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Innovative Journal of Computer Technology
Volume 1 Issue 1

Simulation and Optimization of the Computerized Safety Program in Designing of the Aircraft

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ABSTRACT

According to Systems-Theoretic Accident Model and Processes (STAMP), the interactions among the system components and the necessary constraints that must be fulfilled during these interactions must be incorporated into the design of the system for ensuring safety. In the present research, a model has been developed, which considers the sequence of interactions among the components of the aircraft system. It also includes the necessary constraints that must be fulfilled during interaction. This system-design approach is used to detect abnormalities in the aircraft system according to STAMP, which is better than the method of chain-of-events for analysis.

Keywords: *Constraints, Interactions, STAMP, Sequence Diagrams, Unified Modeling Language.*

INTRODUCTION

The theory of Systems-Theoretic Accident Model and Processes (STAMP) considers the aircraft as a system (Leveson, 2004, 2011). The STAMP approach takes into account the system-component-interactions and the necessary constraints (Leveson 2015; Fleming *et al.*, 2013; Thomas, 2013) rather than the traditional method of chain-of-events for accident analysis.

In the present research work, the aircraft flight is divided into twelve phases: start, taxi, before takeoff, takeoff, climb out, cruise, descent, approach, landing, taxi to the ramp, shutdown and secure. Object-Oriented modeling is used to study the interactions among the components of the aircraft system. In object-oriented modeling, the communications in the system are studied by behavioral modeling using Unified Modeling Language (UML). The sequence diagrams are developed for each phase of flight by using Unified Modeling Language (UML) (Figure 1).

A sequence diagram is an interaction diagram that shows the interaction among the components of a system along with time order (Dimitrov et al., 2002). Graphically, a sequence diagram is a table that shows objects arranged along the X-axis and messages, ordered in increasing time, along the Y-axis (refer figure 1). The object that initiates the interaction is placed at the left, and increasingly more subordinate objects are put to the right. The messages that these objects send and receive are placed along the Y-axis, in order of increasing time from top to bottom (Booch *et al.*, 2004). Sequence diagram includes the object lifeline, which is the vertical dashed line that represents the existence of an object over some time. The focus of control is a tall, thin rectangle that shows the period during which an object is acting, either directly or through a subordinate procedure.

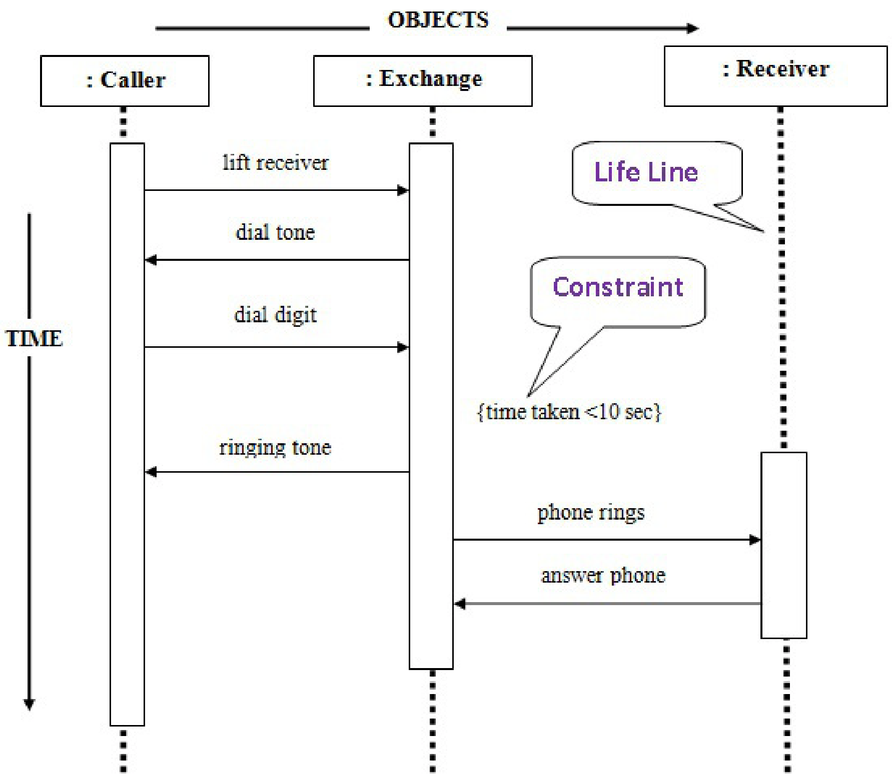


Fig.1. Sequence Diagram showing Interactions among Objects

Modeling Safety Program for Aircraft System

Interactions and constraints that must be enforced during an interaction in a particular phase of flight:-

In the safety program model, abnormalities are detected if there is any deviation from the expected interactions during a particular phase of flight or if there is any constraint violation during that interaction. The interactions among the components of the aircraft system in a specific aspect of flight are expressed in the form of a tuple. Eq. 1 shows the communication (*I*) during a specific stage of flight *(ph)*. Eq. 2 represents the constraints that must be enforced during an interaction.

(a) Interaction during a particular phase of flight

$$I^{i}_{ph} = (\mathrm{Obj}_1,\ \mathrm{Obj}_2,\ \mathrm{Mg/Ac},\ \varepsilon_i)_i \qquad (\text{for } i = 1 \text{ to n}) \qquad \ldots(1)$$

Object 1 initiates the interaction with purpose 2 to pass any message (Mg) or to perform any action (Ac) (eq. 1). During a particular interaction (*i*), there may be some number of constraints (ε_i) which must be fulfilled.

(b) Constraints that must be enforced during an interaction

The constraints that must be enforced during an interaction involve mandatory actions (M) (eq. 2), not-permissible actions (N) (eq. 3) and required parameters possessing specific values (R) (eq. 4 and eq. 5). In the safety program model, actions (M and N) are represented in the form of string. There are some governing parameters (P_g) during an interaction which govern the required parameters (P_r). The number of governing parameters in a particular communication is denoted by gn_i if there is no governing parameter, then $gn_i = 0$.

$$CM^{i,ph}_{j} = M^{i,ph}_{j} \quad \text{(where } j = 0 \text{ to } u \text{ and } u \text{ varies from 0 to Z)} \qquad ...(2)$$
$$CN^{i,ph}_{k} = N^{i,ph}_{k} \quad \text{(where } k = 0 \text{ to } v \text{ and } v \text{ varies from 0 to Z)} \qquad ...(3)$$
$$CR_{g}{}^{i,ph}_{a} = R_{g}{}^{i,ph}_{a} = (P_g,V_g)^{i,ph}_{a} \quad \text{(where } a = 0 \text{ to } gn_i \text{ and } gn_i \text{ varies from 0 to Z)} \qquad ...(4)$$
$$CR_{r}{}^{i,ph}_{b} = R_{r}{}^{i,ph}_{b} = (P_r,V_r)^{i,ph}_{b} \quad \text{(where } b = 0 \text{ to } w \text{ and } w \text{ varies from 0 to Z)} \qquad ...(5)$$

The number of constraints that must be enforced during a particular interaction (ε_i) is the sum of u, v *and* w i.e. $u + v + w = \varepsilon_i$ where u is the number of mandatory actions in an interaction, v is the number of not-permissible actions in an interaction and w is the number of required parameters in an interaction. For example, if there are three constraints which are required to be enforced during a particular interaction then $u + v + w = \varepsilon_i = 3$.

I) Constraints that must be enforced in a particular phase of flight to ensure overall flight safety

To ensure the overall flight safety, the abnormal conditions can also be detected if the constraints required during a particular phase of flight are violated. The restrictions that must be enforced during a specific phase involve mandatory actions (M) (eq. 6), not-permissible actions (N) (eq. 7) and required parameters possessing specific values (R) (eq. 8 and eq. 9). There are some governing parameters (P_g) during a particular phase which govern the required parameters (P_r). The number of governing parameters for a specific step is denoted by gn_{ph}. If there is no governing parameter in a stage, then $gn_{ph} = 0$.

$$CM^{ph}_{J} = M^{ph}_{J} \quad \text{(where } J = 0 \text{ to } x \text{ and } x \text{ varies from 0 to Z)} \qquad ...(6)$$
$$CN^{ph}_{K} = N^{ph}_{K} \quad \text{(where } K = 0 \text{ to } y \text{ and } y \text{ varies from 0 to Z)} \qquad ...(7)$$
$$CR_{g}{}^{ph}_{A} = R_{g}{}^{ph}_{A} = (P_g,V_g)^{ph}_{A} \quad \text{(where } A = 0 \text{ to } gn_{ph} \text{ and } gn_{ph} \text{ varies from 0 to Z)} \qquad ...(8)$$
$$CR_{r}{}^{ph}_{B} = R_{r}{}^{ph}_{B} = (P_r,V_r)^{ph}_{B} \quad \text{(where } B = 0 \text{ to } z \text{ and } z \text{ varies from 0 to Z)} \qquad ...(9)$$

The number of constraints that must be enforced during a particular phase (Ψ_{ph}) is the sum of x, y, *and* z, i.e. $x + y + z = \Psi_{ph}$ where x is the number of mandatory actions in a phase, y is number of not-permissible steps in a period and z is the number of required parameters in a stage. For example, if there are five constraints that are needed to be enforced during a particular phase then $x + y + z = \Psi_{ph} = 5$.

Figure 2 shows the sequence diagram for the climb out phase as a representative case. There are total seven number of interactions in this phase, i.e. $n = 7$ (eq. 11 to Eq. 17). The interactions during climbout phase are as follows (Eq. 10):-

$I^{i}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_i)_i$ (for i = 1 to 7) ...(10)

where

$I^{1}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_1)_1$ = ("pilot", "trimtab", "trim", 1) ...(11)

$I^{2}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_2)_2$ = ("pilot","autothrottle", "arm & set", 0) ...(12)

$I^{3}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_3)_3$ = ("pilot", "autopilot", "on & set", 0) ...(13)

$I^{4}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_4)_4$ = ("pilot", "autobrake", "off", 0) ...(14)

$I^{5}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_5)_5$ = ("pilot", "TCAS", "get info for climbout", 0) ...(15)

$I^{6}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_6)_6$ = ("TCAS", "pilot", "analyze info for climbout", 0) ...(16)

$I^{7}_{climbout}$ = (Obj$_1$, Obj$_2$, Mg/Ac, $\varepsilon_7)_7$ = ("pilot", "ADAHRS", "set speed", 2) ...(17)

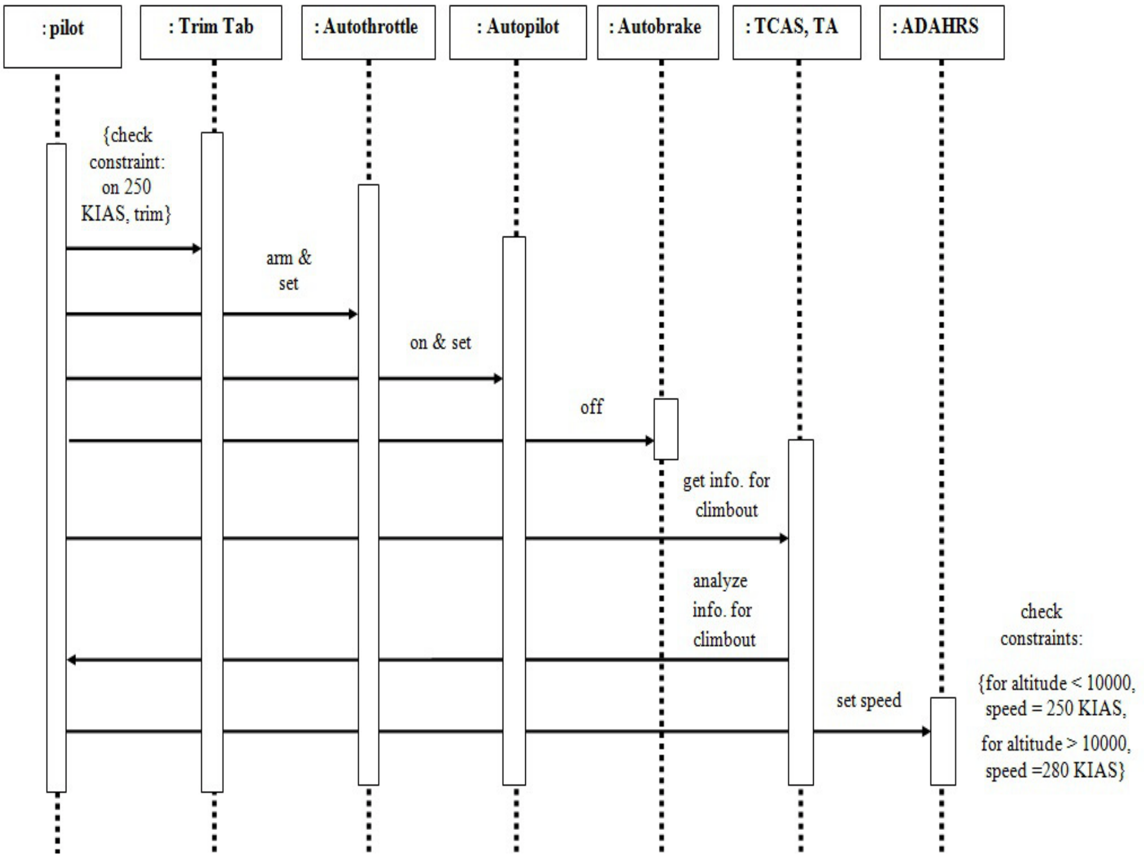


Fig. 2. Sequence Diagram for Climbout Phase

The constraint that must be enforced during the course of first interaction (i = 1) in the climbout phase involves $u + v + w = \varepsilon_1 = 1$ where $u = 0$, $v = 0$, $w = 1$ (eq. 18 to eq. 23). There is one governing parameter (gn_i = 1) which is governing one required parameter (w = 1). The particular governing parameter governs its associated required parameter i.e. the first governing parameter ($CR_g{}^{1,climbout}{}_{1}$) governs the first required parameter ($CR_r{}^{1,climbout}{}_{1}$). When the governing parameter speed is "250 KIAS", the required parameter trim-tab should be "trim" (eq. 21 and eq. 23).

$CM^{1,climbout}{}_{j} = M^{1,climbout}{}_{0}$ = No mandatory action (here $j = 0$, $u = 0$) ...(18)

$CN^{1,climbout}{}_{k} = N^{1,climbout}{}_{0}$ = No not-permissible action (here $k = 0$, $v = 0$) ...(19)

$CR_g{}^{1,climbout}{}_{a} = R_g{}^{1,climbout}{}_{1} = (P_g,V_g)^{1,climbout}{}_{1}$ (here $a = 1$, $gn_i = 1$) ...(20)

where $(P_g,V_g)^{1,climbout}{}_{1}$ = ("speed", "250 KIAS") ...(21)

$CR_r{}^{1,climbout}{}_{b} = R_r{}^{1,climbout}{}_{1} = (P_r,V_r)^{1,climbout}{}_{1}$ (here $b = 1$, $w = 1$) ...(22)

where $(P_r,V_r)^{1,climbout}{}_{1}$ = ("trimtab", "trim") ...(23)

The constraint that must be enforced during the course of seventh interaction ($i = 7$) in the climbout phase involves $u + v + w = \varepsilon_7 = 2$ where $u = 0$, $v = 0$, $w = 2$ (eq. 24 to eq. 33). In this case, there is no mandatory action and no not-permissible action.

There are two governing parameters ($gn_i = 2$), which are governing two required parameters ($w = 2$). The particular governing parameter governs its associated required parameter. The first governing parameter ($CR_g{}^{7,climbout}{}_{1}$) governs the first required parameter ($CR_r{}^{7,climbout}{}_{1}$) and the second governing parameter ($CR_g{}^{7,climbout}{}_{2}$) dictates the second required parameter ($CR_r{}^{7,climbout}{}_{2}$), i.e. if the altitude is "<10000" then speed should be "250 KIAS" and if the height is ">10000" then speed should be "280 KIAS" (eq. 26 to Eq. 33).

$CM^{7,climbout}{}_{j} = M^{7,climbout}{}_{0}$ = No mandatory action (here $j = 0$, $u = 0$) ...(24)

$CN^{7,climbout}{}_{k} = N^{7,climbout}{}_{0}$ = No not-permissible action (here $k = 0$, $v = 0$) ...(25)

$CR_g{}^{7,climbout}{}_{a} = R_g{}^{7,climbout}{}_{1} = (P_g,V_g)^{7,climbout}{}_{1}$ (here $a = 1$, $gn_i = 2$) ...(26)

where $(P_g,V_g)^{7,climbout}{}_{1}$ = ("altitude", "<10000") ...(27)

$CR_r{}^{7,climbout}{}_{b} = R_r{}^{7,climbout}{}_{1} = (P_r,V_r)^{7,climbout}{}_{1}$ (here $b = 1$, $w = 2$) ...(28)

where $(P_r,V_r)^{7,climbout}{}_{1}$ = ("speed", "250 KIAS") ...(29)

$CR_g{}^{7,climbout}{}_{a} = R_g{}^{7,climbout}{}_{2} = (P_g,V_g)^{7,climbout}{}_{2}$ (here $a = 2$, $gn_i = 2$) ...(30)

where $(P_g,V_g)^{7,climbout}{}_{2}$ = ("altitude", ">10000") ...(31)

$CR_r{}^{7,climbout}{}_{b} = R_r{}^{7,climbout}{}_{2} = (P_r,V_r)^{7,climbout}{}_{2}$ (here $b = 2, w = 2$) ...(32)

where $(P_r,V_r)^{7,climbout}{}_{2}$ = (“speed”, “280 KIAS”) ...(33)

The model considers some necessary constraints during the climb out phase of flight. Total twelve constraints are taken into consideration i.e. $x + y + z = \Psi_{climbout} = 12$ where $x = 1$, $y = 1$, $z = 10$. One mandatory and one not-permissible action are considered. The constraints ensuring the normal functioning of both left and right engines during climbout phase are taken into consideration for overall flight safety (eq. 39 to Eq. 58). The fuel flow of both the engines should be “on”, and the Engine Pressure Ratio (EPR), Fan Speed (N1), High-Pressure Compressor Rotor Speed (N2) and Exhaust Gas Temperature (EGT) of both left and right engines should be “normal.” There is no governing parameter in this phase i.e. $gn_{ph} = 0$ (eq. 38). There are ten required parameters ($z = 10$) (eq. 39 to Eq. 58).

$CM^{climbout}{}_{1} = M^{climbout}{}_{1}$ (here $J = 1$, $x = 1$) ...(34)

where $M^{climbout}{}_{1}$ = “Take clearance from ATC” ...(35)

$CN^{climbout}{}_{1} = N^{climbout}{}_{1}$ (here $K = 1$, $y = 1$) ...(36)

where $N^{climbout}{}_{1}$ = “Passenger door should not be open” ...(37)

$CR_g{}^{climbout}{}_{0} = R_g{}^{climbout}{}_{0} = (P_g,V_g)^{climbout}{}_{0}$ = No governing parameter

(here $A = 0$, $gn_{ph} = 0$) ...(38)

$CR_r{}^{climbout}{}_{1} = R_r{}^{climbout}{}_{1} = (P_r,V_r)^{climbout}{}_{1}$ (here $B = 1, z = 10$) ...(39)

where $(P_r,V_r)^{climbout}{}_{1}$ = ("leftenginefuelflow","on") ...(40)

$CR_r{}^{climbout}{}_{2} = R_r{}^{climbout}{}_{2} = (P_r,V_r)^{climbout}{}_{2}$ (here $B = 2, z = 10$) ...(41)

where $(P_r,V_r)^{climbout}{}_{2}$ = ("leftengineEPR","normal") ...(42)

$CR_r{}^{climbout}{}_{3} = R_r{}^{climbout}{}_{3} = (P_r,V_r)^{climbout}{}_{3}$ (here $B = 3, z = 10$) ...(43)

where $(P_r,V_r)^{climbout}{}_{3}$ = (“leftengineN1”,”normal”) ...(44)

$CR_r{}^{climbout}{}_{4} = R_r{}^{climbout}{}_{4} = (P_r,V_r)^{climbout}{}_{4}$ (here $B = 4, z = 10$) ...(45)

where $(P_r,V_r)^{climbout}{}_{4}$ = ("leftengineN2","normal") ...(46)

$CR_r{}^{climbout}{}_{5} = R_r{}^{climbout}{}_{5} = (P_r,V_r)^{climbout}{}_{5}$ (here $B = 5, z = 10$) ...(47)

where $(\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{5}$ = ("leftengineEGT","normal") ...(48)

$\mathrm{CR}_r{}^{climbout}{}_{6} = \mathrm{R}_r{}^{climbout}{}_{6} = (\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{6}$ (here $B = 6$, $z = 10$) ...(49)

where $(\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{6}$ = (“rightenginefuelflow”,”on”) ...(50)

$\mathrm{CR}_r{}^{climbout}{}_{7} = \mathrm{R}_r{}^{climbout}{}_{7} = (\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{7}$ (here $B = 7$, $z = 10$) ...(51)

where $(\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{7}$ = (“rightengineEPR”,”normal”) ...(52)

$\mathrm{CR}_r{}^{climbout}{}_{8} = \mathrm{R}_r{}^{climbout}{}_{8} = (\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{8}$ (here $B = 8$, $z = 10$) ...(53)

where $(\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{8}$ = ("rightengineN1","normal") ...(54)

$\mathrm{CR}_r{}^{climbout}{}_{9} = \mathrm{R}_r{}^{climbout}{}_{9} = (\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{9}$ (here $B = 9$, $z = 10$) ...(55)

where $(\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{9}$ = ("rightengineN2","normal") ...(56)

$\mathrm{CR}_r{}^{climbout}{}_{10} = \mathrm{R}_r{}^{climbout}{}_{10} = (\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{10}$ (here $B = 10$, $z = 10$) ...(57)

where $(\mathrm{P}_r,\mathrm{V}_r)^{climbout}{}_{10}$ = ("rightengineEGT","normal") ...(58)

Figure 3 shows the sequence diagram for the landing phase as another representative case. There are total seven number of interactions in this phase, i.e. $n = 7$ (eq. 60 to 66). The interactions during the landing phase are as follows (Eq. 59):-

$I^{i}{}_{landing} = (\mathrm{Obj}_1,\ \mathrm{Obj}_2,\ \mathrm{Mg/Ac},\ \varepsilon_i)_i$ (for $i = 1$ to 7) ...(59)

where

$I^{1}{}_{landing} = (\mathrm{Obj}_1, \mathrm{Obj}_2, \mathrm{Mg/Ac}, \varepsilon_1)_1$ = ("pilot", "landinggear", "down", 0) . ..(60)

$I^{2}{}_{landing} = (\mathrm{Obj}_1, \mathrm{Obj}_2, \mathrm{Mg/Ac}, \varepsilon_2)_2$ = ("pilot", "autopilot", "off", 0) ...(61)

$I^{3}{}_{landing} = (\mathrm{Obj}_1, \mathrm{Obj}_2, \mathrm{Mg/Ac}, \varepsilon_3)_3$ = ("pilot","airspeed", "150 KIAS", 0) ...(62)

$I^{4}{}_{landing} = (\mathrm{Obj}_1, \mathrm{Obj}_2, \mathrm{Mg/Ac}, \varepsilon_4)_4$ = ("pilot", "ADAHRS", "apply reverse thrust", 1)...(63)

$I^{5}{}_{landing} = (\mathrm{Obj}_1, \mathrm{Obj}_2, \mathrm{Mg/Ac}, \varepsilon_5)_5$ = ("pilot", "spoiler", "extended", 0) ...(64)

$I^{6}{}_{landing} = (\mathrm{Obj}_1, \mathrm{Obj}_2, \mathrm{Mg/Ac}, \varepsilon_6)_6$ = ("pilot", "brake", "apply", 0) ...(65)

$I^{7}{}_{landing} = (\mathrm{Obj}_1, \mathrm{Obj}_2, \mathrm{Mg/Ac}, \varepsilon_7)_7$ = ("pilot", "autobrake", "off" ,0) ...(66)

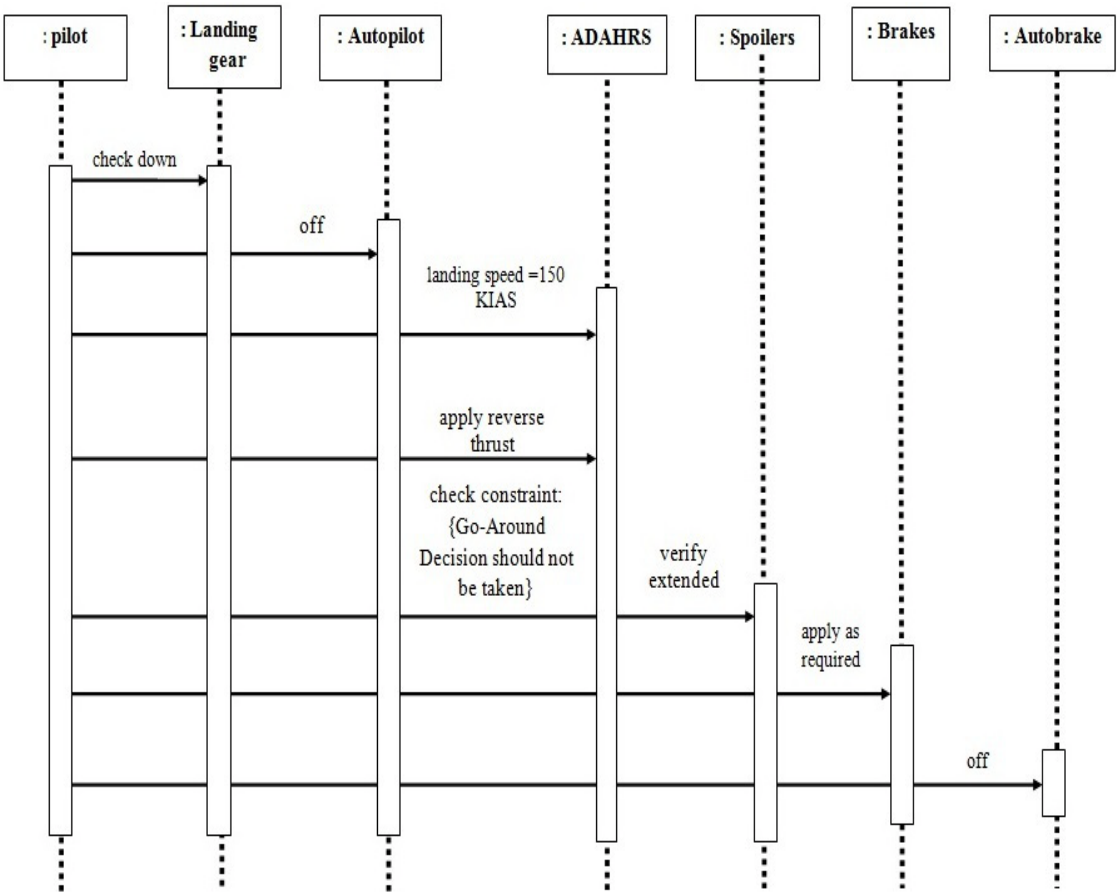


Fig. 3. Sequence Diagram for Landing Phase

During the fourth interaction, there is one constraint that must be enforced ($\varepsilon_4 = 1$). It is the not-permissible action (N) according to which once the reverse thrust is applied, the go-around decision should not be taken (eq. 69). It is included in ASPM to avoid human error in decision making due to impulsiveness bias during emergency conditions.

$CM^{4,landing}{}_{j} = M^{4,landing}{}_{0}$ = No mandatory action (here $j = 0$, $u = 0$) ...(67)

$CN^{4,landing}{}_{k} = N^{4,landing}{}_{1}$ (here $k = 1$, $v = 1$) ...(68)

where $N^{4,landing}{}_{1}$ = “the Go-Around decision should not be taken” ... (69)

$CR_g{}^{4,landing}{}_{a} = R_g{}^{4,landing}{}_{0} = (P_g,V_g)^{4,landing}{}_{0}$ = No governing parameter

(here $a = 0$, $gn_i = 0$) ...(70)

$CR_r{}^{4,landing}{}_{b} = R_r{}^{4,landing}{}_{0} = (P_r,V_r)^{4,landing}{}_{0}$ = No required parameter

(here $b = 0$, $w = 0$) ...(71)

ASPM considers some necessary constraints during the landing phase of flight. One mandatory and one not-permissible action are considered. The constraints ensuring the normal functioning of both left and right engines during landing phase are considered which are same as that of the climb out phase. Total twelve constraints are taken into consideration, i.e., $\Psi_{landing} = 12$. There is no governing parameter in this phase i.e. $gn_{ph} = 0$ (eq. 76) and there are ten required parameters ($z = 10$) (eq. 77 to Eq. 96). Following are the constraints that must be enforced to ensure flight safety during landing phase (eq. 72 to 96):-

$CM^{landing}_{1} = M^{landing}_{1}$ (here $J = 1,\ x = 1$) ...(72)

where $M^{landing}_{1}$ = “Take clearance from ATC” ...(73)

$CN^{landing}_{1} = N^{landing}_{1}$ (here $K = 1,\ y = 1$) ...(74)

where $N^{landing}_{1}$ = “Passenger door should not be open” ...(75)

$CR_{g}{}^{landing}{}_{0} = R_{g}{}^{landing}{}_{0} = (P_{g},V_{g})^{landing}{}_{0}$ = No governing parameter

(here $A = 0$, $gn_{ph} = 0$) ...(76)

$CR_{r}{}^{landing}{}_{1} = R_{r}{}^{landing}{}_{1} = (P_{r},V_{r})^{landing}{}_{1}$ (here $B = 1$, $z = 10$) ...(77)

where $(P_{r},V_{r})^{landing}{}_{1}$ = ("leftenginefuelflow","on") ...(78)

$CR_{r}{}^{landing}{}_{2} = R_{r}{}^{landing}{}_{2} = (P_{r},V_{r})^{landing}{}_{2}$ (here $B = 2$, $z = 10$) ...(79)

where $(P_{r},V_{r})^{landing}{}_{2}$ = ("leftengineEPR","normal") ...(80)

$CR_{r}{}^{landing}{}_{3} = R_{r}{}^{landing}{}_{3} = (P_{r},V_{r})^{landing}{}_{3}$ (here $B = 3$, $z = 10$) ...(81)

where $(P_{r},V_{r})^{landing}{}_{3}$ = (“leftengineN1”,”normal”) ...(82)

$CR_{r}{}^{landing}{}_{4} = R_{r}{}^{landing}{}_{4} = (P_{r},V_{r})^{landing}{}_{4}$ (here $B = 4$, $z = 10$) ...(83)

where $(P_{r},V_{r})^{landing}{}_{4}$ = ("leftengineN2","normal") ...(84)

$CR_{r}{}^{landing}{}_{5} = R_{r}{}^{landing}{}_{5} = (P_{r},V_{r})^{landing}{}_{5}$ (here $B = 5$, $z = 10$) ...(85)

where $(P_{r},V_{r})^{landing}{}_{5}$ = ("leftengineEGT","normal") ...(86)

$CR_{r}{}^{landing}{}_{6} = R_{r}{}^{landing}{}_{6} = (P_{r},V_{r})^{landing}{}_{6}$ (here $B = 6$, $z = 10$) ...(87)

where $(P_{r},V_{r})^{landing}{}_{6}$ = (“rightenginefuelflow”,”on”) ...(88)

$CR_{r}{}^{landing}{}_{7} = R_{r}{}^{landing}{}_{7} = (P_{r},V_{r})^{landing}{}_{7}$ (here $B = 7$, $z = 10$) ...(89)

where $(P_{r},V_{r})^{landing}{}_{7}$ = (“rightengineEPR”,”normal”) ...(90)

$CR_{r}{}^{landing}{}_{8} = R_{r}{}^{landing}{}_{8} = (P_{r},V_{r})^{landing}{}_{8}$ (here $B = 8$, $z = 10$) ...(91)

where $(P_{r},V_{r})^{landing}{}_{8}$ = ("rightengineN1","normal") ...(92)

$CR_{r}{}^{landing}{}_{9} = R_{r}{}^{landing}{}_{9} = (P_{r},V_{r})^{landing}{}_{9}$ (here $B = 9$, $z = 10$) ...(93)

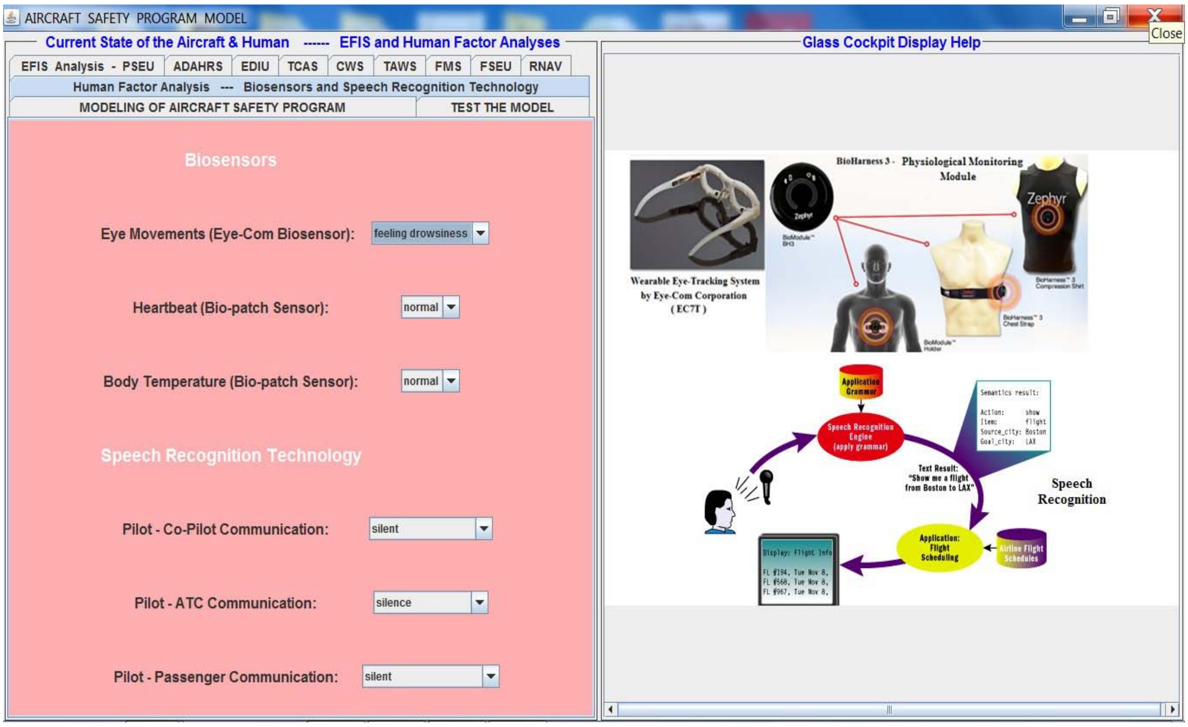
$$\text{where} \quad (P_r,V_r)^{landing}{}_{9} = (\text{"rightengineN2","normal"}) \qquad ...(94)$$

$$CR_r{}^{landing}{}_{10} = R_r{}^{landing}{}_{10} = (P_r,V_r)^{landing}{}_{10} \qquad (\text{here } B = 10, z = 10) \qquad ...(95)$$

$$\text{where} \quad (P_r,V_r)^{landing}{}_{10} = (\text{"rightengineEGT","normal"}) \qquad ...(96)$$

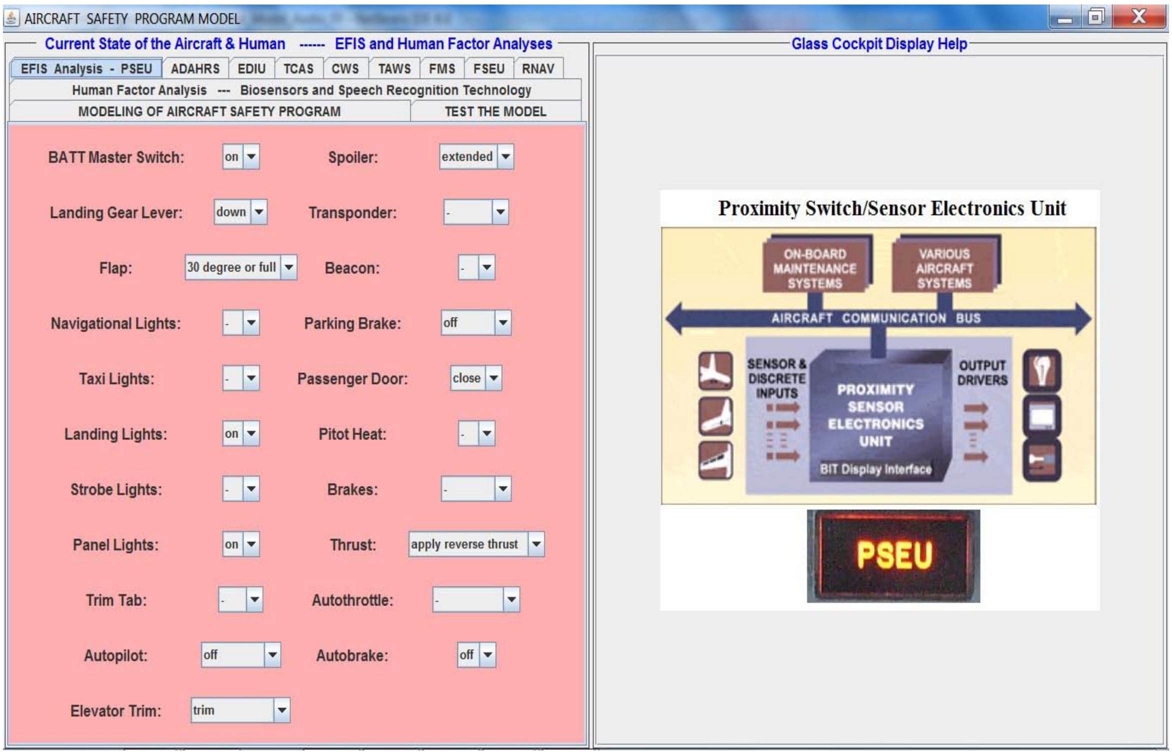
Implementation of the Model

The developed model has been implemented by using the Java programming language. The interface has been designed which takes input from Electronic Flight Instrument Systems (EFIS), biosensors, and speech recognition technology to analyze the current state of the aircraft and human (refer figure 4). The model detects the abnormalities in the aircraft system if there is a deviation from the expected interactions among the components and there is any constraint violation. For example, during landing phase, there is a constraint of not-permissible action (N) according to which once the reverse thrust is applied, the go-around decision should not be taken (refer figures 5 and 6). This constraint has been represented as Eq. 69 in the developed model. At situation = 1, the safety program provides the alert about the problem, as shown in figure 7. However, on detection of the biased condition, it gives the recommended safety step to the pilot at situation = 2 as shown in figure 8. In response to the recommended safety step, the pilot has applied brakes (refer figure 9). Figure 10 shows that the pilot has overcome the bias and has responded to the recommended safety step at situation = 2. However, if the pilot has not returned and is still biased, then the automatic emergency control is executed by ASPM involving communicating with ATC at situation = 3 (refer figure 11).



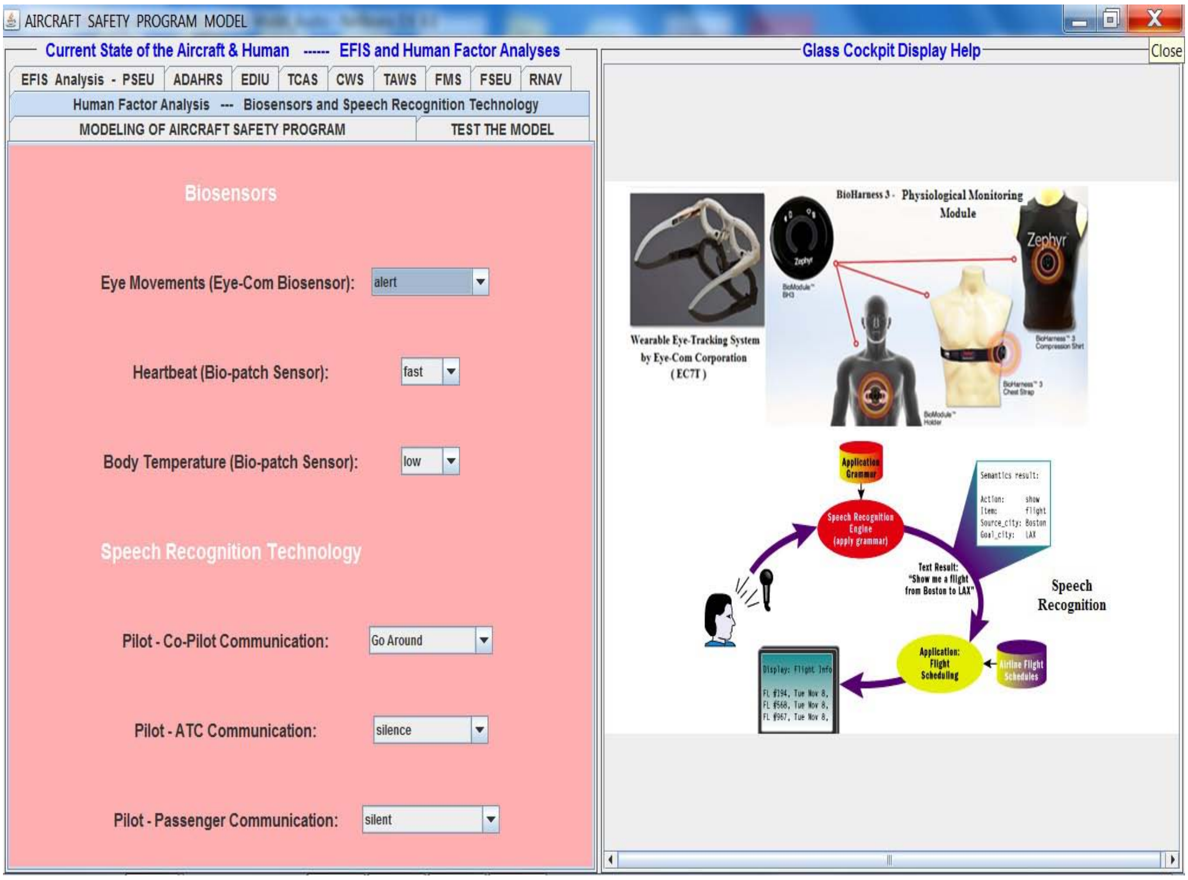
Eye Movements (Eye-Com Biosensor): feeling drowsiness
Heartbeat (Bio-patch Sensor): normal
Body Temperature (Bio-patch Sensor): normal
Pilot - Co-Pilot Communication: silent
Pilot - ATC Communication: silence
Pilot - Passenger Communication: silent

Fig. 4. Current State of the Aircraft and Human – EFIS and Human Factor Analyses



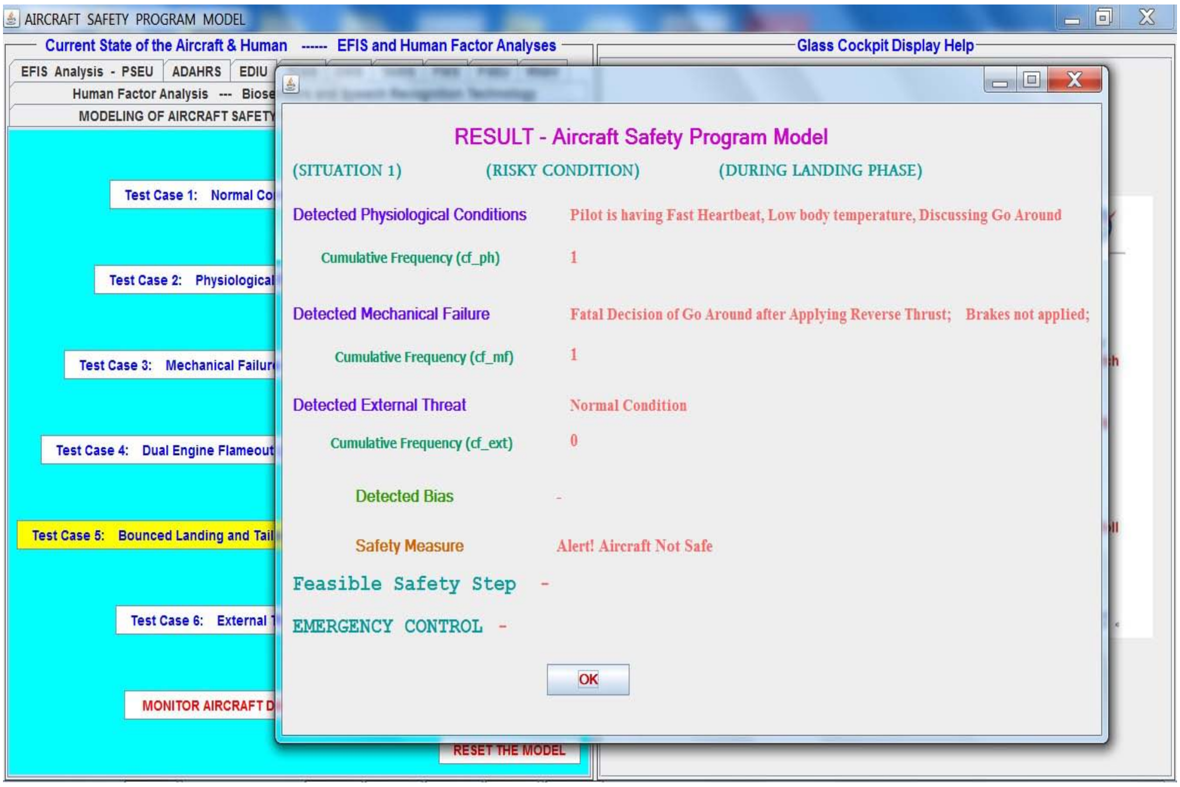
BATT Master Switch: on
Spoiler: extended
Landing Gear Lever: down
Transponder: -
Flap: 30 degree or full
Beacon: -
Navigational Lights: -
Parking Brake: off
Taxi Lights: -
Passenger Door: close
Landing Lights: on
Pitot Heat: -
Strobe Lights: -
Brakes: -
Panel Lights: on
Thrust: apply reverse thrust
Trim Tab: -
Autothrottle: -
Autopilot: off
Autobrake: off
Elevator Trim: trim

Fig. 5. Applying Reverse Thrust during Landing Phase (PSEU data)



Eye Movements (Eye-Com Biosensor): alert
Heartbeat (Bio-patch Sensor): fast
Body Temperature (Bio-patch Sensor): low
Pilot - Co-Pilot Communication: Go Around
Pilot - ATC Communication: silence
Pilot - Passenger Communication: silent

Fig. 6. Wrong Go Around Decision Detected after Applying Reverse Thrust during Landing Phase (Information by Speech Recognition)



RESULT - Aircraft Safety Program Model

(SITUATION 1) (RISKY CONDITION) (DURING LANDING PHASE)

Detected Physiological Conditions: Pilot is having Fast Heartbeat, Low body temperature, Discussing Go Around

Cumulative Frequency (cf_ph): 1

Detected Mechanical Failure: Fatal Decision of Go Around after Applying Reverse Thrust; Brakes not applied;

Cumulative Frequency (cf_mf): 1

Detected External Threat: Normal Condition

Cumulative Frequency (cf_ext): 0

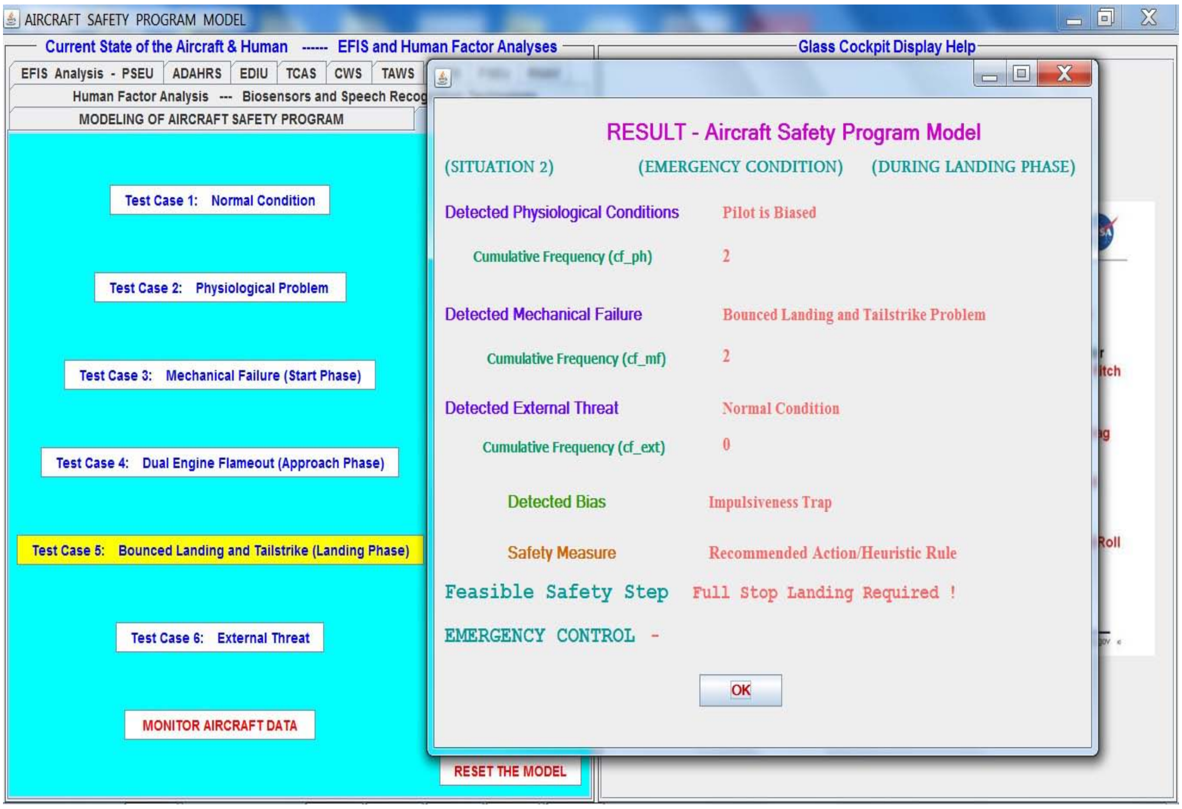
Detected Bias: -

Safety Measure: Alert! Aircraft Not Safe

Feasible Safety Step -

EMERGENCY CONTROL -

Fig. 7. The pilot is Alerted by ASPM regarding Wrong Decision of Go Around (Result at Situation = 1)



RESULT - Aircraft Safety Program Model

(SITUATION 2) (EMERGENCY CONDITION) (DURING LANDING PHASE)

Detected Physiological Conditions: Pilot is Biased

Cumulative Frequency (cf_ph): 2

Detected Mechanical Failure: Bounced Landing and Tailstrike Problem

Cumulative Frequency (cf_mf): 2

Detected External Threat: Normal Condition

Cumulative Frequency (cf_ext): 0

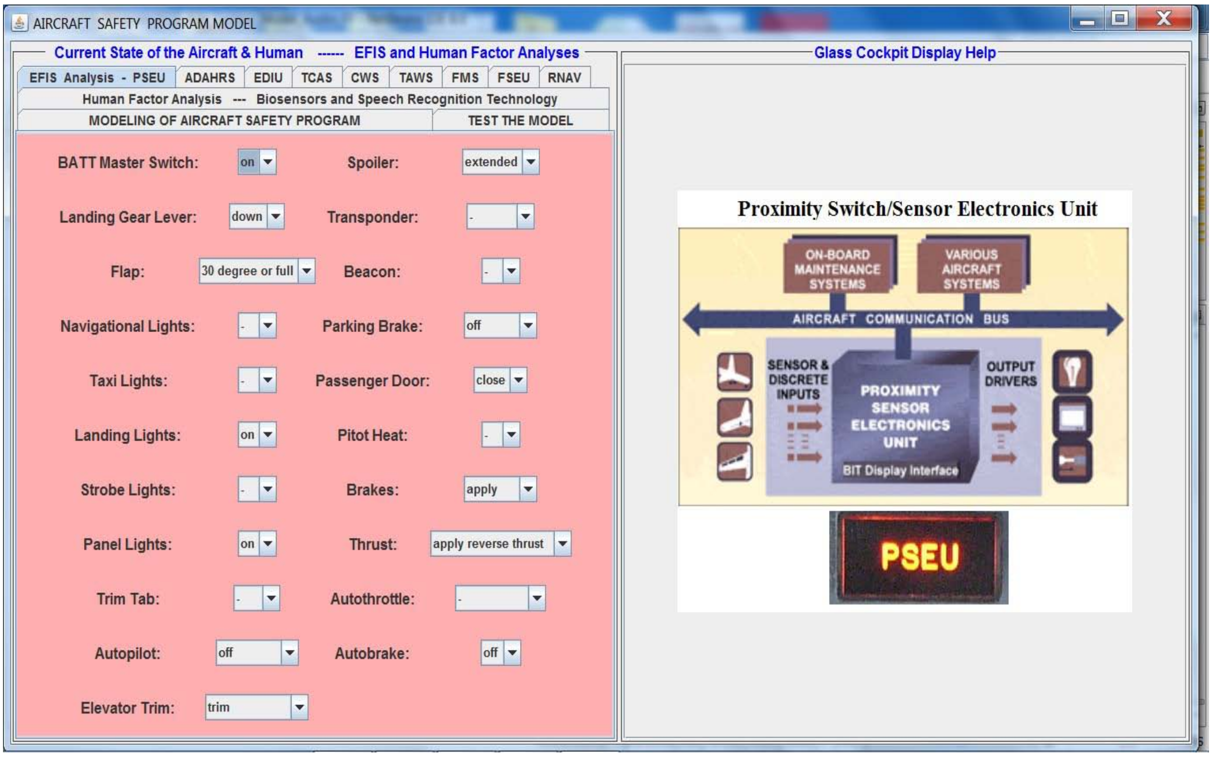
Detected Bias: Impulsiveness Trap

Safety Measure: Recommended Action/Heuristic Rule

Feasible Safety Step Full Stop Landing Required !

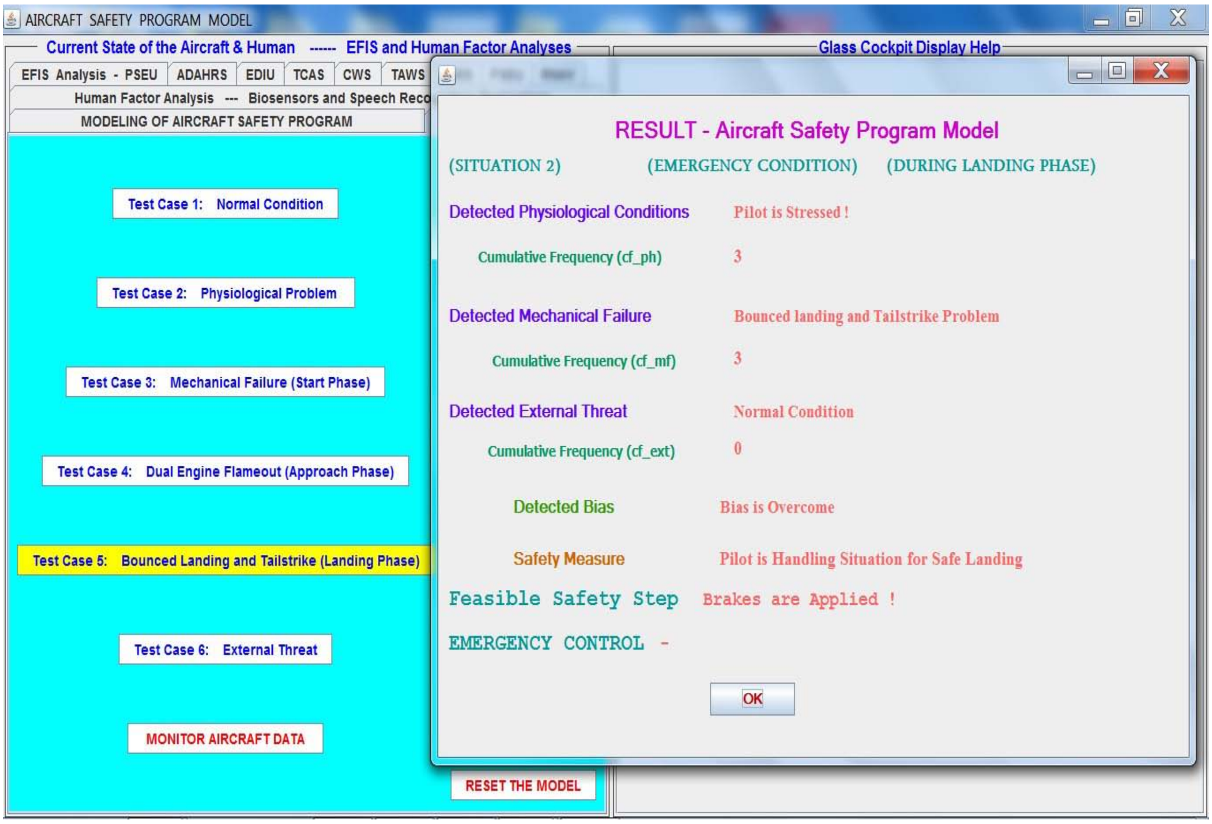
EMERGENCY CONTROL -

Fig. 8. Recommended Safety Step is provided by ASPM for Quick Pilot Action (Result at Situation = 2)



BATT Master Switch: on
Spoiler: extended
Landing Gear Lever: down
Transponder: -
Flap: 30 degree or full
Beacon: -
Navigational Lights: -
Parking Brake: off
Taxi Lights: -
Passenger Door: close
Landing Lights: on
Pitot Heat: -
Strobe Lights: -
Brakes: apply
Panel Lights: on
Thrust: apply reverse thrust
Trim Tab: -
Autothrottle: -
Autopilot: off
Autobrake: off
Elevator Trim: trim

Fig. 9. Brakes are applied in response to the Safety Step provided by ASPM (Result at Situation = 2)

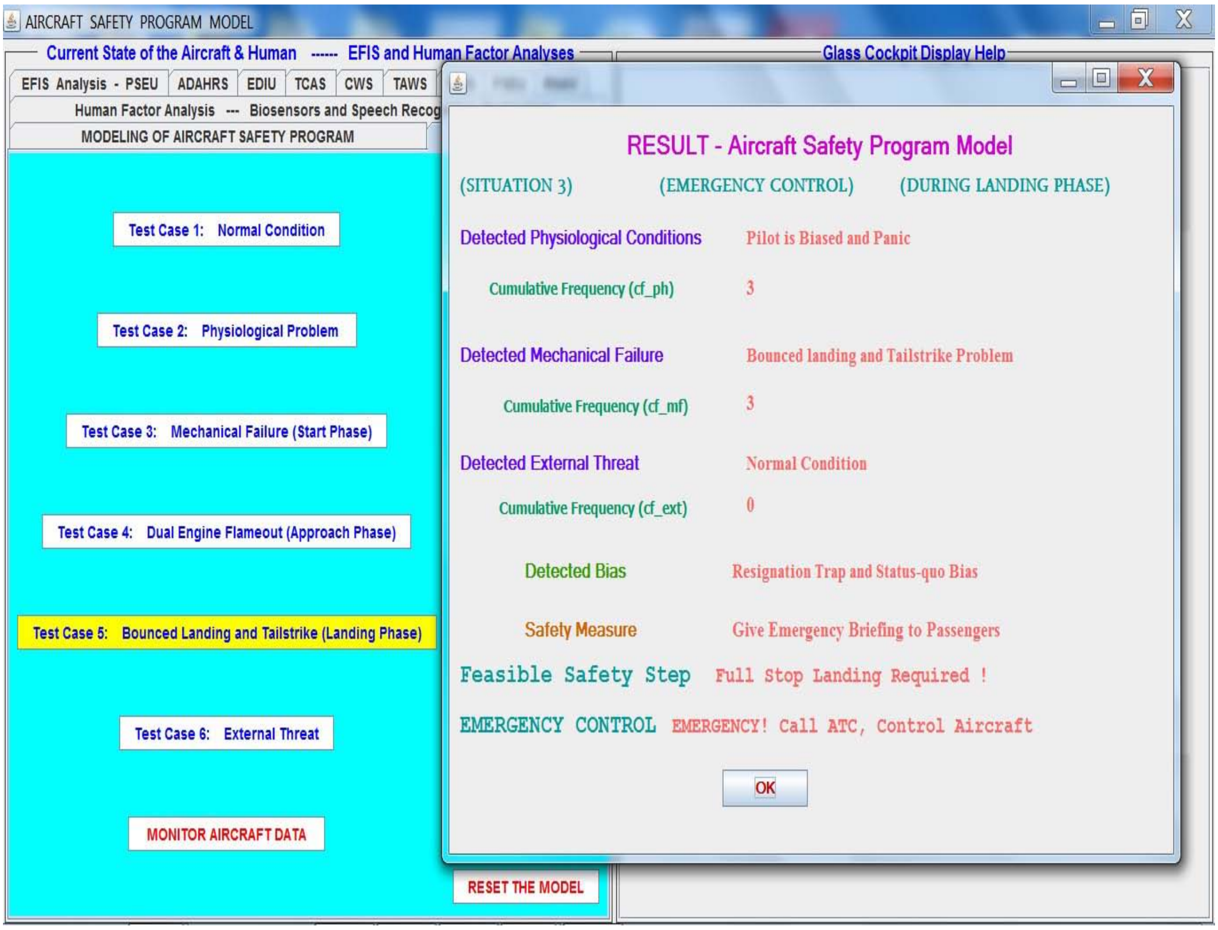


RESULT - Aircraft Safety Program Model

(SITUATION 2) (EMERGENCY CONDITION) (DURING LANDING PHASE)

Detected Physiological Conditions: Pilot is Stressed !
Cumulative Frequency (cf_ph): 3
Detected Mechanical Failure: Bounced landing and Tailstrike Problem
Cumulative Frequency (cf_mf): 3
Detected External Threat: Normal Condition
Cumulative Frequency (cf_ext): 0
Detected Bias: Bias is Overcome
Safety Measure: Pilot is Handling Situation for Safe Landing
Feasible Safety Step: Brakes are Applied !
EMERGENCY CONTROL -

Fig. 10. The pilot has Overcome the Bias in response to the Safety Step provided by ASPM (Result at Situation = 2)



RESULT - Aircraft Safety Program Model

(SITUATION 3) (EMERGENCY CONTROL) (DURING LANDING PHASE)

Detected Physiological Conditions Pilot is Biased and Panic

Cumulative Frequency (cf_ph) 3

Detected Mechanical Failure Bounced landing and Tailstrike Problem

Cumulative Frequency (cf_mf) 3

Detected External Threat Normal Condition

Cumulative Frequency (cf_ext) 0

Detected Bias Resignation Trap and Status-quo Bias

Safety Measure Give Emergency Briefing to Passengers

Feasible Safety Step Full Stop Landing Required !

EMERGENCY CONTROL EMERGENCY! Call ATC, Control Aircraft

Figure 11. Automatic Emergency Control by ASPM during Wrong Go Around Decision (Result at Situation = 3)

CONCLUSION

The developed safety program model incorporates the interactions among the components of the aircraft system and the constraints that must be fulfilled during interactions into the design of the aircraft safety program. The model supports the theory of STAMP. The implementation of the model demonstrates that the abnormalities in the aircraft system can be detected if there is any deviation from the expected interaction or if there is any violation of the necessary constraint(s). To enhance the robustness of the safety software, the new or additional system interactions and restrictions can be easily added in the model.

NOMENCLATURE

Ac	action performed during an interaction
CM	constraint related to mandatory action
CN	constraint related to not-permissible action
CR	constraint related to the required parameter
I	interaction
M	mandatory action
Mg	the message passed during an interaction
N	not-permissible action
Obj_1	object 1

Obj_2	object 2
P	particular parameter
R	required parameter possessing specific value
V	value of a particular parameter
Z	any natural number
gn	number of governing parameters, $gn = 0$ means no governing parameter(s) exist
n	number of interactions in a particular phase of flight
u	number of mandatory actions in an interaction, $u = 0$ means no mandatory action(s) exist in that particular interaction
v	number of not-permissible actions in an interaction, $v = 0$ means no not-permissible action(s) exist in that particular interaction
w	number of required parameters in an interaction, $w = 0$ means no required parameter(s) exist in that particular interaction
x	number of mandatory actions in a phase, $x = 0$ means no mandatory action(s) exist in that particular phase
y	number of not-permissible actions in a phase, $y = 0$ means no not-permissible action(s) exist in that particular phase
z	number of required parameters in a phase, $z = 0$ means no required parameter(s) exist in that particular phase
ε	number of constraints that must be enforced during an interaction, $\varepsilon = 0$ means no constraint, $\varepsilon = 1$ means one constraint and so on
Ψ	number of constraints that must be enforced during a particular phase of flight, $\Psi = 0$ means no constraint, $\Psi = 1$ means one constraint and so on

SUPERSCRIPTS

i	particular interaction
ph	particular phase of flight, e.g. *climbout*, *landing*, etc

SUBSCRIPTS

A	the particular governing parameter in a phase
B	particular required parameter in a phase
J	particular mandatory action in a phase
K	particular not-permissible action in a phase
a	the particular governing parameter in an interaction
b	particular required parameter in an interaction
g	governing parameter
i	particular interaction
j	particular mandatory action in an interaction
k	particular not-permissible action in an interaction
ph	particular phase of flight, e.g. *climbout*, *landing*, etc
r	required parameter

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