STATISTICS ON AIRCRAFT GAS TURBINE ENGINE ROTOR
FAILURES THAT OCCURRED IN (U) NAVAL AIR PROPULSION
CENTER TRENTON NJ PROPULSION ENGINEERING

UNCLASSIFIED  R A DELUCIA ET AL  MAR 87 NAPC-PE-154C  F/G 21/5  NL
MICROCOPY RESOLUTION TEST CHART
Statistics on Aircraft Gas Turbine Engine Rotor Failures that Occurred in U.S. Commercial Aviation During 1981

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Trenton, New Jersey

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Final Report

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This report presents statistical information relating to gas turbine engine rotor failures which occurred during 1981 in commercial aviation service use. The predominant failure involved blade fragments, 83 percent of which were contained. Three disk failures occurred and all were uncontained. Fifty-seven percent of the 136 failures occurred during the takeoff and climb stages of flight.

This service data analysis is prepared on a calendar year basis and published yearly. The data is useful in support of flight safety analysis, proposed regulatory actions, certification standards and cost benefit analysis.
ACKNOWLEDGEMENTS

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- Mr. Bruce Fenton, Project Manager, Engine/Fuel Safety Branch, ACT-320, for his technical assistance.
- New England Region, Burlington, MA for providing verification of the uncontained engine rotor failure occurrences during calendar year 1981.
- Flight Standards National Field Office, Oklahoma City, OK, for providing the basic data used to prepare this report.
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EXECUTIVE SUMMARY

This service data analysis is prepared on a calendar basis and published yearly. The data are useful in support of flight safety analyses, proposed regulatory actions, certification standards and cost benefit analyses. The following statistics are based on gas turbine engine rotor failures that have occurred in U.S. commercial aviation during 1981.

One hundred and thirty-six rotor failures occurred in 1981. These failures accounted for approximately 2.7 percent of the 5095 shutdowns experienced by the U.S. commercial fleet. Rotor fragments were generated in 84 of the failures and, of these 16 were uncontained. This represents an uncontained failure rate of 2.1 per million gas turbine engine powered aircraft flight hours, or 0.8 per million engine operating hours. Approximately 7.5 million and 20.7 million aircraft flight and engine operating hours, respectively, were logged in 1981.

Turbine rotor fragment producing failures were approximately four times greater than that of the compressor rotor fragment producing failures; 62 and 15 respectively, of the total. Fan rotor failures accounted for 7 of the fragment producing failures experienced.

Blade failures were generated in 78 of the rotor failures; 13 of these were uncontained. The remaining 6 fragment generating failures were produced by disk, rim, or seal.

Total uncontained engine failure rates per million engine type flight hours were: turbofan 0.7 and turboprop 1.5. No uncontained rotor failures were reported for turboshaft and turbojet engines in 1981.

Of the 92 known causes of failures (because of the high percentage of unknown causes of rotor failures, the percentages were based on the total number of known causes), the causal factors were: (1) Secondary Causes 38 (41.3 percent); (2) Foreign Object Damage 35 (38.0 percent); (3) Design and Life Prediction Problems 16 (17.4 percent); and (4) Other 3 (3.3 percent). Seventy-eight (57.4 percent) of the 136 rotor failures occurred during the takeoff and climb stages of flight. Fifty-two (61.9 percent) of the 84 rotor fragment producing failures and 9 (56.3 percent) of the 16 uncontained rotor failures occurred during these same stages of flight.

CONCLUSION:

Although the incidence of engine rotor failures producing fragments has declined 20 percent (84 in 1981 compared to a 1975 through 1980 average of 105), the uncontained engine rotor failure rate has remained constant (16 in 1981 compared to a 1975 through 1980 average of 16).
INTRODUCTION

This report is sponsored by the Department of Transportation (DOT), Federal Aviation Administration (FAA), Technical Center, Engine/Fuel Safety Branch, located at the Atlantic City International Airport, New Jersey.

This service data analysis is prepared on a calendar year basis and published yearly. The data are useful in support of flight safety analyses, proposed regulatory actions, certification standards and cost benefit analyses.

The intent and purpose of this report is to present data as objectively as possible on rotor failure occurrences in U.S. commercial aviation.

Presented in this report are statistics on gas turbine engine failures that have occurred in U.S. commercial aviation during 1981. These statistics are based on data compiled from the Flight Standards Service Difficulty Reports that were published by the DOT, FAA. Independent cross checks to other accident data sources, such as the FAA New England Region Directorate, were made to substantiate the exact nature of an engine failure incident (i.e., contained or uncontained). The compiled data were analyzed to establish:

1. The incidence of rotor failures and the incidence of contained and uncontained rotor fragments; (An uncontained rotor failure is defined as a rotor failure that produces fragments which penetrate and escape the confines of the engine casing).
2. The distribution of rotor failures with respect to engine rotor components, i.e., fan, compressor or turbine rotors and their rotating attachments or appendages such as spacers and seals.
3. The type of rotor fragment (disk, rim or blade) typically generated at failure.
4. The cause of failure.
5. The engines involved by model (JT8D, JT9D, etc.) and by engine type (turbojet, turboshaft/turboprop, and turbofan).
6. The flight conditions at the time of failure.
7. Engine failure rate according to engine fleet hours.

RESULTS

1. The data used for analysis are contained in appendix A. The results of these analyses are shown in Figures 1 through 8.

   a. Figure 1 shows that 136 rotor failures occurred in 1981. These rotor failures accounted for approximately 2.7 percent of the 5095 shutdowns experienced by the gas turbine powered U.S. commercial aircraft fleet during 1981. Rotor fragments were generated in 84 of the failures experienced and, of these, 16 (19.0 percent of the fragment producing failures) were uncontained. This represents an uncontained failure rate of 2.1 per million gas turbine engine powered aircraft flight hours, or 0.8 per million engine operating hours. Approximately 7.5 million and 20.7 million aircraft flight and engine operating hours, respectively, were logged by the U.S. commercial aviation fleet in 1981. Gas turbine engine fleet
operating hours according to the number and type of engines in use is shown in Figure 2.

b. Figure 3 shows the distribution of rotor failures that produced fragments according to the engine component involved (fan, compressor, turbine), the types of fragments that were generated, and the percentage of uncontained failures according to the type of fragment generated. These data indicate that:

1. The incidence of turbine rotor fragment producing failures was approximately four times greater than that of the compressor rotor fragment producing failures; these corresponded to 62 (73.8 percent) and 15 (17.9 percent), respectively, of the total number of rotor failures. Fan rotor failures accounted for 7 (8.3 percent) of the fragment producing failures experienced.

2. Blade fragments were generated in 78 (92.9 percent) of the rotor failures; 13 (16.7 percent) of these were uncontained. The remaining 6 (7.1 percent) rotor fragment failures were produced by disk, rim, or seal.

c. Figure 4 shows the rotor failure distribution among the engine models that were affected, and the total number of the models in use.

d. Figures 5, 6, and 7 illustrate engine failure rates per million engine flight hours according to engine model, engine type, and containment condition. The total engine failure rate per million engine type flight hours are: turbofan 3.7, turboprop 11.8, turboshaft 34.2, and turbojet 27.0. Total uncontained engine failure rates per million engine type flight hours were: turbofan 0.7 and turboprop 1.5. No uncontained rotor failures were reported for turboshaft and turbojet engines in 1981.

The data used to generate figures 5, 6, and 7 is contained in appendix B, page B-1.

e. Figure 8 shows what caused the rotor failures to occur. Of the 92 known causes of failure (because of the high percentage of unknown causes of rotor failure, the percentages were based on the total number of known causes), the causal factors were: (1) Secondary Causes 38 (41.3 percent); (2) Foreign Object Damage 35 (38.0 percent); (3) Design and Life Prediction Problems 16 (17.4 percent); and Other 3 (3.3 percent).

f. Figure 9 indicates the flight conditions that existed when the various rotor failures occurred. Seventy-eight (57.4 percent) of the 136 rotor failures occurred during the takeoff and climb stages of flight. Fifty-two (61.9 percent) of the rotor fragment producing failures and 9 (56.3 percent) of the uncontained rotor failures occurred during these same stages of flight. The highest number of uncontained rotor failures, 7 (43.8 percent) was experienced during climb.

g. Figure 10 is a cumulative tabulation that describes the distribution of uncontained rotor failures according to fragment type, engine component involved, cause category, and flight condition (takeoff and climb are defined as "high power," all other conditions are defined as "low power") for the years 1976 through 1981. This figure is expanded yearly to include all subsequent uncontained rotor failures. These data indicate that: for "secondary causes," the number of uncontained failures was approximately 8 times greater at "high" power than "low" power (namely 23 and 3). For "Design and Life Prediction Problems" the number of
"high" power uncontained failures was approximately three times greater than "low" power (namely 19 and 6); and for "Foreign Object Damage" the number of uncontained failures was six times greater at "high" power than "low" power (namely 6 and 1). This tabulation also indicates that of the 95 total uncontained incidences, blade failures accounted for 75.8 percent, disks failures 10.5 percent, rim failures 7.4 percent, and seal/spacer failures 6.3 percent.

h. Figure 11 shows the annual incidence of uncontained rotor failures in commercial aviation for the years 1962 through 1981. During 1981, the incidence of uncontained rotor failure increased by five over the previous year, 1980. Over the past six years, 1976 through 1981, an average of 16 uncontained rotor failures per year have occurred. During the same time period, the rate of uncontained rotor failures has remained relatively constant at an average of approximately one per million engine operating hours.

The high incidences of uncontained rotor failures in calendar years 1967 through 1973 (except for 1968) were probably due to the introduction of newly developed engines entering the commercial aviation fleet such as the JT9D and CF6 engines.

Structural life prediction and verification is being improved by the increased use of spin chamber testing by government and industry as a means of obtaining failure data for statistically significant samples. In addition, increased development and application of high sensitivity non-destructive inspection methods, should increase the probability of cracks being detected prior to failure. The capability to reduce the causes of failures from secondary effects, also is being addressed through technology development programs. However, causes due to foreign object damage still appear to be beyond the control or scope of present technology.

CONCLUSION

Although the incidence of engine rotor failures producing fragments has declined 20 percent (84 in 1981 compared to a 1975 through 1980 average of 105), the uncontained engine rotor failures has remained constant (16 in 1981 compared to a 1975 through 1980 average of 16).
FIGURE 1: INCIDENCE OF ENGINE ROTOR FAILURE IN U. S. COMMERCIAL AVIATION 1981
FIGURE 2: GAS TURBINE ENGINE FLEET OPERATING HOURS IN U.S. COMMERCIAL AVIATION ACCORDING TO NUMBER OF ENGINES IN SERVICE - 1981

TOTAL NO. OF ENGINES IN USE

FLEET ENGINE HOURS X 10^6

NOTE: (1) DERIVED FROM YEARLY AVERAGE OF AIRCRAFT IN USE AT END OF EACH MONTH
## Table: Type of Fragment Generated

<table>
<thead>
<tr>
<th>ENGINE ROTOR COMPONENT</th>
<th>DISK</th>
<th>RIM</th>
<th>BLADE</th>
<th>SEAL</th>
<th>TOTAL</th>
</tr>
</thead>
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<tr>
<td></td>
<td>TF</td>
<td>UCF</td>
<td>TF</td>
<td>UCF</td>
<td>TF</td>
</tr>
<tr>
<td>Fan</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Compressor</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Turbine</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>59</td>
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<tr>
<td>Total</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>78</td>
</tr>
</tbody>
</table>

(1) Failures that produced fragments
TF - Total failures
UCF - Uncontained failures

## Figure 3: Component and Fragment Type Distributions for Contained and Uncontained Rotor Engine Failures

(Failures that produced fragments) - 1981
ENGINE TYPE

- PW JT8D
- PW JT9D
- PW PT6A
- PW JT7D
- ALL 501
- GE CF6
- RR RB211
- ARCH TPE331
- RR DART
- GE CF7
- PW JT4A
- RR SPEY
- TMCA BASTAN
- TMCA AST14
- RR TUNE
- PW JT150
- RR AVON
- ARCH TFE731
- ALL 250C

% AFFECTED

<table>
<thead>
<tr>
<th>ENGINE TYPE</th>
<th>NF</th>
<th>NE</th>
<th>%</th>
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<td>PW JT9D</td>
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<td>0.6</td>
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<td>1.3</td>
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<tr>
<td>ALL 501</td>
<td>0</td>
<td>11</td>
<td>1.1</td>
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<td>GE CF6</td>
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<td>1</td>
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<tr>
<td>RR RB211</td>
<td>0</td>
<td>12</td>
<td>4.0</td>
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<tr>
<td>ARCH TPE331</td>
<td>0</td>
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<td>2.7</td>
</tr>
<tr>
<td>RR DART</td>
<td>0</td>
<td>3</td>
<td>1.6</td>
</tr>
<tr>
<td>GE CF7</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>PW JT4A</td>
<td>0</td>
<td>7</td>
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</tr>
<tr>
<td>RR SPEY</td>
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<td>10</td>
<td>0.0</td>
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<td>TMCA BASTAN</td>
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<td>ARCH TFE731</td>
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<tr>
<td>ALL 250C</td>
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TOTAL NO. OF ENGINES IN USE (NE)(2)

NO. OF ROTOR FAILURES (NF)(1)

NOTES:

(1) FAILURES THAT PRODUCED FRAGMENTS
(2) YEARLY AVG. OF ENGINES IN USE AT END OF EACH MONTH
(3) SEAL/SPACER FAILURES INCLUDED IN DISK/RIM COMPILATION

FIGURE 4: THE INCIDENCE OF ENGINE ROTOR FAILURE IN U.S. COMMERCIAL AVIATION ACCORDING TO ENGINE TYPE AFFECTED - 1981
LIIZO
LZ4cc2~zW-w
d3ujWxr4-iWo
Zag-
UOZI-CMZ1Au
UOM-Q4zwo

TABLE
ENGINE MODEL
JT8D
JT9D
CF6
RB211
SPEY
CF7
JT15D
TFE731
TOTAL
ENGINE FLIGHT HOURS X 10^6
11.5
1.64
2.13
1.34
0.944
0.140
0.063
0.006
0.001
17.77

FIGURE 5: TURBOFAN ENGINE FAILURE RATE ACCORDING TO ENGINE MODEL - 1981
Figure 6: Turboprop Engine Failure Rate According to Engine Model - 1981
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<th>ENGINE MODEL</th>
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<th>250C</th>
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<th>JT4A</th>
<th>AVON</th>
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<tr>
<td>ENGINE FLIGHT HOURS x 10^5</td>
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**Figure 7:** Turboshaft and Turbojet engine failure rate according to engine model - 1981.
FIGURE 8: ENGINE ROTOR FAILURE CAUSE CATEGORIES - 1981
FIGURE 9: FLIGHT CONDITION AT ENGINE ROTOR FAILURE - 1981
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<th>ENGINE ROTOR COMPONENT</th>
<th>DESIGN/LITE PREDICTION PROBLEMS</th>
<th>SECONDARY CAUSES</th>
<th>FOREIGN OBJECT DAMAGE</th>
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<td>HI</td>
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<td>0</td>
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(1) TAKE OFF AND CLIMB ARE DEFINED AS "HIGH POWER" AND ALL OTHER CONDITIONS ARE DEFINED AS "LOW POWER".

**FIGURE 10: UNCONTAINED ENGINE ROTOR FAILURE DISTRIBUTIONS**
Figure 11: The incidence of uncontained engine rotor failure in U.S. commercial aviation 1962 - 1981.
APPENDIX A

Data of Engine Rotor Failures in U. S. Commercial Aviation for 1981. Compiled from the Federal Aviation Administration Service Difficulty Reports.

DATA COMPILATION KEY

Component Code:
- F - Fan
- C - Compressor
- T - Turbine

Fragment Type Code:
- D - Disk
- R - Rim
- B - Blade
- S - Seal
- N - None

Cause Code:
- 1 - Design and Life Prediction Problems
- 2 - Secondary Causes
- 3 - Foreign Object Damage
- 4 - Quality Control
- 5 - Operational
- 6 - Assembly and Inspection Error
- 7 - Unknown

Containment Condition Code:
- C - Contained
- NC - Not Contained
- N - No Fragments Generated

Flight Condition Code:
- 1 - Insp/Maint
- 2 - Taxi/Grnd Hdl
- 3 - Takeoff
- 4 - Climb
- 5 - Cruise
- 6 - Descent
- 7 - Approach
- 8 - Landing
- 9 - Hovering
- 10 - Unknown
<table>
<thead>
<tr>
<th>SUB NO.</th>
<th>SUBMITTER</th>
<th>AIRCRAFT</th>
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| Northwestern University (1)    | Director DuCentre Exp DE LA (1) |
| Trisnet Repository             | Navigation Aerineene         |
| Transportation Center Library  | 941 Orly, France             |
| Evanston, ILL 60201            |                                 |

| ANE-40 (2)                     | ACT-61A (2)                    |
| ASO-52C4 (2)                   | AAL-400 (2)                    |
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| ADL-32 North (1)               | APM-1 (1)                      |
| AES-3 (1)                      | APA-300 (1)                    |
| ANM-60 (2)                     | AGL-60 (2)                     |
FAA, Chief, Civil Aviation Assistance Group (1)
Madrid, Spain
c/o American Embassy
APO-New York 09285-0001

Dick Tobiason (1)
ATA of America
1709 New York Avenue, NW
Washington, DC 20006

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APPENDIX C

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DOT/Federal Aviation Administration Alaskan Region (2)
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<th>Name</th>
<th>Affiliation</th>
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<tr>
<td>Dr. Robert C. Oliver</td>
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<tr>
<td>Mr. George Opdyke</td>
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<td>550 South Main Street, Stratford, CT 06497</td>
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<tr>
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</tr>
<tr>
<td>Mr. Roy E. Pardue</td>
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<tr>
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<tr>
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<td>C. C. Randall, P.E.</td>
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<td>D72-47 Zone 418, Marietta, GA 30063</td>
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<tr>
<td>M. Rippen</td>
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<td>Mr. Dick Stutz</td>
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<td>Mr. A. F. Taylor</td>
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<td>Cranfield, Bedford, MK 43 OAL, ENGLAND</td>
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<td>Dr. F. F. Tolle</td>
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<td>P.O. Box 3707, M/S 4152, Seattle, WA 98124</td>
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<td>M. Trimble</td>
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Naval Air Systems Command  
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Department of the Navy  
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Mr. Barry Scott  
Commander  
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United Airlines, Inc.
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P.O. Box 66100
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400 Main Street
East Hartford, CT 06108

Piper Aircraft Corporation
ATTN: Mr. Walter C. Jamouneau
Chief Engineer
Lock Haven, PA 17745

Rolls-Royce Limited
ATTN: D. McLean, Chief Design Engineer
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6633 Canoga Avenue
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Redhill, Surrey
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Hawker Siddley Aircraft
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Hawsidair, Hatfield
ENGLAND

Ministry of Defense
W. J. Moschini, Engines T1, Room 151
St. Giles Court 1-13
St. Giles High St., London WC2H 8LD
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Picatinny Arsenal
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