32nd Congress of the International Council of the Aeronautical Sciences
September 6-10, 2021
Pudong Shangri-La, Shanghai, China

Development of a Human Piloted Air Combat Engagement Database

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Abstract

At present, a variety of autonomous air combat technologies have emerged. However, due to the low degree of algorithm intelligence and the limitations of the airborne computational power, there has not yet been a complete autonomous air combat solution (especially for within-visual-range air combat). This paper proposes that in the short term, the autonomous air combat technology should still be developed in a human-machine collaborative form. To realize such formulation, the tactical decisions and controls of the aircraft must correspond to the human. It is thus necessary to collect and analyze the tactical decisions and commands of human pilots in the air combat. This paper is focused on this work. First, a simulation-based air combat environment is established to construct the human pilots' within-visual-range air combat flight maneuver database. A preliminary analysis was also carried out. It has revealed promising results in terms of time window and decision logics for pilot maneuvering.

Keywords: Autonomous air combat; within-visual-range air combat; human-machine collaboration; flight maneuver database; artificial intelligence.

1. Background

Autonomous air combat (AAC) technology is an important research direction in the field of aerospace control. Back to 1960s, NASA proposed the Trial Maneuver (TM) method [1-4]. More than ten years' research on TM method provided a solid foundation for the subsequent research and development of related technologies, including the TGRES [5-9] in the 1990s, and the Game Matrix method [10-11] proposed by the US Army. Subsequent related work also included the method based on Approximate Dynamic Programming (ADP) proposed by McGrew from MIT [12-13], and the Influence Diagram proposed by Virtanen of Finland [14-15]. DARPA has hosted aerial combat competitions for the F-15 and F-16 fighter jets using aircraft guns at visual range. The winning team demonstrated drastic advantages over human pilots in within-visual-range air combats.

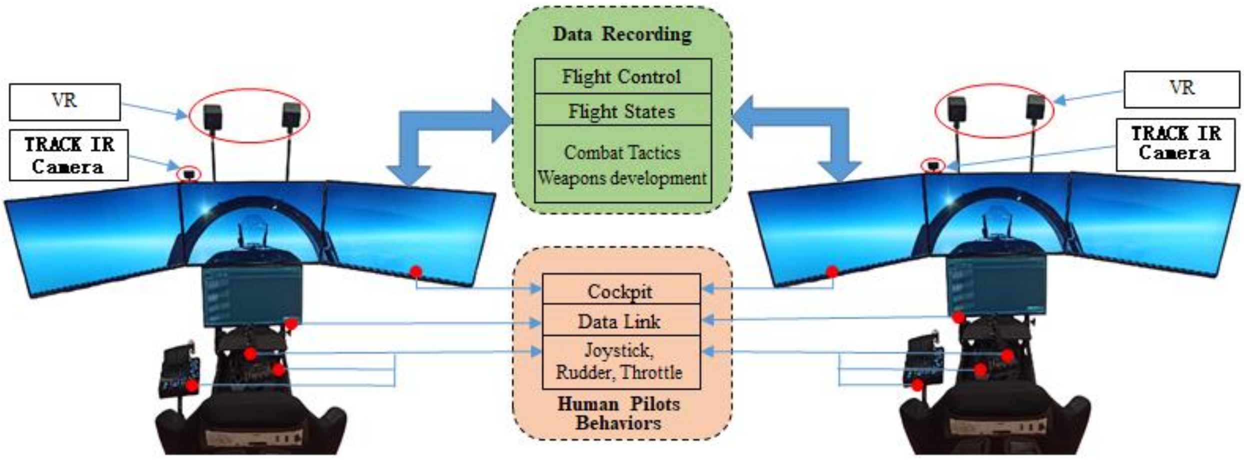

Figure 1 – The simulated cockpits and data collection scheme.

However, due to the complex nature of air combat, there is no air combat algorithm applicable to various aircraft types and different battlefield situation. In the recent review], the existing AAC technologies were divided into three categories: mathematical analytical solution, machine search algorithm, and knowledge-driven framework. It was also pointed out that the future AAC technology should absorb the advantages of these three methods, and in the short term, human-machine collaboration should still be the main form of AAC algorithm development.

To realize the air combat technology of human-aircraft cooperation, it is necessary to systematically establish a flight database of human pilots in air combat within the visual range by referring to the researches in relevant fields such as driverless cars. The database should record the flight state and battlefield situation of both sides, and the flight control input of the pilot of our aircraft. At the same time, relevant decisions and commands of pilots need to be labeled to facilitate data analysis and effective human-aircraft cooperation. However, few databases have been published.

2. Air Combat Database Within Visual Range

2.1 Simulation Environment

Due to the limitation of flight cost and collection efficiency, it is not yet possible to use real aircraft to collect large quantities of data. Previous works pointed out the potential of flight simulation for the development of air combat technologies. A number of preliminary research works also rely on flight simulation to carry out verification [1-9]. Based on the flight simulation, this paper also constructs the virtual environment of air combat as real as possible, and systematically collects and records the relevant data of air combat flight maneuvers.

The carrier of air combat environment mainly relies on some commercial flight simulation software. The simulation of flight dynamics, avionics system and fire control system are highly realistic. At present, it has been used in flight training of some military services, and some previous studies have been carried out based on it, which achieved good results.

The virtual cockpit built by this software is shown in Figure 1. In this figure, the simulation software provides the cockpit visual simulation (radar, fire control and other buttons have touch control function, and the ground, sky and enemy aircraft simulation display). With throttle, joystick and rudder, the complete control of the aircraft can be realized effectively based on the avionics system with good real degree attached in the software.

In the air combat studied in this paper, the visual perception ability of the pilot is particularly important. Due to the limitation of equipment space and simulation hardware, the 360° view display cannot be provided. Based on the relevant flight experience, and referring to the form of existing technical achievements, two kinds of perspective capture functions based on VR and Track IR5 are provided. The former has a similar vision to the actual flight, and has good resolution, refresh rate, etc. The latter adjusts the cockpit view based on the head movement of the pilot, which also provides good visual perception effect by relying on the large field of view displayed on the triplet screen.

2.2 Air Combat Settings

The results presented in this paper are mainly for 1V1 aerial combat within visual range. Considering the visibility of the simulation environment and the relevant background of aerial combat within visual range, the initial battlefield distance between own aircraft and enemy aircraft is set at 10km. Both were manned by human pilots with good aerial combat skills, and the data was recorded primarily for the more experienced pilots. In order to analyze the control rules of pilots under different battlefield situations, the database currently includes four initial battlefield situations, namely equilibrium (opposite, parallel flight), advantage (equal altitude chase) and disadvantage (equal altitude chase), as shown in Figure 2.

In within-visual-range air combat, the flight characteristics, maneuverability and cockpit vision of both sides of the fighter have a great influence on the flight maneuver decision and flight control. The data collection so far has examined four different types of aircraft, including a light, medium and heavy third-generation aircraft and a typical second-generation aircraft.

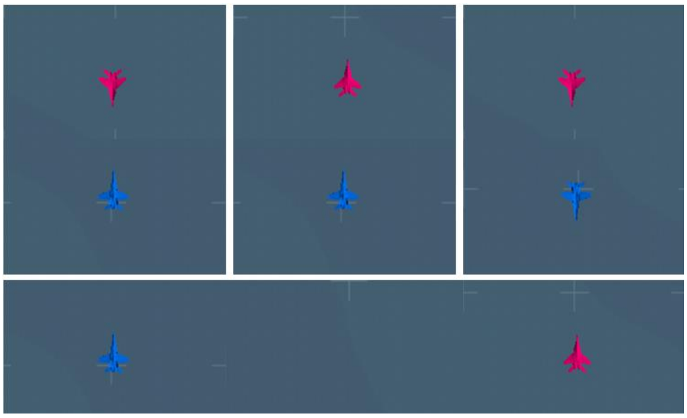

Figure 2 – Four initial situations we studied; top left to right: head to head, pursuing, pursued, bottom: flight in parallel.

Table 1– Four fighter aircraft involved in the database.

Aircraft type	Weight (t)	Wing load (t/m^2)	Max-velocity (km/h)	Thrust-weight ratio (-)
F	16.9	0.445	2205	0.95
M_1	8.8	0.383	2237	0.70
M_2	14.9	0.392	2400	1.09
S	24.9	0.402	2120	1.00

Based on data communication interface, flight performance adaptation and other factors, in the data collection of this paper, more experienced pilots mainly fly a medium-sized third-generation aircraft (F in Table 1). The current data collection is focused on aerial combat. The F fighter has two modes for cannon fire, including the unlocked Funnel Mode and the locked SHOOT Mode (Figure 3). Considering the shooting stability and the killing efficiency of the aircraft gun, the data collection in this paper encourages shooting in the SHOOT mode, but there are funnel line shooting records.

2.3 Data Collection Process

Considering the software interface and other factors, it only supports the two-way communication of flight control command of F fighter (radar scanning mode, aircraft gun and missile launch, etc.) at present, so the data collection is mainly carried out for F fighter (flown by more experienced pilots).At present, the data mainly records the control input and flight status of F fighter, as well as the position and attitude of enemy aircraft. Figure 5 shows the position and attitude records of both sides of a flight, as well as the control inputs and key maneuverability data (overload, Mach number) of the F fighter.

Figure 3 – Two cannon firing modes; left: Funnel, right: SHOOT.

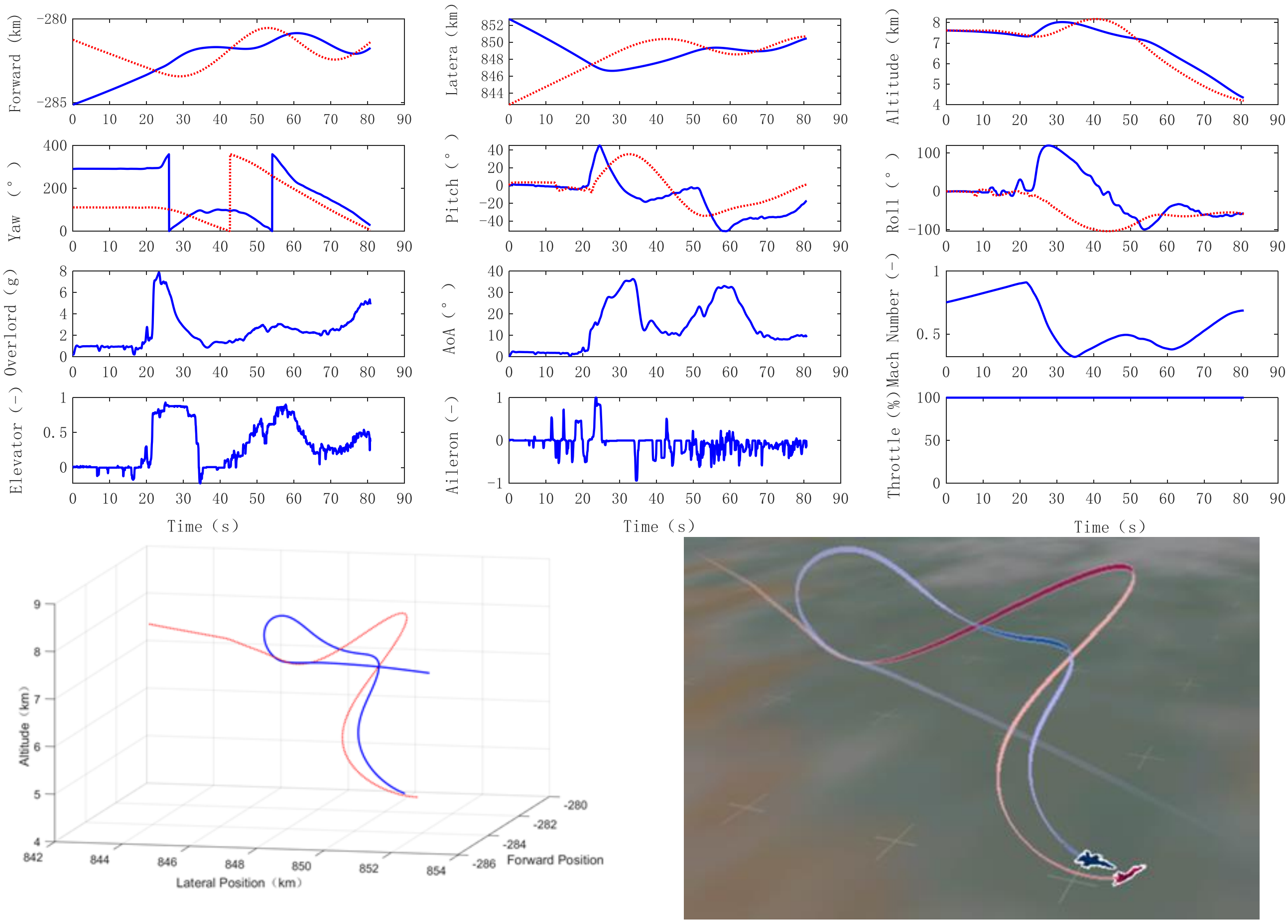

Figure 4 – Flight states and control inputs of both own (blue solid) and enemy (red dot) aircraft

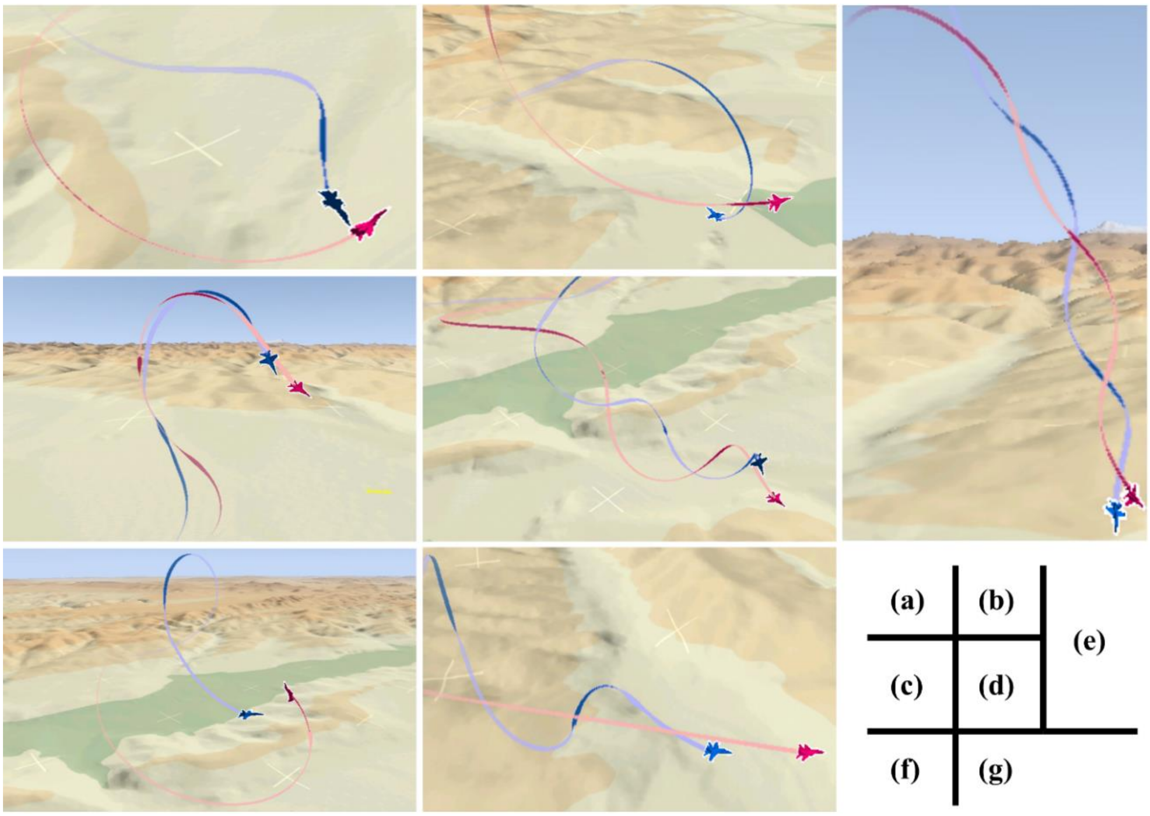

Figure 5 – Basic fighter maneuvers collected in the database: (a) High-Yo-Yo (b) Split-S (c) Pure-chase (d) Horizontal scissors(e)Vertical scissors (f) Loop (g) Barrel roll.

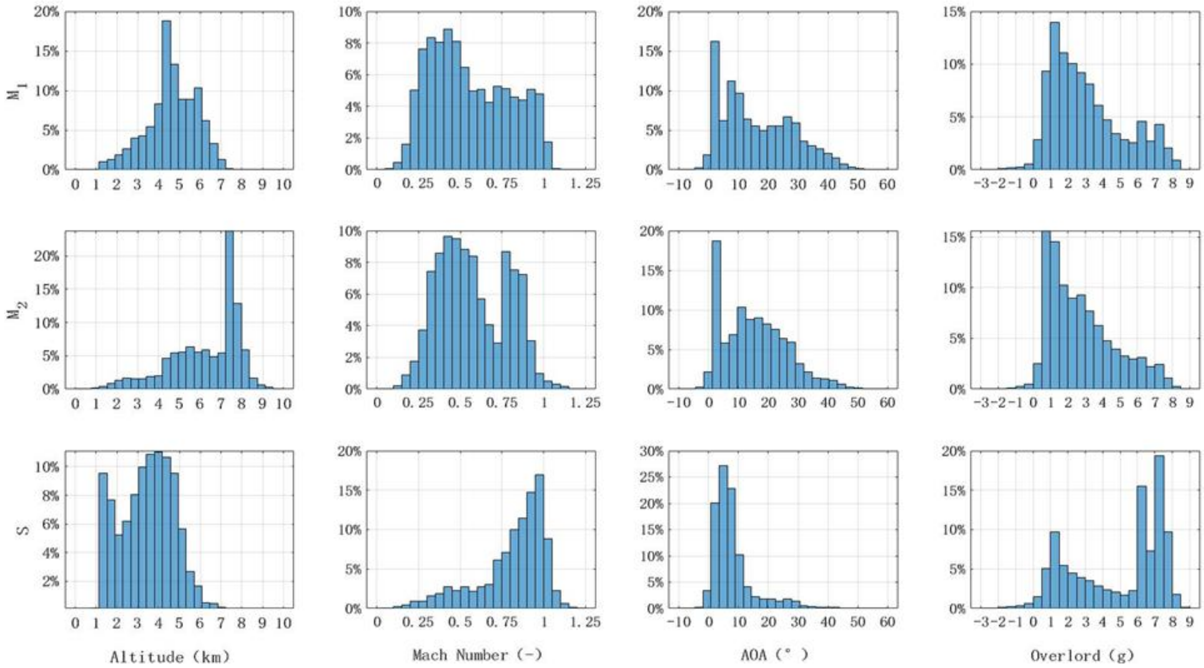

Figure 6 – Overall distribution of the collected engagement data.

The wing load of S fighter is also less than that of F, but it is a heavy fighter and has a large weight along the span, it is not better than F in terms of roll speed and other aspects. This paper encourages the use of BFM maneuvering, and Figure 7 is consistent with this requirement. That is, F mostly changes its maneuvering plane by rolling, points to S aircraft in the direction of lift line, and flies BFM within the allowable overload range. The overload distribution has more high values. In addition, due to overload restrictions, the distribution of flight Angle of attack is relatively small, and pilots mostly fly air combat with classical BFM maneuvers.

In order to better reflect the relevant characteristics of the existing air combat data, Table 2 also presents the extreme value distribution of the key data in the engagement records of the three fighter jets, including the minimum, maximum and standard difference of distribution, etc. The results are consistent with Figure 7 and the discussion above.

Table 2 – Overall specifics of the collected engagement data.

Aircraft type	Height(km)	Mach (-)	Angle of attack (°)	Overload (g)
M_1	[1.0, 7.8, 1.02]	[0.04,1.05,0.21]	[-8, 55, 11]	[-3, 9, 1]
M_2	[0.9, 9.6, 1.25]	[0.12,1.34,0.20]	[-9, 56, 9.9]	[-2, 9, 1]
S	[0.08, 8.8, 1.3]	[0.05,1.16,0.18]	[-15, 60, 8]	[-2, 9, 3]

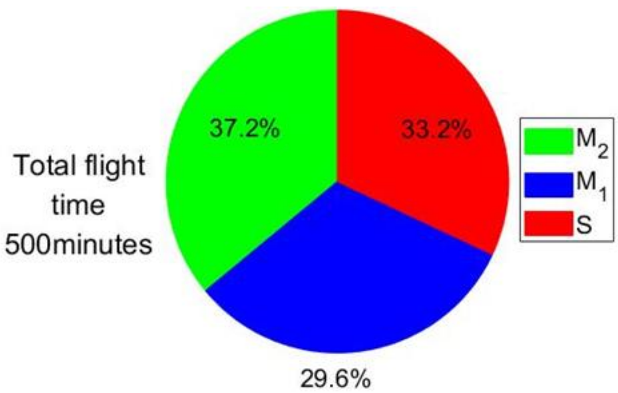

Figure 8 – Distribution of F and the three fighters engagement.

3. Conclusion

In this paper, the air combat environment within visual range is constructed using flight simulation. It is operated by human pilots which collects and records in batches the data of flight maneuvering and control of the pilots. The current situation of the collected data is analyzed, including the distribution of relevant control inputs and key manipulation data, etc. The results are consistent with the pilot's tactical summary. The relevant conclusions correspond to the pilot control and previous research results, which proves the rationality of the research and development of air combat correlation algorithm based on the collected data. Later research will focus on decision-making and control in autonomous air combat technology.

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5. Copyright Statement

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