Original Article

Analysis of combat acceleration profiles of MiG-21, MiG-29 and Mirage 2000 aircraft

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The combat acceleration profiles of MiG - 21, MiG - 29 and Mirage 2000 aircraft were studied to determine the extent of in-flight acceleration stress. Flight data recorder (FDR) data of all the three aircrafts were analysed. The mean peak +Gz found was 5.26 G for MiG-21, 6.35 G for MiG-29 and 6.39 G for Mirage 2000 aircraft. The mean duration of aerial combat manoeuvre (ACM) for MiG-21 was 114.05 seconds 148 .78 seconds for MiG-29 and 65.47 seconds for Mirage 2000. The mean rate of onset for the three aircraft during ACM were 1.05, 1.14 and 1.17 G/s respectively. The duration of ACM above +6 Gz was 1.51 s for MiG -21 in 18.1% of situations. 2.92 s for MiG-29 in 75.5% of situations and 7.32 s for Mirage 2000 in 68.12% situations. The findings suggest that acceleration stress during combat manoeuvers is determined by the performance capabilities of the aircraft and the tactics employed of the weapon delivery system.

Keywords : Aerial combat manoeuvres(ACM), Acceleration stress, High sustained G (HSG), Air superiority fighter (ASF), Flight data recorder.

A tactical military aviator is frequently exposed to positive acceleration by changes in the direction of flight. During air combat, the degree of positive acceleration experienced can be extremely stressful. Air combat in any tactical mission depends upon the relative position and speed of the attacker and the defender and the performance capabilities of the aircraft involved. The manoeuverability of the aircraft is also important in terms of the ability to change the direction of flight.

The acceleration stress imposed on an aviator depends upon the duration of the flight, the length of G manoeuvering, rate of G onset and offset, peak G, and G-time integration [1]. A study of these factors allows an understanding of the actual exposure of aircrew to the stressful acceleration environment. This knowledge is useful for aeromedical research and aids in clinical evaluation.

The acceleration profiles of three aircraft of the IAF, viz. MiG-21, MiG-29 and Mirage 2000, during combat were analysed in this study. The study had been undertaken to understand the acceleration environment during aerial combat manoeuvres (ACM) in two air superiority fighters (ASF) with high, sustained performance capability. One earlier generation aircraft, MiG-21 Type 75 has been included to understand the changing acceleration environment during ACM, if any.

Material and methods

The data relevant to this study was collected from the flight data recorder (FDR) recordings of each aircraft. The FDR is used in an aircraft to record and store a certain number of parameters to read the stored information at a later stage, and protect the stored information in case of an accident [2].

A retrospective analysis of some combat sorties was done. Profiles of the sorties undertaken by 28 fully operational pilots were analyzed. They had 2038 h ± 648 h of flying (Mean ± SD) of which 565 h ± 319 h were on the current aircraft types.

The data collected from the FDR included a total of 333 situations from 163 sorties. There were 90 sorties as attacker and remaining 73 were defender sorties.

The data was obtained from the graphs and/or digital print out of the FDR. The parameters derived from the FDR were duration of aerial combat manoeuvre in seconds, flight altitude in meters or feet, indicated air speed in km/hr or Knots, magnitude of +Gz in G, duration of +Gz at difference of 0.99 Gz each, e.g. 2 to 2.99, 3 to 3.99 upto 9 to 9.99 +Gz, rate of onset in G/s and rate of offset in G/s

Results

Table I presents the analysis of aerial combat manoeuvres on MiG-21 per situation.

Analysis of acceleration profiles of MiG-21 aircraft during ACM revealed mean peak +Gz level of 5.26 G. The mean rate of onset of acceleration was 1.05 G/s. The mean rate of offset was 0.55 G/s. The mean duration of ACM was 114 s.

Table II presents the analysis of aerial combat manoeuvres on MiG-29 per situation. The mean peak +Gz during ACM in MiG-29 aircraft was 6.35 G. The mean rate of onset and offset was 1.14 G/s and 0.59 G/s. The mean duration of ACM was 148 s.

Table III presents the analysis of aerial combat manoeuvres of Mirage 2000 per situation. Analysis of acceleration profiles of Mirage 2000 aircraft during ACM revealed mean peak +Gz level of 6.69 G. The mean rate of onset of acceleration was 1.17 G/s. The mean rate of offset was 0.73 G/s. The mean duration of ACM was 66 s.

Table IV presents the difference in aerial combat manoeuvres of MiG-21 and MiG-29 per situation.

Table I- ACM of MiG-21 aircraft

Aircraft	Peak G (G)	Minimum G (G)	Total Duration (s)	Onset Rate (G/s)	Offset Rate (G/s)
Maximum	8.0	1.0	340.0	6.0	3.0+
Minimum	3.0	0	30.0	0.06	0.07
Mean	5.26	0.99	114.05	1.05	0.5
SD	0.99	0.09	44.15	1.06	0.55

Table II- ACM of a MiG - 29 aircraft

Aircraft	Peak G (G)	Minimum G (G)	Total Duration (s)	Rate Onset (G/s)	Rate Offset (G/s)
Maximum	9.1	1.62	380.0	3.03	1.83
Minimum	4.2	0.11	20.0	0.07	0.11
Mean	6.35	0.94	147.78	1.14	0.59
SD	0.84	0.22	86.14	0.57	0.36

Table V presents the difference in aerial combat manoeuvre of MiG-21 and Mirage 2000 per situation.

Table VI presents the difference in aerial combat manoeuvres of MiG-29 and Mirage 2000 per situation.

Table VII presents the mean duration at various G levels per flight

The detailed analysis of duration at each +Gz level per sortie revealed that MiG-21 pilots spent a mean duration of 1.51 s in 18.1% of ACM situations (n = 21) above 6 G, whereas it was 2.92s in 75.47% situations (n = 80) for MiG - 29 and 7.32 in 68.12% situations (n = 75) for Mirage 2000.

Discussion

An analysis of combat acceleration profiles of MiG-21, MiG-29 and Mirage 2000 aircraft has been done to study the in-flight acceleration stress. The determinants of acceleration stress were peak G - magnitude and duration, rates of onset and offset, and duration of aerial combat manoeuvre.

The MiG-21 was developed as an high altitude, high speed interceptor. The emphasis in this aircraft is placed on good transonic and supersonic handling, high rate of climb, small size and light weight using a turbojet engine of medium power [3]. Considering the years of service from the time of its induction, MiG-21 compares well in terms of its combat manoeuverability with other ASF, except the possible lack of sustaining G at high rates of turn.

A comparison of MiG-21 with the ASF

Table III - ACM of Mirage 20000 aircraft

Aircraft	Peak G (G)	Minimum G (G)	Total Duration (s)	Onset Rate (G/s)	Offset Rate (G/s)
Maximum	9.09	1.88	167.0	3.25	2.72
Minimum	4.1	-1.49	26.0	0.19	0.13
Mean	6.69	0.7	65.47	1.17	0.73
SD	1.3	0.47	30.01	0.62	0.52

Table IV - ACM per Situation - Mig - 21 Vs MiG-29

Aircraft	Peak G (G)	Minimum G (G)	Total Duration (s)	Rate Onset (G/s)	Rate Offset (G/s)
MiG - 21					
Mean	5.26	0.99	114.05	1.05	0.55
SD	0.99	0.09	44.15	1.06	0.56
MiG - 29					
Mean	6.35	0.94	147.78	1.14	0.59
SD	0.84	0.22	86.14	0.57	0.36
't' value	8.764		3.70	0.773	0.623
probability	<0.001 d		<0.01	NS	NS

NS : Not significant

revealed significantly high peak +Gz levels for both the ASFs. The rates of onset did not vary much but rates of offset were found to be significantly higher for Mirage 2000. The mean duration of combat in MiG-21 was significantly less than that in MiG-29 and Mirage 2000. The peak G capability of MiG-21 is 8G [4] but the combat limit is restricted to 7G. In comparison both the ASFs have a peak G capability of 9 G [5,6] (Tables IV, V). The extra engine power available allows the ASF high sustained performance capability. Therefore the peak G pulled was higher for both the ASFs. Mirage 2000 was found to engage in combat for the shortest duration. This could probably be because of better controls and better missile launch envelope of Mirage 2000. The higher offset rate from high peak G levels attained was to manoeuvre the aircraft as per the requirements of combat.

A comparison of MiG-29 with Mirage 2000 revealed that mean peak G was

Table V - ACM per situation - MiG - 21 Vs Mirage 2000

Aircraft	Peak G (G)	Minimum G (G)	Total Duration (s)	Onset Rate (G/s)	Offset Rate (G/s)
MiG - 21					
Mean	5.26	0.99	114.05	1.05	0.55
SD	0.99	0.09	44.15	1.06	0.56
Mirage 2000					
Mean	6.69	0.7	65.47	1.17	0.73
SD	1.3	0.47	30.01	0.62	0.52
't' value	9.291		9.58	1.027	2.489
probability	<0.001		<0.001	NS	<0.01

NS : Not significant

Table VI - ACM per situation - MiG - 29 Vs Mirage 2000

Aircraft	Peak G (G)	Minimum G (G)	Total Duration (s)	Onset Rate (G/s)	Offset Rate (G/s)
MiG - 29					
Mean	6.35	0.94	147.78	1.14	0.59
SD	0.84	0.22	86.14	0.57	0.36
Mirage 2000					
Mean	6.69	0.7	65.47	1.17	0.73
SD	1.3	0.47	30.01	0.62	0.52
't' value	2.263		9.401	0.368	2.281
probability	<0.05		<0.001	NS	<0.05

NS : Not Significant

significantly higher for the latter. There was no difference in rates of onset. Significantly higher rates of offset were found in case of Mirage 2000. The duration of ACM was significantly less for Mirage 2000. (Table VI). While employing similar combat tactics, the significant differences between the two competitively manoeuverable ASFs was probably due to electronic flight control (fly by wire) of Mirage 2000 [7]. The electronic flight control system makes Mirage 2000 highly agile, thus allowing better manoeuverability. Therefore higher peak +Gz and offset rates were found in this aircraft. The shorter duration of combat was because of better avionics interface, reduced cockpit workload and range of the missiles, which along with agile performance capability, allowed ease of positioning for attack or for evading an attack.

It must be added here that commenting upon better performance capability of Mirage 2000 vis-à-vis MiG-29 is not

Table VII - Mean Duration at various G levels per Flight

Aircraft	Mean Duration (s)							
	2-2.99	3-3.99	4-4.99	5-5.99	6-6.99	7-7.99	8-8.99	9-9.99
MiG-21								
Mean	11.68	12.79	10.34	4.5	1.32	1.5	1.0	-
SD	6.8	6.92	7.0	3.62	0.57	0.5		
MiG-29								
Mean	45.13	15.53	12.45	14.59	3.86	2.07	1.67	1.0
SD	33.72	13.0	8.14	8.22	3.14	2.07	1.7	(n = 1)
Mirage 2000								
Mean	30.12	20.17	14.9	9.92	7.6	4.56	2.9	3.0
SD	19.85	15.11	11.06	8.38	6.72	4.19	3.01	(n=1)

justified since none of the combat sorties included in this study were Mirage 2000 versus MiG-29. A real evaluation of performance is only possible after analysis of combat sorties between the two ASFs.

In the present day scenario of high sustained G (HSG), duration of stress at various G levels is an ideal indicator of magnitude of stress (Table VII). The duration at +Gz levels of more than 6 G was analysed for each ACM situation included in this study. From the analysis of duration at various +Gz levels, it was evident that Mirage 2000 pilots spent a longer duration at higher G levels. It is easy to understand that the MiG-21 does not have power to sustain G for longer duration, but MiG-29, with matching performance capabilities as Mirage 2000, employing similar tactics spent lesser time at various G levels. This can be explained on the basis of simulation of missile envelope carried by each aircraft. The MiG-29 simulates carriage of missiles with a smaller launch envelope. Hence sustained manoeuvering at one go does not achieve a launch condition. In comparison, in the Mirage 2000, due to an expanded launch envelope of its missiles, it can achieve the launch conditions invariably by sustained manoeuvres at high G levels.

Conclusion

This study revealed that MiG-21, an older generation aircraft, has high G capability. The air superiority fighters viz. MiG-29 and Mirage 2000 have capabilities to sustain high G. This study has revealed a short duration of ACM. However, the requirement of sustaining higher G has become an essential feature of aerial combat, as is also evident from this study. Therefore the pilots of these high performance aircraft are susceptible to +Gz induced symptoms including G-induced loss of consciousness.

In view of the G levels found in this study, it is felt that high G training is essential for the pilots of MiG-29 and Mirage 2000 aircraft who are exposed to high G for varying duration. High-G training is also recommended for MiG-21 pilots because of high onset rates and 8 G capability of the aircraft. The Simulated Aerial Combat manoeuvre (SACM) at Institute of Aerospace Medicine, Bangalore can be modified based on +Gz levels, in terms of both magnitude and duration, as per aircraft type depending on the current aircraft type of the aircrew.

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