Center for Aircraft Structural Life Extension

Providing Structural Integrity Technology to the Aerospace Community

Environmental Effects on Fatigue Crack Growth

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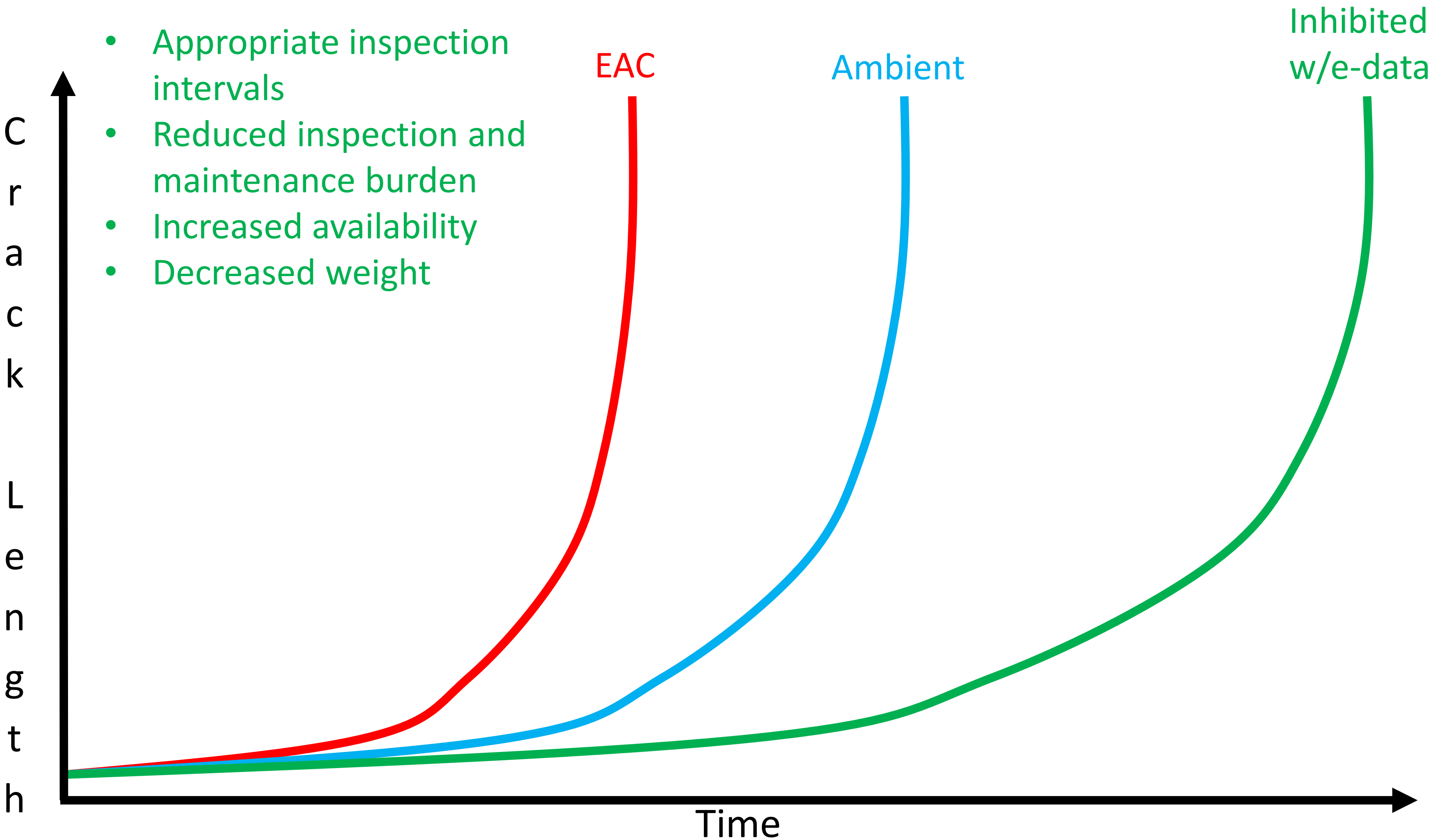
Outline

- Relevance
- Background
- Flight Environment
- Fatigue Resistance
- Hydrogen Embrittlement
- Preliminary Results
- Next Steps

Relevance

- Appropriate inspection intervals
- Reduced inspection and maintenance burden
- Increased availability
- Decreased weight



Background

- How does the environment affect crack growth
  - Develop a robust database of crack growth rate data as a function of exposure (P_{H20} / f)
  - Understand the environmental fatigue process
- Can we slow the corrosion fatigue rate?
  - Standard test protocol for inhibitor evaluation
  - Effect of chromate on crack growth rate
  - Effect of ionic inhibitors on crack growth rate
  - Inhibitor leaching behavior
- Update life prediction software to
  - Use appropriate rate data for given mission segment
  - Track damage accumulation by segment
  - Include new stress intensity factor solutions

Flight Environment

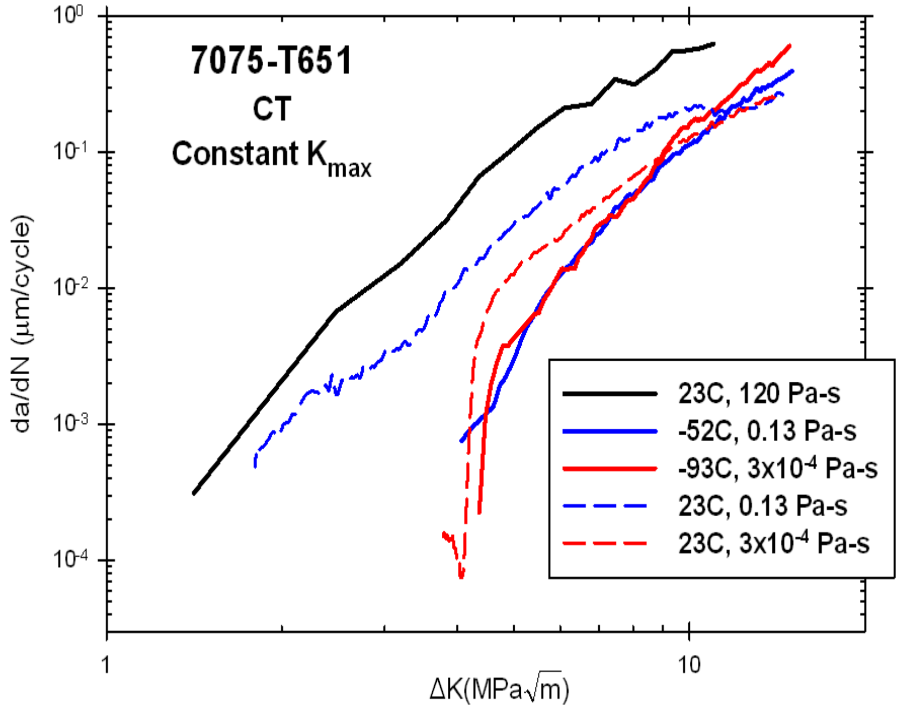
Primary Loading
- Aggressive Maneuvers
- **≈30,000 ft = -44°C**
- *f* = 0.005-0.2 Hz
- *Aicher, 1976; Aronstein, 1997*

Fuselage Loads
- Pressurization
- **8,000-50,000 ft -5 to -57°C**
- *f* = 0.00003-0.001 Hz
- *Hunt; Wanhill, 2001*

Wing Loads
- Taxi/Take-off/Landing
- **Wind Gusts**
- **40% >10,000 ft; Thus < -5°C**
- *f* = 0.1-10 Hz
- *Jorge, 1979*

Aerodynamic Loads
- Fuselage/Control Surfaces
- **0-50,000ft; Thus 0-60°C**
- *f* = 0.0003-30 Hz

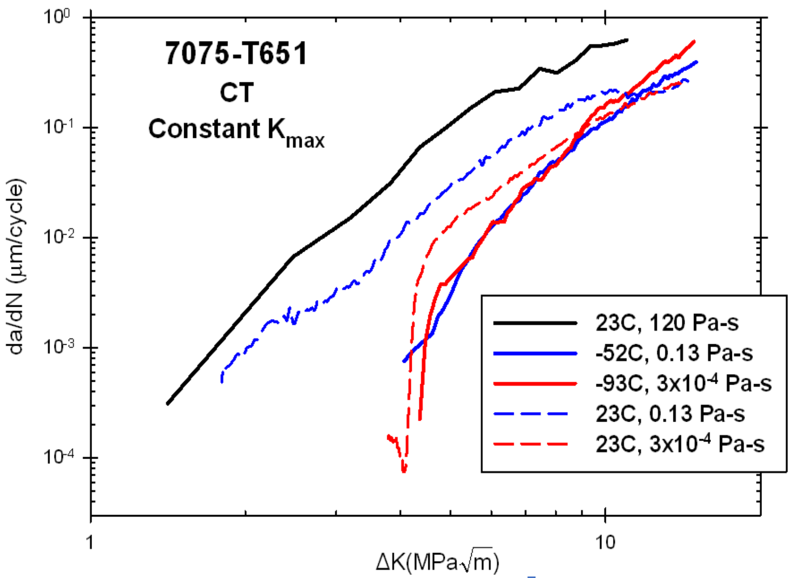
Fatigue Resistance at Low *T* and P_{H2O}

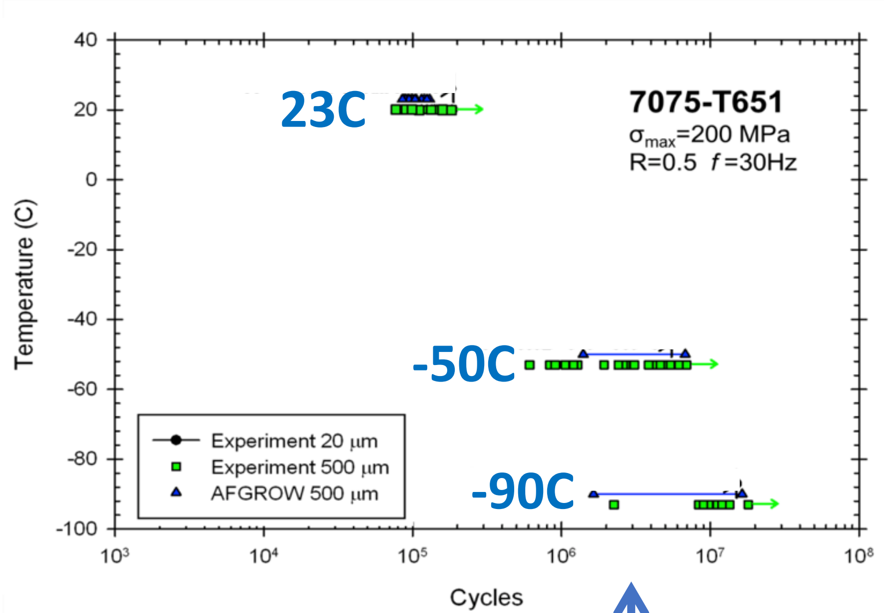


Altitude (ft)	T (°C)	$P_{H2O(-ICE)}$ (Pa)
0	15	≈1,500 @85% RH
5,000	5	≈750 @85% RH
10,000	-5	402
15,000	-14	181
20,000	-24	70
25,000	-34	25
30,000	-44	7
35,000	-54	2
40,000-60,000	-57	1

- **Characterize the effect of P_{H2O} on fatigue crack propagation**
- **Increase understanding of the governing mechanisms**

Fatigue Resistance is Increased at Low *T* and P_{H2O}



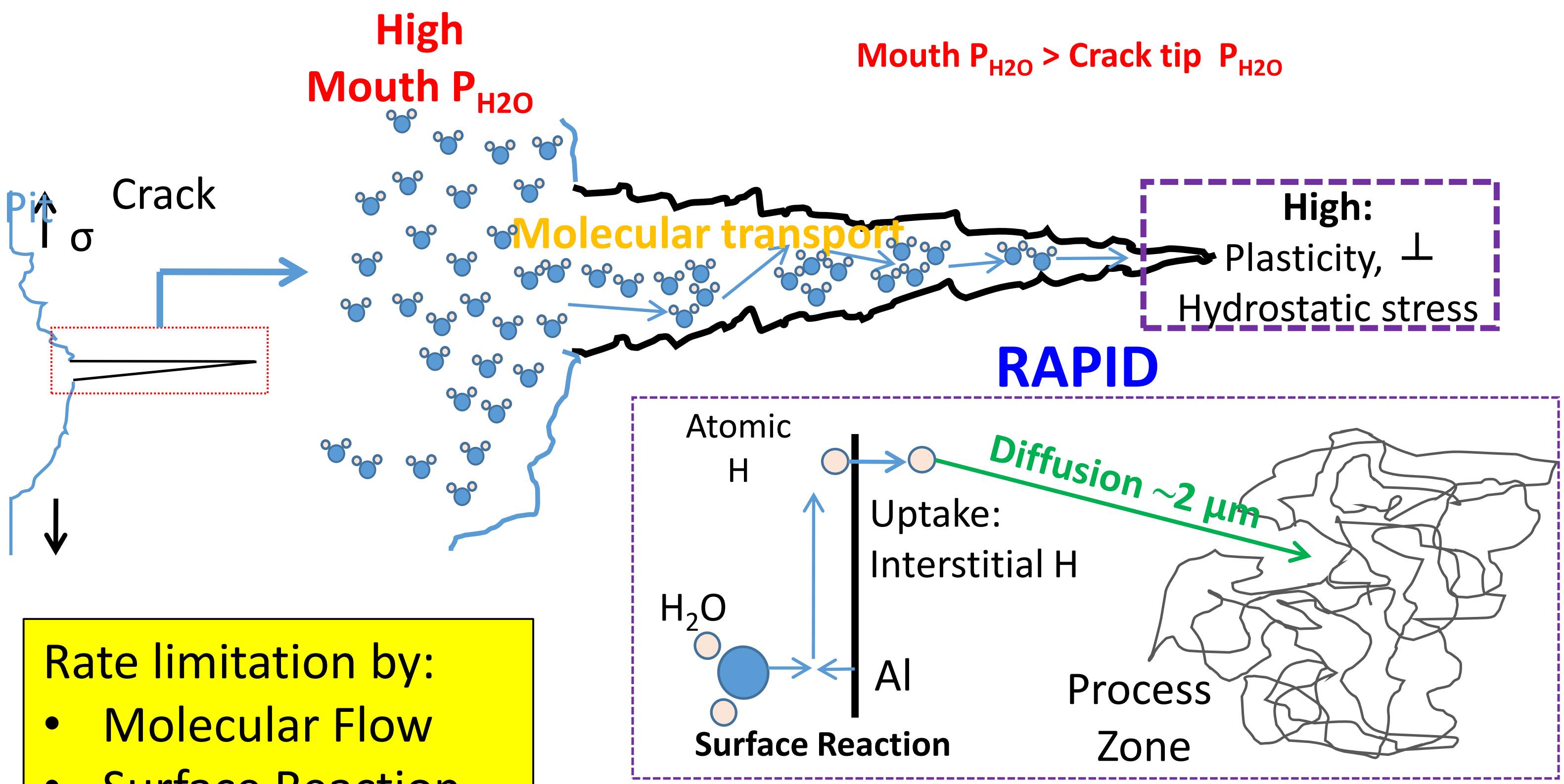


Temperature/P_{H2O} Specific Growth Rate Data

LEFM Code (AFGROW)

Hydrogen Environment Embrittlement Process

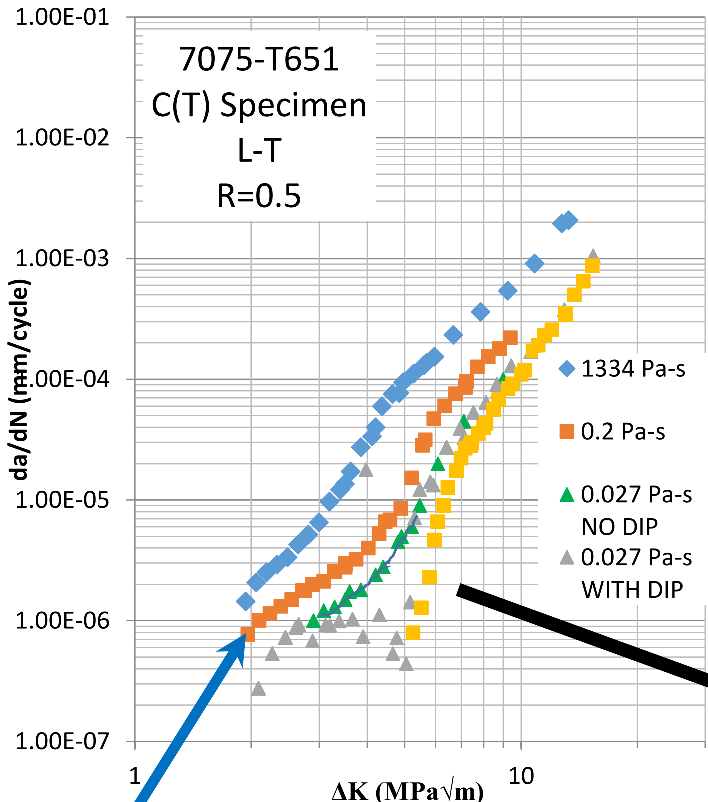
23C HUMID



Rate limitation by:

- Molecular Flow
- Surface Reaction
- Diffusion

Preliminary LEFM Modeling Results



1 week per test

Large effect on life

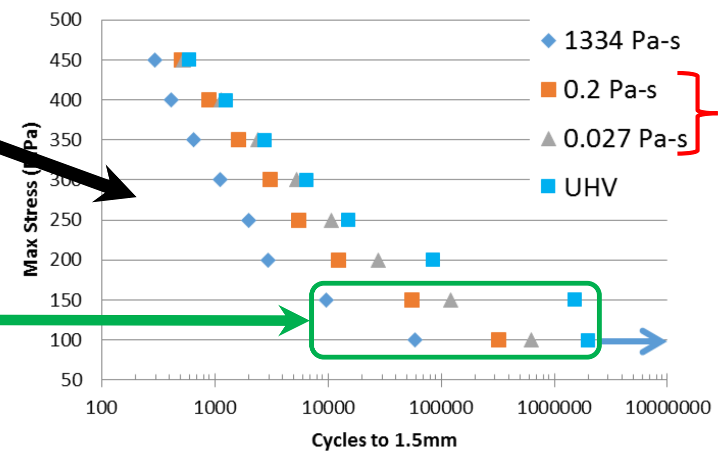
- Modeling Requirements
  - Environmental FCGR data
  - Defined environment by mission segment (taxi, takeoff, climb, cruise, descent, flaps, landing, etc.)
  - Known/assumed cycle frequency
- Software that can accept the above

AFGROW

AFGROW Predictions

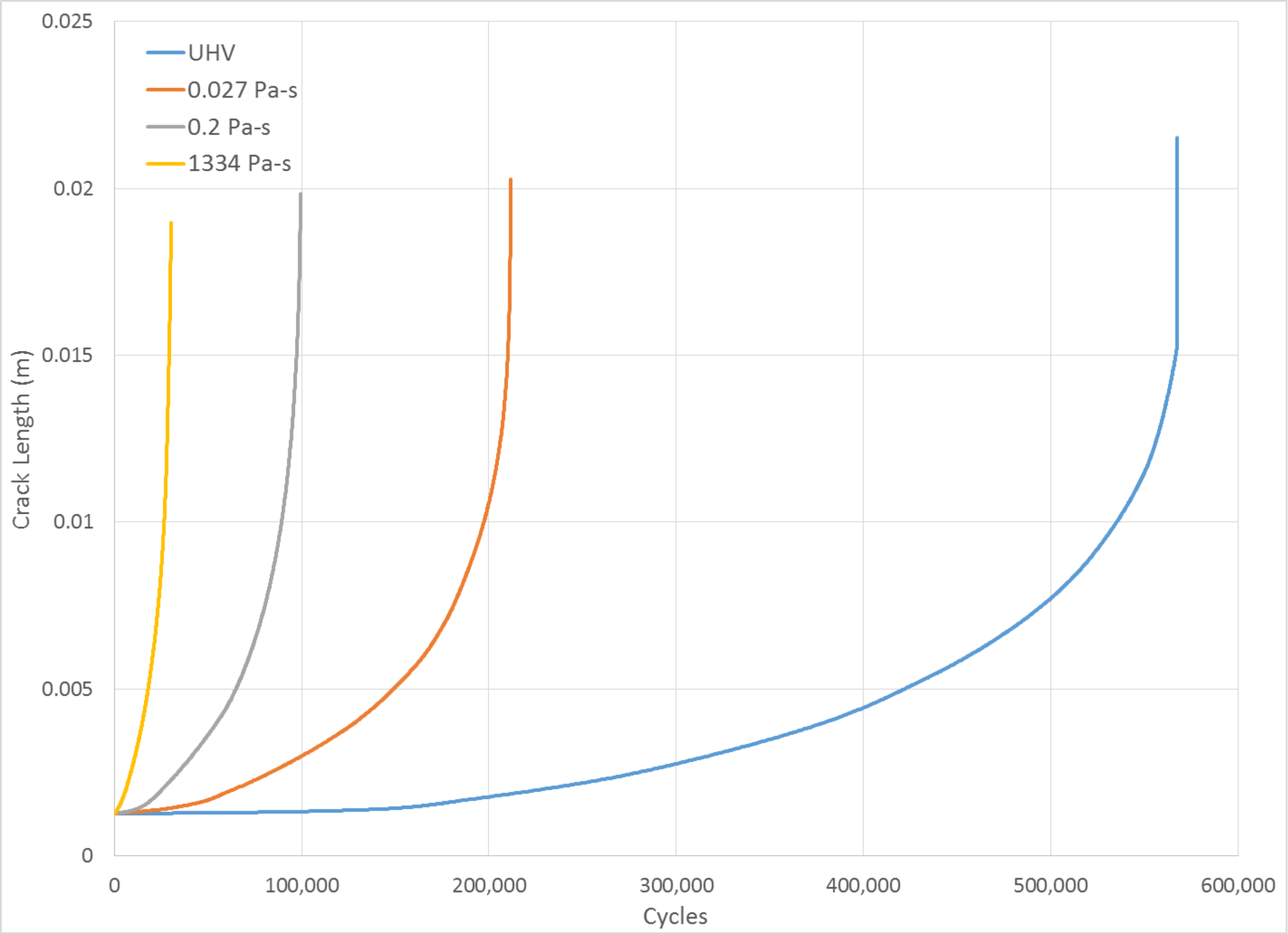
Single Corner Crack at Hole

R=0.5; a=250µm, c=250µm



Cruise Altitude (40,000 – 60,000 ft)

Crack Growth as a Function of Exposure

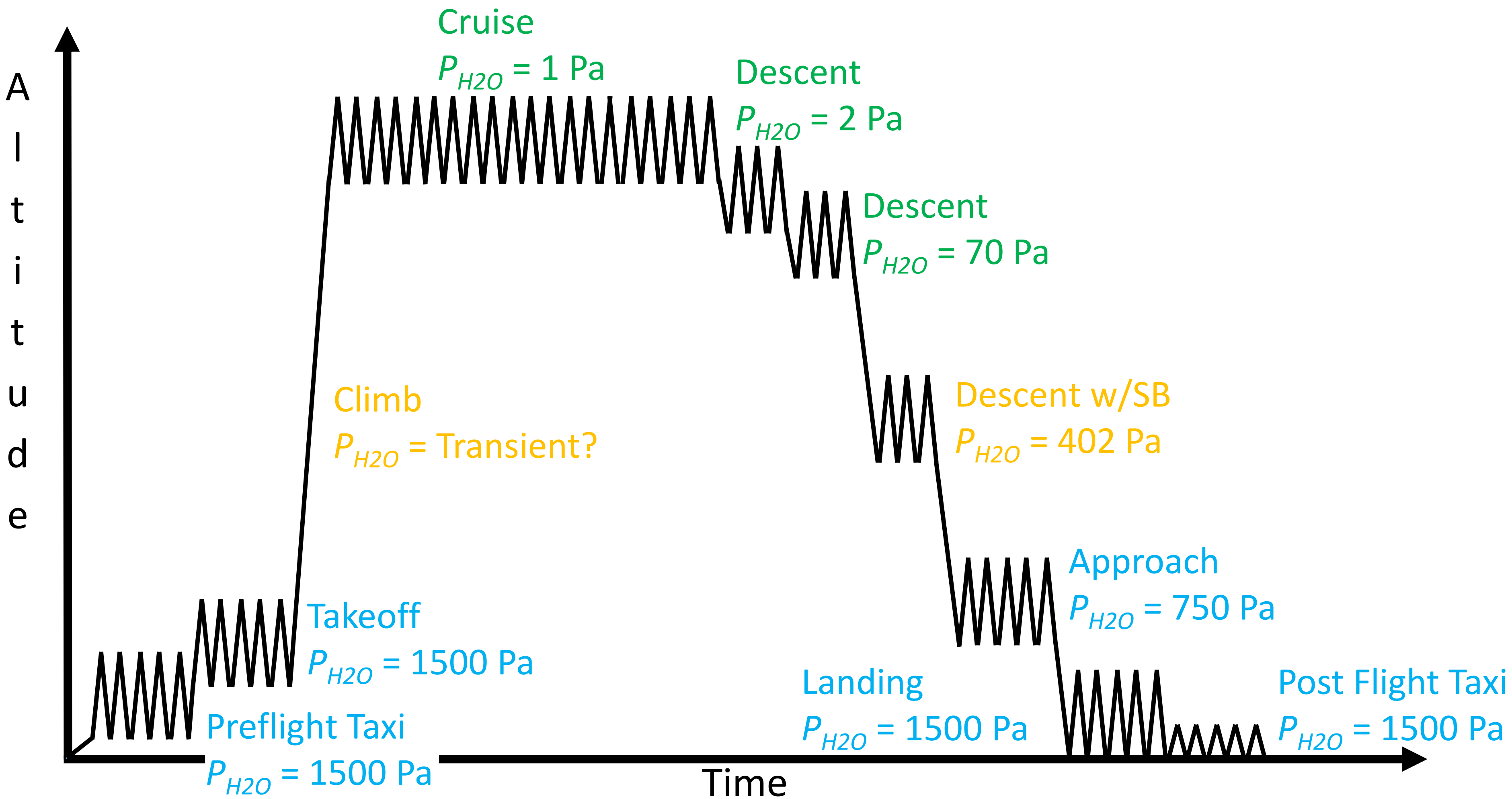


Significant effect on fatigue life and inspection intervals

Mission Segment Definition by Flight

Segment Name	Segment Time (s)	Total Time (s)	Altitude (ft.)
Start	0	0	0
Pre-Flight Taxi	600	600	0
Takeoff	60	660	0
Climb	112	772	5000
Climb	152	924	15000
Climb	201	1125	25000
Climb	295	1420	35000
Cruise	5142	6562	41000
Descent	421	6983	35000
Descent	389	7372	25000
Descent with S/B	424	7796	15000
Descent	452	8248	5000
Approach	300	8548	5000
Landing	0	8548	0
Post-Flight Taxi	300	8848	0

Crack Growth Rate Data by Mission Segment



Integrity – Service – Excellence

Next Steps

- LexTech Capability Enhancements
  - Spectrum Manager
    - Each mission segment in the spectrum can have environmental parameters (T, P_{H2O}, user, etc.) defined
  - AFGROW
    - Accept multiple material data input
- Verification - LexTech
- Validation - SAFE
  - Compare to lab test results
  - Can compare to in-service cracking results if the data is available

