Proceedings of the 1995 Winter Simulation Conference
ed. C. Alexopoulos, K. Kang, W. R. Lilegdon, and D. Goldsman

SOAR/IFOR: INTELLIGENT AGENTS FOR AIR SIMULATION AND CONTROL

Paul E. Nielsen

Department of Electrical Engineering and Computer Science
University of Michigan
Ann Arbor, Michigan 48109-2110, U.S.A.

ABSTRACT

Producing realistic computer generated forces in a distributed integrated simulation requires flexible mission execution and behavior coordination within the agent itself as well as in its interactions with other agents. This paper focuses on the types of behavior required to produce a realistic airborne forward air controller in closely coordinated attack missions.

1 INTRODUCTION

By 1997, DOD plans to host a virtual theater of war involving up to 50,000 entities interacting in a synthetic environment. These entities will be real, semi-automated, or computer generated. Because of the enormous number of entities involved, computer forces will outnumber humans by at least a factor of 10. Our interest is in the development of intelligent computer generated forces (IFORs) for this event as well as to provide a cost effective and flexible environment for training, mission rehearsal, and tactics development.

This paper focuses on the airborne forward air controller (FAC(A)), which is situated in a fixed wing aircraft such as the A-10. The FAC(A) serves as an interesting example of IFOR agents because of its combined flying/control capability. The duties of the FAC(A) are to locate enemy targets of opportunity, advise the company commander on proper employment of air assets, control aircraft during attack profiles, and assess damage to enemy targets.

To accomplish these duties the FAC(A) must fly a variety of air missions including point-to-point route flight, target acquisition, and target surveillance. It must also coordinate its actions with air and ground based forces to guide attack aircraft in their target approach, consult with other controllers in resource allocation, and deconflict ground forces in proximity to the target.

This paper discusses the current state of development of an realistic, intelligent FAC(A) for simulated close air support engagements. This agent and others discussed in this paper have been implemented using Soar (Laird et al. 1987, Rosenbloom et al. 1993), ModSAF (Calder et al. 1993), and the Soar/ModSAF interface (Schwamb et al. 1994).

2 BACKGROUND

Since the summer of 1992, the Soar/IFOR research group has been building intelligent automated agents for tactical air simulation. Our goal is the development of intelligent forces (IFOR's), computer agents which are functionally indistinguishable from human agents in their ability to interact with distributed interactive simulation environments. The Soar/IFOR consortium, involving the University of Michigan, Information Sciences Institute of the University of Southern California, and Carnegie Melon University, is developing IFORs for all military air missions (Laird et al. 1995). To accomplish this task we have developed a number of fixed and rotary wing aircraft as well as control agents for the aircraft.

From 1992 through early 1994, our efforts focused on beyond visual range air-to-air combat (Jones et al. 1993, Tambe et al. 1995). In early 1994 we were tasked with providing synthetic pilots for the majority of air platforms and missions flown by the U.S. military. The various missions include air-to-air, air-to-ground, air-to-surface, rotary wing, and support missions. In the summer of 1995 we were tasked with developing control agents which provide additional information to the flying agents during their missions.

Within this domain, coordination is necessary for success. Individual units have only limited ability to sense their environment and limited ways in which to act. Through coordination, multiple agents can share information about the environment and make better informed decisions. Through coordination of their actions, they can perform actions which no agent could perform alone, such as mutual defense. The problem is how to get different agents, in different locations, with different world models, with different capabilities, and differing short-term goals, to work together to achieve common long term goals.

Previous work in computer generated forces has either focused on individual agents working in relative isolation or groups of agents which may be treated as a whole (Rao et al. 1994). More recent work toward agent coordination has attempted to create new simulation interfaces, since "real world messages may not be sufficient for current command agents" (Lankester 1995). Our approach treats each agent as an autonomous entity and relies exclusively on models of real world communication for coordination. We are able to overcome the claimed inadequacy of real world messages by providing the individual agents with extensive background knowledge. This knowledge includes the specific roles and duties to be performed, as well as doctrine and tactics.

2.1 Method

All of the agent's reasoning capabilities are developed within Soar (Laird et al. 1987, Rosenbloom et al. 1993) a problem solving architecture that uses universal weak methods for general intelligent behavior. Soar provides the basic architecture for building Soar/IFOR agents by integrating a number of human cognitive functions, including problem solving, perception, and learning.

Some of the capabilities previously demonstrated by Soar/IFOR agents are machine learning (Johnson & Tambe 1995), flight planning (Jones et al. 1994) agent tracking (Tambe & Rosenbloom 1995), and general problem solving and planning (van Lent 1995).

3 CLOSE AIR SUPPORT

Close air support is "air action against hostile targets which are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces" (U.S. Marine Corps 1988). The salient properties here are close proximity and detailed integration.

Waging a successful CAS mission involves a number of agents, including the FAC(A). There must be attack aircraft available to actually drop the bombs and ground/sea based controllers to ensure the effectiveness of the missions.

Figure 1 illustrates an example CAS mission. In addition to the FAC(A) within this scenario (rightmost plane) there is a division of FA-18's (approaching Tiger) whose mission is to attack ground targets; a tactical air command center (TACC) which provides air traffic control, routing, and deconfliction within the amphibious operations area (AOA); a fire support coordination center (FSCC) which determines the type of support to utilize (air, artillery, or naval gunfire); and a direct air support center (DASC) which controls planes while in transit through the operating area.

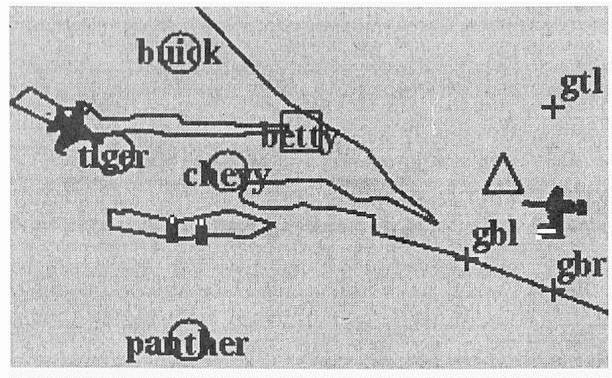


Figure 1: CAS Scenario

4 FAC(A) MISSION

The FAC(A) is a naval aviator, flight officer, or aviation observer specifically trained for conducting aerial reconnaissance and controlling aircraft engaged in close air support (CAS) of ground forces. As previously noted, the four aspects of the FAC(A) mission are target acquisition, interacting with other controllers, controlling aircraft during attack, and assessing damage. This section discusses the first three aspects of FAC(A) mission in more detail. Damage assessment is both self explanatory and not yet implemented in our system.

4.1 Target Acquisition

For the FAC(A) target acquisition involves point-to-point flight to a designated grid area then exhaustively searching it for potential targets. These route and grid points are prespecified in the creation of the scenario. A separate "waypoint computer" process continuously determines heading, range, and time of flight to the next point for point-to-point flight. This is similar to waypoint computers currently used by pilots to reduce their cognitive load. Grid search consists of flying in bands along one length of the search grid, then repeating the search in a perpendicular direction.

Once a target is located the FAC(A) needs to keep it under visual surveillance until other aircraft arrive to attack it. In our current implementation the FAC(A) holds a surveillance position over the target at all times. Though this is acceptable, is may be desirable to fly away and return closer to the designated attack time because of the risk of prolonged exposure in visual proximity to enemy forces. Being a FAC(A) is a very high risk mission, and according to one fighter pilot, "No one volunteers to be a FAC(A)."

Finally, successful neutralization of the designated target allows the FAC(A) to return to its search.

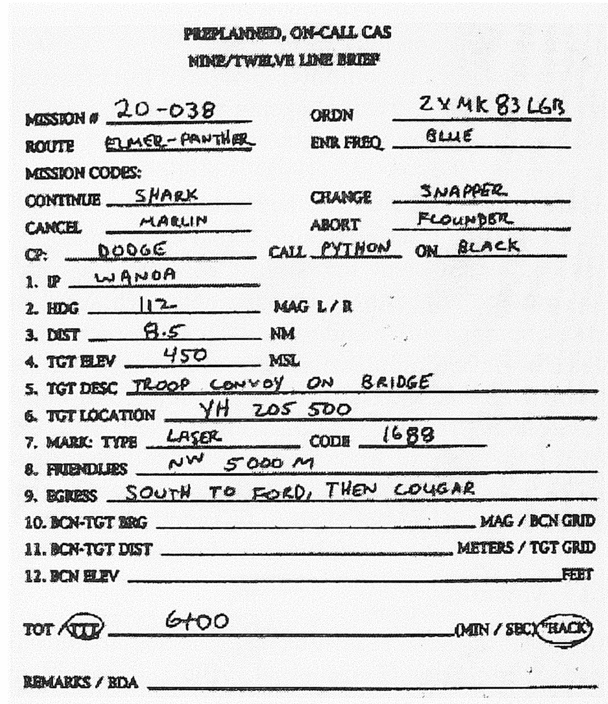
Most controllers, including airborne controllers such as the E-2 or AWACS, experience no significant positional changes during the time period of an attack flight. The FAC(A) is an exception in that it is actively maneuvering and seeking out targets at speeds only slightly less that the attack aircraft. When the attack mission is on final approach the FAC(A) needs to track its own position with respect to the incoming attack to avoid collision, as well at track the motion of the target with respect to the incoming flight to provide accurate targeting information.

Managing the interacting responsibilities in real-time is handled by making the speed of operator execution comparable to experimental results in humans (Newell 1990). Since this can only guarantee soft real-time, our agents will react quickly, but may fail to react quickly enough when faced with overly complex situations, just as people do.

4.2 Interaction with Other Controllers

The FAC(A) is one of several controllers monitoring sections of the AOA and there may be several FAC(A)'s working different regions of the AOA. The general mission of the controller is to continually assess the situation, then allocate or re-allocate forces for maximum effect. The FAC(A)'s specific interactions with other controls are requesting fire support from the FSCC upon location of suitable target, and accepting reports from the TACC concerning flight availability and locations.

We model the real world language communications using standardized forms, dialog from actual pilot communications, and examples from training manuals. While, we do not yet use a full natural language interface for handling messages (effort toward this goal may be found in Lehman et al. 1995) we've had considerable success with a template based parsing method. This is possible because of the highly constrained nature of military communications. For example, requesting fire support and altering a flight's mission are both accomplished through standard forms with prescribed techniques for reading these forms.


PREPLANNED, ON-CALL CAS
NINE/TWELVE LINE BRIEF

MISSION # 20-038 ORDN 2 X MK 83 LGB
ROUTE ELMER-PANTHER ENR FREQ BLUE
MISSION CODES:
CONTINUE SHARK CHANGE SNAPPER
CANCEL MARLIN ABORT FLOUNDER
CP: DODGE CALL PYTHON ON BLACK
1. IP WANDA
2. HDG 112 MAG L/R
3. DIST 8.5 NM
4. TGT ELEV 450 MSL
5. TGT DESC TROOP CONVOY ON BRIDGE
6. TGT LOCATION YH 205 500
7. MARK: TYPE LASER CODE 1688
8. FRIENDLIES NW 5000 M
9. EGRESS SOUTH TO FORD, THEN COUGAR
10. BCN-TGT BRG MAG / BCN GRID
11. BCN-TGT DIST METERS / TGT GRID
12. BCN ELEV FEET
TOT / TTT 6400 (MIN / SEC) "HACK"
REMARKS / BDA

Figure 2: Nine/Twelve Line Brief

With template based parsing only messages in a prespecified format are possible and these messages are interpreted as complete utterances. While understandable by human pilots, it takes discipline to generate messages strictly according in this format. To assist in human to computer message passing, the human interface panel (van Lent & Wray 1994) provides a menu oriented template for message passing. To further facilitate computer to human communication, we have digitized voice recordings of the possible utterances. Finally, in order to communicate with other CGFs we will be adopting CCSIL protocols (Salisbury 1995).

There are several reasons for preferring to use real world messages over an specialized simulation interface language. First is comprehensibility; people can easily understand the simulation. Second is realism; the information conveyed does not exceed that which could be reasonably conveyed by a human. Finally, it facilitates interfacing to other agents. When dealing with simulations on the scale of STOW-97 it is both unreasonable to expect to only have to coordinate with your own agents nor expect to develop a new language for each pairwise agent interaction. By using current military parlance we can leverage extensive effort in techniques which prescribe what to say and how to say it.

4.3 Aircraft Control

Figure 2 shows the standard format for altering an attack mission, the "Nine/Twelve Line Brief." This allows the FAC(A) to change almost every aspect of a mission including routes, target times, and ultimately the targets. In this form, the information above line 1 is either predefined or communicated by controllers other than the FAC(A). Line 1 is the initial point for starting the ingress. Line 2, 3, and 4 give the heading, distance and elevation of the target. Line 5 is a free format description of the target which we require to be understandable by the underlying (ModSAF) simulator. Line 6 gives the target location in any of several formats. Line 7 tells how the FAC(A) will mark the target. Line 8 tells the direction and distance to friendly forces in the area. Line 9 indicates egress routing. Lines 10 through 12 are currently unused. Following that is the time the FAC(A) desires the target hit. Finally, the remarks section is provided for anything else.

Transmitting the brief simply involves reading the information in the order given without reference to line numbers. Parsing this is almost unambiguous with the exceptions being some pathological cases in the remarks section.

In controlling the incomming attack aircraft the FAC(A) relies entirely on visual sensors and radio communication. It will begin tracking the attack mission sometime after it has left the initial point. At that time the FAC(A) calls out to indicate sighting. When it is confident the bombers are pointed at the correct target and not threatening friendly forces it gives permission to drop.

```
Sparrow (silver): Bronco this-is Sparrow
Sparrow (silver): immediate-mission
Sparrow (silver): target-is tank
Sparrow (silver): target-location-is
Sparrow (silver): x 132400
Sparrow (silver): y -4372
Sparrow (silver): target-time ASAP
Sparrow (silver): desired-results destroy
Sparrow (silver): final-control FAC Sparrow
Sparrow (silver): on red
Bronco (silver): roger Sparrow
```

Figure 3: FAC(A) Sends Tactical Air Request to FSCC

```
Mustang (red): Sparrow this-is Mustang
Sparrow (red): go-ahead
Mustang (red): expect-cas-mission 05-008
Mustang (red): at Chevy
Sparrow (red): roger
```

Figure 4: DASC Contacts FAC

5 EXAMPLE

Figure 1 illustrates a CAS scenario. The agents involved are described in section 3. In this scenario, the FAC(A) launches and begins its sweep of the search grid. During the search, the bomber division launches and is initially tasked to destroy a radio spotting tower indicated as a targeting triangle.

After some time, the FAC(A) locates a target of opportunity and calls it in to the FSCC. Figure 3 shows this exchange. The FSCC determines CAS is necessary to neutralize this target and passes the request off to the DASC.

The DASC decides that the new mission has higher priority then the flight's current assignment and informs the FAC(A) of the new assignment and where to expect it. Figure 4 shows this exchange.

Once the FAC(A) knows where the flight is coming from it can determine ingress and egress routing. When the mission checks in with the FAC(A) it is given this information along with additional mission changes in a nine line brief as shown in figure 5.

Once the FAC(A) has visual contact with the FA-18's it calls out "Tally-ho." The FAC(A) then marks the target (not currently implemented), and finally, when the FAC(A) is confident the flight is pointed at the target, it calls out "Cleared hot."

6 DISCUSSION

We have described the current state of development of a FAC(A) in a DIS environment. The FAC(A) serves as an interesting example of the combined forces overcoming individual limitations. By itself the FAC(A) is virtually impotent. It has neither the armament necessary to wage an attack, nor the authority to launch aircraft, nor sophisticated sensors. Rather, it relies on visual target acquisition, proximity, and coordination with other agents to accomplish its objectives.

We claim the key to successful coordination in this domain is based on knowledge (Laird et al. 1994). Agents must know the appropriate techniques and methods for performing their specific tasks. They

```
Hornet-1 (red): Sparrow this-is Hornet-1
Sparrow (red): go-ahead
Hornet-1 (red): Hornet-1
Hornet-1 (red): mission-number 05-008
Hornet-1 (red): 2 FA-18 holding at Chevy
Hornet-1 (red): 10 mk82 time-on-station 1+30
Hornet-1 (red): no-laser-capability
Sparrow (red): Sparrow roger Hornet-1
Sparrow (red): standing-by-with-9-line-brief
Hornet-1 (red): ready-to-copy
Sparrow (red): Betty
Sparrow (red): 111
Sparrow (red): 31.2
Sparrow (red): 0
Sparrow (red): tank
Sparrow (red): x 132400 y -4372
Sparrow (red): wp
Sparrow (red): E 10067 meters
Sparrow (red): Chevy
Sparrow (red): tot ASAP
```

Figure 5: FAC Gives 9 Line Brief

must know their responsibilities for the current mission and that of the agents they must interact with. They must also know when, what, and how to communicate with other agents during the course of their missions so that communication is clear, brief, timely, and effective.

7 ACKNOWLEDGMENTS

This work was done in close cooperation with John Laird, Randy Jones, and Frank Koss. I am especially grateful to BMH Associates, Inc. for their technical assistance. This research was supported as part of contract N00014-92-K-2015 from the Advanced Systems Technology Office of the Advanced Research Projects Agency and the Naval Research Laboratory, and contract N66001-95-C-6013 from the Advanced Research Projects Agency and the Naval Command and Ocean Surveillance Center, RDT&E division.

REFERENCES

Calder, R., Smith, J., Courtenmanche, A., Mar, J., & Ceranowicz, A. 1993. ModSAF behavior simulation and control. In *Proceedings of the Third Conference on Computer Generated Forces and Behavioral Representation*, ed. D. E. Mullally, Jr., 347–358. Institute for Simulation and Training, Orlando, Florida.

Johnson, W. L., & Tambe, M. 1995. Using machine learning to extend autonomous agent capabilities. In *Proceedings of the 1995 Summer Computer Simulation Conference*. Society of Computer Simulation.

Jones, R. M., Tambe, M., Laird, J. E., & Rosenbloom, P. S. 1993. Intelligent automated agents for flight training simulators. In *Proceedings of the Third Conference on Computer Generated Forces and Behavioral Representation* ed. D. E. Mullally, Jr., 33–42. Institute for Simulation and Training, Orlando, Florida.

Jones, R. M., Wray, R. E., van Lent, M., & Laird, J. E. 1994. Planning in the tactical air domain. In *Planning and Learning: On to Real Applications, Papers from the 1994 AAAI Fall Symposium*. Menlo Park, CA: AAAI Press.

Laird, J. E., Newell, A., & Rosenbloom, P. S. 1987. Soar: An architecture for general intelligence. *Artificial Intelligence*, **33**(3).

Laird, J. E., Jones, R. M., & Nielsen, P. E. 1994. Coordinated behavior of computer generated forces in TacAir-Soar. In *Proceedings of the Fourth Conference on Computer Generated Forces and Behavioral Representation*, ed. D. E. Mullally, Jr., 325–332. Institute for Simulation and Training, Orlando, Florida.

Laird, J. E., Johnson, W. L., Jones, R. M., Koss, F., Lehman, J. F., Nielsen, P. E., Rosenbloom, P. S., Rubinoff, R., Schwamb, K., Tambe, M., Van Dyke, J., van Lent, M., & Wray, R. 1995. Simulated intelligent forces for air: The Soar/IFOR project 1995. In *Proceedings of the Fifth Conference on Computer Generated Forces and Behavioral Representation*, ed. D. E. Mullally, Jr., 27–38. Institute for Simulation and Training, Orlando, Florida.

Lankester, H. 1995. Multi-application command agents. In *Proceedings of the Fifth Conference on Computer Generated Forces and Behavioral Representation*, ed. D. E. Mullally, Jr., 169–177. Institute for Simulation and Training, Orlando, Florida.

Lehman, J. F., Rubinoff, R., & Van Dyke, J. 1995. Natural language processing for IFORs: Comprehension and generation in the air combat domain In *Proceedings of the Fifth Conference on Computer Generated Forces and Behavioral Representation*, ed. D. E. Mullally, Jr., 115–124. Institute for Simulation and Training, Orlando, Florida.

Newell, A. 1990. *Unified theories of cognition*. Cambridge, MA: Harvard University Press.

Rao, A., Lucas, A., Selvestrel, M., & Murray, G. 1994. *Agent-oriented architecture for air combat simulation*. Techinal Note 42, The Australian Artificial

Intelligence Institute.

Rosenbloom, P. S., Laird, J. E., & Newell, A. (eds). 1993. *The Soar papers: Research on integrated intelligence*. Cambridge, MA: MIT Press.

Salisbury, M. 1995. Command and control simulation interface language (CCSIL): Status update. In *Proceedings of the the 12th Distributed Interactive Simulation Workshop*. Sponsored by STRICOM and the Institute for Simulation and Training (IST) at the University of Central Florida.

Schwamb, K. B., Koss, F. V., & Keirsey, D. 1994. Working with ModSAF: Interfaces for programs and users. In *Proceedings of the Fourth Conference on Computer Generated Forces and Behavioral Representation*, ed. D. E. Mullally, Jr. 395–400. Institute for Simulation and Training, Orlando, Florida.

Tambe, M., & Rosenbloom, P. S. 1995. RESC: An approach for real-time, dynamic agent tracking. In *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*.

Tambe, M., Johnson, W. L., Jones, R. M., Koss, F., Laird, J. E., Rosenbloom, P. S., & Schwamb, K. 1995. Intelligent agents for interactive simulation environments. *AI Magazine*, **16**(1).

U.S. Marine Corps. 1988. *Close air support and close-in fire support*. FMFM 5-4A. U.S. Marine Corps.

van Lent, M. 1995. *Planning and learning in a complex domain*. Technical Report, Department of Electrical Engineering and Computer Science, The University of Michigan.

van Lent, M., & Wray, R. 1994. A very low cost system for direct human control of simulated vehicles. In *Proceedings of the Fourth Conference on Computer Generated Forces and Behavioral Representation*, ed. D. E. Mullally, Jr., 79–86. Institute for Simulation and Training, Orlando, Florida.

AUTHOR BIOGRAPHY

PAUL E. NIELSEN is an assistant research scientist at the Artificial Intelligence Laboratory of the University of Michigan. He received his Ph.D. from the University of Illinois in 1988. Prior to joining the University of Michigan he worked at the GE Corporate Research and Development Center. His research interests include intelligent agent modeling, qualitative physics, machine learning, and time constrained reasoning.