Current Important Wheel and Axle Issues

C. P. Lonsdale
Vice President - Technical
Standard Steel, LLC
Burnham, PA

Presentation Outline

- High Impact Wheels
- Thermal-Mechanical Shelling
- What Can We Do About High Impact Wheel Removals?
- Locomotive Wheel Stresses
- Axle Fatigue Issues
- Axle Radial UT Testing

High Impact Wheels

- Number of removals has accelerated dramatically in recent years
- For a 36” wheel, 560 impacts per mile, or, an impact every 9.4 feet
- Some cars accrue 100,000 miles per year
- Very damaging to wheels, rails, etc.
- Must work to fix this problem

Cause of High Impact Wheels?

- Spalling – Sliding/martensite formation
- Shelling – Rolling contact fatigue
- Thermal-Mechanical Shelling (TMS)
  - Based on car inspections in 2004, western Nebraska, TMS seems to occur often in unit coal fleets
  - Heat from braking, combined with rolling contact fatigue loads causes TMS

What Can We Do About These High Impact Wheel Removals?

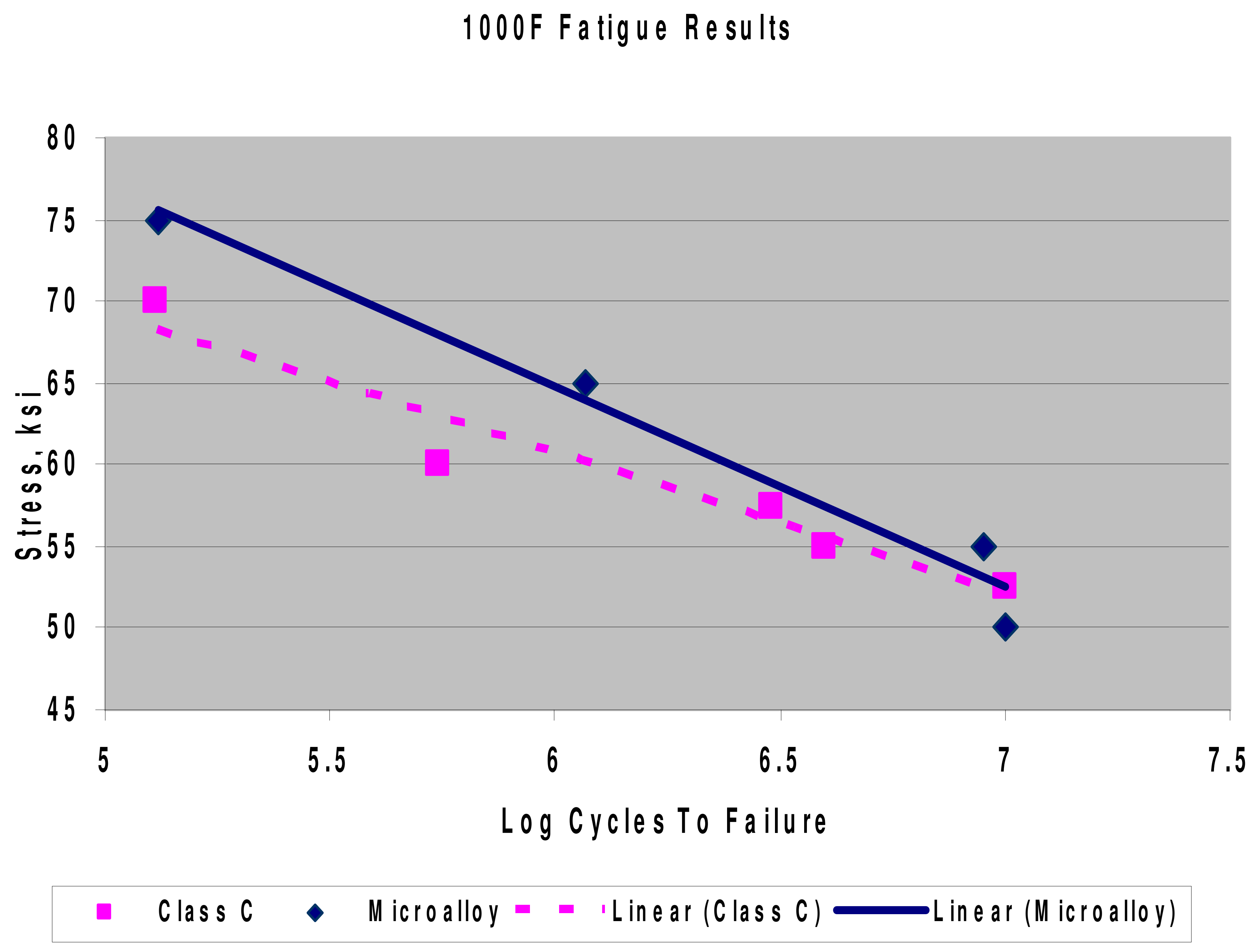
- Always best to fix the root cause of a problem….
- However, perhaps we could treat the "symptom" by improving the wheel steel
- Desired – A steel with:
  - Improved hot hardness/yield strength
  - Improved fatigue resistance

Does Microalloying Wheels Help?

- Small alloy additions made to Cl. C steel
- Longitudinal tensile samples from rim
- Room temp.- UTS and Yield
  - Class C: 164.5 ksi & 113.5 ksi
  - Microalloy: 157 ksi & 110 ksi
- 1000F - UTS and Yield
  - Class C: 63.2 ksi & 46.3 ksi
  - Microalloy: 78.1 ksi & 63.1 ksi

Does Microalloying Wheels Help?

- Fracture toughness for microalloy is 23% better than Class C
- Fatigue testing of Cl. C vs. Microalloy wheels shows that the fatigue life of microalloy steel is slightly better
- Temperature has a strong effect on fatigue life of wheel steels



1000F Fatigue Results
80
75
70
65
60
55
50
45
Stress, ksi
5
5.5
6
6.5
7
7.5
Log Cycles To Failure
Class C
Microalloy
Linear (Class C)
Linear (Microalloy)

Microalloy Wheel Discussion

- Maximum current Class C hardness limit of 363 BHN does not maximize fatigue benefits
- Amount of alloy elements should be further increased to combat TMS
  - Drawback, more elements means more susceptible to martensite formation from wheel sliding.....
- AAR "Class D" wheel?
  - We suggest a hardness range of 363-403 BHN
  - Further resistance to thermal mechanical shelling
  - Must be produced with existing heat treatment methods and equipment for best economics

Microalloy Wheel Discussion

- However, wheel tread damage is a symptom of other problems
- Improving the wheel steel fixes a symptom, not the root cause
- To fix thermal mechanical shelling we need to look at:
  - Tread brake heating/brake system issues
  - Truck steering issues
  - Etc.

Locomotive Wheel Stresses

- Loading environment for high-horsepower, high-adhesion locomotive wheels is still not well understood
- Need further over-the-road service testing with strain gauged wheels
- Effects of slow-speed, stick-slip, high torque?
- Effects of vibration on various designs?
- Role of residual stress in the wheel?

Axle Fatigue Failures

- Vast majority of axle fatigue failures are caused by surface initiated fatigue cracks

Comments on Axle Fatigue

- Establishing endurance limit is a key factor
  - Based upon many assumptions
- We currently do not have an epidemic of axle fatigue failures in North America, therefore operating stresses are below the endurance limit most of the time
- Axles that fail due to fatigue have exceeded their endurance limit

Comments on Axle Fatigue

- TTCI has presented data on axle service stresses at FAST
  - Highest stress levels in axles occur during curving, lead axle, high rail
  - Lateral loads are important to axle fatigue
- Notch defects shown to reduce fatigue life in TTCI FEA work
- Full scale fatigue testing of axles was last done by AAR many years ago – this is necessary to determine the endurance limit for today’s axles – New TTCI work is underway now

Comments on Axle Fatigue

- Smaller axle bodies have higher bending stress levels and are more susceptible to fatigue damage in service
  - Allowable 2nd hand axle body diameter is 6-3/4” – too small !!
- If nicks and dents occur on smaller axles, fatigue damage will be accelerated
- AAR recently granted Standard Steel conditional approval to manufacture the Modified K axle with 7-7/8” body diameter and no taper
  - Designated as the “K+” axle by AAR
  - 4,000 car sets can be made

Comments on Axle Fatigue

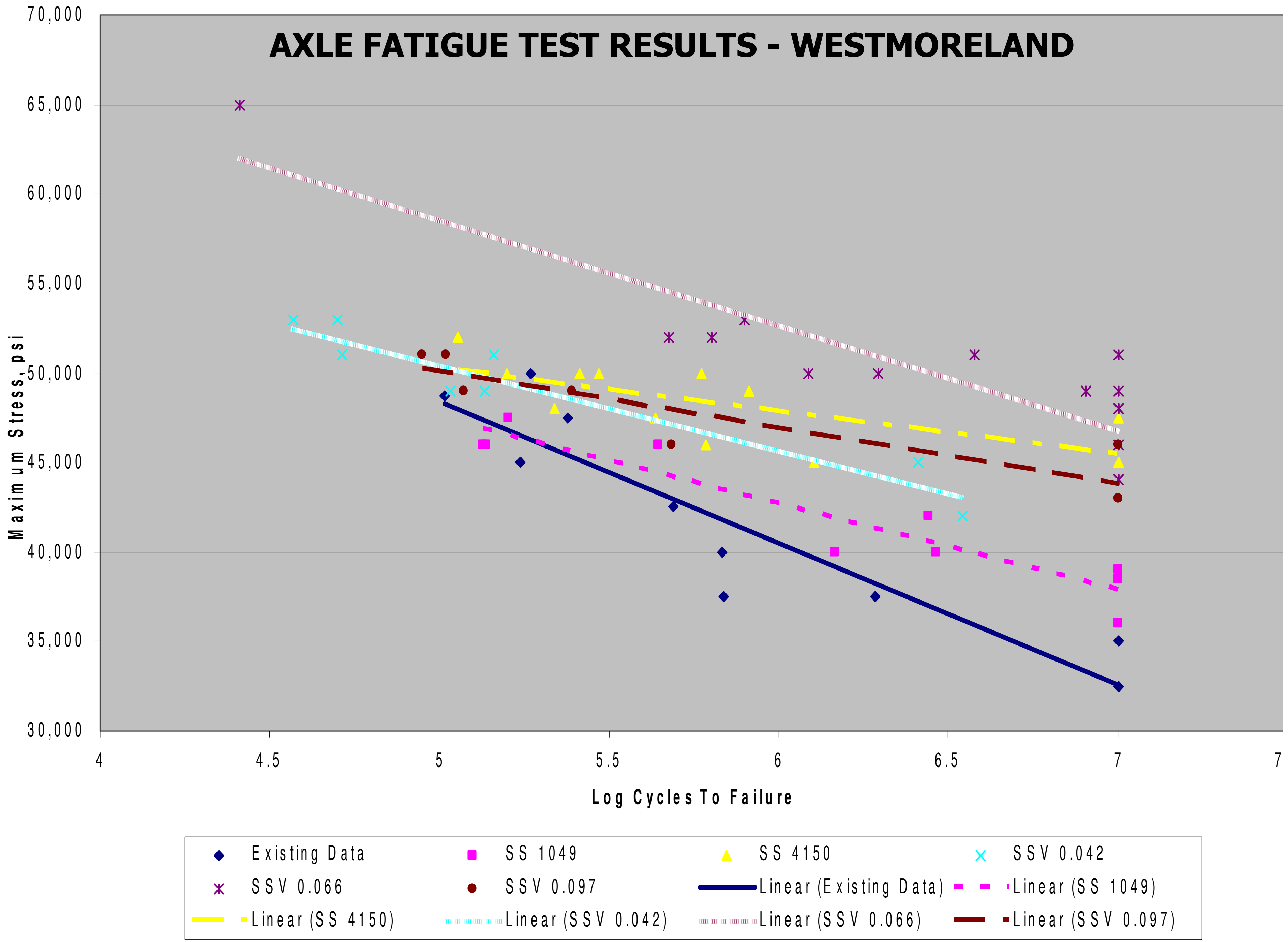
- Increase the minimum allowable body diameter for newly manufactured K and F axles in 286 GRL service
- Remove body taper in axle – no need for minimum dimension in axle center
- Increase the minimum allowable body diameter for 2nd hand axles, perhaps to at least 7 inches. Condemning diameters should be determined through further testing

Comments on Axle Fatigue

- Efforts to improve axle handling should continue
  - Reduce nicks, dents, etc. on axle body surface
  - Although damage can be repaired by grinding or machining, the body diameter is reduced
- Magnetic Particle Inspection of all axle bodies in wheel shops should be adopted
  - Find and remove surface initiated cracks
  - Axles in 286 GRL service should be targeted

Axle Fatigue Improvement

- Goal: “Improve fatigue strength of axles while maintaining current manufacturing and heat treating methods”
- Review of past Standard Steel axle fatigue results with various Vanadium additions
- Additional steel grades are now under consideration


AXLE FATIGUE TEST RESULTS - WESTMORELAND
Maximum Stress, psi
70,000
65,000
60,000
55,000
50,000
45,000
40,000
35,000
30,000
4
4.5
5
5.5
6
6.5
7
7
Log Cycles To Failure
Existing Data
SS 1049
SS 4150
SSV 0.042
SSV 0.066
SSV 0.097
Linear (Existing Data)
Linear (SS 1049)
Linear (SS 4150)
Linear (SSV 0.042)
Linear (SSV 0.066)
Linear (SSV 0.097)

Additional Steel Grades For 2006 Fatigue Testing

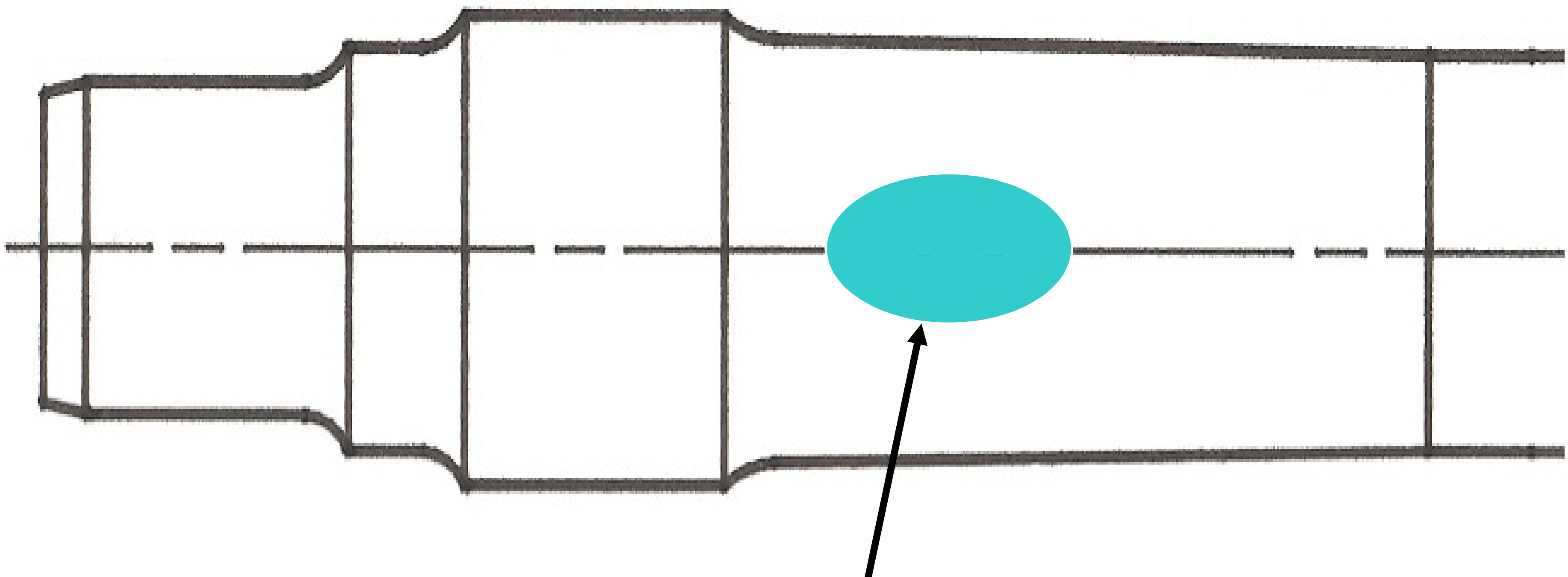
- 1049, 0.025 V, no Al, no Ti
- 1049, 0.25 Mo, 0.012 V
- 1049, 0.25 Mo, 0.025 V
- 1049, 0.25 Mo, 0.027 V, 0.49 Cr
- 1049, 0.025 V, 1.16 Mn, 0.49 Si

- Yield strength improvements have been noted
- Fracture toughness testing also will be performed as part of this study

Need for Radial UT Testing of Axles

- Current AAR UT "end testing" does not "see" the sort of discontinuity found by radial UT testing
- The current AAR UT test for axles needs to be updated and improved
- Increased GRL (286K GRL), improved car utilization, and more severe wheel impact loads means that axles are under greater service stresses than ever before
- Radial UT testing finds large central axis discontinuities using a "Loss of Back Reflection" (LBR) criteria

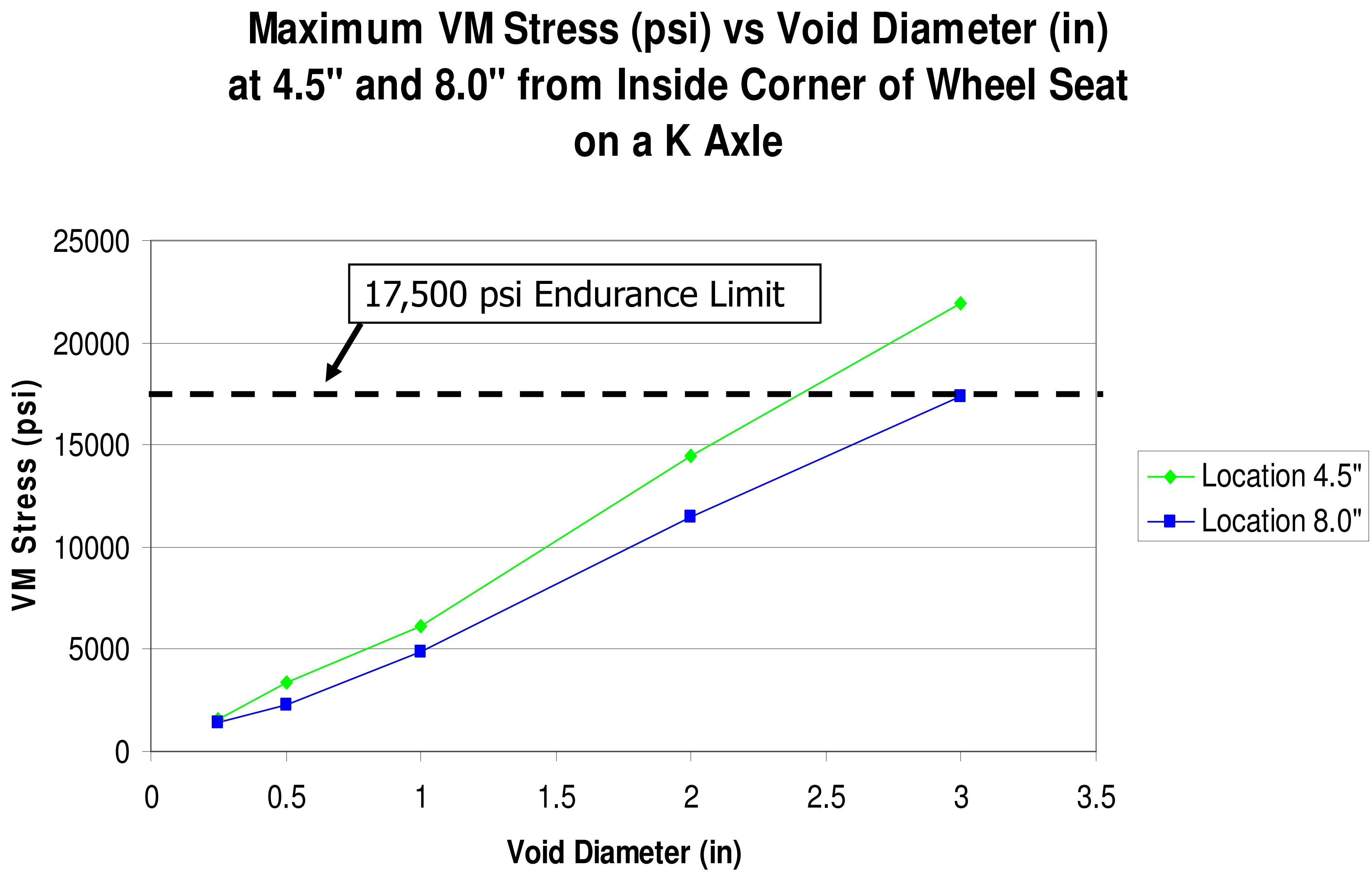
Diagram Showing Approximate Large Discontinuity Location



Radial UT Test Can Find Large Discontinuities

Finite Element Analysis

- Simulated discontinuities at centerline in axle body near wheelseat
- Analysis done by Rusin Consulting Corp.
  - Press fit, 286K GRL bending and 8K lateral loads
  - Discontinuity diameters: ¼″, ½″, 1″, 2″, 3″
- 1″ discontinuity – 6,000 psi stress result
- Fatigue endurance limit (AAR 1938-1950 full scale axle fatigue tests were conducted), body 17,500 psi



FEA Simulations By Rusin Consulting Corp.

Axle Evaluations

- Axles UT tested radially along length
- 63 Axles with various LBR % cut open to examine physical size of discontinuity
- Wheelseat test blocks, side drilled holes at central axis, tested with 1″ diameter transducer, 2.25 MHz
  - 1″ diameter hole 100% LBR
  - 2″ diameter hole, 100% LBR
- Able to detect large discontinuities

Axle Radial UT Recommendations

- Adopt proposed new radial UT specification for new axles and publish in AAR M101
- Also maintain current AAR UT test for new axles in M101
- Begin testing second-hand axles with same radial UT testing procedure proposed for new axles
  - Pre-1970 axles (approx. date) had no UT test at all
  - Some number of second-hand axles will benefit from this improved inspection procedure
- 80% LBR rejection can find large discontinuities

QUESTIONS

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