Challenges in Tactical Support Functions for Fighter Aircraft

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Abstract—This paper describes challenges for tactical support functions in a fighter aircraft systems with one or several cooperating members. A short description of the domain of cooperating fighter aircraft is presented, which is linked to tactical support functions using an air-to-air scenario. The main rationale for developing an advanced tactical support system is to aid the pilot in handling complex time-critical scenarios and missions involving extensive cooperation. Important research directions include developing quality measures/metrics for situation awareness, methods for pro-active tactical support functions, and methods to automatically reduce the tactical information gap.

Index Terms—*Tactical support, discussion paper, fighter aircraft*

1. Introduction

Modern fighter aircraft must deal with a variety of both peace-keeping and pure military missions with a multitude of different objectives. They typically carry a sensor suite with varying combinations of passive and active sensors. This puts new demands on task automation, data fusion and tactical support. Task automation means putting more focus on the situation at hand rather than specific aircraft modes. It also entails controlling the use of entire sensor suites rather than handling individual sensors. In order to control costs, individual sensors are best integrated with thin interfaces where track data from each sensor are associated and fused into track data in a centralized database. Tactical support functions will help the pilot to cope with tracks from several sensors, prioritizing targets and threats for presentation and provide a pro-active predictive function to increase probablility of mission success.

Historically the tactical support area for fighter aircraft has been dominated by American initiatives, such as DARPAs “Pilot’s Associate” [1] [2]. Also some European initiatives has been provided such as “Copilote Electronique” [3] and “Pilot Oriented Workload Evaluation and Redistribution” POWER project at NLR [4]. A recent Danish study [5] demonstrated the pros and cons in predicting and recommending countermeasures and evasive maneuvers using methods from logic, probabilistic inferences and numerical optimization methods.

To achieve cooperation between platforms not only infrastructure is needed. We also have to define what information that needs to be exchanged and how a competent tactical support system will use that information.

The aim of this paper is to identify and describe challenges for tactical support functions in a fighter aircraft, using an air-to-air scenario (including a desktop simulation). In order to make the description less abstract, tactical support functions are linked to the various phases in the scenario.

2. The Domain: Fighter Aircraft

2.1. The D.I.E.D. Model

A useful concept in fighter aircraft tactics is the so called D.I.E.D. model [6]: Detect, Identify, Engage, Destruct, see Fig 1.

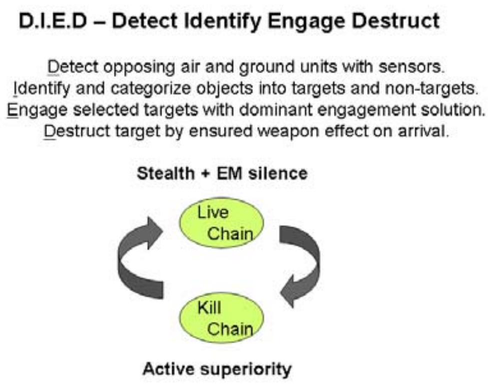

Fig 1. The concept of "D.I.E.D." has its origins in game theory and is a useful tool to describe and understand air combat. The main idea is to make sure that one or a group of aircraft survives long enough to successfully engage in combat with an adversary. Game theoretical analysis is a useful tool to design and understand the tactical support functions in the different phases of a mission.

Each phase in a fighter scenario is associated with a “live chain” (survival first) and a “kill chain” (prevail in combat), equivalent to the theory of hypergames with two or more opponents [7]. For example, during the first phase, detection, an aircraft should behave as stealthily as possible, avoiding exposure of the exhaust flame and reduce electromagnetic emission ("Live Chain"). Simultaneously, the own aircraft should use a combination of own sensors and cooperating with other aircraft to defeat low observable enemy aircraft ("Kill Chain"). The kill and live chain are two sides of the same coin of the D.I.E.D. and are observed from the detection to the destruct phase.

2.2. Rationale for Tactical Support Functions

2.2.1. Automatic Silent Ranging and Identification

An important air-to-air scenario is passive ranging and targeting using cross-triangulation from passive sensors [8]. Experience from modern conflicts have clearly shown that keeping electromagnetic silence is vital for survival and mission execution, and using an active radar is often not an option. Examples of sensor combinations include multi-platform passive radars (assuming the existence of detectable active emitters) and passive IRST (InfraRed Search and Track) measurements. Passive ranging from emitter sources can be done at very large distances, while IRST detection ranges typically lie below 100 km and depend critically on the altitude, the atmospheric profile and target emissivity, aspect angle and size. Passive ranging can also be done using own-ship maneuvering; here the performance will depend heavily on the parameter settings of the tracking filters and the geometry of the scenario [9]. A good tactical support system will automatically choose the best sensor combinations for estimates of both kinematics and target attributes (sometimes including identity).

2.2.2. Joint Situation Awareness

Human system interaction and tactical support with situation analysis are central themes in the fighter aircraft air-to-air engagement domain, where the primary goal is to make the right decision at the right time. The decisions are made in coordination between various cognitive agents in a tactical air unit: the pilots and tactical support systems. This is sometimes referred to as a joint cognitive system – JCS [10] [11] [12] [13]. A central issue is what information should be distributed and how it should be displayed and acted upon. Tactical support with situation analysis includes analysis of threats based on measured variables such as proximity, kinematics, identity and a-priori threat models which leads to assumptions on the ability to act *(What will my opponent do next?)*. Given the results from the situation analysis, suggestions on ownship and cooperative actions are made regarding maneuvering and the use of counter measures and weapons *(What should I do next?)*. Attempts with temporal displays to focus events in a time domain have been studied for fighter aircraft in air-to-air scenarios [16].

2.2.3. Multi-Sensor Control

Multi-sensor control is the natural extension of single-sensor pilot interaction. This is made easier with a modern and agile AESA radar (that provides range + bearing) and a passive IRST system that provides high accuracy bearings-only measurements. Multi-sensor control can incorporate two aspects:

- Ownship multi-sensor control
- Multi-platform multi-sensor control

Ownship sensor control is fairly straightforward from a sensor fusion perspective, and the real challenge lies in finding the "right" combinations and search programs. Each sensor is delivered with its own set of pre-defined search programs and the goal is to find a design where the pilot asks "what do I want to do", rather than "what sensor modes do I want to use". Multi-platform sensor control is made complicated by the level of minimum allowed EM-radiation, called EMCON (EMission CONtrol). On a low EMCON level – lots of EM radiation is allowed – aircraft may send data automatically or on demand to other aircraft for global situation awareness (with or without a central information node). On the other silent end, each aircraft may have to rely entirely using its own sensors.

3. Example Scenario: Air-to-Air Cross-Triangulation

An example of sensor fusion is shown in Fig 2 and Fig 3 below. In this example two aircraft combine passive measurements of active emitters (possible at very large distances) from their respective radar to track two intruders. This makes it possible to obtain a much better range estimate compared to what is possible based on passive measurements from a single sensor. Sensor measurements are associated with a central track and the data fusion is performed using information fusion [14]. The main advantage with the information fusion formula is that adding and removing information is very easy, which makes it ideal for track-to-track fusion.

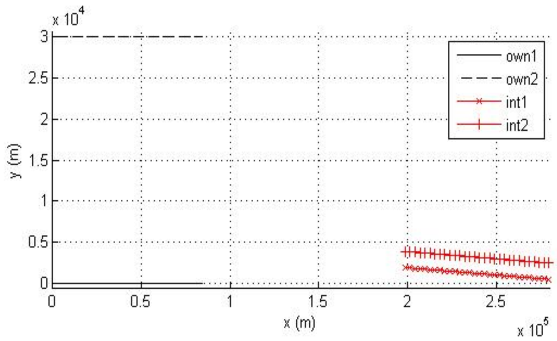

Fig 2. The figure shows a simulation of two own aircraft (solid and dashed lines to the left) approach two intruders (solid lines to the right). The distance to the intruders is 280 km at the beginning of the simulation, after 300 seconds the distance is approximately 110 km. The positions are given

in a bird's eye view in Cartesian coordinate system with the origin at the bottom left.

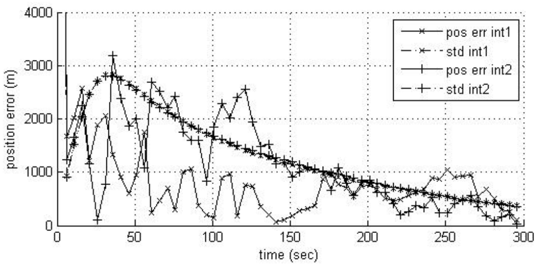

Fig 3. The figure shows the development of the simulated ("true") position errors and estimated covariances over time during the tracking of the two intruders. Information fusion is performed in the first own aircraft using tracks from the second aircraft. The true position error is less than 400 meters after five minutes, and estimated covariance is consistent with the true error.

Following the passive radar tracking example we can consider explicit functions for a tactical support system. The time sequence can be split into two main phases:

- Detection phase
- Engagement phase

During the detection phase the main objective is to gather as much information about the situation, which will be acted upon in the second engagement phase. This description is simplified for the purpose of the discussion in this paper: In practice there is a fuzzy boundary, especially in asymmetric conflicts where aircraft have very different capabilities.

3.2.4. Phase 1: Detection

Examples on explicit support functions for tactical support during the first phase are:

1. Maximize target tracking accuracy using optimal paths for cross triangulation, while minimizing probability of detection.
2. Estimation of intruder identity can be performed along with target tracking. Identity may be based on measured radar signatures, visual identification or intelligence reports.
3. Based on estimated identity we can make inferences on capability and intent, and decide whether we should engage the target or not. Capability is a function of hostile platform and weaponry, and intention on the top level air-to-air or air-to-ground mission and threat situation. For an air-to-ground case, possible threats in the vicinity of or lying close to the direction of travel of the target can be included in the threat estimation. Known enemy tactics can be used together with estimated enemy formation for inference on capability and intent.

3.2.5. Phase 2: Engagement

Examples on support functions for tactical support during the second phase are:

1. If a decision to engage is taken, the system could provide a suggestion on how to engage using various schemes for missile tactics, sometimes involving cooperating sensors on different aircraft. Scheduling of multiple platform sensors must be done carefully to obtain good tracking quality while maintaining good situation awareness.
2. If a decision *not* to engage is taken, the tactical support system may suggest a maneuver with a low likelihood of missile intercept. Threat areas based on missile ranges and probabilities of hit should be taken into consideration here.

The scenario becomes more complex if we instead study a tactical air unit with several members and where each member has its own objective. For instance, different members may carry different weapons and sensors. The members can help each other by gathering information for each other, warn and protect other members against threats. This means that the tactical support system for one member needs to consider both the own mission and requests from other members. Castor [15] has described how the concept of sensor effectiveness, usability of information, mental workload, situation awareness and teamwork relates to each other and performance of a fighter tactical air unit, in air-to-air scenarios.

4. DISCUSSION

Pilot situation awareness should not only give a snapshot of the current state but also be able to make prediction on future states. Assessing situation awareness, which is mainly performed during the first phase "detection" in the scenario (see 3.2.4), requires information, and conversely acquiring information is connected with different constraints:

- Technical limitations. All sensors have physical limitations as discussed in 2.2.1. For example, IR-sensors deliver high-accuracy bearings but no range, while radar delivers a good range and a lower accuracy bearing. A priori knowledge can be used from threat libraries pre-loaded into the system, including maps and intelligence data. Matching the measurement with a-priori data is a process prone to errors.

- Resource conflicts. There might be conflicting requests for the use of sensors. An example is a simultaneous wide area search request, while maintaining an existing track with high accuracy. The complexity of this scheduling problem increases with the number of sensors and members in the tactical air unit.

- Time criticality. In order to reduce the noise and establish target tracks, the sensor needs time to collect measurements (section 3). For many scenarios, there is a conflict between achieving data quality and the time to react.

- Type of mission. The mission and mission phase may set restrictions on the sensors, for instance electromagnetic emission control (EMCON, see 2.2.3.). An emitting sensor, such as active radar, performs high quality range measurements, but is vulnerable to detection by adversaries. In the "live chain" in the D.I.E.D model (see 2.1) the EMCON level is likely to be more restricted than in the "kill chain".

- Tactical behavior. By illuminating an interesting target with the radar, your intentions might be disclosed and the enemy might take actions in order to protect him from future threats. By acting as a civil aircraft on the other hand, might trick the enemy into classify you as harmless and unnecessary attention is avoided.

Generally, all new information will contribute to situation awareness. This however assumes (1) that the information is interpreted correctly, (2) no spoofing is involved and (3) that the quality of the information is known.

However the value of having more information depends highly on the mission, the situation and the existing level of awareness. If nothing is known, almost any information will improve situation awareness. Conversely when the situation awareness is already good, new information will confirm the situation awareness rather than change it. If the mission is to engage a target, it is important to know the exact target position. On the other hand, if we want to avoid being detected, the exact positions of threats are not important; rather we need to know what area to avoid.

A pro-active tactical support system that gives recommendations of suitable actions based on the situation awareness is mainly active in the second phase "engage" of the scenario (see section 3.2.5). The aircraft and the pilot form a joint cognitive system, JCS, and one important aspect of the design of a tactical support system is pilot trust. If the recommendations from the tactical support system contradict the pilot's preconceived expectations, the pilot might not trust the system and even turn it off.

As described in the rationale in 2.2 and the scenario in section 3, time is an important parameter and the pilot needs to make quick decisions. In these cases, the recommendations from the tactical support system need to be followed by a confidence measure, describing the reliability of the recommendations. When the confidence of the situation awareness is too low for producing reliable recommendations, the tactical support system should determine what kind of information it needs and take actions to gather this information. Examples include steering more sensors towards an interesting target, asking for information from a member in the tactical air unit or ask for manual pilot input (e.g. when identifying a target). In a complex scenario the system must consider the situation awareness for the whole tactical air unit and, for instance, re-plan the emission control levels for the members, enabling one member to turn on its radar, while another should turn its off.

5. Conclusions

Providing a robust and useful tactical support in a fighter aircraft is difficult for many reasons. Apart from pilot trust and system robustness, we have seen that more effort needs to focus on the following areas:

- Gather information to create a situation awareness constrained by
  - Technical limitations of sensors
  - Resource conflicts.
  - Time criticality.
  - Type of mission: Balance the information need with the EMCON level.
  - Tactical behaviour.
- Assess the confidence of the situation awareness and present both the situation awareness and its confidence for the pilot. The situation awareness includes both a snapshot of the present situation and prediction of the future.
- Design a pro-active tactical support system based on situation awareness that
  - Presents recommendation of pilot actions, such as engage target, avoidance maneuvers, etc.
  - Presents confidence levels for the recommendations based on confidence of the situation awareness.
  - Concludes what kind of information is missing in order to derive more confident recommendations. In order to achieve this information, control the sensors and/or request the information from other members in the tactical air unit. The limitations mentioned in the first point needs to be considered.

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References

[1] Rouse, W. B., Geddes, N. D., & Curry, R. E. "An Architecture for Intelligent Interfaces: Outline of an Approach to Supporting Operators of Complex Systems". *Human-Computer Interaction, 3*, 87-122, 1987.

[2] Banks, S. B., & Lizza, C. S. "Pilot's Associate: A Cooperative, Knowledge-Based System Application" *IEEE Expert, 6(3),* 18-29, 1991.

[3] Amalberti, R., & Deblon, F. "Cognitive Modeling of Fighter Aircraft Process Control: A Step Towards an Intelligent On-Board Assistance System". *International Journal of Man-Machine Studies, 36*, 639-671, 1992.

[4] Hesselink, H. H., Zon, G. D. R., Tempelman, F., Beetstra, J. W., Vollebregt, A. M., & Hannessen, D. P. "On-Board Decision Support through the Integration of Advanced Information Processing and Human Factors Techniques: The POWER project." *Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory NLR),* NLR-TP-2001-611, 2001.

[5] Lars Rosenberg Randleff, "Decision Support System for Fighter Pilots". Ph.D. Thesis, Kongens Lyngby IMM-PHD-2007-172, 2007.

[6] WgCrd Chris Mills, RAAF. The D.I.E.D. concept is briefly outlined here:http://www.ausairpower.net/APA-NOTAM-030808-1.html

[7] Fraser N.M & Hipel K.W, "Conflict Analysis: Models and Resolutions". *North Holland Series System Science and Engineering*, Vol 11, 1984.

[8] Lanz F. et al, "Sensorsamverkan för störundertryckning". *Totalfösvarets forskningsinsitut FOI*, FOI-R-2330—SE, Metodrapport Ledningssystem, 2007.

[9] Blackman S. & Populi R, "Design and Analysis of Modern Tracking Systems". Artech House, 1999.

[10] Hollnagel, E. "Flight decks and free flight: Where are the system boundaries?" *Applied Ergonomics, 38*(4), 409-416, 2007.

[11] Woods, D. D., & Hollnagel, E. *Joint cognitive systems: Patterns in cognitive systems engineering*. Boca Raton, FL: Taylor & Francis, 2006.

[12] Madhavan, P., Wiegmann, D. A. "Effect of information source, pedigree, and reliability on operator interaction with decision support systems". *Human Factors*, *49*(5), pp. 773-785, 2007.

[13] Woltjer, R.. "On how constraints shape action". *Licentiate thesis (No. 1221)*. Linköping, Sweden: Linköping University, 2005.

[14] Manyika, J., and Durrant-Whyte, H. "Data Fusion and Sensor Management, a decentralized information-theoretic approach". *Ellis Horwood,* 1994

[15] Castor, M. "The use of structural equation modelling to describe the effect of operator functional state on air-to-air engagement outcomes". *Doctoral dissertation (No. 1251).* Linköping, Sweden: Linköping University, 2009.

[16] Linde, L., Strömberg, D., Pettersson, G., Andersson, R., and Alfredson, J. "Evaluation of a temporal display for presentation of threats in air combat". In R. Onken (Ed.), *Proceedings of CSAPC'01 8th conference on cognitive science approaches to process control "The cognitive work process: Automation and interaction"*, 2001.

[17] Strömberg D., Andersson M., Pettersson G., Forsgren R., "Temporala Displayer". *Totalfösvarets forskningsinsitut FOI*, FOI-R-0576-SE, Linköping, 2002.