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Austin TX

Development of a Residual Stress Standard

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This work was a collaborative effort of:
ASM Technical Committee on Residual Stress
Subcommittee on Residual Stress Standard Development

Development of a Residual Stress Standard

ABSTRACT

In the past ten to fifteen years, significant progress toward the understanding and management of residual stresses in metallic structure has been made under the auspices of numerous Metals Affordability Initiative (MAI) projects, Small Business Innovative Research (SBIR) projects, USAF program funded projects, and many others. In January of 2020, the ASM International Technical Committee on Residual Stress formed a sub-committee on residual stress standards development, whose goal is to promote the development of standards and specifications for the measurement, modeling, understanding and management of residual stress. This activity has resulted in a draft AMS standard, the purpose of which is to provide uniform methods for defining, quantifying and classifying the residual stress in metallic structural alloy products and finished parts. Such quantification and classification may be required when residual stresses within components can impact further in-process distortion during machining or other methods, and when residual stresses within components can impact final component mechanical properties and performance.

The draft standard establishes residual stress classification criteria in terms of residual stress category and class. The currently defined residual stress categories are: 1) bulk residual stress, or near zero controlled residual stress, 2) joining residual stress, or tensile controlled residual stress, 3) engineered residual stress, or compressive controlled residual stress, and 4) targeted residual stress, or other residual stress not characterized as Category 1, 2 or 3. Within each category, there are four residual stress classes which identify the range of stress needed to achieve a given level of quality assurance or product performance, as well as a fifth class for reporting purposes only. In general terms, the residual stress classes are: A) tightly controlled, B) moderately controlled, C) loosely controlled, D) uncontrolled, and E) report only. The standard provides process guidance with regard to product or part zoning and then residual stress assessment within a zone. Residual stress assessment within a zone can be accomplished either by measurement or modeling, or a combination of the two. Finally, the product or part is classified according to the assessed value of residual stress within the zone. This presentation will include a high level summary of the standard, the current status of the standard (in terms of its release), and several examples of the potential application of the standard.

Development of a Residual Stress Standard

ASM Technical Committee on Residual Stress
Subcommittee on Residual Stress Standard Development

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Background

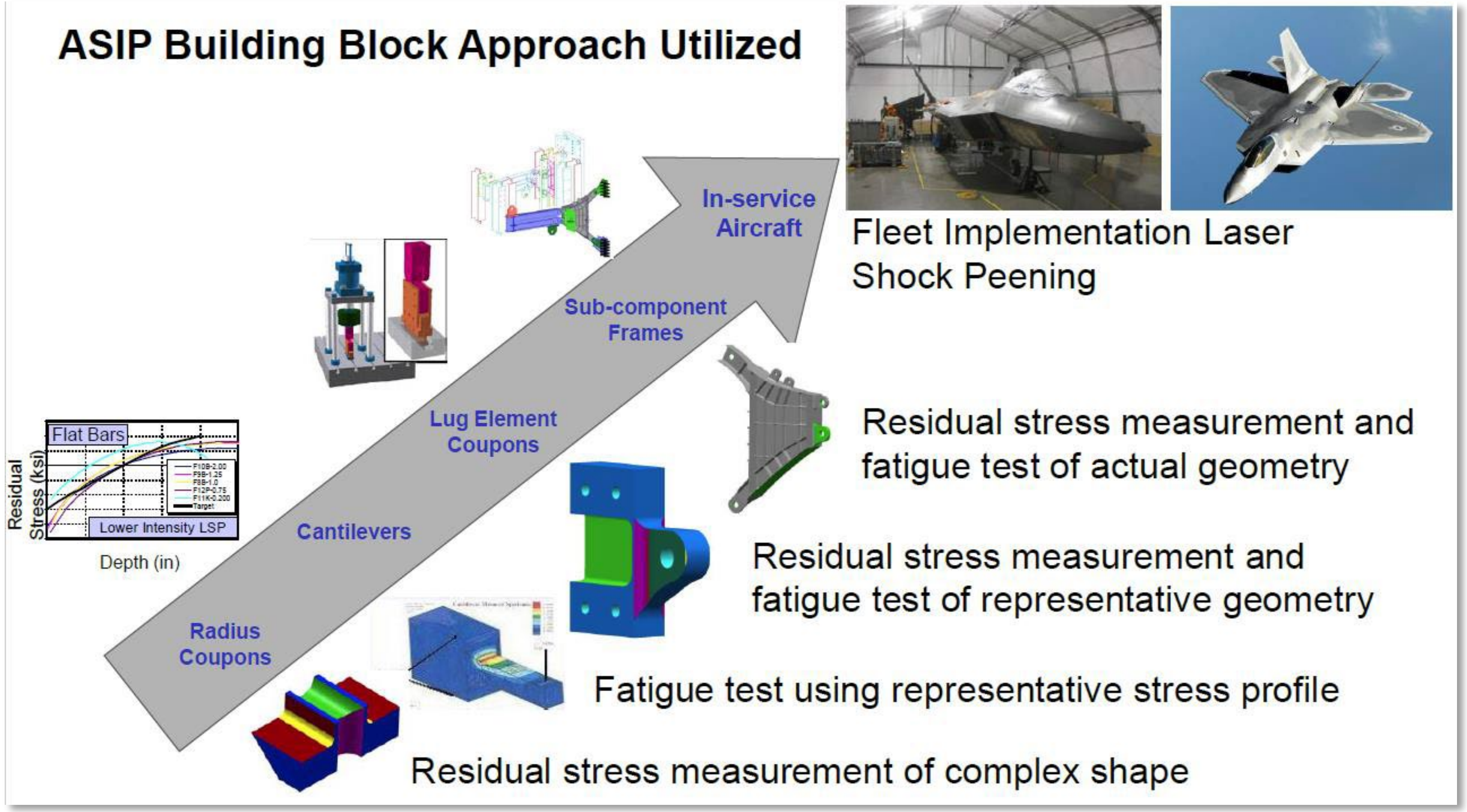
- **The understanding of residual stresses and their effects can be critical to the optimization of the manufacturability and performance of aerospace structural components.**
- **Residual stresses (RS) can be of several types and result from many different processes:**
  - *Manufacturing-process-induced, "bulk" RS:*
    - Caused by quenching, forging, heat treating, etc.…
    - May be compressive to > 50% TYS in magnitude
    - Results in distortion, fatigue and damage tolerance impacts
  - *Joining RS:*
    - Caused by welding, brazing, diffusion bonding, etc….
    - Typically highly non-uniform, may be > 50% TYS in magnitude
    - Results in distortion, fatigue and damage tolerance impacts
  - *Engineered RS:*
    - *Intentionally induced by peening, LSP, LPB, cold-expansion, etc…*
    - *Magnitude may exceed 75% YS locally, usually has steep stress gradient.*
    - *Applied intentionally to improve durability and damage tolerance*
  - *Others*

Background

- **Historically: RS effects have been accounted for on a case-by-case basis.**
- ***Detrimental (tensile) RS*** **are typically mitigated by modifying or adding processing steps:**
  - *Modified quench, heat treatment protocols*
  - *Mechanical or thermal stress relief*
  - *etc.*
- ***Beneficial (compressive) RS*** **are frequently introduced by applying post production processes:**
  - *In the case of beneficial RS, many specifications require that the RS be installed but do not allow the associated performance benefit (typically increased fatigue life) to be considered for margin calculation*
  - *When RS benefit is allowed for design, effects on strength and life (DaDT) must be quantified and validated by empirically-based "point design solutions," and in many cases, very expensive and time consuming qualification programs must be performed.*

Background

- **Example "Point design solution" approach**
- **Highly empirical assessments:**
  - *Specialized RS measurements*
  - *Many experimental coupons*
  - *Empirical assessment of effects*
  - *Mission-specific validation*
- **Fatigue benefit finally captured**



M.R. Hill, "Analytical Considerations for Residual Stress Best Practices and Case Studies," July 2018.

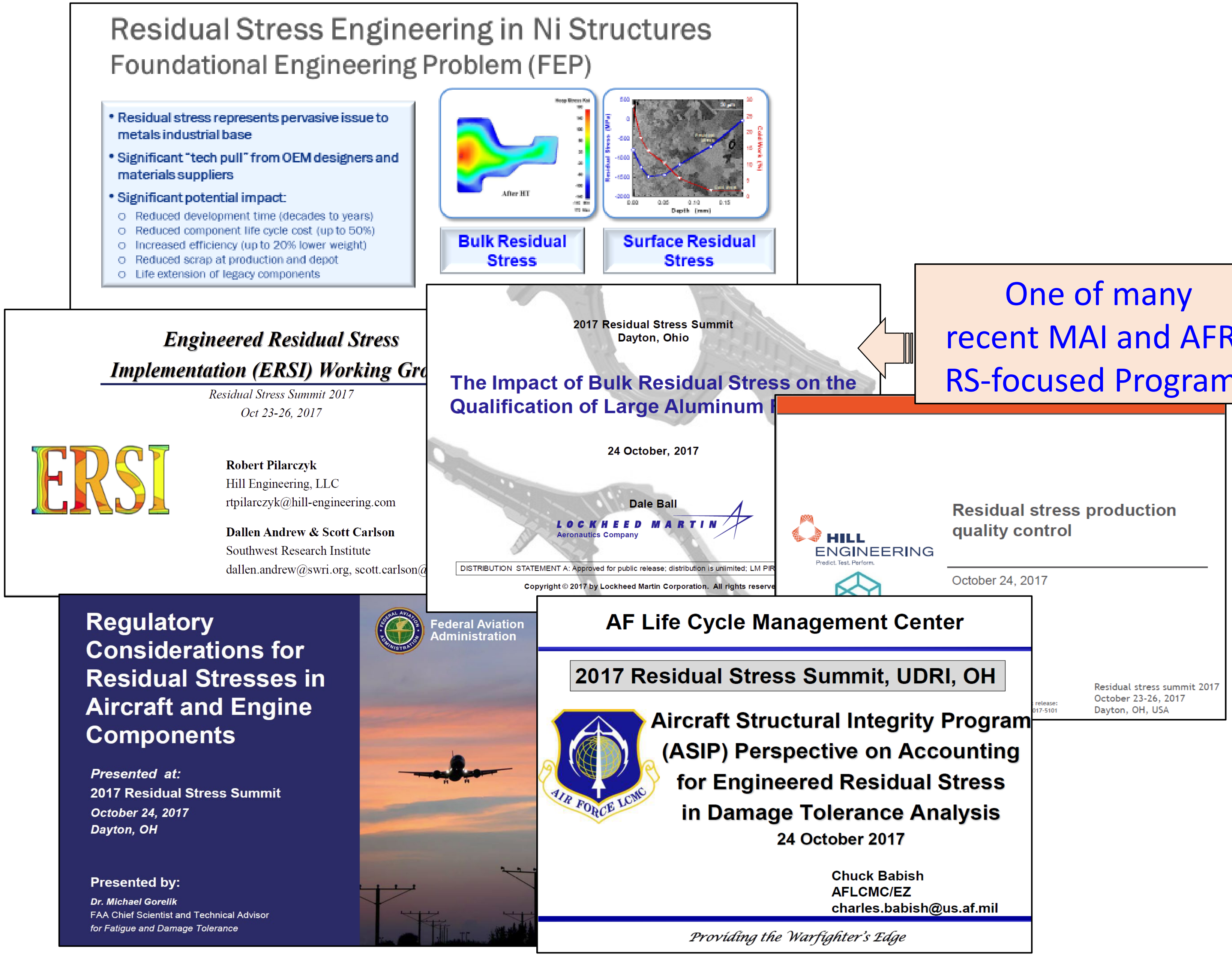
Background

- **Today: there is broad interest in the quantification of RS in structural components, as well as the development, validation, and use of computational tools which allow the explicit inclusion of RS in engineering design / analysis**
- **For process-induced RS – to achieve:**
  - *Reduced component development and manufacturing costs*
  - *Reduced impact on strength, durability and damage tolerance capability*
- **For joining RS – to achieve:**
  - *Reduced assembly and manufacturing costs*
  - *Reduced impact on strength, durability and damage tolerance capability*
- **For engineered RS – to achieve:**
  - *Improved HCF and associated damage tolerance*
  - *Increased LCF life and LCF damage tolerance*
- **Successful, broad implementation will require significant, integrated demonstration of analytical and experimental tools, RS measurement methods, and:**

Development of measurement and quality assurance standards for RS.

Background

- **Increasing research directed toward residual stress measurement and modeling:**
  - *AFRL / MAI projects,*
  - *AFRL SBIRs,*
  - *ERSI,*
  - *Many others.*



One of many recent MAI and AFRL RS-focused Programs

Initial RS standard development

- **Increasing need for improved residual stress management:**
  - *Manufacturing quality control,*
  - *Structural performance enhancement.*
- **During a recent Metals Affordability Initiative (MAI) project, LM07: "Residual Stress Management in Aluminum Structure," a draft residual stress standard was developed.**
- **Significant document review was conducted in preparation for development of proposed standard:**
  - *High (system) level MIL specifications / standards:*
    - *JSSG-2006, MIL-HDBK-1587, and downstream documents*
    - *JSSG 2007A, MIL-STD-2014, and downstream documents*
    - *Structural integrity documents: MIL-HDBK-1783B, MIL-STD-1530D*
    - *Detailed review for content related to residual stress*
  - *MIL standards for NDI:*
    - *MIL-STD-2154, Inspection, Ultrasonic, Wrought Metals, Process for*
  - *AMS specifications for forgings:*
    - *AMS2375E, AMS4333D, AMS4403A*
    - *Some recommended revisions drafted to address bulk, process-induced RS*
- **Conclusion was that a stand-alone RS standard is needed…**

Initial RS standard development

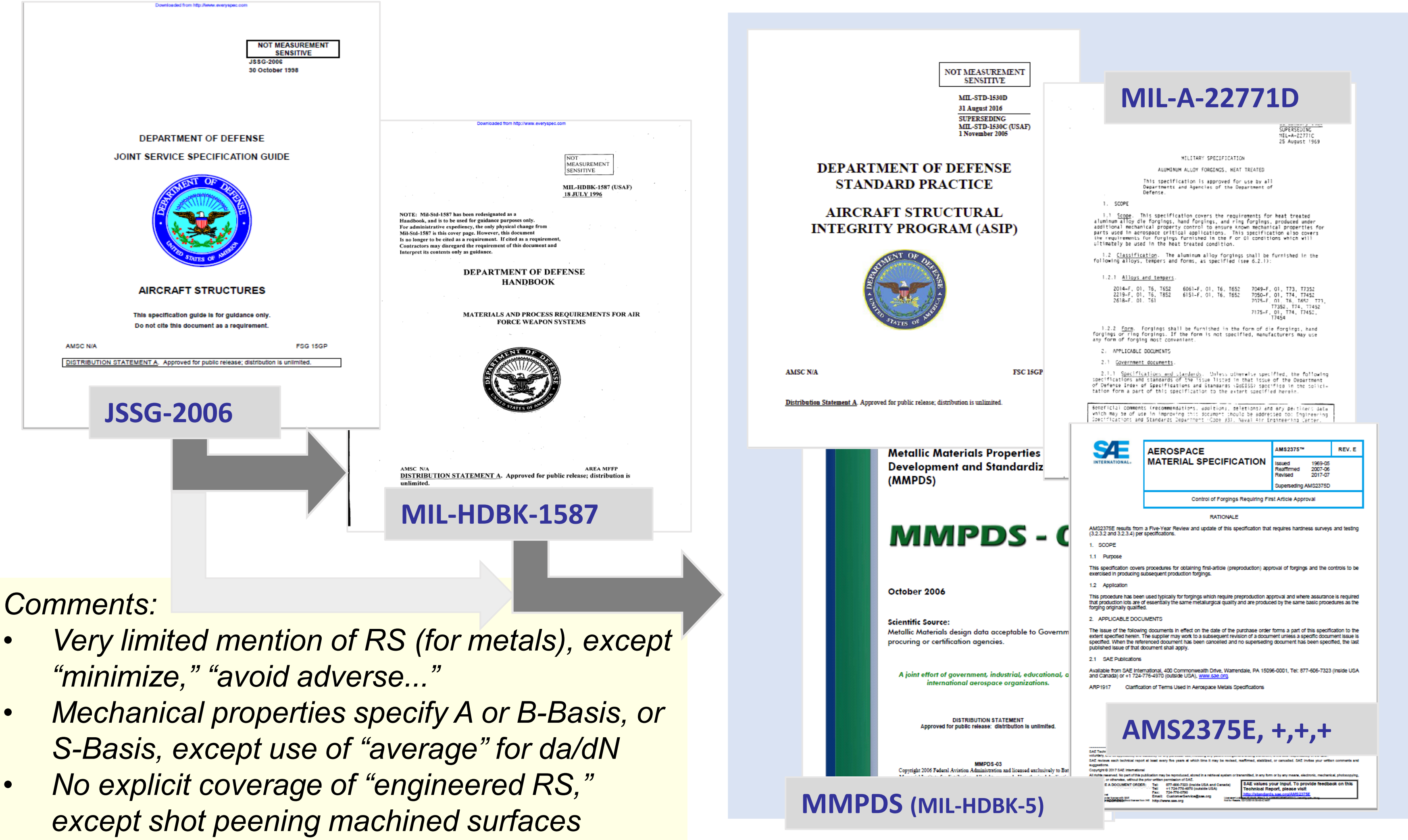
Brief summary of documents reviewed during LM07 related to aircraft structures:

Document (Rev Date)	**Title**	**Brief Description**	**Pages**
JSSG-2006 (Oct 1998)	"Joint Service Specification Guide – Aircraft Structures"	DOD overarching specification guidance; references aluminum forging specs. Very limited citing of RS: "minimize" for critical forgings.	497 (85 plus appendices)
MIL-HDBK-1587 (USAF) (July 1996)	"Materials and Process Requirements for Air Force Weapons Systems"	General DOD Handbook; references specific aluminum specs including heat treatment, damage tolerant design requirements. Some residual stress guidance, specifically for peening.	36
MIL-A-22771D (Jan 1984)	"Aluminum Alloy Forgings, Heat Treated"	Military Specification for general requirements for aluminum forgings; mechanical properties, compositions. No citing of RS. SC impact?	24
MIL-STD-2154 (Sept 1982)	"Inspection, Ultrasonic, Wrought Metals, Process for"	Military Standard for UT inspection, including zoning and definition of UT classes for forgings. No citing of RS.	44
AMS2375E (July 2017)	"Control of Forgings Requiring First Article Approval"	SAE Aerospace Materials Specification; addresses specifics for process control, material acceptance, ongoing quality. Does not specifically address RS.	6
AMS4333D (July 2015)	"Aluminum Alloy, Die Forgings – (7050-T7452)"	SAE Aerospace Materials Specification; addresses specifics for 7050-T7452 aluminum alloy die forgings up to 4.0" thick. Allows 1-5% compression stress relief. Does not specifically address RS.	7
AMS4403A (Nov 2017)	"Aluminum Alloy, Die Forgings – (7085-T7452)"	SAE Aerospace Materials Specification; addresses specifics for 7085-T7452 aluminum alloy die forgings 4.0" to 12" thick. Allows 1-5% compression stress relief. Does not specifically address RS.	8

Initial RS standard development

Partial hierarchy of relevant documents – for aircraft structures;

Note: similar hierarchy exists for propulsion:



Comments:

- *Very limited mention of RS (for metals), except "minimize," "avoid adverse..."*
- *Mechanical properties specify A or B-Basis, or S-Basis, except use of "average" for da/dN*
- *No explicit coverage of "engineered RS," except shot peening machined surfaces*

Initial RS standard development

Brief summary of ancillary documents reviewed:

Document (Rev Date)	Title	Brief Description	Pages
JSSG-2007A (Jan 2004)	"Joint Service Specification Guide – Engines, Aircraft, Turbines"	DOD overarching specification guidance for aircraft turbine engines; references numerous specs, standards, handbooks - DOD, FAA, commercial. Main relevant ref: MIL-HDBK 1783B.	722 (76 plus appendices)
MIL-STD-3024 (April 2008)	"Propulsion System Integrity Program"	DOD Standard Practice for engine system integrity. Main relevant ref: MIL-HDBK 1783B.	89
MIL-HDBK-1783B (ENSIP) (June 2009)	"Engine Structural Integrity Program (ENSIP)"	DOD Handbook (Version B, Change 2, with Notice 1); provides detailed guidance for materials, property requirements, HCF, life prediction, and damage tolerance assessments, NDE. Cites LSP, LPB, other.	188
MIL-STD-1530D (Aug 2016)	"Aircraft Structural Integrity Program (ASIP)"	DOD Standard Practice for aircraft structures. General guidelines for ASIP, not specific. No mention of residual stresses.	45
Un-marked (July 2018)	"Analytical Considerations for Residual Stress Best Practices and Case Studies"	Draft "Best Practices" document sponsored by AFRL and the A-10 and T-38 Aircraft Structural Integrity Program (ASIP) Offices. Work-in-progress. Linked to Engineered Residual Stress Integration (ERSI) working group.	135

Initial RS standard development

Comments and recommendations regarding DOD docs:

Document (Rev Date)	**Comments**	**Recommendation**
JSSG-2006 (Oct 1998)	Note last revision date – 23 years ago. Appendix A, pg164: "minimize" RS for critical forgings	***Near term: no additions/mods*** recommended at this level. ***Long term*** – may have to supplement or change A.3.2.19.1 requiring "minimize RS" for critical forgings.
MIL-HDBK-1587 (USAF) (July 1996)	Note last revision date – 25 years ago. Shot peen forming allowed; but no straightening/coldwork processes with detrimental RS or SC impact. Requires shot peen of machined surfaces.	***Propose changes*** to 5.1.3 to add forging RS. References future MIL-STD-XXXX or AMS RS standard. ***Notes:*** needs future MIL-STD-XXXX or AMS RS standard in place first or concurrently (may take years). Only addresses bulk RS. Consider expanding to engineered RS
MIL-A-22771D (Jan 1984)	Note last revision date – 37 years ago.	***Propose additions*** of 3.7, 4.3, 4.4.8 to add forging RS. References future MIL-STD-XXXX or AMS RS standard. Adds 7085. ***Notes:*** needs future MIL-STD-XXXX or AMS RS standard in place (may take years). Review potential SC impact.
MIL-STD-2154 (Sept 1982)	Note last revision date – 39 years ago. Long-established UT standard.	***No changes recommended.***
MIL-STD-1530D (Aug 2016)	General guidelines for ASIP, not specific. No mention of residual stresses.	***No changes recommended.***

Bottom line: ***Changes to MIL-HDBK-1587 and MIL-A-22771D were recommended, but no further action was taken. (Revision of MIL docs requires DoD sponsor.)***

Initial RS standard development

Comments and recommendations regarding AMS docs:

Document (Rev Date)	**Comments**	**Recommendation**
AMS2375E (July 2017)	"Control of Forgings Requiring First Article Approval"	***Opinion after review: no changes or additions needed short term. Specific call-out of RS desirable in long term.*** Could use for bulk RS without change by requiring a "code designation" per 4.4.2.1.1. This would ensure "first article" evaluations and process change controls.
AMS4333D (July 2015)	"Aluminum Alloy, Die Forgings – (7050-T7452)" up to 4.0" thick.	***Opinion after review: no changes or additions needed short term.*** Minor note: High bulk RS could affect large-scale toughness test results. May require location control for test specimens.
AMS4403A (Nov 2017)	"Aluminum Alloy, Die Forgings – (7085-T7452)" 4.0" – 12" thick.	***Opinion after review: No changes or additions needed in short term. Note: spec permits "AMS4403A(EXC)*** because of the following exceptions…" This may be useful for specifying bulk RS controls if they impact other requirements. Not found in AMS4333D. Minor note: High bulk RS could affect large-scale toughness test results. May require location control for test specimens.

Bottom line:

Changes to AMS2375E (specific call-out of RS) were recommended, but no further action was taken.
Team decided best path forward was development of a new AMS STD for residual stress through SAE.

Initial RS standard development

Summary of document reviews regarding RS measurement/quality specifications or standard:

- **Many relevant high level DOD specifications, standards, and guidelines were reviewed in detail-**
  - *Coverage of residual stress is limited.*
  - *Most of these documents are seldom revised (sometimes for decades)*
  - *They do not prohibit use of RS, so revision is desirable but not essential*
- **Selected AMS specs were reviewed – related to aluminum forgings**
  - *Proposed changes to explicitly address RS have been drafted*
  - *Revisions are desirable, but current documents appear adequate as-is for short term..*
- **Proposed RS measurement/quality standard should be pursued through the SAE Aerospace Metals and Engineering Committee (AMEC):**
  - *AMS approach is more conducive to commercial applications*
  - *Intent was to make as broad as possible, pending feedback from AMEC.*
- **"Best practices" documents are also highly desirable:**
  - *ERSI doc represents good place to start – ERSI doc is a "WIP."*
  - *ASTM E08.04.06 task group: "Best Practices Guide for Residual Stresses in Design and Sustainment," also a "WIP."*

Initial RS standard development

Desired attributes and content for proposed RS standard:

1. ***Provide broadly applicable guidance for RS management***
   - *Basis for communication and contracting between customer and suppliers.*
   - *Be broadly applicable – to most if not all structural metals and forms.*
   - *Ensure critical content is addressed for specification of measurement methods, modeling practice, quality assurance, data records, and acceptance criteria.*
   - *Provide for zoning of parts where various RS criteria may be applied*
   - *Address multiple types (categories) of residual stresses.*
2. ***Define acceptable methods for RS measurement***
   - *Provide brief definitions and characteristics.*
   - *Provide guidance on appropriate range of application for each method*
3. ***Provide for flexibility in use of RS modeling and measurement***
   - *Provide guidance for RS determination by measurement only*
   - *Provide guidance for use of "model only" determination of RS.*
   - *Provide guidance for use of "model-assisted" RS determination.*

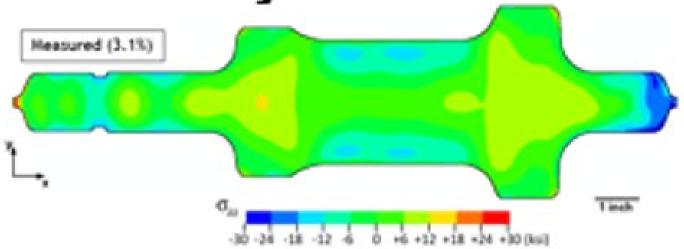
Item 1 represents expected attributes and content in such a standard.
Some clarification for Items 2 and 3 follows ….

Current SAE RS standard

- **Proposal to convert the initial draft to an AMS Standard was made to the AMEC in April 2019:**
  - *AMEC endorsed development of RS standard,*
  - *AMEC received draft from sponsor and converted from MIL format to SAE format, assigned AMEC19AB.*
- **No further activity until March 2020, at which time the ASM Technical Committee on Residual Stress (TCRS) agreed to resume development of the standard.**
- **Under ASM TCRS sponsorship, the standard scope was increased to include residual stress in metallic products and parts (not just aluminum, and not just forgings).**
- **The draft AMS standard was extensively revised over the next 15 months.**
- **AMEC19AB was first balloted July 2021, submitted for 2nd ballot Oct. 2021**

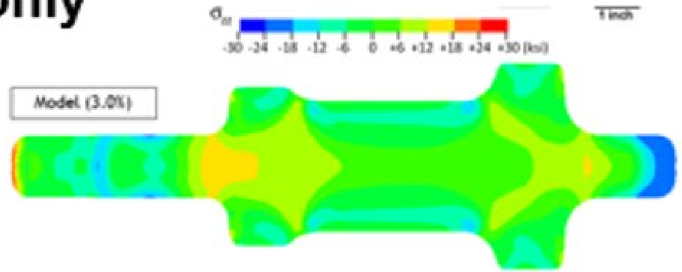
Current SAE RS standard

- **Measurement only**



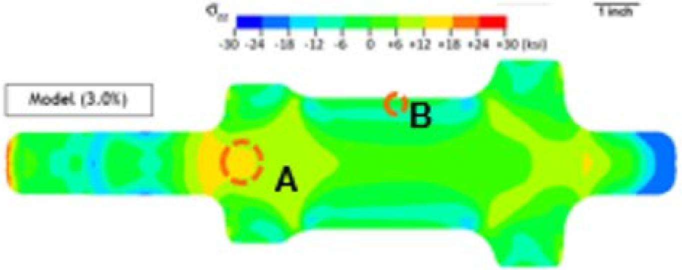
Qualifying RS is based on measured data

- **Model only**



Qualifying RS is based on computed data alone

- **Model-assisted measurement**



Qualifying RS at location A is inferred based on measured data at location B, and computed relationship between A and B

Note that RS modeling is regarded critical to broad implementation of RS in design and structures assessments.

Current SAE RS standard

The draft standard provides information regarding commonly used RS measurement techniques:

Measurement Technique	Applicable Standards or Citation	Typical Precision[1] (%Fty)	Application Region	Suggested Characteristic Residual Stress Definition[2]
Hole drilling[3]	ASTM E837	±3 to ±5	Useful for residual stress assessment at locations within 0.080 inch (2 mm) of material surface	Mean of of measured values in specified direction, taken at depths between 25% and 100% of maximum measurement depth, at specified surface location (point)
Ring core[3]	Schajer 2013	±3 to ±5	Useful for residual stress assessment at locations within 0.240 inch (6 mm) of material surface	Mean of of measured values in specified direction, taken at depths between 25% and 100% of maximum measurement depth, at specified surface location (point)
Deep Hole drilling	Schajer 2013	±2 to ±3	Useful for residual stress assessment at locations greater than 0.040 inch (1 mm) from material surface	Maximum magnitude of measurement values in specified direction, taken at depths between 25% and 100% of maximum measurement depth, at specified surface location (point)
Slotting[3]	Schajer 2013	±2 to ±3	Useful for residual stress assessment at locations within 0.120 inch (3 mm) of material surface	Mean of of measured values in direction normal to slot, taken at depths between 25% and 100% of maximum measurement depth, at specified surface location (point)
Slitting	Schajer 2013	±2 to ±3	Useful for residual stress assessment along one-dimensional path at locations greater than 0.020 inch (0.5 mm) from material surface	Maximum magnitude measurement values in direction normal to slit, taken at depth greater than 0.020 inch (0.5 mm).
Contour method	Schajer 2013	± 2 to ±3	Useful for residual stress assessment over two-dimensional cross-section at locations greater than 0.040 inch (1 mm) from material surface	Maximum magnitude measurement values in direction normal to cutting plane, taken at depth greater than 0.040 inch (1 mm).

Relaxation-based residual stress measurement techniques

Current SAE RS standard

The draft standard provides information regarding commonly used RS measurement techniques:

Measurement Technique	Applicable Standards or Citation	Typical Precision[1] (%Fty)	Application Region	Suggested Characteristic Residual Stress Definition[2]
X-ray diffraction, lab source[3]	EN15305, SAE HS-784, ASTM E915, ASTM E2860	±4 to ±5	Useful for residual stress assessment at surface locations only	Measured value in specified direction at specified surface location (point)
X-ray diffraction with layer removal, lab source[3]	EN15305, HS-784, ASTM E915, ASTM E2860	±4 to ±5	Useful for residual stress assessment at locations within 0.080 inch (2 mm) of material surface	Maximum magnitude of measured values in specified direction at specified location
X-ray diffraction, high energy source	Schajer 2013	±5 to ±15	Useful for residual stress assessment at locations greater than 0.020 inch (0.5 mm) from material surface	Maximum magnitude of measured values in specified direction at specified location
Neutron diffraction	Schajer 2013	±5 to ±15	Useful for residual stress assessment at locations greater than 0.040 inch (1 mm) from material surface	Maximum magnitude of measured values in specified direction at specified location

Diffraction-based residual stress measurement techniques

Current SAE RS standard

- **The draft standard provides guidance for residual stress management:**
  - *Classification (type and magnitude)*
  - *Quality control*
  - *Documentation*
- **The standard establishes residual stress classification criteria for product / part / zone:**
  - *Residual stress **CATEGORY**:*
    - Cat 1: Bulk residual stress, or near zero controlled residual stress
    - Cat 2: Joining residual stress, or tensile controlled residual stress
    - Cat 3: Engineered residual stress, or compressive controlled residual stress
    - Cat 4: Targeted residual stress, or other residual stress not characterized as Cat 1, 2 or 3
  - *Residual stress **CLASS**:*
    - Class A: Tightly controlled residual stress
    - Class B: Moderately controlled residual stress
    - Class C: Loosely controlled residual stress
    - Class D: Uncontrolled residual stress
    - Class E: Report only

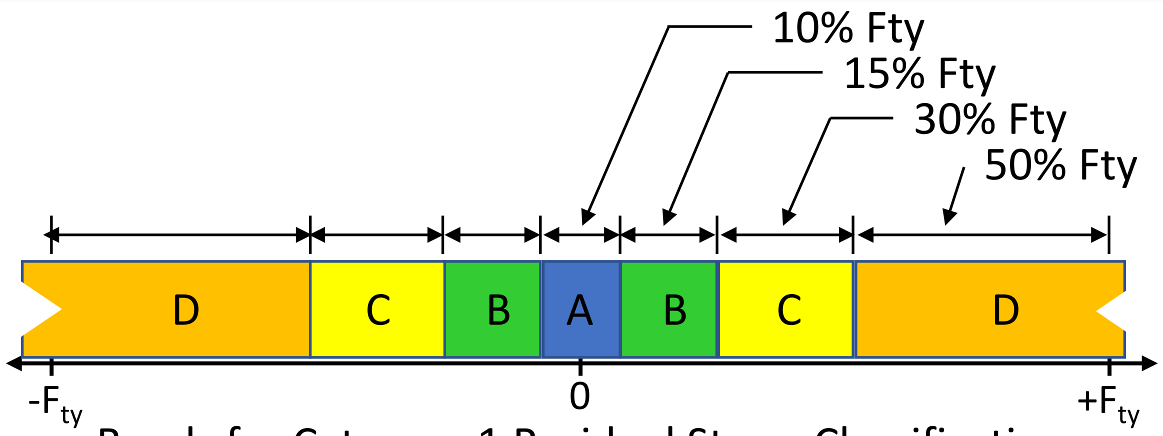
Category 1 Residual Stress

- **Category 1, Bulk RS or near zero controlled RS:**
  - *Typically produced by material production, process, or forming,*
  - *Generally bulk in nature,*
  - *Can be managed first by applying post-production processes such as mechanical cold working thermal stress relieving to reduce or eliminate them, and second by assessing the value of residual stress at one or more critical locations and demonstrating by analysis or test that if the assessed residual stress is within a known range (class) then the product or part will meet its design performance requirements,*
  - *The objective is generally to identify and limit the presence of detrimental tensile residual stresses, however, there are scenarios in which the objective could be to control compressive residual stress because compression at one location is an indicator of equilibrating tension at another location.*

Category 1 Residual Stress Classification

- **Four classes with stress bands prescribed in terms of material yield strength, and a fifth for reporting purposes only**

  Class A (Very low stress): $-5\% F_{ty} \leq RS_{assess} \leq 5\% F_{ty}$
  Class B (Low stress): $-20\% F_{ty} \leq RS_{assess} < -5\% F_{ty}$ or $5\% F_{ty} < RS_{assess} \leq 20\% F_{ty}$
  Class C (Medium stress): $-50\% F_{ty} \leq RS_{assess} < -20\% F_{ty}$ or $20\% F_{ty} < RS_{assess} \leq 50\% F_{ty}$
  Class D (High stress): $RS_{assess} < -50\% F_{ty}$ or $50\% F_{ty} < RS_{assess}$
  Class E: *Report only*



Bands for Category 1 Residual Stress Classification

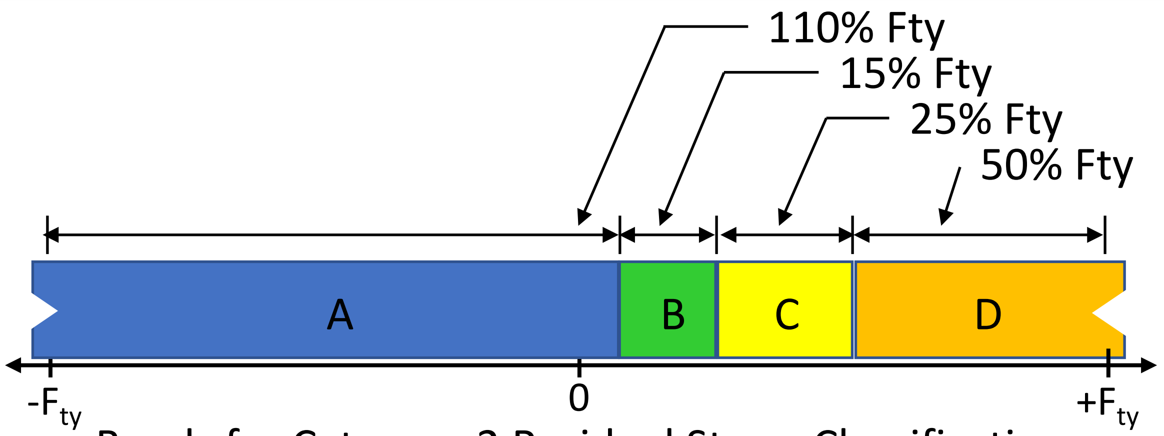
Category 2 Residual Stress

- **Category 2, Joining RS or tensile controlled RS:**
  - *Typically generated by processes such as welding (arc, electron beam, laser, pressure or friction, etc.), thermal or kinetic deposition processes, soldering, etc.*
  - *Typically confined to the vicinity of the joint or deposit.*
  - *Can be managed first by applying post-weld or post-deposition processes such as heat treating or cold working to reduce or eliminate the residual stresses, and second by assessing the value of residual stress at one or more critical locations and demonstrating by analysis or test that if the assessed residual stress is within a known range (class) then the product or part will meet its design performance requirements.*
  - *The objective is generally to identify and limit the presence of detrimental tensile residual stresses*

Category 2 Residual Stress Classification

- **Four classes with stress bands prescribed in terms of material yield strength, and a fifth for reporting purposes only**

Class A (Very low stress):	$RS_{assess} \leq 10\% \ F_{ty}$
Class B (Low stress):	$10\% \ F_{ty} < RS_{assess} \leq 25\% \ F_{ty}$
Class C (Medium stress):	$25\% \ F_{ty} < RS_{assess} \leq 50\% \ F_{ty}$
Class D (High stress):	$RS_{assess} > 50\% \ F_{ty}$
Class E:	*Report only*



Bands for Category 2 Residual Stress Classification

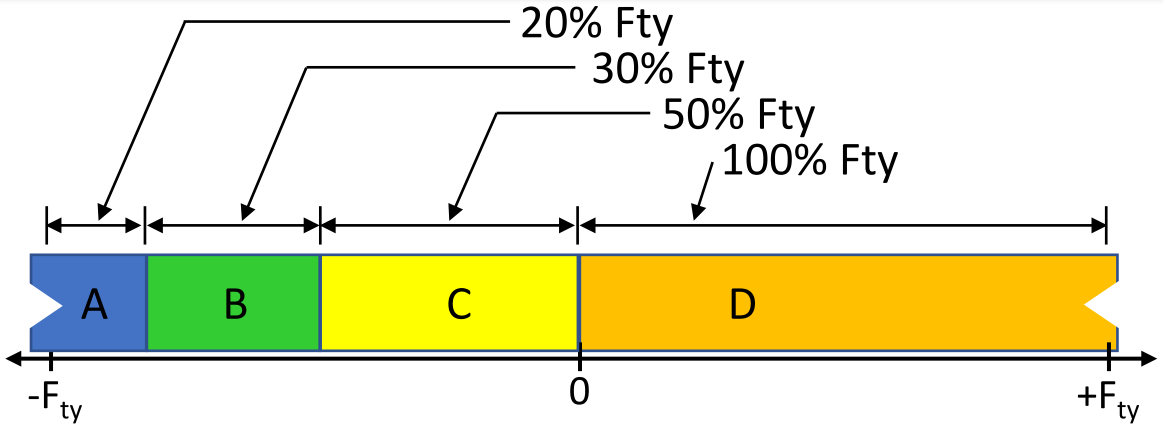
Category 3 Residual Stress

- **Category 3, Engineered RS, or compressive controlled RS:**
  - *Typically installed using controlled plastic deformation at specific (critical) locations within a product or part,*
  - *Generally localized in nature,*
  - *Can be managed first by ensuring that the installation process is properly executed and second by assessing the value of residual stress at one or more critical locations and demonstrating by analysis or test that if the assessed residual stress is within a known range (class) then the product or part will meet its design performance requirements,*
  - *The objective is virtually always to ensure that sufficient, beneficial compressive residual stress has been installed.*

Category 3 Residual Stress Classification

- **Four classes with stress bands prescribed in terms of material yield strength, and a fifth for reporting purposes only**

Class A (Very low stress):	$RS_{assess} \leq -80\% \ F_{ty}$
Class B (Low stress):	$-80\% \ F_{ty} < RS_{assess} \leq -50\% \ F_{ty}$
Class C (Medium stress):	$-50\% \ F_{ty} < RS_{assess} \leq 0\% \ F_{ty}$
Class D (High stress):	$RS_{assess} > 0$
Class E:	*Report only*



Bands for Category 3 Residual Stress Classification

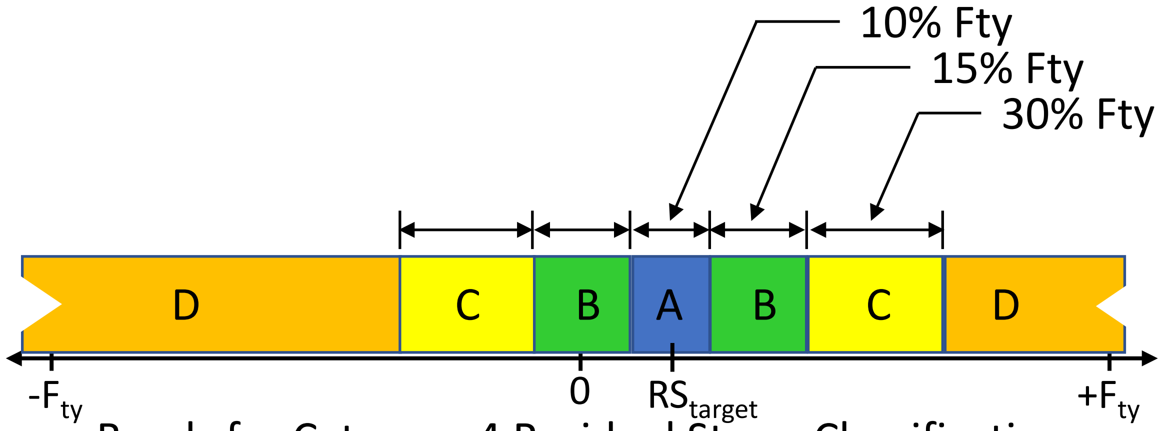
Category 4 Residual Stress

- **Category 4, Targeted RS:**
  - *General category in which the specifier defines a target value of RS and the product or part is classified according to how close (in magnitude) the assessed value of residual stress is to the target value*
  - *This category can be used when the required target value of residual stress does not match any of the implied target values of the other categories*
    - RS_{target}=0 for Categories 1 and 2
    - RS_{target}=-Fty for Category 3
  - *This category can also be used for any RS stress not characterized as category 1, 2 or 3, for example machining induced stresses or coating application (thermal or chemical) stresses which and tend to be very localized in nature*

Category 4 Residual Stress Classification

- **Four classes with stress bands prescribed in terms of material yield strength, and a fifth for reporting purposes only**

Class A (Very low stress):	$\lvert RS_{assess} - RS_{target} \rvert \leq 5\% \, F_{ty}$
Class B (Low stress):	$5\% \, F_{ty} < \lvert RS_{assess} - RS_{target} \rvert \leq 20\% \, F_{ty}$
Class C (Medium stress):	$20\% \, F_{ty} < \lvert RS_{assess} - RS_{target} \rvert \leq 50\% \, F_{ty}$
Class D (High stress):	$\lvert RS_{assess} - RS_{target} \rvert > 50\% \, F_{ty}$
Class E:	*Report only*



Bands for Category 4 Residual Stress Classification

Procedure:

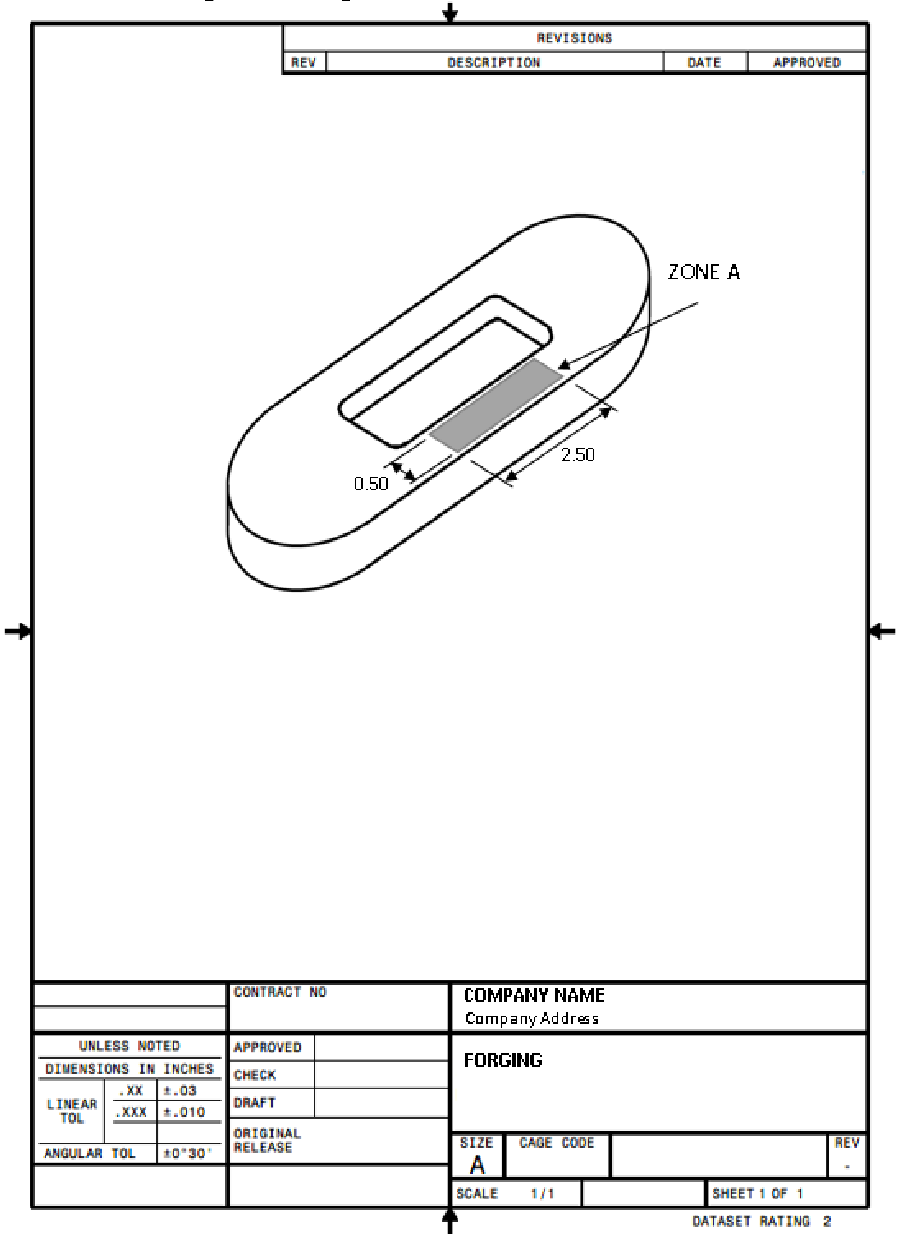
- **Product or part is zoned**

- **Residual stress is "assessed" within a zone – residual stress assessment can be accomplished by:**
  - ***measurement****, or*
  - ***modeling****, or*
  - *a combination of the two*

- **The product or part is classified according to the assessed value of residual stress within the zone**

- **NOTE: uncertainty in selected residual stress assessment technique (modeling or measurement), must be considered when assigning class – meaning uncertainty associated with assessment technique must be less than stress band width associated with the class**

Example problem 1 – bulk residual stress in a forging

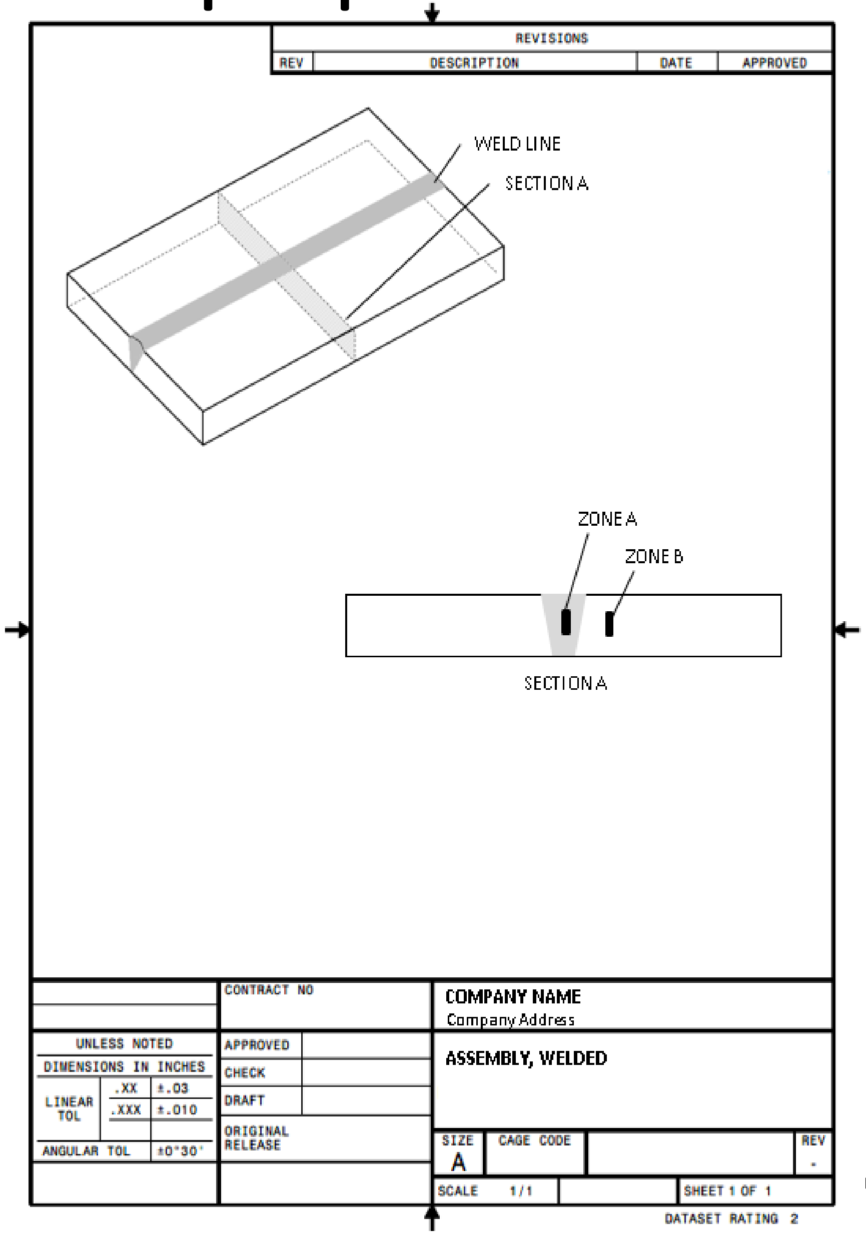


Suggested drawing notes:

NOTES:
1. FORGE AND INSPECT PER XXX-XXXX.
2. FOR CMM INSPECTION PROFILE TOLERANCES SEE XXX.
3. PROFILE TOLERANCES TO BE USED FOR PART ACCEPTANCE CRITERIA.
4. MEASURE SURFACE RESIDUAL STRESS IN ZONE A BY HOLE DRILLING.
   RESIDUAL STRESS TO BE CAT 1, CLASS A IN ZONE A PER AMSXXXX.

If the design requirement is that the RS be 0±3 ksi, then specifier could call out category 1, class A.

Example problem 2 – welding residual stress

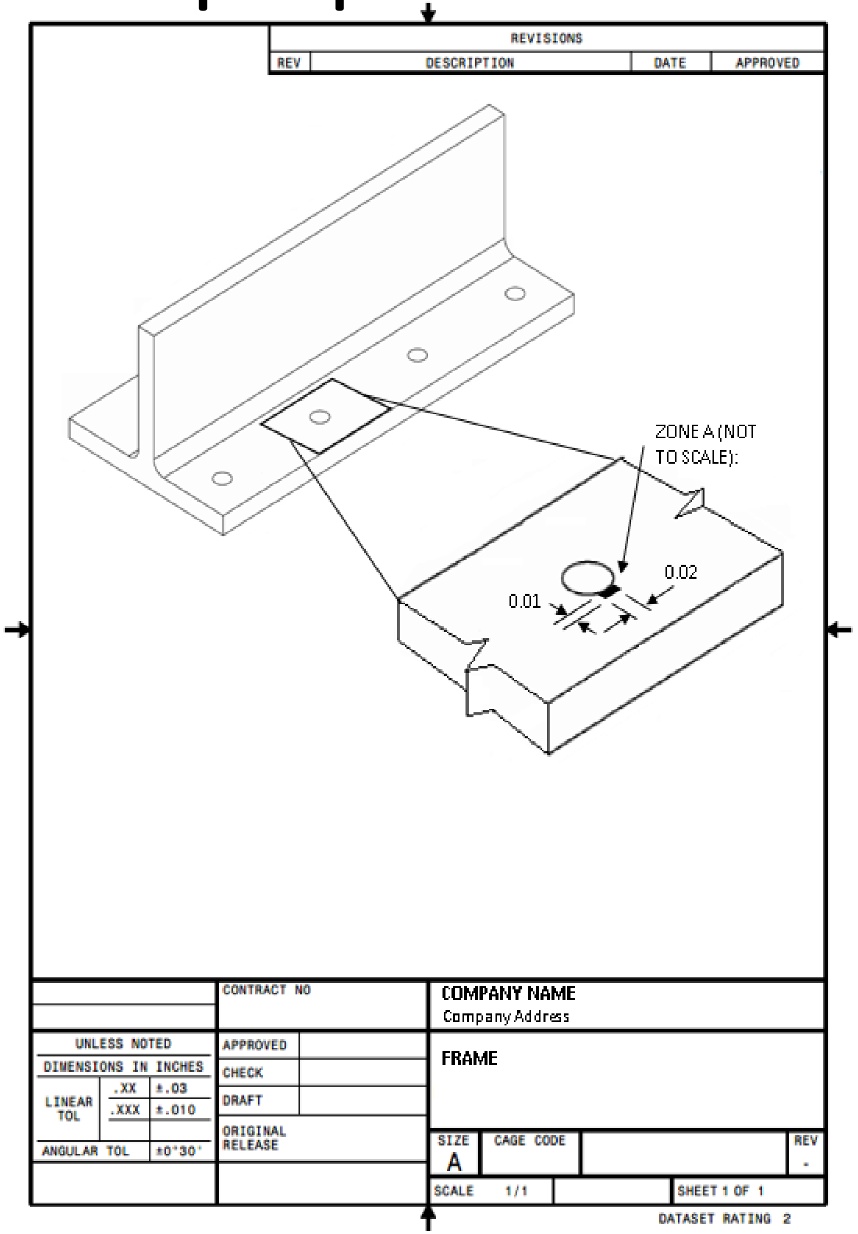


Suggested drawing notes:

NOTES:
1. INSTALL WELD AND INSPECT PER XXX-XXXX.
2. MEASURE RESIDUAL STRESS ON SECTION 'A' BY CONTOUR METHOD.
   RECORD RESIDUAL STRESS CAT 2, CLASS E IN ZONE B PER AMSXXXX.
   RESIDUAL STRESS TO BE CAT 2, CLASS B IN ZONE A PER AMSXXXX

By calling out Category 2 Class B for Zone A, specifier will only accept part with RS<0.25*Fty in zone A

Example problem 3 – residual stress at Cx hole



Suggested drawing notes:

NOTES:

1. INSTALL COLDWORK HOLE AND INSPECT PER XXX-XXXX, 4PL.
   STARTING HOLE SIZE ø.161-.171
   FINAL HOLE SIZE TO BE ø.190-.193
2. DEBURR AFTER FINAL REAM.
3. SURFACE RESIDUAL STRESS TO BE CAT 3, CLASS A IN ZONE A PER AMSXXXX.
   RESIDUAL STRESS TO BE DETERMINED BY NON-DESTRUCTIVE MEANS, XRD OR NEUTRON

Assuming Fty=60 ksi, the drawing callout indicates that specifier will accept part provided RS_{asses} is no larger than -48 ksi.

Conclusion

- **Many relevant high level DOD specifications, standards, and guidelines were reviewed in detail** -
  - *Coverage of residual stress is limited, revisions are rare. They do not prohibit use of RS, so revision is regarded desirable but not essential.*

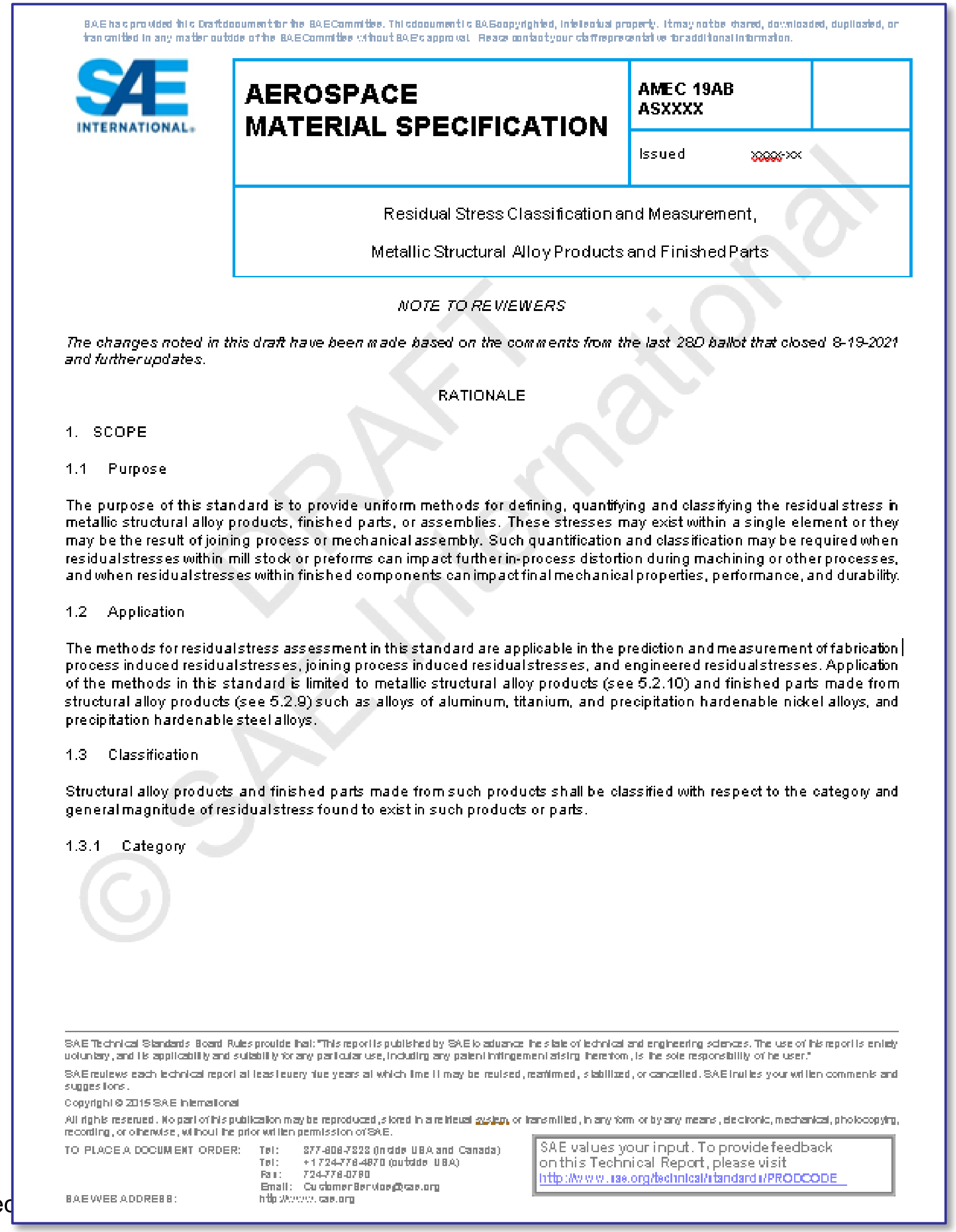
- **AMS NDI specs were reviewed**
  - *UT standard provided good guidance for QA aspects of current standard.*

- **AMS forging specs were reviewed**
  - *Proposed changes to explicitly address RS have been drafted, but current documents appear adequate as-is for short term..*

- **A general RS management standard (measurement/QA/reporting) was developed:**
  - *Regarded essential and best path forward,*
  - *AMS standard (rather than MIL STD) considered preferred path,*
  - *Broadly applicable – addresses use of RS modeling, RS measurement, and any structural alloy and form,*
  - *Addresses multiple types (categories) of RS.*

Conclusion

- **The purpose of the AMS standard is to provide uniform methods for defining, quantifying and classifying the residual stress in metallic structural alloy products and finished parts.**
- **Such quantification and classification may be required:**
  - *When residual stresses within components can impact further in-process distortion during machining or other methods, and/or*
  - *When residual stresses within components can impact final component mechanical properties and performance.*
- **Summary of current status:**
  - *Initial MIL standard drafted Jan. 2019*
  - *AMS standard, AMEC19AB, drafted Apr. 2019*
  - *AMEC19AB balloted July 2021, 2nd ballot Oct. 2021*



AEROSPACE MATERIAL SPECIFICATION

AMEC 19AB
ASXXXX

Issued XXXX-XX

Residual Stress Classification and Measurement,
Metallic Structural Alloy Products and Finished Parts

NOTE TO REVIEWERS

The changes noted in this draft have been made based on the comments from the last 2ND ballot that closed 8-19-2021 and further updates.

RATIONALE

1. SCOPE

1.1 Purpose

The purpose of this standard is to provide uniform methods for defining, quantifying and classifying the residual stress in metallic structural alloy products, finished parts, or assemblies. These stresses may exist within a single element or they may be the result of joining process or mechanical assembly. Such quantification and classification may be required when residual stresses within mill stock or preforms can impact further in-process distortion during machining or other processes, and when residual stresses within finished components can impact final mechanical properties, performance, and durability.

1.2 Application

The methods for residual stress assessment in this standard are applicable in the prediction and measurement of fabrication process induced residual stresses, joining process induced residual stresses, and engineered residual stresses. Application of the methods in this standard is limited to metallic structural alloy products (see 5.2.10) and finished parts made from structural alloy products (see 5.2.9) such as alloys of aluminum, titanium, and precipitation hardenable nickel alloys, and precipitation hardenable steel alloys.

1.3 Classification

Structural alloy products and finished parts made from such products shall be classified with respect to the category and general magnitude of residual stress found to exist in such products or parts.

1.3.1 Category

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