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# Enhanced Oceanic Operations Human-In-The-Loop In-Trail Procedure Validation Simulation Study

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## **Symbols & Abbreviations**

|         |  |
|---------|--|
| ADS:    | Automatic Dependent Surveillance                       |
| ADS-B:  | Automatic Dependent Surveillance-Broadcast             |
| ADS-C:  | Automatic Dependent Surveillance-Contract              |
| ASAS:   | Airborne Separation Assistance System                  |
| ASTOR:  | Aircraft Simulation for Traffic Operations Research    |
| ATC:    | Air Traffic Control                                    |
| ATM:    | Air Traffic Management                                 |
| ATOL:   | Airspace and Traffic Operations Laboratory             |
| ATOS:   | Airspace and Traffic Operations Simulation             |
| ATSP:   | Air Traffic Service Provider                           |
| BADA:   | Base of Aircraft Data                                  |
| CPDLC:  | Controller Pilot Data Link Communications              |
| DME:    | Distance Measuring Equipment                           |
| DSP:    | Display Select Panel                                   |
| EFB:    | Electronic Flight Bag                                  |
| EFISCP: | Electronic Flight Instrumentation System Control Panel |
| EICAS:  | Engine Indication and Crew Alerting System             |
| EOO:    | Enhanced Oceanic Operations                            |
| FAA:    | Federal Aviation Administration                        |
| FIS-B:  | Flight Information Services Broadcast                  |
| FL:     | Flight Level   |
| FMB:    | Flight Manual Bulletin                                 |
| FMC:    | Flight Management Computer                             |
| FMS:    | Flight Management System                               |

fpm: Feet Per Minute  
ft: feet  
HF: High Frequency  
HITL: Human-In-The-Loop  
HLA: High-Level Architecture  
ICAO: International Civil Aviation Organization  
ID: Identifier  
ITP: In-Trail Procedure  
kts: knots  
LaRC: Langley Research Center  
LCD: Liquid Crystal Display  
LNAV: Lateral Navigation  
M: Mean (arithmetic average)  
MCDU: Multi-Function Control and Display Unit  
MCP: Mode Control Panel  
MCH: Modified Cooper-Harper  
MFD: Multi-Function Display  
N: Sample size  
NASA: National Aeronautics and Space Administration  
NATOTS: North Atlantic Organized Track System  
ND: Navigation Display  
NextGen: Next Generation Air Transportation System  
NLR: National Aerospace Laboratory of The Netherlands  
nm: nautical miles  
OSED: Operational Services and Environment Description

|            |   |
|------------|---|
| p:         | Probability; level of (statistical) significance    |
| PC:        | Personal Computer                                   |
| PF:        | Pilot Flying  |
| PFD:       | Primary Flight Display                              |
| PNF:       | Pilot Not Flying                                    |
| Q:         | Q statistic   |
| RFG:       | Requirements Focus Group                            |
| RTCA:      | formerly Radio Technical Commission for Aeronautics |
| RTP:       | Radio Tuning Panel                                  |
| RVSM:      | Reduced Vertical Separation Minimum                 |
| SA:        | Situation Awareness                                 |
| SATCOM:    | Sattellite Communication                            |
| SD:        | Standard Deviation                                  |
| TCAS:      | Traffic Alert and Collision Avoidance System        |
| TMX:       | Traffic Manager (Executable)                        |
| VHF:       | Very High Frequency                                 |
| VMC:       | Visual Meteorological Conditions                    |
| VNAV:      | Vertical Navigation                                 |
| VSD:       | Vertical Situation Display                          |
| XCP:       | Transponder Control Panel                           |
| $\chi^2$ : | Chi-square statistic                                |



## Definitions

*Automatic Dependent Surveillance-Broadcast (ADS-B).* A system by which airplanes constantly broadcast their current position and altitude, category of aircraft, ground speed, flight number, and whether the aircraft is turning, climbing or descending over a dedicated radio datalink.

*Automatic Dependent Surveillance-Contract (ADS-C).* ADS-C enables appropriately equipped aircraft to send position information messages at predetermined geographical locations, at specified time intervals or at the occurrence of specified events. ADS-C can be relayed via SATCOM data link, or VHF data link.

*Flight Level.* A surface of constant atmospheric pressure, which is related to a specific pressure datum of 29.92 inches of mercury (1013.2 hectopascals), and is separated from other such surfaces by specific pressure intervals. Each is stated in three digits that represent hundreds of feet (ft). For example, flight level (FL) 370 represents a barometric altimeter indication of 37,000 ft.

*Following Climb or Descent.* A Same Track climb or descent performed by an aircraft when following a reference aircraft.

*Ground Speed Differential.* The difference between the In-Trail Procedure (ITP) Aircraft's ground speed and a Reference or Same Direction Potentially Blocking Aircraft's ground speed.

*Initial Flight Level.* The flight level of the ITP Aircraft when it determines a climb or descent is desired.

*Intermediate Flight Level.* Any Flight Level between the Requested Flight Level and the Initial Flight Level of the ITP Aircraft.

*Intervening Flight Level.* Any Intermediate Flight Level that has Same Direction aircraft whose ADS-B report data are available to the ITP Aircraft.

*In-Trail Procedure (ITP).* A procedure employed by an aircraft that desires to change its flight level to a new flight level by climbing or descending in front or behind one or two Same Track, Potentially Blocking Aircraft which are at an Intervening Flight Level.

*ITP Aircraft.* An aircraft that is fully qualified (from an equipment, operator, and flight crew qualification standpoint) to conduct an ITP and whose flight crew is considering a change of flight level.

*ITP Criteria.* A set of conditions that must be satisfied prior to initiating or executing an ITP clearance.

*ITP Distance.* The distance between Reference or Potentially Blocking Aircraft and the ITP Aircraft as defined by the difference in distance to a common point along each aircraft's track. For the special case of parallel tracks, an along-track distance measurement would be used to determine this value.

*ITP Separation Minimum.* The longitudinal separation minimum between the ITP Aircraft and Reference Aircraft. The ITP Separation Minimum is based on the International Civil Aviation Organization (ICAO) Distance Measuring Equipment (DME) separation method and is 10 nautical miles (nm).

*ITP Equipment.* Equipment needed on the ITP Aircraft that provides ADS-B information on Potentially Blocking Aircraft with regard to ADS-B data qualification (i.e., information sufficient to determine if

ADS-B data are, or are not, Qualified ADS-B Data), Same Direction, ITP Distance, Ground Speed Differential, flight level, and aircraft identification.

*ITP Speed/Distance Criteria.* A specified set of maximum Positive Ground Speed Differential and minimum ITP Distance values between a Same Direction Potentially Blocking Aircraft and the ITP Aircraft, required to be met prior to requesting or initiating an ITP with that aircraft as a Reference Aircraft.

*Leading Climb or Descent.* A Same Track climb or descent performed by an aircraft when ahead of a reference aircraft.

*Positive Ground Speed Differential.* A Ground Speed Differential value which would cause the ITP Distance between the ITP Aircraft and the Reference Aircraft to decrease.

*Potentially Blocking Aircraft.* Aircraft at an Intervening Flight Level whose ADS-B report data are available to the ITP Aircraft.

*Positive Mach Difference.* A difference in Mach between the ITP Aircraft and the Reference Aircraft that would result in a decrease in the ITP Distance between them.

*Qualified ADS-B Data.* Received ADS-B data that meet the accuracy and integrity requirements determined to be required for the ITP.

*Reference Aircraft.* One or two Same Direction, Potentially Blocking Aircraft with Qualified ADS-B Data that meet the ITP Speed/Distance Criteria and that will be identified to ATC by the ITP Aircraft as part of the ITP clearance request.

*Requested Flight Level.* A flight level above (for a climb) or below (for a descent) all Intervening Flight Levels that is no more than 4,000 ft from the Initial Flight Level.

*Same Direction.* Same direction tracks and intersecting tracks or portions thereof, the angular difference of which is less than 45 degrees or more than 315 degrees.

*Same Track.* Same direction tracks and intersecting tracks or portions thereof, the angular difference of which is less than 45 degrees or more than 315 degrees, and whose protection areas overlap (i.e., without lateral separation).

## Abstract

*The Enhanced Oceanic Operations Human-In-The-Loop In-Trail Procedure (ITP) Validation Simulation Study investigated the viability of an ITP designed to enable oceanic flight level changes that would not otherwise be possible. Twelve commercial airline pilots with current oceanic experience flew a series of simulated scenarios involving either standard or ITP flight level change maneuvers and provided subjective workload ratings, assessments of ITP validity and acceptability, and objective performance measures associated with the appropriate selection, request, and execution of ITP flight level change maneuvers. In the majority of scenarios, subject pilots correctly assessed the traffic situation, selected an appropriate response (i.e., either a standard flight level change request, an ITP request, or no request), and executed their selected flight level change procedure, if any, without error. Workload ratings for ITP maneuvers were acceptable and not substantially higher than for standard flight level change maneuvers, and, for the majority of scenarios and subject pilots, subjective acceptability ratings and comments for ITP were generally high and positive. Qualitatively, the ITP was found to be valid and acceptable. However, the error rates for ITP maneuvers were higher than for standard flight level changes, and these errors may have design implications for both the ITP and the study's prototype traffic display. These errors and their implications are discussed.*

## Introduction

The Human-In-The-Loop (HITL) In-Trail Procedure (ITP) Validation Simulation Study was conducted in September 2006 under sponsorship of the Enhanced Oceanic Operations (EOO) research element, which is part of the National Aeronautics and Space Administration (NASA) Next Generation Air Transportation System (NextGen) Air Traffic Management (ATM) Airspace Project. EOO's objective is to develop a globally accepted, early application of airborne Automatic Dependent Surveillance-Broadcast (ADS-B) that results in more efficient oceanic and remote non-radar operations while providing opportunities for research of Airborne Separation Assistance Systems (ASAS). The early application should provide operational experience with ASAS and be an incentive for operators to voluntarily equip their aircraft with transformational technologies.

The oceanic and remote non-radar airspace was selected as a proving ground for researching ASAS concepts since these domains already contain key characteristics of NextGen. They provide performance-based services where the individual equipage level impacts separation services, and aircraft use trajectory-based operations that include time management for separation and traffic flow management.

Aircraft in oceanic and remote non-radar airspace frequently fly for extended periods of time in the same direction and along similar flight paths as other aircraft. These flight paths, or tracks, are typically either defined by the authority controlling the airspace or requested by the respective aircraft, but in either case are designed to optimize flight safety and efficiency. The track definitions are additionally constrained by the requirement, for air traffic control (ATC) coordination, to connect at each end with a relatively small number of defined waypoints in the respective continental flight information regions. The end result of these track design constraints is that for practical considerations, the enormous expanse of airspace is reduced to only a few "optimal" tracks for use by many of the transport-category aircraft, with only one or two of these tracks considered "best" for any given flight.

Since there is no radar surveillance and only limited direct communications available in oceanic and remote airspace, controllers use procedural separation rules to ensure that aircraft remain separated. Procedural separation typically requires much greater times or distances between aircraft than when radar surveillance and direct communications are available. For example, in the North Atlantic Organized Track System (NATOTS) (Figure 1), the tracks are spaced no closer than 60 nautical miles (nm) from each other to allow for the position uncertainties involved with aircraft joining or leaving the track system [1]. This lateral spacing requirement limits the total number of tracks. Along a given track, aircraft must be spaced at track entry so that even with their different flight-planned airspeeds, they will transit and exit the track separated by at least 10 minutes in time, which is approximately 80 nm in distance, at typical transport category aircraft cruise speeds with no closure rate. This longitudinal spacing requirement limits the number of aircraft on a given track at a given altitude or flight level.

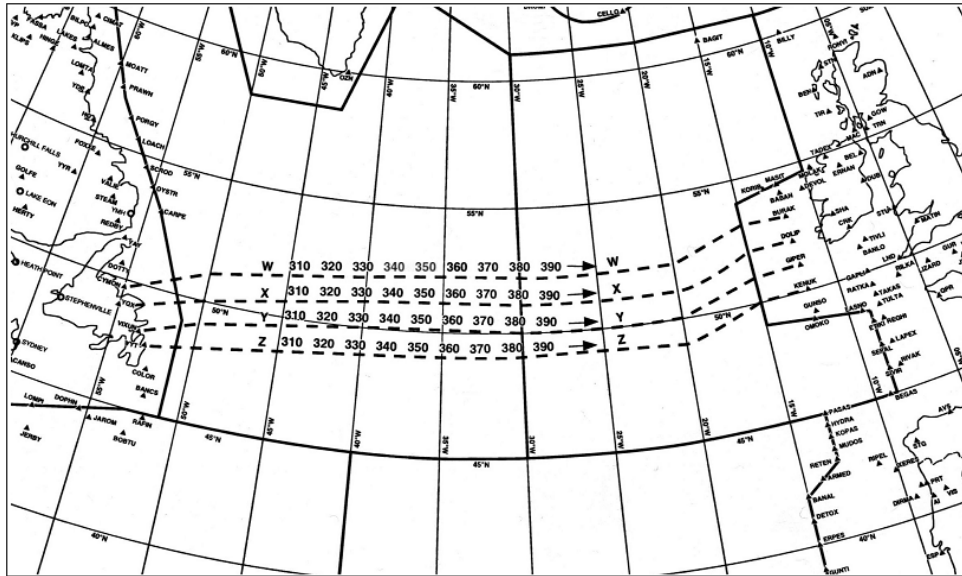


Figure 1. North Atlantic Organized Track System

Depending on the specific airspace rules in effect, controllers can separate aircraft vertically by as little as 1,000 feet (ft) (e.g., at multiple flight levels on a track) which somewhat alleviates the traffic density limits imposed by lateral and longitudinal procedural separation requirements. However, not all flight levels are practical for all aircraft. Some flight levels may be unusable due to an unacceptable level of turbulence or headwinds. Also, it is important that long-range aircraft fly near their most fuel-efficient altitudes. Flying several thousand feet higher or lower than the optimal altitude can result in thousands of pounds of additional fuel being burned during an oceanic crossing, and in some cases can even result in a diversion to a closer airport due to insufficient fuel to complete the originally-planned flight.

An aircraft's most fuel-efficient altitude is lower during the early segments of a flight, when the aircraft has a heavy fuel load, and higher during the later segments when much of the fuel has been consumed. Hence, operational efficiency is generally enhanced by climbing to a higher flight level one or more times during a long flight segment. There are also occasionally times when descent to a lower flight level is desirable, usually to avoid turbulence or unfavorable winds. However, in many situations the standard longitudinal separation does not exist at one or more higher or lower flight levels, but does exist at a succeeding flight level. An aircraft desiring a flight level change to such a succeeding flight level would therefore be prevented or "blocked" from making the climb or descent through the intervening flight level(s). For example, in Figure 2, the trailing aircraft at Flight Level (FL) 340 (shown in blue) desires a climb to FL360 but cannot be cleared for the climb because there would be insufficient longitudinal separation with the aircraft at FL350 (shown in red) during the climb.

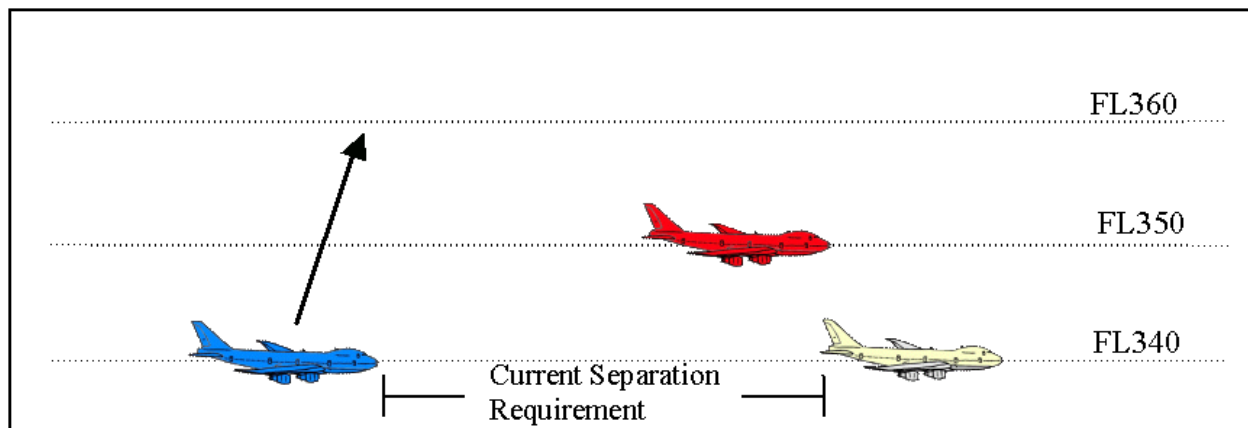


Figure 2. Aircraft at Flight Level 340 (FL340) desires a climb to FL360

Researchers at NASA LaRC, along with others in the worldwide ATM research and development community, have been developing an ITP concept which would increase the opportunities for such flight level changes that would otherwise be blocked. The ITP would employ new onboard avionics equipment that would provide an equipped aircraft's crew with improved information about nearby traffic and would introduce new procedures that would enable the crew, when appropriate criteria are met, to request an ITP flight level change referencing one or two of these nearby aircraft that might otherwise block the flight level change. The ITP equipment would use a surveillance technology known as ADS-B that broadcasts aircraft position and other essential data via an onboard transponder. ADS-B data received from nearby aircraft would yield more accurate position data than that available to controllers of oceanic/remote airspace, enabling controllers to approve ITP flight level change requests that reference these aircraft even if standard separation criteria would not otherwise exist with these reference aircraft. That is, the availability of more accurate airborne surveillance data would enable safe flight level changes through intervening flight levels, with lower separation minima than when using current ground-based non-radar separation rules. It should be noted that the ITP concept departs from conventional ground-based ATM practices because it would more actively involve flight crews in air traffic separation procedures, beyond their current level of conforming to clearances, and seeing and avoiding traffic in visual conditions.

## Description of the In-Trail Procedure

The ground rules for ITP are described in the Operational Services and Environment Description (OSD) document [2] from the RTCA/EUROCAE Requirements Focus Group (RFG). The ITP is designed to enable altitude changes through flight levels that would otherwise be blocked. The procedure requires the crew to use information derived on the aircraft to determine if the criteria required for an ITP are met. In actual airborne operation, onboard ITP equipment would receive ADS-B data from aircraft within reception range that are broadcasting these data, and derive information required for the ITP from these data. The aircraft-derived information includes flight identifier (ID), flight level, same direction, ITP distance, and ground speed differential (all relative to potentially blocking aircraft). The ITP equipment receives the ADS-B data and, along with onboard navigation data, calculates appropriate separation information for these aircraft and portrays this information to the crew (note that this information could be portrayed in a number of ways depending on the implementation; one specific implementation will be described subsequently). Using this information, the crew determines whether to make a flight level change request, and if so, whether to request a standard or ITP flight level change. If the desired flight level appears available but potentially blocking aircraft are observed on the intervening flight levels and the requested flight level is no more than 4,000 ft from the initial flight level, then the crew would evaluate the available information for these potentially blocking aircraft to determine if they can be used as reference aircraft in an ITP flight level change request. An aircraft at an intervening flight level can be used as a reference aircraft if it meets the following criteria:

- same direction of flight as the ITP Aircraft,  $\pm 45$  degrees,
- qualified ADS-B data are being received from the aircraft, and
- ITP distance/speed criteria are met.

The ITP equipment calculates for each aircraft the ITP distance, which is the difference in distance to a common point as shown in Figure 3 (for identical ground tracks, ITP distance is simply the distance between the two aircraft). The ITP speed criterion is a ground speed differential, also calculated by the ITP equipment and is simply the difference in ground speed between the two aircraft. A positive ground speed differential is one in which the ITP distance between the two aircraft is decreasing.

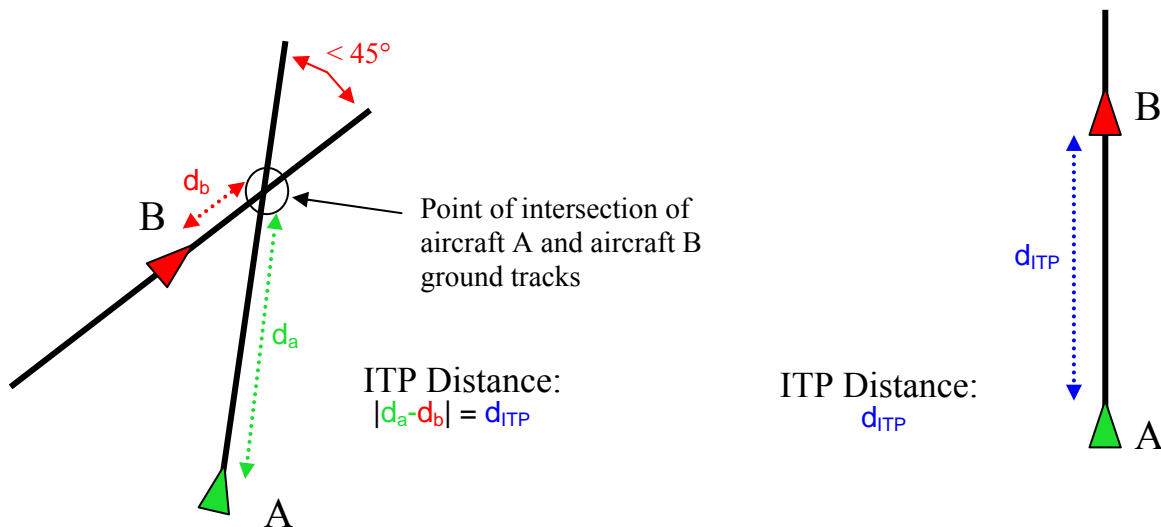


Figure 3. ITP distance (non-identical ground tracks vs. identical ground tracks)

A reference aircraft must meet the following ITP distance/speed criteria:

- ITP distance at least 15 nm, and positive ground speed differential of 20 knots (kts) or less, or
- ITP distance at least 20 nm, and positive ground speed differential of 30 kts or less.

Up to two reference aircraft can be included in an ITP flight level change request to ATC. The reference aircraft are identified in the request by call sign and the ITP distance. If more than two potentially blocking aircraft meet the criteria for reference aircraft, then the crew would identify the one or two that, in their judgment, would be most likely to block the flight level. Typically this would be the closest one or two such aircraft, ahead of and/or behind the ITP aircraft, and on either one or two intervening flight levels, depending on the situation.

All possible ITP geometries are permissible as long as all aircraft in the request meet the criteria for reference aircraft. Possible geometries include:

- following climb/descent;
- leading climb/descent;
- combined leading-following climb/descent;

- combined leading-leading climb/descent (with reference aircraft on different flight levels); and
- combined following-following climb/descent (with reference aircraft on different flight levels).

The reference aircraft is located behind the ITP aircraft during a leading maneuver, and the reference aircraft is located ahead of the ITP aircraft during a following maneuver.

Given that the ITP is an airborne traffic situation awareness application, no change in the responsibilities of either pilots or controllers takes place. The flight crew continues to be responsible for the operation of the aircraft and conformance to its clearance, and the controller continues to be responsible for separation and the issuance of clearances. However, the controller would use additional information from the ITP aircraft's request to determine if separation can be assured and a clearance can be issued.

Upon reception of an ITP request, ATC can:

- deny the ITP flight level change request due to traffic or other constraints;
- approve a standard flight level change if sufficient separation exists and ITP clearance is not necessary;  
or
- issue an ITP flight level change clearance, identifying the reference aircraft call sign(s).

ATC determines if standard separation will be met for all aircraft at the requested flight level and at all flight levels between the initial flight level and requested flight level. If so, a standard (non-ITP) flight level change clearance may be granted. Otherwise, if the reference aircraft are the only blocking aircraft, the controller evaluates the ITP request. ATC determines if the reference aircraft have been cleared to change speed or change flight level, or are about to reach a point at which a significant change of track will occur. The controller also determines that the requesting aircraft is not referenced in another procedure and that the positive Mach difference with the reference aircraft is no greater than 0.04 Mach. If the separation criteria are met at the requested flight level with other aircraft, the requesting aircraft itself is not referenced, and the reference aircraft are maintaining speed, flight level, and track, then ATC may issue the ITP flight level change clearance.

If an ITP clearance is received, then the crew must reassess the reference aircraft identified in the clearance to assure that the ITP distance/speed criteria are still met before accepting the clearance. If the criteria are no longer met, then the clearance must be rejected.

If the criteria are still met and an ITP clearance has been accepted, the crew should commence the flight level change without delay and maintain cruise Mach number and at least 300 feet per minute (fpm) vertical speed throughout the flight level change. If this minimum performance cannot be maintained, then regional contingency procedures for inability to conform to an ATC clearance should be followed.

The ITP aircraft crew is not required to monitor the ITP distance to the reference aircraft during the climb or descent. The safety of the ITP is assured by the initial conditions, which include the ITP distance, ground speed differential, and requested vertical distance for the flight level change, and by the required minimum vertical speed during the flight level change. The ITP is completed when the ITP flight crew reports being established at the new flight level.

## **Current Study**

The EOO HITL ITP Validation Simulation Study was conducted to collect quantitative and qualitative data to assess the validity and pilot acceptability of an ITP designed to enable oceanic flight level changes that would

not otherwise be possible. The results of this study address fundamental questions regarding the design and correctness of the EOO ITP concept of operations.

## **Research Objectives and Hypotheses**

The first objective of the EOO HITL ITP Validation Simulation Study was to assess the validity of the ITP by determining if subject pilots: a) were able to perform ITP maneuvers during simulated flights over the Atlantic Ocean and b) found the procedural steps that they were instructed to use while executing ITP maneuvers to be correct, complete, and appropriately specified.

It was hypothesized that subject pilots would be able to perform ITP maneuvers during simulated oceanic flights (i.e., that the instructed procedural steps would be performed correctly and in the appropriate order) and that subject pilots would not find any missing, incomplete, or extraneous procedural steps associated with the ITP. To test these hypotheses, 12 commercial airline pilots with current oceanic experience were asked to perform standard and ITP flight level change maneuvers while using a desktop aircraft simulator to fly along assigned routes in the NATOTS. The validity of the ITP was evaluated using the subject pilots': 1) flight level change procedure selection errors; 2) execution errors for selected flight level change procedure; 3) post-scenario questionnaire responses; 4) post-experiment questionnaire responses; and 5) feedback obtained during post-experiment group debrief sessions.

The second objective of the EOO HITL ITP Validation Simulation Study was to assess pilot acceptability of the ITP. In addition to collecting subject pilots' impressions of the overall acceptability of the ITP, the study attempted to determine if subject pilots found that: a) the level of workload that they experienced while performing ITP maneuvers was acceptable and b) the ITP will likely provide perceived benefits to flight crews, passengers, and airline operators in the form of improved traffic situation awareness, smoother rides, and fuel savings.

It was hypothesized that subject pilots would find the workload level associated with performing ITP flight level changes to be acceptable [i.e., that a subjective workload rating of "3" or less would be chosen using the Modified Cooper-Harper (MCH) Rating Scale (a description of this rating scale is provided in the "Dependent Measures" section and in Appendix A)] and that the subjective workload level experienced during ITP flight level changes would not be significantly higher than that experienced during standard flight level changes. Additionally, it was hypothesized that subject pilots would find the ITP to be beneficial in situations where climbs or descents would not otherwise be possible. The acceptability of the ITP was evaluated based on the subject pilots': 1) workload ratings; 2) post-scenario questionnaire responses; 3) post-experiment questionnaire responses; and 4) feedback obtained during post-experiment group debrief sessions.

## **Method**

### **Participants**

Participants consisted of 12 commercial airline pilots employed by a single major U.S. air carrier. Each pilot had completed the ITP Display Interface User Survey (included in Appendix B) and had expressed an interest in participating in NASA LaRC's investigations of the ITP concept. Survey respondents were invited to serve as subject pilots in the HITL ITP Simulation Validation Study because it was anticipated that their exposure to the ITP concept via the survey would reduce the training time required to prepare them for the performance of the study's evaluation tasks. Survey respondents who were currently flying or who had recent experience flying Boeing 747 and/or 777 aircraft were invited to serve as subject pilots since their experience with glass cockpit technology would facilitate their training and use of the experiment's desktop flight simulator.



All of the subject pilots were male and ranged in age between 42 – 59 years [mean ( $M$ ) = 49, standard deviation ( $SD$ ) = 6]. Five of the participants were captains, and the other seven were first officers. On average, the participants had 18 years of airline experience ( $M$  = 18.6,  $SD$  = 7.2, Range = 11 – 32) and over 9,000 hours of airline flying experience ( $M$  = 9,892,  $SD$  = 5,829, Range = 3,000 – 23,000). At the time of the study, six of the participants served as 747-400 pilots; five of the participants served as 777-200 pilots; and 1 participant served as a 767-300 pilot; however, the 767 pilot had recent experience flying a 747 aircraft. All subject pilots had experience flying in the NATOTS and had, on average, completed nearly 60 oceanic flights during the previous year ( $M$  = 59.7,  $SD$  = 32.5, Range = 25 – 120). When asked to rate their level of familiarity with flying oceanic routes on a scale from 0 (“very unfamiliar”) to 10 (“very familiar”), the mean response was 9.38 ( $SD$  = 0.71).

All of the participants had previous experience with the use of data-link communications, and two of the participants had previous experience using EFB devices. All of the subject pilots viewed themselves as being relatively computer savvy. When asked to rate their level of computer usage on a scale from 0 (“I never use a computer”) to 10 (“I use a computer multiple times every day”), the mean response was 8.75 ( $SD$  = 1.71).

All of the subject pilots participating in the ITP HITL simulation study did so voluntarily and were compensated for their participation. Throughout the experiment, all participants were treated in accordance with the “Ethical Principles of Psychologists and Code of Conduct”[3].

## **Test Facilities and Apparatus**

The EOO HITL ITP Validation Simulation Study took place in the Air Traffic Operations Laboratory (ATOL) at NASA LaRC. The ATOL is a facility that hosts the Airspace and Traffic Operations Simulation (ATOS), a distributed simulation environment, built using a High-Level Architecture (HLA) network communications model, enabling the investigation of overall airspace system behaviors while retaining highly sophisticated models of the various system components. These system components include piloted computer workstation-based commercial transport and general aviation aircraft simulations, links to onsite high-fidelity motion-based flight deck simulators, background traffic generators, links to offsite radar and ATC host simulations, models of various communications and surveillance infrastructure elements (e.g., Flight Information Services Broadcast, or FIS-B), a simulation manager that controls modes and timing, and data collection and analysis tools [4]. A simplified diagram of the basic architecture of ATOS is shown in Figure 4.

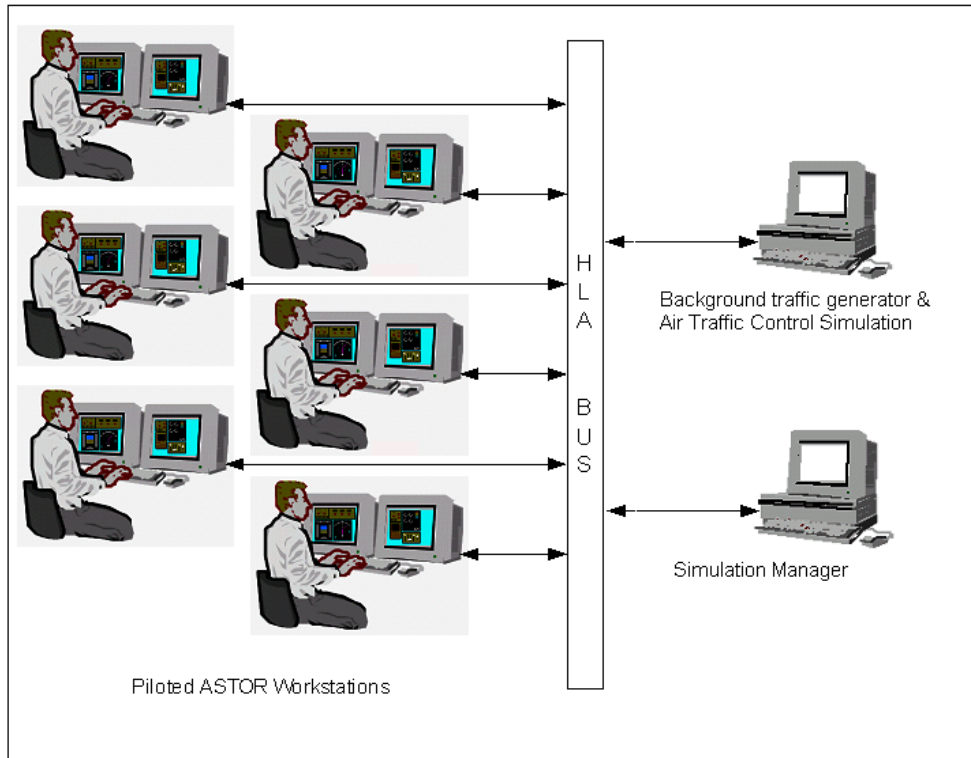


Figure 4. Simplified basic architecture of the ATOS system components

For this experiment, the components of ATOS that were used included the commercial transport aircraft simulation [i.e., the Aircraft Simulation for Traffic Operations Research (ASTOR)], a new EFB simulation that hosted the Oceanic Operations application, the background traffic generator and ATC simulation (i.e., TMX), the simulation manager, and the data collection and analysis tools. The ASTOR, EFB, and TMX components will be described in more detail in the following sub-sections.

#### ***Aircraft Simulation for Traffic Operations Research (ASTOR)***

The aircraft simulation used for this experiment, known as the ASTOR, is a medium-fidelity computer workstation-based desktop flight simulator whose displays and control panels are representative of a current-generation transport aircraft flight deck (e.g., a Boeing B-777). As shown in Figure 5, the pilot interface to ASTOR includes an Electronic Flight Instrumentation System Control Panel (EFISCP), auto-flight system Mode Control Panel (MCP), Multifunction Control and Display Unit (MCDU), Engine Indication and Crew Alerting System (EICAS) display, Display Select Panel (DSP), Primary Flight Display (PFD), Navigation Display (ND), Radio Tuning Panel (RTP), Transponder Control Panel (XCP), throttle control stand panel including a variety of aircraft configuration controls, and a simulation status panel.

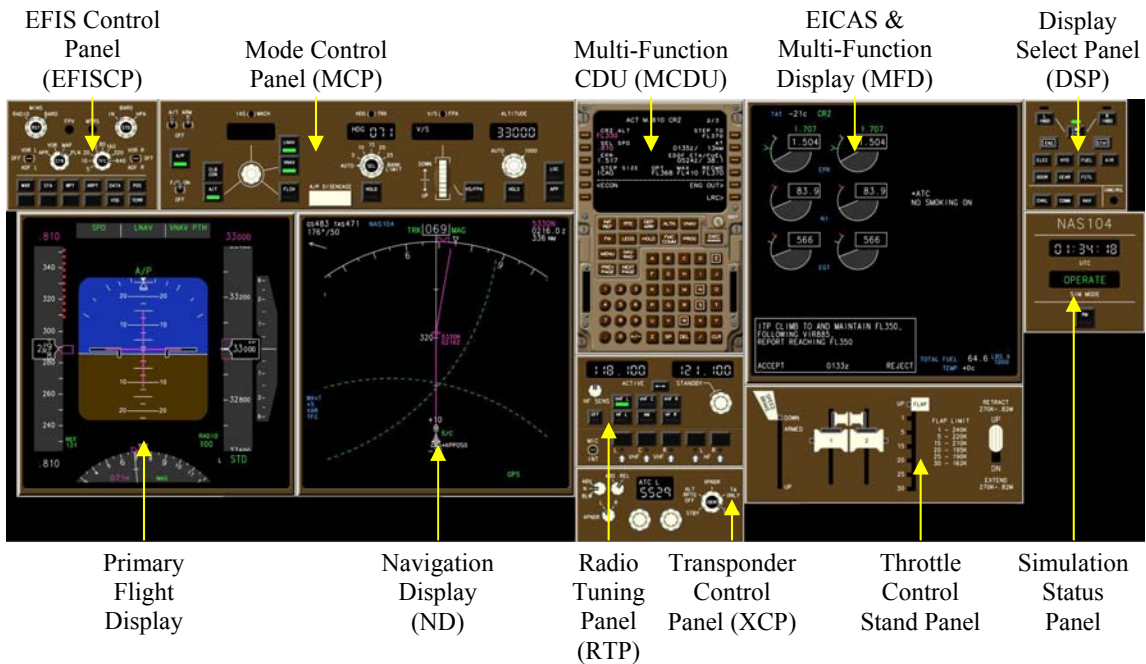


Figure 5. General layout of the on-screen pilot interface to ASTOR

For this experiment, the EICAS display also doubled as the Multi-Function Display (MFD) that hosted the Controller Pilot Data Link Communications (CPDLC) application, which was used by the subject pilots to send requests to and receive clearances from the ATC simulation. Although in a real flight deck this CPDLC application is normally accessed through a separate MFD located below the EICAS display, space considerations required that the MFD and EICAS share a common display area. The subject pilots used the DSP to switch between the two displays.

Each ASTOR included a research prototype Flight Management Computer (FMC) simulation that was capable of supporting most normal oceanic flight management operations, such as route planning and modification, lateral and vertical trajectory computation, and lateral and vertical guidance generation. The subject pilots interacted with the FMC using the MCDU. The aircraft and engine performance models used for this experiment were representative of a large twin-engine commercial transport aircraft, and although simulated winds aloft were present in each scenario, no wind prediction errors were introduced that would have resulted in the aircraft flying a different path than predicted by the simulated FMC. All ASTOR components, including the FMC and other elements of the autoflight system, communicated with each other using an onboard avionics architecture based on a simulated ARINC 429 digital data bus [5].

Surveillance data on those nearby traffic aircraft which were designated as ADS-B equipped aircraft were provided to each ASTOR aircraft using simulated ADS-B reports [6]. The modeled ADS-B reports included the state vector, mode status, air-referenced, target state, and trajectory change reports, and the contents of these reports conformed to the Minimum Aviation System Performance Standards (MASPS) for ADS-B [7]. Range limitations and interference effects were modeled to provide realistic representations of the data that would be available in the real world from ADS-B equipped aircraft. Surveillance data for aircraft not equipped with ADS-B were provided using simulated Traffic Alert and Collision Avoidance System (TCAS) information, which was more limited than the ADS-B data and consisted primarily of range, azimuth, and altitude data. Symbols for the TCAS data were displayed on the ND, while symbols for both the TCAS and ADS-B data were displayed on the simulated EFB.

### *Electronic Flight Bag (EFB)*

In addition to the main ASTOR displays and control panels, which were presented on two 19-inch liquid crystal display (LCD) flat panel screens, the pilot interface for this experiment also included an EFB simulation. This EFB simulation hosted the ITP application and was run on a separate tablet personal computer (PC) to the left of the two LCD screens (see Figure 6). Interaction with the ITP Oceanic Operations application on the tablet PC was accomplished by the subject pilots using a separate computer mouse from the one used to interact with the main ASTOR displays and control panels.



Figure 6. Location of simulated EFB relative to the main ASTOR displays

The ITP application interface was designed for this experiment. The design goal was to minimally satisfy the OSED requirements, without adding any feature or display element that was not clearly traceable to a specific requirement. In addition, the following design assumptions were made: 1) with the exception of selecting the desired flight level, the pilot interface would be totally passive, so that no pilot interaction would be required other than viewing the display; 2) the pilot interface would show the results of evaluating all relevant procedural criteria associated with each maneuver, so that pilots would not be required to remember these criteria themselves; and 3) the pilot interface would require very little information from the onboard avionics, limited to position, ground speed, ground track, and barometric altitude.

Additionally, a larger-scale survey of oceanic airline pilots was conducted as a means to better evaluate the current ITP interface display design (Appendix B). Based on the results from the user survey (Appendix C), a prototype implementation of the ITP interface was created and integrated with the existing EFB software running on the tablet PC as part of ASTOR. An example of the final interface display is shown in Figure 7. The details and purpose of each element of the display are explained in the Flight Manual Bulletin (FMB) presented in Appendix D, which was given to the subject pilots as part of their experiment training materials.



Figure 7. Final ITP application interface display as used in the experiment

In addition to the ITP application interface, a prototype implementation of the logic contained in the OSED document describing the ITP maneuver constraints was also created. This ITP algorithm logic, described in a formal specification language [8], was used to determine the status of many of the elements on the ITP interface display. For example, the vertical profile view of nearby traffic aircraft on the display only showed those aircraft that met the definition of “same track” and “same or opposite direction,” so the ITP algorithm selected these aircraft according to the appropriate rules. Likewise, the “range” value shown beneath traffic aircraft at intervening altitudes was computed as a distance to or from a common point by the ITP algorithm (i.e., the value displayed is the ITP distance for that aircraft). Additionally, the ITP algorithm actually applied the reference aircraft criteria to the appropriate traffic aircraft, so that the interface display could clearly label as “NO REF” (no reference) those aircraft that failed to meet the criteria and were therefore ineligible to be included as reference aircraft in an ITP flight level change request.

### ***Traffic Manager (TMX)***

A desktop ATM simulation program called the Traffic Manager (TMX) performed the function of background traffic generator and ATC simulation. TMX was also extensively used for scenario development and data collection. TMX (Figure 8) is a medium-fidelity computer workstation-based desktop simulation application designed for interaction studies of aircraft in a future ATM environment. TMX was originally developed by the National Aerospace Laboratory (NLR) in The Netherlands, and it serves as a stand-alone traffic simulator, flight simulation scenario generator, scenario editor, experiment control station, data-recording



tool, and rapid prototyping environment. Both NLR and NASA LaRC have continued to enhance and improve TMX, making it a valuable asset to many ATM research projects [9].

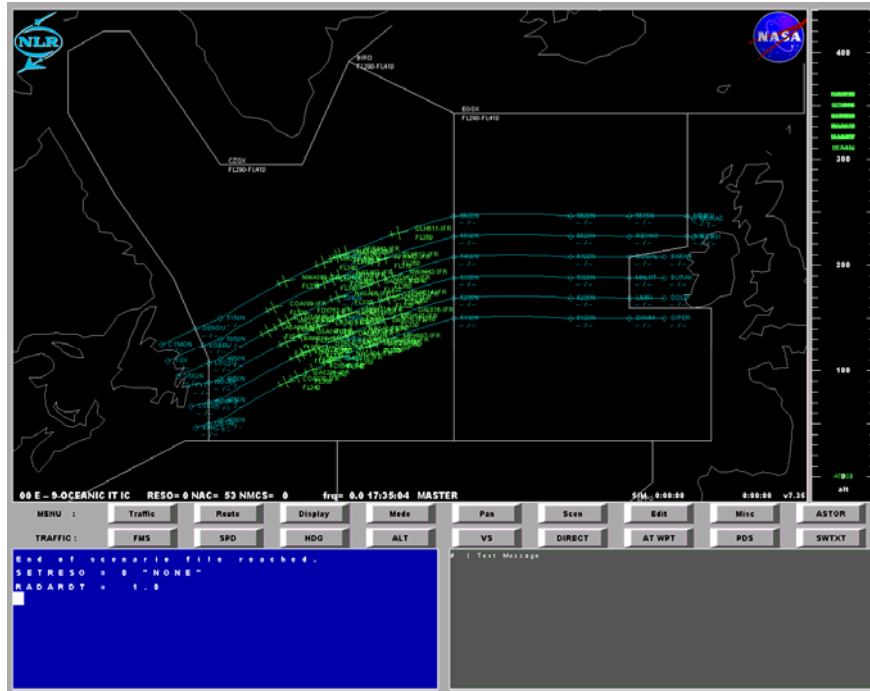


Figure 8. Traffic Manager user interface

The simulator is capable of simulating up to 2,000 aircraft simultaneously, and each aircraft uses a six-degrees-of-freedom dynamics model, augmented with performance parameters from the EUROCONTROL Base of Aircraft Data (BADA) database [10]. Other features are shown in Table 1.

Table 1. TMX functionality

|   |
|---|
| Gate to Gate Operations: includes approach and taxi control   |
| Autoflight Model: basic altitude, heading, and speed modes, plus Flight Management System (FMS) modes with autothrottles and Required Time of Arrival functionality |
| ADS-B Model: includes range limits  |
| Airborne Separation Assistance Systems (ASAS): conflict detection, resolution, and prevention systems selectable among multiple variants                            |
| Airborne Precision Spacing: for merging and spacing operations  |
| Pilot Model: includes parameters for reaction time and scheduling of tasks  |
| Wind Model: three-dimensional “truth” and predicted wind fields   |
| Weather Model: includes moving weather cells  |
| Datalogging: time and event based   |

TMX also supports external connection interfaces (including HLA) to connect to full motion simulators and to integrate with the NASA ATOS.

For use during the EOO HITL ITP Validation Simulation Study, a new ATC model was developed to provide the necessary separation assurance services. The model consisted of individual ATC centers, each of which was capable of handling multiple requests simultaneously. The communication between the ATC model and the requesting aircraft was accomplished via data-link, and all data-link messages were formatted using a consistent set of syntax rules according to the ARINC 702 standard. Controller response times were modeled

based on actual oceanic data obtained from oceanic air traffic service providers (ATSP), and ranged from one to four minutes depending on the operation.

### Pilot Procedure

During the experiment scenarios, each subject pilot sat at an ASTOR station and was instructed not to interact with any of the other experiment participants. The initial condition of each ASTOR simulation was set so that the ownship aircraft was positioned roughly one hour into a flight occurring on a NATOTS track, with the Flight Management System (FMS) initialized and the auto-pilot fully coupled. Upon start of the simulation, the subject pilots were instructed to try to get as close as possible to the recommended flight level as reported on the Vertical Navigation (VNAV) page of the MCDU (Figure 9).



Figure 9. FMS recommended Flight Level

To determine the appropriate flight level change request, the recommended flight level had to be selected on the EFB's Oceanic Operations application (shown in green in Figure 10). Once selected, the application displayed aircraft symbols and data tags for all aircraft at the current flight level, desired flight level, and intervening flight levels that were transmitting position information.

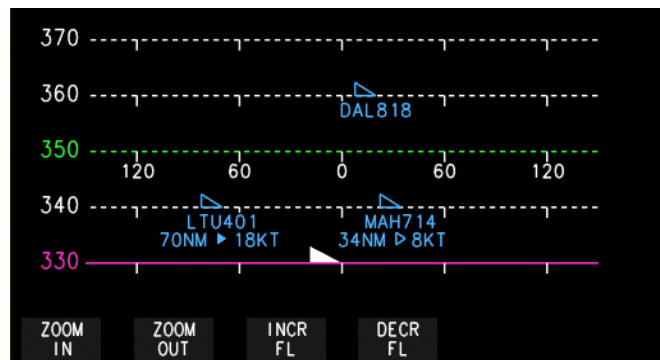


Figure 10. EFB desired altitude selection

Using this traffic information, the subject pilot determined whether to request a standard or an ITP flight level change. Subject pilots were advised that “if in doubt, request an ITP.” That is, if the subject pilot was unsure if standard separation would exist at one or more of the intervening flight levels, then the pilot should request an ITP to maneuver through the intervening flight level(s) (assuming all of the ITP criteria are met)

rather than request a standard flight level change. While an ITP request would be more involved, it would allow the controller to use less restrictive separation standards. Alternatively, if standard separation was clearly apparent [e.g., no aircraft were visible on the intervening flight level(s)], then the subject pilot should request a standard flight level change. If aircraft on the intervening flight level(s) clearly blocked the desired flight level change under even the ITP criteria, then no request should be made.

If the subject pilot determined that an ITP request was required, he chose the one or two potentially blocking aircraft, ahead of and/or behind the ownship aircraft and on either one or two intervening flight levels, that would most likely block the flight level change. The ITP criteria would be evaluated for these aircraft to determine whether or not they could be used as reference aircraft in an ITP request.

To request an ITP flight level change, the subject pilot used a data-link interface, similar to that required to make a standard flight level change request. Additional ITP-specific information was entered on the available free text lines. With this design choice, an actual flight deck implementation would not require modifications to the aircraft's existing data-link interface or underlying software.

Subject pilots entered free-text on the MCDU scratchpad and transferred the text to the ATC data-link page (Figure 11).

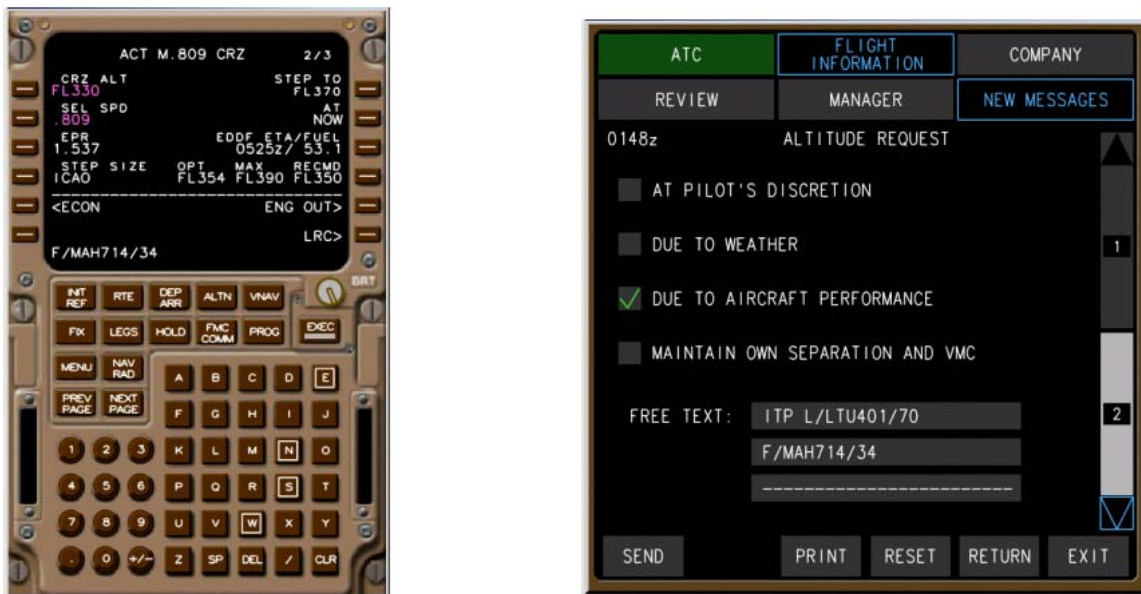


Figure 11. Constructing ITP Flight Level change request

The keyword “ITP” had to start the first (and only the first) free text line and was followed by the information pertaining to each of the one or two reference aircraft, according to the following format:

F/<reference aircraft flight id>/nn or L/<reference aircraft flight id>/nn

Where:

F/ means that the ITP Aircraft is *following* this reference aircraft

L/ means that the ITP Aircraft is *leading* this reference aircraft

/nn is the ITP Distance for this reference aircraft, in nm

After the ITP request was sent, ATC (simulated in software) would evaluate the request and reply either by denying the request, approving a standard flight level change, or approving an ITP flight level change. Upon reception of an ITP clearance (Figure 12), the subject pilot had to reassess the reference aircraft identified in the



clearance to assure that the ITP criteria were still met before accepting the clearance. The clearance had to be rejected if the criteria were no longer met.

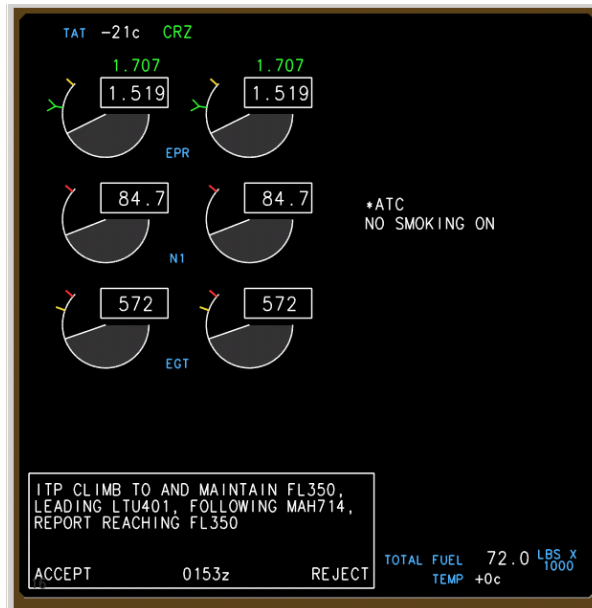


Figure 12. Reception of ITP clearance

Once a clearance was accepted, the subject pilot was instructed to arm an automatic report to inform ATC once the reported altitude was established, per standard operating procedures for flight level changes in the simulated NATOTS airspace and with this data-link capability. The subject pilot was then able to commence the flight level change without delay, while maintaining the current cruise Mach number and at least 300 fpm vertical speed throughout the flight level change. The subject pilots were at liberty to choose their own means of changing altitude, while adhering to the procedure requirements. No further reference to the Oceanic Operations application (e.g., traffic monitoring) was required after the climb or descent was initiated.

## Experiment Design

The experiment design used for data collection was an 8 x 2 full-factorial, within-subject design (Figure 13).

|                            |     |                   |                   |                     |                       |                   |                     |                    |                      |
|----------------------------|-----|-------------------|-------------------|---------------------|-----------------------|-------------------|---------------------|--------------------|----------------------|
| Achievability of FL Change | Yes | S <sub>1-12</sub> | S <sub>1-12</sub> | S <sub>1-12</sub>   | S <sub>1-12</sub>     | S <sub>1-12</sub> | S <sub>1-12</sub>   | S <sub>1-12</sub>  | S <sub>1-12</sub>    |
|                            | No  | S <sub>1-12</sub> | S <sub>1-12</sub> | S <sub>1-12</sub>   | S <sub>1-12</sub>     | S <sub>1-12</sub> | S <sub>1-12</sub>   | S <sub>1-12</sub>  | S <sub>1-12</sub>    |
|                            |     | Standard Climb    | Standard Descent  | ITP Following Climb | ITP Following Descent | ITP Leading Climb | ITP Leading Descent | ITP Combined Climb | ITP Combined Descent |
|                            |     | Type of FL Change |                   |                     |                       |                   |                     |                    |                      |

Figure 13. Experiment design matrix

The eight levels of the Type of Flight Level Change Maneuver independent variable were: 1) Standard Climb, 2) Standard Descent, 3) ITP Following Climb, 4) ITP Following Descent, 5) ITP Leading Climb, 6) ITP Leading Descent, 7) ITP Combined Climb, and 8) ITP Combined Descent. The two levels of the Achievability of Flight

Level Change Maneuver independent variable were: 1) Yes, and 2) No. Twelve subject pilots (S<sub>1-12</sub>) performed all 16 test conditions in random order.

In addition to the experiment's 16 test conditions, all of which involved a flight level change of 2,000 ft, seven additional simulated flight scenarios involving flight level changes greater than 2,000 ft were completed during a post-experiment supplemental data collection session. The additional scenarios were designed to get feedback on scenarios that were more complex. Due to the fact that these scenarios were not part of the matrix, not all subject pilots flew the same additional scenarios.

### ***Independent Variables***

The two independent variables included in the experiment design were Type of Flight Level Change Maneuver and Achievability of the Flight Level Change Maneuver. This second independent variable, Achievability of the Flight Level Change Maneuver, will be more fully explained in a subsequent sub-section describing the design of the experiment scenarios.

### ***Additional Variable of Interest***

While not recognized as a factor salient enough to be included in the experiment design as an independent variable, Direction of Flight was identified as a variable of interest since the Oceanic Operations application that subject pilots used during the experiment provided a vertical profile view of aircraft traveling from left-to-right across the lower portion of an EFB display screen. Although subject pilots were expected to be capable of using the Oceanic Operations application's vertical profile view equally well during simulated flights performed East-to-West and West-to-East over the Atlantic Ocean, the decision was made to evaluate the effects that Direction of Flight might have on the ability of subject pilots to interpret information presented in the vertical profile view, particularly when performing simulated Westbound flight scenarios.

Each subject pilot flew East-to-West during half of the test conditions and flew West-to-East during the remaining half of the test conditions. The order in which Eastbound versus Westbound flights were performed was completely randomized. However, each simulated flight scenario was flown East-to-West by half of the subject pilots and was flown West-to-East by the other half of the subject pilots to ensure that each scenario was flown Eastbound and Westbound an equal number of times.

### ***Dependent Measures***

**Selection Errors.** Prior to making a flight level change request, subject pilots were required to determine which type of flight level change maneuver, if any, was most appropriate given the situation at hand. It was necessary to determine whether the most appropriate course of action was to request a standard flight level change, request an ITP flight level change, or elect to make no request and remain at the current flight level.

During four of the experiment's simulated flight scenarios, subject pilots were expected to request a standard flight level change. During the other 12 scenarios, subject pilots were expected to consider requesting an ITP flight level change but, ultimately, were expected to refrain from making a flight level change request during three of the 12 "ITP scenarios." These three scenarios were designed so that either: 1) the distance of a reference aircraft did not meet the ITP distance criteria, 2) the ground speed differential of a reference aircraft did not meet the required ITP speed criteria, or 3) an observable traffic aircraft was blocking the ITP maneuver.

Selection errors were logged when subject pilots made a flight level change request that was different from the expected request for a given scenario. For example, a selection error was logged if subject pilots requested: a) a standard flight level change when they were expected to request an ITP flight level change, b) an ITP flight level change when they were expected to request a standard flight level change, or c) an ITP or standard flight level change when they were expected to have realized that neither an ITP nor standard maneuver was possible.

**Execution Errors.** Execution errors were evaluated after subject pilots chose to request a given type of flight level change maneuver, and any execution errors committed were attributed to the type of flight level change actually requested (rather than to the expected flight level change for the scenario, in the case of a selection error). An execution error was logged if subject pilots failed to: a) correctly communicate required information to ATC while making either a standard or an ITP flight level change request, or b) adhere to the aircraft performance criteria required during ITP flight level change maneuvers. Depending on the potential consequences associated with a given execution error, it may have been identified as a “safety-related execution error.” Criteria for identifying safety-related execution errors are described subsequently in the Results and Discussion section.

**Subjective Assessments of the ITP’s Validity.** Subject pilots’ perceptions regarding the validity of the ITP were collected using a post-scenario questionnaire (Appendix E) that was administered after the completion of each test condition and a post-experiment questionnaire (Appendix F) that was administered after the completion of the final test condition. Subject pilots used the post-scenario questionnaire to record their impressions of the correctness, completeness, appropriate specification, and logical sequencing of the procedural steps that they were instructed to use while executing ITP maneuvers. The post-experiment questionnaire was used by the subject pilots to document any performance concerns they had with the ITP (e.g., the ability to maintain climb rate and/or Mach). Additional comments regarding the validity of the ITP were also collected from the subject pilots during the post-experiment group debrief session.

**Subjective Assessments of the ITP’s Acceptability.** Subject pilots’ perceptions regarding the acceptability of the ITP were collected using the post-scenario questionnaire and the post-experiment questionnaire. The post-scenario questionnaire provided subject pilots with a means through which to document any alternative ways that they would have preferred to perform a given flight level change maneuver. Examples of the information recorded by the post-experiment questionnaire include subject pilots’ impressions regarding: the level of safety associated with performing the ITP as compared with current day procedures; how the workload required to perform standard flight level changes during the experiment compared with the workload required to perform ITP flight level changes; and the perceived benefits that the ITP might have for flight crews, passengers, and airline companies. Subject pilots were also encouraged to comment on their perceptions of the ITP’s acceptability during the post-experiment group debrief session.

**Subjective Assessments of the ITP’s Workload.** Subjective assessments of the workload associated with performing the experiment’s simulated flight scenarios were obtained through the use of the Modified Cooper-Harper (MCH) Rating Scale [11] (Appendix A), the post-experiment questionnaire, and the post-experiment group debrief sessions. The MCH scale required subject pilots to make a series of decisions regarding: whether or not the instructed task could be accomplished most of the time; if adequate performance was attainable (i.e., if errors were small and inconsequential); and whether or not the level of mental workload required by the instructed task was acceptable. Upon answering questions according to a predetermined logical sequence, an overall rating ranging from “1” (indicating that the instructed task was very easy/highly desirable; operator mental effort was minimal; and desired performance was easily attainable) to “10” (indicating that the instructed task was impossible; it could not be accomplished reliably) was selected (Figure 14).

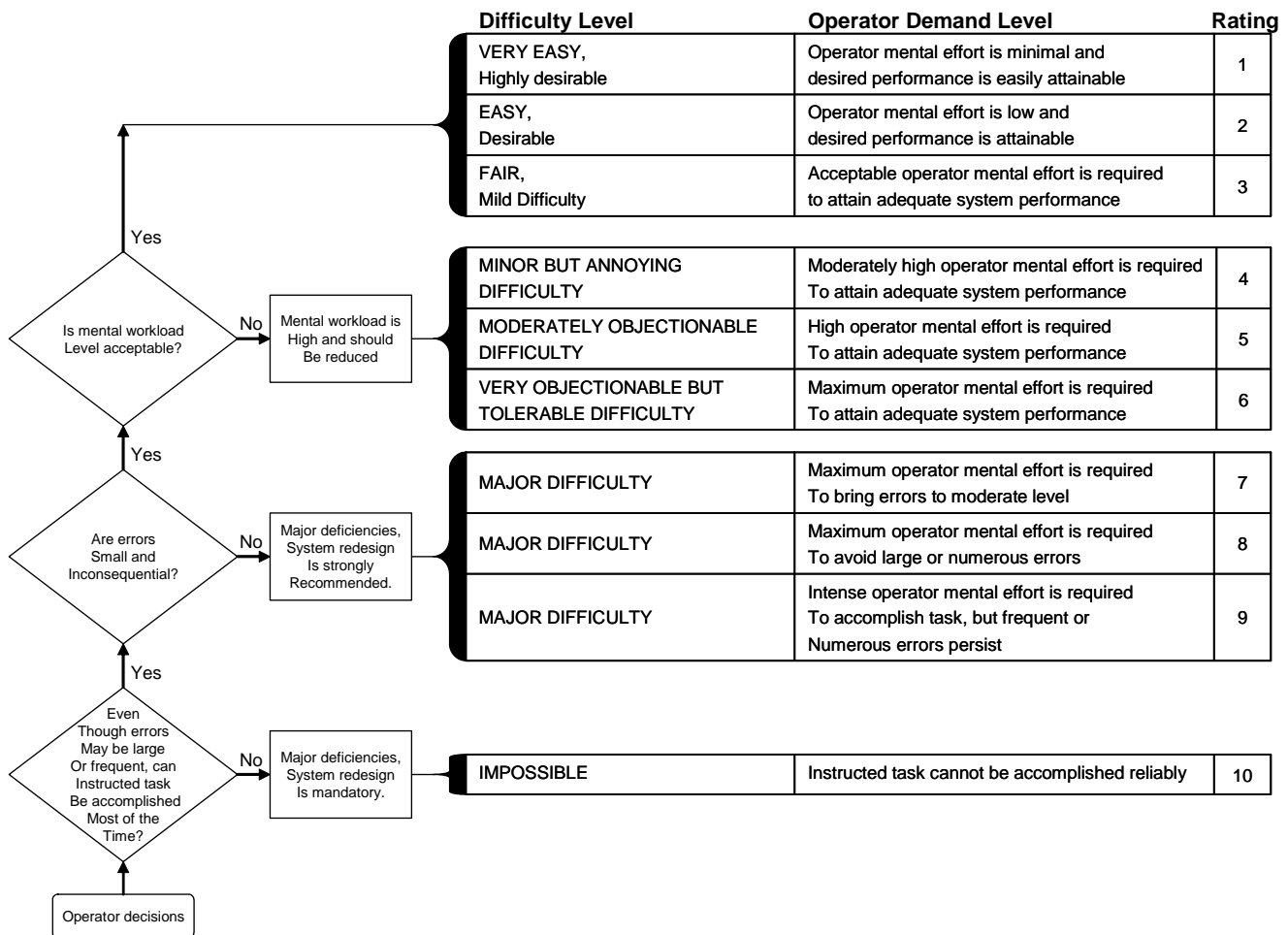


Figure 14. Modified Cooper-Harper (MCH) Rating Scale

The post-experiment questionnaire was used to record the subject pilots' descriptions of how the workload required to perform standard flight level changes during the experiment compared with the workload required to perform the ITP flight level changes. Feedback regarding their impressions of the workload associated with performing simulated flights East-to-West versus West-to-East over the Atlantic Ocean was obtained from the subject pilots during the post-experiment group debrief sessions.

## Scenario Design

The experiment's simulated flight scenarios were designed in accordance with the requirements of the 8 x 2 experiment design matrix. The 16 experiment matrix scenarios involved maneuvers through one intervening flight level, while the additional seven supplemental scenarios were designed to evaluate more complex situations involving maneuvers through multiple intervening flight levels.

Every experiment scenario was designed based on the eight types of flight level change maneuvers:

- SC = Standard climb
- SD = Standard descent
- FC = ITP Following climb
- FD = ITP Following descent

- LC = ITP Leading climb
- LD = ITP Leading descent
- CC = ITP Combined climb
- CD = ITP Combined descent

and the achievability of the flight level change:

- Yes (AC = Accept)
- No (RJ = Reject, or UA = Unable)

A flight level change was not achievable if either the target and/or intermediate flight level was blocked by traffic aircraft of which the subject pilot was unaware (RJ, i.e., controller rejects the flight level change request) or blocked by traffic aircraft of which the subject pilot was aware (UA, i.e., the pilot should not request the flight level change, or should reject the ITP clearance received). The achievability of the flight level change could be restricted by:

- Distance to reference aircraft not meeting ITP distance criteria (UAD)
- Ground speed differential of reference aircraft not meeting ITP speed criteria (UAG)
- Failed reassessment (i.e., reference aircraft no longer meet ITP criteria upon receiving an ITP clearance, so the clearance must be rejected) (UAR)
- Observable traffic blocking the maneuver (UAT)

To prevent sequence effects, which scenarios would be accepted, rejected, or unable to be completed were randomly chosen. This resulted in the following list of scenarios:

- |     |         |  |
|-----|---------|--|
| 1.  | SC1_AC  | Standard Climb through 1 FL – Accepted                                   |
| 2.  | SC1_RJ  | Standard Climb through 1 FL – Rejected                                   |
| 3.  | SD1_AC  | Standard Descent through 1 FL – Accepted                                 |
| 4.  | SD1_RJ  | Standard Descent through 1 FL – Rejected                                 |
| 5.  | FC1_AC  | Following Climb through 1 FL – Accepted                                  |
| 6.  | FC1_RJ  | Following Climb through 1 FL – Rejected                                  |
| 7.  | FD1_AC  | Following Descent through 1 FL – Accepted                                |
| 8.  | FD1_UAD | Following Descent through 1 FL - Unable due to Distance                  |
| 9.  | LC1_AC  | Leading Climb through 1 FL – Accepted                                    |
| 10. | LC1_UAR | Leading Climb through 1 FL - Unable due to Reassessment of ITP criteria  |
| 11. | LD1_AC  | Leading Descent through 1 FL – Accepted                                  |
| 12. | LD1_UAT | Leading Descent through 1 FL - Unable due to Traffic                     |
| 13. | CC1_AC  | Combined Climb through 1 FL – Accepted                                   |
| 14. | CC1_UAR | Combined Climb through 1 FL - Unable due to Reassessment of ITP criteria |
| 15. | CD1_AC  | Combined Descent through 1 FL – Accepted                                 |
| 16. | CD1_UAG | Combined Descent through 1 FL - Unable due to Ground Speed               |

Each scenario was designed using a graphics program. Aircraft significant to the scenario were placed in a way that resulted in the desired maneuver, while other aircraft were added to improve the operational realism (Figure 15). A full list of all experiment scenarios can be found in Appendix G. Care was taken to prevent

unexpected pilot actions by making the desired maneuvers unambiguous. In the example of Figure 15, the blue ITP Aircraft was placed such that an ITP request was required, using the red aircraft as a reference. The aircraft at the desired altitude was placed outside the oceanic separation requirement of 10 minutes (approximately 80 nm).

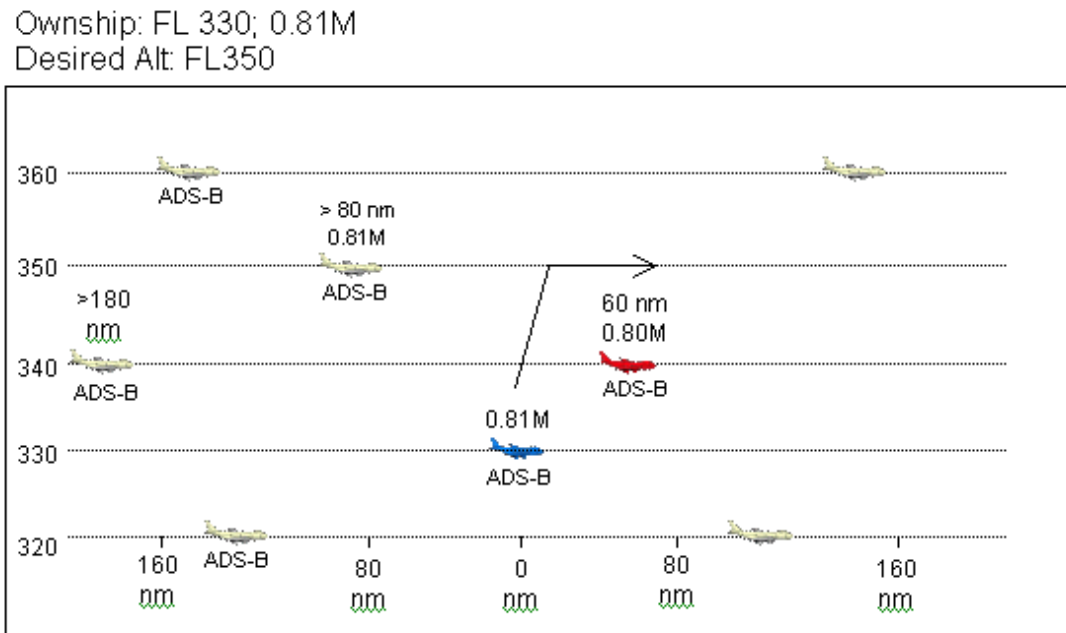


Figure 15. Following Climb through 1 FL – Accept

Once created, unique scenarios were combined into experiment sets to present each subject pilot with a different maneuver. Experiment sets included all available tracks and were randomly chosen to be either Eastbound or Westbound. An example of an Eastbound experiment set is provided in Table 2.

Table 2. Eastbound experiment set 1 (ITP\_Exp\_Set\_1\_EAST)

| Subject Pilot: | Track: | Scenario     |
|----------------|--------|--------------|
| ASTOR 1        | X      | CD1_UAG_EAST |
| ASTOR 2        | W      | CC1_AC_EAST  |
| ASTOR 3        | U      | SC1_RJ_EAST  |
| ASTOR 4        | Y      | LD1_AC_EAST  |
| ASTOR 5        | T      | FC1_RJ_EAST  |
| ASTOR 6        | V      | SC1_AC_EAST  |

In total, 32 experiment sets were created (16 experiment scenarios x 2 directions of flight). Subject Pilots 1-6 flew experiment set 1-16, and Subject Pilots 7-12 flew experiment sets 17-32. The scenarios within each set were again randomized to prevent any sequence effects during the experiment.

In addition to the test condition scenarios, the subject pilots were also asked to complete seven supplemental scenarios. One of the supplemental scenarios is shown in Figure 16, and the remaining six are presented in Appendix H. The scenario shown in Figure 16 involved a 4,000 ft climb by the ownship aircraft (shown in blue) with opposing traffic and reference aircraft (shown in red) on different altitudes.

Ownship: FL 330; 0.81M  
 Desired Alt: FL370

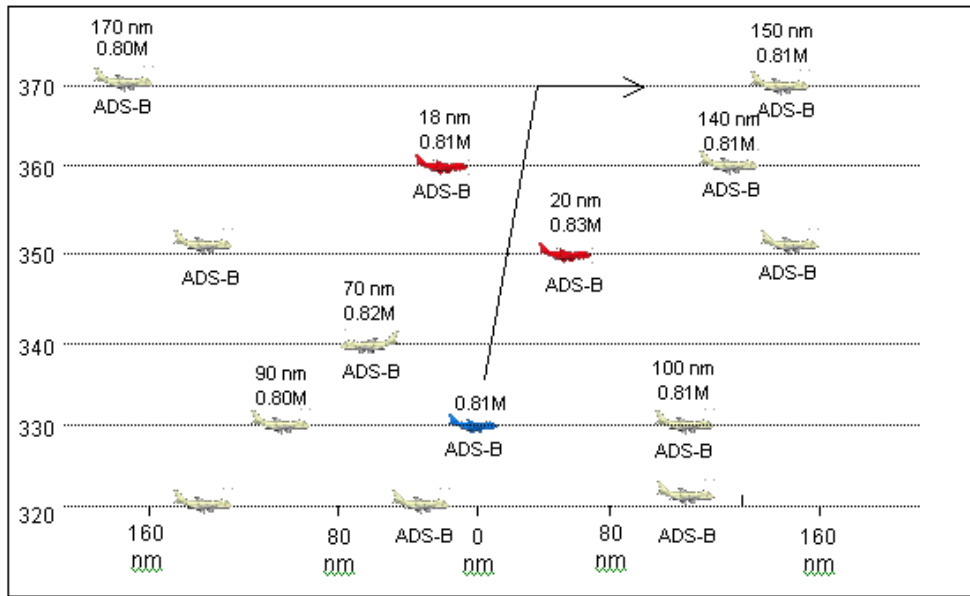


Figure 16. CC3\_POST\_EXP scenario

The purpose of the supplemental scenarios was to test the use of the ITP during more complex situations such as flight level changes greater than 2,000 ft, opposite direction traffic, and reference aircraft on more than one intervening flight level. All of the supplemental scenarios are listed below.

- |                 |   |
|-----------------|---|
| 1. CC3_POST_EXP | Combined Climb through 3 FL – Leading / Following - Accepted        |
| 2. CC3_LF_AC    | Combined Climb through 3 FL – Leading / Following - Accepted        |
| 3. CC2_LF_AC    | Combined Climb through 2 FL – Leading / Following - Accepted        |
| 4. CC2_FF_AC    | Combined Climb through 2 FL – Following / Following - Accepted      |
| 5. CC2_LL_AC    | Combined Climb through 3 FL – Leading / Leading - Accepted          |
| 6. FC3_UAT      | Following Climb through 3 FL – Unable Traffic                       |
| 7. CC3_LF_UAD   | Combined Climb through 2 FL – Leading / Following – Unable Distance |

## Experiment Procedure

Subject pilots participated in the EOO HITL ITP Validation Simulation Study in groups of up to four, with each group participating in the study over the course of two consecutive days. Subject pilots arrived at the ATOL at 8:00 a.m. (EDT) on the first day of the experiment and completed a pre-experiment session, a comprehensive period of training exercises (described below in the “Training” section), and eight of the experiment’s 16 test conditions before concluding the day’s activities no later than 5 p.m. On the second day of the experiment, subject pilots arrived at the ATOL at 7:30 a.m. and completed a brief refresher training session, the remaining eight test conditions, a post-experiment questionnaire, a post-experiment supplemental data collection session, and a post-experiment group debrief session before the study was concluded at 3 p.m. (Note that the subject pilots were provided with several breaks and a 45-minute lunch period each day.)

The first day of the experiment began with a 45-minute pre-experiment session during which the subject pilots were provided with an introductory overview of NASA’s EOO project. Following this brief presentation to the group, the subject pilots were asked to individually read and sign an informed consent document (Appendix I) and complete a demographic information questionnaire (Appendix J). After the pre-experiment session, subject pilots were given approximately 30 minutes to re-review the Oceanic Operations ITP FMB that they had been given the preceding evening and were then given two 45-minute viewgraph-style presentations

described in the Training section. Following a 45-minute lunch break, subject pilots completed a “video wall” ITP training session. After the video wall training, the subject pilots spent approximately 30 minutes completing the hands-on ASTOR training and becoming familiar with the MCH Rating Scale and post-scenario questionnaire. Following this, subject pilots were given the opportunity to pose questions to the researchers and were then asked to individually complete a post-training quiz (Appendix K). The completion of the quiz and final question-and-answer session required approximately 30 minutes.

During the remaining three hours of the experiment’s first day, the subject pilots used the ASTOR stations to individually perform eight of the experiment’s 16 test conditions. After each simulated flight scenario, the subject pilots individually completed a MCH Rating Scale response form and a post-scenario questionnaire.

The second day of the experiment began with a 15-minute review during which the researchers stepped through the performance of an ITP flight scenario to provide the group of subject pilots with a brief period of refresher training. Following this, the subject pilots spent approximately three hours using the ASTOR stations to individually perform the experiment’s final eight test conditions. As before, the subject pilots individually completed a MCH Rating Scale response form and a post-scenario questionnaire after each simulated flight scenario. Once the final test condition’s post-scenario questionnaire was completed, each subject pilot was asked to complete a post-experiment questionnaire. Completion of the post-experiment questionnaire required approximately 30 minutes.

Following a 45-minute lunch break, the subject pilots used the ASTOR stations to individually complete six simulated flight scenarios as part of a 1-hour supplemental data collection effort. Again, each subject pilot completed MCH Rating Scale response forms and post-scenario questionnaires after the performance of each scenario. Once the supplemental data collection effort was completed, the subject pilots and researchers spent the remainder of the afternoon (approximately 1.5 hours) discussing various topics, both planned and spontaneous, during a post-experiment group debrief session.

## **Training**

The overall objective of the experiment training was to train the subject pilots to performance standard and as a result minimize “learning effects” during the experiment scenarios; that is, to reasonably ensure that, prior to beginning their first experiment scenario, all participants were uniformly and fully trained in, and familiar with, the experiment tasks they were expected to accomplish. To this end, a variety of techniques were employed to train the experiment participants, not only to provide redundant coverage of the training material but also to accommodate the different learning styles and preferences of different individuals. These techniques are described below.

The experiment training actually began the evening prior to the experiment, when the participants arrived in the local area. Upon check-in to their hotel, each participant was provided with a Flight Manual Bulletin (FMB) (Appendix D) and instructed to read the bulletin prior to arriving at the experiment site on the following morning. This FMB is designed to be in a format similar to an FMB that line pilots might receive from their respective companies, and covers all aspects of the ITP concept and specific experiment tasks. The FMB starts by describing the background and purpose of the ITP and then describes the ITP systems and operations at a conceptual level. It subsequently describes specific controls, indicators, and operational procedures for the ASTOR (including the ATC communications data-link interface), EFB, and Oceanic Operations application. The FMB then provides a detailed, step-by-step ITP example, from initiation through completion of the flight level change, and concludes with an ITP checklist for use by the pilot.

The training continued on the following morning during the experiment session, when the subject pilots were given an additional block of time (approximately 30 minutes) to read and/or review the FMB. This additional time block ensured that all subject pilots had seen the FMB prior to further training, even if they were unable or



unwilling to read it on the previous evening, and provided additional exposure to the concepts and procedures using written communications means.

After their FMB review time, the experiment subject pilots received two 45-minute viewgraph-style presentations, which covered the same material as that contained in the FMB, but in an interactive, classroom setting. The first presentation described the ITP background, purpose, use, and procedures from a conceptual perspective, and the second presentation illustrated the specific steps necessary to perform experiment tasks using the ASTOR. At the outset of these presentations, the subject pilots were informed of the training objective and told to expect to see redundant coverage of the concepts and tasks to ensure complete training coverage. They were also told that they would be quizzed on the material at the end of the training sessions. Additionally, they were told that while questions were encouraged, some answers might have to be deferred until after the experiment in the interest of consistent training across participants and sessions, if the question was beyond the scope of the planned training.

Following the classroom presentations, the subject pilots were given “video wall” ITP training. The video wall is a large bank of multiple interlinked video screens in the ATOL that allows a complete set of interactive simulator displays to be concurrently projected onto a large wall-sized display surface (approximately 6 ft high by 9 ft wide), viewable in a classroom presentation setting. The video wall training enabled the subject pilots to observe the steps necessary to perform the experiment tasks on the same simulator displays that they would be using during the experiment scenarios. These steps were performed by a NASA experiment trainer flying the simulator shown on the video wall, using a prepared script to demonstrate: 1) basic ASTOR displays, indicators, and operations, 2) the controls, features, and use of the EFB and Oceanic Operations application, and 3) the steps required to evaluate, request, and execute both standard and ITP flight level changes. The decision processes required for all steps were discussed, and questions for clarification on any aspects of performing the experiment tasks were encouraged.

After the video wall training, the subject pilots were each assigned to an ASTOR station and given the opportunity to complete three training flight scenarios that were representative of the experiment scenarios. One of the training flight scenarios involved a standard flight level change request, and the other two involved ITP flight level change requests. The subject pilots were supplied with the ITP checklist (Appendix L) and were coached as necessary through all steps of the training flight scenarios. At the end of each training flight scenario, the subject pilots were given the post-scenario questionnaire and MCH Rating Scale to familiarize them with the process of filling out these materials prior to commencing the experiment scenarios. When the training flight scenarios were finished, the subject pilots were given a written quiz (Appendix K). After the quiz was completed, they were presented with the answers and asked to self-grade and correct their quizzes. The experiment training was then completed by giving the subject pilots a final opportunity to ask any questions about the experiment tasks.

It should be noted that in addition to the ITP and simulator instruction, the experiment training also included instructions that were specific to this experiment protocol. For example, in actual operations there could be many factors that might cause a crew to request a flight level change, but for this experiment, the subject pilots were instructed to always try to get as close as possible to the recommended flight level as reported by the ASTOR FMS. They were also told to expect this guidance to result in an approximately equal number of climb and descent requests across all of the scenarios, even though it was noted that in actual operations, climb requests would be more common. They were also given general guidance as to when to request a standard flight level change versus an ITP flight level change, or when to refrain from making a request. In actual operations, this decision would likely depend on a given crew’s judgment, but for this experiment they were advised, as previously described in the Pilot Procedure section, that “if in doubt [about adequate separation], request an ITP.”

## **Qualitative Data Collection**

A post-scenario questionnaire, a post-experiment questionnaire, and a post-experiment group debrief session were used to collect qualitative data from the subject pilots during and after the HITL ITP validation study. Each of these qualitative data collection tools is described below.

### ***Post-Scenario Questionnaire***

Subject pilots completed a post-scenario questionnaire (Appendix E) after each of the experiment's 16 test conditions. The purpose of this questionnaire was to collect data regarding: why subject pilots chose not to request a flight level change during certain test conditions (e.g., an observable traffic aircraft prevented the execution of an ITP maneuver); the ability of subject pilots to understand why a given flight level change request was denied by ATC based on information provided via the ITP display (e.g., a traffic aircraft that was not visible to the subject pilot via ADS-B or TCAS prevented the execution of an ITP maneuver); the perceived correctness, completeness, appropriate specification, and logical sequencing of the procedural steps outlined for use during each ITP flight level change; subject pilots' suggestions for performing a given flight level change differently; and subject pilots' suggestions for improving the ITP display interface.

### ***Post-Experiment Questionnaire***

Subject pilots completed a post-experiment questionnaire (Appendix F) after performing the experiment's final test condition. Subject pilots used this questionnaire to record their impressions of: the overall manner in which the experiment was conducted; the adequacy of the training that they received prior to performing the experiment's first test condition; the experiment's simulated flight scenarios and desktop flight simulator; the acceptability of the ITP and any ITP performance concerns; their use of the Oceanic Operations ITP Checklist; the workload levels that they experienced during the experiment; the perceived benefits of the ITP; the level of safety associated with performing the ITP as compared with current day procedures; the ITP display interface and the phraseology used when performing the ITP; and the ease of reverting back to standard procedures in the event that an ITP flight level change maneuver was abandoned.

### ***Post-Experiment Group Debrief Session***

During the final 1.5-hour period that they spent together, the subject pilots and researchers engaged in a post-experiment group debrief session in which they discussed various topics, both planned (Appendix M) and spontaneous, related to the ITP concept, the performance of ITP flight level change maneuvers, and the execution of the ITP HITL simulation study. The purpose of this debrief session was to answer any questions that the subject pilots wanted to ask and to collect the subject pilots' comments regarding the experiment itself and, more importantly, the validity and acceptability of the ITP. Specific feedback was elicited from the subject pilots regarding their impressions of: the benefits and operational improvements potentially gained through the use of the ITP; possible ITP display enhancements that could improve performance and situation awareness; the usefulness of the ITP display in domestic en-route or terminal environments; any ITP safety concerns; and how pilots might react during a variety of situations that could be encountered while performing the ITP [e.g., what kind of action(s) pilots might take if they observed that their separation from a reference aircraft had decreased to a certain distance during an ITP maneuver].

## **Quantitative Data Collection**

Quantitative data were collected using TMX. The data that were of most interest included the correctness of the request and the adherence to the procedural requirements. For that purpose TMX recorded the data-link requests, ATC assessments and procedure adherence. Furthermore, track data (comma-delimited aircraft parameters data) were collected to analyze aircraft performance and state.

Every request received by “ATC” was validated against an assessment that TMX made based on the data contained in its internal ADS-B and ITP models. Disparities between the subject pilot request and the request assessment by TMX were identified and logged as an assessment failure (i.e., selection error). In addition to the request assessment and validation (i.e., execution errors), TMX also logged the number of times that aircraft failed to maintain assigned Mach number and the number of aircraft failing to maintain a minimum vertical speed of 300 fpm during the maneuver.

All data-link messages between the subject pilots and the ATC model were logged. This included position report messages as well as all flight level change request related messages. Each message was logged with a timestamp (both simulation wall-clock time as well as simulation run-time), source identifier, and destination identifier. These data could be used to examine whether or not the subject pilot followed all correct procedural steps.

TMX also logged specific aircraft parameters to track the position and state of all aircraft in the scenario. These track or history data were logged in a comma-delimited file so that a spreadsheet program could be used for data analysis.

In case any ambiguity remained, either about the request or the procedural steps taken, it was possible to playback and review the ASTOR displays, showing exactly what happened during the experiment run. This review provided the final determination as to whether or not the subject pilot followed the procedure correctly.

## **Results and Discussion**

### **Overview**

In presenting and discussing the results obtained from the experiment, it is useful to start by revisiting the initial two objectives of the study: to assess 1) the validity of, and 2) pilot acceptability of, the ITP. This experiment represented a first opportunity to present line pilots with the ITP in simulated operations, with an initial prototype Oceanic Operations application, and to evaluate their ITP performance and impressions. It was not intended as a quantitative safety assessment of the ITP nor of the initial prototype application, but rather as an initial qualitative assessment, and therefore no specific success/failure criteria were defined a priori to evaluate ITP validity. Similarly, the only acceptability criterion established beforehand was that workload ratings of “3” or less on the MCH Rating Scale would be considered acceptable.

When the overall results are examined, it is apparent that in the majority of scenarios, subject pilots were able to correctly assess the traffic situation and select an appropriate response (i.e., either a standard flight level change request, an ITP request, or no request), and to execute their selected flight level change procedure, if any, without error. It is also apparent that the workload ratings for ITP maneuvers were operationally acceptable and not substantially higher than for standard flight level change maneuvers and that, for the majority of scenarios and subject pilots, the subjective acceptability ratings and comments for ITP were generally high and positive. It could then be asserted that, from a first-order qualitative point of view, the ITP is generally both valid and acceptable. However, the error rates for ITP maneuvers were higher than for standard flight level changes, and these errors have design implications for both the ITP and the prototype traffic display.

The next two sub-sections present quantitative data for, and statistical analyses of, the subject pilots’ procedure selection errors and execution errors, respectively, along with discussions of their implications. Subsequent sub-sections present results of the pilots’ subjective assessments of the ITP’s validity, acceptability, and workload, respectively, along with statistical analyses of the workload results. The final sub-section presents results from the additional, more complex ITP scenarios that the pilots performed as part of the supplemental data collection effort after the experiment scenarios.

A 5-percent significance level for the statistical analyses of all data collected in this experiment was set *a priori*.

## **Selection Errors**

Each scenario presented to the subject pilots was designed to elicit one expected action from the pilot. That is, for each scenario, the subject pilot was expected to make either a standard flight level change request, or an ITP request of some type (leading, following or combined), or no request, based on their evaluation of the traffic situation displayed on the Oceanic Operations application. For example, “standard” scenarios were designed with no traffic displayed on the intervening flight level, so there was no need for an ITP request and a standard flight level change request would be appropriate. Similarly, “ITP” scenarios were designed with traffic displayed on the intervening flight level that would block a standard request, based on NATOTS separation standards. If the blocking aircraft met ITP reference aircraft conditions, then the subject pilot was expected to make an appropriate ITP flight level change request; otherwise, the subject pilot was expected to make no request. During their training, the subject pilots were instructed to consider an ITP request, rather than a standard request, for any scenario in which they were unsure whether NATOTS standard separation existed at the intervening flight level.

It should be noted that in today’s flight environment it would not be erroneous for a pilot to request a flight level change in the presence of blocking traffic; in contrast with the air traffic controller’s responsibilities, the pilot is currently not expected to be aware of all other conflicting traffic nor of the specific separation rules in effect, and can make a request at any time. This would also be the case in a future ITP environment; a correctly-made standard or ITP request would not be considered erroneous if made in the presence of blocking traffic (but the controller would deny the request due to that traffic, just as in today’s flight environment). In this experiment, though, the subject pilots were asked to use the traffic information on the Oceanic Operations application along with their training guidelines and best judgment in selecting an appropriate action, so unexpected actions (including ITP requests with missing or extra reference aircraft) were considered “selection errors.” In effect, the selection error measurement is an assessment of the subject pilots’ understanding of, and judgment in, the use of the displayed traffic information to make an informed request to ATC.

Collectively, the 12 subject pilots performed 192 simulated flight scenarios while completing the experiment’s 16 test conditions:

- 4 scenarios during which subject pilots were expected to request standard flight level changes x 12 subject pilots = 48, and
- 12 scenarios during which subject pilots were expected to consider requesting ITP flight level changes x 12 subject pilots = 144.

From this point forward, the scenarios during which subject pilots were expected to *request* standard flight level changes will be referred to as “expected standard scenarios,” and the scenarios during which subject pilots were expected to *consider requesting* ITP flight level changes will be referred to as “expected ITP scenarios.” Note that in 3 of the 12 (or 36 of the 144 total) expected ITP scenarios, the pilots were ultimately expected to make no request after evaluating the scenarios, due to either observable blocking aircraft or ITP criteria not being met.

Overall, the subject pilots made 19 selection errors out of the 192 scenarios, yielding an overall selection error rate of 9.9%. Of these 19 selection errors, only one involved inappropriately requesting a standard flight level change (when no request was expected, due to observable blocking traffic), but 18 involved requesting an inappropriate ITP flight level change (six when a standard flight level change was expected, eight when a

different ITP request geometry was expected, and four when no request was expected due to observable blocking traffic).

During the 48 expected standard scenarios, subject pilots made a total of six ITP flight level change requests. That is, 12.5% of the time subject pilots requested an ITP flight level change when they were expected to request a standard flight level change.

Thirteen selection errors occurred during the 144 expected ITP scenarios resulting in an ITP selection error rate of 9.0%. Four of the 13 ITP selection errors involved instances in which subject pilots requested an ITP flight level change when they were expected to have realized that an ITP maneuver was not possible because an observable traffic aircraft was blocking the ITP maneuver. Seven ITP selection errors occurred when subject pilots included an additional reference aircraft (but located at the desired, rather than intervening, flight level) in their request for an expected leading or following ITP scenario. While allowed by the ATC module, the inclusion of an additional reference aircraft in these flight level change requests resulted in requests being made for combined ITP flight level change maneuvers instead of for the expected leading or following ITP flight level change maneuvers. Although this type of ITP selection error may be attributable to subject pilots' attempts to assist ATC by providing additional information, a reference aircraft (by definition) cannot be located at the desired flight level, and subject pilots were trained repeatedly with respect to this definition (these errors will be discussed in more detail later in this section). The remaining ITP selection error involved a subject pilot requesting a standard flight level change when he was expected to have realized that a standard flight level change was not possible due to blocking aircraft, nor was an ITP maneuver possible because the ground speed differential of the blocking aircraft did not meet the required ITP speed criteria for a reference aircraft.

The error rates associated with subject pilots' expected standard and ITP flight level change selections are shown in Table 3.

Table 3. Percentages of Selection Errors Associated with Expected Standard and ITP Flight Level Change Procedures

| Type of Expected Flight Level Change Procedure | Number of Selection Errors | Number of Matrix Scenarios | Percentage of Incorrect Flight Level Change Procedure Selections (Selection Errors) |
|--|----------------------------|----------------------------|---|
| Standard                                       | 6                          | 48                         | 12.5  |
| ITP  | 13                         | 144                        | 9.0   |

A McNemar Test (a nonparametric within-subject test appropriate for analyzing two related samples of nominal data) [12] was performed to determine if a significant difference existed between the number of selection errors that occurred during the 48 expected standard scenarios and the number of selection errors that occurred during the 144 expected ITP scenarios. This test revealed no significant difference ( $p = 0.4244$ ) between standard and ITP scenarios for the selection errors measure.

The overall procedure selection error rate of 9.9% indicates that while in most cases the subject pilots correctly understood how to use their traffic display to make an informed request to ATC, there was still some confusion. Whether an "error" rate of this magnitude would be operationally acceptable is beyond the scope of this study, but in all likelihood this error rate would diminish in actual operations as crews became more familiar with air traffic separation standards and the use of a traffic display to determine an appropriate request to make, or not make, to ATC.

It is significant to note that 18 of these 19 selection errors involved inappropriate ITP requests, while only one involved an inappropriate standard request. Recall that of the 18 selection errors that involved requesting an inappropriate ITP flight level change, six occurred when a standard flight level change was expected, and four

occurred when no request was expected due to observable blocking traffic (the remaining eight occurred when a different ITP request geometry was expected). One explanation for these 10 errors might be that the subject pilots were advised in their training that “if in doubt [if standard separation existed], request an ITP.” This training, combined with the fact that the subject pilots knew they were participating in an “ITP experiment,” might have predisposed them to ask for an ITP even in the presence of blocking traffic, rather than “correctly” doing nothing (i.e., making no request) during such a scenario. It might also have predisposed them to request an ITP in scenarios where a standard flight level change request was expected because there was no observable blocking traffic. However, all six of the standard flight level change scenarios with inappropriate ITP requests and all eight of the inappropriate ITP geometry requests had execution errors, implying an incomplete understanding of the ITP concepts. These execution errors will be presented and discussed in the following subsection.

## Execution Errors

Execution errors were evaluated after subject pilots chose to request a given type of flight level change maneuver. These errors could occur during the communication of a request (e.g., in the form of typographical or procedural errors) or during the performance of an ATC-approved flight level change maneuver. As a result of the subject pilots’ selection errors, there was a change in the total number of standard scenarios and ITP scenarios during which execution errors could occur. Of the original 48 expected standard scenarios, six were “converted into” ITP scenarios by the subject pilots based on their flight level change requests. Since 12 of the 13 selection errors that occurred during the expected ITP scenarios resulted from incorrect ITP flight level change requests, these 12 errors did not affect the number of expected standard scenarios versus expected ITP scenarios. However, the remaining ITP selection error resulted in the conversion of an expected ITP scenario into a standard scenario. Therefore (and as shown in Table 4):

- 48 expected standard scenarios – 6 standard selection errors + 1 ITP selection error = 43 “requested standard scenarios,” and
- 144 expected ITP scenarios + 6 standard selection errors – 1 ITP selection error = 149 “requested ITP scenarios.”

Table 4 shows the breakdown of standard and ITP scenarios requested by each subject pilot.

Table 4. Expected Standard and ITP Scenarios versus Requested Standard and ITP Scenarios

| Subject Pilot              | Standard |           | ITP      |           |
|----------------------------|----------|-----------|----------|-----------|
|                            | Expected | Requested | Expected | Requested |
| 1                          | 4        | 2         | 12       | 14        |
| 2                          | 4        | 4         | 12       | 12        |
| 3                          | 4        | 3         | 12       | 13        |
| 4                          | 4        | 3         | 12       | 13        |
| 5                          | 4        | 4         | 12       | 12        |
| 6                          | 4        | 4         | 12       | 12        |
| 7                          | 4        | 4         | 12       | 12        |
| 8                          | 4        | 4         | 12       | 12        |
| 9                          | 4        | 4         | 12       | 12        |
| 10                         | 4        | 4         | 12       | 12        |
| 11                         | 4        | 4         | 12       | 12        |
| 12                         | 4        | 3         | 12       | 13        |
| Total Number of Scenarios: | 48       | 43        | 144      | 149       |

Subject Pilot #6 is shown to have requested four standard scenarios and 12 ITP scenarios because he committed both a standard selection error and an ITP selection error that resulted in expected scenarios being converted from one type into another. Therefore, these two selection errors resulted in the final number of requested standard and ITP scenarios remaining unchanged for this particular subject pilot.

Since some execution errors could potentially be associated with more serious consequences than others, some of the execution errors described below were identified as being “safety-related execution errors.” In general, two types of errors were classified as being safety-related: 1) failures to adhere to performance requirements and 2) the inclusion of inaccurate information in a flight level change request. The errors related to performance requirements are not unique to the ITP since these errors could occur during any operation but might be more serious during an ITP due to reduced separation between aircraft compared to standard non-radar flight level changes. However, the errors involving the inclusion of inaccurate information in a flight level change request are unique to the ITP in that certain information provided in a flight level change request has the potential of either not being verified by ATC or not being seen by ATC as containing inaccuracies. For example, a pilot might mistype a reference aircraft’s call sign while requesting an ITP flight level change; but, if this mistyped call sign belongs to another aircraft located nearby, this inaccurate information might not be identified as such by ATC. While the occurrence of such situations might be rare during actual flight operations, the seriousness of the potential consequences associated with such errors warrants their classification as safety-related execution errors.

Subject pilots did not commit any execution errors during the 43 requested standard scenarios. During 29 of the 149 requested ITP scenarios (19.5%), subject pilots committed at least one execution error. Of the 29 requested ITP scenarios involving at least one execution error, nine (6.0%) were identified as involving safety-related execution errors. Table 5 depicts the subject pilots’ execution error rates for requested standard and ITP scenarios, and Table 6 depicts the subject pilots’ safety-related execution error rates for requested standard and ITP scenarios.

Table 5. Percentages of Requested Standard and ITP Scenarios Involving At Least One Execution Error

| Type of Requested Flight Level Change Procedure | Number of Scenarios with At Least One Execution Error | Number of Requested Scenarios | Percentage of Scenarios with At Least One Execution Error |
|---|---|-------------------------------|---|
| Standard  | 0   | 43                            | 0%  |
| ITP   | 29  | 149                           | 19.5%   |

A McNemar Test was performed to determine if a significant difference existed between the number of execution errors that occurred during the 43 requested standard scenarios and the number of execution errors that occurred during the 149 requested ITP scenarios. This test revealed that significantly fewer execution errors occurred during the requested standard scenarios than during the requested ITP scenarios ( $p < 0.0001$ ).

Table 6. Percentages of Requested Standard and ITP Scenarios Involving At Least One Safety-Related Execution Error

| Type of Requested Flight Level Change Procedure | Number of Scenarios with At Least One Safety-Related Execution Error | Number of Requested Scenarios | Percentage of Scenarios with At Least One Safety-Related Execution Error |
|---|--|-------------------------------|--|
| Standard  | 0  | 43                            | 0%   |
| ITP   | 9  | 149                           | 6.0%   |

A McNemar Test was also performed to determine if a significant difference existed between the number of safety-related execution errors that occurred during the 43 requested standard scenarios and the number of safety-related execution errors that occurred during the 149 requested ITP scenarios. This implies that significantly fewer safety-related execution errors occurred during the requested standard scenarios than during the requested ITP scenarios ( $p < 0.0001$ ).

As mentioned previously, execution errors occurred during 29 of the requested ITP scenarios. However, since it was possible for a subject pilot to make multiple errors during a single scenario, a total execution error count greater than 29 occurred. Specifically, 33 execution errors occurred during the requested ITP scenarios, and, as stated above, nine of the ITP execution errors were identified as being safety-related. Two of the safety-related ITP execution errors involved instances in which subject pilots identified a leading aircraft as a following aircraft when communicating their desire to perform an ITP flight level change to ATC. Although it was also possible for a subject pilot to incorrectly identify a following aircraft as a leading aircraft during a communication with ATC, this type of error did not occur. Two safety-related ITP execution errors occurred when subject pilots failed to include the third number of a reference aircraft's call sign in their requests to make an ITP flight level change, and three safety-related ITP execution errors occurred when subject pilots referenced an incorrect aircraft. When referencing an incorrect aircraft, the subject pilots transposed or incorrectly entered one or two of the letters in the three-letter airline code. For example, one subject pilot entered "DHL615" rather than "DLH615." In another case a subject pilot entered "DAL615" instead of "DLH615." The remaining two safety-related ITP execution errors occurred when one subject pilot failed to adhere to the aircraft performance criteria required during two different requested ITP scenarios. In one instance, the subject pilot failed to maintain his required Mach number. The subject made a speed change of 0.01 Mach that allowed a maneuver that otherwise would not have been possible. In the other instance, the same subject pilot failed to maintain required vertical speed. The subject pilot entered a 1,000 foot altitude change via the desktop simulator's MCP resulting in a positive vertical speed over a span of 10 seconds during which the aircraft climbed approximately 20 ft while performing a descent maneuver. While a 20 ft deviation in the opposite direction is not operationally significant from a vertical separation point of view, it would result in extending the overall time required to complete the flight level change and could thus potentially result in a loss of longitudinal separation.

Twenty-four non-safety-related execution errors occurred during the scenarios involving ITP flight level changes. Sixteen of these ITP execution errors involved instances in which subject pilots referenced an aircraft at the desired flight level during a flight level change request; three errors involved subject pilots requesting a climb or descent to an incorrect flight level; three errors were related to syntax errors in the ITP phraseology; one error occurred when a subject pilot failed to comply with the ATC instruction to "report reaching" when level at the completion of the approved maneuver (per ICAO procedures for oceanic/remote flight operations); and one ITP execution error involved a subject pilot failing to acknowledge ATC's denial of an ITP flight level change request (per the briefed standard procedures for data-linked ATC communications) before making a second ITP flight level change request.

In addition to examining the percentages of requested standard and ITP scenarios involving the occurrence of at least one execution error or safety-related execution error, the distribution of execution errors (both safety-related and non-safety-related) was examined according to subject pilot, type of flight level change maneuver, ITP geometry, direction of flight level change maneuver (i.e., climb versus descent), achievability of flight level change maneuver, and direction of flight (i.e., Eastbound versus Westbound). Since execution errors did not occur during the requested standard scenarios, requested standard climb and descent maneuvers are discussed only in conjunction with the distribution of execution errors across the different types of flight level change maneuvers. Specific types of flight level change maneuvers are not discussed in conjunction with the distribution of execution errors across individual subject pilots. Requested ITP flight level change maneuvers are discussed in conjunction with the distribution of execution errors across ITP geometries, direction of flight level change maneuvers, achievability of flight level change maneuvers, and directions of flight.



### *ITP Execution Errors by Subject Pilot*

The distribution of ITP execution errors across individual subject pilots is presented in Figure 17. In this figure, groups of subject pilots who participated in the experiment during the same two day period are indicated by the vertical lines within the area delineated by the x and y axes. For example, Subject Pilots #1 and #2 participated in the experiment together, and Subject Pilots #3, #4, and #5 participated in the experiment together. Note that although at least three subject pilots always participated in the experiment together, data from some subject pilots were not usable due to simulation glitches and/or data recording errors, and these subject pilots are not shown in the figure (nor were their data analyzed or reported in this paper).

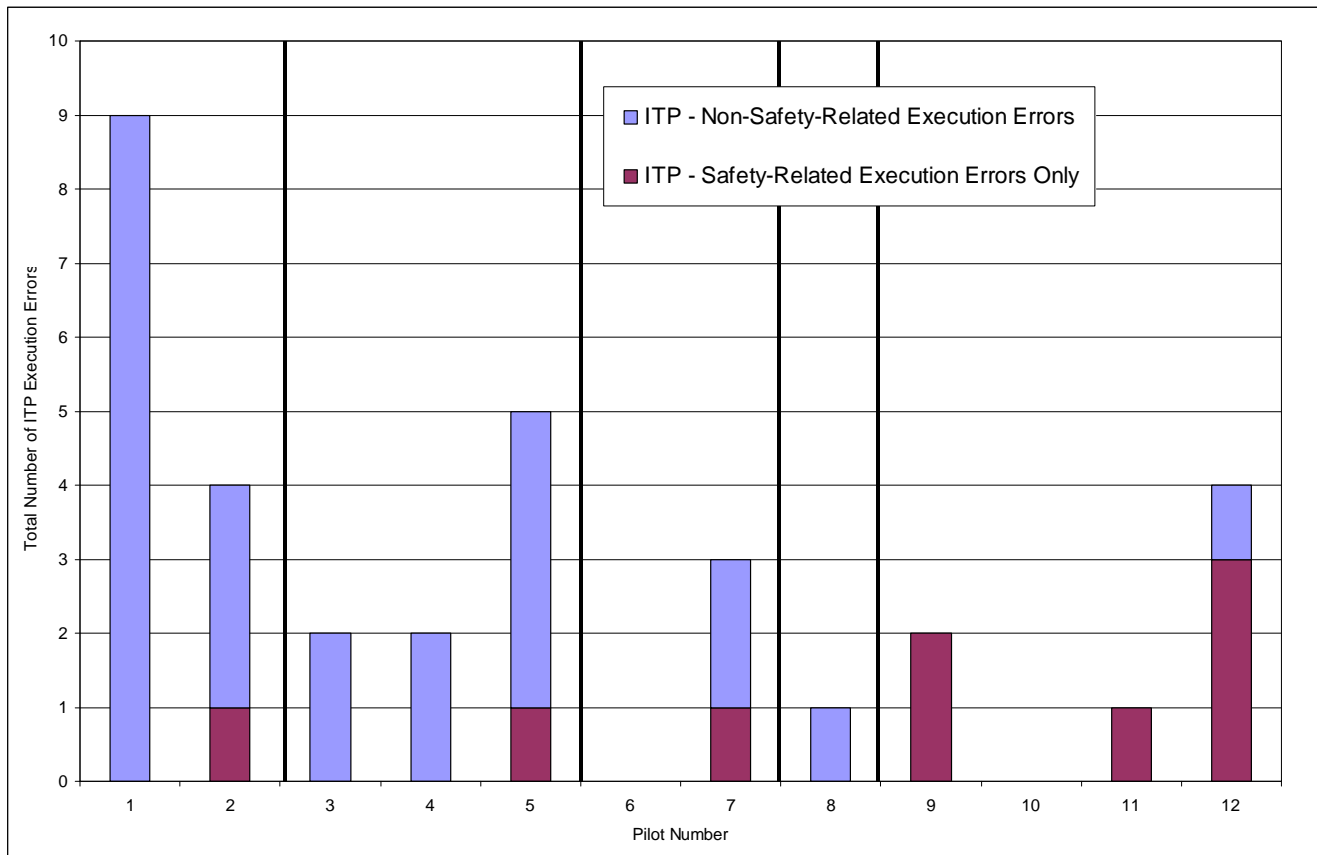


Figure 17. Total number of execution errors associated with individual subject pilots

As shown in Figure 17, two subject pilots (i.e., #6 and #10) did not commit any execution errors; and of the 10 subject pilots that did commit errors, nine committed five or less. Six subject pilots committed safety-related execution errors, but four of these subject pilots committed only a single safety-related error. One subject pilot committed two safety-related execution errors, and one subject pilot committed three safety-related execution errors. One subject pilot committed nine execution errors, but none of his errors were safety-related. Since individual differences are expected to occur among research participants, no statistical analysis was performed in conjunction with the execution error rates associated with individual subject pilots.

Cochran's Q Tests and McNemar Tests (nonparametric within-subject tests appropriate for analyzing related samples of nominal data) [12][13] were performed in conjunction with the total number of execution errors associated with the different types of flight level change maneuvers, ITP geometries, directions of flight level change maneuver, achievability of flight level change maneuvers, and directions of flight. Graphical presentations of the percentages of requested scenarios involving safety-related execution errors versus non-safety-related execution errors are provided, and total numbers of safety-related execution errors versus non-

safety-related execution errors and percentages of requested scenarios involving safety-related execution errors versus non-safety-related execution errors are presented in tabular form as well.

**Execution Errors by Type of Flight Level Change Maneuver**

The distribution of execution errors across the different types of flight level change maneuvers is presented in Figure 18 (means associated with different capital letters are significantly different in McNemar Tests at  $p < 0.05$ ). Within this graph, the numbers in parentheses shown with the x-axis' labels of flight level change maneuver type correspond to the number of requested scenarios calculated using the data presented in Table 7. Within Table 7, The "Total Number of Scenarios" corresponds to the "Total Number of Test Conditions involving a Particular Type of Flight Level Change Maneuver."

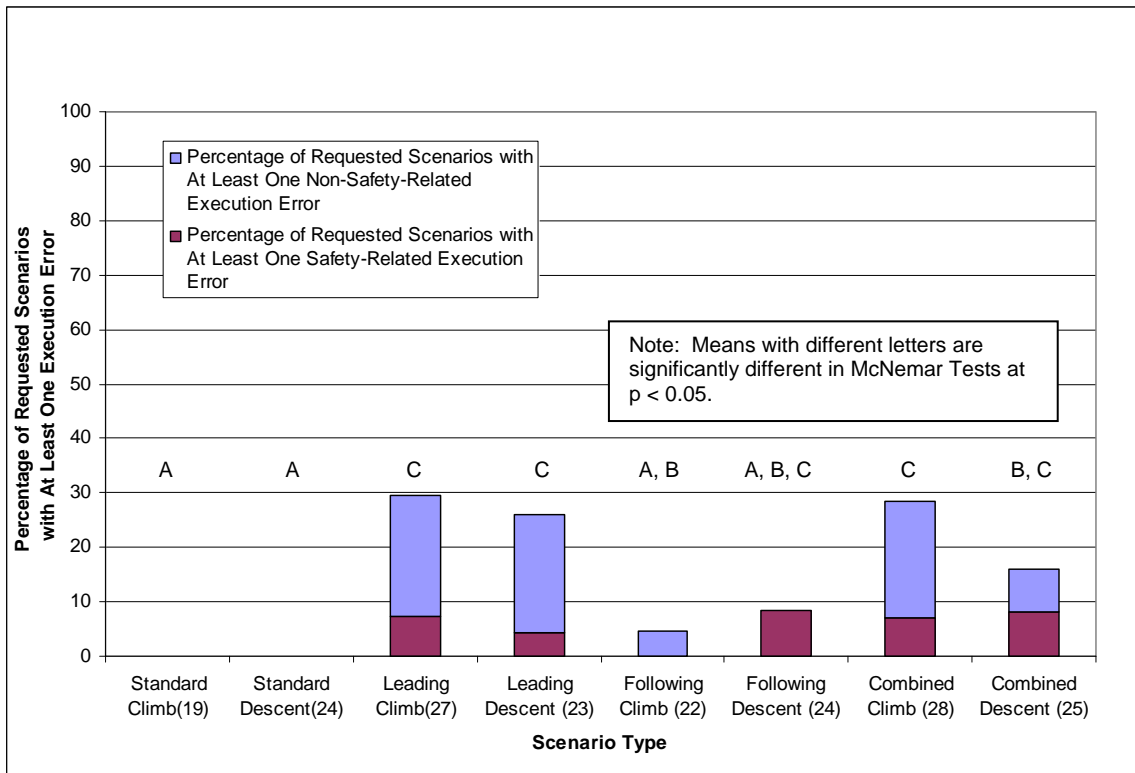


Figure 18. Percentages of requested types of flight level change maneuvers that had at least one execution error

Table 7. Expected versus Requested Type of Flight Level Change Maneuver

| Subject Pilot              | Flight Level Change Maneuvres<br>Expected vs. Requested |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|----------------------------|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|                            | SC  | SC | SD | SD | LC | LC | LD | LD | FC | FC | FD | FD | CC | CC | CD | CD |
| 1                          | 2   | 1  | 2  | 1  | 2  | 2  | 2  | 3  | 2  | 1  | 2  | 2  | 2  | 4  | 2  | 2  |
| 2                          | 2   | 2  | 2  | 2  | 2  | 1  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 3  | 2  | 2  |
| 3                          | 2   | 1  | 2  | 2  | 2  | 3  | 2  | 1  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 3  |
| 4                          | 2   | 1  | 2  | 2  | 2  | 3  | 2  | 2  | 2  | 1  | 2  | 2  | 2  | 3  | 2  | 2  |
| 5                          | 2   | 1  | 2  | 3  | 2  | 3  | 2  | 1  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 6                          | 2   | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 7                          | 2   | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 8                          | 2   | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 9                          | 2   | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 10                         | 2   | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 11                         | 2   | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| 12                         | 2   | 1  | 2  | 2  | 2  | 3  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| Total Number of Scenarios: | 24  | 19 | 24 | 24 | 24 | 27 | 24 | 23 | 24 | 22 | 24 | 24 | 24 | 28 | 24 | 25 |

Note: “SC” = Standard Climb; “SD” = Standard Descent; “LC” = ITP Leading Climb; “LD” = ITP Leading Descent; “FC” = ITP Following Climb; “FD” = ITP Following Descent; “CC” = ITP Combined Climb; and “CD” = ITP Combined Descent.

Total numbers of safety-related execution errors and non-safety-related execution errors are presented in Table 8.

Table 8. Distribution of Execution Errors across Different Types of Requested Flight Level Change Maneuvers

| Requested Flight Level Change Maneuver | Number of Non-Safety-Related Execution Errors | Number of Safety-Related Execution Errors | Total Number of Execution Errors |
|--|---|---|----------------------------------|
| Leading Climb                          | 6   | 2   | 8                                |
| Leading Descent                        | 8   | 1   | 9                                |
| Following Climb                        | 1   | 0   | 1                                |
| Following Descent                      | 0   | 2   | 2                                |
| Combined Climb                         | 7   | 2   | 9                                |
| Combined Descent                       | 2   | 2   | 4                                |

A Cochran’s Q Test was performed to determine if a significant difference existed among the total number of execution errors that occurred during the requested types of flight level change maneuvers. Since this test revealed a significant difference between the number of execution errors that occurred during at least two of the requested types of flight level change maneuvers ( $Q[7] = 27.3974$ ;  $p = 0.0003$ ), McNemar Tests were performed to determine which of the requested types of flight level change maneuvers were associated with significantly different numbers of execution errors. With respect to statistically significant differences revealed by the McNemar Tests ( $p < 0.05$ ), it was found that:

- Significantly fewer execution errors occurred during the requested standard climb maneuvers and the requested standard descent maneuvers than during the requested leading climb maneuvers, the requested leading descent maneuvers, the requested combined climb maneuvers, and the requested combined descent maneuvers; and
- Significantly fewer execution errors occurred during the requested following climb maneuvers than during the requested leading climb maneuvers, the requested leading descent maneuvers, and the requested combined climb maneuvers.

With respect to non-significant differences revealed by the McNemar Tests ( $p \geq 0.05$ ), it was found that, statistically speaking:

- The same number of execution errors occurred during the requested standard climb maneuvers, the requested standard descent maneuvers, the requested following climb maneuvers, and the requested following descent maneuvers;
- The same number of execution errors occurred during the requested following climb maneuvers, the requested following descent maneuvers, and the requested combined descent maneuvers; and
- The same number of execution errors occurred during the requested following descent maneuvers, the requested leading climb maneuvers, the requested leading descent maneuvers, the requested combined climb maneuvers, and the requested combined descent maneuvers.

### ***Execution Errors by ITP Geometry***

As described in the “In-Trail Procedure” section of this document, the ITP geometries included leading maneuvers, following maneuvers, and combined maneuvers. The reference aircraft is located behind the ITP Aircraft during a leading maneuver, and the reference aircraft is located ahead of the ITP Aircraft during a following maneuver. During a combined maneuver, which involves both a leading and a following reference aircraft, there is a reference aircraft located ahead of and behind the ITP Aircraft. Due to subject pilot selection errors, there were also two requested ITP scenarios that involved a combined maneuver with two leading reference aircraft instead of one leading and one following reference aircraft. During these two requested ITP scenarios, both reference aircraft were located behind the ITP Aircraft.

The distribution of execution errors across the different ITP geometries is presented in Figure 19 (means associated with different capital letters are significantly different in McNemar Tests at  $p < 0.05$ ). Within this graph, the numbers in parentheses shown with the x-axis’ labels of ITP geometries correspond to the number of requested scenarios that occurred during the experiment. Table 9 presents the data used to calculate the number of requested leading, following, and combined flight level change maneuvers. Within Table 9, the “Total Number of Scenarios” corresponds to the “Total Number of Test Conditions involving a Particular ITP Geometry.” Total numbers of safety-related execution errors and non-safety-related execution errors are presented in Table 10.

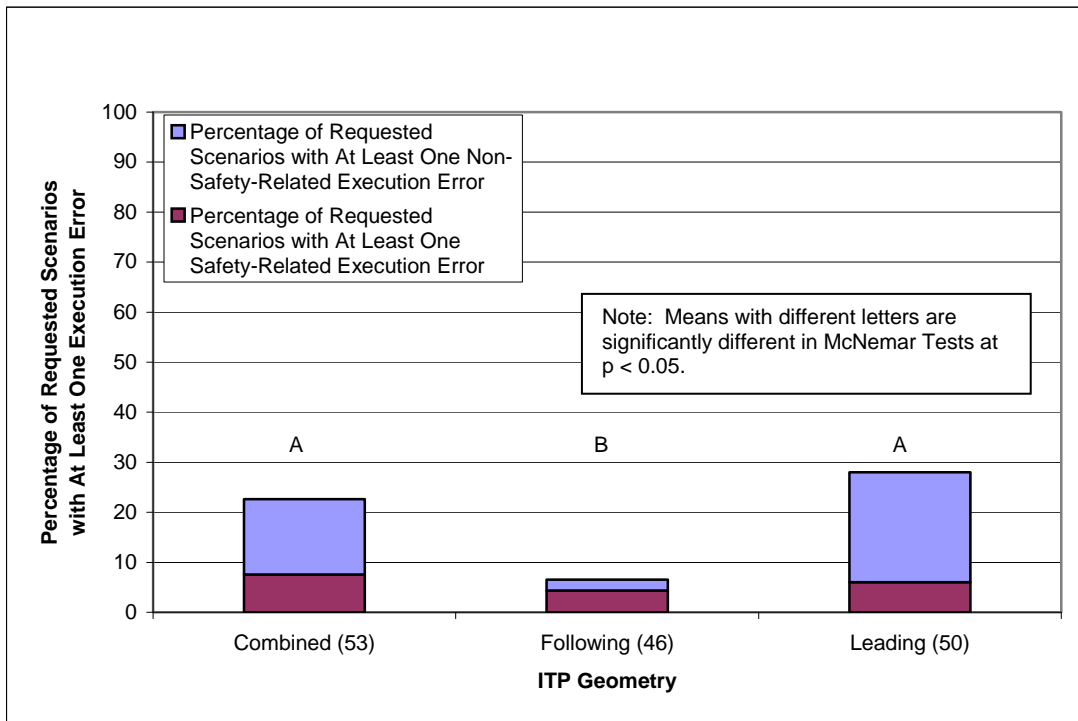


Figure 19. Percentages of requested ITP geometries that had at least one execution error

Table 9. Expected versus Requested ITP Geometries

| Subject Pilot             | ITP Geometries    |                    |                    |                     |                  |                   |
|---------------------------|-------------------|--------------------|--------------------|---------------------|------------------|-------------------|
|                           | Expected Combined | Requested Combined | Expected Following | Requested Following | Expected Leading | Requested Leading |
| 1                         | 4                 | 6                  | 4                  | 3                   | 4                | 5                 |
| 2                         | 4                 | 5                  | 4                  | 4                   | 4                | 3                 |
| 3                         | 4                 | 5                  | 4                  | 4                   | 4                | 4                 |
| 4                         | 4                 | 5                  | 4                  | 3                   | 4                | 5                 |
| 5                         | 4                 | 4                  | 4                  | 4                   | 4                | 4                 |
| 6                         | 4                 | 4                  | 4                  | 4                   | 4                | 4                 |
| 7                         | 4                 | 4                  | 4                  | 4                   | 4                | 4                 |
| 8                         | 4                 | 4                  | 4                  | 4                   | 4                | 4                 |
| 9                         | 4                 | 4                  | 4                  | 4                   | 4                | 4                 |
| 10                        | 4                 | 4                  | 4                  | 4                   | 4                | 4                 |
| 11                        | 4                 | 4                  | 4                  | 4                   | 4                | 4                 |
| 12                        | 4                 | 4                  | 4                  | 4                   | 4                | 5                 |
| Total Number of Scenarios | 48                | 53                 | 48                 | 46                  | 48               | 50                |

Table 10. Distribution of Execution Errors across Different Types of Requested ITP Geometries

| Requested ITP Geometry | Number of Non-Safety-Related Execution Errors | Number of Safety-Related Execution Errors | Total Number of Execution Errors |
|------------------------|---|---|----------------------------------|
| Combined               | 9   | 4   | 13                               |
| Following              | 1   | 2   | 3                                |
| Leading                | 14  | 3   | 17                               |

A Cochran’s Q Test was performed to determine if a significant difference existed among the total number of execution errors that occurred during the requested ITP geometries. Since this test revealed that a significant difference existed between the number of execution errors that occurred during at least two of the requested ITP geometries ( $Q [2] = 19.5000$ ;  $p = 0.0001$ ), McNemar Tests were performed to determine which of the requested ITP geometries were associated with significantly different numbers of execution errors. The McNemar Tests revealed that significantly fewer execution errors occurred during the requested following maneuvers than during the requested leading maneuvers ( $p = 0.0005$ ) and that significantly fewer execution errors occurred during the requested following maneuvers than during the requested combined maneuvers ( $p = 0.0039$ ). Statistically speaking, an equivalent number of execution errors occurred during the requested leading maneuvers and the requested combined maneuvers ( $p = 0.2500$ ). At this point, it is not clear why the error rates are lower for following maneuvers than for leading maneuvers. A possible explanation for the higher error rates with combined maneuvers would be the additional complexity of including a second reference aircraft in an ITP request, but at this point, without further data, such an explanation is little more than conjecture.

***Execution Errors by Direction of Flight Level Change Maneuver***

The distribution of execution errors associated with the different directions of the flight level change maneuvers (i.e., climbs versus descents) is presented in Figure 20. Within this graph, the numbers in parentheses shown with the x-axis’ labels of the flight level change maneuver direction types correspond to the number of requested scenarios calculated using the data presented in Table 11. Within Table 11, the “Total Number of Scenarios” corresponds to the “Total Number of Test Conditions involving a Particular Flight Level Change Maneuver Direction.” Total numbers of safety-related execution errors and non-safety-related execution errors are presented in Table 12.

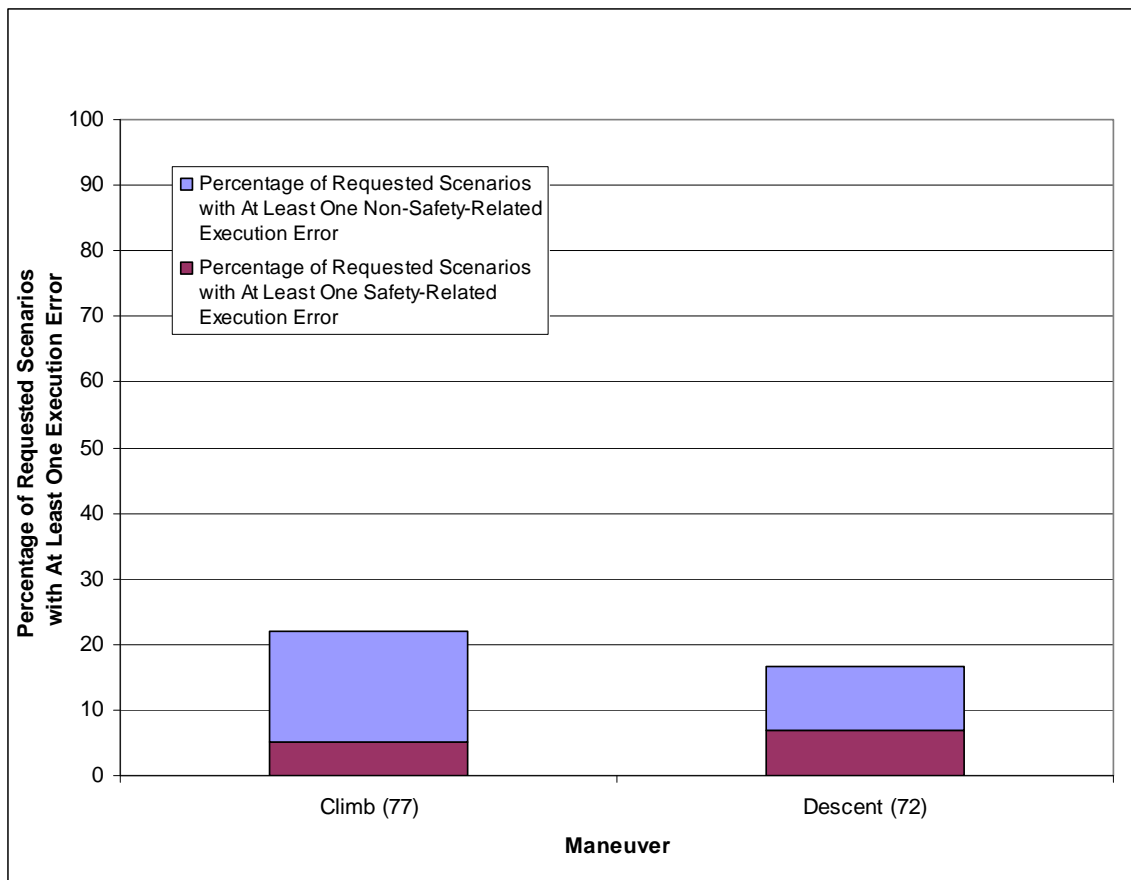


Figure 20. Percentages of requested flight level change maneuvers involving climbs versus descents that had at least one execution error

Table 11. Expected versus Requested Flight Level Change Maneuvers Involving Climbs versus Descents

| Subject Pilot             | Climb Scenarios |           | Descend Scenarios |           |
|---------------------------|-----------------|-----------|-------------------|-----------|
|                           | Expected        | Requested | Expected          | Requested |
| 1                         | 6               | 7         | 6                 | 7         |
| 2                         | 6               | 6         | 6                 | 6         |
| 3                         | 6               | 7         | 6                 | 6         |
| 4                         | 6               | 7         | 6                 | 6         |
| 5                         | 6               | 7         | 6                 | 5         |
| 6                         | 6               | 6         | 6                 | 6         |
| 7                         | 6               | 6         | 6                 | 6         |
| 8                         | 6               | 6         | 6                 | 6         |
| 9                         | 6               | 6         | 6                 | 6         |
| 10                        | 6               | 6         | 6                 | 6         |
| 11                        | 6               | 6         | 6                 | 6         |
| 12                        | 6               | 7         | 6                 | 6         |
| Total Number of Scenarios | 72              | 77        | 73                | 72        |

Table 12. Distribution of Execution Errors associated with Different Requested Flight Level Change Maneuver Directions (i.e., Climbs versus Descents)

| Requested Flight Level Change Maneuver Direction | Number of Non-Safety-Related Execution Errors | Number of Safety-Related Execution Errors | Total Number of Execution Errors |
|--|---|---|----------------------------------|
| Climb  | 14  | 4   | 18                               |
| Descent  | 10  | 5   | 15                               |

A McNemar Test was performed to determine if a significant difference existed between the total number of execution errors that occurred during requested flight level change maneuvers involving climbs and those involving descents. This test revealed that, statistically speaking, an equivalent number of execution errors occurred during the requested flight level change maneuvers involving climbs and the requested flight level change maneuvers involving descents ( $p = 0.0625$ ).

***Execution Errors by Achievability of Flight Level Change***

The distribution of execution errors associated with the achievability of flight level changes (i.e., achievable versus unachievable) is presented in Figure 21. Within this graph, the numbers in parentheses shown with the x-axis' labels correspond to the number of requested scenarios calculated using the data presented in Table 13. Within Table 13, the "Total Number of Scenarios" corresponds to the "Total Number of Test Conditions involving the Achievability of Flight Level Change." Total numbers of safety-related execution errors and non-safety-related execution errors are presented in Table 14.

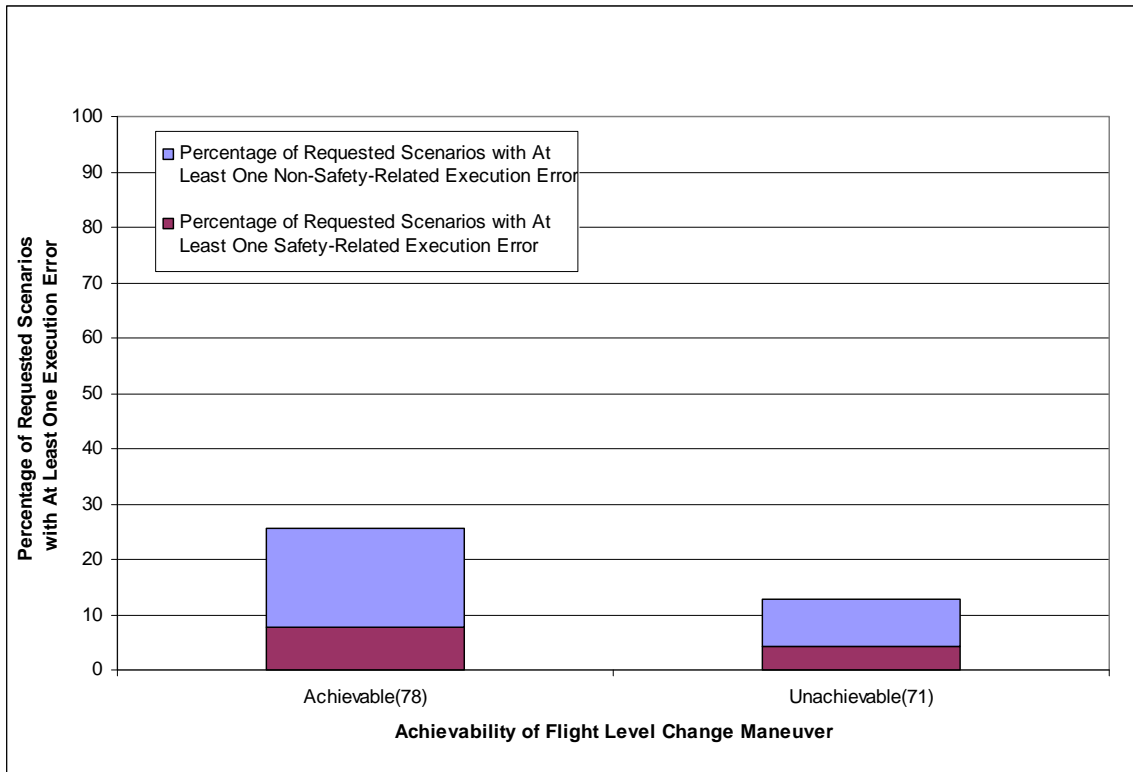


Figure 21. Percentages of requested flight level change maneuvers that were achievable or unachievable and had at least one execution error

Table 13. Expected versus Requested Types of Flight Level Change Maneuver Achievability

| Subject Pilot             | Achievable Flight Level Change Maneuver |           | Unachievable Flight Level Change Maneuver |           |
|---------------------------|---|-----------|---|-----------|
|                           | Expected                                | Requested | Expected                                  | Requested |
| 1                         | 6                                       | 8         | 6   | 6         |
| 2                         | 6                                       | 6         | 6   | 6         |
| 3                         | 6                                       | 7         | 6   | 6         |
| 4                         | 6                                       | 7         | 6   | 6         |
| 5                         | 6                                       | 7         | 6   | 5         |
| 6                         | 6                                       | 6         | 6   | 6         |
| 7                         | 6                                       | 6         | 6   | 6         |
| 8                         | 6                                       | 6         | 6   | 6         |
| 9                         | 6                                       | 6         | 6   | 6         |
| 10                        | 6                                       | 6         | 6   | 6         |
| 11                        | 6                                       | 6         | 6   | 6         |
| 12                        | 6                                       | 7         | 6   | 6         |
| Total Number of Scenarios | 72                                      | 78        | 72  | 71        |



Table 14. Distribution of Execution Errors across Different Requested Flight Level Change Maneuver Achievabilities

| Requested Type of Flight Level Change Maneuver Achievability | Number of Non-Safety-Related Execution Errors | Number of Safety-Related Execution Errors | Total Number of Execution Errors |
|--|---|---|----------------------------------|
| Achievable   | 15  | 6   | 21                               |
| Unachievable   | 9   | 3   | 12                               |

A McNemar Test was performed to determine if a significant difference existed between the total number of execution errors that occurred during the requested flight level change maneuvers that were achievable as opposed to unachievable. This test revealed that significantly fewer execution errors occurred during the requested flight level change maneuvers that were unachievable than during the requested flight level change maneuvers that were achievable ( $p = 0.0020$ ).

A partial explanation for the higher error rates observed during the achievable flight level change maneuvers is that the unachievable maneuvers left pilots with no opportunity to commit errors in the actual performance of the flight level change, e.g., failure to maintain cruise Mach or minimum vertical speed. This explanation accounts for two of the additional three safety-related execution errors incurred during the achievable maneuver scenarios, but cannot account for any of the additional non-safety related errors. The reasons for these differences are currently unknown.

***Execution Errors by Direction of Flight***

The distribution of execution errors associated with the two directions of flight (i.e., Eastbound versus Westbound) is presented in Figure 22. Within this graph, the numbers in parentheses shown with the x-axis' labels of direction of flight correspond to the number of requested scenarios calculated using the data presented in Table 15. Within Table 15, the "Total Number of Scenarios" corresponds to the "Total Number of Test Conditions involving a Particular Direction of Flight." Total numbers of safety-related execution errors and non-safety-related execution errors are presented in Table 16.

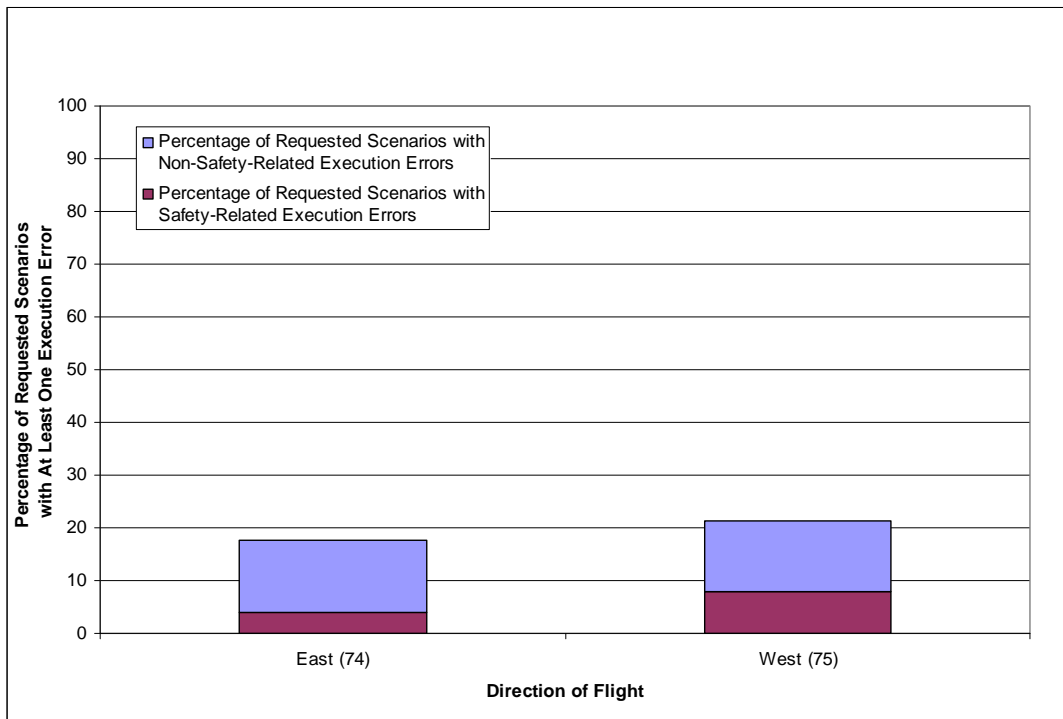


Figure 22. Percentages of requested scenarios involving Eastbound versus Westbound flights that had at least one execution error

Table 15. Expected versus Requested Direction of Flight

| Subject Pilot             | Eastbound |           | Westbound |           |
|---------------------------|-----------|-----------|-----------|-----------|
|                           | Expected  | Requested | Expected  | Requested |
| 1                         | 6         | 6         | 6         | 8         |
| 2                         | 6         | 6         | 6         | 6         |
| 3                         | 6         | 7         | 6         | 6         |
| 4                         | 6         | 7         | 6         | 6         |
| 5                         | 6         | 6         | 6         | 6         |
| 6                         | 6         | 5         | 6         | 7         |
| 7                         | 6         | 5         | 6         | 7         |
| 8                         | 6         | 5         | 6         | 7         |
| 9                         | 6         | 6         | 6         | 6         |
| 10                        | 6         | 8         | 6         | 4         |
| 11                        | 6         | 6         | 6         | 6         |
| 12                        | 6         | 7         | 6         | 6         |
| Total Number of Scenarios | 72        | 74        | 72        | 75        |

Table 16. Distribution of Execution Errors across Requested Directions of Flight

| Requested Direction of Flight | Number of Non-Safety-Related Execution Errors | Number of Safety-Related Execution Errors | Total Number of Execution Errors |
|-------------------------------|---|---|----------------------------------|
| Eastbound                     | 12  | 3   | 15                               |
| Westbound                     | 12  | 6   | 18                               |

A McNemar Test was performed to determine if a significant difference existed between the total number of execution errors that occurred during the requested Eastbound versus Westbound flights. This test revealed that, statistically speaking, an equivalent number of execution errors occurred during the flights traveling Eastbound and the flights traveling Westbound ( $p = 0.2500$ ).

### *Discussion of Execution Errors*

The fact that no execution errors occurred during standard flight level change scenarios, while errors occurred in over 18% of ITP scenarios, can be neither ignored nor minimized. Of at least equal significance is the fact that no safety-related execution errors occurred during standard flight level change scenarios but occurred in over 6% of ITP flight level change scenarios. The specific safety-related execution errors were described previously, but collectively they represent errors that potentially cannot be detected by ATC or by other means and that could result in a loss of separation between aircraft. Each of the execution error types committed, beginning with the safety-related execution errors, will be discussed in this subsection along with possible procedure or display design changes that might reduce or eliminate the errors.

Seven of the nine safety-related execution errors involved subject pilots sending incorrect information in their ITP request that could not necessarily be detected by the ground controller. These included two errors where subject pilots identified a leading aircraft as a following aircraft, three errors where the subject pilots entered an incorrect call sign for a reference aircraft, and two errors where subject pilots left off the third number of a reference aircraft's call sign (in effect, another form of incorrect call sign). These errors might be mitigated through a change in the Oceanic Operations application display design and/or the ATC data-link interface. For example, if the display and data-link interface were interfaced in such a way that the pilot only needs to select the desired reference aircraft (e.g., by "clicking" on the displayed image of the reference aircraft) rather than having to compose an ITP text message (e.g., "ITP L/UAL123/25"), then most of these operator entry errors might be eliminated. The disadvantage of such a system is that it would require expensive changes to certified aircraft systems such as the data-link communications interface. A less comprehensive but also less expensive alternative might be to redesign the current display so that the data tag includes the appropriate "L/" or "F/" prefix in front of the call sign, which might reduce or eliminate the leading/following errors. Lastly, the development of crew crosscheck procedures, where one crewmember checks the other's data entry before the ITP request is sent, would likely reduce or eliminate these safety-related errors.

The remaining two safety-related execution errors involved failure to maintain cruise Mach, or appropriate vertical speed, during the ITP flight level change. The latter case apparently involved either pilot error or "tinkering" while operating the autoflight system (it was unclear which was the case), and in another circumstance could just as likely have occurred during a standard flight level change. The design implication, though, is that the ITP safety analyses must assume that such errors or events will occur from time to time, and assure that design vertical speeds, distances, ground speed differentials, etc. for ITP are sufficient to assure the necessary levels of safety in the presence of such pilot errors. The former case (failure to maintain cruise Mach) is interesting in that the error was intentional; that is, the subject pilot "gamed" the scenario by intentionally changing ownship speed by 0.01 Mach to allow an ITP that would not otherwise have been possible (at the original Mach, the reference aircraft would have been too close before ATC could have responded to the subject pilot's ITP request, so the reassessment would have failed and the ITP clearance would have had to be refused). The possibility of pilots "gaming" such situations was widely discussed both prior to the experiment by the researchers, and during the debrief sessions with the subject pilots, and the consensus was that such behavior would inevitably occur occasionally, at some unknown frequency. When subject pilots were asked if they thought such speed changes would be hazardous to safety, they generally responded in the negative. However, when it was noted that their aircraft might already be a reference aircraft for another in-progress ITP when they chose to alter their speed, some changed their minds on the safety implications. To summarize, without further study, the safety effects of such intentional "gaming" by pilots is unknown.

Sixteen of the 24 non-safety-related execution errors (i.e., two-thirds of these errors) involved subject pilots incorrectly referencing aircraft at the desired, rather than the intervening, flight level. This type of error was committed by slightly more than half of all the subject pilots (seven of 12). The error occurred in all six of the expected standard scenarios where subject pilots inappropriately requested an ITP (i.e., committed selection error), as there was no observable aircraft available for them to reference on the intervening flight level. It also occurred in seven of the eight scenarios involving selection errors where subject pilots requested an inappropriate ITP geometry; that is, in these cases, rather than requesting either a leading or following ITP as appropriate for a particular scenario, subject pilots made a combined leading-following ITP request by incorrectly referencing an “extra” aircraft at the desired flight level in addition to the one appropriately referenced at the intervening flight level. The remaining three occurrences of this error were made separately by three different subject pilots but all in the same scenario – an ITP leading descent scenario with observable blocking traffic at the desired flight level, so the subject pilots were expected to make no request. Not only did these subject pilots request an ITP descent referencing an aircraft at the desired flight level, but they requested an ITP descent of only 1,000 ft when, by design, ITP flight level changes are always at least 2,000 ft. (i.e., they committed a second execution error).

Why the above-described errors occurred (i.e., referencing aircraft at the desired flight level), and especially why they occurred in such large numbers, is a source of significant puzzlement and speculation among the authors. All of the subject pilots had received prior exposure to the ITP concepts via the survey they had completed, and during the experiment training they received explicit and repeated instruction that only aircraft on intervening flight level(s) could be referenced in an ITP request. In fact, when it became apparent halfway through the experiment sessions that this error was occurring in large numbers, the researchers broke with the usual practice of keeping training identical across all experiment sessions and emphasized this concept even more strongly with the second half of the subject pilots. The results were unchanged, however, as this error continued to occur in significant numbers. During the debrief sessions with this second half of the subject pilots, the fact that these errors were repeatedly occurring among multiple subject pilots was brought up, and the subject pilots were asked for possible explanations. The answers varied but basically came down to three responses: either the subject pilots didn’t realize they had made the error and couldn’t say why they had done so; did it by mistake and recognized afterward that they had done so in error; or intentionally did it to let ATC know that, for example, they “knew about that aircraft.”

This last response has an analogy in current-day operations with direct voice communication in visual flight conditions, when ATC will call out the position of a nearby aircraft and a pilot will answer that he or she “has them on TCAS” (as opposed to the proper responses of either “traffic in sight” or “negative contact”). The fact that the crew sees the called traffic on their TCAS display has no operational significance to the controller – that is, the controller cannot delegate separation by instructing the pilot to maintain visual separation with traffic “seen” only on TCAS – but pilots continue to respond in this way to let ATC know that they “know about that aircraft” (and therefore imply that they may soon acquire it visually). It is possible that this same mentality is causing some subject pilots to incorrectly reference aircraft at the desired flight level in an ITP request.

Changes to the design of the Oceanic Operations application’s traffic display might mitigate the error of pilots referencing aircraft at the desired flight level. For example, the display could be designed so as to remove call signs from the data tags of aircraft at other than intervening flight levels, preventing pilots from mistakenly referencing them in an ITP request. Alternatively, errors of these types might be minimized by adding decision support to the Oceanic Operations application, so that “allowable” reference aircraft are highlighted or otherwise made apparent to pilots, and other aircraft are de-emphasized for use as reference aircraft. Similarly, the ITP could be changed procedurally such that ATC is instructed to always deny any ITP requests with inappropriately-referenced aircraft, and if pilots were informed of this in their ITP training they might check more rigorously for this error prior to sending an ITP request. Lastly, the error could be treated by ATC as “harmless” superfluous information and ignored when evaluating the received ITP request.

On a broader note, the ATC knowledge and experience level of the pilots participating in the experiment and in the airline pilot population at large must inevitably be considered in light of the non-safety-related execution errors discussed in the previous paragraphs. While airline pilots are highly trained and experienced in their respective flight crew tasks, and while some have doubtless gained some knowledge of air traffic control procedures at “the other end of the microphone” through their flight experience or independent study, the fact remains that in general they receive little or no formal training in ATM and separation concepts, standards, and techniques as part of their airline pilot training. The subject pilots in the experiment were generally learning about ground-side ATM and separation concepts and techniques as well as active airborne involvement in new ATM procedures (i.e., the ITP), for essentially the first time, before being asked to appropriately select and perform the procedures. While the ITP is relatively simple in concept, in its current form it can be applied in a diverse set of traffic conditions and geometries, and does require pilots to exercise some air traffic separation judgment and proper application of the ITP concepts in each of these diverse sets of conditions and geometries. In general, it may be that some level of conceptual training on ATM separation standards is required to minimize errors of the type discussed in the previous paragraphs, or that 1) the applicability of the ITP is limited to well-defined simple geometries; 2) specific rules-of-thumb (versus the current judgment-based guidance) as to when pilots should request an ITP are defined; and/or 3) the level of automation/decision support provided by the Oceanic Operations application is increased. As an example, the Oceanic Operations application could be enhanced to construct the appropriate ITP request string, if any, based on built-in rules-of-thumb and the pilots’ selection of the desired flight level.

### **Subjective Assessments of the ITP’s Validity**

With respect to the ITP’s validity, subject pilots used the post-scenario questionnaire, the post-experiment questionnaire, and the post-experiment group debrief sessions to describe their impressions of the correctness, completeness, appropriate specification, and logical sequencing of the procedural steps that they were instructed to use while executing ITP maneuvers. Subject pilots described their ITP performance concerns through the use of the post-experiment questionnaire and during the post-experiment group debrief sessions. These subjective impressions and concerns are provided in the following paragraphs, as are additional subjective impressions and concerns regarding acceptability and workload in subsequent sub-sections. In most cases these subject pilots’ assessments are presented without editorial comment from the authors, except where necessary for clarification, in keeping with the concept that much of the value of these subjective assessments lies in the unedited impressions of current-day subject matter experts (i.e., oceanic line pilots) after initial exposure to ITP concepts and technologies in their present form.

Through their post-scenario questionnaire responses, subject pilots indicated in 92.7% of their responses that the procedural steps used to execute ITP maneuvers were correct, complete, and appropriately specified and indicated in 94.3% of their responses that the procedural steps occurred in a logical sequence. No particular type of ITP maneuver was characterized as being associated with procedural steps that were found to be problematic. Although it was hypothesized that subject pilots would not find any missing, incomplete, or extraneous procedural steps associated with the ITP, this was not the case. With respect to procedural steps found to be “missing” from the ITP Checklist, one subject pilot stated that the checklist should include an additional “Verify Message” step to be completed by the Pilot Flying (PF). This additional step should come after the “Prepare” and before the “Send” step is completed. It was suggested that this checklist modification would help pilots “avoid syntax errors” and provide an additional “independent check.” This same subject pilot also recommended that it might be more appropriate to execute the checklist’s “Reassess ITP Criteria” step using three independent steps, as is currently done with CPDLC clearances. These steps would occur as follows: 1) PNF pulls up message and prints it; 2) PNF silently reads message and reassesses situation; and 3) PF silently reads message and reassesses situation. Another subject pilot suggested including an additional procedural step (not specified) that would facilitate subsequent requests for alternatives to improve performance options when an initial “optimum/desired/recommended” request is denied by ATC. This same subject pilot indicated that due to the fact that the procedure includes a checklist, it should outline a means to cancel a request

if ITP criteria are not met in the time between requesting and receiving an ATC clearance. The pilot also indicated that the ITP Checklist should include an “Arm” or “Report Reaching Assigned Altitude” step.

Using the post-experiment questionnaire, the subject pilots commented on their use of the procedural steps outlined in the ITP Checklist and described any performance concerns that they had with the ITP. According to these responses, two of the subject pilots used the ITP Checklist during every ITP maneuver while, on average, the other 10 subject pilots reported using the checklist during 37% (SD = 17.4%) of the ITP maneuvers. In general, the subject pilots that used the checklist intermittently indicated that they did not need to refer to the checklist during every ITP maneuver since the procedures were “intuitively obvious.” When asked if they reassessed the ITP criteria every time they received an ITP clearance, as required by the checklist, eight of the subject pilots stated that they always performed the required reassessment while four of the subject pilots stated that they did not adhere to this procedural step. Two subject pilots indicated that they only reassessed the ITP criteria when distance or speed requirements were “nearing the limits.” With respect to identifying potential performance related ITP issues, six of the subject pilots reported that they had ITP performance concerns. For example, a question was posed regarding the possibility of the ITP Aircraft encountering wake turbulence during an ITP following maneuver and the possibility of the reference aircraft encountering wake turbulence during an ITP leading maneuver. Also, the impact of non-participating aircraft (reference or non ADS-B aircraft) on the success or failure of the ITP was identified as being a “significant factor.” Lastly, it was mentioned that an emphasis will need to be placed on constant Mach operations since current day operations in regions other than NATOTS, heavily rely on the FMC’s “econ” setting. This FMC setting adjusts the Mach to the most efficient fuel or time operation and as a result is not associated with constant Mach.

Subject pilots were also encouraged to comment on their perceptions of the ITP’s validity during the post-experiment group debrief sessions. With respect to the correctness, completeness, and appropriate specification of the procedural steps used to execute ITP maneuvers, one item of interest was identified by the subject pilots as missing. Specifically, it was noted that the need to consult winds information was not addressed within the ITP. However, the ITP was designed such that pilots do not need to consult winds information before making an ITP request. When commenting on their use of the ITP Checklist, several subject pilots stated that, while the checklist should be made available to flight crews, it will probably only be used during the procedure’s initial implementation; subject pilots expressed the opinion that flight crews are not likely to refer to the checklist once they are familiar with the ITP, given that the procedure is relatively “simple.” When asked to describe their ITP performance concerns, the subject pilots mentioned two issues during the post-experiment group debrief sessions. First, the potential consequences associated with failures of aircraft to comply with ITP performance requirements were identified as a cause for concern. Second, the existence of wake vortices during the execution of an ITP maneuver was discussed as a potential concern; however, it was acknowledged that the impact of wake vortices must also be considered during current day operations.

### **Subjective Assessments of the ITP’s Acceptability**

Subject pilots used the post-scenario questionnaire and the post-experiment group debrief sessions to comment on the ITP’s acceptability and to describe alternate ways in which they might have performed a given flight level change maneuver. Subject pilots used the post-experiment questionnaire and the post-experiment group debrief sessions to comment on issues associated with the general acceptability of the ITP and to describe the ways in which the ITP could be potentially beneficial to flight crews, passengers, and airline companies. The workload level associated with the performance of the ITP is directly related to the procedure’s acceptability; however, the subject pilots’ subjective assessments of workload are discussed in a subsequent section.

When asked via the post-scenario questionnaire to document their suggestions for performing a given flight level change differently, two subject pilots reiterated the opinion of another subject pilot (mentioned previously in conjunction with “Subjective Assessments of the ITP’s Validity”) who stated that he would like for a

procedural step to be added to the ITP's Checklist to facilitate subsequent flight level change requests when an initial request is denied by ATC. These additional two subject pilots indicated that the ITP's acceptability would increase if pilots were afforded the opportunity to communicate alternate altitude requests to ATC in hopes of securing approval for a flight level change should their initial requests be denied. One subject pilot provided this comment in response to a standard climb scenario involving a request that was rejected by ATC, and the other subject pilot expressed this opinion in terms of a more general, overarching preference. Another subject pilot indicated that the ITP would be more acceptable if its safety distance and speed tolerances were reduced (however, these criteria are directly tied to safety analyses used to guide the design of the ITP [2]). While completing post-scenario questionnaires associated with ITP maneuvers that could not be completed due to a failure to maintain ITP speed requirements (e.g., "Unable due to Ground Speed" scenarios), two subject pilots reported that, given the chance during actual flight operations, they would alter the speed of their aircraft to maintain ITP spacing long enough to complete a flight level change maneuver. These subject pilots indicated that the acceptability of the ITP would be increased if the requirement for constant Mach was eliminated.

When asked via the post-experiment questionnaire if, given their operational experience, they thought of the ITP as being an acceptable procedure, all 12 subject pilots answered "yes." But, two subject pilots mentioned concerns regarding the procedure's reliance on an "honor system" in which the distances among aircraft must be accurately reported to ATC. The ITP free text phraseology used to communicate with ATC during the experiment was characterized by all 12 subject pilots as being acceptable in that it was "easy to understand and use." With respect to their impressions regarding the level of safety associated with performing the ITP as compared with current day procedures, the subject pilots' responses were somewhat mixed. One subject pilot characterized the ITP as being "less safe than" current day procedures but stated that the ITP is still "procedurally sound"; seven subject pilots characterized the ITP as being "equally as safe as" current day procedures; and four subject pilots characterized the ITP as being "safer than" current day procedures. The subject pilots that characterized the ITP as being "safer than" current day procedures stated that the ITP display: is similar to onboard weather radar in that the operator gets to see more of the current operating environment; provides "eyes" in IMC and enhanced SA; provides more SA than the TCAS does; and reduces misinterpretations of clearances. The enhanced SA was considered to be a result of the display implementation and not the procedure.

Since it was hypothesized that subject pilots would find the ITP to be beneficial in situations where climbs or descents would not otherwise be possible, the post-experiment questionnaire was used to elicit subject pilots' comments regarding potential benefits that the ITP might have for flight crews, passengers, and airline companies. For flight crews, the subject pilots identified potential benefits as being: improved traffic SA; more efficient aircraft operation (resulting from the ability to manage climbs at efficient times); enhanced job satisfaction associated with the opportunity to achieve optimum performance; and improvements in safety due to the avoidance of weather and turbulence. For passengers, the subject pilots identified potential benefits as being: smoother rides due to the flight crew's ability to vacate turbulent altitudes; improved ticket prices if airline companies experience savings (see below) that are passed on to the consumer; and increased instances of on-time arrivals since delays due to oceanic congestions may be avoided, more fuel may be available to hold at a destination thereby improving passengers' chances of making connecting flights, and having more fuel at the destination lowers the likelihood of required diversions. For airline companies, the subject pilots identified potential benefits as being: fuel savings; safety and passenger comfort; and improved scheduling due to route planning.

The post-experiment questionnaire also presented subject pilots with a "what if" type question whose purpose was to collect their thoughts regarding off-nominal conditions, even though off-nominal conditions were outside the scope of the experiment. Specifically, subject pilots were asked the following question: "If you encountered off-nominal conditions while performing an ITP flight level change (e.g., you observe the reference aircraft deviating), how easy would it be for you to revert back to the use of standard regional contingency procedures?" Four subject pilots indicated that it would be "very easy" to revert to standard regional contingency procedures if an off-nominal situation was encountered during the performance of an ITP

maneuver; five subject pilots indicated that it would be “easy” to revert back to standard regional contingency procedures; two subject pilots were undecided as to how easily they could revert back to standard regional contingency procedures; and one subject pilot indicated that it would be “somewhat difficult” to revert back to standard regional contingency procedures; this last subject pilot stated that “[t]here needs to be a defined procedure” in place for flight crews to use when off-nominal situations are encountered. (It should be noted that during their training, subject pilots were told that in actual implementation that regional contingency procedures would be followed for off-nominal situations; but, for the experiment, they could notify an experimenter if an off-nominal situation was encountered during the experiment.)

During the post-experiment group debrief sessions, subject pilots were asked to comment on the general acceptability of the ITP and to describe any ways in which they might have preferred to perform flight level change maneuvers. Three alternate, or more acceptable, methods for performing flight level change maneuvers were discussed. First, it was suggested that a definitive reason be provided to flight crews via the ITP display whenever a flight level change request is denied as this would enhance crews’ SA. Second, it was suggested that ATC informs flight crews or issues “auto-clearances” as soon as the traffic aircraft associated with previous denials were no longer “blocking” a requested flight level change. Third, it was suggested that speed change requests be allowed and that ATC be notified of such requests whenever the 0.01 Mach buffer range was exceeded.

Subject pilots’ comments regarding the acceptability of the ITP centered around four primary topics during the post-experiment group debrief sessions: overall acceptability, safety, phraseology, and ATC’s role in separation assurance. In support of the procedure’s overall acceptability, several subject pilots said that they would like to see the ITP implemented for use during actual oceanic flight operations and were interested in knowing how quickly this might happen. Subject pilots’ made comments such as “[i]t’s time to shrink the airspace between aircraft” and that “too much separation [between aircraft is] required” in the current system. One subject pilot, however, raised an interesting question about how often his aircraft would serve as a reference aircraft for another flight crew and therefore be ineligible to complete an ITP flight level change maneuver during actual oceanic flight operations, since “[e]veryone is always looking for a higher altitude.” The frequency of this situation occurring is a topic for further research.

With respect to safety, several subject pilots voiced concerns about the possibility of “cheating” or “gaming” the system. For example, one subject pilot mentioned the potential for requesting a clearance with 15 nm separation with the intention of using a separation of 10 nm. Another subject pilot suggested that speed manipulations will occur, particularly when only “a couple of knots” are involved, and stated that flight crews may use speed changes to maintain separation as well as to “make a hole” through which their aircraft can maneuver. On the other hand, subject pilots expressed confidence in the ITP’s level of safety, especially since ATC would still have a presence in the system and be responsible for separation. A subject pilot suggested that potential increases in safety could be associated with the enhanced SA provided to the flight crew via the ITP display and stated that “no degradation of the system should take place” since ATC is still present in the system. When asked to comment on their use of free text phraseology to communicate with “ATC” during the experiment’s simulated flight scenarios, subject pilots indicated that, in general, they found that the “/L” and “/F” terminology to be straightforward and easy to learn and felt that “Leading” and “Following” were good terms to use since it is logical for pilots to reference their ITP Aircraft. It was pointed out, however, that airline companies often discourage the use of free text due to language barriers and the possibility of misinterpretation. Therefore, one subject pilot suggested that the ITP display provide “clickable” information that could be used to populate free text fields to reduce typographical errors and/or language differences (e.g., ITP climb/descend could be selectable).

In addition to providing feedback regarding the ITP’s overall acceptability, safety, and phraseology, the subject pilots also shared enlightening viewpoints regarding ATC’s role in separation assurance during discussions that took place in the post-experiment group debrief sessions. Several of the subject pilots indicated that if the appropriate information is made available to flight crews, then the level of responsibility for



separation assurance that is given to pilots during ITP maneuvers is acceptable. One subject pilot stated that the level of pilot responsibility for separation assurance associated with the ITP is similar to that experienced while flying under Visual Meteorological Conditions (VMC). However, another prevalent viewpoint was expressed when the potential for increasing pilot responsibility for separation assurance was considered. One commonly expressed opinion was that pilots do not want more responsibility for separation assurance, particularly because of “violation potential,” and that pilots have “no interest in being an air traffic controller.” One subject pilot stated that separation assurance is “ATC’s job,” and another subject pilot stated that responsibility for separation assurance should be kept “on the ground.” Yet another subject pilot stated that since flight crews don’t have access to the convergence information that ATC has that it would be a better use of resources to provide the additional information that makes the ITP possible to ATC rather than to flight crews.

### **Subjective Assessments of the ITP’s Workload**

The subject pilots’ perceptions of the workload associated with performing standard flight level changes and ITP flight level changes were collected using the MCH Rating Scale, the post-experiment questionnaire, and feedback obtained during the post-experiment group debrief sessions. It should be noted that workload assessments are associated with a desktop PC-based operation and that the results are therefore relative to workload levels experienced during baseline operations for standard climbs and descents rather than being directly representative of workload levels experienced during actual flight operations. After completing each of the experiment’s 16 test conditions, subject pilots used the MCH Rating Scale to report the level of workload that they had just experienced. The post-experiment questionnaire was used to record the subject pilots’ descriptions of how the workload required to perform standard flight level changes during the experiment compared with the workload required to perform the ITP flight level changes. Feedback regarding their impressions of the workload associated with performing simulated flights East-to-West versus West-to-East over the Atlantic Ocean was obtained from the subject pilots during the post-experiment group debrief sessions.

It was hypothesized that subject pilots would find the workload level associated with performing ITP flight level changes to be acceptable (i.e., that a subjective workload rating of “3” or less would be provided using the MCH Rating Scale) and that the subjective workload level experienced during ITP flight level changes would not be significantly higher than that experienced during standard flight level changes. As described below, nonparametric statistical tests were employed as a conservative method for analyzing workload ratings associated with the MCH Rating Scale’s discrete rating scale items.

The MCH workload ratings associated with the requested standard scenarios revealed a mean of 1.20 [Standard Deviation (SD) = 0.40, Sample Size (N) = 43], and the MCH workload ratings associated with the requested ITP scenarios revealed a mean of 1.58 (SD = 0.75, N = 149) (Figure 23).

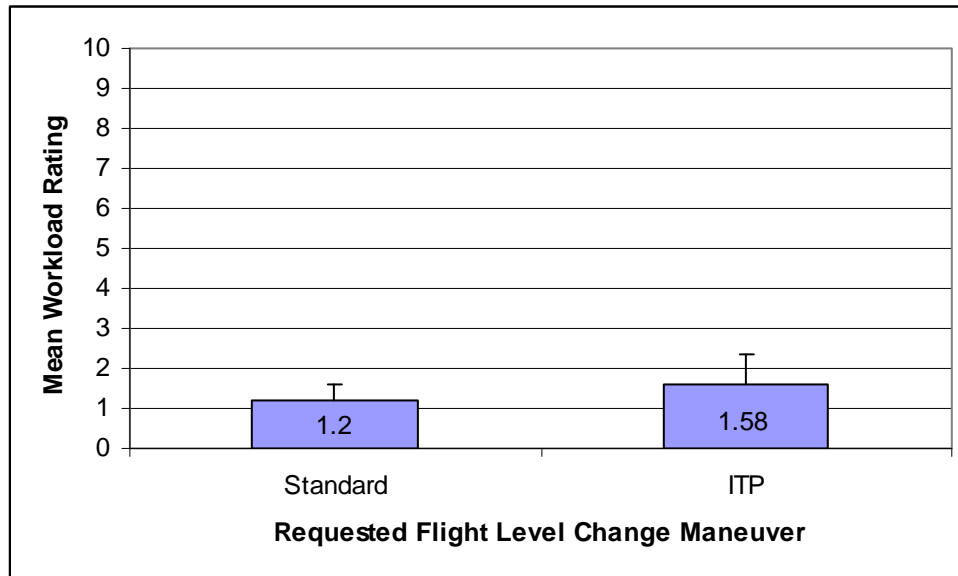


Figure 23. Mean Modified Cooper-Harper (MCH) workload ratings associated with requested standard scenarios and requested ITP scenarios

A Wilcoxon Test (a nonparametric within-subject test appropriate for analyzing two related samples of ordinal data) [13] was performed to evaluate the hypothesis that the workload level experienced by subject pilots during ITP flight level changes would not be significantly higher than that experienced during standard flight level changes. The results of this test failed to support the hypothesis since it revealed that a statistically significant difference existed between the workload ratings that subject pilots provided for the requested standard flight level change maneuvers as compared with the requested ITP flight level change maneuvers ( $p = 0.0009$ ). It is asserted, however, that the difference between the subject pilots' workload ratings for the standard flight level change maneuvers and the ITP flight level change maneuvers is not operationally significant. Subject pilots indicated that other phases of flight (i.e.: approach) have much higher workload ratings than ITP flight level change maneuvers. This assertion is supported by the comments regarding workload that the subject pilots' provided via the post-experiment questionnaire (see below).

The mean MCH workload ratings associated with the eight types of requested flight level change maneuvers are shown in Figure 24. In this figure, means with different letters are significantly different in Wilcoxon Tests at  $p < 0.05$ .

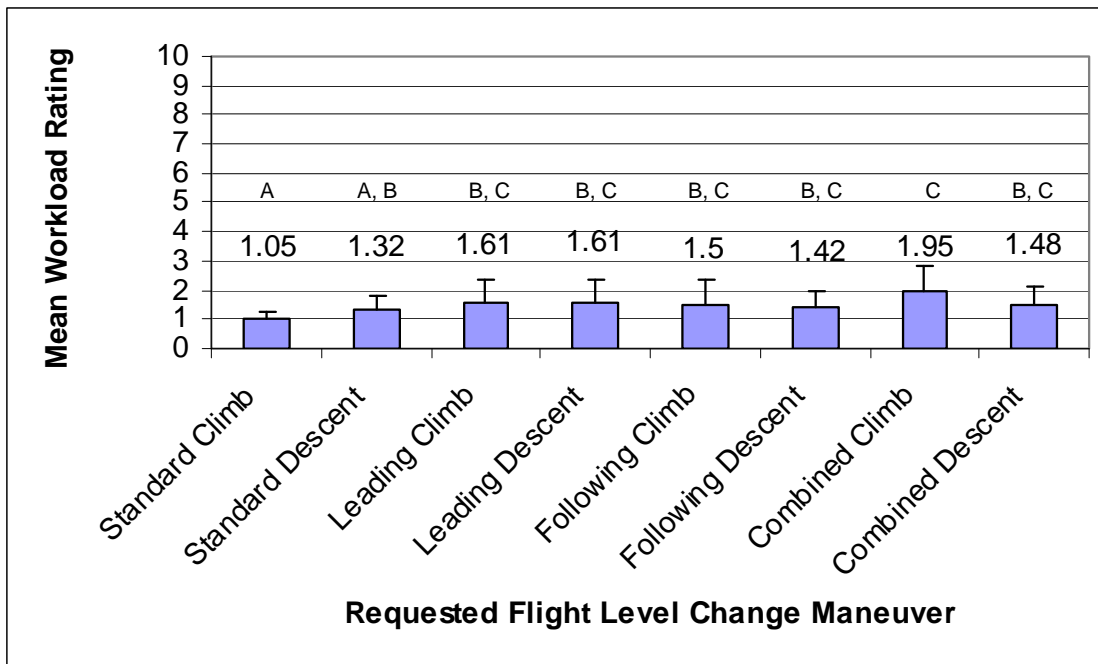


Figure 24. Mean Modified Cooper-Harper (MCH) workload ratings associated with requested flight level change maneuvers

The subject pilots' mean MCH workload ratings ranged from 1.42 to 1.95 for the requested ITP flight level change maneuvers (Figure 24). Therefore, these data support the hypothesis that subject pilots would find the workload level associated with performing ITP flight level changes to be acceptable (i.e., that a subjective workload rating of "3" or less would be provided using the MCH Rating Scale).

A Friedman Test (a nonparametric within-subject test appropriate for analyzing three or more related samples of ordinal data) [12][13] was performed to determine if differences existed among the workload ratings that the subject pilots provided for the eight types of requested flight level change maneuvers. Since this test revealed that a significant difference existed between the workload ratings that subject pilots provided for at least two of the eight types of requested flight level change maneuvers ( $X^2 [7] = 44.2503$ ;  $p = 0.0001$ ), Wilcoxon Tests were performed to determine which of the requested flight level change maneuvers were perceived as having significantly different levels of workload. These Wilcoxon Tests revealed that the subject pilots provided significantly lower workload ratings for the requested standard climb maneuvers than they did for any of the requested ITP flight level change maneuvers (all  $p < 0.05$ ) and that the subject pilots provided significantly lower workload ratings for the requested standard descent maneuvers than they did for the requested ITP combined climb flight level change maneuvers ( $p = 0.0325$ ).

Wilcoxon Tests were also performed to determine if differences existed between the workload ratings that subject pilots provided for requested flight level change maneuvers that: involved climbs versus descents; were achievable versus unachievable; and were associated with Eastbound versus Westbound flights. These tests revealed that significant differences did not exist between the workload ratings provided for requested flight level change maneuvers that: involved climbs ( $M = 1.53$ ,  $SD = 0.77$ ,  $N = 96$ ) versus descents ( $M = 1.49$ ,  $SD = 0.71$ ,  $N = 96$ ) ( $p = 0.7389$ ); were achievable ( $M = 1.49$ ,  $SD = 0.65$ ,  $N = 96$ ) versus unachievable ( $M = 1.50$ ,  $SD = 0.75$ ,  $N = 96$ ) ( $p = 0.7630$ ); or were associated with Eastbound ( $M = 1.54$ ,  $SD = 0.78$ ,  $N = 96$ ) versus Westbound flights ( $M = 1.45$ ,  $SD = 0.62$ ,  $N = 96$ ) ( $p = 0.3657$ ).

Through their post-experiment questionnaire responses, three subject pilots indicated that the workload level required to perform the ITP flight level changes was "about the same" as that required to perform the standard flight level changes, whereas the remaining nine subject pilots indicated that a "slightly higher" workload level

was required to perform the ITP flight level changes when compared to the standard flight level changes. The subject pilots who reported that the ITP flight level changes required a slightly higher workload level stated that the increase resulted from the additional key strokes required to submit the ITP flight level change request and the need to re-assess the situation to ensure that ITP distance and speed criteria were met prior to executing the flight level change maneuver. One subject pilot who stated that the workload level that he experienced was somewhat elevated for the performance of the ITP flight level change maneuvers as compared with the standard flight level change maneuvers also mentioned that he experienced an increase in workload when he performed ITP flight level change maneuvers involving two reference aircraft (i.e., combined climbs/descents) as compared with ITP flight level change maneuvers involving one reference aircraft (i.e., leading or following climbs/descents). Another subject pilot who reported experiencing a slightly higher level of workload when performing the ITP flight level change maneuvers as compared with the standard flight level change maneuvers stated that the increase in workload was offset by the improved SA provided by the ITP display.

With respect to feedback obtained during the post-experiment group debrief sessions, subject pilots unanimously agreed that they experienced no difference in the level of workload required to complete simulated flight scenarios performed in an Eastbound versus Westbound direction. This finding supports the expectation that subject pilots would be capable of using the Oceanic Operations application's vertical profile view (which depicted aircraft traveling from left-to-right across the lower portion of the EFB display screen) equally well during simulated flights performed East-to-West and West-to-East over the Atlantic Ocean.

### **Supplemental Data Collection**

After completing the experiment's 16 test conditions and the post-experiment questionnaire (but prior to the post-experiment group debrief session), the subject pilots were asked to perform an additional set of seven simulated flight scenarios as part of a supplemental data collection effort. The purpose of this effort was to assess the ability of the subject pilots to use the ITP to complete flight level change maneuvers involving more than one intervening flight level (i.e., to extend the use of the ITP to situations other than those involving the typical 2,000-foot flight level change that they had performed during the experiment's simulated flight scenarios). While the experiment scenarios were identical for all subject pilots, the supplemental scenarios varied between subject pilots. Five of the supplemental scenarios were flown by all 12 subject pilots, and the remaining two supplemental scenarios were split evenly between the subject pilots. As a group, the subject pilots performed 72 supplemental ITP scenarios. However, due to a data collection error, selection error and execution error data were recorded for only 11 of the subject pilots resulting in the availability of these data for only 66 of the 72 supplemental ITP scenarios.

Some of the supplemental ITP scenarios were designed such that multiple expected flight level change requests could be made. For example, during the "CC3\_LF\_UAD" scenario (Figure 25), the desired altitude was located 4,000 ft above the altitude at which the ITP aircraft was initialized in simulated flight.

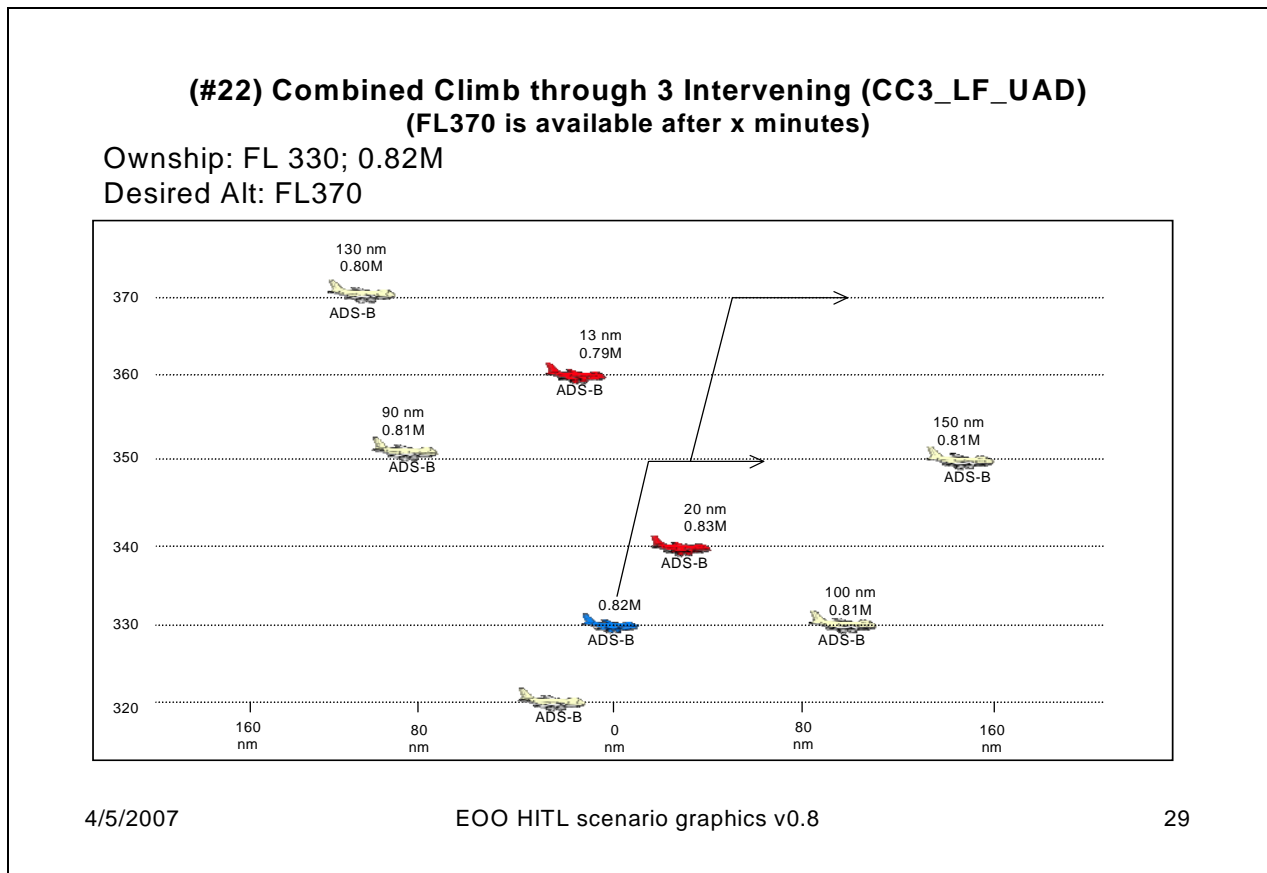


Figure 25. Combined Climb through 3 Intervening Flight Levels

Due to the spacing between the ITP aircraft and one of the intended reference aircraft (i.e., 13 nm), a combined climb maneuver was not possible when the scenario initially began, but became a viable maneuver approximately three minutes into the scenario. An alternative option available to the subject pilots during this scenario was to request two consecutive 2,000-foot ITP maneuvers, each with a single reference aircraft. The subject pilots could have considered this option as a possibility since an available altitude existed between the two potential reference aircraft.

Since the supplemental ITP scenarios were not part of the formal experiment design matrix, statistical analyses were not performed using the data collected during the execution of these scenarios. However, expected versus requested scenario counts are provided; selection and execution errors are described; and the subject pilots’ workload ratings and comments regarding their impressions of the supplemental simulated flight scenarios are discussed.

***Selection and Execution Errors***

The subject pilots committed a total of eight selection errors while performing the supplemental ITP scenarios. One of the supplemental ITP scenarios was designed such that one of the two expected requests that subject pilots could make involved a standard climb maneuver. Since seven of the subject pilots requested the standard climb maneuver instead of making the available ITP request, seven of the 66 expected supplemental ITP scenarios were “converted into” requested supplemental standard scenarios. Therefore, the supplemental data collection effort involved seven requested standard scenarios and 59 requested ITP scenarios.

While execution errors were not committed during the requested standard scenarios, nine execution errors occurred during eight of the 59 requested ITP scenarios. One of the execution errors was classified as a safety-

related execution error since the subject pilot failed to maintain vertical speed while executing a flight level change maneuver. The remaining eight execution errors were classified as being non-safety-related execution errors and were similar to those that occurred during the experiment's 16 test conditions. Six execution errors occurred when subject pilots requested an incorrect altitude during a flight level change request; one execution error occurred when a subject pilot referenced an aircraft at the desired altitude; and one execution error occurred when a subject pilot made a typographical error in the ITP syntax used to make a flight level change request.

It is important to realize that the supplemental data are not directly comparable to the data collected during the experiment's 16 test conditions for a number of reasons. Although subject pilots were trained to use the ITP to execute flight level change maneuvers through multiple intervening flight levels, they only had the opportunity to practice and perform 2,000-foot ITP maneuvers during the pre-experiment training session as well as throughout the experiment itself. Also, the 2,000-foot ITP maneuvers that subject pilots completed prior to the supplemental data collection session were intermingled with scenarios involving standard flight level changes, and the experiment's 16 test conditions were presented in random order. Hence, the results of the data obtained during the experiment cannot be compared directly to the supplemental data due to possible sequence effects. However, it is still interesting to loosely compare the numbers and types of execution errors that occurred during the experiment's 149 requested ITP scenarios with those that occurred during the supplemental data collection session's 59 requested ITP scenarios.

Subject pilots committed at least one execution error during 28 of the experiment's 149 requested ITP scenarios and committed at least one execution error during eight of the supplemental data collection session's 59 requested ITP scenarios. Therefore, execution errors occurred in 18.8% of the experiment's scenarios involving ITP flight level change requests and in 13.6% of the supplemental data collection session's scenarios involving ITP flight level change requests. Since nine of the experiment's 149 requested ITP scenarios involved safety-related execution errors, subject pilots committed safety-related ITP execution errors 6.0% of the time. In comparison, one of the supplemental data collection session's 59 requested ITP scenarios involved a safety-related execution error, therefore subject pilots committed safety-related ITP execution errors 1.7% of the time.

### ***Subjective Assessments of Workload***

After completing each of the supplemental data collection session's simulated flight scenarios, subject pilots used the MCH Rating Scale to report the level of workload that they had just experienced. As shown by the mean MCH workload ratings presented in Figure 26, the subject pilots' mean MCH workload ratings ranged from 1.42 to 2. These data appear to indicate that subject pilots found the workload level associated with performing the supplemental data collection session's scenarios to be acceptable.

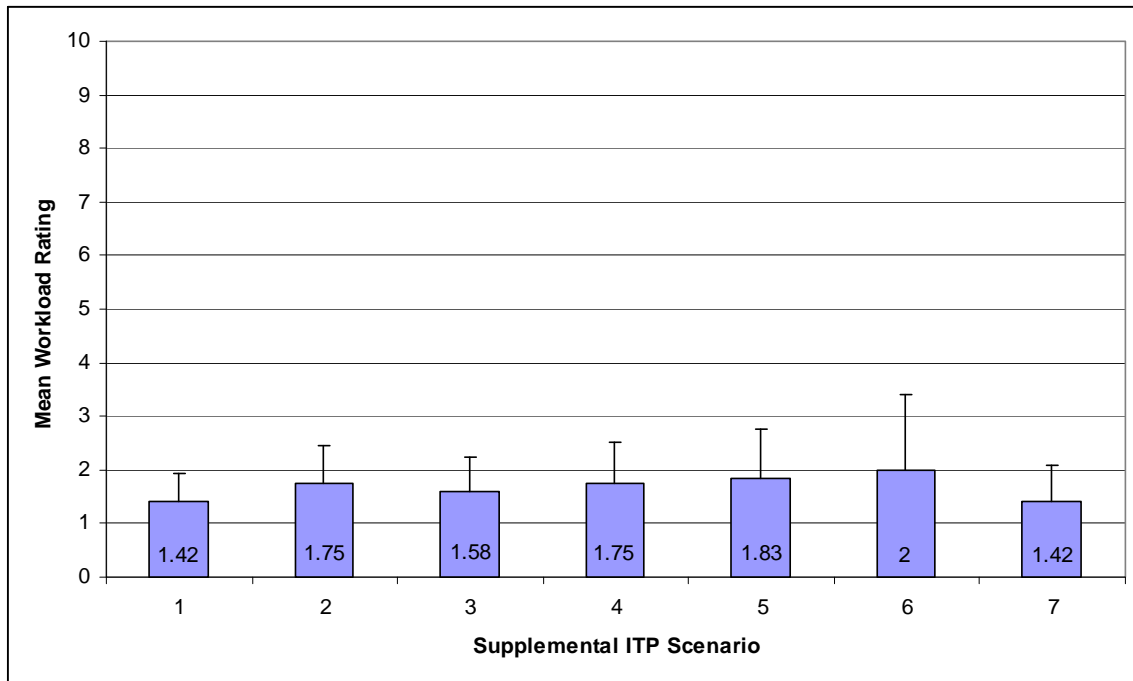


Figure 26. Mean Modified Cooper-Harper (MCH) workload ratings associated with the supplemental data collection session's scenarios (for scenario description see Table 17)

Table 17. Supplement data collection scenario description

| # | Scenario name | Scenario description   |
|---|---------------|--|
| 1 | CC2_FF_AC     | Combined Following/Following Climb through 2 Flight Levels – Accept        |
| 2 | CC2_LF_AC     | Combined Leading/Following Climb through 2 Flight Levels – Accept          |
| 3 | CC2_LL_AC     | Combined Leading/Leading Climb through 2 Flight Levels – Accept            |
| 4 | CC3_LF_AC     | Combined Leading/Following Climb through 3 Flight Levels – Accept          |
| 5 | CC3_LF_UAD    | Combined Leading/Following Climb through 3 Flight Levels – Unable distance |
| 6 | CC3_POST_EXP  | Combined Leading/Following Climb through 3 Flight Levels – Accept          |
| 7 | FC3_UAT       | Following Climb through 3 Flight Levels – Unable traffic                   |

### ***Subjective Assessments of the Supplemental Data Collection Session's Scenarios***

With respect to feedback obtained during the post-experiment group debrief sessions that took place following the supplemental data collection sessions, subject pilots indicated that they were able to use the ITP to perform 3,000 and 4,000-foot flight level change maneuvers during the supplemental data collection session's scenarios just as they had used it to perform 2,000-foot flight level change maneuvers during the experiment's scenarios. In general, the subject pilots did not believe that safety would be compromised by using the ITP to maneuver through multiple intervening flight levels. However, it was suggested by one subject pilot that altitude change requests involving only a single intervening flight level might help him avoid climbing or descending to an incorrect altitude. In terms of the usefulness of making altitude changes through multiple intervening flight levels, several of the subject pilots stated that flight crews typically do not request 3,000 or 4,000-foot climbs or descents due to aircraft performance limitations, indicating that such flight level changes would not be useful.

## Summary & Conclusions

Under sponsorship of NASA LaRC's EOO research element, a HITL flight simulation experiment was conducted in September 2006 to assess the validity and pilot acceptability of a proposed new air traffic "In Trail Procedure" or ITP. The ITP operational concept was developed by researchers at NASA LaRC and others in the international ATM research community, and if deployed would represent an early application of airborne ADS-B technology that would increase opportunities for ITP-equipped aircraft to fly at their optimal altitudes on flights in oceanic and remote non-radar flight regions. This experiment represented a first opportunity to present airline pilots with the ITP in a controlled experimental environment, with a medium-fidelity set of simulated operational scenarios and an initial prototype Oceanic Operations application, and to evaluate their ITP performance and impressions.

In-house preparations for this experiment included developing a prototype ITP Oceanic Operations software application and simulating an EFB hardware device on which this application was displayed. Preparations also included extensive modifications to NASA LaRC's ATOL simulation software, including the development of new air traffic modules to simulate appropriate air traffic controller responses and the generation of realistic air traffic simulation scenarios on the NATOTS. Many such scenarios were generated in support of an experiment matrix designed to systematically explore pilot responses to 16 situations where different types of ITP request geometries and maneuvers were, or were not, applicable. An additional 7 scenarios were also developed to explore pilot responses to more complex ITP situations after completion of the experiment's 16 test conditions.

Twelve commercial airline pilots, all with current oceanic flight experience, participated in the experiment in groups of up to four, with each group participating in the study over the course of two consecutive days. The subject pilots were provided with training and practice sessions regarding ITP concepts and procedural steps, as well as on the operation of relevant aircraft simulation equipment in the ATOL. The subject pilots then flew the simulated ITP scenarios and answered questionnaires at the end of each scenario, as well as answered a final questionnaire and participated in a group discussion at the conclusion of all scenarios. The subject pilots' subjective assessments of ITP validity and acceptability were measured via these questionnaires and discussion results, and their objective performance in appropriately selecting, requesting, and performing ITP flight level changes, where ITP flight level changes might be appropriate, was evaluated for each scenario. Objective performance and subjective workload assessment data from the experiment's 16 test conditions were analyzed for statistical and operational significance and discussed.

In the majority of scenarios, subject pilots were able to correctly assess the traffic situation, select an appropriate response (i.e., either a standard flight level change request, an ITP request, or no request), and execute their selected flight level change procedure, if any, without error. Subjective workload assessments were slightly higher for ITP than for standard flight level change requests, but were well within acceptable limits. In addition, the subject pilots' subjective acceptability ratings and comments regarding the ITP were generally high and positive, respectively. Based on these results, the ITP is asserted to be generally both valid and acceptable for the experiment scenarios as flown in a medium fidelity simulation environment.

Regarding the validity of the procedure, it was hypothesized that subject pilots would not find any missing, incomplete, or extraneous procedural steps associated with the ITP, but at least one subject pilot stated that additional steps should be included to "avoid syntax errors" and provide an additional "independent check" (i.e., crew crosscheck procedures). During the discussion, potential concerns were raised with regard to the existence of wake vortices during the execution of an ITP maneuver, as well as the impact of non-participating aircraft on the success or failure of the ITP. Subject pilots also mentioned that an emphasis will need to be placed on constant Mach operations since current day operations in oceanic regions outside of the North Atlantic heavily rely on the FMC's "econ" setting, which is not a constant Mach function.



All 12 subject pilots indicated that the ITP was an acceptable procedure, but two subject pilots mentioned concerns regarding the procedure's reliance on an "honor system" in which the distances among aircraft must be accurately reported to ATC, and several subject pilots voiced concerns about the possibility of "cheating" or "gaming" the system. Some subject pilots indicated that the ITP's acceptability would increase if pilots were afforded the opportunity to communicate alternate altitude requests to ATC and if the requirement for constant Mach was eliminated.

From comments regarding potential benefits that the ITP might have for flight crews, passengers, and airline companies, subject pilots identified potential benefits for flight crews as being: improved traffic SA; more efficient aircraft operation; enhanced job satisfaction associated with the opportunity to achieve optimum performance; and improvements in safety due to the avoidance of weather and turbulence. For passengers, the subject pilots identified potential benefits as being: smoother rides due to the flight crew's ability to vacate turbulent altitudes; on-time arrivals since delays due to oceanic congestions may be avoided and improved ticket prices if airline companies experience savings. For airline companies, the subject pilots identified: fuel savings; safety and passenger comfort; and improved scheduling due to route planning as potential benefits.

While the ITP was generally regarded to be valid and acceptable, the error rates for ITP maneuvers were higher than for standard flight level changes, and these errors have design implications for both the ITP and the Oceanic Operations application prototype traffic display. It is beyond the scope of this paper to evaluate the operational acceptability of the reported error rates, but several explanations and mitigation strategies for the various errors are discussed in the paper. In summary, these error mitigation strategies might involve: 1) improving the prototype Oceanic Operations display interface and symbology; 2) limiting the applicability of the ITP to well-defined simple geometries; 3) defining specific rules-of-thumb (versus the current judgment-based guidance) as to when pilots should request an ITP; and/or 4) increasing the level of automation/decision support provided by the Oceanic Operations application.

In summary, the subject pilots found the procedure valid, acceptable, "procedurally sound," and "intuitively obvious" and were very enthusiastic about the enhanced SA provided by the Oceanic Operations application display. The subject pilots were less excited about more future pilot responsibility for separation assurance, but would like to see the ITP implemented for use during actual oceanic flight operations and were interested in knowing how quickly this might happen.

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## **Appendix A**

### **Modified Cooper-Harper Rating Scale Introductory Materials**

#### Overview

After completing each scenario, you will be asked to give a rating on a Modified Cooper-Harper Scale for workload. This rating scale and important definitions are described below.

#### *Important Definitions*

To understand and use the Modified Cooper-Harper Scale properly, it is important that you understand the terms used on the scale and how they apply in the context of this experiment.

First, the “instructed task” is the flight task you have been assigned to perform in this experiment. It includes flying the aircraft simulator within specified levels of accuracy and performing all duties that are requested of you during the time interval designated by the experimenters.

Second, the “operator” in this situation is you. Since the scale can be used in different situations, the person performing the ratings is called an operator. You will be operating the system and then using the rating scale to quantify your experience.

Third, the “system” is the complete group of equipment you will be using in performing the instructed task. Together you and the system make up the “operator/system.”

Fourth, “errors” include any of the following: mistakes, incorrect or incomplete actions or responses, and blunders. In other words, errors are any appreciable deviation from desired “operator/system” performance.

Finally, “mental workload” is the integrated mental effort required to perform the instructed task. It includes such factors as level of attention, depth of thinking, and level of concentration required by the instructed task.

#### *Rating Scale Steps*

On the Modified Cooper-Harper Scale, you will notice that there is a series of decisions that follow a predetermined logical sequence. This logic sequence is designed to help you make more consistent and accurate ratings. Thus, you should follow the logic sequence on the scale for each of your ratings in the experiment.

The steps that you will follow in using the rating scale logic are as follows:

1. First, you will decide if the instructed task can be accomplished most of the time; if not, then your rating is a 10, and you should circle 10 on the rating scale.
2. Second, you will decide if adequate performance is attainable. Adequate performance means that the errors are small and inconsequential in performing the instructed task. If errors are not small and inconsequential, then there are major deficiencies in the system, and you should proceed to the right. By reading the descriptions associated with the numbers 7, 8, and 9, you should be able to select the one that best describes the situation you have experienced. You would then circle the most appropriate number.
3. If adequate performance is attainable, your next decision is whether or not your mental workload for the instructed task is acceptable. If it is not acceptable, you should select a rating of 4, 5, or 6. One of these three ratings should describe the situation you have experienced, and you would circle the most appropriate number.

4. If mental workload is acceptable, you should move to one of the top three descriptions on the scale. You would read and carefully select the rating 1, 2, or 3 based on the corresponding description that best describes the situation you have experienced. You would circle the most appropriate number.

Remember that you are to circle only one number, and the number should be arrived at by following the logic of the scale. You should always begin at the lower left and follow the logic path until you have decided on a rating. In particular, do not skip any steps in the logic. Otherwise, your rating may not be valid and reliable.

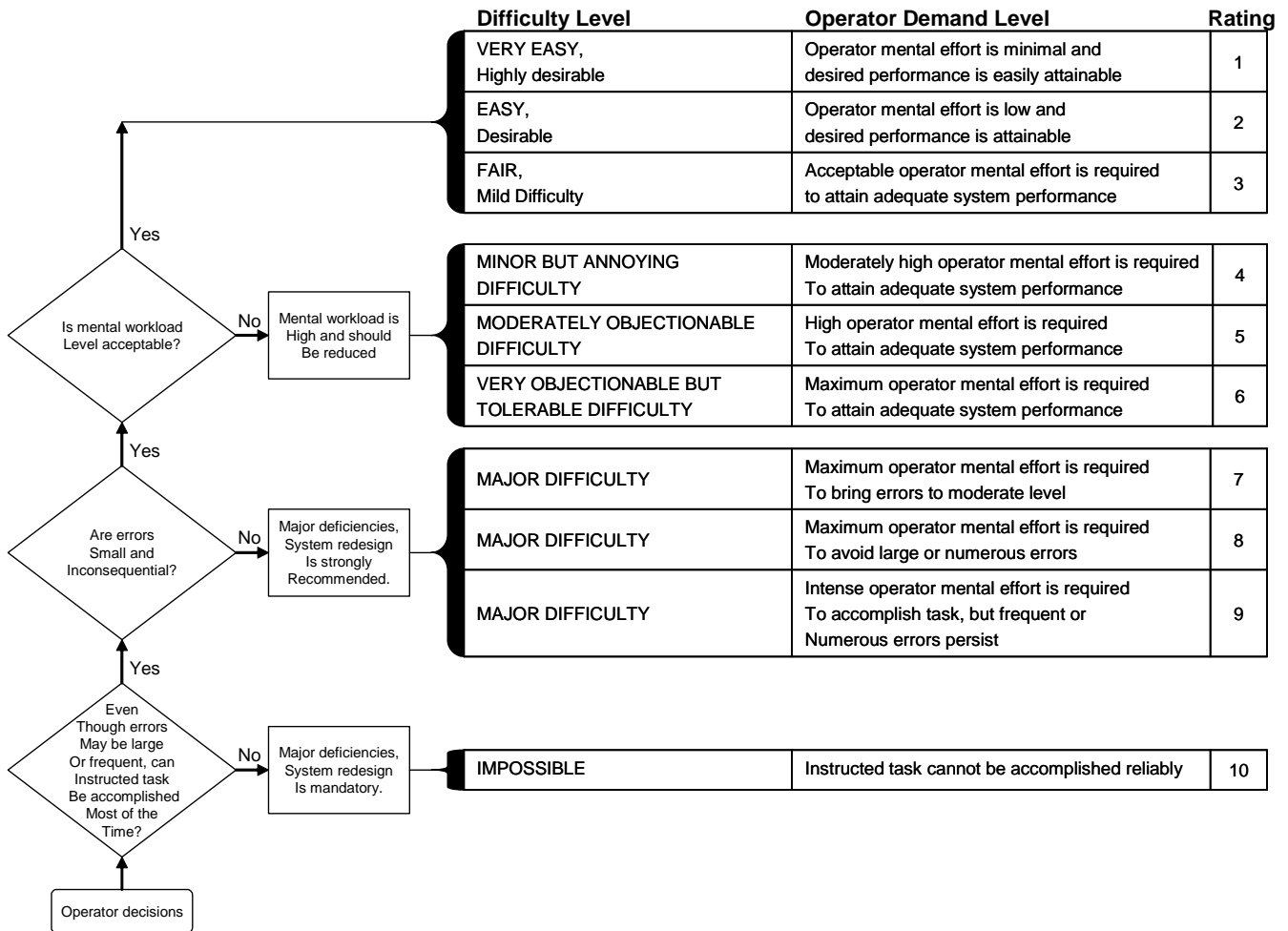
#### *How You Should Think of the Rating*

Before you begin making ratings, there are several points that need to be emphasized. First, be sure to try to perform the instructed task as instructed and make all of your evaluations within the context of the instructed task. Try to maintain adequate performance as specified for your task.

Second, the rating scale is not a test of your personal skill. On all of your ratings, you will be evaluating the system for a general user population, not yourself. You may assume that you are an experienced member of that population. You should make the assumption that problems you encounter are not problems you created. They are problems created by the system and the instructed task. In other words, don't blame yourself if the system is deficient; blame the system.

Third, try to avoid the problem of nit picking an especially good system, and of saying that a system that is difficult to use is not difficult to use at all. These problems can result in similar ratings for systems with quite different characteristics. Also, try not to overreact to small changes in the system. This can result in ratings that are extremely different when the systems themselves are quite similar. Thus, to avoid any problems, just always try to "tell it like it is" when making your ratings.

The Rating Scale



## **Appendix B**

### **ITP Display Interface User Survey**

#### ***Thank you!***

Thank you for participating in the In-Trail Procedure (ITP) Evaluator Display User Survey.

#### ***Background***

NASA and the FAA are developing an airborne surveillance system which allows a properly equipped aircraft to determine and display the position, altitude, groundspeed, direction of flight, and the identification of aircraft in surrounding airspace. This surveillance system is based on a technology known as Automatic Dependent Surveillance-Broadcast (ADS-B), which transmits aircraft position and other essential data via the radar transponder. Aircraft equipped to receive ADS-B data can then determine the position, ground track and altitude of other ADS-B equipped aircraft. With aircraft properly equipped, ADS-B can serve as a precise surveillance system, ultimately enabling new operational procedures. ADS-B will have an operational range of approximately 150NM, and is expected to be especially useful in non-radar environments.

#### ***Purpose of the Survey***

NASA is developing an In-Trail Procedure (ITP) that is based on the ADS-B. Using this ADS-B enabled procedure, flight crews could request and receive clearance to change altitudes more often while operating in non-radar environments. This research is being conducted in coordination with the aviation industry through the RTCA/EUROCAE Requirements Focus Group, reference ADS-B Initiated Flight Level Change in Oceanic and Remote Airspace (ATSA-AIFLC) OSED version 3.6. The purpose of this survey is to collect your ideas and opinions regarding the design of an ITP display interface. The ITP potentially could be operated on an Electronic Flight Bag (EFB) independently of other flight guidance and navigation displays. The information contained in this document will assist pilots in assessing the feasibility of requesting an ITP climb or descent in oceanic airspace. Your feedback will help us define the display's requirements so that when this becomes an operational system flight crews are ultimately provided with a useful and usable tool. Input from subject matter experts and line pilots who will be the eventual "end users" of the ITP Evaluator is critical to the successful development of this tool, hence your participation is very much appreciated.

#### ***Executive Summary of the ITP***

Aircraft in oceanic and remote non-radar airspace frequently fly for extended periods of time in the same direction and along the same or similar paths over the earth's surface as other aircraft. Oceanic controllers utilize procedural separation to ensure aircraft remain separated while flying in this airspace. Particularly during such long flights, these aircraft may enhance operational efficiency and safety through a change of flight level by climbing (usually to increase fuel efficiency) or descending (usually to avoid turbulence or unfavorable winds). In many situations however, the standard longitudinal separation does not exist at the next higher or lower flight level, but does exist at the succeeding flight level. The aircraft desiring the flight level change would therefore be prevented or "blocked" from making the climb or descent. Leveraging the capabilities of ADS-B and onboard automation, the ITP concept has been designed to enable the use of temporarily reduced distance or time-based separation minima during the maneuver to allow an aircraft to pass through the intervening flight level of the blocking aircraft. To make this possible, an onboard ITP Evaluator is being designed. The ITP Evaluator will reduce pilot workload by gathering all relevant information from the surrounding airspace (approximately 150 nm radius), computing the suitability of the ITP maneuver, and displaying that suitability status to the flight crew. The crew would then decide to request an ITP clearance to make an altitude change, providing the controller with appropriate call sign and separation information from the ITP Evaluator using a new standard phraseology. This is a crucial step, as there are additional separation and spacing criteria beyond the scope of the ITP Evaluator that the controller must consider before issuing a clearance. Additional information regarding the ITP maneuvers and the ITP Evaluator is available in the detailed description sections.

#### ***Survey Instructions***

Please take a few moments to review and understand the "Introduction to the ITP Maneuvers" and "Introduction to the ITP Evaluator" before proceeding to the survey questions section. Once you have completed the survey,

please return your responses to the NASA Langley Research Center using the postage paid envelope that has been provided. Please keep the introductory material for your records.

Please note that the information collected from individual survey respondents will be kept strictly confidential. At no time will your individual responses be released to anyone other than individuals working directly on the project without your written consent. The information you provide will have your name removed, and only a participant number (i.e., Participant #1, Participant #2, etc.) will identify your responses during analyses and any written reports regarding the results of this survey.

If you have any questions about this survey now or in the future, please contact:

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Mail Stop 156A, NASA Langley Research Center, Hampton, VA 23681-2199  
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Email: [Jennifer.L.Murdoch@nasa.gov](mailto:Jennifer.L.Murdoch@nasa.gov)

### ***Introduction to the ITP Maneuvers***

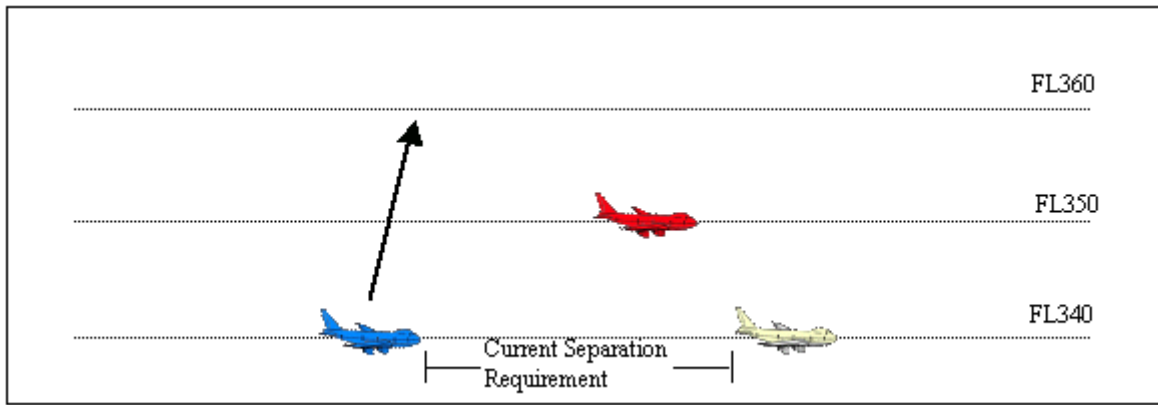
The ITP enables an aircraft to perform a climb or descent maneuver to a requested flight level through one intervening flight level that is occupied by another aircraft (referred to as a potentially blocking aircraft) on the same oceanic track. A total of six ITP climb and descent maneuvers are defined: following climbs and descents, in which the ownship is behind the other aircraft; leading climbs and descents, in which the ownship is ahead of the other aircraft; and combined climbs and descents, in which the ownship is behind one aircraft at the intervening flight level, but ahead of another. A typical ITP climb initial condition scenario, on a same-direction track structure in RVSM airspace, is presented in the figure below. In this example, the aircraft at FL 350 is defined as the reference aircraft.

Each ITP maneuver terminates when the ownship reports established at the new flight level. Any additional flight level changes would be initiated via either a new ITP maneuver request, if a potentially blocking aircraft is present, or otherwise a regular non-ITP flight level change request.

The ITP requires the flight crew to use information derived on the flight deck to determine if the criteria for an ITP are met, and to relay some of this information to ATC for a clearance decision. The following aircraft and flight crew requirements must be met before requesting an ITP:

- The ownship aircraft must have ADS-B in equipment that provides the flight crew with the flight identifier, altitude, range (from the ownship to the reference aircraft), and ground speed differential of the potentially blocking ADS-B out equipped aircraft.
- The flight crew must be properly qualified for ITP maneuvers.
- The airline operational specifications for the ownship aircraft must permit use of the ITP.
- The ownship aircraft must be able to maintain cruise Mach throughout the procedure.
- The ownship aircraft must also be able to maintain a minimum climb or descent rate of 300 fpm until established at the requested flight level.
- The ownship's position data must meet the ITP accuracy requirements, and the ADS-B data from the potentially blocking aircraft must be qualified for meeting the requirements of the ITP.

In addition to the requirements listed above, specific criteria for range and ground speed differential with potentially blocking aircraft must be met in order to request an ITP maneuver. When the range from ownship to the other aircraft is less than 15 nm, the ITP is not applicable. When the range is between 15 and 20 nm, the ground speed differential must not exceed 20 kt of closure. When the range is greater than 20 nm, the ground speed differential must not exceed 30 kt of closure. These range and ground speed differential criteria are applicable to all six ITP climb or descent maneuvers.



Typical initial condition for executing an ITP climb.

The sequence followed by the ownship flight crew and the oceanic controller is as follows:

1. The ownship flight crew decides that a flight level change is desirable based on fuel efficiency, ride quality, or other considerations. The crew also determines, based on the evaluator display, that an ITP maneuver appears to be required.
2. The ownship flight crew reviews the ITP Evaluator information to determine that the criteria for executing an ITP maneuver are met. These criteria include crew qualifications, aircraft equipage and performance capabilities, and the relative ranges and groundspeed differentials with all potentially blocking aircraft at intervening flight levels.
3. The ownship flight crew requests clearance from ATC to conduct the appropriate ITP maneuver to the requested flight level. The request will include the flight identifiers of any reference aircraft (i.e., potentially blocking aircraft that meet the ITP criteria) and the range in nautical miles to each of those reference aircraft. This request will be made using a new standard phraseology.
4. The controller will assess the requested altitude using standard separation minima and procedures, and will grant the request if all applicable criteria are met. These criteria include standard longitudinal separation minima, limits on the acceptable Mach difference between the ownship and reference aircraft (maximum of 0.03 Mach), knowledge of the positions and speeds of all other ADS-B equipped and non-ADS-B equipped aircraft that may be in the area, and any other appropriate considerations. Alternatively, the controller may, if appropriate, issue a standard climb clearance. At all times, the controller maintains responsibility for separation, granting clearance for the maneuver based on the information provided by the requesting aircraft. The controller also ensures that the reference aircraft does not maneuver during the ITP maneuver.
5. After receiving the clearance to conduct the ITP, the ownship flight crew again verifies that the ITP criteria are met immediately before initiating the ITP climb or descent maneuver, and initiates the maneuver without delay. However, after acceptance of the ITP clearance and initiation of the maneuver, the ownship flight crew is not required to monitor any information regarding the reference aircraft, such as range or ground speed difference – this information was only necessary to make the ITP request.
6. While performing the ITP maneuver, the ownship flight crew monitors their speed as well as their climb or descent rate. If the maneuver cannot be accomplished at the original cruise Mach and also meet the minimum continuous climb or descent rate of 300 fpm, the ownship aircraft must return to its initial flight level, and the flight crew must immediately notify the controller.
7. Upon issuance of the ITP clearance, the controller will protect both the initial flight level and the requested flight level until the controller receives a report from the requesting aircraft that it is established at the requested flight level (or that it has returned to the initial altitude, in case it cannot complete the



ITP). The controller will also refrain from issuing any maneuver clearances to the reference aircraft until the requesting aircraft reports that it has completed maneuvering.

8. The ownship flight crew reports to the controller when they have reached the requested flight level. This completes the ITP.

## ***Introduction to the ITP Evaluator***

The ITP Evaluator is intended to serve as a tool that flight crews may interact with via a cockpit mounted EFB. These notional depictions of the information required to perform an ITP are not intended to be used as navigation displays. The ITP Evaluator tracks, analyzes, and displays relevant same-track ADS-B air traffic in the ITP range according to the rules described in the *Introduction to the ITP Maneuvers* section, and operates independently of other flight guidance, navigation and traffic displays. This section presents several candidate EFB presentation configurations. Definitions of some key words, display functionality, candidate display combinations, and additional features are provided.

### **Definitions:**

Vertical: Two dimensional view of airspace providing multiple altitudes with no graphical lateral or track information.

Horizontal: Two dimensional view of airspace providing look-down perspective with no graphical altitude information.

Track Up: Presentation of path upward on the Horizontal view.

Track Right: Presentation of path towards the right on the Horizontal view.

### **Display Functionality:**

On all displays, the ownship aircraft is represented by a solid white triangle, and “same-track” traffic aircraft are depicted by hollow cyan triangles on the vertical display and by hollow cyan chevrons on the horizontal display. An aircraft is considered to be “same-track” if its lateral distance and flight path angle fall within standards-defined limits with respect to the ownship aircraft. The apex of the triangles and chevrons indicates the direction of travel of the depicted aircraft, as well as its center of mass. A cyan data tag containing flight identifier, range, and groundspeed differential (difference between ownship and reference aircraft) is provided for potentially blocking aircraft located at intervening flight levels, and a cyan “unavailable” tag is used to indicate that a blocking aircraft is preventing an ITP maneuver through its respective flight level. The groundspeed differential is presented with a triangle-arrow that either points towards or away from the ownship. The arrow points towards the ownship when the distance between the ownship and the tagged aircraft is decreasing while the arrow points away from the ownship when the distance is increasing. On the horizontal displays, the data tag follows TCAS conventions. The ownship MCP altitude is depicted on the vertical display as a solid magenta line, while other flight levels are depicted as dotted lines. These examples depict a non-organized track system region such as the South Pacific.

Vertical and horizontal display range selectors provide an interface for choosing the desired visible ranges to display. A display range selector is located at the bottom left corner of the display and indicates the current total visible display range. It is associated with buttons that allow the user to increase or decrease the visible display range.

An altitude range selector is located at the bottom center of the display and indicates the current total visible display altitude range. It is associated with buttons that allow the user to increase or decrease the visible altitude display range. Note, however, that display ranges and altitudes in excess of those usable by the ITP can be

presented. These are provided as reference ranges and altitudes only to facilitate situation awareness. Information regarding accessibility at these greater altitude ranges is not presented.

### **Candidate Display Configurations:**

Figure 1 presents the “Vertical-toggle-Horizontal” configuration (described below) with annotations that explain the encoding details of the symbology. Figures 2-4 present the configurations as they might actually appear on an EFB.

Vertical-toggle-Horizontal, Track Up: This candidate is presented in Figure 2a (and also in Figure 1 with annotations). This configuration implements each of the two views as separate pages on the EFB, requiring the user to manually switch or “toggle” between them. The Horizontal view is presented as Track Up. It is envisioned that an EFB control device (e.g., bezel button, rotary knob, switch, etc.) will be used to toggle between vertical and horizontal ITP Evaluator display formats.

Vertical-toggle-Horizontal, Track Right: This candidate is presented in Figure 2b, and is the same as Figure 2a, except that the Horizontal view is presented with the aircraft tracking to the right.

Combined with Vertical-on-Bottom, Track Up: This candidate is presented in Figure 3a. This configuration combines each of the two views on a single page on the EFB, with the Vertical view below the Horizontal view. The Horizontal view is presented as Track Up.

Combined with Vertical-on-Bottom, Track Right: This candidate is presented in Figure 3b, and is the same as Figure 3a, except that the Horizontal view is presented with the aircraft tracking to the right.

Combined with Vertical-on-Top, Track Up: This candidate is presented in Figure 4a. This configuration combines each of the two views on a single page on the EFB, with the Vertical view above the Horizontal view. The Horizontal view is presented as Track Up.

Combined with Vertical-on-Top, Track Right: This candidate is presented in Figure 4b, and is the same as Figure 4a, except that the Horizontal view is presented with the aircraft tracking to the right.

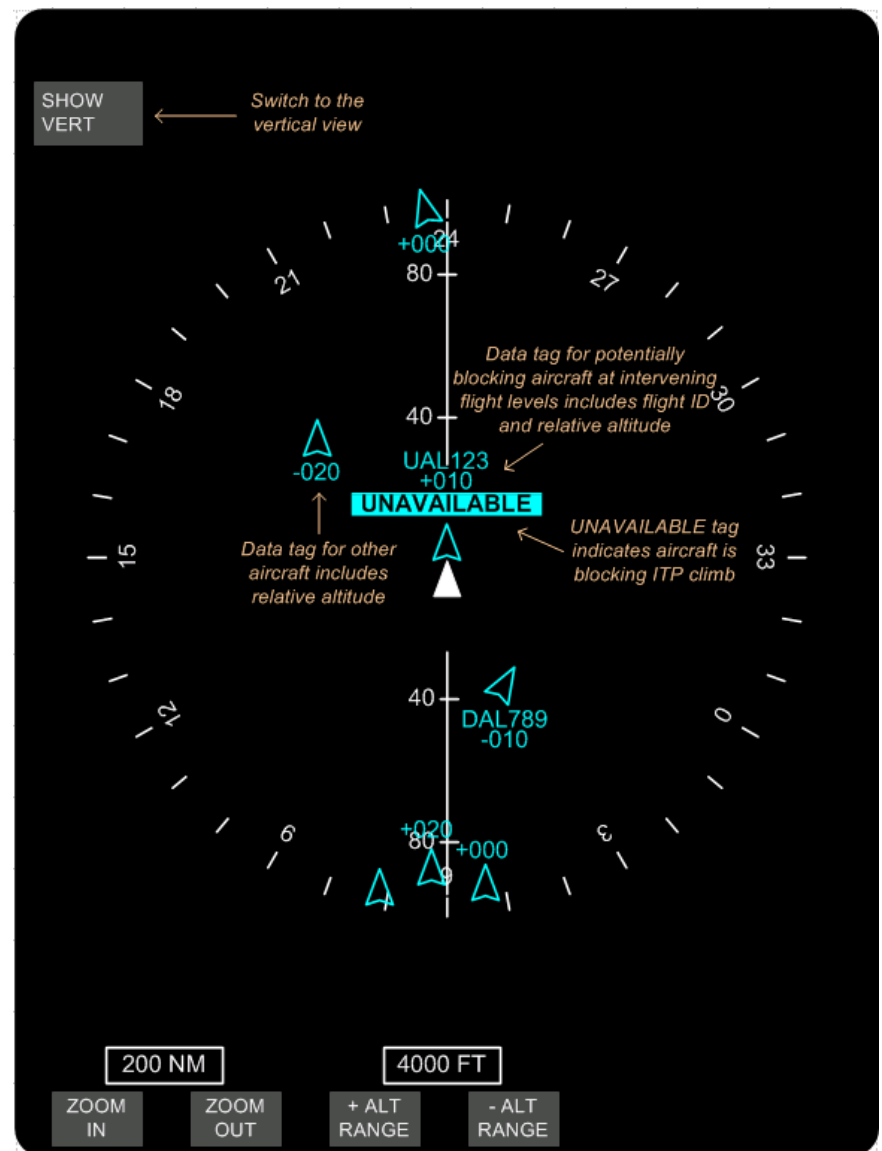
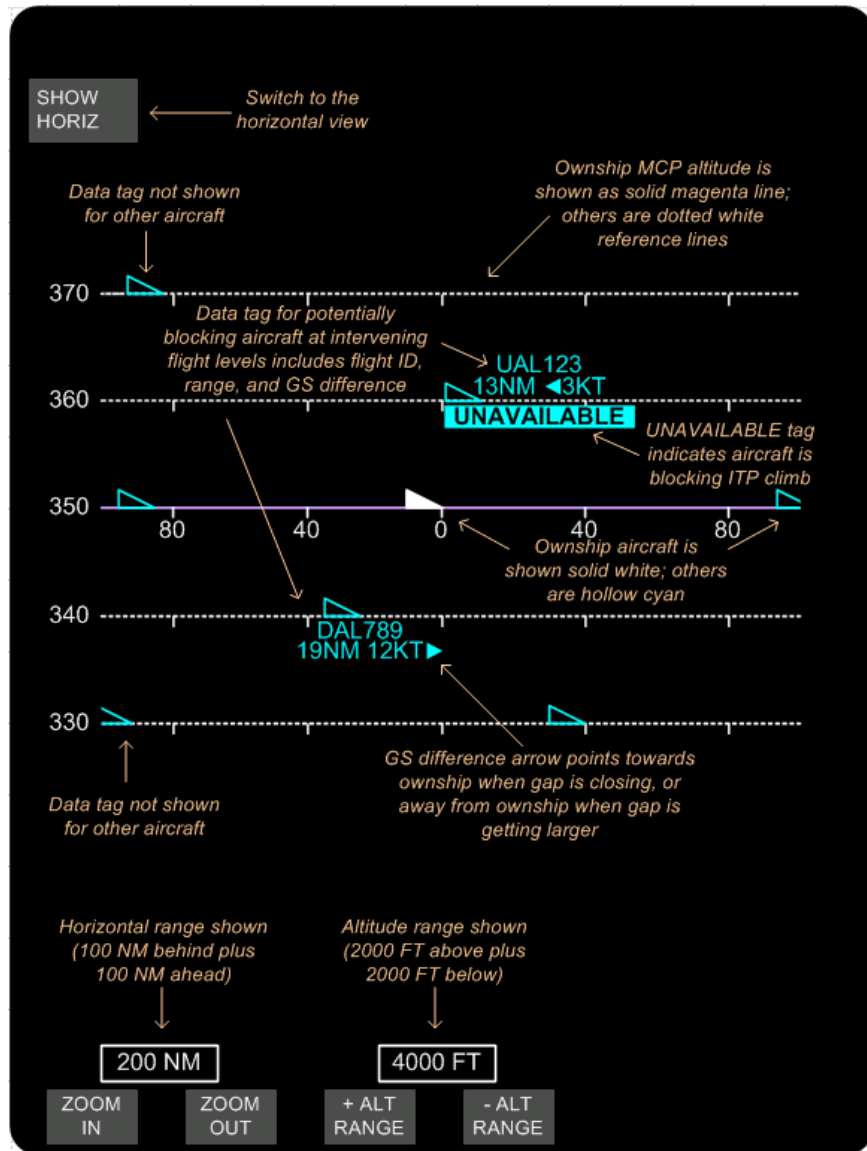


Figure 1. Vertical-toggle-Horizontal, Track Up Candidate EFB configuration, with annotations

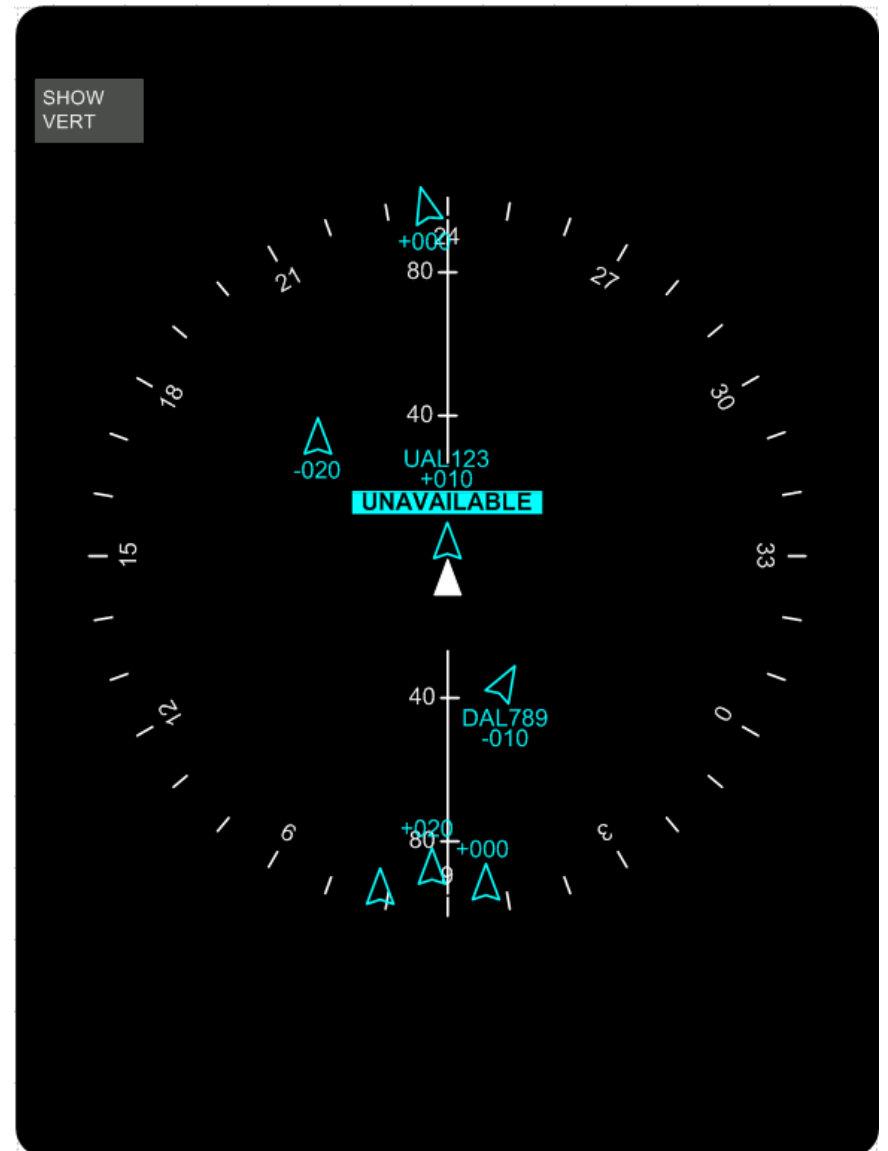
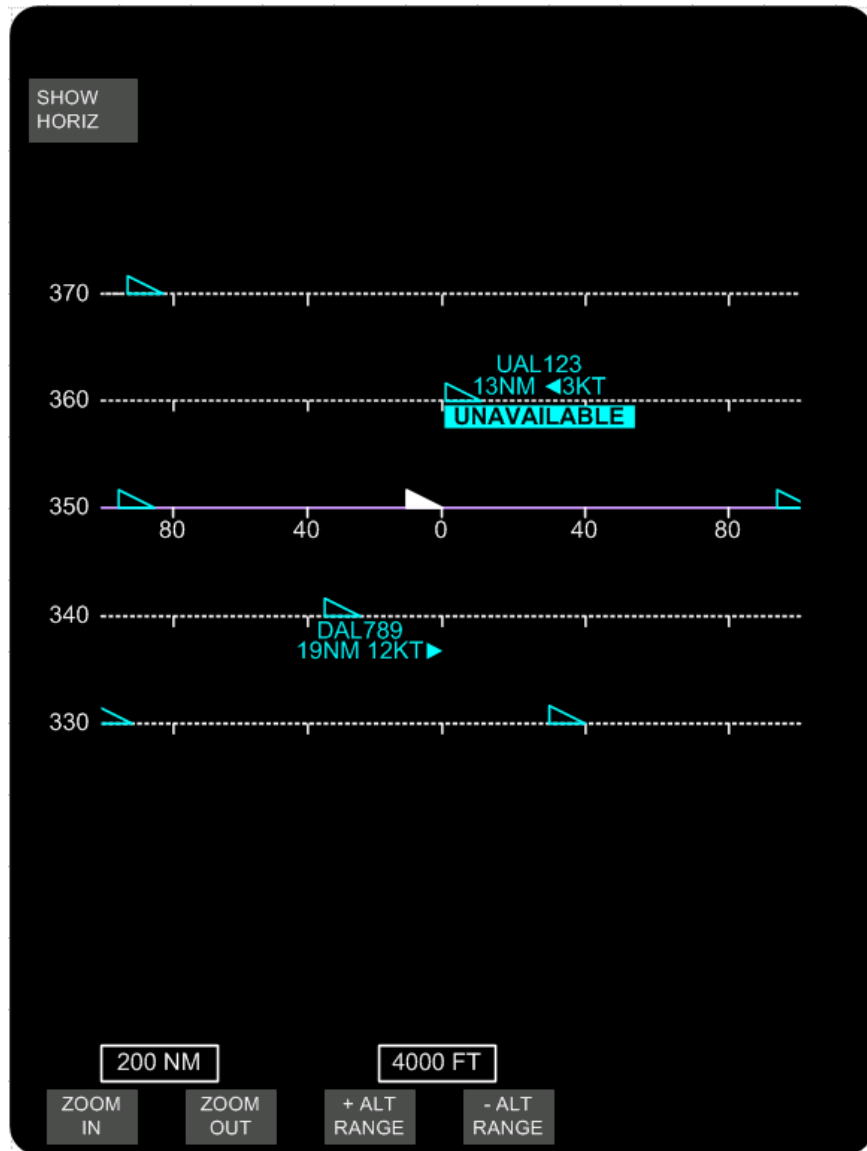


Figure 2a. Vertical-toggle-Horizontal, Track Up Candidate EFB configuration

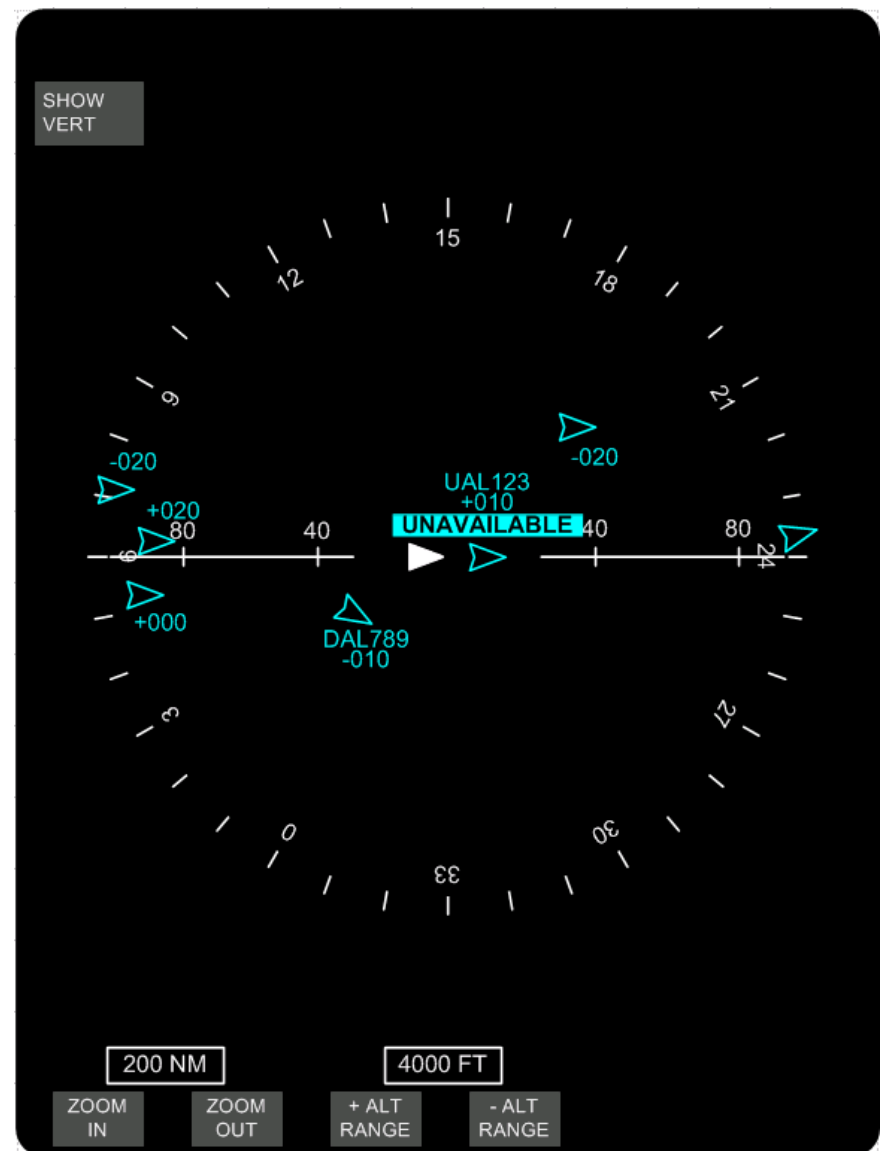
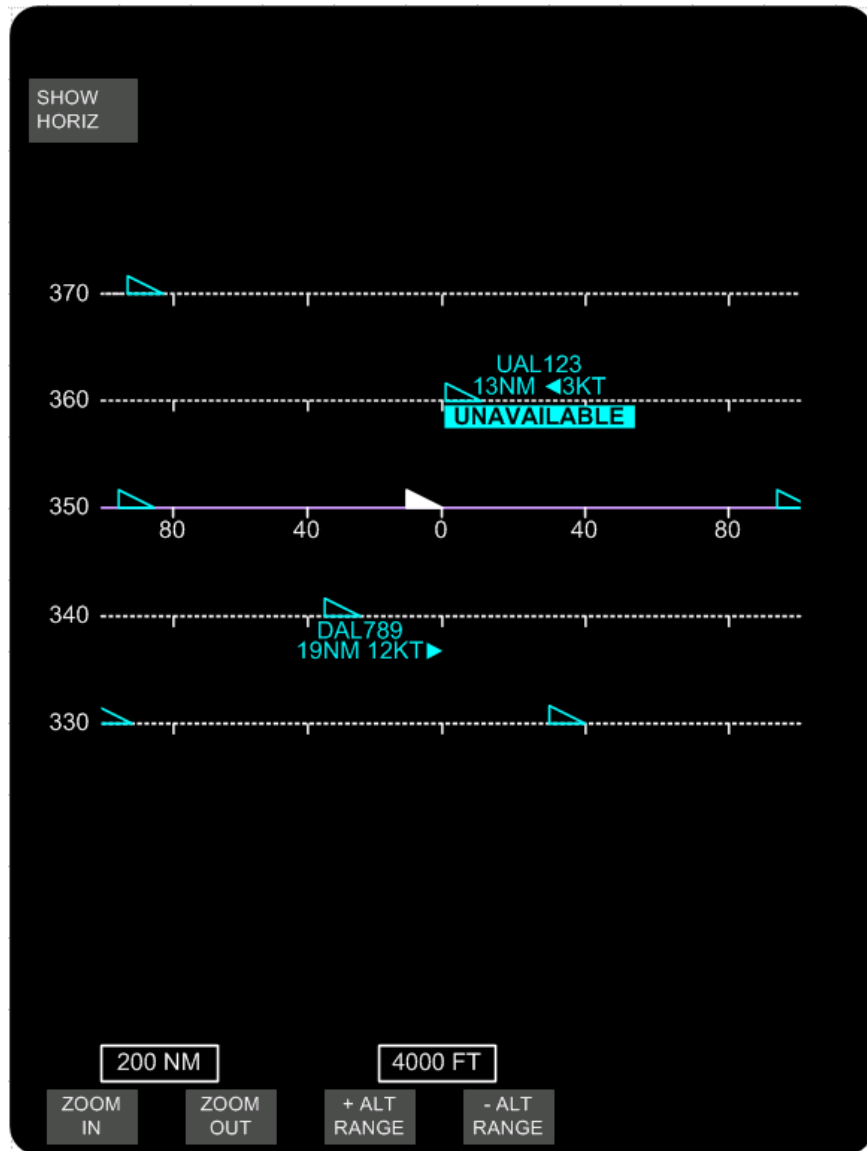


Figure 2b. Vertical-toggle-Horizontal, Track Right Candidate EFB configuration

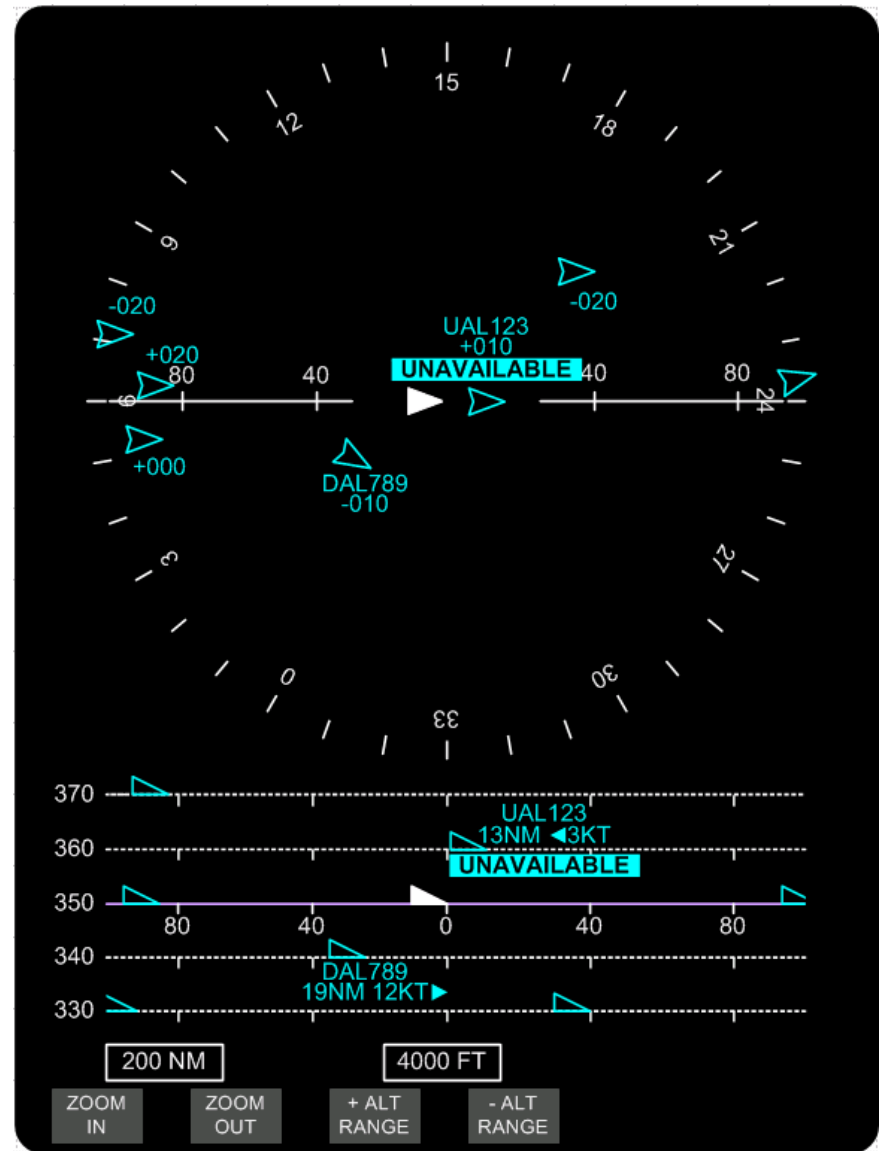
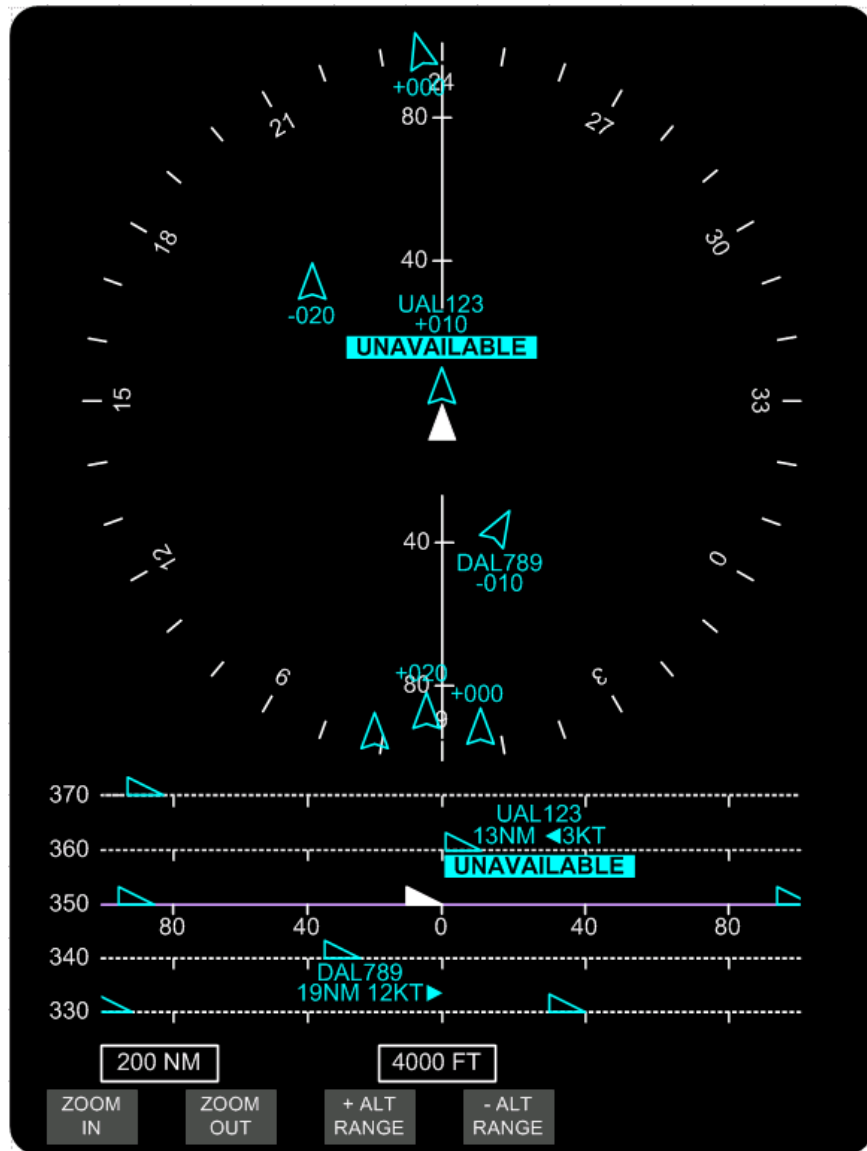


Figure 3a-b. Combined with Vertical-on-Bottom, (a) Track Up and (b) Track Right Candidate EFB configurations

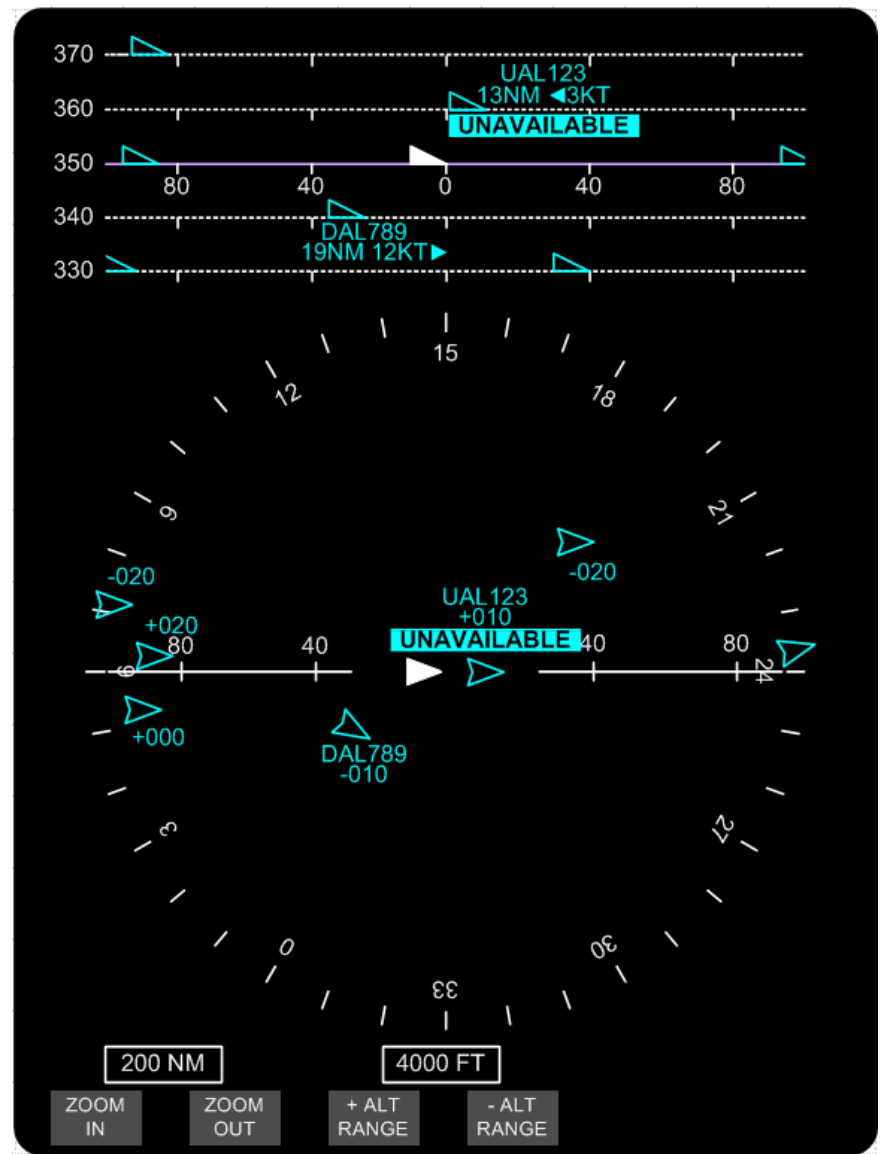
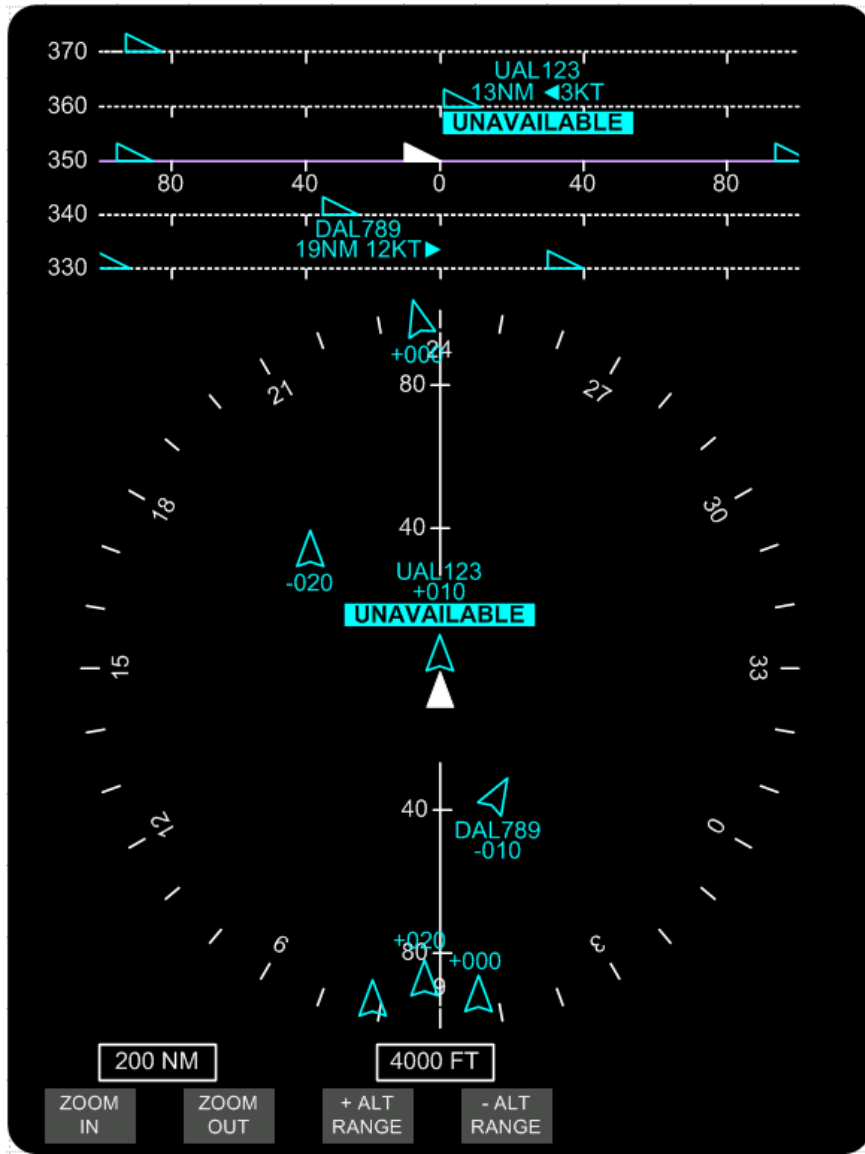


Figure 4a-b. Combined with Vertical-on-Top, (a) Track Up and (b) Track Right Candidate EFB configurations

## **In-Trail Procedure (ITP) Evaluator Display User Survey: Questionnaire**

Now that you have reviewed the ITP Evaluator Display User Survey's introductory materials and have acquired an understanding of the proposed ITP maneuvers and the ITP Evaluator, you are now prepared to complete the survey questions section. The primary aim of the survey questions is to elicit your feedback regarding the ITP Evaluator display interface. Additional demographic questions are also included so that general characteristics of the survey participants may be understood.

With respect to the ITP Evaluator display interface, you will be asked to comment on the:

- three proposed display formats (i.e., Vertical-toggle-Horizontal; Combined with Vertical-on-Bottom; and Combined with Vertical-on-Top);
- Horizontal Track Up configuration versus the Horizontal Track Right configuration; and
- use of symbology, color, and information coding.

Please refer to the figures included in the introductory materials while you complete the questionnaire.

Throughout the survey, spaces are provided for you to explain your selections as well as suggest alternatives and/or improvements. Please provide as much or as little detail in your written responses as you would like, and feel free to use the back of each sheet to continue your comments if needed. Additionally, you will have an opportunity to illustrate your ideal ITP Evaluator display interface.

With respect to demographic information, you will be asked to provide information regarding your:

- military, business/corporate, and/or scheduled airline experience
- general flying experience;
- experience with Vertical Situation Displays (VSDs), Electronic Flight Bags (EFBs), and Personal Computers (PCs); and
- gender, date of birth, willingness to be contacted by researchers to discuss your survey responses, and interest in participating in future ITP simulation experiments.

Please complete and return this survey within one week of receiving it to the NASA Langley Research Center using the postage paid envelope that has been provided. Thank you for participating in the ITP Evaluator Display User Survey.



## *Display Interface Feedback*

1. Various combinations of the vertical and horizontal graphical displays have been presented. Please rank the display formats listed below according to your preferences.

The rank of **1** should correspond with the display format you like the **most**.

The rank of **6** should correspond with the display format you like the **least**.

- \_\_\_\_\_ Vertical-toggle-Horizontal, Track Up, Figure 2a
- \_\_\_\_\_ Vertical-toggle-Horizontal, Track Right, Figure 2b
- \_\_\_\_\_ Combined with Vertical-on-Bottom, Track Up, Figure 3a
- \_\_\_\_\_ Combined with Vertical-on-Bottom, Track Right, Figure 3b
- \_\_\_\_\_ Combined with Vertical-on-Top, Track Up, Figure 4a
- \_\_\_\_\_ Combined with Vertical-on-Top, Track Right, Figure 4b

Please explain your rank ordering:

2. Considering the display format you ranked as number 1 (i.e., liked the most):

- a. How useful do you think this display format would be for supporting the six ITP maneuvers?  
(Circle one response.)

Very  
Useful

Useful

Somewhat  
Useful

Marginally  
Useful

Not at all  
Useful

- b. Do you have a suggested alternative or improvement, particularly if you think that this display format would not be useful for supporting a particular procedure?

- c. If you do not think you could safely execute the full range of ITPs using this display format, which procedure(s) do you think would be difficult to perform? Why?

- d. What information could be added to, removed from, or changed in this display format to increase the safety of executing ITPs or otherwise improve the display interface?

2.1. If you wish, you may comment on a second display format (and any others as well); otherwise, skip to question 3 on page 4:

- a. What ranking number are these comments about? \_\_\_\_\_
- b. How useful do you think this display format would be for supporting the new ITP maneuvers?

|             |        |                 |                   |                   |
|-------------|--------|-----------------|-------------------|-------------------|
| Very Useful | Useful | Somewhat Useful | Marginally Useful | Not at all Useful |
|-------------|--------|-----------------|-------------------|-------------------|

- c. Do you have a suggested alternative or improvement, particularly if you think that this display format would not be useful for supporting a particular procedure?

- d. If you do not think you could safely execute the full range of ITPs using this display format, which procedure(s) do you think would be difficult to perform? Why?

|  |
|--|
|  |
|  |
|  |

- e. What information could be added to, removed from, or changed in this display format to enhance your ability to perform an ITP, or otherwise improve the display interface?

|  |
|--|
|  |
|--|

3. Do you feel that the inclusion of the Horizontal display format enhances the ITP Evaluator?

Yes                  No

Please explain your selection:

|  |
|--|
|  |
|--|

4. Which Horizontal display orientation do you prefer?

Track Up                  Track Right

Please explain your selection:

|  |
|--|
|  |
|--|

- a. What information could be added to, removed from, or changed in the Horizontal Track Up display format to increase the safety of executing ITP maneuvers or otherwise improve the display interface?

5. How useful would it be to have the ability to simplify the display interface by requesting that either a “climb only” or a “descent only” option be depicted? A climb only configuration would show only those flight levels above the ownship on the vertical display, and for both displays, only those aircraft at higher flight levels. Conversely, a descent only option would show only lower flight levels and aircraft.

Very  
Useful

Useful

Somewhat  
Useful

Marginally  
Useful

Not at all  
Useful

Please explain your selection:

6. Consider the display interface’s symbology:

- a. How appropriate is the use of color?

Very  
Appropriate

Appropriate

Somewhat  
Appropriate

Neutral

Somewhat  
Inappropriate

Inappropriate

Very  
Inappropriate

- b. Do you have suggested alternatives or improvements, particularly if you found the display interface’s use of color to be inappropriate?

c. How appropriate is the information included in the traffic aircraft's data tags?

Very Appropriate      Appropriate      Somewhat Appropriate      Neutral      Somewhat Inappropriate      Inappropriate      Very Inappropriate

d. Do you have suggested alternatives or improvements, particularly if you found the information included in the traffic aircraft's data tags to be inappropriate?

e. Is it helpful to have the word "unavailable" included in a traffic aircraft's data tag when applicable (see examples below)?

Yes      No



Please explain your selection:

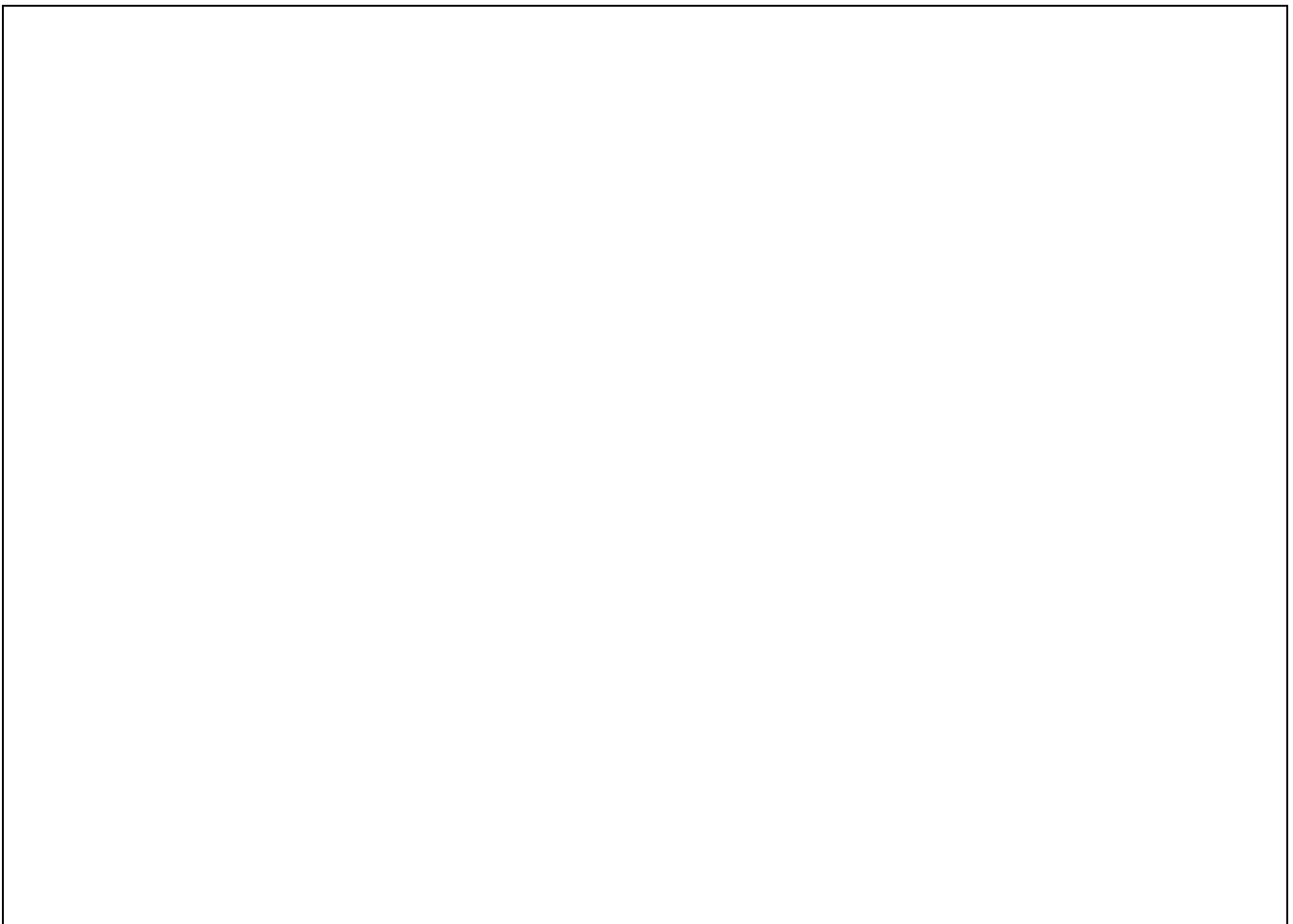
f. How intuitive is the representation of the ground speed differential between the ownship and the potentially blocking aircraft (i.e., the use of an arrow pointing to the ownship when the distance between the ownship and the tagged aircraft is decreasing, and with the arrow pointing away from the ownship when the distance is increasing)?

Very Intuitive      Intuitive      Somewhat Intuitive      Neutral      Somewhat Unintuitive      Unintuitive      Very Unintuitive

Please explain your selection:

A large, empty rectangular box with a thin black border, intended for the user to provide an explanation for their selection.

7. In your opinion, what would the ideal ITP Advisor display interface look like? (Please illustrate your design ideas in the space provided below.)

A large, empty rectangular box with a thin black border, intended for the user to illustrate their design ideas for the ideal ITP Advisor display interface.

## ***Demographic Information***

### General Experience

1. Please provide your best estimate for each of the following (values may be rounded if desired):

- Total Flight Hours: \_\_\_\_\_
- Hours as Pilot-in-Command: \_\_\_\_\_
- Hours as Second-in-Command: \_\_\_\_\_
- Hours as Flight Engineer: \_\_\_\_\_
- Total Years Flying: \_\_\_\_\_
- Long Range Over Water, 3 or 4 engine, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_
- Long Range Over Water, 2 engine, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_

### Military Experience

2. Do you have any military flying experience? (Circle one.)

Yes    No    If Yes, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_

### Business/Corporate Experience

3. Do you have any business/corporate flying experience?

Yes    No    If Yes, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_

### Scheduled Airline Experience

4. How many years and hours of airline flying have you completed: \_\_\_\_\_ / \_\_\_\_\_

5. What is your current position? (Circle one.)                      Captain              First Officer              Flight Engineer

6. Have you ever flown trans-oceanic routes?                      Yes                      No

(If “yes,” proceed to question #6a; if “no,” skip to question 7 on p.9).

a. On a scale of 0 to 10, rate your level of familiarity with flying oceanic routes.

A rating of **0** corresponds to “**very unfamiliar.**”

A rating of **10** corresponds with “**very familiar.**”

***Level of familiarity with flying oceanic routes:*** \_\_\_\_\_

b. What oceanic regions have you flown in? List in order of experience, with most as first.

c. Considering the trans-oceanic route that you fly most frequently, how many times do you request altitude changes during a typical flight, and what percentage of the time are your altitude change requests granted?

Number of altitude change requests during a typical flight: \_\_\_\_\_

Percentage of time that altitude change requests are granted during a typical flight: \_\_\_\_\_

d. While in Oceanic airspace do you expect ATC will allow you to climb while not in radar contact?  
Yes            No

e. What kinds of techniques do you use to facilitate your ability to get the best Oceanic crossing altitude?

f. While operating beyond VHF range of ATC, have you ever coordinated Oceanic Climbs with other proximate aircraft on a common VHF frequency (123.45) before asking ATC for a climb via HF or CPDLC?            Yes            No

If so, how often have you done so? \_\_\_\_\_

7. What route(s) do you currently fly?



8. What type of equipment do you currently fly?

9. Is your typical aircraft equipped with ADS?    Yes    No    Sometimes    Don't Know

10. Is your aircraft equipped with CPDLC?    Yes    No    Sometimes    Don't Know

11. Is HF radio your primary means of communicating with ATC in Non-Radar environments?  
Yes    No    Sometimes

12. Do you use ETOPS procedures on your current aircraft?    Yes    No

13. How do you determine what altitude to request for an oceanic crossing? (select all that apply)  
Flight Plan  
FMC Cruise page  
If another method is used please describe:

14. When requesting an Oceanic crossing altitude do you typically request an altitude higher or lower than optimum altitude displayed on the FMC cruise page?

Higher    Lower

Experience with Vertical Situation Displays

15. Have you ever used a vertical situation display (VSD)?    Yes    No

(if "yes," proceed to question #15a; if "no," skip to question #16 on p.11)

a. How would you characterize your previous experience(s) using VSDs?

|               |          |                   |         |                   |          |               |
|---------------|----------|-------------------|---------|-------------------|----------|---------------|
| Very Positive | Positive | Somewhat Positive | Neutral | Somewhat Negative | Negative | Very Negative |
|---------------|----------|-------------------|---------|-------------------|----------|---------------|

Please explain:

Experience with Electronic Flight Bags

16. Have you ever used an EFB?

Yes    No

(if “yes,” proceed to question #16a; if “no,” skip to question #17 on p.12)

a. What class(es) of EFB(s) have you used? (Please circle all that apply.)

Class 1 EFBs [i.e., Commercial-Off-The-Shelf (COTS)-based systems, including laptop computers, that are fully portable]

Class 2 EFBs (i.e., COTS-based systems that are portable, are connected to the aircraft during normal operations, and require an administrative control process for removal)

Class 3 EFBs (i.e., installed equipment)

b. How would you characterize your previous experience(s) using EFBs?

|                  |          |                      |         |                      |          |                  |
|------------------|----------|----------------------|---------|----------------------|----------|------------------|
| Very<br>Positive | Positive | Somewhat<br>Positive | Neutral | Somewhat<br>Negative | Negative | Very<br>Negative |
|------------------|----------|----------------------|---------|----------------------|----------|------------------|

Please explain:

c. Please describe the functionality of the EFB application(s) you have used most frequently in the past:

Miscellaneous Information

17. On a scale of 0 to 10, rate how often you use a personal computer.  
A rating of **0** corresponds to **“I never use a personal computer.”**  
A rating of **10** corresponds with **“I use a personal computer multiple times every day.”**

*Level of personal computer usage:* \_\_\_\_\_

18. What is your current age? \_\_\_\_\_

19. Would you be willing to discuss your comments regarding the ITP Evaluator display interface with someone working on this research project?

Yes    No

If "yes," please provide your preferred contact information (i.e., name, phone, email address, etc.):

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Please note that the information collected from individual survey respondents will be kept strictly confidential. At no time will your individual responses (including those provided in person, by phone, or via email) be released to anyone other than individuals working directly on the project without your written consent. The information you provide will not have your name associated with it; only a participant number (i.e., Participant #1, Participant #2, etc.) will identify you during analyses and any written reports regarding the results of this survey.

20. Would you be interested in participating in future ITP simulation experiments?

Yes    No

If “yes,” please complete the on-line questionnaire located at:

<http://flight-research.larc.nasa.gov/>, and/or contact:

Jennifer L. Murdoch  
Aircraft Operations & Evaluation Branch  
Mail Stop 156A, NASA Langley Research Center, Hampton, VA 23681-2199  
Phone: (757) 864-8304  
Email: [Jennifer.L.Murdoch@nasa.gov](mailto:Jennifer.L.Murdoch@nasa.gov)

## Appendix C

### ITP Display Interface User Survey: Overview of Results

As described in Appendix B, the purpose of the “In-Trail Procedure (ITP) Evaluator Display User Survey” was to collect commercial airline pilots’ “ideas and opinions regarding the design of an ITP display interface.” The survey was distributed to approximately 1,500 oceanic line pilots, and 245 pilots completed and returned their surveys by mail to NASA Langley Research Center. Pertinent characteristics of the survey’s respondents and an overview of the survey’s results are provided below.

The 245 survey respondents consisted of 97 commercial airline captains and 148 first officers who ranged in age between 35 – 59 years [Mean ( $M$ ) = 49; Standard Deviation ( $SD$ ) = 7]. On average, these pilots had approximately 28 years ( $M$  = 28.7,  $SD$  = 6.9) and 10,500 hours of airline flying experience ( $M$  = 10,518,  $SD$  = 4,633). Over 75% of the pilots had experience flying in the North Atlantic and South Pacific track systems, and 13% had experience flying oceanic routes in the Caribbean and Polar regions as well as in Southeast Asia. With respect to flying long range over water, the survey respondents had, on average, 6.5 years ( $M$  = 6.5,  $SD$  = 7.7) and 2,800 hours ( $M$  = 2,800;  $SD$  = 3,760) of experience flying three or four engine aircraft and had, on average, 4.5 years ( $M$  = 4.5,  $SD$  = 3.5) and 2,390 hours ( $M$  = 2,390;  $SD$  = 2,137) of experience flying two engine aircraft. When asked to rate their level of familiarity with flying oceanic routes on a scale from 0 (i.e., “very unfamiliar”) to 10 (i.e., “very familiar”), the mean response was 9.44 ( $SD$  = 1.22). When asked to rate their level of computer usage on a scale from 0 (i.e., “I never use a computer”) to 10 (i.e., “I use a computer multiple times every day”), the mean response was 8.86 ( $SD$  = 1.85).

The survey respondents overwhelmingly preferred the “Combined with Vertical-on-Bottom, Track Up” ITP display interface, presented in Figure 3a of the survey’s introductory materials Appendix B, with 39.18% of the pilots providing this display format with a rank of “1” thereby indicating that it was the format that they liked the most.

The “Combined with Vertical-on-Bottom, Track Up” ITP display configuration, combines a “vertical” view (i.e., a two dimensional view of airspace providing multiple altitudes with no graphical lateral or track information) and a “horizontal” view (i.e., a two dimensional view of airspace providing “look-down” perspective with no graphical altitude information) on a single display screen. The vertical view is presented below the horizontal view, and the horizontal view is presented as “track up” (i.e., an upward presentation of path).

The “Combined with Vertical-on-Top, Track Up” ITP display format (Figure 4a in Appendix B), which combines a vertical view and a horizontal view on a single display screen and presents the vertical view above the “track up” horizontal view, was selected by 22.86% of the survey respondents as their favorite display format. The remaining four display configurations presented in the survey’s introductory materials (Appendix B) included: 1) the “Vertical-toggle-Horizontal, Track Up” display format, 2) the “Combined with Vertical-on-Bottom, Track Right” display format, 3) the “Combined with Vertical-on-Top, Track Right” display format, and 4) the “Vertical-toggle-Horizontal, Track Right” display format. Each of these display configurations was ranked as “1,” or as being the “most liked” display format, by 13.47%, 12.24%, 11.43%, and 0.82% of the survey respondents, respectively.

When asked how useful their preferred display format would be for supporting the execution of ITP flight level change maneuvers, 78% of the survey respondents indicated that they would find their preferred display format to be “very useful.” Twenty-one percent of the pilots reported that their preferred display format would be “useful,” and the remaining 1% reported that their preferred display format would be “somewhat useful” or “marginally useful” during the execution of ITP flight level change maneuvers.

Ninety-five percent of the survey respondents indicated that the inclusion of the horizontal view enhanced the ITP display, and 75.51% preferred that the horizontal view be presented as “track up” rather than “track right.” When asked how useful it would be to have the ability to simplify the display interface by requesting that either a “climb only” or a “descent only” option be depicted, 57% of the pilots indicated that they would find this feature to be “very useful” or “useful”; 38% indicated that they would find this feature to be “somewhat useful” or “marginally useful”; and 5% indicated that they would find this feature to be “not at all useful.”

Survey respondents were also asked to provide feedback regarding specific aspects of the ITP display interface symbology. With respect to the display’s use of color, 77.5% of the survey respondents indicated that it was either “very appropriate” or “appropriate”; 9% indicated that it was “somewhat appropriate”; 11% held a “neutral” opinion; 2% indicated that the display’s use of color was “somewhat inappropriate”; and 0.5% indicated that the display’s use of color was “inappropriate.” With respect to the information included in the traffic aircrafts’ data tags, 92% of the pilots indicated that it was either “very appropriate” or “appropriate”; 6% indicated that it was “somewhat appropriate”; 1.5% held a “neutral” opinion; and 0.5% indicated that the information included in the traffic aircrafts’ data tags was “inappropriate.” Ninety percent of the survey respondents found that having the word “unavailable” included in a traffic aircraft’s data tag, when applicable, was helpful while 10% did not. Lastly, with respect to the intuitiveness of the display’s presentation of ground speed differential, 62% of the survey respondents indicated that it was either “very intuitive” or “intuitive”; 23% indicated that it was “intuitive”; 5% held a “neutral” opinion; 7% indicated that the ground speed differential’s presentation was “somewhat unintuitive”; and 3% indicated that it was either “unintuitive” or “very unintuitive.”

## Appendix D Flight Manual Bulletin

### INSTRUCTIONS TO SUBJECT PILOTS, NASA LANGLEY OCEANIC IN-TRAIL PROCEDURE EXPERIMENT, SEPTEMBER 2006



## FLIGHT MANUAL BULLETIN

2006-01

Insert following the BULLETINS tab.

Revision 1.1 September 6, 2006.

### OCEANIC IN-TRAIL PROCEDURE

#### Background

Aircraft in oceanic and remote non-radar airspace frequently fly for extended periods of time in the same direction and along similar flight paths as other aircraft. Oceanic controllers use procedural separation to ensure aircraft remain separated in this airspace, typically requiring much greater separation times or distances between aircraft than when in radar airspace. During these long flight segments, aircraft may enhance operational efficiency and safety through a change of flight level by climbing (usually to increase fuel efficiency) or descending (usually to avoid turbulence or unfavorable winds). However, in many situations the standard longitudinal separation does not exist at one or more higher or lower flight levels, but does exist at a succeeding flight level. An aircraft desiring a flight level change to such a succeeding flight level would therefore be prevented or “blocked” from making the climb or descent through the intervening flight level(s).

NASA is developing and testing in simulation an In-Trail Procedure (ITP), which would increase the opportunities for such flight level changes that would otherwise be blocked. The ITP employs new onboard avionics equipment that provides the crew with improved information about nearby traffic, and new procedures that enable the crew, when appropriate criteria are met, to request an ITP flight level change referencing one or two of these nearby aircraft that might otherwise block the flight level change. The ITP equipment uses airborne surveillance data broadcast from nearby aircraft that yields more accurate position data than that available to oceanic controllers, enabling controllers to approve ITP flight level change requests that reference these aircraft, even if standard separation would not otherwise exist with these reference aircraft. That is, the availability of more accurate airborne surveillance data enables safe flight level changes through intervening flight levels with lower separation minima than when using current ground-based non-radar separation rules.

#### System description

The onboard ITP equipment receives Automatic Dependent Surveillance – Broadcast (ADS-B) data from aircraft within reception range that are broadcasting these data. The received data includes flight id, altitude, position, groundspeed and quality-of-data information. The ITP equipment receives the ADS-B data from these aircraft and along with onboard navigation data calculates appropriate separation information for these aircraft.

The ITP equipment portrays the information derived from received ADS-B data on the traffic displays of an Oceanic Operations application, which runs on the Electronic Flight Bag (EFB). TCAS-derived traffic data

are also portrayed for additional situation awareness. Both planform and profile views of traffic are provided, with symbols and data tags depicting the relative position, separation information, and flight id id of aircraft for which these data are available. Additional labels are included in the aircraft data tags, as appropriate, to indicate the quality of the received data or if the criteria are met to reference that aircraft in an ITP flight level change request. The crew controls the display of this traffic information through the EFB interface, and uses the information presented to decide whether, and how, to request an ITP flight level change.

**Operational information**

The crew uses the EFB’s Oceanic Operations application to select the desired flight level, either above or below the current flight level. This desired flight level can be **up to 4000 feet** from the current flight level. Once the desired flight level is selected, the application will display aircraft symbols and data tags for all aircraft at the current flight level, desired flight level, and intervening flight levels that are transmitting position information.

Using this traffic information, the crew determines whether to make a flight level change request to the desired flight level, and if so, whether to request a standard or ITP flight level change. If the desired flight level appears available and adequate separation would appear to exist at intervening flight levels, then a standard flight level change could be requested. However, if potentially blocking aircraft are observed on the intervening flight levels, then the crew should evaluate the available information for these aircraft to determine if they can be used as reference aircraft in an ITP flight level change request.

An aircraft at an intervening flight level can be used as a reference aircraft if it meets the following:

- **Same Direction** of flight as the Ownship, +/- 45 degrees,
- **Qualified ADS-B Data** are being received from the aircraft, and
- **ITP Distance/Speed Criteria** are met.

The ITP Distance is calculated by the Oceanic Operations application for each aircraft with this calculation performed as shown in the following figure (for identical ground tracks, ITP Distance is simply the distance between the two aircraft). The ITP speed criterion is a groundspeed differential, also calculated by the application and is simply the difference in groundspeed between the two aircraft. A closing groundspeed differential is one in which the aircraft are getting closer together.

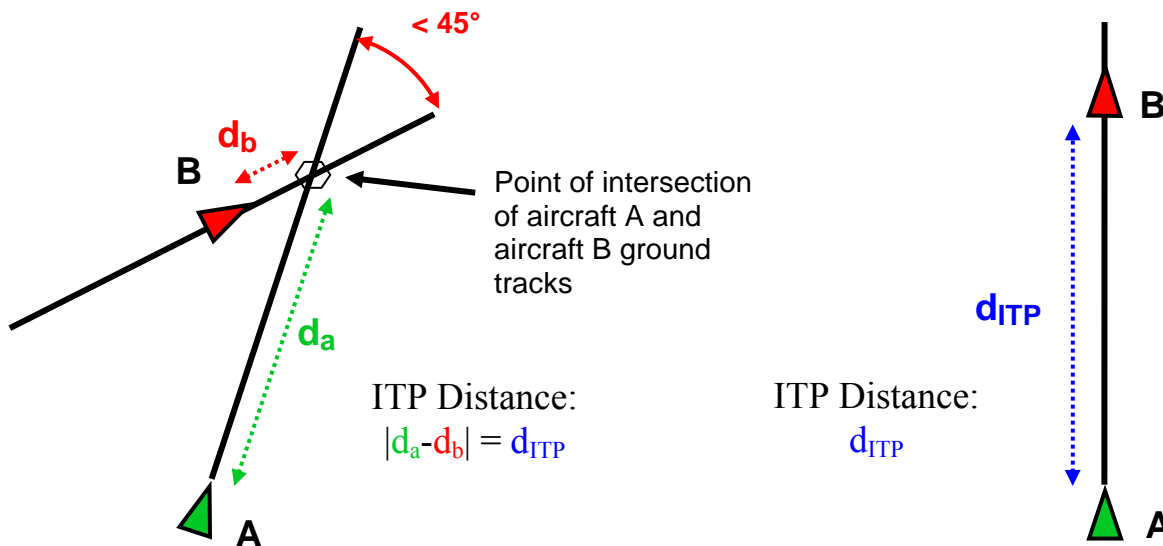


Figure 1 - ITP distance (non identical ground tracks vs. identical ground tracks)

A reference aircraft must meet these ITP Distance/Speed Criteria:

- ITP Distance **at least 15 nautical miles**, and closing groundspeed differential of **20 knots or less**,  
*or*
- ITP Distance **at least 20 nautical miles**, and closing groundspeed differential of **30 knots or less**.

**Up to two** reference aircraft can be included in an ITP flight level change request to ATC. If more than two potentially blocking aircraft meet the criteria for reference aircraft, then the crew would identify the one or two that, in their judgment, would be most likely to block the flight level. Typically this would be the closest one or two such aircraft, either ahead of and/or behind the Ownship aircraft, and on either one or two intervening flight levels, depending on the situation.

ATC can either:

- 1) deny the ITP flight level change request due to traffic or other constraints,
- 2) approve a **standard** flight level change if sufficient separation exists and ITP clearance is not necessary, or
- 3) issue an **ITP** flight level change clearance, identifying the reference aircraft id's

If an ITP clearance is received, then the crew must **reassess the reference aircraft identified in the clearance** to assure that the ITP criteria are still met before accepting the clearance. If the criteria are no longer met then the clearance must be rejected.

Once an ITP clearance has been accepted, the crew should commence the flight level change without delay and maintain **cruise Mach number** and **at least 300 fpm** vertical speed throughout the flight level change. If this minimum performance cannot be maintained, then regional contingency procedures for inability to conform to an ATC clearance should be followed.

No further reference to the Oceanic Operations application is required after the climb or descent has been initiated.

#### **ITP data link request syntax**

ITP flight level change requests are made via data link in a manner similar to a standard flight level change request, but with additional ITP-specific information entered in the free text fields. This information may be entered on more than one free text line if necessary, but the keyword "ITP" should start the first (and **only** the first) free text line of the flight level change data link request.

Information about each of the one or two reference aircraft is entered in the free text field after the ITP keyword. Information is entered regarding the relative position, flight id, and ITP Distance of each reference aircraft, in the following format:

F/<reference aircraft flight id>/nn      **or**      L/<reference aircraft flight id>/nn

Where            F/ means that the Ownship aircraft is **following** this reference aircraft,  
                     L/ means that the Ownship aircraft is **leading** this reference aircraft, and  
                     /nn is the ITP Distance for this reference aircraft, in nautical miles



For example, a flight level change data link request with two free text lines of

ITP F/UAL123/65  
L/DAL456/30

would be interpreted as an ITP flight level change request with two reference aircraft: following (i.e., behind) UAL123, which is at an ITP Distance of 65 nm, and leading (in front of) DAL456, at an ITP Distance of 30 nm.

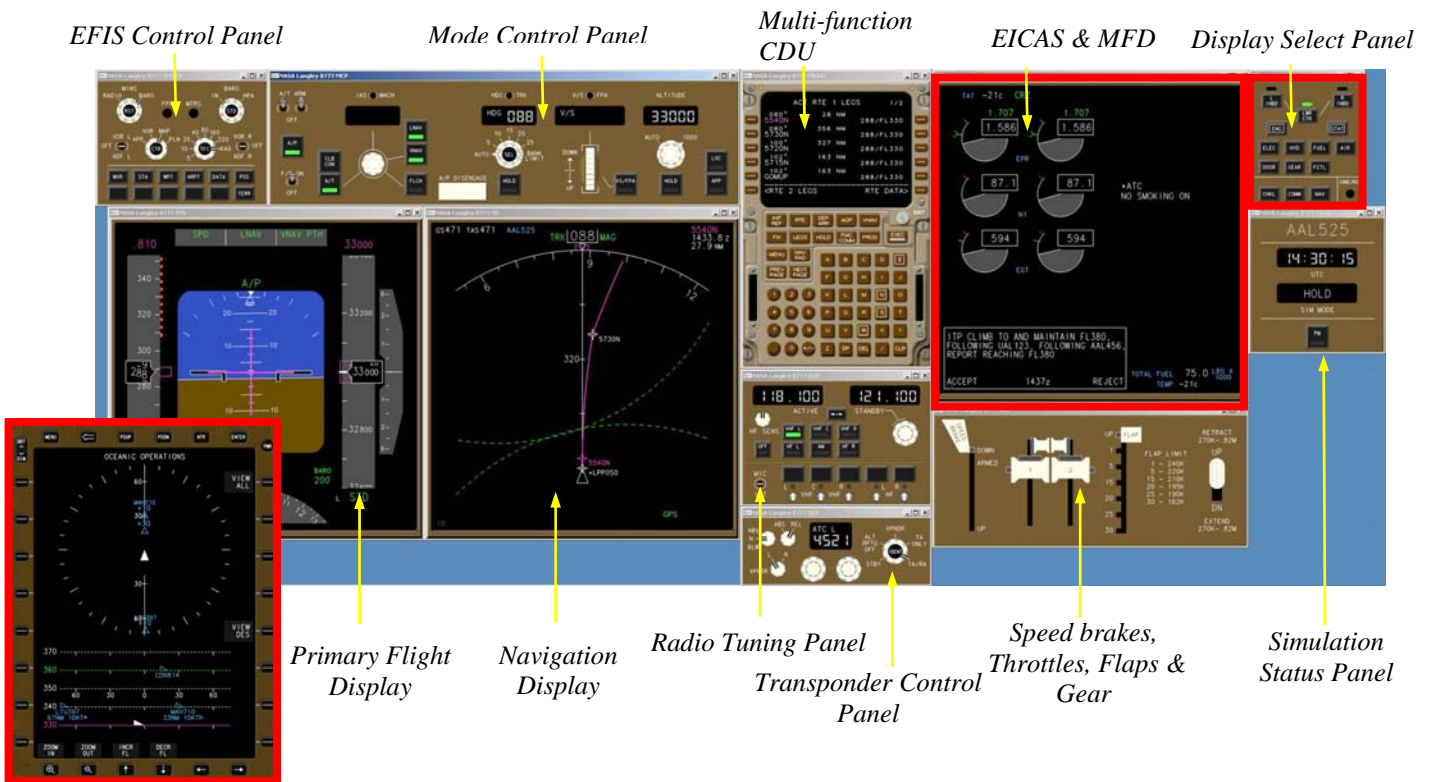
Since there is insufficient text space to include an ITP request with two reference aircraft on a single free text line, the information for the second reference aircraft should be entered on the second free text line.

Note also that if two reference aircraft are identified in an ITP request, all possible geometries are permissible as long as both aircraft meet the criteria for reference aircraft. That is, it is permissible to be following both reference aircraft, or leading both, or following one and leading the other. It is also permissible for the reference aircraft to be at a different intervening flight level.

**ASTOR controls and indicators**

The Oceanic Operations experiment will be conducted using the NASA LaRC Aircraft Simulation for Traffic Operations Research (ASTOR) simulator. ASTOR is a medium-fidelity human-in-the-loop computer workstation-based aircraft simulation, which supports research of air traffic operations within future airspace environments. ASTOR currently simulates a Boeing 777 like interface, with aerodynamic performance that is more representative of a Boeing 757 transport aircraft.

ASTOR components include (figure 2): aircraft and engine models; autopilot and autothrottle systems; flight management computer (FMC) and multi-function control display unit (MCDU); mode control panel (MCP) and electronic flight instrumentation system (EFIS) control panel; displays such as the primary flight display (PFD), navigation display (ND), and engine indication and crew alerting system display (EICAS); sensor systems; an Electronic Flight Bag (EFB) and a sophisticated simulation model of ADS-B.



*Electronic Flight*

Figure 2. Aircraft Simulation for Traffic Operations Research (ASTOR)

The key components for the Oceanic Operations experiment are the EFB, the MFD and the Display Select Panel (DSP). The Display Select Panel is used primarily to cycle between the shared EICAS and MFD windows, using the ENG and COMM buttons respectively, while the MFD windows are used for data link communications with ATC.

### Electronic Flight Bag

The Electronic Flight Bag (EFB) is a multi-function display, which can enable many different applications. For the purpose of this experiment, only the functionality of the Oceanic Operations application (figure 3) will be described.

The Oceanic Operations application was designed to present surveillance information about the surrounding traffic to the flight crew. The information, which is presented on both a horizontal planform and vertical profile view, includes the relative positions of other aircraft and other traffic information (e.g., call-sign, relative altitude, etc.) needed to help the crew to maintain a high level of traffic awareness and to allow them to evaluate a possible flight level change.

Simulated line select keys on the edge of the display can be used for selecting certain functions and/or display modes. Some of these functions and modes can also be selected by touching the adjacent screen icon using the stylus/mouse.

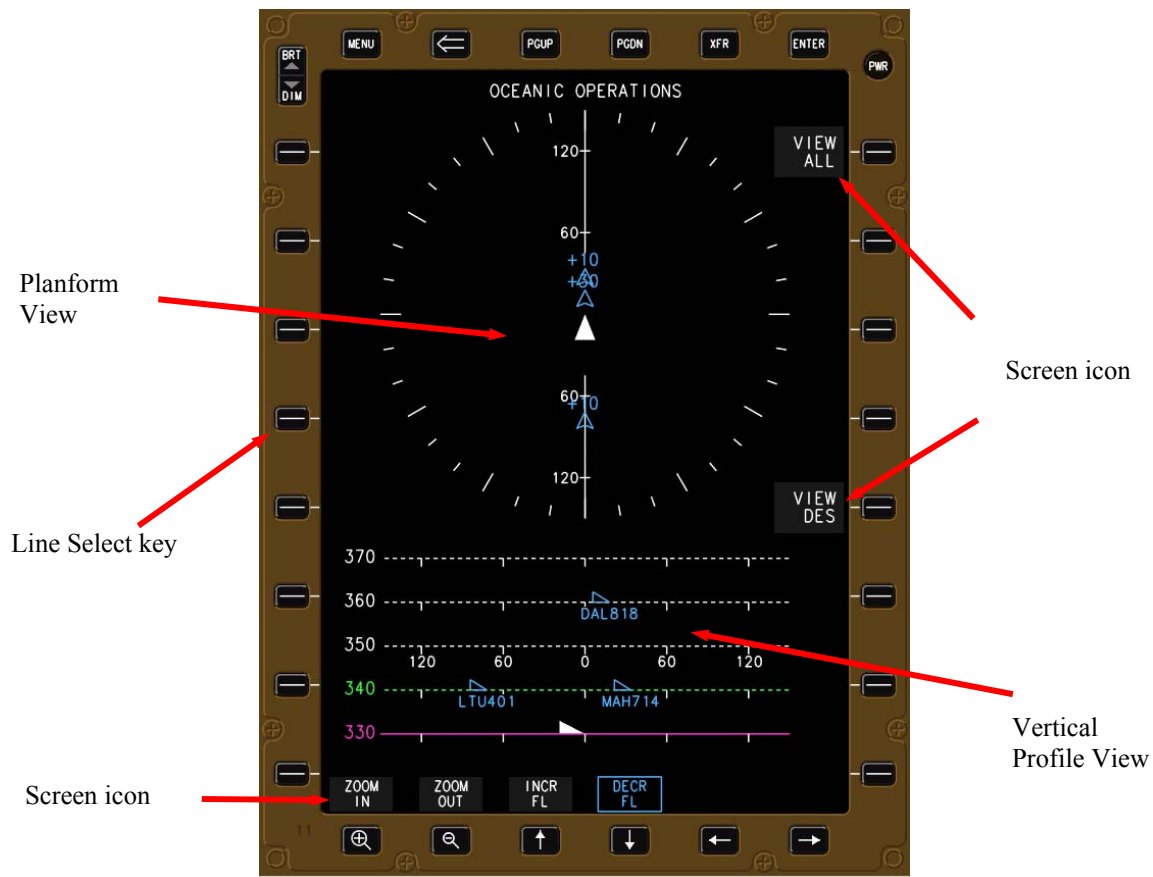


Figure 3. EFB OCEANIC OPERATIONS application

Note: The display may **NOT** be used for navigating the aircraft. It does **NOT** have position data, heading, air speed or ground speed information.

**Menu pages**

The default page of the EFB is the MAIN MENU page (figure 4). It is displayed whenever the EFB is turned on. This page provides selections to multiple sub-pages of which only the OCEANIC OPERATIONS page has been implemented.

To access the Oceanic Operations application, select the APPLICATIONS MENU and subsequently OCEANIC OPERATIONS (figure 5).

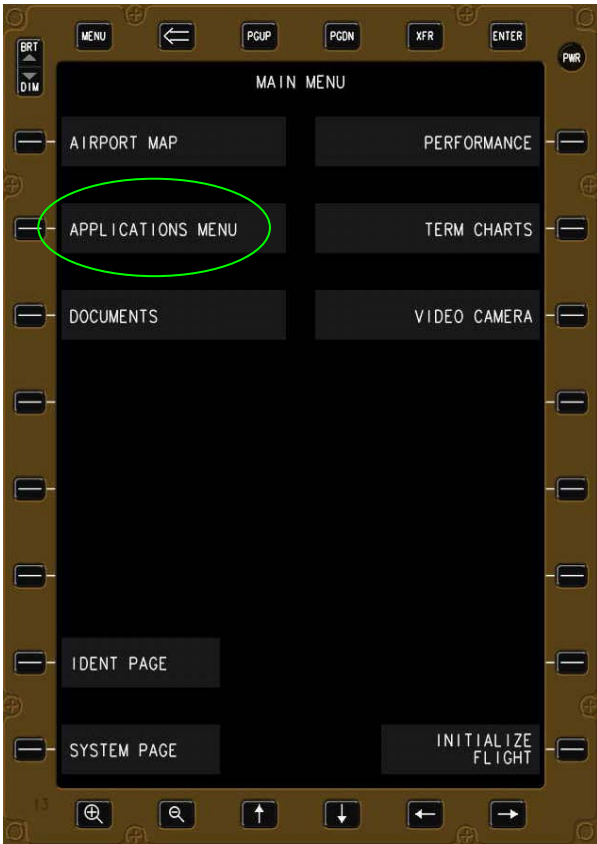


Figure 4. EFB main menu

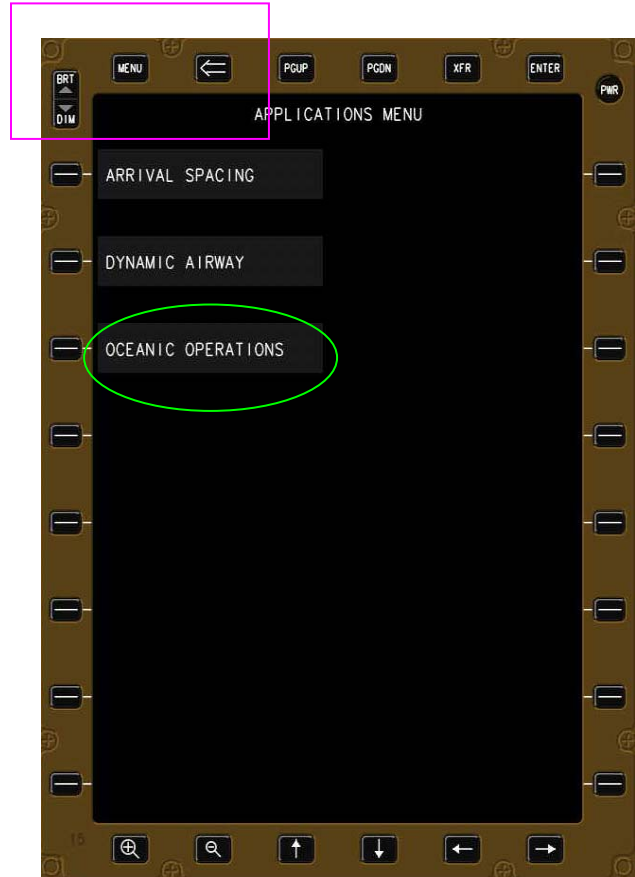


Figure 5. EFB applications menu

The MENU button or subsequent selections of the back arrow (<-) bezel button can be used to return to the MAIN MENU.



## OCEANIC OPERATIONS application



Figure 6 - Oceanic default display

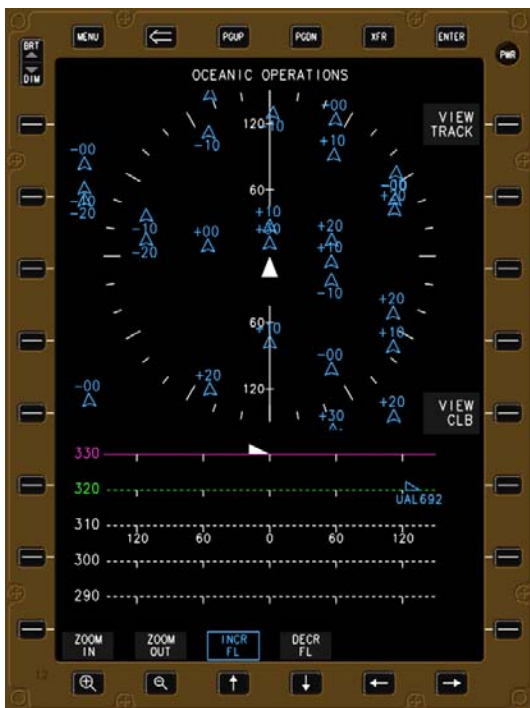


Figure 7. Oceanic descent display with all tracks

The default display (figure 6) presents surveillance data of all (ADS-B and TCAS) aircraft that are on the same track as the Ownship.

Ownship is depicted by a white triangle on both the planform and profile view of the display.

On the planform view a dashed rose is available that can be used for relative angular position information. A white line, stretching out in front and behind the Ownship includes tick marks, to indicate range in Nautical Miles.

On the profile view, horizontal dashed lines show subsequent Flight Levels. Tick marks again indicate range to Ownship in Nautical Miles.






The MCP selected flight level is indicated by a solid magenta line. A dashed green line indicates the selected desired flight level.




To increase the value for the desired flight level, press the **INCR FL** bezel button or use the stylus/mouse to touch the screen icon. To decrease the value for the desired flight level use the **DECR FL**. Note that the selection cannot be increased or decreased beyond the ITP limit of 4,000 feet nor can it be within less than 1000ft of the current flight level. A cyan box around the screen icon will indicate the user has reached this limit. When changing the desired flight level, additional ITP information will appear on the data tags for those aircraft that are between the current and desired flight level.

The range of both the planform and profile view can be adjusted by pressing the **ZOOM IN** or **ZOOM OUT** bezel button or by using the stylus/mouse to touch the screen icon at the bottom of the display. The tick marks will indicate the new scale. A cyan box around the screen icon will indicate the zoom limit.










By default the display will come up in Climb View mode, indicated by the Ownship residing on the lowest flight level of the profile view. This mode enables flight level changes to a higher altitude. When a lower flight level is desired, the profile view can be changed to a Descent View mode (figure 7) by pressing the **VIEW DES** bezel button or using the stylus/mouse to touch the screen icon. In this mode the Ownship will reside on the highest flight level. To return to the climb mode select **VIEW CLB**.

For enhanced situation awareness, select the **VIEW ALL** bezel button or use the stylus/mouse to touch the screen icon. This view will enable additional aircraft to be drawn that are not on the Ownship track. The additional aircraft will only be displayed on the planform view. To return to the track only view select **VIEW TRACK**.

| Planform View Symbol                | Meaning  | Example   |
|-------------------------------------|--|---|
| Ownship                             | The aircraft you are flying.   |    |
| ADS-B aircraft                      | A cyan chevron with the tip of the chevron indicating the direction of travel. The altitude relative to Ownship is indicated by a numerical value (in hundreds of feet) right above or below the chevron. Example aircraft is 1,000 feet above Ownship. The absolute altitude will be displayed when ABS is selected on the Transponder Control Panel.   |    |
| Potentially blocking ADS-B aircraft | A cyan chevron with the tip of the chevron indicating the direction of travel. The altitude relative to Ownship is indicated by a numerical value (in hundreds of feet) right above or below the chevron. The aircraft call-sign / flight identifier will be displayed for all ADS-B aircraft that reside from the MCP selected up to and including the desired altitude. Additional information for this aircraft is presented in the data tag on the profile view. |    |
| TCAS-only aircraft                  | A cyan diamond indicates that it is a TCAS-only aircraft. The altitude relative to Ownship is indicated by a numerical value (in hundreds of feet) right above or below the diamond. Example aircraft is 2,000 feet below Ownship. The absolute altitude will be displayed when ABS is selected on the Transponder Control Panel.  |   |
| (Blocking) TCAS-only aircraft       | A cyan diamond indicates that it is a TCAS-only aircraft. NO ADS-B (TCAS-only) aircraft are considered to be blocking aircraft when they reside from the MCP selected up to and including the desired altitude.  |  |

| Profile View Symbol                                       | Meaning  | Example   |
|---|--|---|
| Ownship   | The aircraft you are flying.   |  |
| ADS-B aircraft  | A cyan chevron with the tip of the chevron indicating the direction of travel. Aircraft equipped with ADS-B will show a call-sign / flight identifier (CDN814).  |  |
| Potentially blocking ADS-B aircraft In front & Separating | Potentially blocking aircraft are all qualified ADS-B aircraft that reside from the MCP selected up to and including the desired altitude. The open triangle indicates that this aircraft is moving away from Ownship. In this case, VIR884 is 21 Nautical Miles away and pulling away from Ownship at 9KTs. |  |



|   |   |   |
|---|---|---|
| Potentially blocking ADS-B aircraft Behind & Closing    | Potentially blocking aircraft are all qualified ADS-B aircraft that reside from the MCP selected up to and including the desired altitude. The closed triangle indicates that this aircraft is closing in on Ownship. In this case, SAS316 is 26 Nautical Miles away and is closing on Ownship at 8KTs. |    |
| Potentially blocking ADS-B aircraft Behind & Separating | Potentially blocking aircraft are all qualified ADS-B aircraft that reside from the MCP selected up to and including the desired altitude. The open triangle indicates that this aircraft is moving away from Ownship at 2KTS.  |    |
| Potentially blocking ADS-B aircraft In front & Closing  | Potentially blocking aircraft are all qualified ADS-B aircraft that reside from the MCP selected up to and including the desired altitude. The closed triangle indicates that this aircraft is closing in on Ownship at 9KTs.   |    |
| ADS-B aircraft NO REF                                   | Potentially blocking aircraft that do not meet the ITP criteria. These NO REF aircraft cannot be used as reference aircraft for an ITP request. In this case the closure rate is greater than 30KTs.  |    |
| TCAS-only aircraft                                      | TCAS-only aircraft do not broadcast a call-sign / flight identifier, this is indicated by NO ADSB in the data tag.  |   |
| TCAS-only (blocking) aircraft                           | TCAS-only (NO ADS-B) aircraft do not meet the ITP criteria for reference aircraft and are considered to be blocking (indicated with the NO REF data tag) when the aircraft reside from the MCP selected up to the desired altitude. These aircraft cannot be used for the ITP.                          |  |
| Opposite direction aircraft                             | Aircraft that is flying on the same track as Ownship but from an opposite direction.  |  |
| Commanded Altitude                                      | Altitude selected on the MCP.   |  |
| Desired Altitude  | Desired altitude selected on the EFB.   |  |

## Multi Function Display

The Multi Function Display (MFD) for the OCEANIC OPERATIONS experiment is primarily used for Data-Link communication with the Air Traffic Service Provider. Pressing the **COMM** button on the Display Select Panel (figure 8) will give access to the communications menu on the MFD (figure 10). To return to the primary engine instruments display, press the **ENG** button (figure 9).



Figure 8. Display Select Panel

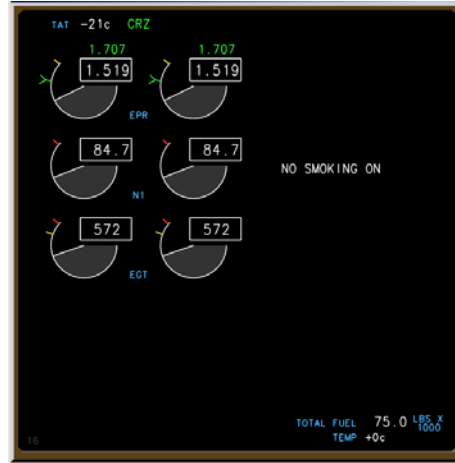


Figure 9. Primary Engine display



Figure 10. MFD comm. menu

Using the mouse and clicking on the appropriate MFD button will give access to the available sub-pages. Only pages that are required for the OCEANIC OPERATIONS experiment have been fully implemented. Other pages will either be unavailable (indicated by a cyan color) or empty (figure 11). Certain pages also include an upper and lower part, which can be viewed by clicking the bar, which will become available on the right-hand side.

An uplink message from ATC will be displayed in the lower left-hand side of the primary engine instruments display (figure 12). The reception of a message will be accompanied by an aural sound.

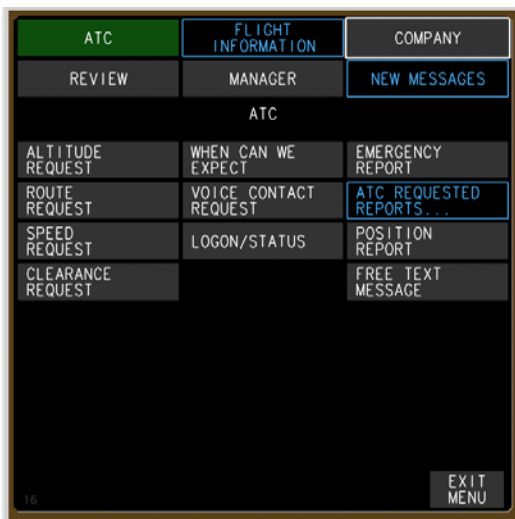


Figure 11. ATC menu



Figure 12. ATC uplink message

Note: To conserve display space, the ASTOR has been configured to switch the normal Upper EICAS display on the 777 with the MFD. This causes the primary engine instruments to disappear whenever the COMM menu is selected.



### Example: ITP climb request

The subsequent chapter will describe an example of the OCEANIC IN-TRAIL PROCEDURE in the ASTOR. This example will include all of the steps required to complete the ITP procedure.

#### Step 1: Determine desired altitude

The first step in the procedure is to determine whether a flight level change is desired. On an actual aircraft there might be many reasons that determine whether to request a flight level change. In this experiment the scenarios are designed such that the recommended flight level on the VNAV page of the Multi-function Control and Display Unit (MCDU) indicates which flight level is currently desired. To obtain the recommended flight level press VNAV on the MCDU.

The operation of the MCDU on the ASTOR is very similar to MCDU's found on Boeing aircraft. Figure 13 depicts the VNAV Cruise page for an aircraft enroute to Frankfurt Germany that is currently cruising at FL330. As indicated by the optimum flight level indicator, this aircraft is currently 2,200 feet below its optimum flight level while FL350 is recommended (figure 13).



Figure 13 - MCDU VNAV cruise page

#### Step 2: Select desired Flight Level on EFB

After determining that a flight level change is desired, select the desired flight level on the EFB. Press the INCR FL button until the green dashed line lines up with the desired flight level (in this case FL350). Aircraft that reside on the desired or a flight level between the current flight level and the desired flight level will now show additional data in their data tags (figure 14). This data can be used for the ITP request.

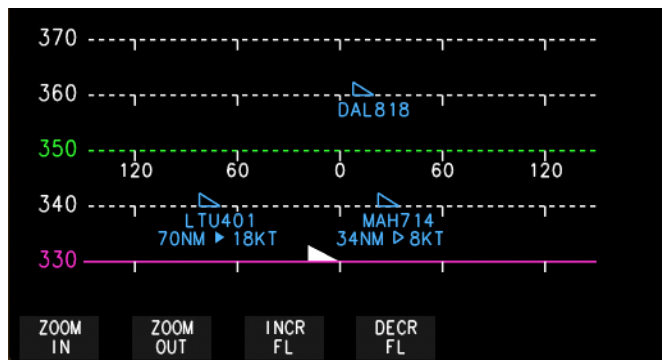


Figure 14 - EFB desired altitude selection

#### Step 3 Identify Potentially Blocking Aircraft

On the EFB, look for aircraft that might potentially block a climb request. If the desired flight level is blocked, do not make the request. In this example, two aircraft (LTU401 and MAH714) potentially block the climb request. No aircraft is blocking the desired flight level. DAL818 is beyond the desired FL, so no speed or distance information is included on the data tag.

Based on the reduced separation of the two aircraft potentially blocking the climb, a Standard Altitude request is not available and an ITP is required. Note: when in doubt consider an ITP request.

#### Step 4: Evaluate for ITP criteria

Next select from the list of potentially blocking aircraft the one or two, ahead of and/or behind the Ownship aircraft, and on either one or two intervening flight levels, that would be most likely to block the flight level change. In the example this would be LTU401 and MAH714. Observe the data tag and determine that neither aircraft displays a "NO REF" or "NO ADSB" tag meaning that the aircraft meet the ITP ADS-B qualification, distance and speed criteria.

**Step 5: Prepare and send ITP altitude change request**

Now that you have determined that you would like to make an ITP request and have selected the reference aircraft, you need to construct and send the ITP request message. To do so, switch to the MFD display by selecting the **COMM** button on the Display Select Panel (figure 15). This will take you to the COMM page where you select the **ATC** icon to access the ATC communications page.



Figure 15. Display Select Panel



Figure 16. COMM page

From the ATC communications page select the **ALTITUDE REQUEST** icon (figure 17), which will take you to the altitude request page (figure 18). This page consists of two separate parts, which can be accessed by clicking the scroll bar on the right-hand side. On the upper part (1) enter the desired altitude. On the lower part (2) select a reason for the flight level change request and enter in the Free Text field the data required for ITP.

Note: It is not required to provide a reason for the flight level change request.

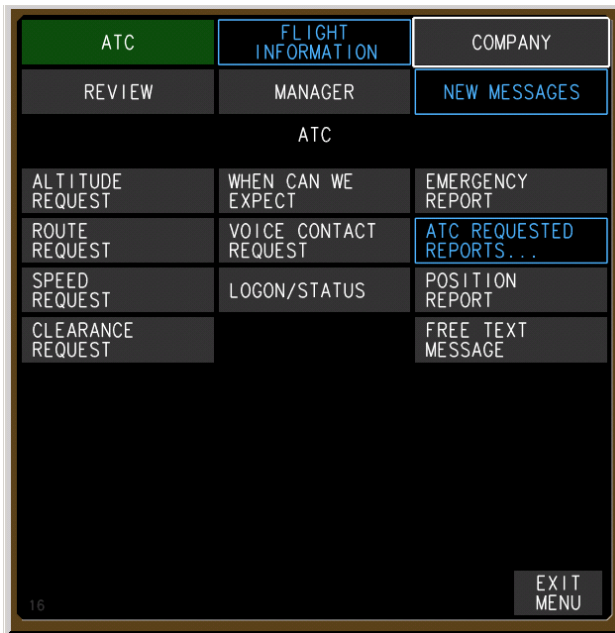


Figure 17. ATC COMM page

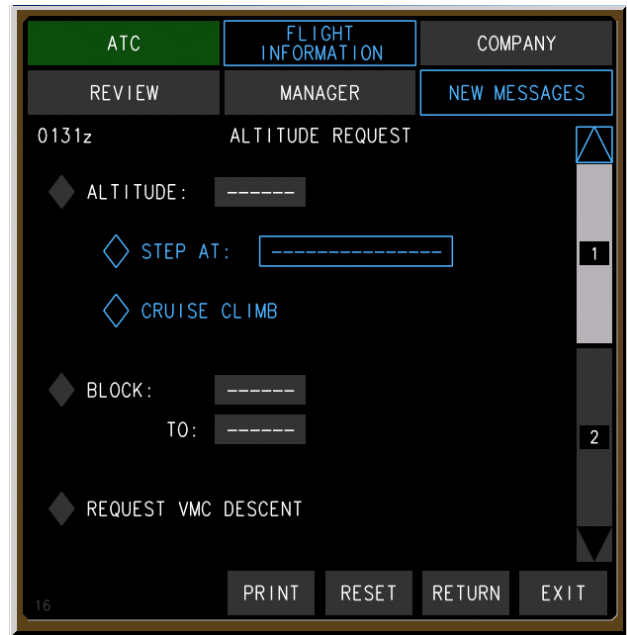


Figure 18. Altitude Request page



Figure 19. MCDU 350 in scratchpad

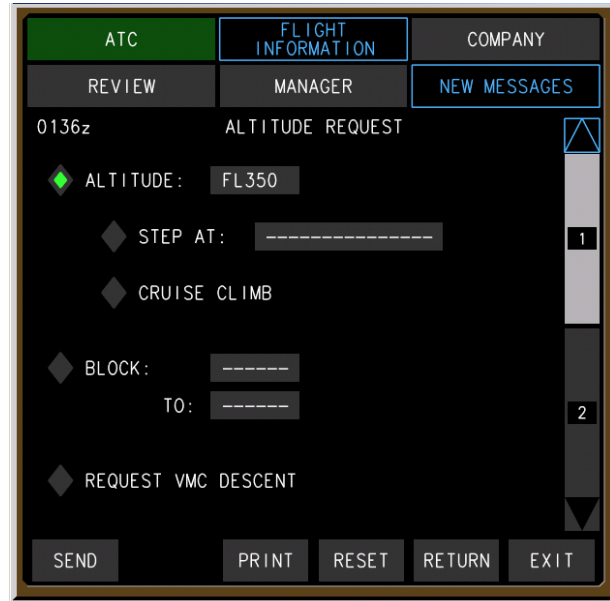


Figure 20. MFD FI.350 in altitude window

To enter the desired flight level, click on the MCDU and enter a value in the MCDU scratchpad (figure 19). As the ASTOR is a window-based simulation, the MCDU must be “clicked” to make the MCDU the active window. To transfer the data from the MCDU scratchpad to the ALTITUDE window click on the blank altitude entry box of the MFD (figure 20).

As on the 777 the reason for climbing can be checked (optional). The Oceanic ITP was designed to facilitate altitude changes DUE TO AIRCRAFT PERFORMANCE or DUE TO WEATHER. AT PILOT'S DISCRETION and MAINTAIN OWN SEPERATION AND VMC are **NOT** valid options for requesting an Oceanic ITP.

As described in the ITP data link request syntax section of this FMB, an ITP is requested by specially formatted FREE TEXT. Enter the text on the MCDU scratchpad (figure 21) similar to what was done with the altitude and click on the FREE TEXT line to transfer this information (figure 22). For the first aircraft, you enter: **ITP L/LTU401/70**



Figure 21. MCDU reference aircraft 1

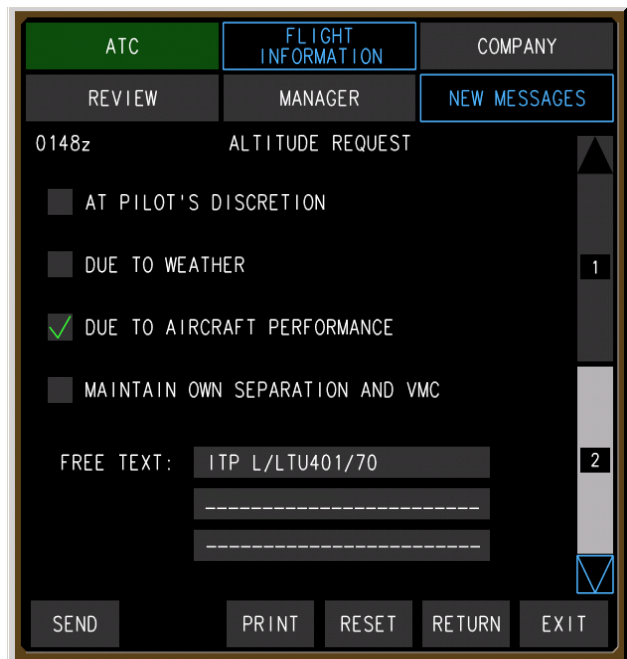


Figure 22. MFD reference aircraft 1



Figure 23. MCDU reference



Figure 24. MFD reference aircraft 2

In an ITP with two reference aircraft, the information for the second reference aircraft needs to be entered on a separate line. The text is again entered on the MCDU scratchpad (figure 23) and transferred to the MFD by clicking on the second FREE TEXT line (figure 24). Note that the second line of FREE TEXT is **NOT** preceded by 'ITP'. For the second aircraft enter: **F/MAH714/34**

When the ALTITUDE REQUEST FORM is completed click the SEND button.

After the ITP request is sent, expect a STANDBY message from ATC (figure 25).

ATC will send a reply after ATC has evaluated the request. In the example, you received a clearance for an ITP CLIMB TO FL350 LEADING LTU401 AND FOLLOWING MAH714 (figure 26). The message also includes the instruction to report reaching FL350.

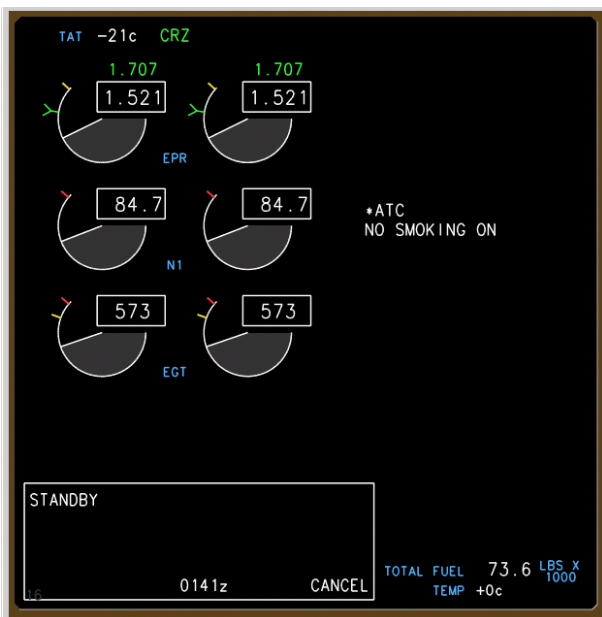


Figure 25. MFD STANDBY

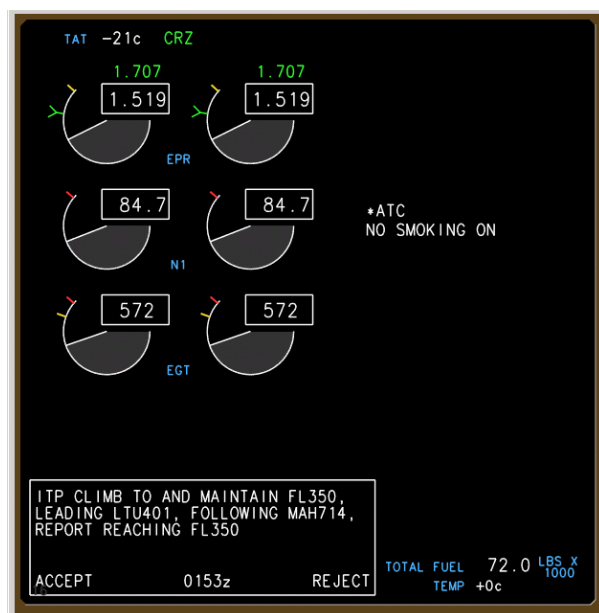


Figure 26. MFD ITP Clearance





Figure 27. MFD Messages list



Figure 28. MFD Message information

### Step 6: Retrieve message

To retrieve the information from the ATC message, click the COMM button on the Display Select Panel. Clicking this button will take you to the NEW MESSAGES page. Here you will find a list of all available messages (figure 27). If only one message is available, you will immediately be directed to the additional information of that message (figure 28), otherwise click on the message to retrieve the additional information.

ACCEPT and REJECT buttons appear in the lower left and right corner of the ATC message page. At this point ACCEPT or REJECT the instruction. Before doing this, first reassess the ITP instruction.

### Step 7: Reassess ITP Criteria

The crew must **reassess the reference aircraft identified in the clearance** to assure that the ITP criteria are still met before accepting the clearance. The clearance must be rejected if the criteria are no longer met.

In the example the aircraft referenced by ATC in the clearance are **LTU401** and **MAH714**. When you examine their data tags on the EFB, you see that both aircraft are still meeting the ITP range and speed criteria (figure 29). The clearance has to be rejected if any of the aircraft, referenced by ATC, do not meet the criteria. A “NO REF” or “NO ADSB” data tag will indicate this.

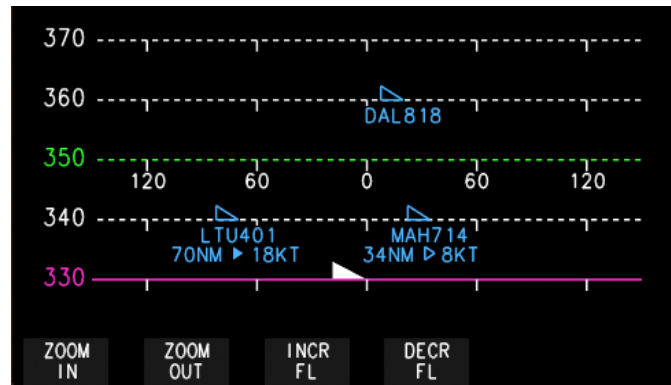


Figure 29. EFB Reassess

The next step is to accept the ITP clearance.

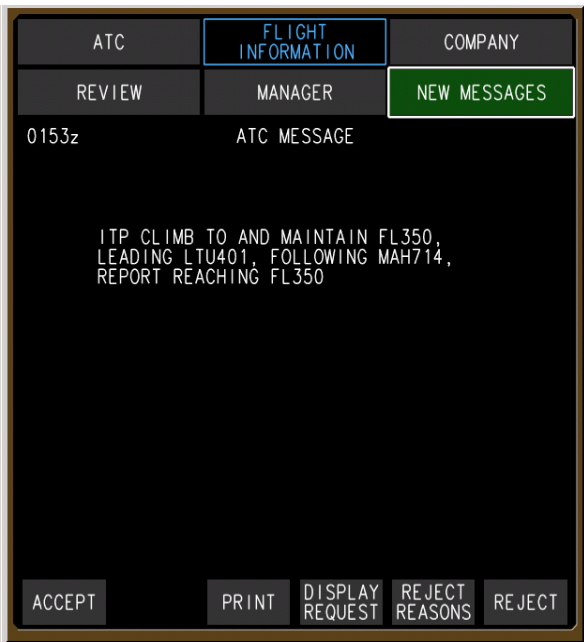


Figure 30 - MFD ATC MESSAGE ACCEPT



Figure 31. MFD ATC MESSAGE ACCEPTED

**Step 8: Accept (or reject) clearance**

To accept the IPT clearance, click the ACCEPT icon in the lower left corner of the display (figure 30). To reject click the REJECT button in the lower right corner. When the accept message is sent, the word ACCEPTED will be displayed in the upper right corner and a DISPLAY REPORT button will appear replacing the ACCEPT button (figure 31). When pressed, this button takes us to the ATC Report page, where you arm the ATC report.

In order to cancel a request, click the FREE TEXT MESSAGE icon in the lower right corner of the main ATC menu page (figure 11). To cancel the request, the free text has to include the word 'CANCEL' or 'DISREGARD'. Free text is entered into the MCDU scratchpad (figure 32) and transferred to the Free Text line by clicking on the line (figure 33). After the text has been entered click the send button and wait for a reply from ATC.



Figure 32. MCDU Cancel

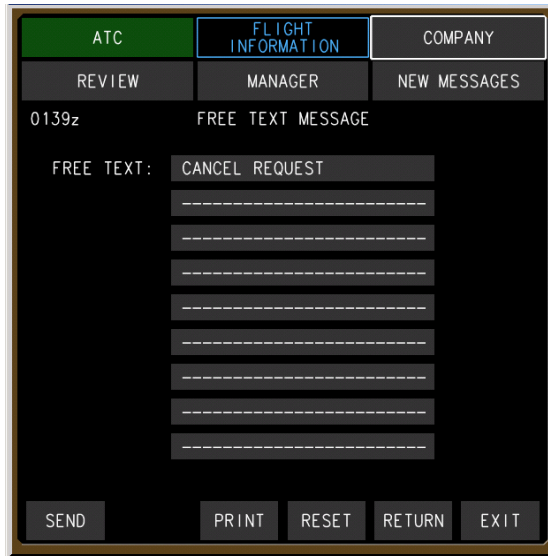


Figure 33. MFD Cancel

Note: Keep in mind that requests can only be canceled before an instruction has been received. When an instruction is received you need to follow that instruction.

**Step 9: Arm report message**

For the purpose of closing the maneuver, you need to send a report to ATC when established on the new altitude. To arm this report, click ARM on the ATC REPORT page (figure 34). The word ARMED will appear in the upper right corner (figure 35). Upon meeting the report condition an automatic report will be sent. In the example a message will be sent when the aircraft is established at FL350.



Figure 34. DISPLAY REPORT ARM



Figure 35.- DISPLAY REPORT ARMED

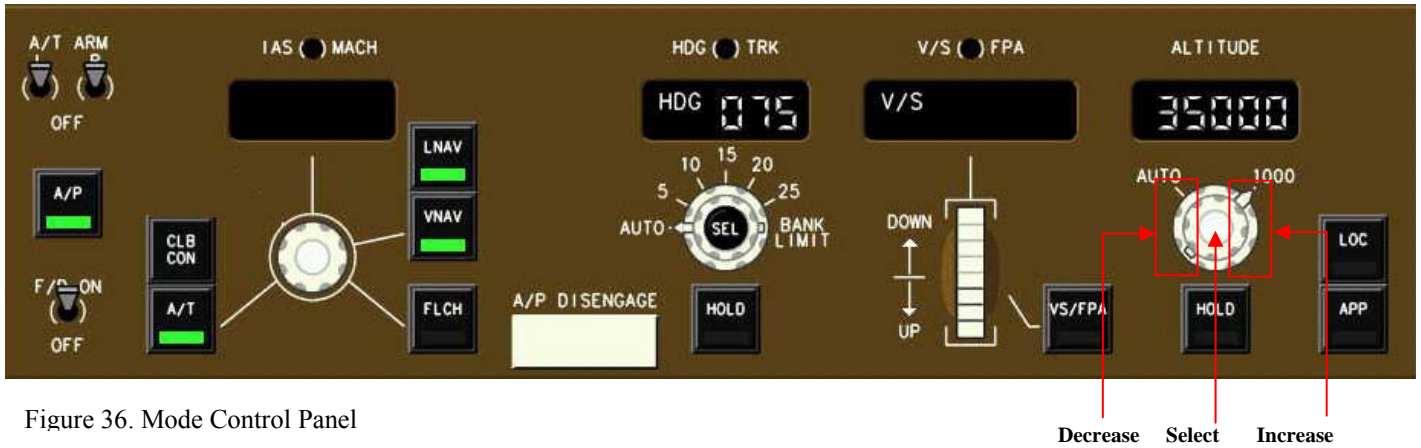


Figure 36. Mode Control Panel

**Step 10: Commence flight level change**

Once an ITP clearance has been accepted, the crew should commence the flight level change without delay, while maintaining the current **cruise Mach number** and **at least 300 fpm** vertical speed throughout the flight level change. If this minimum performance cannot be maintained, then regional contingency procedures for inability to conform to an ATC clearance should be followed. No further reference to the Oceanic Operations application is required after the climb or descent has been initiated.

Any method for climbing the aircraft with a minimum of 300 fpm while maintaining the current Mach number can be used.

The MCP Altitude is adjusted on the ASTOR by clicking on the edge of the MCP altitude knob (figure 36). To increase the value in the MCP altitude window click on the right side on the altitude knob. To reduce the value in the MCP altitude window click on the left side of the altitude knob. The cleared flight level in the ATC message will turn green (figure 31) when it is identical to the MCP selected value. To enter the MCP altitude into the FMC click on the center of the MCP altitude knob.

To execute a FLCH altitude change, click the FLCH button after the new altitude has been entered in the MCP altitude window. Maintain the required Mach number and vertical speed.

A Vertical Speed climb is executed by clicking on the lower portion of the VS knob after the new altitude has been entered in the MCP altitude window. A Vertical Speed descent is executed by clicking on the upper portion of the VS Knob. The operational limitations of using Vertical Speed need to be observed.

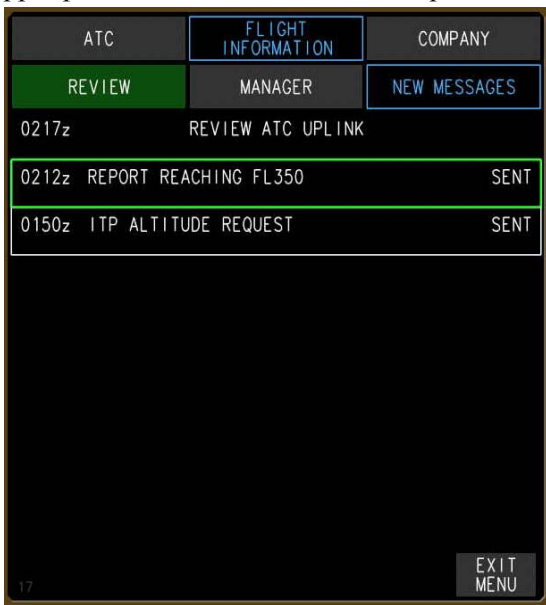


Figure 37. REVIEW ATC UPLINK

**Step 11: Review messages**

Messages, which have been sent or received via Data-Link, can be reviewed by selecting REVIEW on the communications page of the MFD. To review the received messages click REVIEW ATC UPLINK (figure 37), to review the downlink messages, click REVIEW ATC DOWNLINK.

The procedure is closed once established at the new flight level and the automated report message has been sent.





# OCEANIC OPERATIONS ITP CHECKLIST

PNF Desired flight level . . . . . SELECT on EFB

PNF Intermediate flight levels . . . IDENTIFY POTENTIALLY BLOCKING A/C

PNF Reference A/C (select a max of 2) . . . . . EVALUATE FOR ITP CRITERIA

- Same Direction
- Qualified ADS-B Data
- ITP Distance/Speed Criteria:

| ITP Distance at least | Closing Ground Speed Differential<br>no more than |
|-----------------------|---|
| 15 NM                 | 20 KTS  |
| 20 NM                 | 30 KTS  |

PNF ITP flight level change data link request . . . . . PREPARE AND SEND

*Format free text field:*

ITP F/<Reference A/C flight id>/<distance>

*Note 1: Use "L" if you are Leading this Reference A/C, "F" if following*

*Note 2: Enter 2<sup>nd</sup> Reference A/C, if any, on 2<sup>nd</sup> free text line, without ITP prefix*

*Example: ITP F/TWA123/35*

*L/TWA456/26*

*On receipt of ITP clearance:*

PNF Reference A/C in ITP clearance . . . . . REASSESS ITP CRITERIA

*If ITP Criteria not met then reject clearance. Otherwise:*

PF Acknowledge and comply with ATC clearance

Monitor

- Constant Mach
- Minimum 300 FPM vertical speed

## Appendix E

### Post-Scenario Questionnaire

*Please consider the flight scenario that you just completed and respond to the questionnaire items that follow. (If you made multiple ITP requests during the scenario that you just completed, please answer the questionnaire in terms of the first request that you made.)*

1. What type of flight level change did you request? (Check one.)

Standard Climb

Standard Descent

ITP Leading Climb

ITP Leading Descent

ITP Following Climb

ITP Following Descent

ITP Combined Climb

ITP Combined Descent

None (Please explain why you chose not to request a flight level change:)

I did not request a flight level change because:

2. Was your flight level change request approved or denied by ATC?

\_\_\_\_\_ Approved (If your ITP flight level change request was approved, skip to Question #4)

\_\_\_\_\_ Denied

For ITP Flight Level Changes Only

3. Was it obvious from the ITP display why your flight level change request was denied by ATC?

\_\_\_\_\_ Yes

\_\_\_\_\_ No

4. Did the procedure outlined for use during this ITP flight level change contain any incorrect, missing, and/or extra steps?

\_\_\_\_\_ Yes

\_\_\_\_\_ No (If No, skip to Question #6)

5. Please complete the appropriate statement(s) below and explain your rationale if you have not already done so in another post-scenario questionnaire:

a. The following procedural step(s) were incorrect:

b. The following procedural step(s) were missing:

c. The following procedural step(s) were extraneous/overly specified:

6. Did the procedural steps that you were instructed to use during this ITP flight level change occur in a logical sequence?

\_\_\_\_\_ Yes

\_\_\_\_\_ No (If No, please explain which steps were ordered incorrectly if you have not already done so in another post-scenario questionnaire:)

I was instructed to perform the following procedural steps in an illogical sequence:

7. Would you want to perform this flight level change differently?

\_\_\_\_\_ Yes

\_\_\_\_\_ No

Please explain:

8. Would you recommend changes to the display interface to assist you with this ITP geometry?

\_\_\_\_\_ Yes (If Yes, please describe your recommended display changes unless you have already done so in another post-scenario questionnaire:)

\_\_\_\_\_ No

Please explain:

## Appendix F Post-Experiment Questionnaire

*Please respond to each questionnaire item that follows:*

1. Please share your impressions of the flight scenarios (e.g., comment on their level of realism, appropriateness, and/or diversity):

2. Please share your impressions of the simulator (e.g., comment on the level of realism and appropriateness for this experiment):

3. Did you receive adequate training with respect to: a) performing the ITP, b) flying the simulator, and c) using the EFB's Oceanic application?

\_\_\_\_\_ Yes

\_\_\_\_\_ No

Please explain and provide any suggested improvements for the training protocol:

4. Please share any suggested improvements for other aspects of the experiment (e.g., schedule, facilities, etc.):

5. Given your operational experience, please describe any performance concerns that you have with the ITP (e.g., the ability to maintain climb rate or Mach):

6. Given your operational experience, do you think this procedure would be acceptable?

Yes

No

Please explain:

7. Did you use the Oceanic Operations ITP Checklist during every ITP maneuver?

\_\_\_\_\_ Yes

\_\_\_\_\_ No

If “no,” please estimate the percentage of time that you used the ITP Checklist:

8. Did you reassess the ITP criteria every time you received an ITP clearance?

\_\_\_\_\_ Yes

\_\_\_\_\_ No

If “no,” please estimate the percentage of time that you reassessed the ITP criteria when you received an ITP clearance:

9. Please describe how the workload required to operate the simulator compares with the workload required to fly an actual aircraft in the domain that was simulated:



10. Please describe how the workload required to perform standard flight level changes during the experiment compared with the workload required to perform ITP flight level changes:

11. Please comment on the perceived benefits that the ITP may have for a) the flight crew, b) passengers, and c) the airline company:

a) Benefits that the ITP may have for the flight crew include:

b) Benefits that the ITP may have for passengers include:

c) Benefits that the ITP may have for the airline company include:

12. Compared with current day procedures, the ITP is:

\_\_\_\_\_ Less safe than current day procedures

\_\_\_\_\_ Equally as safe as current day procedures

\_\_\_\_\_ Safer than current day procedures

Please explain:

13. What did you like about the ITP display interface?

14. What did you dislike about the ITP display interface?

15. How would you improve the ITP display interface and why?

16. What is the minimum required information that should be presented on the ITP display?

17. Was the ITP free text phraseology easy to understand and use?

\_\_\_\_\_ Yes

\_\_\_\_\_ No

Please explain:

18. If you encountered off-nominal conditions while performing an ITP flight level change (e.g., you observe the reference aircraft deviating), how easy would it be for you to revert back to the use of standard procedures?

Very  
Easy

Easy

Somewhat  
Easy

Undecided

Somewhat  
Difficult

Difficult

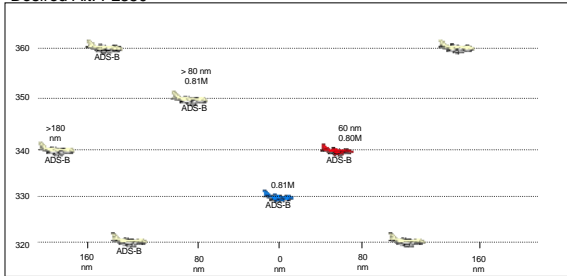
Very  
Difficult

Please explain your answer:

# Appendix G Experiment Scenarios

## Following Climb through 1 Intervening FL (FC1\_AC)

Ownship: FL 330; 0.81M  
Desired Alt: FL350



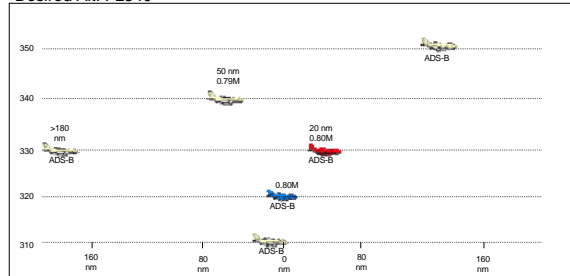
4/5/2007

EOO HITL scenario graphics v0.8

1

## Following Climb through 1 Intervening FL (FC1\_RJ)

Ownship: FL 320; 0.80M  
Desired Alt: FL340



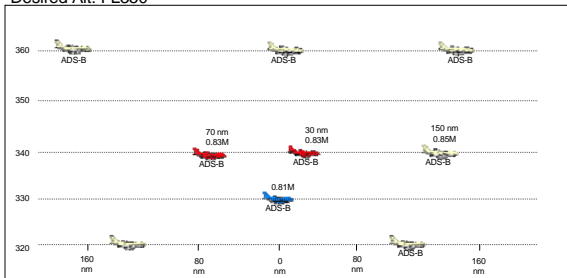
4/5/2007

EOO HITL scenario graphics v0.8

2

## Combined Climb through 1 Intervening FL (CC1\_AC)

Ownship: FL 330; 0.81M  
Desired Alt: FL350



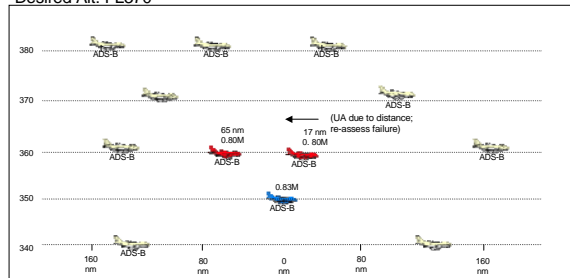
4/5/2007

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3

## Combined Climb through 1 Intervening FL (CC1\_UAR)

Ownship: FL 350; 0.83M  
Desired Alt: FL370



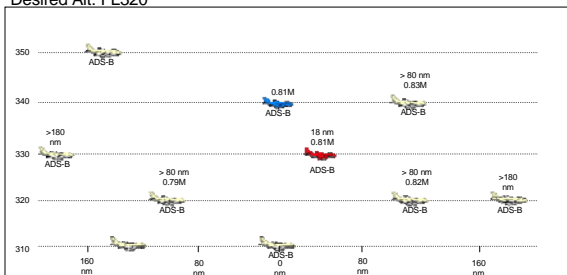
4/5/2007

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4

## Following Descent through 1 Intervening FL (FD1\_AC)

Ownship: FL 340; 0.81M  
Desired Alt: FL320



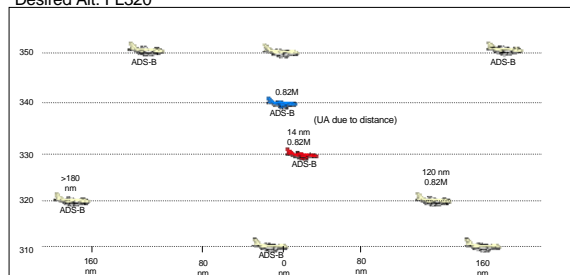
4/5/2007

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5

## Following Descent through 1 Intervening FL (FD1\_UAD)

Ownship: FL 340; 0.82M  
Desired Alt: FL320



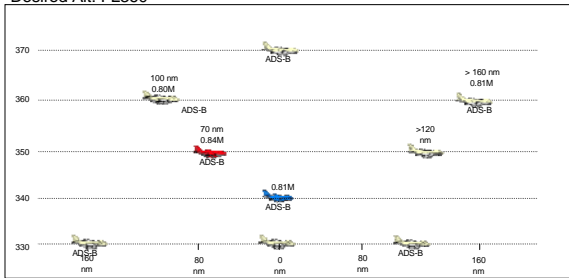
4/5/2007

EOO HITL scenario graphics v0.8

6

### Leading Climb through 1 Intervening FL (LC1\_AC)

Ownship: FL 340; 0.81M  
Desired Alt: FL360



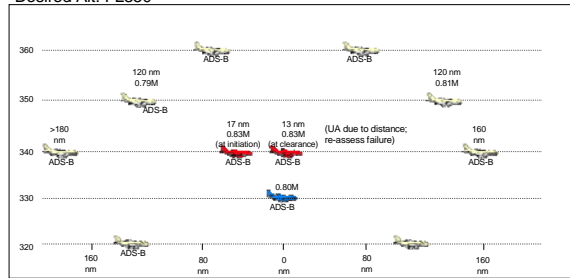
4/5/2007

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7

### Leading Climb through 1 Intervening FL (LC1\_UAR)

Ownship: FL 330; 0.80M  
Desired Alt: FL350



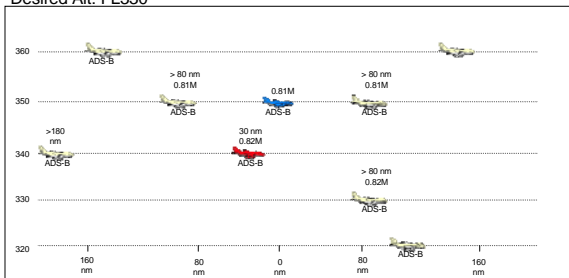
4/5/2007

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8

### Leading Descent through 1 Intervening FL (LD1\_AC)

Ownship: FL 350; 0.81M  
Desired Alt: FL330



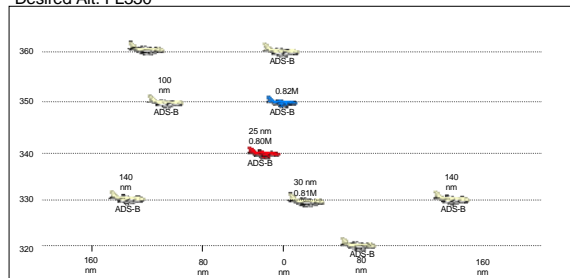
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9

### Leading Descent through 1 Intervening FL (LD1\_UAT)

Ownship: FL 350; 0.82M  
Desired Alt: FL330



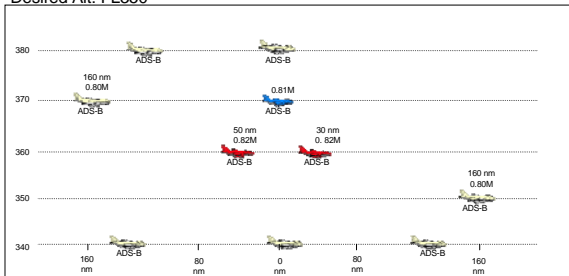
4/5/2007

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10

### Combined Descent through 1 Intervening FL (CD1\_AC)

Ownship: FL 370; 0.81M  
Desired Alt: FL350



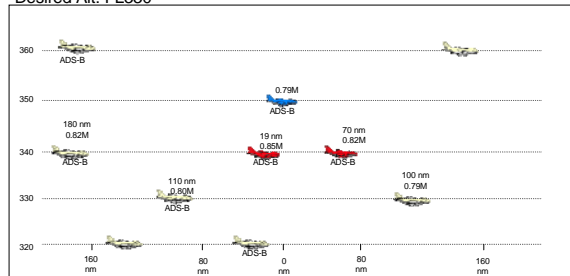
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11

### Combined Descent through 1 Intervening FL (CD1\_UAG)

Ownship: FL 350; 0.79M  
Desired Alt: FL330



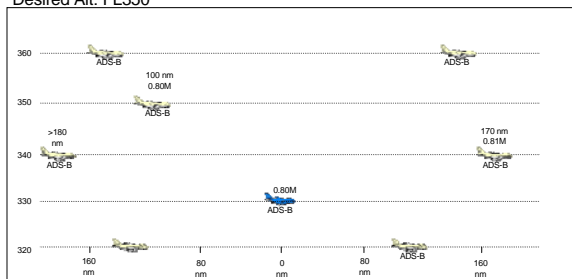
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12

**Standard Climb through 1 Intervening (SC1\_AC)**

Ownship: FL 330; 0.80M  
Desired Alt: FL350



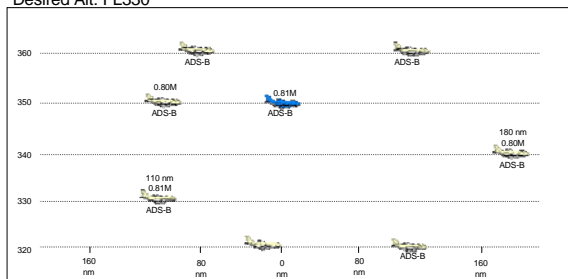
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13

**Standard Descent through 1 Intervening (SD1\_AC)**

Ownship: FL 350; 0.81M  
Desired Alt: FL330



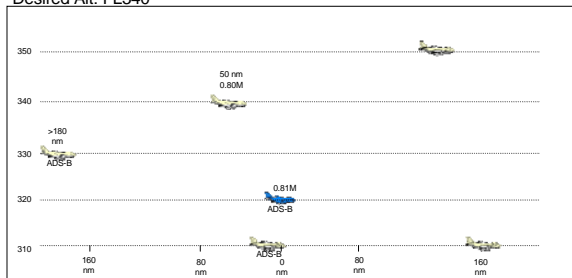
4/5/2007

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14

**Standard Climb through 1 Intervening (SC1\_RJ)**

Ownship: FL 320; 0.81M  
Desired Alt: FL340



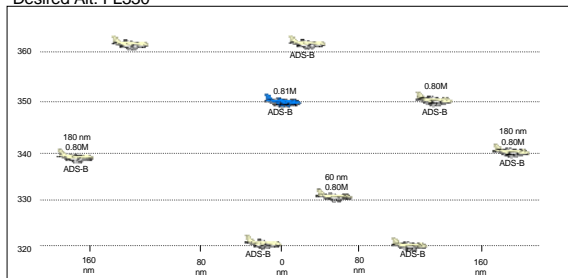
4/5/2007

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15

**Standard Descent through 1 Intervening (SD1\_RJ)**

Ownship: FL 350; 0.81M  
Desired Alt: FL330

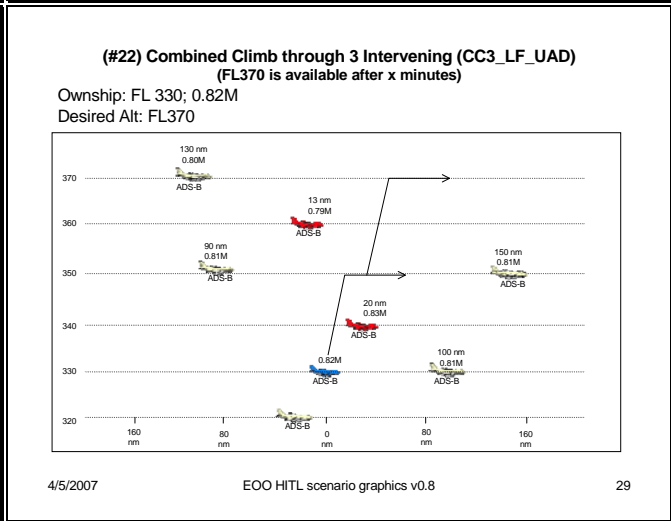
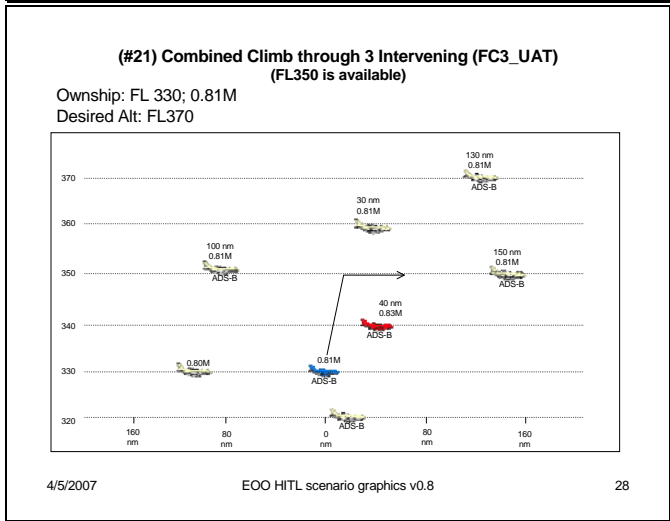
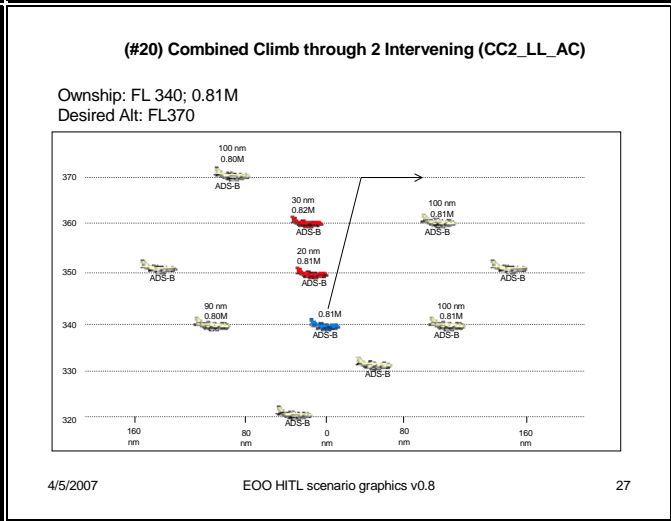
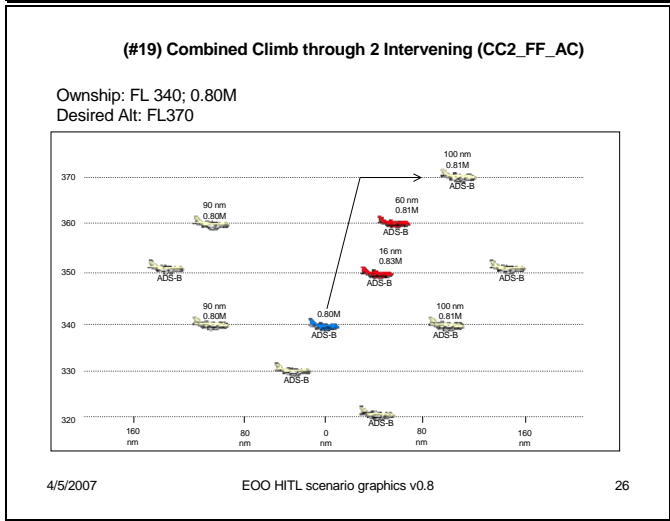
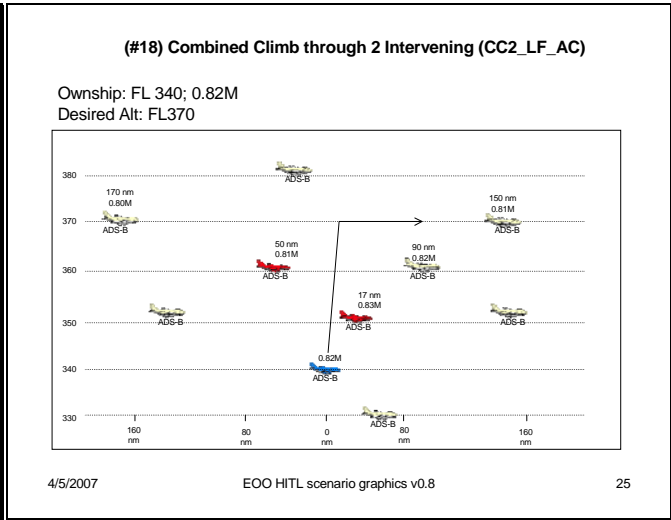
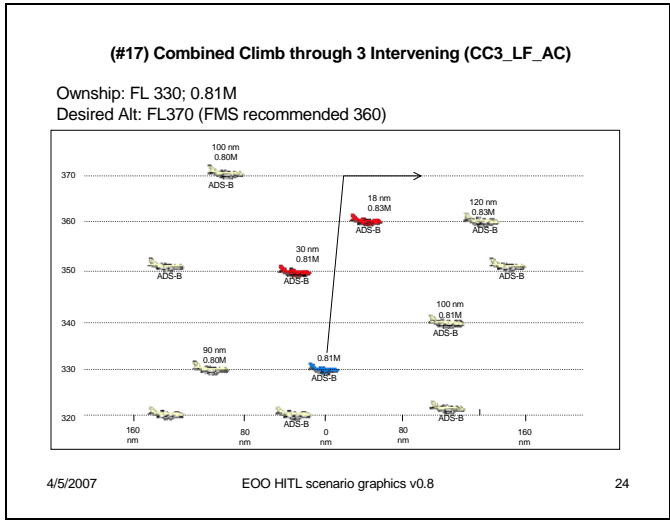


4/5/2007

EOO HITL scenario graphics v0.8

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# Appendix H Supplemental Data Collection Scenarios



## **Appendix I Informed Consent Document**

**Project Title:** Enhanced Oceanic Operations (EOO) Human-In-The-Loop  
In-Trail Procedure (ITP) Validation Simulation Study

**Principal Investigator:** Jennifer L. Murdoch, Ph.D., (757) 864-8304,  
<Jennifer.L.Murdoch@nasa.gov>

### **PURPOSE**

The purpose of NASA Langley Research Center's (LaRC) Enhanced Oceanic Operations (EOO) Human-In-The-Loop In-Trail Procedure (ITP) Validation Simulation Study is to validate the procedures associated with normal execution of oceanic ITP maneuvers and to assess pilot acceptability of ITP maneuvers.

You are invited to participate in this research because you are a Boeing 777 or 747-400 captain or first officer with current oceanic experience.

Eighteen to 24 participants are expected to take part in this study. Your participation in this research endeavor will assist with the design and development of more efficient oceanic operations.

### **PROCEDURES**

If you agree to participate, you can expect the following to occur. You and up to five other pilots (who meet the same criteria that you do) will be asked to participate in a training session designed to help you understand the tasks you will be asked to perform during the experiment. You will be given ample training time to become comfortable with all of the experimental tasks.

The experiment will involve the following:

- You will be asked to fly a series of scenarios using a desktop aircraft simulator.
- Each scenario will be flown across the North Atlantic Ocean and will potentially involve either a standard or ITP flight level change request.
- During scenarios involving ITP maneuvers, the percentage of time that you maintain cruise Mach, the percentage of time that you maintain a minimum climb or descent rate, and the point of closest approach between your aircraft and simulated traffic aircraft will be recorded.
- After each scenario, you will be asked to complete a workload rating scale and a post-scenario questionnaire.
- General comments regarding the ITP will be collected at the end of the study.

Participation in this study will require approximately 18 hours of your time over the course of two consecutive days. A lunch period and ample breaks will be provided each day.



## **RISKS**

There are no apparent risks associated with participation in this study other than those experienced during normal participation in flight simulation activity. There is a very slight risk that you could confuse the procedures for this activity with standard Approved ICAO procedures.

In the unlikely event that you are injured or otherwise experience discomfort, NASA LaRC has an on-site Occupational Health Clinic. The Clinic has hours of operation from 7:00 a.m. to 3:30 p.m. The clinic number is 864-3193. Emergency medical personnel and ambulance service is also available to transport you to nearby health care providers.

If you have questions about the research and your rights should you experience any injury, you may contact the Principal Investigator listed at the beginning of this document.

## **BENEFITS**

There are no personal benefits associated with participating in this study. However, your participation in this research endeavor will provide information that may be helpful in the design and development of more efficient oceanic operations.

## **COSTS AND COMPENSATION**

There are no costs associated with participating in this study. You will be compensated by receiving a stipend of \$200.00 a day, plus travel expenses.

Non-civil servant volunteers injured as a result of participating in this research may file a claim under the Federal Tort Claims Act (FACA) by filing a Standard Form 95. For additional information, you may contact the NASA LaRC Office of Chief Counsel at 864-3221.

## **CONFIDENTIALITY**

Records of participation in this study will be kept confidential to the extent permitted by law. To ensure confidentiality, an arbitrary identification number will be assigned to your responses. In the event of any report or publication from these studies, the identity of participants will not be disclosed. Results will be reported in a summarized manner in such a way that you cannot be identified.

## **VOLUNTARY PARTICIPATION**

Taking part in this study is voluntary. You may withdraw from participating at any time, a decision which will not result in any penalty or loss of benefits to which you may otherwise be entitled.

## **SAFETY**

As a voluntary test subject participating in this research, I understand that:

- NASA is committed to ensuring my safety, health, and welfare plus the safety and health of all others involved with this research.

- I should report any accident, injury, illness, changes in my health condition, hazards, safety concerns, or health concerns to Jennifer Murdoch at (757) 864-8304. If I am unable to reach the above named individual or am not satisfied with her response, I should contact the NASA LaRC Safety Office at (757) 864-7233 or the Chairperson of the NASA LaRC Institutional Review Board, Mr. Jeffrey S. Hill, at (757) 864-5107.
- If I detect any unsafe condition that presents an imminent danger to myself, or others, I have the right and authority to stop the activity or test. In such cases, the Principal Investigator and associated research personnel will comply with my direction, stop the activity, and take action to address the imminent danger.

**QUESTIONS**

Questions are encouraged. If there are any questions about this study, please contact Jennifer Murdoch of NASA LaRC at (757) 864-8304.

I certify that I have read and fully understand the explanation of procedures, benefits, and risks associated with the research described herein, and I agree to participate in the research described herein. My participation is given voluntarily and without coercion or undue influence. I understand that I may discontinue participation at any time. I have been provided with a copy of this consent statement. If I have any questions or modifications to this consent statement, they are written below.

Participant’s Name (printed): \_\_\_\_\_

\_\_\_\_\_  
(Signature of Participant)

\_\_\_\_\_  
(Date)

\_\_\_\_\_  
(Participant’s Date of Birth)

**INVESTIGATOR STATEMENT**

I have discussed the above points with the participant, using a translator when necessary. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

Investigator’s Name (printed): \_\_\_\_\_

\_\_\_\_\_  
(Signature of Investigator)

\_\_\_\_\_  
(Date)

## Appendix J Demographic Information Questionnaire

### Personal Information

1. On a scale of 0 to 10, rate how often you use a personal computer.

A rating of **0** corresponds to “**I never use a personal computer.**”

A rating of **10** corresponds with “**I use a personal computer multiple times every day.**”

*Level of personal computer usage:* \_\_\_\_\_

2. What is your current age? \_\_\_\_\_

### General Experience

3. Provide your best estimate for each of the following (values may be rounded if desired):

- Total Flight Hours: \_\_\_\_\_
- Total Years Flying Oceanic Operations: \_\_\_\_\_
- Over Water, 3 or 4 engine, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_
- Over Water, 2 engine, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_

### Military Experience

4. Do you have any military flying experience?

Yes

No

If Yes, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_

### Business/Corporate Experience

5. Do you have any business/corporate flying experience?

Yes

No

If Yes, number of Years/Hours: \_\_\_\_\_ / \_\_\_\_\_

### Scheduled Airline Experience

6. How many years and hours of airline flying have you completed: \_\_\_\_\_ / \_\_\_\_\_

7. What is your current position?

Captain

First Officer

8. On a scale of 0 to 10, rate your level of familiarity with flying oceanic routes.

A rating of **0** corresponds to “**very unfamiliar.**”

A rating of **10** corresponds with “**very familiar.**”

*Level of familiarity with flying oceanic routes:* \_\_\_\_\_

9. Approximately how many oceanic flights have you completed during the last year?

Approximate number of oceanic flights completed during the last year: \_\_\_\_\_

10. What oceanic regions have you flown in? List in order of experience, with most as first.

11. Considering the trans-oceanic route that you fly most frequently where radar service is provided, how many times do you request flight level changes during a typical flight, and how many of your flight level change requests are approved?

Number of flight level changes **requested** during a typical flight: \_\_\_\_\_

Number of flight level change requests **approved** during a typical flight: \_\_\_\_\_

12. Under what circumstances would you expect to be more or less likely to obtain approval for a flight level change in oceanic, non-radar airspace? Consider the time of year, time of day, direction of flight, particular tracks, and/or particular flight levels.

13. What kinds of techniques do you use to facilitate your ability to get the best oceanic crossing flight level upon entering the track system and later in the flight?

14. Use a scale of 0 to 10 to indicate how important it is to obtain FMS optimal flight level: a) at track entry, and b) at any point during an oceanic flight. Also, describe what drives this decision (e.g., airline policy) and indicate how often fuel efficiency is deemed to be more important than time during oceanic crossings.

A rating of **0** corresponds to “**very unimportant.**”

A rating of **10** corresponds with “**very important.**”

a) *Importance of obtaining FMS optimal flight level at track entry*: \_\_\_\_\_

b) *Importance of obtaining FMS optimal flight level at any point during an oceanic flight*: \_\_\_\_\_

c) Decisions regarding optimal flight level are determined by:

d) How often is fuel efficiency deemed to be more important than time during oceanic flights?

15. While operating beyond VHF range of ATC, have you ever coordinated oceanic climbs with other proximate aircraft on a common VHF frequency (123.45) before asking ATC for a climb via HF or data link?

Yes                      No                      If Yes, how often have you done so? \_\_\_\_\_

16. Do you have experience with data link communications?

Yes                      No                      If Yes, how many years of experience do you have? \_\_\_\_\_

17. Do you have experience with ADS-C (i.e., data link position reporting)?

Yes                      No                      If Yes, how many years of experience do you have? \_\_\_\_\_

18. What route(s) do you currently fly?

19. What type of aircraft and model do you currently fly on your oceanic routes?

20. Is your oceanic aircraft equipped with ADS-B?

Yes                  No                  Sometimes                  Don't Know

21. Is your oceanic aircraft equipped with data link?

Yes                  No                  Sometimes                  Don't Know

22. Is HF radio your primary means of communicating with ATC in non-radar environments?

Yes                  No                  Sometimes

23. How do you determine what flight level to request for an oceanic crossing? (Select all that apply.)

Flight Plan Information Obtained from Dispatch  
FMC Cruise Page  
If another method is used please describe:

24. When requesting an oceanic crossing flight level, do you typically request a flight level that is the same as, higher than, or lower than the flight level identified in the dispatch release?

Same                  Higher                  Lower

25. If you typically request a flight level that is higher or lower than the flight level identified in the dispatch release, how much higher or lower is your typical request and why?

Experience with Vertical Situation Displays

26. Have you ever used a vertical situation display (VSD)?

Yes                  No

(if “yes,” proceed to question #27; if “no,” skip to question #28)

27. How would you characterize your previous experience(s) using VSDs?

Very Positive          Positive          Somewhat Positive          Neutral          Somewhat Negative          Negative          Very Negative

Please explain:

Experience with Electronic Flight Bags

28. Have you ever used an Electronic Flight Bag (EFB)?

Yes                  No

(if “yes,” proceed to question #29; if “no,” you have completed this questionnaire)

29. What class(es) of EFB(s) have you used? (Please circle all that apply.)

Class 1 EFBs [i.e., Commercial-Off-The-Shelf (COTS)-based systems, including laptop computers, that are fully portable]

Class 2 EFBs (i.e., COTS-based systems that are portable, are connected to the aircraft during normal operations, and require an administrative control process for removal)

Class 3 EFBs (i.e., installed equipment)

30. How would you characterize your previous experience(s) using EFBs?

|                  |          |                      |         |                      |          |                  |
|------------------|----------|----------------------|---------|----------------------|----------|------------------|
| Very<br>Positive | Positive | Somewhat<br>Positive | Neutral | Somewhat<br>Negative | Negative | Very<br>Negative |
|------------------|----------|----------------------|---------|----------------------|----------|------------------|

Please explain:

31. Please describe the functionality of the EFB application(s) you have used most frequently in the past:



## Appendix K

### Post-Training Quiz with Answers

1. What are reference aircraft?

Aircraft at intervening flight levels that could potentially block a flight level change, that meet ITP conditions, and are identified by the crew for inclusion in an ITP flight level change request.

2. What are the ITP conditions a reference aircraft must meet?

Same direction of flight (+/- 45 degrees),  
Qualified ADS-B data, and  
Meet ITP distance/speed criteria

3. ITP distance/speed criteria are met when:

ITP distance is at least 15 nautical miles, and closing groundspeed differential is no more than 20 knots

***or***

ITP distance is at least 20 nautical miles, and closing groundspeed differential is no more than 30 knots

4. What is the maximum altitude change that can be made with an ITP? 4000'

5. What minimum performance must be maintained during an ITP flight level change?

At least 300 feet per minute at assigned Mach number

6. Given **ITP F/UAL123/65** in the free text field of an ITP request:

- a. Is UAL123 ahead of you, or behind you? \_\_\_\_\_ ahead of \_\_\_\_\_
- b. What is the ITP distance to UAL123? \_\_\_65\_\_\_ nautical miles

7. Given **ITP L/DAL456/23** in the free text field of an ITP request:

- a. Is DAL456 ahead of you, or behind you? \_\_\_\_\_ behind \_\_\_\_\_
- b. What is the ITP distance to DAL456? \_\_\_23\_\_\_ nautical miles

8. For this experiment, when deciding whether to change flight levels, you should try to get as close as possible to your recommended flight level.

9. If an ITP flight level change clearance is received from ATC, what must first be done before starting the flight level change?

Recheck that the reference aircraft in the clearance still meet ITP conditions.

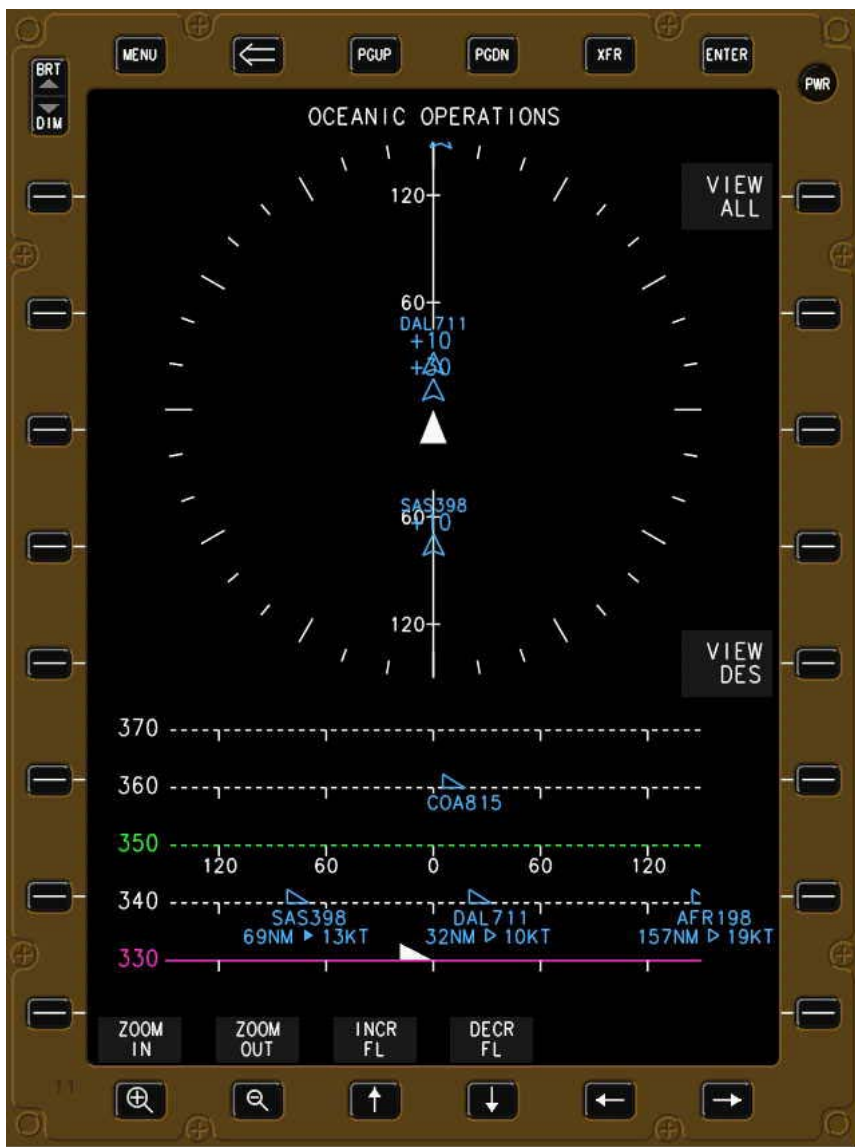
10. What minimum performance should be maintained during an ITP flight level change?

At least 300 feet per minute vertical speed, at assigned Mach number.

11. For this experiment, what should be done if minimum performance cannot be maintained during an ITP flight level change?

Notify an experimenter.

Please refer to the following figure when answering questions 12 through 18:



12. What is the commanded flight level (as entered on the Mode Control Panel)?

Flight Level 330

13. What desired flight level is selected? Flight Level 350

14. What aircraft meet ITP conditions for reference aircraft?

SAS398, DAL711, and AFR198

15. What is the ITP distance of DAL711? 32 nautical miles

16. What is the groundspeed differential for DAL711? 10 knots

17. Is SAS398 moving closer to you, or moving away? closer

How do you know from the display?

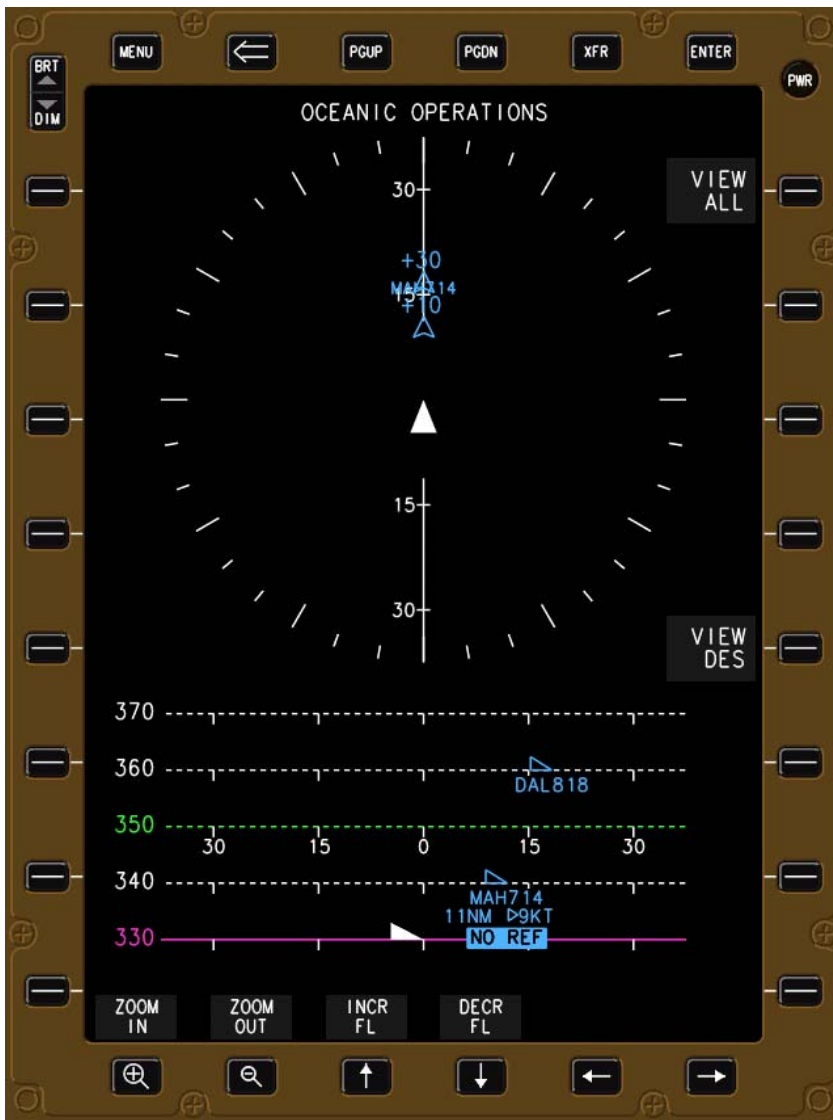
White triangle is filled in (and is pointing toward ownship)

18. Please write out the two free text lines for an ITP request with DAL711 and SAS398 as reference aircraft:

ITP F/DAL711/32\_\_\_\_\_

L/SAS398/69\_\_\_\_\_

Please refer to the following figure when answering questions 19 and 20:



19. Is an ITP climb to Flight Level 350 possible? \_\_\_No\_\_\_ Why or why not?

\_\_MAH714 does not meet ITP distance/speed criteria, indicated by NO REF label in data tag and by ITP distance of only 11 NM (need at least 15 NM in all cases)\_\_

20. What does the “NO REF” label mean in the data tag for MAH714?

\_\_MAH714 cannot be used as a reference aircraft in an ITP request \_\_\_\_\_

\_\_ (does not meet ITP distance/speed criteria) \_\_\_\_\_

## Appendix L Oceanic Operations ITP Checklist

- [PNF] Desired flight level . . . . . **SELECT ON EFB**
- [PNF] Intermediate flight levels . . . **IDENTIFY POTENTIALLY BLOCKING AIRCRAFT**
- [PF/PNF] Reference aircraft (select at most 2) . . . . . **EVALUATE FOR ITP CRITERIA**

- Same direction with qualified ADS-B data
- ITP distance/speed criteria.

| ITP Distance at least | Closing Ground Speed Differential<br>no more than |
|-----------------------|---|
| 15 NM                 | 20 KTS  |
| 20 NM                 | 30 KTS  |

- [PNF] ITP flight level change data link request . . . . . **PREPARE AND SEND**

*Free Text Format: ITP F/<flight id>/<distance>*

*Note 1: F means you are FOLLOWING this Reference Aircraft*

*Note 2: L means you are LEADING this Reference Aircraft*

*Note 3: Enter 2<sup>nd</sup> Reference Aircraft, if any, on 2<sup>nd</sup> free text line, without ITP prefix*

*Example:*

|                        |
|------------------------|
| <b>ITP F/UAL123/35</b> |
| <b>L/UAL456/26</b>     |

***On receipt of ITP clearance:***

- [PF/PNF] Reference Aircraft in . . . . . **REASSESS ITP CRITERIA**  
ITP clearance

***If ITP criteria not met then reject clearance. Otherwise:***

- [PF] Acknowledge/comply with ATC clearance . . . . . **MONITOR**

- Constant Mach
- Minimum 300 FPM vertical speed

## **Appendix M**

### **Group Debrief Questions**

- 1) Do you believe you could benefit from the ITP procedure during normal oceanic operations on a regular basis?
- 2) Do you believe you could improve your operation with the EFB traffic display on some percentage of oceanic operations?
- 3) How could the EFB display be enhanced to improve the performance of the ITP maneuver?
- 4) How could the display be improved to enhance your situation awareness?
- 5) Do you believe the EFB traffic display would be of use in a domestic en-route or terminal environment?
- 6) Should the call sign of “NO REF” aircraft be removed when positioned as potentially blocking aircraft?
- 7) Do you believe an expanded vertical only display would be useful?
- 8) Should relative closure rate be displayed on all targets regardless of ITP desired altitude?
- 9) Do you have any safety concerns with the ITP procedure?
- 10) The controller is responsible for separation throughout the ITP maneuver; do you feel a need or responsibility to monitor the separation while performing the maneuver?
- 11) If during the ITP maneuver, you observe your separation from the reference aircraft decrease to 8 miles, would you take action? 4 miles?

**REPORT DOCUMENTATION PAGE**

*Form Approved  
OMB No. 0704-0188*

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| <b>14. ABSTRACT</b><br>The Enhanced Oceanic Operations Human-In-The-Loop In-Trail Procedure (ITP) Validation Simulation Study investigated the viability of an ITP designed to enable oceanic flight level changes that would not otherwise be possible. Twelve commercial airline pilots with current oceanic experience flew a series of simulated scenarios involving either standard or ITP flight level change maneuvers and provided subjective workload ratings, assessments of ITP validity and acceptability, and objective performance measures associated with the appropriate selection, request, and execution of ITP flight level change maneuvers. In the majority of scenarios, subject pilots correctly assessed the traffic situation, selected an appropriate response (i.e., either a standard flight level change request, an ITP request, or no request), and executed their selected flight level change procedure, if any, without error. Workload ratings for ITP maneuvers were acceptable and not substantially higher than for standard flight level change maneuvers, and, for the majority of scenarios and subject pilots, subjective acceptability ratings and comments for ITP were generally high and positive. Qualitatively, the ITP was found to be valid and acceptable. However, the error rates for ITP maneuvers were higher than for standard flight level changes, and these errors may have design implications for both the ITP and the study's prototype traffic display. These errors and their implications are discussed. |                    |  |                                   |  |  |
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