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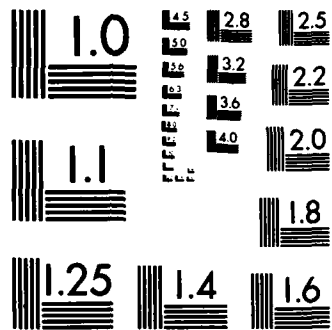
STUDY OF PARTICULATED FLOWS AND EROSION IN
TURBOMACHINERY(U) CINCINNATI UNIV OH DEPT OF AEROSPACE
ENGINEERING AND ENGINEER W TABAKOFF AUG 86 86-57
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the results of an investigation of the solid particle dynamics and the resulting blade erosion through a helicopter engine with inlet particle separator. The particle trajectories are computed in the inlet particle separator. The particle trajectories are computed in the inlet separator which is characterized by considerable hub and tip contouring and radial variation in the swirling vane shape. The nonseparated particle trajectories and the erosion are determined through the deswirling vanes and the 5-stage axial and 1-stage radial compressors. Also, effects of high temperatures on erosion rate was determined in erosion wind tunnel for AM355 steel and Al₂O₃ ceramics.

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STUDY OF PARTICULATED FLOWS AND EROSION IN TURBOMACHINERY

ABSTRACT

This report summarizes the results of an investigation of the solid particle dynamics and the resulting blade erosion through a helicopter engine with inlet particle separator. The particle trajectories are computed in the inlet separator which is characterized by considerable hub and tip contouring and radial variation in the swirling vane shape. The nonseparated particle trajectories are determined through the deswirling vanes and the five stage axial and one stage radial compressors. The impact data for a very large number of ingested particles is used to calculate the resulting blade surface erosion. The erosion pattern indicates the location of maximum blade erosion. In addition, the effect of high temperature on the erosion rate was determined in erosion wind tunnel for AM355 steel and Al_2O_3 ceramics.

INTRODUCTION

The problem of a gas-flow mixed with solid particles in axial and radial flow turbomachines has great importance in aeronautical, industrial, and naval applications. The performance of the aircraft engines is known to deteriorate rapidly when they operate in areas where the atmosphere is laden with solid particles. In general, these particles do not follow the flow streamlines in the engine and tend to impact the blade surfaces due to their higher inertia. These blade impacts can cause severe erosion damage that is manifested in the pitting and cutting of the leading and trailing edges, and a general increase in the blade surface roughness. Excessive erosion damage can lead to the structural failure of the blades.

The erosion problems in military and commercial airplane gas turbine engines are generally recognized in industry. The operating life of helicopter engines performing in sandy areas is very short. Recently, many reported industrial gas turbine engine failures have been connected to their exposition to particulate flows. Research efforts are still needed to provide a thorough knowledge of the various parameters which influence the extent of erosion damage.

a) A Study of Compressor Erosion in Helicopter Engine with Inlet Separator

The erosion of metals by solid particle laden flow have been investigated experimentally and theoretically under this contract to

determine the parameters that affect the erosion rate and to arrive at empirical equations for the target material erosion in terms of these parameters. The results of these investigations demonstrate that for a given particle-target material combination, the erosion rate is affected by the impacting velocity, impingement angle, and by the metal and the gas temperatures. Prediction of turbomachine blade erosion hence requires that a large number of particle trajectory calculations are carried throughout the machine to determine the pattern and frequency of particle blade impacts as well as the magnitude and direction of the impacting velocities relative to the blade. This data can then be combined with the empirical equation to calculate the blade erosion pattern and intensity.

Erosion cascade tunnels have also been used to determine experimentally the change in compressor cascade performance due to erosion. The changes in the airfoil configuration and its surface roughness were found to influence both the blade loading and the cascade loss coefficient. However, blade erosion in multistage turbomachines differ significantly from the cascade erosion due to the difference in the particle impact locations as well as in their impacting velocities and impingement angles relative to these surfaces. Since the particles impact the blades as well as the casings, the geometrical configuration of the latter would also influence the blade erosion. It was found that the hub contour geometry and the radial variation in the blade shape not only affect the particle trajectory but also their radial and circumferential distribution after the blade row. Furthermore, since the particles are generally redistributed in the radial direction under the influence of the centrifugal forces as they travel through the machine and repeatedly impact the different blade rows, the erosion of the blades in the multistage machines is dependent on their stage locations.

The results of the detailed study performed under this contract provides the blade and vane surface erosion through the inlet separator, in the deswirling vanes, the five stage axial compressor, and the radial compressor of the G.E. T700 helicopter gas turbine engine. The inlet is characterized by swirling vanes placed in a highly contoured hub zone to centrifuge the particles for separation. The unscavenged flow proceeds through deswirling vanes placed in an annulus zone with decreasing inner and outer radii before the five stage axial flow compressor.

Two separate computer codes, one for predicting the particle dynamics, and another for predicting the erosion are used to obtain the presented results. The three dimensional particle trajectory calculation, in the various components of the machine provide the particle blade impact locations and the magnitude and direction of the particle impacting velocity relative to each blade. A computer code that is especially developed to predict the blade surface erosion uses the computed blade impact data and the experimental results for blade material erosion. The presented results show the magnitude and pattern of blade erosion in the various blade rows. The results indicate that the deswirling and swirling vane erosion is strongly influenced by the inlet separator geometry. The multistage axial compressor blade erosion is found to be strongly influenced by the blade row location. The results also indicate that the erosion intensity in the compressor increases in the latter stages and that higher local values of erosion are generally encountered in the rotor blades than in the stator blades. It was also found that the erosion intensity of the radial impeller is as high as axial compressor later stages.

For further detailed information, see University of Cincinnati Report No. 86-55.

b) Investigation of Erosion Behavior of Ductile and Nonductile Materials

In order to provide basis for alloy selection in future turbomachinery exposed to particulate flows, an investigation was undertaken to obtain a basic understanding of the mechanism of erosion at different temperatures. The test equipment has been designated to simulate the aerodynamic and thermodynamic conditions in the engine. This facility can provide between ambient and 1093°C (2000°F) environment temperature for erosion testing of various materials. The effect of high temperature on the erosion rate was determined and the test results from AM355 stainless steel and Al_2O_3 ceramics are presented. The experiments were carried out at several particle velocities from 76 to 305 m/s, at various angles of attack and for different particle sizes and different particle materials. Erosion prediction model was developed for the AM355 steel alloy and was compared with the test results.

For further detailed information, see University of Cincinnati Report No. 86-56.

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CONCLUSIONS

Numerous technical presentations and publications are associated with this research work with topics ranging from basic to applied nature. It is difficult to present conclusions for each of these publications, therefore I will concentrate only on the investigations made in the two Final Reports to the U.S. Army.

a) Erosion in Helicopter Engine with Inlet Separator

The dynamics of the suspended solid particles which are entrained by the air through the helicopter engine inlet separator and its axial and centrifugal compressors were investigated. The distribution of the unseparated particles and the locations of the particle-blade impacts were determined from the particle trajectory computations and presented throughout the five stage axial flow compressor and the single stage centrifugal compressor. The trajectories of the 165 micron sand particles are generally dominated by their impacts with the blade pressure surfaces, after which they tend to migrate in the radial direction under the influence of the centrifugal forces. This process is initiated at the first rotor and continues throughout the five stages leading to increased particle concentration toward the outer annulus and the absence of the particles near the inner annulus. This in turn affects the particle blade impact locations and the resulting blade erosion pattern in the various stages. The presented results indicate that most of particle blade impacts are with the pressure surface in both the axial and radial flow compressors. The results also show a nonuniform particle distribution in both the centrifugal and radial directions between each pair of sequential blade rows. In the axial compressor, the maximum blade erosion is generally observed in the rotors, not the stator. The maximum stator blade erosion is always at the tip, but not at the leading edge, and the maximum rotor blade erosion is near the leading edge at the tip. In the centrifugal compressor, the maximum erosion occurs on the pressure surface of the impeller blade closer to the impeller inlet. The results also indicate that the maximum erosion in the centrifugal compressor is comparable to that of the axial compressor earlier stages, but generally lower than the axial compressor lower stages. This can be attributed to the higher particle impact velocities relative to the axial compressor blade surfaces in the latter stages.

b) Erosion Behavior of AM355 Steel Used in Turbomachinery and Al₂O₃ Ceramic

1. For the ductile material (AM355), the erosion rate increases with the increase in the impacting particle velocities.
2. For the same material, the erosion rate increases with temperature. The ceramic Al₂O₃ showed a decreasing erosion trend over the 600°F to 1000°F temperature range.
3. It was found that the degree of erosion increases with increase of the particle size. In this investigation, the particle sizes varied between 100 microns and 2,000 microns.
4. For AM355 material, it was found that the erosion rate is proportional to the particle size.
5. The velocity exponent "n" in the erosion equation varied depending on the temperature, angle of attack and particle property. The velocity index "n" for the Al₂O₃ was considerably low compared to AM355 steel.
6. The erosion rate was not found to be very sensitive to a particulate concentration up to 0.014 mgm/cm³, however a decreasing trend of erosion was observed by increasing the concentration over 0.25 mgm/cm³.
7. The erosion rate was maximum for AM355 maximum at 30° angle of attack and minimum at 90°. On the other hand, for Al₂O₃ ceramic, the erosion rate was maximum at 90° angle of attack and continuously decreasing to 0°.
8. Combustion chamber ceramic coated samples were investigated for the U.S. Army Research and Technology Laboratories (AVSCOM) Lewis Research Center. The coated samples were tested in the erosion wind tunnel at elevated temperature. The life duration of the coating was very short when exposed to particulate flow.
9. Scanning Electron Micrographs for AM355 and Al₂O₃ were performed on the tested samples. The degree of erosion was very well documented for different particle velocities, angles of attack and the influence of the temperature. From the inspection of the Scanning Electron Micrographs, it is very clear that the degree of erosion of AM355 is higher at increased particle velocity, temperatures and the particle size.

RECOMMENDATIONS

It is recommended that further data analysis and studies be continued in order to design better and more efficient separators. The following experimental tasks are necessary:

1. Particle rebound characteristic testing in the cold erosion wind tunnel: Particle rebound correlations must be developed for a minimum of 5 composites for impact velocity of 250 ft/sec and the angle of attack from 0 - 90 degrees. The test should be conducted for particle sizes ranging between 5 and 1000 microns.
2. Particle shattering characteristic testing: Particle fracture correlation must be performed on an aluminum, stainless steel and composite targets with particle velocities ranging between 200 and 1000 ft/sec and particle sizes from 5 to 1000 microns.
3. Particle drag coefficient measurements must be performed for different sizes and shapes of particles.
4. Trajectory calculations must be performed from the compressor exit through the diffuser and the combustion chamber.
5. Detailed trajectory analysis for different types of combustion chambers must be performed to find which type of combustor configuration will be the most suitable to prevent erosion of ceramic materials used for combustion chamber wall coatings.

APPENDIX A

The following scientific and technical personnel were participating in this research project.

<u>Name</u>	<u>Title</u>	<u>Degree Obtained</u>
W. Tabakoff	Professor	
A. Hamed	Professor	
T. Wakeman	Graduate Research Assistant	Ph.D.
B.V.R. Vittal	Graduate Research Assistant	Ph.D.
M. Malak	Graduate Research Assistant	Ph.D.
C. Balan	Graduate Research Assistant	Ph.D.
E. Elfeki	Graduate Research Assistant	Ph.D.
M. Janssen	Graduate Research Assistant	M.S.
S. Kang	Graduate Research Assistant	M.S.
A. Jain	Graduate Research Assistant	M.S.
A. Lakshminarasimha	Graduate Research Assistant	M.S.
Y. Jianjong	Graduate Research Assistant	M.S.
M. Mansour	Graduate Research Assistant	--
H. Eroglu	Graduate Research Assistant	--
D. Doerr	Assistant	--

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