Original Article

Ergonomic factors during spin recovery in HJT - 16 trainer aircraft

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Spin manoveuvre familiarization is an essential part of flying training syllabus and requires simultaneous two-handed operation in recovery of aircraft (ac). Amongst trainer ac in IAF, spin recovery problems were percevied more in HJT-16 (Kiran). An ergonomic laboratory study involving 10 experienced male fighter pilots in applicable flying clothing revealed that the overall forces on control column were within tolerance limits of single hand operations, the second hand guidance was required for better precision. The 'reach envelope studies' in harness tight condition for maximum forward operation of control column with permissible shoulder movements and without shoulder movements showed mean angular motion difference at the control column 4.320°±1.26°. The mean difference between the forward movement of hands in two study protocols involving one hand and simultaneous two hand operation was 1.81°± 0.86°. The observed differences are statistically significant ($p<0.001$) influencing reach compromises under static and dynamic flying conditions of spin under simultaneous accelerative stresses. The situation could get further compounded by anthropometric and geometrical variations in elbow-wrist and shoulder–arm complex of individual crew and in woman pilots who generally have shorter limb parameters compared to their male counterparts. The paper discusses various spin releated ergonomic problems considering anthropometric and cockpit design factors.

Keywords : Human factors, spin manoeuvre, crew operational compatibility, women pilots, range of movements, cockpit design factors.

The fixed wing aircraft can execute two types of manoeuvres viz., those that are performed in normal flight attitudes, but requires skill, thought and precision, e.g., turns about a fixed point, figure eight, rectanglar courses and those which put the aircraft into unusual attitudes. The latter put severe demands on the pilot and the aircraft. Spin in aviation is one such manoeuvre, others being barrel rolls, loops etc. Aircraft manoeuvre are very challenging and help in building skills that are useful in everyday learning, training sports and emergency situations. Recovery from spin in HJT-16 'Kiran' jet trainer is part of the training syllabus for all military aviators trained in India. During spin manoeuvre the aircraft reaches a stall condition, and while in this condition the aircraft spins in the direction of rudder pedal and aileron movements. To enter in the spin, the pilot

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applies full rudder in the intended direction of spin with control column fully back at about 92 knots IAS. There is moderate tendency for the ailerons to snatch in the direction of spin, which does not have any adverse effect [1]. As the aircraft is under stall condition, the aircraft tends to lose altitude in each turn. The aircraft is cleared for erect spinning up to 8 turns, however during training and sports, depending upon the altitude of initiation, the number of turns are carefully regulated as to remain well above minimum safe altitude. A timely recovery from the spin is of critical importance for flight safety.

During recovery from spin the control column of the aircraft is required to be pushed forward progressively ensuring that ailerons are neutral (aileron neutral), till the aircraft recovers to straight and level attitude. The recovery may occur at any length, usually about mid position, during forward flight situation. [1] The existing instructions on the subject specify that this forward movement is to be carried out by the operator, by gripping the control column in both the hands simultaneously. During such movement, the control column must be pushed in midline without any lateral movements of the control column. Maximum of 4 turns are permitted for instructional sorties and 1-2 turns for solo spin by flying trainees. Spin is carried out with flaps and under-carriage in up position [2] In carrying out this procedure, apprehension was expressed by the pilots about the ergonomic compromises involved in two hands operation of the control column, as it would diminish the overall forward push by the pilot as compared to identically performed single hand operation for recovery. The problem was projected to the Human Engineering Department of IAM by HQ Training Command for a laboratory study, within a specified time frame of one month. The following study was designed to quantify the compromises incurred during simultaneous two hand operations of the control column and to study the ergonomic reasons for any such compromises.

Material and methods

The study was conducted in the following phases :

a. Survey and selection of experienced aircrew
b. Discussions with test pilots
c. Static anthropometry of crew subjects
d. Measurement of 'reach envelope' in Universal Cockpit
e. Data analysis
f. Inferences

a. Survey and selection of the experienced aircrew: Ten healthy, experienced male aircrew from fighter stream of IAF, having minimum day ops status on different fighter aircraft, were selected for the study. These pilots had experience on all the available aircraft in IAF other than Mirage-2000, Mig-29 and SU-30. By doing so, the aim was to ensure the following :

i. Previous experience on HJT-16
ii. Anthropometric compatibility with HJT-16
iii. Absence of restriction in body movements
iv. Adequate experience to give prudent opinion

Two of the subject had come for medical evaluation on account of old ejection spinal injuries. The disabilities were healed with lumbar spinal involvement and hence did not interfere with movements of upper spine, shoulder and upper limbs, in any phase of the study. one of them was re-flighted after human engineering and other medical evaluation, while the other was asked for subsequent review after 12 weeks. All the subjects were interviewed for their total flying hours and experience related to the recovery from spin.

b. Discussion with test pilots : Relevant discussions were carried out with the test pilots of ASTE, including those who participated in recent symposium of spin recovery at Air Force Academy [2]

c. Static anthropometry : Static anthropometry of the subject volunteers was carried out on IAM Portable Anthropometric Platform. The measurements were done in authorized flying overalls and ABEU Mk II helmet with inner helmet, flying gloves and boots. Critical anthropometric parameters relevant to the study were identified and analyzed.

d. Measurements in Universal cockpit : The Universal Cockpit (U.C) is three-dimensional platform availabe at IAM useful in measurement of subjects' reach envelopes and limited dynamometric measurement in various directions and angles. At present, it is fitted with a replica Martin Baker Mk IV seat with a Personal Survival Pack (PSP) in situ covered by an airworthy cushion. The seat is fitted with a 'four point' restraint system, with a circular 'Quick Release Box' (QRB). There is no negative 'G' strap or inertia reel system in the harness system. The rudder pedal assembly is adjustable and was set to keep the pilot in optimal posture in fully strapped up condition, as it would be desirable in actual aircraft during such manoeuvres. The control column is affixed to the floor of the UC. The overall height of the control column is 68 cm and its uppermost 21-cm is pivoted on to the lower column to achieve movements in all directions. The horizontal distance of the control column for the 'Seat Reference Point' (SRP) is set to 52 cm in the lowermost position of the seat. The maximum angular movement of the control column in the forward direction that can be achieved is 24 degrees. The seat height was adjusted to the sitting height of the subject based on his best and most comfortable posture achievable, similar to that in the aircraft. The up and down adjustability of the seat in UC is more than 8 cm, beyond the present requirement of the subject

The subject pilot, in normal strapping conditions to his own comfort (relaxed), was asked to grip the control column in his right hand in normal manner. The horizontal distance from the tip of the right shoulder to the seat back was measured using standard measuring tape with least count of 1.0 mm. The pilot was then asked to move the stick maximally forwards, avoiding any jerky motion of the column. At this, the forward movement of the shoulder from the seat back was remeasured. The difference between the two was calculated as an additional forward movement of the shoulder for two single hand operations.

The pilot was then restrained in the harness to achieve a tight fit with the seat back as desirable during actual flying. He was then advised to move the control column in straightforward direction with one hand first followed by both hands together. The movement of the control stick was determined in degrees with a large sized protractor palced at the pivot point, with its angular aspect towards the upper movable portion of the column. The protractor had least count of 1 degree. The reference line of motion was seleted as vertical Knuckle line formed on gripping the control column. The difference in the angular movement in both operations was recorded for further analysis.

e. Data analysis : The data generated in the UC was corrected to Kiran ac control column geomentry in view of the existing differences between the control columns of the two. The detailed analysis involved mathematical and geometrical calculations.

The statistical analysis was done with standard Microsoft Statistical pakage. Paired 'T' test was done to determine the statistical difference observed between the shoulder movements observed in the first test and the arc of motion executed by the control column in the second test, i.e. between one hand and two hand operations. Regression analysis to determine the 'best line fit' relationship of the observed differences between one and two hand reaches at the control column and the anthropometric parameters of the subject was done by using Excel statistical package. The best fit plots so achieved and the mathematical derivatives were extrapolated, with known extremes of earlier recorded anthropometric values, with a view to predict the compromises on the forward control column movements at such extremes of range of body parameters. Correlation analysis was done using Excel package to find, if the differences varied directly or indirectly with the anthropometric parameters. Correlation coefficient was determined using the standard formula.

Results

The mean age of the subjects was 25.35 ± 1.67 years in range of 23 - 28.25 years. Their mean flying experience was 603.8 hours ± 429.47 hours in range of 170-1500 hrs. The mean experience on spin recovery was 28.8 times

The obseved anthropometric dimensions of the subjects were as follows: mean sitting height 90.79 ± 2.60cms, shoulder height 60.59 ± 2.46 cms shoulder width 44.03 ±1.12 cms, arm length 73.56 cms and elbow length (knuckle) 36.59 ± 1.49 cms. The mean shoulder movement observed with maximum forward movement of control column in one hand operation was 5.46 ± 1.98cm in range of 2.1-8.7 cms. The mean forward movement with two hand movement of control column was 9.89 ± 1.69 cms in range of 7.9 - 12.4 cms. The observed differences between the two operations was 4.43 ± 1.47 cm in range of 0.8 cms - 5.8 cms. The observed differences were found to be statistically significant on paired 'T' tests t = 8.33248 ($p = < 0.001$)

In shoulder restraint condition i.e. test two, the mean angular movement in forward direction with one hand operation was 6.13 ± 1.45 degrees when corrected to Kiran geometry. The corrected mean angular movement with two hand operation was found to be 4.32 ± 1.26 degrees. The angular difference between the two was 1.81 ± 0.86 degrees, which was found statistically significant ($p = < 0.001$).

The correlation between the arm length and the difference between shoulder fixed test was 0.6. Correlation and regression analysis was found non-significant.

Discussion

Spin manoeuvre is required to be practised during flying training to familiarise the crew with its recovery and master the procedures involved, should it ever occur inadvertently or due to wrong inputs at the controls any time in the career of the pilot. Spin manoeuvre, other than fully controlled and intentional, is an emergency, which may end up in ejection, loss of aircraft and life. It is invariably a grave emergency in operational fighters, as the ability of the aircraft to spin depends upon the ratio of the mass of air under the wings and the fuselage of the aircraft. Amongst the existing jet trainers in IAF, the problem of recovery from spin is reported more often in Kiran aircraft [2]. Some of the experienced pilots were unable to pinpoint the genesis of the problem. It was clear from the discussion and the literature that the operator requires to hold the control column with both the hands, as to ensure the midline movement of the control column and to counter the effects of 'aileron snatch.' The latter is felt as forceful jerky movement of the control column to either side, during recovery from the spin. The aircraft usually recovers in 1/2 to 1 turn. The peak forces in spin recovery on the control column are reported to be 30 lbs [3]. Though these forces are well tolerable by one hand, in order to maintain control and precision, the second hand is as well required.

In our study, the test protocol was divided into two distinct tests. The first test allowed the pilot to move his shoulders forward maximally i.e. by 24 degrees in Universal cockpit equivalent to 7.41 degree of the control column in actual aircraft, in view of the difference in heights between the two. The total arc to be executed was predefined in the test, and the subjects were required to reach this target range. The shoulder movements during this effort were found to be a significant determinant for in-flight reach. To achieve 7.41 degree forward movement, mean 9.89 cm of shoulder movement was required. It is therefore quite obvious that in fully restrained condition, a pilot would not be able to achieve it. In the second test which included the determination of the ability to reach forward in fxied shoulder condition, the arc of movement of control stick could only be measured accurately in terms of angles moved to eliminate inaccuracies incurred on account of several interfering variables viz., inherent difficulties in taking measurements in three dimensional space, possibility of interference with pilot's movement by the observer contribution of adduction, flexion and rotation at the shoulder, elbow and wrist as an indirect attribute of anthropometric measurements and body cybernetics. Therefore, the observed angular movement was converted into the predictable arc, and it was assumed that through small degrees of movements, the arc would approximate closely with the actual movements in straight forward line. The angular movement at elbows would get further affected in actual spin manoeuvre due to the effects of acceleration forces (+Gz) acting on the individual, which could be as much as + 3 Gz. These effects could not be simulated in Universal cockpit. The ergonomic layout of gondola in human centrifuge is not confirming to the Kiran geometry. Along with the other problems of taking manual measurements in gondola, the study could not be carried out in gondola. Thus the study had limitations of not including the effects of acceleration, tension exerted by inertia reel system, variance of posture under G stress and abnormal attitude of the aircraft during spin. Hence, the tests carried brought out only the reach compromises in two extreme conditions under static conditions which are likely to get further compounded in the cockpit. These include the uncontrolled situation, when the aircraft does not recover despite large inputs on the control column by the pilot. The second situation could be, when the pilot is completely restrained in his forward reach with negligible shoulder movements. The situation gets fruther complicated with induction of women pilots, who have shorter stature and limb mean parameters as compared to their male counterparts [4,5]. Therefore the maximal achievable reach of the women pilots is likely to adversely affect her spin recovery, though no such case has been reported as yet.

Fortunately the forward movement of the control column required for spin recovery is only 3°, which corresponds to an arc of 3.56 cms on the HJT with control column's height of 68 cm(6). With one hand operation, all the subjects could go past 3.56 cm of arc; however, with two-hand grip on the control column, 50% of the subject pilots were unable to reach fully forwards. This finding is significant and clearly indicates that a large number of the pilots in fully restrained condition, more so, under dynamic accelerative stresses would be compromising during spin recovery procedures. With the inferences of above two tests it can be deduced that two-hand forward reach is 4.43 cm shorter than one hand reach on the control column of the HJT-16. The sum of the arm length and the shoulder movement required in two hand operations is not comparable to the actual distance between the seat back and the shoulder joint and the grip at the control column. In healthy adults the wrist geometry and the holding patterns in different subjects may influence this parameter, consequently the elbow movement is variable. Further, the shoulder besides moving forwards, tends to shift upwards in order to facilitate the elbow extension during forward push to the control column. These factors were not addressed in this limited study. The correlation between the difference of the achieved angles during one hand and two hand operations and the arm length of the subjects is 0.6 in the study. In our study, one of the subjects could not achieve the forward angular movement of even 3° due to shorter arm reach. The correlation of other anthropometric parameters and the observed differences were found to be poor. It was probably due to relatively small number of subjects, which could not represent full cross section of the population data. The following design features specific to Kiran aircraft could be contributory to the present problem of pushing the stick forward in recovery from spin :

a. The NRSP to control column distance of 52 cms is in excess of the ideal [7].

b. The control column of Kiran is in two different parts.. The top 21 cm column is responsible for lateral movements which tends to cause unintended lateral movements when moved in a single piece column. It is because the lateral torque required to deviate the upper column on top of lower larger column, is lesser than that required for the lower main column alone for its movements on the fulerum. This is likely to become more critical during recovery from spin under forces of 'aileron snatch.'

In the present study, we could not arrive at the minimum arm length requirement that would not cause any compromise in two hands operation of the control column for the recovery from spin on Kiran aircraft. Once identified such pilots may not be given Kiran training, but could be given training on 'Iskara' aircraft, if otherwise his anthropometric parameters are confirming with laid down standards. A further study with large number of subjects to reach relevant anthropometric correlation is required to make this bifurcation more specified and bring out the limitations. As an interim measure, however, the instructors at training establishments could be specially briefed to check the maximum forward reach of the trainee pilots in presence of an Aviation Medicine Specialist, in a tightly harnessed condition to determine the anthropometric suitability of the trainees by cockpit trial on HJT 16. Additionally, the issue of ergonomic difficulties in spin operation could be studied by ;

a. Study of accident database and detailed findings of the 'Court of Inquiries' held for aviation accidents due to non-recovery from 'Spin' on Kiran and other aircraft. The inflight events immediately prior to the accident/ejection could be related to the anthropometric parameters availabe in the AFMSF-1 of the pilot or No 2 AMTC/IAM

b. Actual measurement of arm reach of the subjects on Kiran aircraft by locally available Aviation Medicine Specialist, to avoid extrapolation of related data from that available on Unviersal Cockpit.

As the task was specified to be completed at IAM within one month, the first approach could not be taken. The second approach too, would have involved flying establishments significantly; hence we chose to continue with the pilot study as planned. As the study has come out with significant contributory findings the respective studies could be undertaken at Dte of Flight Safety, Air HQ and the relevant training establishments, involving locally available Aviation Medicine Specialists.

Conclusions and recommendations

a. There is significant probability of ergonomic compromises in 'Kiran' aircraft in executing dual hand forward push of control column during recovery from 'Spin'.

b. The problem is more pronounced in 'Kiran' aircraft due to certain design features.

c.. Women pilots may face further compromises due to gender anthropometric differences.

d. This limited study did not address the role of other contributory variables viz., movements and postural changes at shoulders, elbow and wrist joints at rest and under effects of accelerative forces.

e. In order to achieve adequate forward movement by the affected trainees, maintenance of harness little loose cannot be recommended in view of increased injury potential, should there be any exposure to short duration decelaration.

f. further studies be taken up to ascertain minimum arm reach criteria for trainer and general flying duties for Indian aircrew.

References

1. Pilot's Notes Kiran (HJT-16) Part IV, Chapter 3, para 12

2. Personal discussions with subjects and test pilots of ASTE, IAF.

3. Mohla JK, Sahni RD et al. HJT -16 Aircraft. Report on Spinning Trials. HAL Report No. CTP-FTG/JT/ 10/2 dt. Feb 1970

4. Croney J. Anthropometry for designers. Growth, maturity and old age. Van Nostrand Reinhold Co. NY. 1981, pp 14-35

5. Gopal V, Bandopadhyay P; Female anthropometry-Perceived problems. Ind J Aerospace Med 1996; 40(1) : 36-42

6. Randhir Singh. Three dimensional atlas of aircraft cockpit controls. AFMRC 828/76

7. Aircrew station geometry for military aircraft. Mil-STD - 1333