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# Using STPA in the evaluation of fighter pilots training programs

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**Abstract**

This paper presents how the application of the STPA method might support the evaluation of fighter pilots training programs and trigger procedural and technological changes. We applied the STPA method by considering the safety constraints documented in the Standard Operating Procedures (SOPs) of a South European Air Force and regard a flight of a two F-16 aircraft formation. In this context, we derived the control actions and feedback mechanisms that are available to the leader pilot during an Aircraft Combat Maneuver (ACM) mission, and we developed the control flow diagram based on the aircraft manuals. We compared the results of each analysis step with the respective flight training program, which is based on a mixed skill and rule-based decision-making, and we examined the role of the feedback mechanisms during multiple safety constraints violations. The analysis showed that: the flight training program under study does not structurally include cases of infringement of multiple safety constraints; the maintenance of some safety constraints are not supported by alerts, or rely on only one human sense; the existing procedures do not refer to the prioritization of pilot actions in cases of violation of multiple safety constraints; operation manuals do not address the cases of possible human performance deterioration when simultaneous information from feedback mechanisms is received. The results demonstrated the benefits of the STPA method, the application of which uncovered various inadequacies in the flight training program studied, some of them related to the F-16 cockpit ergonomics. The analysis lead to recommendations in regard to the amendment of the corresponding fighter pilots training program, and the conduction of further research regarding the aircraft – pilot interaction when multiple safety constraints are violated. The approach presented in this paper can be also followed for the (re)evaluation of flight training schemes in military, civil and general aviation, as well by any human-machine interface intensive domain.

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## 1. Introduction

Fighter aircraft pilots face an array of challenges during the execution of every mission, and need to remain constantly alerted in order to ensure that each mission will meet its goals, safety included. Typically, air force missions are performed by at least two aircraft, which are called aircraft formation. In addition to operating the aircraft, the mission leader has to consider various factors affecting the formation and the tactics, so that he/she can confront with emergent situations and complete the mission safely. When airborne, fighter pilots process every input in a timeframe between three (3) and five (5) seconds in order to make a decision and perform the actions required [1], thus time constituting a crucial factor especially during missions with high demands (e.g., steep maneuvers, limited air space, interception of armed aircraft). Although fighter pilots are trained to perform in a multi-tasking environment [2], they are still subjected to human performance limitations when they handle multiple requirements under time constraints [3].

Military aviation uses cause-and-effect hazard analysis in the design of flight training [4]. Such analysis is inherently based on a “find and fix” thinking [5] and corresponds to a mixed skill and rule-based decision-making [6]; thus, the concept “if you see this, do that” is fundamental in military flight training programs. Fighter pilots are trained in simulators, where they deal with various complicated scenarios that “picture” a mixture of potential unwanted situations; this practice corresponds to the recognition-primed decision-making model [7]. It is expected that trained pilots are able to recall every possible scenario taught or experienced, recognize the corresponding conditions and react timely in order to handle simple or complex situations rising from aircraft failures, hostile aircraft tactics, aircraft formation position etc. Operational experience, automated functions of modern fighter jets and recurrent training are deemed as means to support the ability of pilots to identify hazards and assess risks [4].

Systemic models that move beyond linearity and address variability and interconnectivity have not yet been widely introduced in the defense sector. The System-Theoretic Process Analysis (STPA) is a top-down hazard analysis method based on systems engineering and suggests that hazardous states derive from insufficiently designed and/or operated control mechanisms. The STPA technique includes specific steps, from the foundation of the basic system diagram to the determination of the way control actions might provoke hazards, and is able to reveal systemic flaws not previously identified during system design and operation [8].

The present paper presents the first phase of a study related to risk management in military aviation. The question of this phase was: Could an analysis based on the STPA method reveal deficiencies in current fighter pilot training programs? In order to answer the aforementioned question, we applied the STPA technique taking into account the safety constraints (SC), control actions (CA) and feedback mechanisms (FM) referred in a fighter aircraft’s documentation and the Standard Operating Procedures (SOPs) of a South European Air Force (SEAF). During a qualitative analysis we identified various safety related issues that are vaguely or not at all addressed in the fighter pilot training program considered.

**Nomenclature**

| | |
|---|---|
| A/C | aircraft |
| ACM | Air Combat Maneuvers |
| AGSM | Anti-G Straining Maneuver |
| CA | control action |
| FM | feedback mechanism |
| HUD | Head-Up Display |
| SOP | standard operating procedure |
| STPA | System-Theoretic Process Analysis |

## 2. Methodology

The researchers contemplated a typical mission of F-16 fighter aircraft (A/C) operated by a SEAF. The mission scenario regarded two aircraft formation that protect an area from hostile aircraft and engage in air fight in the case of imminent and persistent threats; this type of mission is known as Air Combat Maneuvers (ACM). The references we consulted for the scope of the study were: the aircraft operating and technical manuals [9, 10], where the available control actions and feedback mechanisms are documented; the SEAF SOPs referring to the mission safety constraints [9]; the United States Air Force (USAF) documentation [5], which thoroughly describes the risk management to be performed by fighter pilots.

In order to simplify this initial study, we made the following assumptions:

a. The two aircraft are loaded with two wing tanks, four air-to-air missiles and a gun machine. This configuration imposes restrictions in aircraft maneuvers.
b. Organizational flaws were not examined.
c. The A/C are airworthy and their systems fully operative, except of the case of Head-Up Display (HUD) failure during one or more SC violations, as discussed later in this paper.
d. The aircraft formation system was considered when operating over the designated training area. Thus, we excluded hazards during other flight phases such as take-off and landing.

The researchers first listed the SCs, CAs and FMs referred in the relevant documents [5, 9, 10]. Afterwards, we applied the STPA method [11] by setting the formation leader as a controller who interacts with another controller (i.e. the pilot of the other aircraft), called “Wingman”. The application of the STPA technique was facilitated by the A-STPA software [12]. The results from each STPA step were discussed in the light of the existing training program; in addition, we qualitatively explored combinations of SC infringements and the respective information flow from FMs.

## 3. Application of the STPA and results

### *3.1. Safety constraints, control actions and feedback mechanisms*

Table 1 presents the SCs along with the CAs and FMs referred in the aircraft manuals and the SOPs.

Table 1. Safety constraints with control actions and feedback mechanisms

| No | Safety constraints | Control actions. | Feedback mechanism |
|---|---|---|---|
| **1** | Do not violate minimum distance separation 1000ft. | a. At 9000ft put the head on aircraft 20 degrees off boresight.<br>b. At 6000ft both aircraft turn towards clear flight path.<br>c. Keep 1000ft minimum distance separation. | 1. Aircraft radar.<br>2. HUD track target indicators.<br>3. “Brake X” warning message on HUD<br>4. “Brake X” warning message on Main Flight Display (MFD).<br>5. Visual scanning of closure rate and distance between aircraft.<br>6. Verbal alert from the wingman |
| **2** | Do not violate the minimum altitude | Keep minimum altitude | 1. HUD altitude indications.<br>2. Analogical altitude indicator.<br>3. Warning messages from radio altimeter.<br>4. Verbal warnings from aircrafts anti-collision system.<br>5. Verbal alert from the wingman |
| **3** | Do not violate the flight control limits in high-performance maneuvers with low airspeed. | Keep the flight control limits during high-performance maneuvers. | 1. HUD airspeed indication.<br>2. Analogical airspeed indicator.<br>3. Angle of attack indexers<br>4. Voice warning (horn) for low speed and high nose-up angle.<br>5. Aircraft’s response to pilots’ action. |
| **4** | Do not exceed fuel level limitations. | Manage remaining fuel level for mission and return to base. | 1. Fuel level and fuel flow indicator<br>2. HUD fuel waning message. |
| **5** | Do not violate G loads and airspeed limits. | Keep G load and airspeed limits. | 1. HUD G indication.<br>2. Analogical G indicator.<br>3. Analogical airspeed indicator.<br>4. Physiology effects of G force. |
| **6** | Do not perform maneuvers above 2 Gs without executing AGSM. | Perform AGSM in every maneuver above 2 Gs. | 1. HUD G indication.<br>2. Analogical G indicator. |

| No | Safety constraints | Control actions. | Feedback mechanism |
|---|---|---|---|
| **7** | Do not fly with Visual Flight Rules (VFR) in adverse weather conditions. | Change to Instruments Flight Rules (IFR) in adverse weather conditions. | 1. Physical environment.<br>2. Aircraft radar.<br>3. Verbal information from the wingman |
| **8** | Do not execute AMC mission with visibility lower than 8Km and separation of clouds less than 1-mile horizontally and 2000ft vertically. | Abort the mission if visibility lower than 8Km and separation of clouds less than 1-mile horizontally and 2000ft vertically. | 1. Visual scanning of the physical environment.<br>2. Verbal information from the wingman. |
| **9** | Do not fly without radio communication contact with GCI/Radar and other formation members. | Abort the mission if there is problem with your radio communications. | Audio transmissions |

*3.1.1. Possible combinations of safety constraints violation*

The researchers designed a 9 x 9 matrix (Table 2) where both rows and columns represent the SCs of the 2nd column of Table 1 above. Thereafter, we assessed which SCs might be breached simultaneously (i.e. symbol S in Table 2) and which SC might mask others if it is violated first (i.e. symbol M in Table 2).

Table 2. Combined SCs in ACM mission.

| Other SCs violations: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| SC violated first | | | | | | | | | |
| 1 | | S | S | S | S | S | S | | S |
| 2 | S | | S | S | S | S | S | | S |
| 3 | | | | S | | | S | | S |
| 4 | S | S | S | | S | S | S | | S |
| 5 | | S | M | S | | S | S | | S |
| 6 | S | S | M | S | S | | | | S |
| 7 | | | | S | | | | | S |
| 8 | S | S | S | S | S | S | S | | S |
| 9 | S | S | S | S | S | S | S | | |

S: Simultaneous, M: Masked

The evaluation led to the following results:

a. The SC No 8 (i.e. "Do not execute AMC mission with visibility lower than 8Km and separation of clouds less than 1-mile horizontally and 2000ft vertically") regards an assessment to be made before executing the mission. Hence, it might be violated only prior to the arrival over the flight training area.
b. If the SCs No 5 and No 6 are violated first (i.e. "Do not violate G loads and airspeed limits" and "Do not execute maneuvers above 2 Gs without executing AGSM"), they will mask the infringement of SC No 3 (i.e. "Do not violate the flight control limits in high-performance maneuvers with low airspeed") because if the pilot falls in a black-out state, the aircraft will be by default uncontrollable.
c. The violation of the SC No 3 cannot be followed by the infringement of SCs No 5 and No 6 (i.e. "Do not execute maneuvers above 2 Gs without executing AGSM") because the aircraft will not have enough airspeed and adequate angle-of-attack to perform high-G maneuvers.

*3.1.2. Available feedback mechanisms*

The first steps of the STPA analysis revealed that:

a. The Head-Up Display (HUD) comprises a basic FM for 6 out of the 9 constraints (i.e. SC No1 to No6). The aircraft manual considers the HUD as the most important display because it provides a lot of information on a small area at the pilot's line-of-sight (LOS), and assists pilots in recognizing a wide range of data.
b. The human sensory system is used to receive information from the HUD and the rest of the feedback mechanisms, as in every case with human controllers. The continuous awareness of factors that might negatively affect human performance is a requirement explicitly stated in the SOPs.
c. A successful reception of the information provided by the feedback mechanisms requires the maintenance of the vision, audition and vestibular senses as depicted in Table 3; the first figure represents the number of alerts (i.e. warning messages, flash lights and audio warnings) and the second figure corresponds to the total number of feedback mechanisms (i.e. alerts and indications) that require the use of the specific sense.

Table 3: Senses used to receive information from feedback mechanisms

| SC: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Sight | 1/5 | 1/3 | 0/3 | 1/2 | 0/3 | 0/2 | 0/2 | 0/1 | |
| Hearing | 1/1 | 2/2 | 1/1 | | | | 1/1 | 1/1 | 1/1 |
| Vestibular | | | 0/1 | | 0/1 | | | | |

According to the information provided in Table 3, it is apparent that:

- The maintenance of SCs No 4, No 6 and No 9 rely on one sense only; thus, in cases of temporary degradation of the vision or hearing capabilities due to physiological or cognitive factors, the pilot is not properly informed about possible infringement of the aforementioned SCs.
- The SC No 3 is the only one that can be monitored based on information from all three senses considered.
- There is no alert to support the maintenance of SCs No 5 and No 6, and their monitoring depends solely on the visual attention and vestibular feeling of the pilot.

### *3.1.3. Feedback mechanisms during violation of multiple safety constraints*

In response to each alert the pilot is expected to visually scan the HUD and crosscheck the HUD indications with other instruments and/or the physical environment; the cross-checking is also required upon recognition of unwanted indications on the HUD (e.g., target and altitude indications). According to the present procedures, the pilot must decide and act timely to each SC infringement. However, if SCs are violated simultaneously or within a short time difference, the pilot might receive in parallel or consecutively visual and audio alerts from many sources.

Since the average time for the information processing and pilot's reaction is about 4 seconds [1, 13], under ideal conditions SCs must not be violated within shorter a timeframe, so the pilot can recover successfully from each SC's infringement. However, if the aforementioned time gap is less, the pilot will be exposed to various incoming alerts, required to scan various indications on and outside the HUD, and, yet, expected to react to multiple demands. This constitutes a condition that might jeopardize human performance and lead to an accident; it can be further worsened if the HUD fails.

Based on the aforementioned observations, it seems that the existing FMs, which were originally designed to support the pilot, might cause adverse effects in the case of multiple SCs breaches. In order to elucidate this potential problem, Table 4 presents the case where the SC No 1 is firstly violated, followed by violations of the rest of the SCs but SC No8 (see paragraph 3.1.1.a). The last row in Table 4 shows the available indications the pilots can consult after each visual or audio alert; the first figure corresponds to the indications shown on the HUD and the second number regards the ones that are available to other displays and instruments, the latter positioned lower than the pilot's LOS and requiring pilot's head movement downwards. It is notified that for simplification reasons the feedbacks from vestibular were not considered, and that for illustration purposes the SCs violations were considered in an ascending order from No 1 to No 9.

Table 4. Feedback mechanisms in multiple SC violations

| SCs violated: | **1+2** | **1+2+3** | **1+2+3+4** | **1+2+3+4+5** | **1+2+3+4+ 5+6** | **1+2+3+4+ 5+6+7** | **1+2+3+4+5+6 +7+9** |
|---|---|---|---|---|---|---|---|
| Number of visual alerts (on HUD / on other displays or instruments)* | 1/2 | 1/2 | 2/2 | 2/2 | 2/2 | 2/2 | 2/2 |
| Number of audio alerts* | 2 | 3 | 3 | 3 | 3 | 3 | 4 |
| Requirements to consult other indications (on the HUD / on other displays, instruments / physical environment)* | 2/2/1 | 3/4/1 | 3/5/1 | 4/6/1 | 4/6/1 | 4/6/1 | 4/6/1 |

* Feedback mechanisms related to multiple SCs were considered once.

The analysis shown in Table 4 suggests that if the SCs are violated simultaneously or within a short time difference:

a. The pilot will receive almost in parallel 1 to 2 visual alerts on the HUD and 2 to 4 audio alerts.
b. The pilot might observe up to 2 visual warnings on displays out of the LOS.
c. Following the perception of visual and verbal alerts, the pilot needs to check 2 to 4 indications on the HUD, and move the head several times in order to check 2 to 6 indications on other displays and instruments and the physical environment.
d. If the HUD fails during the first SC infringement, the pilot will rely only on verbal alerts and have to check for other indications and warning messages on 2 to 6 displays and instruments and the environment by moving the head.

### *3.2. STPA step 1: Control structure and hazardous states*

Based on the SOPs, we draw the basic control structure for the aircraft formation (Fig. 1) and we defined the control algorithm of the leader pilot; the latter is not presented due to papers' length limitations. Thereafter, we identified the potential hazardous states sourcing from the unsafe control actions, as presented in Table 5. It is clarified that:

- The case of "provided too early" does not apply to any control action.
- The case of "provided with a wrong order" depends on the prioritization of control actions when multiple SCs are violated; such prioritization cannot be determined beforehand.
- The case "applied too long" applies:
    - in the No 6 control action, leading to physical fatigue;
    - when the pilot is unaware of the infringement of other SCs; this might further cause various hazardous states sourcing from the rest of the "not provided" conditions.

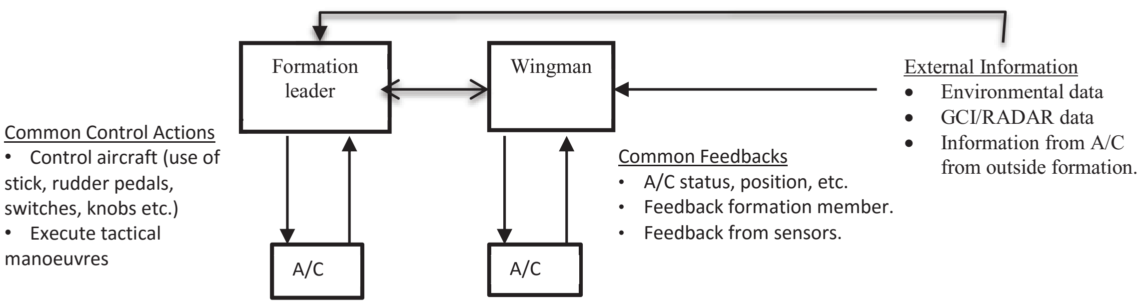


Fig.1. Basic control structure

Table 5. Hazardous states.

<table>
<tr><th rowspan="2">No</th><th rowspan="2">Control Action(s)</th><th colspan="4">Hazardous States</th></tr>
<tr><th>Not provided</th><th>Provided (incorrectly)</th><th>Applied too late</th><th>Stopped too soon</th></tr>
<tr><td>1</td><td>At 9000ft put the head on aircraft 20 degrees off boresight.<br>At 6000ft both aircraft turn towards clear flight path.<br>Keep 1000ft minimum distance separation.</td><td colspan="4">1. Unsafe separation between aircraft.<br>2. Loss of aircraft control due to exposure to exhaust gasses of formation aircraft.</td></tr>
<tr><td>2</td><td>Keep minimum altitude</td><td colspan="4">Flying too close to the terrain.</td></tr>
<tr><td>3</td><td>Keep the flight control limits during high-performance maneuvers.</td><td colspan="4">1. Loss of aircraft control due to disturbance of aerodynamic capabilities.<br>2. Unsafe separation between aircraft.</td></tr>
<tr><td>4</td><td>Manage remaining fuel level for mission and return to base.</td><td colspan="4">Aircraft engine's shut down due to fuel starvation.</td></tr>
<tr><td>5</td><td>Keep G load and airspeed limits.</td><td colspan="4">1. Loss of external storages.<br>2. Aircraft fuselage and wing cracks.<br>3. G-Lock phenomenon.</td></tr>
<tr><td>6</td><td>Execute AGSM in every maneuver above 2 Gs.</td><td colspan="4">1. G-Lock phenomenon.<br>2. Loss of pilot's consciousness.<br>3. Physical fatigue (only for the case "applied too long").</td></tr>
<tr><td>7</td><td>Change to Instruments Flight Rules (IFR) in adverse weather conditions.</td><td colspan="4">1. Unsafe separation between aircraft.<br>2. Human performance deterioration (e.g., disorientation and illusions)</td></tr>
<tr><td>8</td><td>Abort the mission if visibility lowers than 8Km and separation of clouds less than 1-mile horizontally and 2000ft vertically.</td><td colspan="4">1. Unsafe separation between aircraft.<br>2. Human performance deterioration (e.g., disorientation and illusions)</td></tr>
<tr><td>9</td><td>Abort the mission if there is problem with your radio communications.</td><td colspan="4">Loss of information flow.</td></tr>
</table>

Taking into consideration the information provided in Table 5 in conjunction with the existing flight training scheme, it was noticed that:

a. The aircraft and mission documentation do not explicitly mention the variations that a control action might be subjected. Also, there is no structural reference to the hazardous state(s) each control action case might result if not provided in the way and timing that the procedures dictate.

b. Four out of the 10 distinct hazardous states (i.e., unsafe separation between aircraft, loss of aircraft control, G-Lock phenomenon and human performance deterioration) might result from the breach of various SCs. Thus, if we consider the example provided in section 3.1.3 (i.e. consecutive or simultaneous SCs), the fact that the pilot might successfully confront with one violation and avoid the respective hazards, does not exclude the possibility for an exposure to the same hazardous state during the infringement of another SC.

c. The aircraft and mission documentation do not clearly refer to the prevalence of the aforementioned four hazardous states.

### *3.3. Control flow diagram*

At the last phase of the STPA we identified the causal factors and constructed the control flow diagram for the lead pilot (Fig. 2). It is noticed that the violation of multiple SC constraints was considered as causal factor; however, such cases might also be considered as additional hazardous states. Also, the case of overlapping feedback mechanisms was included in the list of potential causal factors in addition to the typical feedback flaws the STPA methodology suggests.

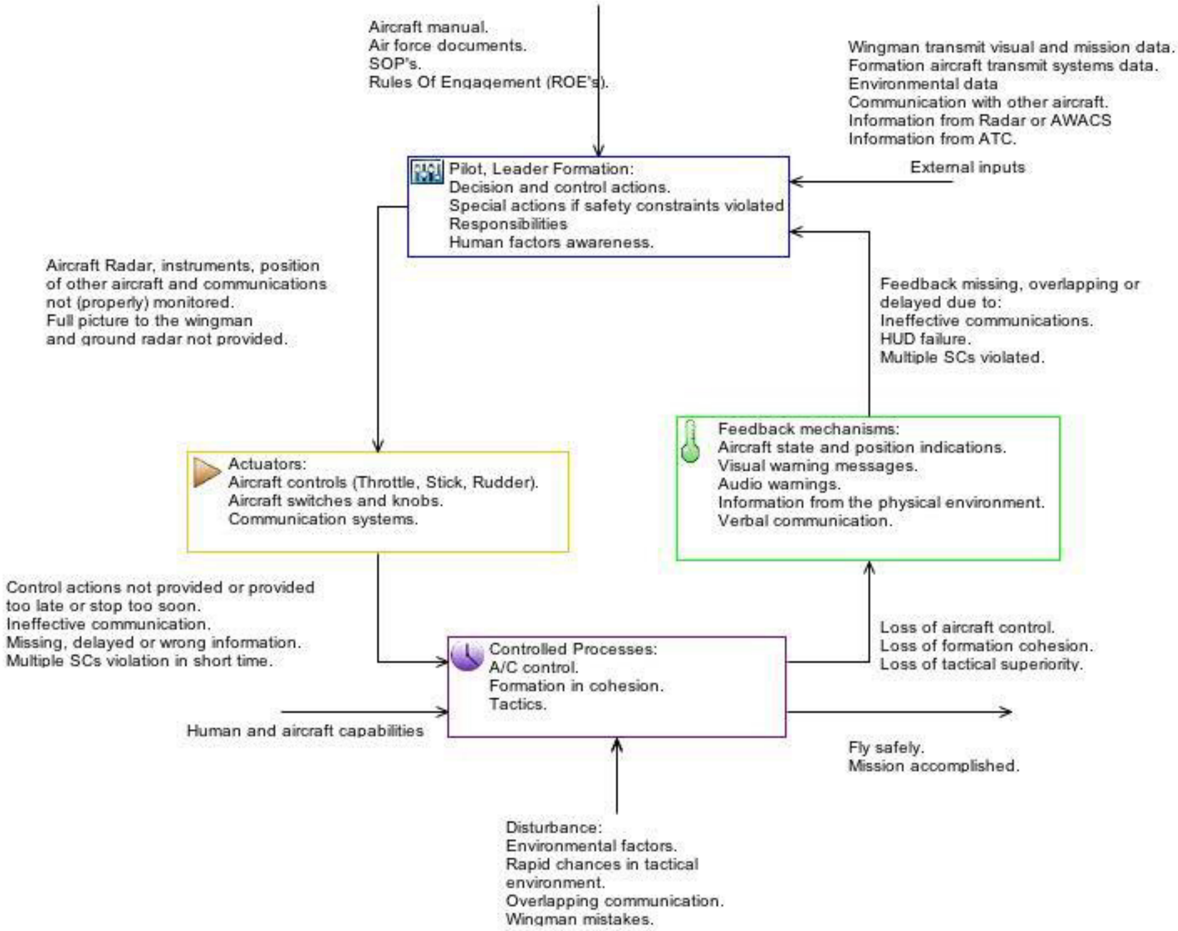


Fig. 2. Control flow for the formation leader

## 4. Discussion

The results suggest that the flight training scheme under study, which is based on the cause-effect and mixed skill and rule-based concepts, does not address several safety related issues. Firstly, the violation of SCs are seen as independent events and their possible combinations have not been considered. Current training practice in flight simulators includes scenarios with some mixture of SCs infringements; however, these scenarios source from accidents and are selected by the instructors based on their knowledge and discretion. Therefore, present training in responses to violations of multiple SCs is rather reactive; if an accident has not occurred the corresponding SC patterns will not be demonstrated during flight simulator training.

Secondly, although there is a variety of available feedback mechanisms, the maintenance of 3 out of the 9 SCs relies on one sense only. This increases the possibility of a non-timely identification of imminent hazardous states if the pilot temporarily uses less or more capacity of one physical sense due to other flying or mission requirements. Such adverse possibility escalates because no alert or warning is available for 2 SCs, the latter depending only on pilot's visual perception.

It was confirmed that the HUD comprises the primary reference during flight and it is a critical component, as this is referred in the aircraft manuals. The ergonomic design of the HUD allows the pilot to spot timely the information needed and react under time restrictions imposed by the mission (e.g., attack from a hostile aircraft). When an indication or warning message on the HUD triggers pilot's attention, current procedures require a crosscheck with other available displays and instruments. The latter are collectively known as Head Dow Displays (HDD) because they are located out of the LOS and their checking requires pilot's head movement downwards. Yet, in the case of multiple SC breaches, the flying procedures do not consider that multiple crosschecks will be needed in response to each adverse event, a condition that might increase pilot's workload considerably and lead to an unwanted decline of human performance. Such cases might become worse if the HUD fails and the pilot needs to further increase his/her head movements in order to perceive the situation, make decisions and react. Consequently, the pilot's reaction time might increase under conditions that time is vital for meeting the objectives of aircraft control, formation's cohesion and survival from hostile attacks.

Interestingly, the traditional "the more, the better" approach regarding the FMs available to the pilot was found rather questionable. A redundancy of alerts, warning and indications of various types might effectively support pilot's awareness, decision-making and response to a single SC breach. However, the analysis showed that in the case of simultaneous or consecutive violations of SCs the pilot might become overwhelmed by the incoming information; assistance from technology in relieving the workload and prioritizing the activities required to recover from multiple SCs is not available.

In addition to the above, the existing flight training practice suggests a binary approach to control actions and indicates that the latter can either successfully or wrongly being provided by the pilot. An exposure to risk due to an unsafe control action is attributed to human error, without exploring the temporal variable as the STPA technique proposes (e.g., control action provided too early or too late). This might lead to ignoring the effects of feedback delays that might source from aircraft system failures or ineffective communication among formation pilots, and underestimate the influences of late responses, which might stem from increased workload.

## 5. Conclusions

The analysis with the STPA technique, even from the first steps, lead to the identification of various safety issues, which are not addressed by the existing aircraft and mission documentation, and, consequently, are not structurally included in the flight training program considered. The following conclusions and recommendations aim to assist in the management of the flaws identified in this study:

a. A transition from the traditional cause-effect thinking to the systemic approach suggested by the STPA might increase the effectiveness of military flight training.
b. Military aviation training might not unfold its full potential when considering violations of SCs as isolated events. Training in flight simulators must consistently and structurally include scenarios with multiple SCs infringements (e.g., starting from combinations of few SCs and introducing gradually conditions of increased complexity).
c. In combination with the previous recommendation, the flight training program, A/C manuals and SOPs considered in this study need to:
    i. Address that the maintenance of the SCs No 5 and No 6 is not supported by any type of alert, and that the maintenance of each of the SCs No 4, No 6 and No 9 relies on one only sense.
    ii. Provide guidance for the prioritization of actions when multiple SCs are breached, and increased amount of information is received. Such guidance might be based on the most frequent hazardous states referred in section 3.2 above, and it needs to explicitly address the cases with HUD failures.
    iii. Include all types of problems related to CAs (provided too late, applied too long etc.).
d. The manufacturer of the specific aircraft needs to:
    i. Explore the possibility for the provision of alerts that will support all types of SCs and trigger more than one sense.
    ii. Conduct studies in order to investigate more thoroughly the potential adverse effects of multiple SCs infringements on human performance, and examine how technology might support pilots accordingly (e.g., automated or manual masking of alerts based on the type of the SC violated and the current conditions).

Although the present study considered a specific military aircraft model and type of mission, and included an initial qualitative approach to the question posed in section 1, the researchers contemplate that a similar approach could be used to (re)evaluate flight training programs in military, general and civil aviation, and other human-machine interface intensive domains.

Finally, it is suggested that professionals and researchers address the case of multiple SCs violations and overlapping feedback mechanisms when applying the STPA methodology.

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