# SPECIAL STUDY **TURBINE ENGINE ROTOR DISK FAILURES**

ADOPTED: DECEMBER 18, 1974

NATIONAL TRANSPORTATION SAFETY BOARD Washington, D.C. 20594

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15.Supplementary Notes

16. Abstract This report examines 41 cases of turbine engine rotor disk failures and one case of turbine shaft failure in which the entire low pressure turbine separated from the engine. The causes of failure and resultant aircraft damage are analyzed. Forty-four percent of the failures were categorized as primary, caused by material, manufacturing, or design discrepancies. Forty-one percent were considered secondary failures, caused by something other than the disk itself, and 15 percent were categorized as unknown cause or type of failure. Compression disks had a higher failure rate than turbine disks. Aircraft damage from disk failure ranged from minimal to nearly catastrophic, including fuel tank penetration and fire and loss of a portion of wing in one instance. Proposed methods to reduce the hazards of disk failure are presented.

Specific detailed case histories and accident data from the Safety Board's data bank which relate to fan, compressor, and turbine disk failures have been analyzed and are available. These data will be of interest primarily to aircraft and engine manufacturers and governmental or private sector agencies which have an interest in engine and aircraft performance.

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## NATIONAL TRANSPORTATION SAFETY BOARD WASHINGTON, D. C. 20594

#### SPECIAL STUDY

Adopted: December 18, 1974

#### TURBINE ENGINE ROTOR DISK FAILURES

#### I. INTRODUCTION

Turbine engine rotor disk failures were studied by the National Transportation Safety Board because of the hazard they create for an aircraft and its occupants and in response to numerous requests and questions by the aircraft and engine manufacturers and other governmental and private sector agencies regarding this matter.

Forty-one case histories of such failures were examined for the years 1962 through early 1973. /Twenty-nine failures affected engines with turbofans,/seven affected turbojets, four affected turboprops, and one affected a turboshaft engine. These case histories involved 41 disk failures and one separation of an entire low pressure turbine assembly.

Two case histories involving failures of centrifugal flow compressor impellers are included in the 41 disk failures studied. Since a centrifugal flow compressor impeller has the same function as an axial flow compressor disk/blade assembly and since the effects on the aircraft can be as serious as a failure of a conventional disk, these histories were examined.

A case history of the failure of an advanced technology turbofan engine low-pressure turbine shaft was also considered. The failure of the turbine shaft released all five stages of the low-pressure turbine assembly of the engine from the airplane. The separation of this assembly amounted to a record mass of engine lost off an aircraft. This case history was also similar to another involving the same type of engine/airplane wherein the fifth stage turbine disk failed. In both instances, the resultant effects to the aircraft were similar.

The fan, compressor, and turbine disk failures documented in this report were caused by operational problems, mechanical problems, or material problems.

The study is presented in two volumes. The first volume is a general discussion of the operational environment of an engine rotor disk, and the mechanical/operational factors which can induce an engine rotor disk failure. The disk failures discussed in this volume have been categorized into primary, secondary, and unknown types of failures.

For purposes of the study, a primary failure is a situation wherein the disk was not subjected to any external operating influences, but

failed as a result of improper machining or forging, material contamination, or plating discrepancies. Fatigue from unknown cause, fatigue corrosion, 1/ or initial design problem were also included in this category.

Secondary disk failures are those that resulted from external operating influences such as improper assembly, improperly sized components, component failure, or operational influence. Unknown failures are those in which no cause(s) could be found or in which critical parts were not recovered and therefore the cause of the failure could not be determined.

Specific detailed case histories and accident data from the Safety Board's data bank which relate to fan, compressor, and turbine disk failures have been analyzed and are available in the second volume. 2/ These data will be of interest primarily to aircraft and engine manufacturers and governmental or private sector agencies which have an interest in engine and aircraft performance.

#### II. TURBINE ENGINE ROTOR DISK FAILURES

#### Mechanical or Operational Factors

Fatigue is a major problem which limits a disk's service life. It is a mechanical phenomenon which causes a disk to fracture by repeated or fluctuating stresses which have maximum values, each of which is less than the ultimate tensile strength of the disk. Disks are subjected to either high- or low-cycle fatigue. High-cycle fatigue results from a large number of loading cycles at relatively low stress levels. Low-cycle fatigue results from a low number of loading cycles at relatively high stress levels.

In addition to high-cycle and low-cycle fatigue, fan, compressor, and turbine disks have failed as a result of engine assembly errors, substandard material, bearing failure, overtemperature, engine overspeed, operating interference from such as stator, blade, or component failures, and foreign object damage. These factors have often combined in many cases to cause a rotor disk failure.

Fan and compressor disks are subject to centrifugal stresses and highor low-cycle fatigue. In addition, the rear stage compressor disks are subject to thermal gradients, which induce some degree of thermal stress,

<sup>1/</sup> Fatigue aggravated by simultaneous corrosion.

This volume, entitled TURBINE ENGINE ROTOR DISK FAILURE CASE HISTORIES, can be purchased, as provided in 14 CFR 401.12, upon request and payment of fees by writing to: National Transportation Safety Board, Attn: Accident Inquiry Unit, Washington, D. C. 20591. Reproduction and billing will be accomplished by the current commercial firm under contract with the Safety Board at the price in effect at the time of the request.

although the stresses are not as severe as those experienced by turbine disks. To a lesser extent, stresses induced by distorted inlet airflow and resultant bending stresses induced by the gas flow through the compressor are environmental conditions under which these disks must operate.

In addition to high- and low-cycle fatigue problems, the turbine disk is subjected to centrifugal stresses induced by its rotating mass, and to thermal stresses which are induced by temperature differentials between the disk bore and rim and the front and rear disk faces. tion, there are residual stresses from fabrication and previous engine operation. Furthermore, the rotating blades transmit centrifugal and gas loads to the turbine disk. Although the centrifugal stresses in the blade may be designed to reduce the gas bending stresses, and the tensile stresses in the bore may be decreased by residual compressive stresses, design considerations are still needed to provide sufficient creep 3/ margin at the rim and adequate yield strength in the hub throughout the operating range. Additional complexities arise in the disk material as the operating temperatures increase; not only do the strength characteristics rapidly decrease, but also the resistance to corrosion and oxidation may diminish, which further affects the strength characteristics and possibly the thermal conductivity of the disk. High-temperature operation generally requires cooling air to turbine components to maintain adequate material strength and to reduce heat transfer into the bearing components.

#### Hazard Potential and Secondary Damage

In addition to initial damage caused by disk failures, secondary damage may also occur and thus increase the hazard potential and accident risk of a disk failure.

When a rotor disk fails, large masses of disk segments which possess large amounts of kinetic energy (see Photograph No. 1), are liberated from the main disk assembly. The resultant velocities of these liberated disk segments or other debris, are sufficient to cause extensive penetration and shrapnel damage to the fan, compressor, or turbine cases. Other powerplant components also may be damaged, such as engine cowlings and pylons of the affected engine or an adjacent or remotely installed engine.

In several instances, the loss of one engine because of a disk failure has resulted in an adjacent engine ingesting disk material and foreign debris or projectiles from the failed engine, which necessitated the shutdown of this engine. In some instances, the liberated disk debris was of sufficient magnitude to adversely affect a third or fourth engine.

<sup>3/</sup> Steady flow of a metal under a sustained load.



Photograph No. 1 Typical separated disk segments.

Several of the engines that were affected by ingestion of foreign debris were subsequently restarted after it was determined that the engines were capable of operation.

In one instance, an engine was shut down as a precautionary measure because of abnormal operational indications; however, subsequent events required that the engine be restarted. This particular instance was an accident which involved a two-engine turbo-propeller aircraft. The left engine flamed-out during turbulence and heavy rain. When the flame-out was discovered, the engine was shut down and the propeller was feathered. The right engine then began to operate erratically; at this time the left engine was restarted and promptly experienced a disk failure. The aircraft was landed safely.

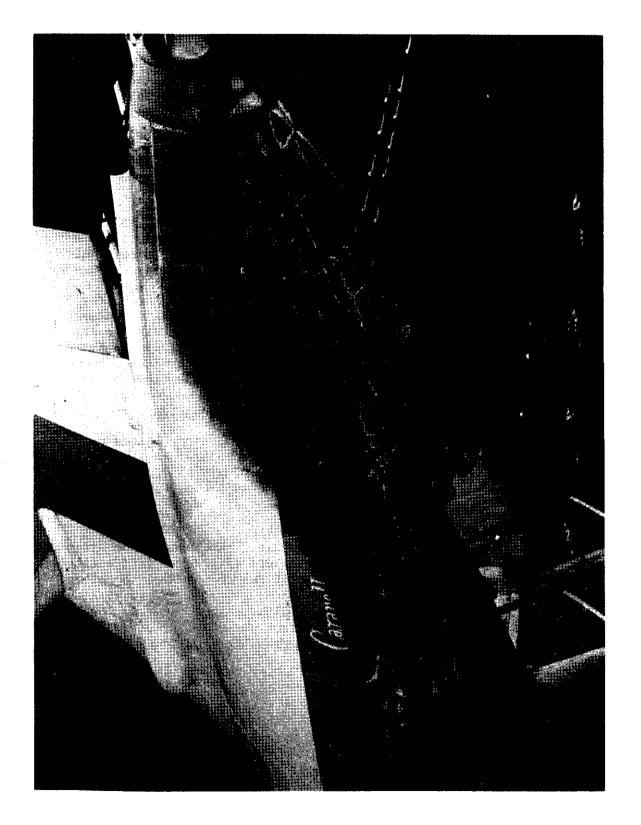
Fuel tanks and wing structure also are vulnerable. Fragments may enter into the cabin as well; fortunately, this has occurred only rarely, although personal injury or cabin fire has resulted when it did occur.

Debris damage from disk separations, in general, has ranged from minor to moderate fuselage damage, and from minor to extensive wing, pylon and cowling damage or separation. A number of these disk separations have also induced varying degrees of fire damage which ranged from minor engine and pylon burning or both, to severe burning of the undersides of the aircraft in the vicinity of the empennage section. (See Photograph No. 2.) In addition, a disk failure caused the near catastrophic loss of a portion of outboard wing section in another aircraft accident.

Two instances of disk disintegration of wing mounted engines occurred during the takeoff roll, in which liberated disk projectiles struck the runway and ricocheted into the underside of the wing. The projectiles penetrated the fuel tanks, causing fuel leakage and subsequent wing heat and fire damage. In one of the above cases, six passengers were injured during the evacuation.

Two disk failures were almost catastrophic. In one case the aircraft experienced an almost simultaneous failure of its two left engines at aircraft rotation (V<sup>r</sup>) speed. The loss of the engines led to severe directional control problems as well as severely limited thrust available at a critical time. In the second case, a disk failure caused a low order explosion of the No. 4 reserve fuel tank and the loss of 25 feet of right wing; this failure occurred during the early stage of climb. (See Photograph No. 3.)

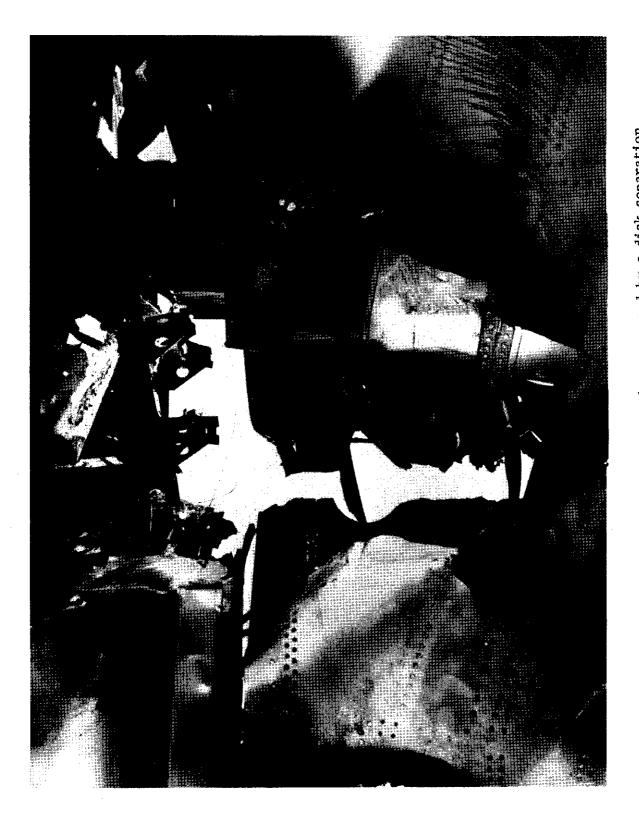
There have been seven disk failures on wide-bodied jet aircraft. Only two of these, however, were potentially catastrophic. One of these failures severed an engine. (See Photograph No. 4). This failure caused an intense pylon fire which burned for approximately 3 minutes. The initial landing approach had to be abandoned because of an operational malfunction of the body landing gear and inboard leading edge flaps.



Photograph No. 2. Burned aircraft empennage section caused by a disk separation.



Photograph No. 3. Loss of outboard right wing section caused by a disk separation.



Wide bodied jet pylon damage caused by a disk separation. Figure No. 4.

Fuel that spilled from the leaking tanks also presented hazards to passengers during their evacuation. The second disk separation resulted in the loss of three of the four hydraulic systems, at least one of which is required for flight control.

Other hazards presented to the aircraft and its occupants included instances of inactivation of the engine fire extinguishing system because of debris damage to the system's electrical lines. Debris, on occasion, has entered the aircraft cabin and resulted in severe injuries to one passenger and minor injuries to two other passengers.

With respect to the new generation of advanced technology turbofan engines, the effects of a separation of rotating members of the engine have been demonstrated vividly by a recent accident. While a rotor disk failure did not occur in this instance, and the disk was not involved in the accident, separation of a majority of the first stage fan blades occurred. The projectiles released during the separation sequence not only penetrated and depressurized the aircraft cabin, but also struck and failed the retaining structure of a cabin window, and a passenger was ejected through the window opening at a 39,000-foot altitude. Since a disk burst can generate high energy projectiles, the Safety Board is equally concerned with the effects of a disk failure in terms of the hazard potential created to the aircraft and its occupants by the release of these high energy projectiles.

#### III. ANALYSIS OF DISK FAILURE DATA

#### Operational Information

The following operational information data table, which is comprised of two sections, considers the engine wherein the failure occurred and the particular segment of flight in which the failure occurred. (See Table No. 1.)

An evaluation was made of the reported resultant aircraft damage pattern. The parameters that were considered included: (1) Fire damage to the pylons or aircraft structure which resulted from a disk disintegration; (2) fuel tank penetrations with resultant fuel leakage, and wing penetrations which were caused by disk disintegration; (3) disk debris which entered the cabin; (4) penetration of nonpressurized (nonwing) empennage area, or the ventral stair area by disk segments; and (5) reported or apparent control difficulties wherein the crew reported or inferred control difficulties such as loss of altitude and yaw.

In one instance, disassembly of a failed engine revealed the presence of two separated disks. Since it could not be determined which disk failed initially, the two disk separations were considered as two failures. Hence, a figure of 41 actual disk failures was used in the percent of disk failure computation for the compressors and turbines. The low-

ANALYSIS OF DISK FAILURE DATA Disk Failure Analytical Tables Onerational Information

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pressure turbine (LPT) assembly failure was not included in the tabulation of the total turbine disk failures, nor was it used in computing the percent of disk failures for the turbine. However, the LPT assembly failure was considered a case history for the remaining appropriate analytical study tables and graphical analytical summations.

A fan is not installed in a number of the engine models that experienced disk failures; therefore, the baseline used to compute the total number of fan disk failures and the percent of disk failures attributed to the fan was only those 29 engines in which a fan was installed.

A baseline of 41 cases was also used in computing the type of disk failures, the segment of flight, and the aircraft damage pattern parameters. In considering the type of failure data tabulations for primary and secondary failures, the total primary and the total secondary failures were individually used where applicable for the baseline computations.

Table 1 shows that there were 7 fan disk failures which affect 29 turbofan engines, or 24 percent of the failures of those engines in which a fan was installed. The remaining 34 failures consisted of 19 compressor and 15 turbine disk failures. By using a baseline index of 41 total disk failures, it was found that compressors were the engine modules which failed most frequently (45 percent) followed by the turbine module which comprised 36 percent of the disk failures.

The segment of flight section incorporated in Table 1 shows that there were six failures during the takeoff roll, or 15 percent of the total failures. The number of failures during aircraft rotation speed (VR) and takeoff safety speed (V2) was four, which comprised 10 percent of the total failures. The time period beginning during the latter stages of the takeoff roll through V2 is considered to be the most hazardous time for a disk failure to occur. Thus, the combined failure rates during the takeoff roll through V2 are considered quite high in view of the hazard potential to the aircraft. The climb segment of the flight was more prone to disk failures; 58 percent occurred during this segment of flight. Two of these failures occurred during an en route climb from the affected aircraft's assigned altitude. Only one disk failure occurred during descent or 2 percent of the total segment of flight failures. aircraft damage pattern incorporated in Table 1 shows that fire and wing penetration had the highest failure incidence. There were 17 wing penetrations and 13 instances of fire damage to the aircraft, giving failure rates of 41 and 31 percent, respectively. The remaining parameters of fuel tank penetration and reported fuel leakage, cabin penetration, nonwing unpressurized area penetrations, and control difficulties occurred at about the same levels of incidence. There were six fuel tank penetrations and reported fuel leakage and six nonwing unpressurized area penetrations, which was equal to a 6-percent failure rate. Seven cabin penetrations and seven reported or apparent control difficulties occurred as a result of disk failures. This equated to a 17 percent failure rate.

It should be noted that the aircraft damage pattern may have involved one or more damage pattern parameters. The above data is also in the bar graph on page 14 and depicts the percent of disk failures for each operational parameter.

#### Primary and Secondary Disk Failures

Of the 41 case histories that are shown in Table 1, it was determined that there were 18 primary, 17 secondary, and 8 unknown types of failures. Using a baseline figure of 41 cases, it was determined that there were 44 percent primary failures, 41 percent secondary failures and 15 percent unknown causes or types of failures. These data are also shown in bar graph form on page 15.

#### Primary Disk Failures

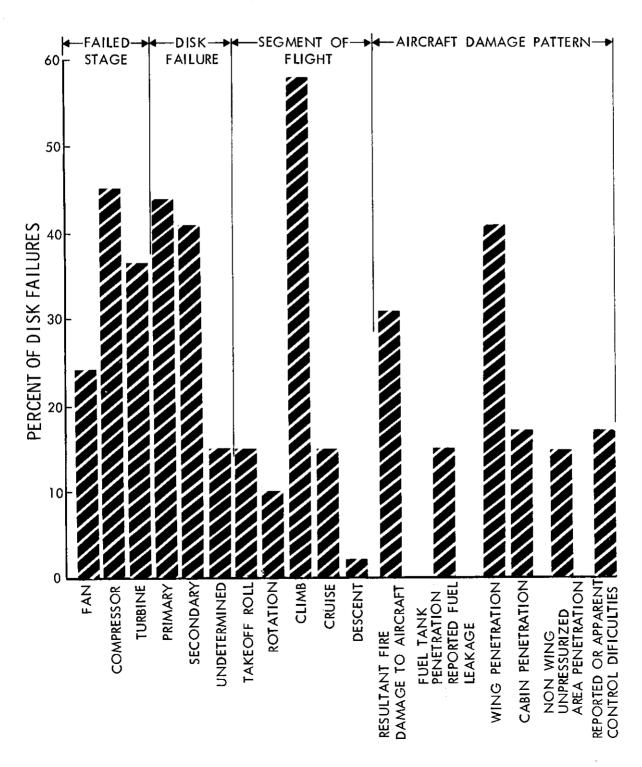
The primary failures (Table No. 2) were further categorized as follows: (1) Processing discrepancies such as machining, forging, material contamination and plating; (2) fatigue-unknown causes; (3) fatigue corresion; and (4) initial design problem.

Seventeen percent of the primary disk failures occurred because of machining problems. Two of these failures were attributed to defective tools used during a machining operation. The third failure was caused by improper rounding of the disk slot edges. Forging defects such as inclusions or material porosity accounted for three disk failures, while the remaining two were caused by processing discrepancies involving the top half of the forging billet. Excessive lead content within the forging billet accounted for the material contamination failures. Fatigue cracking of nickel plating was the cause of the single failure that was attributed to plating defects. Three cases of fatigue from unknown origin were the causes of disk disintegrations, while two other failures were attributed to fatigue corrosion. An insufficient radius on the aft side of a turbine disk caused the failure of a turbo shaft The insufficient radius was considered as an initial design engine. problem.

#### Secondary Disk Failures

Improper assembly or improperly sized components accounted for 6 out of 17 secondary disk failues. (Table No. 3) The most notable type of secondary disk failures was caused by failure of engine components. Typically, these failures were caused by blade tang galling, bearing disintegration, third stage turbine nozzle guide vane retention lug discrepancies, bearing supports, blades, pressure tubes located within the high pressure turbine shaft, and excessive programmed flow from the water methanol flow meters.

# ANALYSIS OF DISK FAILURE DATA Graphic Analytical Summation Operational Information





### ANALYSIS OF DISK FAILURE DATA Graphic Analytical Summation Primary/Secondary Failures

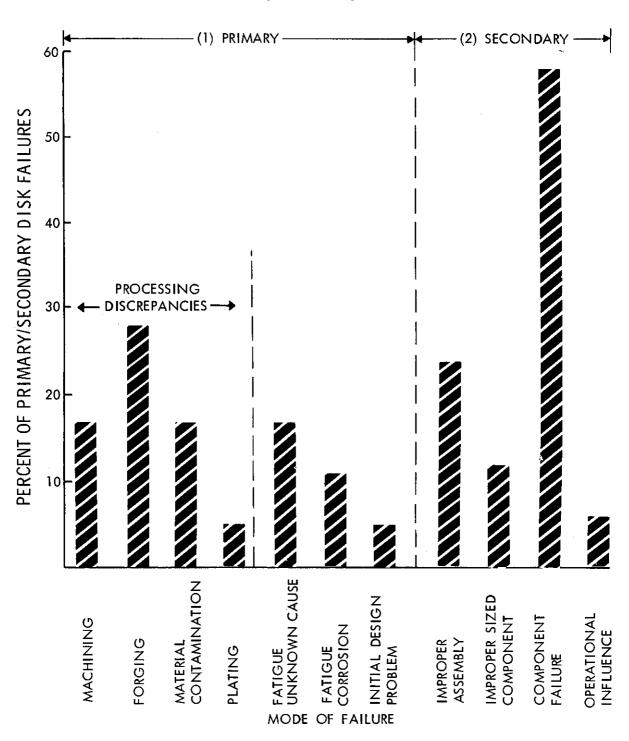


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Percent of Primary Disk Failures 7 28 17 5

#### ANALYSIS OF DISK FAILURE DATA Disk Failure Analytical Tables Failure Mode Data

Secondary Disk Failures Table 3 I FNGNE MODEL -14/PCRAFT NPE Terranomos "(CGMCN (MPROPER) 80 18. S. S. 104TE BCEING 707-321B PAN San Francisco P&WA 1 6/28/65 **AMERICAN** California JT3D-3B Honolulu Rolls-Royce BOEING 2 **BCAC** 11/21/67 707-465 Hawaii Conway P&WA PAN BOEING Agana 3 10/14/69 **AMERICAN** JT3D-3B 707-321 Guam Elk Grove BOEING P&WA **AMERICAN** 4 1/20/73 707-321B Village, Illinois JT3D-3B BOEING Miami P&WA 5 2/24/64 CRIENT 720B Florida JT3D **BCEING** P&WA Nassau 7/7/68 11 727 Bahamas JT8D-I BOEING AIR St. Jean P&WA 17 8/17/70 FRANCE JT9D-3A 747-128 P.Q. Canada San Francisco BOEING **P&WA** 18 9/18/70 **AMERICAN** California 747-131 JT9D-3A **DOUGLAS** P&WA Miami 22 **EASTERN** 6/13/72 DC-8-61 Florida JT3D-3B **DOUGLAS** Chattanooga P&WA 6/9/69 23 EASTERN DC-9-31 JT8D-7 Tennessee **DOUGLAS** Nashville P&WA 12/14/69 24 **ALLEGHENY** JT8D-7 DC-9-31 Tennessee DOUGLAS G.E. Tucson 26 5/2/72 CONTINENTAL CF-6-6D DC-10 Arizona **DOUGLAS** Los Angeles G.E. 7/27/72 27 CONTINENTAL California CF-6-6D DC-10 CONVAIR Yosemite G.E. 10/25/65 33 **AMERICAN** 990 California CJ-805-23 LAKE NORD Morgantown Turbomeca 8/4/66 38 Bastan VI-C West, Virginia CENTRAL <u> 262-A-12</u> Martinsburg Turbomeca LAKE NORD 8/11/66 39 West, Virginia 262-A-12 Bastan VI-C Washington NIHON Rolls-Royce 41 PIEDMONT 6/3/71 YS-II D.C. 542-10 **TOTALS** 4 2 10 Percent of Secondary Disk Failures 24 12|58

The third stage nozzle guide vane retention lugs, blades, and blade tang galling were among the most prevalent areas of failure, with two each occurring in the component failure category.

The only failure that was categorized as operational influence occurred after an attempted relight of a flamed-out windmilling engine after unfeathering the propeller. The failure occurred as a result of unburned fuel continuing to be injected and remaining within the engine, while the engine was windmilling. The relight caused a spontaneous eruption of the unburned fuel which resulted in shrinkage of clearances and subsequent rubbing and burning between rotating and stationary components of the turbine, thus resulting in a turbine disk failure.

In examining the various parameters that have been developed for this study, it is apparent that, except for component failure, the other failures have occurred at similar percentage levels. Thus, no visibly unique disk failure pattern emerged from the results of this study. Rather, these failures tend to be isolated. In the instances where an identifiable cause was found, corrective action was initiated with minimum delay.

#### IV. CONCLUSIONS

Based on this study, engine disk failures have been, and continue to be, a problem since the inception of the jet engine with its high energy internal rotating components.

Compressor disks had a higher rate of failure when compared to fan or turbine disks. Additionally, the distribution between primary and secondary failures is nearly equal. The climb segment of flight has the highest incidence of disk failures. The aircraft damage pattern parameters are relatively uniform, except for the relatively high values associated with fire damage and wing penetration.

In evaluating the primary and secondary failures, the highest-ranking type of failure involves components, such as blade and bearing disintegration.

Although comparative statistical evidence is not yet available to substantiate fully such a finding, it appears that the disk failure problem has not been lessened with the introduction of the latest state-of-the-art engines which power the wide-bodied aircraft. On the other hand, the problem may be more serious because of the greater rotating mass, and, therefore, the greater kinetic energy associated with liberated rotating disk segments of the larger engines.

Federal Aviation Regulations require that compressor and turbine rotor cases be designed to provide for the containment of damage from rotor blade failure (14 CFR 33.19). Turbine rotors also must demonstrate sufficient strength to withstand damage-inducing factors, such as those

which might result from abnormal rotor speeds, temperatures, or vibrations (14 CFR 33.27a). Further, engine control devices and instrumentation must provide reasonable assurance that those engine operating limitations that affect turbine rotor structural integrity will not be exceeded in service (14 CFR 33.27b). Although much design consideration has been given to 14 CFR 33.27, rotor disk fragment containment is a more involved problem. Therefore, if complete containment of these disk fragments is not now feasible, the Safety Board believes, based on the results of this study, that greater attention must be given to the protection of vital aircraft systems such as hydraulic and fire extinguishing systems.

The Safety Board believes that the fail safe design philosophy underlying the design and certification standards of the new wide-bodied aircraft could not be fully applied to the disk failure problem. The physical size of the disk, the size and inherent fragment energy within a liberated disk segment may tend to compromise these standards. The disk failure problem could be one of the few areas in a new wide-bodied aircraft in which a single failure can have catastrophic results for the entire aircraft.

The Safety Board is aware of the efforts of the engine and aircraft manufacturers to alleviate this problem. The Safety Board notes that one commercial airplane manufacturer has identified three possible methods by which the noncontainment hazard could be minimized or hopefully alleviated. These are:

- "1. A continued emphasis be directed by the engine manufacturer, both informally and through specification requirements, to increase substantially the engine rotor burst containment capability. An objective should be full containment of three blades and their included disk serrations.
  - 2. Establish a broader company program to develop a feasible engine fragment containment or deflection barrier. This barrier may or may not be an integral part of the noise suppression additions to the engines.
- 3. Establish a study program to determine the absorption characteristics of existing airplane structure in reducing the disk fragment energies to below critically damaging levels."

The manufacturer indicated that they have determined that over 50 percent of the disk burst failure cases that they studied had fragment energies of less than  $0.3 \times 10^6$  inch pounds. They also indicated that an engine manufacturer has determined that a 14,500- to 16,000-pound thrust turbofan engine fan blade has  $0.18 \times 10^6$  inch pounds fragment energy and that a high pressure turbine blade has  $0.10 \times 10^6$  inch pounds fragment energy. Based on these data, the aircraft manufacturer has postulated that if present engine cases could be stressed to contain at

least three blades and their included disk serrations, rather than one blade as currently designed, a majority of the disk failures that were investigated would have been contained.

If the above achievement could be implemented by the engine manufacturers for the present and future generation jet engines, this would be a monumental step in the forward progression of aviation safety in terms of reducing the hazard potential that is associated with disk failures.

The National Aeronautics and Space Administration is administering a research program which is being carried out by the Naval Air Propulsion Test Center and the Aeroelastic and Structure Research Laboratory of the Massachusetts Institute of Technology. The program deals with protection against rotor disk failures.

The program's objective is to develop design criteria and methods or devices to protect passengers and critical aircraft systems from engine rotor disk failures. The approach used is to conduct experiments to study interaction between rotor fragments and protective devices; develop analytical methods to determine effects of fragment geometry, mass, material energy, etc.; establish feasibility of disk crack detector to prevent rotor disk failure; and evaluate disk designs to increase resistance to crack propagation.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/	JOHN H. REED
	Chairman
/s/	FRANCIS H. McADAMS
	Member
/s/	LOUIS M. THAYER
	Member
/s/	ISABEL A. BURGESS
	Member
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/s/	WILLIAM R. HALEY
	Member

#### APPENDIX

## NATIONAL TRANSPORTATION SAFETY BOARD WASHINGTON, D.C.

ISSUED:

Forwarded to:
Dr. James C. Fletcher
Administrator
National Aeronautics and Space
Administration
Washington, D. C. 20546

SAFETY	RECOMMENDAT	I	ON	(s)	

A-75-16

The National Transportation Safety Board has issued a Special Study, "Turbine Engine Rotor Disk Failures." Forty-one case histories of rotor disk failures which occurred during the period 1962 through early 1973 were analyzed and studied. The study revealed that engine disk failures have been, and will continue to be, a problem of the jet engine with its high energy internal rotating components.

One large aircraft manufacturer has concluded, from its study of 50 disk failures and from data developed by an engine manufacturer regarding fragment energies, that most disk failures investigated would have been contained if engine cases had been stressed to contain at least three blades and their included disk serrations, rather than one blade, as required by current Federal Aviation Regulations.

If the above achievement could be implemented by the engine manufacturers for present and future generation jet engines, the hazard potential associated with disk failures would be reduced.

The Safety Board considers the National Aeronautics and Space Administration's rotor disk failure containment research program a logical step toward developing an effective rotor disk failure containment system. In addition, the Safety Board believes that containment of the three blades and their included disk serrations should be required, and a goal of total disk containment should be pursued.

Accordingly, the National Transportation Safety Board recommends that the National Aeronautics and Space Administration:

Dr. James C. Fletcher

- 2 -

Provide, as soon as possible, from the Rotor Burst Protection Program, technological guidelines for use by the Federal Aviation Administration in establishing a requirement to contain three rotor blades and their included disk serrations or fragments.

We would appreciate being advised of any action you might take as a result of this Safety Recommendation.

REED, Chairman, McADAMS, BURGESS, and HALEY, Members, concurred in the above recommendation. THAYER, Member, did not participate.

John H. Reed

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