Continued Airworthiness of Bonded Composite Propeller Joints

FAA Boned Structures Workshop

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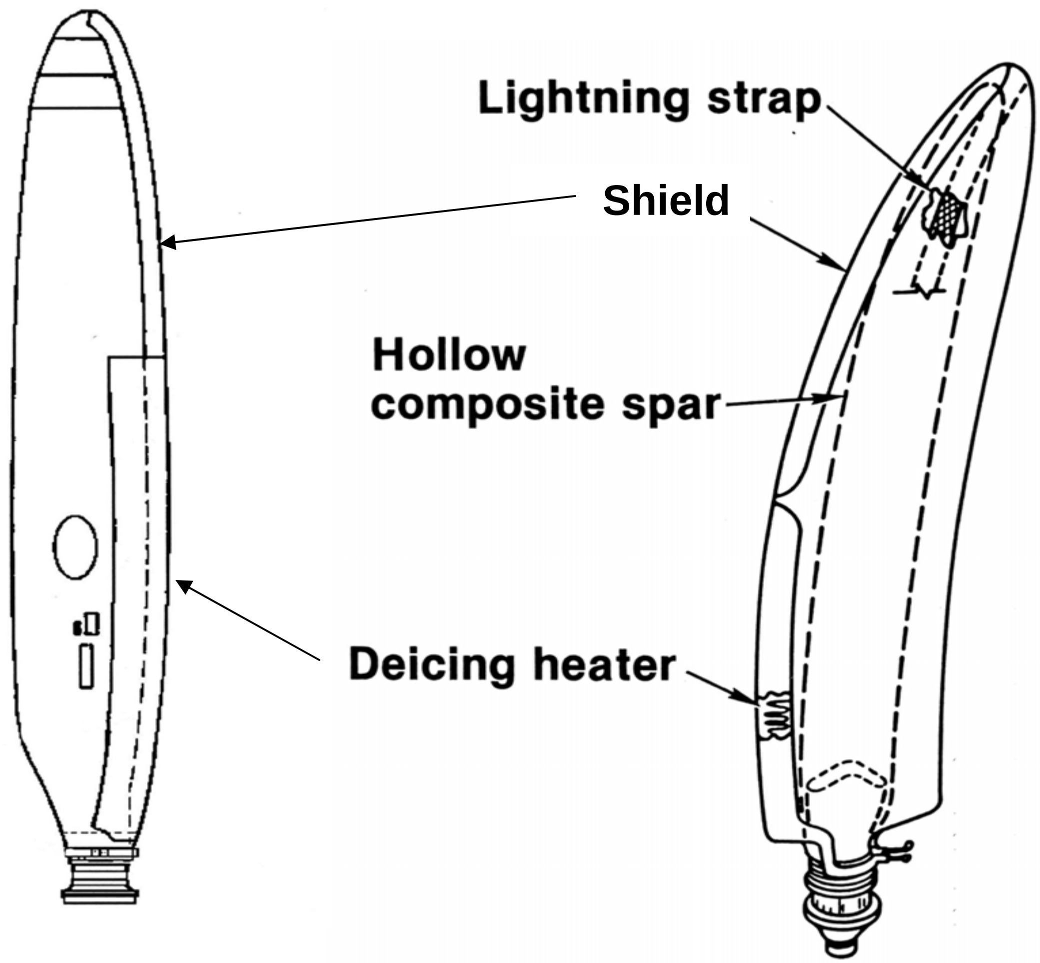
Topics

- Blade Erosion Sheath Bonding Repair Service Experience
- Primary Blade Metal to Composite Joint Life Evaluation

Composite Blade Components



Blade Erosion Shield/Sheath Bonding Repair Service Experience

Example Shield Bonding Process

- Repair: Post-bond
  - Remove shield from storage bag
  - Clean bonding surface
  - Apply adhesive
  - Assemble shield to blade
  - Cure adhesive

Note: Some manufactures use different processes for production and repair

Historical Causes of Failure

- Silicone contamination
  - Silicone transfer from masking tape to bond surface during cleaning
- Improper adhesive mixing
- Skipped process steps
  - Lack of or inadequate primer
  - Primer removal not preformed

Corrective Actions

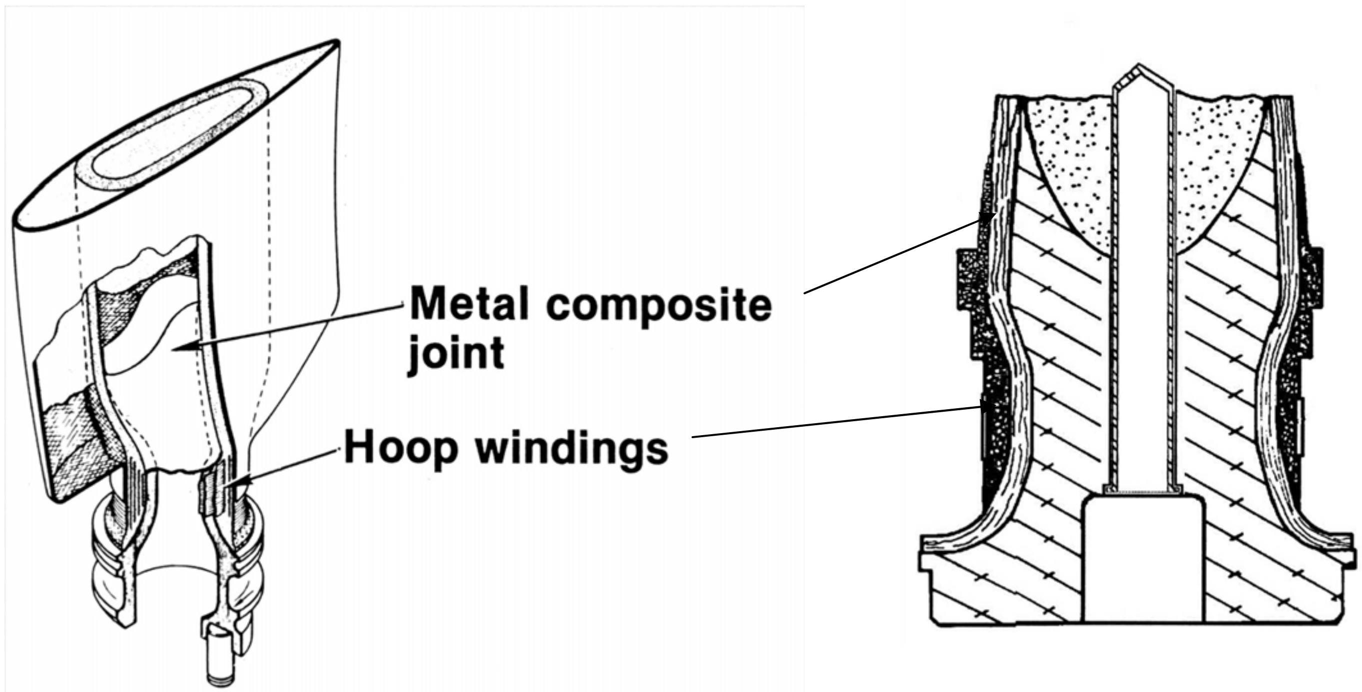
- Manual changes
  - Cautionary notes added
  - List of approved tapes added to the manual
  - Extra Inspection steps added
- Repair shop audits and training
- Removal from service of affected blades

Primary Blade Metal to Composite Joint Life Evaluation

Background Joint Information

- The blade primary joint is the attachment for the composite blade to the metallic retention
- The area is a complex construction Materials include: Primer, Adhesive, Resin, Graphite, Kevlar, and Glass
- Joint damage includes de-bonding, delamination, and cracking

Primary Metal to Composite Joint
Two Examples



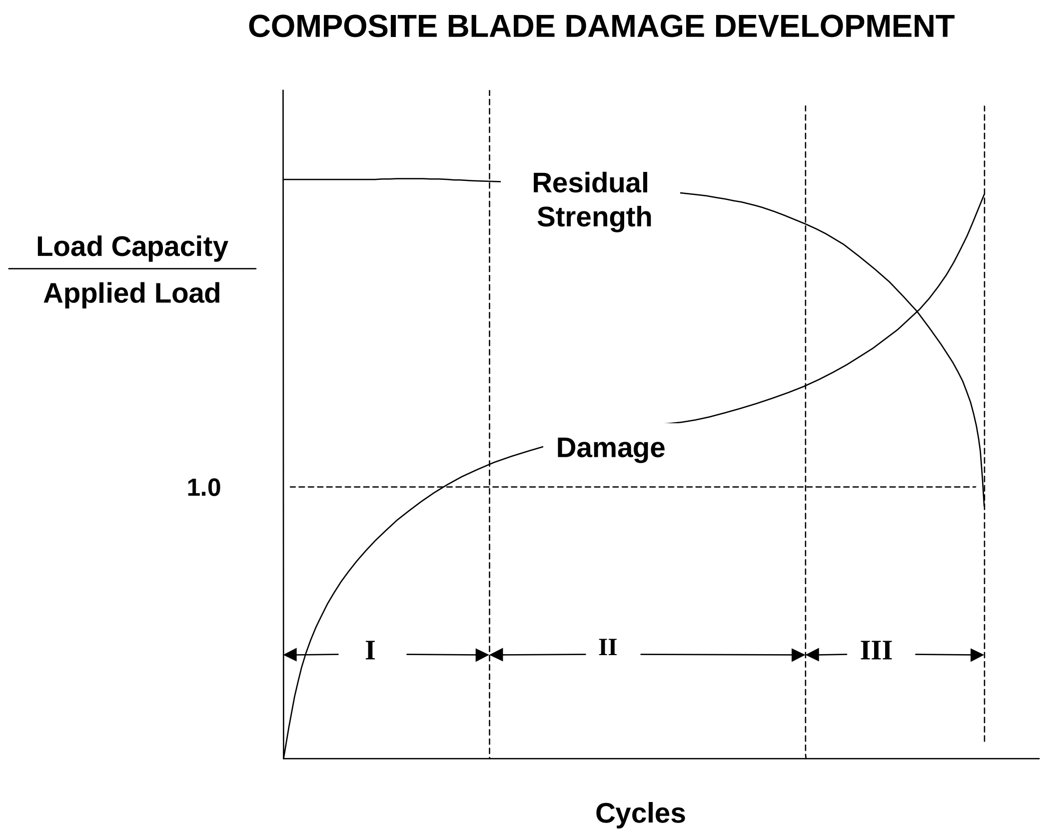
Joint Design Philosophy

- Damage is inherent in the joint and may grow with the repeated application of high loads

- The joint may be qualified such that it requires inspection at regular interval to assess damage growth

- The joint may be qualified such that it will require retirement prior to damage reaching a defined maximum permissible size

Phases of Damage Growth



- Region I - damage initiation phase
- Region II - damage growth propagates steadily and predictably
- Region III - advanced damage state

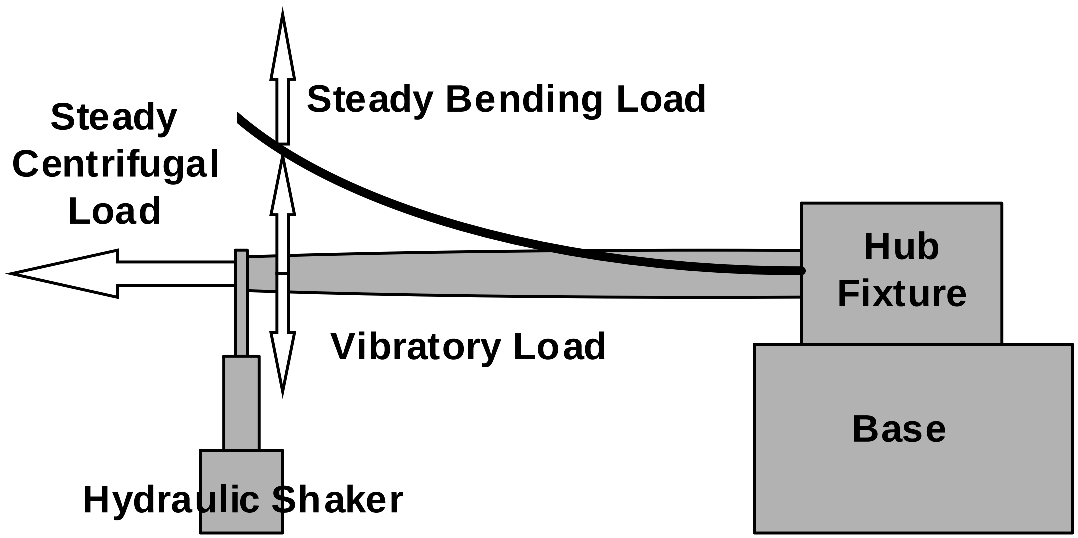
Life Qualification Process

The life qualification process
requires full scale testing

- Lab test to determine failure mechanism
- Lab test to determine flaw growth data
- Flight test to determine loading
- Life Analysis to determine inspection interval and/or retirement time
- Lab test to validate analysis
- Lab test to determine residual strength

Full Scale Test Rig

MEAN STRESS TEST



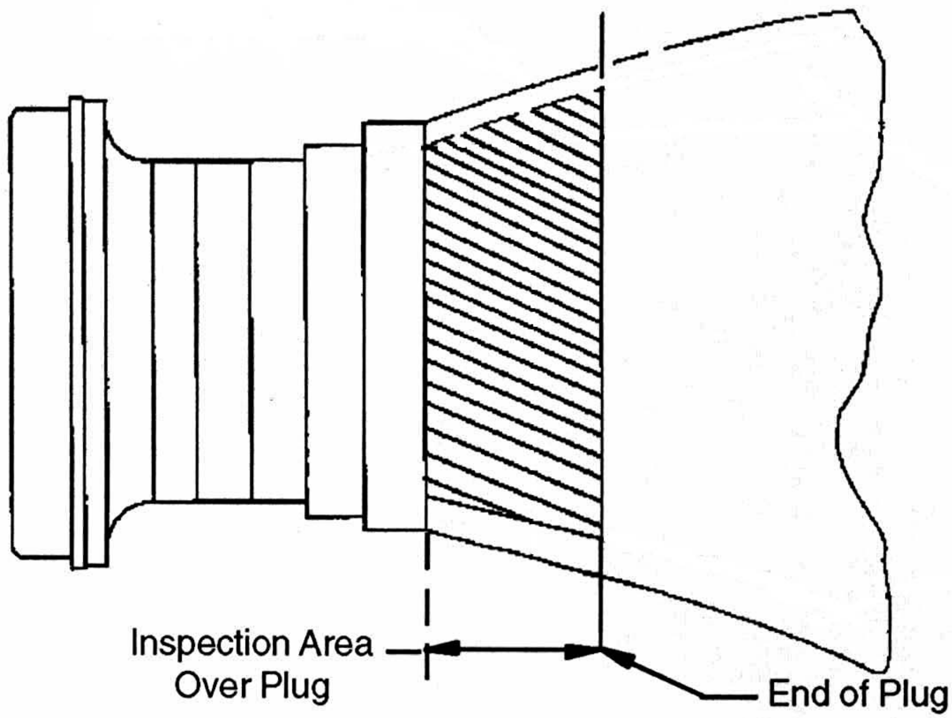
- Peak stress near the blade root
- R ratio adjusted for flight condition simulated
- Forced response test

Determine Failure Mechanism

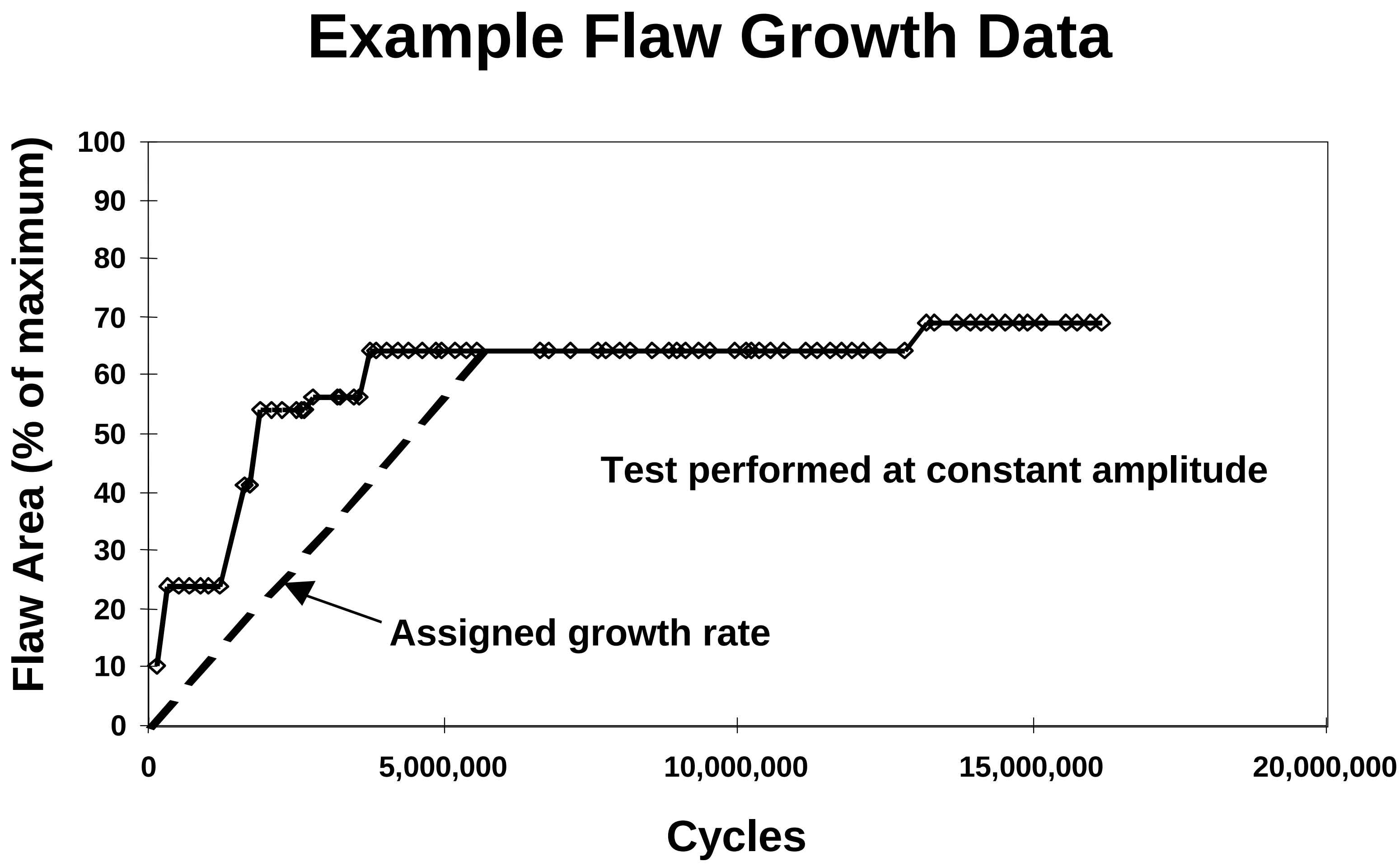
- Test Specimen. The specimen must represent actual type design
- Loading. The blade must be loaded to simulate the predicted critical loading environment
- Monitoring Failure Mechanism using NDI
  - Flaw Initiation
  - Flaw Growth
  - Test to Failure
  - Define the failure in terms of inspection criteria

Flaw Growth Inspection Area

(Available region for inspection may be limited)

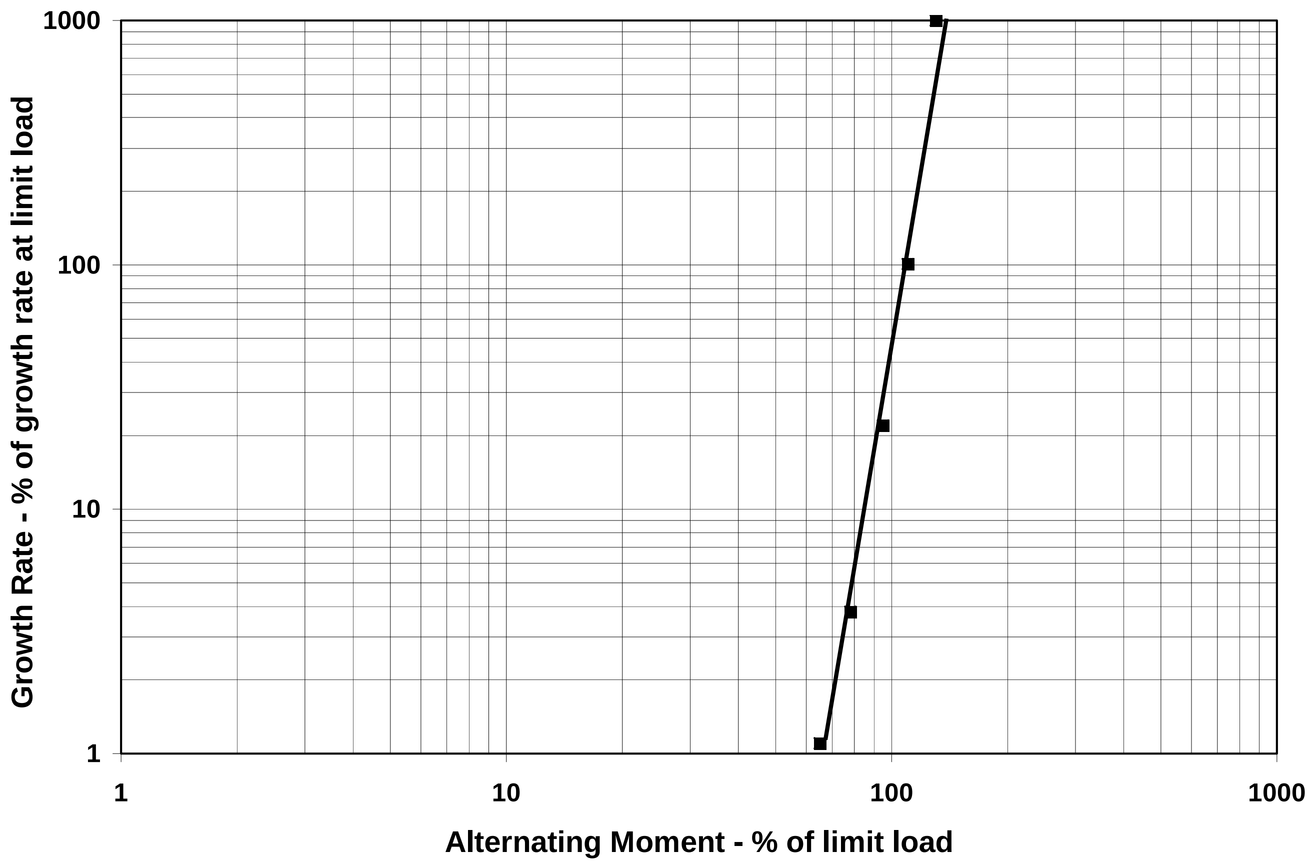


Progression of Flaw Growth



Develop Flaw Growth Curve

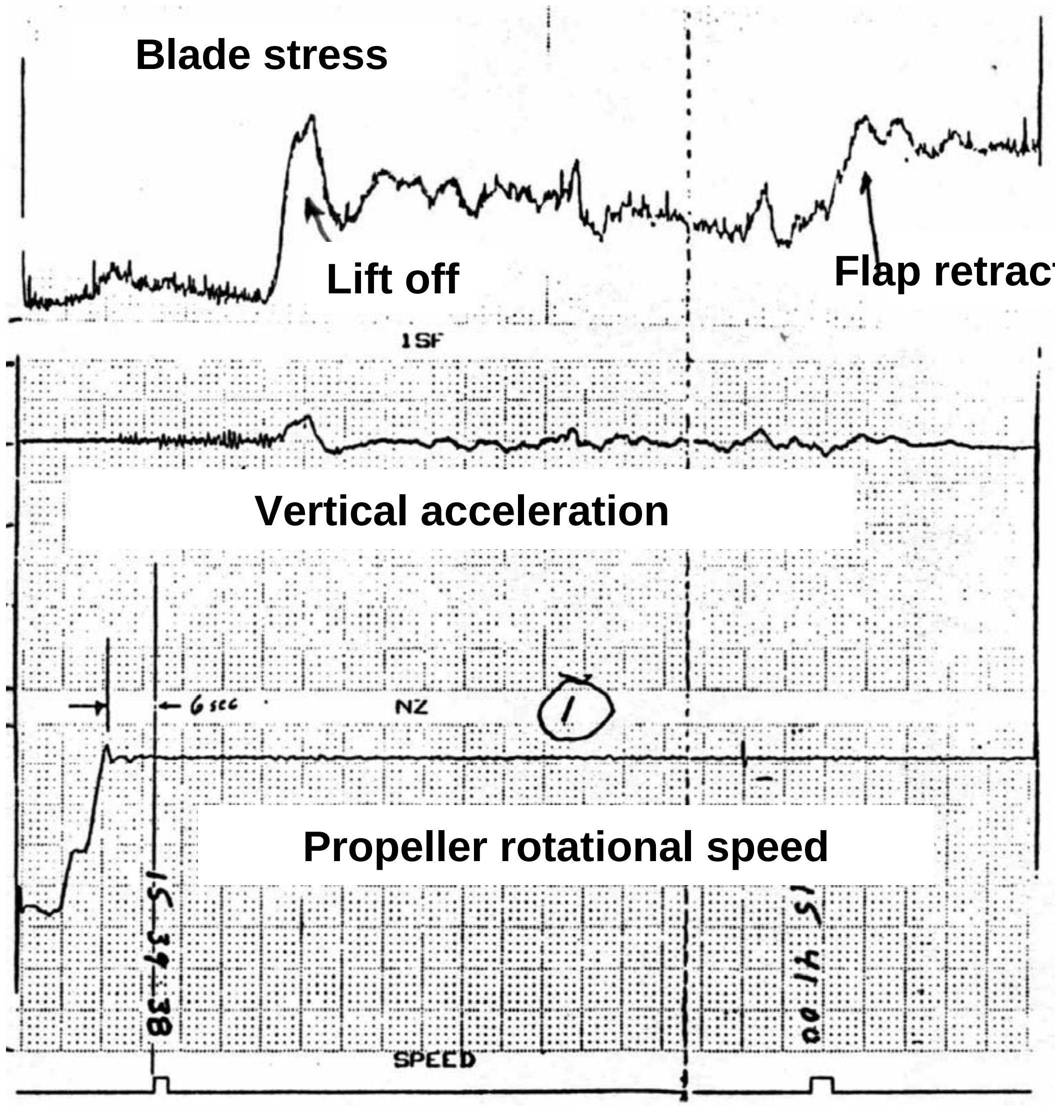
Example Flaw Growth Rate



Example Measured Blade Loads on the Airplane

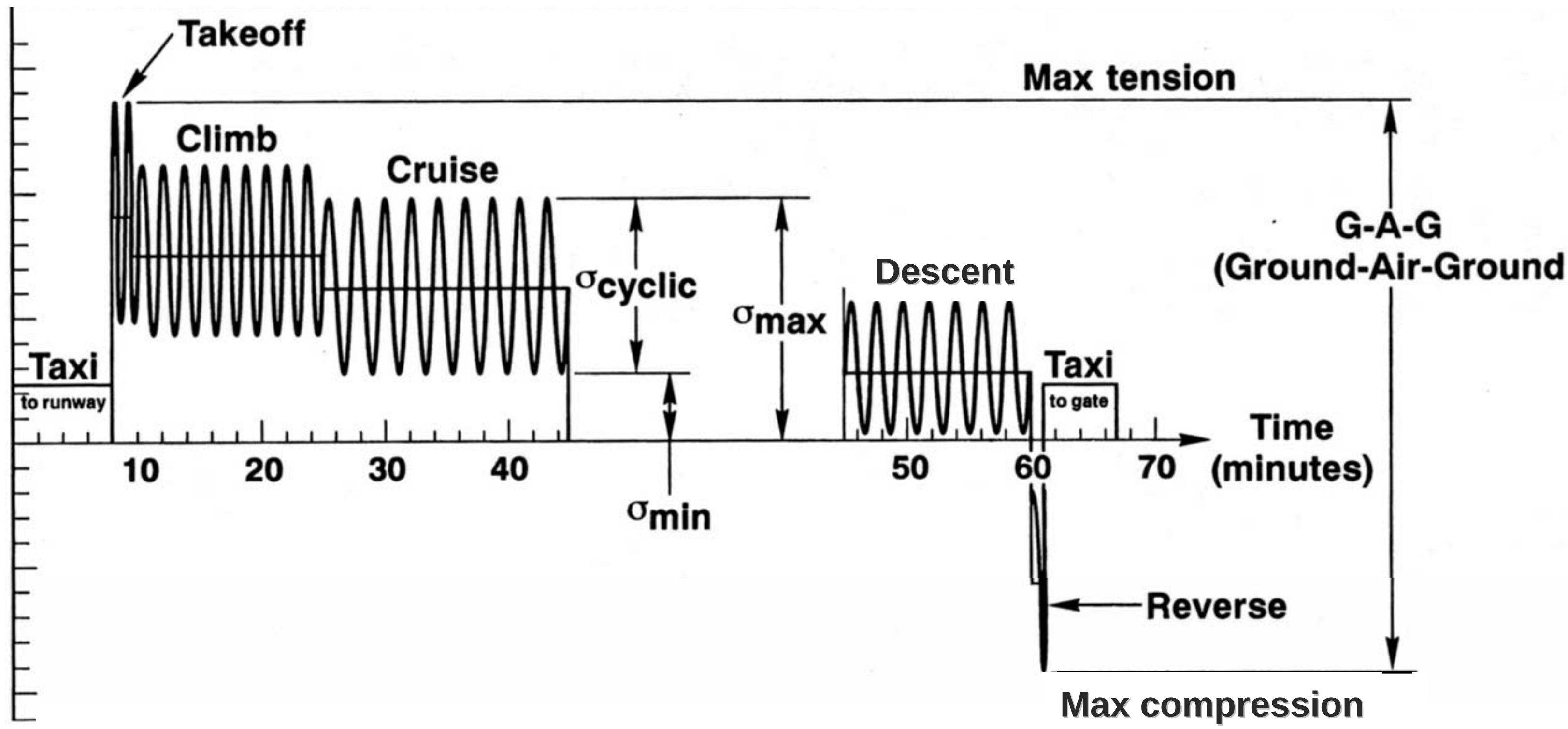
Blade response follows the:

- acceleration
- airspeed
- flap angle



Sample Components of a Flight Profile

Propeller fatigue is a combination of HCF and GAG cycles



Evaluation of propeller loads using aircraft load spectra

- The aircraft load spectra is supplied by the aircraft company.
- Propeller loads are computed for each condition from flight data.
- Each aircraft maneuver or gust represents many propeller load cycles due to propeller rotation.
- Stabilized ground and flight conditions and many maneuvers are verified by flight test.
- Non-testable flight conditions (such as vertical and lateral gusts) are estimated based on test data and analysis.

Sample aircraft spectra

No.	Condition	GW	Yaw deg.	Bank deg.	Flaps deg.	Load g's	RPM %	Torque %	V KCAS	Time Event sec.	Events per 70k hrs	Stress cycles per 70k hrs	Stress cycles per Flight
Typical Flight													
1	Taxi no crosswind	1	0	0	0	1	70	GI	0	100	35000	4.90E+07	466.66667
2	Taxi 15kt crwind	1	0	0	0	1	70	GI	0	100	35000	4.90E+07	466.66667
3	Taxi 25kt crwind	1	0	0	0	1	70	GI	0	100	35000	4.90E+07	466.66667
4	TO roll	1	0	0	15	1	100	100	0-100	40	105000	8.40E+07	800
5	TO rotation	1	0	0	15	1	100	100	110	2	105000	4.20E+06	40
6	Climb A	1	0	0	15	1	100	100	110	30	105000	6.30E+07	600
7	Climb B	1	0	0	15	1	100	100	130	40	105000	8.40E+07	800
8	Climb Spectrum	Contained in spectrum data below											
10	Cruise Spectrum	Contained in spectrum data below											
13	Descent Spec.	Contained in spectrum data below											
15	Approach Spec.	Contained in spectrum data below											
17	Reverse max	1	0	0	20	1	100	70	120	10	35000	7.00E+06	66.666667
18	Reverse 1/2	1	0	0	20	1	100	35	120	10	35000	7.00E+06	66.666667
Vertical Maneuver Spectrum													
19	Vertical Maneuver	2	0	0	0	2.6	100	70	180	15	5.6	1.68E+03	0.016
20	Vertical Maneuver	2	0	0	0	2.2	100	70	180	18	47	1.69E+04	0.1611429
21	Vertical Maneuver	2	0	0	0	1.8	100	70	180	22	576	2.53E+05	2.4137143
22	Vertical Maneuver	2	0	0	0	1.4	100	70	180	25	23838	1.19E+07	113.51429
23	Vertical Maneuver	2	0	0	0	1	100	70	180	30	122354	7.34E+07	699.16571
24	Vertical Maneuver	2	0	0	0	-1.4	100	70	180	25	23838	1.19E+07	113.51429
25	Vertical Maneuver	2	0	0	0	-1.8	100	70	180	22	576	2.53E+05	2.4137143
26	Vertical Maneuver	2	0	0	0	-2.2	100	70	180	18	47	1.69E+04	0.1611429
27	Vertical Maneuver	2	0	0	0	-2.8	100	70	180	15	5.6	1.68E+03	0.016
28	Vertical Maneuver	2	0	0	0	2.6	80	70	200	15	5.6	1.34E+03	0.0128
29	Vertical Maneuver	2	0	0	0	2.2	80	70	200	18	47	1.35E+04	0.1289143
30	Vertical Maneuver	2	0	0	0	1.8	80	70	200	22	576	2.03E+05	1.9309714
31	Vertical Maneuver	2	0	0	0	1.4	80	70	200	25	23838	9.54E+06	90.811429
	etc.												
Lateral Gust - Yaw Spectrum													
72	Lateral Gust - Yaw	2	9.12	0	0	1	100	70	180	0.5	34	3.40E+02	0.0032381
73	Lateral Gust - Yaw	2	7.45	0	0	1	100	70	180	0.5	364	3.64E+03	0.0346667
74	Lateral Gust - Yaw	2	5.23	0	0	1	100	70	180	0.5	7324	7.32E+04	0.6975238
75	Lateral Gust - Yaw	2	3.12	0	0	1	100	70	180	0.5	56398	5.64E+05	5.3712381
76	Lateral Gust - Yaw	2	0	0	0	1	100	70	180	0.5	345626	3.46E+06	32.916762
77	Lateral Gust - Yaw	2	-3.12	0	0	1	100	70	180	0.5	56398	5.64E+05	5.3712381
78	Lateral Gust - Yaw	2	-5.23	0	0	1	100	70	180	0.5	7324	7.32E+04	0.6975238
79	Lateral Gust - Yaw	2	-7.45	0	0	1	100	70	180	0.5	364	3.64E+03	0.0346667
80	Lateral Gust - Yaw	2	-9.12	0	0	1	100	70	180	0.5	34	3.40E+02	0.0032381
	etc.												
Vertical Gusts													
	etc.												
Extreme Maneuvers													
213	Limit Yaw	1	32	0	0	1	100	100	170	3.3	1	6.60E+01	0.0006286
214	Limit Pull out	1	0	0	0	3	100	100	150	3.2	1	6.40E+01	0.0006095
215	Rudder kick	1	21	0	0	1	100	100	150	2.3	4	1.84E+02	0.0017524
	etc.												

Test to validate analysis

- The damage growth model must be verified by spectrum loading for the full-scale structure using loads established from the flight test.
- The detectable damage size and location must be established and be consistent with the inspection techniques employed in service.
- The definition of failure must be based upon the inspection method employed in service.

Test to determine residual strength

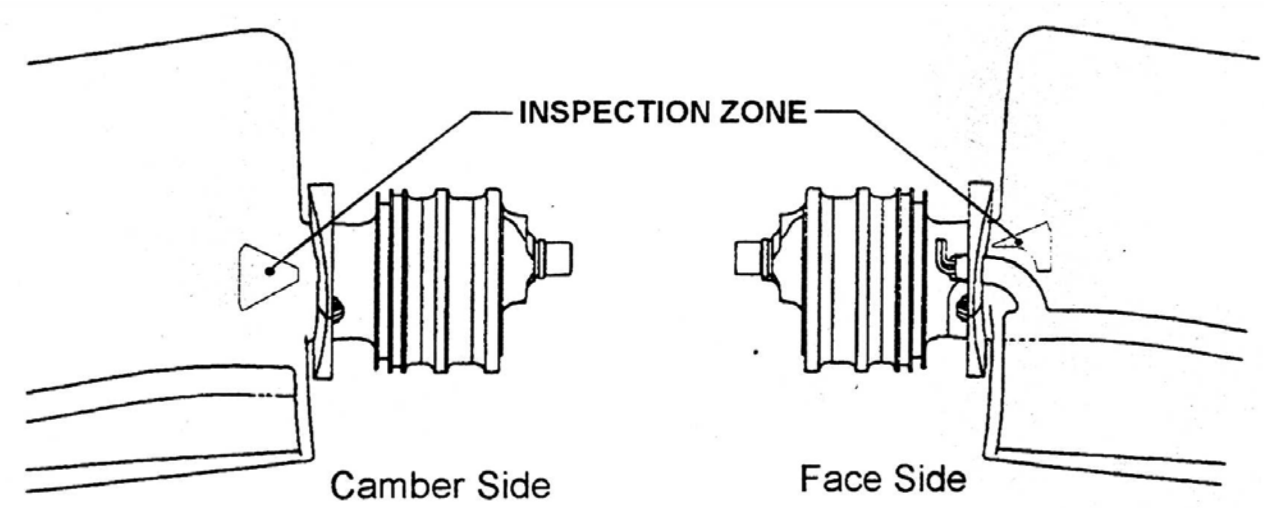
- The end of life condition is established in conjunction with the service life.
- The component at the end of life condition meets all airworthiness loading requirements.

Inspection Criteria

- Inspection methods should have a POD of 90% probability with 90% confidence.
- The defined inspection interval must permit multiple opportunities, usually three, to find the damage before the component reaches the end of life condition.

Final Inspection Program

- Conduct an inspection (usually ultrasonic) of the blade retention area at each inspection interval of xxx hours.



- Retire blade when the total area of acceptable bond is less than yyy sq centimeters.