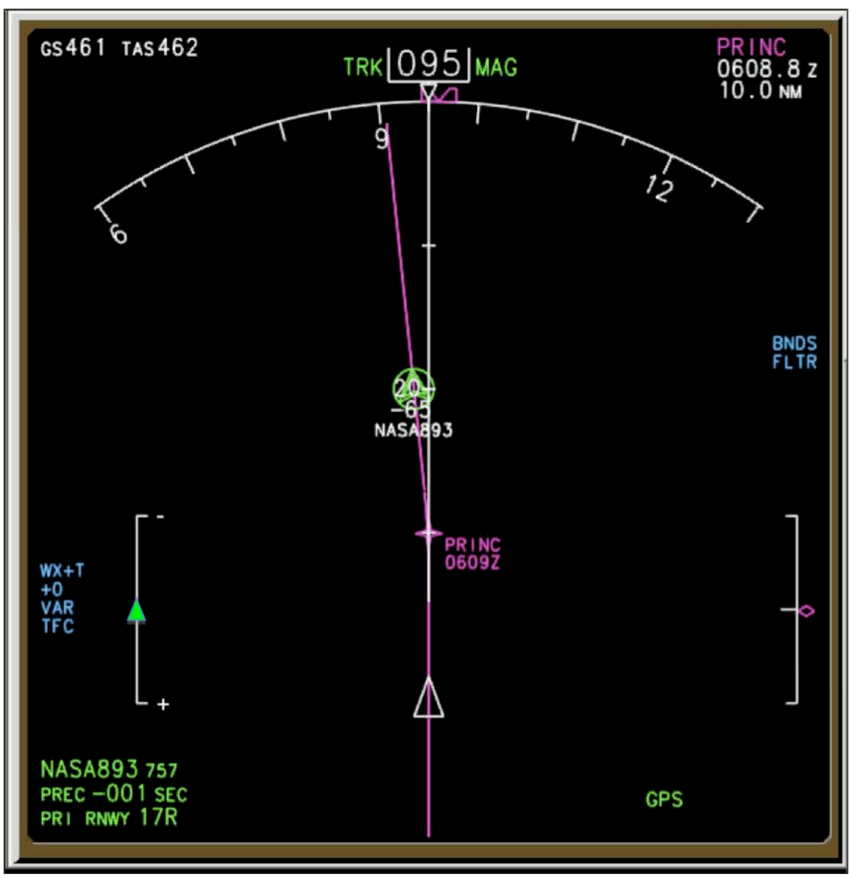

Figure 6-6: Alternate Trend Indicator Concept.

7 Conclusions

This study built upon previous experiments focused on the Airborne Precision Spacing concept. Several candidate interfaces were designed to support spacing operations for aircraft performing CDAs while also managing assigned spacing intervals from two other arriving aircraft on dependent parallel approaches. An experiment was designed to verify the usability of these interfaces using recorded spacing scenarios, which were implemented using an existing procedure simulator (ASTOR).

The results of the study indicate that several options exist for usable interfaces to support these spacing operations. All of the interface options evaluated by subject pilots were considered acceptable, and valuable insight was collected on their relative effectiveness and importance to the conduct of spacing operations. In particular, the key results indicate the following:

1. both textual and graphical presentations of pds target speed were considered useful;
2. target aircraft indication is considered especially useful if it also indicates which of the two targets is the active spacing aircraft;
3. subject pilots favored the flight mode annunciator option over the text option for pds mode annunciation, which should be considered carefully since it would likely present a more significant pilot training issue than the text option; and
4. spacing trend indication was considered the least important design element, yet it was also considered useful by most subject pilots.

The results also highlighted the need for additional investigation. The evaluations of options for presenting PDS target speed indicated equal preference, and suggestions to display both on the PFD (similar to the commanded speed) have merit. A more thorough consideration of the integration of PDS annunciation into the FMA is recommended, as most subject pilots preferred this for monitoring autopilot controlled modes of operation, and there were issues noted with the study's implementation. The actual benefit of the data block containing target aircraft information may have been masked by its association with the active spacing aircraft select circle, but sufficient support existed for the refinement of data block information to be investigated. Future studies should characterize the behavior of the trend indicators using a variety of spacing scenarios, including scenarios with less benign conditions than used in this experiment. The responses for the trend indicator showed it to be lowest in relative importance, yet a trend indicator was always included in preferred combinations of elements. This result warrants further investigation, especially with off-nominal scenarios, of whether a trend indicator is imparting useful information during a spacing operation, or if off-nominal alerts of another form (EICAS messages, audio alerts, etc.) would be sufficient.

Finally, the ASTOR implementation used to create the spacing scenarios leaves a legacy of usable software which can easily be used to support future studies or demonstrations. Many of the discussed suggestions for improvement of the interfaces involve simple software development and/or "bug" fixes.

8 Acknowledgements

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10 Appendix A: Tabulated Experimental Results

10.1 Results of Post-Run Questionnaires

This is the response data from the post-run questionnaire for the eight (8) test runs R1-R8. This questionnaire was structured to gather responses regarding design element usability and acceptability (i.e., were they understandable, helpful, intuitive, confidence-inspiring). Questions were asked which explored the usability of individual design elements and their characteristics, and also for combinations of elements. Except for solicited additional comments, responses were collected using Likert-type scales.

The text of each question precedes a set of tables showing the results. The data collected for each question is tabulated to make it easier to compare the results from individual test runs. Refer to Table 10-1 for a matrix which shows which display elements were presented to the subject during each run. Table data is organized by grouping runs which displayed a particular option. A summary entry identifies the design option, the overall ratings and sample size. Note that the "Rating Average" is the weighted average of the responses based on the values shown in the "Weight" row in the table, the "SD" is the population standard deviation, and "N" is the sample size, which is the number of valid responses collected for the particular run.

Table 10-1: Test Run Matrix Showing Display Options Enabled

Run	PDS Target Speed Option	PDS Mode Option	Target Aircraft Option	Trend Indicator Option
R1	Text	Text	Coupled Only	None
R2	Text	FMA	Coupled Only	None
R3	Speed Bug	Text	Coupled Only	None
R4	Speed Bug	FMA	Coupled Only	None
R5	Text	Text	Coupled Only	Conformance Box
R6	Text	Text	Coupled Only	Deviation Scale
R7	Text	Text	Coupled w/Data	Conformance Box
R8	Text	Text	Coupled w/Data	Deviation Scale

10.1.1 Usability of Display Elements

The following post-run questionnaire responses rated the subject's ability to understand the information being presented by the design elements, which was considered a key component of usability. Questions about PDS target speed, PDS mode annunciation and target aircraft depiction were sub-divided according to characteristics of the information presented, i.e., for PDS target speed, both current target speed and changes to target speed were rated. The runs are grouped by the design element option presented during the run. An overall rating for the design element option is shown in a summary line of the table. The results are discussed in more detail in 6.1.

“Based on what you experienced during the scenario you just completed, please ***rate your ability to identify*** the following information regarding the spacing operation.”

10.1.1.1 PDS Target Speed

Table 10-2: Current Target Speed

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Text Option Ratings										
R1	11	12	2	0	0	0	0	5.36	25	0.62
R2	13	9	3	0	0	0	0	5.40	25	0.69
R5	10	13	2	0	0	0	0	5.32	25	0.61
R6	13	10	2	0	0	0	0	5.44	25	0.64
R7	14	8	3	0	0	0	0	5.44	25	0.70
R8	13	10	2	0	0	0	0	5.44	25	0.64
Total	58	60	31	1	0	0	0	5.40	150	0.65
Speed Bug Option Ratings										
R3	12	9	3	0	1	0	0	5.24	25	0.95
R4	12	7	5	1	0	0	0	5.20	25	0.89
Total	24	15	9	0	1	1	0	5.22	50	0.92

Table 10-3: Changes to Target Speed

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Text Option Ratings										
R1	7	8	10	0	0	0	0	4.88	25	0.82
R2	10	6	8	1	0	0	0	5.00	25	0.94
R5	7	11	6	1	0	0	0	4.96	25	0.82
R6	8	9	7	1	0	0	0	4.96	25	0.87
R7	10	9	6	0	0	0	0	5.16	25	0.78
R8	12	8	3	2	0	0	0	5.20	25	0.94
Total	74	62	14	0	0	0	0	5.40	150	0.65
Speed Bug Option Ratings										
R3	10	9	5	0	1	0	0	5.08	25	0.98
R4	10	7	5	2	1	0	0	4.92	25	1.13
Total	20	16	10	2	2	0	0	5.00	50	1.06

10.1.1.2 PDS Mode

Table 10-4: Current Mode

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Text Option Ratings										
R1	8	12	5	0	0	0	0	5.12	25	0.71
R3	8	8	9	0	0	0	0	4.96	25	0.82
R5	10	13	2	0	0	0	0	5.32	25	0.61
R6	11	10	3	1	0	0	0	5.24	25	0.81
R7	9	9	7	0	0	0	0	5.08	25	0.80
R8	12	8	5	0	0	0	0	5.28	25	0.78
Total	58	60	31	1	0	0	0	5.17	150	0.77
FMA Option Ratings										
R2	12	9	4	0	0	0	0	5.32	25	0.73
R4	12	6	5	0	1	1	0	5.00	25	1.30
Total	24	15	9	0	1	1	0	5.16	50	1.07

Table 10-5: Changes to Mode

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)	(0)			
Text Option Ratings										
R1	5	10	6	3	0	0	1	4.52	24	0.93
R3	5	8	10	2	0	0	0	4.64	25	0.89
R5	7	9	9	0	0	0	0	4.92	25	0.80
R6	7	10	7	1	0	0	0	4.92	25	0.84
R7	7	9	9	0	0	0	0	4.92	25	0.80
R8	8	8	7	2	0	0	0	4.88	25	0.95
Total	39	54	48	8	0	0	1	4.83	149	0.88
FMA Option Ratings										
R2	9	10	6	0	0	0	0	5.12	25	0.77
R4	9	8	5	1	1	1	0	4.80	25	1.30
Total	18	18	11	1	1	1	0	4.96	50	1.08

Table 10-6: Next Mode in Sequence

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Text Option Ratings										
R1	3	3	3	1	0	10	5	2.90	20	2.02
R3	3	1	5	3	1	8	4	2.95	21	1.81
R5	5	2	3	1	0	8	6	3.32	19	2.13
R6	4	6	2	2	0	5	6	3.84	19	1.90
R7	4	4	2	0	0	11	4	3.00	21	2.16
R8	4	3	4	2	0	7	5	3.40	20	1.96
Total	23	19	19	9	1	49	30	3.23	120	2.03
FMA Option Ratings										
R2	10	9	1	1	0	3	1	4.79	24	1.61
R4	7	11	1	2	0	1	3	4.91	22	1.20
Total	17	20	2	3	0	4	4	4.85	46	1.43

10.1.1.3 Target Aircraft:

Table 10-7: How Many (one or two)

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R0	2	4	2	0	0	0	17	5.00	8	0.71
R1	7	15	3	0	0	0	0	5.16	25	0.61
R2	9	12	4	0	0	0	0	5.20	25	0.69
R3	9	13	3	0	0	0	0	5.24	25	0.65
R4	9	14	2	0	0	0	0	5.28	25	0.60
R5	12	11	2	0	0	0	0	5.40	25	0.63
Total	58	73	19	0	0	0	0	5.26	150	0.67
Coupled w/ Data Block Option Ratings										
R7	13	11	1	0	0	0	0	5.48	25	0.57
R8	16	9	0	0	0	0	0	5.64	25	0.48
Total	29	20	1	0	0	0	0	5.56	50	0.54

Table 10-8: Active Spacing Aircraft

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	2	5	6	8	2	1	1	3.75	24	1.23
R2	3	6	10	3	2	1	0	4.08	25	1.23
R3	4	7	8	6	0	0	0	4.36	25	1.02
R4	3	7	11	4	0	0	0	4.36	25	0.89
R5	4	8	6	6	0	1	0	4.28	25	1.22
R6	2	6	10	6	0	1	0	4.04	25	1.08
Total	18	39	51	33	4	4	1	4.15	149	1.14
Coupled w/ Data Block Option Ratings										
R7	20	4	1	0	0	0	0	5.76	25	0.51
R8	20	4	0	1	0	0	0	5.72	25	0.66
Total	40	8	1	1	0	0	0	5.74	50	0.59

Table 10-9: Ownship Position Relative to Spacing Aircraft

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	5	8	8	1	2	1	0	4.40	25	1.30
R2	4	8	9	3	1	0	0	4.44	25	1.02
R3	8	4	8	4	1	0	0	4.56	25	1.20
R4	5	9	6	4	1	0	0	4.52	25	1.10
R5	9	7	5	2	2	0	0	4.76	25	1.24
R6	4	10	10	1	0	0	0	4.68	25	0.79
Total	35	46	46	15	7	1	0	4.56	150	1.13
Coupled w/ Data Block Option Ratings										
R7	17	7	1	0	0	0	0	5.64	25	0.56
R8	17	6	2	0	0	0	0	5.60	25	0.63
Total	34	13	3	0	0	0	0	5.62	50	0.60

Table 10-10: Aircraft ID(s)

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	6	5	9	2	1	2	0	4.28	25	1.43
R2	4	11	7	1	1	1	0	4.52	25	1.17
R3	7	8	6	2	1	1	0	4.60	25	1.30
R4	2	9	11	0	1	2	0	4.20	25	1.23
R5	6	6	10	2	1	0	0	4.56	25	1.06
R6	3	8	11	1	1	1	0	4.32	25	1.12
Total	28	47	54	8	6	7	0	4.41	150	1.23
Coupled w/ Data Block Option Ratings										
R7	15	7	3	0	0	0	0	5.48	25	0.70
R8	18	6	1	0	0	0	0	5.68	25	0.55
Total	33	13	4	0	0	0	0	5.58	50	0.64

Table 10-11: Spacing Interval Type: NASA 893

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	2	5	13	3	1	1	0	4.04	25	1.08
R2	4	2	12	4	3	0	0	4.00	25	1.17
R3	2	7	13	1	1	1	0	4.20	25	1.06
R4	0	6	15	1	1	2	0	3.88	25	1.07
R5	2	7	8	6	2	0	0	4.04	25	1.08
R6	1	8	11	3	1	1	0	4.08	25	1.06
Total	11	35	72	18	9	5	0	4.04	150	1.09
Coupled w/ Data Block Option Ratings										
R7	9	11	4	1	0	0	0	5.12	25	0.82
R8	7	13	4	1	0	0	0	5.04	25	0.77
Total	16	24	8	2	0	0	0	5.08	50	0.80

Table 10-12: Spacing Interval Type: NASA 859

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	1	4	14	3	1	2	0	3.80	25	1.13
R2	4	2	12	3	4	0	0	3.96	25	1.22
R3	2	7	13	1	1	1	0	4.20	25	1.06
R4	0	6	15	1	1	2	0	3.88	25	1.07
R5	2	7	8	5	2	1	0	3.96	25	1.22
R6	1	6	13	3	1	1	0	4.00	25	1.02
Total	10	32	75	16	10	7	0	3.97	150	1.13
Coupled w/ Data Block Option Ratings										
R7	8	10	6	1	0	0	0	5.00	25	0.85
R8	7	11	6	1	0	0	0	4.96	25	0.82
Total	15	21	12	2	0	0	0	4.98	50	0.84

Table 10-13: Spacing Deviation: NASA 893

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	0	3	14	4	3	1	0	3.60	25	0.98
R2	1	3	11	3	6	1	0	3.48	25	1.20
R3	1	5	10	5	2	2	0	3.68	25	1.22
R4	0	5	14	3	3	0	0	3.84	25	0.88
R5	3	7	11	1	3	0	0	4.24	25	1.11
R6	1	9	8	4	2	1	0	4.00	25	1.17
Total	6	32	68	20	19	5	0	3.81	150	1.13
Coupled w/ Data Block Option Ratings										
R7	11	9	4	1	0	0	0	5.20	25	0.85
R8	5	12	6	1	1	0	0	4.76	25	0.95
Total	16	21	10	2	1	0	0	4.98	50	0.93

Table 10-14: Spacing Deviation: NASA 859

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	0	3	14	4	3	1	0	3.60	25	0.98
R2	1	3	12	3	5	1	0	3.56	25	1.17
R3	1	5	10	5	2	2	0	3.68	25	1.22
R4	0	5	13	3	3	1	0	3.72	25	1.04
R5	3	6	10	2	3	1	0	4.04	25	1.28
R6	1	8	10	4	2	0	0	4.08	25	0.98
Total	6	30	69	21	18	6	0	3.78	150	1.14
Coupled w/ Data Block Option Ratings										
R7	9	9	5	1	1	0	0	4.96	25	1.04
R8	5	10	7	2	1	0	0	4.64	25	1.02
Total	14	19	12	3	2	0	0	4.80	50	1.04

Table 10-15: Assigned Runway: NASA 893

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	1	1	8	5	4	5	1	2.96	24	1.37
R2	1	4	3	8	3	5	1	3.04	24	1.46
R3	2	1	4	7	4	6	1	2.83	24	1.49
R4	1	1	8	5	3	6	1	2.92	24	1.41
R5	2	1	7	7	2	5	1	3.13	24	1.45
R6	1	5	2	8	3	4	2	3.17	23	1.46
Total	8	13	32	40	19	31	7	3.01	143	1.45
Coupled w/ Data Block Option Ratings										
R7	12	9	3	0	0	1	0	5.20	25	1.10
R8	12	8	2	3	0	0	0	5.16	25	1.01
Total	24	17	5	3	0	1	0	5.18	50	1.05

Table 10-16: Assigned Runway: NASA 859

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	0	1	6	5	5	7	1	2.54	24	1.26
R2	1	3	2	9	3	6	1	2.83	24	1.43
R3	1	1	4	7	4	7	1	2.63	24	1.38
R4	0	1	5	7	4	7	1	2.54	24	1.22
R5	0	1	4	10	2	7	1	2.58	24	1.19
R6	1	1	2	10	3	6	2	2.65	23	1.31
Total	3	8	23	48	21	40	7	2.63	143	1.30
Coupled w/ Data Block Option Ratings										
R7	10	10	1	3	0	1	0	4.96	25	1.25
R8	11	7	3	2	1	1	0	4.88	25	1.37
Total	21	17	4	5	1	2	0	4.92	50	1.31

Table 10-17: Aircraft Type (i.e., 757, hvy, etc.): NASA 893

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	0	1	2	7	1	10	4	2.19	21	1.26
R2	0	0	2	7	4	9	3	2.09	22	1.04
R3	0	0	2	6	0	14	3	1.82	22	1.11
R4	0	0	2	4	2	14	3	1.73	22	1.05
R5	0	1	2	7	1	11	3	2.14	22	1.25
R6	0	1	1	8	0	10	5	2.15	20	1.24
Total	0	3	11	39	8	68	21	2.02	129	1.17
Coupled w/ Data Block Option Ratings										
R7	13	8	2	1	0	1	0	5.20	25	1.17
R8	13	7	3	1	0	1	0	5.16	25	1.19
Total	26	15	5	2	0	2	0	5.18	50	1.18

Table 10-18 Aircraft Type (i.e., 757, hvy, etc.): NASA 859

Run	Very Easy	Easy	Identi-fiable	Not Easy	Difficult	Not Able	N/A	**Rating Avg.**	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)				
Coupled Only Option Ratings										
R1	0	0	2	6	3	10	4	2.00	21	1.07
R2	0	0	2	7	4	9	3	2.09	22	1.04
R3	0	0	2	6	0	14	3	1.82	22	1.11
R4	0	0	2	4	2	14	3	1.73	22	1.05
R5	0	1	1	8	1	11	3	2.09	22	1.20
R6	0	0	1	9	0	10	5	2.05	20	1.07
Total	0	1	10	40	10	68	21	1.96	129	1.10
Coupled w/ Data Block Option Ratings										
R7	11	8	2	3	0	1	0	4.96	25	1.28
R8	11	6	4	1	0	3	0	4.72	25	1.61
Total	22	14	6	4	0	4	0	4.84	50	1.46

10.1.1.4 Trend Indication

"Based on what you experienced during the scenario you just completed, please ***rate your ability to determine and understand the aircraft's progress*** toward achieving the assigned spacing goal."

Table 10-19: Trend Indication

Run	Very Easy to Under-stand	Easy To Under-stand	Under-stand-able	Not Easy to Under-stand	Difficult to Under-stand	Not Able to Under-stand	Rating Avg	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)			
No trend indicator ratings									
R1	1	5	14	5	0	0	4.08	25	0.74
R2	1	5	17	1	1	0	4.16	25	0.73
R3	1	7	14	2	1	0	4.20	25	0.80
R4	1	7	16	0	1	0	4.28	25	0.72
Total	4	24	61	8	3	0	4.18	100	0.75
Conformance Box option ratings									
R5	0	15	10	0	0	0	4.60	25	0.49
R7	6	15	4	0	0	0	5.08	25	0.63
Total	6	30	14	0	0	0	4.84	50	0.61
Deviation Scale option ratings									
R6	0	14	9	2	0	0	4.48	25	0.64
R8	9	12	4	0	0	0	5.20	25	0.69
Total	9	26	13	2	0	0	4.84	50	0.76

The following post-run questionnaire responses rated the subject's opinion on the helpfulness of the information being presented by the design element, which was considered a key component of usability. The runs are grouped by the design element option presented during the run. An overall rating for the design element option is shown in a summary line of the table. Note that a trend indicator was not displayed in runs R1, R2, R3, and R4, so the results are not shown. The results are discussed in more detail in 6.1.

"Using the rating scales, please ***rate the helpfulness of each element*** in understanding the spacing operation:"

Table 10-20: PDS Target Speed Indicator Helpfulness

Run	Very Helpful	Helpful	Mod. Helpful	Little Help	Not Helpful	Avg. Rating	N	SD
Wt.	(5)	(4)	(3)	(2)	(1)			
Text option ratings								
R1	9	12	4	0	0	4.20	25	0.69
R2	8	13	4	0	0	4.16	25	0.67
R5	6	18	1	0	0	4.20	25	0.49
R6	8	12	3	0	0	4.22	23	0.66
R7	8	15	1	0	0	4.29	24	0.54
R8	12	9	3	1	0	4.28	25	0.83
Total	51	79	16	1	0	4.22	147	0.66
Speed Bug Option Ratings								
R3	10	6	7	0	1	4.00	24	1.04
R4	11	9	3	2	0	4.16	25	0.92
Total	21	15	10	2	1	4.08	49	0.99

Table 10-21: PDS Mode Annunciation Helpfulness

Run	Very Helpful	Helpful	Mod. Helpful	Little Help	Not Helpful	Avg. Rating	N	SD
Wt.	(5)	(4)	(3)	(2)	(1)			
Text option ratings								
R1	5	13	7	0	0	3.92	25	0.69
R3	4	11	7	2	0	3.71	24	0.84
R5	7	14	4	0	0	4.12	25	0.65
R6	6	13	4	0	0	4.09	23	0.65
R7	5	16	2	1	0	4.04	24	0.68
R8	7	15	2	1	0	4.12	25	0.71
Total	34	82	26	4	0	4.00	146	0.72
FMA Option Ratings								
R2	8	10	5	2	0	3.96	25	0.92
R4	8	12	4	0	1	4.04	25	0.92
Total	16	22	9	2	1	4.00	50	0.92

Table 10-22: Target Aircraft Indicator Helpfulness

Run	Very Helpful	Helpful	Mod. Helpful	Little Help	Not Helpful	Avg. Rating	N	SD
Wt.	(5)	(4)	(3)	(2)	(1)			
Coupled Only Option Ratings								
R1	5	15	2	3	0	3.88	25	0.86
R2	4	15	3	3	0	3.80	25	0.85
R3	2	15	4	3	0	3.67	24	0.80
R4	8	12	3	2	0	4.04	25	0.87
R5	4	18	3	0	0	4.04	25	0.53
R6	6	15	1	1	0	4.13	23	0.68
Total	29	90	16	12	0	3.93	147	0.79
Coupled w/Data Block Option Ratings								
R7	18	6	0	0	0	4.75	24	0.43
R8	23	1	1	0	0	4.88	25	0.43
Total	41	7	1	0	0	4.82	49	0.44

Table 10-23: Trend Indicator Helpfulness

Run	Very Helpful	Helpful	Mod. Helpful	Little Help	Not Helpful	Avg. Rating	N	SD
Wt.	(5)	(4)	(3)	(2)	(1)			
Conformance Box Option Ratings								
R5	9	7	5	1	3	3.72	25	1.31
R7	12	8	3	0	1	4.25	24	0.97
Total	21	15	8	1	4	3.98	49	1.19
Deviation Scale Option Ratings								
R6	4	8	5	3	3	3.30	23	1.27
R8	7	8	5	4	1	3.64	25	1.16
Total	11	16	10	7	4	3.48	48	1.22

10.1.2 Preference for Combinations of Display Elements

The following post-run questionnaire responses rate the subject's preferences for combinations of the design elements presented in the categories of overall understanding, confidence and intuitiveness. The tabulated results, shown in rank order of rating average each run, illustrate which combinations of elements the subjects preferred in each category. The significance of the shaded areas pertains to significant differentiations in the elements enabled during the run (see Table 10-1). The gray shaded runs significant differentiation from the other runs is that they displayed both the "Coupled w/ Data Block" target aircraft depiction and one of the trend indicators (conformance box or deviation scale). The tan shaded runs significant differentiation from the other runs is that they displayed both the "Coupled Only" target aircraft depiction and one of the trend indicators (conformance box or deviation scale).The unshaded runs significant differentiation is that they displayed no trend indicator. This differentiation is also illustrated in Table 6-1, and preferred combinations of results are also discussed in 6.4 (Subject Pilot Preferences for Combinations of Interfaces).

"Please ***rate your overall understanding*** of what was happening during the APS-DPA operation."

Table 10-24: Overall Understanding

Run	Very Easy to Under-stand	Easy to Under-stand	Able to Under-stand	Not Easy to Under-stand	Difficult to Under-stand	Not Able to Under-stand	Rating Avg.	N	SD
Wt.	(6)	(5)	(4)	(3)	(2)	(1)			
Coupled w/ Data Block & Trend Indicator									
R8	10	12	3	0	0	0	5.28	25	0.66
R7	7	15	3	0	0	0	5.16	25	0.61
Coupled Only & Trend Indicator									
R5	0	20	5	0	0	0	4.80	25	0.40
R6	1	16	6	2	0	0	4.64	25	0.69
No trend indicator									
R4	2	11	11	0	1	0	4.52	25	0.81
R3	2	10	11	2	0	0	4.48	25	0.75
R1	1	11	8	5	0	0	4.32	25	0.84
R2	1	10	11	2	1	0	4.32	25	0.84

"Please ***rate your level of confidence in the elements presented*** in the scenario if this were an actual APS-DPA operation."

Table 10-25: Overall Confidence Level

Run	Very Confi-dent	Confi-dent	Somewhat Confi-dent	Not Very Confi-dent	Not Confi-dent at All	Rating Avg.	N	SD
Wt.	(5)	(4)	(3)	(2)	(1)			
Coupled w/ Data Block & Trend Indicator								
R7	9	14	2	0	0	4.28	25	0.60
R8	9	12	4	0	0	4.20	25	0.69
Coupled Only & Trend Indicator								
R5	0	20	5	0	0	3.80	25	0.40
R6	0	19	6	0	0	3.76	25	0.43
No trend indicator								
R4	2	14	7	2	0	3.64	25	0.74
R2	1	15	7	2	0	3.60	25	0.69
R3	2	13	8	2	0	3.60	25	0.75
R1	0	12	11	2	0	3.40	25	0.63

"Please give an overall ***rating of the intuitiveness and user-friendliness*** of the combination of the display elements presented during the scenario you just completed:"

Table 10-26: Overall Intuitiveness

Run	Very Intui-tive	Intui-tive	Moder-ately Intui-tive	Not Very Intui-tive	Not at All Intui-tive	Rating Avg.	N	SD
Wt.	(5)	(4)	(3)	(2)	(1)			
Coupled w/ Data Block & Trend Indicator								
R7	10	13	1	0	0	4.38	24	0.56
R8	9	12	4	0	0	4.20	25	0.69
Coupled Only & Trend Indicator								
R5	2	19	4	0	0	3.92	25	0.48
R6	0	16	5	2	0	3.61	23	0.64
No trend indicator								
R4	2	12	10	1	0	3.60	25	0.69
R3	2	12	7	3	0	3.54	24	0.82
R2	1	11	10	3	0	3.40	25	0.75
R1	0	13	8	4	0	3.36	25	0.74

10.1.3 Comments and Suggestions for Improvement

The written responses made by subject pilots in the post-run questionnaires are discussed in Section 6.5.

10.2 Results of Final Questionnaire

This is the response data from the final questionnaires completed by each of the subjects at the completion of the eight (8) experimental runs R1-R8. The final questionnaire differed from the post-run in its focus, with questions designed to solicit overall impressions of design element importance, individual element preferences, and suggestions for improvement of the elements. A variety of responses types were collected using Likert-type scales, multiple choice responses and written comments.

10.2.1 Importance of Display Elements

The following final questionnaire responses explored the subject's impressions of the importance of each category of design element (i.e., PDS target speed, PDS mode annunciation, etc.). The tabulated results, shown in rank order by rating average for each category or characteristic, illustrate the relative importance of the information which was intended to be provided by the design elements during the spacing simulations. The results of the importance of display elements responses are discussed in 6.2.

"Using the rating scales, please ***indicate which of the following should be required*** in performing the spacing operation:"

Table 10-27: Required Elements for Spacing Operation

Element	Very Imp.	Imp.	Mod. Imp.	Little Imp.	Not Imp.	Rating Avg.	N	SD
Weight	(5)	(4)	(3)	(2)	(1)			
PDS target speed indicator	23	2	0	0	0	4.92	25	0.27
Target aircraft depiction	20	3	2	0	0	4.72	25	0.60
PDS mode annunciation	15	5	4	1	0	4.36	25	0.89
Trend indicator	13	6	4	0	2	4.12	25	1.18

"Using the rating scales, please ***rate how important*** it is to be able to determine the following during a spacing operation."

Table 10-28: PDS Target Speed Characteristic Importance

Element Characteristic	Very Impor-tant	Impor-tant	Mod. Impor-tant	Little Impor-tance	Not Impor-tant	Rating Avg.	N	SD
Weight	(5)	(4)	(3)	(2)	(1)			
Current target speed	23	2	0	0	0	4.92	25	0.27
Changes to target speed	21	3	1	0	0	4.80	25	0.49

Table 10-29: Target Aircraft Display Characteristics Importance

Element Characteristic	Very Impor-tant	Impor-tant	Mod. Impor-tant	Little Impor-tance	Not Impor-tant	Rating Avg.	N	SD
Weight	(5)	(4)	(3)	(2)	(1)			
Ownship position relative to spacing aircraft	22	3	0	0	0	4.88	25	0.32
Active spacing aircraft	21	4	0	0	0	4.84	25	0.37
How many (one or two)	18	5	2	0	0	4.64	25	0.62
Spacing deviation(s)	10	10	3	2	0	4.12	25	0.91
Aircraft ID(s)	7	10	7	1	0	3.92	25	0.84
Assigned runway(s)	5	11	7	1	1	3.72	25	0.96
Aircraft type (i.e., 757, hvy, etc.)	5	10	7	3	0	3.68	25	0.93
Spacing Interval type	4	11	6	4	0	3.60	25	0.94

Table 10-30: PDS Mode Characteristic Importance

Element Characteristic	Very Impor-tant	Impor-tant	Mod. Impor-tant	Little Impor-tance	Not Impor-tant	Rating Avg.	N	SD
Weight	(5)	(4)	(3)	(2)	(1)			
Current mode	13	6	5	1	0	4.24	25	0.91
Changes to mode	11	10	2	2	0	4.20	25	0.89
Next Mode in Sequence	6	7	5	6	1	3.44	25	1.20

10.2.2 Display Element Individual Preferences

In the following final questionnaire responses, the subjects were asked to express a preference for design element options in each of the four categories listed (PDS target speed, PDS mode annunciation, target aircraft depiction and trend indication.) If subjects preferred not to see the design element at all, they could answer "none". Supporting comments about these preferences were captured later in the final questionnaire. The results are tabulated in preference order shown below. At the end of this question, subjects were asked if their answer would change if considering the design element options in combination, rather than individually.

"Please ***indicate if you have a preference*** in each of the four categories of display elements listed below:"

Table 10-31: PDS Target Speed Preference

Element Option	Response Percentage	Response Count
Speed bug	52.0%	13
Text	48.0%	12
None	0.0%	0
Total	100.0%	25

Table 10-32: PDS Mode Annunciation Preference

Element Option	Response Percentage	Response Count
FMA	60.0%	15
Text	40.0%	10
None	0.0%	0
Total	100.0%	25

Table 10-33: Target Aircraft Display Preference

Element Option	Response Percentage	Response Count
Coupled w/data block	96.0%	24
Coupled only	4.0%	1
None	0.0%	0
Total	100.0%	25

Table 10-34: Trend Indicator Preference

Element Option	Response Percentage	Response Count
Conformance box	68.0%	17
Deviation scale	20.0%	5
None	12.0%	3
Total	100.0%	25

10.2.3 Combined Display Element Preferences

"Do your preferred display elements differ when considered in ***combination than individually***?"

Eight (8) of the twenty-five subjects responded "yes" to this question. However, only one of the eight actually changed any of the preferred element selections. These responses indicate that the question may have been confusing and misinterpreted by at least seven of the subjects. The one subject who changed the response for the combined elements did so as follows:

Table 10-35 Individual Subject Combined vs. Individual Preferences

Display Element	Individual Option Pref.	Combined Element Pref.
PDS Target Speed	Text	Text
PDS Mode Annunciation	FMA	Text
Target Aircraft Depiction	Coupled w/Data	Coupled w/Data
Trend Indicator	Deviation Scale	Deviation Scale

10.2.4 Comments and Suggestions for Improvement

The written responses made by subject pilots in the final questionnaire are discussed in Section 6.5.

11 Appendix B: Supplemental Design Concepts for Fully Integrated Implementation

11.1 Engine Instrument & Crew Alerting System/Multifunction Display

The Engine Instrument & Crew Alerting System (EICAS/MFD) implements several functions that can be adapted to manage a datalinked APS-DPA clearance in the fully integrated concept. The interface displays datalinked messages from an Air Traffic Service Provider (ATSP). If the message is a clearance, an interface is provided to transfer datalinked clearance parameters to an on-board application in the Flight Management Computer (FMC), such as ASTAR. A facility is provided for the crew to accept or reject the clearance via datalink. The EICAS/MFD is also generally used to display information from on-board applications, especially off-nominal conditions. These annunciations are in the form of alphanumeric message(s) which contains specific information about the condition and its associated priority, often associated with an aural indication.

The ASTOR used for the previous HITL experiment [5] was modified to support the fully integrated APS-DPA spacing scenarios used for this study. Simulations were created to generate the datalinked clearances for the spacing scenario (see Table 5-1: Spacing Scenario Clearance Parameters). The ASTOR was modified to parse the uplinked clearance and provide the spacing parameters to ASTAR. The spacing parameters could then be viewed and verified via the PDS main menu page in the MCDU (see Section 11.3). Due to time constraints, the off-nominal condition outputs from ASTAR were not implemented, and no off-nominal scenarios were generated for the usability study.

Examples of the ASTOR implementation of the EICAS/MFD for APS-DPA clearance management are shown in the following illustrations. Figure 11-1 shows a spacing clearance received via CPDLC (Controller Pilot Data Link Clearance) displayed on the EICAS/MFD. Note that the length of the clearance (greater than 128 characters) necessitated that it be viewed on the MFD, also indicated by the “LARGE ATC UPLINK” message on the EICAS.

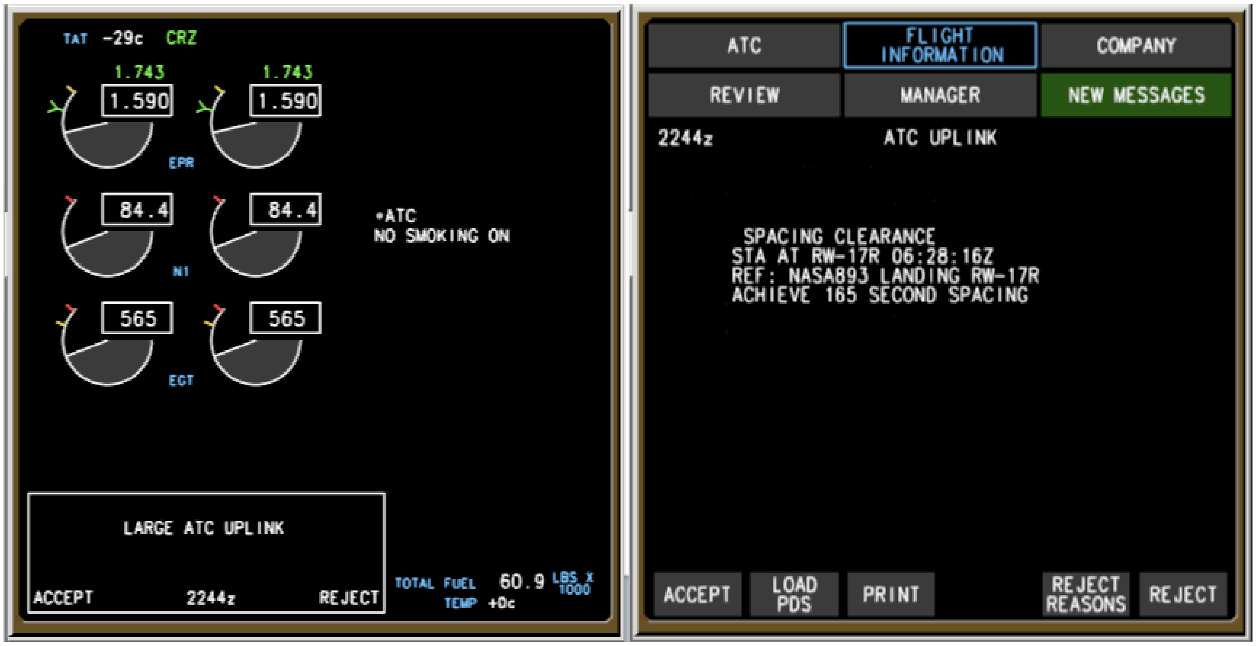

Figure 11-1: Example of Spacing Clearance Displays on EICAS/MFD

11.2 Mode Control Panel

In the proposed concept, the Mode Control Panel (MCP) allowed the crew to control the engagement and disengagement of PDS speed guidance to the autopilot. The MCP provides control of the autopilot, flight director, altitude alert, and auto-throttle systems, and is used to select and activate Autopilot Flight Director System (AFDS) modes, establish altitudes, speeds and climb/descent profiles. There were two concepts considered for the MCP and its associated control logic: 1) addition of new "PDS" mode control select to the MCP, and; 2) modification of MCP control logic to make PDS mode a sub-mode of the existing VNAV mode.

In considering the limited time for training subject pilots prior to the experimental session, it was decided that the first concept would be potentially less confusing to subject pilots who were already familiar with the operation of the existing VNAV mode of the AFDS. As the focus of the experiment was primarily on design elements for the Primary Flight and Navigation displays, only the first concept was implemented in the modified ASTOR.

The implementation of the first concept required the straightforward addition of a new "PDS" mode to the MCP to implement the engagement of PDS speed guidance for spacing operations. Its implementational advantage was that the logic that controls its operation was constructed to include little or no interaction with existing AFDS modes. The diagram in Figure 11-2 shows the proposed logic to control the engagement of PDS guidance via the MCP, and describes the progression of nominal PDS modes for a typical spacing operation. The diagram does not include the logic for degraded mode annunciations due to PDS off-nominal conditions.

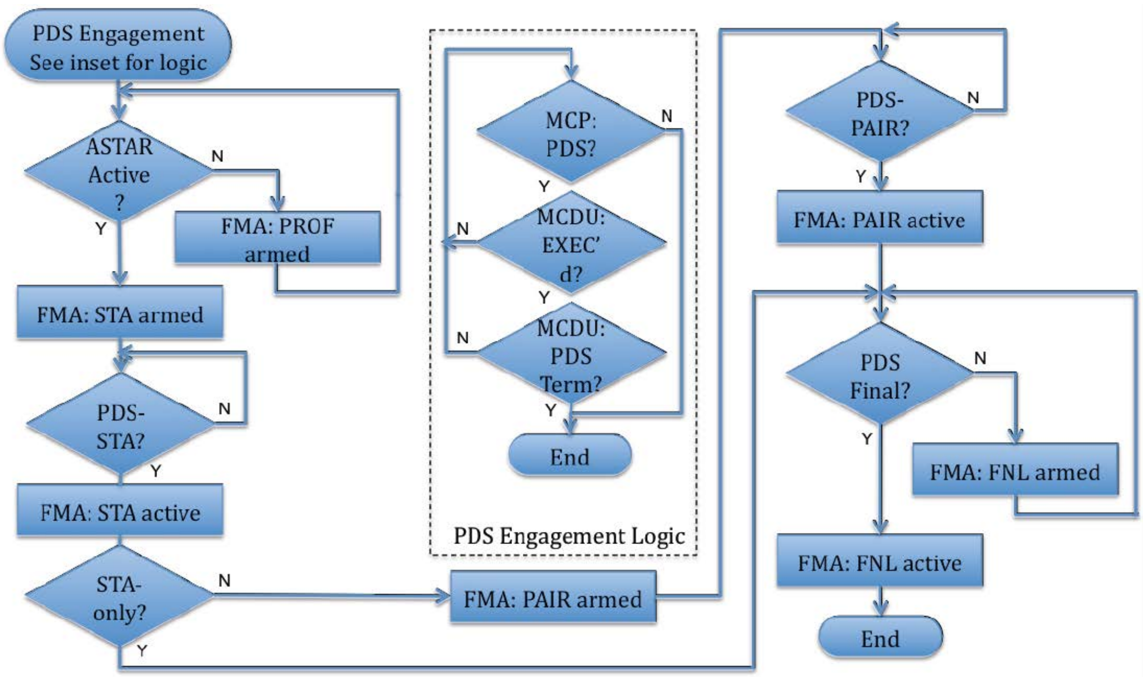

Figure 11-2: PDS MCP FMA Logic Diagram

Figure 11-3 shows an example of how the modified MCP appeared with the new PDS mode select (highlighted by arrow) when PDS guidance was engaged (indicated by the green light.)

Figure 11-3: MCP with PDS Mode Select Added

The implementation of PDS mode as a sub-mode of the VNAV mode is conceptually consistent with the operation of APS-DPA, which provides profile-driven speed corrections to a CDA. It is also consistent with the paradigm of dividing VNAV operation into other sub-modes (i.e., VNAV SPD, VNAV PTH, VNAV ALT). This concept would require the modification of the logic that controls the VNAV mode and (possibly) its interaction with other existing AFDS modes. In any practical implementation of APS-DPA in the cockpit, some modifications to the AFDS are bound to occur anyway, and it is believed that this type of software-only modification may have an economic advantage over the implemented concept described above.

11.3 Multifunction Control and Display Unit

In the fully integrated concept, the Multifunction Control and Display Unit (MCDU) provided an interface to the on-board ASTAR application for selecting modes of operation, entering spacing parameters, validating spacing clearances, monitoring the status of an in-progress APS-DPA operation, and terminating ASTAR if necessary. The ASTOR implementation for this study developed several new MCDU menu pages to facilitate the required additional functions.

The ASTOR implementation added three (3) new PDS-specific pages to the MCDU. A calling page was modified to allow the main PDS menu to be invoked (see Figure 11-4). From the main PDS menu, two sub-menu pages for display and control of approach parameters ("PDS APPR DATA") and PDS profile mode ("PDS Profile") were defined. PDS profile mode is discussed in the APS ConOps, but was not implemented or evaluated in this study.

Figure 11-4: MCDU Main Calling Menu

Within the new pages, PDS-specific status and control functions were assigned to the twelve (12) "soft" keys aligned vertically on either side of the display bezel. The soft keys are arranged in two vertical rows of six (6) each on the left and right, referred to as 1L through 6L for the left side, and 1R through 6R on the right side. Per MCDU convention, a left or right pointer to any of the twelve bezel keys indicated that a programmable action was performed by pressing that key. The action was either indicated by the associated label (i.e., “TERMINATE”) or was implied as an editing action in the case of an alphanumeric parameter. The absence of the pointer indicated the parameter was non-editable. Refer to Table 11-1 and Table 11-2 for a description of the soft key functions defined for the PDS main menu menu and approach data pages.

The main PDS menu page provided most of the necessary control and monitoring functions for the APS-DPA operation; the “PDS APPR DATA” page provided supplemental information and a means for the crew to enter, modify or monitor ASTAR parameters including landing runway assignment(s) for target aircraft, target aircraft approach speed(s), minimum in-trail distance behind target aircraft, and ownship approach speed.

Table 11-1: PDS Main Menu Page

MCDU Soft Key	Label	Functional Description
1L	< PRECISION REFAC	Precision REFerence AirCraft (target aircraft); auto-loaded or pilot-entered ID; when magenta, indicates active spacing aircraft.
2L	< SPACING INTERVAL	Auto-loaded or pilot-entered interval in seconds or nm; when magenta, indicates PDS speed guidance engaged using this parameter.
3L	SPACING DEV	ASTAR-provided deviation in seconds.
4L	< STA	Auto-loaded or pilot-entered STA in Zulu format; when magenta, indicates PDS speed guidance engaged using this parameter; when REFAC ADS-B data is acquired, STA will no longer be displayed.
5L	< PROFILE*	In some implementations, invokes PDS Profile menu page.
6L	< APPR DATA	Invoke PDS Approach Data menu page.
1R	NCT REFAC >	No Closer Than target aircraft; auto-loaded or pilot-entered ID; when magenta, indicates active spacing aircraft.
2R	SPACING INTERVAL >	Auto-loaded or pilot-entered interval in seconds or nm; when magenta, indicates PDS speed guidance engaged using this parameter.
3R	SPACING DEV	ASTAR-provided deviation in seconds or nm.
4R	STA DEV	ASTAR-provided deviation in seconds; when target aircraft ADS-B data is acquired, STA DEV will no longer be displayed.
5R	ERASE >	Only appears if parameters have been changed; erase all page modifications (revert to previous unmodified parameters).
6R	TERMINATE >	Only appears if ASTAR is active; terminate ASTAR until new parameters entered; disengage PDS from AFDS (see MCP description in 11.2).

*PDS Profile mode was not implemented for this study, but is discussed in Appendix D: Additional Interface Concepts for APS-DPA

Table 11-2: PDS Approach Data Menu

MCDU Soft Key	Label	Function
1L	PRECISION REFAC	Precision REFerence AirCraft (target aircraft); AC ID from PDS main page.
2L	< APPROACH SPEED	Auto-loaded from ASTAR from ADS-B on-condition report or pilot-entered.
3L	< MIN DISTANCE	*Auto-loaded from ASTAR or pilot-entered
4L	< LANDING RWY	Landing runway for precision REFAC from one of following: auto-loaded from clearance; pilot-entered, or; auto-loaded from ABS-B on-condition report.
5L	Unused	
6L	< PDS	Invoke PDS main menu page.
1R	NCT REFAC	No Closer Than target aircraft; AC ID from PDS main page.
2R	APPROACH SPEED >	Auto-loaded from ASTAR from ADS-B on-condition report or pilot-entered.
3R	MIN DISTANCE >	*Auto-loaded from ASTAR or pilot-entered.
4R	LANDING RWY >	Landing runway for precision target aircraft from one of following: auto-loaded from clearance; pilot-entered, or; auto-loaded from ABS-B on-condition report.
5R	OWNSHIP APPR SPEED >	Auto-loaded from profile or pilot-entered.
6R	ERASE >	Only appears if parameters have been changed; erase all page modifications (revert to previous unmodified parameters).

*Minimum Distance represents the minimum wake turbulence avoidance in-trail distance for the category of aircraft involved. In an ADS-B environment, this parameter could be automatically entered via an on-board “look-up” table.

The following are pictorial examples of MCDU PDS menu pages that were implemented for the study, shown in chronological order as a typical spacing scenario progressed.

Figure 11-5 shows the PDS Main menu as it appeared after loading the received CPDLC spacing clearance to the FMC via the EICAS/MFD interface. Unpopulated fields for Spacing Deviation and STA Deviation indicate that ASTAR had not yet provided spacing guidance from the input spacing parameters, but was in the process of computing them. The “PDS-MOD” heading indicate parameters were changed but not executed, also indicated by the lit “EXECute” button on the MCDU.

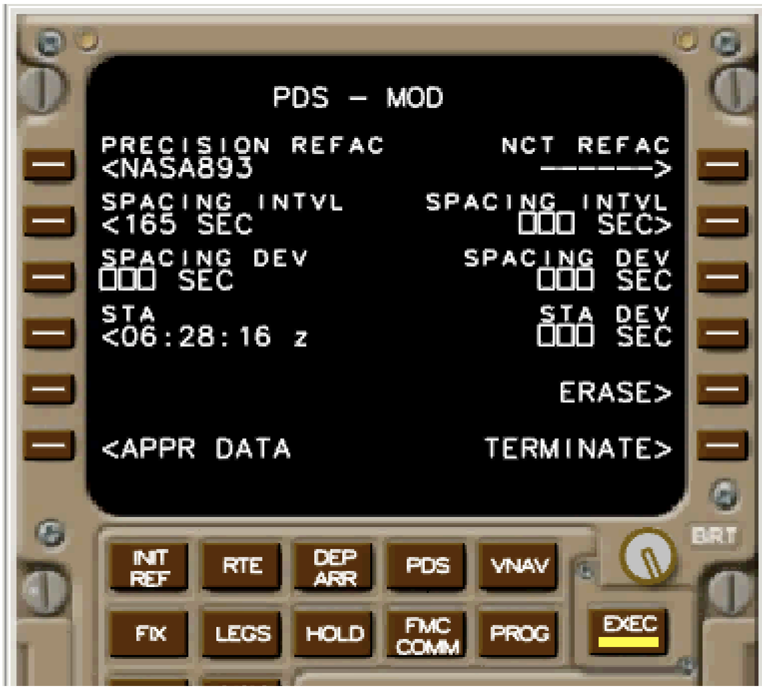

Figure 11-5: PDS Main Menu Page; Clearance Loaded

Figure 11-6 shows the PDS Approach Data page as it appeared after loading the received CPDLC spacing clearance to the FMC. The approach speed, minimum distance and landing runway for the precision target (NASA 893) have been provided by ASTAR, indicating ADS-B on-condition reports have been received from NASA 893. The same parameters for the no closer than (NCT) target (NASA 859) are not populated, but would be automatically filled by ASTAR when ADS-B on-condition reports from the target aircraft were received. The ownship approach speed has been loaded from the current profile being flown by the FMC.

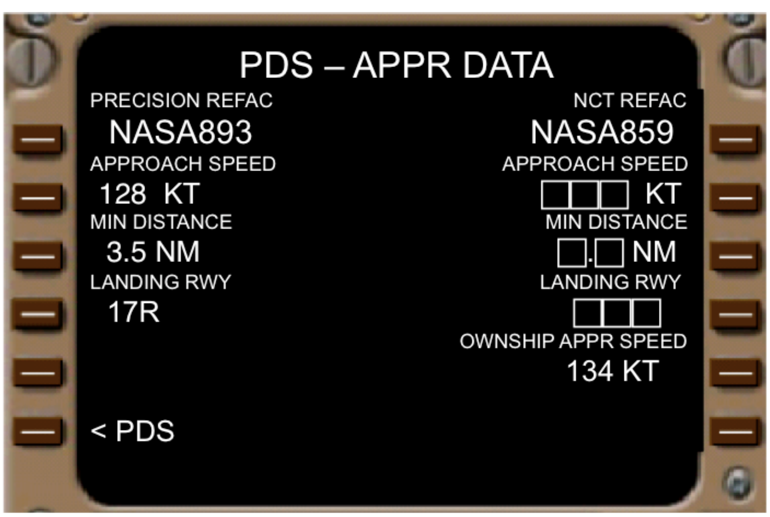

Figure 11-6: PDS Approach Data Page

Figure 11-7 shows the PDS main menu page after ASTAR has determined that the precision target (NASA 893) is the active spacing aircraft (responsible for the current PDS target speed), indicated by the "PRECISION REFAC" and "SPACING INTVL" in magenta. ASTAR also maintained the STA Deviation parameter throughout the operation, though it did not provide spacing guidance after ADS-B reports were received for the target aircraft.

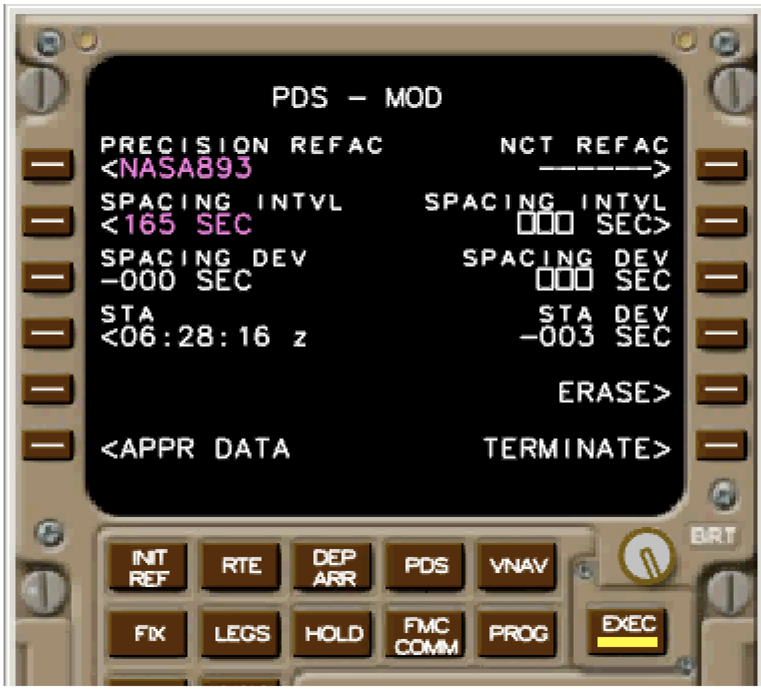

Figure 11-7: PDS Main Menu; ASTAR Guidance Active

Figure 11-8 is similar to Figure 11-7, except that the test operator had entered the spacing parameters for the NCT target aircraft in the spacing scenario (NASA 859, NCT 90 sec), and had executed the entire combined spacing clearance. Note that the "EXECute" button light is extinguished, and the "PDS-MOD" heading has reverted to "PDS". Spacing deviations from ASTAR now appear for the precision and NCT target aircraft and the STA, and the precision target is still the active target, indicated in magenta.

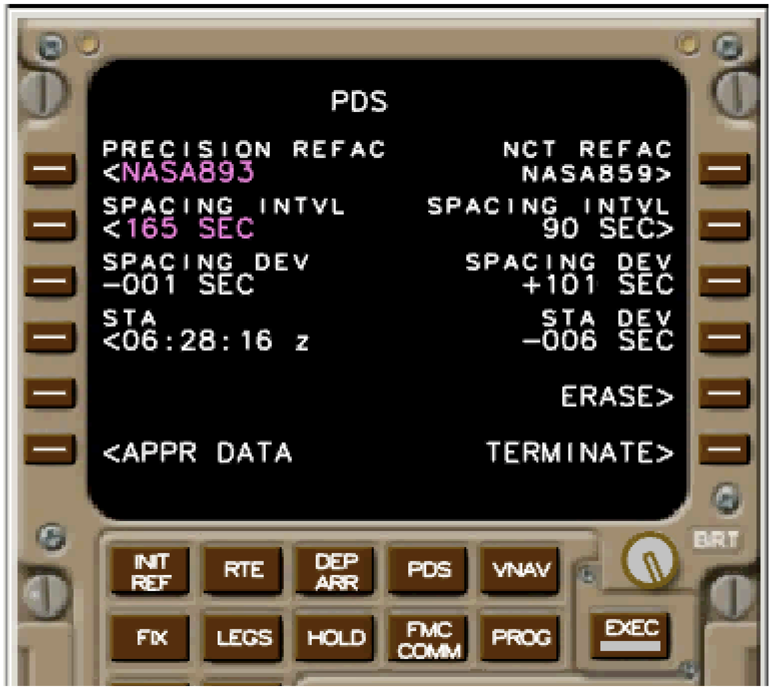

Figure 11-8: PDS Main Menu; NCT Interval Added

Figure 11-9 is similar to Figure 11-8 except that ASTAR determined that the NCT target (NASA 859) was the active spacing aircraft, indicated in magenta.

Figure 11-9: PDS Main Menu; NCT REFAC Active

12 Appendix C: Electronic Flight Bag Interface Concepts for APS-DPA

12.1 Description of Design Concept

The goal for the EFB version of the APS-DPA interface was to propose concepts allowing pilots to perform the following required functions:

1. initialize ASTAR with spacing clearance parameters;
2. verify validity of spacing clearance parameters before accepting;
3. display PDS target speed necessary to achieve spacing interval(s); and
4. monitor progress of APS-DPA, including;
   a. PDS operation mode;
   b. target aircraft position and information;
   c. spacing deviation and trend information; and
   d. off-nominal indications.

It was proposed to develop an EFB-based application to provide the required functions (the application is referred to as Pair Dependent Speed or "PDS" for this discussion.) Pilots would initialize PDS with spacing parameters received via voice clearance. Once verified and executed, PDS would provide the target speed necessary to achieve the spacing interval, which the pilot would use to manually set the speed of the aircraft. PDS would provide strategic information about APS-DPA by implementing displays similar to those developed for those on the ND in the fully integrated concept.

In order to function, the embedded ASTAR algorithm in PDS would require access to data available from the aircraft (ARINC429) data bus, such as the profile being flown by the aircraft and the ADS-B on-condition reports from the target aircraft. This would necessitate a minimum class 2 EFB for read-only access to this data; it was not envisioned that PDS would require write access to ARINC429 for the implementation of this concept.

Since EFBs differ in user control interfaces, a representative implementation is used for illustration purposes that employs a combination of soft keys along the bezels, pre-defined keys above and below the screen and a touch screen interface. It is assumed that the concepts shown here could be easily transferred to other EFB implementations

12.1.1 PDS Home Page

Figure 12-1 shows a concept of the PDS application home page on the EFB. This page would be accessible by navigating through the EFB main menu to the PDS application. In this concept, the PDS home page is used to monitor the APS-DPA operation.

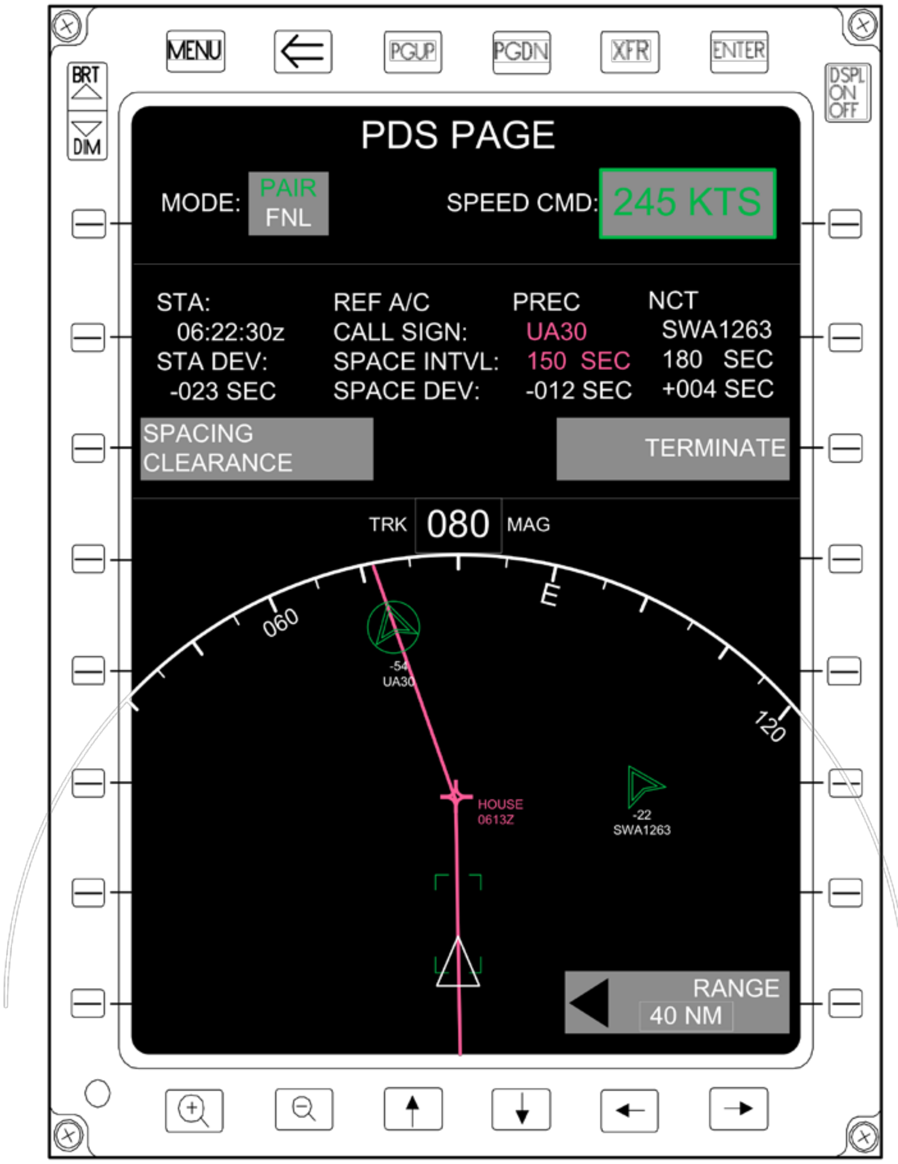

Figure 12-1: EFB PDS Home Page Concept

The top of the PDS home page displays PDS mode and target speed. The crew would be alerted to target speed changes by highlighting the “Speed Cmd” area (with a box or shading) for ten seconds. Similarly, changes to “Mode” would be highlighted for ten seconds.

Below this, an area of the EFB screen is dedicated to displaying clearance parameters and ASTAR-supplied information such as active target aircraft (shown in magenta), spacing deviation (in seconds) from the assigned interval for each target aircraft, and spacing deviation from the original STA. Also, a soft key is implemented to access a sub-menu to enter the spacing clearance parameters. Another soft key is implemented to terminate PDS speed guidance and clear the current spacing parameters.

The area below the clearance spacing data values implements a moving map. The concept for this map draws directly from the concepts for the Navigation display (ND) in the fully integrated implementation. The ownship aircraft symbol is a white triangle at the bottom center. The current magnetic heading is displayed at the top of the map for reference. A soft key is implemented to control the range of the map (set to 40 NM in the illustration). The target aircraft are shown as green double chevrons. An example of the trend indicator is also shown. If the stagger interval display concept were implemented, it would also be shown here.

12.1.2 Spacing Clearance Sub-Page

Figure 12-2 is a concept drawing of the PDS Spacing Clearance sub-menu. This menu facilitates entry or amendment of the spacing clearance parameters. A touch screen keyboard interface is shown which would simplify entry of alphanumeric clearance parameters.

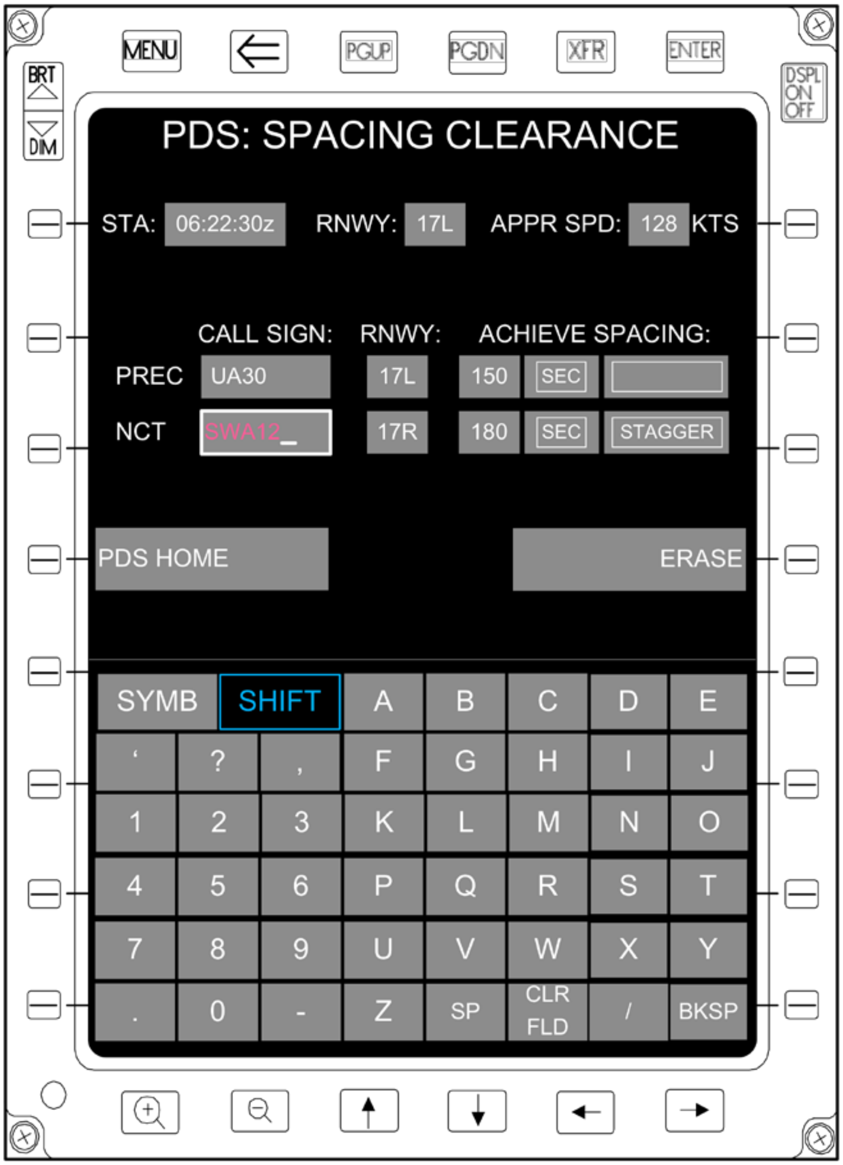

Figure 12-2: EFB Spacing Sub-Page Concept

13 Appendix D: Additional Interface Concepts for APS-DPA

Additional interface concepts were considered for the situations which might occur during APS-DPA operations. These concepts were not evaluated in this study, because schedule and resource limitations did not permit the development of alternative concepts and/or implementation in the ASTOR. The concepts are captured in this appendix to be considered in the future.

13.1 Stagger Interval Depiction

It was considered possible for a step change in the PDS target speed to occur if ASTAR transitioned from using the assigned spacing interval to using the stagger interval for a target aircraft on approach to a parallel runway. The APS ConOps [7] describes this situation in more detail. While not an abnormal situation, abrupt changes in PDS target speed might cause the crew to question the new speed unless the context for the change was also displayed. For this reason, a concept was developed to inform the crew that the stagger interval either was or would soon be the governing spacing interval for ASTAR.

ASTAR's transition to stagger interval was considered strategic information, and a concept was developed to display this situation on the Navigation display (ND). The concept consists of a white dashed line, which pictorially represents the stagger geometry relative to the target aircraft on the parallel runway approach. This depiction is shown in Figure 13-1. The concept was intended to show the crew where the intercept of the stagger interval would occur, and in doing so, provide the necessary context for the PDS target speed change.

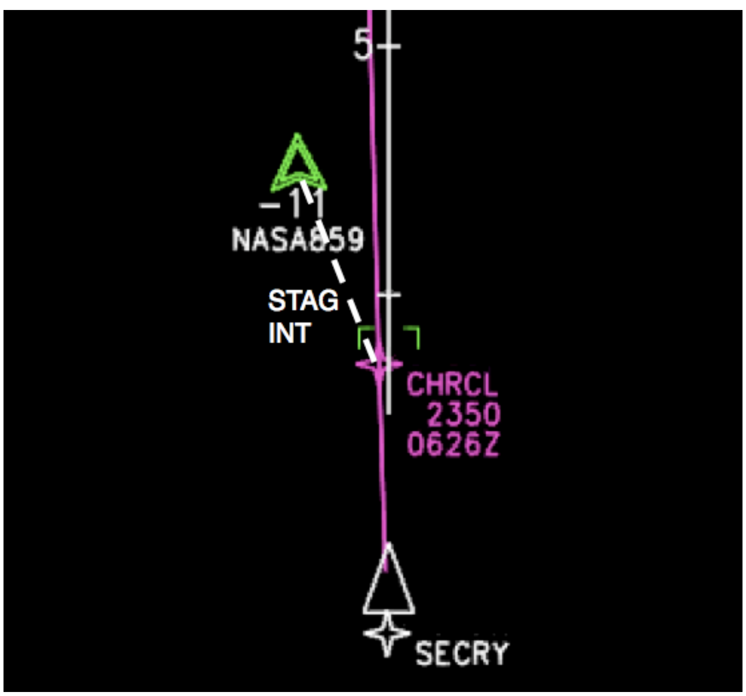

Figure 13-1: Stagger Interval Depiction

Figure 13-2 shows the main PDS menu page as would appear after ASTAR had transitioned to using the stagger interval. In this depiction, the precision target is the active spacing aircraft, and ASTAR has changed the spacing interval from the assigned interval (in seconds) to the stagger interval. The stagger interval would have been pre-programmed for this particular dependent parallel approach.

Figure 13-2: ASTAR Transition to Stagger Interval

13.2 PDS Speed Reversion Mode

PDS Speed Reversion mode is an off-nominal condition indicating PDS speed guidance is no longer valid due to invalid target aircraft data. This condition could occur because ADS-B on-condition reports from the target aircraft are no longer being received, and the condition could be temporary or permanent. The annunciation of PDS Speed Reversion mode would inform pilots that PDS's ability to provide target speed guidance was on hold. The APS ConOps describes this condition in more detail.

A concept was developed to display PDS Speed Reversion mode for the PDS mode annunciation option in which the FMA was used to display PDS modes. In this concept, a yellow line would be drawn through the PDS Paired mode annunciation in the FMA for as long as the condition persists, or until ASTAR was terminated by the crew. (PDS Paired mode is the only PDS mode that requires ADS-B reports from the target aircraft.) See Table 13-1 for an illustration of this concept.

Table 13-1: PDS Speed Reversion Mode Concept

PDS FMA Example	Description	FMA Depiction
PDS Mode Degraded	PDS off-nominal condition (i.e., Speed Reversion mode); EICAS message provides additional detail; pilot action may be required to disengage PDS	

13.3 PDS Profile Mode

PDS Profile mode provides a capability that leverages ASTAR's ability to provide target speeds while flying any programmed profile. While these target speeds would be identical to the speeds contained in the profile in most cases, ASTAR is programmed to use stabilized approach speeds on final approach as the target speed, and may therefore be a preferable type of speed guidance for this phase of flight. The APS ConOps describes Profile mode in more detail.

A concept was developed to allow the pilot to control the use of Profile mode via the MCDU. Figure 13-3 shows a typical PDS main menu page on the MCDU with the profile mode select implemented for soft key 5L. Figure 13-4 shows the The PDS-PROFILE sub-page that would be used by the crew to control, execute and monitor the PDS Profile mode of ASTAR operation. The only choices available are to "Enable" the PDS Profile mode, or to return to the main PDS menu. Figure 13-5 shows the PDS-PROFILE menu after PDS Profile mode has been enabled. In this example, the profile name appears in magenta, indicating Profile mode has been engaged by selecting PDS mode on the MCP. Refer to Table 13-2 for a description of this sub-page's status and control functions.

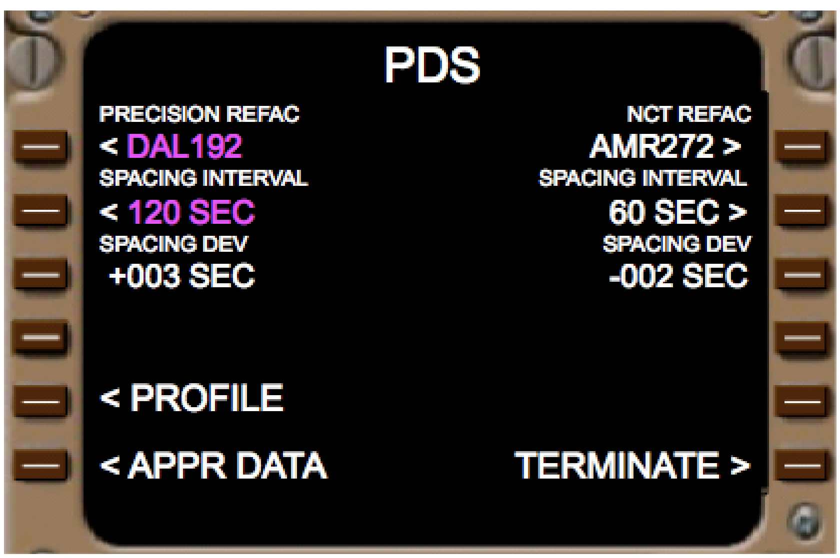

Figure 13-3: PDS Main Menu with Profile Mode Selection

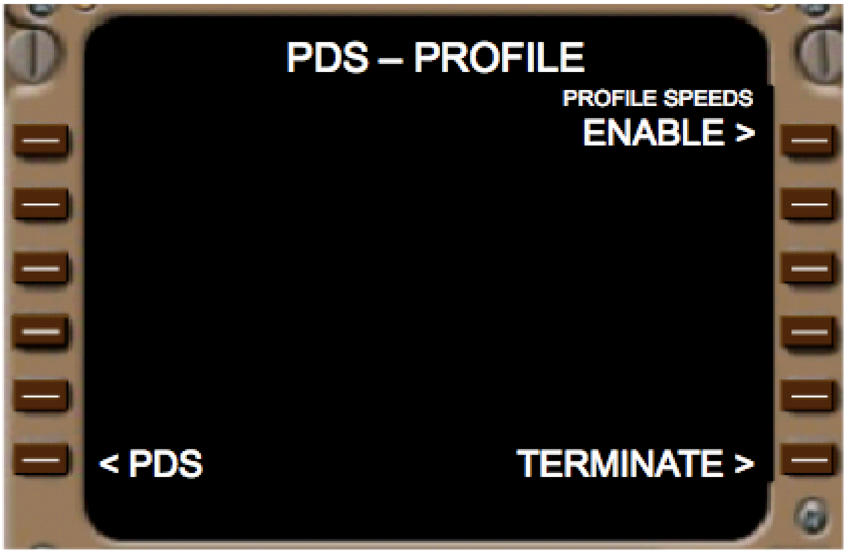

Figure 13-4: PDS Profile Menu Page

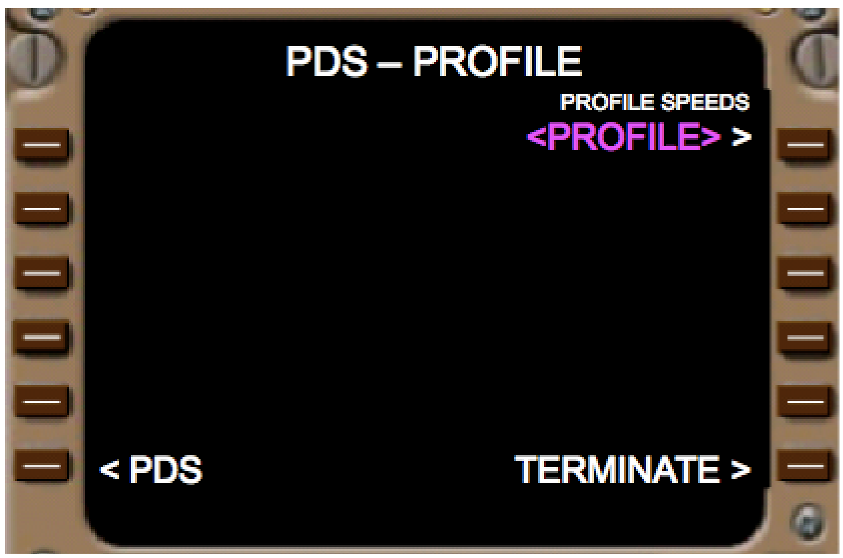

Figure 13-5: PDS Profile Menu: Profile Mode Engaged

Table 13-2: PDS Profile Menu Page

MCDU Soft Key	Label	Function
1L	Unused	
2L	Unused	
3L	Unused	
4L	Unused	
5L	Unused	
6L	< PDS	Invoke PDS main menu page.
1R	PROFILE SPEEDS: ENABLE >	Used to enable PDS Profile mode; when enabled and engaged, <Profile Name> of profile in use appears in magenta.
2R	Unused	
3R	Unused	
4R	Unused	
5R	Unused	
6R	TERMINATE >	Terminate ASTAR until new parameters entered; disengage PDS from AFDS (see MCP description in 11.2).

14 Appendix E: ASTOR Implementation Issues

This section documents ASTOR implementation issues or problems noted during the conduct of the experiment. These anomalies were not corrected in the interest of making identical presentions to the subject pilots. Any anomalies which may affected the outcome of the experiment have been noted in the main body of the report. The anomalies are documented here to be of use in any subsequent efforts to leverage the ASTOR implementation used for this experiment in future studies or simulations.

14.1 PDS Mode Annunciation

For the text mode option of this design element, it was noted by one subject pilot that when PDS mode appeared by itself in text (i.e., without PDS target speed text), that the display simply indicated the mode without also indicating "PDS". For instance, in PDS Paired mode, the text on the PFD indicated "PAIR" instead of "PDS PAIR". This is a result of the ASTOR implementation, which removed "PDS" from the text display when PDS target speed was configured to display the speed bug option.

For the FMA option of this design element, several subject pilots noted that the specific VNAV mode currently in use (i.e., VNAV PTH, VNAV SPD, VNAV ALT) was never shown. This is a result of the ASTOR implementation ignoring the VNAV mode, and simply displaying 'VNAV' in the pitch mode segment. This VNAV mode is obviously important information and should also be shown in the pitch segmant.

For the FMA mode of this design element, one subject pilot noted that in the FMA segment shared by VNAV and PDS modes, a change to VNAV or PDS mode would cause a box to be drawn around the entire segment. This obscured the meaning about whether the VNAV or PDS mode had caused the change. This is a result of the ASTOR implementation not creating a separate box for each portion of the shared pitch segment.

14.2 Target Aircraft Depiction

For the "coupled with data block" option of this design element, several subject pilots noted that the active target aircraft data block location was in conflict with the existing implementation in the Boeing glass cockpit for the display of NAVAID data, normally selected using the EFIS control panel. This is a result of the ASTOR implementation ignoring this potential conflict.

Also, the data block implementation always contained the text "PRI", which was meant to indicate that the the associated information in the data block was for the active spacing aircraft. This information was unnecessary, since the data block only appeared in association with the active spacing aircraft. This is a result of the ASTOR implementation using an older concept which would have been able to show a data block for either target aircraft. (The "PRI" indicated "Primary", which was a term formerly used for the active spacing aircraft).

14.3 Trend Indicators

For the conformance box option of this design element, it was noted that the range-sensitive braces used to depict the box could potentially be driven off-scale by the ND range select. The convention for depicting off-scale CDTI symbols is to depict a half-symbol at the edge of the range arc at the appropriate bearing. Adapting this convention to the conformance box braces would have prevented the depiction from disappearing at lower ND range settings.

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14. ABSTRACT
This paper describes a usability study of proposed cockpit interfaces to support Airborne Precision Spacing (APS) operations for aircraft performing dependent parallel approaches (DPA). NASA has proposed an airborne system called Pair Dependent Speed (PDS) which uses their Airborne Spacing for Terminal Arrival Routes (ASTAR) algorithm to manage spacing intervals. Interface elements were designed to facilitate the input of APS-DPA spacing parameters to ASTAR, and to convey PDS system information to the crew deemed necessary and/or helpful to conduct the operation, including: target speed, guidance mode, target aircraft depiction, and spacing trend indication. In the study, subject pilots observed recorded simulations using the proposed interface elements in which the ownship managed assigned spacing intervals from two other arriving aircraft. Simulations were recorded using the Aircraft Simulation for Traffic Operations Research (ASTOR) platform, a medium-fidelity simulator based on a modern Boeing commercial glass cockpit. Various combinations of the interface elements were presented to subject pilots, and feedback was collected via structured questionnaires. The results of subject pilot evaluations show that the proposed design elements were acceptable, and that preferable combinations exist within this set of elements. The results also point to potential improvements to be considered for implementation in future experiments.

15. SUBJECT TERMS
Airborne precision Spacing; Dependent runway operations; Interval management

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