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NAC Off-vehicle

Brake Testing Project

Version: 01 May 2007 Final R1

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The Soldier and Ground Systems
Life Cycle Management Command

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U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

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NAC Off-vehicle Brake Testing Project

(including Secondary Items)

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Supporting the Objective Force –

NAC Aftermarket Brake Components Project “To Promote Full-and-Open Competition”

Internal Tasker by NAC Director: “Fix” sole-source brake component issues on HMMWV-ECV based on contractor and Congressional complaints.

Objectives established 4Q FY05: Reduce O&S burdens by establishing cost-effective, off-vehicle brake component testing to establish a viable process for submittal of alternative items or R&D efforts.

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What's an ESA ? (Short version!)

- The inclusive term “ESA” (Engineering Support Activity) shall be defined as the responsible Army vehicle system engineering authority, equivalent non-Army Governmental vehicle design authority, or non-US Governmental civilian engineering activity’s designated vehicle or brake program engineer when used solely as a commercial/civilian undertaking.

- *DOD procurement offices/activities, other Government and quasi-Government procurement offices/activities, civilian/commercial buying offices/activities, and other similar non-engineering functions are specifically excluded from this definition as they do not have the vehicle system engineering expertise and/or legal approval authority required for brake systems and their subcomponents.*

- Note: The following was removed due to internal/external comments on earlier working drafts and the NAC’s concerns that other non-military and/or non-engineering Government activities might claim it applies to them and allow them to make vehicle system engineering decisions on acceptability. “This definition may also include civilian commercial fleet owners or their designated surrogates when subject specification is used as a decision support tool for the specific brake replacement items covered by subject specification.”

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Innovative and original approaches taken by team.

- Project originally focused on secondary items (aftermarket or “spare parts”), then reduced in scope to pads/rotors and drums/brake shoes, but now covers off-vehicle systems testing too without addition risks to project.
- 1. “Mandatory” shall be minimum acceptable for a reasoned decision by the cognizant “ESA” to accept or reject alternative items!
- 2. ATPD-2354(TA) not “pass-or-fail”! Only responsible vehicle system engineer, aka “ESA” (or equivalent), has full decision & approval authority. Testers/buyers can’t make decision.
- 3. “Army” decision cancelled follow-on Federal Test Standard objective.
- 4. Created a “specification of specifications” whenever possible, with development only for those tests not readily available in the public domain.

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Innovative and original approaches taken by team. (cont.)

- Created “apples-to-apples” comparison testing processes using OEM test sample’s “average” as baseline.
- With LINK’s permission, will use their copyrighted test procedures converted to mil-format due to the lack of existing specs; e.g. replicate TOP 2-2-608 and others.
- Brake burnishing was TOP 2-2-608, now to FMVSS based on GVW; more accurate and consistent for off-vehicle testing.
- Must use brake/hub-end ratings, not traditional axle ratings, to preclude all the hoopla about weight transfer and more accurately reflect brake loading including hill-hold/parking (on military vehicles).
- Majority of testing more focused on intended use and performance instead of brake/component design or process quality controls.

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Method “A” Process/Procedure (aka “Standard”).

- Suitable for the following off-vehicle testing:
 - alternative brake component comparison analysis (primary)*
 - brake system design analysis, not including FMVSS quals
 - brake system component failure analysis
 - (*) self-limited to disc pads/rotors and drum shoe assemblies/drums
- Must use vehicle “OEM” brake/hub-end hardware, or ESA-approved alternate !
- Must use actual brake/hub-end ratings by OEM, or by “ESA”, which precludes issues about weight transfer, plumbing, timing, and similar.
- Test procedures are grouped by GVW similar to FMVSS, but weight band brakes are higher using TOP 2-2-608, ISO/EC, and others.

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Method “B” Process/Procedure (aka “Overload”).

- Suitable for the following off-vehicle testing for “overload” conditions; not normally used in commercial/civilian marketplace; e.g. “up-armored” legacy and future vehicles, emergency and combat mission scenarios, limited “safety” testing.
 - alternative brake component comparison analysis (primary)*
 - brake system design analysis
 - brake system component failure analysis
 - (*) limited to disc pads/rotors and drum shoe assemblies/drums
- Must use vehicle “OEM” brake/hub-end hardware !
- Must use actual brake/hub-end ratings by OEM, or by “ESA”, which precludes issues about weight transfer, plumbing, timing, and similar.



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Method “D” Process/Procedure (aka “R&D”).

- Suitable for the following off-vehicle testing: restricted to research and development (R&D) use; may be used for some “overload” (see Method “B”).
 - brake system design and alternative solution analysis
 - brake system component design and alternative solution analysis, but limited to friction material and contact surface; e.g. disc pads/rotors, drum shoe assemblies/drums.
- Not limited to “OEM” brake/hub-end hardware as there is none !
- Weight transfer, plumbing, timing, and similar could present issues and risks to include “unintended consequences.”
- Test procedures are grouped by GVW similar to FMVSS, but weight bands are higher using TOP 2-2-608, ISO/EC, and similar or may be not applicable.

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Where's Method "C" (aka "Commercial") and Method "W" (aka "Wet") now? GONE!

- A separate "commercial" method still possible, but far more expensive and not as effective compared to ATPD-2354 Method "A".
 - Although counterintuitive to industry, TOP 2-2-608 more effective; would've been defined as "no off-road requirements, period!"; cost-prohibitive due to 2X-3X dyno time needed, probably double or more.
- After initial enthusiasm at project start, military tracked vehicle PMO withdrew support in Jan 07 based on external engineering recommendations.
 - Method "W" was terminated as potential addition to ATPD-2354 or separate ATPD/MIL-SPEC effort; preliminary agreement with LINK management to do one under the existing CRADA at some future point; higher priorities at present; LINK technical POC established, and plenty of industry specs out there to play with.

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ATPD-2354 Test Methodology

1. Characterization of GVBS by vehicle models/types/OEMs.
2. Characterization of OEM (or approved designated similar) Components through standardized testing.
3. Characterizations of Proposed Replacement Components through standardized testing.
4. Characterization of Proposed Replacement Components When Mixed With OEM through standardized testing.
5. Compile and Conduct Comparative Analysis of results to support Suitability Determination by external customer.
6. Post-test Suitability Determination for Proposed Use by each vehicle type/model by external customer.



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“Test Plans”

- Five (5) basic areas covered for “dry” brakes unchanged:
 1. Dimensional, physical, and materials if applicable
 2. Friction Characterization +, for pad and shoe assemblies
 - or
 2. Crack and Strength Testing +, for rotor and drum assemblies
 3. Added testing in text; e.g. “Wet Braking Performance” to FMVSS
 4. Performance, wear, and noise (aka Laurel Mt. & Jennerstown)
 5. Test sample quantities/assignments; some restrictions apply.

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Thinking with both feet outside the box!

- Laurel Mountain/Jennerstown (re: Army TOP 2-2-608)
- Slope/Hill-hold (re: military 60% vs. 20% civilian)
- “Fatigue & Crack” testing for rotors and drums (EC or LINK)
- Added FMVSS-based Wet Effectiveness Test” as Mandatory, but still within overall cost targets; formerly listed as Optional.
- Changed to FMVSS (GVW-based) to standardize brake burnishing; original “TOP” process (temperature-based) both problematic and ill-suited for off-vehicle testing.



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Thinking outside the box some more!

- Must allow for the additive effects of the tire/rim combination (weight & diameter) for total mass calculations
 - Actual computation for Methods “A” and “B”.
 - 7% ($\pm$?) mandatory value for Method “D”
- Must add effects of downstream geared devices for non-hub mounted service brakes; e.g. HMMWV differential mounted disc brakes
- Dictated “manual” adjusters due to known ASA issues
- Sometimes faster/easier/cheaper to have tester buy parts; getting the parts/pieces far harder than testing them.



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How it will read using MIL-STD-962 structure instead of more familiar MIL-STD-961 for ATPD-2354.

- Cover Page. (Same as “regular” MIL-SPEC to -961)
- Section 1. Intro (Same/similar)
- Section 2. Referenced Documents (Same/similar)
- Section 3. Definitions (Design & Performance)
- Section 4. General Requirements (Quality)
- Section 5. Detailed Requirements (Packaging)
- Section 6. Notes (Same/similar)
- Appendices. (Same/similar)
- Other. (e.g. Attachments and Drawings/charts)



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1. Appendix A. Definitions (continued).
2. Appendix B. Test Plans and Sample Assignments for Disc Brake Pads and (Foundation) Drum Brake Shoes.
3. Appendix C. Test Plans and Sample Assignments for Disc Brake Rotors and Drum Brake Drums.
4. Appendix D. Off-vehicle Inertia Dynamometer Test Procedures.
5. Appendix E. “Crack & Strength Tests” for rotors and drums.
6. Appendix F. Inertia-dynamometer testing standardized mathematical calculations and equations.
7. Appendix G. Flow chart describing methodology required to initially approach, independently test, and then submit to Government for approval.

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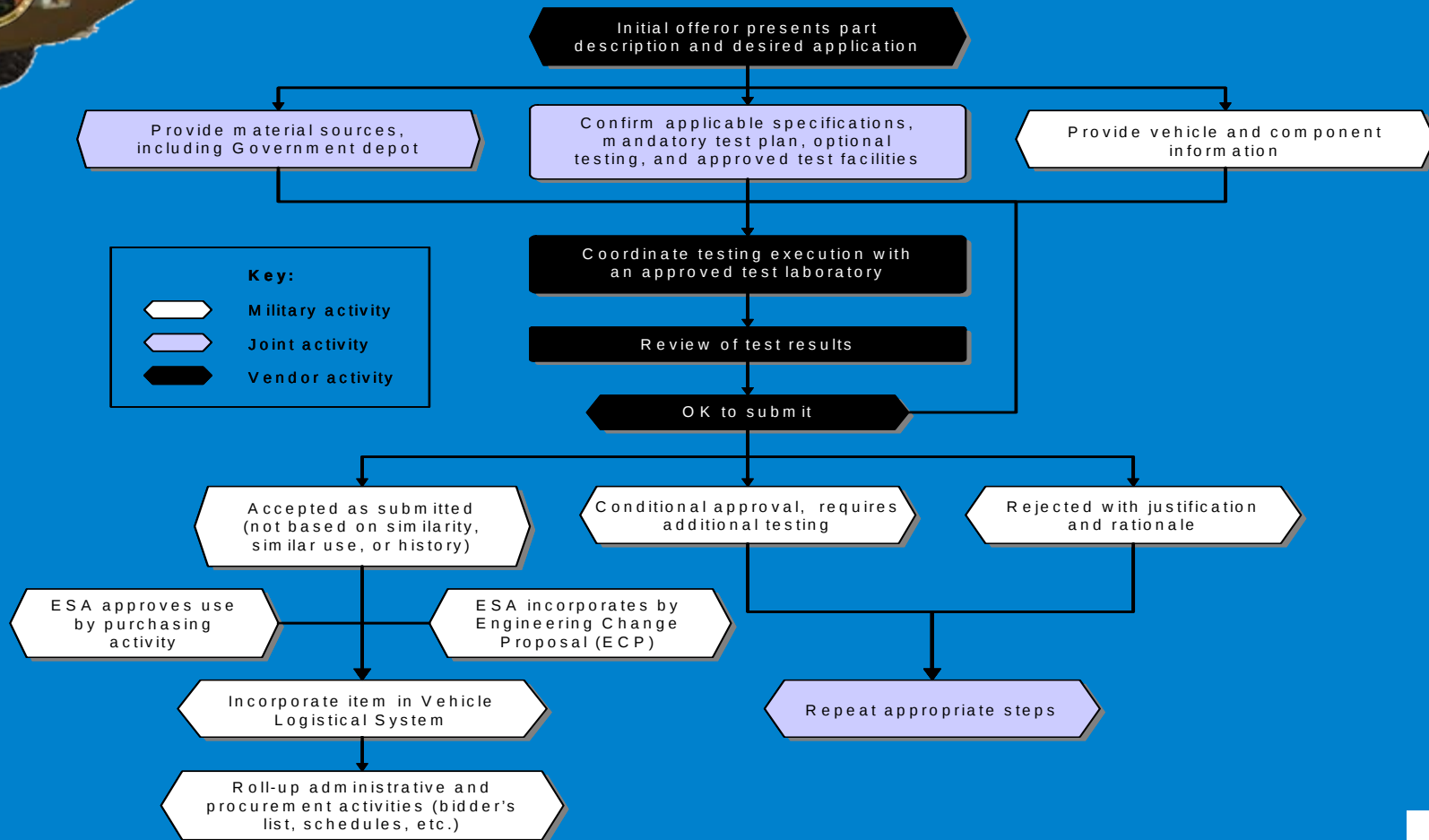
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THE MOST IMPORTANT CHART!

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Project Status (01 May 2007)

- Verification testing nearly completed. Some disc and drum testing run concurrently to offset delays due to parts problems.
- ATPD-2354 to be released to DLA and TACOM for immediate use in mid-late May 07; ATPD and subsequent versions will be controlled and maintained by TARDEC-Warren (MI).
- SAE T&B Brake Committee brief on final product, May 07; draft new Standard scheduled to be delivered concurrently, but may slip.
- TMC/ATA update brief under CRADA effort was early Feb 07, but couldn't present their draft RP then due to incomplete testing.
- Will continue CRADA (LINK and TMC/ATA) and LOA (SAE-Troy).
- Punishment for the righteous, and glory and honors for the naysayer's, is anticipated shortly after ATPD release based on common management practices for programs of this sort!

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SAE Potential Changes/Conflicts with ATPD-2354

- Allow use of GVW or axle ratings as alternative to hub/brake-ends w/pre-approval by responsible ESA equivalent?
- Restrict Method “B” (Overload) to military only!
- Computed and “7% Solution” (R&D) solutions for tire/rim impacts?
- Use OEM-supplied values on case-by-case basis instead of J-Spec fixed weight-transfer value/formula? (Stan?)
- Provide for “pitch” & “yaw” for mixed use by hub and/or axles within design/weight limits prescribed by FMVSS and/or SAE T&B?
- Allow use of alternative test methods to “TOP”-based Laurel Mountain/Jennerstown for performance, wear, and noise; “high risk”; e.g. “LA Duty Cycle”, J2707 Method “B”, and similar?



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SAE Potential Changes/Conflicts with ATPD-2354

- Is 10K+ GVW bogie still appropriate? (re: CVEDR problems)
 - Other regulatory and SDOs use different breakpoints
 - TOP 2-2-608 and EC-based “Crack & Strength Test” aren’t consistent with FMVSS 10K bogie
 - Too much medium truck marketplace noise due to pre-regulatory/proprietary designs in-place (also re: HVCDR)
- Does SAE want common RP or multiples separated by hydraulic versus air, disc versus drum, or (fill-in-the-blank)? Be careful here!
 - SAE can’t avoid addressing air disc brakes (ADB) and SA/DA “wedge” brakes here! No ADB in Army-managed fleets.
 - Military’s choices mostly limited to what’s offered commercially as they buy vehicles, not components.
- Military aware of current wheel & brake conflicts and will probably choose to let industry work it out for now.





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Tire/Rim Assembly Weights Impacts Brake Testing. (Military mostly “Super Singles”)

- HMMWV: 162lbs and 36.6 inches + (Geared-hub ratio) = + 4.9%
- HEMTT: 510lbs and 52.9 inches = + 6.6%
- M915A2/A3: 225.5lbs (2X) and 40.5 inches (11R22.5) = ?
(Note: Freightliner standard tandem, day-cab OTR tractor)
- R&D will be presumed 7.0% in ATPD for now.

$\text{Inertia (slug*ft}^2\text{)} = \text{Mass (slug)} * \text{Rolling Radius (ft)} * \text{Rolling Radius (ft)}$



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Governmental Players (01 Jan 077)

- Director, USA National Automotive Center (NAC)
- Chief, TACOM Safety Office (System Safety/Compliance)
- TACOM Packaging (PPS Engineering)
- Team Leader, TARDEC-EBG (Specs & Standards)
- TARDEC- EBG Legacy Vehicle Engineering Support (All)
- PM-HTV (Heavy Truck Engineering)
- PM-MTV (FMTV/Medium Vehicle Engineering plus ASV)
- PM-LTV (HMMWV/Light Vehicle Engineering)
- PM-CCE (CE Support Team Leader)
- TACOM Competition Advocates Office
- PEO CS & CSS (New Products/Technology Insertion)
- PEO-GCS, Tracked Vehicles - Withdrew Jan 07
- PM-Stryker, Engineering Support

Backup #1

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Other Government and Industry Players (01 Jan 07)

- Developmental Test Command (DTC)-Aberdeen POC's
- USAF- WRAFB, GA
- USAF TARDEC LNO, TARDEC-Warren
- TARDEC-DLA Liaison, TARDEC-EBG
- DLA-Columbus (DSCC) to TARDEC LNO
- LINK Testing Laboratories, Detroit, MI (2005 CRADA)
- SAE-Troy (2006 Letter of Agreement [LOA])
- SAE T&B Brake Committees – voting memberships
- TMC/ATA (2006 CRADA Mod)
- SAE Automotive equivalents – pending/unknown
- YOUR NAME HERE?

Back-up #2

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ITEM	ATPD 2354 (MIL-SPEC) Test Plan TYPE OF TEST Disc pads and brake shoes	Hydraulic Air/Both	Standard/Test procedure
PHYSICAL & DIMENSIONAL PROPERTIES			
1	Material Identification/Certifications - as required when identified by requirement, specification, drawing, or purchase order.	both	CoC/Lab Results
2	Visual inspection	both	TBD (ISO CD 22574)
3	Critical dimensions verifications	both	STM
4	Shear strength adhesion/bonding (-40 °C)	hydraulic	SAE J840 (ISO 6312)
5	Shear strength adhesion/bonding (750 °F) (400 °C)	hydraulic	SAE J840 (ISO 6312)
6	Compressibility, ambient	both	SAE J2468 (ISO 6310)
7	Compressibility, elevated temperature	both	SAE J2468 (ISO 6310)
8	Brinell Hardness on metallic parts (rotor, drum, shoe, backing plate)	both	ASTM E 10
9	Thermal swell and growth	both	SAE J160
INERTIA-DYNAMOMETER FRICTION COUPLE PERFORMANCE AND DURABILITY			
10	Friction Behavior and Performance Assessment Hydraulic Brakes single-ended; with front/rear balance assessment (up to V_{max})	hydraulic	SAE J2522 (ISO NWI 2560)
11	Friction Behavior and Performance Assessment Air Brakes single-ended; with front/rear balance assessment	air	SAE J2115
12	Friction Behavior and Performance Assessment Hydraulic Brakes dual-ended left/right (up to V_{max})	hydraulic	SAE J2522 (ISO NWI 2560)
13	Friction Behavior and Performance Assessment Air Brakes dual-ended left/right	air	SAE J2115
14	Jennerstown Fade Dyno test with noise	both	Link W05065LINKA-C1©
15	Wear and durability (Laurel Mountain 4 Cross-Country cycles) with noise	both	Link W05065LINKA-C1©

Proposed Mandatory Testing Plan Pads and Shoes (April 2006)



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ITEM	ATPD 2354 (MIL-SPEC) Test Plan TYPE OF TEST Disc pads and brake shoes	Hydraulic/Air/Both	Standard/Test procedure	SAMPLE ASSIGNMENT				
				HYDRAULIC		AIR		ROTOR/DRUM
				Test pad number baseline (A)	Test pad number candidate (B)	Test shoe number baseline (A)	Test shoe number candidate (B)	
	PHYSICAL & DIMENSIONAL PROPERTIES							
1	Material Identification/Certifications - as required when identified by requirement, specification, drawing, or purchase order.	both	CoC/Lab Results	N/A	N/A	N/A	N/A	N/A
2	Visual inspection	both	TBD (ISO CD 22574)	All A	All B	All A	All B	
3	Critical dimensions verifications	both	STM	All A	All B	All A	All B	
4	Shear strength adhesion/bonding (-40 °C)	hydraulic	SAE J840 (ISO 6312)	1-3A	1-3B			
5	Shear strength adhesion/bonding (750 °F) (400 °C)	hydraulic	SAE J840 (ISO 6312)	4-6A	4-6B			
6	Compressibility, ambient	both	SAE J2458 (ISO 6310)	7-9A	7-9B	1-3A	1-3B	
7	Compressibility, elevated temperature	both	SAE J2458 (ISO 6310)	7-9A	7-9B	1-3A	1-3B	
8	Brinell Hardness on metallic parts (rotor, drum, shoe, backing plate)	both	ASTM E 10	7-9A	7-9B	1-3A	1-3B	
9	Thermal swell and growth	both	SAE J160	10-12A	10-12B	3-4A	3-4B	
	INERTIA-DYNAMOMETER FRICTION COUPLE PERFORMANCE AND DURABILITY							
10	Friction Behavior and Performance Assessment Hydraulic Brakes single-ended; with front/rear balance assessment (up to V _{max})	hydraulic	SAE J2522 (ISO NWI 2560)	12-17A	12-17B			1-6C
11	Friction Behavior and Performance Assessment Air Brakes single-ended; with front/rear balance assessment	air	SAE J2115			5-10A	5-10B	1-6C
12	Friction Behavior and Performance Assessment Hydraulic Brakes dual-ended left/right (up to V _{max})	hydraulic	SAE J2522 (ISO NWI 2560)	18-23A	18-23B			7-12C
13	Friction Behavior and Performance Assessment Air Brakes dual-ended left/right	air	SAE J2115			11-16A	11-16B	7-12C
14	Jennerstown Fade Dyno test with noise	both	Link W05065LINKA-C1©	24-29A	24-29B	17-22A	17-22B	13-18C
15	Wear and durability (Laurel Mountain 4 Cross-Country cycles) with noise	both	Link W05065LINKA-C1©	24-29A	24-29B	17-22A	17-22B	13-18C
	Total number of test samples submitted by axle sets			10	10	8	8	12

Proposed Mandatory Test Sample Distribution Friction (April 2006)



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ITEM	ATPD 2354 (MIL-SPEC) Test Plan TYPE OF TEST Brake rotors and drums	Hydraulic Air/Both	Standard/Test procedure
PHYSICAL & DIMENSIONAL PROPERTIES			
1	Material Identification/Certifications - as required when identified by requirement, specification, drawing, or purchase order.	both	CoC/Lab Results
2	Visual inspection	both	STM
3	Critical dimensions verifications	both	STM
4	Brinell Hardness	both	ASTM E 10
5	Lateral/radial Run-Out; DTV measurement (rotors only)	both	STM
INERTIA-DYNAMOMETER ROTOR/DRUM PHYSICAL PERFORMANCE			
6	Disc and Drum crack and strength test	both	Link W05036LINKB-D0© (SAE J2686 drum) (ECE R90 rotors/drums)
INERTIA-DYNAMOMETER FRICTION COUPLE PERFORMANCE AND DURABILITY			
7	Friction Behavior and Performance Assessment Hydraulic Brakes single-ended; with front/rear balance assessment (up to V_{max})	hydraulic	SAE J2522 (ISO NWI 2560)
8	Friction Behavior and Performance Assessment Air Brakes single-ended; with front/rear balance assessment	air	SAE J2115
9	Jennerstown Fade Dyno test with noise	both	Link W05065LINKA-C1©
10	Wear and durability (Laurel Mountain 4 Cross-Country cycles) with noise	both	Link W05065LINKA-C1©

Proposed Mandatory Testing Plan Rotors and Drums (April 2006)



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ITEM	ATPD 2354 (MIL-SPEC) Test Plan TYPE OF TEST Brake rotors and drums	Hydraulic Air/Both	Standard/Test procedure	SAMPLE ASSIGNMENT				
				HYDRAULIC		AIR		Pad/Shoe number
				Rotor/Drum number baseline (A)	Rotor/Drum number baseline (B)	Rotor/Drum number baseline (A)	Rotor/Drum number baseline (B)	
PHYSICAL & DIMENSIONAL PROPERTIES								
1	Material Identification/Certifications - as required when identified by requirement, specification, drawing, or purchase order.	both	CoC Lab Results	N/A	N/A	N/A	N/A	N/A
2	Visual inspection	both	STM	All A	All B	All A	All B	
3	Critical dimensions verifications	both	STM	All A	All B	All A	All B	
4	Brinell Hardness	both	ASTM E 10	1-3A	1-3B	1-3A	1-3B	
5	Lateral/radial Run-Out; DTV measurement (rotors only)	both	STM	1-3A	1-3B	1-3A	1-3B	
INERTIA-DYNAMOMETER ROTOR/DRUM PHYSICAL PERFORMANCE								
6	Disc and Drum crack and strength test	both	Link W05036LINKB-D0© (SAE J2186 drum) (ECE R90 rotors/drums)	1-3A	1-3B	1-3A	1-3B	As required
INERTIA-DYNAMOMETER FRICTION COUPLE PERFORMANCE AND DURABILITY								
7	Friction Behavior and Performance Assessment Hydraulic Brakes single-ended; with front/rear balance assessment (up to V _{max})	hydraulic	SAE J2522 (ISO NWI 2560)	4-6A	4-6B			1-6C
8	Friction Behavior and Performance Assessment Air Brakes single-ended; with front/rear balance assessment	air	SAE J2115			4-6A	4-6B	1-6C
9	Jennerstown Fade Dyno test with noise	both	Link W05065LINKA-C1©	7-9A	7-9B	7-9A	7-9B	7-18C
10	Wear and durability (Laurel Mountain 4 Cross-Country cycles) with noise	both	Link W05065LINKA-C1©	7-9A	7-9B	7-9A	7-9B	7-18C
Total number of test samples submitted by axle sets				6	6	6	6	15

Proposed Mandatory Test Sample Distribution Rotors/Drums

Backup Slide 4 of 4

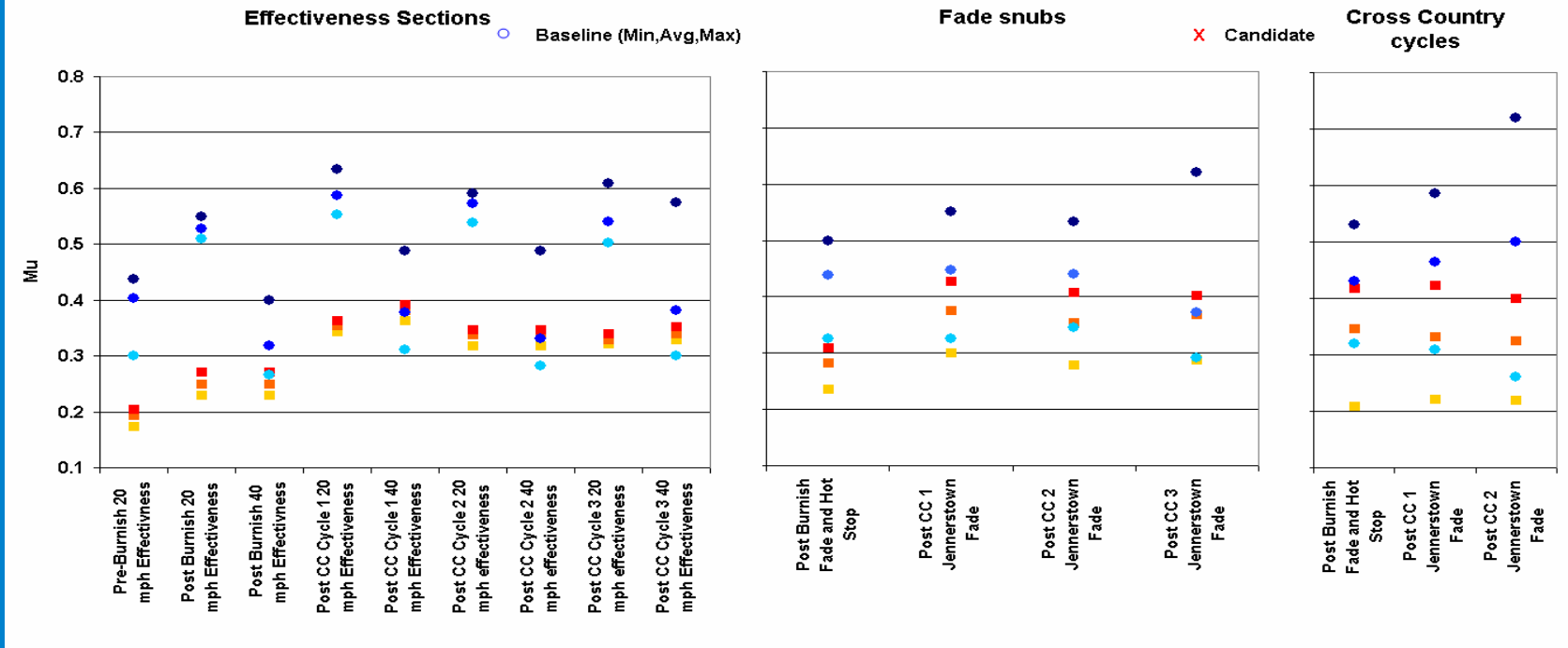
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Friction behavior: TOP 2-2-608 inertia-dynamometer simulation (3 c/c cycles).

NOTE: A second “candidate” material did not survive the test.

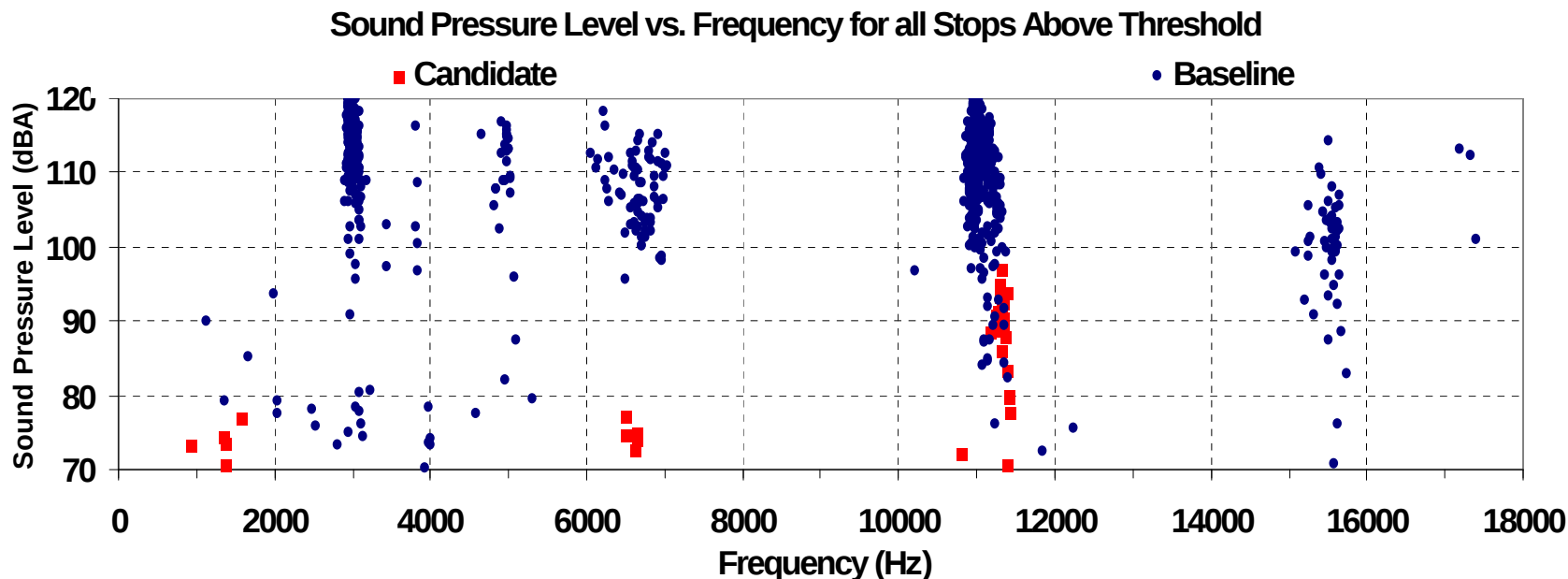
(Jan 07) Back-up Slide 1 of 2

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Noise level behavior: TOP 2-2-608 inertia-dynamometer simulation.
(3 cross-country)

NOTE: A second “candidate” material did not survive the test.

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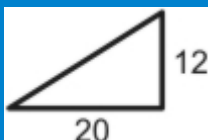
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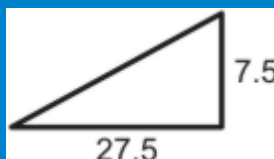
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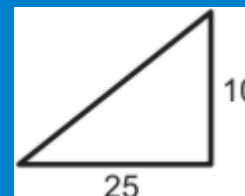
Some possible examples to use are shown below:



Percent Slope
= 60%



Percent Slope
= 27.3%



Percent Slope
= 40%

Computing percent slope is demonstrated by the examples above.
Note: May be expressed as a “super-elevation” ($\pm$ grade).

Vertical Leg (Rise)/Horizontal Leg (Run) X 90 = Slope (%)

Also use charts in US Army TM 5-236, Surveying Tables and Graphs, C1, 13 May 2057.

Slope/incline versus Angle Instructional Slide



(Feb 07) Backup Slide 1 of 1

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