Acceleration stress during combat dynamics of a supermanoeuvrable aircraft: A comprehensive analysis of 72 Air Combat Manoeuvre (ACM) sorties

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ABSTRACT

Air combat depends upon the performance capabilities and manoeuvrability of the aircraft. The integral aerodynamic configuration combined with thrust vectoring capabilities and a highly effective fly-by-wire flight control system aids on to the unlimited manoeuvring capability of a supermanoeuvrable aircraft. The acceleration profiles of such supermanoeuvrable aircraft were studied to quantify the extent of inflight acceleration stress during conventional air combat. Randomised selection of aerial combat manoeuvre sorties were done. The relevant data was collected from graphs and / or digital print outs of the flight data recorder and data processing system and was analysed to study the in-flight acceleration environment during such ACM. The average number of aerial combat situations were 3.2 per flight with a mean duration of 382.29 seconds. The mean duration of engagement was 137.74 seconds. The aircraft crossed 6 G in 83% and 7 G in 36% of combat situations. The mean peak +Gz was 6.73 G. The mean duration of stay was 15.87 s between 4 – 4.99 G, 10.15 s between 5 – 5.99 G, 3.65 s between 6 – 6.99 G, 2.12 s above 7 G and 19.6 s below 1 Gz. The mean maximum rate of onset and offset was 2.54 G/s and 2.20 G/s respectively during ACM. This study revealed that in addition to experiencing high G levels, very high onset and offset rates, these aircraft are capable of going into combat situations more frequently and sustaining the combat situations for a longer period of time.

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Key Words: Supermanoeuvrable aircraft, Aerial combat manoeuvre, Flight data recorder, Air superiority fighters (ASFs).

Introduction

Air combat is the most stressful event during any fighter mission and is primarily dependent upon the performance capabilities and manoeuvrability of the aircraft [1]. The acceleration profiles of conventional aircraft and ASFs of IAF have been studied in depth previously and the results of these studies clearly indicate the spectrum of acceleration environment to which the pilots of fighter aircraft are exposed [2, 3, 4, 5, 6]. However, the combat dynamics of supermanoeuvrable aircraft is unique because of its unlimited manoeuvring capability. This is made feasible by a series of factors such as high thrust - weight ratio, thrust vectoring, increased unusual lift, an electronically monitored control system and unique aerodynamic features especially a negative stability margin [7]. The possession of auxiliary aerofoil offers additional control movement and thus allows the AOA to reach very high values. The integral aerodynamic configuration combined with thrust vectoring capability and a highly efficient digital fly-by-wire (FBW) flight control system makes the aircraft hyper agile during air combat. The acceleration profile of such an aircraft during peacetime operation was studied to quantify the extent of inflight acceleration stress during air combat manoeuvre (ACM) sorties.

Materials and Methods

Seven aircraft flown by 24 highly experienced pilots from two different squadrons were utilised to collect the relevant data. The mean age of the

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pilots was 32.62 ± 3.68 years. The pilots had considerable flying experience of 133.2 ± 112.8 hours for day and 23.3 ± 28.1 hours for night flying on type. Details of the ACM sorties (n=72) flown by the pilots to study the inflight acceleration stress are depicted in Table 1.

Table 1 : Details of the sorties

Type of sorties	Number
1 Vs 1	13
2 Vs 1	41
2 Vs 2	10
3 Vs 2	03
4 Vs 2	05
Total	**72**

The data relevant to this study was collected from the flight data recorder (FDR) mounted on the aircraft and relevant parameters were retrieved from ground based flight data processing system. The data so collected was analysed to document the in-flight acceleration environment during Air Combat Manoeuvre sorties.

Results

The present study analysed 72 Air Combat Manoeuvre (ACM) sorties to understand the extent of acceleration stress imposed on the pilots of a supermanoeuvrable aircraft. It was observed that such manoeuvres are executed between 3465m to 5039m altitude. The range of Indicated Air Speed during ACM varied from 388 to 859 km/h and the average pitch angle ranged from -0.56° to 19.4°. The results of the study during such specific manoeuvres are given in subsequent tables detailed as under :

1. The Gz profile during ACM is given in Table 2.
2. Duration of stay at various Gz levels at difference of 0.99 G and below 1 Gz during ACM is given in Table 3.
3. Frequency of stay at various Gz levels at difference of 0.99 G during ACM per flight during ACM is given in Table 4.

Table 2 : 'Gz' profile during ACM (n=72)

Parameters	Maximum	Minimum	Mean	SD
TotalDuration (Sec)	849	107	382.29	154.93
No ofACM / Sortie	6	2	3.2	0.74
Duration of ACM Selected (Sec)	475	51	137.74	67.31
Peak G (G)	8.03	5.54	6.73	0.66
Minimum G (G)	1	-0.22	0.46	0.28
Max. Rate of Onset (G/Sec)	4.7	1	2.54	0.85
Max. Rate of Offset (G/Sec)	3.96	1	2.20	0.83

Table 3 : Duration of stay at various 'Gz' levels during ACM (n=72)

'Gz' Levels (G)	Duration (Sec)			
	Maximum	Minimum	Mean	SD
2–2.99	84	11	27.03	14.38
3–3.99	35	5	16.64	7.08
4–4.99	31	2	15.87	6.86
5–5.99	27	3	10.15	6.08
6–6.99	9	1	3.65	2.47
7–7.99	7	1	2.12	1.67
8–8.99	1	0	-	-
<1	139	2	19.16	19.76

Table 4 : Frequency of stay at 2 G and above during ACM per sortie (n=72)

'Gz' Levels (G)	Frequency			
	Maximum	Minimum	Mean	SD
2–2.99	113	40	54.7	13.6
3–3.99	69	23	32.8	9.06
4–4.99	40	15	23.35	5.80
5–5.99	21	10	14.63	3.15
6–6.99	12	1	4.37	2.53
7–7.99	5	1	1.72	0.93
8–8.99	1	0	-	-

Analysis and Discussion

Analysis of combat dynamics (Table - 2) revealed that the total time spent in air combat varied from 107 to 849 sec with an average of 382 sec per sortie. The number of combat situations ranged from 2 to 6 with a mean of 3.2 per sortie. The mean duration of engagement was 138 sec with a range of 51 to 475 sec per combat situation. The increased frequency of combat situations per flight indicates the high endurance capability of the aircraft. Moreover, increased duration of ACM clearly demonstrates the combat potential of the aircraft.

The mean peak + Gz was 6.73 G with a range of 5.54 to 8.03 G. The minimum Gz varied from – 0.22 G to 1 G with a mean of 0.46 G. The peak + Gz attained by the aircraft is comparable with other ASFs [5, 6]. The ability to sustain long duration of ACM at higher rates of onset is not possible in the older generation fighters like Mig 21, 23 and 27 as the speed washes off rapidly. However supermanouvrable aircraft is capable of manoeuvring even at low speed. This enhances the combat capabilities of the aircraft. The integral aerodynamic configuration combined with thrust vectoring results in practically unlimited manoeuvrability.

The maximum onset rate ranged from 1 to 4.7 G/s with a mean of 2.54 G/s. The average maximum offset rate was 2.2 G/s with a range of 1 to 3.96 G/s. This is comparable with the maximum onset rates of other ASFs of IAF. Previous studies [5, 6] have documented a maximum onset rate of up to 3.83 G/s for Mig-29 and 5.51 G/s for Mirage 2000 aircraft. Thus the aircrew of ASFs of IAF are exposed to very high rates of onset of acceleration during specific combat missions.

Analysis of the Gz profile during ACM revealed that the aircraft crossed 6 G in 83% and 7 G in 36% of combat situations. Further it was found that the pilot spent a mean duration of 3.65 sec between 6 G and 7 G, while he spent 2.12 sec above 7 G (Table 3). Even though the aircraft is capable of pulling high sustained G (7 G for 15 sec or 8 G for 10 sec) and all pilots have been trained in the IAM centrifuge to sustain HSG, such high G load was not observed in this study. This can be explained on the basis of better manoeuvring capabilities and advanced missile launch envelop simulated by the aircraft. The aerodynamic configuration and TVC capabilities along with a highly effective digital FBW system allows the aircraft to manoeuvre at very low speed, in very less airspace and in a very shorter period of time. This along with an advanced radar and better missile envelope allows the aircraft the ease of achieving the position of advantage, thus explaining the lesser duration of time spent at high Gz levels.

Analysis of stay at various Gz levels (Ref Table 3) during ACM revealed that the mean duration of stay below 1 Gz was 19.16 sec with a range of 2 to 139 sec. It was further observed that on most of the occasions the sub 1 Gz condition was followed by a high + Gz. Transition to sub 1 Gz condition is known as unloading and is one of the common methods employed during ACM to gain kinetic energy prior to entering high + Gz environment. Transition between hypogravity and hypergravity induces a spectrum of physiological effects known as 'G - transition' effects or 'push-pull effects' [8, 9, 10]. The 'effect' can lower G tolerance of the aviators.

Analysis of frequency of being exposed to high Gz levels revealed that the aircrew on an average were exposed to 4 – 4.99 G for 23.35 times, 5 – 5.99 G for 14.63 times, 6 – 6.99 G for 4.37 times and > 7 G for 1.72 times per flight as shown in table – 4. Thus the aircrew of supermanoeuvrable aircraft are exposed to multiple and repetitive + Gz environment, as evidenced from this study. Frequent high G excursions during ACM represent an important challenge to the baroreceptor mechanisms of the pilot [11].

Recommendations

1. This study provides useful information, which can be utilized in future to simulate ACM profile for a supermanoeuvarable aircraft in human centrifuge for aircrew training, aeromedical evaluation and acceleration research.

2. The data obtained in this study can be used to design a Tactical Air Combat Manoeuvre (TACM) profile as it would simulate more realistically the see-saw pattern of +Gz forces of aerial combat and retain the reproducibility needed for acceleration research and evaluation.

Conflict of interest : None.

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