HUMAN-CENTERED COCKPIT STUDY

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Abstract

Next generation cockpit concept aiming to reduce the risk of pilot-error-induced accident was studied. This new cockpit concept, called Human-Centered Cockpit incorporates several ideas which aim to improve the pilot's situation awareness for the terrain and the aircraft situation without increasing the pilot's cognitive workload. Through several times of the airline pilot reviews using partial task simulation of new functions, design issues were identified and the design was brushed up. Fully functional cockpit simulator was finally developed to evaluate the effectiveness of this cockpit concept in the realistic commercial aircraft operational environment from preflight to spot-in, including the ATC. Six pilots participated in the final evaluation and the result showed that this cockpit concept enhances the pilot's situation awareness in the actual operation environment, and improves the pilot's cognitive workload in flight.

1 Introduction

"Human-Centered Cockpit" is a cockpit trying to eliminate any possible causes of human-factor-induced aircraft accidents, by optimizing the interaction between human and machine in a highly automated aircraft control system.

As the statistics [1] shows, rate of hull-loss accident remains almost stable for more than 20 years. This fact and continuous growth of the commercial traffic in the future imply that the number of the aircraft accident will continue to increase if proper action will not be taken by the manufacturer and/or the operator.

On the other hand, about 70 percents of the accidents are said to be due to the pilot error [1]. Introduction of the highly-automated glass-cockpit has been contributing to the reduction of the pilot workload, however, it does not lead to the reduction of the accident rate, and on the contrary, it induces new type of the human error unseen in the past due to improper interaction between the highly-automated system and the pilot.

This study is trying to establish and propose the "Human-Centered Cockpit", as a next generation cockpit improving the man-machine interface in the glass cockpit. The study focused not only on working out the improvement ideas and evaluating their effectiveness, but also on how to integrate them into the cockpit and it's pilot procedure for practical use in the actual operational environment without imposing "special" effort to the pilot.

This 4-year study started from 2000 under the foundation from Japanese Ministry of Economy, Trade and Industry (METI), was performed by Mitsubishi Heavy Industries, Ltd. under the program management of Japan Aircraft Development Corporation (JADC).

2 Development Flow

2.1 Function level concept study

Accident cause investigation was conducted for the human-factor-induced accidents including those described in the FAA Human Factors Team report [2]. The investigation result showed that;

- Most of the accidents can be avoided if the pilot could realize the situation well before the warning.
- Warning system informs the pilot of the imminent hazard as a last resort, though, it cannot be an ultimate accident stopper.
- The improvement of the situation awareness especially for the aircraft automation system and the terrain in *normal* operation, ie. cutting off the error chain on the root cause is a key issue to cope with the human-factor-induced accident.

We suggested several new function ideas focusing on the improvement of the auto-pilot situation awareness and the terrain awareness well before the warning situation. Some major items are shown below.

1) 3D Terrain View Display
CG-based external view is displayed, to provide the virtual VMC (Visual Meteorological Condition) environment to the pilot even in the low visibility condition. The 3D perspective view enables the pilot to intuitively recognize the terrain of the extensive area ahead without increasing workload.

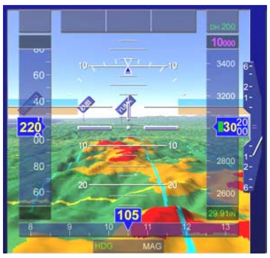

Figure 1. 3D Terrain View Display

2) Graphical Flight Mode Annunciator
Auto-pilot (AP) system lateral/vertical modes and Auto-throttle (AT) system mode are annunciated in a graphical pattern, to improve the auto-pilot mode situation awareness. In addition to the text indication, colored illumination box is assigned to each mode, and the pilot can recognize the AP/AT modes intuitively in a graphical manner by the combination of the illumination pattern and it's coloring.

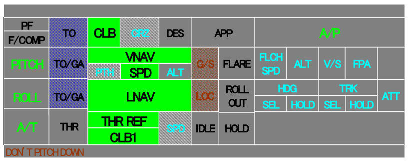

Figure 2. Graphical Flight Mode Annunciator

3) Vertical Manager (V-MNG)
V-MNG is an automatic AP/AT mode selection function. Unlike the VNAV function which controls the aircraft with it's own unique AP/AT mode usually having very complicated logic, V-MNG does the FMS vertical navigation by managing the basic AP/AT modes (ALT, VS, FPA, SPD mode, etc.) and it's parameter settings (Vertical Speed, FPA, Altitude, Airspeed, etc.) only. The pilot can understand the "behavior and intention" of the V-MNG by the combination of the basic AP/AT modes and it's parameter, and that improves the awareness for the highly automated vertical navigation system.
4) Full-time Speed Management (S-MNG)
S-MNG is an automatic speed command function which commands appropriate speed, according to the altitude, flight phase, and flap setting, and speed constraint at the waypoint. S-MNG is not a part of the FMS, and is available in any flight situation from takeoff to landing, unlike the conventional speed management system available only when the FMS vertical navigation is active (ie. the pilot is required to set the speed bug during the final approach which is said to be the highest workload phase.).
5) Vertical Profile/Aircraft Situation Display
6) Graphical FMS, etc…

Each improvement idea was reviewed by the airline pilots using partially functional cockpit mockup, and design issues were identified to make these primitive ideas into more effective situation awareness tools in the actual airline flight operation.

2.2 Cockpit level concept development

Whole functions of the cockpit including the improvement ideas were defined and integrated into one complete system configuration, to evaluate the effectiveness of these ideas in the operational environment.

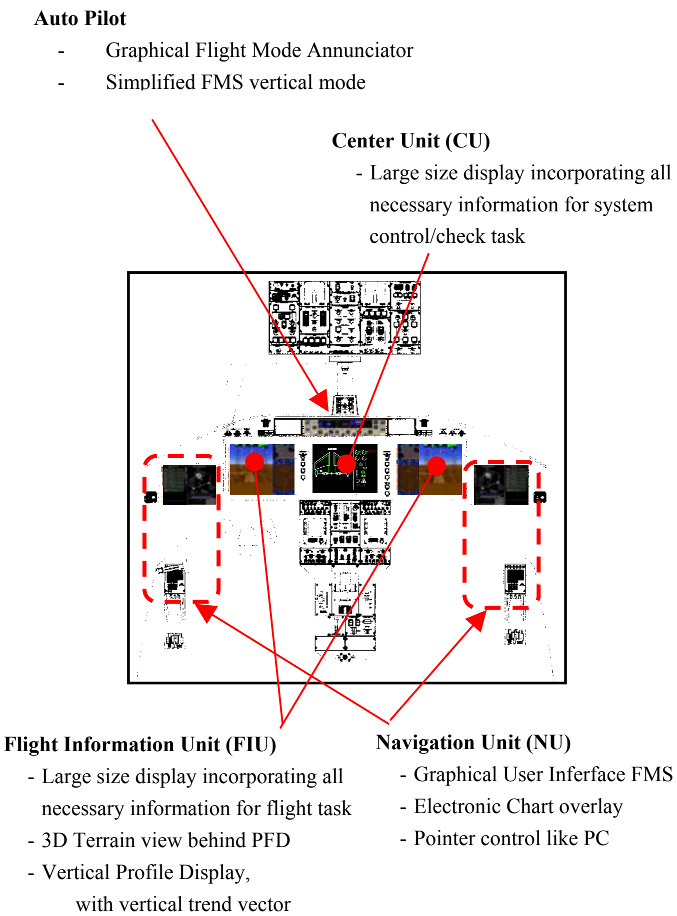

Figure 3. Overall Cockpit System Configuration

Functional Mock-up which simulates most of the functions were developed to confirm the concept in more realistic operational environment.

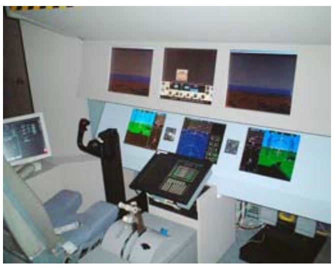

Figure 4. Functional Mock-up

2.3 Display/control detail design

Based on the established cockpit configuration, following key design features which characterize the differential from the existing cockpit, were designed more in detail, including the operation procedure.

- Flight Information Unit Display
- Navigation Unit Display/Cursor Control Device/Keyboard
- Auto pilot Display/Control/Logic
- Cockpit 3D Layout

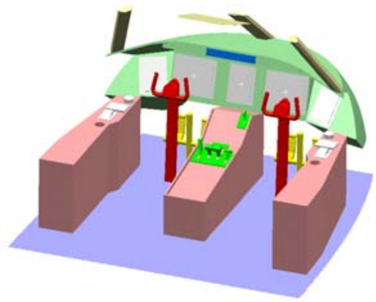

Figure 5. Cockpit Detail 3D Layout

Regulation compliance of the detail design was verified analytically or by the simulator demonstration in view of the Human Factors Certification [3] and reviewed by the DER (Designated Engineering Representative) pilot, and the design was found to be acceptable for the certification.

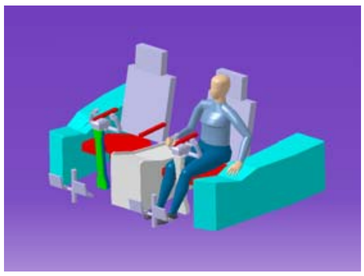

Figure 6. Panel Controllability check by CATIA

Fully functional simulator was developed, and the final verification test was carried out in a simulated full flight by the airline pilots, to validate if the developed functions and the associated procedures are effective for the situation awareness without imposing additional workload to the pilot.

Figure 7. Full Function Simulator

3 Cockpit Design Overview

The developed cockpit, established for the two-man crew, regional jet size flight deck space, is designed under the following top design philosophies.

- *Leave pilot at the top of hierarchy…*
  Pilot should be always in the control loop as a manager having final authority, while automated system is "royal servant".
- *Pilot is busy enough…*
  Information should be provided to the pilot only when necessary, at right time, in adequate format – Dark Cockpit concept.
  And, pilot should be released from "donkey" work.
- *Human capability is limited…*
  Design should be as simple and intuitive as possible, to provide better situation awareness to the pilot.

3.1 Instrument Panel Layout

Mixed size, five display units installed on the instrument panel provide ever larger, extensive indication area in front, which allow the pilot to access most of the information without head-down to the center pedestal nor head-up to the overhead panel. Two of five displays located just in front of each pilot are landscape-oriented, large displays called FIU (Flight Information Unit), integrating all flight task information into one to minimize eye movement. Left/right outboard side displays are the NU (Navigation Unit), displaying the flight plan information including the aeronautical chart for the flight management task. The NU is located beside the FIU so that the pilot can access flight management information with his/her eyes looking at the FIU. Remaining display in the middle of five displays is the CU (Center Unit), indicating the engine and system information for the system management task in a same way as the conventional Engine Instrument and Crew Alerting System (EICAS) and Multi Function Display (MFD).

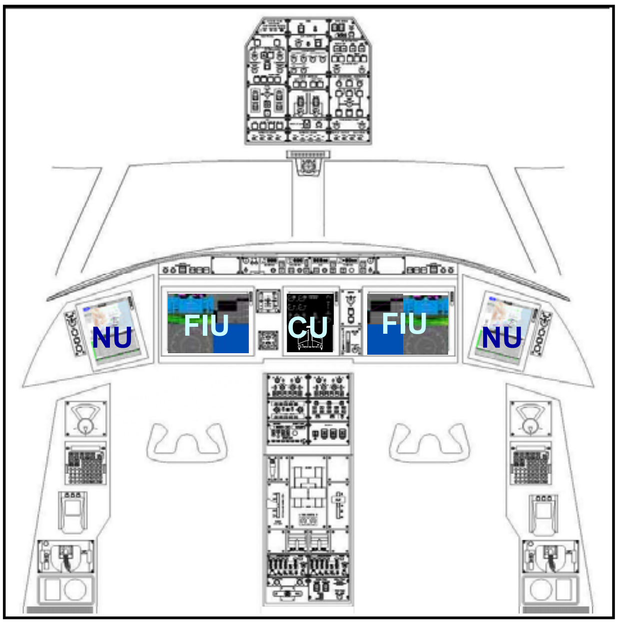

Figure 8. Instrument Panel Layout

3.2 Flight Information Unit

The 15" diagonal landscape display installed in front of each pilot integrates all flight information essential for the flight control. Display area is unevenly divided into following four sections.

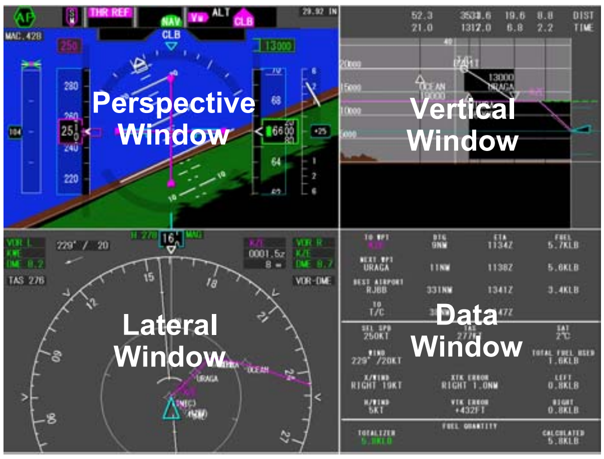

Figure 9. Flight Information Unit Display

Perspective Window…Basic-T instrument, Supplemental engine indicator, and Flight Mode Annunciator.
Lateral Window…Nose-up lateral flight path map
Vertical Window…Vertical profile display
Data Window…Flight plan progress information, and "pop-up" ATC datalink communication uplink message.

Typical display image is shown on Figure 9. Total display area for the Perspective Window and the Lateral Window which are both flight essential instruments is designed to be equal to that of the other portrait displays, to enable the reversion to the NU or CU without changing the format in case of the FIU failure.

The FIU incorporates new functions in view of the human-centered approach.

a) 3D Terrain View Overlay on PFD
CG-based 3D Terrain View using the EGPWS terrain database is overlaid behind the Attitude Indicator instead of the blue/brown artificial horizon, to enhance the terrain awareness. Normally the Attitude Indicator shows the conventional blue/ brown artificial horizon, and the 3D view automatically pops up when i) altimeter setting is in manual setting mode (which is certainly selected by the pilot when the aircraft is below the transition altitude), ii) flap is set to other than "up" position, or iii) EGPWS caution/warning alert is active, and pops down automatically when descending to Decision Height or Minimum Descent Altitude, in order to enhance the pilot to look out the actual external view. Manual on/off push button is also equipped.

b) Graphical Flight Mode Annunciator
Auto pilot and auto throttle system modes are indicated in a graphical pattern. In addition to the text information, engaged and armed modes are identified by multiple graphical cues; location, color, and shape.
- ➢ Indicated location…Specific indicator position is assigned for each mode. Mode change always follows the change of the indicator location and which enhances the mode change awareness.
- ➢ Indicator color (for vertical auto pilot and auto throttle mode)… Engaged mode is indicated in green or magenta background depending on which (the FMS or the pilot) has the authority to select the mode. Mode annunciation with green background shows the current mode manually engaged by the pilot, while magenta colored annunciation means the current vertical mode managed by the FMS.
- ➢ Indicator shape…Specific indicator shape is assigned for each mode and that gives the pilot the second cue to recognize the current engaged mode other than by the text.

Figure 10. Graphical Flight Mode Annunciator

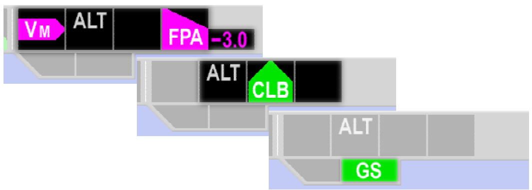

Figure 11. Examples of the Mode Annunciation

c) Vertical Profile Display
This display aims at improving the terrain awareness and the vertical flight plan/path awareness. Terrain cutout and vertical flight profile along the expected lateral path are displayed with the aircraft position and vertical trend vector, as an aid to visually check the deviation from the planned vertical profile or to determine the VS (Vertical Speed) or FPA (Flight Path Angle) value when VS or FPA mode is engaged.
Lateral displayed range is linked to that of the nose-up lateral flight path map, and vertical range is fixed in an optimized value for each lateral range so that the display can show the entire vertical profile within the selected lateral range.

The expected lateral path used for cutting the vertical flight profile and the terrain, depends on the engaged lateral mode. When the LNAV (Lateral Navigation) mode is engaged, the display shows the cutout along the FMS lateral flight plan course, and for other modes, along the current track.

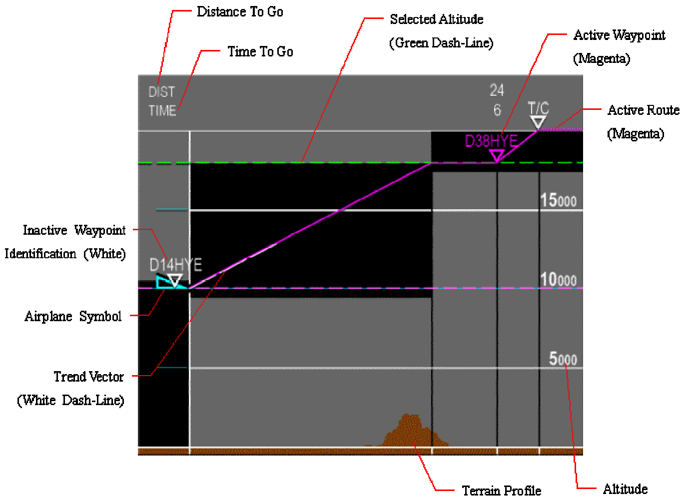

Figure 12. Vertical Profile Display

d) Supplemental N1 Indicator
Engine N1 parameter is indicated on the PFD, to provide engine thrust information to the pilot without excessive eye movement to the EICAS. This supplemental indicator shows actual, expected and commanded N1 value for each engine as well as the N1 indicator on the EICAS, which allows the pilot to manage the thrust as a flight control task completely within the FIU while engine indication on the EICAS is for the engine health monitoring.

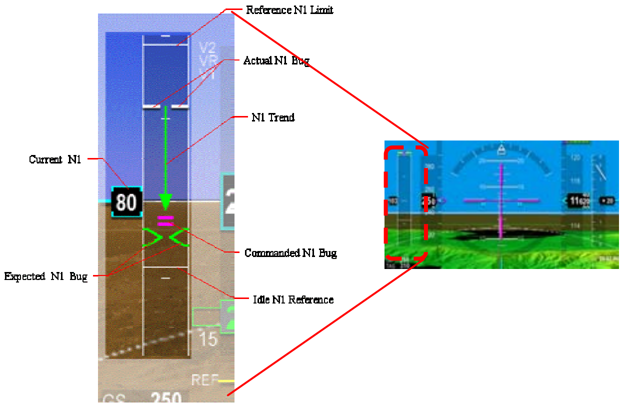

Figure 13. Supplemental N1 Indicator

3.3 Navigation Unit

The 12.8" diagonal portrait displays installed left/right outboard side of the main instrument panels are the Navigation Unit (NU) displays integrating the flight management information. In conjunction with the Cursor Control Device (CCD) and the keyboard equipped on the left/right outboard side panels, the NU system replaces the FMS CDU (Control and Display Unit) on the conventional aircraft which manages the flight plan information in the text-based display and the keyboard.

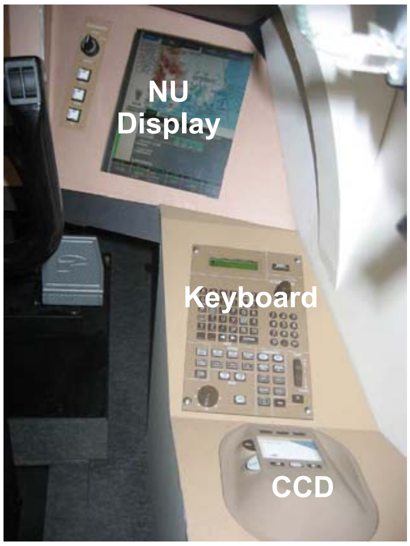

Figure 14. Navigation Unit System Installation

Graphical User Interface (GUI) is adopted for the NU, to provide more intuitive and error-tolerant flight plan input/modification/ verification method to the pilot. Graphical map is integrated with the electronic chart viewer. Flight plan route is overlaid on appropriate chart and the pilot can visually confirm the compliance or the deviation from the published aeronautical chart information. Controls including route modification are through the CCD, while conventional keyboard input method and text-based information window is still available for all functions. The pilot can select either method and that enables smoother transition from the current generation FMS CDU.

Display area is divided into following three sections.

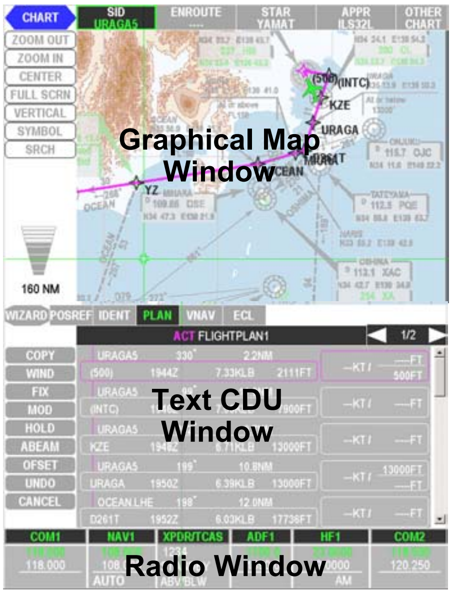

Figure 15. Navigation Unit Display

Graphical Map Window…Electronic chart is displayed, and the flight plan data with the aircraft position are overlaid on the chart. Vertical profile corresponding to the displayed lateral route can be displayed as required. Displayed charts are automatically changed per the flight plan route. Manual chart selection is also available. Page tabs are provided to change the displayed charts, so that the pilot can manually select the chart page.

Window controls including the scroll and zoom of the map are available either by the keyboard or by the CCD. In addition to the window control operation, GUI route modification can be accomplished in the map using the "point and click on the map" CCD operation.

Text CDU Window…This window is used for input and display of various text-based parameters both on ground and in flight. These parameters are grouped into the several pages per function, such as Position page, Flight Plan page, Takeoff Reference page, etc., which are hierarchically structured.

Page tabs are provided for some of the pages, to allow for direct page selection. Also, wizard function is provided to help navigating appropriate page selection among those pages at the preflight and the predescent preparation.

The text CDU window is controlled either by the Keyboard or by the CCD.

Radio Window…This window is used for the control of the navigation and communication radio equipments. They are controlled either by the rotating knob on the keyboard or by the numerical keys on the keyboard panel.

4 Evaluation

The developed cockpit system was evaluated by the commercial pilots to confirm if the system is designed to be an effective situation awareness improvement tool for practical use in the actual operational environment.

4.1 Method

Six pilots participated in the evaluation. Four of them are the airline pilots all belong to the flight operating engineering section in the large transport carrier, and each has following background;

- Boeing 777 Captain,
- Airbus 320 Captain,
- Boeing 777 First Officer, and
- Boeing 747-400 First Officer.

Other two are the flight test pilot usually operating the business and military jet on the aircraft manufacturer.

Subjective rating method was taken for the evaluation of the effectiveness of the developed cockpit system in the aspects of the situation awareness, workload, safety and operational acceptance. In addition, heuristic comments were provided to help understanding the reason for each given rating.

Before the evaluation flight, pilots received a handout-based tutorial for the cockpit system and operation including the control method of the Navigation Unit, and took an introductory full flight in the function simulator to be familiar with overall procedures.

After the introductory flight, each two of them were seated on the left and right seat on the function simulator, and made a evaluation flight, simulating the normal IFR flight operation from the preflight to the post-flight, except for unusual many times of the flight plan changes aimed to increase the workload. Mission profile is shown on Figure 16. Left and right pilots cooperatively performed all of the operational procedures of the developed systems (ie. the display system, the auto flight control system and the navigation unit system) in a real time from the preflight to the post flight. In order to provide equal opportunity to operate the Navigation Unit for both the left and right pilot, they changed their PF (Pilot Flying) and PNF (Pilot Not Flying) duties in flight.

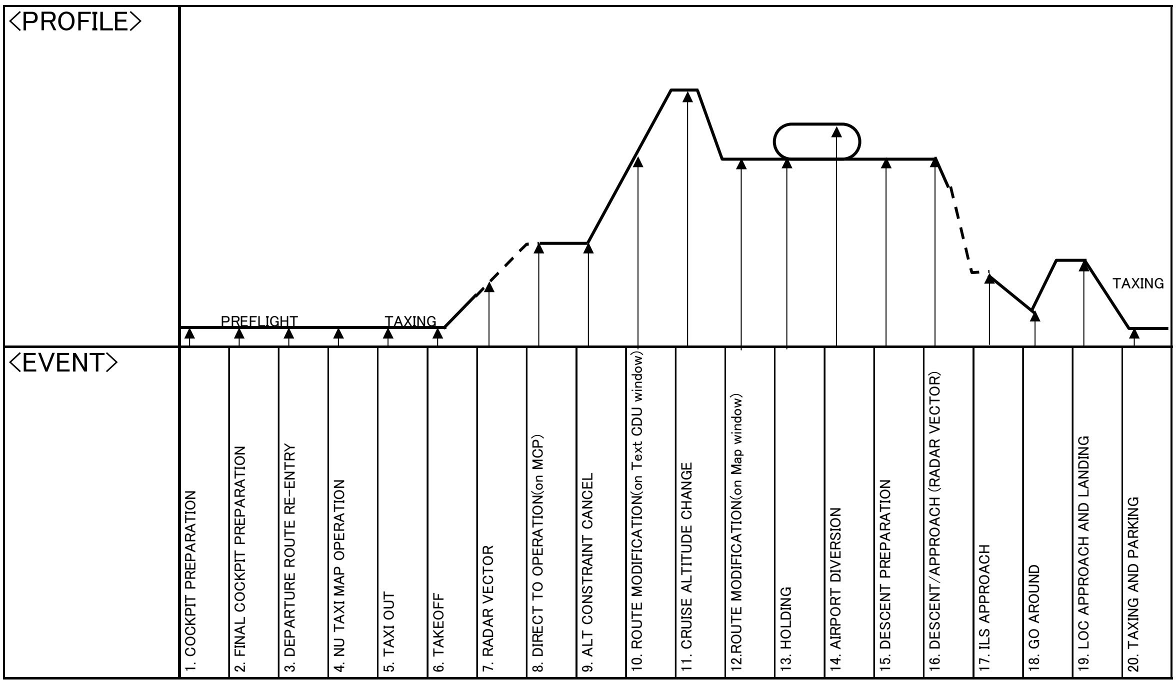

Figure 16. Evaluation Flight Mission Profile

4.2 Result

The result of the subjective rating is summarized in Figure 17.

In view of the aircraft situation awareness, the effectiveness of various improvement functions were positively accepted. Heuristic comments also supported the rating result;

- VPD is an effective tool to recognize the aircraft situation.
- VPD is especially useful on the non-precision approach, which requires the pilot to decide appropriate descent path looking into many “step down” altitude constraints.
- Graphical FMA improves the mode awareness, though “AP” or ”FD” annunciation is located too far left to give the positive awareness.

The cockpit was also evaluated to be effective for the terrain situation awareness improvement. Heuristic comment showed that the VPD, the 3D Terrain View Overlay, and the Navigation Unit display contributed to this rating;

- Terrain perspective view and ILS approach tunnel on the 3D Terrain Overlay function are very effective to avoid the CFIT accident.

Effectiveness rating for the task workload was split among the pilots. Heuristic comments were mainly described for the full time speed management function;

- Full time speed management function eliminates the speed bug setting task and contributes to the reduction of the task workload.
- Full time speed management does not always reduce the task workload, because call out action may be required in order to avoid unintended speed command change.

Negative impact for the task workload by the introduction of new function was not pointed out, except for a comment that new training system needs to be established suitable for this new cockpit system.

On the other hand, the effectiveness for the reduction of the cognitive workload was very positively accepted. Heuristic comments supported the rating result in the following reasons;

- VPD and NU display provide much better cognition for the flight plan and improve the cognitive workload.
- N1 indication on the PFD is effective for the reduction of the cognitive workload especially in manual flight.

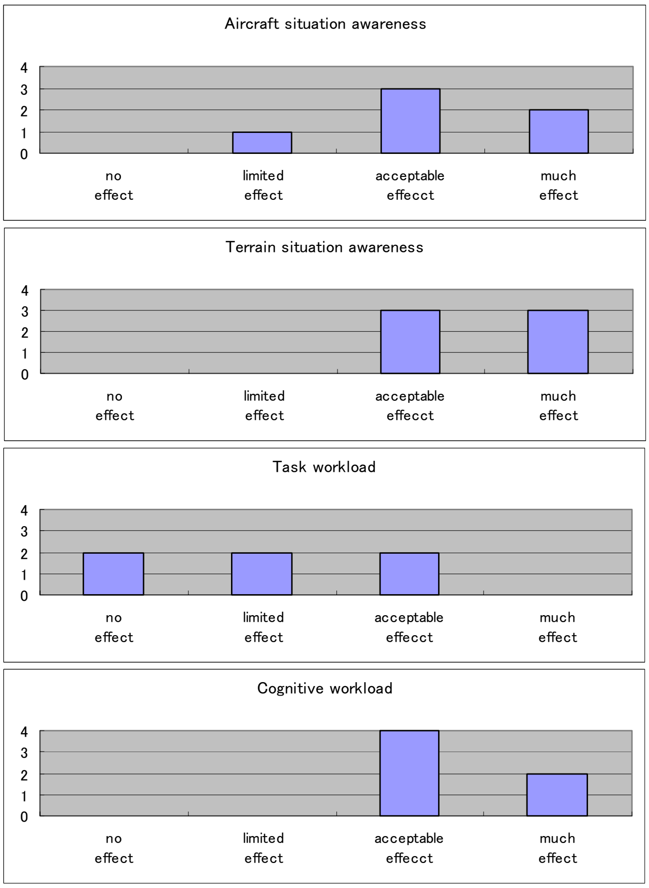

Figure 17. Subjective Rating Result

5. Conclusion

Human-Centered Cockpit system, incorporating many ideas to improve the situation awareness aiming to reduce the risk of pilot-error-induced accident was developed and was evaluated by the commercial pilots. The subjective rating and heuristic comments showed that the developed cockpit system improves the aircraft/terrain situation awareness. Contribution factor for the reduction of the task workload was not confirmed, however, the system was evaluated to reduce the cognitive workload without inducing negative task workload by the additional function.

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