DEPOSITION, EROSION AND CORROSION OF BIOMASS PYROLYSIS FUELS FOR INDUSTRIAL GAS TURBINES

by

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for

Gas Turbine Materials and Component Lifing

Challenges and Opportunities in Future Gas Turbine Development and Operation

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OUTLINE

- Introduction
- Erosion
- Deposition
- Corrosion – Hot Corrosion
- Fuel Requirements and Alternate Fuels
- Materials and Coatings
- Life Prediction
- Summary

INTRODUCTION

OBJECTIVES

- Background of DEC -- Deposition, Erosion and Corrosion
- Discuss Fuel Requirements and Alternate Fuels
- Discuss Impact of Corrosion on Materials and Coatings
- Briefly Discuss Life Prediction for DEC and Life Management Systems

TALK BASED UPON

"Impact Study on the Use of Biomass-Derived Fuels in Gas Turbines for Power Generation," Final Report prepared for the National Renewable Energy Laboratory under Contract AV-2-12148-1, June 1993

"Fuel-Specification Considerations For Biomass Pyrolysis Liquids to be Used in Stationary Gas Turbines"
ASME Paper 96-GT-406

Co-Author Dr. Clifford A. Moses

EROSION

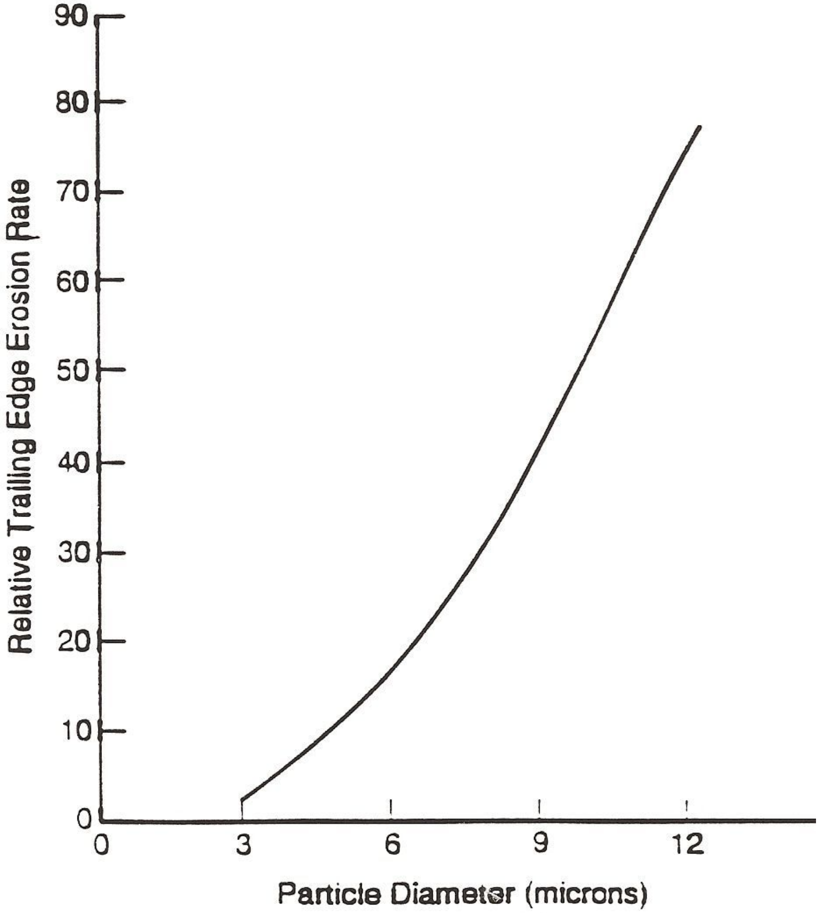
EROSION

Erosion is the Removal of Metal by Abrasive Particles in the Gas Stream.

It is Controlled by:

- Hardness of Abrasive Particles
- Size and Shape of Abrasive Particles
- Number of Abrasive Particles
- Angle of Attack
  - Have all angles of interest in the turbine section

EROSION OF A TRAILING EDGE VANE



50 MW Gas Turbine

- Can Reduce Performance by Enlarging the Flow Path
- Can Lead to Cracking Due to Thinning and Grooving

EROSION OF COATINGS

Erosion Can Remove Protective Coatings

– Corrosion – Oxidation Coatings

– Thermal Barrier Coatings

Results in Loss of Protection

DEPOSITION

DEPOSITION

Deposition Is the Buildup of
Foreign Material on the Airfoils

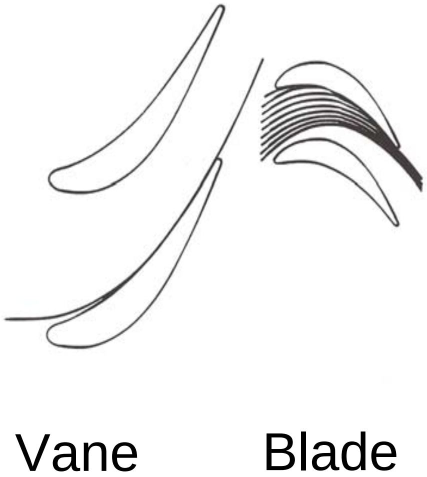
It is Controlled by:

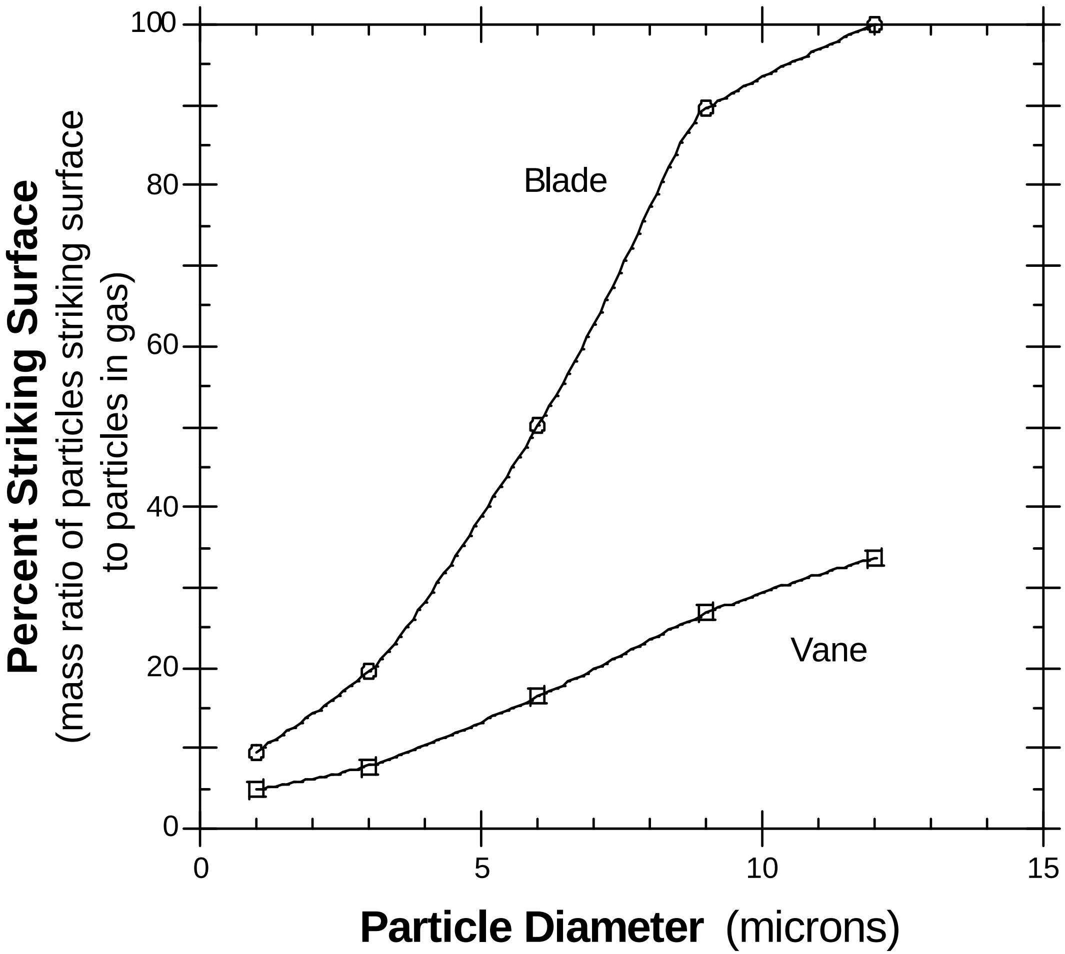
- Stickiness of Particles
- Size of Particles
- Number of Particles
- Angle of Attack
  - Have all angles of interest in the turbine section

DEPOSITION

Sticking vs. Particle Diameter

Particle Trajectories





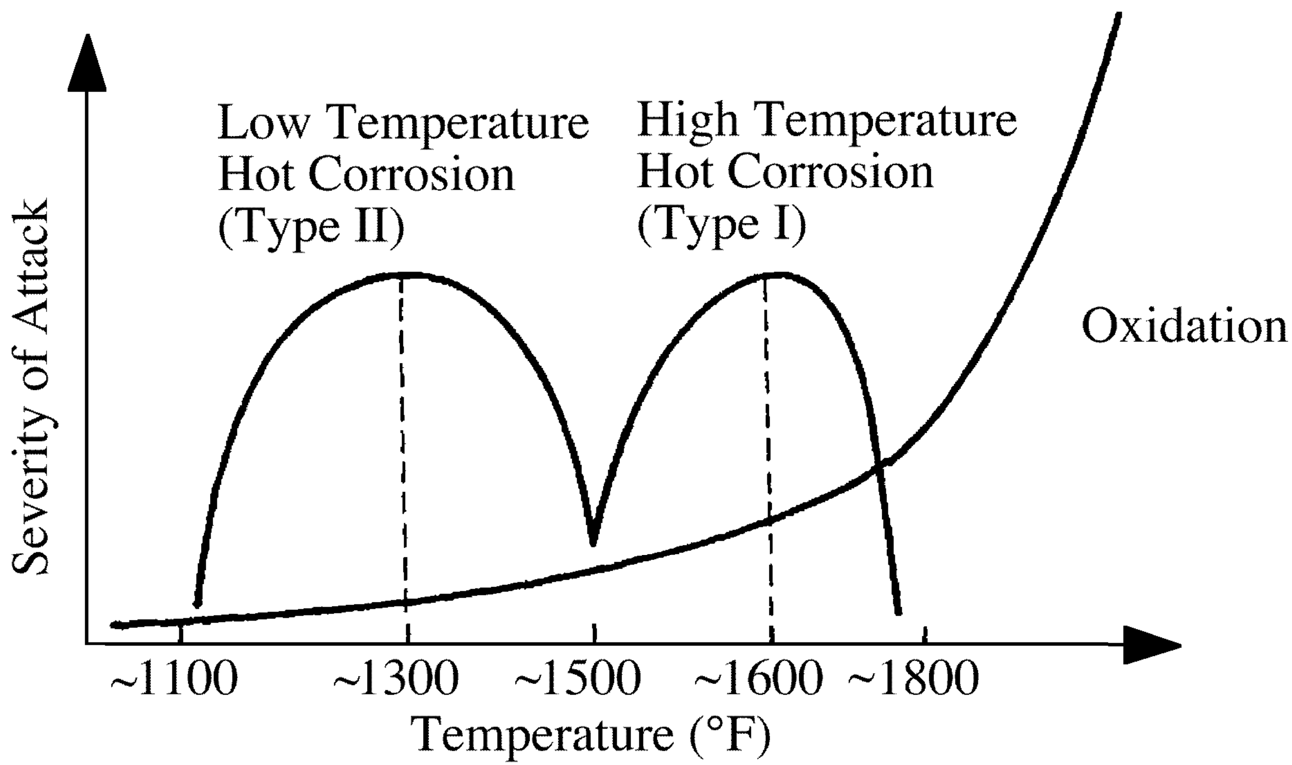
DEPOSITION

- Reduces Performance – Can Be Drastic
- Can Reduce Blade Creep Life by Increasing Blade Weight (i.e. Stress)

CORROSION

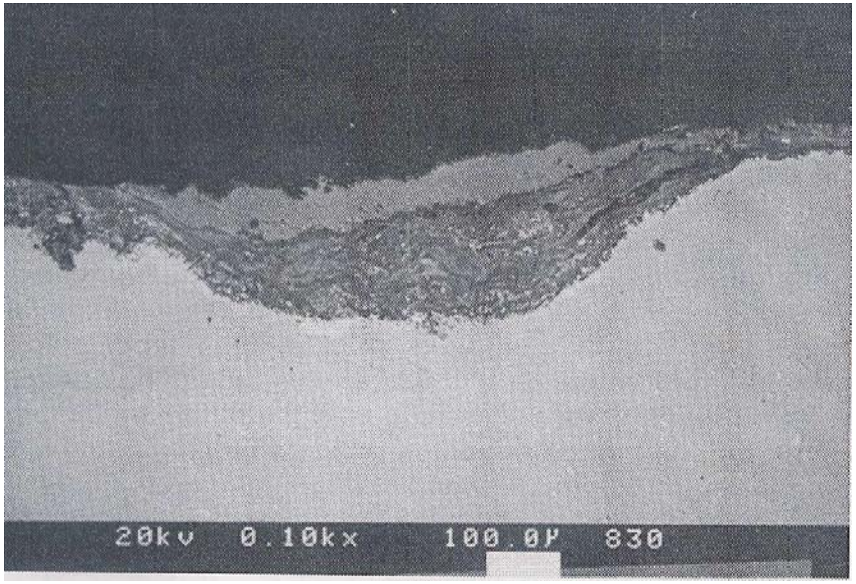
HOT CORROSION

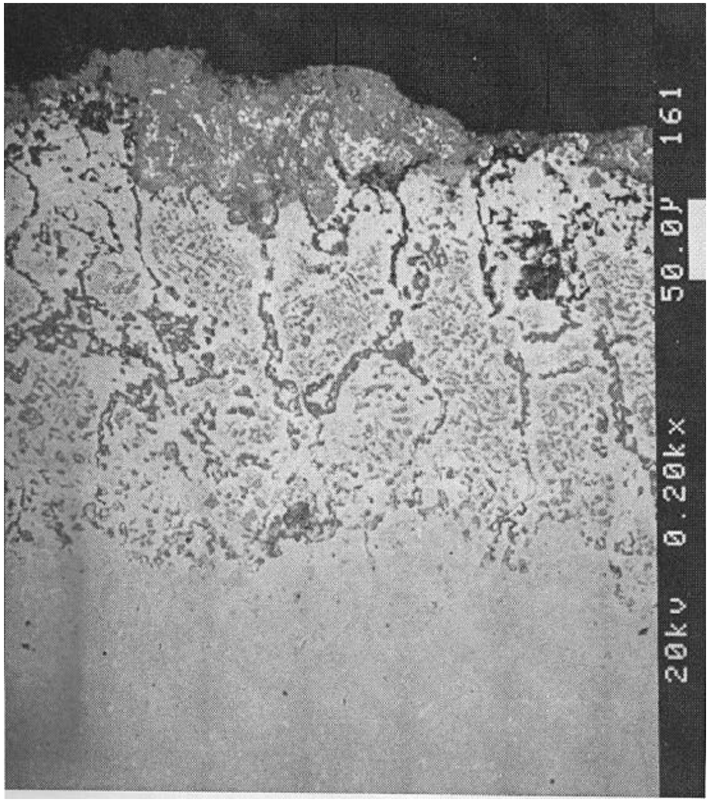
TEMPERATURE REGIMES OF HIGH TEMPERATURE ATTACK



HOT CORROSION (1 of 4)

LOW TEMPERATURE HOT CORROSION (TYPE II)	HIGH TEMPERATURE HOT CORROSION (TYPE I)





HOT CORROSION (2 of 4)

- High Temperature Hot Corrosion (Type I)
  - 1500 to 1750°F (815 to 955°C)
  - Maximum Between 1550 to 1700°F (845 to 925°C)
  - Due to Molten Alkali Sulfates Reacting with Protective Oxide Scale
  - Broad, Relatively Uniform Attack of the Metal (and Coating)
- Low Temperature Hot Corrosion (Type II)
  - 1100 to 1500°F (675 to 815°C)
  - Maximum Between 1259 to 1350°F (675 to 730°C)
  - Due to Molten Alkali Sulfates Reacting with Protective Oxide Scale
  - Need High Amounts of SO_3 to Occur at Low Temperatures
  - Non-Uniform, Pitting Attack of the Metal (and Coating)

HOT CORROSION (3 of 4)

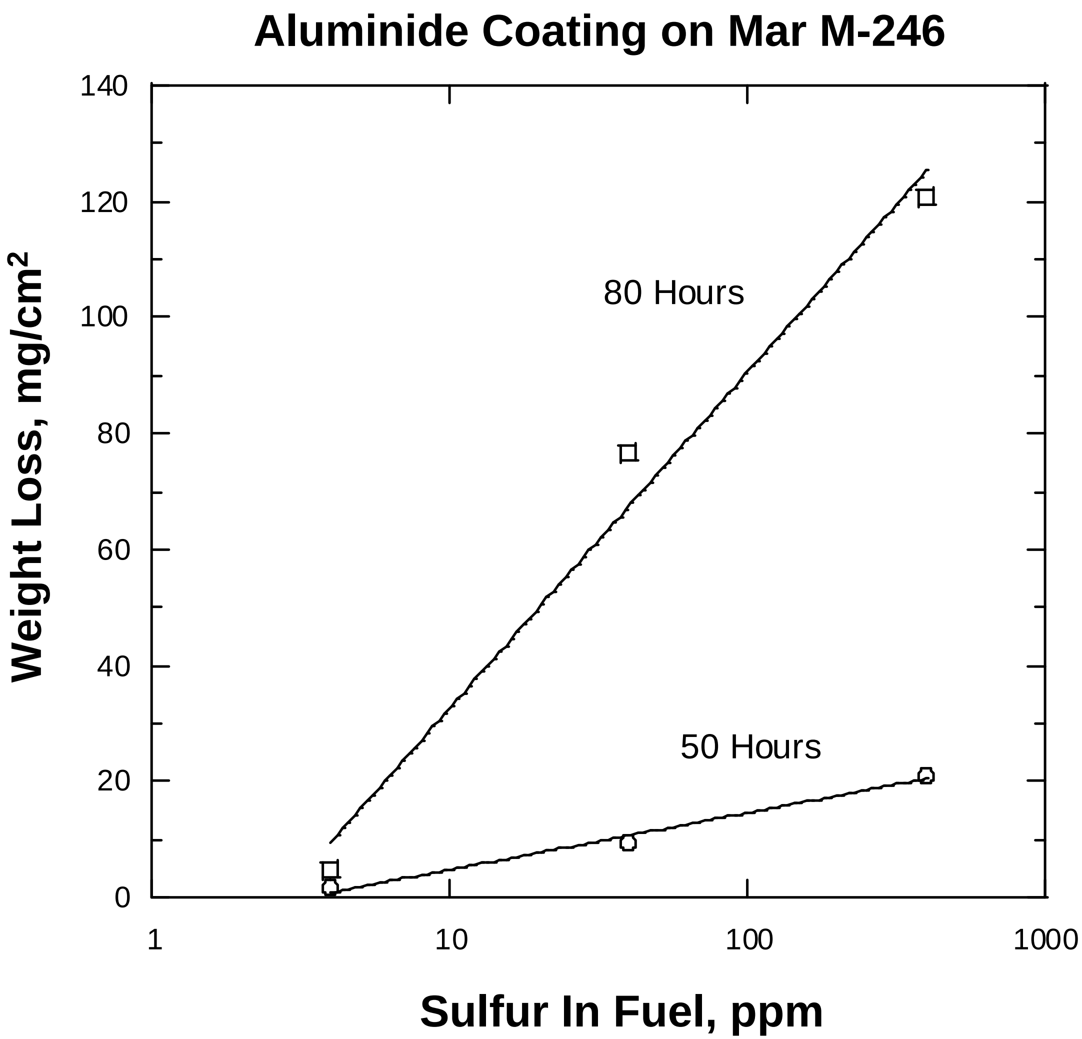
- Caused by Contaminants
  - Sulfur PLUS
  - Sodium and/or Potassium
  - Form Sodium and Potassium Sulfates

- Contaminants Come from
  - Fuel
  - Air
  - Water / Steam
    - NO_x Control
    - Power Augmentation

HOT CORROSION (4 of 4)

- Lead Induced Hot Corrosion (Lead Oxides)
- Vanadium Induced Hot Corrosion (Vanadium Pentoxide)
- Mixed Hot Corrosion (Chemical Soup)

EFFECT OF SULFUR ON CORROSION



FUEL REQUIREMENTS
and
ALTERNATE FUELS

TYPICAL FUEL REQUIREMENTS

Fuel Property	Frame	Aeroderivative	Purpose
Ash, % mass, max	0.01%	NS	Deposition
Particulates, mg/l	NS	2.6	Deposition and Erosion
Sulfur, %mass, max	0.3%	1.0%	Emissions
Sulfur, ppm	3,000	10,000	
Trace Metals	ppm wt, max		Hot Corrosion
Na + K	0.5	0.2	
Ca	0.5	2.0	
Pb	0.5	1.0	
V	0.5	0.5	

TRACE METALS

Amount of Trace Metals Allowed

Is the Sum from All Sources

Fuel + Air + Water/Steam

ALTERNATE FUELS

Biomass Pyrolysis Oils:

- Switchgrass Oils
- Oakwood Oils
- Pine Oils
- Hawker Siddley Pyrolysis Oils

BIOMASS PYROLYSIS OILS

Property	Typical #2 Fuel	Switchgrass	Oakwood	Pine	Hawker Siddley	
					A	B
Sulfur, wt%	0.1-0.3	0.03-0.04	0.01-0.03	---	0.01	0.01
Sulfur, ppm	1000-3000	300-400	100-300	---	100	100
Alkali, ppm						
Na	<0.5	20-40	10-52	10	39.5	74.8
K	<0.5	580-1380	<10-40	<10	8.0	4.2
Ca	<0.5	490-660	23-80	60	36.0	15.1
Ash, wt%	0.01	0.12-0.95	<0.05-0.05	0.05	0.1	---
LHV, MJ/kg	~ 42	21.9-23.1	19.6-28.7	21.4	---	---

BIOMASS PYROLYSIS OILS

- Sulfur: ~10x Lower than Typical Fuel
- Alkali: 10 to 1000x Greater than Typical Fuel
- Ash: 5 to 100x Greater than Typical Fuel
- LHV (Lower Heating Valve): ~2x Lower than Typical Fuel
  - Need more fuel for same power
  - Therefore, allowable contaminates must be lower

MATERIALS AND COATINGS

SUPERALLOYS

Nickel Base

- Higher Strength
- Blades, Vanes and Combustor Hardware
- Chromium – Hot Corrosion and Oxidation Protection
- Aluminum – Oxidation Protection
- Normally Coated for Corrosion and Oxidation Protection
- Frame GT's – Higher Cr and Greater Corrosion Resistance
- Aeroderivative GTs' – Lower Cr and Higher Strength

Cobalt Base

- Greater Corrosion Resistance
- Vanes
- Chromium – Hot Corrosion and Oxidation Protection
- May or May Not Be Coated
- Same Alloys for Frame and Aeroderivative

COATINGS (1 OF 2)

Surface Layer on Blades and Vanes Enriched in :

- Chromium
- Aluminum
- Other Elements Added to Improve Resistance to Attack
  - Silicon – Resists Type II Hot Corrosion
  - Platinum – Resists Type I Hot Corrosion

Provides Increased Resistance to
Hot Corrosion and Oxidation

COATINGS (2 OF 2)

Separate Metallurgical System

Many Different Types of Coatings and Application Methods

Aluminides

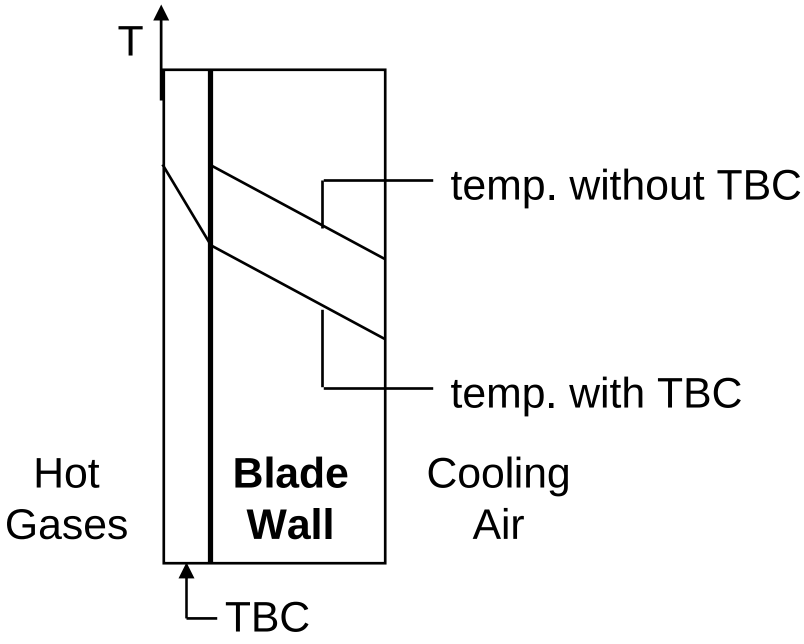
- Simple Aluminides
  - Ni-Aluminides
  - CoAl
- Platinum Aluminides
  - 2 Phase
  - 1 Phase
- Silicon Modified Aluminides
- Other Modified Aluminides
- Usually applied by pack, CVD or slurry methods

Overlays

- MCrAlY’s
- M = Ni, Co or Ni+Co
- Cr
- Al
- Y – ties up sulfur, increasing scale adherence
- Other elements sometimes added
- Usually applied by thermal spray

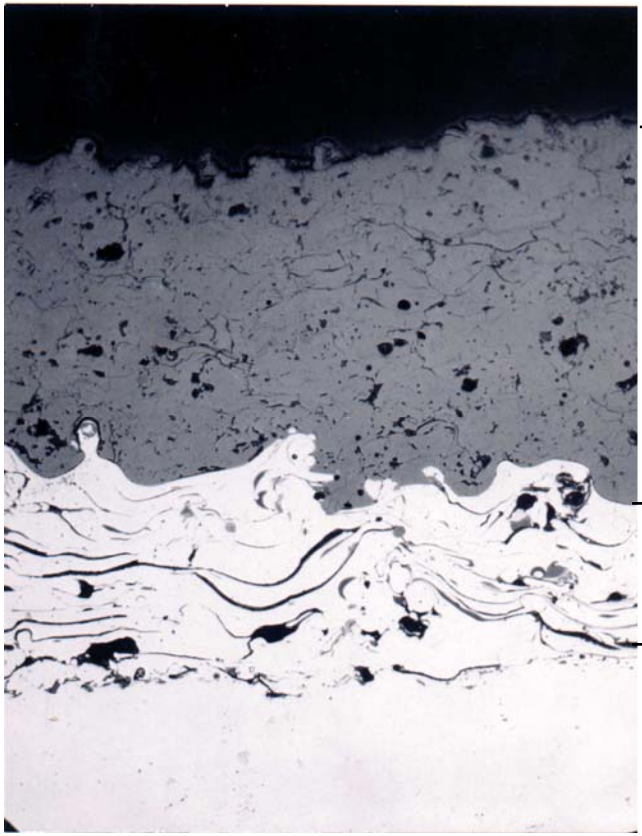
THERMAL BARRIER COATINGS

- Ceramic Layer on the Outside of the Blade or Vane
- Ceramic Layer Is an Insulator
  - Lowers the Metal Temperature
  - Requires a Heat Sink
- Lower Temperature Increases the Blade Life



AIR PLASMA SPRAY
THERMAL BARRIER COATING

Ceramic Layer of TBC on Top
APS Bond Coat on Bottom



Ceramic – Yittria Stabilized Zirconia

Bond Coat - Overlay

Base Metal

LIFE PREDICTION

LIFE PREDICTION FOR EROSION AND DEPOSITION IN IGT's

- Erosion Is Typically Not Lifed
- Source(s) of Erosion Are Eliminated

- Deposition Is a Performance Issue and Not a Lifing Issue
- Deposition is Typically Handled by Either:
  - Removing the Source(s) of Deposition
  - Empirically Determining Appropriate Cleaning Intervals

LIFE PREDICTION FOR HOT CORROSION

- Hot Corrosion Is Typically Not Lifed
- Source(s) of Hot Corrosion Are Eliminated

- Base Metals and Coatings Typically Can Withstand Hot Corrosion Conditions for Only a Short Time
  - 2,000 to 8,000 Hours Before Parts Begin to Fail

TBC's AND HOT CORROSION

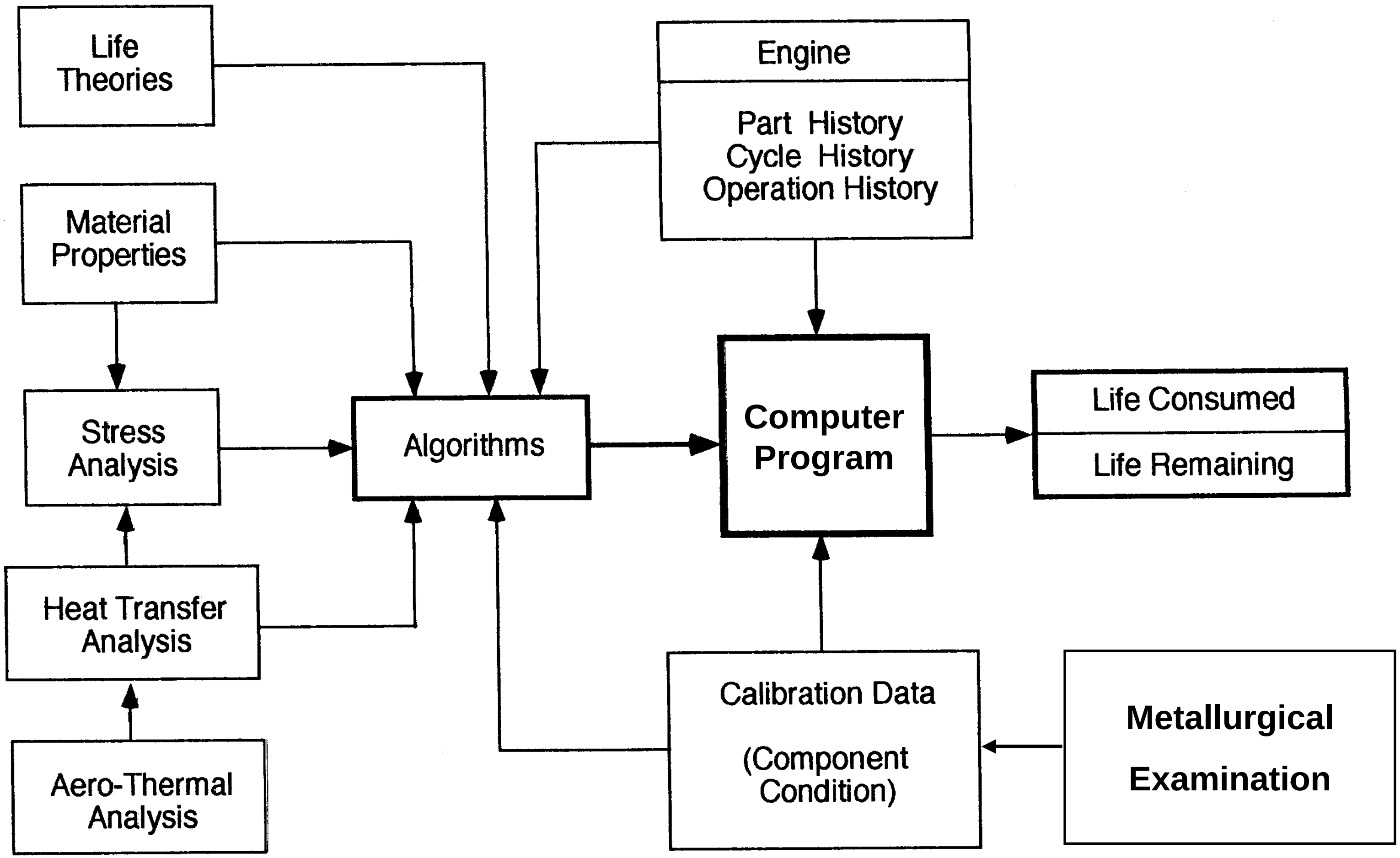
- TBC's Can Not Tolerate Hot Corrosion Conditions

- The Liquid Sulfates Wick into the Ceramic, Causing It to Spall Off
  - Difference in Thermal Expansion Between Sulfate and Ceramic

LIFE MANAGEMENT SYSTEMS

- First Stage Nozzle
  - Cracking
- First Stage Bucket / Blade
  - Creep
  - TMF
- GE MS7001 Gas Turbine – Models B, E & EA
- RB211-24C HPT Blade – TMF
- Compute Life Consumed and Life Remaining Based Upon Engine Operation / Metallurgical Exam

STRUCTURE OF THE LIFE MANAGEMENT SYSTEM



RESULTS of LIFE MANAGEMENT SYSTEM

- First Stage Nozzle
  - Cracking Predicted to Within a Factor of 2 – Material Variation
- First Stage Bucket
  - Creep Predicted, but No Creep Failures or Cracks / Voids
  - TMF Crack Initiation Predicted to Within a Factor of 2 – Mat'l Var
- Has Saved Operators Millions of Dollars
  - Longer Operation of Engine & Components – Direct Benefit
  - Improved Knowledge of Components and Engines – Indirect Benefit

SUMMARY

THE KEY IS TO KEEP DEC MANAGABLE

- Deposition and Erosion
  - Keep Ash and Particulates Very Low
- Corrosion
  - Keep Alkali Sulfates, Lead and Vanadium Very, Very Low
  - Lower Sulfur in Alternate Fuels May Allow Higher Alkali Metals
  - Mix Higher Alkali Fuels into Fuels with few Alkalis
- NO Magical Material Solutions
- NO Real Life Prediction Solutions for DEC

COMPONENT LIFE PREDICTION

- Feasible
  - Nozzles
  - Blades
  - Creep
  - Thermal Mechanical Fatigue

- Has Been Used
  - Saved Millions of Dollars

DISCUSSION QUESTIONS

1. Can alkali levels be raised if sulfur is lowered ?
2. Does the future use of alternate fuels require significant improvements in base metals and coatings ? These may not occur !
3. Can TBC's be developed to resist hot corrosion ?
4. What is the value of accurate component life prediction for gas turbine operators ?
   - Industrial
   - Civil Aviation
   - Military Aviation
   - Marine – Military (Civil)