Fatigue Life Improvement of Arrestment Hook Shanks by Application of Laser Peening

SAND2020-9463PE

SAND 2020-3462 PE

M. J. Leap & J. Candela

NAVAIR

J. Rankin, J. Harrison & L. Hackel

Metal Improvement

J. Nemeth

CTC- Navy Metalworking Center

PROGRAM SPONSORSHIP

- THIS WORK WAS JOINTLY CONDUCTED BY NAVAIR, METAL IMPROVEMENT CORPORATION, AND THE NAVY METALWORKING CENTER AT CONCURRENT TECHNOLOGIES UNDER CONTRACT N00014-06-D-0048 FOR THE OFFICE OF NAVAL RESEARCH.

- REFERENCE: *INTERNATIONAL JOURNAL OF FATIGUE*, 33(211) 788-799.

NAVAIR

CURTISS WRIGHT

mi

NMC

ACKNOWLEDGEMENTS

- GREG WOODS OF THE OFFICE OF NAVAL RESEARCH FOR PERMISSION TO PUBLISH THE RESULTS OF THIS WORK.
- JOHN SCHNEIDERS OF BOEING FOR VALUABLE INSIGHT INTO ARRESTMENT HOOK SHANKS.
- RYAN FIELDS AND CHRIS HESS OF NAVAIR AIR-4.3.4 FOR EXPERIMENTAL SUPPORT DURING THE COURSE OF THIS PROGRAM.

NAVAIR CURTISS WRIGHT mi NMC

BOTTOM LINE UP FRONT

COMPRESSIVE RESIDUAL STRESS PROVIDES PROTECTION AGAINST TENSILE FATIGUE LOADING

BUT. . .

NAVAIR CURTISS WRIGHT mi NMC

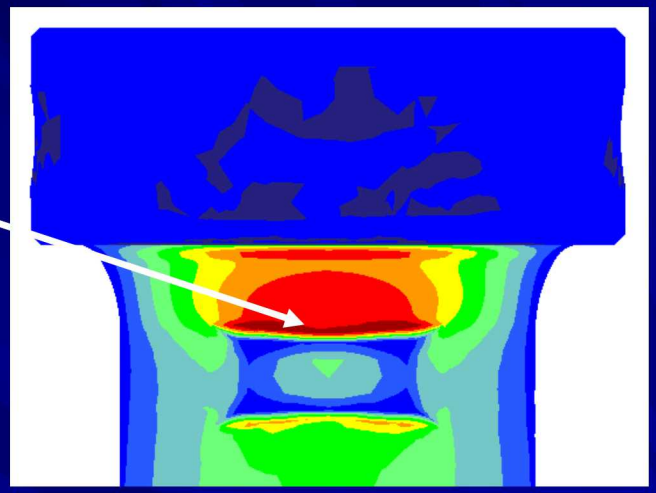
BACKGROUND

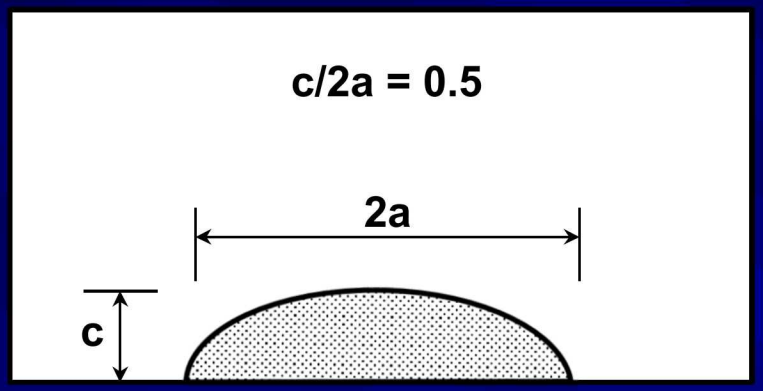
- ARRESTMENT HOOK SHANKS (AHS) FOR T-45 AIRCRAFT EXPERIENCED PREMATURE CRACKING IN THE FLEET.
- FULL-SCALE COMPONENT TESTING ESTABLISHED AN OVERHAUL INTERVAL OF 1,500 ARRESTMENTS.
- FLEET IDENTIFIED ANOMALOUS CRACKING AT SERVICE LIFE INTERVALS AS LOW AS 700 ARRESTMENTS.

NAVAIR CURTISS WRIGHT mi NMC

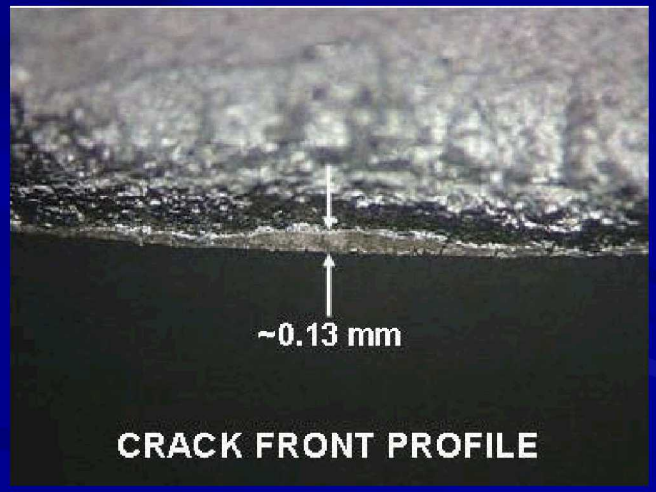
HIGH-STRESS REGION OF ARRESTMENT HOOK SHANK (AHS)

HIGH-STRESS REGION ALONG AFT EDGE OF RAISED BOSS





COMMON SURFACE CRACK GEOMETRY



NAVAIR

CURTISS WRIGHT

mi

NMC

HIGH-STRESS REGION OF ARRESTMENT HOOK SHANK (AHS)

LOCATION	AXIAL RESIDUAL STRESS (MPa)	CIRCUMFERENTIAL RESIDUAL STRESS (MPa)
REMOVED FROM HIGH-STRESS REGION	-628	-731
	-634	-655
	-621	-641
	-662	-600
HIGH-STRESS REGION	-48	NM
	-14	NM
	0	NM
	62	-76
	-69	NM
	-69	NM
	-110	NM
	-55	NM
	-97	NM
NM: NOT MEASURED		

NAVAIR

CURTISS WRIGHT

mi®

NMC

SIMPLE MECHANISTIC VIEW FOR FATIGUE LIFE REDUCTIONS

APPLY LOAD TO A STRESS CONCENTRATION IN A SHOT PEENED COMPONENT

DEEP MECHANICAL PLASTIC ZONE RELATIVE TO SHOT PEENED LAYER

GEOMETRIC COMPATABILITY CONSTRAINTS RELAX RESIDUAL STRESSES ON UNLOADING

LOW NEAR-SURFACE DUCTILITY AND REDUCTIONS IN RESIDUAL STRESS COMPROMISE FATIGUE RESISTANCE

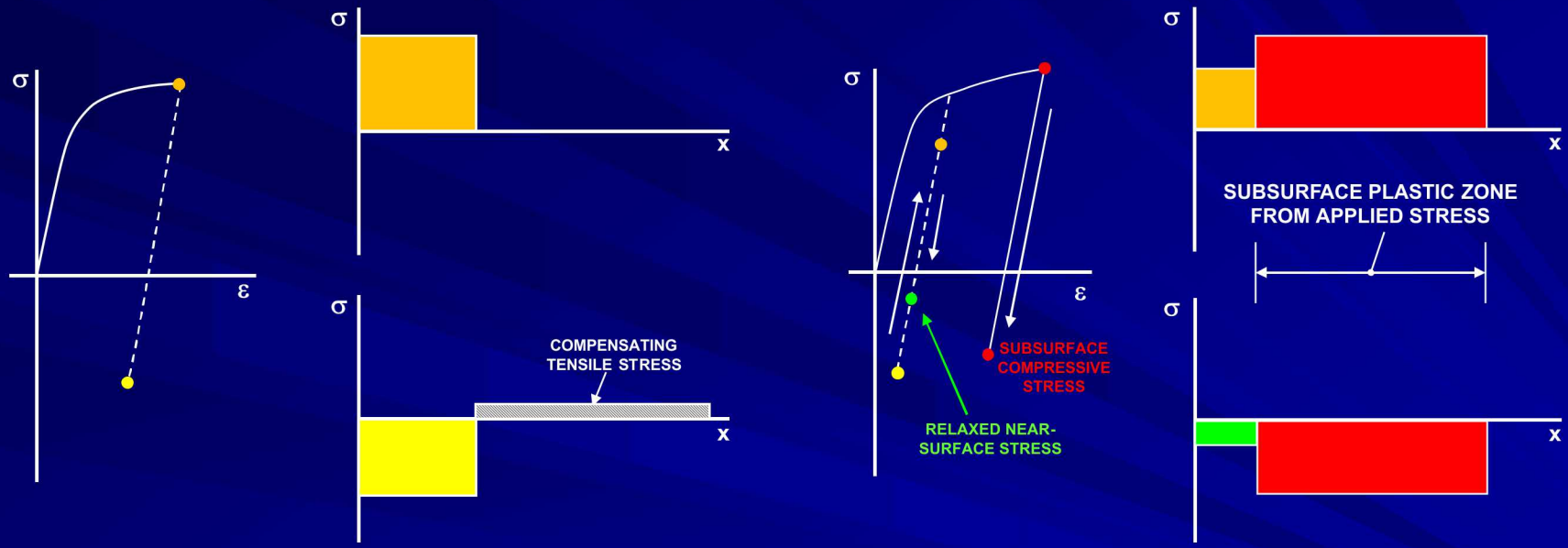
NAVAIR

CURTISS WRIGHT

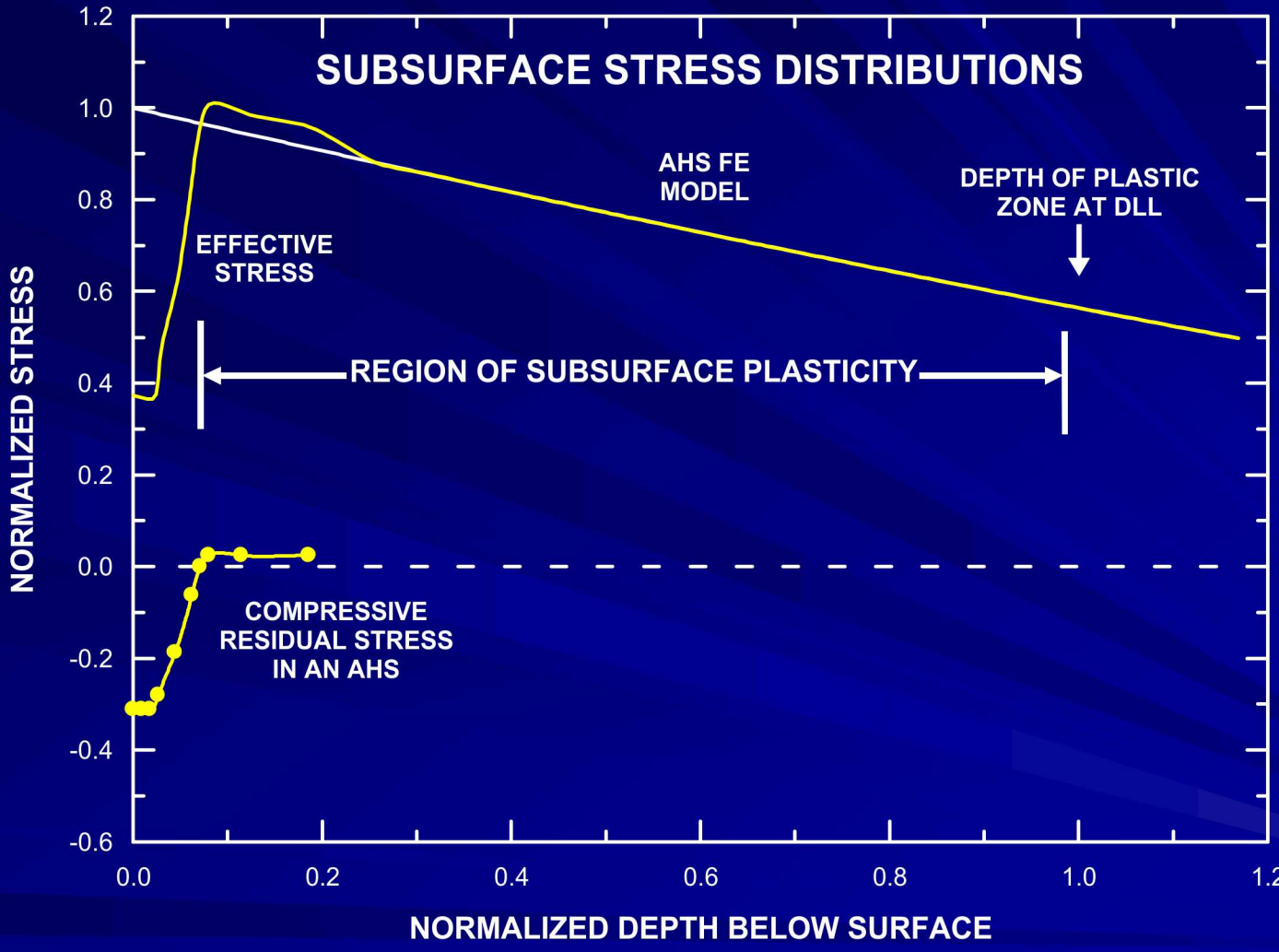
mi

NMC

SIMPLE MECHANISTIC VIEW FOR RESIDUAL STRESS RELAXATION



SIGNIFICANT FACTOR AFFECTING FATIGUE LIFE



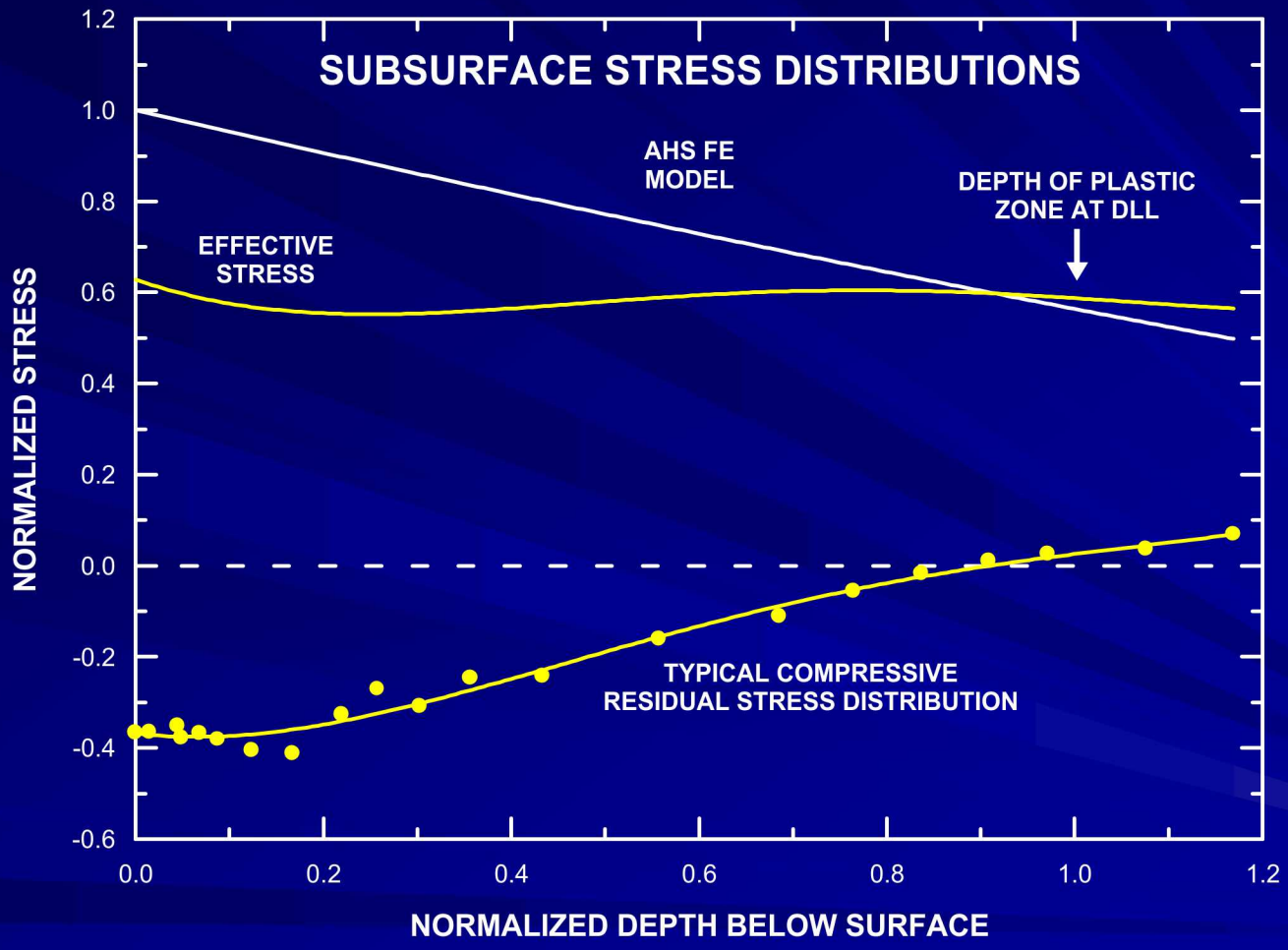
NAVAIR

CURTISS WRIGHT

mi

NMC

LASER PEENING TO MITIGATE CRACKING PROBLEM & IMPROVE FATIGUE LIFE



NAVAIR

CURTISS WRIGHT

mi

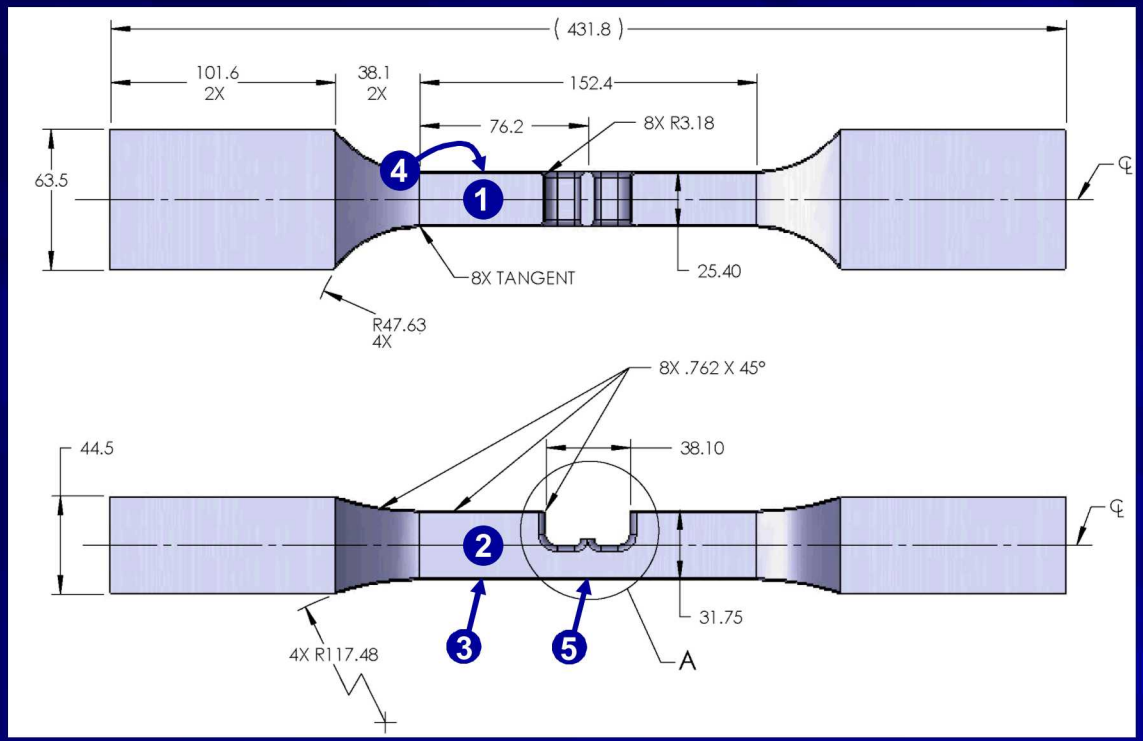
NMC

TEST PROGRAM OBJECTIVES

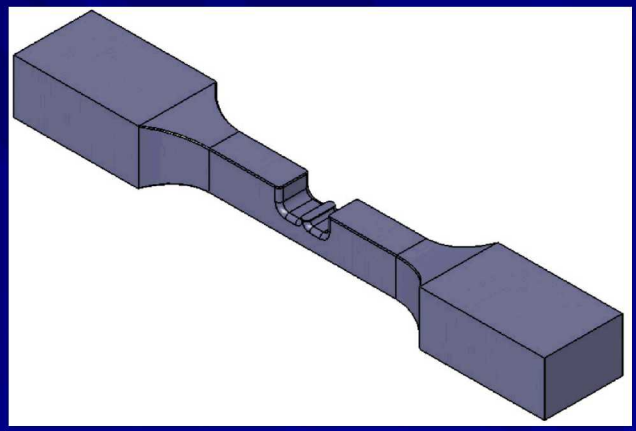
- Determine the relative benefits of Conventional Shot Peening (CSP) and Laser Shock Peening (LSP) on the spectrum fatigue life of a specimen that possesses a distribution of notch root stress similar to the highly-loaded region in the arrestment hook shank (AHS).
- Evaluate the combined effects of material strength and peening process on fatigue life in the AHS simulation specimen.
- Evaluate the combined effects of proof loading and peening process on fatigue life in the AHS simulation specimen.

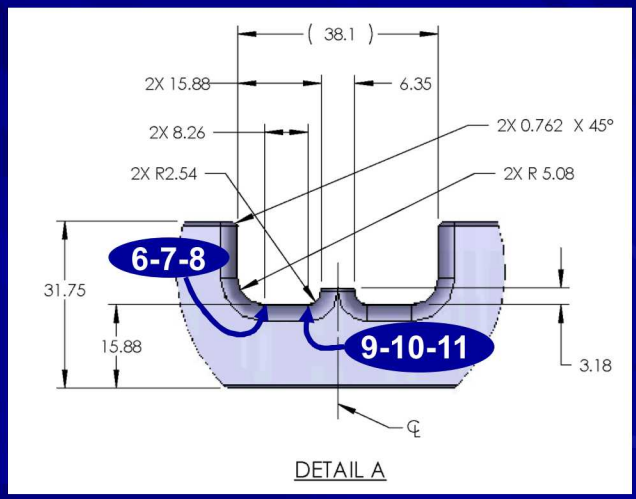
NAVAIR CURTISS WRIGHT mi NMC

TEST SPECIMEN DESIGN



SPECIMEN DIMENSIONS IN MILLIMETERS



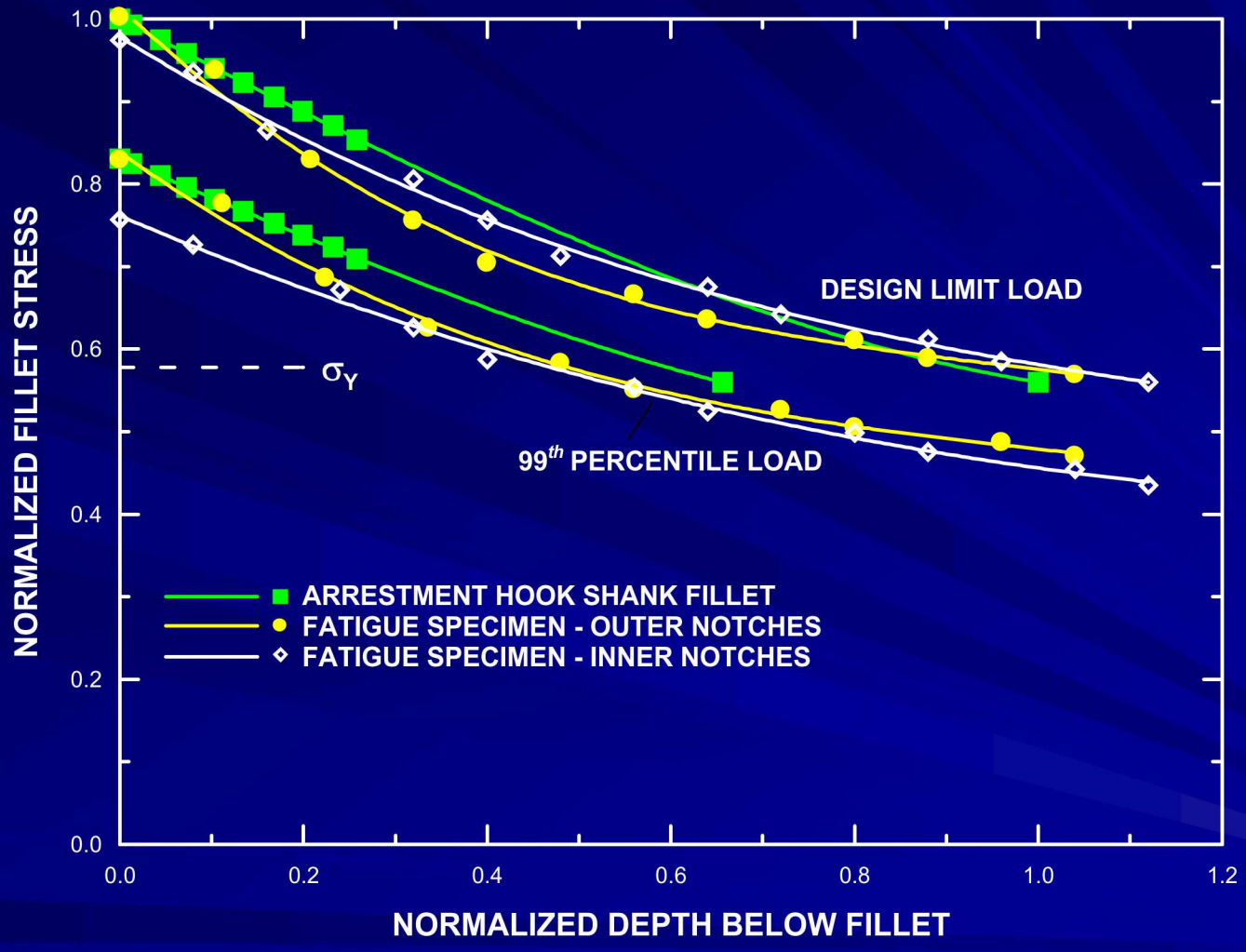


TEST SPECIMEN CHARACTERISTICS

- Notch design is geometrically similar to the arrestment hook shank.
- Depth of plasticity below both notches scales with the predicted plastic zone depth in the arrestment hook shank (no scaling of LSP process required as part of the test program).
- Stress gradient in both notches is similar to the predicted gradient in the FE model of the arrestment hook shank.
- Specimen design exhibits tensile stress on the back face, suggesting the proportion of bending to tension is generally representative of that in an arrestment hook shank.
- Fatigue cracking in the test specimen mimics the failure mode in the arrestment hook shanks.
- Two sets of two notches with similar stress-plastic zone depth profiles are tested with this specimen geometry.

NAVAIR CURTISS WRIGHT mi NMC

COMPARISON OF NOTCH STRESS DISTRIBUTIONS



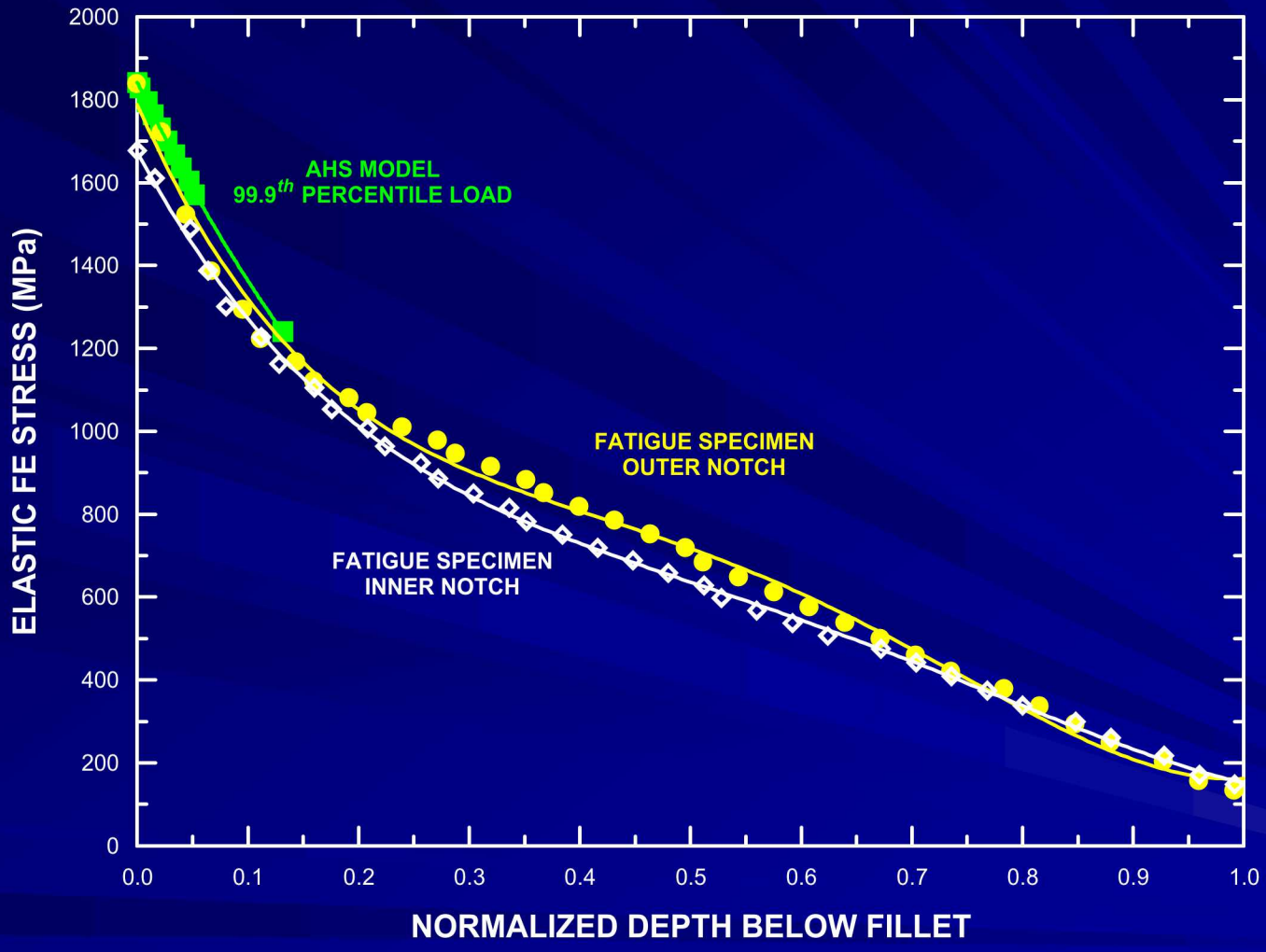
NAVAIR

CURTISS WRIGHT

mi

NMC

STRESS DISTRIBUTIONS THROUGH LIGAMENT



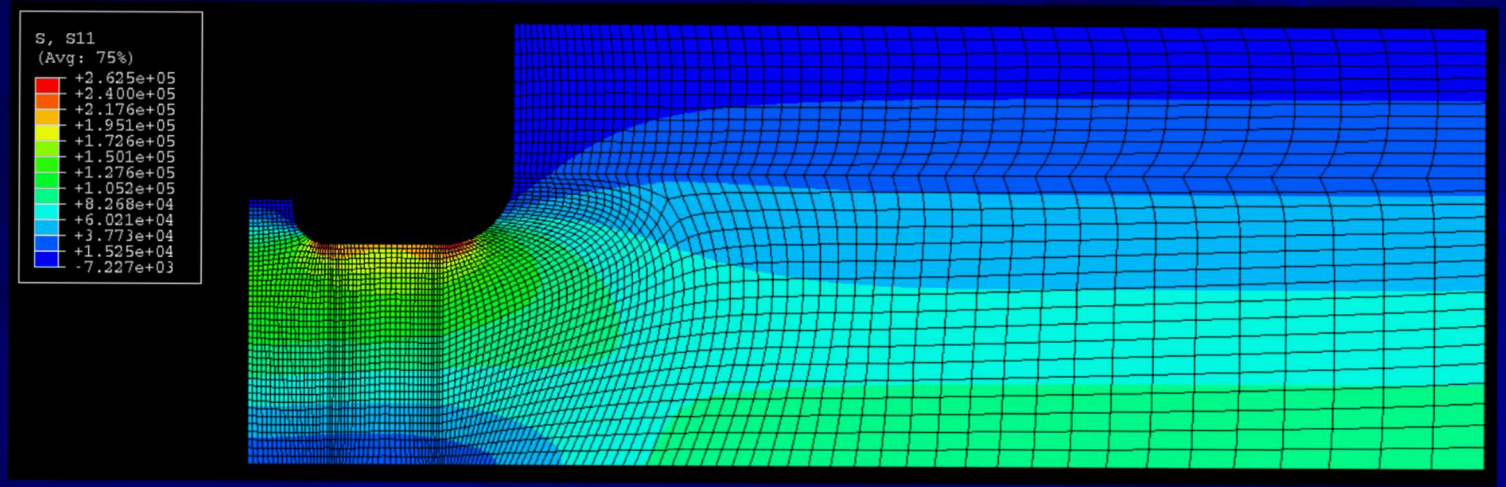
NAVAIR

CURTISS WRIGHT

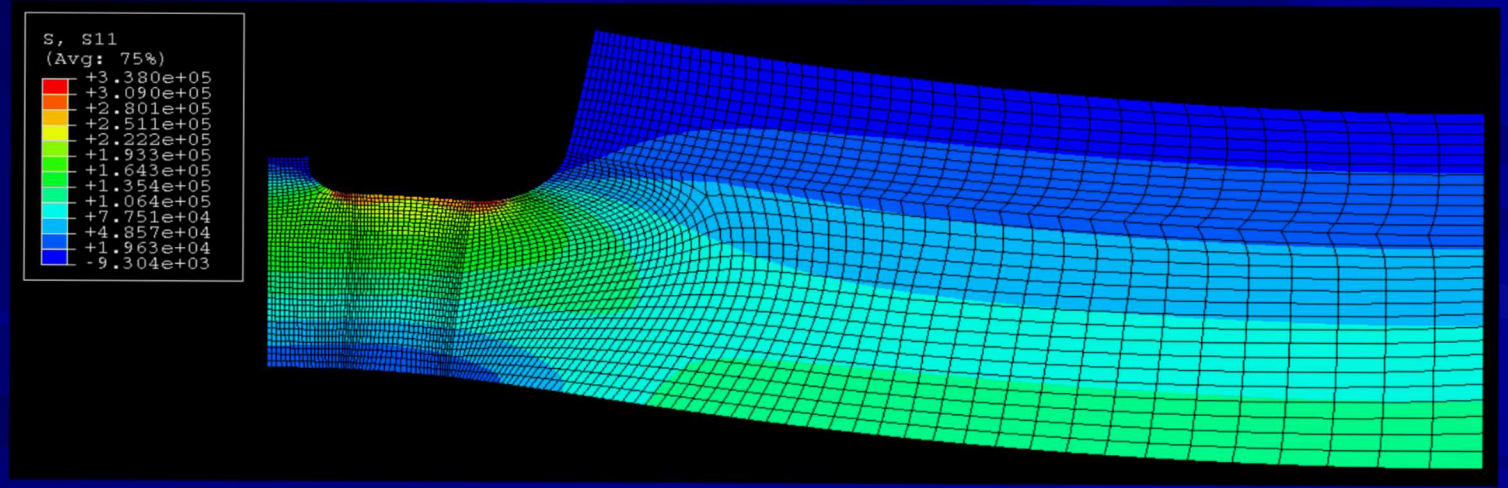
mi

NMC

ELASTIC FE ANALYSIS OF SPECIMEN DESIGN



99.9th PERCENTILE LOAD



DESIGN LIMIT LOAD

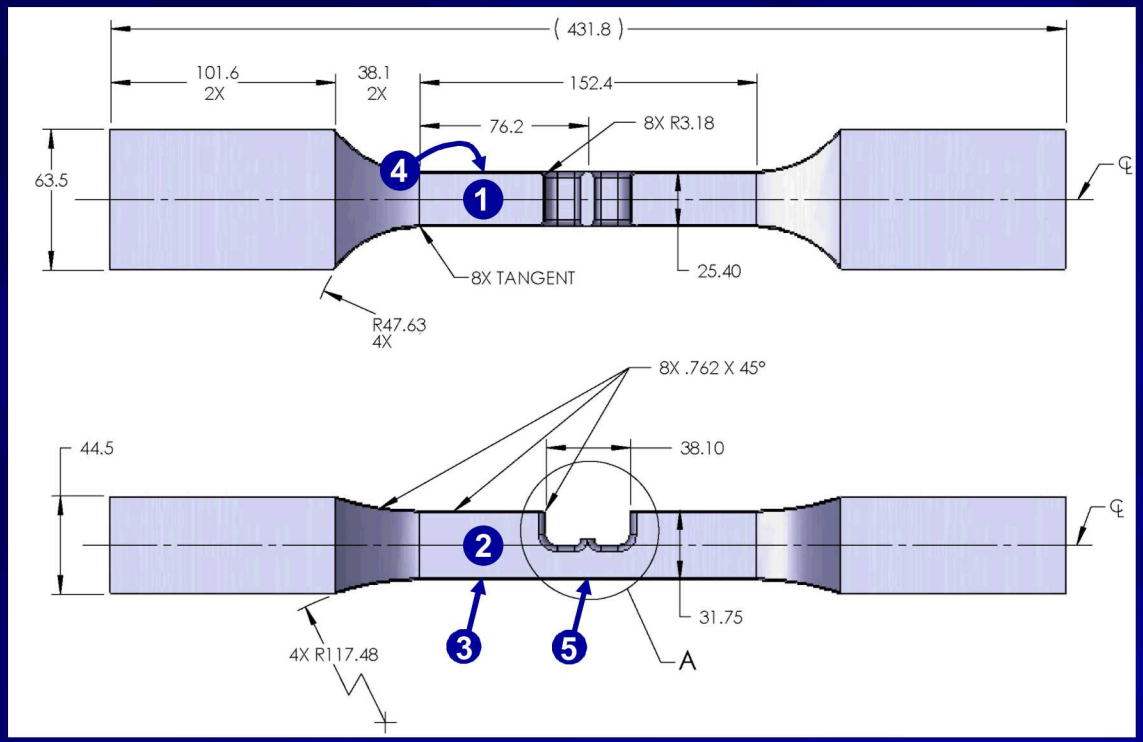
NAVAIR

CURTISS WRIGHT

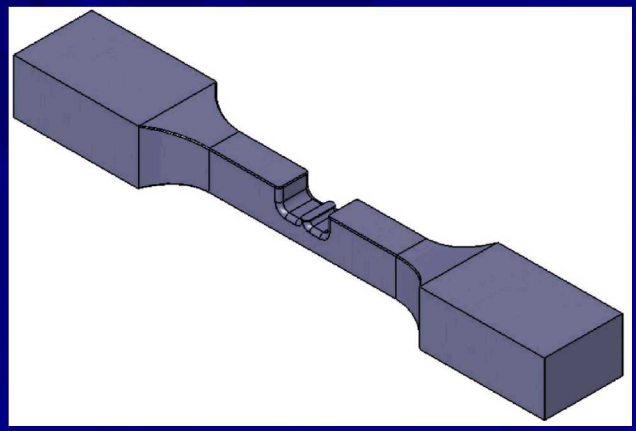
mi

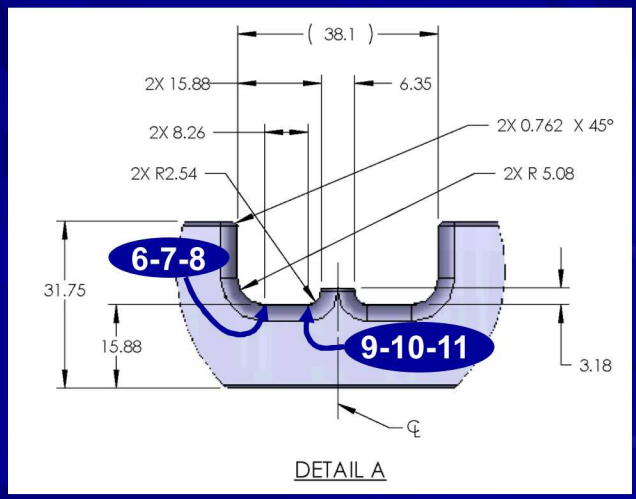
NMC

FATIGUE SPECIMEN VALIDATION

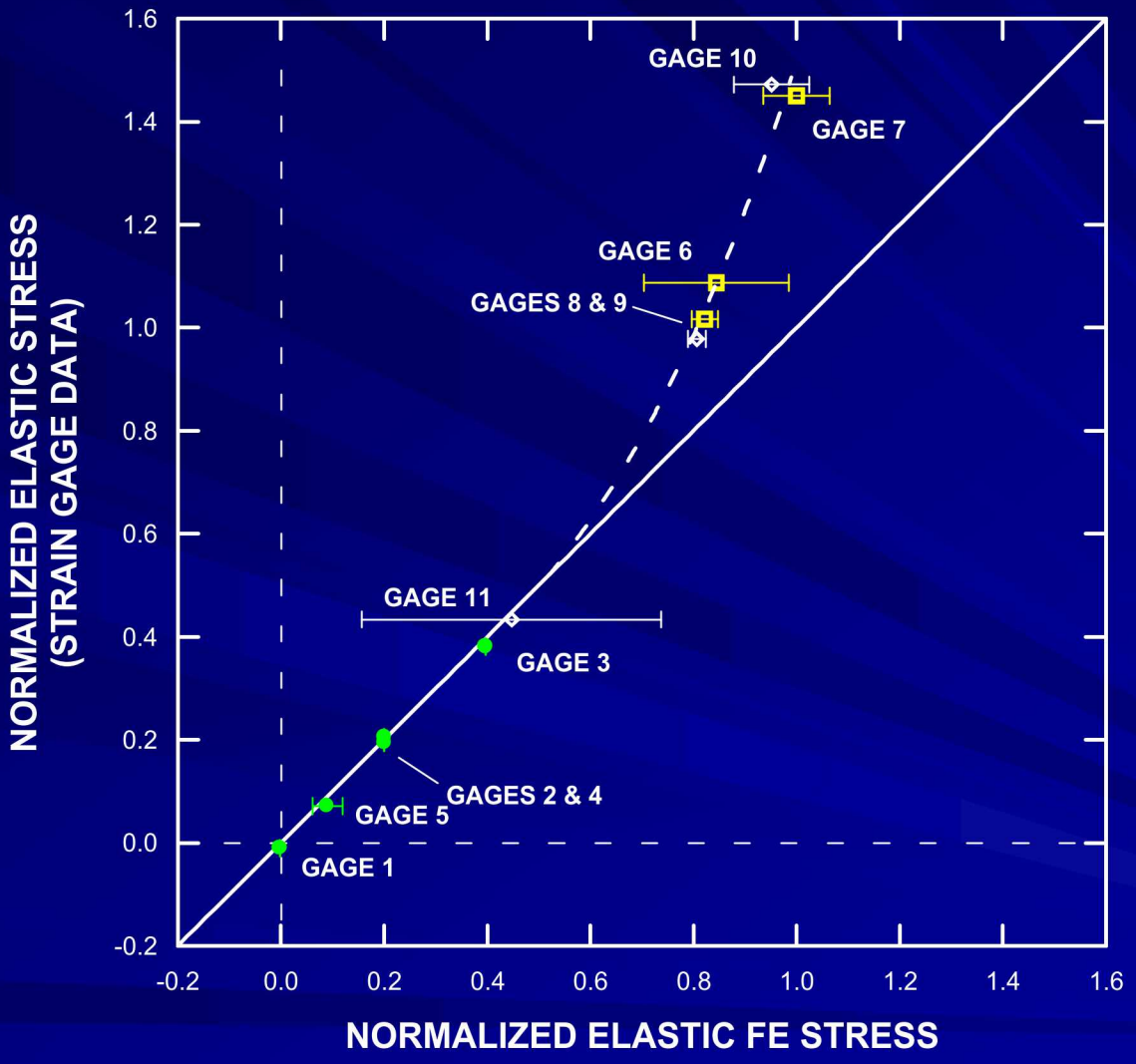


SPECIMEN DIMENSIONS IN MILLIMETERS





FATIGUE SPECIMEN VALIDATION



NAVAIR

CURTISS WRIGHT

mi

NMC

MATERIALS

STEEL	YIELD STRENGTH (MPa)	TENSILE STRENGTH (MPa)	ELONGATION (%)	REDUCTION IN AREA (%)	FRACTURE TOUGHNESS ($MPa\cdot m^{1/2}$)
Hy-Tuf	1338	1596	14	50	148*
Ferrium S53	1470	1960	14	56	70

*The reported value of fracture toughness, obtained from three measurements, represents a candidate K_Q value based on ASTM E399. Specimens failed the thickness and P_{MAX}/P_Q validity requirements.

NAVAIR CURTISS WRIGHT mi NMC

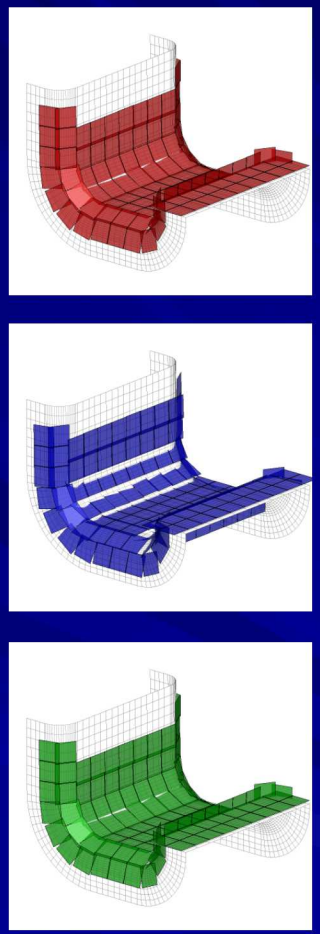
PROCESSING

CSP SPECIMENS

- HEAT TREAT & MACHINE
- PEEN WITH 230H SHOT TO 10A, 100% COVERAGE

LSP SPECIMENS

- HEAT TREAT & MACHINE
- LASER PEEN AT 10 GW/cm^2 (16 J) WITH 18 ns PULSES, 3 x 3 mm SPOT SIZE, AND 3 LAYERS
- CONVENTIONAL SHOT OVER-PEEN WITH 230H SHOT TO 10A, 100% COVERAGE



LAYER 1
(3% OVERLAP)

LAYER 2
(OFFSET PATTERN)

LAYER 3
(ALIGNED WITH LAYER 1)

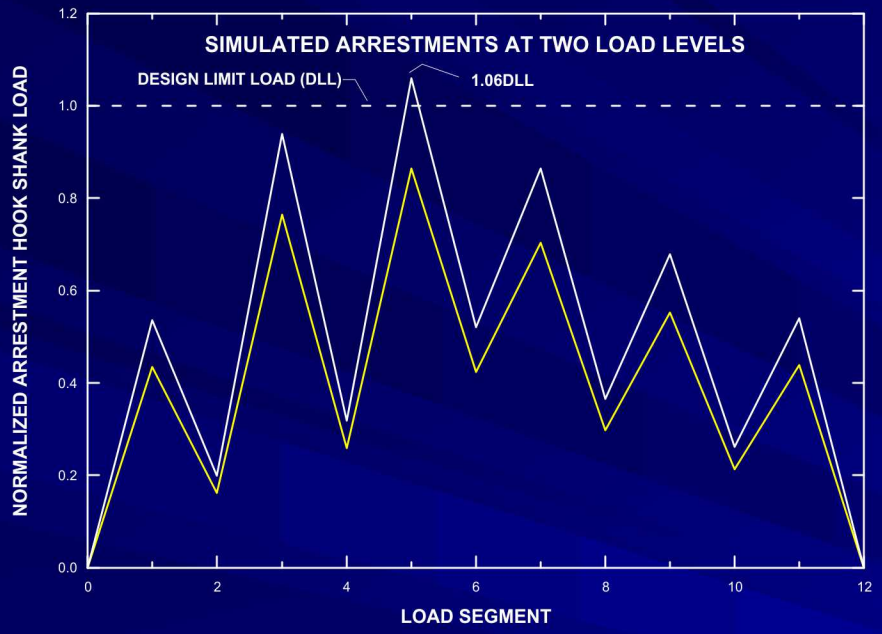
NAVAIR

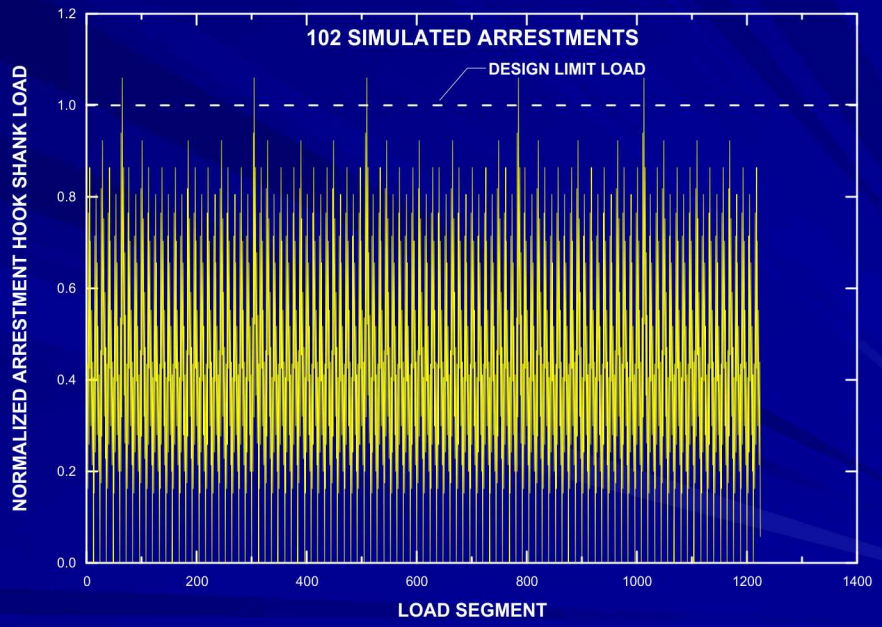
CURTISS WRIGHT

mi

NMC

FATIGUE TEST SPECTRUM





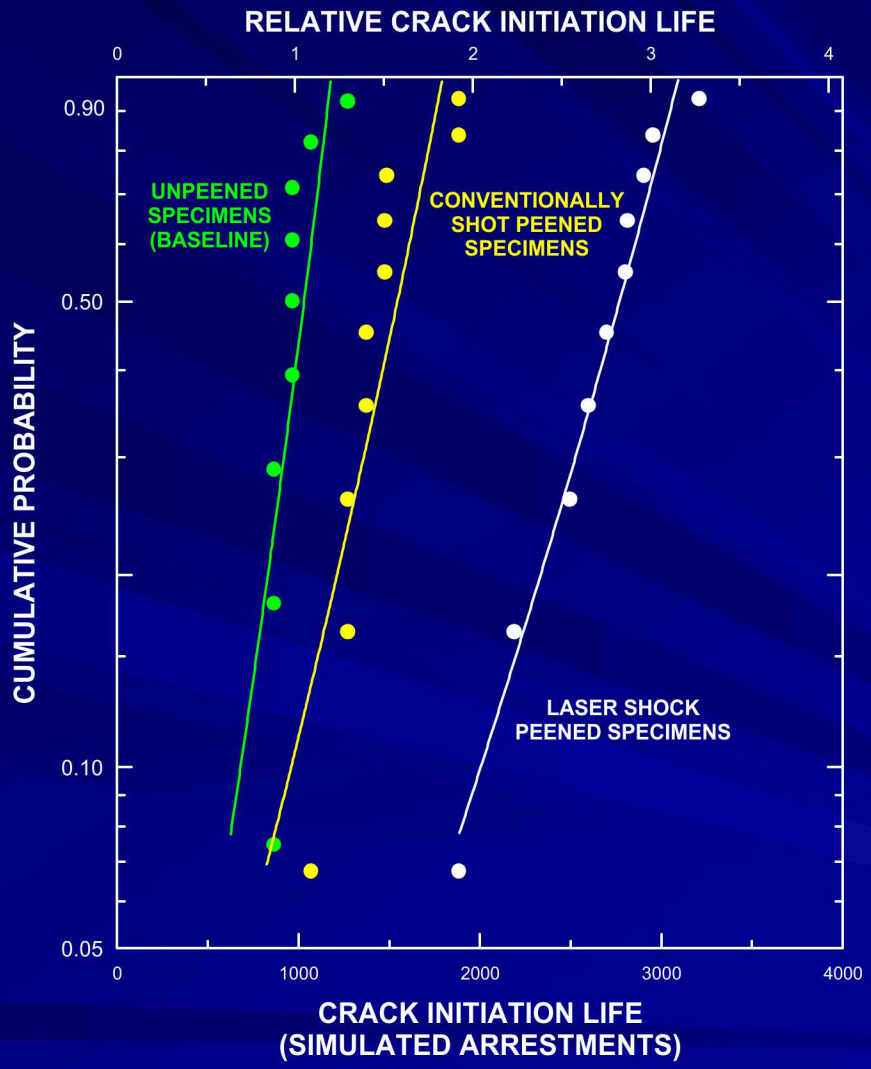
NAVAIR

CURTISS WRIGHT

mi

NMC

BASELINE FATIGUE TESTS



NAVAIR

CURTISS WRIGHT

mi

NMC

BASELINE FATIGUE TESTS

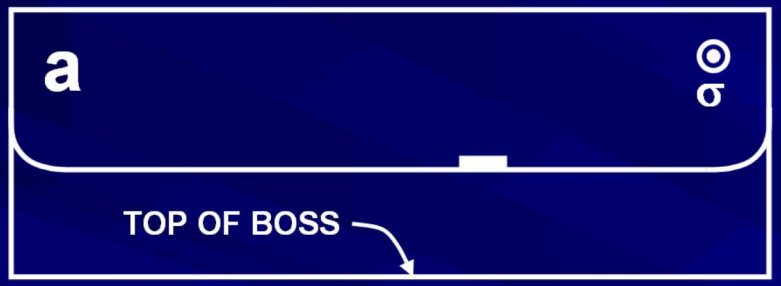
SPECIMEN GROUP	MEAN CRACK INITIATION LIFE RATIO	LOWER-BOUND CRACK INITIATION LIFE RATIO (S BASIS)
UNPEENED (BASELINE)	1	1
CSP	1.49	0.97
LSP + CONVENTIONALLY OVERPEENED	2.71	2.51

MATERIAL	MATERIAL CONDITION	SIMULATED ARRESTMENTS		
		CRACK INITIATION LIFE	TOTAL LIFE	CRACK PROPAGATION LIFE
HY-TUF STEEL	UNPEENED	969	2591	1622
HY-TUF STEEL	CSP	1275	2693	1418
HY-TUF STEEL	LSP + CONVENTIONALLY OVERPEENED	2601	6102	3501
FERRIUM S53 STEEL	LSP + CONVENTIONALLY OVERPEENED	3927	6961	3034

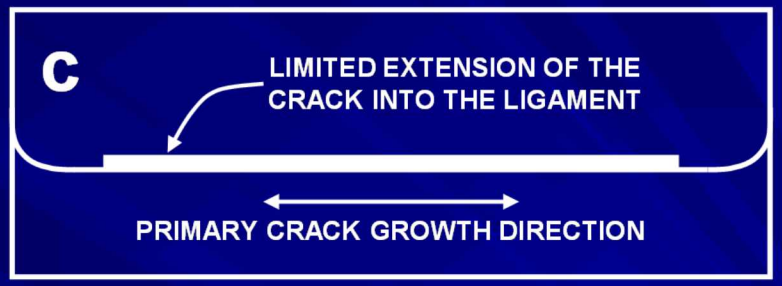
NAVAIR CURTISS WRIGHT mi NMC

FRACTURE SURFACE DEVELOPMENT

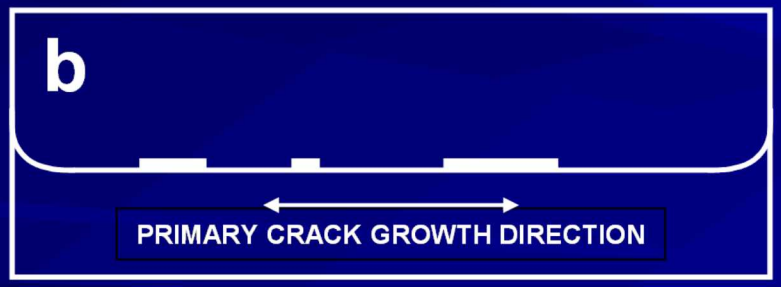
INITIATION AND GROWTH OF A SHALLOW SURFACE CRACK



GROWTH AND COALESCENCE INTO A LONG, SHALLOW SURFACE CRACK

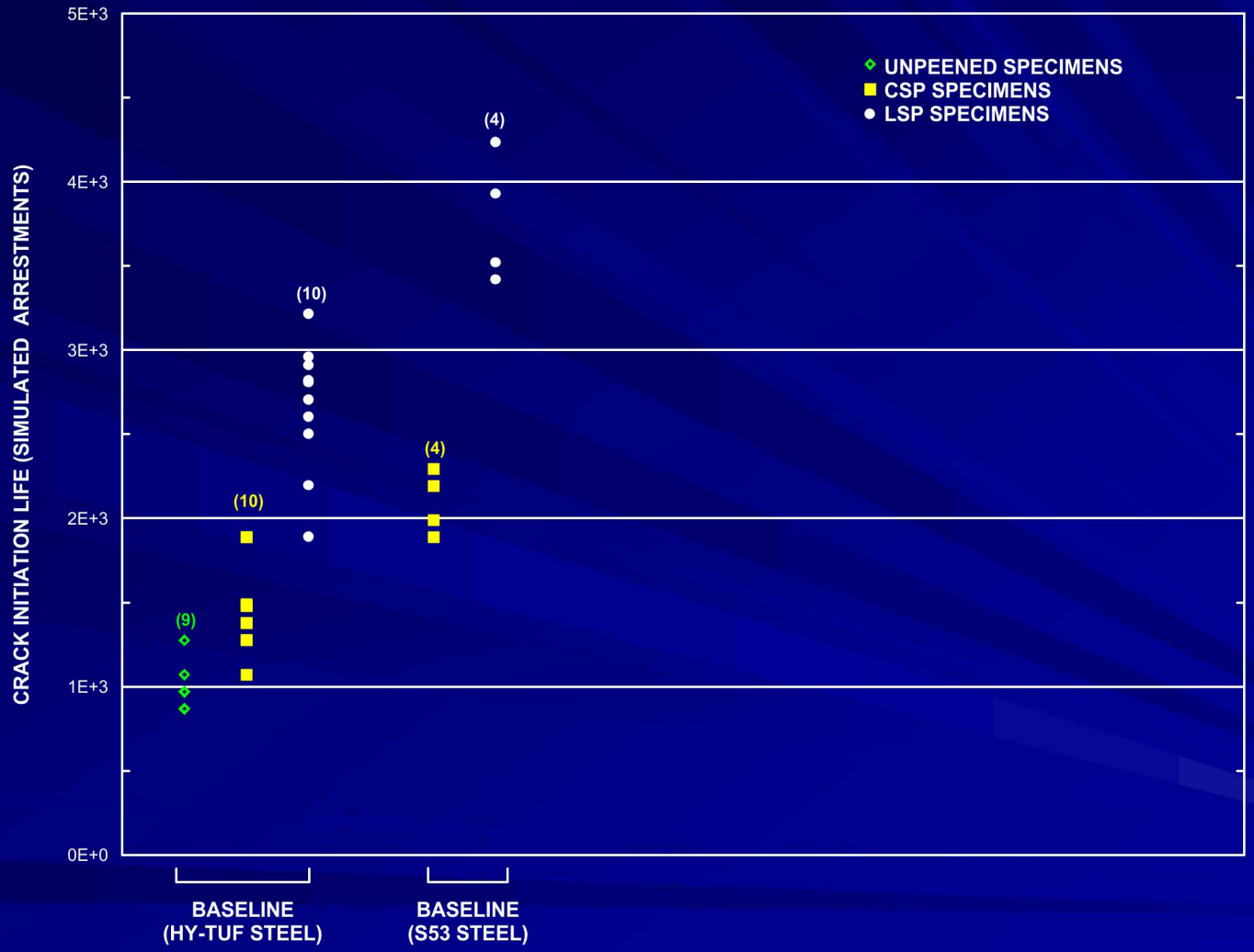


CONTINUED INITIATION AND GROWTH OF SHALLOW SURFACE CRACKS



GROWTH OF THE LONG, SHALLOW SURFACE CRACK THROUGH THE LIGAMENT

FATIGUE TEST RESULTS
(MATERIAL STRENGTH EFFECTS)



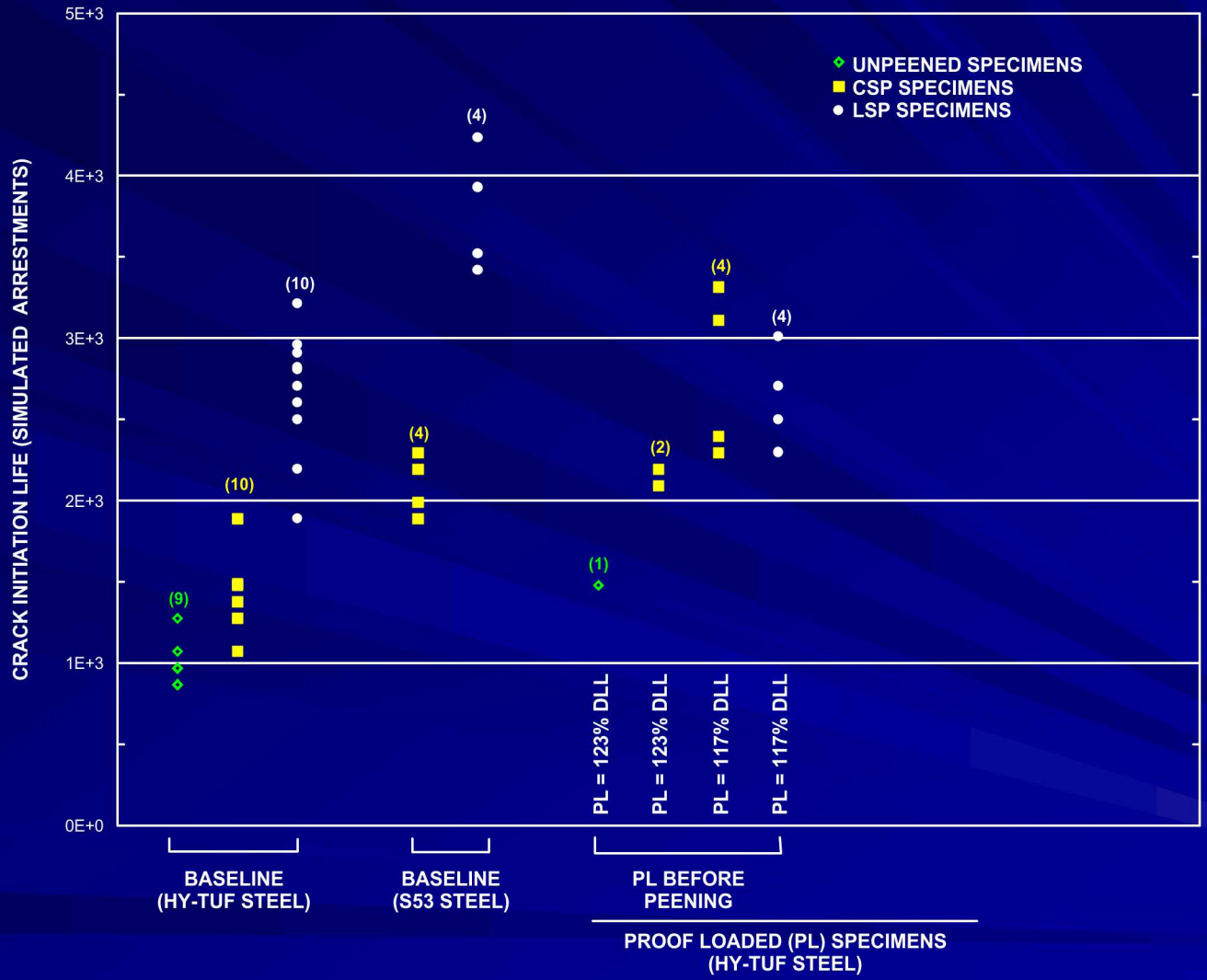
NAVAIR

CURTISS WRIGHT

mi

NMC

FATIGUE TEST RESULTS
(PROOF LOADING EFFECTS)



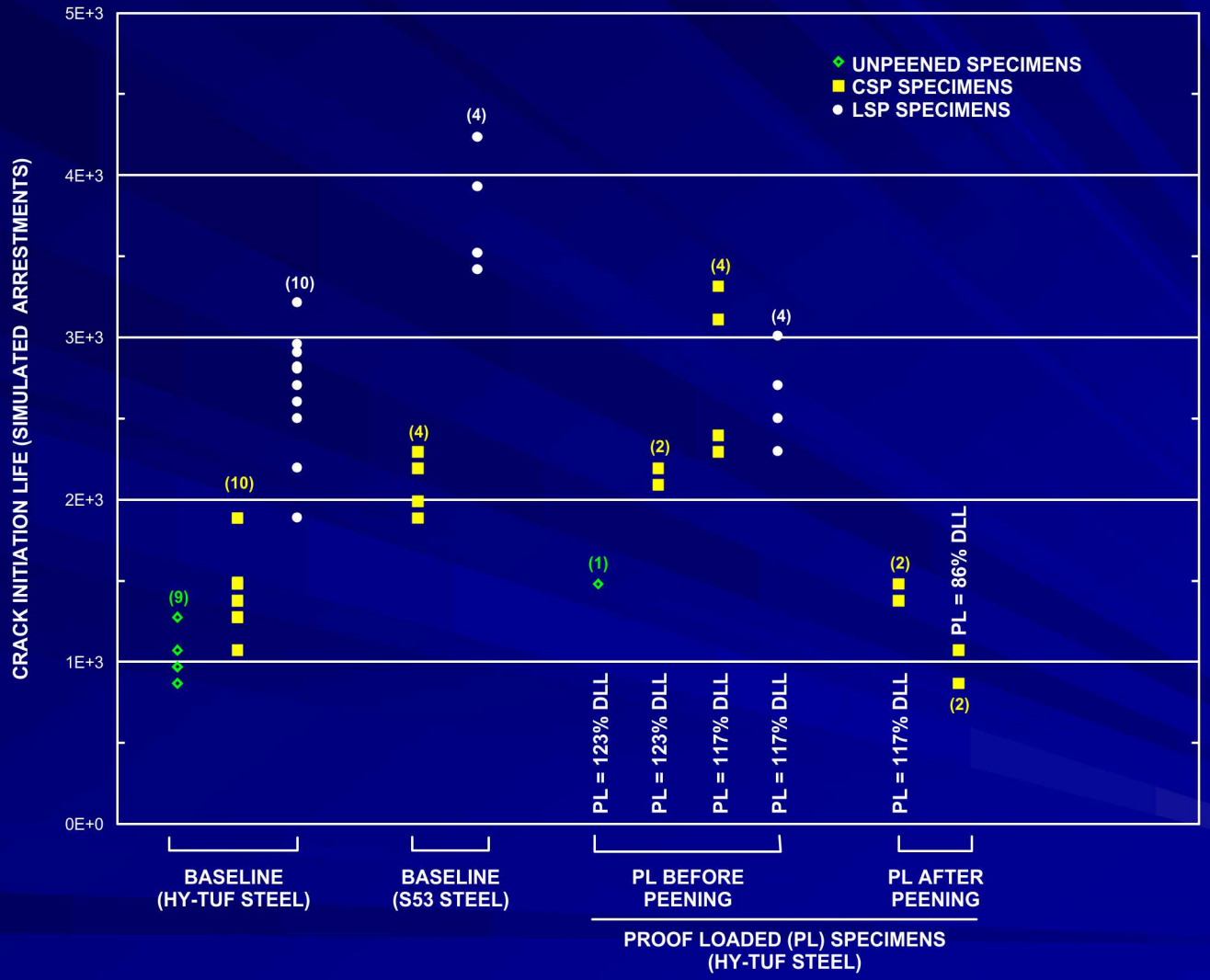
NAVAIR

CURTISS WRIGHT

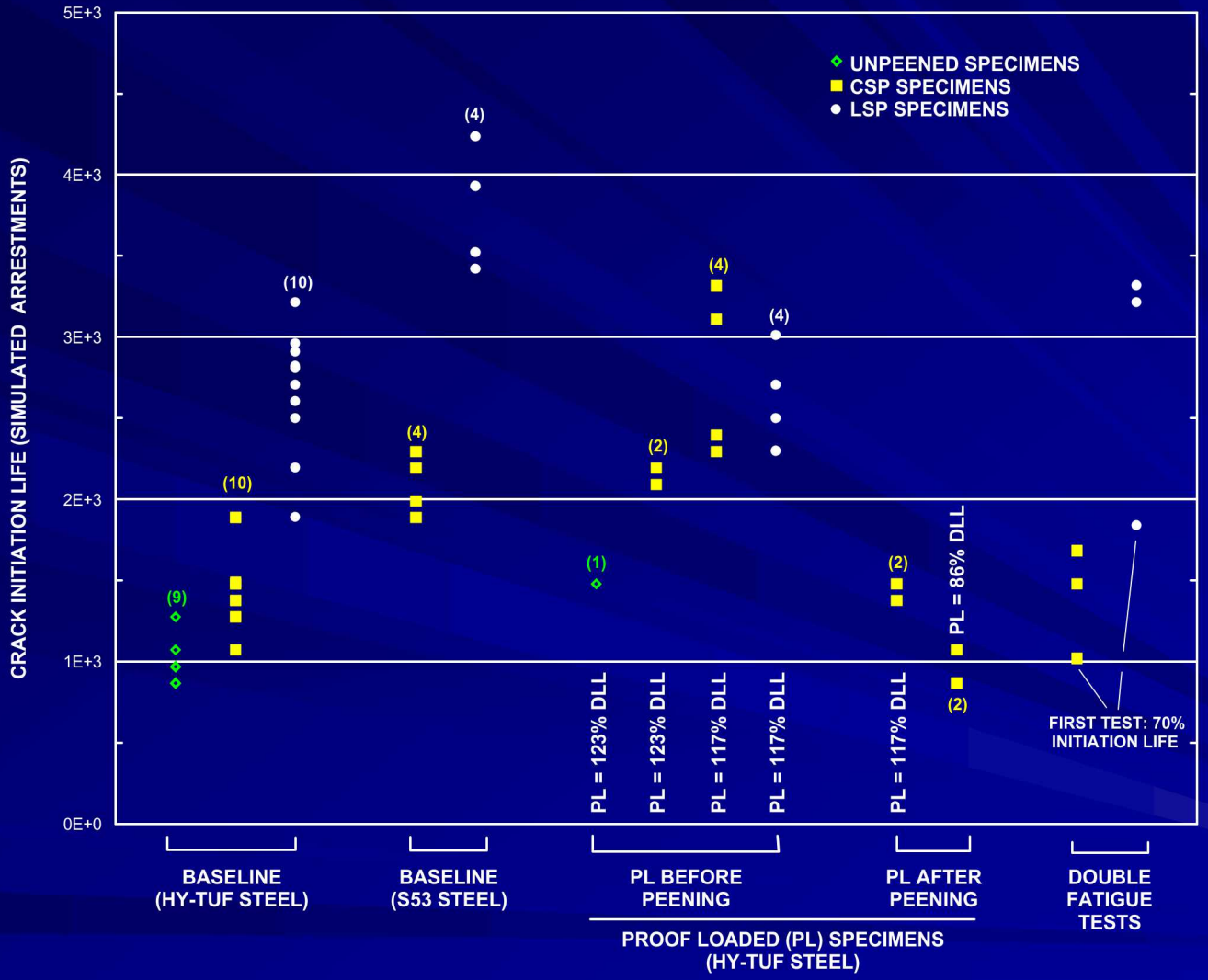
mi

NMC

FATIGUE TEST RESULTS
(PROOF LOADING EFFECTS)



FATIGUE TEST RESULTS
(DOUBLE FATIGUE TESTS)



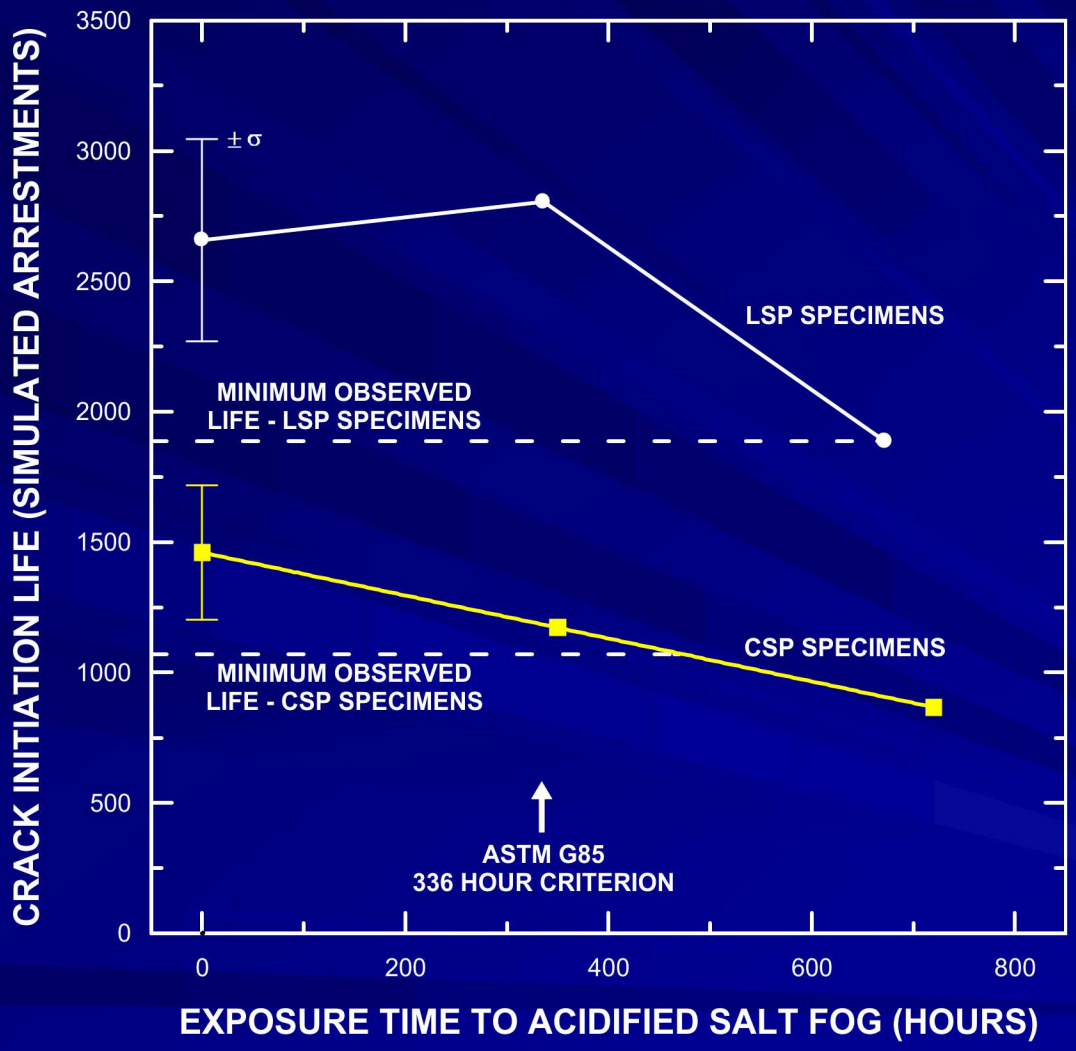
NAVAIR

CURTISS WRIGHT

mi

NMC

ENVIRONMENTAL EXPOSURE EFFECTS



NAVAIR

CURTISS WRIGHT

mi

NMC

SUMMARY

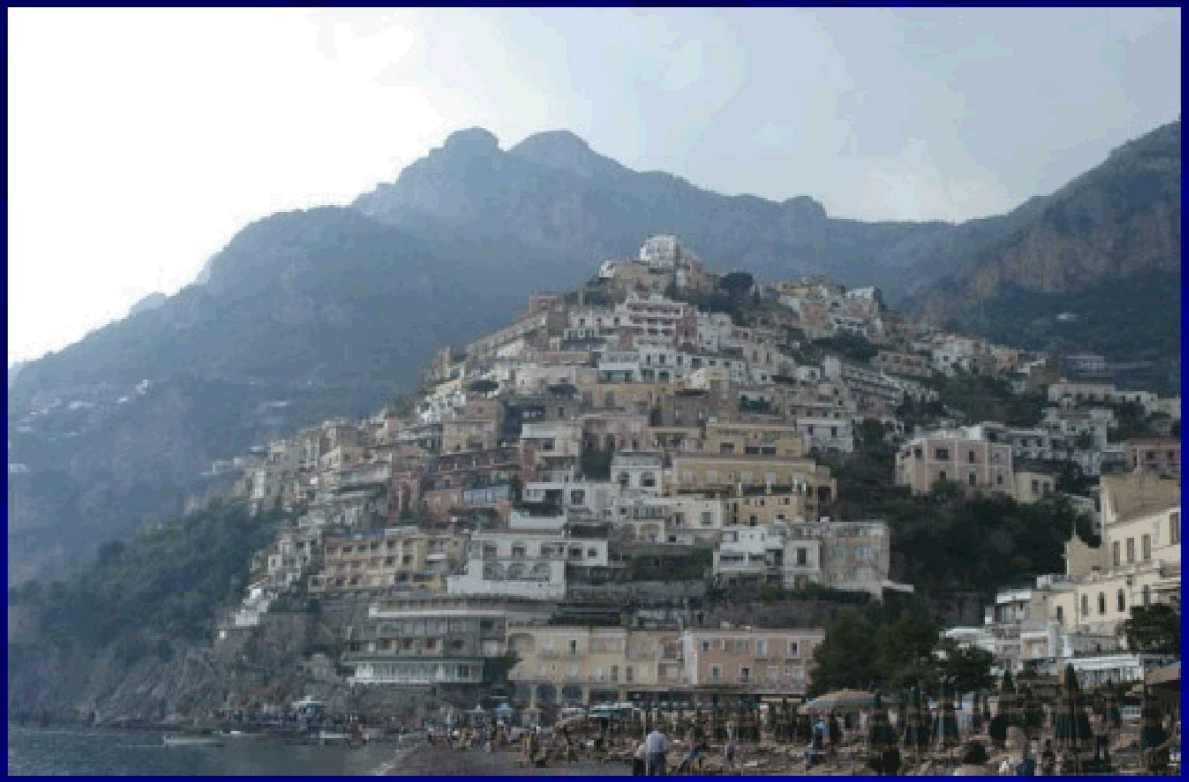
- Laser peening provides substantial improvements over conventional shot peening in the fatigue life of a test specimen designed to simulate the high-stress region in an arrestment hook shank for a Naval aircraft.

- An increase in yield strength from 1338 to 1470 MPa substantially increases the crack initiation life of conventional and laser peened specimens. High material strength in combination with laser peening is associated with the development of particularly high levels of fatigue life.

- The combined effects of proof loading and conventional or laser peening on fatigue life can be rationalized in terms of the relative depths of plastic deformation and compressive residual stress below the surface of the stress concentration.

NAVAIR CURTISS WRIGHT mi NMC

THANK YOU!



This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy, National Nuclear Security Administration under contract DE-NA0003525.

NAVAIR

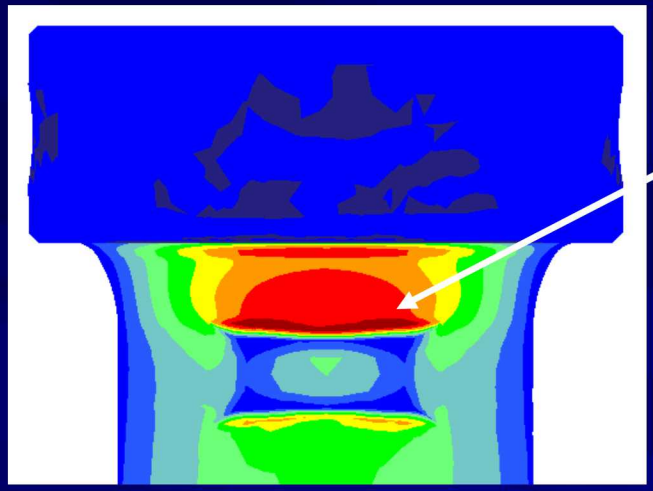
CURTISS WRIGHT

mi

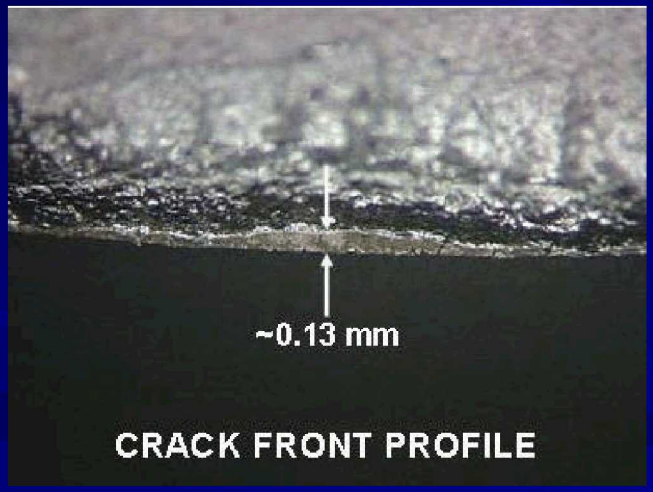
NMC

EXTRA SLIDES

HIGH-STRESS REGION OF ARRESTMENT HOOK SHANK (AHS)



HIGH-STRESS REGION ALONG AFT EDGE OF RAISED BOSS



LOCATION	AXIAL RESIDUAL STRESS (MPa)	CIRCUMFERENTIAL RESIDUAL STRESS (MPa)
REMOVED FROM HIGH-STRESS REGION	-628	-731
	-634	-655
	-621	-641
	-662	-600
HIGH-STRESS REGION	-48	NM
	-14	NM
	0	NM
	62	-76
	-69	NM
	-69	NM
	-110	NM
	-55	NM
	-97	NM
NM: NOT MEASURED		