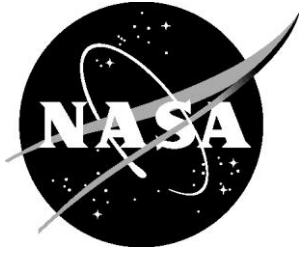


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Cockpit Interfaces, Displays, and Alerting Messages for the Interval Management Alternative Clearances (IMAC) Experiment

*Brian T. Baxley, Michael T. Palmer, and Kurt A. Swieringa
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July 2015

Preface

This document provides a description of the cockpit displays and alerting used during the Interval Management Alternative Clearances (IMAC) human-in-the-loop experiment conducted at NASA Langley in the summer of 2015. The authors gratefully acknowledge the many individuals who made important contributions to the IMAC experiment and this paper over the past two years. They include: Dylan Drake, Michael Harper, Fred Hibbard, Missy Hill, Clay Hubbs, Terry Abbott, Tom Britton, Sara Wilson, Mike Clark, Paul Goess, Richard Jessop, Joe King, Carolyn Malloy, Doug Mielke, Sharon Otero, Roy Roper, Jim Smail, Jim Sturdy, and especially Bryan Barmore and Rick Shay. We also benefited greatly from the assistance of Maryam Amer, Tim Beyer, Stuart Cooke, and Karlus Grant, and thank our college interns for their contributions.

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Abbreviations and Acronyms

AC	Aircraft
ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance–Broadcast
ARP	Aerospace Recommended Practice
ASTAR	Airborne Spacing for Terminal Arrival Routes
ASTOR	Aircraft Simulation for Traffic Operations Research
ATC	Air Traffic Control
ATD-1	ATM Technology Demonstration–1
ATM	Air Traffic Management
CDTI	Cockpit Display of Traffic Information
CGD	Configurable Graphics Display
CMS	Controller Managed Spacing
DTS	Development and Test Simulator
EFB	Electronic Flight Bag
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FCST	Forecast
FOV	Field-Of-View
ID or IDS	Identification (the aircraft’s “callsign”)
IFD	Integration Flight Deck simulator
IM	Interval Management
IMAC	Interval Management Alternative Clearances
KDEN	Denver International Airport
MACS	Multi-Aircraft Control System
MASPS	Minimum Aviation System Performance Standards
MCP	Mode Control Panel
MOPS	Minimum Operational Performance Standards
NASA	National Aeronautics and Space Administration
PF	Pilot Flying
PM	Pilot Monitoring
PWR	Power On
SFC	Surface
TGT	Target aircraft
TMA-TM	Traffic Management Advisor with Terminal Metering
WPT	Waypoint
XFR	Transfer

1 Introduction

1.1 Background

The National Aeronautics and Space Administration (NASA) Langley Research Center Interval Management (IM) research team has been part of NASA's Air Traffic Management (ATM) Technology Demonstration #1 (ATD-1) Project for the past four years. This Langley IM research team was an integral part of the joint NASA Ames and Langley effort to develop the ATD-1 Concept of Operations (ConOps), which integrates three NASA technologies to achieve high throughput, fuel-efficient arrival operations into a busy terminal airspace (ref. 1). These three technologies are: the Traffic Management Advisor with Terminal Metering (TMA-TM), which generates precise time-based schedules to the runway threshold and other points within the airport terminal area; the Controller-Managed Spacing (CMS) decision support tools, which provide additional information to allow terminal area air traffic controllers to better manage aircraft delay using speed control; and Interval Management (IM) avionics, which provide the speed guidance necessary to allow flight crews to conduct airborne spacing operations.

The goals of ATD-1 include increasing the throughput of high-density airports, reducing controller workload, increasing efficiency of arrival operations, and promoting aircraft Automatic Dependent Surveillance–Broadcast (ADS-B) equipage. The ATD-1 concept provides de-conflicted and efficient operations of multiple arrival streams of aircraft from a point prior to top-of-descent to the Final Approach Fix (FAF). Aircraft on these arrival streams primarily use speed control along their optimized profile descents to maintain adequate separation from other aircraft and to achieve precise schedule conformance, decreasing the number of instances that aircraft are vectored off path (ref. 1).

The Langley IM research team has also worked closely with the Federal Aviation Administration (FAA) and industry partners to support the development of the IM concept and operations. These partnerships resulted in significant contributions to recently published documents that define the avionics requirements (ref. 2 and ref. 3).

In response to the ATD-1 ConOps (ref. 1) and the new requirements defined in the industry standards (ref. 2 and ref. 3), new interfaces, displays, and alerting messages were developed and integrated into the simulation software to test and validate the new procedures and requirements. Accordingly, the ATD-1 Project commissioned a human-in-the-loop experiment, called the Interval Management Alternative Clearances (IMAC) experiment, to explore, test, and validate these new IM procedures and requirements.

The goal of IM (one of the three ATD-1 technologies) is to improve the precision of spacing between aircraft in order to improve traffic flow and airport throughput, and potentially reduce the overall voice communication requirement for controllers. The algorithm used by the spacing software in the aircraft avionics is called Airborne Spacing for Terminal Arrival Routes (ASTAR), and is described in ref. 4 and ref. 5.

The term Flight Deck Interval Management is frequently used to describe cockpit-specific equipment or displays, while IM is typically defined as the overall integrated system that includes both ground tools for controllers and airborne tools for flight crews. However, the taxonomy used by NASA, the FAA, and industry has changed over the years; therefore, this document exclusively uses the term IM to describe both the integrated system and the cockpit-specific avionics.

The term Ownship is used throughout this document to refer to an aircraft that is equipped with the IM spacing software and displays and has been assigned an IM clearance. The term Target is used to refer to the aircraft that the Ownship has been instructed to follow during the IM operation. The term clearance refers to the instruction issued by the controller (generated by the TMA-TM ground scheduler software) to the pilot of the IM equipped aircraft, and contains sufficient information for the onboard avionics to generate a speed command that will cause the aircraft to move to the intended location within the arrival stream.

1.2 Purpose of document

This document describes the IM cockpit interfaces, displays, and alerting capabilities that were developed for and used in the IMAC experiment, which was conducted at NASA Langley in the summer of 2015. Specifically, this document includes: (1) screen layouts for each page of the interface; (2) step-by-step instructions for data entry, data verification and input error correction; (3) algorithm state messages and error condition alerting messages; (4) aircraft speed guidance and deviation indications; and (5) graphical display of the spatial relationships between the Ownship aircraft and the Target aircraft. The controller displays for IM will be described in a separate document.

Due to the significant redesign and enhancement of the IM interfaces, displays, and alerting functions, an invention disclosure was submitted in May 2015 to the NASA new technology representative (LAR-18690).

1.3 Description of the IMAC experiment

IMAC is a human-in-the-loop experiment conducted by the ATD-1 Project, designed to investigate the expanded ATD-1 ConOps that includes two new IM clearance types. Research issues to be explored during IMAC include the efficacy and acceptability of the alternative IM operations, the impact of mixed operations or environmental conditions on the IM operations, and identifying possible issues with implementation into real-world operations.

Subject pilots in the IMAC experiment will fly one of the following types of aircraft simulators: Langley's medium-fidelity computer-based Aircraft Simulation for Traffic Operations Research (ASTOR) simulators, a medium-fidelity full-scale Development and Test Simulator (DTS), and a high-fidelity full-scale Integration Flight Deck (IFD) simulator. Additionally, the Multi-Aircraft Control System (MACS) software, developed at NASA Ames, was used to simulate additional aircraft and served as the displays for the air traffic controllers. NASA Ames also provided the Traffic Management Advisor with Terminal Metering (a modified version of their TMA-TM) software that not only generated the schedule used by controllers, but also provided the information needed to issue one of three different IM clearances: CAPTURE, CROSS, or MAINTAIN. Each of these clearance types is described in detail in Section 3 of this document.

The ASTOR simulators used a software emulated Electronic Flight Bag (EFB) and Configurable Glass Display (CGD) that together provided the interface between the flight crew and the on-board IM avionics application, while the DTS used a hardware-based EFB and a software emulated CGD, and the IFD used a hardware-based EFB and CGD. This document uses illustrations from the ASTOR simulators.

A software emulated Aircraft Communications Addressing and Reporting System (ACARS) system was used to transmit from the airline operations center to the aircraft a simulated data link messages containing the descent forecast winds, which the flight crew loaded via a button press into the IM equipment. The flight crew were given a text version of the airport surface winds, which they entered manually into the surface forecast wind data field.

The IMAC experiment used three groups of 12 commercial pilots and 4 controllers as subjects, conducting medium- to high-density arrival operations in the Denver enroute airspace (ZDV) and in the Denver International Airport (KDEN) terminal airspace. Each group flew two replicates of five different scenarios. The scenario types were: 1) TMA-TM tools only, 2) TMA-TM plus the CAPTURE clearance, 3) TMA-TM plus the CROSS clearance, 4) TMA-TM plus the MAINTAIN clearance, and 5) TMA-TM plus the controllers provided with the discretion to choose between the three IM clearance types.

1.4 IM Clearance Types

The three IM clearance types used in the IMAC experiment are defined in ref. 2 (section A.3.2.1), and they are the CAPTURE (or Capture then Maintain), CROSS (or Achieve then Maintain), and MAINTAIN (or Maintain Current Spacing) clearance types. This reference also defines the data elements required by clearance type as described in the three sub-paragraphs below.

1.4.1 IM Capture Clearance

The CAPTURE (Capture then Maintain) clearance type is used when the controller wants the IM aircraft to capture the Assigned Spacing Goal and then maintain it to the Planned Termination Point (“capture” implies to accelerate or decelerate to a moderate rate of closure to the assigned spacing goal interval, see ref. 3). The advantages of this clearance type are that it allows for the utilization of IM in situations where no suitable Achieve-By Point is available, and that controller workload should be reduced due to the shorter IM clearance that must be issued via voice communication.

The Target aircraft’s route is not required since the Ownship and Target aircraft are required to be flying the same arrival and approach procedure, and the Ownship aircraft’s wind information is not required to be entered into the IM avionics because the constant time delay spacing algorithm that is used for the capture and maintain clearance does not use wind forecast information.

Data elements in the IM capture clearance include the:

- IM clearance type;
- Assigned Spacing Goal;
- Target aircraft identification;
- Target aircraft routing (optional); and
- Planned Termination Point (optional).

An example of a controller-issued IM CAPTURE clearance is:

- *NASA01, for interval spacing, capture 120 seconds behind NASA09.*

1.4.2 IM Cross Clearance

The CROSS (Achieve then Maintain) clearance type is used when the controller wants the IM aircraft to achieve the Assigned Spacing Goal at a specific Achieve-By Point, and then maintain that spacing until the Planned Termination Point. If the Achieve-By and Planned Termination Points coincide, there is no maintain phase of the IM operation.

Both the Target aircraft's route and the Ownship aircraft's route information is required to be entered into the IM avionics for the CROSS clearance. It is highly desirable for the flight crew to enter the Ownship forecast wind information, and a message is shown on the EFB to notify the flight crew that they have not entered the forecast descent or forecast surface winds.

Data elements in the IM cross clearance include the:

- IM clearance type;
- Achieve-By Point;
- Assigned Spacing Goal;
- Target aircraft identification;
- Target aircraft routing; and
- Planned Termination Point.

An example of a controller-issued IM CROSS clearance in which the Achieve-By Point and Planned Termination Point are both the default of the Ownship final approach fix (and therefore the controller does not need to issue them) is:

- *NASA01, for interval spacing, cross FRONZ 120 seconds behind NASA09 on the ANCHR2 arrival.*

An example of a controller-issued IM CROSS clearance in which the Achieve-By Point and Planned Termination Point are not the default of the Ownship final approach fix (and therefore the controller does need to issue them) is:

- *NASA01, for interval spacing, cross CTFSH 120 seconds behind NASA09 on the ANCHR2 arrival, terminate at DOGGG.*

1.4.3 IM Maintain Clearance

The MAINTAIN (Maintain Current Spacing) clearance type is used when the controller wants the IM aircraft to maintain the current spacing interval (in time or distance), as determined by the IM software. This requires the Ownship and Target aircraft to be on the same route, and the figures in this document show the IM displays auto-populate the Ownship aircraft's route into the data field for the Target aircraft's route. Unlike the other two clearance types that are intended for use when aircraft metering is in effect (high-density operations), the MAINTAIN clearance is intended for use when metering is not in effect (during medium to low density operations or at airports that are not equipped with Terminal Sequencing and Spacing).

The Target aircraft's route is not required since the Ownship and Target aircraft are required to be flying the same arrival and approach procedure, and the Ownship aircraft's wind information is not required to be entered into the IM avionics because the constant time delay spacing algorithm that is used for the capture and maintain clearance does not use wind forecast information.

Data elements in the IM maintain clearance include the:

- IM clearance type;
- interval spacing type (time or distance);
- Target aircraft identification.

An example of a controller-issued IM maintain clearance is:

- *NASA01, for interval spacing, maintain current time behind NASA09.*

1.5 Standards, Goals, and Functional Operation

1.5.1 Industry Standards

The guiding design principals used when creating the IM displays described in this document are based on the aerospace recommended practices (ARP) from the Society of Automotive Engineers (SAE) S-7 committee for Flight Deck and Handling Qualities Standards for Transport Aircraft, the SAE G-10 committee for Aerospace Behavioral Engineering Technology, FAA Advisory Circulars (AC), RTCA Minimum Operational Performance Standards (MOPS), and Minimum Aviation System Performance Standards (MASPS) for ADS-B and cockpit display of traffic information (CDTI).

Industry standards used by the IM research and development teams include

- ARINC 726 Flight Warning Computer System
- DOT/FAA/TC-13/44 Human factors considerations in the design and evaluation of flight deck displays and controls
- FAA AC 25-11A Electronic flight deck displays
- FAA AC 25.1322-1 Flight crew alerting
- FAA AC 25.1329-1B Flight guidance systems
- FAA AC 120-76B Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags
- MIL-STD-1472G DoD design criteria standard human engineering
- RTCA DO-317B Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System
- RTCA DO-338 Minimum Aviation System Performance Standards (MASPS) for ADS-B Traffic Surveillance Systems and Applications (ATSSA)
- SAE S-7 ARP 4101 Flight deck layout and facilities
- SAE S-7 ARP 4101/4 Flight deck environment
- SAE S-7 ARP 4102/4 Flight deck alerting system
- SAE S-7 ARP 4102/7 Electronic displays
- SAE S-7 ARP 4103 Flight deck lighting for commercial transport aircraft
- SAE S-7 ARP 4102/5 Primary flight controls by electrical signaling
- SAE G-10 ARP 5365 Human interface criteria for cockpit display of traffic information

1.5.2 Research Team Design Goals

While developing the IM displays, the Langley IM research team incorporated the standards and recommended practices described above and employed additional, internally-developed design goals to create displays that will mitigate human error.

- Provide pilots with all the necessary information to safely conduct airborne spacing.
 - Provide system monitoring and alerting to keep the pilot fully aware of changes.
 - Data entry intuitive and aligned with voice clearances issued by controllers.
- Minimize the workload associated with conducting IM operations.
 - Minimize the number and types of IM system alerts.
 - Minimize the number of operational IM states of the IM system.
 - Present IM commanded speeds within the pilot's primary field-of-view (FOV).
 - Annunciate IM state changes and speed changes in the primary FOV.
 - Support information only shown on auxiliary displays not in the primary FOV.
 - IM speed changes salient but not distracting to pilots.
 - Only provide information relevant to that IM clearance type or that IM page.

1.5.3 Functional Operation of Cockpit Interfaces

The illustrations of the EFB and the CGD in this document are approximately two-thirds the size of the actual devices (actual EFB is 10.4" x 8.0" versus 7.1" x 5.4" shown in this document, and actual CGD is 2.1" x 2.9" versus 1.6" x 2.0" shown in this document). The CGD is a repeater of the upper-right portion of the EFB, with the exception of the EARLY/LATE indicator which is removed from the CGD due to its smaller size.

- Auto-populate information in IM equipment when reasonable based on typical retrofit installation across a range of aircraft types.
- Soft-key buttons shall align with the bezel (line select) keys as much as possible.
- Buttons that result in page changes should include a caret in their label pointing to the associated bezel key (if any).
- Buttons on multiple pages that perform the same action shall be located in the same position as much as possible.
- Buttons displayed in the same location as a previously selected button shall never cause an irreversible action; for example, if pressing the CANCEL IM button causes a confirmation button to appear, that confirmation button shall be located in a different screen position to require a deliberate pilot hand movement to help prevent accidental double-hit actions.
- Mandatory data entry fields (when empty) shall be shown with boxes.
- Optional data entry fields (when empty) shall be shown with dashes.
- Only uppercase characters shall be used in button labels and other elements.
- Font sizes and styles shall be consistent both within and between pages.
- Keyboards shall only appear when a data entry button has been selected (the field is active), and that field requires a text entry (for example, destination airport and Target callsign).
- Keyboard layouts should align with other aircraft avionic standards to the maximum extent possible (for example, the ABCDE keyboard was used in IMAC).
- Pressing the ENTER key to complete typing into a data entry field shall not force a page change.

- Button selection behavior shall match Boeing B-777 multi-function display behavior.
 - Selectable buttons shall be solid shaded in light grey.
 - Un-selectable buttons shall be drawn as an outline only, and in cyan.
 - A magenta cursor shall appear when the pilot's finger touches the screen or when a mouse is located within the EFB display screen area.¹
 - As the cursor tracks a finger or mouse moving over screen, selectable buttons shall be highlighted with bold white outline when cursor is on top of them.
 - Un-selectable (cyan outline) buttons shall never be highlighted.
 - When multiple buttons selections on a page can be valid at the same time (that is, the pilot is selecting multiple options from a menu of non-exclusive options), then after each button is selected that button shall be displayed shaded in green along with other previously selected buttons, and the page shall not change until the pilot invokes a specific action to do so.
 - Selected buttons that do not result in page changes shall be displayed shaded in green whenever the page is shown.
- Data entry into a field shall be completed by either:
 - Selecting another button on the current page, or
 - Pressing the ENTER bezel key
- Selecting a data entry field that already has a value entered shall activate the field, display the current value, and place the cursor at the end of the value text.
- The cursor shall be clearly distinguishable from all text characters, and shall blink at the rate of 1 Hz (0.5 sec visible, 0.5 sec invisible).
- Validation of entered data shall be performed as soon as the entry or selection of that data has been completed.
- Notification of invalid data shall be provided immediately; this notification shall include sufficient information to allow the pilot to correct the invalid entry or selection.
- Data validity notifications shall be displayed as a boxed message covering the line below the button with the responsible data entry field, unless the data entry field is immediately above the keyboard, in which case the message shall appear covering the line above the button with the responsible data entry field.
- The data entry field responsible for the display of a validity notification shall remain active until a valid entry is entered or the data entry field is cleared.
- If a page change is forced while a validity notification is active, the responsible data entry field shall be cleared of the invalid value.

¹ The computer-based ATOS simulator allowed pilot participants to interact with the emulated EFB using either a touch screen interface or a mouse, whereas the higher fidelity simulators only allowed the pilot participants to interact with the EFB hardware using the touch screen interface or bezel keys.

2 IM State Logic

IM state logic that was developed for the IM application used in the IMAC experiment includes a total of seven states. These states are:

1. OFF/TERMINATE where clearance data is entered into the EFB;
2. ARMED where the IM application is waiting for all necessary constraints to be met before the IM commanded speed can be calculated;
3. AVAILABLE where the IM speed can be produced (and that speed is displayed to the flight crew as pending, i.e., the flight crew has not yet notified air traffic control that the IM operation has commenced);
4. PAIRED where the IM commanded speed is displayed to the flight crew (i.e., the IM operation is being conducted by the flight crew);
5. SUSPENDED-ARMED where the IM equipment is suspended because the IM commanded speed cannot be calculated (e.g., if the target aircraft is vectored off path);
6. SUSPENDED-AVAILABLE where the IM speed can be calculated (and that speed is displayed to the flight crew as pending, e.g., if the pilot manually suspended the IM operation); and
7. UNABLE that indicates that an unrecoverable error has occurred.

Section 7 contains a detailed description of the transition logic between each state and the displays shown in each state. Additionally, section 3.2 contains a detailed description of messages displayed to the flight crew to explain the reason behind automated state changes.

Figure 1 illustrates the IM States used in the IM application, the manual actions taken by the flight crew (pressing the ARM, EXECUTE, SUSPEND, RESUME, and CANCEL buttons), and transitions done automatically by the IM application software (to the AVAILABLE, SUSPENDED-ARMED, UNABLE, and TERMINATE states). This IM state logic for IMAC was designed so that the OFF and TERMINATE States as defined in reference 3 are the same.

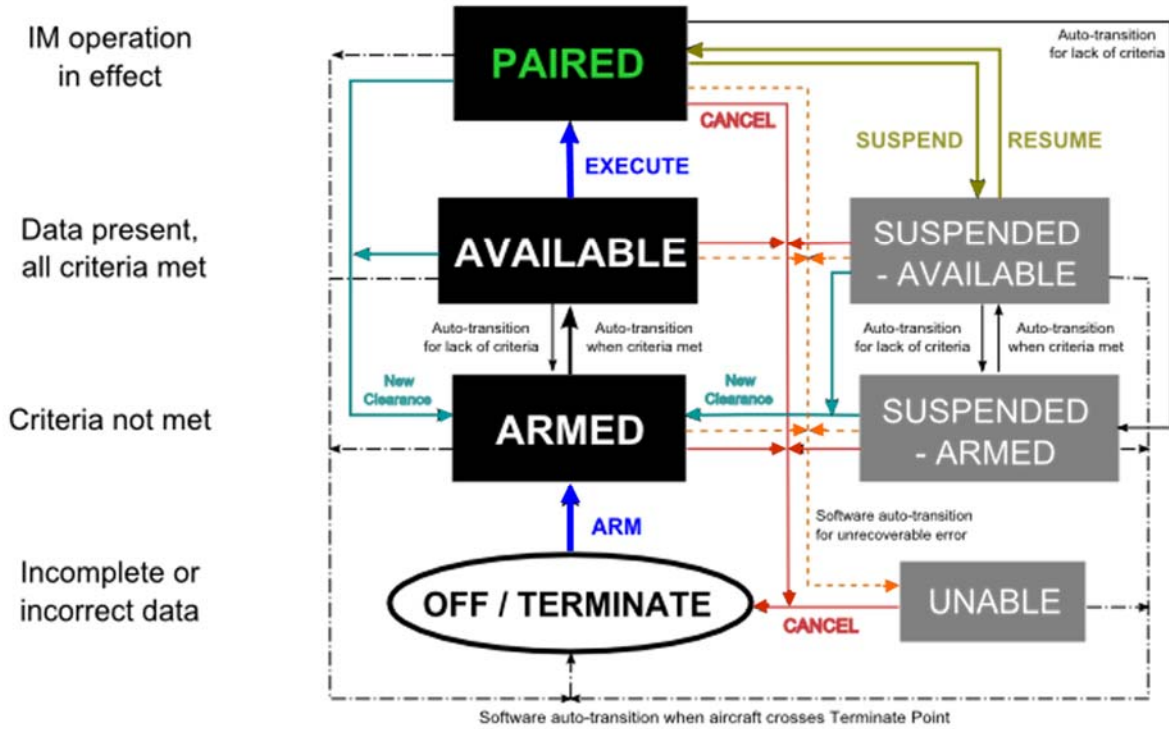


Figure 1. IM state logic flow diagram.

The ARMED and SUSPENDED-ARMED states are identical from a criteria stand-point, as are the AVAILABLE and SUSPENDED-AVAILABLE states. The only difference between them is whether or not the IM operation has been initiated at some point during the flight or not. This differentiation was necessary due to different phraseology between pilots and controllers used prior to first initiating an IM operation, and the phraseology used when resuming an IM operation.

One new feature of this IM state diagram is that a pending IM commanded speed is presented to the flight crew when the IM state is either AVAILABLE or SUSPENDED-AVAILABLE. The flight crew must then press the EXECUTE button to switch the state to PAIRED, displaying an active IM speed command. Previous ATD-1 human-in-the-loop experiments found that the acceptability of IM operations improved when the flight crew notified air traffic controllers of their pending IM speed prior to beginning the IM operation. This procedure enabled air traffic controllers to predict the future speed of the IM aircraft and to verify that the IM commanded speed would not cause any conflicts with other aircraft in their sector. The IM pending speed and associated states were implemented to enable the pilots to notify air traffic control (ATC) of the pending IM speed prior to beginning an IM operation.

Table 1 lists how the name of the IM state and the shape and color of the Target aircraft are shown on the EFBs and CGDs described later this document.

Table 1. State name and Target display by IM state

ASTAR State	Name shown on EFB and CGD	Target aircraft icon shape and color	Annunciation color
OFF/ TERMINATE	nothing	Single cyan chevron	n/a
ARMED	ARMED	Double white chevron	White
AVAILABLE	AVAILABLE	Double white chevron	White
PAIRED	PAIRED	White w/ green outline	Green
SUSPENDED-AVAILABLE	SUSPENDED	Double white chevron	White
SUSPENDED-ARMED	SUSPENDED	Double white chevron	White
UNABLE	UNABLE	Double white chevron	White

3 IM Alerting Messages and Filter Annunciations

3.1 Alert Levels

A structured alert hierarchy that aligns with other cockpit display philosophies was used for the IM displays. IM displays and messages are assigned the lowest possible alert level, and do not change levels if the pilot does not take action. No audio tones are used to alert the pilot of a message during the IM operation since none of the IM messages meet the criteria for a warning level alert as described in Table 2.

Table 2. Alert levels and characteristics used for IM displays

Alert Level	Criteria	Alert Characteristics			
		Aural	Visual		Tactile
			Display	Color	
3 Warning	Emergency operational or aircraft systems conditions which require immediate corrective or compensatory action by the crew.	ATTENTION or DISCRETE aural alert. Time critical alerts and annunciations may be supplemented by voice message.	<ul style="list-style-type: none"> Alpha-numeric alert messages. 	Red	Stick shaker
2 Caution	Abnormal operational or aircraft systems conditions which require immediate crew awareness and subsequent corrective or compensatory crew action.	None	<ul style="list-style-type: none"> Alpha-numeric alert messages. Flashing reverse video for IM speed (indicates a change in the IM speed greater than 10 seconds ago; returns to normal video when speed set in MCP). 	White	None
1 Advisory	Operational or aircraft systems conditions which require crew awareness and may require crew action.	None	<ul style="list-style-type: none"> Alpha-numeric alert messages. Reverse video for IM speed (indicates a change in the IM speed less than 10 seconds ago; returns to normal video when speed set in MCP). 	White.	None
0 Info	Operational or aircraft systems conditions which require flight deck indication.	None	<ul style="list-style-type: none"> Discrete lights, alpha-numeric readout, or icon. 	White	None

3.2 IM Alerting Messages

The IM alerting messages in this section are categorized from highest to lowest alert level outlined in Table 2 (caution, then advisory, then info), with no IM messages reaching the criticality of a warning level. A maximum of three messages are shown on either the EFB or CGD, with the messages listed in order of the alert level categorization. The IM alerting messages displayed on the EFB and CGD contain a maximum of 18 characters (including spaces) to help ensure the message itself can be shown on any display device.

Only those messages that enable the pilot to take direct action based on the information in that message are shown in the pilot’s primary FOV on the CGD (Table 3). All other messages (Table 4, Table 5, and Table 6) provide an explanation for the current IM software state, and are therefore only shown on the EFB outside of the primary FOV.

Table 3. IM caution messages shown on the EFB and CGD

Message	Criteria	Initial IM State	IM State Transitioned To
AIRCRAFT TOO FAST	The aircraft is faster than 0.02 Mach or 10 kt above the IM instantaneous speed for more than 10 seconds.	PAIRED	No change
		All other states	Not applicable
AIRCRAFT TOO SLOW	The aircraft is slower than 0.02 Mach or 10 kt below the IM instantaneous speed for more than 10 seconds.	PAIRED	No change
		All other states	Not applicable

Table 4. IM caution messages shown only on the EFB

Message	Criteria	Initial IM State	IM State Transitioned To
IM SYS FAIL	A failure of the IM software or hardware has occurred, or the Ownship data is not valid.	All states	UNABLE
IM DB NOT CURRENT	Navigation database (DB) used by IM system is not current, therefore IM speed will not be calculated. This check occurs when the IM application is initially selected (prior to entry of either Ownship data or IM clearance data).	ARMED	UNABLE
		All other states	Not applicable

Message	Criteria	Initial IM State	IM State Transitioned To
OWNSHIP BAD ROUTE	A valid Ownship traffic record and an Ownship route definition exists, but the calculated trajectory cannot be calculated, or it does not meet speed or altitude constraints.	All states	UNABLE
TGT BAD ROUTE	A valid Target traffic record and a Target route definition exists, but the calculated trajectory cannot be calculated, or it does not meet speed or altitude constraints.	All states	UNABLE

Table 5. IM advisory messages shown only on the EFB

Message	Criteria	Initial IM State	IM State Transitioned To
OWNSHIP OFF ROUTE	<p>A valid Ownship traffic record exists and the Ownship's calculated trajectory is valid, but the Ownship is greater than 2 nautical miles laterally or greater than 8000 feet vertically from the intended flight path.</p> <p>NOTE: a new Ownship trajectory is calculated once the aircraft is greater than 4000' vertically from the current trajectory. The OFF ROUTE vertical deviation criteria is triggered when the aircraft is greater than 8000' from the trajectory required to meet an altitude constrained waypoint.</p>	ARMED or AVAILABLE	ARMED
		PAIRED	SUSP-ARM
		SUSPENDED-AVAILABLE or SUSPENDED-ARMED	SUSPENDED-ARM
		UNABLE	Not applicable
TGT OFF ROUTE	<p>A valid Target traffic record exists and the Target's calculated trajectory is valid, but the Target is greater than 2 nautical miles laterally or greater than 8000 feet vertically from the intended flight path.</p> <p>NOTE: a new Target trajectory is calculated once the aircraft is greater than 4000' vertically from the current trajectory. The OFF ROUTE vertical deviation criteria is triggered when the aircraft is greater than 8000' from the trajectory required to meet an altitude constrained waypoint.</p>	ARMED or AVAILABLE	ARMED
		PAIRED	SUSP-ARM
		SUSPENDED-AVAILABLE or SUSPENDED-ARMED	SUSPENDED-ARM
		UNABLE	Not applicable
TGT DATA LOST	<p>The ADS-B track file for the Target aircraft has been lost or removed (data invalid or no longer received for a longer time period than the Air Traffic Computer allows).</p> <p>If the track file becomes valid again, the message is removed and the IM state changes from SUSPENDED-ARMED to SUSPENDED-AVAILABLE.</p>	ARMED or AVAILABLE	ARMED
		PAIRED	SUSP-ARM
		SUSPENDED-AVAILABLE or SUSPENDED-ARMED	SUSPENDED-ARM
		UNABLE	Not applicable

SPC GOAL TOO LARGE	<p>The assigned spacing goal cannot be attained, even with the Ownship flying its slowest possible speed profile. Occurs when the Ownship's current position is closer to the Achieve-By Point than its nominal position by >15% of the distance-to-go.</p> <p>This infeasibility check is performed from IM operation initiation until the Progress Indicator is turned on.</p>	ARMED or AVAILABLE	ARMED
		PAIRED, SUSPENDED-AVAILABLE, or SUSPENDED-ARMED	SUSPENDED-ARM
		UNABLE	Not applicable
SPC GOAL TOO SMALL	<p>The assigned spacing goal cannot be attained, even with the Ownship flying its fastest possible speed profile. Occurs when the Ownship's current position is further from the Achieve-By Point than its nominal position by >15% of the distance-to-go.</p> <p>This infeasibility check is performed from IM operation initiation until the Progress Indicator is turned on.</p>	ARMED or AVAILABLE	ARMED
		PAIRED, SUSPENDED-AVAILABLE, or SUSPENDED-ARMED	SUSPENDED-ARM
		UNABLE	Not applicable

Table 6. IM informational messages shown only on the EFB

Message	Criteria	Initial IM State	IM State Transitioned To
IM SPEED LIMITED	<p>The IM speed limited message is displayed when the IM software calculated speed is being limited by one of the criteria below:</p> <ul style="list-style-type: none"> regulatory (i.e., 250 knots or less < 10,000') airframe (M_{mo}, V_{mo}, maximum speed for flap setting) more than 15% difference from the published speed for that segment 	PAIRED	No change
		All other states	Not applicable
NO DESCENT WIND	No forecast descent wind is entered, either via data comm or manually.	All	No change
NO SURFACE WIND	No forecast surface wind is entered.	All	No change

Message	Criteria	Initial IM State	IM State Transitioned To
WAITING OWN WPT	The Ownship aircraft is on the specified route, however has not yet passed a speed constrained waypoint (only relevant during achieve-phase with the trajectory-based algorithm).	ARMED	No change
		All other states	Not applicable
WAITING TGT WPT	The Target aircraft is on its specified route, however the aircraft has not yet passed a speed-constrained waypoint (only relevant during an achieve-phase when the trajectory-based algorithm is used).	ARMED	No change
		All other states	Not applicable
WAITING TGT DATA	ADS-B data has never been received from the Target aircraft. (This message is different from the TGT DATA LOST message in that IM guidance has not previously occurred.)	ARMED	No change
		All other states	Not applicable
MANUALLY SUSPENDED	IM operation was manually suspended by the pilot.	PAIRED	SUSPENDED-AVAILABLE
		All other states	Not applicable

3.4 Pilot Response to Alerting Messages

Table 7 in this section describes the pilot response to the IM alerting messages of the previous section.

Table 7. Pilot response to IM messages

Message	Criteria	Pilot Response
AIRCRAFT TOO FAST	The aircraft is faster than 0.02 Mach or 10 kt above the IM instantaneous speed for more than 10 seconds.	Reduce throttle and/or deploy speed brake
AIRCRAFT TOO SLOW	The aircraft is slower than 0.02 Mach or 10 kt below the IM instantaneous speed for more than 10 seconds.	Increase throttle and/or retract speed brake
IM SYS FAIL	A failure of the IM software or hardware has occurred, or the Ownship data is not valid.	Notify ATC unable to initiate the IM operation
IM DB NOT CURRENT	Navigation database (DB) used by IM system is not current, therefore IM speed will not be calculated. This check occurs when the IM application is initially selected (prior to entry of either Ownship data or IM clearance data).	Notify ATC unable to initiate the IM operation
OWNSHIP BAD ROUTE	A valid Ownship traffic record and an Ownship route definition exists, but the calculated trajectory cannot be calculated, or it does not meet speed or altitude constraints.	Either notify ATC unable to initiate the IM operation, or notify ATC must terminate the IM operation
TGT BAD ROUTE	A valid Target traffic record and a Target route definition exists, but the calculated trajectory cannot be calculated, or it does not meet speed or altitude constraints.	Either notify ATC unable to initiate the IM operation, or notify ATC must terminate the IM operation
OWNSHIP OFF ROUTE	A valid Ownship traffic record exists and the Ownship's calculated trajectory is valid, but the Ownship is greater than 2 nautical miles laterally or greater than 8000 feet vertically from the intended flight path.	Either update route in IM application if required (any state except PAIRED), or notify ATC must suspend IM operation (if in the PAIRED state)
TGT OFF ROUTE	A valid Target traffic record exists and the Target's calculated trajectory is valid, but the Target is greater than 2 nautical miles laterally or greater than 8000 feet vertically from the intended flight path.	No action (any state except PAIRED), or notify ATC must suspend IM operation (if in the PAIRED state)

Message	Criteria	Pilot Response
TGT DATA LOST	The ADS-B track file for the Target aircraft has been lost or removed (data invalid or no longer received for a longer time period than the Air Traffic Computer allows).	No action (any state except PAIRED), or notify ATC must suspend IM operation (if in the PAIRED state)
SPC GOAL TOO LARGE	The assigned spacing goal cannot be attained, even with the Ownship flying its slowest possible speed profile. Occurs when the Ownship's current position is closer to the Achieve-By Point than its nominal position by >15% of the distance-to-go.	Notify ATC unable to initiate or must terminate the IM operation
SPC GOAL TOO SMALL	The assigned spacing goal cannot be attained, even with the Ownship flying its fastest possible speed profile. Occurs when the Ownship's current position is further from the Achieve-By Point than its nominal position by >15% of the distance-to-go.	Notify ATC unable to initiate or must terminate the IM operation
IM SPEED LIMITED	The software calculated speed is being limited by one of the criteria below: <ul style="list-style-type: none"> regulatory (i.e., 250 knots or less < 10,000') airframe (M_{mo}, V_{mo}, maximum speed for flap setting) more than 15% difference from the published speed for that segment 	No action
NO DESCENT WIND	No forecast descent wind is entered, either via data comm or manually.	Enter wind if available
NO SURFACE WIND	No forecast surface wind is entered.	Enter wind if available
WAITING OWN WPT	The Ownship aircraft is on the specified route, however has not yet passed a speed constrained waypoint (only relevant during achieve-phase with the trajectory-based algorithm).	no action
WAITING TGT WPT	The Target aircraft is on its specified route, however the aircraft has not yet passed a speed-constrained waypoint (only relevant during an achieve-phase when the trajectory-based algorithm is used).	no action
WAITING TGT DATA	ADS-B data has never been received from the Target aircraft.	no action
MANUALLY SUSPENDED	IM operation was manually suspended by the pilot.	no action

4 Modifying the EFB Display

The information shown on the CGD cannot be modified by the flight crew; however, the EFB does provide the flight crew with bezel buttons to navigate the pages and scale the display (Figure 2), and an IM DISPLAY FILTERS page (Figure 3) to allow the flight crew to modify information shown on the device about the surrounding traffic, the IM Target, and route information.

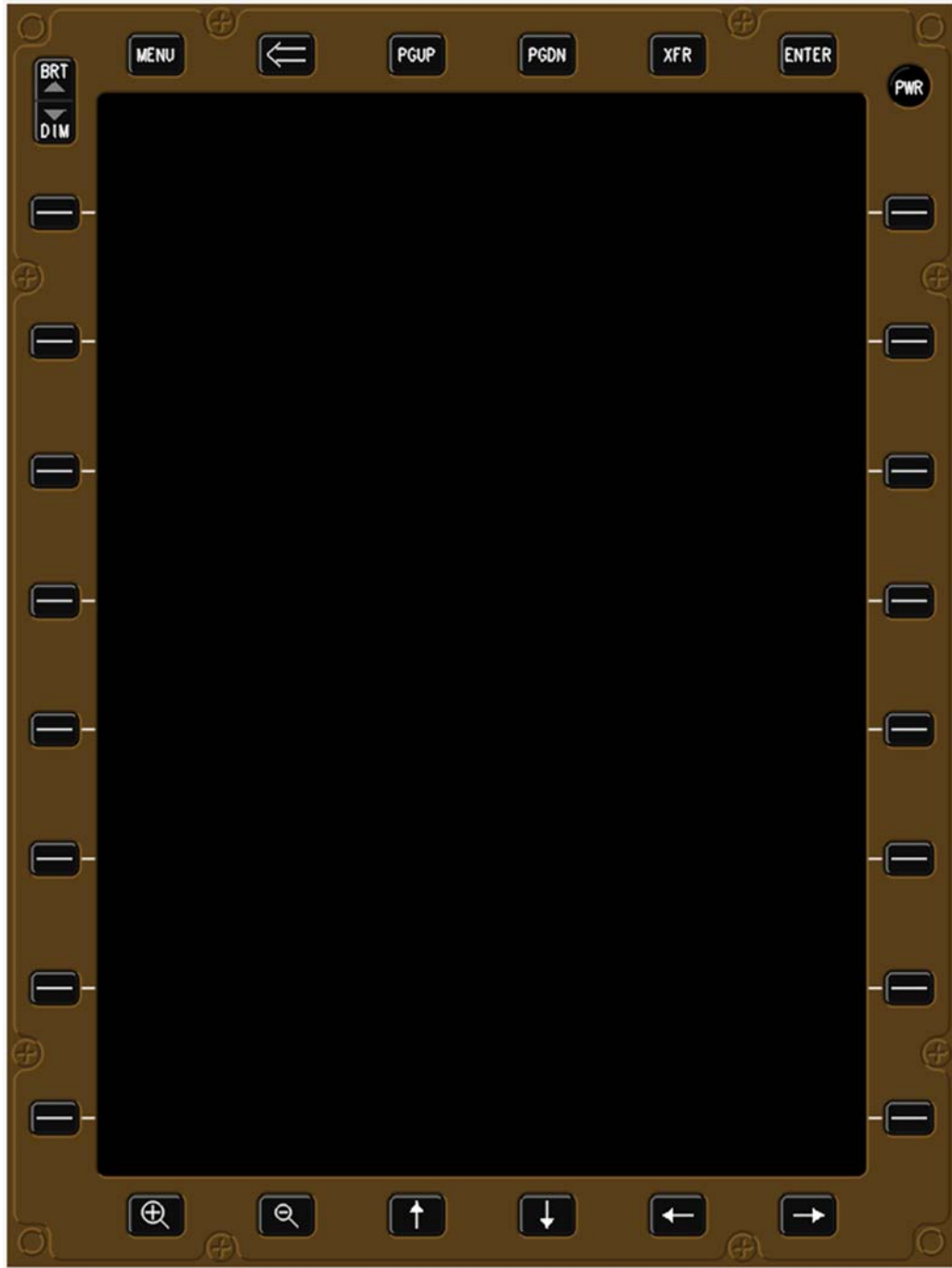


Figure 2. EFB bezel buttons.

4.1 Top and Bottom Bezel Buttons

This sub-section describes the functions of the bezel button at the top and bottom of the EFB (from left to right), and these functions remain constant as the IM page changes.

4.1.1 Menu (MENU)

The MENU bezel button always returns the EFB to the MAIN MENU page (Figure 21).

4.1.2 Back Arrow (<=)

The Back Arrow bezel button always returns the EFB to the previous page. If information is entered into that data field (for example, Figure 27 shows the text KDEN on the second line and the soft-key is not green), that information is retained in that data field if the Back Arrow is used. Therefore, when the pilot subsequently returns to the Ownship and Wind entry page, KDEN will still be entered in the airport data field.

If the data had been typed but not entered (for example, Figure 26 shows KDEN typed into the destination airport data field but the soft-key is still green indicating the ENTER soft-key has not been pressed), that data is not retained if the Back Arrow is used. Therefore, when the pilot subsequently returns to the Ownship and Wind entry page, no data will be in the airport data field.

4.1.3 Page Up and Page Down (PGUP & PGDN)

The Page Up and Page Down bezel buttons are used to navigate multiple pages and are intended to align with typical flight management system operations. The IM sub-pages where the Page Up and Page Down buttons may be needed are those used for entering:

- Ownship Arrival Route
- Achieve-By Point
- Select Target Aircraft
- Target Arrival Route
- Planned Termination Point

4.1.4 Transfer (XFR)

To take full advantage of a two-EFB configuration in the cockpit, pressing the transfer (XFR) bezel button allows a pilot to force their EFB to display the same page as the other EFB (that is, pressing the XFR bezel button causes that pilot's EFB to "pull" the page and data from the other EFB). Once the two EFBs have the same IM page displayed, the pilot not entering information will see data after the other pilot has entered the information in that data field. Either pilot may enter data on their respective EFB (unlike current commercial avionics).

Section 6.4 provides an illustrated example of how the button causes the two EFBs to interact with each other.

4.1.5 Enter (ENTER)

The ENTER bezel button is functional for IM procedures, and causes the same effect as pressing the ENTER soft-key (available for use when entering destination airport, descent forecast winds, Assigned Spacing Goal, and Target aircraft identification).

4.1.6 Power On/Off (PWR)

The Power On/Off (PWR) bezel button was functional in the IMAC experiment; however, it was not used as part of normal flight crew operations (i.e., the EFBs were always on).

4.1.7 Zoom Out and Zoom In (- / +)

The Zoom Out and Zoom In bezel buttons cause the display to zoom out or in by a predetermined scale factor in the indicated direction, respectively. This function is available when viewing graphics (airport maps or instrument procedures) or the horizontal situation display showing the Ownship aircraft, Target Aircraft, and other surrounding traffic on the IM Home page.

4.1.8 Pan Arrows (Left/Right & Up/Down)

The Pan Arrow bezel buttons cause the displayed content to shift in the indicated direction, and are typically available when viewing graphics (for example, the airport map or instrument procedures). The Pan Arrow buttons were not used for any IM page or display.

4.2 Left and Right Side Bezel Buttons and Soft-keys

These bezel buttons and soft-keys remain as constant as possible from page to page, however at times a particular function is not relevant for that page and therefore that function is not present (for example, L8 for cancelling an IM operation prior to entering the IM clearance), or a different function is required (for example, R8 to execute, suspend, and resume an IM operation).

The text displayed in any soft-key indicates the action that will be taken if it or the bezel button is pressed, and the color indicates whether it is selectable or not, i.e., causes an action to occur (cyan indicates non-selectable, and white indicates selectable).

Most actions are obvious and consistent regardless of the page being displayed; however, the L1, L8, R1, and R8 buttons have critical importance and vary, therefore an expanded discussion is given below for those bezel buttons and soft-keys by the respective IM page.

4.2.1 Left Side

The eight bezel buttons along the left side of the EFB are referred to as L1 – L8 (from top to bottom), and the action of each of these bezel buttons depends on the page being displayed. If the button is active, it will have a soft-key label immediately to the right of it, and pressing either the bezel button or the soft-key will cause the identical action to be performed.

4.2.1.1 L1

4.2.1.1.1 IM Home page

- OWNSHIP & WINDS, white: pressing the white OWNSHIP & WINDS button allows the flight crew to manually enter information about the aircraft and forecast wind; available in all IM states except OFF/TERMINATE. See section 7.8 for more detail and illustrations.

4.2.1.1.2 OWNSHIP ROUTE and TARGET ROUTE page

- CLEAR SELECTIONS, white: pressing the white CLEAR SELECTION button removes data entered into that sub-page.

4.2.1.1.3 All other pages

- The button is not active.

4.2.1.2 L8

4.2.1.2.1 IM Home page

- CANCEL IM, white: pressing the white CANCEL IM button allows the flight crew to manually cancel the IM operation; available in all IM states except OFF/TERMINATE. See section 7.8 for more detail and illustrations.

4.2.2 Right Side

The eight bezel buttons along the right side of the EFB are referred to as R1 – R8 (from top to bottom), and the action of each of these bezel buttons depends on the page being displayed. If the button is active, it will have a soft-key label immediately to the left of it, and pressing either the bezel button or the soft-key will cause the identical action to be performed.

Most actions are obvious and consistent regardless of the page being displayed; however, the R1 and R8 buttons have critical importance on several pages, and expanded discussion is given below for the subset of pages where the action changes by page type or what has occurred to that page.

4.2.2.1 R1

4.2.2.1.1 IM Home page

- IM CLRNCE: causes the IM CLEARANCE ENTRY page to be displayed

4.2.2.1.2 OWNSHIP AND WIND ENTRY and IM FILTERS page

- IM HOME: causes the IM Home page to be displayed

4.2.2.1.3 IM CLEARANCE page

- IM HOME: if not all of the IM clearance information has been entered, R1 shows IM Home (same as previous bullet). Pressing it causes the IM state to remain in OFF/TERMINATE, the IM Home page to be displayed, with the R8 button on that page a cyan ARM.
- ARM IM HOME: if all the IM clearance information has been entered, R1 shows ARM IM Home. Pressing it causes the IM state to transition to ARMED, the IM Home page to be displayed, and the R8 button on that page a cyan EXECUTE.

4.2.2.2 R8

4.2.2.2.1 IM Home page

- ARM, cyan: shown when not all of the Ownship and IM clearance data required to initialize ASTAR has been entered.
- EXECUTE, cyan: shown when all required Ownship and IM clearance data has been entered, however not all of the criteria to initiate the IM operation has been met.
- EXECUTE, white: shown when all required Ownship and IM clearance data has been entered, and all criteria required to initiate the IM operation has been met. Pressing the soft-key or bezel button causes a transition to the PAIRED state.
- SUSPEND, white: shown when the IM application is in the PAIRED state. Pressing the soft-key or bezel button causes a transition to the SUSPENDED-AVAILABLE state
- RESUME, cyan: shown when the IM application is in the SUSPENDED-ARMED state (i.e., not all criteria is met to conduct an IM operation).
- RESUME, white: shown when the IM application is in the SUSPENDED-AVAILABLE state (i.e., all criteria met to conduct an IM operation). Pressing the soft-key or bezel button causes a transition to the PAIRED state.

4.2.2.2.2 OWNSHIP ARRIVAL ROUTE sub-page

- OWNSHIP & WINDS: causes the OWNSHIP AND WIND ENTRY page to be displayed

4.2.2.2.3 IM CLEARANCE ENTRY Target Aircraft page

- ENTER, cyan: no action (indicates Target aircraft ID not selected yet)
- ENTER, white: causes the IM CLEARANCE ENTRY page to be displayed

4.2.2.2.4 TARGET ARRIVAL ROUTE sub-page

- IM CLRNCE: causes the IM CLEARANCE ENTRY page to be displayed

4.3 Display Filter Page and Annunciations

The IM DISPLAY FILTERS page (Figure 3) is accessible by pressing the FILTERS bezel button or soft-key (R7) on the IM Home page (Figure 7). Pressing the IM Home bezel button or soft-key (R1) on the IM DISPLAY FILTERS page causes the display to return to the IM Home page. Filters are active when the associated soft-keys are shown in green, and multiple filters or any combination of filters can be selected concurrently (for example, Target ID and Target Bearing).



Figure 3. EFB IM display filters page.

4.3.1 Aircraft Display Filters and Annunciations

All aircraft regardless of altitude were shown on the EFB during the IMAC experiment if no aircraft filter was selected. To assist the pilot in understanding the surrounding traffic, various filters were created for their use (the AIRCRAFT NEAR ROUTE filter was not implemented in time for the IMAC experiment). The aircraft filters and annunciations are shown in Figure 4.

4.3.1.1 L4: AIRCRAFT ABOVE

The AIRCRAFT ABOVE filter was provided to the flight crew to limit the aircraft shown to only those within plus 9900 feet to minus 2700 feet of the Ownship aircraft's altitude. An annunciation "AC ABOVE" is shown on the IM Home page immediately below the OWNSHIP & WINDS information. This filter can be selected simultaneously with the Aircraft Below filter.

4.3.1.2 L5: AIRCRAFT BELOW

The AIRCRAFT BELOW filter was provided to the flight crew to limit the aircraft shown to only those within minus 9900 feet to plus 2700 feet of the Ownship aircraft's altitude. An annunciation "AC BELOW" is shown on the IM Home page immediately below the OWNSHIP & WINDS information. This filter can be selected simultaneously with the Aircraft Above filter.

4.3.1.3 L6: AIRCRAFT NEAR ROUTE

Displays only surrounding traffic within 25 nautical miles of Ownship Route (postulated to be useful for the IM Turn operation). An annunciation "AC NEAR RTE" is shown on the IM Home page immediately below the OWNSHIP & WINDS information. This filter was not implemented for IMAC (the IM Turn operation was not part of IMAC).

4.3.1.4 L7: ALL ACFT IDENTIS

Displays the ADS-B transmitted callsign immediately next to all of the aircraft shown on the IM Home page. An annunciation "ALL AIRCRAFT IDS" is shown on the IM Home page immediately below the OWNSHIP & WINDS information.

4.3.1.5 Annunciations on IM Home page

The IM Home page displays the annunciations for the above filters immediately below the OWNSHIP & WINDS data anytime that filter is selected, which aligns with the location of the filters themselves on the FILTER page.

- AC ABOVE (aircraft above)
- AC BELOW (aircraft below)
- ALL AIRCRAFT IDS (all aircraft identification)
- AC NEAR ROUTE (aircraft near route)

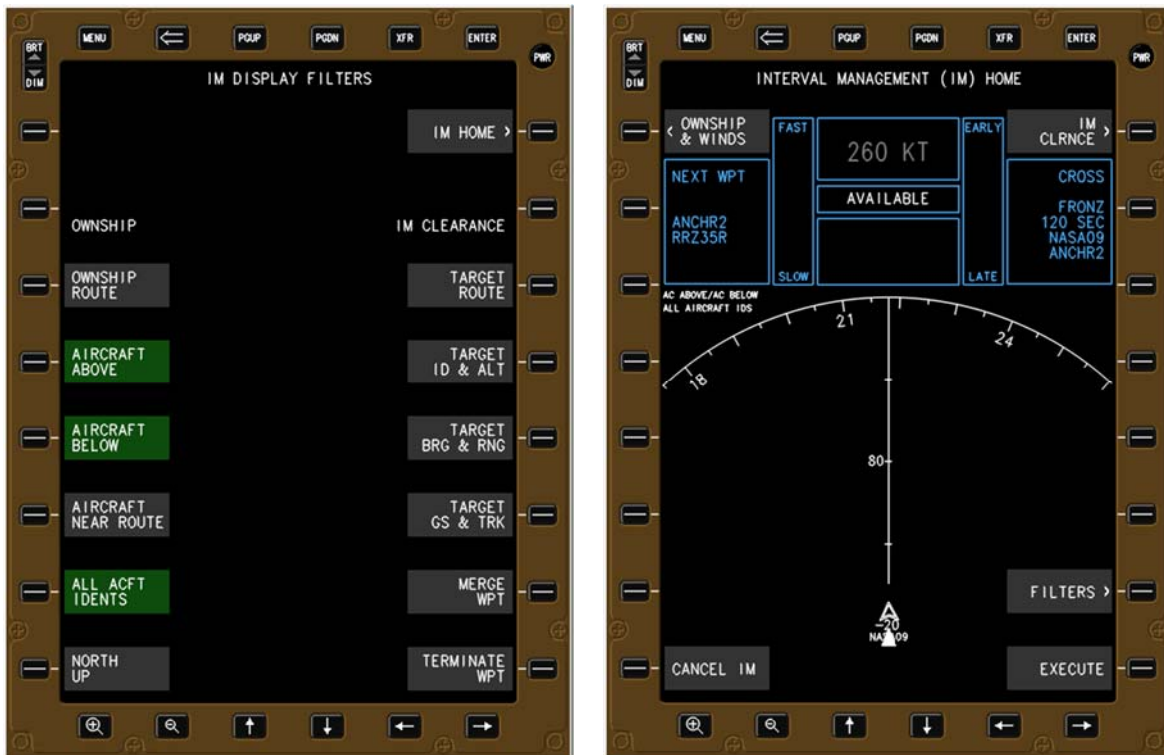


Figure 4. Aircraft display filters and annunciations.

4.3.2 Target Information Filters and Annunciations

Figure 5 shows an example of three of the four Target related filters selected (indicated by the soft-key's green color). The left panel shows the IM filter page with a description of the function below, and the right panel is the IM Home page with the corresponding annunciations displayed to indicate those filters have been selected and the data those filters generate.

4.3.2.1 R4: TARGET ID & ALT

Pressing this bezel button or soft-key causes the Target aircraft's identification (callsign) and relative altitude (in thousands of feet) to be displayed on the EFB next to the Target aircraft icon (double chevron). An annunciation is also shown on the IM Home page immediately below the IM clearance information to indicate this filter has been selected.

4.3.2.2 R5: TARGET BRG & RNG

Pressing this bezel button or soft-key causes the Target aircraft's absolute bearing (magnetic) and range (nautical miles) to be displayed on the IM Home page immediately below the IM clearance information.

4.3.2.3 R6: TARGET GS & TRK

Pressing this bezel button or soft-key causes the Target aircraft's ground speed (knots) and track (magnetic) to be displayed on the IM Home page immediately below the IM clearance information.

4.3.2.4 Annunciations on IM Home page

The IM Home page displays the annunciations for the above filters immediately below the IM CLEARANCE data anytime that filter is selected, which aligns with the location of the filters themselves on the FILTER page.

- TGT IDENT & ALT (Target aircraft identification and altitude)
- BRG / RNG (Target absolute bearing and range from Ownship)
- GS / TRK (Target ground speed and track)

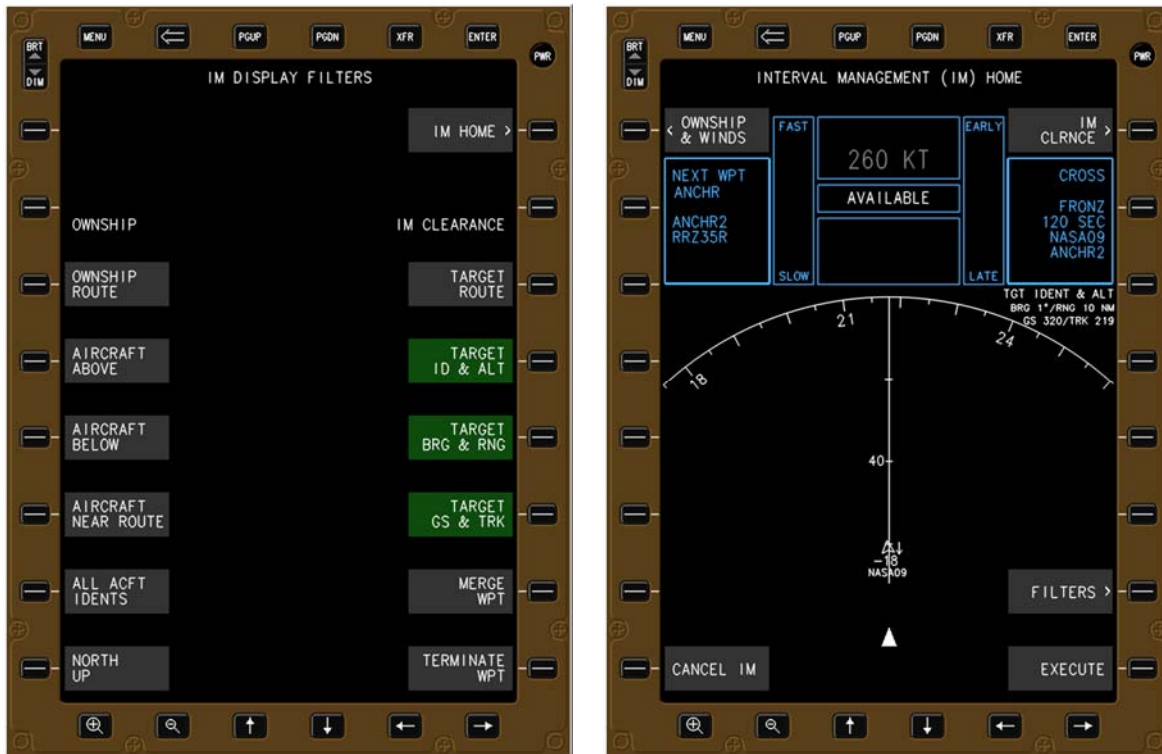


Figure 5. Target information filters and annunciations.

4.3.3 Routes, Waypoints, and Map Orientation Filters

The filters in this section do not trigger an annunciation on the IM Home page. Figure 6 shows the Ownship Route, Target Route, and North Up filters selected. Although this figure displays all three filters selected simultaneously, as with all other filters, each filter may be selected independently of any other one. The Merge and Terminate filters are not shown in this document.

4.3.3.1 L3: OWNSHIP ROUTE

The Ownship Route filter displays icons for each waypoint on that respective route (in this example they are on the same route). In this example the Target aircraft is approaching FIISH.

4.3.3.2 R3: TARGET ROUTE

The Target Route filter displays icons for each waypoint on that respective route. In this example the Ownship has just passed ANCRH and is approaching LANDR.

4.3.3.3 R7: MERGE WPT

Pressing this bezel button or soft-key causes the Merge waypoint and name to be displayed (only relevant during a CROSS clearance when the Ownship and target aircraft are on different routes).

4.3.3.4 R8: TERMINATE WPT

Pressing this bezel button or soft-key causes the Planned Termination Point to be displayed.

4.3.3.5 L8: NORTH UP

The North Up filter changes the IM Home page display from aircraft track up to north up, moves the aircraft from the bottom half to the center of the display area, and removes the compass rose (similar to selecting PLAN mode on an aircraft's navigation display).



Figure 6. Routes and North Up filters selected.

5 Overview of IM Pages and Displays

This section describes the top-level pages of the EFB and CGD, and IM unique displays.

5.1 Electronic Flight Bag (EFB)

5.1.1 IM Home Page

The IM Home page is shown with no information entered (Figure 7). Pressing the OWNERSHIP & WINDS bezel button or soft-key (L1) causes the OWNERSHIP AND WIND ENTRY page to be displayed (Figure 9). Pressing the IM CLRNCCE bezel button or soft-key causes the IM CLEARANCE ENTRY page to be displayed (Figure 10). Pressing the FILTERS bezel button or soft-key (R7) causes the FILTER page to be displayed (Figure 3).

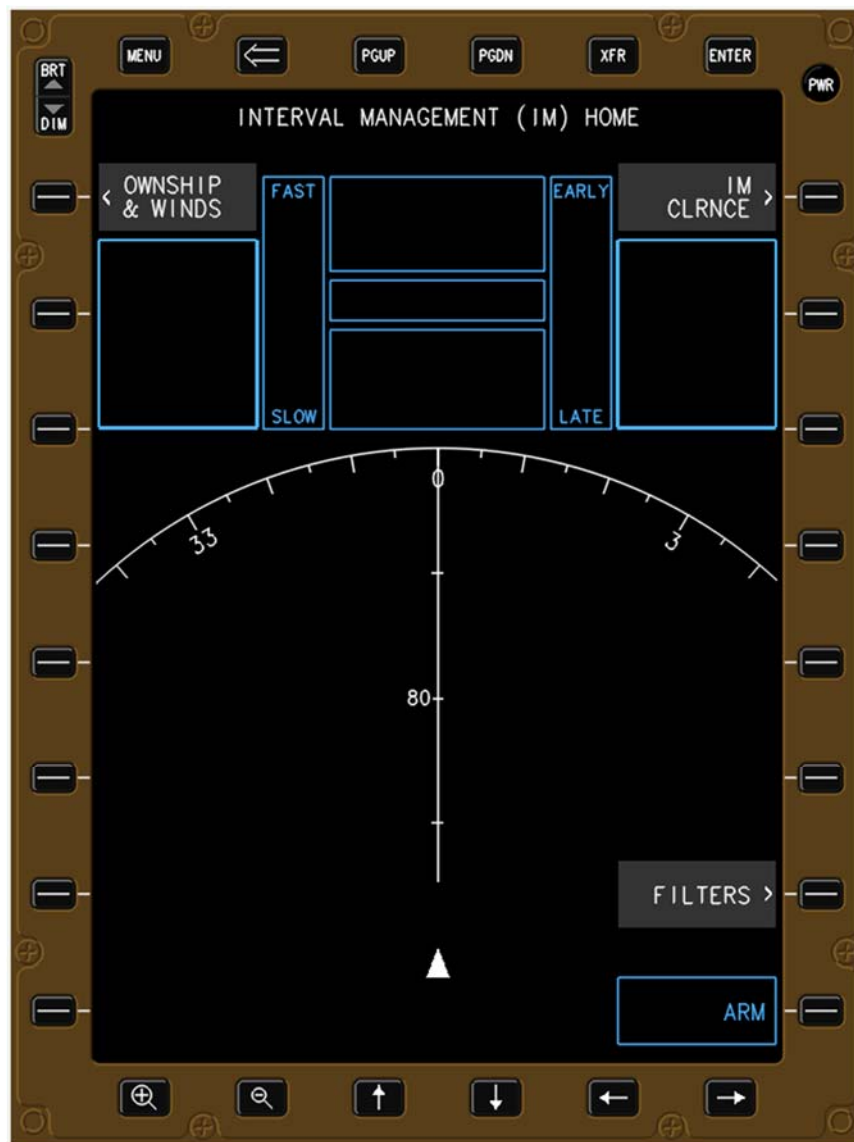


Figure 7. IM Home page.

Figure 8 is a legend of an IM Home page in the PAIRED state, with the explanation provided below.

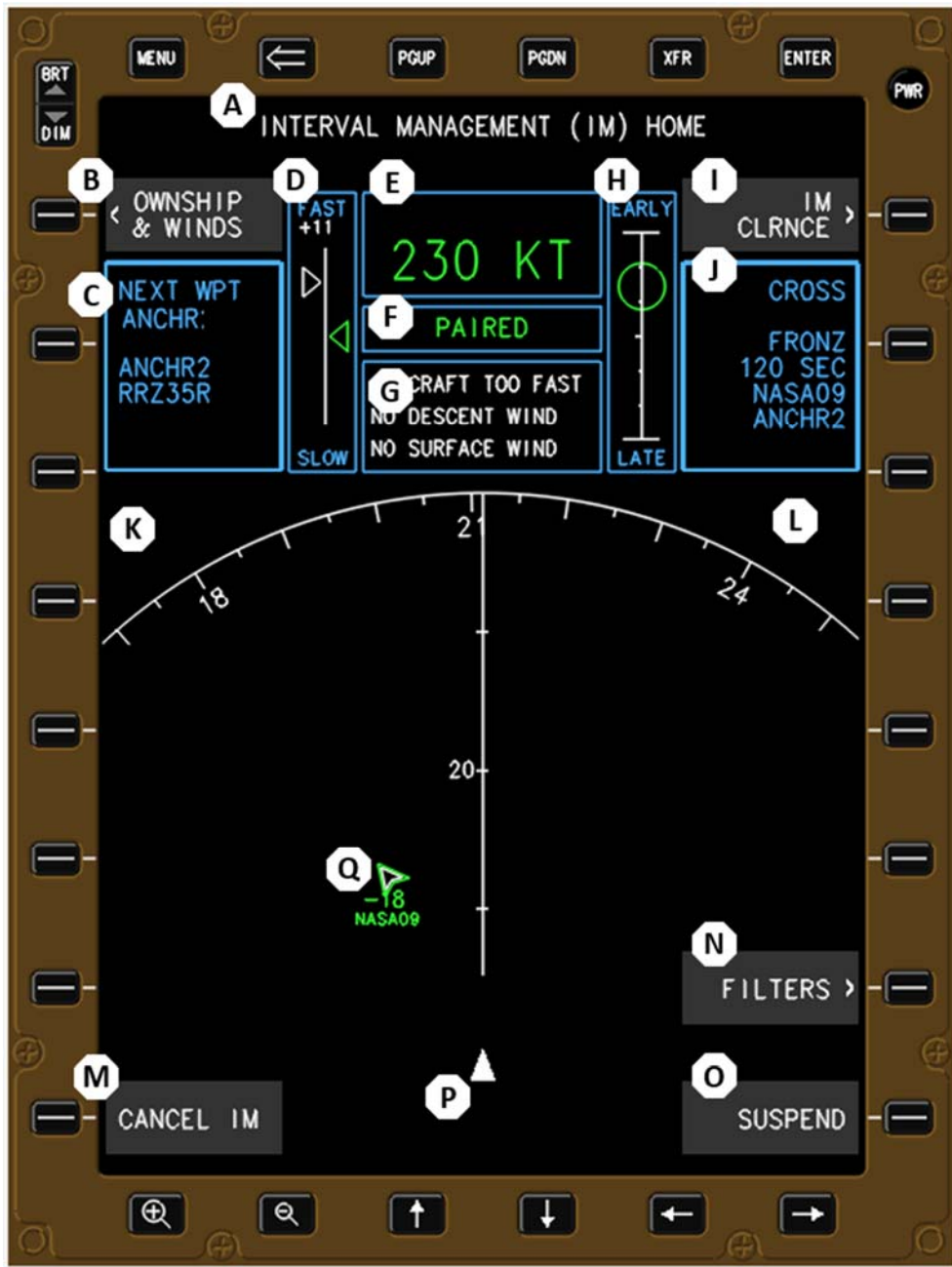


Figure 8. IM Home page legend.

- A) Title of IM page; changes to state function of the page
- B) Selectable soft-key and bezel button to enter ownship and forecast wind information
- C) Non-selectable text box that displays ownship information

- D) FAST/SLOW indicator; only displayed in PAIRED state (see section 5.2)
- E) IM commanded speed; green in PAIRED state, grey in AVAILABLE or SUSPENDED-AVAILABLE, blank otherwise
- F) IM state; all states shown in white except for PAIRED shown in green (see Table 1)
- G) IM alert message box; applicable messages shown in white, four maximum (see Table 3 through Table 6)
- H) EARLY/LATE indicator; only shown within 30 nautical miles of Achieve By Point or during a maintain phase of the IM operation (see section 5.3)
- I) Selectable soft-key and bezel button to enter or modify the IM clearance information
- J) Non-selectable text box that displays the IM clearance information
- K) Area where aircraft filter annunciations are displayed (see section 4.3.1)
- L) Area where Target aircraft filter annunciations are displayed (see section 4.3.2)
- M) Selectable soft-key and bezel button to cancel the IM operation; present in all states except OFF/TERMINATE (see section 4.2.1)
- N) Selectable soft-key and bezel button to display FILTERS page (see section 4.3)
- O) Selectable soft-key and bezel button to suspend the IM operation; button varies based on IM state (see section 4.2.2)
- P) Ownship location
- Q) Traffic location; shown as double-white chevron in AVAILABLE state, shown as white-green chevron in PAIRED state (other traffic shown as single cyan chevron)

5.1.2 Ownship and Wind Entry Page

On the OWNSHIP AND WIND ENTRY page (Figure 9), once the destination airport has been entered by the flight crew using the pop-up keypad shown in section 6.2.2, the IM software is able to provide a selectable list of Ownship routes (section 6.2.3) and Target routes (section 6.3.7) to the flight crew. Forecast descent winds and surface winds are not required to be entered to conduct an IM operation, however a message is displayed to the crew on the EFB if they are not entered due to the potential performance degradation of the IM operation (Table 6).



Figure 9. Ownship and Wind Entry page.

5.1.3 IM Clearance Entry Page

5.1.3.1 IM Clearance Entry Initial Selection Page

This page only occurs during the initial IM clearance data entry. Pressing the CLEARANCE TYPE button (L1) causes a list of options to be displayed (Figure 11). Subsequent selection of the IM CLEARANCE button (Figure 7) causes the previously selected specific IM clearance type page to appear (Figure 12, Figure 13, or Figure 14) with the data that had been entered still present.



Figure 10. IM Clearance Entry initial selection page.

5.1.3.2 IM Clearance Types

Three of the five IM clearance types defined in the Flight-deck IM SPR (reference 2) were implemented and are shown below (white text indicating the button is selectable, cyan indicating the button is not selectable). Illustrations of the specific page for each clearance type are shown for CAPTURE (Figure 12), CROSS (Figure 13), and MAINTAIN (Figure 14).

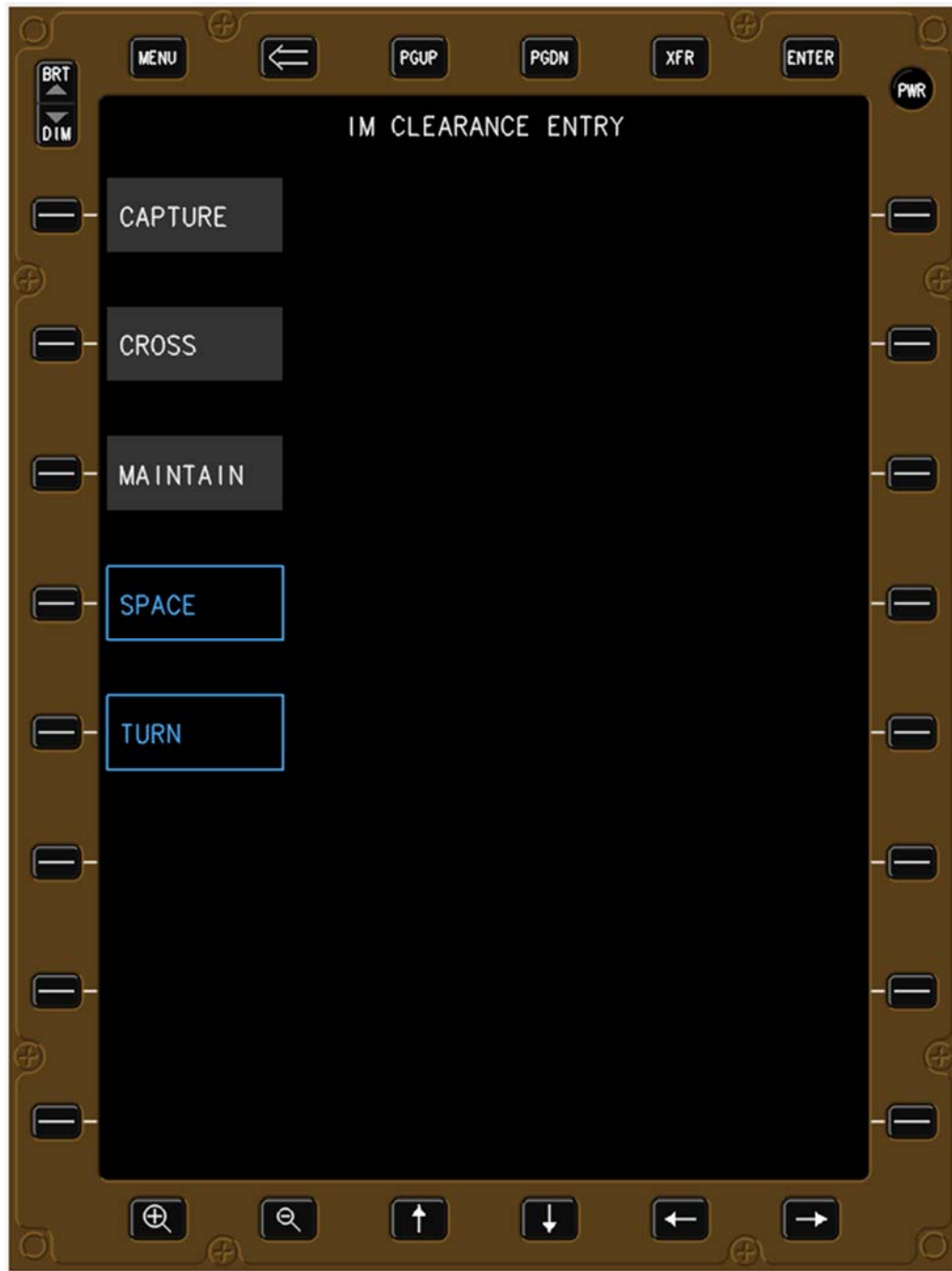


Figure 11. IM Clearance Entry type options.

5.1.3.3 IM CAPTURE Clearance Entry Page

Data elements for the CAPTURE operation are shown in Figure 12. For the CAPTURE operation, the Target aircraft's route is required to be the same as the Ownship's route; therefore, the TARGET ROUTE is not selectable and is auto-populated as the Ownship's entered by the flight crew. The Planned Termination Point is auto-populated as the Final Approach Fix to conform to the ATD-1 ConOps and to reduce crew workload when entering the IM clearance, but can be manually changed by the flight crew as described in section 6.3.8.

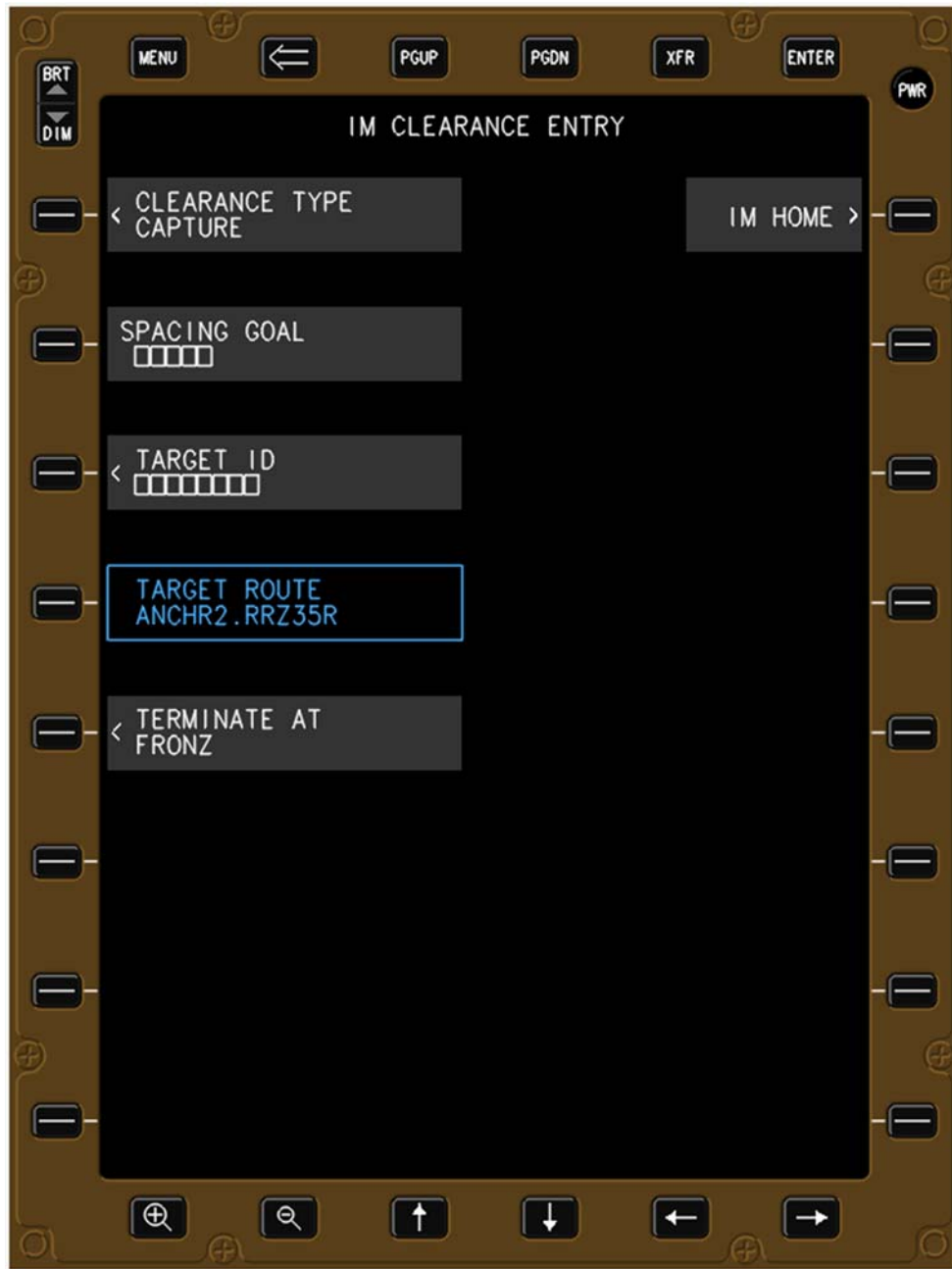


Figure 12. IM CAPTURE Clearance Entry page.

5.1.3.4 IM CROSS Clearance Entry Page

Data elements relevant to the CROSS operation are shown in Figure 13. The Achieve-By and Planned Termination Point data fields are auto-populated with the Final Approach Fix, based on the Ownship route previously entered. Both waypoints may be changed by the flight crew by selecting the appropriate bezel button or soft-key (see Figure 44 and Figure 57).

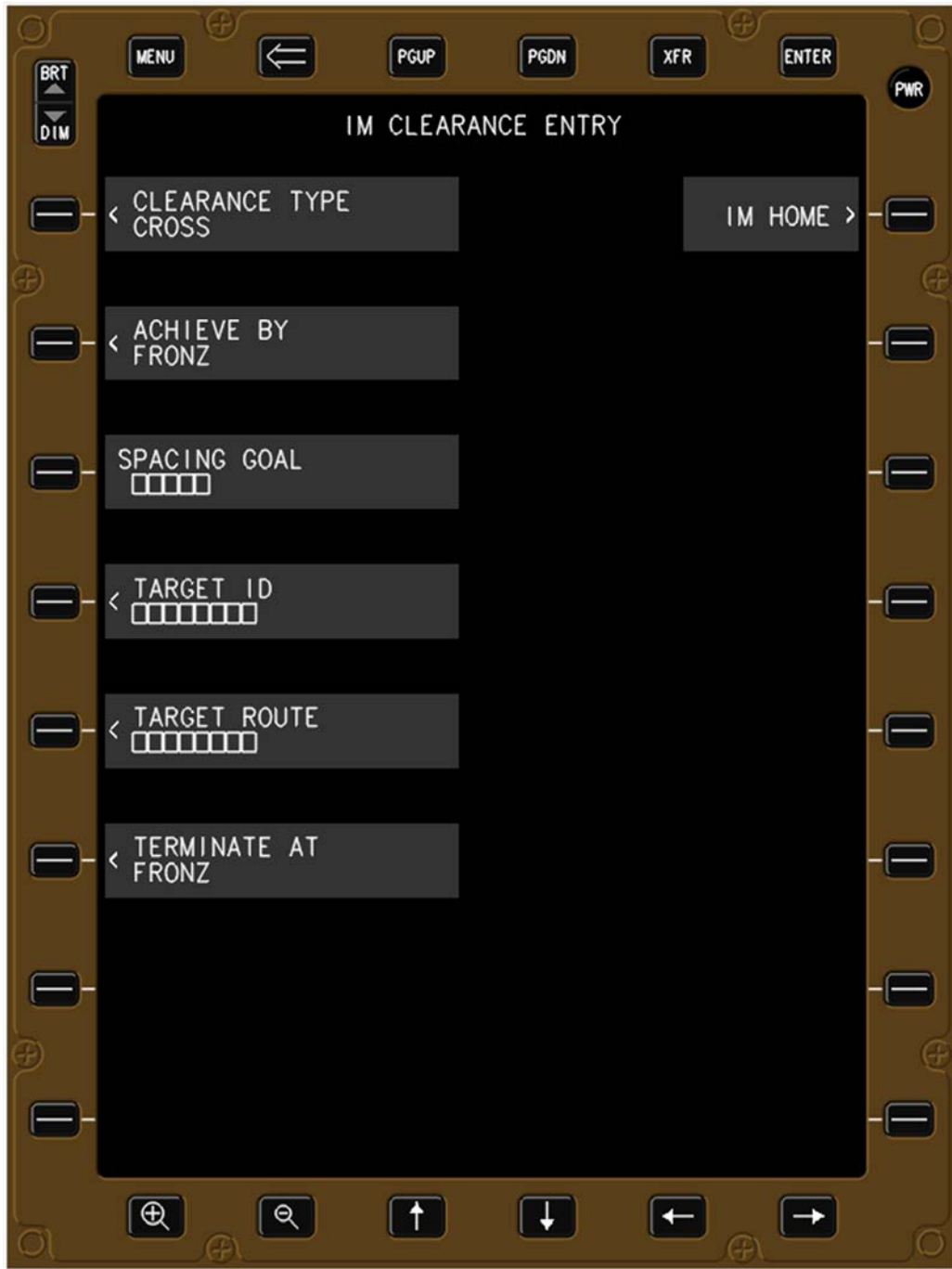


Figure 13. IM CROSS Clearance Entry page.

5.1.3.5 IM MAINTAIN Clearance Entry Page

Data elements relevant to the MAINTAIN operation are shown in Figure 14. The Target route and Termination Point are auto-populated and the Target route is non-selectable (cyan) based on the Ownship route previously entered.

The CURRENT SPACING bezel button and soft-key (L2) toggles the data field between SECONDS and MILES (i.e., time and distance), with SECONDS set as the default.



Figure 14. IM MAINTAIN Clearance Entry page.

5.2 FAST/SLOW Indicator

The FAST/SLOW indicator displays the aircraft's current airspeed and the IM instantaneous speed, and is intended to allow pilots to quickly compare the relationship between the two speeds and then take appropriate action. The solid white triangle is the aircraft's current airspeed, and the hollow green triangle is the IM instantaneous speed and displayed as the reference speed (i.e., it remains fixed in the middle of the vertical FAST/SLOW display). The IM instantaneous speed takes the discrete IM command speed, adds compensation for the delay due to pilot recognition and reaction time, then estimates the deceleration rate of the aircraft to produce a smooth and continuous value. When the aircraft's airspeed does not match the IM instantaneous airspeed the pilots are expected to move the throttle in the direction towards the green reference speed in the center of the display. In the example shown in Figure 15, the pilots would pull the throttles aft, which would slow the aircraft and resolve the error calculated by the ASTAR algorithm.

The IM instantaneous speed takes the discrete IM command speed, adds compensation for the delay due to pilot recognition and reaction time, then estimates the deceleration rate of the aircraft to produce a smooth and continuous value. Therefore, the panels from left to right in Figure 15 represent 1) an aircraft on speed at 270 knots, 2) an IM speed change to 240 knots occurs and the IM instantaneous speed calculated by the ASTAR algorithm is not yet expecting the aircraft to decelerate, 3) the algorithm is expecting the aircraft to have begun slowing but the aircraft has either not begun or is not slowing quickly enough, and 4) the aircraft is now considerably faster than what the spacing algorithm expected, therefore the alerting message AIRCRAFT TOO FAST is also displayed.



Figure 15. Sequence of FAST/SLOW indicator during IM speed change.

5.3 EARLY/LATE Indicator

The EARLY/LATE indicator provides the flight crew an awareness of their ability to meet the assigned spacing goal within the expected tolerance and is not used to actively control the aircraft. The EARLY/LATE indicator is only presented on the side-mounted EFB, and only shown when the aircraft is within 30 nautical miles of the Achieve By Point (CROSS clearance only) or during the MAINTAIN phase of an IM operation (between the Achieve By and Planned Termination Points in a CROSS clearance, or anytime during a CAPTURE and a MAINTAIN IM operation).

From 30 nautical miles prior to the Achieve-By Point until the aircraft is within 210 seconds of the Achieve-By Point, the scale of the display is ± 2 minutes, with tick marks at zero, +60 and -60

seconds. The “bug” is located at the current spacing error value and is a circle with a diameter equal to 20 seconds (left panel of Figure 16).

From 210 seconds prior to the Achieve-By Point until the Termination Point, the scale is ± 45 seconds with tick marks at +30, +15, 0, -15, and -30 seconds. The “bug” is located at the current spacing error value and is a circle with a diameter equal to 20 seconds (right panel of Figure 16). The 20 second diameter of the circle is the same as the IM error tolerance for a maintain operation described in the IM MOPS. Thus, if the center mark is not within the circle, the spacing error is greater than the ± 10 second tolerance.

The final version of this software will make the horizontal tick marks symmetrical around the vertical scale.

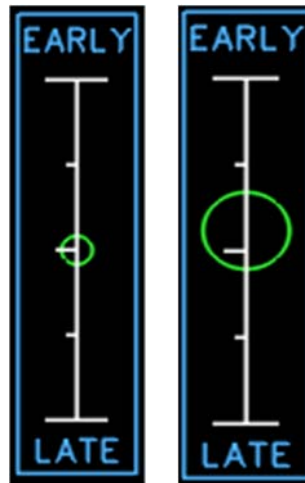


Figure 16: Progress Indicator with 2 minute (left) and 45 second (right) scales.

5.4 Configurable Glass Display (CGD)

5.4.1 IM Operation in OFF/TERMINATE State

When an IM operation is not being attempted (the OFF/TERMINATE States), the outlines of the boxes on the CGD are shown in cyan (to indicate power is on and the device is communicating with the IM equipment), however no IM data is shown (Figure 17).

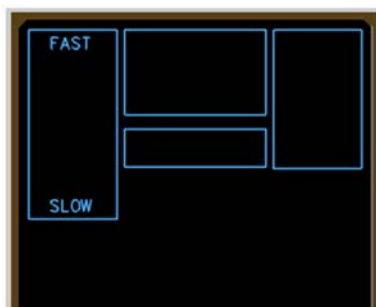


Figure 17. CGD in OFF/TERMINATE state.

5.4.2 IM Operation in ARMED, SUSPENDED-ARMED, or UNABLE State

This CGD display state occurs after the flight crew has entered all the required Ownship and IM clearance information; however, not all the criteria to initiate the IM operation have been met (Figure 18). The clearance type is shown in green (CAPTURE, CROSS, or MAINTAIN), the IM clearance information in white, and the IM state in white (ARMED, SUSPENDED, or UNABLE). No IM speed is shown in these states.



Figure 18. CGD in ARMED, SUSPENDED-ARMED, and UNABLE state.

5.4.3 IM Operation in AVAILABLE or SUSPENDED-AVAILABLE State

This CGD display state occurs after the flight crew has entered all the required Ownship and IM clearance information, and all the criteria to initiate the IM operation have been met (Figure 19). The clearance type is shown in green, the IM clearance information in white, and the IM state in white (AVAILABLE or SUSPENDED-AVAILABLE). The IM speed to be flown once the IM operation is initiated is shown in grey.



Figure 19. CGD in AVAILABLE or SUSPENDED-AVAILABLE state.

5.4.4 IM Operation in PAIRED State

This CGD display state occurs after the flight crew presses the EXECUTE soft-key or bezel button on the IM Home page in the AVAILABLE state (Figure 71). The IM state and IM speed are shown in green (along with the outer chevron of the Target icon) to highlight that the IM operation is in progress (Figure 20). The FAST/SLOW indicator is also displayed in this state.



Figure 20. CGD in PAIRED state.

6 EFB Data Entry to Initiate an IM Operation

6.1 Navigation to the IM Home Page

6.1.1 Main Menu Page

When the EFB is first powered on or the MENU bezel button is pressed, the MAIN MENU page is displayed (Figure 21). Pressing the APPLICATIONS MENU (L2) bezel button or soft-key causes the list of cockpit-based procedures to be displayed to the flight crew (Figure 22).



Figure 21. EFB Main Menu page.

6.1.2 Applications Menu Page

The APPLICATIONS MENU page displays the procedures available to the flight crew (dependent on the avionics vendor). Pressing the INTERVAL MANAGEMENT (L1) bezel button or soft-key causes the IM Home page to be displayed (Figure 7).

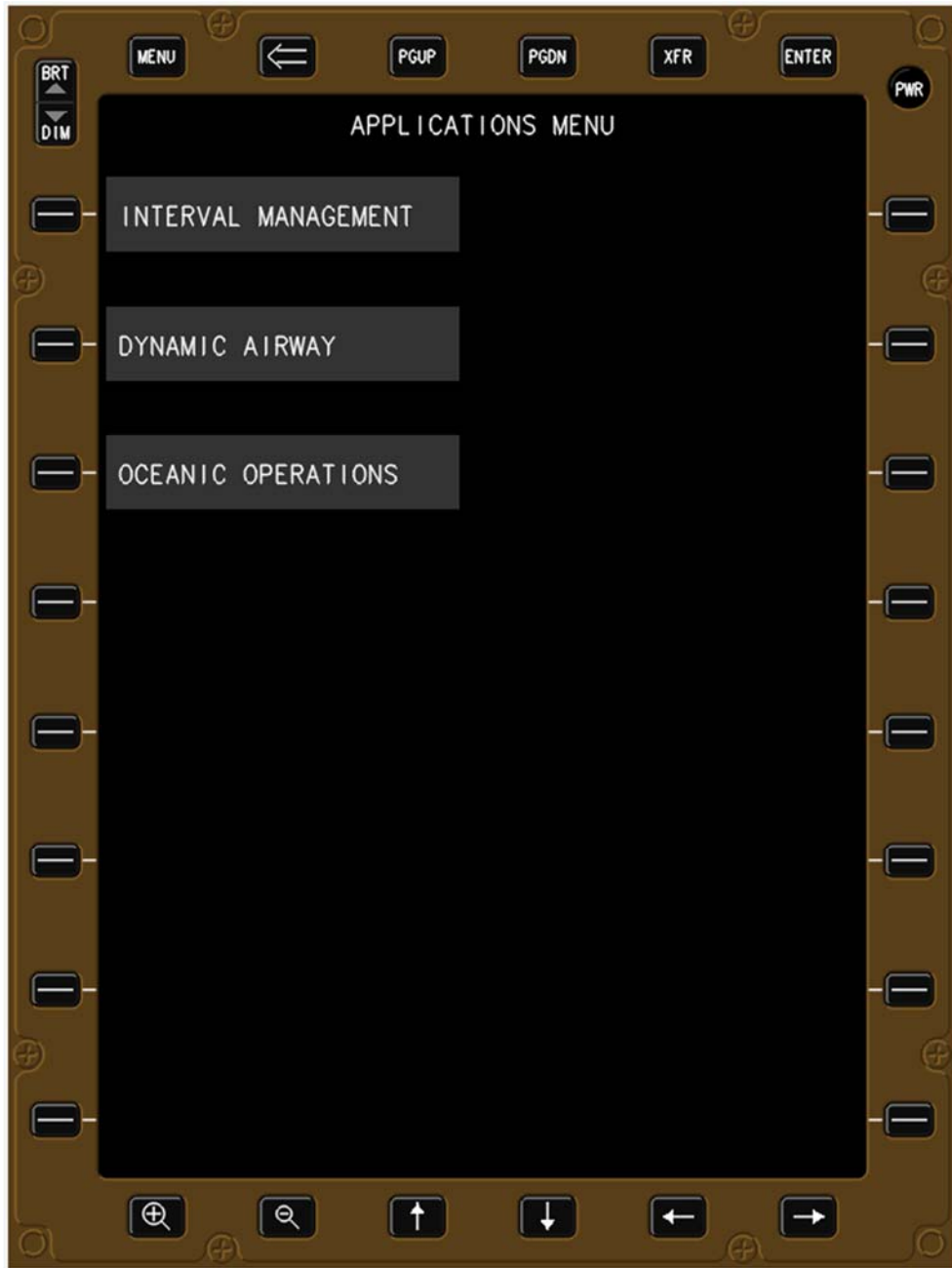


Figure 22. EFB Applications Menu page.

6.2 Ownship and Wind Data

Pressing the OWNSHIP AND WINDS bezel button or soft-key (L1) on the IM Home page (Figure 23) causes the OWNSHIP AND WIND ENTRY page to be displayed (Figure 24). The flight crew enter the Ownship information as soon as feasible (typically prior to receiving an IM clearance from ATC), then enter the IM clearance information after it has been issued by ATC.

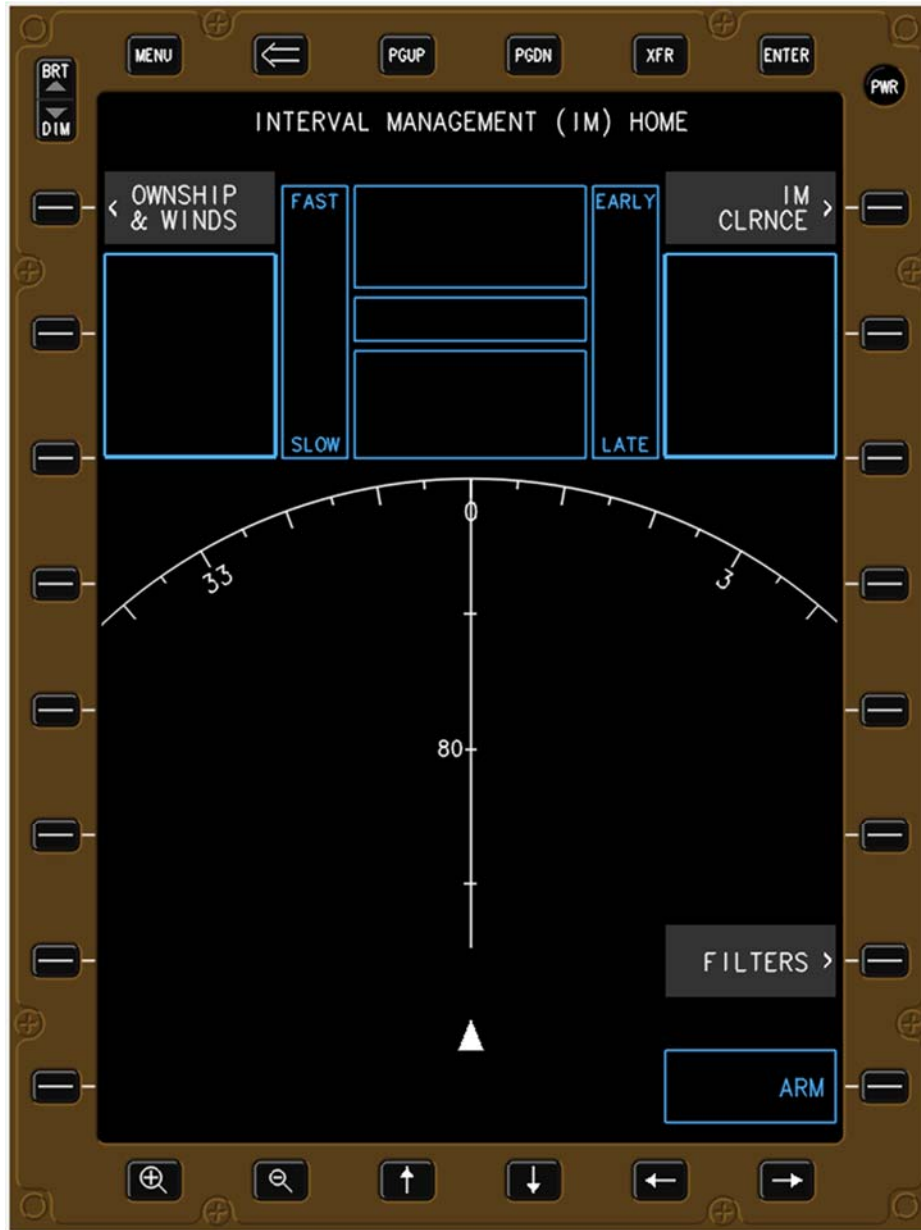


Figure 23. IM Home page with no data entered.

6.2.1 Ownship and Wind Entry Page

Mandatory entries are indicated by boxes (e.g., four characters must be entered for the destination airfield), and non-mandatory entries are indicated by dashes (e.g., forecast wind).

Pressing the DESTINATION AIRPORT bezel button or soft-key (L1) causes that data field to be highlighted in green, and causes the keypad to be displayed as well (Figure 25).



Figure 24. EFB Ownship and Wind Entry page.

6.2.2 Destination Airport

When a data field is active (indicated by the green hue and underscore cursor), any value touched on the keypad is entered into that field. In this example, the flight crew will select the four letter identifier of their destination airport, causing the display to change to Figure 26.

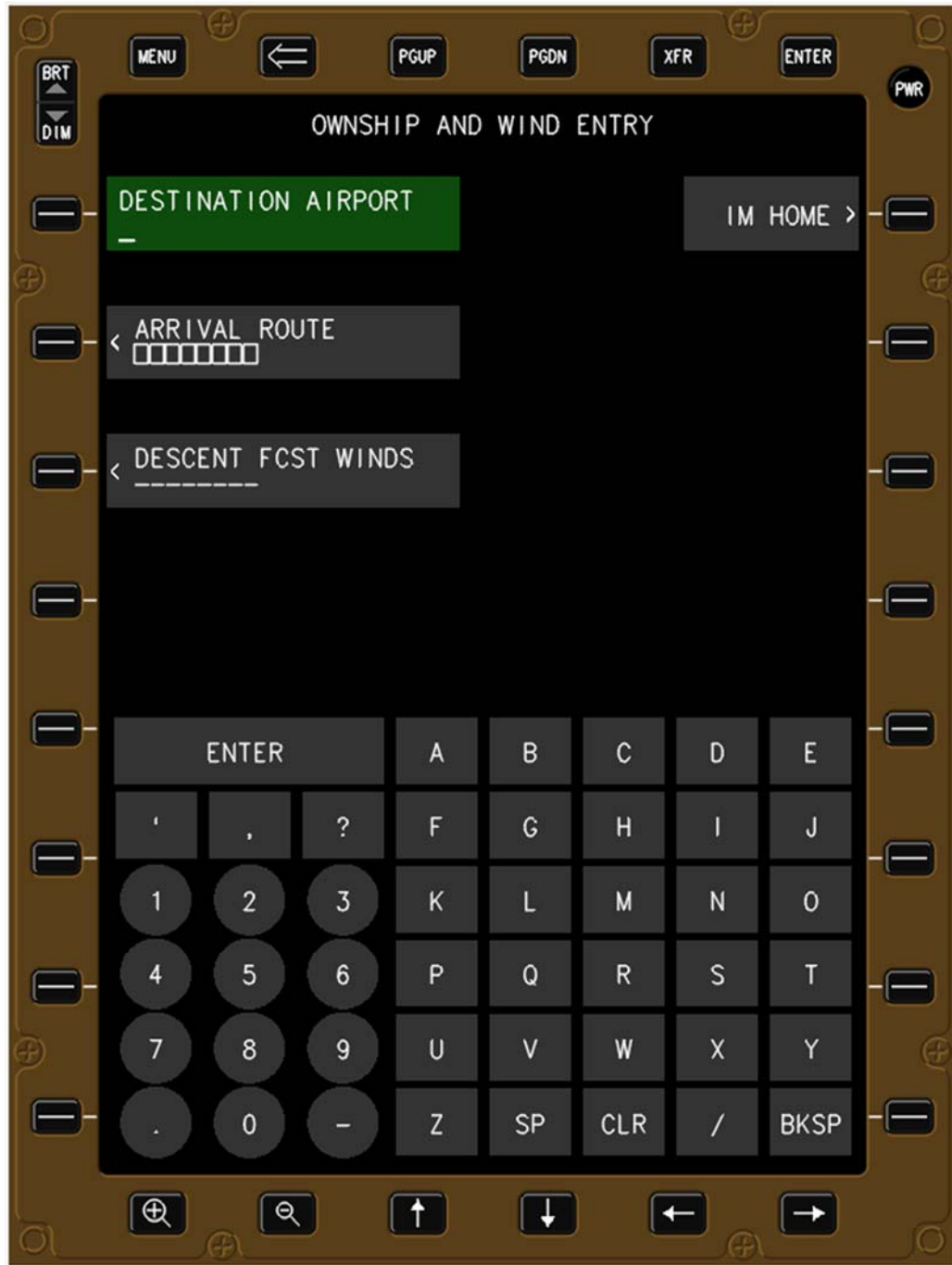


Figure 25. Airport data field selected.

Once the four letters have been typed into the data field, the flight crew may either 1) press the ENTER soft-key at the left-middle of the EFB (in which case no data field is active, shown in Figure 27), or 2) may press the ARRIVAL ROUTE bezel button or soft-key to activate that sub-page (Figure 28).

The flight crew must enter the destination airport prior to entering the arrival route information. Selecting the arrival data field prior to entering the destination airport results in no routes shown.

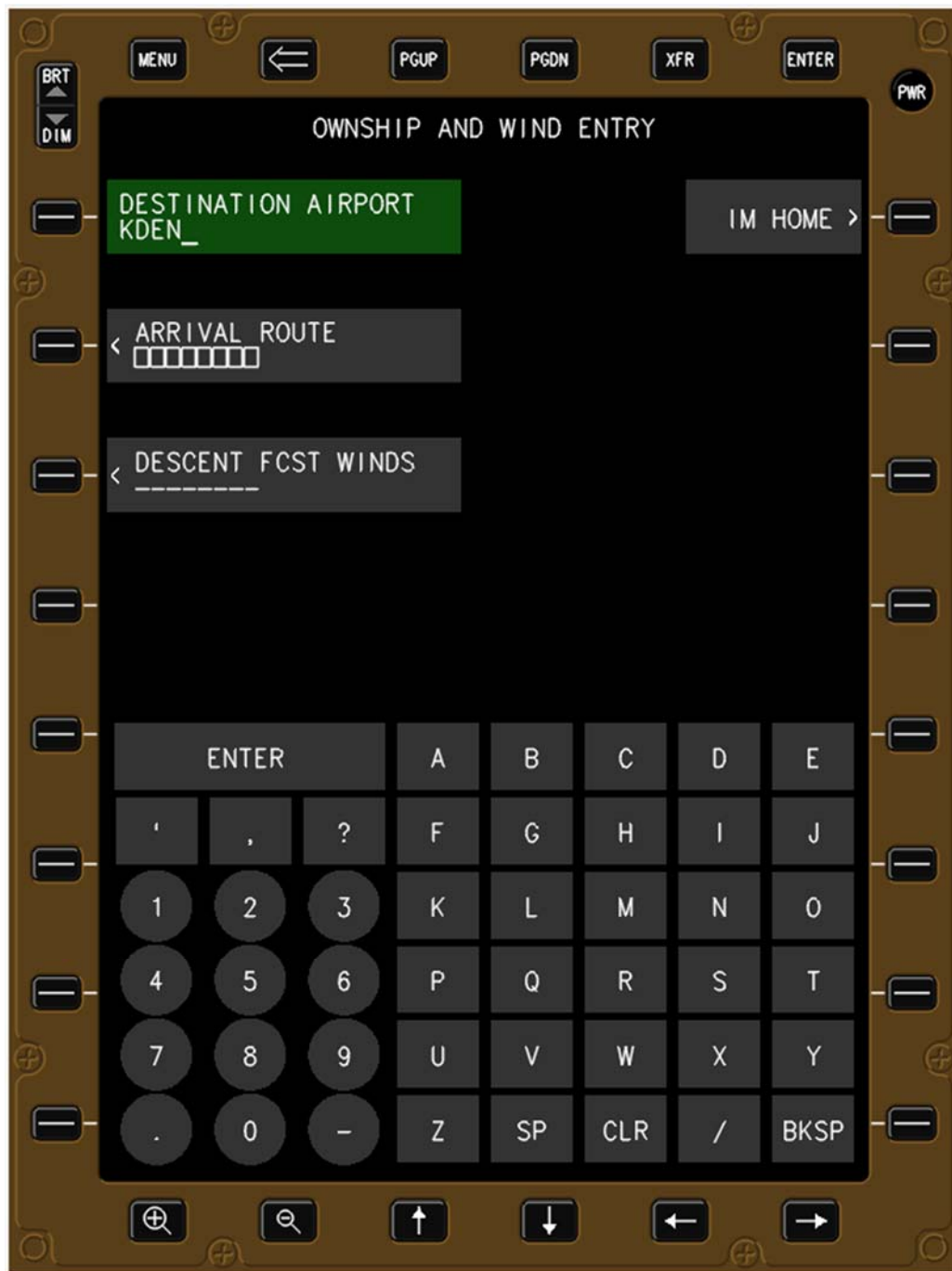


Figure 26. Data typed into airport data field.

If the flight crew elects to press the ENTER button, the EFB will display Figure 27. From this page, the flight crew must press the ARRIVAL ROUTE bezel button or soft-key (L2) to cause the ARRIVAL ROUTE sub-page to be displayed (Figure 28).

To minimize the likelihood of data entry error by the flight crew, the arrival route information is entered by the crew using a selectable list of options (not feasible for airport and forecast winds).



Figure 27. Ownship page after entering destination airport.

6.2.3 Ownship Arrival Route Sub-Page

The OWNSHIP ARRIVAL ROUTE sub-page displays all the arrival and approach procedures to the destination airport. The format is structured similar to a flight management system format, and displays the page number in the top-right. If the arrival is selected first, only those approaches that connect to it will be displayed (Figure 29). If the approach is selected first, only those arrivals that connect to that approach will be displayed (no Figure shown for this case).



Figure 28. Ownship Arrival Route sub-page.

Pressing the appropriate arrival procedure 1) causes that arrival to be highlighted in green, 2) removes the remaining arrival procedures, 3) displays the possible transitions to that arrival, and 4) removes any approach not connected to that arrival procedure (Figure 29). The page number display in the upper-right is updated if appropriate. Note that a page number is displayed here even if only one page is necessary.

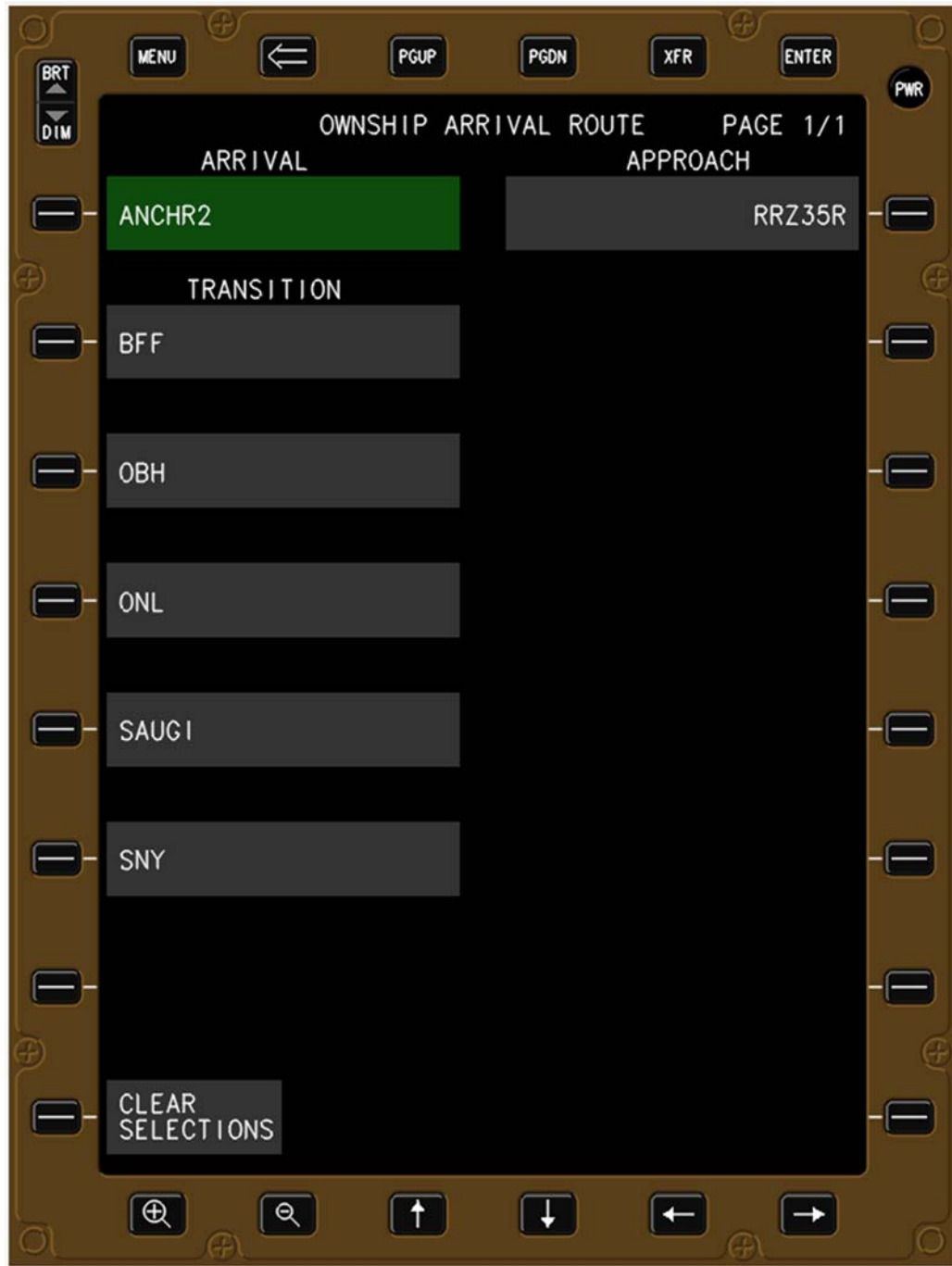


Figure 29. Ownship arrival procedure selected.

The flight crew selects the appropriate transition to the previously selected arrival procedure, causing it to be highlighted in green (Figure 30).



Figure 30. Ownship arrival transition selected.

The flight crew selects the appropriate instrument approach procedure, which highlights the selection in green (Figure 31). For the IMAC experiment using the KDEN airspace and instrument procedures, each arrival procedure connects to only one approach procedure, which is atypical of most airports. Pressing the OWNERSHIP & WINDS bezel button or soft-key (R8) returns the EFB to that page and enters the data into the ownship arrival route data field (Figure 32).



Figure 31. Ownship arrival and approach selected.

The airport and arrival route have been entered (indicated by text on the second line of each data field), and no data field is active (no green). The forecast (FCST) descent and surface (SFC) winds are highly desired but not required to initiate an IM operation, therefore the flight crew may press the IM HOME bezel button or soft-key (R1) and return to that page (Figure 40). Normally the flight crew will enter the forecast winds, which is accomplished by pressing the DESCENT FCST WINDS bezel button or soft-key (L3), causing that sub-page to appear (Figure 34).



Figure 32. Destination airport and Ownship route entered.

6.2.4 Descent Forecast Winds Sub-Page

It is expected that the flight crew will receive the descent forecast winds via electronic ACARS message, and that this message will be used to enter the forecast winds into the aircraft's FMS and the EFB. Figure 33 displays the descent forecast wind page prior to the ACARS message being received.

The keypad is not shown since no data field is active.



Figure 33. Descent Forecast Wind sub-page prior to receiving ACARS message.

Once the descent forecast wind is received via ACARS, the bezel button and soft-key (R6) to auto-load the wind direction and speed at four different altitudes is shown (Figure 34). The time stamp of the message is shown on the second line of the data field.



Figure 34. Descent Forecast Wind sub-page after receiving ACARS message.

Pressing the LOAD DEC FCST WIND bezel button or soft-key causes 1) the data from the ACARS message to be auto-loaded into the appropriate data fields, 2) the time of the message to be displayed in the page title, 3) activates the next data field (surface wind direction), and 4) causes the keypad to appear for manual data entry (Figure 35).



Figure 35. Wind sub-page with descent forecast auto-loaded via ACARS.

The flight crew enters the wind direction (one to three digits, from 1 to 360), then either selects the next desired data field or presses the ENTER button (Figure 36). Pressing the ENTER soft-key (just above the keypad) causes the value to be entered in that data field and activates the next data field (surface speed in this example) as shown in Figure 37. The ENTER button sequences the active data field and cursor from left to right, top to bottom.



Figure 36. Wind direction field selected with data present but not entered.

Figure 37 shows the flight crew has entered the forecast surface wind direction, and is ready now to enter the forecast surface wind speed. When the ENTER soft-key is pressed to enter data into the bottom right cell (surface temperature), the keypad is removed (Figure 38).



Figure 37. Wind speed field selected.

After the flight crew enter the wind and temperature information, pressing the OWNERSHIP & WINDS bezel button or soft-key (R7) returns the display to that page (Figure 39). For the illustration below where the forecast descent winds are not entered, a message would be displayed on the EFB stating that no descent winds were entered (Table 6).



Figure 38. All surface wind information entered.

The second line of the DESCENT FORECAST WINDS bezel button soft-key (L3) will contain either 1) dashes indicating a non-mandatory entry has not been accomplished, 2) “ACARS 0002z” indicating that an ACARS message was used to load the descent winds with the time contained in that message, or 3) “MANUAL 1845z” indicating some wind was entered manually and the time it occurred (Figure 39).

Pressing the IM HOME bezel button or soft-key (R1) causes the display to return to the IM Home page, with the airport and route information visible in the left side of the page (Figure 40).



Figure 39. All Ownship and wind information entered.

6.2.5 IM Home Page with Ownship Information Entered

Figure 40 illustrates the IM Home page with the Ownship information entered (airport and route data entry is required, wind entry is highly desired). The three Ownship data elements shown on the IM Home page are 1) the next waypoint from the flight management system, 2) the arrival procedure, and 3) the instrument procedure.

Pressing the BACK arrow button causes the application page (Figure 22) to be shown, pressing the OWNSHIP & WINDS bezel button or soft-key (L1) causes the OWNSHIP AND WIND ENTRY page to be shown (Figure 39), and pressing the IM CLEARANCE bezel button or soft-key (R1) causes the initial IM CLEARANCE ENTRY page to be shown (Figure 41).

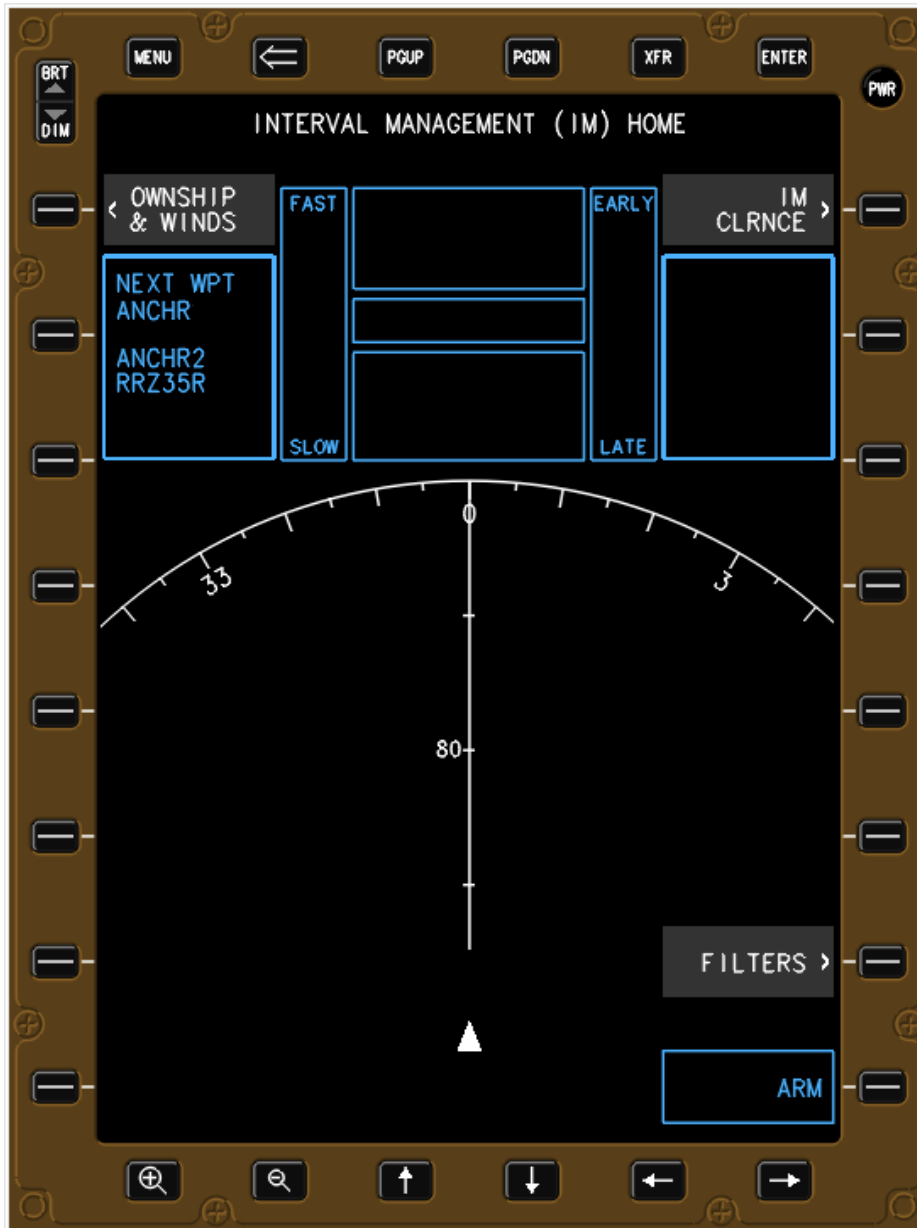


Figure 40. IM Home page with Ownship data entered.

6.2.6 Modifying Ownship Data

Any Ownship data may be modified by pressing the OWNSHIP & WINDS bezel button or soft-key (R1) on the IM Home page to return to the OWNSHIP AND WIND ENTRY page. All three data fields (airport, route, and winds) can be changed using the same procedure that was used for the initial data entry.

Changing the destination airport terminates the IM operation since both the Ownship's and Target's entered route information is no longer valid, and all ownship and IM clearance information should be removed from the IM equipment (not implemented for IMAC).

Changing the Ownship's arrival and instrument procedure while maintaining the same runway causes the IM software to revert to an ARMED state, and the Target information is not modified.

Changing the Ownship's runway causes the IM software to revert to an ARMED state, and the Target's information is updated if known (for example, the CAPTURE and MAINTAIN clearance types), or must be entered (the CROSS clearance type).

Changing any of the wind or temperature values causes a new trajectory and time to be calculated, but does not cause a change to the IM state.

6.3 IM Clearance Entry Page

This section uses the CROSS clearance type as the example since it has the most data elements and is the most complex of the clearances implemented for the IMAC experiment.

To minimize the probability of data entry error by the flight crew, the IM clearance information is entered by the crew using a selectable list of options (not feasible for the assigned spacing goal or if the Target aircraft is not within ADS-B range of the IM aircraft).

6.3.1 IM Clearance Initialization Page

Figure 41 illustrates the initial IM CLEARANCE ENTRY page, displayed when no data has been entered. Pressing the CLEARANCE TYPE bezel button or soft-key (L1) causes the clearance type sub-page to be displayed (Figure 42).

The R1 soft-key displays IM HOME, which indicates that not all of the IM clearance information has been entered to enable the IM equipment to transition from the OFF to the ARMED state. Once the data has been entered, the text will change to ARM IM HOME (see Figure 56).



Figure 41. IM Clearance Entry initial page.

6.3.2 IM Clearance Type Sub-Page

The clearance types are listed in alphabetical order from top to bottom, and any type that has been implemented is shown in grey and those not implemented are shown in cyan (not selectable). Pressing the appropriate bezel button or soft-key (L2 for CROSS clearance in this example) causes a page to appear that displays only those data elements relative to that clearance type (Figure 43).

The information required to be entered by the flight crew by clearance type was shown previously in section 5.1.3 (CAPTURE in Figure 12, CROSS in Figure 13, and MAINTAIN in Figure 14).

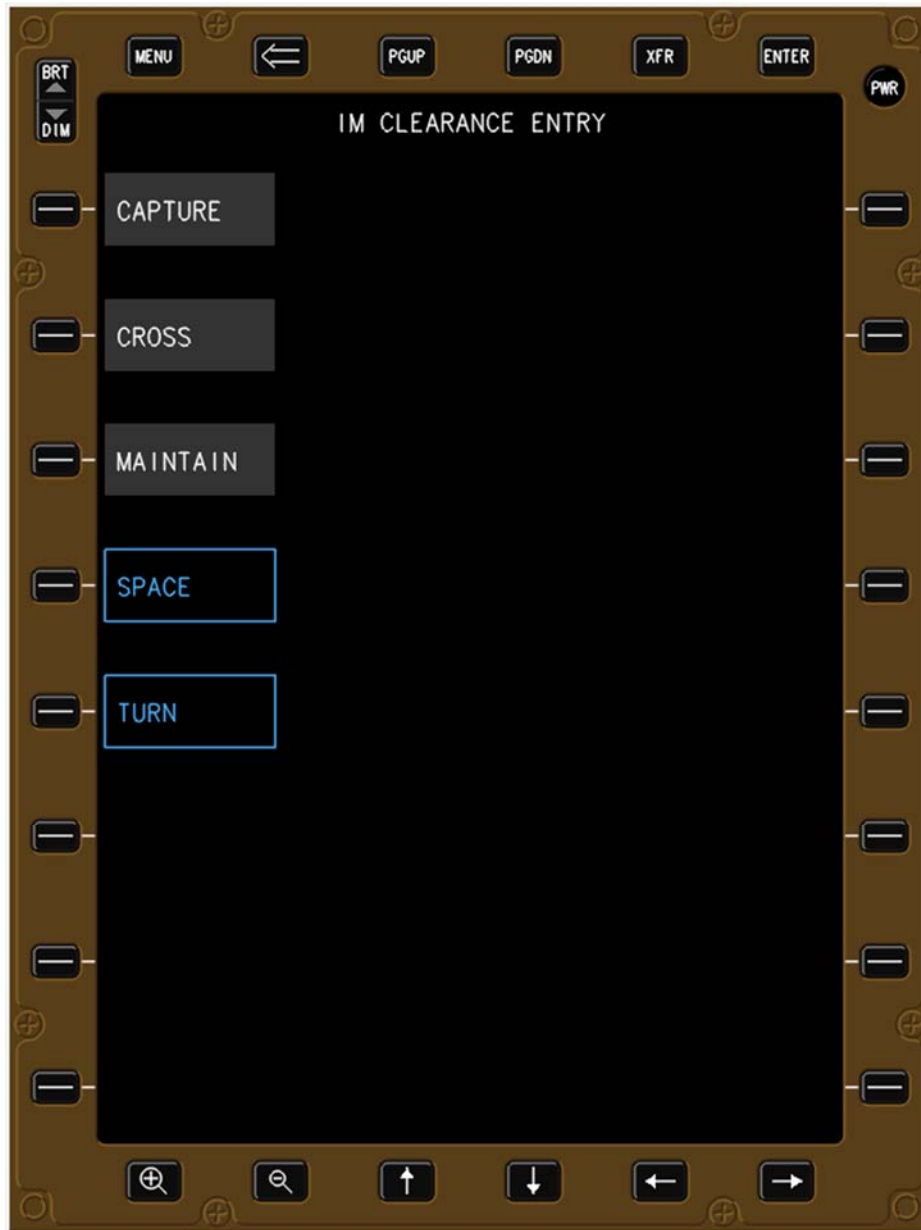


Figure 42. IM clearance type sub-page.

6.3.3 IM CROSS Clearance Entry Page

Figure 43 illustrates the required data elements for the IM CROSS clearance type, shown top to bottom in the order that the controller will issue the clearance, with the Achieve-By and Termination Points auto-populated with the Ownship final approach fix. Pressing the bezel button or soft-key for the corresponding data element triggers a sub-page for that information to be entered.

Pressing the ACHIEVE BY bezel button or soft-key (L2) causes the ACHIEVE BY POINT sub-page to appear (Figure 44). If the controller issued the default value (final approach fix) as the Achieve-By Point, then the flight crew would skip selecting the ACHIEVE BY data field and proceed to the SPACING GOAL data field (L3 shown in Figure 46).



Figure 43. IM CROSS clearance home page.

6.3.4 Achieve-By Point Sub-Page

The Achieve-By Point sub-page lists waypoints in alphabetical order that are common to the Ownship and Target routes. Initially the waypoints were listed in order of closest to the farthest; however, it was postulated that an alphabetical listing might be easier to navigate when the flight crew is not familiar with the arrival or approach procedure waypoints.

Pressing the appropriate Achieve-By Point bezel button or soft-key automatically causes the IM clearance page to reappear with that waypoint entered in the ACHIEVE BY data field (Figure 45).

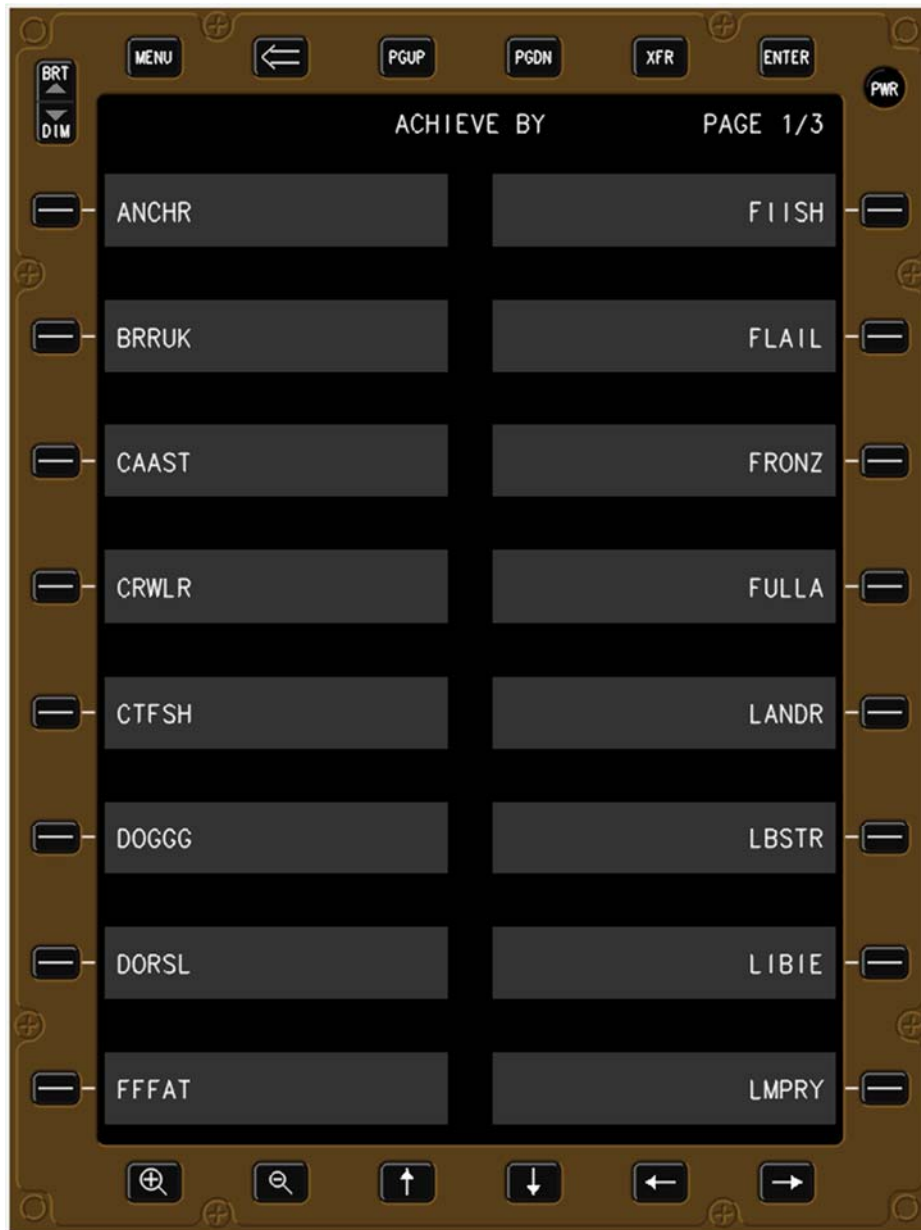


Figure 44. The Achieve-By Point sub-page.

6.3.5 Spacing Goal Entry

Figure 45 illustrates the IM CROSS clearance entry page with the Achieve-By and Planned Termination Points auto-populated based on the Ownship's final approach fix specified as part of the arrival route (occurs also in the CAPTURE and MAINTAIN clearance types). The flight crew selects the next field without data (the spacing goal) and presses the SPACING GOAL bezel button or soft-key (L3) to activate that data field, causing a keypad to appear (Figure 46).

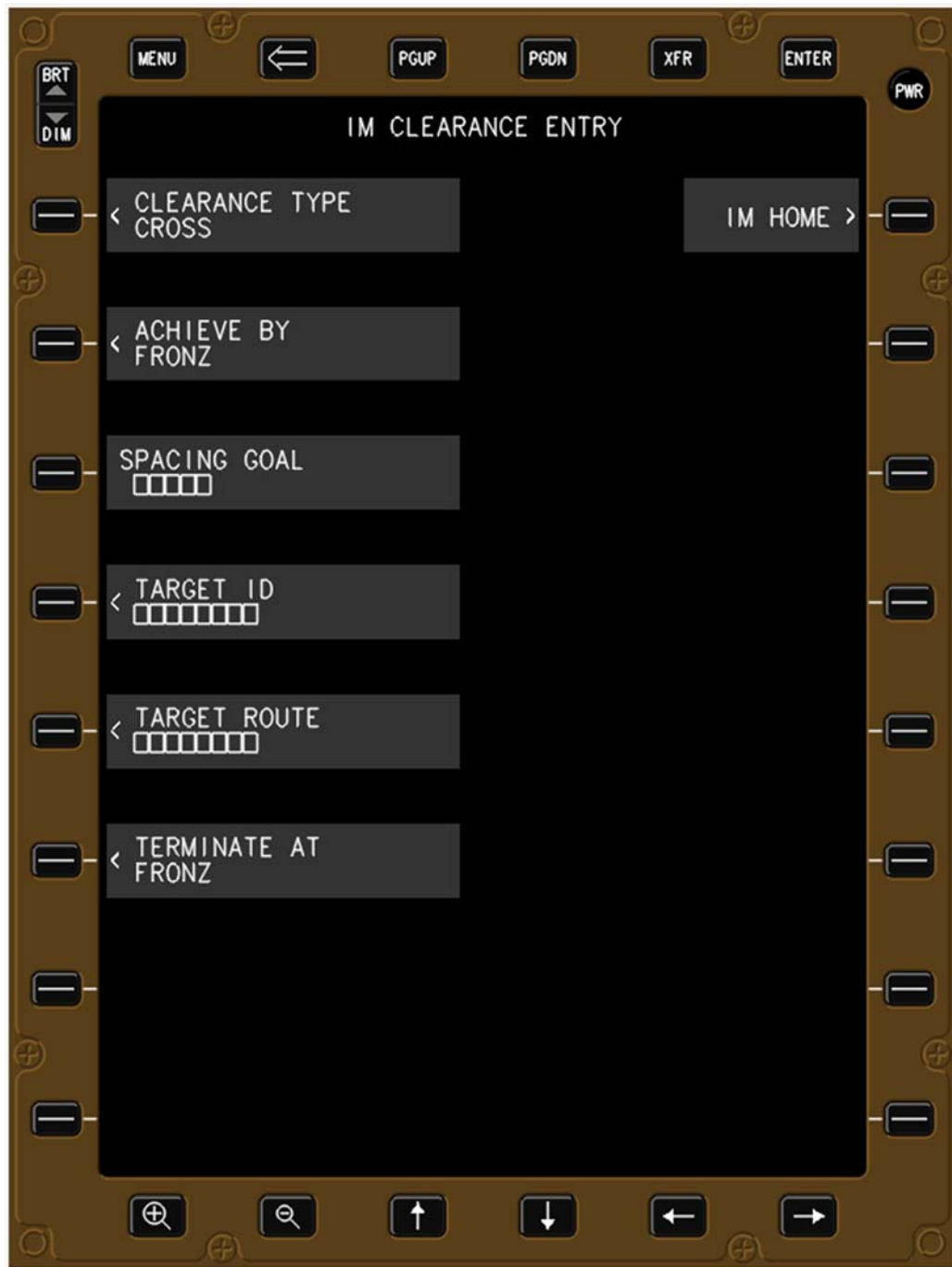


Figure 45. IM CROSS clearance entry page.

The SPACING GOAL data field in Figure 46 is active (indicated by the green color), and a cursor replaces the mandatory entries (signified by boxes) in the second line of that data field.

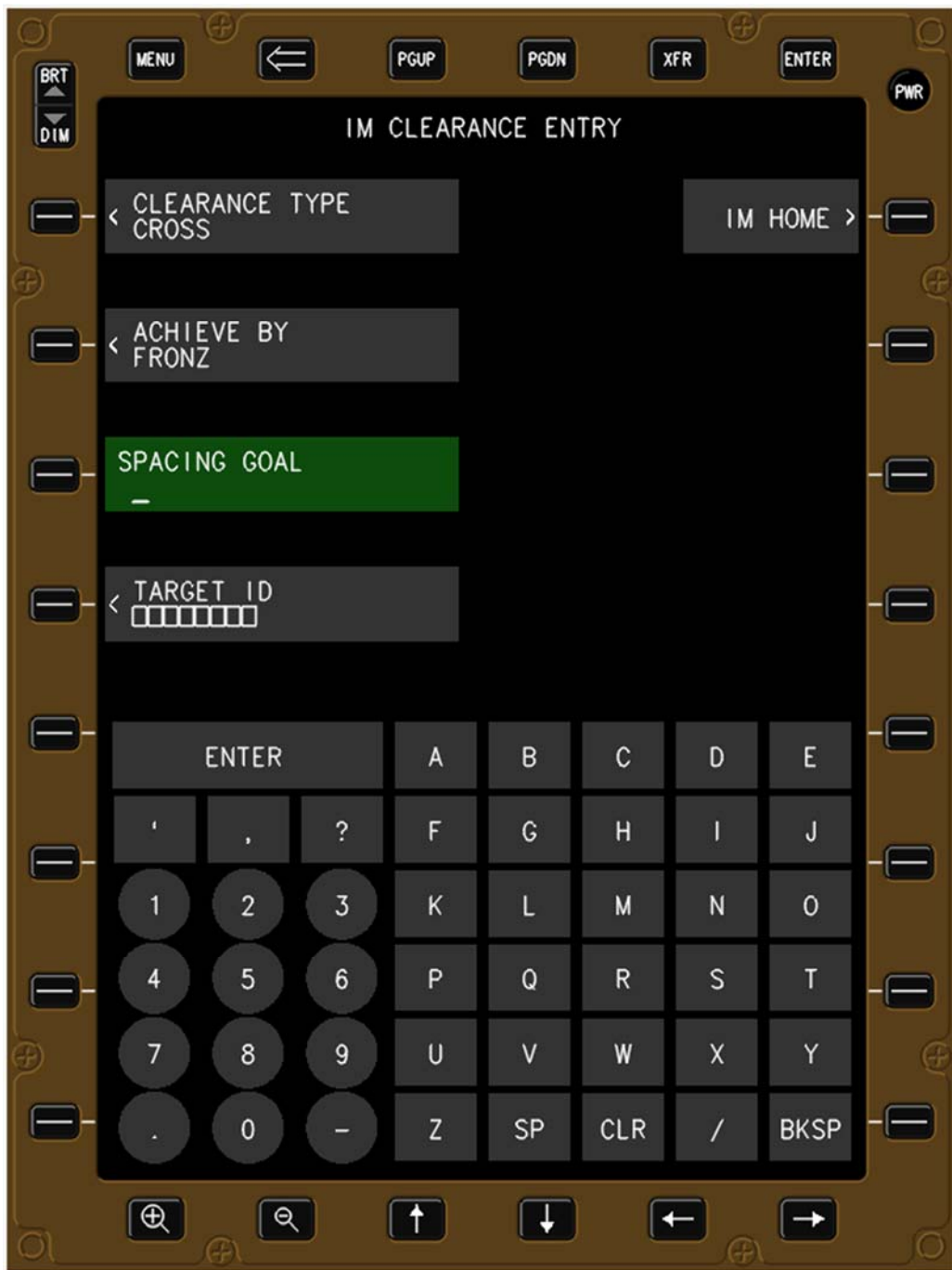


Figure 46. The Spacing Goal data field selected.

Values entered in the SPACING GOAL data field between 2.0 to 20.0 are treated as nautical miles (in tenths of a mile increments), and values between 60 and 240 are treated as seconds (in integer increments). Entering values outside of those ranges causes a message to appear stating the entry is out of range, and what the valid ranges are for both distance and time.

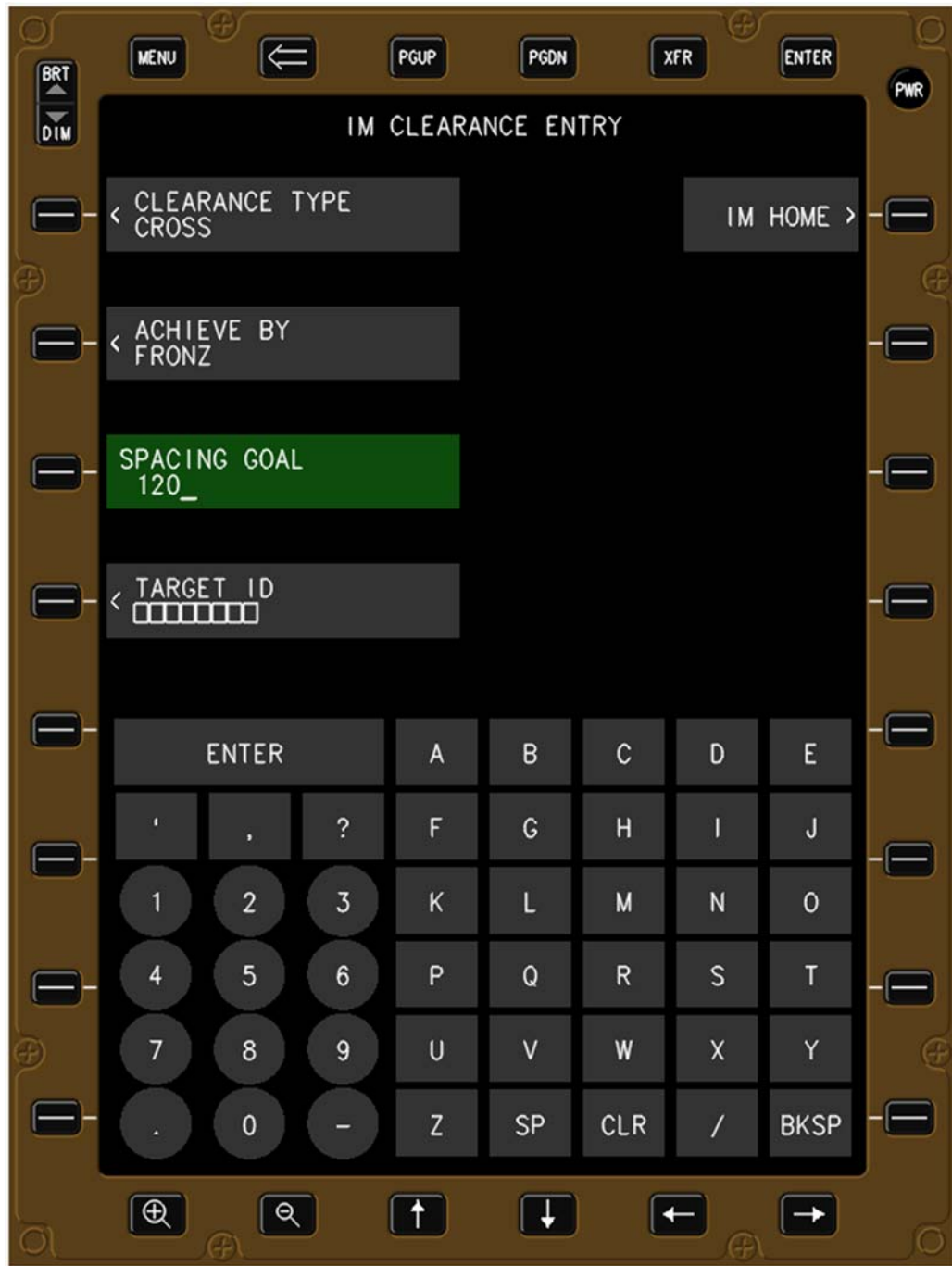


Figure 47. Value typed into the Spacing Goal data field.

Pressing the ENTER soft-key enters the value into the IM CROSS clearance entry page and deactivates the SPACING GOAL data field (Figure 48) and removes the keypad.

NOTE: If the BACK arrow button is used prior to pressing ENTER (Figure 47), that value will not be retained when the EFB is returned to the IM CROSS clearance entry page nor be shown on the IM Home page. If the BACK arrow button is used after pressing ENTER (Figure 48), the data is retained when returning to this page and is shown on the IM Home page as well. This functionality of the BACK button applies to all buttons, not just the spacing goal button.

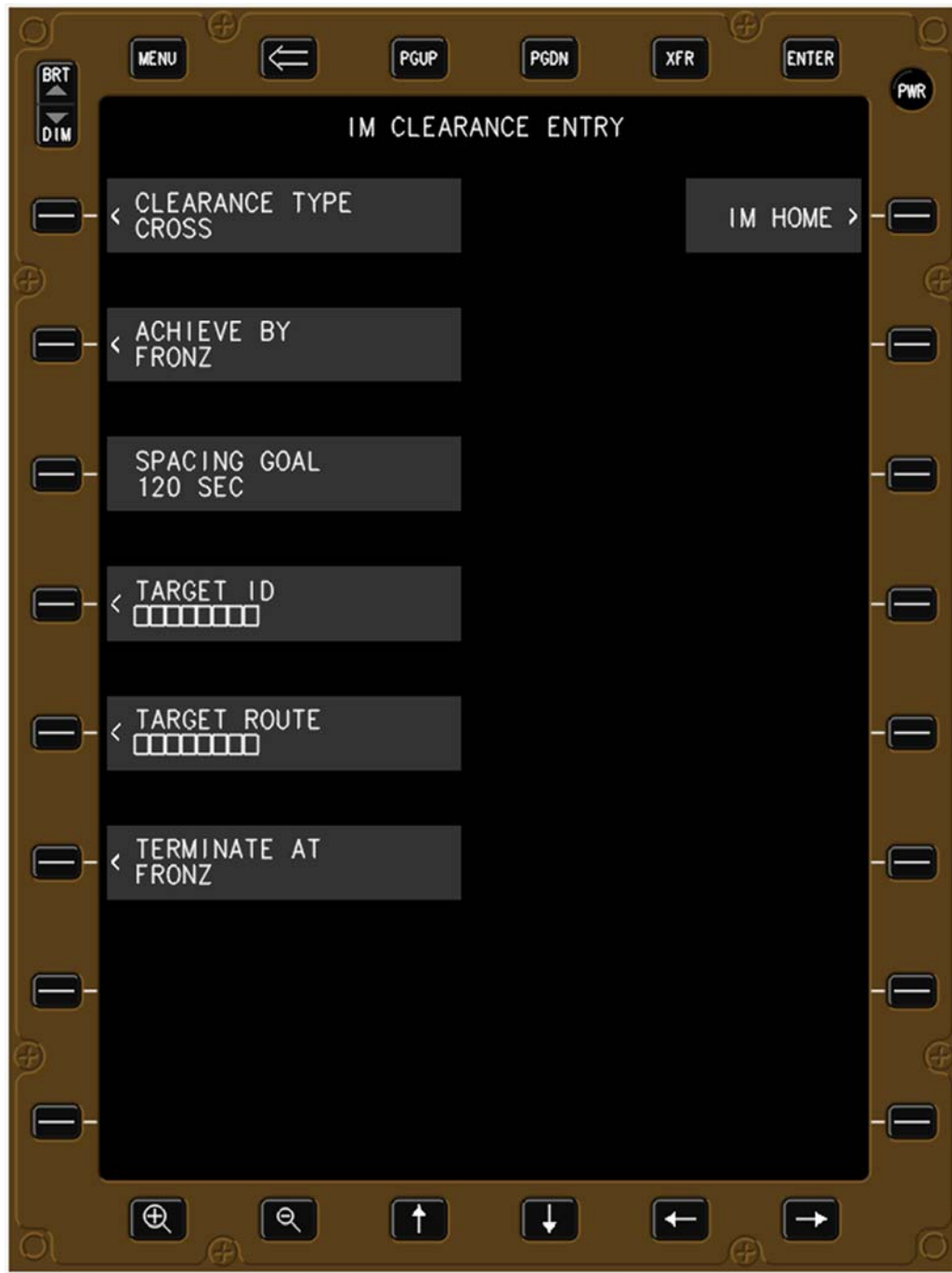


Figure 48. IM clearance entry page with Spacing Goal entered.

6.3.6 Select Target Aircraft Sub-Page

Pressing the Target ID bezel button or soft-key (L4 in Figure 48) causes the SELECT TARGET AIRCRAFT sub-page to appear. Shown in alphabetical order from top to bottom, left to right, are all the callsigns of aircraft for which the IM equipment has valid ADS-B data. Pressing the bezel button or soft-key of the assigned Traffic callsign causes that field to be activated (Figure 50).

The MANUAL ID ENTRY bezel button and soft-key (R7 in Figure 49) also allows the flight crew to manually enter the assigned Target aircraft callsign if the aircraft is not yet within ADS-B range of the Ownship. Pressing it causes the IM Cross clearance entry page to reappear with the Target ID button active (green with cursor) and a keypad for manual entry below it (Figure 51).

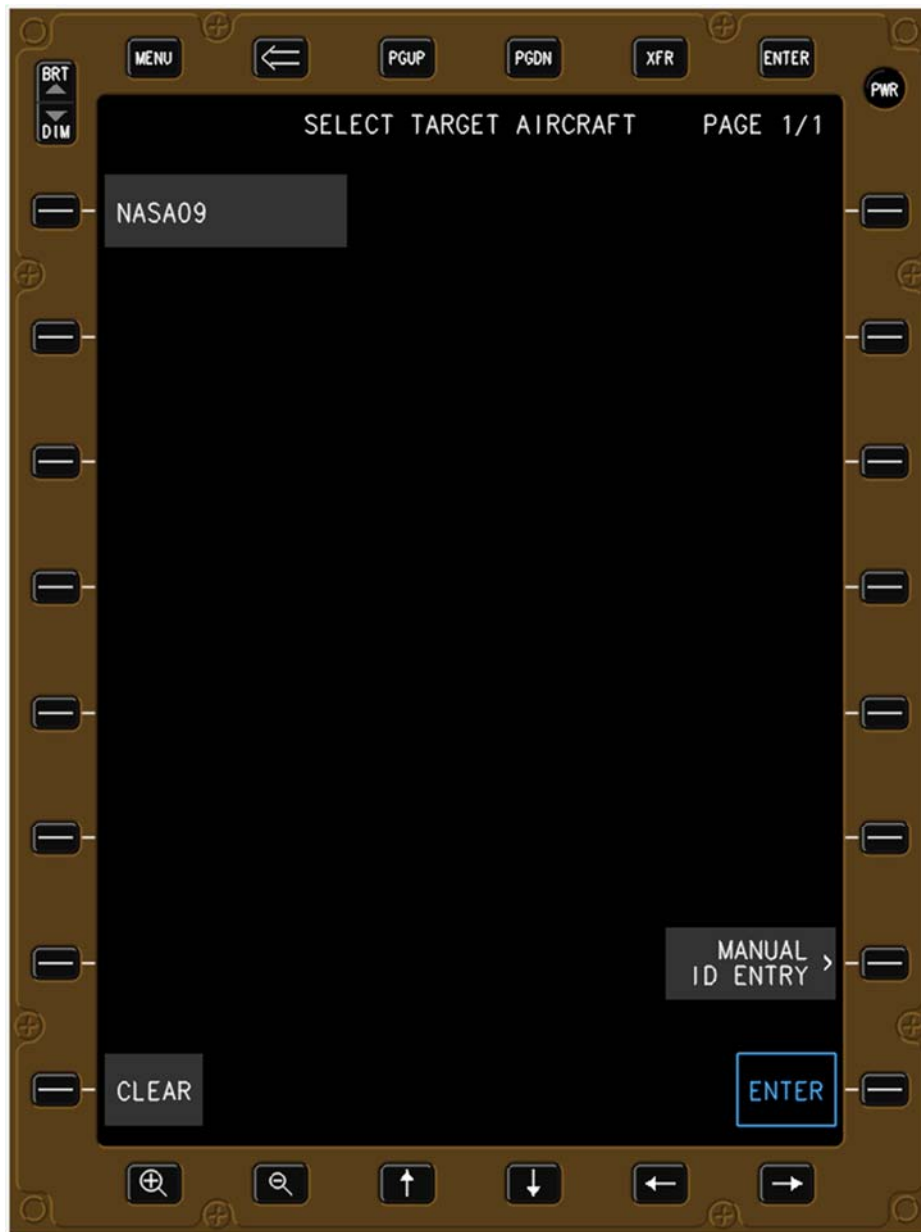


Figure 49. Select Target Aircraft sub-page.

Figure 50 illustrates that NASA09 has been selected by the flight crew (data field is green). Pressing the ENTER bezel button or soft-key (R8) will cause the display to return to the respective IM clearance entry page with that callsign entered into the Target ID data field (Figure 52).

The page count is shown in the upper right (similar to the procedures page) to indicate to the flight crew that the Page Up and Page Down bezel buttons may be required to view all available aircraft.

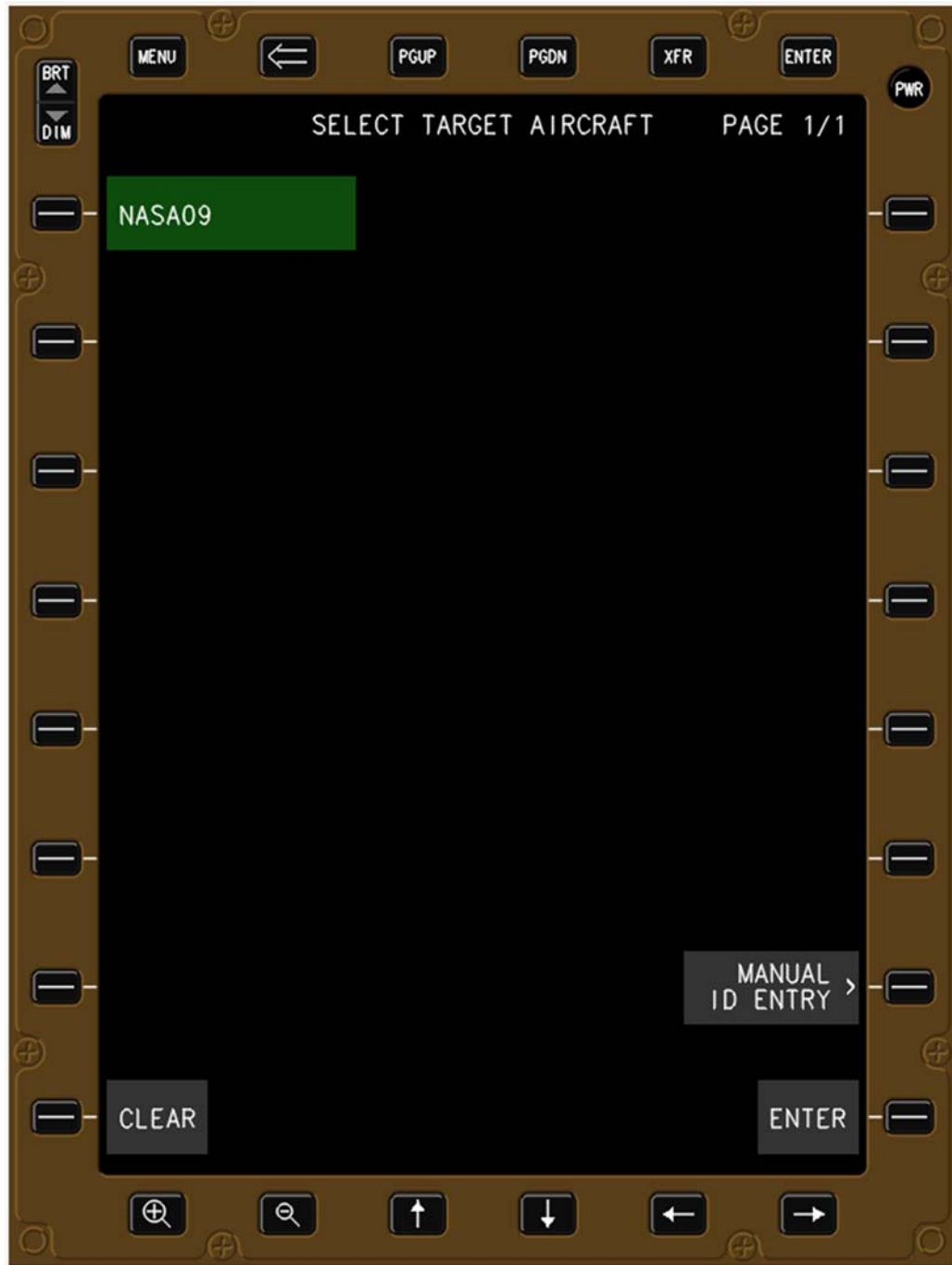


Figure 50. Target selected from list of available traffic.

If the flight crew elects to or must use (for example, when outside of ADS-B range of the Target aircraft) the MANUAL ID ENTRY bezel button or soft-key (R7 in Figure 49), the IM CROSS clearance entry page reappears with the Target ID data field active and the keypad visible at the bottom of the EFB. The flight crew manually enters the Target aircraft's callsign, then presses the ENTER soft-key, causing the data to be entered and the data field deactivated (Figure 52).

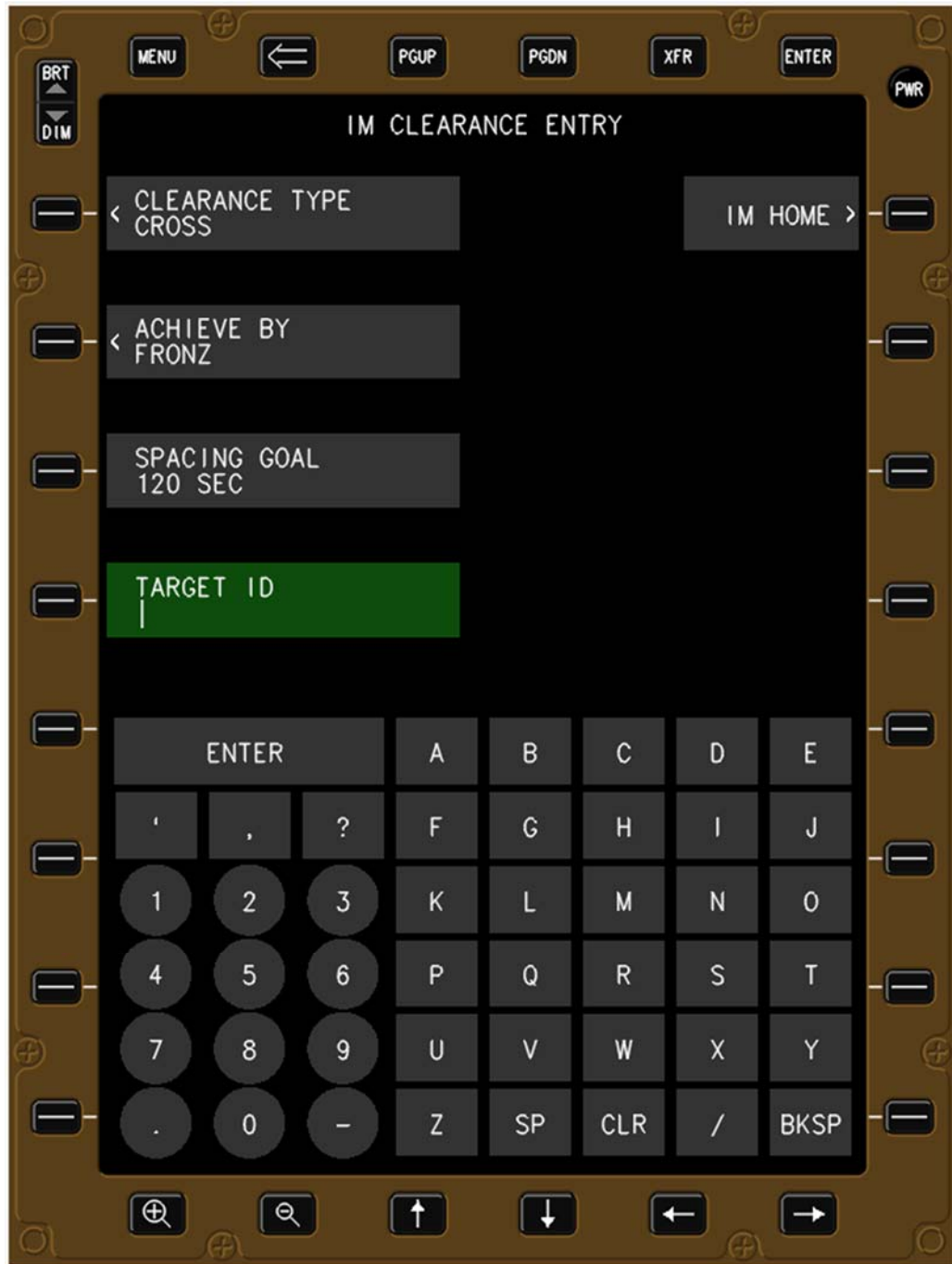


Figure 51. Target entered manually via keypad.

Figure 52 shows the Target aircraft's callsign has been entered into the IM clearance entry page.

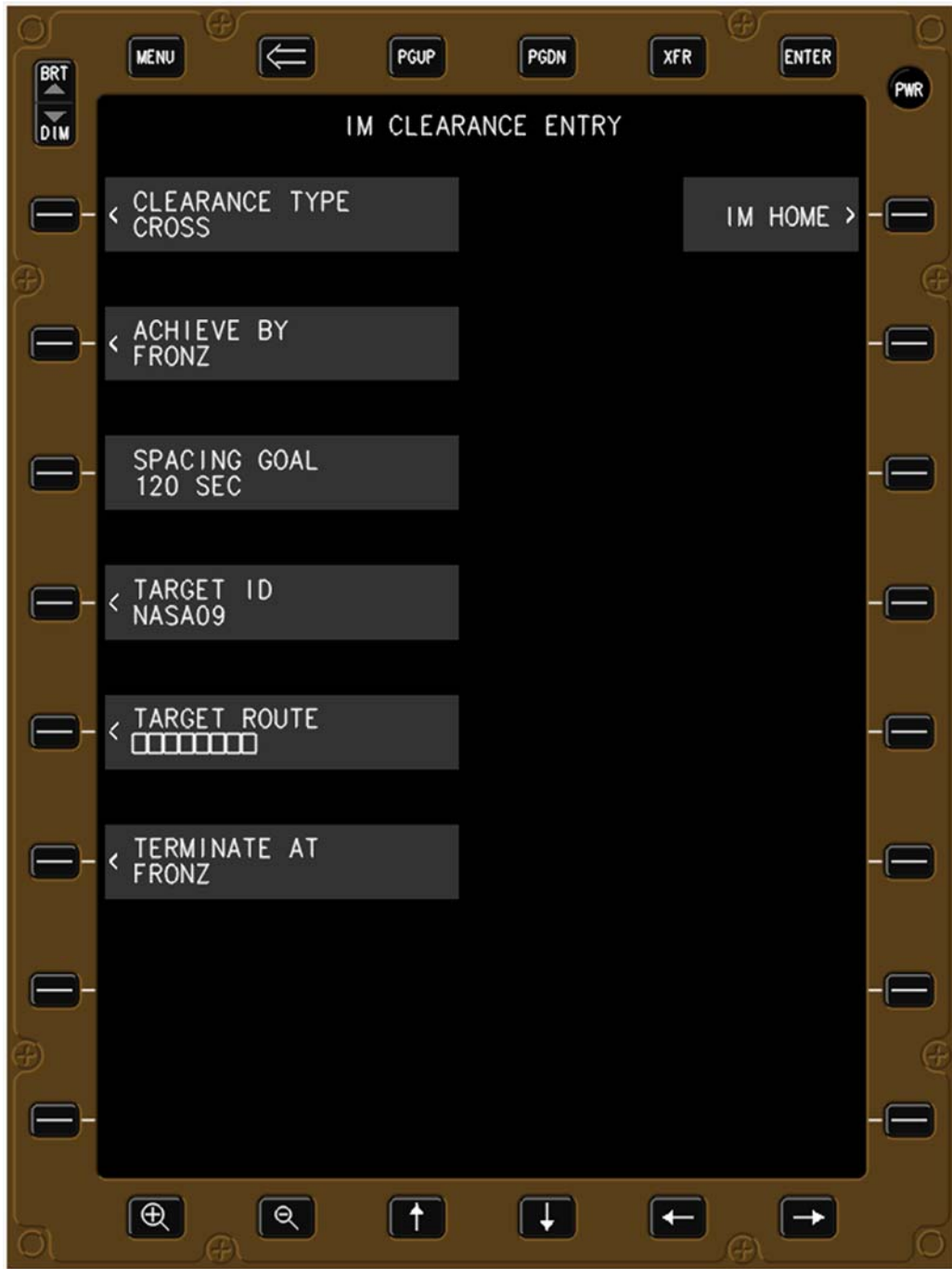


Figure 52. IM CROSS clearance page with Target ID entered.

6.3.7 Target Arrival Route Sub-Page

Pressing the Target Route bezel button or soft-key (L5 in Figure 52) causes the TARGET ARRIVAL ROUTE sub-page to appear (Figure 53). Structured similarly to the OWNSHIP ARRIVAL ROUTE sub-page, the arrivals are shown on the left and the approaches on the right, in alphabetical order from top to bottom. The page count is shown in the upper right to indicate multiple pages may be available.

The final version of this software will only display the sub-set of instrument approaches that are to the same runway as the Ownship aircraft.

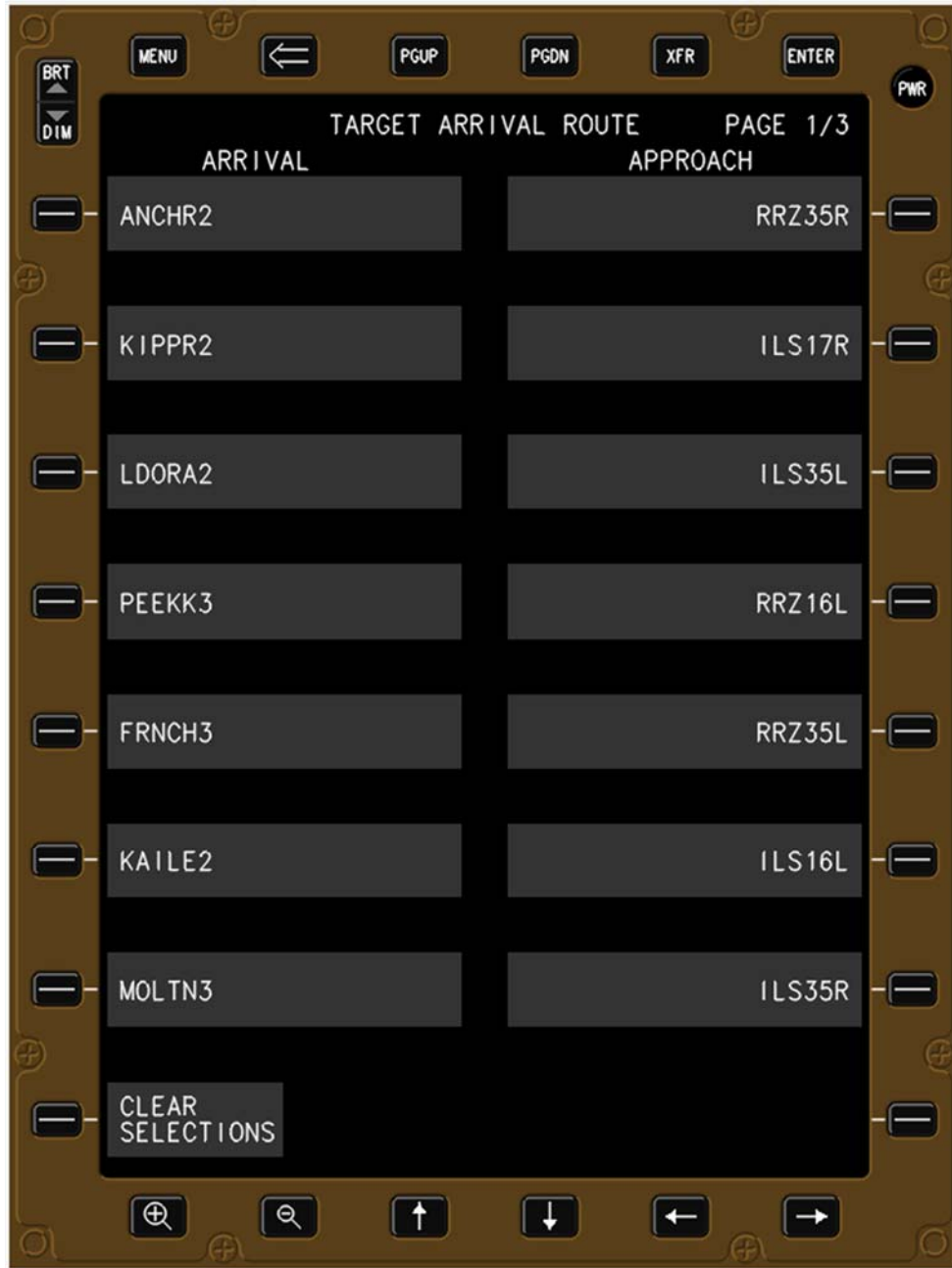


Figure 53. Target Arrival Route sub-page.

The transitions to the beginning of the Target's arrival procedure are not shown as a flight crew selectable option (Figure 54) since in previous ATD-1 research some controllers and pilots found it challenging to use multi-part voice instructions during high-density operations. If data communication between the controller and the flight crew was available, the IM equipment would implement a more robust and sophisticated capability, to include multiple waypoints to connect the arrival and approach. This results in the IM operation commencing at the beginning of the arrival procedure, and not at the transition to the arrival procedure.

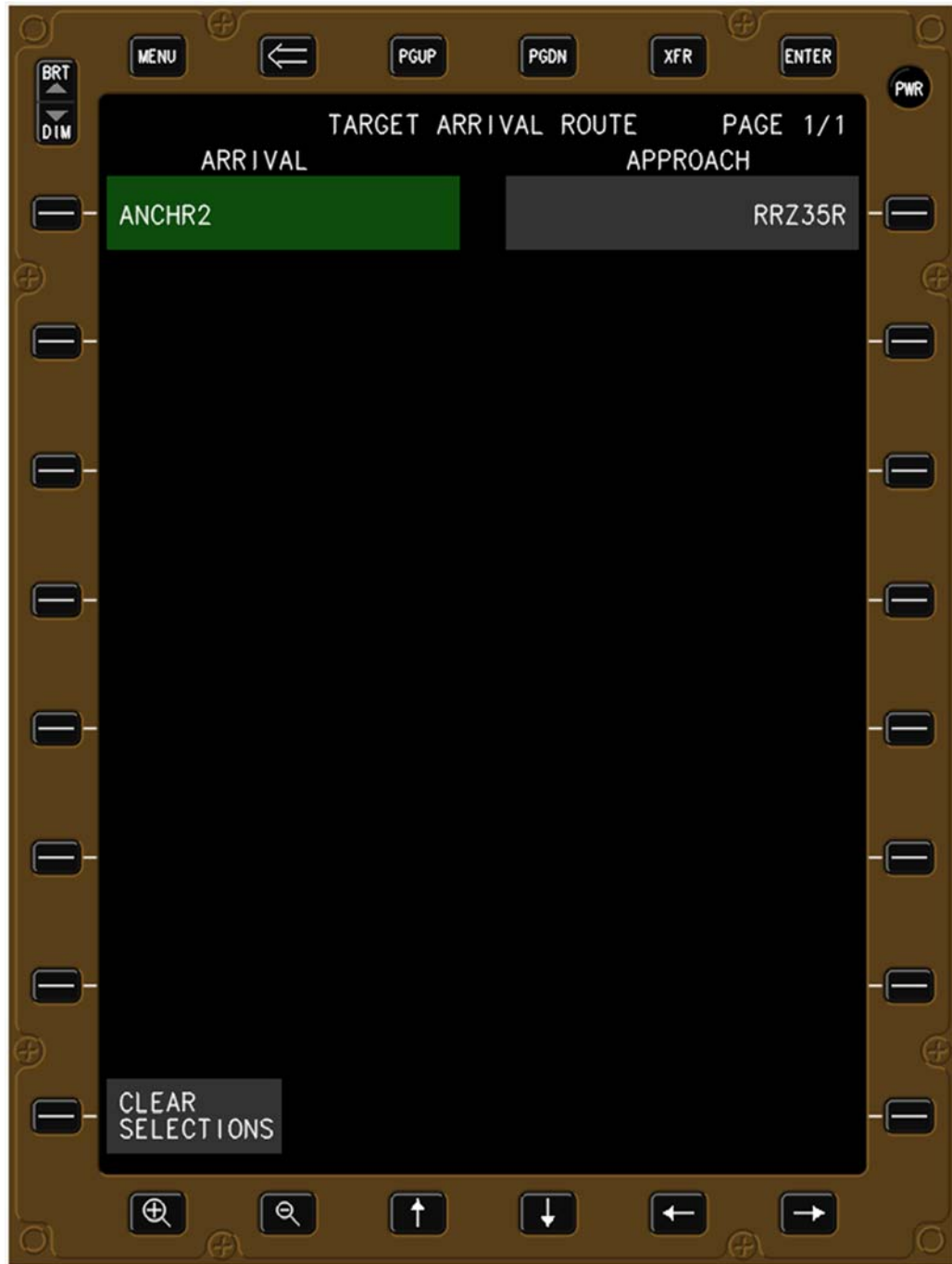


Figure 54. Target arrival procedure selected.

The Target aircraft's approach must be to the same runway as the Ownship's runway, although it does not need to be the identical approach.

After the Target aircraft's arrival and approach procedures have been specified, the flight crew presses the IM CLRNCE bezel button or soft-key (R8), causing the display to return to the IM CROSS clearance entry page (Figure 56).

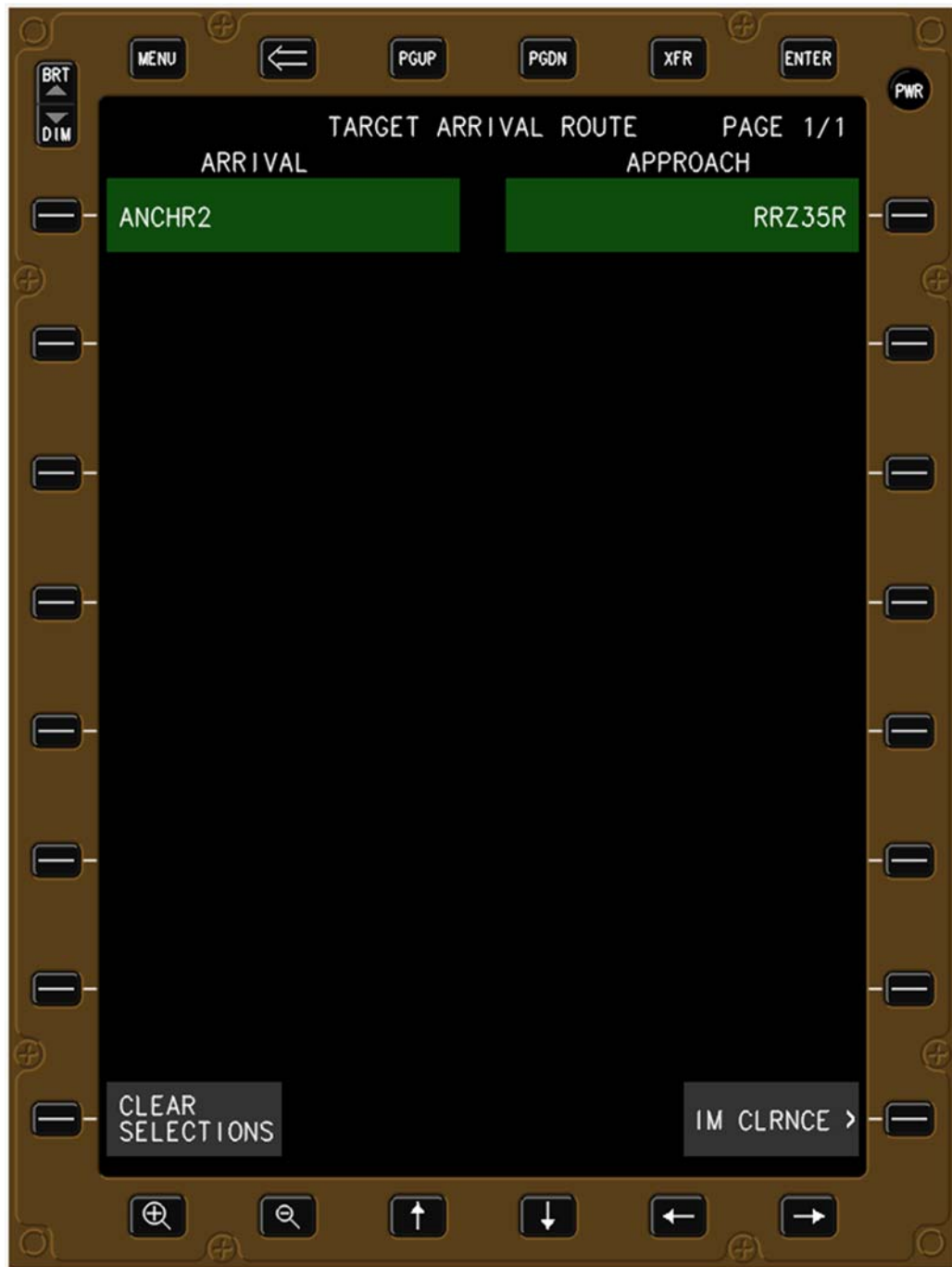


Figure 55. Target arrival and approach procedure selected.

6.3.8 Planned Termination Point

If the controller issued a Planned Termination Point other than the default final approach fix of the Ownship's approach procedure, the flight crew can press the TERMINATE AT bezel button or soft-key (L6) to cause the Terminate At sub-page to appear (Figure 57).

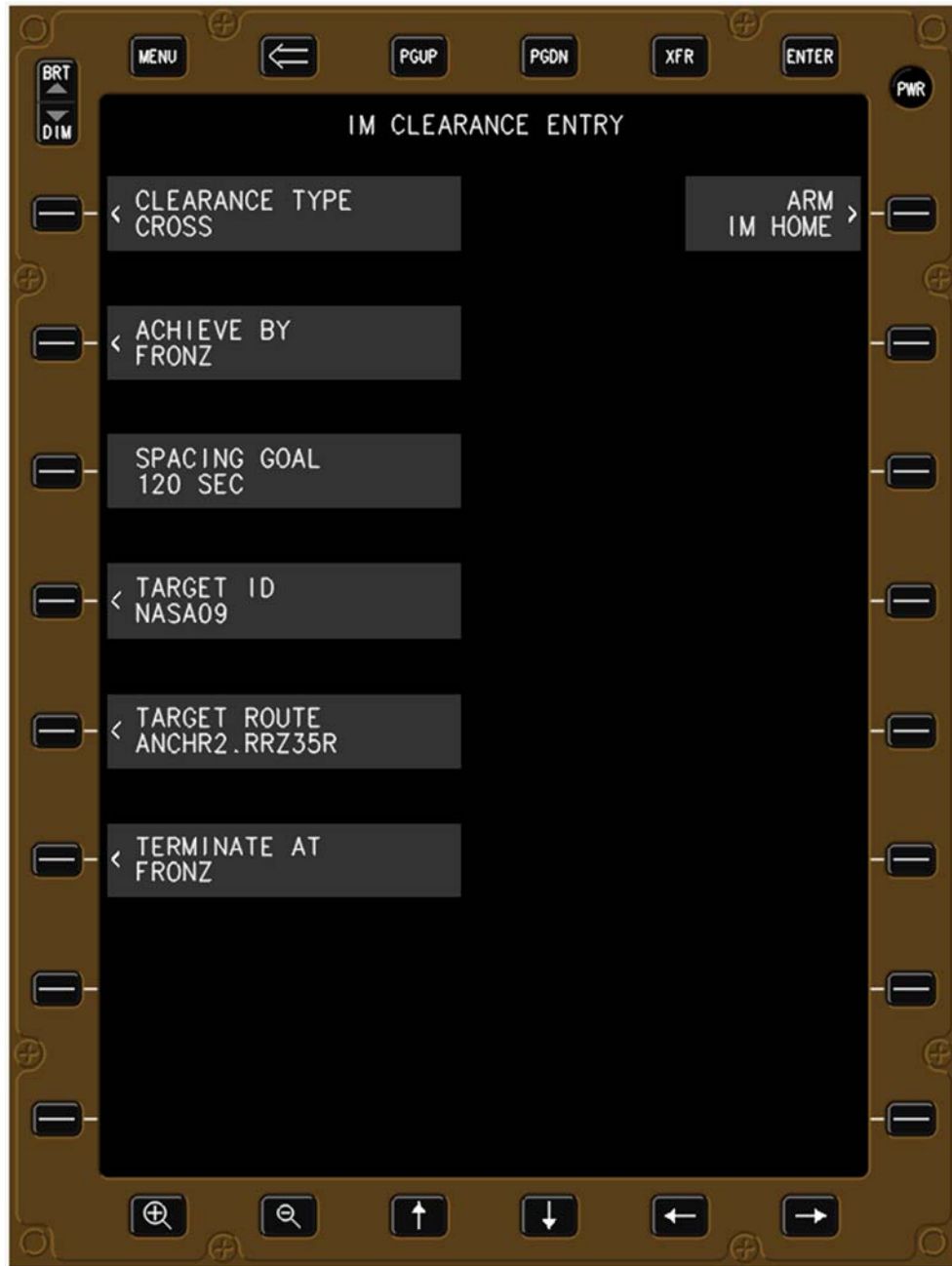


Figure 56. IM CROSS clearance home page with all data entered.

The Terminate At sub-page lists waypoints on the Ownship's route in alphabetical order.

Pressing the appropriate Planned Termination Point bezel button or soft-key automatically causes the IM clearance entry page to reappear with that waypoint entered in the TERMINATE AT data field (Figure 58).

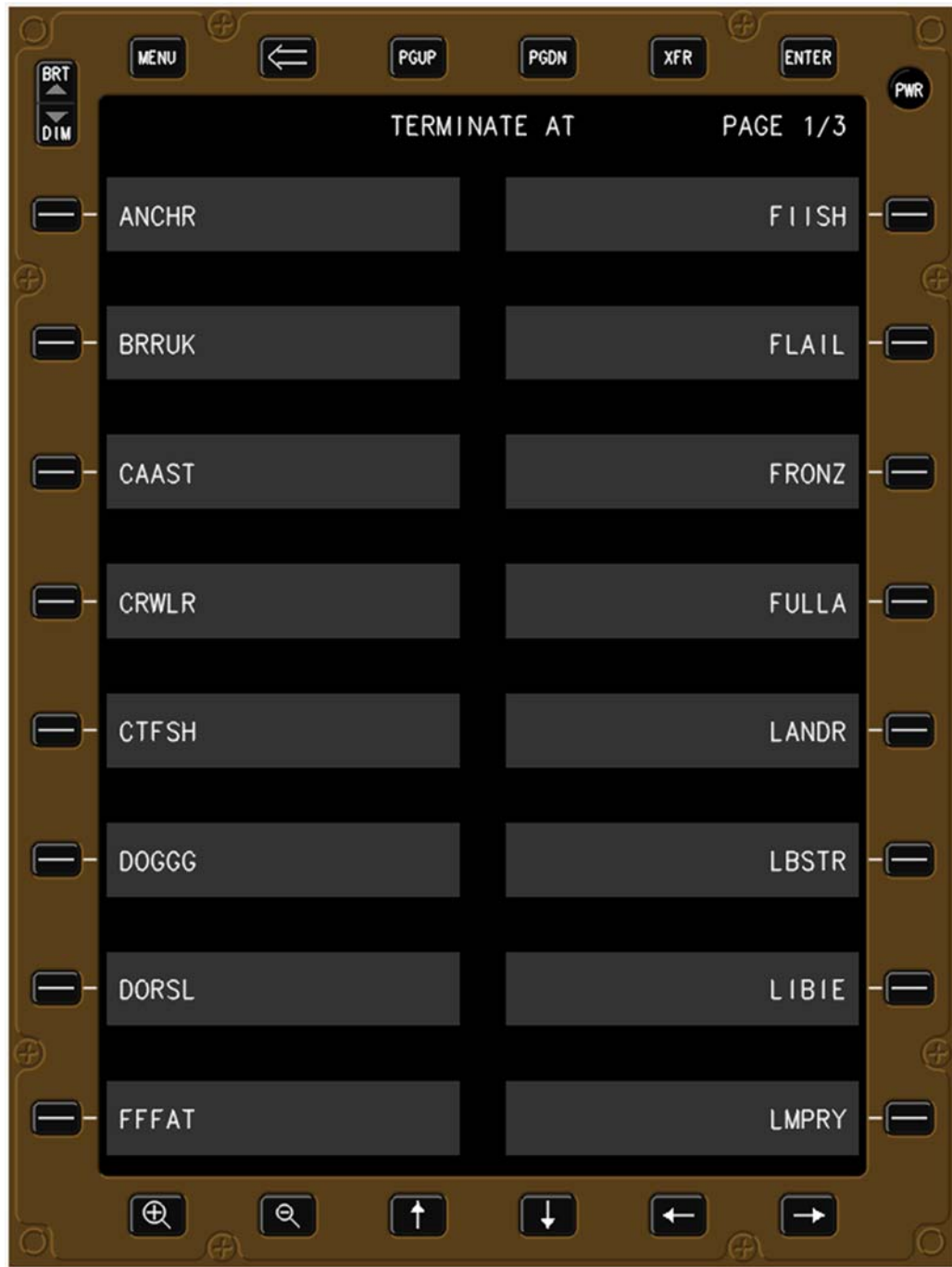


Figure 57. Planned Termination Point sub-page.

6.3.9 Return to IM Home Page and enter the ARMED State

Once all the information has been entered, the IM HOME soft-key (R1) changes to the ARM IM HOME soft-key. The flight crew presses the ARM IM HOME bezel button or soft-key (R1) to return to the IM Home page (Figure 59) and transition the IM state to ARMED, which is the action shown by the blue arrow labeled ARM in Figure 1.

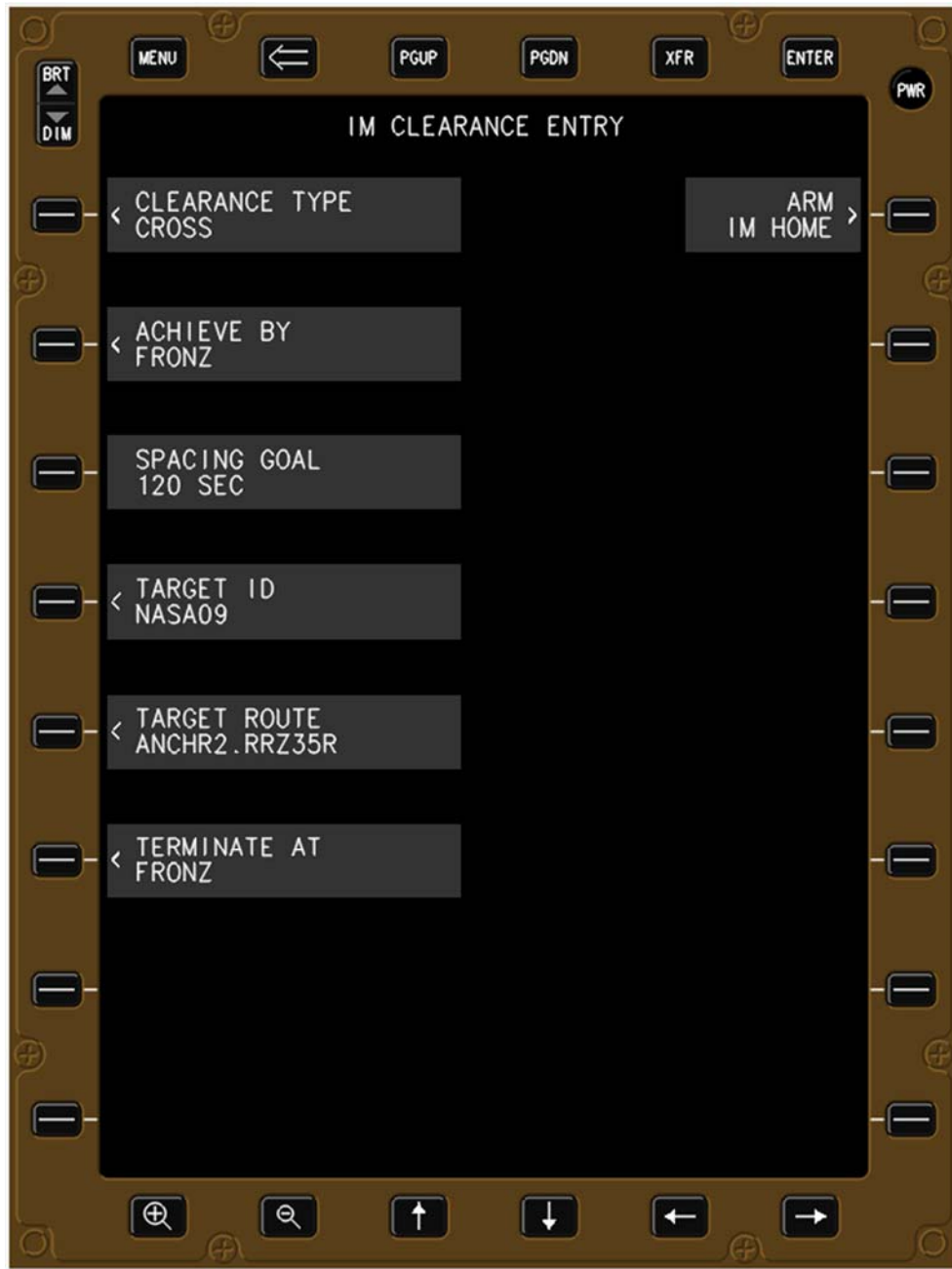


Figure 58. The ARM IM HOME button.

Figure 59 illustrates the IM Home page with both Ownship and IM clearance information displayed, and the software has transitioned from the OFF to the ARMED state. The CANCEL IM function is now visible and selectable (L8 in grey), and the EXECUTE function is visible but not selectable (R8 in cyan, turns white in the AVAILABLE state). Up to three highest priority reasons (listed in Table 3 through Table 5) for remaining in the ARMED state will be shown immediately below the state name.

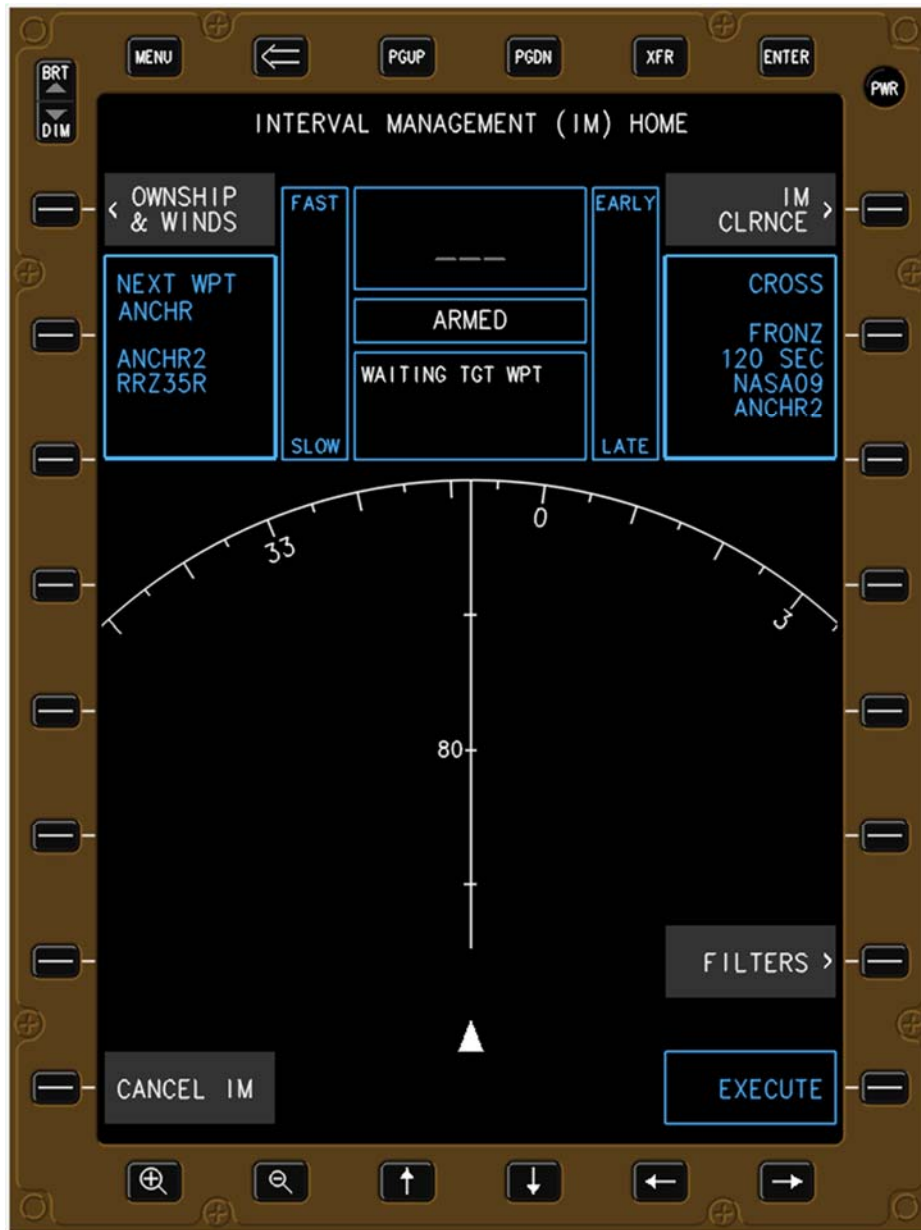


Figure 59. IM Home page with all data entered.

6.3.10 Modifying IM Clearance Data

The only IM clearance data that cannot be modified is the Target ID. The IM clearance must be cancelled and then reentered to change the Target ID. All other data fields can be modified, and when the ARM IM HOME bezel button or soft-key (R1) is pressed, the IM state changes to ARMED. When all criteria to conduct an IM operation are met, the software automatically transitions to the AVAILABLE state.

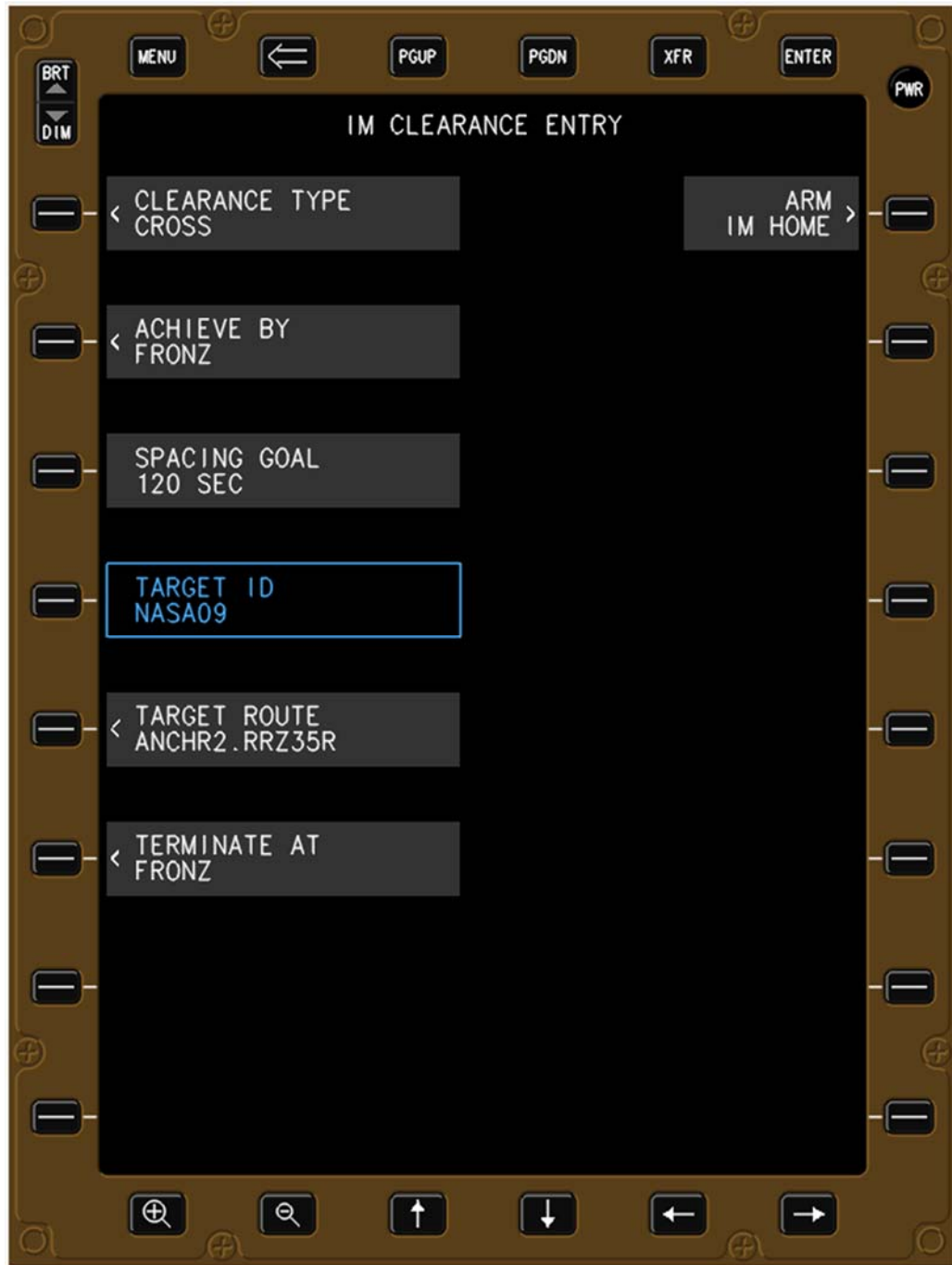


Figure 60. Modifying the IM CROSS clearance home page.

6.4 Interaction of a Two EFB Configuration

The simulators in the IMAC experiment were all configured with a left (Captain's) and right (First Officer's) EFB. As pilots enter Ownship and IM clearance information, the data is stored in a shared interface that is used to populate both EFBs. Data entered by one pilot will be visible to the other once data entry in a given field is completed by pressing the ENTER bezel button or soft-key, or by selecting a different data field. Operationally, it is expected that the pilot monitoring (PM) would conduct most or all IM data entry into the EFB, while the pilot flying (PF) has the option to observe what is occurring. This can be done by directly selecting the desired IM page, or use the transfer button to display the IM page shown on the other EFB.

The Ownship or IM clearance data must be complete prior to being sent to the spacing algorithm (occurs as two separate actions). Once data has been sent to the spacing algorithm it will be displayed on the IM Home page until the clearance is canceled or modified, at which point the data displayed on the IM Home page will either be removed or updated according to the most recent modification.

Shown below are sequential illustrations of simultaneous snapshots of the left EFB (the PF observing) and the right EFB (the PM entering data). Initially the EFBs are on different pages (Figure 61), then the XFR button (see section 4.1.4) on the left EFB is pressed to cause the page shown on the other EFB to appear (Figure 62). Data field selection or typing of values is not seen on the other EFB (Figure 63 and Figure 64); however, once the data has been entered it will be seen on the other EFB (Figure 65). In this example, the left EFB does not see KDEN until the right EFB enters it into the destination airport data field.

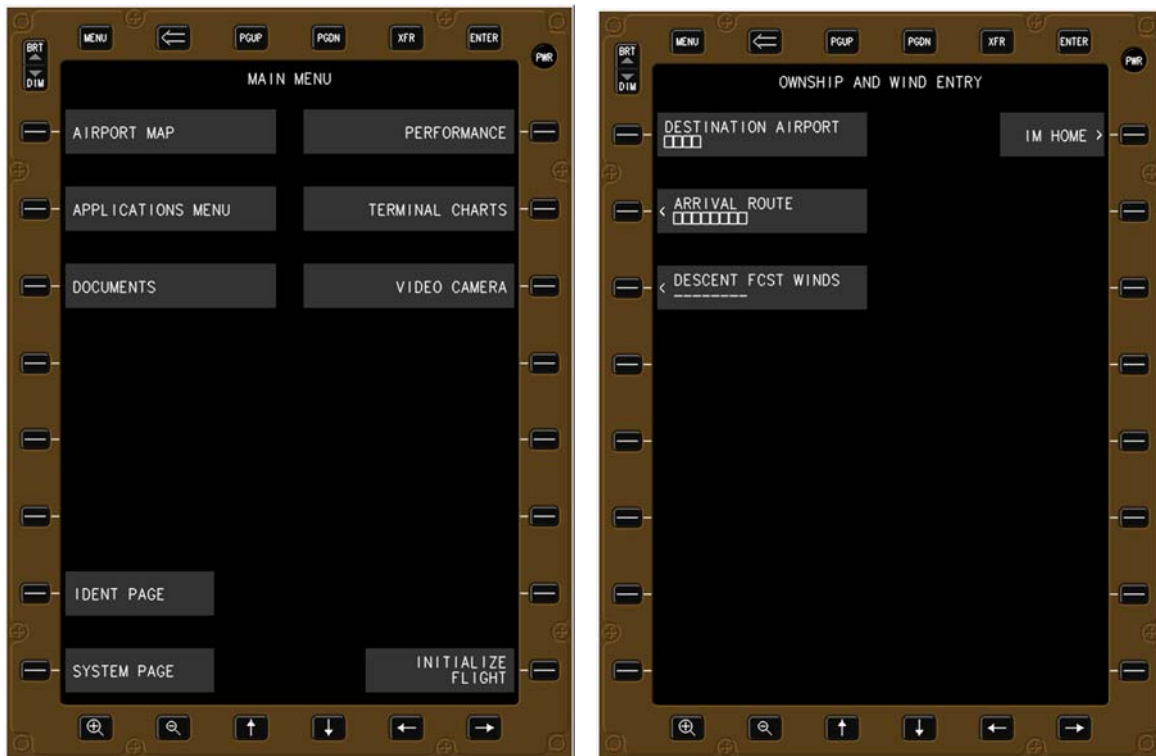


Figure 61. Left EFB and right EFB on different IM pages.



Figure 62. XFR button to change left EFB to same page as right EFB.



Figure 63. Data field selection in right EFB is not seen by left EFB.



Figure 64. Typing values in right EFB is not seen by left EFB.



Figure 65. Data entered in right EFB is seen by left EFB.

7 Transitions and Displays of States in an IM Operation

Once all Ownship and IM clearance information has been entered (see section 6), the flight crew conducts the IM operation using speed guidance from the ASTAR algorithm in the IM equipment. This section describes the action of the flight crew and the associated displays as a function of the normal progression of IM equipment state (Figure 1).

7.1 The OFF/TERMINATE State

7.1.1 Transition from OFF/TERMINATE to ARMED State

The IM equipment transitions from the OFF/TERMINATE state to the ARMED state when the flight crew presses the ARM IM HOME bezel button or soft-key (R1) on the IM clearance home page (Figure 56), which is only available after all required Ownship and IM clearance information has been entered. This transition is shown by the solid blue up arrow line in Figure 1 (flight crew action required).

7.1.2 CGD and EFB Displays in OFF/TERMINATE State

No data is shown on the CGD in the OFF/TERMINATE state (Figure 66).

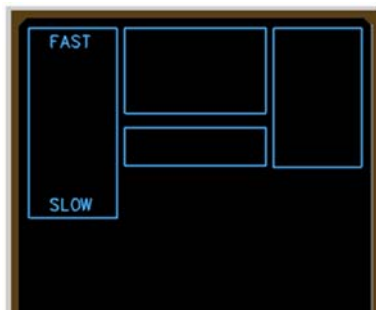


Figure 66. CGD in the OFF state.

The EFB in Figure 67 illustrates the OFF state, prior to any Ownship information being entered. The MENU, BACK arrow, FILTERS, and OWNSHIP & WINDS bezel buttons are all functional.

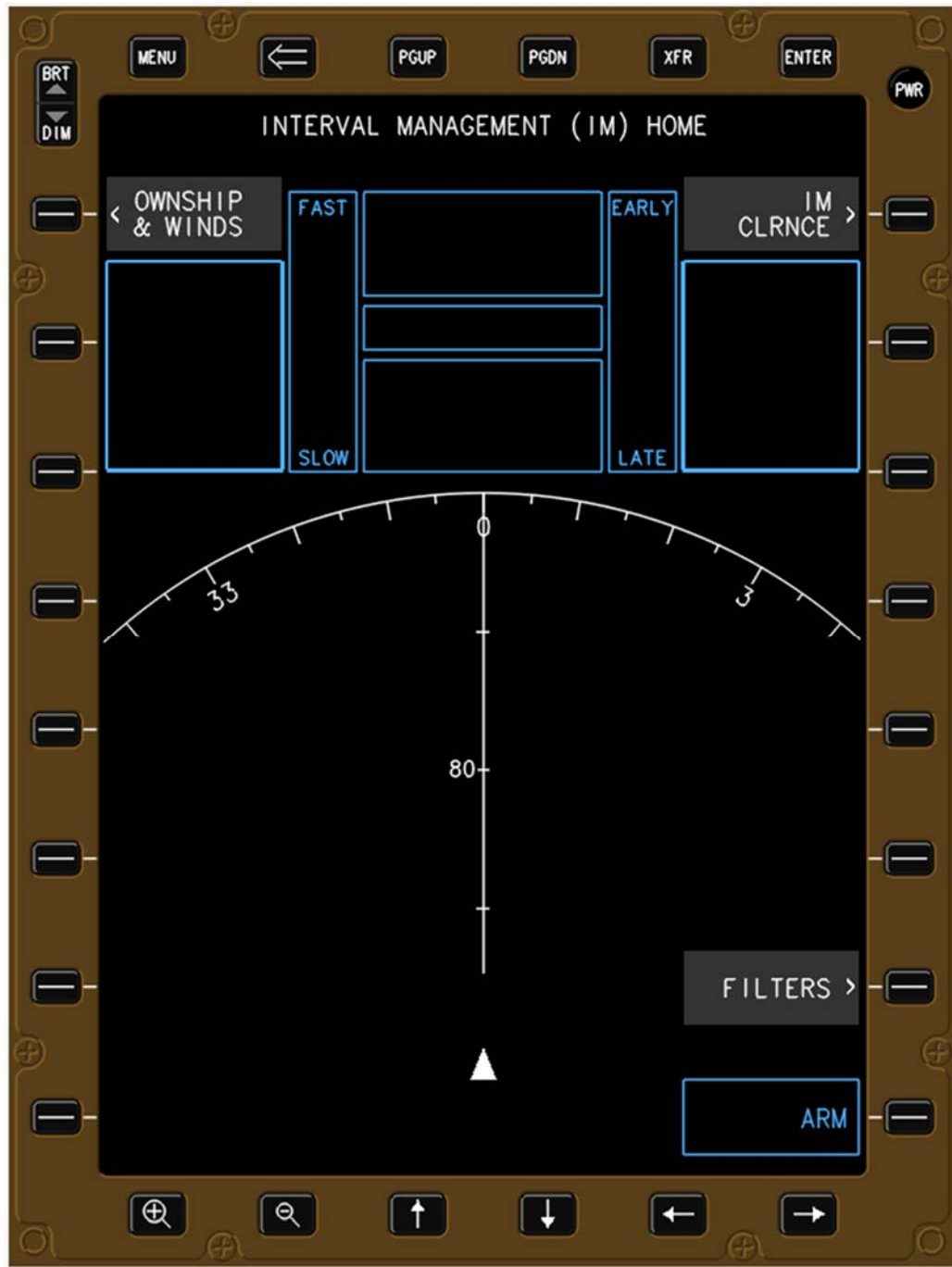


Figure 67. EFB in OFF state with Ownship data not entered.

7.2 The ARMED State

7.2.1 Transition from ARMED to OFF/TERMINATE State

The transition from the ARMED state to the OFF/TERMINATE state occurs when any of the following conditions are met:

- The flight crew presses the CANCEL IM button on the EFB (L8 in Figure 71), or
- The Ownship crosses the Planned Termination Point

When the state transitions from ARMED to OFF/TERMINATE all of the IM clearance information is cleared. The Ownship information that was entered is retained in the system in case another IM clearance is given.

7.2.2 Transition from ARMED to AVAILABLE State

The transition from the ARMED state to the AVAILABLE state automatically occurs when the following criteria are met (see Table 5 and Table 6 for a detailed descriptions of the criteria that triggers the messages):

- The Ownship aircraft is on its route (OWNSHIP OFF ROUTE message not shown)
- The Target aircraft is on its route (TGT OFF ROUTE message not shown)
- Target aircraft ADS-B data is available (TGT DATA LOST and WAITING TGT DATA messages not shown)
- The Ownship has passed its first speed constrained waypoint (WAITING OWN WPT message not shown)
- The Target aircraft has passed its first speed constrained waypoint (WAITING TGT WPT message not shown)
- The assigned spacing goal is feasible (SPC GOAL TOO SMALL and SPC GOAL TOO LARGE messages not shown)

The transition from the ARMED state to the AVAILABLE state is shown by the thin solid black down line in Figure 1.

7.2.3 Transition from ARMED to UNABLE State

The transition from the ARMED state to the UNABLE state automatically occurs when the criteria for any of the following IM messages are met (see Table 4 and Table 5 for a detailed descriptions of the criteria that triggers the messages):

- IM SYS FAIL
- IM DB NOT CURRENT
- OWNSHIP BAD ROUTE
- TGT BAD ROUTE

The transition from the ARMED state to the UNABLE state is shown by the dashed orange lines in Figure 1.

7.2.4 CGD and EFB Displays in ARMED State

In the ARMED state, the IM state, the IM clearance type, and the IM clearance information are shown on the CGD, but the IM commanded speed is shown as grey dashes and the FAST/SLOW indicator is not shown. No alerting messages are shown on the CGD in the ARMED state.

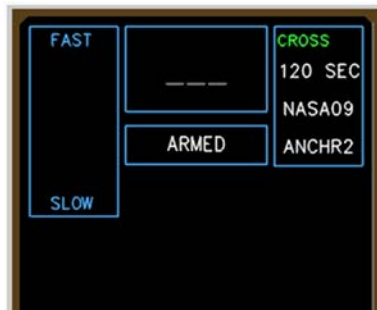


Figure 68. CGD in ARMED state.

In the ARMED state, all IM information is shown on the EFB except for the FAST/SLOW and EARLY/LATE indicators and the IM commanded speed (which is shown as grey dashes). Up to three IM alerting messages (prioritized by alert level) are also displayed on the EFB (Table 5 and Table 6). All traffic for which a valid ADS-B data file exists are shown on the EFB as single white chevrons (traffic not depicted in Figure 69).

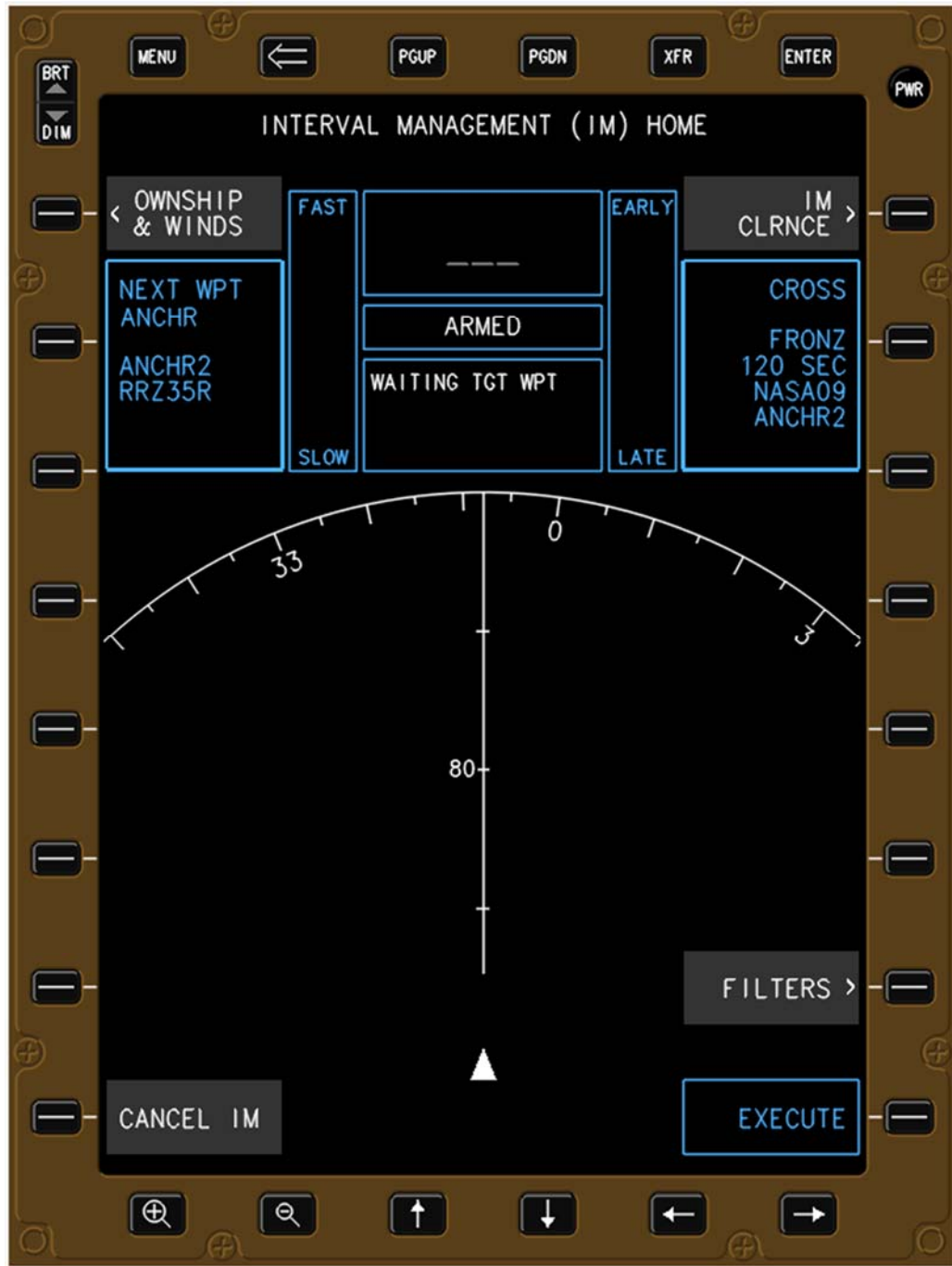


Figure 69. EFB in ARMED state.

7.3 The AVAILABLE State

7.3.1 Transition from AVAILABLE to OFF/TERMINATE State

The transition from the AVAILABLE state to the OFF/TERMINATE state occurs when any of the following conditions are met:

- The flight crew presses the CANCEL IM button on the EFB (L8 in Figure 71), or
- The Ownship crosses the Planned Termination Point

When the state transitions from AVAILABLE to OFF/TERMINATE all of the IM clearance information is cleared. The Ownship information that was entered is retained in the system in case another IM clearance is given.

7.3.2 Transition from AVAILABLE to ARMED State

The transition from the AVAILABLE state to the ARMED state automatically occurs when the flight crew amends their IM clearance, when the flight crew amends the Ownship information, or when the criteria for any of the following IM messages are met (see Table 5 and Table 6 for a detailed descriptions of the criteria that triggers the messages):

- OWNSHIP OFF ROUTE
- TGT OFF ROUTE
- TGT DATA LOST
- SPC GOAL TOO SMALL
- SPC GOAL TOO LARGE

The transition from the AVAILABLE state to the ARMED state is shown by the thin solid black down line in Figure 1.

7.3.3 Transition from AVAILABLE to PAIRED State

The transition from the AVAILABLE state to the PAIRED state when the flight crew presses the EXECUTE button (R8 in Figure 71). The transition from the AVAILABLE state to the PAIRED state is shown by the solid blue up arrow line in Figure 1.

7.3.4 Transition from AVAILABLE to UNABLE State

The transition from the AVAILABLE state to the UNABLE state automatically occurs when the criteria for any of the following IM messages are met (see Table 4 and Table 5 for a detailed descriptions of the criteria that triggers the messages):

- IM SYS FAIL
- IM DB NOT CURRENT
- OWNSHIP BAD ROUTE
- TGT BAD ROUTE

The transition from the AVAILABLE state to the UNABLE state is shown by the dashed orange lines in Figure 1.

7.3.5 CGD and EFB Displays in AVAILABLE State

In the AVAILABLE state, the IM state and IM clearance information are shown in white on the CGD. The IM commanded speed is shown in grey, the IM clearance type is shown in green, and the FAST/SLOW indicator is not shown. No alerting messages are shown on the CGD in the AVAILABLE state.



Figure 70. CGD in AVAILABLE state.

All IM information is shown in white font on the EFB in the AVAILABLE state, except for the IM commanded speed (shown in grey) and the FAST/SLOW and EARLY/LATE indicators, which are not shown. The white Target aircraft chevron is outlined with a second white chevron.

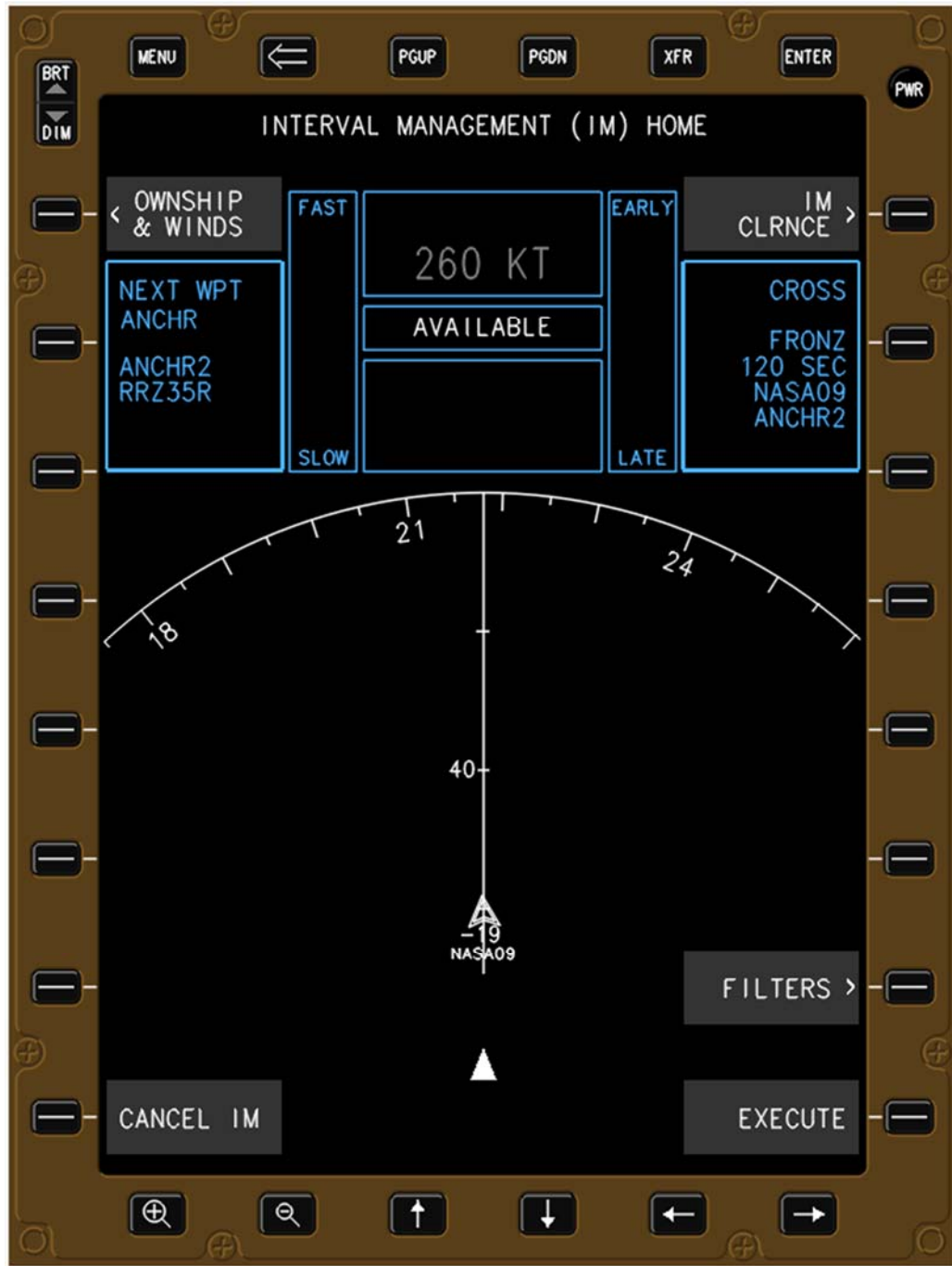


Figure 71. EFB in AVAILABLE state.

7.4 The PAIRED State

7.4.1 Transition from PAIRED to OFF/TERMINATE State

The transition from the PAIRED state to the OFF/TERMINATE state occurs when any of the following conditions are met:

- The flight crew presses the CANCEL IM button on the EFB (L8 in Figure 75), or
- The Ownship crosses the Planned Termination Point

When the state transitions from PAIRED to OFF/TERMINATE all of the IM clearance information is cleared. The Ownship information that was entered is retained in the system in case another IM clearance is given.

7.4.2 Transition from PAIRED to ARMED State

The transition from the PAIRED state to the ARMED state occurs when the flight crew modifies any Ownship information or IM clearance information. It should be noted that the Target ID is the only data field that cannot be modified, and requires the IM clearance to be cancelled (Figure 60).

This transition was created so that the flight crew has to take an action to execute a clearance amendment. This transition may not be needed if modifications are made to the method used to enter and execute clearance modifications (see section 8 for additional details).

7.4.3 Transition from PAIRED to SUSPENDED-AVAILABLE State

The transition from the PAIRED state to the SUSPENDED-AVAILABLE state will occur when the flight crew manually suspends the IM operation by pressing the SUSPEND button on the EFB, generating the MANUALLY SUSPENDED message (see Table 6). This transition is shown by the solid yellow-green line in Figure 1.

7.4.4 Transition from PAIRED to SUSPENDED-ARMED State

The transition from the PAIRED state to the SUSPENDED-ARMED state automatically occurs when the criteria for any of the following IM messages are met (see Table 5 and Table 6 for detailed descriptions of the criteria that triggers the messages):

- OWNSHIP OFF ROUTE
- TGT OFF ROUTE
- TGT DATA LOST
- SPC GOAL TOO SMALL
- SPC GOAL TOO LARGE

The transition from the PAIRED state to the SUSPENDED-ARMED state is shown by the thin solid black line in Figure 1.

7.4.5 Transition from PAIRED to UNABLE State

The transition from the PAIRED state to the UNABLE state automatically occurs when the criteria for any of the following IM messages are met (see Table 4 and Table 5 for detailed descriptions of the criteria that triggers the messages):

- IM SYS FAIL
- IM DB NOT CURRENT
- OWNERSHIP BAD ROUTE
- TGT BAD ROUTE

The transition from the PAIRED to UNABLE is shown by the dashed black lines in Figure 1.

7.4.6 CGD and EFB Displays in PAIRED State

In the PAIRED state, the IM commanded speed, IM state, and the IM clearance type are shown in green, and the IM clearance information is shown in white on the CGD. Only those alerting messages shown in Table 3 are displayed on the CGD in the PAIRED state. The FAST/SLOW indicator is shown on the CGD anytime in the PAIRED state (Figure 72).



Figure 72. CGD in PAIRED state.

When an IM commanded speed change occurs, the colors of the green text and black background is reversed to provide a salient cue to the flight crew (Figure 73). The reverse video is maintained until the flight crew sets the IM commanded speed in the MCP speed window. If the correct speed is not set in the MCP within 10 seconds, the normal and reverse video configuration is alternated at approximately 1 Hz until the speed is set in the MCP.



Figure 73. CGD with IM speed in reverse video.

The EARLY/LATE indicator is shown only on the EFB (Figure 74), and is only visible from the time the ownship comes within 30 nautical miles of the Achieve-By Point until the ownship crosses the Planned Termination Point or in the maintain phase of an IM operation (see section 5.3).

The Ownship and IM clearance information is displayed, as well as any message described in Table 3 through Table 6. In this particular illustration, the aircraft has been faster than 10 knots for more than 10 seconds which triggered the AIRCRAFT TOO FAST message (Table 3), and the flight crew did not enter either the forecast descent wind or the forecast surface wind which triggered the two NO WIND messages (Table 6).



Figure 74. EFB in PAIRED State with EARLY/LATE indicator shown.

In this illustration, the aircraft is not within 30 nautical miles of the Achieve By Point nor in a maintain phase of an IM operation, therefore the EARLY/LATE indicator is not shown.

Pressing the SUSPEND bezel button or soft-key (R8) causes the IM equipment to transition to the SUSPENDED-AVAILABLE state (Figure 77 and Figure 78).

Pressing the CANCEL IM bezel button or soft-key (L8) causes a transition to the CONFIRM CANCEL IM CLEARANCE message to appear (Figure 83).



Figure 75. EFB in PAIRED state.

Figure 76 illustrates that an IM commanded speed change has occurred, and the flight crew has not yet set that speed in the MCP. The IM commanded speed remains in reverse video for 10 seconds, then after that flashes at a 1 Hz rate until the flight crew sets the speed in the MCP speed window.



Figure 76. EFB with IM commanded speed in reverse video.

7.5 SUSPENDED-AVAILABLE State

The logic and criteria described in these sub-sections are essentially identical to the logic and criteria described in the ARMED state (section 7.3).

7.5.1 Transition from SUSPENDED-AVAILABLE to OFF/TERMINATE State

The transition from the SUSPENDED-AVAILABLE state to the OFF/TERMINATE state occurs when any of the following conditions are met:

- The flight crew presses the CANCEL IM button on the EFB (L8 in Figure 78), or
- The Ownship crosses the Planned Termination Point

When the state transitions from SUSPENDED-AVAILABLE to OFF/TERMINATE all of the IM clearance information is cleared. The Ownship information that was entered is retained in the system in case another IM clearance is given.

7.5.2 Transition from SUSPENDED-AVAILABLE to ARMED State

The transition from the SUSPENDED-AVAILABLE state to the ARMED state occurs when the flight crew modifies any Ownship information or IM clearance information. It should be noted that the Target ID is the only data field that cannot be modified, and requires the IM clearance to be cancelled (Figure 60).

This transition was created so that the flight crew has to take an action to execute a clearance amendment. This transition may not be needed if modifications are made to the method used to enter and execute clearance modifications (see section 8 for additional details).

7.5.3 Transition from SUSPENDED-AVAILABLE to SUSPEND-ARMED State

The transition from the SUSPENDED-AVAILABLE state to the SUSPENDED-ARMED state automatically occurs when the criteria for any of the following IM messages are met (see Table 5 and Table 6 for a detailed descriptions of the criteria that triggers the messages):

- OWNSHIP OFF ROUTE
- TGT OFF ROUTE
- TGT DATA LOST
- SPC GOAL TOO SMALL
- SPC GOAL TOO LARGE

The transition from the SUSPENDED-AVAILABLE state to the SUSPENDED-ARMED state is shown by the thin solid black line in Figure 1.

7.5.4 Transition from SUSPENDED-AVAILABLE to PAIRED State

The transition from the SUSPENDED-AVAILABLE state to the PAIRED state when the flight crew presses the RESUME button (R8 in Figure 78). The transition from the SUSPENDED-AVAILABLE state to the PAIRED state is shown by the solid green line in Figure 1.

7.5.5 Transition from SUSPENDED-AVAILABLE to UNABLE State

The transition from the SUSPENDED-AVAILABLE state to the UNABLE state automatically occurs when the criteria for any of the following IM messages are met (see Table 4 and Table 5 for a detailed descriptions of the criteria that triggers the messages):

- IM SYS FAIL
- IM DB NOT CURRENT
- OWNERSHIP BAD ROUTE
- TGT BAD ROUTE

The transition from the AVAILABLE state to the UNABLE state is shown by the dashed orange lines in Figure 1.

7.5.6 CGD and EFB Displays in SUSPENDED-AVAILABLE State

In the SUSPENDED-AVAILABLE state, the IM state and the IM clearance information are shown in white on the CGD (Figure 77). The IM clearance Type is shown in green, the FAST/SLOW indicator is removed, and the IM commanded speed is removed. No alerting messages are shown on the CGD in the SUSPENDED-AVAILABLE state.



Figure 77. CGD in SUSPENDED-AVAILABLE state.

All IM information shown on the EFB in the SUSPENDED-AVAILABLE state (Figure 78) is in white, except for the IM commanded speed shown in grey, and the FAST/SLOW and EARLY/LATE indicators are removed. The Target aircraft chevron is outlined with a second white chevron (outlined in green in the PAIRED state).

Pressing the RESUME bezel button or soft-key (R8) causes the software to transition to the PAIRED state (Figure 75). This is the only time the RESUME function is available.



Figure 78. EFB in SUSPENDED-AVAILABLE state.

7.6 SUSPENDED-ARMED State

The logic and criteria described in these sub-sections are essentially identical to the logic and criteria described in the ARMED state (section 7.2).

7.6.1 Transition from SUSPENDED-ARMED to OFF/TERMINATE State

The transition from the SUSPENDED-ARMED state to the OFF/TERMINATE state occurs when any of the following conditions are met:

- The flight crew presses the CANCEL IM button on the EFB (L8 in Figure 80), or
- The Ownship crosses the Planned Termination Point

When the state transitions from SUSPENDED-ARMED to OFF/TERMINATE all of the IM clearance information is cleared. The Ownship information that was entered is retained in the system in case another IM clearance is given.

7.6.2 Transition from SUSPENDED-ARMED to ARMED State

The transition from the SUSPENDED-ARMED state to the ARMED state occurs when the flight crew modifies any Ownship information or IM clearance information. It should be noted that the Target ID is the only data field that cannot be modified, and requires the IM clearance to be cancelled (Figure 60).

This transition was created so that the flight crew has to take an action to execute a clearance amendment. This transition may not be needed if modifications are made to the method used to enter and execute clearance modifications (see section 8 for additional details).

7.6.3 Transition from SUSPENDED-ARMED to SUSPEND-AVAILABLE State

The transition from the SUSPENDED-ARMED state to the SUSPEND-AVAILABLE state automatically occurs when the following criteria are met (see Table 5 and Table 6 for detailed descriptions of the criteria that triggers the messages):

- The Ownship aircraft is on its route (OWNSHIP OFF ROUTE message not shown)
- The Target aircraft is on its route (TGT OFF ROUTE message not shown)
- Target aircraft ADS-B data is available (TGT DATA LOST message not shown)
- The assigned spacing goal is feasible (SPC GOAL TOO SMALL and SPC GOAL TOO LARGE messages not shown)

The transition from the SUSPENDED-ARMED state to the SUSPEND-AVAILABLE state is shown by the thin solid black down line in Figure 1.

7.6.4 Transition from SUSPENDED-ARMED to UNABLE State

The transition from the SUSPENDED-ARMED state to the UNABLE state automatically occurs when the criteria for any of the following IM messages are met (see Table 4 and Table 5 for a detailed description of the criteria that triggers the messages):

- IM SYS FAIL
- IM DB NOT CURRENT

- OWNERSHIP BAD ROUTE
- TGT BAD ROUTE

The transition from the SUSPENDED-ARMED state to the UNABLE state is shown by the dashed orange lines in Figure 1.

7.6.5 CGD and EFB Displays in SUSPENDED-ARMED State

The IM state and the IM clearance information are shown in white on the CGD. The IM clearance type is shown in green, and the IM commanded speed and the FAST/SLOW indicator are removed. No alerting messages are shown on the CGD in the SUSPENDED-ARMED state.



Figure 79. CGD in SUSPENDED-ARMED state.

Figure 80 shows the EFB in the SUSPENDED-ARMED state, with the IM information visible but the FAST/SLOW and EARLY/LATE indicators removed, and the IM speed in grey. Up to three IM alerting messages (prioritized by alert level) are displayed on the EFB (Table 4 and Table 5). All traffic on the EFB is shown as a single white chevron (traffic not depicted in Figure 80).

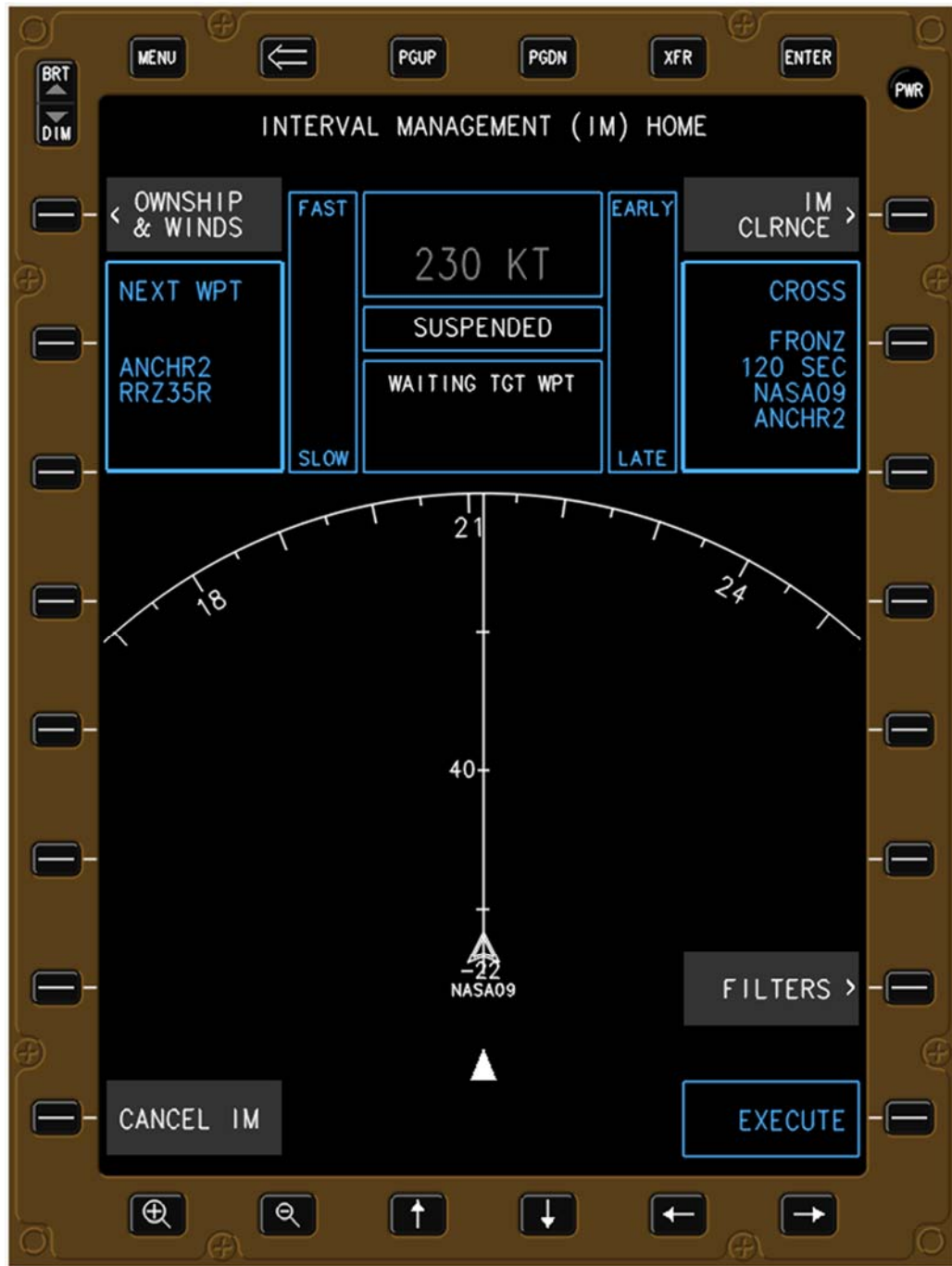


Figure 80. EFB in SUSPENDED-ARMED state.

7.7 UNABLE State

7.7.1 Transition from UNABLE to the OFF/TERMINATE State

The transition from the UNABLE state to the OFF/TERMINATE state occurs when the flight crew presses the CANCEL IM button on the EFB (L8 in Figure 82).

When the state transitions from UNABLE to OFF/TERMINATE all of the IM clearance information is cleared. The Ownship information that was entered is retained in the system in case another IM clearance is given.

7.7.2 CGD and EFB Displays in UNABLE State

In the UNABLE state, the IM state and clearance information remains visible, however all other information is removed (Figure 82). No alerting messages are shown on the CGD in the UNABLE state.

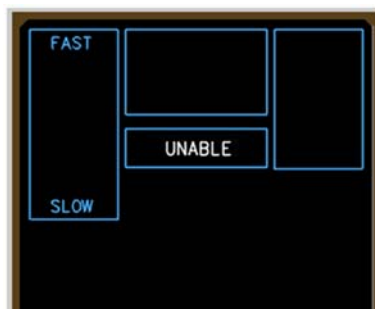


Figure 81. CGD in UNABLE state.

The IM state and up to three IM alerting messages (prioritized by alert level) are displayed on the EFB (Table 3). The FAST/SLOW and EARLY/LATE indicators and the IM commanded speed are removed from the display. In Figure 82 the IM equipment transitioned to the UNABLE state due to the algorithm not being able to calculate a route for the Target aircraft. All traffic on the EFB is shown as a single white chevron (traffic not depicted in Figure 82).

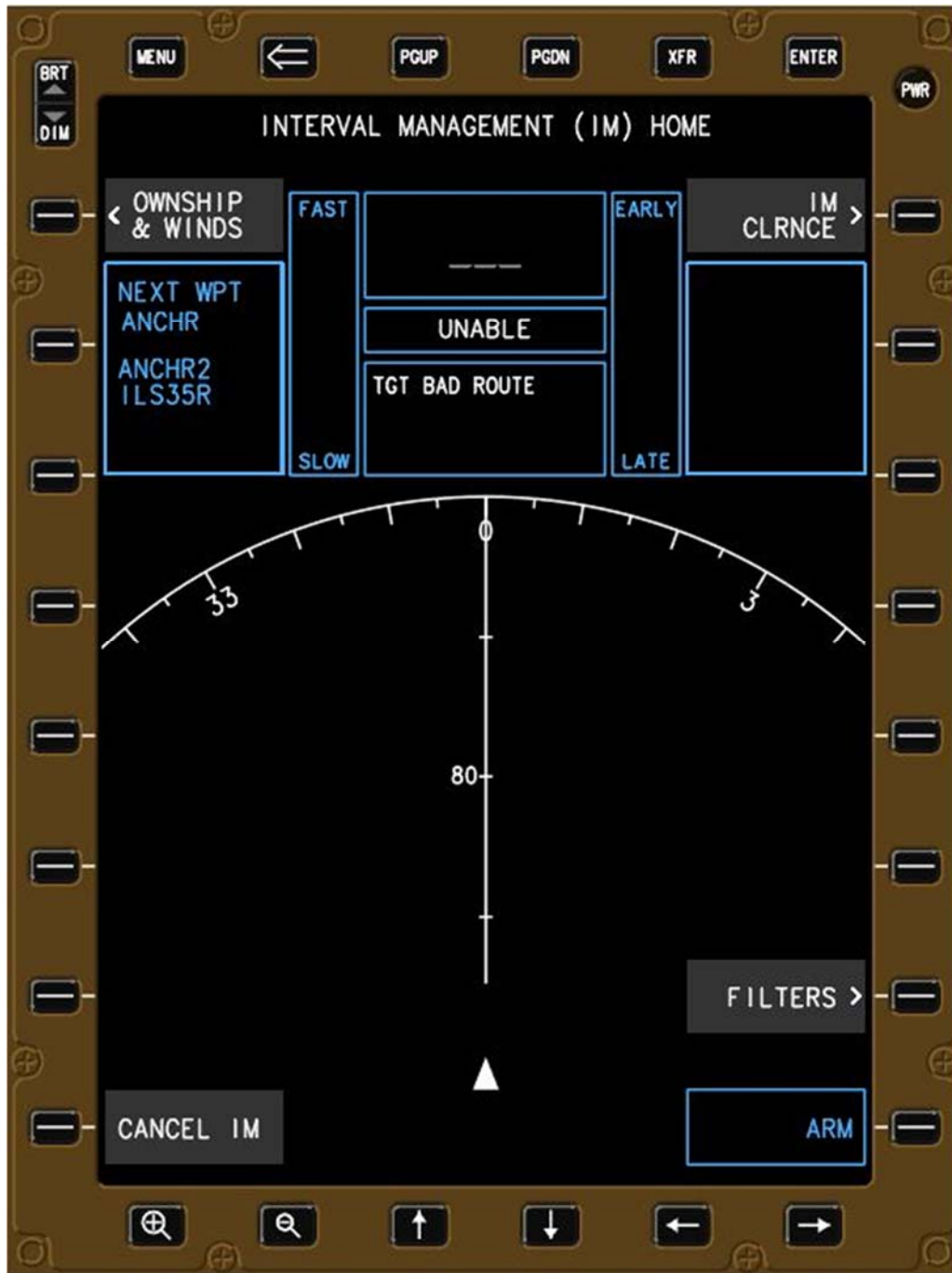


Figure 82. EFB in UNABLE state.

7.8 Cancellation of an IM Operation

When the pilot presses the CANCEL IM bezel button or soft-key, a page is displayed on the EFB that requires the flight crew to confirm their intention to cancel the IM operation (Figure 83). The YES bezel button and soft-key (R8) is on the opposite side of the EFB from the previous CANCEL IM button (L8) to prevent accidental termination of the IM operation.

Pressing the YES bezel button or soft-key (R8) terminates the IM operation and returns the IM equipment to the OFF/TERMINATE state (Figure 84). Pressing the NO bezel button or soft-key (L8) returns the IM display to whatever the previous IM state and page were.



Figure 83. EFB display to confirm cancellation of IM operation.

Figure 84 illustrates the EFB after an IM operation has been manually cancelled by the flight crew, or automatically cancelled by the software (crossing the Planned Termination Point).

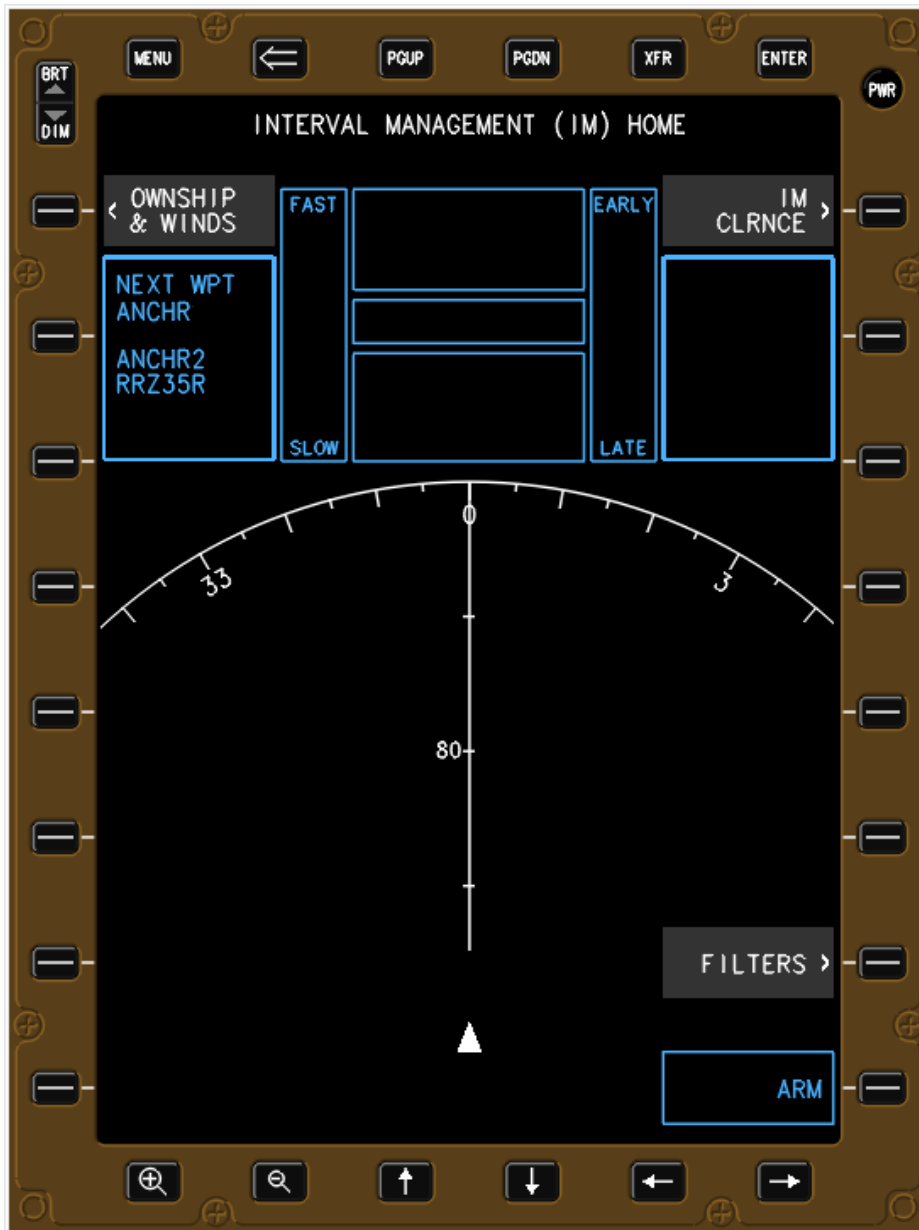


Figure 84. EFB after IM operation cancelled.

8 Changes for Future Implementations

This section contains a list of areas that need further discussion to improve the spacing logic, interface design, or, and alerting messages described in this document.

- The FAST/SLOW indicator shown on the EFB and CGD has generated flight crew responses during previous IM research that range from strongly dislike and not functional, to ambivalent, to finding it somewhat helpful. It would be useful for other researchers and aviation experts to develop a display that provides the flight crew with a secondary cue that provides awareness of the aircraft's current speed compared to the speed expected by the spacing algorithm at that moment in time (not the discrete IM commanded speed).
- The EARLY/LATE indicator is relatively new to the Langley IM research team, and more time should be invested exploring when the display turns on (for example, at a waypoint, at an altitude, or at the entry to the TRACON) and how the position error is displayed as a function of distance remaining to the Planned Termination Point (smooth versus step-transition).
- The entry of Ownship and IM clearance information should be restructured to align with how flight crew enter information into the FMS, that is, a parallel modification page should be used instead of changing data fields individually.
- The Ownship and IM clearance pages should have data fields to enter waypoints to connect the arrival and instrument approach procedures (not envisioned in a voice environment).
- The IMAC research team believed not knowing the Target aircraft's planned speeds during cruise and the initial Mach/CAS transition during descent, created the possibility of injecting spacing error into the ASTAR13 calculations (previous research experiments had flight crew enter the Mach and Mach/CAS speeds into the EFB for the ASTAR calculations). Therefore, ASTAR13 was inhibited from displaying IM commanded speeds during the Mach segment of flight, which in turn caused the IM operation not to transition to the PAIRED state even when in trail with the Target in a CAPTURE or MAINTAIN clearance.
- If a CROSS clearance is entered and the Ownship is in trail with the Target, the IM software should transition to a CAPTURE clearance type. Some of the Denver arrival routes used in IMAC had the initial speed constrained waypoint just outside of the TRACON boundary, which resulted in the Ownship flying for an extended period of time in the ARMED state while in trail with the Target when a CROSS clearance was issued with the Target on the same arrival as the Ownship. It is not expected that controllers would issue a CROSS clearance to aircraft in trail, nonetheless, the software should have logic to optimize the operation if it occurs.
- The IM clearance type should be included in the title of those pages, for example, the EFB page should state IM CROSS CLEARANCE ENTRY and not IM CLEARANCE ENTRY.
- The "traffic near route" filter should be implemented and evaluated for usefulness (hypothesized to be useful for IM during enroute or oceanic operations).
- Additional discussion should occur to determine if the Achieve By and Terminate waypoints should be listed alphabetically or in sequential order.
- The transfer (XFR) functionality should be restructured to align with the convention used by current commercial equipment, that is, the EFB enters a "transfer" state where data can only be viewed on that EFB and data cannot be edited.
- The wind entry methodology and resultant labels could be improved. When the crew enters the ACARS for descent winds and manually enters the surface winds, the only label and time shown in the page title is the last field to be entered, in this case MANUAL xxxxZ.

9 Conclusion

This document describes the cockpit interfaces, displays, and alerting messages created by the NASA Langley IM research team for the IMAC experiment conducted in the summer of 2015. In addition to addressing issues identified in earlier research, the redesign of the IM software and application was also required to implement two new IM clearance types – the CAPTURE clearance and the MAINTAIN clearance (all previous research only studied the CROSS clearance).

Conducted over a two-year time period by the entire IM team, the redesigned software and application appears to offer a simpler and more intuitive interaction for the user (the flight crew), and enables the operation of all three IM clearance types. Results from the IMAC experiment, including user acceptability of the displays and workload, are expected to be published by 2016.

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Appendix A: IMAC Displays in DTS and IFD Simulators

Section 1.3 described three simulators used in the IMAC experiment: ASTORs, DTS, and IFD. The body of this document used exclusively graphics generated from the ASTOR simulator, which used a software-based EFB and CGD. This Appendix provides graphics generated by the DTS and IFD simulators. Since the bezel buttons were hardware, they are not shown in the figures.

The two Astronautics EFBs in both the DTS and IFD were positioned on three-axis rotating mounts, which could be rotated from portrait to landscape mode. The DTS used a software emulated CGD located next to the navigation display, and the IFD used a hardware-based CGD.

Corresponding to the information in section 5.1.3 (Figure 12, Figure 13, and Figure 14), the three figures below show the CAPTURE (Figure 85), CROSS (Figure 86), and MAINTAIN (Figure 87) clearances in the DTS and IFD.

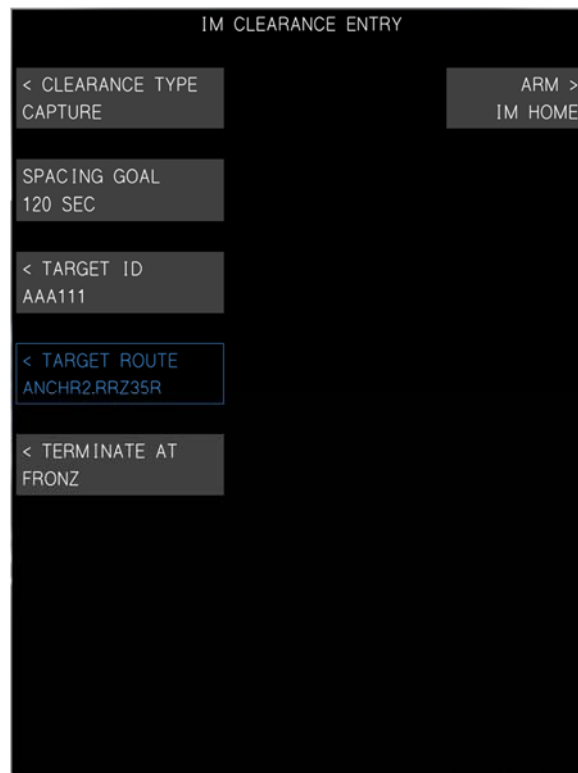


Figure 85. IM CAPTURE Clearance page in DTS and IFD.

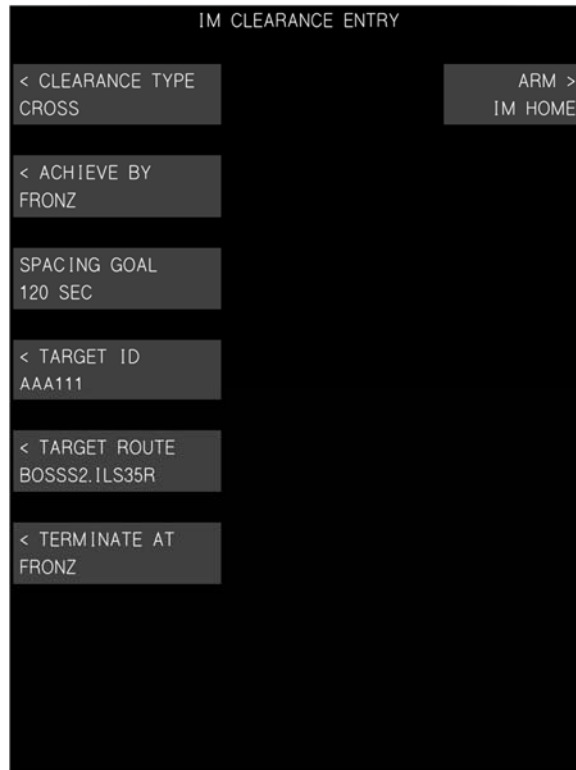


Figure 86. IM CROSS Clearance page in DTS and IFD.

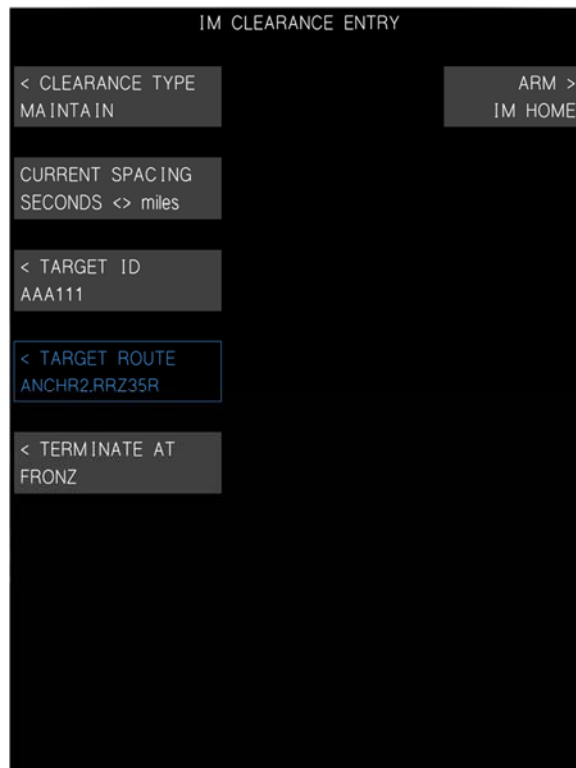


Figure 87. IM MAINTAIN Clearance page in DTS and IFD.

The next four pictures mirror the outline of sections 7.2 (ARMED), 7.3 (AVAILABLE), 7.4 (PAIRED), and 7.5 (SUSPENDED-AVAILABLE). Figure 88 illustrates the ARMED state, Figure 89 illustrates the AVAILABLE state, Figure 90 illustrates the PAIRED state, and Figure 91 illustrates the SUSPENDED-AVAILABLE state.

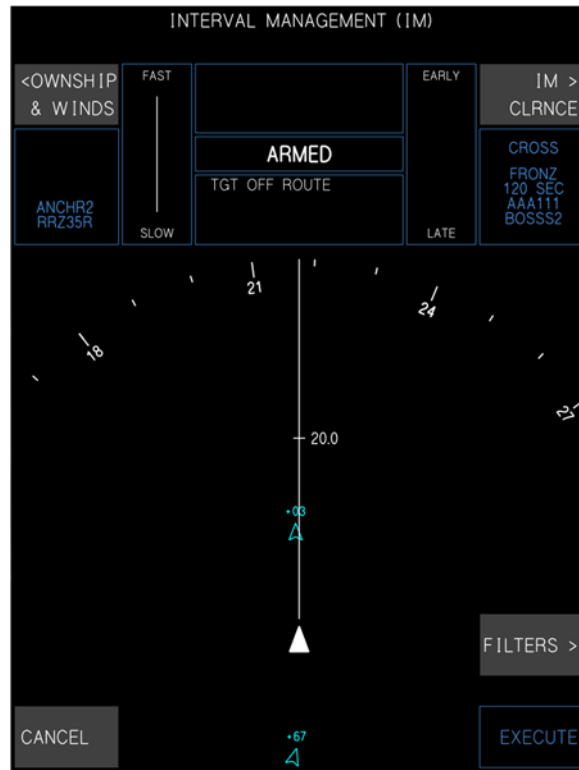


Figure 88. ARMED state in the DTS and IFD.



Figure 89. AVAILABLE state in DTS and IFD.



Figure 90. PAIRED state in DTS and IFD.

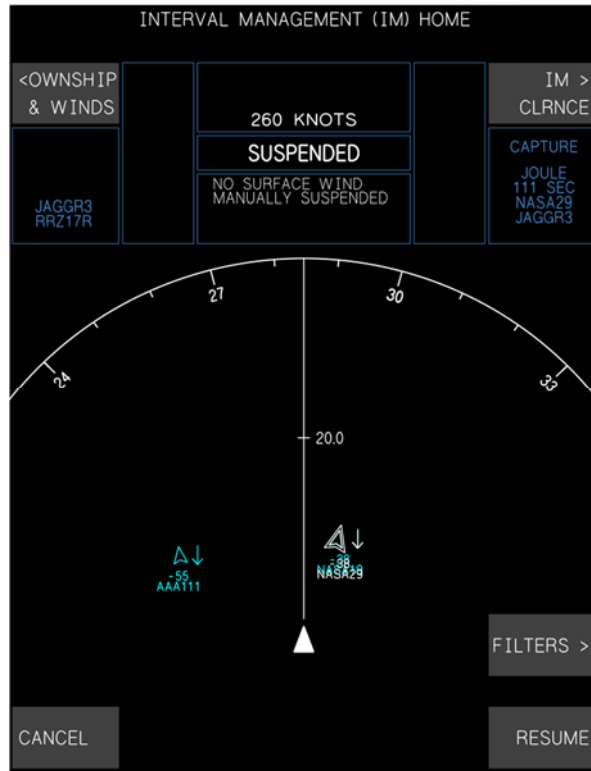


Figure 91. SUSPENDED-AVAILABLE state in DTS and IFD.

Figure 92 illustrates the confirm cancellation page in the DTS and IFD, similar to Figure 83 for the ASTORs. The absence of the next waypoint in the Ownship text box is due to the graphics being generated on a desktop computer and not in the simulator itself.



Figure 92. The Confirm Cancel message in the DTS and IFD.

Figure 93 illustrates the CGD as displayed in the DTS and IFD in the AVAILABLE state (Figure 70 for the ASTORs) and PAIRED state (Figure 73 for the ASTORs).



Figure 93. The CGD showing AVAILABLE and PAIRED in the DTS and IFD.

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