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Critical Elements in Piloting Techniques in Aerobatic Teams

R. Rozenberg*, V. Socha, L. Socha*, S. Szabo**, V. Nemec****

**Technical University of Košice, Rampová 7, 040 01, Košice, Slovakia, E-mail: robert.rozenberg@tuke.sk, lubos.socha@tuke.sk*
***Czech Technical University in Prague, Horska 3, 128 03, Prague, Czech Republic, E-mail: vladimir.socha@fbmi.cvut.cz, szabo@fd.cvut.cz, nemecvl1@fd.cvut.cz*

Abstract

Human factor is the most important factor in aviation. Interaction between the pilot, flying equipment and the environment in acrobatic groups is exactly where human factor plays key role. In group flying experience, piloting skills are crucial for creating new combinations of acrobatic elements, which then are the main aspect of safe performance of the acrobatic group as a whole. The articles examines flight accidents of selected acrobatic groups from the point of view of pilots` errors, flying equipment malfunction and other causes of flight accidents. It then analyses aspects of piloting techniques in acrobatic groups' experience considering their difficulty and demands on pilots. The work describes the cooperation among the acrobatic group members to manage the most demanding elements of piloting technique in the display team. It sets the most difficult aspects of piloting technique of group experience which acrobatic group`s performance have to focus on.
KEY WORDS: *pilot, elements of piloting technique, acrobatic group, group experience, human factor*

1. Introduction

Flight days rank among the most interesting part of aviation. There is no doubt that the performance of acrobatic group is the main part of every flight day. Each acrobatic group has its own list of acrobatic parts used to interest the audience. These piloting elements are the outcome of their longtime experience with flying on selected types of planes and high piloting proficiency of display pilots [1], [2]. Preparation for every performance of an acrobatic group in public means rehearsing group flying focused on the most demanding piloting technique elements. Perfectly cooperating pilots thus create a strong display team. Display pilot has to master and be able to put maximum effort into solo flying or group cooperation. The vest pilot always come up with something new, which puts them into the foreground and thus create new elements of piloting technique. Recently, there is more than 50 military and civic acrobatic groups [3]. Usually, every country is represented by one military acrobatic group, which is given mainly by the demanding nature of group flying. Over the past ten years, the number of civic acrobatic groups performing on comparable level as their military counterparts is rising.

Almost each of the prominent acrobatic groups has its predecessor and their history reaches back to 1920s. The oldest of the groups, Blue Angels, which was founded in 1946 was the only one to perform with rotor airplanes. Groups Blue Angels and Thunderbirds flew on both supersonic and non-supersonic airplanes and represent respective parts of the US army. Recently, they are using supersonic aircraft. Red Arrows, Patrouille de France and Frecce Tricolori groups use non-supersonic airplanes representing respective countries and their air forces. The Blue Angels group has the most members (126) despite the fact that they fly using only 6 planes. Patrouille de France group can only provide for a functioning display team with 57 members of the acrobatic group. The greatest group as for the number of planes is Frecce Tricolori with 10 planes, even in the solo pilot (#10) performs with the rest of the group inly in the initial and the final part of the performance. The average age of the pilots of the selected groups is 33.4 years. As for 2011, the oldest display pilot from the Patrouille de France is 39 years old. The youngest pilot is 29 years old, from the Frecce Tricolori group. The minimum number of flight hours for a new display pilot is 1,000 for the Thunderbirds group, even if these use supersonic planes. Red Arrows and Patrouille de France expect the minimum of 1,500 hours on jet plane. The period of the service for these groups is two years. Blue Angels and Thunderbirds strictly follow the length of service of two years. The period of service for Red Arrows, Patrouille de France and Frecce Tricolori is three years on average. There was also cases of more than 4-year long service, but these were rather exceptions [4].

The listed acrobatic groups sure rank among the most recognized in the world. Examining the air accidents among these groups closely (see Fig. 1), it is safe to say that the major cause of the majority of flight accidents is the pilots` error. The analysis of accident ratio was created using the information from the available accident reports of the examined acrobatic teams. Based on the above it can be stated that the primary task of group flying is to eliminate the human factor in acrobatic group. A part of the preparation for any performance in public is rehearsing of group flying. This has to be preceded by a preparation focused on set elements of piloting technique following the plane type and pilots` skills. Setting the critical elements of piloting technique of group experience in acrobatic group is the basic condition for its success. That is why this article will focus on identifying these critical elements which are from the point of view of professional pilots the most demanding and the most critical.

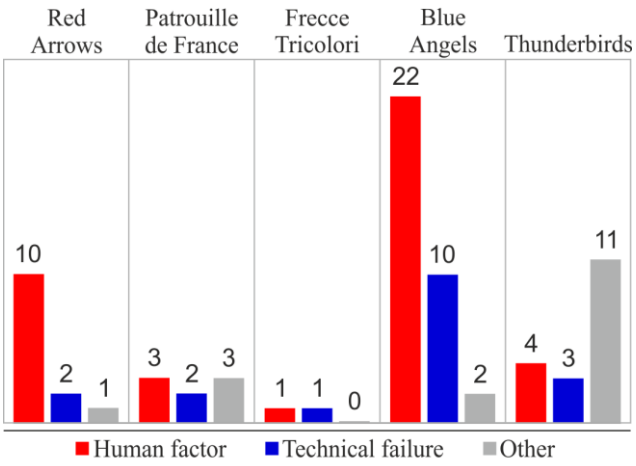

Fig. 1 Air accidents of the aerobatic teams

2. Materials and Methods

The first phase of the research in this article was the selection of experts. The selection of experts was an important acticity determining the effectiveness of the entire prognosis process. Only a professional – pilot with deep knowledge in the field of group flying can be an expert. The expert group consisted of acrobatic group Biele Albatrosy and Košická šestka pilots. Košická šestka was the name of acrobatic group of Czechoslovakia air forces in years 1974 - 1988. Their piloting craft is the group of six piloting Aero L-39 Albatros planes performing on various flying occasions across Czechoslovakia. Biele Albatrosy was the name of acrobatic group of Czechoslovakia air forces in years 1991 – 2004. The idea to create this acrobatic group was born in the late 80s. This group has done over 300 performances in 15 countries. Košická šestka and Biele Albatrosy only had permanent pilots. Based on personal contacts with the pilots and long term cooperation of authors within acrobatic groups, all of the 10 living members of Biele Albatrosy and three pilots of Košická šestka were asked to participate in the research. The pilots agreed to cooperate and their professional characteristics are summed up in Table 1.

Table 1

Professional characteristics of the research respondents

Position in the group	Time spent with the group	Age when recruited	Number of flight hours when recruited
BIELE ALBATROSY			
#1 – group leader	1991 - 2004	35	2300
#2 – inner side right	1991 - 1997	35	2000
#2 - slot, inner side left	1997 - 2004	32	1000
#3 - inner side left	2000 - 2004	38	1100
#4 - slot	1991 - 2001	30	1300
#4 - pilot in training	2002 - 2004	36	900
#5 – outer side left	1991 - 2004	33	1400
#6 - outer side right	1991 - 2004	34	1800
#7 - solo pilot	1995 - 2004	40	2400
#0 – group manager	1991 - 2001	33	900
KOŠICKÁ ŠESTKA			
#3 - inner side left	1974 - 1989	32	1700
#4 - slot	1974 - 1989	35	2500
#6 - outer side right	1979 - 1989	30	1400

The research itself was realized by a questionnaire by asking the pilots questions. The answers was the basis for obtaining the answers required for the research. The questioning was performed during personal contact with the respondents. This brings an advantage in the form of feedback between the interviewer and interviewee. The interviewer may motivate the interviewee to answer questions, ask questions with more detail, or change the order of the questions depending on the situation. Furthermore, this kind of interview depends on the willingness or the skill of respondents to answer questions. In practice, structured (standardized) or non-structured (non-standardized) interview is used. In the case of this study, we opted for semi-structured interview as a part of the interview was carried out in the set order and the questions were freely added. This concept is an advantage mainly in the case of qualitative research which was realized on the sample of 13 pilots, which yielded, among other, their opinions and attitudes which would be unable to obtain in the case of the structured interview.

The interview itself consisted of questions creating a complex picture of professional characteristics of pilots (see Table 1), training, rehearsing flight performances, ground preparation etc. In this study, we only focused on the questions characterizing the difficulty of respective elements of piloting in the acrobatic group, or flight phases for the purposes of determining subjectively most difficult and most critical elements of piloting techniques on group experience. These were questions in which the respondents had to evaluate the difficulty of respective flying phases or respective piloting techniques. In particular, these were the questions:

- On the scale of 9, evaluate the difficulty of respective flight phases in group experience in acrobatic group;
- On the scale of 25, evaluate the difficulty of respective elements of piloting technique in group experience in acrobatic group;
- On the scale of 16, evaluate the difficulty of respective elements of piloting technique of the solo pilot in acrobatic group.

Respective entries which had to be evaluated are described in Table 2, 3 and 4. The evaluation itself of the questionnaires consisted of basic statistical methods used for these purposes [5]. It was primarily the calculation of the mean point value of the *j*-th answer according to the formula:

$$M_j = \frac{1}{m_j} \sum_{j,i=1}^{n,m} C_{ij} \ , \tag{1}$$

where M_j is the arithmetic average of point evaluation, $j(1,2,...,n)$ is the answer, m_j is the number of expert answering the *j*-th question, C_{ij} is the number of points, which the *i*-th expert ascribed to the *j*-th answer and $i(1, 2,...,m)$ is the expert. M_j defines the overall opinion on the relevance of the answer. The greatest relevance is ascribed to the answer with the maximum value of M_j.

Another evaluating parameter was the relative number of the maximum points ascribed by the experts to the *j*-th question following the formula:

$$K_j = \frac{max_j}{m_j} \ , \tag{2}$$

where K_j represents the relative number showing the priority of the answer for the number of instances when the ascribed maximum points for *j*-th answer (max_j) by the total number of experts (m_j) answering the *j*-th question. K_j represents the priority of the answer, while the greatest points to the greatest priority.

The final evaluated aspect obtained from the ascribed score to the respective entries in the answer was the sum of evaluations for the *j*-th answer by the formula:

$$S_j = \sum_{j,i=1}^{n,m} R_{i,j} \ , \tag{3}$$

where S_j is the sum of the *j*-th answer, R_{ij} is the number of points given by the *i*-th expert to the given question. S_j shows the importance of the given answer. The maximum value determines the greatest importance.

3. Results

The analysis of *Mj*, *Kj* and *Sj* suggest that the most demanding phases of flight were considered by the pilots as flying in cloudy weather and close proximity, piloting technique in working environment and flying to another airport (see Table 2).

Table 2

Phases of flight in group experience in acrobatic group

Phase of flight	***Mj***	***Kj***	***Sj***
Roll	1,07	0	14
Take off	4,69	0	61
Flying to the working environment.	3,23	0	42
Flying to different airport	6,76	0	88
Flight in cloudy weather	8,76	0,77	114
Piloting technique in working environment	7,61	0,23	99
Retreat from working environment	2,76	0	36
Approaching to landing	5	0	65
Landing	5	0	65

Table 3

Elements of piloting technique in group experience in acrobatic group

Elements of piloting technique	*Mj*	*Kj*	*Sj*
Individual takeoff with min. interval in the group	1.15	0	15
Takeoff in group	13.76	0	179
Horizontal turn at β 60°.	13.61	0	177
Straight ascending flight at 60°.	7.76	0	101
Diving flight at 60°.	7.61	0	99
Combat turn.	7.38	0	96
Loop without changing position	8.38	0	109
Loop with changing position – sting ray	15.53	0	202
Loop with changing position - swan	15.38	0	200
Loop with changing position - vixen.	15.3	0	199
Loop with changing position - oscar.	14.92	0	194
Loop with changing position - dragon.	15.53	0	202
Loop with changing position - snake.	16.84	0	219
Loop without changing position with ascending turned at 90°.	12.07	0	157
Loop without changing position with descending turned at 90°.	11.69	0	152
Slant loop with β 30°.	12	0	156
Barrel roll	21	0.07	273
Roll in the shape of „snake“.	19.46	0	253
Changing configuration through rolls	23.46	0.3	305
Roll around the group	19.92	0	259
Inverted flight	24.83	0.61	315
Division and joining the group (fan, umbrella).	19.84	0	258
Division of the group before landing	6.07	0	79
Individual landing with min. interval in the group	4.15	0	54
Landing in group	17.38	0	226

Pilots consider as the most difficult those elements of piloting technique in group experience in acrobatic group, which are normally not described in the methodology of piloting for the given type of airplane. These are primarily the special elements of higher piloting technique for individual pilots in the aerobatic group and elements of higher piloting technique with changing position in the entire aerobatic group. Analyzing the values of *Mj*, *Kj* and *Sj* suggests that the most difficult elements of piloting technique are inverted flight in close proximity and changing configuration through rolls (see Table 3).

Table 4

Elements of piloting technique of a solo pilot in an aerobatic group

Elements of piloting technique of a solo pilot	*Mj*	*Kj*	*Sj*
Turn with $\beta max.$ in zero altitude	14.69	0.38	191
Dive at 60°.	4.38	0	57
Straight ascending flight at 60°.	3	0	39
Half roll at 60°.	7.76	0	101
Loop	2.38	0	31
Loop at 90° during ascending and descending flight	7.07	0	92
Loop at 180°.	9.84	0	128
Slant roll β = 30° from vertical line	9.46	0	123
Wingover	4.07	0	53
Vertical eight	13.07	0	170
Roll	8.15	0	106
Wingover at 90°.	12.61	0	164
Slow wingover.	12.23	0	159
Combat turn	3.23	0	42
Inverted flight	10.61	0	138
Snake-like “crazy flight“.	15.53	0.53	202

The analysis of *Mj*, *Kj* and *Sj* suggest that the most difficult piloting techniques for a solo pilot are the snake-like “crazy flight“ and turn with βmax in zero altitude (see Table 4).

4. Discussion

Pilots consider the most demanding phases of flight to be flying in cloudy weather in close proximity during flight days. Under difficult weather conditions, they had to keep close to each other during the whole flight. During these flights, flight illusions oftentimes took place. After a certain period, which usually did not exceed 10 minutes in a cloudy weather, pilots at the right side felt they are doing sharp turns left, pilots on the right side felt they are doing sharp turns right, and pilots at the back thought as if they were doing rolls all the time. These illusions could only be overcome by realizing the actual position by watching the artificial horizon. Among other critical phases of the flight there were piloting techniques in working environment and flying to a different airport.

Critical elements of piloting techniques in group experience were identified as inverted flight, changing configuration through rolls, rolls around the group and division and joining the group (fan, umbrella). Participating pilots of aerobatic groups in the research set the above elements of piloting techniques, which can be divided into three groups.

The first distinctive group would be so called special elements of higher piloting technique for individual pilots in an aerobatic group. These elements require maximum concentration of pilots both during the preparation for flights as well as during the actual flight. Pilot has to manage to pilot the plane taking into consideration the group as well as individually master the given element relating to the group as a whole. The difficulty of these elements of piloting technique is given also by the zero altitude in which these take place, and these elements must be paid special attention to as early as during the preparations for the performances. Then, these elements must be mastered, individually, in pairs, and finally in the whole aerobatic group. A particular example would be the inverted flight of wingmen during the rolls of the solo pilot around the whole group (Fig. 2, A). The difficulty of this elements is in the coordination of wingmen in the inverted flight and relatively "independent" performance of the rolls of the solo pilot around the group in zero altitude. During the inverted flight of the wingmen, it is important to keep the same distances as during the "normal" horizontal flight despite the fact that the movements of the steering levers are in this position inverted. Solo pilot has to perform rolls around the group with minimum altitude change and must not be left behind the rest of the group.

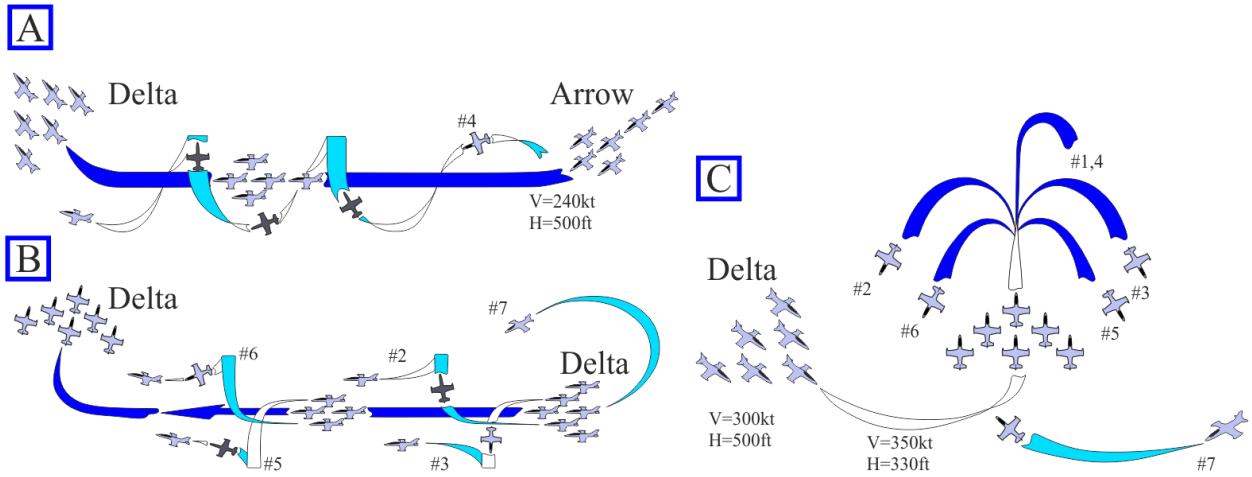

Fig. 2 Configuration of aircraft in inverted flight and barrel rolls formation (A), barrel rolls formation (B) and umbrella formation (C)

Another critical aerobatic element, which may be characterized as a special element of higher piloting technique is changing configuration through rolls (Fig. 2, B). In this aerobatic element, the pilots gradually change positions durinf horizontal flight from the left side to the right and vice versa. Changing the position happens through a roll over the group. The difficulty of this element is given by the spatial orientation of individual pilots which perform the roll. Over a short period of time, pilots must switch from group experience to solo flight and shortly after back to flying in group, in zero altitude.

Division and joining the group (fan, umbrella) was also identified as critical aerobatic element (Fig. 2, C). Its difficulty is in the change of position of pilots in aerobatic group and strict following of the set directions after dividing the aerobatic group. It is then important to realize the precise position of wingmen after the division. This means the left side becomes the right side and vice versa.

Further specific group are special elements of piloting technique and elements of higher piloting technique with a change of the position in the whole aerobatic group. These elements of piloting technique usually repeat in the configurations from the previous years. Despite this fact, it is necessary to master these elements already during rehearsals from flying in pairs to flights in the whole group. They require maximum concentration of pilots considering the precise following of the set distances in respective elements of piloting techniques. These are elements of piloting techniques in group experience in aerobatic group such as barrel roll in the group, roll in the whole group – snake,

takeoff and landing in group, loop in the whole group – snake, dragon, sting ray, swan, vixen, Oscar. The difficulty of barrel roll lies in strict following of the side plane of wingmen during the entire roll. During the roll of the group in the shape of a snake it is necessary to keep the alongside plane of the whole formation. The takeoff and landing in group elements are demanding when it comes to the possibility of coming into the fumes of the previous plane and the maximum possibilities of maneuvering. The difficulty of rolls in the whole group (snake, dragon, sting ray, swan, vixen, oscar) comes from the basic element of roll during which changes of positions of individual pilots within the group take place. These changes normally begin to take place during the ascending phase, so that the following formation change is visible during the descending phase

The third specific group are standard elements of higher piloting techniques in aerobatic group. These proceed from basic elements of piloting technique for the given type of an aircraft. Compared to standard performance they include further additions, usually turns at certain degrees during ascending or descending. These include the following: horizontal turn at β30°, loop without changing position with ascending turned at 90°, loop without changing position, ascending dive at 60°, and combat turn. Among these, the most difficult are the inverted flight with rolls of the solo pilot around the whole group, changing configuration through rolls, dividing and joining the group.

5. Conclusion

It is the effort of a number of pilots to reach the possibility of flying in an aerobatic group. This kind of flying is significantly different from standard forms of flying, and therefore it is important for the pilots to be proficient in aerobatic flights. Setting the critical elements of piloting technique in group experience in aerobatic group is the basic condition for its future success. The issue which follows is setting the process of training pilots in the aerobatic groups [6]. It will always be true that the most important is to make flying the most effective for the audience and the safest for the pilots. This eventually means a series of compromises which finally reflects in the most impressive flying performance of the aerobatic group. An aerobatic group will fly only as good as its “weakest” pilot.

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