SAND2012-6766C

Quantitative Assessment of Crack Detection in Aerospace Engine Disks using Acoustic Thermography Inspection

38th Conference on Quantitative Nondestructive Evaluation

July 18,2012

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Presentation Outline

- **Siemens Acoustic Thermography System**
- **Jet Engine Disk Specimens**
- **Sonic IR Inspection Process**
- **Sonic IR Inspection Results**
- **Reliability Evaluation**
- **Recommendations for Acceptable Inspections**

Acknowledgements

Delta Air Lines Technical Operations provided engine disks.
Florida Turbine Technologies, Inc. performed defect fabrication on disks.
Siemens Power Generation, Inc. was funded through the FAA BAA-08-004.
Sandia National Laboratories was funded through the FAA Technical Center proposal 064070723. need contractual statement
Steve Cargill and Jon Bartos provided independent expert consultation.

Capability Evaluation at Sandia National Laboratories Nov. 7-18, 2011

Siemens SIEMAT® Acoustic Thermography System

Siemens Power Generation Inc (SPG) conducted a two-year Cost Reimbursable contract to demonstrate to the Federal Aviation Administration the applicability of the Siemens Acoustic Thermography (SIEMAT®) nondestructive evaluation (NDE) technology in response to Federal Aviation Administration BAA-08-004.

Several acquired disks were inspected with the system and the system was demonstrated in a double blind study at the Airworthiness Assurance NDI Validation Center (AANC).

SIEMAT® System Components

- FLIR SE6100 IR Camera
- Branson UT Welding System 20 kHz
- Siemens SInE Software
- Integrated Pneumatic Part Holder Table
- Modified horn for radial excitation (left) and SIEMAT system configuration (right) for inspecting JT8D disks

Jet Engine Disk Specimen Sets

- FAA funded program at the Sandia Airworthiness Assurance NDI Validation Center (AANC)
- Support development and implementation of improved inspections of jet engine components
- Retired disks collected from industry (especially Delta Air Lines)
- Characterization of disks was performed
- In certain cases cracks were grown to simulate in-service defects
- Used for performing quantitative evaluation of inspection technologies.

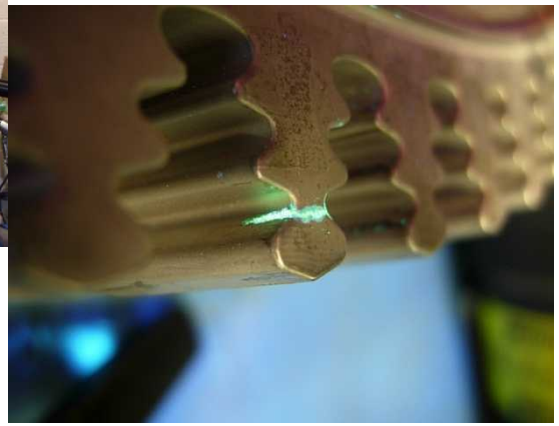
Jet Engine Disk Specimen Sets

- Commercial Propulsion Engine Disks
  - Pratt & Whitney JT8D Stage 2 Turbine Disks
  - Steel Alloy
  - Total of 12 disks available with 3 used in this work.

- Commercial Auxiliary Power Unit Engine Disks
  - Honeywell APU 2nd Stage Turbine Disks
  - Nickel Alloy
  - Total of 40 disks available with 6 used in this work.

Pratt & Whitney JT8D Stage 2 Turbine Disks

- Retired at end of service life with no inspection at Delta.
- Characterized by fluorescent penetrant and eddy current inspection
  - FPI Method D, Level 4
  - ET High Frequency (1-2 MHz) Small Diameter Probe
- One disk had cracks Installed in 19 fir tree slots.
- Two other disks had one each naturally occurring cracks.



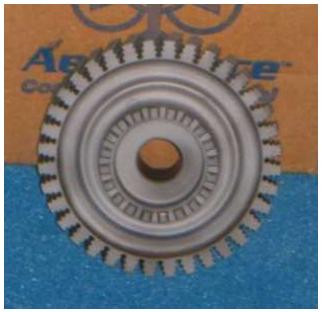
FABRICATED CRACKS

NATURAL CRACKS

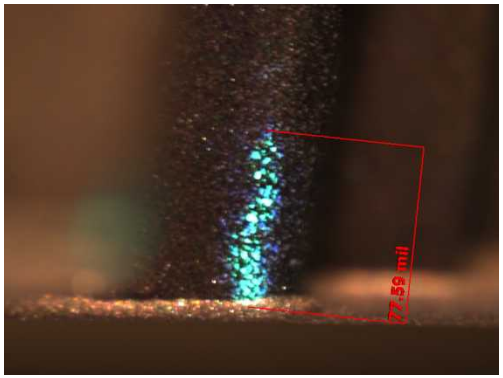
Pratt & Whitney JT8D Stage 2 Turbine Disks Defect Distribution

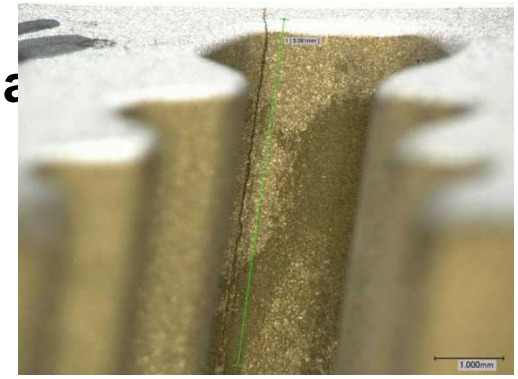
Disk SN	FPI Top (in)	FPI Leading (in)	FPI Trailing (in)	Note
1		0.100		Natural
2		0.070		Natural
3	0.160	0.160	0.270	Fabricated
3	0.118	0.305		
3	0.141		0.202	
3	0.085		0.194	
3	0.080		0.136	
3	0.103		0.154	
3	0.154	0.446	0.267	
3	0.155		0.111	
3	0.051		0.148	
3	0.137		0.197	
3	0.044		0.052	
3	0.067	0.104		
3	0.082	0.151		
3	0.102	0.147		
3	0.020	0.062		
3	0.217	0.308		
3	0.190	0.020	0.342	
3	0.160	0.244	0.438	
3	0.139	0.108		

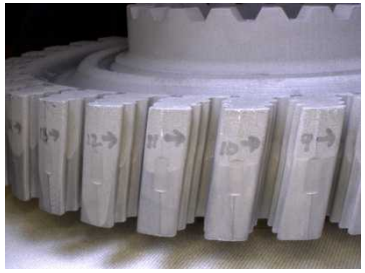
Honeywell APU 2nd Stage Turbine Disks



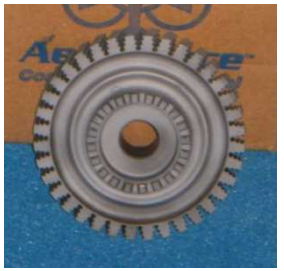
- Retired at end of service life with no inspection at Delta.
- Characterized by fluorescent penetrant inspection
  - FPI Method B, Level 4
- Post-inspection etch and 50X optical microscope crack length measurement by Sandia Metallography Laboratory provided destructive defect characterization.
- All six disks had naturally occurring cracks in fir tree slots.







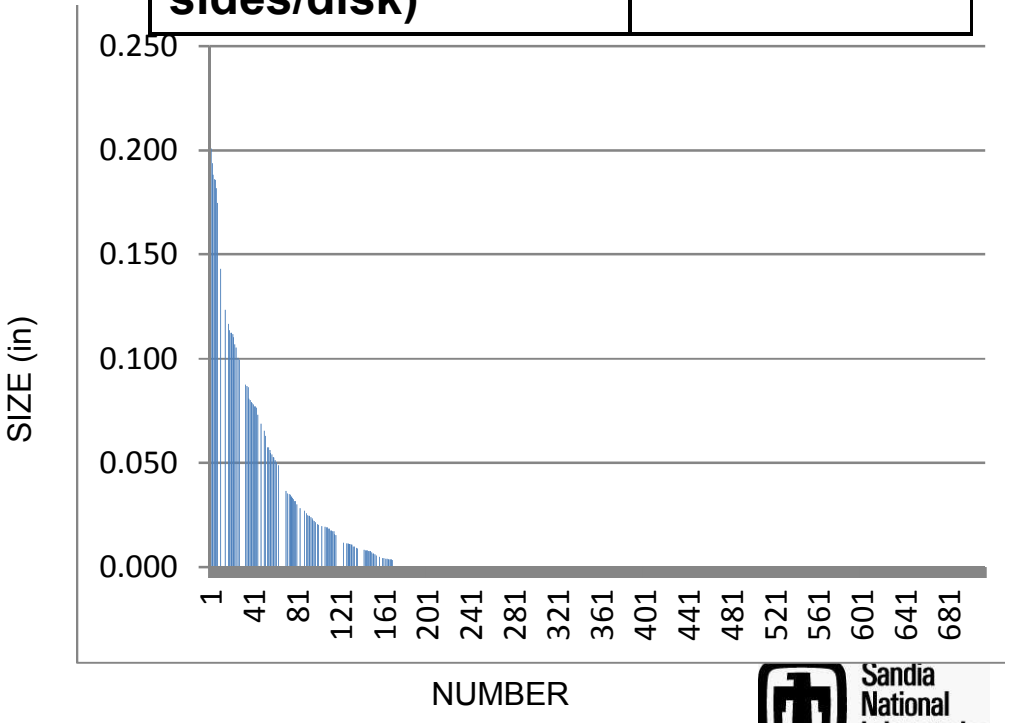
Honeywell APU 2nd Stage Turbine Disks Defect Distribution



CRACK SUMMARY

Total Number of Cracked Slots in Six Disks	119
Maximum Crack Length (in)	0.202
Minimum Crack Length (in)	0.004
Number of Slots with Multiple Cracks	32
Total Number of Cracks	167

Total Number of Slots in Six Disks (36 slots/disk)	216
Number of Inspection Sites (2 sides/disk)	432



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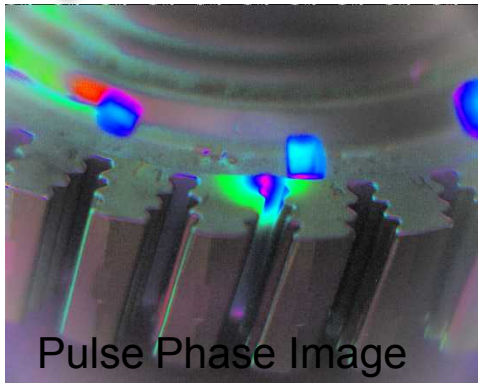
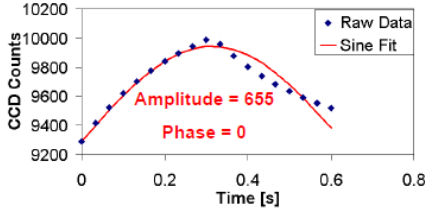
Sonic IR Inspection Process
Radial Excitation

Sonic IR Inspection Process
Axial Excitation

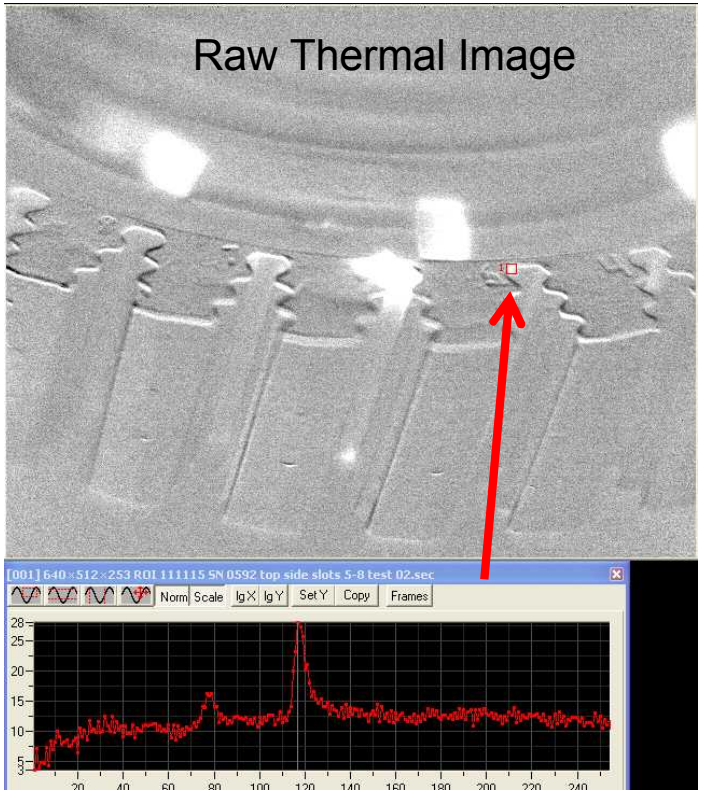
Sonic IR Inspection Process
Call Thresholds and Pulse Phase Analysis



- **Call thresholds:** **50 counts for JT8D disks**
  34 counts for APU disks.
- **Counts were averaged over an 8x8 pixel array spot selected by the inspector from the raw thermal image.**



Steps in Pulse-Phase analysis:
1) Sequence of images is acquired
2) Each pixels counts vs. time curve is fit with a Sine wave
Counts = Amplitude*Sin(Phase*time)
3) Result of the fit for each pixel are encoded in a color image. Phase is Hue and Amplitude is Saturation. Color palette is set by the inspector.
4) The result is overlaid on the live image of the part or first frame of the IR sequence.



time-Temperature Plot

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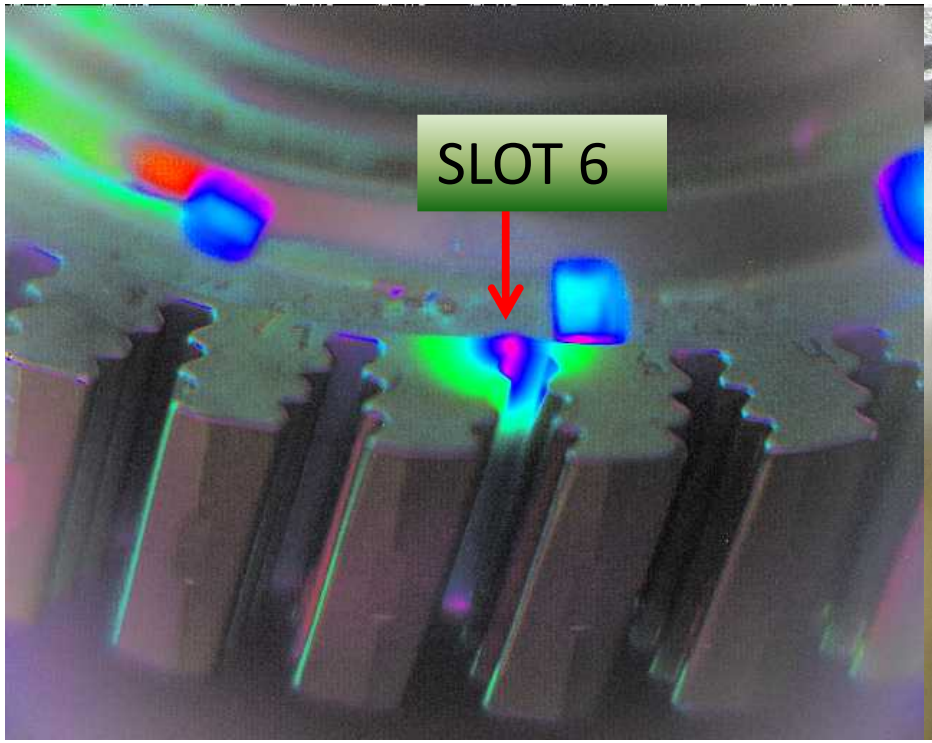
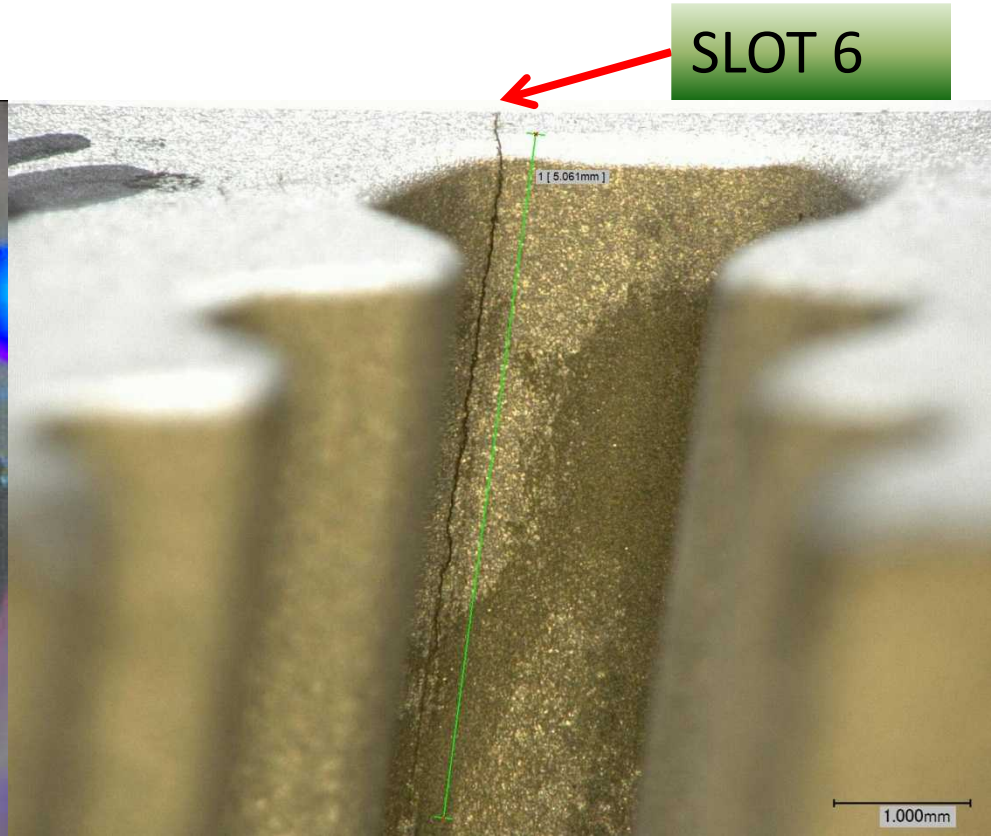
Sonic IR Inspection Process
Pulse Phase Analysis and Thresholds





Counts: 4204 Energy: 144J
Counts exceeds threshold of 34
Crack Called

Disk 0592 Slot 6 Top
Length =.202”

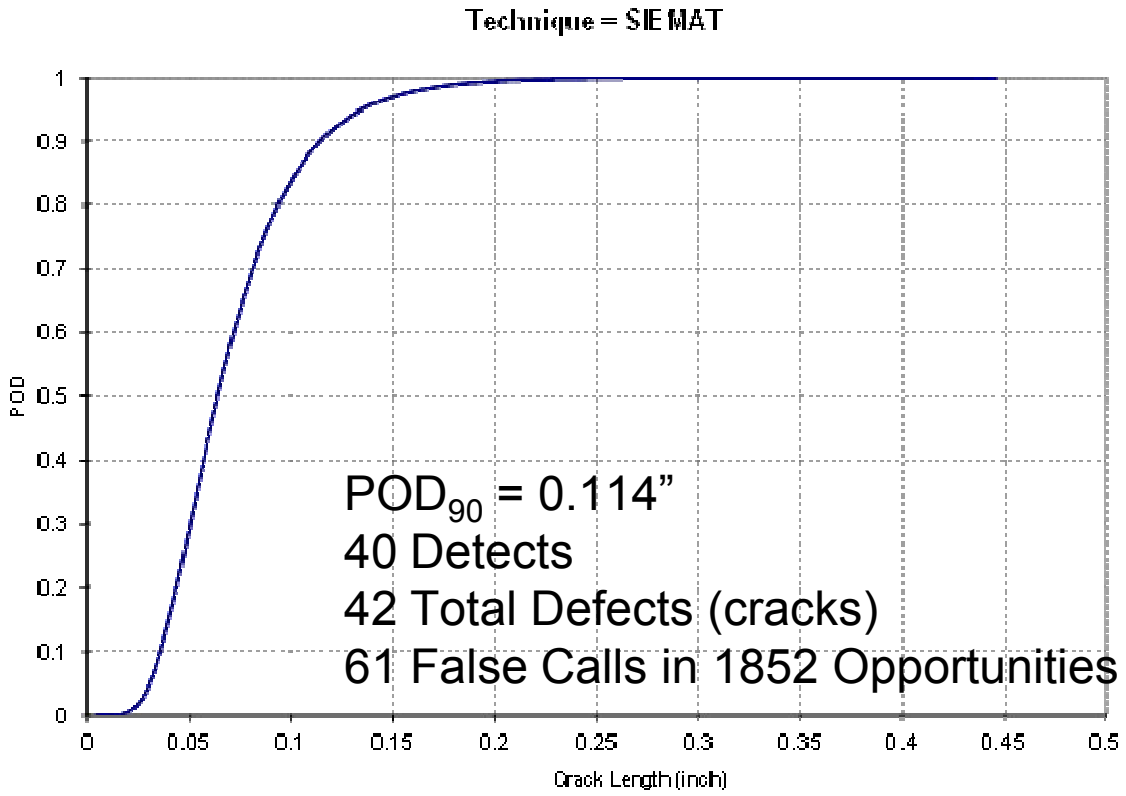
Sonic IR Inspection Results
Pratt & Whitney JT8D Stage 2 Turbine Disks

Disk SN	Note	Defects/ Disk	Cracked Slots/ Disk	Calls/ Disk	Largest Missed	Smallest Detected	False Call/ Opportunity
1	Natural	1	1	0	0.07	na	50/935
2	Natural	1	1	1	na	0.1	11/935
3	Fabricated	42	19	40	0.062	0.044	0/917

Sonic IR Inspection Results
Pratt & Whitney JT8D Stage 2 Turbine Disks

Disk SN	FPI Top (in)	FPI Leading (in)	FPI Trailing (in)	Sonic IR Counts	Sonic IR Energy (J)	Sonic IR Hit/Miss	Note
2		0.070				0	Natural
1		0.100		373	1104	1	Natural
3	0.160	0.160	0.270	9126	1090	1	Fabricated
3	0.118	0.305		520	960	1	
3	0.141		0.202	140	960	1	
3	0.085		0.194	495	874	1	
3	0.080		0.136	430	874	1	
3	0.103		0.154	95	893	1	
3	0.154	0.446	0.267	1689	893	1	
3	0.155		0.111	80	870	1	
3	0.137		0.197	363	963	1	
3	0.051		0.148	273	963	1	
3	0.082	0.151		155	963	1	
3	0.067	0.104		97	963	1	
3	0.044		0.052	NA	NA	1	
3	0.102	0.147		NA	NA	1	
3	0.020	0.062		34	NA	0	
3	0.217	0.308		1687	988	1	
3	0.190	0.020	0.342	86	1227	1	
3	0.160	0.244	0.438	11550	1128	1	
3	0.139	0.108		909	1073	1	

Sonic IR Inspection Reliability Curve
Pratt & Whitney JT8D Stage 2 Turbine Disks



POD calculated using Spencer’s Multi-Flaw Model (which takes into account the possibility of more than one defect at each independent inspection location) with a 2-parameter probit model fit of hit/miss data.

Sonic IR Inspection Results
Honeywell APU 2nd Stage Turbine Disks

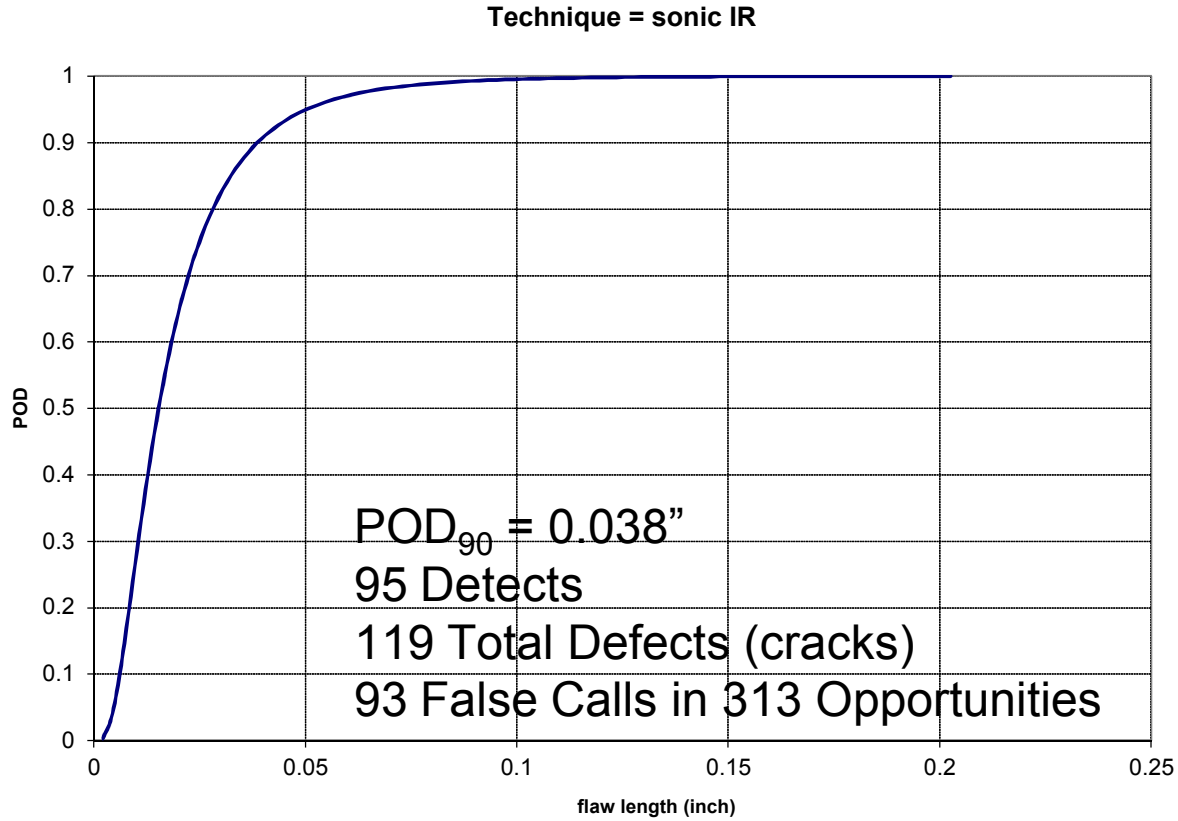
Disk SN	Cracks/ Disk	Cracked Slots/ Disk	Calls/ Disk	Largest Missed	Smallest Detected
592	11	9	3	0.02	0.112
1146	39	36	35	0.02	0.019
1435	22	19	16	0.022	0.011
2328	31	23	15	0.037	0.011
2666	10	8	1	0.025	0.114
2743	31	25	25	na	0.006

Back Side False Calls

Cause for further investigation of disks by a second etching and 50X optical microscopic review. Few additional cracks found.

Disk Number	Number of Opportunities	Number of False Calls	False Call Rate
592	32	0	0%
1146	25	10	40%
1435	34	32	94%
2328	27	1	4%
2666	34	14	44%
2743	32	24	75%

Sonic IR Inspection Reliability Curve
Honeywell APU 2nd Stage Turbine Disks



POD calculated using Spencer’s Multi-Flaw Model (which takes into account the possibility of more than one defect at each independent inspection location) with a 2-parameter probit model fit of hit/miss data.

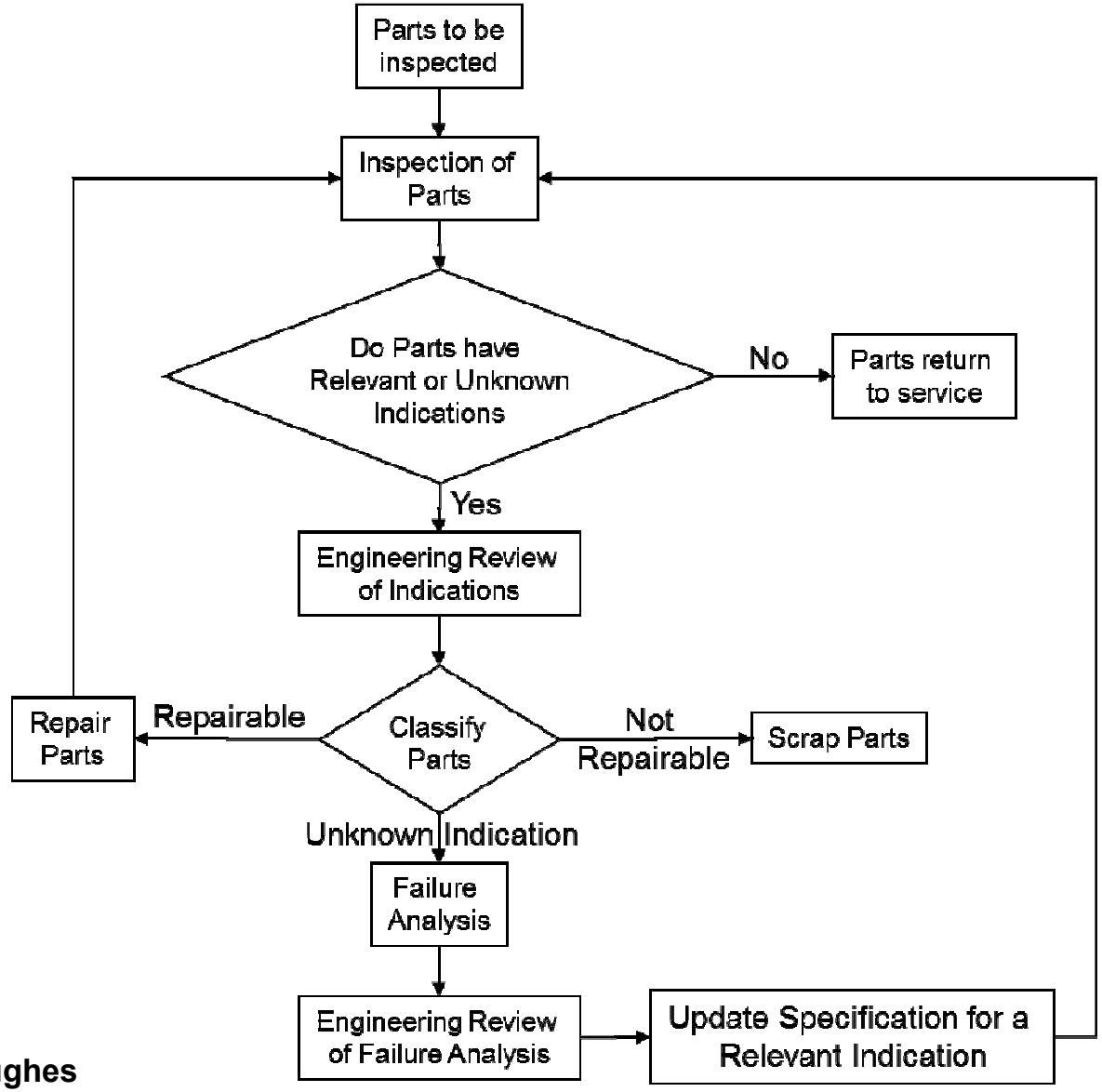
Whole-Disk Inspections for Initial Screening of APU Disks

- 40 APU Disks Inspected
- Generally good agreement with FPI results for larger defects
- Preliminary Screening Only
  - Defective disks show up immediately
  - Non-Defective disks warrant additional complimentary inspections
  - Increase operator efficiency, especially for high part volume operations

Recommendations for Acceptable Inspections

- Special measurements, precautions and attention to component response is warranted
  - proper vibrational modes at regions of interest provide most sensitive inspections
  - Minimizing damage potential must also be considered
- Design Engineers and NDE Specialists must collaborate during process development
  - DO NOT OVER ENERGIZE PART!
  - Design inspection to properly energize part
  - Use proper interface material between part & horn tip
  - Prevent metal to metal contact
- Many of our conclusions are in agreement with recommendations discussed in a draft ASTM Standard
  - Standard Practice/Guide for Crack Detection using Sonic Infrared Thermography

Resolution Process for Indications



Conclusions

- Siemens SIEMAT acoustic thermography inspection is capable of inspecting aerospace jet engine disks.
- The SIEMAT system was easy to set up and operate and requires minimal utilities, safety considerations and space.
- Determining the correct detection threshold values, horn to part pressure, and excitation energy levels require access to a large number of parts that can be fully characterized for defects.
- Raw image/movie analysis, pulse phase analysis, and time temperature plot methods were used for defect identification.
- PW JT8D steel turbine disks POD_{90} = 0.114 inches (not full 1823)
- HW APU nickel alloy turbine disks POD_{90} = 0.038 inches
- High false call rates were observed in both JT8D and APU disk inspections, yet some individual parts exhibited almost none.
- Inspections of whole disks in a single image per side was demonstrated
- Interface material and energization research for part protection, and a false call resolution process is required for each new part application.