Human Performance Modeling of Synthetic Vision System Use

Koji Muraoka[1], Savita Verma, Amit Jadhav, Kevin M. Corker and Brian F. Gore,

Industrial and Systems Engineering Department
Human Automation Integration Laboratory
San Jose State University
San Jose, CA 95192-0180

[1] Senior Researcher, Human Factors Team, Air Safety Technology Center, Institute of Space Technology and Aeronautics, Japan Aerospace Exploration Agency

Abstract

The San Jose State University, Human Performance Human Automation Integration Laboratory (HAIL) under support from the NASA Aviation Safety Program[2] has developed human models to predict the performance of operators using the NASA Synthetic Vision System (SVS). The standard Air MIDAS model of visual performance (Corker, 2000) was augmented to simulate pilot's monitoring of instrument and out-the-window scanning while on approach to landing. An aircraft dynamic simulation model PC Plane,© was integrated into the human-system model in order that Air MIDAS operators would be controlling aircraft performance under realistic temporal constraints. Test scenarios for the simulation were developed and procedures were established based on established cockpit procedures for a current aircraft. Simulation runs were performed under several conditions: approach & landing, and go around both with "current day" technologies or SVS cockpit configurations. Simulation results suggest that SVS use might cause small delays initiating several cockpit tasks, however, its use did not provide any issues with respect to flight safety during normal approach, landing and go around flight phase. The SVS does offer approach and landing support in all-weather conditions and support in approach to "non-instrumented" airports.

Abbreviations

AOI	Area of Interest
ATC	Air Traffic Control
DA	Decision Altitude
DLL	Dynamic Link Library
EICAS	Engine Indication and Crew Alerting System
FMS/CDU	Flight Management System/Control Display Unit
GA	Go Around
IMC	Instrument Meteorological Condition
MCP	Mode Control Panel
MIDAS	Man-machine Integration Design and Analysis System
ND	Navigation Display
OTW	Out The Window
PFD	Primary Flight Display
SOM	Symbolic Operator Model
SVS	Synthetic Vision System
UWR	Updatable World Representation
VMC	Visual Meteorological Condition
WM	Working Memory

[2] This work was supported under NASA Grant NAG2-1563. Dr. David Foyle was the contracting officer's technical representative. The SJSU team wishes to thank Dr. Foyle and his team for the unflagging support of this effort in both administrative and technical support.

© PcPlane has been developed by NASA Langely Research Center and the NASA Ames Research Center.

Introduction

NASA is developing a number of technologies designed to aid the flight crew in the safe operation of the aircraft under conditions that in the past have been shown to contribute to increased hazard in aviation operations. Those technologies have a common purpose in aiding the flight crew by providing information that has either been not available (e.g. improved traffic position information or rapid update of local meteorological conditions like turbulence) or has been obscured and degraded (e.g. visual acuity reduction in weather and at night). The advancements in computational techniques, sensor and communication technologies have resulted in an enviable design situation in which the amount and quality of information available is large and therefore must be carefully selected to avoid overwhelming the flight crew. Interesting issues of information selection, information integration requirements and display operation are open to investigation in the conceptual and early design stages of the systems development.

Synthetic Vision System(SVS)

Recently, NASA has been developing augmentative technologies for enhancing safety in flight deck operations. These developments include a synthetic vision system (SVS) for commercial aviation as well as for business jets, and general aviation operations. The system is designed to generate a texture-mapped (or wire-frame) display of the terrain in proximity to the aircraft. Text and other symbology is intended to be overlaid onto the terrain display to display, for instance, the aircraft itself, its velocity, a “follow-me” aircraft, a “tunnel-in-the-sky” indication of the route, and indications of other nearby aircraft. In addition, flight controls (air speed, attitude, pitch, etc.) are planned to be overlaid on the display. A more complete review of the several designs under development for the support and provision of synthetic vision can be found in Corker & Guneratne, (2002). In addition to these augmentations, the existing display elements of current aircraft will be maintained in an SVS equipped aircraft. Inclusion of both current presentation modes and SVS presentation modes offers a challenge in research into the operational concept of their joint usage. Specifically, providing both of these sources of information may be problematic. On one hand, they support cross checking of flight deck systems. On the other hand, two types of information that are similar in source and content, but different in presentation mode may cause transformation workload for the pilot. When systems such as that proposed for the SVS are being designed, we suggest that computational human performance models can be used to predict various performance effects of introducing such augmented technologies in early design phases.

Purpose

The purpose of this study was to generate predictions of human performance using the synthetic vision system under several conditions of approach and landing. These predictions are provided by a computational model of human-system performance called Air MIDAS (Air Man-machine Integration Design and Analysis System).

To support these predictions in an accurate representation of the time-varying dynamics of approach to landing a high fidelity aircraft performance model, PC Plane model (Palmer et. al., 1997), was integrated into the human performance model’s knowledge-base and the aircraft model interacted with the SVS display generation models. The combined human and aircraft model and the flight’s evolution in time served as a forcing function, or triggering mechanism, for emergent human performance in interaction with the display and control systems. The visual perception model, previously used in Air MIDAS which has been developed and validated in the course of Air MIDAS SVS project, was further enhanced and used to simulate pilot's instruments and Out The Window (OTW) scan pattern.

Approach/Landing and Go Around, which are the most critical part of a normal flight phases were selected for the simulation scenario and human performance was predicted in terms of a number of dependent variables that include aircraft control performance (e.g., cross track and vertical error, workload, decision making) and visual scan pattern change caused by SVS usage.

Human Model Architecture

Figure 1 depicts functional architecture of the entire Air MIDAS SVS simulation environment. The Air MIDAS software (a NASA Ames Research Center, SJSU development effort) is a performance prediction software system that uses models of human performance within an integrated computational framework to generate workload, and activity timelines in response to operational environments. The main components of the model exercised in this study were the simulated operator’s perceptual processes and the world representation in the symbolic operator model (SOM) representing perceptual and cognitive activities of an agent. In the SOM, the Updateable World Representation (UWR) contains information about the environment, crew-station, vehicle, physical constraints and the terrain. Updates of the states of these elements are provided through the perceptual and attention processes of the SOM. The world representation serves to trigger activities in the simulated operator to serve mission goals in nominal operations or respond to anomalies. The UWR also contains the Working Memory (WM) of the simulated operator, the domain knowledge, and a goal-based procedural activity structures. Activities to be performed are managed through a queuing process and scheduled according to priority and resource availability. Four resource pools (Visual, Auditory, Cognitive, and Psychomotor) are checked for resource availability in response to the demands for those resources by the required tasks (McCracken & Aldrich, 1984).

PC Plane flight simulation model framework was integrated to the existing Air MIDAS architecture as a part of the operator's world representation. PC Plane is a NASA-developed PC-based flight simulation software mainly used for human-in-the loop part-task simulation of flight management system, cockpit display and future air traffic operation. PC Plane aircraft dynamics provide flight and system status to equipment components comprising of Primary Flight Display (PFD), Navigation Display (ND), Engine Indicating and Crew Alert System (EICAS), SVS and OTW and is controlled by inputs from Air MIDAS pilots. Visual scan pattern and flight crew's cockpit tasks were implemented into SOM for SVS application. Following sections describe system architecture of the simulation environment as well as detailed implementation of PC Plane and visual scan pattern model.

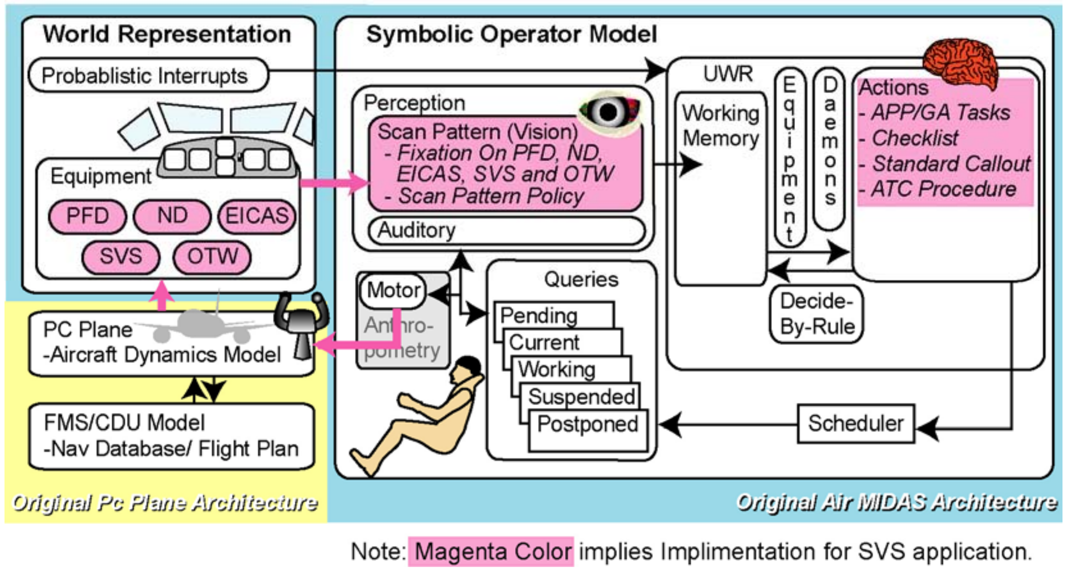


Figure 1 Overall Air MIDAS SVS application Architecture

<u>System Architecture</u>

Figure 2 depicts the system architecture of Air MIDAS SVS simulation environment. Three modules including PC Plane aircraft dynamics, Flight Management System/Control Display Unit (FMS/CDU) and Air MIDAS were integrated into the simulation. A set of Dynamic Link Library (DLL) functions that generate cockpit control input and time synchronization control to PC Plane through socket connection were prepared. DLL functions were invoked by Air MIDAS module, which was written in LISP, through JAVA network interface architecture. Time synchronization control function realized precise synchronization of Air MIDAS and PC Plane during simulation and enabled dynamic closed loop simulation.

Microsoft Office Access database architecture was used to share flight and aircraft system parameters between SOM and world representation. The database comprises PFD, ND, EICAS, SVS and OTW data sheets and each sheet includes parameter values displayed on it. PC Plane updates all of the parameters in the database as time proceeds. Air MIDAS visual scan pattern model reads data from a particular data sheet when the agent fixates on a corresponding display.

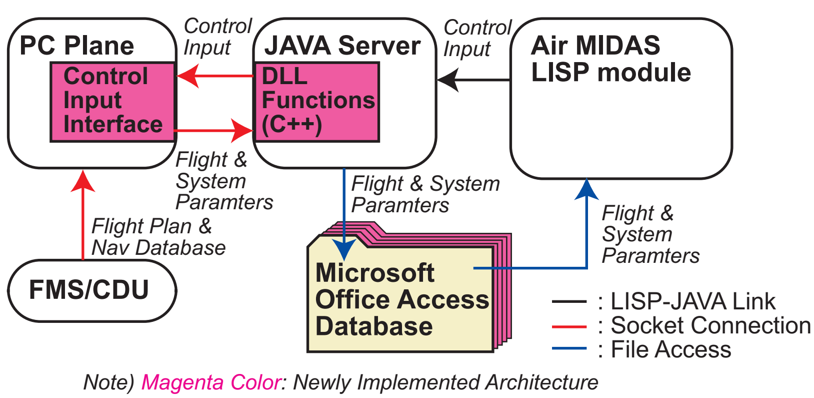
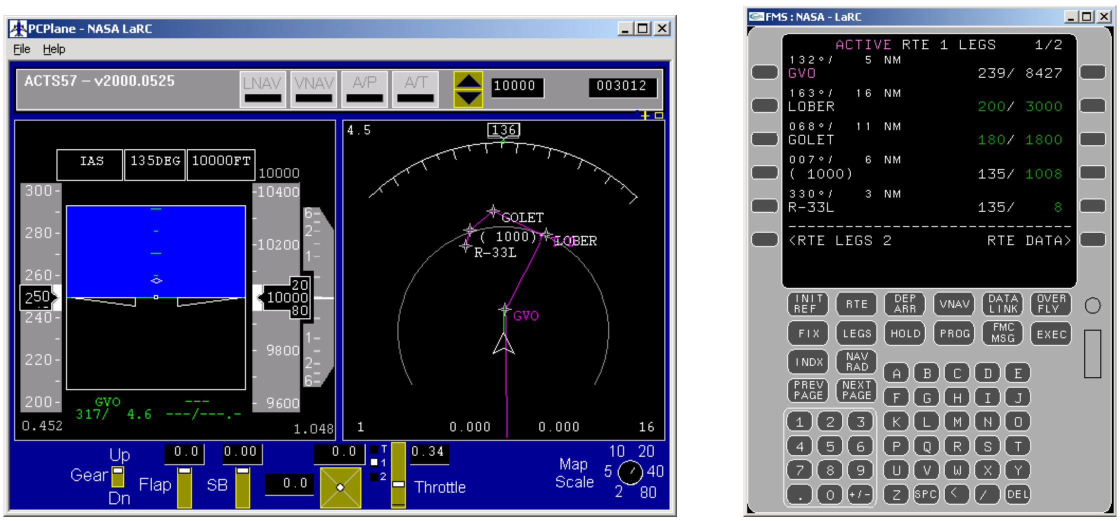


Figure 2 System Architecture

Equipment Model

PC Plane Architecture

The original PC Plane has the functions of an aircraft mathematical model, PFD, ND and a processor for human control input such as flight control from mouse and game stick devices. Also, it has the function of communicating with external modules such as FMS/CDU and Mode Control Panel (MCP). For the Air MIDAS world representation, FMS/CDU were used and PC Plane software was further enhanced by adding interface functions that process control input from Air MIDAS pilot agent (instead of a real human pilot). Also, a simulation time control function was added to PC Plane. This enabled fast time simulation synchronization with Air MIDAS instead of the real time human-in-the-loop simulation. Boeing B757 aerodynamic and engine model of PC Plane was used for this study. FMS/CDU module of Air MIDAS was connected to PC Plane through socket connection to provide navigation database and flight plan data. Since scenarios of this study did not require FMS operation, no input functions from Air MIDAS operator agent to replace the human input were added to the original module.

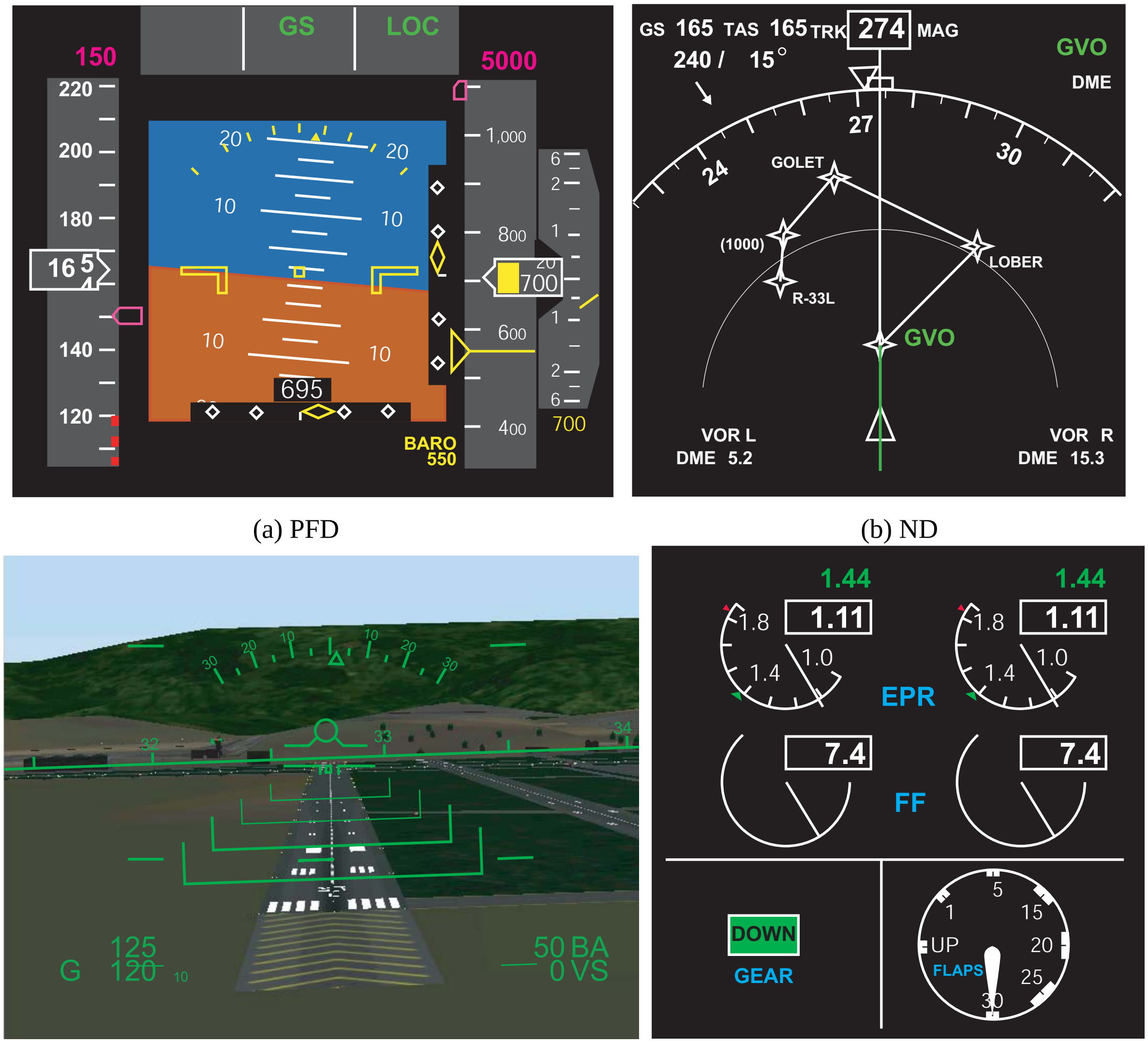


(A) PC Plane (b) FMS/CDU

Figure 3 PC Plane Modules

Cockpit Display

The cockpit display model was developed to simulate the PC plane's flight and system status for Air MIDAS pilot agent. We assumed displays shown in Figure 4 were equipped on the aircraft. Air MIDAS does not have a vision function of depth perception or transformation mechanism from visual image perception (in a plan view display, for example) to recognition of the meaning of that information with respect to route of flight. Therefore, the display model was designed to provide the flight and system status by means of numerical values. Microsoft Office Access Database framework was used to share the parameter values between Air MIDAS SOM and PC Plane. The database is comprised of data sheets for PFD, ND, EICAS, SVS and OTW. Each sheet includes flight parameter values that would be shown on an equivalent display. Each sheet also includes the location of displayed area was specified for each parameter. Figure 5 summarizes specification of the data sheets. All of the parameter values in the data sheets were continuously updated by PC plane. However, the pilot's internal representation was only updated when Air MIDAS vision model read part of them by "fixating" on an equivalent area of a display.



(a) PFD (b) ND

(c) SVS (d) EICAS

Figure 4 Assumed Displays Images

PFD

Parameter	Description	UNIT	VALUE (ex)	AREA
thedg	Pitch Angle	(deg)	5.20	ATT
phidg	Bank Angle	(deg)	10.1	ATT
easkt	IAS	(kt)	213	SPDTAPE
selias	Speed Command	(kt)	200	SPDTAPE
altft	Press. Altitude	(ft)	3,235	ALTTAPE
selalt	Altitude Command	(ft)	3,000	ALTTAPE
roc	Rate of Climb	(fpm)	500	ALTTAPE
apth_e01	Autothrottle Mode		SPD	FMA
appt_e01	Aitopilot Pitch Mode		VNAV	FMA
aprl_e01	Autopilot Roll Mode		LNAV	FMA

EICAS

Parameter	Description	UNIT	VALUE (ex)	AREA
flap	Flap Angle	(deg)	20.0	CONTROL
nsgear	Gear Position		1	CONTROL
sbrk	Speed Brake Angle	(ratio)	0.1	CONTROL

OTW

Parameter	Description	UNIT	VALUE (ex)	AREA
thedg	Pitch Angle	(deg)	5.20	ATT
phidg	Bank Angle	(deg)	10.1	ATT
visibility	Visibility	(smi)	5.0	TRR
rpos_tw_dme	DME to Runway	(nm)	20.1	NAV
rpos_rw_brg	Bearing to Runway	(deg)	32.0	NAV

ND

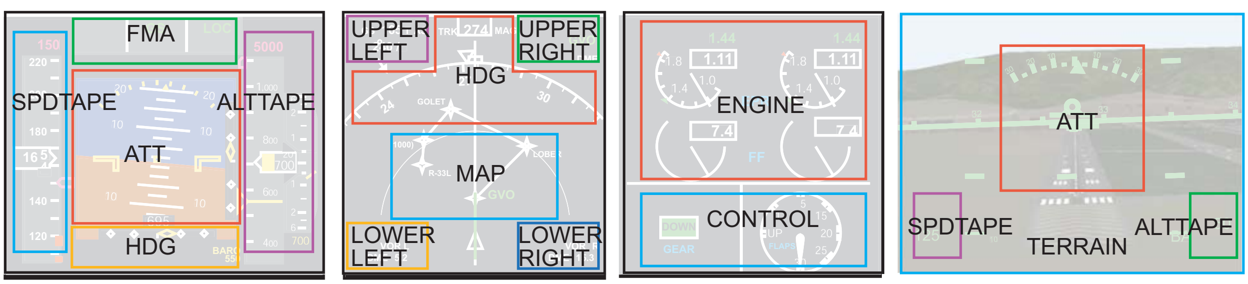
Parameter	Description	UNIT	VALUE (ex)	AREA
psidg	Heading Angle	(deg)	276.0	HDG
track	Track Angle	(deg)	269.0	HDG
selhdg	Heading Command	(deg)	300.0	HDG
to_wpt	Name of To Waypoint		GOLET	MAP
rpos_to_dme	DME to To WPT	(nm)	11.2	MAP
rpos_to_brg	Bearing to To WPT	(deg)	125.0	MAP
rpos_tw_dme	DME to Runway	(nm)	20.1	MAP
rpos_rw_brg	Bearing to Runway	(deg)	32.0	MAP

SVS

Parameter	Description	UNIT	VALUE (ex)	AREA
thedg	Pitch Angle	(deg)	5.20	ATT
phidg	Bank Angle	(deg)	10.1	ATT
easkt	IAS	(kt)	213	SPDTAPE
selias	Speed Command	(kt)	200	SPDTAPE
altft	Press. Altitude	(ft)	3,235	ALTTAPE
selalt	Altitude Command	(ft)	3,000	ALTTAPE
roc	Rate of Climb	(fpm)	500	ALTTAPE
rpos_tw_dme	DME to Runway	(nm)	20.1	OTW
rpos_rw_brg	Bearing to Runway	(deg)	32.0	OTW

Note) Altitude and Speed on SVS was not used for the trigger of procedural tasks.

Figure 5(a) Cockpit Display Data Sheets Specification



(a) PFD (b) ND (c) EICAS (d) SVS

Figure 5(b) Cockpit Display Area Definition

<u>Air MIDAS Symbolic Operator Model</u>

Flight and system information provided by cockpit display models was passed into the SOM through its visual perception models. Once this information was perceived through the scan pattern, it was passed into the UWR and salient values of the data were used to trigger cockpit activities.

For this study, WM storage nodes to accommodate PFD, ND, EICAS, SVS and OTW were prepared. In WM domain knowledge and rules to invoke actions regarding cockpit procedures such as (1) Approach & Landing and Go Around procedure, (2) Standard callout, (3) Checklist, (4) ATC communication and (5) Landing/go-around decision were implemented.

In this research effort, perceptual processes associated with the SVS system and/or OTW observation are critically important. Detailed structure is described below.

Scan Pattern Model

Air MIDAS visual perception model simulates pilot's information acquisition process from cockpit displays and OTW. This activity was assumed to be comprised of both periodical information sampling and directed information acquisition associated with demand from a particular cockpit task. During the flight, pilot continuously monitors flight and system status based on the periodical information sampling. If a certain demand comes from a cockpit task, for example pilot's confirmation of his/her own action of setting speed command, the pilot would intentionally focus on a particular information, in this example the speed command indication on PFD speed tape, by interrupting the normal periodic information sampling. Directed information acquisition of visual perception was implemented as a part of Air MIDAS cockpit procedural tasks and periodical information sampling was implemented as a scan pattern model is described below.

A scan pattern model has been developed and validated in the course of ongoing Air MIDAS human performance modeling research efforts (Corker et al., 2003). For this study, the scan pattern policy was a new addition and the scan pattern's specification of display configuration and corresponding human performance database was slightly modified to fit the simulated cockpit configuration.

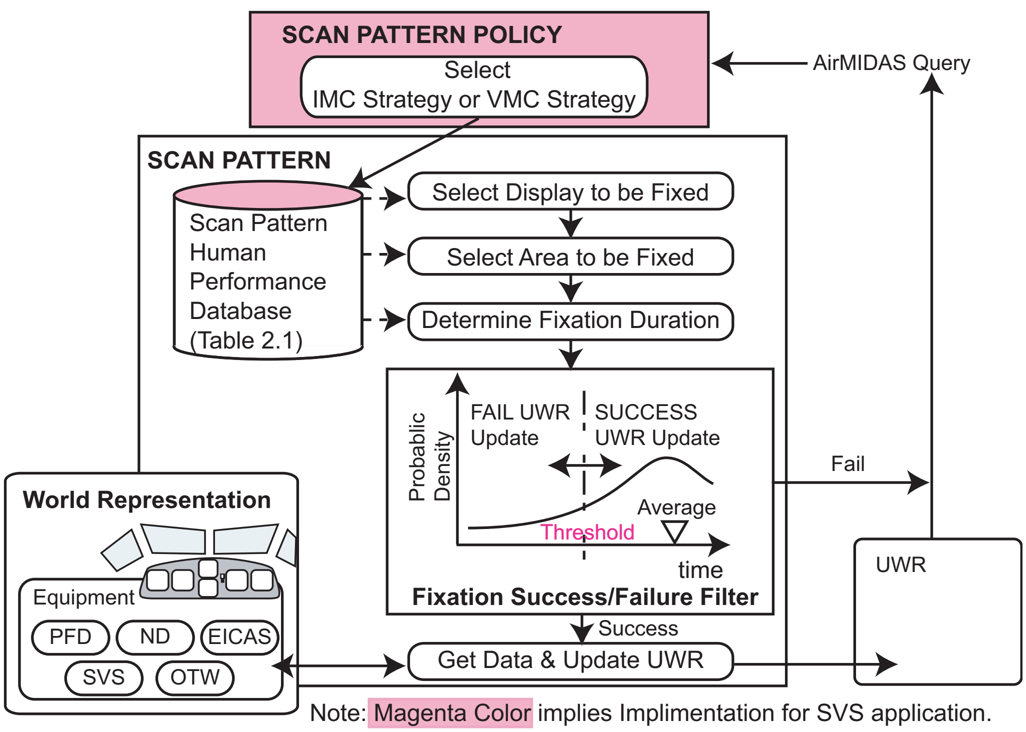


Figure 6 Visual Perception Model Logic

Scan Pattern

Figure 6 depicts logic of Air MIDAS scan pattern model. The scan pattern selects display, selects the area to fixate its eyes, aggregates the values of displayed parameters and then updates UWR. Failure of data aggregation was also simulated, with a corresponding failure to update the UWR.

The normal internal scan pattern and fixation time was based on NASA HPM team's data collected for Human In The Loop simulation (Foyle & Hooey, 2002). The Phase-1 of this modeling effort had used NASA's report on the Analysis of Pilot's Monitoring and Performance on Highly Automated Flight Decks generated by Mumaw et al., (2000). Since their experiments were focused on VNAV descent flight phase without SVS, the data provided by Foyle & Hooey (2002) was used for the current phase of development. The modified scan pattern model shown in Table 1 was prepared based on following assumptions:

1) The pilot applies different scan pattern according to the availability of information on OTW. Two different scan pattern strategies, Instrument Meteorological Condition (IMC) strategy and Visual Meteorological Condition (VMC) strategy, were prepared for both with and without SVS configuration.

2) Off-Area of Interest (AOI) and overlapped AOI fixation percentages in the Foyle & Hooey (2002) data analysis were combined. Off-AOI scans signify inattention to the instruments, but the same logic might not be applied for overlapped AOI. Overlapped AOI simply means that the operator is not foveating, but his/her peripheral vision can detect warnings and similar changes in the instruments. However, Air MIDAS did implement wide area peripheral vision for this version. So, Off-AOI and overlapped fixation patterns were combined.

3) "Fixation on control setting" data in Foyle & Hooey (2002) data analysis report was used for EICAS fixation considering the difference of cockpit configuration. Human-in-the-loop simulation setup did not have EICAS but have PC screen based control input to get data to be shown on EICAS.

(a) VMC Strategy (without SVS)

Area of Interest (Display)	Fixation (%)	Average Duration (sec)	SD (sec)
Off + Overlapp	16.29	0.235	0.65
OTW	11.51	0.214	1.46
SVS	0	0	0
PFD	33.03	0.236	0.74
NAV	35.63	0.299	1.43
MCP	3.18	0.322	2.75
EICAS	0.37	0.274	0.84

(b) VMC Strategy (with SVS)

Area of Interest (Display)	Fixation (%)	Average Duration (sec)	SD (sec)
Off + Overlapp	16.10	0.235	0.65
OTW	11.38	0.214	1.46
SVS	0.14	0.180	0.06
PFD	32.65	0.236	0.74
NAV	35.22	0.299	1.43
MCP	3.14	0.322	2.75
EICAS	0.37	0.274	0.84

(c) IMC Strategy (without SVS)

Area of Interest (Display)	Fixation (%)	Average Duration (sec)	SD (sec)
Off + Overlapp	3.03	0.200	0.21
OTW	2.41	0.222	0.60
SVS	0	0	0
PFD	38.89	0.437	1.22
NAV	47.12	0.421	1.29
MCP	3.28	0.365	2.78
EICAS	5.26	0.530	1.75

(d) IMC Strategy (with SVS)

Area of Interest (Display)	Fixation (%)	Average Duration (sec)	SD (sec)
Off + Overlapp	3.86	0.225	0.58
OTW	0.34	0.285	0.20
SVS	25.34	0.347	2.72
PFD	29.92	0.392	0.82
NAV	32.21	0.393	0.95
MCP	4.19	0.423	3.42
EICAS	4.14	0.392	1.80

(e) Fixation Rate rate for Display Area

PFD		ND		EICAS		SVS		OTW	
Area	Fixation	Area	Fixation	Area	Fixation	Area	Fixation	Area	Fixation
ATT	34.0%	HDG	40.0%	ENGINE	80.0%	ATT	25.0%	Terrain	33.0%
SPDTAPE	27.0%	MAP	40.0%	CONTROL	20.0%	OTW	25.0%	NAV	33.0%
ALTTAPE	29.0%	UPLEFT	5.0%			SPDTAPE	25.0%	ATT	34.0%
FMA	6.0%	UPRIGHT	5.0%			ALTTAPE	25.0%		
HDG	4.0%	LOWLEFT	5.0%						
		LOWRIGHT	5.0%						

Table 1 Scan Pattern Model Human Performance Database

Once the display, its area and duration to be fixated were determined, the fixation success/failure filter evaluated whether the fixation could successfully aggregate data or not. For this filter, we used a simplification of our method of partial information intake. In other simulations, as dwell time increased components of information are gradually provided to the appropriate slots in the UWR update. (This assumes that there are actions that can be taken based on partial information.) In this simulation we applied a threshold function such that it was assumed all the data included in the area can be successfully perceived when the fixation duration was long enough or not perceived at all if the threshold value was not met. Based on this assumption, Air MIDAS updated parameters in UWR when the fixation duration was longer than a specified threshold, but if shorter, it did not perform any UWR update. Since this assumption was associated with failure of perception and selection of a threshold would affect on the results of simulation, threshold setting was examined through simulation runs and determined to be set at (mean_duration-1.0standard_deviation) (sec) so that rate of scan failure was about 10% or less. Examination of threshold setting will be described in Result and Analysis section.

Scan Pattern Policy

Scan pattern policy selects scan pattern strategy to be applied for scan pattern. Algorithms of the scan pattern policy summarized in Table 2 were defined simulating both PF and PNFs' roles in system monitoring. These were defined according to "Scan Pattern Policy" in an aircraft operation manual. The procedures, as specified in the aircraft operation manual, (see Figure 8) were used to implement the scan pattern policy. Since only the PF's eye fixation data of human-in-the-loop simulation in both VMC and IMC condition was available, VMC strategy was applied for PNF's strategy including "outside scan" to detect the runway, and IMC strategy was applied for PNF's "instrument scan."

Table 2 Scan Pattern Policy Algorithm

Pilot	Condition	Strategy Selection	Documented Scan Pattern Policy *(Simulated)*
PF	Before Runway Insight	IMC	PF: -Outside view should be included into his/her scan pattern after "Runway in Sight."
	After Runway Insight or After DA	VMC	After passing Approaching Minimum: - Outside View should be included into his/her scan pattern.
PNF	Before Runway Insight	VMC	PNF: - After passing Final approach fix, outside view should be included in his/her scan pattern. After runway becomes insight, he/she should perform instrument scan.
	After Runway Insight	IMC	After passing Approaching Minimum:

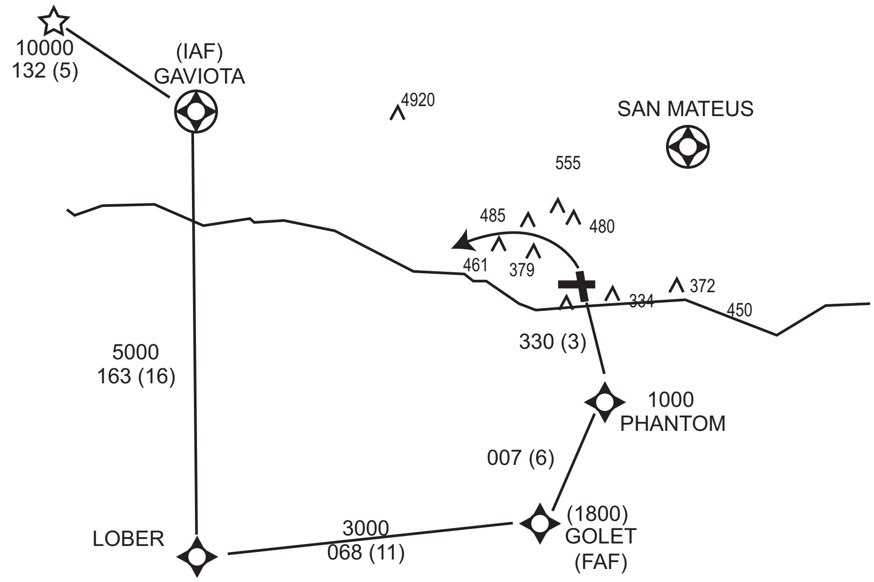
METHOD

A series of simulation runs were performed to evaluate SVS's impact on cockpit performances focusing on scan pattern change associated with SVS implementation. Normal approach and go around flight were simulated and two different decision altitudes (DA) were prepared. The two different go around triggers including ATC command and lack of visibility of runway at decision altitude (DA) were prepared for go around simulation.

<u>Scenario</u>

Flight Area

Figure 7 depicts approach chart for the simulation. Based on the existing GPS approach procedure to Santa Barbara airport, GPS-VNAV/LNAV approach to runway 33L was assumed. Initial position was located 5 (nm) north west of GAVIOTA - initial approach fix, and flight using autopilot and auto throttle with VNAV and LNAV mode was assumed. Two decision altitudes were assigned in order to examine the impact of SVS usage on DA selection for approach procedures. DA 650 (ft) is as high as the usual non-precision approach decision altitude and DA 200 (ft) is as high as category I instrument approach decision height. A detailed missed approach pattern was not prepared as the scope of the go around simulation was focused on the phase of making the go around decision and initiating a go around climb. The go around simulation terminated when aircraft achieved positive climb with gear up and flaps 5 configurations. The landing simulation terminated when aircraft touched down. No other aircraft were assumed to be in the area.



Aircraft Initial Condition (5nm before GAVIOTA)		
Position (Lon)	[deg]	34.599
Position (Lat)	[deg]	-120.133
Weight	[lb]	18000
Altitude	[ft]	10000
Airspeed	[kt]	250
Heading	[deg]	150
Gear		Up
Flap		Up

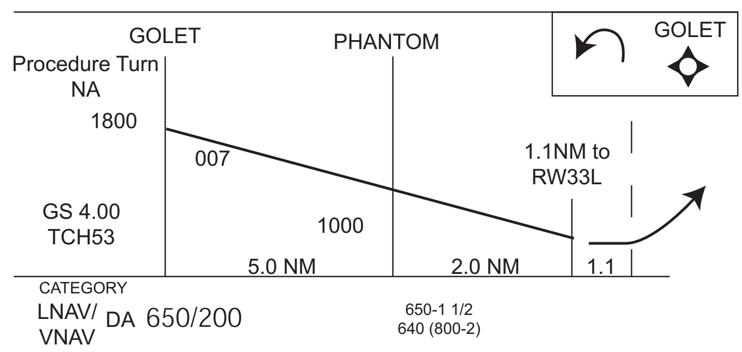


Figure 7 Flight Area

Procedures

Cockpit activities including (a) Approach/Landing/Go Around, (b) Standard Callout, (c) Checklist, (d) Scan Policy and Scan Pattern, (e) ATC Communication, (f) Go Around (GA) decision were implemented as a part of Air MIDAS activities.

Among these activities, (a) through (d) are usually described in an aircraft operating manual and similar documents in figure 8 were used for Air MIDAS implementation. (d)Scan Pattern policy was installed as a part of scan pattern model and others were implemented as a part of Air MIDAS's domain knowledge and tasks. Activity - (e), which was ATC communication included approach clearance, landing clearance, or go around command. PNF model was assumed to be in charge of ATC communication tasks. Activity-(f), GA decision for this model was defined as a set of activities that decide whether to continue landing or perform go around based on the flight and system status such as visibility of the runway, tracking of nominal approach path, and the stability of aircraft etc. Go Around (GA) decision for Air MIDAS was designed so that it was taken immediately after passing DA.

Detailed implementation of cockpit activities are described in Appendix 1.

Scan Policy

PF: -Outside view should be included into his/her scan pattern after PNF calls out "Runway in Sight."
After passing Approaching Minimum:
- Outside View should be included into his/her scan pattern.

PNF: - After passing FAF, outside view should be included in his/her scan pattern. After runway or visual cue to identify the runway becomes insight and s/he callout it, he/she should perform instrument scan.
After passing Approaching Minimum:
- PNF should concentrate on instrument scan.

Standard Callout (Approach & Landing)

Flight Phase	PF	PNF
FAF	**** (GOLET)	****, **ft (GOLET, xx ft)
Field Elv.+1,000 ft (BARO)	(Roger)	(One Thousand)
Field Elev.+500ft (BARO)	Stabilized	(Five Hundred)
DA + 80 ft	Check	(Approaching Minimum)
DA	Landing/Go-Around	Minimum
Runway In Sight		Runway In Sight
MAP		Missed Approach Point
100ft RA		(One Hundred)

Landing Checklist

LANDING GEAR................................DOWN
SPEEDBRAKE.....................................ARMED
FLAPS...XX

Approach & Landing

PF	PNF
Order "Flaps XXX" according to Flap Extension Schedule	Readback "Flaps XXX" Set Flap Lever XXX
Order "Gear Down" Order "Flaps 20"	Readback "Gear Down" Landing Gear DN Readback "Flaps 20" Set Flap Lever 20
Speedbrake Lever ARM	
Landing Flap "Flaps XX"	Readback "Flaps XX" Set Flap Lever
Set Missed Approach Alt on MCP	
Order "Landing Checklist" Callout "Checklist Complete"	Perform "Landing Checklist"
Monitor Approach Progress	

Go Around

PF	PNF
Callout "Go-Around" Push TO/GA Switch Order "Flaps 20"	Readback "Flaps 20" Set Flap lever 20
Confirm Go-Around Attitude and Increasing Thrust	
	Check appropriate GA-Thrust and correct Thrust Setting if necessary.
Positive Rate of Climb "Gear Up"	Check Positive Rate of Climb Readback "Gear Up" Gear Lever Up
⋮	⋮
Followings were omitted for simulation setting	

Figure 8 "Documented" cockpit procedures.

<u>Participants</u>

Three human agent models, pilot flying (PF Air MIDAS), pilot-not-flying (PNF Air MIDAS) and air traffic control (ATC controller Air MIDAS), were included in each simulation run. The ATC agent's set of activities were mostly communication and included providing the clearance message. No cognitive process of traffic control tasks was assumed. The ATC activities were designed in this way so that the researcher could control the timing of message generation for PF and PNF Air MIDAS.

<u>Simulation Cases</u>

Table 3 summarizes simulation cases. Normal approach without SVS case was used as a baseline. Two go around conditions including go around following controller's command and go around based on PF's decision were also examined. Two different out the window visibility levels, which switched at a specified altitude, were used associated with cockpit activities "Runway-In-Sight" callout, and PF's go around decision. Visibility was set so that Runway became insight at 150 ft before DA, except in the PF's go around decision cases. Visibility in case 9, 10, 11 and 12 was set so that go around event is triggered due to an inability to see the runway at DA. In ATC's go around command cases, two sets of the timing were used so that the interruption of pilot activities took place both in busier and the less busy phase of flight. The command was issued about 100 ft before DA, which was the busier phase including the tasks of runway in sight callout and approaching minimum callout, in case 5, 6, 7 and 8, and it was issued at 250ft before DA, where no particular activity was not expected.

In each simulation run, flight parameters such as altitude, airspeed, position etc, VACM workload of PF and PNF model, and the status of visual scan including location and success/failure of the scan were recorded.

Table 3 Simulation Cases

Case No.	Approach	SVS	DA (ft)	Weather vis_abv / alt / vis_blw (smi)/(ft)/(smi)	Events	Description	Runs
1	Normal Approach	Without	650	0.5/800/10.0		Base Line	5
2	Normal Approach	With	650	0.5/800/10.0		Base Line	5
3	Normal Approach	Without	200	0.5/350/10.0		DA@200	5
4	Normal Approach	With	200	0.5/350/10.0		DA@200	5
5	Go-Around	Without	650	0.5/800/10.0	ATC GA Com @750ft	GA by ATC	5
6	Go-Around	With	650	0.5/800/10.0	ATC GA Com @750ft	GA by ATC	5
7	Go-Around	Without	200	0.5/350/10.0	ATC GA Com @300ft	GA by ATC	5
8	Go-Around	With	200	0.5/350/10.0	ATC GA Com @300ft	GA by ATC	5
9	Go-Around	Without	650	0.2/650/0.2		GA by Pilot	5
10	Go-Around	With	650	0.2/650/0.2		GA by Pilot	5
11	Go-Around	Without	200	0.2/200/0.2		GA by Pilot	5
12	Go-Around	With	200	0.2/200/0.2		GA by Pilot	5
13	Go-Around	Without	650	0.5/800/10.0	ATC GA Com @900	ATC@HighWL	5
14	Go-Around	With	650	0.5/800/10.0	ATC GA Com @900	ATC@HighWL	5
15	Go-Around	Without	200	0.5/350/10.0	ATC GA Com @450	ATC@HighWL	5
16	Go-Around	With	200	0.5/350/10.0	ATC GA Com @450	ATC@HighWL	5

Note) vis_abv: Visibility above (boundary) altitude.
vis_blw: Visibility below (boundary) altitude

Results and Analysis

Flight Profile and Task Sequences

In all runs, landing or go around mission were safely completed by Air MIDAS pilots. Followings summarize simulation results of flight and task sequence in landing, go around by ATC command and by PF model's decision cases by selecting some of simulation runs for analyses.

Normal Approach

Figure 9 shows the flight path and task sequence of case 2 run 1, one of the normal approach cases. Speed command setting, flap lever position and gear position are the system parameters, which were manipulated by Air MIDAS pilots. Since the aircraft was flown with autopilot (VNAV and LNAV modes) and auto-throttle (VNAV mode), control surface parameters do not show any Air MIDAS manipulations.

After the flight started, airspeed was reduced overriding the setting of the MCP speed knob. Airspeed was reduced by VNAV programmed airspeed command. Then the PF model set airspeed command to 200 (kt) and overrode the VNAV airspeed command, which is the activation of the speed intervention, by pushing speed knob. When the airspeed was reduced to 218 (kt) at 131.7(sec) PF model ordered flap deployment and PNF model set the flap lever to 5 (deg). At 134.5(sec), PF model decreased airspeed command to 160 (kt) for further flap extension. The timing of this action was before the aircraft had achieved the previous airspeed command since the starting condition of the task was specified by the completion of the flap deployment action and airspeed with a certain margins (between 210kt and 190kt).

After passing 800 (ft), which is a boundary altitude of low and high visibility area, PNF model called out "Runway-In-Sight" at 772(ft), and 784.7(sec) at that moment PNF model fixated on OTW. At 796.3 (sec), after passing DA(= 650ft), PF decided landing and called out "Landing" then aircraft touched down on the runway at 845.4(sec).

Figure 9 (c) and (d) are time history of the PF and PNF model's workload. (For visual clarity among procedures, scan pattern was omitted to plot, since this procedure was performed continuously during the simulation run with visual workload of 5.9). This procedure was always performed as a back ground task and was interrupted by other tasks performed by the PF and PNF agents. Both PF and PNF models had higher density of workload period before they completed the configuration landing flaps, airspeed and gear. PF model also had higher density of workload period from around DA to touch down. PF model/ agent had maximum visual workloads of 7.0 when it performs speed reduction and orders flap extension, and when it performs landing/go ground decision with maximum cognitive workload at 7.0. Maximum auditory and motor workload was 5 in the simulated flight. As for PNF model, it did not have the moment when the workload value reached 7.0.

Go Around according to ATC command

Flight and task sequence of case 8 run 1 is shown on figure 10 as an example of simulation results of go around due to ATC command scenario. At 8126(sec), go around command was issued by air traffic controller model. Both pilot models heard it and PF model called out "Go Around" at 812.9(sec). Then PF model pushed go lever and set pitch attitude to 10 degrees. PNF model set the flap lever to 5(deg) at 818.6 (sec) following the order from PF model. After confirming positive climb, PF model ordered gear up and PNF set the gear lever up position at 821.5(sec).

Figure 10 (c) and (d) shows time history of PF and PNF model's workload. PF model had larger density of visual, cognitive and motor workload after hearing go around command with auditory workload at 5 compared with the density around and after DA in normal approach flight. This was caused by time-critical tasks required to perform go around.

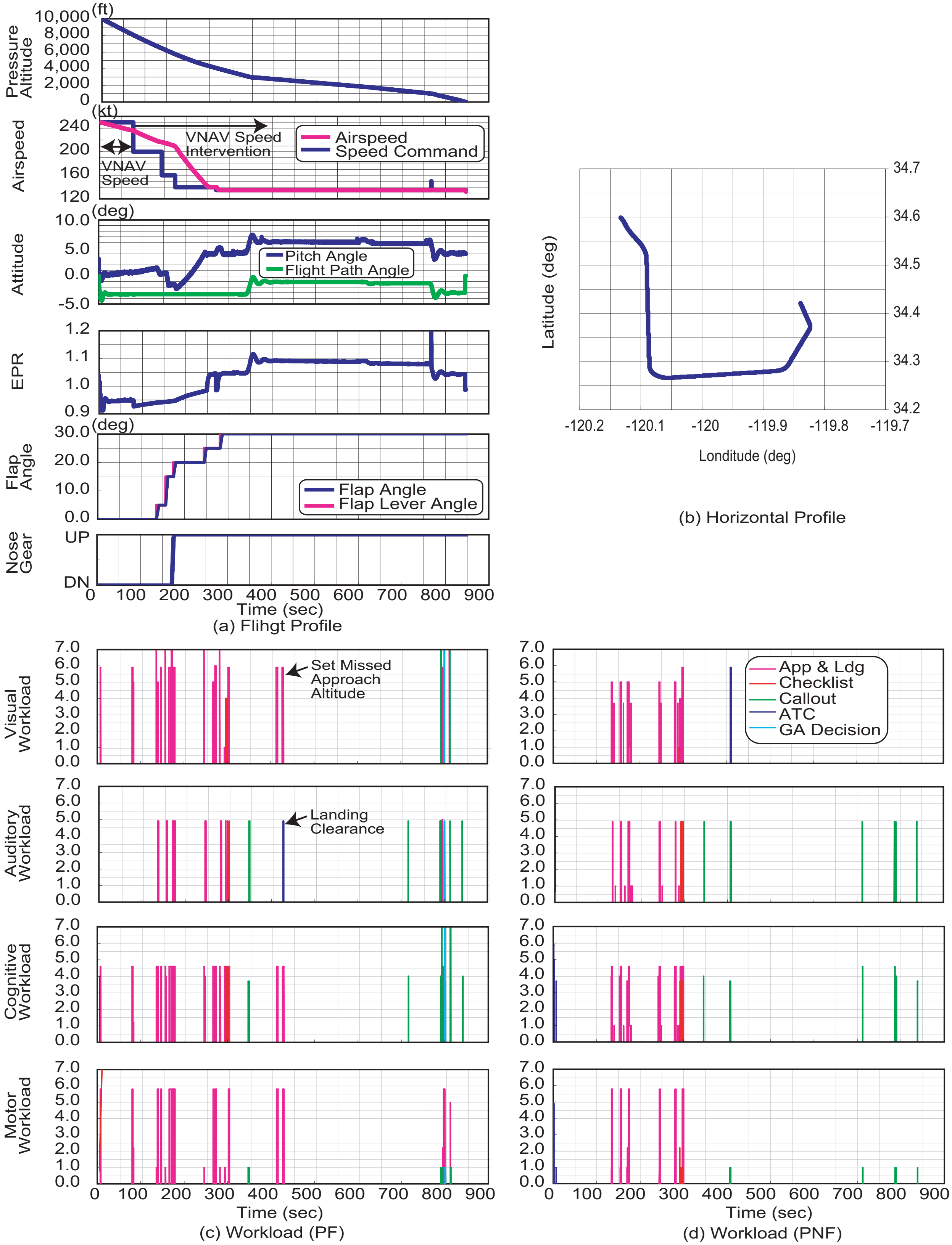


Figure 9 Flight Profile (Case 2, Run 1) - Normal Approach with SVS DA650 -

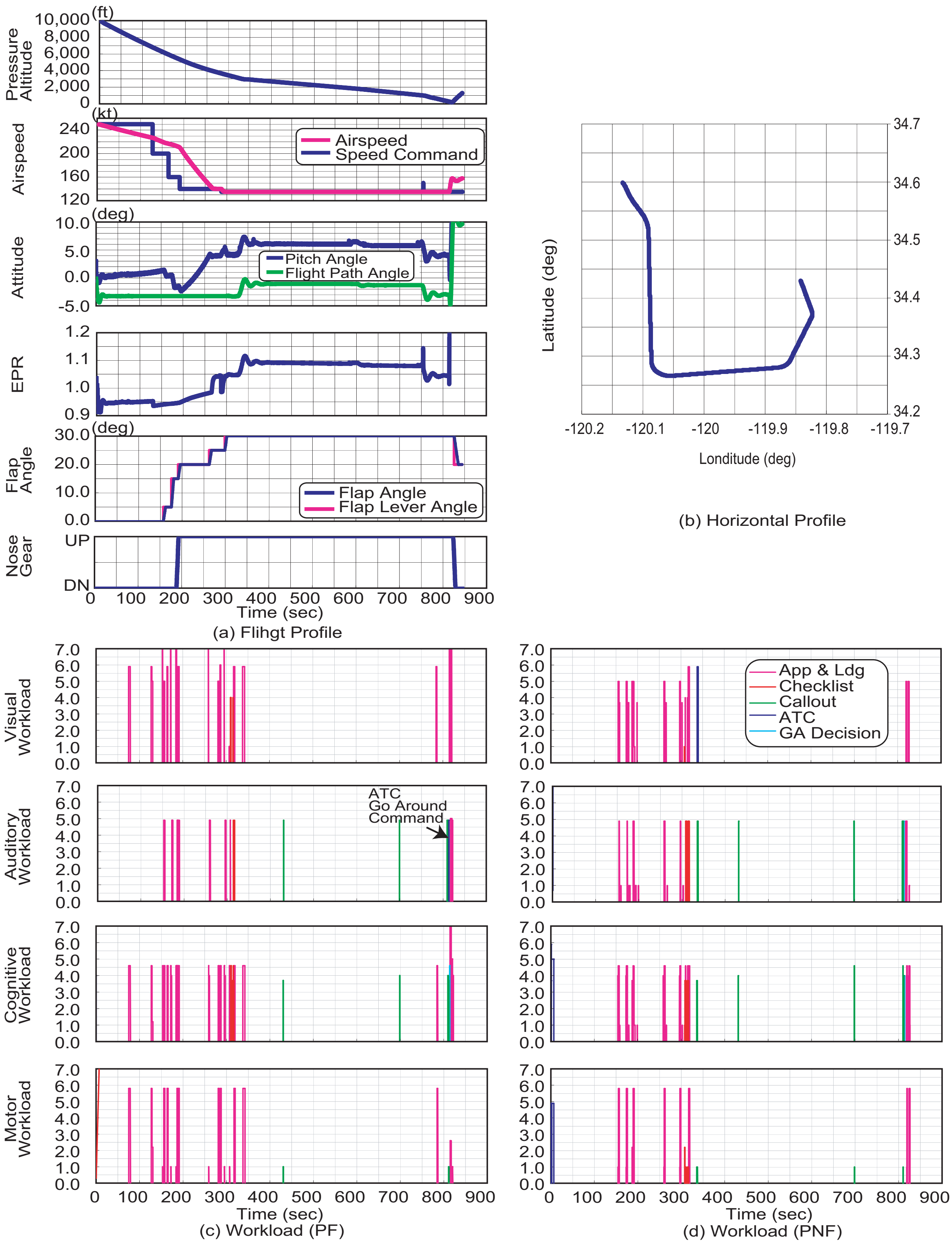


Figure 10 Flight Profile (Case 8, Run 1) - Go Around by ATC Command -

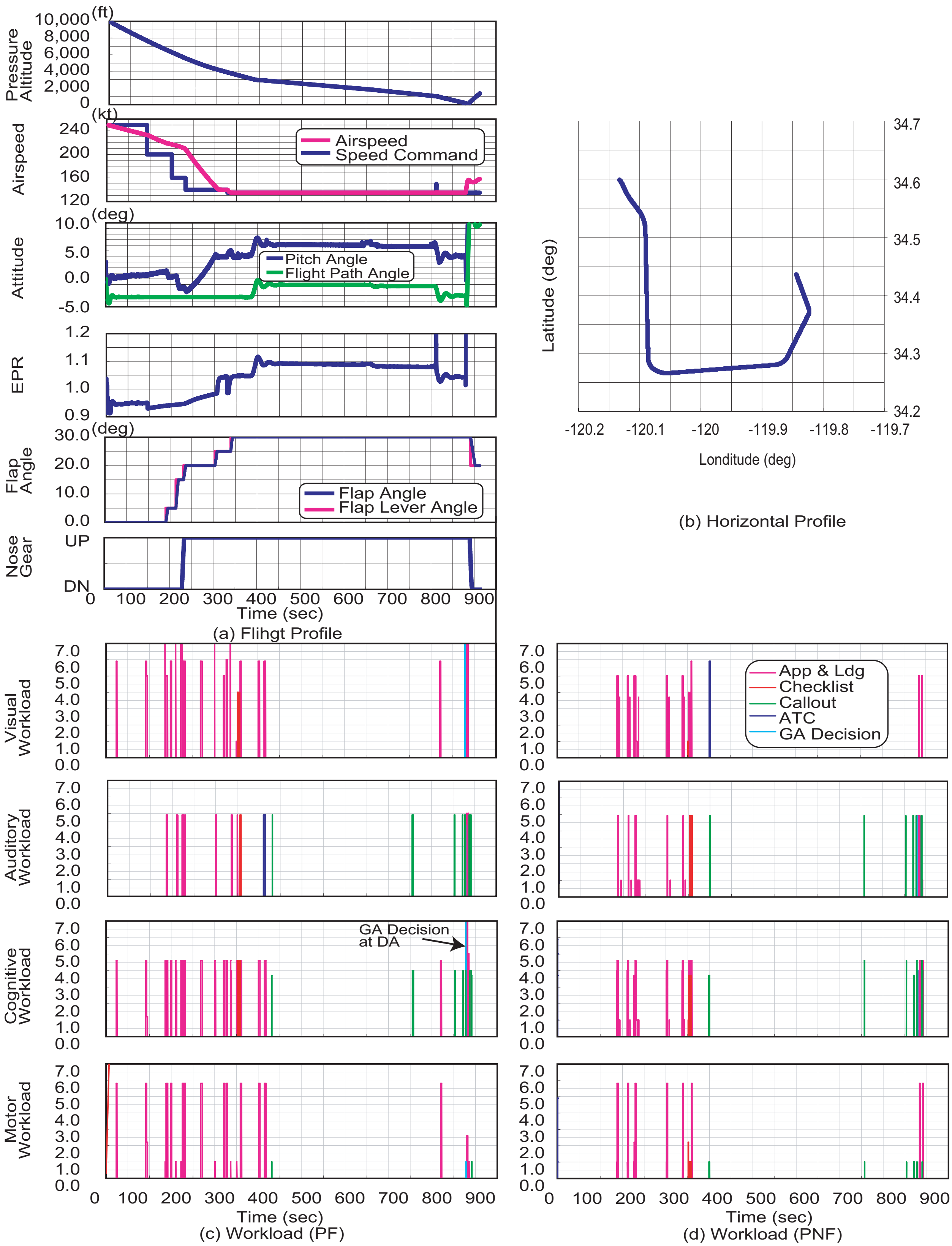


Figure 11 Flight Profile (Case 12, Run 1) - Go Around by PF model's decision -

Go Around by PF model's decision

Figure 11 shows the flight and the task sequence of case 12 run 1 as an example of simulation results of go around by PF's decision scenario. At 827.6 (sec), after the aircraft passed the DA, PF model confirmed whether the runway had become visible, and whether the aircraft had been stabilized. OTW equipment model provided the visibility and the distance to the runway and the computed/perceived value was:

visibility - distance_to_runway = 0.2 - 0.437 = -0.163 (nm)

This value was less than zero, and the PF model found that runway was not visible and decided to perform go around. "Go Around" call out was taken at 827.9(sec) followed by a series of go around tasks.

Figure 11 (c) and (d) shows the time history of PF and PNF model's workload. The PF model had one of maximum cognitive workload 7.0 around the DA which is caused by DA decision procedure. PF model had a larger density of visual, cognitive and motor workload after go around decision with maximum cognitive and visual workload at 7.0.

<u>Average Workload</u>

Figure 12 shows total average and every procedure's workload during each flight mission. Average workload, which was used to examine the contribution of each procedure to the overall workload, was defined by

$$\overline{WL_i}\,\Big|_{total} = \sum_{j}^{j_{all}} \sum_{n}^{n_{all}} WL_{i,j,n} \cdot \Delta t_{i,j,n} / t_{total}$$

: Total Average workload

$$\overline{WL_{i,j}} = \sum_{n}^{n_{all}} WL_{i,n} \cdot \Delta t_{i,n} / t_{total}$$

: Average workload (each procedure)

Where

i : V(Visual), A(Auditory), C(Cognitive) or M(Motor)

j : Procedures (Approach&Landing, GoAround, Scan Pattern, Checklist, Standard Callout, ATC, GA Decision and Others)

n : Number of accomplished activities

$WL_{i,j,n}$: Workload of each task item

$\Delta t_{i,j,n}$: Duration of each task item (sec)

t_{total} : Flight Time (sec)

Total Visual, Auditory and Cognitive average workloads of both PF and PNF were around 4.0, 0.2 and 1.0 respectively in both normal approach and go around cases. Average Motor workload was about 0.25 for PF and 0.16 for PNF in both normal approach and go around simulation. Major differences in activities across each scenario were only in the short final phase and they didn't have any significant impact on total average workload.

Larger visual and cognitive workload than motor workload characterized the flight, which was performed using automatic flight systems. Scan pattern activities mainly contributed towards the Visual workload. Motor workload was experienced by the agent, not due to manual flight control tasks, but due to the autopilot commands, like pull down gears, extension of flaps etc., which were specified in Approach & Landing or Go Around procedure. Figure 12(a) and (b)-(b-2) illustrates that more than 80% of Motor workload was caused by the flight procedures. Ratio of the Approach & Landing and Go Round's auditory workload in case 5~8 and 13~15, that required verbal orders of manipulation such as "Gear Up" and "Set flap 20 degrees", was higher than in the cases 1~4 and 9~12, although the amount of auditory workload was almost same across the cases. This was because the difference in the scenario settings. In case 5~8 and 13~15, Act's approach clearance was omitted to focus on Act's communication task for the Go Around command, while cases 1~4 and 9~12 included approach clearance and landing clearance. The amount of auditory workload of ATC communication procedure was very low and negligible in all cases.

Contributions of the checklist and go around decision towards workload were also small. These procedures contained fewer task items than Approach & Landing, Go Around, or callouts. It is important to note that lower average workload do not reduce the importance of the procedures. Check list and go around decisions are some of the most important procedures to ensure a safe flight.

Scan pattern caused more than half of the Visual workload and almost 30% or more Cognitive workload both for the PF and PNF. No major difference in visual workload was observed between with and without SVS operation.

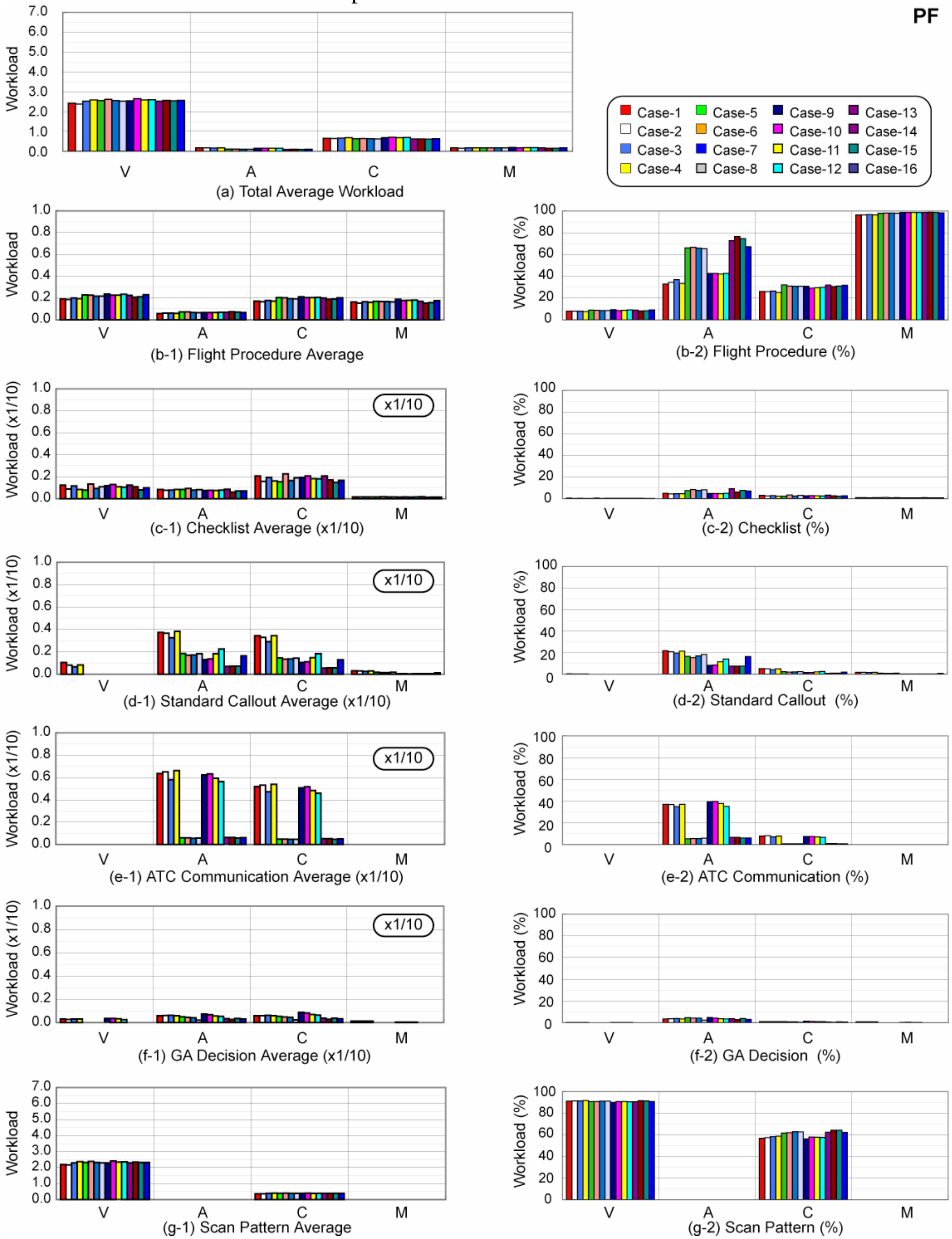


Figure 12 (a) Average Workload (PF)

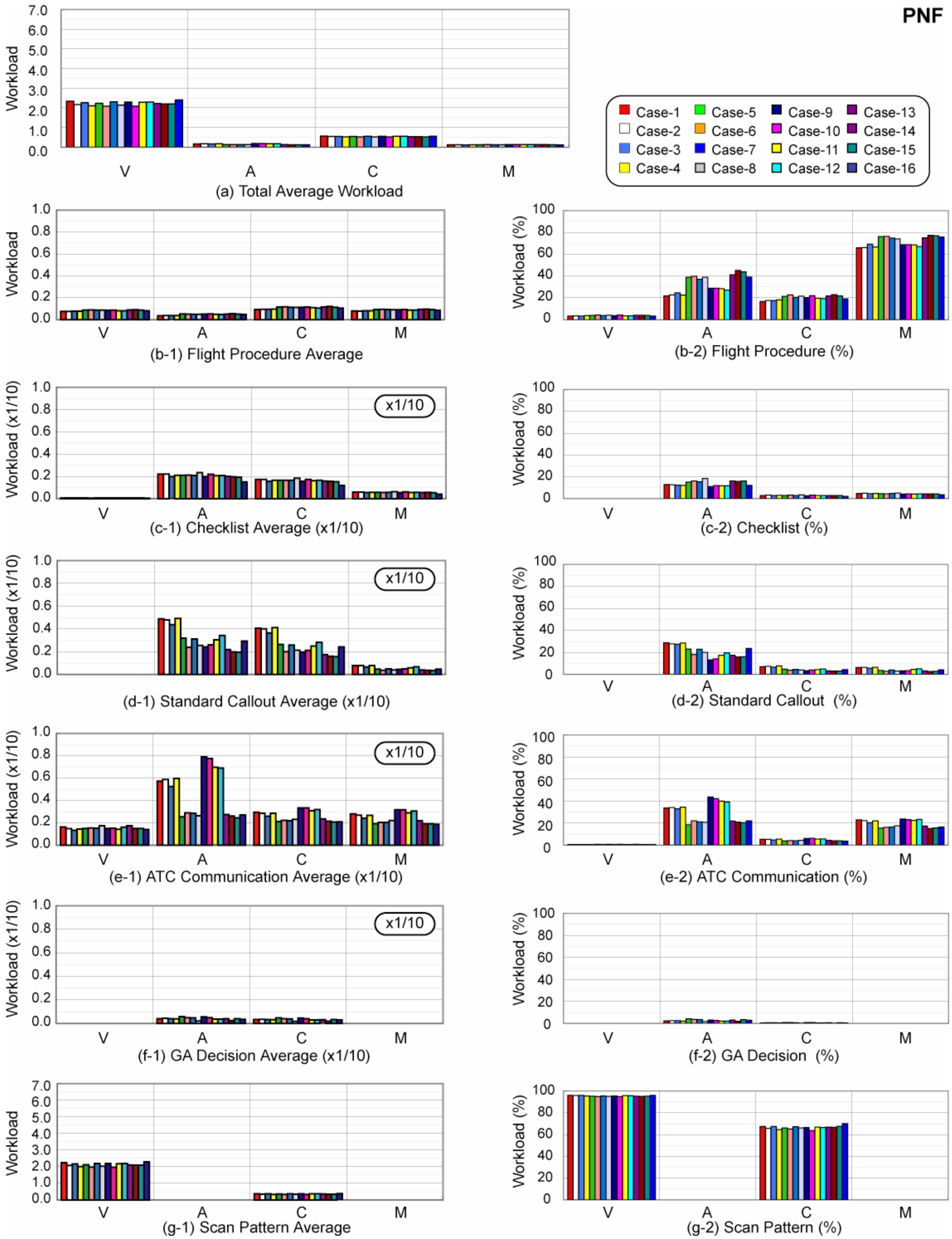


Figure 12 (b) Average Workload (PNF)

Timing of "Runway-In-Sight" Callout

Figure 13 summarizes timing of "Runway-In-Sight" callout analysis. Timing of "Runway-In-Sight" callout Δt_{RwVis} was defined by the time from the moment when the runway became physically visible to the moment when PF realized that the runway was in sight and made the callout after fixating on OTW. Formally by

$$\Delta t_{RwVis} = t_{Srwy} - t_{Vis}$$

Where

t_{Srwy} : Time when PNF started "Runway-In-Sight" callout

t_{Vis} : Time when runway became physically visible ($VIS > d_{rwy}$, VIS: Visibility, d_{rwy}: Distance from Aircraft to Runway)

Average "Runway-In-Sight" timings in without SVS cases (1, 3, 5, and 7) were 0.02 to 1.38 (sec) faster than with SVS cases (2, 4, 6 and 8). It is considered to be caused by the difference of scan pattern. PNF's "Runway-In-Sight" activity was triggered by the PNF's internal evaluation of the status of visibility and the distance to runway, which were both provided by OTW. The earlier the fixation on OTW occurred after runway became physically visible, the earlier the callout was taken. The scan pattern with SVS reduced the chances of fixation on OTW and it caused the delay of the average "Runway-In-Sight" callout timing.

We do not consider that these delays have a significant impact on the entire flight safety because the amount of delay was 0.02 to 1.38 (sec) and this time variation is task is not critical to safety of flight.

Visibility check should be performed at DA by PF to make final decision of landing or go around. This flight phase is much more time critical but the fixation should be performed not by a part of scan pattern sequence but by PF's directed gaze. The delay of "Runway-In-Sight" callout timing should not happen in this phase because the visual search at the DA is not simply part of the standard scan pattern.

Flight Time Analysis

To analyze SVS's impact on overall pilotage tasks flight time in each run were analyzed. Since the approach flight mission requires Air MIDAS pilot to reduce airspeed gradually with the flaps deployment, timing of each procedural task could affect the change of flight time.

Figure 14 summarizes flight time which is defined by the time from initial position to the point of DA or the altitude where visibility changed which was specified in the scenarios. Since the aircraft flies to track the nominal flight path with its VNAV and LNAV modes, it should pass DA and visibility change altitude at almost same position and these altitudes could be used as a measure of the flight time.

Average flight time in all cases with SVS was shorter than those without SVS. Shorter flight time equals to higher speed during the flight, assuming equivalent flight paths. Generally shorter flight time is preferable for efficiency but these simulation results might mean degradation of pilot's procedural activities performance. VNAV speed intervention was applied for airspeed control and its command was set and changed manually by the Air MIDAS PF model. So, shorter flight time was caused directly by later timing of airspeed setting actions. Since a series of speed command setting tasks and flap setting tasks were specified to be triggered by airspeed status, which was perceived by visual perception model, smaller chances of fixation on each display (particularly the SVS Scan pattern) caused delay in initiating these control input tasks and that invariably led to shorter flight times.

While the tendency of reduced flight time was observed in the cases with SVS in the scan pattern, no hazardous flight maneuver was observed and aircraft landed safely or made a go around. So, shorter flight time tendency in the SVS cases cannot be considered as having a great impact on flight safety

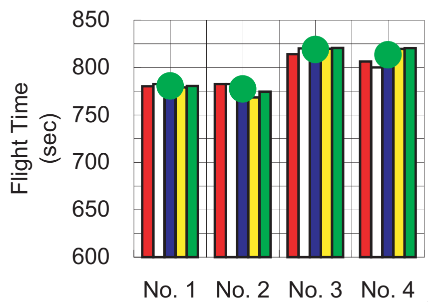
Among 80 runs of simulation runs, there were four “extremely” shorter flight time runs were obtained; four runs of with SVS cases (case 10 run3, case 14 run5 and case 16 run4) and one run of without SVS case(case 13, run 5), which are written in red color in Figure 14. Two of them (case 10 run 3 and case 13 run 5) were caused by the characteristics of autopilot in conjunction with the timing of airspeed command action. Figure 15 shows comparison of airspeed and airspeed command history. Delay of first airspeed command setting and speed intervention action was not so large, however, smaller deceleration that was the resultant motion controlled by aircraft autopilot system was achieved and it caused further delay of airspeed reduction and subsequent task initiation. Usually almost same amount of deceleration is expected to be achieved by speed mode of autopilot system, however sometimes it could differ due to aircraft configuration, initial airspeed and thrust settings when the mode is engaged, and so on. Other two runs (case 14 run 5 and case 16 run 5) were caused by Air MIDAS PF's improper sequence of airspeed command setting actions. Setting airspeed command at 200 kt and pushing VNAV speed intervention switch was performed after a series of reduced airspeed command settings were performed although they should be performed in the beginning of reduced airspeed command setting tasks. While the condition of initiating these tasks was defined by aircraft altitude (ex. altitude becomes less than a particular altitude), the condition of other airspeed command settings was defined by airspeed (ex. airspeed becomes less than a particular airspeed). This setting was considered to cause improper sequence in two runs although it worked fine in other 78 runs. These four cases were not eliminated from the statistical analysis as they represented legitimate behavior by the model (despite their extreme value).

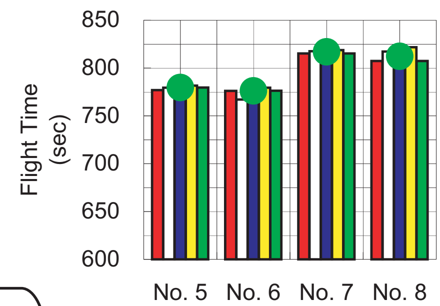
(a) Flight Time (To VisAlt)
(Case 1-4 Summary) (sec)

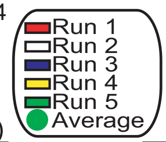
Case	No. 1	No. 2	No. 3	No. 4
Run 1	780.3	782.6	814.2	806.4
Run 2	782.6	782.6	820.1	800.2
Run 3	780.2	779.0	820.6	820.4
Run 4	779.0	768.4	819.8	819.6
Run 5	780.6	774.5	820.7	820.5
AVRG	780.5	777.4	819.1	813.4

(b) Flight Time (To VISALT)
(Case 5-8 Summary) (sec)

Case	No. 5	No. 6	No. 7	No. 8
Run 1	777.0	776.1	815.2	807.3
Run 2	779.4	767.1	817.6	817.3
Run 3	780.3	781.6	817.5	807.3
Run 4	781.6	779.5	818.8	821.7
Run 5	779.6	776.2	815.2	807.3
AVRG	779.6	776.1	816.9	812.2





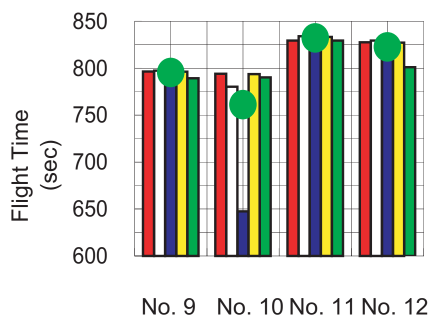


(c) Flight Time (To DA)
(Case 9-12 Summary (sec)

Case	No. 9	No. 10	No. 11	No. 12
Run 1	796.5	794.1	829.3	827.5
Run 2	797.4	780.2	833.9	829.3
Run 3	796.8	647.5	834.5	827.5
Run 4	796.2	793.7	833.3	827.2
Run 5	789.3	790.2	829.4	801.1
AVRG	795.2	761.1	832.1	822.5

(d) Flight Time (To ATCalt)
(Case 13-16 Summary)(sec)

Case	No. 13	No. 14	No. 15	No. 16
Run 1	777.0	751.5	773.4	777.5
Run 2	773.2	764.7	773.6	764.1
Run 3	777.9	751.3	773.4	759.3
Run 4	767.2	751.2	749.3	590.0
Run 5	628.0	628.0	772.1	770.0
AVRG	744.7	729.3	768.4	732.2



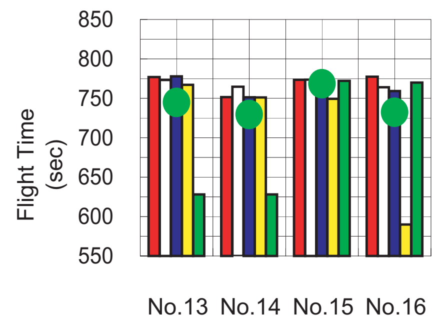
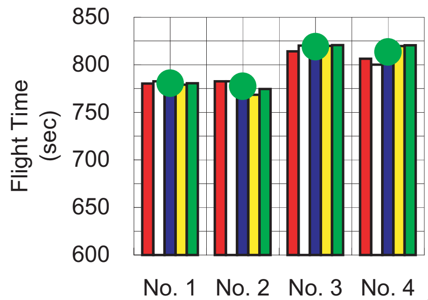


Figure 13 Timing of "Runway-In-Sight" Callout

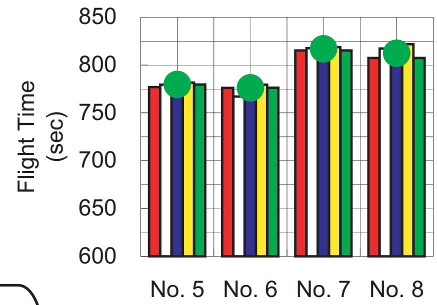
(a) Flight Time (To VisAlt)
(Case 1-4 Summary) (sec)

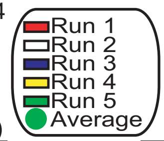
Case	No. 1	No. 2	No. 3	No. 4
Run 1	780.3	782.6	814.2	806.4
Run 2	782.6	782.6	820.1	800.2
Run 3	780.2	779.0	820.6	820.4
Run 4	779.0	768.4	819.8	819.6
Run 5	780.6	774.5	820.7	820.5
AVRG	780.5	777.4	819.1	813.4



(b) Flight Time (To VISALT)
(Case 5-8 Summary) (sec)

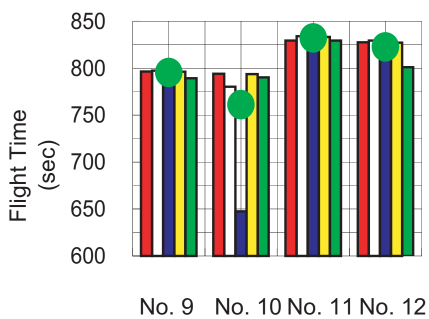
Case	No. 5	No. 6	No. 7	No. 8
Run 1	777.0	776.1	815.2	807.3
Run 2	779.4	767.1	817.6	817.3
Run 3	780.3	781.6	817.5	807.3
Run 4	781.6	779.5	818.8	821.7
Run 5	779.6	776.2	815.2	807.3
AVRG	779.6	776.1	816.9	812.2





(c) Flight Time (To DA)
(Case 9-12 Summary (sec)

Case	No. 9	No. 10	No. 11	No. 12
Run 1	796.5	794.1	829.3	827.5
Run 2	797.4	780.2	833.9	829.3
Run 3	796.8	647.5	834.5	827.5
Run 4	796.2	793.7	833.3	827.2
Run 5	789.3	790.2	829.4	801.1
AVRG	795.2	761.1	832.1	822.5



(d) Flight Time (To ATCalt)
(Case 13-16 Summary)(sec)

Case	No. 13	No. 14	No. 15	No. 16
Run 1	777.0	751.5	773.4	777.5
Run 2	773.2	764.7	773.6	764.1
Run 3	777.9	751.3	773.4	759.3
Run 4	767.2	751.2	749.3	590.0
Run 5	628.0	628.0	772.1	770.0
AVRG	744.7	729.3	768.4	732.2

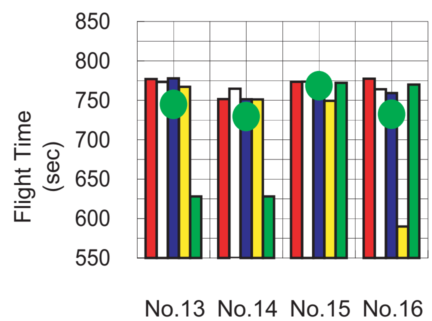
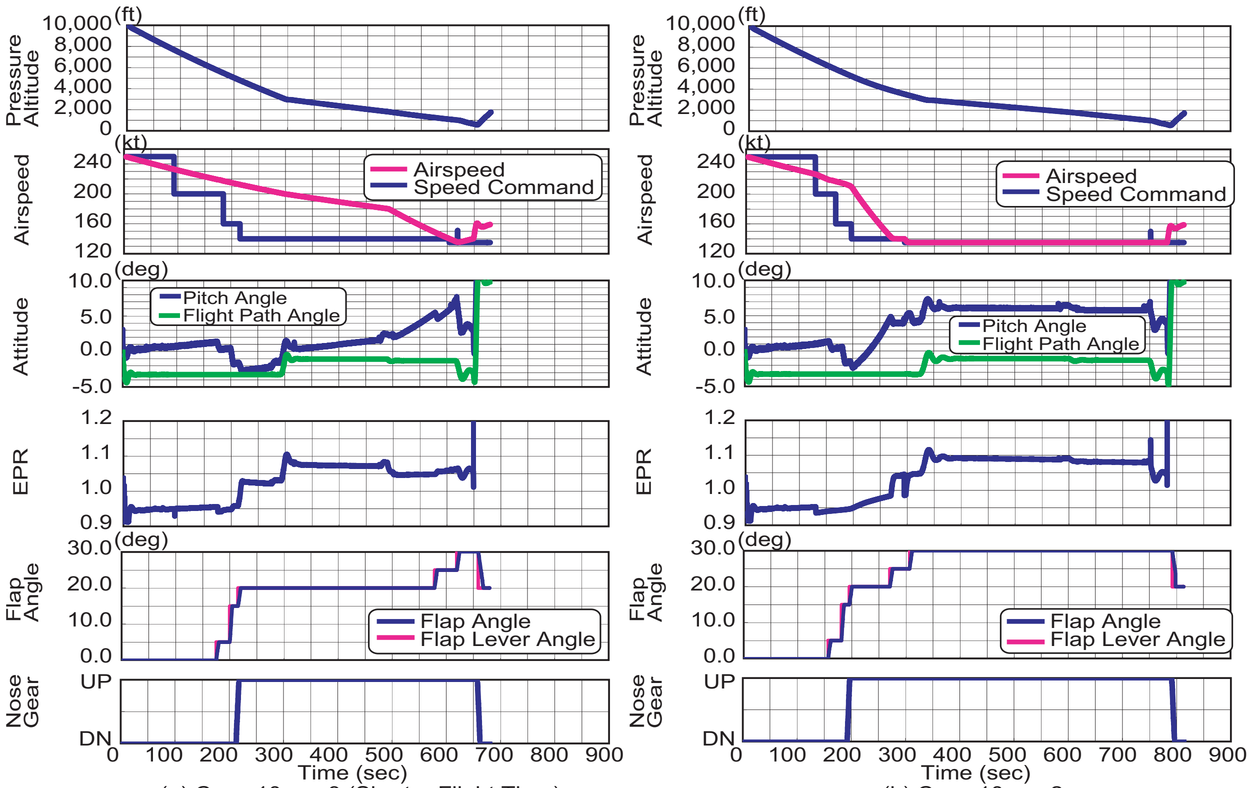


Figure 14 Flight Time Analyses



(a) Case 10 run 3 (Shorter Flight Time) (b) Case 10 run 2

Figure 15 Slower deceleration attained by the autopilot (Case 10 run 3 compared by case 10 run 2)

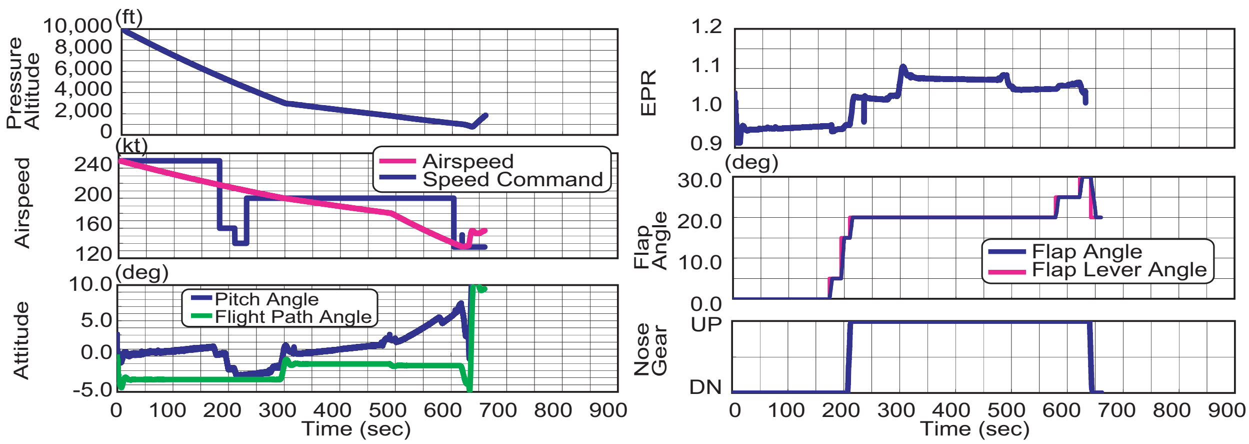


Figure 16 Improper Sequence of Airspeed Command Setting (Case 14 run 5)

<u>Go Around Performance</u>

Go Around due to ATC command

Figure 17 summarizes response time of go around action $\Delta t_{GA_{ATC}}$ (sec) and altitude loss $\Delta H_{GA_{ATC}}$ (ft). Go around response time was defined by the time from completion of ATC controller's go around command communication $t_{end_{ATC}}$ to PF's completion of setting go around pitch attitude. During that period, PF has to make "Go around" callout, maximum thrust setting and pitch up control to perform the go around procedure. These actions should be taken immediately after receiving the go around command. Altitude loss $\Delta H_{GA_{ATC}}$ was defined by the difference between altitude at $t_{end_{ATC}}$ and minimum aircraft altitude in a go around maneuver. The minimum altitude is usually achieved sometime after the go around actions that include maximum thrust setting and pitch up control, because of the inertia of the aircraft. To reduce altitude loss, immediate action is required by the pilots.

Average response time of each case was from 3.8 to 4.7 (sec) and average altitude loss for each case ranged from 88.2 to 114.9 (ft).

With SVS v/s without SVS

Comparing case 5 with 6, case 7 with 8, case 13 with 14 and case 15 with 16, no major difference in average of $\Delta t_{GA_{ATC}}$ (response time of go around action) were found between the with-SVS and without-SVS cases. Since ATC command was perceived not using the visual perception model but via the hearing perception model, this could only affect go around performance if there was competition for resources in the cognitive domain.

Altitude where go around command was issued

Although no major difference in response time was observed when comparing case 13 and 14 (Hatc=higher DA+250ft) with case 15 and 16 (Hatc=lower DA+250ft), response time in case 5 and 6 (Hatc=higher DA+100ft) seems longer than case 7 and 8 (Hatc=lower DA+100ft).

Figure 17(b) shows duration of each task performed during the "response time." Air MIDAS's duration of each action is determined only by Markov process based on specific mean value and standard deviation and so, once initiated, duration is not affected by model's workload status or UWR status. Also, a series of go around tasks were defined as 'sequential activities', that should be serially performed. Therefore the timing of starting a series of go around tasks might be a parameter, which could be affected by the difference in altitude. From Figure 17(b)-(a), no such difference were observed in the timing of initiating "Go Around" callout. So we can conclude that ATC go around altitude does not impact the human and flight system characteristics.

Timing of ATC Command

Comparing case 5, 6, 7 and 8 with case 13, 14, 15, and 16 respectively, no significant relationship regarding the timing of go around command versus response time was observed. Timing of the go around command in cases 5, 6, 7, and 8 was more critical (closer to the ground and busier) than that in cases 13, 14, 15 and 16, and this was due to the 100ft difference between the visibility-change and decision altitude,. However the PF model responded to the ATC command as quickly as it could, and smoothly performed the go around tasks.

Table 4 Go Around Performance 1 (Go Around due to ATC command)

(a) GA Response Analysis (Case 5)

	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	750.0	781.1	782.1	737.8	782.4	783.8	783.8	785.0	785.0	787.5	632.9	5.4	104.9
Run 2	750.0	783.6	784.6	737.2	784.9	785.3	785.3	786.5	786.5	788.6	650.3	4.0	86.9
Run 3	750.0	784.4	785.4	737.6	785.7	786.8	786.8	787.8	787.8	790.4	636.0	5.0	101.6
Run 4	750.0	785.8	786.8	737.5	787.1	788.0	788.0	789.0	789.0	790.8	653.5	4.0	83.9
Run 5	750.0	783.8	784.8	737.0	785.1	786.1	786.1	787.4	787.4	789.9	635.2	5.1	101.8
Average												4.7	95.8

(b) GA Response Analysis (Case 6)

	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	750.0	780.2	781.2	737.9	781.5	782.2	782.2	783.2	783.2	785.9	638.4	4.7	99.4
Run 2	750.0	771.3	772.3	737.2	772.6	772.8	774.0	774.0	774.0	776.3	648.4	4.0	88.9
Run 3	750.0	785.8	786.8	737.2	787.1	788.5	788.5	789.7	789.7	792.2	631.8	5.4	105.5
Run 4	750.0	783.6	784.6	737.9	784.9	786.4	786.4	787.3	787.3	789.8	635.1	5.2	102.8
Run 5	750.0	780.4	781.4	736.9	781.7	782.2	782.2	783.2	783.2	785.0	656.6	3.6	80.3
Average												4.6	95.4

(c) GA Response Analysis (Case 7)

	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	300.0	819.5	820.5	285.9	820.8	822.0	822.0	823.1	823.1	824.9	189.6	4.4	96.3
Run 2	300.0	821.9	822.9	286.3	823.2	824.5	824.5	825.6	825.6	827.6	184.2	4.7	102.1
Run 3	300.0	821.8	822.8	285.5	823.1	823.2	823.2	824.2	824.2	825.8	208.1	3.0	77.5
Run 4	300.0	823.1	824.1	285.5	824.4	825.2	825.2	826.3	826.3	828.3	190.1	4.2	95.4
Run 5	300.0	819.5	820.5	285.9	820.8	821.6	821.6	822.8	822.8	824.6	193.3	4.1	92.6
Average												4.1	92.8

(d) GA Response Analysis (Case 8)

	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	300.0	811.6	812.6	286.1	812.9	813.4	813.4	814.3	814.3	816.7	188.9	4.1	97.2
Run 2	300.0	821.6	822.6	285.8	822.9	823.8	823.8	825.1	825.1	827.3	182.8	4.7	103.0
Run 3	300.0	811.6	812.6	286.1	812.9	813.4	813.4	814.3	814.3	816.7	189.0	4.1	97.2
Run 4	300.0	826.0	827.0	286.7	827.3	827.4	827.4	828.4	828.4	830.7	194.4	3.7	92.3
Run 5	300.0	811.6	812.6	286.5	812.9	813.1	813.1	814.0	814.0	815.7	206.7	3.1	79.8
Average												3.9	93.9

(e) GA Response Analysis (Case 13)

	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	900.0	777.1	778.1	881.7	778.4	779.1	779.1	780.3	780.3	782.1	774.4	4.0	107.3
Run 2	900.0	773.3	774.3	881.9	774.6	775.0	775.0	776.2	776.2	778.5	769.1	4.2	112.8
Run 3	900.0	778.0	779.0	899.9	779.3	780.4	780.4	781.7	781.7	784.4	751.0	5.4	148.9
Run 4	900.0	767.3	768.3	881.7	768.6	769.3	769.3	770.7	770.7	772.4	773.6	4.1	108.1
Run 5	900.0	628.1	629.1	881.8	629.4	629.8	629.8	630.9	630.9	632.6	784.3	3.5	97.5
Average												4.2	114.9

(f) GA Response Analysis (Case 14)

	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	900.0	751.6	752.6	882.6	752.9	753.1	753.1	754.0	754.0	756.3	777.1	3.7	105.5
Run 2	900.0	764.9	765.9	880.0	766.2	767.2	767.2	768.2	768.2	770.5	761.6	4.6	118.4
Run 3	900.0	751.4	752.4	881.8	752.7	752.9	752.9	754.2	754.2	755.8	784.4	3.4	97.4
Run 4	900.0	751.3	752.3	882.5	752.6	752.8	752.8	754.0	754.0	755.6	786.3	3.3	96.1
Run 5	900.0	628.1	629.1	881.9	629.4	630.2	630.2	631.4	631.4	633.2	775.3	4.1	106.6
Average												3.8	104.8

(g) GA Response Analysis (Case 15)

	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	300.0	809.6	810.6	436.1	810.9	811.3	811.3	812.2	812.2	814.5	343.7	3.9	92.4
Run 2	300.0	809.8	810.8	436.4	811.1	812.6	812.6	813.8	813.8	815.3	343.9	4.5	92.5
Run 3	300.0	809.7	810.7	434.6	811.0	811.7	811.7	813.1	813.1	814.7	346.9	4.0	87.7
Run 4	300.0	785.5	786.5	448.4	786.8	787.5	787.5	788.8	788.8	791.2	334.1	4.7	114.3
Run 5	300.0	808.3	809.3	435.9	809.6	810.0	810.0	810.9	810.9	813.2	343.5	3.9	92.4
Average												4.2	95.8

(h) GA Response Analysis (Case 16)

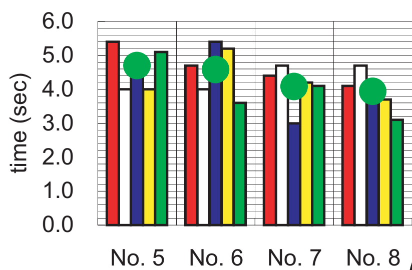
	H_{ATC} (ft)	ATC Command T_{start}	T_{end}	A/C Alt (ft)	Callout T_{start}	T_{end}	Go Lever T_{start}	T_{end}	Pitch Angle T_{start}	T_{end}	H_{min} (ft)	t_{GA} (sec)	H_{GA} (ft)
Run 1	300.0	813.7	814.7	436.0	815.0	815.9	815.9	817.3	817.3	818.9	346.0	4.2	90.0
Run 2	300.0	800.3	801.3	436.2	801.6	802.0	802.0	803.2	803.2	805.8	334.8	4.5	101.4
Run 3	300.0	795.5	796.5	437.0	796.8	797.4	797.4	798.5	798.5	800.6	343.2	4.1	93.8
Run 4	300.0	614.8	615.8	429.7	616.1	616.7	616.7	617.9	617.9	619.9	357.6	4.1	72.1
Run 5	300.0	806.2	807.2	435.8	807.5	807.9	807.9	808.9	808.9	810.7	352.1	3.5	83.8
Average												4.1	88.2

(i) Response Time
(Summary) t_{GA}(sec)

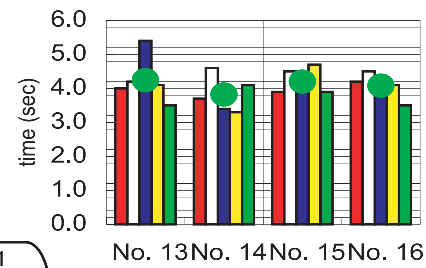
Case	No. 5	No. 6	No. 7	No. 8
Run 1	5.4	4.7	4.4	4.1
Run 2	4.0	4.0	4.7	4.7
Run 3	5.0	5.4	3.0	4.1
Run 4	4.0	5.2	4.2	3.7
Run 5	5.1	3.6	4.1	3.1
AVRG	4.7	4.6	4.1	3.9

(j) Response Time
(Summary) t_{GA}(sec)

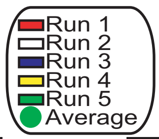
	No. 13	No. 14	No. 15	No. 16
Run 1	4.0	3.7	3.9	4.2
Run 2	4.2	4.6	4.5	4.5
Run 3	5.4	3.4	4.0	4.1
Run 4	4.1	3.3	4.7	4.1
Run 5	3.5	4.1	3.9	3.5
AVRG	4.2	3.8	4.2	4.1



(i) Response Time



(j) Response Time

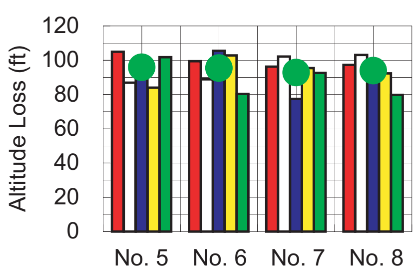


(k) Altitude Loss
(Summary) H_{GA} (ft)

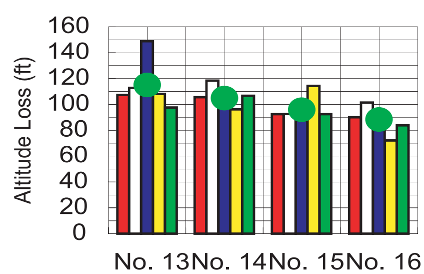
Case	No. 5	No. 6	No. 7	No. 8
Run 1	104.9	99.4	96.3	97.2
Run 2	86.9	88.9	102.1	103.0
Run 3	101.6	105.5	77.5	97.2
Run 4	83.9	102.8	95.4	92.3
Run 5	101.8	80.3	92.6	79.8
AVRG	95.8	95.4	92.8	93.9

(l) Altitude Loss
(Summary) H_{GA} (ft)

	No. 13	No. 14	No. 15	No. 16
Run 1	107.3	105.5	92.4	90.0
Run 2	112.8	118.4	92.5	101.4
Run 3	148.9	97.4	87.7	93.8
Run 4	108.1	96.1	114.3	72.1
Run 5	97.5	106.6	92.4	83.8
AVRG	114.9	104.8	95.8	88.2



(k) Altitude Loss



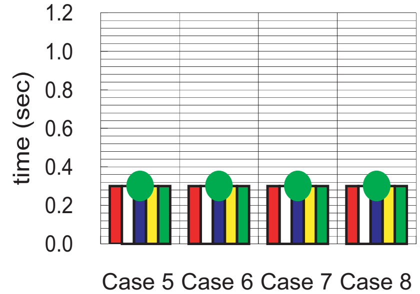
(l) Altitude Loss

Figure 17(a) Go Around Performance 1 (Go Around due to ATC command)

(m) Timing of Initiating GA actions

(Summary) t_{GA}(sec)

	Case 5	Case 6	Case 7	Case 8
Run 1	0.3	0.3	0.3	0.3
Run 2	0.3	0.3	0.3	0.3
Run 3	0.3	0.3	0.3	0.3
Run 4	0.3	0.3	0.3	0.3
Run 5	0.3	0.3	0.3	0.3
AVRG	0.3	0.3	0.3	0.3

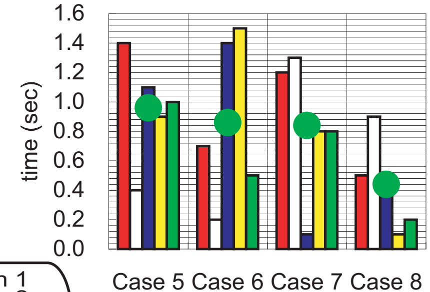


(m) Timing of Initiating GA actions

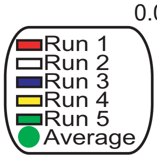
(n) Duration of GA Call Out Action

(Summary) t_{GA}(sec)

	Case 5	Case 6	Case 7	Case 8
Run 1	1.4	0.7	1.2	0.5
Run 2	0.4	0.2	1.3	0.9
Run 3	1.1	1.4	0.1	0.5
Run 4	0.9	1.5	0.8	0.1
Run 5	1.0	0.5	0.8	0.2
AVRG	1.0	0.9	0.8	0.4



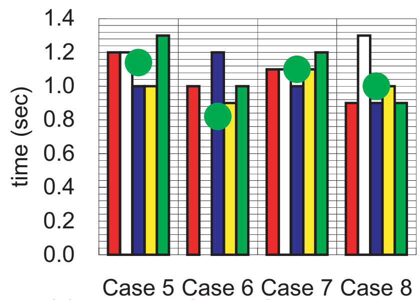
(n) Duration of GA Call Out Action



(o) Duration of Push Go Lever Action

(Summary) t_{GA}(sec)

	Case 5	Case 6	Case 7	Case 8
Run 1	1.2	1.0	1.1	0.9
Run 2	1.2	0.0	1.1	1.3
Run 3	1.0	1.2	1.0	0.9
Run 4	1.0	0.9	1.1	1.0
Run 5	1.3	1.0	1.2	0.9
AVRG	1.1	0.8	1.1	1.0

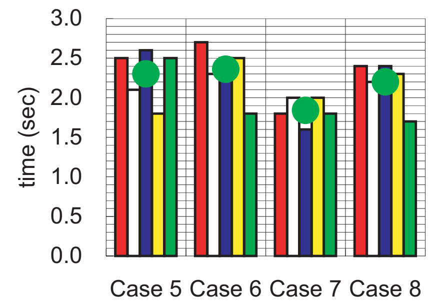


(o) Duration of Push Go Lever Action

(p) Duration of Set Pitch Action

(Summary) t_{GA}(sec)

	Case 5	Case 6	Case 7	Case 8
Run 1	2.5	2.7	1.8	2.4
Run 2	2.1	2.3	2.0	2.2
Run 3	2.6	2.5	1.6	2.4
Run 4	1.8	2.5	2.0	2.3
Run 5	2.5	1.8	1.8	1.7
AVRG	2.3	2.4	1.8	2.2



(p) Duration of Set Pitch Action

Figure 17(b) Go Around Performance 1 (Go Around due to ATC command Detailed Task Duration)

<u>Go Around due to pilot decision</u>

Figure 18 summarizes response time of go around action $\Delta t_{GA_{PF}}$ (sec) and altitude loss $\Delta H_{GA_{PF}}$ in go-around by PF model's decision cases. (Table 5 provides the performance data.)

No major difference in response time and altitude loss was found among cases 9, 10, 11 and 12. In these scenarios, PF model needed to fixate on OTW to get the status of the runway visibility as soon as the aircraft passes the DA. The visibility scan in "Runway-In-Sight" Callout task was assumed to be performed intentionally, whenever aircraft passed DA. Whenever the pilot made the decision to go around, actions were performed at proper times in all the cases, and both SVS and decision altitude did not have any impact on the go around activities.

Table 5 Go Around Performance 1 (Go Around due to Pilot Decision)

(a) GA Analysis (Case 9)

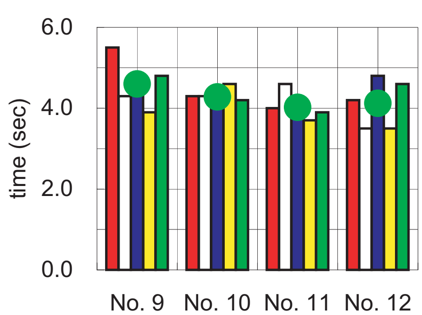
	DA	DA time	A/C Alt	Callout		Go Lever		Pitch Angle		H_{min}	t_{GA}	H_{GA}
	(ft)	(sec)	(ft)	T_{start}	T_{end}	T_{start}	T_{end}	T_{start}	T_{end}	(ft)	(sec)	(ft)
Run 1	650.0	796.5	644.4	797.0	798.2	798.2	799.3	799.3	802.0	533.7	5.5	116.3
Run 2	650.0	797.4	646.7	797.7	798.7	798.7	800.0	800.0	801.7	555.6	4.3	94.4
Run 3	650.0	796.8	647.1	797.0	797.9	797.9	799.0	799.0	801.3	548.0	4.5	102.0
Run 4	650.0	796.2	645.7	796.6	797.2	797.2	798.2	798.2	800.1	559.3	3.9	90.7
Run 5	650.0	789.3	645.3	789.7	790.8	790.8	792.0	792.0	794.1	545.9	4.8	104.1
Average											4.6	101.5
(b) GA Analysis (Case 10)												
Run 1	650.0	794.1	645.1	794.5	795.0	795.0	796.1	796.1	798.4	550.6	4.3	99.4
Run 2	650.0	780.2	645.5	780.6	781.2	781.2	782.1	782.1	784.5	550.4	4.3	99.6
Run 3	650.0	647.5	649.5	647.8	648.2	648.2	649.1	649.1	651.5	561.2	4.0	88.8
Run 4	650.0	793.7	645.6	794.1	795.6	795.6	796.6	796.6	798.3	551.5	4.6	98.5
Run 5	650.0	790.2	647.4	790.4	791.3	791.3	792.7	792.7	794.4	556.2	4.2	93.8
Average											4.3	96.0
(c) GA Analysis (Case 11)												
Run 1	200.0	829.3	196.9	829.6	830.2	830.2	831.1	831.1	833.3	105.9	4.0	94.1
Run 2	200.0	833.9	194.7	834.3	835.5	835.5	836.8	836.8	838.5	101.7	4.6	98.3
Run 3	200.0	834.5	197.7	834.7	835.3	835.3	836.3	836.3	838.4	107.5	3.9	92.5
Run 4	200.0	833.3	194.9	833.7	833.9	833.9	835.0	835.0	837.0	110.3	3.7	89.8
Run 5	200.0	829.4	194.8	829.8	830.7	830.7	831.7	831.7	833.3	111.1	3.9	88.9
Average											4.0	92.7
(d) GA Analysis (Case 12)												
Run 1	200.0	827.5	194.5	827.9	828.7	828.7	829.7	829.7	831.7	104.4	4.2	95.6
Run 2	200.0	829.3	196.9	829.5	829.6	829.6	830.7	830.7	832.8	112.6	3.5	87.4
Run 3	200.0	827.5	196.3	827.8	829.2	829.2	830.3	830.3	832.3	97.8	4.8	102.2
Run 4	200.0	827.2	197.4	827.3	827.5	827.5	828.6	828.6	830.7	111.3	3.5	88.7
Run 5	200.0	801.1	195.6	801.4	802.4	802.4	803.3	803.3	805.7	96.6	4.6	103.4
Average											4.1	95.4

(e) Timing of GA Decision
(Case 9-12 Summary (sec)

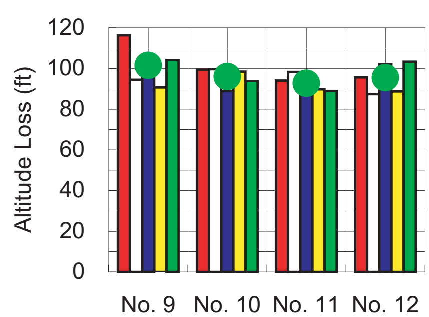
Case	No. 9	No. 10	No. 11	No. 12
Run 1	5.5	4.3	4.0	4.2
Run 2	4.3	4.3	4.6	3.5
Run 3	4.5	4.0	3.9	4.8
Run 4	3.9	4.6	3.7	3.5
Run 5	4.8	4.2	3.9	4.6
AVRG	4.60	4.28	4.02	4.12

(f) Altitude Loss
(Case 9-12 Summary (sec)

Case	No. 9	No. 10	No. 11	No. 12
Run 1	116.3	99.4	94.1	95.6
Run 2	94.4	99.6	98.3	87.4
Run 3	102.0	88.8	92.5	102.2
Run 4	90.7	98.5	89.8	88.7
Run 5	104.1	93.8	88.9	103.4
AVRG	101.5	96.0	92.7	95.4



(g) Timing of GA Decision



(h) Altitude Loss

Figure 18 Go Around Performance 2 (Go Around due to PF model's decision)

Scan Pattern Analysis

This section is comprised of two analyses. The first one, called *Scan Failure Rate*, describes the development of the scan pattern to include the possibility of emergent error rates in perception. The second section on *Scan Pattern Results* details comparisons between different cases/ conditions.

Scan Failure Rate

The visual perception model of the Air MIDAS assumed failure of the scan when the duration of the fixation was not long enough to fetch displayed information. Formally, when

duration_of_fixation < mean – x * SD (x=constant),

Air MIDAS PF agent failed to fetch data from the display and did not update the UWR in the agent's working memory.

Selection of the threshold (x * SD) will affect the occurrence of failure of the scan pattern and it could be one of the important human performance parameters for prediction. Sensitivity of x was examined, to provide the guideline for threshold selection. All of the fixations in the scan pattern activities, in all the scenarios and runs were used for the analyses. In Air MIDAS' the duration of each fixation is determined by a Markov process, and it is not affected by external factors such as the status of workload. All the sample data have been integrated into a single table.

Figure 19 summarizes the sensitivity analysis. Failure rate was defined by

n_{fail}/n_{fix} where n_{fail}: the number of failure, n_{fix}: total number of fixation,

No scan pattern failure happened for the thresholds less than -1.75SD. Failure rate increased linearly with the increase of threshold after threshold was larger than -1.50.

For the series of simulation runs in this paper, we selected (mean-1.0SD) for the threshold of failure occurrence so that the error rate of scan perception is 10% or less.

(a) Failure Rate

x	Success	Fail	Total	Failure Rate
-3.00	39027	0	39027	0
-2.75	39027	0	39027	0
-2.50	39027	0	39027	0
-2.25	39027	0	39027	0
-2.00	39027	0	39027	0
-1.75	39027	0	39027	0
-1.50	39016	11	39027	0.000
-1.25	37157	1870	39027	0.048
-1.00	36693	2334	39027	0.060
-0.75	32971	6056	39027	0.155
-0.50	32003	7024	39027	0.180
-0.25	28962	10065	39027	0.258
0	25730	13297	39027	0.341
0.25	25363	13664	39027	0.350
0.50	23210	15817	39027	0.405
0.75	21226	17801	39027	0.456

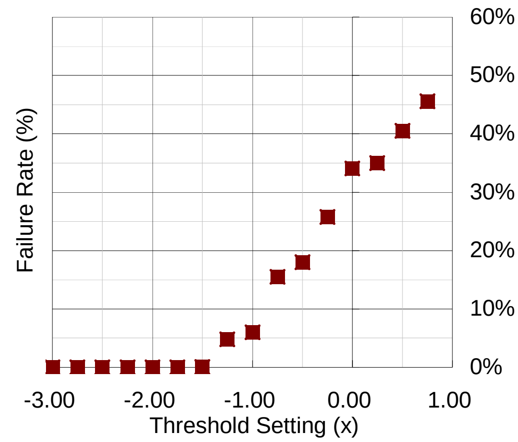


Figure 19 Scan Failure Rate Analyses

Scan Pattern Results

The scan pattern analyses will describe the results of the visual perception model in air-MIDAS. The analyses will include a series of comparisons that mostly focused on whether SVS was included or not in the scan pattern and they are as follows:

a) comparison between Normal Approach procedures with and without SVS included in the scan pattern

b) comparison between Go-Around procedures with and without SVS in the scan pattern

c) comparison of scan patterns in the go-around procedures with different Decision Altitudes

d) comparison of scan patterns with different levels of visibility

e) Comparison of PF model data with scan pattern by Mumaw et. al. (2000)

a) Normal Approach (with v/s without SVS)

Cases 1and 3 were combined to provide values for a scan pattern that included SVS and similarly cases 2 and 4 were combined for scan pattern results that did not include SVS. Fixation percentage, dwell duration and dwell percentages were analyzed for normal approach procedures, with and without SVS in their scan pattern.

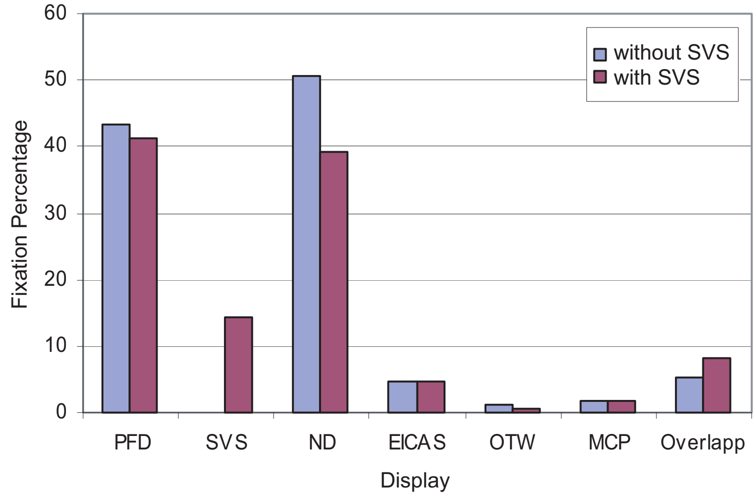


Figure 20. Fixation Percentage for PF with and without SVS on normal approach

The Fixation data (Figure 20) shows that PF agent fixated a little more on PFD and Navigational Display when SVS was not available. This may be because SVS is designed as a display that overlays PFD. Figure 21 shows dwell durations and it is interesting to note that dwell durations are very long for SVS and MCP. This signifies that as the activity was designed in looking at SVS there is cognitive processing involved. This added cognitive process in looking at SVS elongates the fixation duration. Although the dwell durations are not too long for PFD and ND when compared to SVS patterns, overall more time is spent looking at PFD and ND (see Figure 22). This result corresponds to the fixation percentage data where the agent fixated more on PFD and ND.

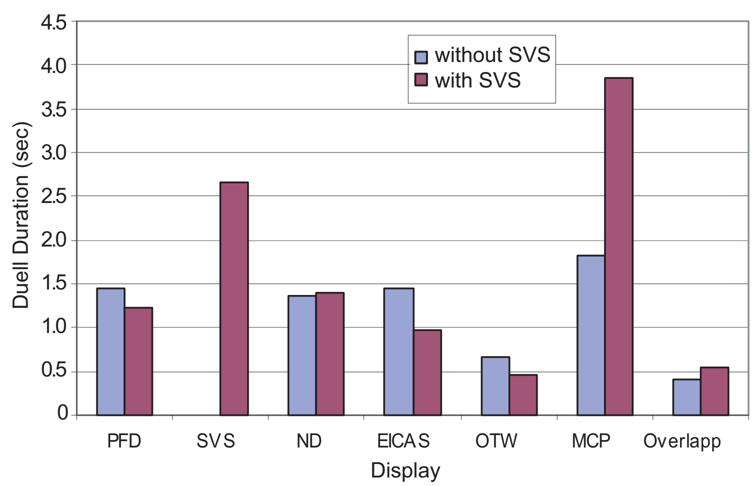


Figure 21. Dwell Duration with and without SVS (PF) on Normal Approach

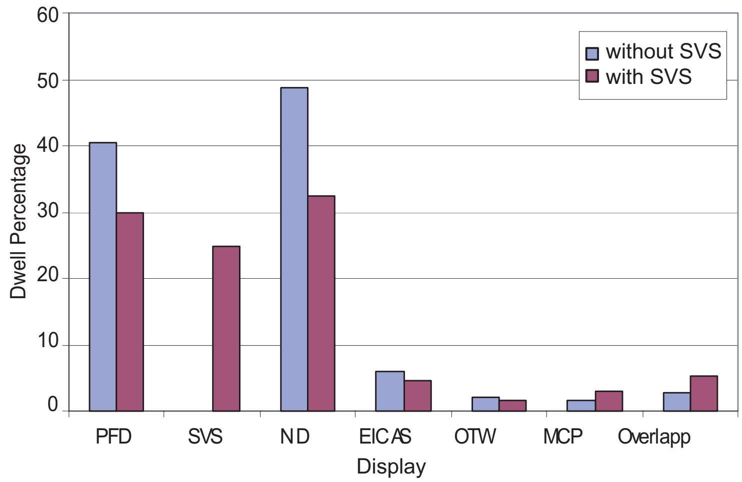


Figure 22. Dwell percentage with and without SVS (PF) on Normal Approach

b) Go-Around Procedures (with and without SVS)

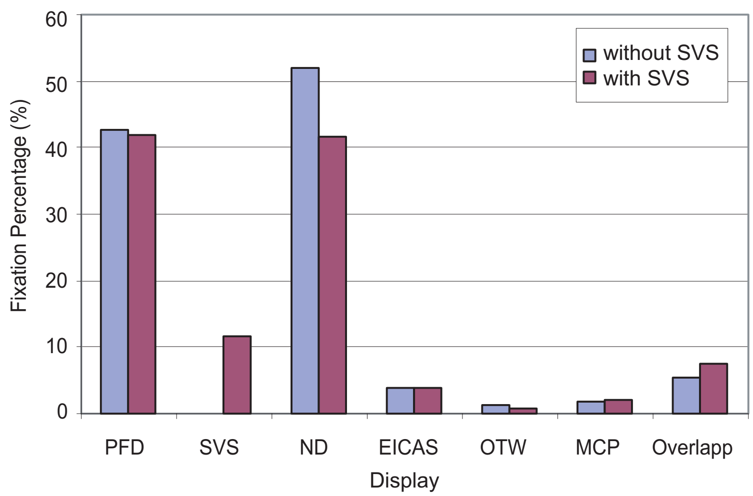


Figure 23 Fixation percentages for Go-Around scenario with and without SVS (PF)

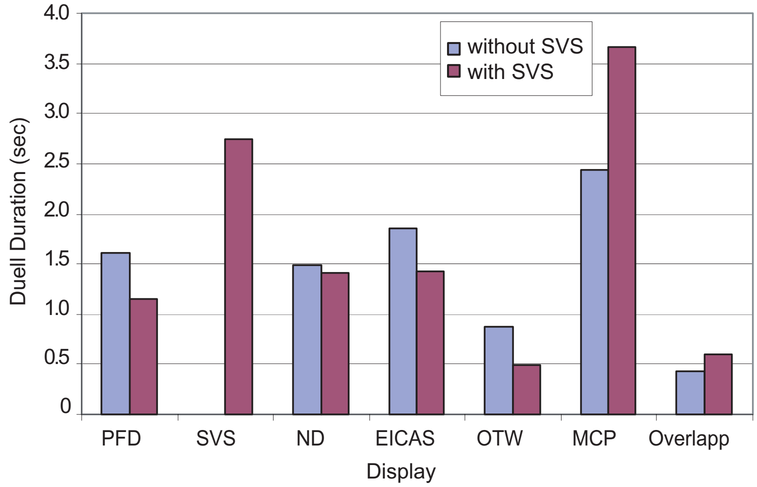


Figure 24 Dwell Duration for Go around Scenario with and without SVS (PF)

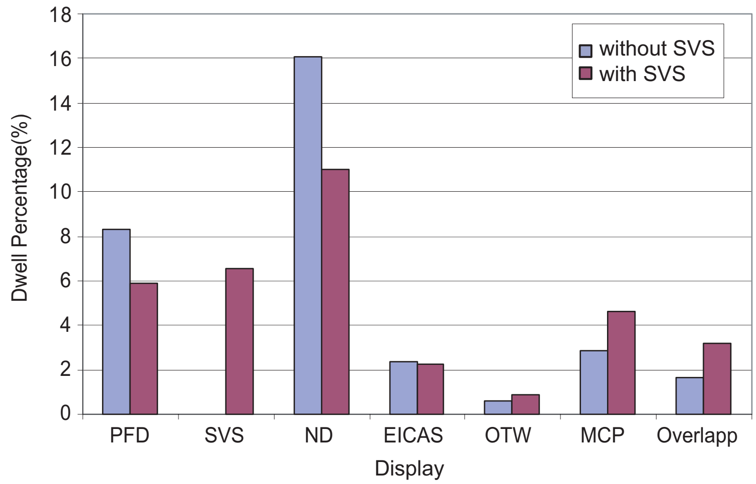


Figure 25 Dwell Percentages Go-Around Scenario with and without SVS (PF)

Overall, dwell percentage reflects the dwell duration and fixation percentage. If both dwell duration and fixation percentage are the high dwell percentage goes up. The scan pattern shows dwell percentages are the same for all displays in the SVS and non-SVS cases, with a few differences. The PFD and ND have higher dwell per4centage in non0SVS cases. MCP and Overlap have higher dwell percentage in SVS cases.

c) Go-Around with different Decision Altitudes

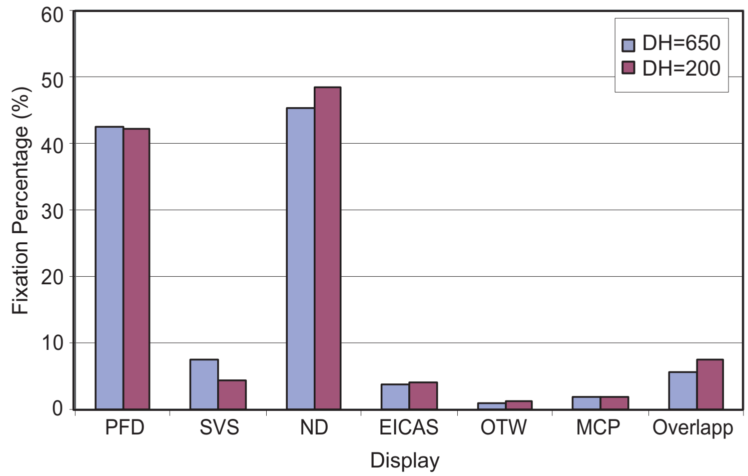


Figure 26. Fixation Percentages for Go-around Scenario with different DA (650 and 200 ft)- PF

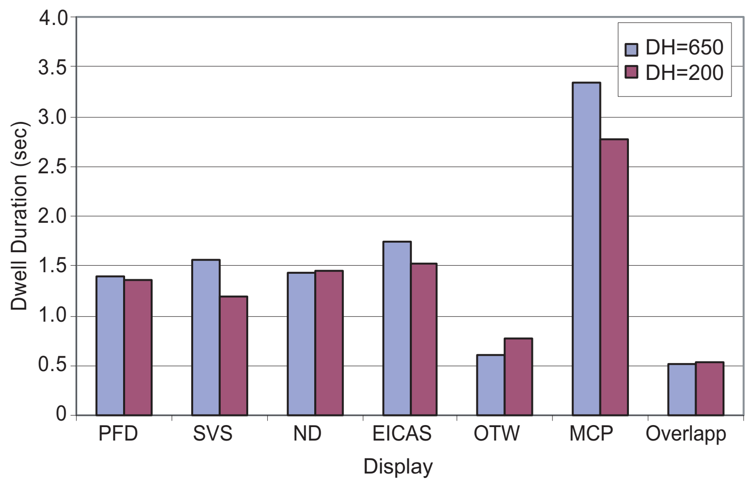


Figure 27. Dwell Durations for Go-Around Scenario with different Decision Heights (650 and 200 ft)

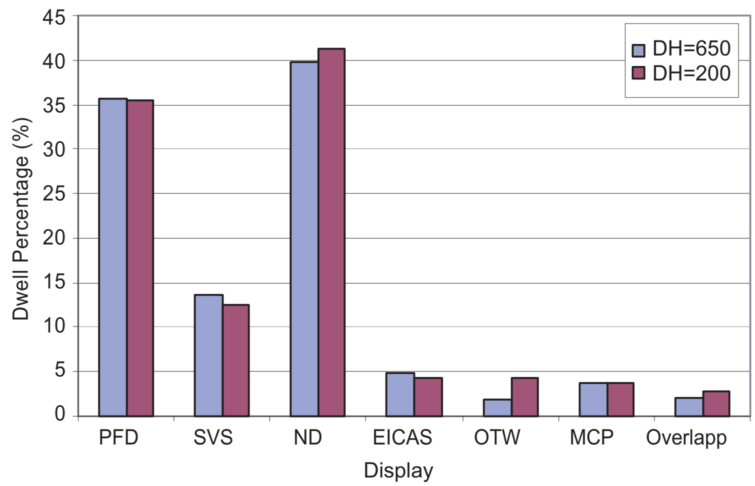


Figure 28. Dwell Percentages G-Around for Different Decision Heights (650 and 200ft)

Figure 26, 27 and 28 show comparisons between scan patterns for different decision Heights (650 and 200ft). It is very evident that decision heights did not impact the scan patterns very significantly. The dwell percentages which are a good metric of the scan pattern have more or less the same values for the two decision height except for OTW fixations. When the decision height is lower i.e. at 200ft, the PF has longer dwell durations that contribute to the higher dwell percentage.

d) Scan Pattern at different visibility

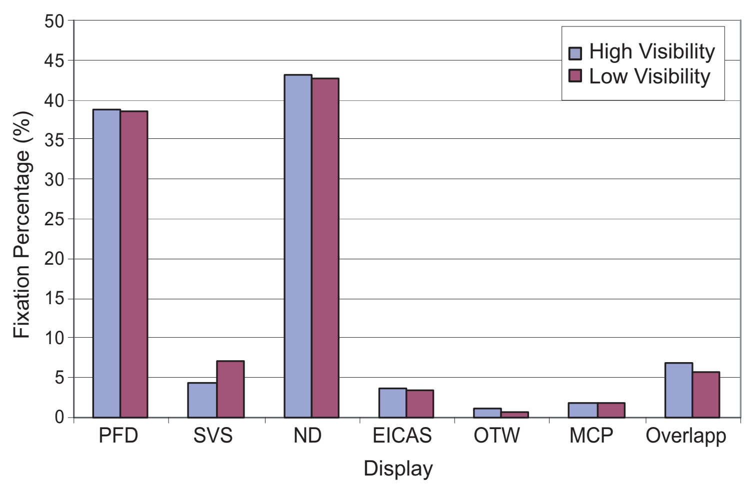


Figure 29. Fixation Percentages for Go-Around High v/s Low visibility (PF)

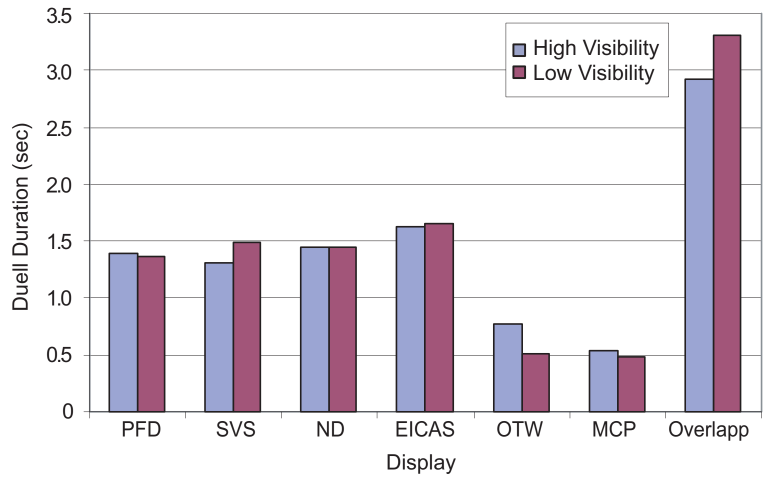


Figure 30. Dwell Duration for Go-Around high v/s low visibility

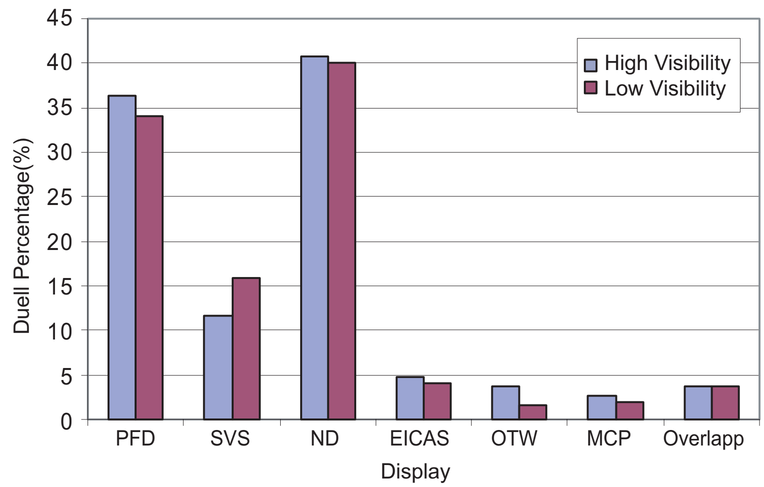


Figure 31. Dwell Percentage High v/s low visibility (PF)

In this analysis, the PF's scan pattern for low and high visibility were explored across normal or go-around approaches. High visibility was set at visibility at or above 10 mi, and low visibility was set at 0.2 mi. The scan pattern shows that PF fixated less on OTW under low visibility conditions and compensated the OTW with more fixations on SVS. Thus SVS was used as source of information about the external world, under low visibility conditions.

e) MIDAS v/s Mumaw

As a part of the validation effort, a comparison of the scan pattern of the PF-model and some empirical data on scan pattern collected by Mumaw et. al. (2000) was also done. Mumaw et. al. collected scan pattern data for pilots flying the in descent phase of flight using VNAV, and it did not have SVS on its flight deck. Thus the dwell duration and dwell percentage model data in the normal approach conditions were compared with the Mumaw data, and the results are shown in Figure 32 and Figure 33.

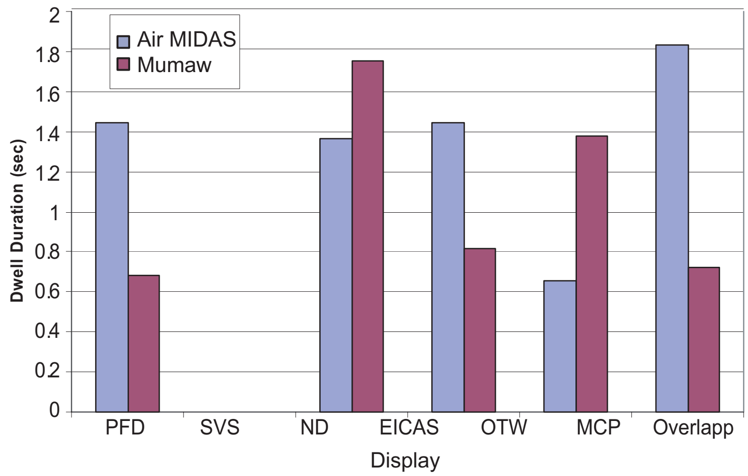


Figure 32. Dwell Duration (sec) Air MIDAS v/s Mumaw

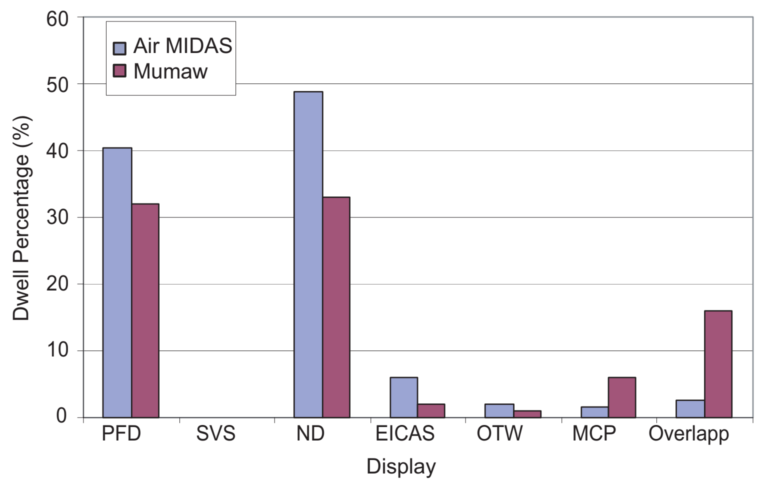


Figure 33. Dwell Duration Percentage Air MIDAS v/s Mumaw et. al.

The PF-model has higher dwell duration on PFD, EICAS and MCP than pilots studied by Mumaw et. al. The dwell percentage, which is calculated as the dwell duration on any one display over the total dwell duration on all the displays, has slightly different numbers. The PF agent's dwell percentages are higher than the Mumaw pilot's for PFD, ND and EICAS displays. Since we did not have fixation data available for Mumaw, we could not compare the same with the model data. However, other researchers (e.g. Bellenekes et. al, 1999) have found that the numbers of fixations are fewer when the dwell durations are long. It seems that the modeled agent is setup to look at more components than human pilots do, which is contributing to long dwell durations. The overall trend in dwell duration data between the model and Mumaw data is more or less the same.

Conclusion

Prediction of human performance using the synthetic vision systems in approach, landing and go-around flight was performed by using Air MIDAS. PC plane aircraft simulation model was used for the world representation interacted by Air MIDAS pilot agents. Detailed scan pattern model was newly implemented and activities including approach, landing and go-around procedures, standard callout, checklist, ATC communication and landing/go-around decision were installed. Result and analysis of 80 simulation runs are summarized as follows:

(1) SVS would not adversely affect the flight safety in approach, landing and go-around phase regardless of decision altitude and triggers of go-around including PF's intention at decision altitude and ATC's command, while it would allow approach and landing in conditions that would otherwise be unattainable.

(2) Small delays of action initiation in flight control were observed in approach phase with SVS operation. This occurred because that the chances of fixation on each display was decreased by adding SVS to conventional display configuration,

(3) No human performance degradation and no delay of task initiation were observed in landing and go around phase, though there were time shifts in the approach phase.

(4) A scan pattern model which simulates pilot's instrument scan was validated by using the data of human-in-the-loop simulation. Sensitivity analysis on threshold setting for information acquisition failure model was performed and (mean-1.0SD) fixation duration was selected for the threshold of failure occurrence so that the error rate of scan perception was 10% or less.

Analysis in this study was performed considering scan pattern change induced by the SVS and it did not include aspects of SVS's benefit which could potentially enhance pilot's Situation Awareness. For further enhancement of model capabilities, more detailed human internal information processing model including perception, comprehension and projection should be developed to predict SVS's features of enhancing situation awareness.

Acknowledgement

The authors would like to thank Mr. Tom Marrow, Silicon Valley Systems Inc. for his technical help and support for this study. The study was undertaken for the NASA Aviation Safety Program under Grant NCC2-1305 to the San Jose State University, Dr. David Foyle.

References

Corker, K.M. (2000). Cognitive Models & Control: Human & System Dynamics in Advanced Airspace Operations. (2000) in N. Sarter and R. Amalberti (Eds.) Cognitive Engineering in the Aviation Domain. Lawrence Earlbaum Associates, New Jersey.

Corker, K.M., Gore, B. et al. (2003) Human Performance Modeling Predictions in Reduced Visibility Operation with and without the use of Synthetic Vision System Operations. HAIL Laboratory Report N). SVS-2-2002. San Jose State University, San Jose CA.

Endsley, M.R. (2000) Situation models: An avenue to the modeling of mental models, *Proceedings of the Human Factors and Ergonomic Society 44th Annual Meeting*, Santa Monica, CA, 2002

Keller, J. and Leiden, K. (2002) Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing, Micro Analysis and Design, Inc. June, 18

Mumaw, R., Sarter, N., Wickens, C., Kimball, S., Nikolic, M., Marsh, R., Xu, W., & Xu, X. (2000) Analysis of pilot monitoring and performance on highly automated flight decks (NASA Final Project Report: NAS2-99074). Moffett Field, CA: NASA Ames Research Center.

McCracken, J.H. and Aldrich, T.B. (1984) Analysis of selected LHX mission functions:

Implications for operator workload and system automation goals (Technical note ASI 479-024-84(b)). Anacapa Sciences, Inc.

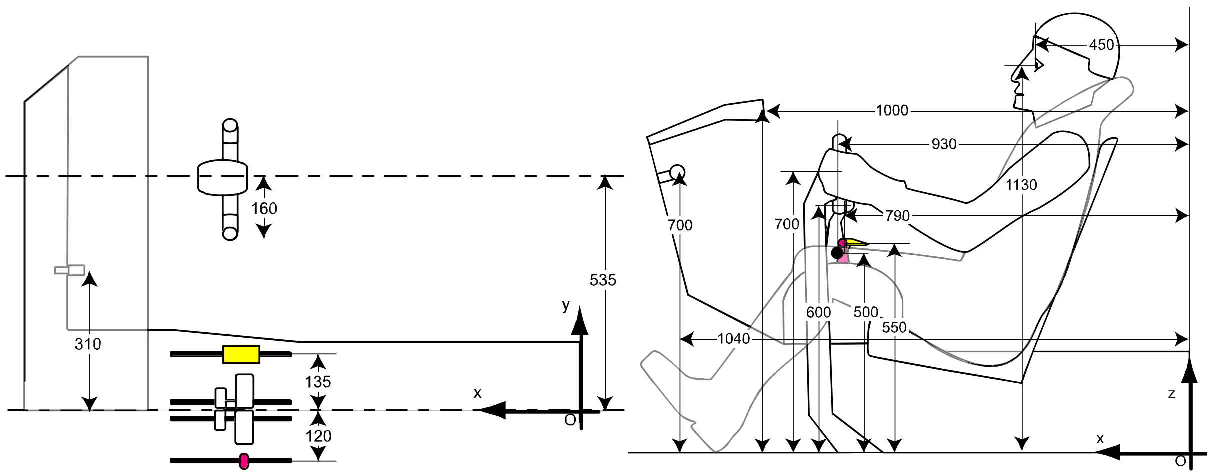
Palmer, M. T., Abbott, T. A., Williams, D. H. (1997) Development of Workstation-Based Flight Management Simulation Capabilities within NASA Langley's Flight Dynamics and Control Division, *Ninth International Symposium on Aviation Psychology*, Columbus, OH, April, 28-May, 1

Purcell, K., Corker, K., and Guneratne, E. (2002) Human Factors Issues and Evaluations for Commercial and Business Aircraft Synthetic Vision Systems, San Jose State University, February

Appendix A. Air MIDAS Activity Design

Cockpit Layout

Figure A.1 shows a cockpit layout prepared for task time calculation. It is as much size as those of large transport aircraft. Table A.1 shows coordinates of cockpit device point to be touched by pilot.



(a) Plan View **(b) Side View**

Figure A.1 Cockpit Layout (Plan View)

Table A.1 Cockpit Device Positions (mm)

Device	x	y	z
PF's Left Hand	930	-660	500
PF's Right Hand	930	-410	500
PNF's Left Hand	930	410	500
PNF's Right Hand	930	660	500
Left Wheel Left Grip	930	-695	700
Left Wheel Right Grip	930	-375	700
Right Wheel Left Grip	930	375	700
Right Wheel Right Grip	930	695	700

Device	x	y	z
Throttle Lever	790	0	600
Speed Brake	790	135	550
Flap Lever	790	-120	500
Gear Lever	1040	310	700
Mode Control Panel	1000	0	980
Display Control Panel	1000	450	980
Front Pedestal (FMS/Right)	965	100	450
Check List	930	760	400

Human Performance Database

Hands Movement

Fit's law was used to calculate time required for moving hands. Size of each cockpit device was assumed as Table A.2.

Fit's law:

$$t_{target} = I_M \log_2(D/S + .5) \text{ (msec)}$$

$$\text{where } I_M = 100[70 \sim 120] \text{ (msec/bit)}$$

Standard deviation (SD) of hands movement was assumed as 25% of the average time (I_M =100).

Table A.2 Cockpit Device Scales (Width mm)

Device	w
Wheel	30
Push to Talk Switch	5
Throttle Lever	80
Speed Brake	30
Flap Lever	30
Gear Lever	30
Mode Control Panel SW	20
Mode Control Panel Knob	20
Display Control Panel Knob	10
Radio FRQ Set (FMS)	30
Check List	50

Device Manipulation Time (t_{dev})

Experimental data (Sundstrom et. al, 1980) of required time to manipulate cockpit devices was used for device manipulation time.

Table A.3 Device Manipulation Time

Control/Display Type	Average Time (sec)
Pushbutton	1.0400
Two-position toggle switch	1.1100
Three-position toggle switch	1.3500
Covered toggle switch	1.5000
Single rotary switch	1.5800
Rotary switch in an array	1.6400
Single thumbwheel	1.9500
Thumbwheel in an array	2.0000
Hand lever 5 deg to 10 deg movement	1.6500
Hand lever 10 deg to 20 deg movement	1.8500
Hand lever 20 deg to 40 deg movement	2.0500
Hand lever 40 deg to 60 deg movement	2.2500
Rotary knob	1.6900
Hand wheel	2.3900
Discrete indicator	0.2500
Analog indicator	2.0000
Digital indicator	0.7500

Speech Rate(f_{speech}) and Cognitive Cycle(τ_{cgn})

Speech Rate(Sundstrom et. al, 1980) and cognitive cycle(Card et. al, 1983) data were used to calculate duration of speech and cognitive activities.

Table A.5 Speech Rate(f_{speech}) and Cognitive Cycle(τ_{cgn})

	Unit	Average
Speech Rate f_{speech}	(word/sec)	166
Cognitive Cycle τ_{cgn}	(sec)	0.0070

<u>Task Time Calculation Methods</u>

Task time was calculated by the following procedures.

Speech

$t_{speech} = words \cdot f_{speech}$ (msec)

words: The number of words contained in a sentence.

Standard deviation (SD) of speech time was assumed as 30% of the average time. Also, noise factor of 500 (msec) was added as variable delay between speech events.

$$SD_{speech} = 0.3 \cdot t_{speech} + 500$$

For radio communication tasks, time required to push push-to-talk switch, which is calculated in Manipulation section, was added to t_{speech}.

Hearing

Haring time was assumed to include processing time of sentence decoding in addition to speech time. Sentence was divided into chunk(s) in which have certain meanings. For example, a sentence "SBR tower, NASA 123, Over GOLET at 8000, GPS RNAV 33L approach, Information Z, Request Landing" was divided into 8chunks; "SBR tower(Receiver ID)," "NASA 123(Sender ID)," "Over GOLET(Position)," "8000(Altitude)," "GPS RNAV(Approach Procedure)," "33L approach(Expected Runway)," "Information Z(ATIS information)," and "Request Landing(Request)." Processing time was calculated by multiplying chunk(s) by cognitive cycle.

$$t_{hear} = t_{speech} + n_{chunks} \cdot \tau_{cgn}$$

SD of processing time was assumed as 30% of average processing time. Also, noise factor of 500 [msec] was added as variable delay between hearing events.

$$SD_{hear} = 0.3 \cdot t_{speech} + 0.3 n_{chunks} \cdot \tau_{cgn} + 500$$

Manipulation

Manipulation time was calculated by adding required time for moving hands to a target and device manipulation time of a target device. All actions except those expected to follow preceding action immediately performed start from nominal hand position and end at completion of device manipulation. Actions expected to follow preceding action immediately starts from hands position on a device manipulated in the preceding action. Nominal positions of each pilot's hands were assumed on his/her knees (since we are simulating automatic flight).

$$t_{manip} = t_{hand} + t_{dev}$$

SD of hands movement time was assumed as 25% of its average time and SD of manipulation time was assumed as 30% of its average time. So,

$$SD_{manip} = 0.25 \cdot t_{hand} + 0.3 \cdot t_{manip}$$

Air MIDAS Task Time

Based on the above methods, duration of each procedural task item were calculated.

Table A.6 Speech and Hearing Tasks

Sentence	Words	Speech (sec)		Chunks	Hearing (sec)		Moving Hand (sec)	
		Av.	SD		Av.	SD	Av.	SD
"NASA123, Make Go Around."	7	2.530	0.759	2	2.670	0.801	4.451	1.291
"Flap 5"	2	0.723	0.217	1	0.793	0.238	N/A	N/A
"Gear Down, Flap 20s, Speed plus 5"	7	2.530	0.759	3	2.740	0.822	N/A	N/A
"Gear Down"	2	0.723	0.217	1	0.793	0.238	N/A	N/A
"Flap 20"	2	0.723	0.217	1	0.793	0.238	N/A	N/A
"Landing Check List"	3	1.084	0.325	1	1.154	0.346	N/A	N/A
"Down"	1	0.361	0.108	1	0.431	0.129	N/A	N/A
"GOLET, Missed Approach 5000 ft"	5	1.807	0.542	2	1.947	0.584	N/A	N/A
"SBR tower, NASA 123, Over GOLET at SA.alftf, GPS RNAV 33L approach, Information Z, Request Landing"	21	7.590	2.277	8	8.150	2.445	9.512	2.809
"NASA 123, Clear to Land RWY 33L"	11	3.976	1.193	3	4.186	1.256	N/A	N/A
"Roger Cleared to Land RWY 33L, NASA123"	12	4.337	1.301	4	4.617	1.385	6.259	1.834
"Cleared to Land RWY 33L"	7	2.530	0.759	4	2.810	0.843	N/A	N/A
"Runway In-Sight"	3	1.084	0.325	1	1.154	0.346	N/A	N/A
"Stabilize"	1	0.361	0.108	1	0.431	0.129	N/A	N/A
"NASA 123, Going Around"	6	2.169	0.651	2	2.309	0.693	4.090	1.183

Table A.7 Manipulating Tasks

Manipulation	Pilot	Av.(Sec)	SD(Sec)
Set MCP Knob	PF	2.290	0.657
Push MCP Mode Switch	PF	1.640	0.462
Set Flap Lever	PNF	2.292	0.665
Set Flap Lever After Gear Down	PNF	2.103	0.608
Set Gear	PNF	1.520	0.435
Push Talk Switch on Wheel	PNF	1.921	0.532
Set Speed Brake Lever	PF	2.097	0.607
Pick Up Check List	PNF	0.524	0.131
Set DA on Display control Panel	PF	2.453	0.698
Set Radio Frequency	PNF	2.133	0.618
Disengage Autopilot on Wheel	PF	1.421	0.407
Push Go Lever	PF	1.040	0.312
GA Decision (=Cognitive Cycle)	PF	0.070	0.021

REFERENCE:

Roskam, J; Airplane Design, PART III: Layout Design of Cockpit, Fuselage, Wing and Empennage: Cutaways and Inboard Profiles, Roskam Aviation and Engineering (1989)

Card, S., Moran, T. and Newell, A.; The Psychology of Human Computer Interaction, Lawrence Erlbaum Associates (1983)

Sundstrom, J. L., NASA TLA Workload Analysis Support Volume 1 Detailed Task Scenarios for General Aviation and Metering and Spacing Studies, NASA CR 3199 (1980)