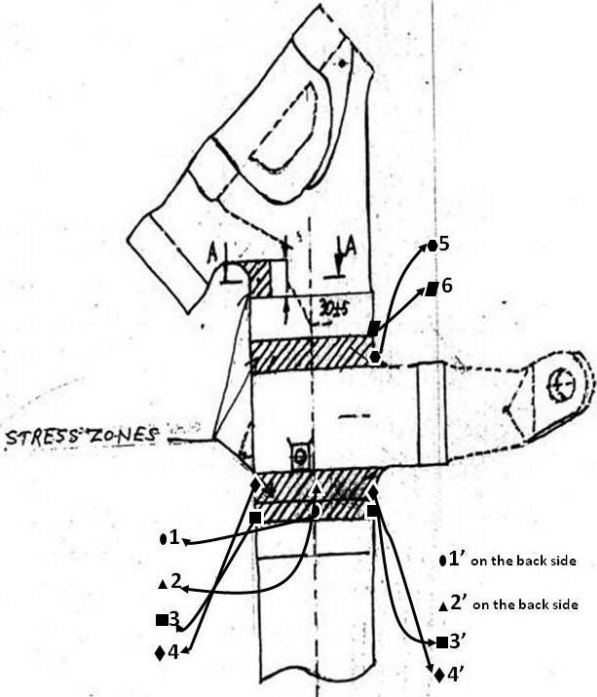
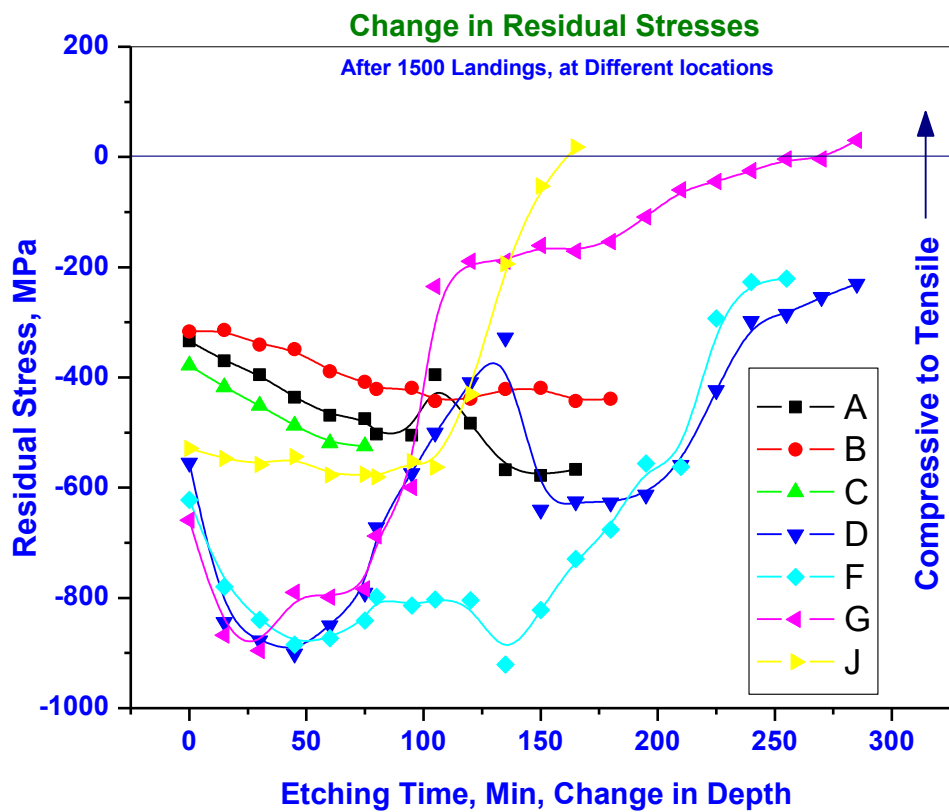
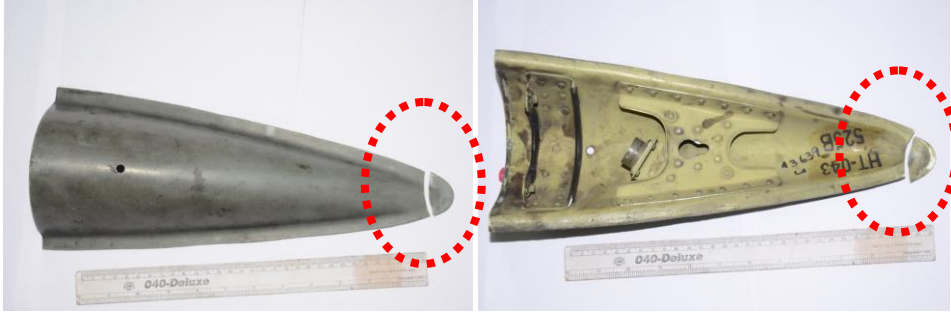


CSIR-NML's EXPERTISE ON LIFE ESTIMATION AND DAMAGE EVALUATION OF AIRCRAFTS

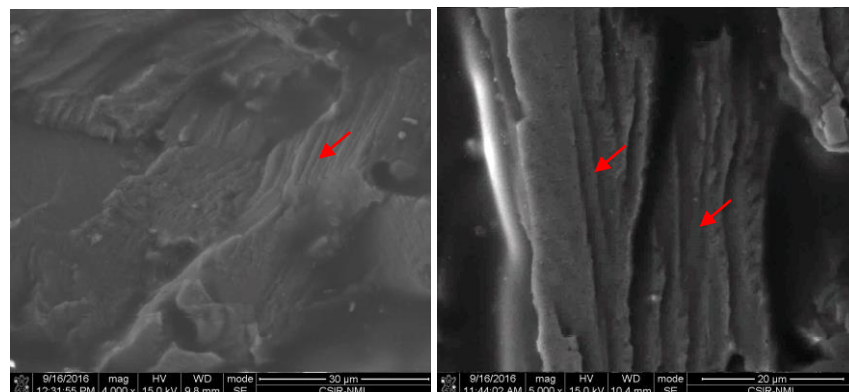
Title	Life Extension Programme of Mig-29 Aircraft Main Landing Gear of Indian Air Force
Scope	<p>Non-destructive assessment of five MLG undergone 0, 1885, 2136, 2445 and 2500 landings.</p> <ol style="list-style-type: none"> 1. Assessment of comprehensive residual stress on four MLGs by X-ray Diffraction (XRD) 2. Identify critical locations based on relaxation residual stress 3. Find a parameter having correlation with the fatigue life
Finding	 <p style="text-align: center;">Residual stress measurement locations</p>

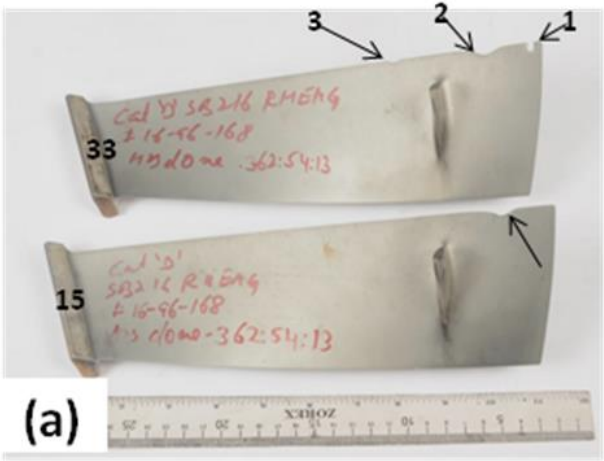
Compressive stress field (CRSF) study by layer removal technique was found to be varied from location to location of life-expired MLG. The profile at location 4 has shown a decreasing trend, location 5 has nearly flat nature and the profile at location 6 was of initial increasing nature and then decreasing. Moreover, the depths of CRSF (Z0) as well as compressive residual stress at the surface (σ_{src}) at various locations are in following order: location 4 > location 5 > location 6. The residual stress at the investigated subsurface region remained compressive at location 4 while it changed to tensile at locations 5 & 6. Typical variation in residual profile after 1500 landings is shown in figure



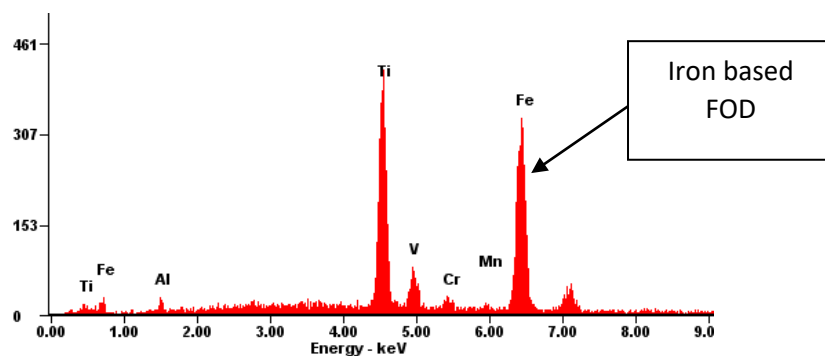
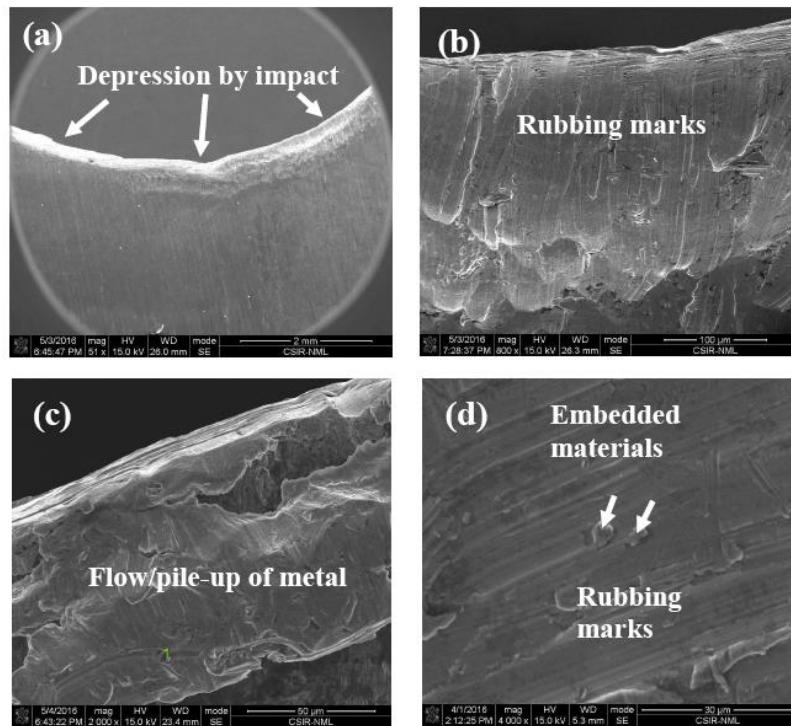
Title	Failure analysis of aileron PCU fairing of HAWK MK 132 aircraft
	 <p>Red dotted circle shows broken region</p>
Scope	<ol style="list-style-type: none"> 1) Visual examination, photographic recording and sampling of the damaged portion of the fairing assembly. 2) Chemical analysis. 3) Microstructural analysis and hardness measurement. 4) Fractography & surface analysis by SEM-EDS. 5) Identification of foreign object if any.
Finding	<p>Failure investigation of the broken fairing of aileron PCU-LH of Hawk MK132 A-3653 aircraft was carried out through visual examination, chemical analysis, microstructure analysis and fractography by SEM-EDS. Visual observation showed that the fairing was broken into two halves approximately at 20 mm from the tip. The broken piece was around 20mm X 35mm X 1.4mm in size. Visual examination and SEM-EDS analysis revealed several line marks near the fractured region due to cracking of the coating on the outer surface of the broken fairing tip. The cracks on the coating occurred due to the deformation of the base metal underneath the coating. Deformation of the base metal occurred because of stress concentration around the region. However, evidence of FOD was not found on the outer surface of the broken tip and rest part of the fairing. Visual examination of the inner surface of the broken fairing tip showed damage/removal of the coating at the tip region. Beside damage of the coating at the tip, no other damage was observed in rest portion of the fairing. SEM-EDS analysis of the damaged coating showed that the inner coating was removed by the repeated knocking of</p>


the tip against the surface of the wing. Chemical analysis of the fairing material showed that it was made of Al-Cu alloy of 2014 grade. Microstructure analysis and hardness measurement also conformed to the aluminium alloy of grade 2014. Fractography of the fractured surface revealed the signatures of progressive mode of failure. Hence it was concluded that the fairing was broken due to fatigue failure and not due to shearing/overload failure. Hence failure due to impact of an object was ruled out. SEM-EDS analysis showed that fatigue crack initiation and propagation was from the inner surface of the fairing. Fatigue failure occurred because of repeated knocking of the tip against the wing. Repeated knocking action might have been due to the existence of slight relative movement and aerodynamic condition prevailing on the fairing during service operation.

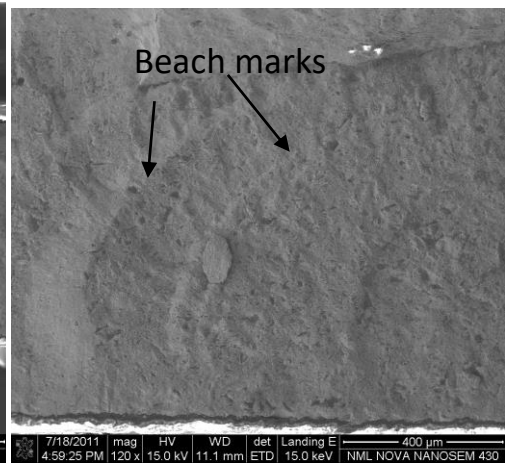
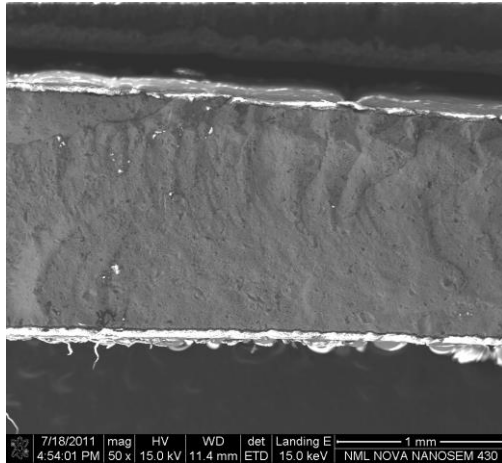
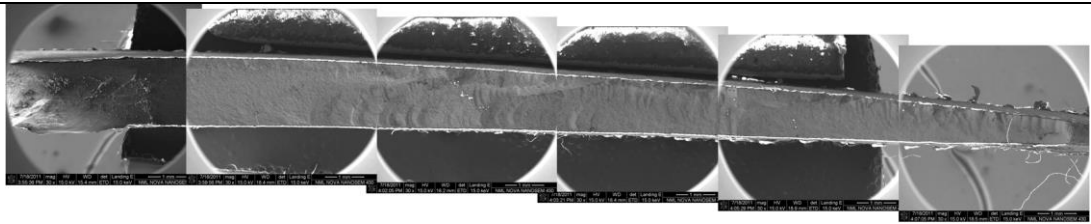


Title	Failure analysis of aero engine damaged blades of SU-30 MKI
	 <p>(a)</p>
Scope	<ol style="list-style-type: none"> 1) Visual examination, photographic recording and sampling of the damaged portion of the blades. 2) Chemical analysis 3) Microstructural analysis and Hardness measurement. 4) Fractography & elemental analysis by SEM-EDS. 5) Identification of foreign object if any based on the above investigation.
Finding	<p>Failure/defect analysis of two damaged blades (Blade No.15 and Blade No.33) of aero engine of SU-30MKI was carried out through visual examination, chemical analysis, microstructure analysis and fractography by SEM-EDS to find the cause of damage. Visual examination showed that both the blades were damaged in the form of dent/notch along the leading edges possibly due to impacts by hard objects. Blade No.15 was damaged at a single location and was located at 27 mm from the tip of the blade on the leading edge. The dent/notch of blade No.15 was approximately 15 mm wide and 3 mm deep. Blade No.33 was damaged at three locations which were marked as Dent 1, Dent 2 and Dent 3 for convenience as shown in Figure. Dent1 was located at 6 mm, Dent 2 was located at 31 mm and Dent 3 was located</p>

at 84.5 mm from the tip of the blade along the leading edge. Dent 1 was approximately 4 mm wide and 5.5 mm deep, Dent 2 was approximately 20.5 mm wide and 3.5 mm deep and Dent 3 was approximately 8.5 mm wide and 1 mm deep. Chemical analysis confirmed that the blades were made of titanium based alloy of type (Ti-6Al-4V). Microstructure analysis did not show any abnormality in the microstructure of the blades. Microstructure of the blades was consisting of alpha (α) and alpha + beta ($\alpha+\beta$) structure of Ti-6Al-4V alloy. Fractography/damaged surface analysis by SEM-EDS confirmed that blades were damaged due to impacts of an iron based metallic object.




Title	Failure analysis of second stage compressor rotor blades of R13 aero-engine of MIG-21 air craft
	
Scope	<ol style="list-style-type: none"> 1. Visual examination and photographs recording 2. SEM Fractographic study to find out the failure mode/mechanism. 3. Surface studies to find out nature and mechanism of surface degradation/damages. 4. Microstructure investigation and EDS microanalysis. 5. Hardness measurement.
Finding	<p>Failure investigation of a damaged second stage compressor rotor blade of R-13 aero engine was carried out. No microstructural/material defect was observed. The blade is made of martensitic stainless steel of Russian grade AE 961W and has protective coating. The hardness value of the blade is within specified limit. The pressure surface of the blade has undergone erosion in the form of cracks, pits/craters by impact of sand particles. Protective coating was completely eroded along the leading edge near tip region due to abrasion of sand particles. The failure of the blade was due to fatigue initiated from the pits/craters formed on the bare base metal due to impact of sand particles. Fatigue crack was propagated from surface crack/crater due to complex cyclic loading condition of engine off and on; coupled with vibration characteristics during flight.</p> <p>In order to mitigate the problem, frequent inspection of blades for coating damages should be carried out. Secondly, feasibility of recoating of blades along leading edges as coating gets damaged may be explored.</p>



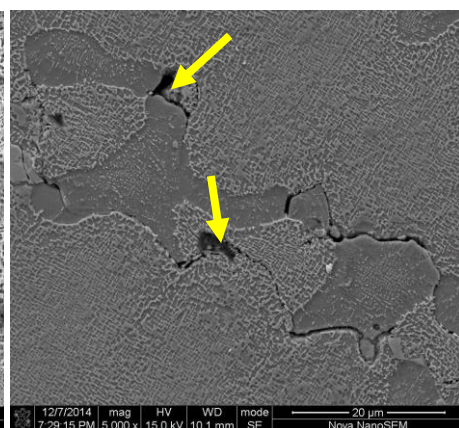
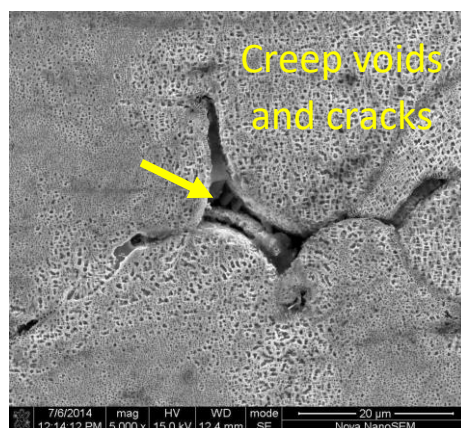
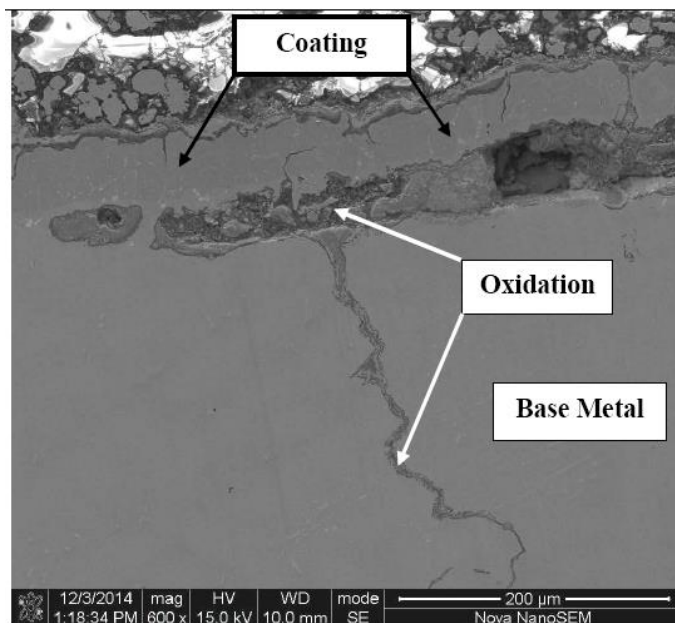
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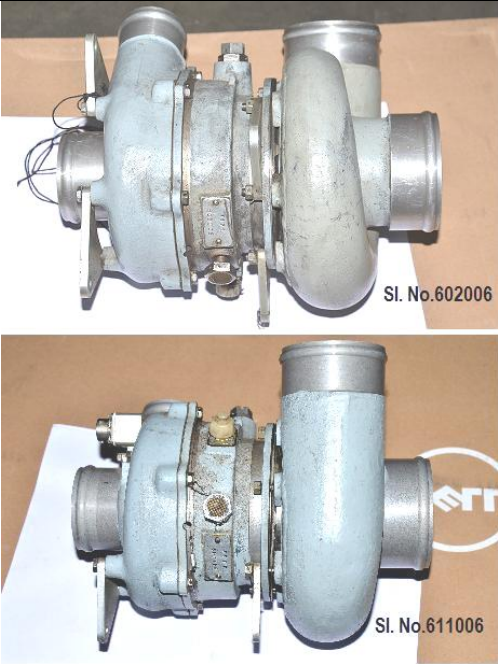
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Title	Failure analysis of damaged 1 st stage NGV (Nozzle Guide Vane) of R-25 aero-engine.
	
Scope	<ul style="list-style-type: none"> ➤ Visual examination and photographs recording. ➤ Chemical analysis. ➤ SEM Fractographic study to find out the failure mode/mechanism. ➤ Microstructure investigation/analysis and Hardness measurement. ➤ Microstructure analysis and Coating analysis of the undamaged NGV by Optical Microscopy and Scanning Electron Microscopy (SEM).
Finding	<p>Failure investigation of a damaged 1st stage nozzle guide vane (NGV) of R-25 aero engine was carried out to determine cause of failure, coating condition and material degradation due to high temperature in comparison to an undamaged nozzle guide vane obtained from the same stage. Chemical analysis of both NGV's conforms to nickel based super alloy of Russian grade ZC6Y-BE. Microstructure analysis showed that both NGV's consist of gamma and gamma prime (γ-γ') matrix having cast dendritic morphology along with coarser primary carbides. Discontinuities/cavities at inter-dendritic region were also observed in both the NGV's. However the microstructural degradation is more predominant at the damaged location of the damaged NGV's. It is interesting to note that at the same location for the undamaged NGV also showed similar microstructural degradation.</p> <p>Coating analysis revealed degradation / depletion of coating at the</p>

leading edge of the undamaged NGV. However at the trailing edge (suction side) the coating thickness was heavy appears to be second coating. In case of failed NGV, the coating was damaged/depleted up to ~5 mm from the damaged portion towards the shrouded end.

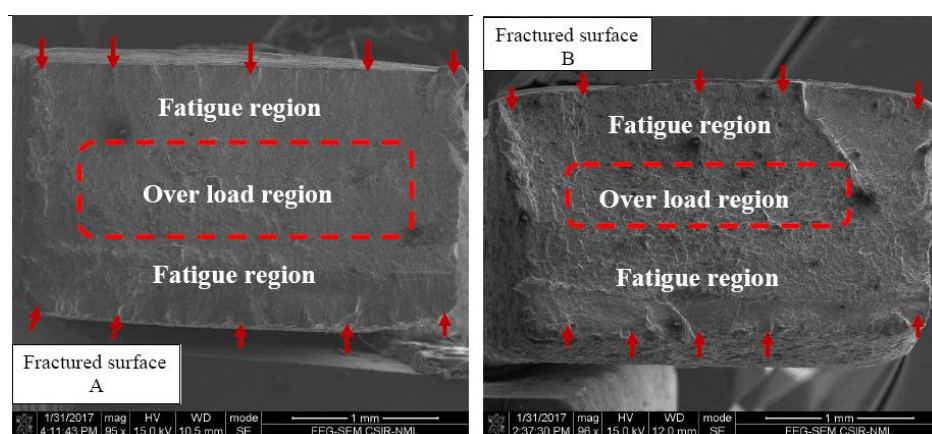
Failure of the 1st stage nozzle guide vane (NGV) was due to high temperature oxidation assisted by creep and thermal fatigue. Degradation /damage of coating might have assisted the high temperature oxidation to occur. Rise in temperature accelerated the precipitation and coarsening of chromium rich secondary carbides rendering the oxidation of Ni base matrix especially around chromium rich precipitates. Inter dendritic cavities/discontinuities were generated because of high temperature creep and thermal fatigue. These cavities/discontinuities provided the easy diffusion paths for oxygen transport enhancing high temperature oxidation of the nickel matrix.


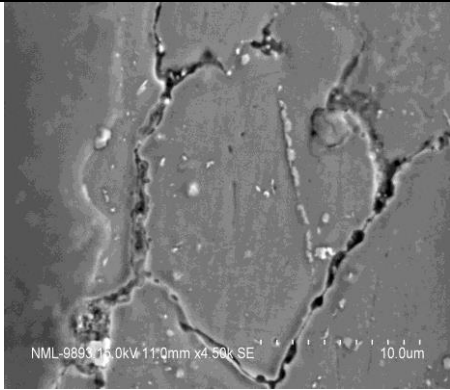


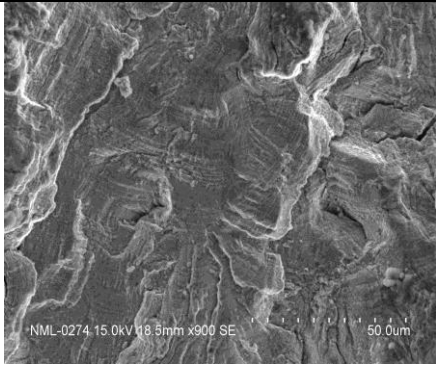
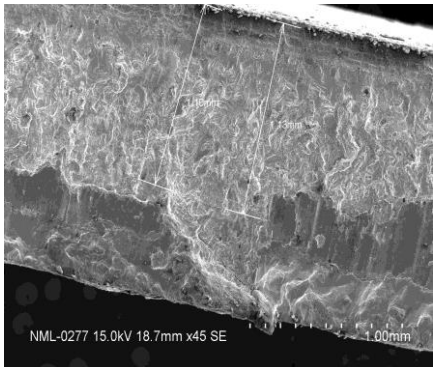
Title	Metallurgical analysis of turbo coolers of MIG-21 Bison	
		
Scope	<ol style="list-style-type: none"> 1. Visual inspection and photography; 2. Chemical analysis; 3. Microstructural analysis; 4. Fractography & SEM-EDS analysis; 5. Identification of probable foreign objects and dislodged metallic particle 	
Finding	<p>Metallurgical analysis of turbo coolers 7171 (Sl. No. 602006 & Sl. No. 611006) of MIG-21 Bison: CU-2069 was carried out by visual examination, fractography, chemical analysis and SEM-EDS analysis. Macro and microscopic examination revealed severe damages in turbo cooler having Sl. No. 602006. The shaft was broken into two pieces and fan blades, fan casing and guide wheel of the turbo cooler were damaged/worn-out. However, only fan blades and casing of the turbo cooler Sl. No. 611006 are found in damaged condition. Severe impingement/impacts marks were found on the casing of the fans of both the turbo coolers. Experimental results confirm that the turbo cooler were failed by erosion and damage due to the impingements/impacts of multiple objects on the fan blades of the turbo coolers. The embedded-foreign-objects-rock/sand consisting of Si, Al, O, Ca, K Mg, Na etc. were detected by SEM-EDS along with carbon sulphur, iron, tin and copper based metallic materials. As received six FODs were identified as magnetic and non-magnetic metallic objects. However, the damages to the rotor shaft, guide wheel and other components of turbo cooler Sl. No. 602006 are secondary in nature.</p>	

Title	Failure analysis of mounting bracket of DASU-1A of MIG-21 (Bison) aircraft
	
Scope	<ul style="list-style-type: none"> ➤ Visual examination and photographic recording. ➤ Chemical analysis ➤ SEM fractography and surface study to find out the failure mode/mechanism. ➤ Metallographic study and hardness measurements to find out any unusual microstructural features, if any. ➤ To find out the causes and circumstances of failure and suggest remedial measures
Finding	<p>Failure investigation of the broken mounting bracket (Pt. No-75-5102-92) of DASU-1A of Mig-21 (Bison) aircraft CU-2316 was carried out through visual examination, chemical analysis, microstructure analysis and fractography by SEM-EDS. The mounting bracket was broken into two pieces from the centre hole. It was ruptured along the transverse section at two locations along the diagonal of the centre hole creating four fractured surfaces (i.e. two mating fracture surfaces from one location). Fractured surface from one location is marked A and the other fractured surface from the diagonally opposite location is marked B for convenience. During visual examination, significant corrosion/oxide</p>

formation observed on the fractured surface B, compared to the fractured surface A. Significant corrosion/oxide formation on the fracture surface may be inferred that it is a time dependent failure and not a sudden failure. Microstructure consists of tempered martensite with slightly higher amount of inclusions. Tempered martensite is common in quenched and tempered low alloy steel. Fractographic studies by SEM-EDS revealed regular steps marks due to crack propagation by cyclic load and elongated radial cracks around the neutral axis (central region) due to the detachment of interfaces between the matrix and inclusions, hence it may be inferred that that the bracket was failed due to reverse bending fatigue. Fatigue was initiated from the inclusions situated on surfaces/subsurface of the bracket under the reverse bending load and propagated for some time before fracture. Moreover, corrosion product/oxides on the fatigue cracked surface were also noticed indicating time dependent fatigue failure. The reverse bending fatigue condition might have arisen due to improper fastening /loose of the mounting bracket coupled with vibration of the aircraft. Moreover, martensitic steels are low fracture toughness materials and aggravated by the presence of inclusions, hence could not with stand the fatigue load.



Title	METALLURGICAL FAILURE ANALYSIS: GROUND INCIDENT TO MIG – 27 ML TS - 615	
		<p><i>Damaged rear flange flame tube</i></p>
Scope	<p>In Kalaikunda during Aug'2010, at the time of crank of engine de-inhibition run on MIG-27 ML TS-615 aircraft, abnormal rattling sound was heard from jet nozzle area after completion of TS cycle. Post flight inspection of the aircraft revealed adherence of non-magnetic metal particle on LPTR blade at 7 o'clock position, small fragment within the jet nozzle and dent at 3 and 4 o'clock positions over second stage nozzle guide vanes. To explore the root cause of this incident, the scope has been illustrated as</p> <ol style="list-style-type: none"> 4. Microstructural examination near damaged, un-damaged and weld location. 5. Fractographic investigation. 6. Mechanical properties evaluation close to the damage. 	
Finding		<p><i>Cavitation in surface section</i></p>

	<div data-bbox="355 192 793 555">  <p><i>Fatigue striation at one end of fragmentation</i></p> </div> <div data-bbox="355 607 793 972">  <p><i>Overall display of regions covered with fatigue striations</i></p> </div>
<p>Inferences</p>	<ol style="list-style-type: none"> 1. The component is made of Ni base solid solution single phase of AE 868, decorated with alloy carbide. At few locations grain boundary de-cohesion was found which may be the manifestation of high temperature exposure. 2. For rear flange flame tube the fatigue crack was found to be initiated near the weld region. Cyclic thermal stress developed within the component owing to the change in temperature from ambient to several hundred degrees. Thermal fatigue is thus a damage mechanism, enhanced by the generated stress during thermal cycling within the component. The phenomenon was manifested by fatigue crack growth and lead to circumferential separation along the weld. 3. The failure of the other parts of the component was secondary in nature and owing to fast fracture. The weld joint failure lead to imbalance in load distribution through the other part of the component; hence the other failed locations exhibited characteristic feature of dimple fracture due to overload under hoop stress.