Failure Analysis of Bubble Canopy: MiG-29 Aircraft

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Abstract: An aircraft canopy is the transparent enclosure on the cockpit of aircrafts which provides a weatherproof and safe environment to its occupants. During World War II, bubble canopies were brought into use in many aircrafts. It was made without bracing and provided a wider field of view to the pilot. Over the years, there has been paradigm shift in the materials used for the construction of aircraft canopies. Earlier it were made of numerous pieces of flat glass held in position by a frame and muntins. The muntins reduced visibility, which was especially problematic for military aircraft. Then came the glass canopies which were soon replaced by acrylic canopies. These not only protected the occupants from being hit by sharp shattered pieces during accidents but also were very light in weight. They are continued to be used in most of the modern fighter planes. This study involves the evaluation of the causes of failure of a MiG-29 Aircraft whose canopy bubble was found to be cracked on the rear portion of the periscope during last flight service check. The canopy made of stretched acrylic was subjected to various examinations like SEM,DSC,TGA,FTIR and it was concluded that the crack generated from a completely chipped area of material from the canopy glass base. This was likely due to foreign object hit while at higher altitude, where the temperatures are low, thereby having a reduced fracture toughness making the organic glass more brittle.

Keywords: Canopy bubble, Stretched Acrylic, DSC, TGA, SEM, FTIR

Introduction

During a last flight service check, the rear canopy bubble of a MiG-29 aircraft was observed to develop a crack. Visual observations revealed that the crack initiated from the metal frame and extended towards the starboard side(as seen from the nose of the aircraft). There was no physical damage noticed on the canopy periscope system. The aircraft was so taken into the hangar and the preliminary tests were conducted. The aircraft canopy system is provided with a periscope system which is operated by the pneumatic system. The canopy periscope system has a top mirror and a lower mirror. The top mirror is operated by the periscope control cylinder and two periscope actuating cylinders, which dampen the operation of the top mirror. The top mirror operates on unblocking of the mechanical lock post which the periscope actuating cylinders and periscope control cylinder operate. After the visual inspection, functional testing of the canopy periscope system was carried out by connecting pneumatic supply which eventually resulted in the successful operation of periscope system. On further disassembly of the canopy periscope system and the metal frame to identify the initiation of crack , it was revealed that the crack had initiated in the form of a 'V' and then it propagated in the form of a clean cut towards the starboard side of the aircraft. Owing to this, the cracked portion of the canopy was used for failure analysis, which included visual analysis under microscope, Scanning Electron Microscopy (SEM), Differential Scanning Calorimetry (DSC), Thermo-gravimetric Analysis (TGA) and Fourier Transform Infrared Spectroscopy(FTIR).

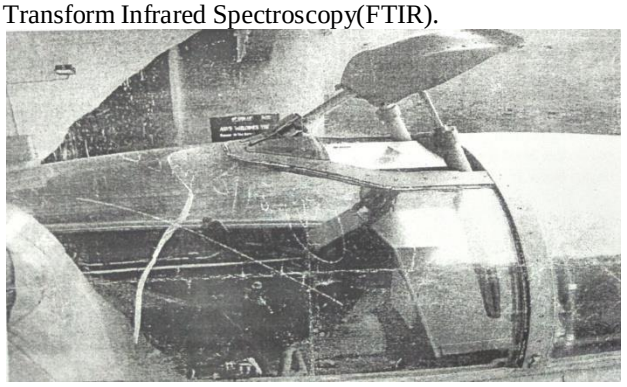


Figure 1- Photograph of canopy of MiG-29 after the accident(side view)

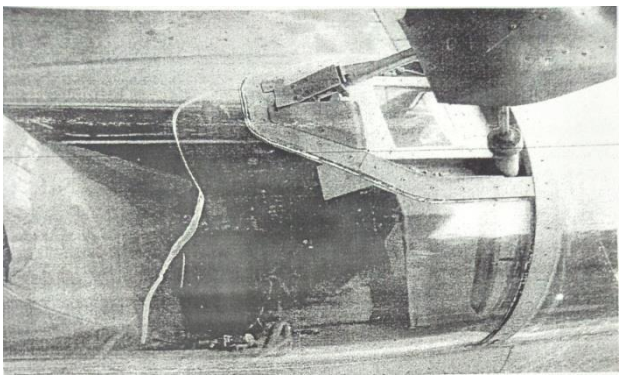


Figure 2- Photograph of canopy of MiG- 29 after the accident(top view)

LITERATURE REVIEW

The Mikoyan MiG-29 is a twin-engine jet fighter aircraft designed in the Soviet Union. While originally crafted to

combat against any enemy aircraft, many MiG-29s have been later improvised to perform multiple operations. It has been improvised gradually to use a higher range of air-to-surface armaments, precision munitions, modern radar and IRST sensors, increased fuel capacity ,and aerial refueling. India was the first international customer of MiG-29. The Indian Air Force (IAF) placed an order for more than 50 MiG-29s in 1980 while the aircraft was still in its initial development phase. Since its induction into the IAF in 1985, the aircraft has undergone a series of modifications with the addition of new avionics, sub-systems, turbofan engines , and radars.

Crew: 1

Length: 17.32 m (56 ft 10 in)

Wingspan: 11.36 m (37 ft 3 in)

Height: 4.73 m (15 ft 6 in)

Wing area: 38 m² (409 ft²)

Loaded weight: 14,900 kg (33,730 lb)

Empty weight: 11,000 kg (24,250 lb)

Max. takeoff weight: 18,000 kg (44,100 lb)

Fuel capacity: 3,500 kg (7,716 lb) internal

Powerplant: 2 × Klimov RD-33 afterburning turbofans, 81.4 kN (18,300 lbf) each

Performance:

Maximum speed:

At high altitude: Mach 1.94 (2,400 km/h; 1,490 mph)

At low altitude: Mach 1.21 (1,500 km/h; 930 mph)

Range: 1,430 km (888 mi; 772 nmi) with maximum internal fuel

Ferry range: 2,100 km (1,300 mi; 1,130 nmi) with 1 drop tank

Service ceiling: 18,000 m (59,100 ft)

Rate of climb: 330 m/s (65,000 ft/min) (initial); 109 m/s (21,500 ft/min) (average) (0–6,000 m)

Wing loading: 403 kg/m² (82 lb/ft²)

Thrust/weight: 1.09

Maximum *g*-load: 9 g

Armament:

Guns: 1 × 30 mm Gryazev-Shipunov GSh-301 autocannon with 150 rounds

Hardpoints: 7 × hardpoints (6 × underwing, 1 × fuselage) with a capacity of up

CANOPY BUBBLE-

The canopy bubble(here) is composed of stretched acrylic with about 0.003% by weight to 0.1% by weight

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of an IR absorbing material, the weight percentage ba on the total weight of the stretched acrylic and the IR absorbing material. The added advantage of this organic glass is that it has reduced solar energy transmittance over known aircraft transparencies and window systems. Stretched Acrylic is a uniquely formulated, cross linked presintink acrylic specifically designed to provide superior craze and solvent resistance for today's changing environment. Improvements such as lower water absorption and increased resistance to acids expands the number of "as cast" applications. Its superior craze resistance makes it ideal for canopies.



Figure 3- Image of a flying MiG-29 Aircraft

Methods and Materials

The following visual under magnification and instrumental analysis were carried out for subject analysis:

Visual analysis of the entire fractured surface was carried out using optical microscope under 5X magnification in order to identify the concerning zones.

Scanning electron microscopy(SEM)was made using a Scanning Electron Microscope(SEM) at magnifications of 25000, 15000, 5000, and 1000X. The canopy sample used for SEM was coated

with a thin layer of gold for efficient secondary electron emission.

Differential Scanning Calorimetry(DSC) study was made using a Dupont DSC 2910 from -100^{o} C to +200^{o}C in an inert atmosphere.

Thermo Gravimetric Analysis(TGA) was carried out using Universal V4 7ATA for in an inert atmosphere from ambient temperature to 500^{o}C.

Fourier Transform Infrared Spectroscopy(FTIR) studies of the glazing canopy material from the debris was carried out using Perkin Elener C100441 ATR/FTIR Specto-photometer from 1800cm^{-1} through 900cm^{-1}.

Result and Discussion

i. Scanning Electron Microscope(SEM) trace

The SEM micrograph(Figure 4) of the fractured canopy exhibits two surface morphologies. The beach marks occur in a non uniform pattern indicating the ductile zone in which the slow growth of crack took place. These significant beach are present throughout the ductile zone and gradually decreased towards the brittle zone. The absence of striation marks attributes to the brittle zone where the crack propagated to its maximum and then was followed by brittle fracture. Looking at the SEM, it is evident that the major area of the fractured surface is attributed to ductile fracture.

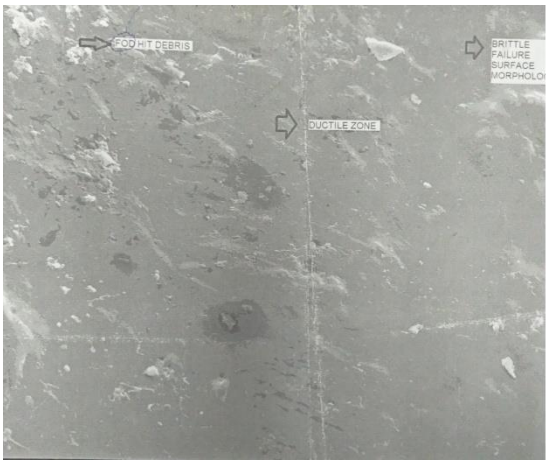


Figure-4. SEM Micrograph of the fractured surface of the crack

ii. Differential Scanning Calorimetry trace

The DSC curve(Fig.5) indicates that the melting temperature of the given sample is 121.32 ^{o} C while the Glass Transition Temperature(T_g) is 121.32^{o}C. This accounts for the melting point and T_g of stretched acrylate and hence confirms that the material has not undergone any atmospheric degradation.

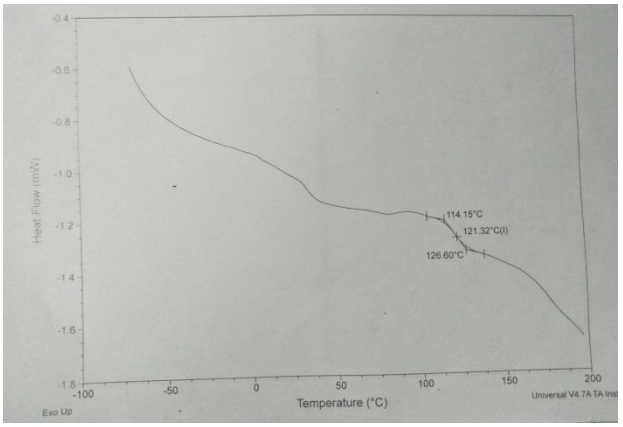


Figure-5. DSC Curve of the Fractured Canopy Sample

iii. Thermo gravimetric Analysis(TGA) trace

From the TGA plot(Figure-6), it can be inferred that the Initial Decomposition Temperature(IDT) of the material is 170^{o} C and the maximum decomposition occurs at 384^{o}C. The plot also depicts that there was no residue after the decomposition. The first decomposition maxima indicates loss of 15.21% by total weight of the sample at the given temperature against 17% loss at first decomposition maxima typically exhibited by a standard stretched acrylic TGA trace. This thermal analysis data resembles with that of the standard stretched acrylic and reaffirms that the canopy material has not chemically or morphologically deteriorated and thus is of sound quality.

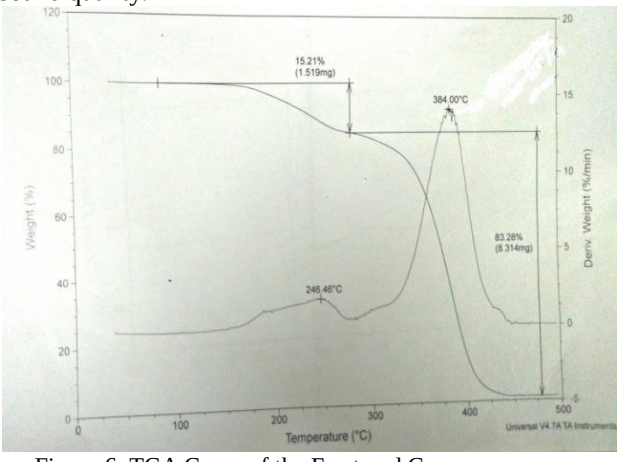


Figure-6. TGA Curve of the Fractured Canopy Sample

i. Fourier Transform Infrared Spectroscopy(FTIR) trace

The FTIR trace of the fractured canopy sample is shown in Figure-7. A very sharp and intense peak comes at 1050cm^{-1} which accounts for C-O stretch. Further peaks are observed at 1126cm^{-1} and 1180cm^{-1} which confirms the -C-O stretch of secondary and tertiary alcohol respectively. The band ranging from 1431-1466 cm^{-1} indicates the presence of -C=C stretching. The sharp and intense peak at 1711cm^{-1} affirms the presence of saturated carboxylic acid (-C=O). The FTIR trace replicates that of the standard sample and thus indicates no abnormality or signs of degradation as no abnormal or strange peaks are visible in the spectra.

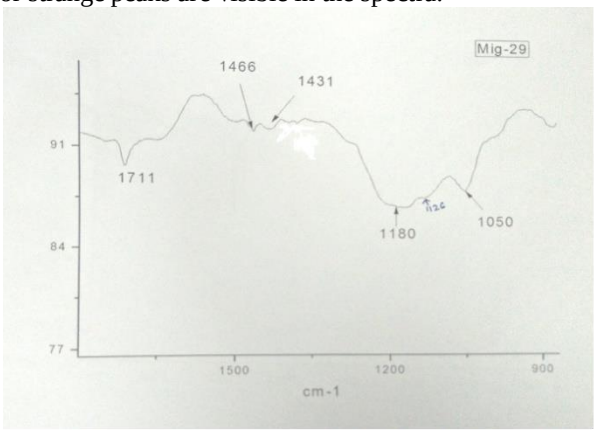


Fig.-7. FTIR Trace OF Fractured Canopy Sample

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Conclusions

No abnormality in the material characteristics of the organic glass material was observed when the sample from the damaged wind shield was subjected to instrument characterization and analysis viz. FTIR, TGA, DSC, SEM, etc. Therefore, degradation of material as a cause for failure is conclusively ruled out.

Since the crack got generated in the radial direction of the canopy, hence cannot be attributed to the differential pressure existing while flying wherein the hoop stress takes a major role to produce a fracture in longitudinal direction in such cases, although the effect of the longitudinal component of cock pit pressurization , can be clearly seen as striations in SEM micrographs taken during the experiments, bring the flaw to the near critical flaw size and a very significant stress generated can further grow the crack leading to brittle fracture/ crack growth.

Having ruled out the possibility of origination of any flaw during assembly, maintenance, and due to deterioration in the material, it is finally concluded that the crack developed was from a completely chipped area of material from the canopy glass base, likely due to foreign object hit while at higher altitude, where the temperatures are low, thereby having a reduced fracture toughness making the organic glass more brittle.

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