# AFRL-ML-WP-TR-1998-4191

# CUT PROGRESSION DURING DYNAMOMETER TESTING OF FOREIGN OBJECT DAMAGED TYPE VII EXTRA HIGH PRESSURE AIRCRAFT TIRES SAE PAPER 912155

PETER C. VORUM

**SEPTEMBER 1991** 

FINAL REPORT FOR 03/15/1984 - 06/15/1991

# APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

THIS PAPER IS DECLARED A WORK OF THE U.S. GOVERNMENT AND AS SUCH IS NOT SUBJECT TO COPYRIGHT PROTECTION IN THE UNITED STATES

# MATERIALS AND MANUFACTURING DIRECTORATE AIR FORCE RESEARCH LABORATORY AIR FORCE MATERIEL COMMAND WRIGHT-PATTERSON AIR FORCE BASE OH 45433-7750



# NOTICE

USING GOVERNMENT DRAWINGS, SPECIFICATIONS, OR OTHER DATA INCLUDED IN THIS DOCUMENT FOR ANY PURPOSE OTHER THAN GOVERNMENT PROCUREMENT DOES NOT IN ANY WAY OBLIGATE THE US GOVERNMENT. THE FACT THAT THE GOVERNMENT FORMULATED OR SUPPLIED THE DRAWINGS, SPECIFICATIONS, OR OTHER DATA DOES NOT LICENSE THE HOLDER OR ANY OTHER PERSON OR CORPORATION; OR CONVEY ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE, OR SELL ANY PATENTED INVENTION THAT MAY RELATE TO THEM.

THIS REPORT IS RELEASABLE TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS). AT NTIS, IT WILL BE AVAILABLE TO THE GENERAL PUBLIC, INCLUDING FOREIGN NATIONS.

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

Petr C. Vorya

PETER C. VORUM Project Engineer AFRL/MLBT

DAVID J. PEREZ, Chief

Plans and Programs Branch Integration and Operations Division

DENNIS SEDLOCK Chief, Flight Systems Division Air Vehicles Division

IF YOUR ADDRESS HAS CHANGED, IF YOU WISH TO BE REMOVED FROM OUR MAILING LIST, OR IF THE ADDRESSEE IS NO LONGER EMPLOYED BY YOUR ORGANIZATION PLEASE NOTIFY AFRL/VACM, WRIGHT-PATTERSON AFB OH 45433-7202 TO HELP MAINTAIN A CURRENT MAILING LIST.

Do not return copies of this report unless contractual obligations or notice on a specific document requires its return

Not expendent of the second	RE	PORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188								
T. AGENCY USE ONLY dave Mark       2. REPORT DATE       1. REPORT TYPE AND DATE SOURCED         T. THE AND SUBTINE       FINAL REPORT 03/15/1084 - 06/15/1991         4. THTE AND SUBTINE       FINAL REPORT 03/15/1084 - 06/15/1991         4. THE AND SUBTINE       FINAL REPORT 03/15/1084 - 06/15/1991         CUT PROCRESSION DURING DYNAMOMETER TESTING OF FOREIGN       FINAL REPORT 03/15/1084 - 06/15/1991         OBJECT DAMAGED TYPE VIL EXTRA HIGH PRESSURE AIRCRAFT TIRES;       FINAL REPORT 03/15/1084 - 06/15/1991         SAE PAPER 912155       TA 01         WU 47       WU 47         PETER C. VORUM       WU 47         PETER C. VORUM       WU 47         AND MANUFACTURING DIRECTORATE       AUTOMOTIVE ENGINEERS TECHNICAL PAP 912155         AIR FORCE MATERIEL COMMAND       SOCIETY OF AUTOMOTIVE ENGINEERS TECHNICAL PAP 912155         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         WRIGHT-PATTERSON AFE, OH 45433-7750       IN SPRESSIMMUM AFEAL         NUMPLEMENTARY FAILED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE	Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Artington, VA 22202:4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704:0188), Washington, DC 20503.											
SEPTEMBER 1991         FINAL REPORT 03/15(1984 - 06/15/1991           4. TITLE AND SUBTRIE CUT PROGRESSION DURING DYNAMOMETER TESTING OF FOREIGN OBJECT DAMAGED TYPE VIL EXTRA HIGH PRESSURE AIRCRAFT TIRES; SAE PAREPS 12155         FA           4. AUTOMOSIS         PR 2402           7. REFORMING DIREATION HAMEIS AND ADDRESSES!         TA           MATERIALS AND MANUFACTURING DIRECTORATE         Reforming DIREATION           AIR FORCE RESEARCH LABORATORY         SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE AIR FORCE RESEARCH LABORATORY           AIR FORCE RESEARCH CHABORATORY         SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE AIR FORCE RESEARCH LABORATORY           AIR FORCE RESEARCH LABORATORY         SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE ADDRESS           11. SPENSORMANDAMING DIRECTORATE         IN SPENSORMAND AND SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE ADDRESS           12. SPENSORMANDATION ARE ADDRATORY         IN SPENSORMAND AND AIR FORCE RESEARCH LABORATORY           AIR FORCE RESEARCH LABORATORY         AFRL-ML-WP-TR-1998-4191           AIR FORCE MATERIEL COMMAND         IN SPENSORM	1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DAT	ES COVERED								
THE AND SUBTINE         E. FUNDAS NUMBERS           CUT PROGRESSION DURING DYNAMOMETER TESTING OF FOREIGN OBJECT DAMAGED TYPE VII EXTRA HIGH PRESSURE AIRCRAFT TIRES; SAE PAPER 912155         E. FUNDASE VII - AUTORS; SAE PAPER 912155           TA UTORS; PETER C. VORUM         WU 47           T. FERFORNING DREAR/2ATION HAMEES AND ADDRESSIES; MATERIALS, AND MANUFACTURING DIRECTORATE AIR FORCE RESEARCH LABORATORY AIR FORCE MATERIEL COMMAND WRIGHT-PATTERSON AFB, OH 45433-7750         I. SPUISSONNEMONITORING AGENT FERSION AFB, OH 45433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750 WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSONNEMONITORING AGENT FERSION AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750 WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSONNEMONITORING AGENT FERSION AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750 WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSONNEMONITORING AGENT FERSION AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSONNEMONITORING AGENT FERSION AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSONNEMONITORING AGENT FERSION AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSON AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSON AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH 3433-7750         II. SPUISSON AFB, OH 3433-7750           WRIGHT-PATTERSON AFB, OH		SEPTEMBER 1991	FINAL REP	ORT 03/15/1984 - 06/15/1991								
CUT PROGRESSION DURING DYNAMOMETER TESTING OF FOREIGN OBJECT DAMAGED TYPE VILEXTRA HIGH PRESSURE AIRCRAFT TIRES; SAE PAPER 912155       C 1N-HOUSE PR 2402         TA 01       WU 47         FETER C. VORUM       WU 47         PETER C. VORUM       Secondarization names and adomesses         T, PERFORMING ORGANIZATION NAMES AND ADDRESSES       8. PENFORMING ORGANIZATION NAMES AND ADDRESSES         MATERIALS AND MANUFACTURING DIRECTORATE       8. PENFORMING ORGANIZATION NAMES AND ADDRESSES         AIR FORCE RESEARCH LABORATORY       SOCIETY OF AUTOMOTIVE SOCIETY OF AUTOMOTIVE AIR FORCE RESEARCH LABORATORY         AIR FORCE RESEARCH LABORATORY       NATERIALS AND MANUFACTURING DIRECTORATE         AIR FORCE RESEARCH LABORATORY       912155         AIR FORCE RESEARCH LABORATORY       AIR FORCE RESEARCH LABORATORY         AIR FORCE RESEARCH LABORATORY       ARFILALS AND MANUFACTURING DIRECTORATE         AIR FORCE RESEARCH LABORATORY       AIR FORCE RESEARCH LABORATORY         AIR FORCE RESEARCH LABORATORY       AFRL-ML-WP-TR-1998-4191         PROCE DATERIEL COMMAND       AFRL-ML-WP-TR-1998-4191         PROVED FOR PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         TA BUSTRIBUTION AVAILABLING STATEMENT         Approved FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         TABUT MEMORY ADVANCE TRANSACTIONS OF THE L	4. TITLE AND SUBTITLE			5. FUNDING NUMBERS								
OBJECT DAMAGED TYPE VILEXTRA HIGH PRESSURE AIRCRAFT TIRES; SAE PAPER 912155       TA 01         E ADTIMAS; PETER C. VORUM       TA 01         T. FARGEMENG DEGANIZATION BAMEISTARD ADDRESSIES; MATERIALS AND MANUFACTURINO DIRECTORATE AIR FORCE RESEARCH LABORATORY       B PRFOMMED DEGANIZATION REFORM WORKS TECHNICAL PAP SOCIETY OF AUTOMOTIVE ENGINEERS TECHNICAL PAP 912155         T. SPENSONMOMONTORING AGENCY MANERS AND ADDRESSIES; MATERIALS AND MANUFACTURINO DIRECTORATE AIR FORCE MATERIEL COMMAND WRIGHT-PATTERSON AFB, OH 45433-7750       I S SPONSONMOMONTORING AGENCY MANERS AND ADDRESSIES; MATERIALS AND MANUFACTURINO DIRECTORATE AIR FORCE RESEARCH LABORATORY AIR FORCE RATERIEL COMMAND WRIGHT-PATTERSON AFB, OH 45433-7750       I S SPONSONMOMONING AGENCY MANERS AND ADDRESSIES; MATERIALS AND MANUFACTURINO DIRECTORATE AIR FORCE MATERIEL COMMAND WRIGHT-PATTERSON AFB, OH 45433-7750       I S SPONSONMOMONING AGENCY MANERS AFL-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC: PFIER C. VORUM ARKLMERT, 937-235-9024       I SPONSONMOMONING AGENCY MANERS THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         Ta. DISTRIBUTION WAILABURY STATEMENT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       I AL DISTRIBUTION CODE         13. ABSTRACT MANIMUM 201 world       I SOUGHY STATEMENT AND ADDIFY OF AUTOMOTY APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       I AL DISTRIBUTION CODE         13. ABSTRACT MANIMUM 201 world       I SOUGHY STATEMENT AND ADDIFY OF AUTOMOTY APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       I AL DISTRIBUTION CODE         14. DISTRIBUTION WAVALABURY STATEMENT APPROVED FOR PUBLIC RELEASE,	CUT PROGRESSION DURIN	G DYNAMOMETER TESTING	OF FOREIGN	C IN-HOUSE								
SAE PAPER 912155       TA       01         E. AUTIONISIS       WU       47         PETER C. VORUM       WU       47         7. PERFORMING DEGAINZATION NAMESIAND ADDRESSIESI       E. PERFORMING DEGAINZATION NAMESIAND ADDRESSIESI       E. PERFORMING DEGAINZATION NAMESIAND ADDRESSIESI         AIR FORCE RESEARCH LABORATORY       SOCIETY OF AUTOMOTIVE       SOCIETY OF AUTOMOTIVE         AIR FORCE RESEARCH LABORATORY       SOCIETY OF AUTOMOTIVE       SOCIETY OF AUTOMOTIVE         AIR FORCE RESEARCH LABORATORY       AIR FORCE RESEARCH LABORATORY       SOCIETY OF AUTOMOTIVE         AIR FORCE RESEARCH LABORATORY       AIR FORCE RESEARCH LABORATORY       AIR FORCE RESEARCH LABORATORY       AIR FORCE RESEARCH LABORATORY         AIR FORCE C. C. VORUM AFRI./MLBT, 937-255-9024       11. SUPPLEMENTAM MOTE       AFRL-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC: PETER C. VORUM AFRI./MLBT, 937-255-9024       11. SUPPLEMENTAM MOTE         11. SUPPLEMENTAM MOTE       IS ABUSTRIBUTION UNLIMITED       12b. DISTRIBUTION CODE       12b. DISTRIBUTION CODE         11. SUPPLEMENTAM MOTE       IS ABUSTRIBUTION UNLIMITED       12b. DISTRIBUTION CODE       12b. DISTRIBUTION CODE         11. ABSTRACT MADEMIN AVAILABLITY STATEMENT       APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       12b. DISTRIBUTION CODE         11. ABSTRACT MADEMIN AVAILABLING SURFACES AND (A DORES SUREM STA SUCH TOR	OBJECT DAMAGED TYPE V	II EXTRA HIGH PRESSURE A	IRCRAFT TIRES;	PR 2402								
E. AUTORNSI PETER C. VORUM         WU 47           7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES) MATERIALS AND MANUFACTURING DIRECTORATE AIR FORCE RESEARCH LABORATORY AIR FORCE WATERIE C. VORUM ANTER THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         10. SPONSONNAMON AFRICAL SAND AFRICATION AVAILABULTY STATEMENT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         12. DISTRIBUTION CODE           11. ABSTRACT Maximum 200 world/         12. DISTRIBUTION AVAILABULTY STATEMENT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         12. DISTRIBUTION CODE           12. DISTRIBUTION AVAILABULTY STATEMENT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         12. DISTRIBUTION CODE           13. ABSTRACT Maximum 200 world/         13. ABSTRACT Maximum 200 world/         13. DISTRIBUTION UNLIMITED           14. SUBJECT TEMMS CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, 13. FORMER OF FAGES CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, 14. FORE COMMENTING ANALABULTY AXIWAY         15. NUMBER OF FAGES CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, 15. FORMER MAX TAXIWAY            14.	SAE PAPER 912155 TA 01											
PETER C. VORUM       Image: C. VORUM         7. PERFORMING ORGANIZATION MAMEES AND ADDRESSEES:       Image: C. VORUM         ATTERIALS AND MANUFACTURING DIRECTORATE       Image: C. VORUM         AIR FORCE RESEARCH LABORATORY       SOCIETY OF AUTOMOTIVE         AIR FORCE MATERIEL COMMAND       PISTONANCE MATERIEL COMMAND         WRIGHT-PATTERSON AFB, OH 45433-7750       Image: C. VORUM         AIR FORCE MATERIEL COMMAND       Image: C. VORUM         WRIGHT-PATTERSON AFB, OH 45433-7750       Image: C. VORUM         TI, SUPERSURINGMONITORING AGENCY RAMESS AND ADDRESSES)       Image: C. VORUM         AIR FORCE MATERIEL COMMAND       AFRI-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC: PETER C. VORUM ARL/MLBT 937-255-9024         TILS SPAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         TA BETRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       Image: C. VORUM ARL PARTEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       Image: Continued flight operations has not been scriously studied. This report will follow a group of TY         TI ABSTRACT MAXIMUM 200       AMATERIAL SCOME AND ADDRESSES       Image: Continue flight operations has not been scriously studied. This report will follow a group of TY         TI ABSTRACT MAXIMUM 200       Tis AUGENTIAL AND ADDRESSES       Image: Continue flight operations has not been	6. AUTHOR(S)			WU 47								
T. PERFORMING DRGARIZATION HAMESI AND ADDRESSIESI <ul> <li>PERFORMING DRGARIZATION HAMESI AND ADDRESSIESI</li> <li>MA TERIALS AND MANUFACTURING DIRECTORATE</li> <li>AIR FORCE RESEARCH LABORATORY</li> <li>AIR FORCE MATERIEL COMMAND</li> <li>WRIGHT-PATTERSON AFB, OH 45433-7750</li> <li>STONSORMERGONOTORING AGENCY MANESI AND ADDRESSIESI</li> <li>AR FORCE MATERIEL COMMAND</li> <li>WRIGHT-PATTERSON AFB, OH 45433-7750</li> <li>PORCE RESEARCH LABORATORY</li> <li>AIR FORCE MATERIEL COMMAND</li> <li>WRIGHT-PATTERSON AFB, OH 45433-7750</li> <li>PORCE PETER C. VORUM. AFRL/MLBT. 937-255-9024</li> <li>I. SPONSONHARMONITORING</li> <li>AFFRL-ML-WP-TR-1998-4191</li> <li>MATERIALS AND MANUFACTURING DIRECTORATE</li> <li>AIR FORCE MATERIEL COMMAND</li> <li>WRIGHT-PATTERSON AFB, OH 45433-7750</li> <li>PORCE PETER C. VORUM. AFRL/MLBT. 937-255-9024</li> <li>I. SUPHEMENTAWAY MOTES</li> <li>I. SUBJECT REASE, DISTRIBUTION UNLIMITED</li> <li>I. ABSTINGUTION AVAILABILITY STATEMENT</li> <li>APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED</li> <li>I. ADSTRIBUTION AVAILABILITY STATEMENT</li> <li>APPROVED FOR PUBLIC RELEASE, OLISTRIBUTION UNLIMITED</li> <li>I. ADSTRIBUTION AVAILABILITY STATEMENT</li> <li>APPROVED FOR PUBLIC RELEASE, OLISTRIBUTION UNLIMITED</li> <li>I. ADSTRIBUTION AVAILABILITY STATEMENT</li> <li>ADSTRIBUTION AVAILABILITY STATEMENT</li> <li>I. SUBJECT TAMAMER AND FORE BACOMONOTORING ADDRESEASE ADDRESEASE ADDRESTING ADDRESEASE ADDRESEASE ADDRESEASE ADDRES</li></ul>	PETER C. VORUM											
MATERIALS AND MANUFACTURING DIRECTORATE       Herond models         AIR FORCE RESEARCH LABORATORY       SOCIETY OF AUTOMOTIVE         AIR FORCE MATERIEL COMMAND       SOCIETY OF AUTOMOTIVE         WRIGHT-PATTERSON AFB, OH 45433-7750       912155         TAR FORCE RESEARCH LABORATORY       ARTERIALS AND MANUFACTURING DIRECTORATE         AIR FORCE RESEARCH LABORATORY       ARTERIALS AND MANUFACTURING DIRECTORATE         AIR FORCE MATERIEL COMMAND       FREDEN MABER         WRIGHT-PATTERSON AFB, OH 45433-7750       POC:         POC:       PETER C. VORUM. AFRL/MLBT, 937-255-9024         TI. SUPPREMATARY MOTES       THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         TA BISTRIBUTION AVAILABLITY STATEMENT       124. DISTRIBUTION CODE         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       124. DISTRIBUTION CODE         T3. ABSTRACT (Maximum 200 wordd)       Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires. Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         YII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         Alemating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developmeter	7. PERFORMING ORGANIZATION NAME(S	S) AND ADDRESS(ES)		8. PERFORMING ORGANIZATION								
AIR FORCE RESEARCH LABORATORY       JOINT 10 F ADTORNO ITY         AIR FORCE MATERIEL COMMAND       BUGINEERS TECHNICAL PAP         WRIGHT-PATTERSON AFB, OH 45433-7750       Its SPONSORINGMONITORING AGENCY KAMEIS AND ADDRESSIES         MATERIALS AND MANUFACTURING DIRECTORATE       AR FORCE MATERIEL COMMAND         AIR FORCE MATERIEL COMMAND       WRIGHT-PATTERSON AFB, OH 45433-7750         POC:       PTER C. VORUMA AFRI, MLBT, 937-255-9024         TI:       SUPPREMENTARY NOTES         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         Ta. DISTRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         T3. ABSTRACT Mommun 200 words/         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires:         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         YII EXTH High Pressure tires which were damaged by running them over a debris strew taxis de, then run though         Idtentating taxi-takeoff and landing-taxi tests on the 3.05 meetr (120 incl) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While         testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grounicluded new and recapped bias ply, and prototype radial main landi	MATERIALS AND MANUFA	CTURING DIRECTORATE		SOCIETY OF AUTOMOTIVE								
AIR FORCE MATERIEL COMMAND       PICINCAL TAY         WRIGHT-PATTERSON AFB, OH 45433-7750       912155         S. SPONSONRE,MONITORING AGENCY NAMELS AND ADDRESSIES)       II. SPONSONRE,MONITORING AGENCY NAMELS AND ADDRESSIES)         AIR FORCE RESEARCH LABORATORY       ARTERIALS AND MANUPACTURING DIRECTORATE         AIR FORCE RESEARCH LABORATORY       AFRL-ML-WP-TR-1998-4191         AR FORCE MATERIEL COMMAND       AFRL-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC: PETER C. VORUM, AFRL/MLBT, 937-255-9024         TI. SUPPLEMENTAR WOTES       THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         12. DISTRIBUTION AVAILABILITY STATEMENT       IPS. DISTRIBUTION UNLIMITED         13. ABSTRACT MAXIMUM 200 world/       IPA. DISTRIBUTION UNLIMITED         14. ABSTRACT MAXIMUM 200 world/       IPA. DISTRIBUTION UNLIMITED         15. AUSTRIBUTION AVAILABILITY STATEMENT       APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         16. AUSTRIBUTION OF THE SWICK WERE COMPACIES AND OF THE STRUCK DATA AND ADDRESS INCOMPANY       IPA ADDRESS INCOMPANY         17. ABSTRACT MAXIMUM 200 world/       IPA ADSTRIBUTION OF ADDRESS INCOMPANY         17. SECURITY CLASSIFICATION AT A INCOMPANY       IPA ADDRESS INCOMPANY         18. DISTRIBUTION CODE       IPA ADDRESS INCOMPANY         19. FINE ADDRESS INCOMPANY       IPA ADDRESS INCOMPANY         18. SECURITY CLAS	AIR FORCE RESEARCH LAE	BORATORY		ENGINEEDS TECHNICAL DADED								
WRIGHT-PATTERSON AFB, OH 45433-7750       912133         S. SPONSORMEMONITORING AGENCY MAMERS AND ADDRESSES)       10. SPONSORMEMONITORING AGENCY MAMERS AND ADDRESSES)         MATERIALS AND MANUPACTURING DIRECTORATE       ARFORCE RESEARCH LABORATORY         AIR FORCE MATERIEL COMMAND       VILLABORATORY         AIR FORCE MATERIEL COMMAND       AFL-ML-MORTARY         AIR FORCE C. SESEARCH LABORATORY       AFRI-ML-WP-TR-1998-4191         VILLSUPPLEMENTARY NOTES       11. SUPPLEMENTARY NOTES         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         12. DISTRIBUTION AVAILABILITY STATEMENT       12. DISTRIBUTION CODE         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       12. DISTRIBUTION CODE         13. ABSTRACT (Maximum 200 words)       Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeOff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Geat Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While esting on the dynamoneter, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test gro included new and recapped bias ply, and prototype radial main landing geat tires. This paper will summarize the tire test and offer re	AIR FORCE MATERIEL COM	MAND		endineers rechnical paper								
T       SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES)       10. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES)         MATERIALS AND MANUFACTURING DIRECTORATE       ARFC-RESEARCH LABORATORY       AFRL-ML-WP-TR-1998-4191         AIR FORCE RESEARCH LABORATORY       AFRL-ML-WP-TR-1998-4191       AFRL-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC: PETER C. VORUM, AFRL/MLBT, 937-255-9024       AFRL-ML-WP-TR-1998-4191         TI: SUPPLEMENTAR WORS       THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE       T2. DISTRIBUTION AVAILABILITY STATEMENT         T22. DISTRIBUTION AVAILABILITY STATEMENT       12. DISTRIBUTION CODE       12. DISTRIBUTION CODE         T3. ABSTRACT Maximum 200 world       Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires Cut progression during continued flight operations has not been seriously studied. This report will follow a group of TY         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wrigh-Patterson Air Force Base. ONJ 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it rached the outer carcass ply, then slowed. The test grounched de outer carcass ply, then slowed. The test grounched new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and ma	WRIGHT-PATTERSON AFB,	OH 45433-7750		912155								
1. SPONSUMBLIAND UNING AGENCY AMARESS AND ADDRESSIEST       10. SPONSUMBLIAND UNING ACTURING DIRECTORATE         AIR FORCE RESEARCH LABORATORY       AGENCY REPORT NUMBER         AIR FORCE MATERIEL COMMAND       AFRL-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC:         POC:       PETER C. VORUM. AFRL/MLBT, 937-255-9024         TI. SUPPLEMENTARY NOTS       THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         Table Strategy and the strategy and th												
INA ENALS AND MANUFACTORING DIRECTORATE       Alle FORCE RESEARCH LABORATORY         AIR FORCE RESEARCH LABORATORY       AIRFORCE RESEARCH LABORATORY         AIR FORCE RESEARCH LABORATORY       AFRL-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC:         POC:       PETER C. VORUM. AFRL/MLBT, 937-255-9024         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         T2a. DISTRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         13. ABSTRACT (Maximum 200 world)         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         CUT progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         atternating taxi-takeoff and landing-taxit tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grouncluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire term and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       18. SECURITY CLASSIFICATION	9. SPONSORING/MONITORING AGENCY N	VAME(S) AND ADDRESS(ES)		1U. SPONSORING/MONITORING AGENCY REPORT NIIMRER								
AIR FORCE RESEARCH LABORATORY       AFRI-ML-WP-TR-1998-4191         AIR FORCE MATERIEL COMMAND       AFRL-ML-WP-TR-1998-4191         WRIGHT-PATTERSON AFB, OH 45433-7750       POC: PETER C. VORUM, AFRI/MLBT, 937-255-9024         TI: SUPPERMENTARY NOTES       THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         12. DISTRIBUTION AVAILABILITY STATEMENT       12b. DISTRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       12b. DISTRIBUTION CODE         13. ABSTRACT (Maximum 200 words)       Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cur damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty       VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm       Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris strew to be so tires resulted in cuts. While         testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grou       The test grou         14. SUBJECT TERMS       15. NUMBER OF PAGES       18         12. UNITING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, 18       18         13. SEQUERT TERMS       19. SECURITY CLASSIFICATION       19. SECURITY CLASSIF	MATERIALS AND MANUFA	CIURING DIRECTORATE										
AIR FORCE MATERIEL COMMAND         WRIGHT-PATTERSON AFB, OH 45433-7750         POC: PETER C. VORUM, AFRL/MLBT, 937-255-9024         TI. SUPPLEMENTARY WATS         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         T2a. DISTRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         13. ABSTRACT Maximum 200 words/         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         CUT progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test groun included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire testing of the ure evaluation of the tires and materials.         14. SUBJECT TERMS       18. SECURITY CLASSIFICATION         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, 18       18. The RICE GODE         17. SECURITY CLASSIFICATION       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRAC	AIR FORCE RESEARCH LAE	BORATORY		AFRL-ML-WP-TR-1998-4191								
WRIGHT-PATTERSON AFE, OH 45433-7750         POC: PETEC C. VORUM. AFRL/MLBT, 937-255-9024         THIS PAPER WAS PUBLISHED IN THE 1991 SAE TRANSACTIONS JOURNAL OF AEROSPACE         12. DISTRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         13. ABSTRACT Maximum 200 words/         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         alternating taxi-takcoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew trajidly until it reached the outer carcass ply, then slowed. The test grov included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. BEURITY CLASSIFICATION DF ABSTRACT         14. SECURITY CLASSIFICATION       19. SECURITY CLASSIFICATION DF ABSTRACT       20. LIMITATION OF ABSTRACT         15. RUNWER OF PAGES	AIR FORCE MATERIEL COM	IMAND										
IDC: PETER C. VORUM, AFRL/MLBT, 937-255-9024       In Supprediction and the second secon	WRIGHT-PATTERSON AFB,	OH 45433-7750										
11.3. URLANT MADE       12. DISTRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       12. DISTRIBUTION CODE         13. ABSTRACT Maximum 200 words/       12. DISTRIBUTION CODE         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. ON 13 23% of the debris struck by these tires resulted in cuts. While         testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grouincluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TEMMS       18. SECURITY CLASSIFICATION         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION       19. SECURITY CLASSIFICATION       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       19. SECURITY CLASSIFICATION       20. LIMITATION OF ABSTRACT	POC: PETER C. VORUM, AF	RL/MLBT, 937-255-9024										
12a. DISTRIBUTION AVAILABILITY STATEMENT       12b. DISTRIBUTION CODE         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       12b. DISTRIBUTION CODE         13. ABSTRACT Maximum 200 words/       13. ABSTRACT Maximum 200 words/         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grouncluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire term and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES         17. SECURITY CLASSIFICATION       18. SECURITY CLASSIFICATION       20. LIMITATION OF ABSTRACT         0F REPORT       UNCLASSIFIED       UNCLASSIFIED       20. LIMITATION OF ABSTRACT	THIS PAPER WAS PUBLISH	ED IN THE 1991 SAE TRANSA	CTIONS JOURNAL OF	AEROSPACE								
12a. DISTRIBUTION AVAILABILITY STATEMENT       12b. DISTRIBUTION AVAILABILITY STATEMENT         APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       12b. DISTRIBUTION CODE         13. ABSTRACT (Maximum 200 words)       13. ABSTRACT (Maximum 200 words)         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grow included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire term and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRICH TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRICH TEAMS       18. FRICE CODE         17. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT         0F REPORT       UNCLASSIFIED       UNCLASSIFIED       SAR         UNC												
T2a. DISTRIBUTION AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED       12b. DISTRIBUTION CODE         13. ABSTRACT Maximum 200 words/       13. ABSTRACT Maximum 200 words/         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test gro included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.       15. NUMBER OF PAGES 18         14. SUBJECT TERMS CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       16. FRICE CODE 18         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LINITATION OF ABSTRACT         19. UNCLASSIFIED       UNCLASSIFIED       SAR Standard Fgm 298(PAGE       SAR Standard Fgm 298(PAGE												
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED         13. ABSTRACT (Maximum 200 words)         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grow included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.               16. NUMBER OF PAGES	12a. DISTRIBUTION AVAILABILITY STATE	MENT		12b. DISTRIBUTION CODE								
13. ABSTRACT (Maximum 200 words)         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test gro included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire te- and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES 18         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT         19. SECURITY CLASSIFIED       UNCLASSIFIED       20. LIMITATION OF ABSTRACT         20. LINITATION OF ABSTRACT       5AR	APPROVED FOR PUBLIC RE	LEASE, DISTRIBUTION UNLI	MITED									
13. ABSTRACT (Maximum 200 words)         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grouincluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES 18         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         17. SECURITY CLASSIFIED       UNCLASSIFIED       UNCLASSIFIED       SAR Standard Fam. 298 (Rev. 249) (EG)												
13. ABSTRACT Maximum 200 words/         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires. Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test groincluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION OF ABSTRACT       18. SECURITY CLASSIFICATION OF ABSTRACT         17. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT         17. SECURITY CLASSIFICATION OF ABSTRACT       19. SECURITY CLASSIFIED         18. UNCLASSIFIED       UNCLASSIFIED												
13. ABSTRACT (Maximum 200 words)         Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test groincluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT         17. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         17. SECURITY CLASSIFICATION       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         20. LIMITATION OF THIS PAGE       UNCLASSIFIED       SAR												
Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While         testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test groi         included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION OF AREPORT       18. SECURITY CLASSIFICATION OF ABSTRACT         0F REPORT       19. SECURITY CLASSIFICATION OF ABSTRACT         0F REPORT       19. SECURITY CLASSIFICATION OF ABSTRACT         0F ABSTRACT       20. LIMITATION OF ABSTRACT         20. LIMITATION OF ABSTRACT       SAR	13. ABSTRACT (Maximum 200 words)											
Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though         alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While         testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test grou         included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test         and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,         DEBRIS, RUNWAY, TAXIWAY         17. SECURITY CLASSIFICATION         OF REPORT         UNCLASSIFIED         UNCLASSIFIED         UNCLASSIFIED         UNCLASSIFIED         UNCLASSIFIED         Standard Figur 298 (Rev. 2.89) (E6)												
Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires         Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test group included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY         18. SECURITY CLASSIFICATION OF ABSTRACT         OF THIS PAGE         17. SECURITY CLASSIFICATION OF THIS PAGE         OF THIS PAGE         UNCLASSIFIED         UNCLASSIFIED         UNCLASSIFIED         Standard Fam 298 (Rev. 2.89) (E6)	Committee and the second secon											
Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Ty         VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test growincluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE         18. SECURITY CLASSIFIED       20. LIMITATION OF ABSTRACT         20. LIMITATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         20. LIMITATION OF ABSTRACT       Standard Farm 298 (Rev. 2-89) (E6)	Ground operations over rough	surfaces and/or debris strewn ta	xiways and runways may	y result in cut damage to the tires.								
VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run though alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test growincluded new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE         18. SECURITY CLASSIFIED       19. SECURITY CLASSIFICATION OF ABSTRACT         20. LIMITATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         20. LIMITATION OF ABSTRACT       Standard Fam 298 (Rev. 2-89) (EG)	Cut progression during continu	ied flight operations has not bee	n seriously studied. This	s report will follow a group of Type								
alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Developm         Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test gro included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire test and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF ABSTRACT         18. SECURITY CLASSIFIED       19. SECURITY CLASSIFIED         19. MCLASSIFIED       UNCLASSIFIED         20. LIMITATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         21. Standard Form 298 (Rev. 2-89) (EG)       5AR	VII Extra High Pressure tires v	which were damaged by running	them over a debris strey	wn test bed, then run though								
Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test gro included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire te and offer recommendations for future evaluation of the tires and materials.         14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY       15. NUMBER OF PAGES         17. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT         18. SECURITY CLASSIFIED       UNCLASSIFIED       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       SAR	alternating taxi-takeoff and lan	ding-taxi tests on the 3.05 meter	r (120 inch) dynamomete	er in the Landing Gear Development								
testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test gro included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire te and offer recommendations for future evaluation of the tires and materials. 14. SUBJECT TERMS CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION, DEBRIS, RUNWAY, TAXIWAY 15. NUMBER OF PAGES 18. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED UNCLASSIFIED UNCLASSIFIED UNCLASSIFIED 19. SECURITY CLASSIFIED UNCLASSIFIED UNCLASSIFIED UNCLASSIFIED SAR	Facility at Wright-Patterson Ai	ir Force Base. Only 1.3 - 23%	of the debris struck by th	ese tires resulted in cuts. While								
included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire te and offer recommendations for future evaluation of the tires and materials.           14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       15. NUMBER OF PAGES         DEBRIS, RUNWAY, TAXIWAY       18. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       Standard form 298 (Rev. 2-89) (EG)	testing on the dynamometer, th	e cut depth grew rapidly until it	reached the outer carca	ss ply, then slowed. The test group								
and offer recommendations for future evaluation of the tires and materials.          14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       15. NUMBER OF PAGES         DEBRIS, RUNWAY, TAXIWAY       18. SECURITY CLASSIFICATION         17. SECURITY CLASSIFICATION       18. SECURITY CLASSIFICATION         OF REPORT       18. SECURITY CLASSIFICATION         UNCLASSIFIED       UNCLASSIFIED         Standard Form 298 (Rev. 2-89) (EG)	included new and recapped bia	s ply, and prototype radial main	landing gear tires. This	s paper will summarize the tire tests								
14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       18         DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION       18. SECURITY CLASSIFICATION         OF REPORT       18. SECURITY CLASSIFICATION         UNCLASSIFIED       UNCLASSIFIED         UNCLASSIFIED       UNCLASSIFIED         Standard Form 298 (Rev. 2-89) (EG)	and offer recommendations for	future evaluation of the tires an	d materials.									
14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       18.         DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       SAR         Standard Form 298 (Rev. 2-89) (EG)												
14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       18         DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION       18. SECURITY CLASSIFICATION         OF REPORT       0F THIS PAGE         UNCLASSIFIED       UNCLASSIFIED         Standard Form 298 (Rev. 2-89) (EG)												
14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       18.         DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       SAR         Standard Form 298 (Rev. 2-89) (EG)												
14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       15. NUMBER OF PAGES         DEBRIS, RUNWAY, TAXIWAY       18.         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       SAR         Standard Form 298 (Rev. 2-89) (EG)       16.												
14. SUBJECT TERMS       15. NUMBER OF PAGES         CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       18.         DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION       18. SECURITY CLASSIFICATION         OF REPORT       18. SECURITY CLASSIFICATION         UNCLASSIFIED       19. SECURITY CLASSIFICATION         OF THIS PAGE       0F ABSTRACT         ABSTRACT       ABSTRACT         Standard Form 298 (Rev. 2-89) (EG)												
CUTTING, FOD, FOREIGN OBJECT DAMAGE, DYNAMOMETER, CUT PROGRESSION,       13. NUMBER OF PAGES         DEBRIS, RUNWAY, TAXIWAY       16. PRICE CODE         17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       SAR         Standard Form 298 (Rev. 2-89) (EG)	14 SUBJECT TERMS											
DEBRIS, RUNWAY, TAXIWAY       18. SECURITY CLASSIFICATION OF REPORT       19. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       SAR         Standard Form 298 (Rev. 2-89) (EG)	CUTTING, FOD, FOREIGN O	BIECT DAMAGE DYNAMOM	ETER, CUT PROGRESS	SION. 10								
17. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       0F THIS PAGE       0F ABSTRACT       ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       SAR         Standard Form 298 (Rev. 2-89) (EG)	DEBRIS RIINWAV TAYWA	V										
17. SECURITY CLASSIFICATION OF REPORT     18. SECURITY CLASSIFICATION OF THIS PAGE     19. SECURITY CLASSIFICATION OF ABSTRACT     20. LIMITATION OF ABSTRACT       UNCLASSIFIED     UNCLASSIFIED     SAR	DEBRIS, KORWAT, TAAIWA	1										
OF REPORT         OF THIS PAGE         OF ABSTRACT         ABSTRACT           UNCLASSIFIED         UNCLASSIFIED         SAR           Standard Form 298 (Rev. 2-89) (EG)         Standard Form 298 (Rev. 2-89) (EG)	17. SECURITY CLASSIFICATION	18. SECURITY CLASSIFICATION	<b>19. SECURITY CLASSIFICATION</b>	20. LIMITATION OF								
UNCLASSIFIED UNCLASSIFIED SAR Standard Form 298 (Rev. 2-89) (EG)	OF REPORT	OF THIS PAGE	OF ABSTRACT	ABSTRACT								
Standard Form 298 (Rev. 2-89) (EG)	UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIEI	D SAR								
FIRSCHORD DY ANDI DIO. 239.18				Standard Form 298 (Rev. 2-89) (EG) Prescribed by ANSI Std. 239.18								

i

# Cut Progression During Dynamometer Testing of Foreign Object Damaged Type VII Extra High Pressure Aircraft Tires

Peter C. Vorum Wright Labs. Wright-Patterson Air Force Base, OH

#### ABSTRACT

Ground operations over rough surfaces and/or debris strewn taxiways and runways may result in cut damage to the tires. Cut progression during continued flight operations has not been seriously studied. This report will follow a group of Type VII Extra High Pressure tires which were damaged by running them over a debris strewn test bed, then run through alternating taxi-takeoff and landing-taxi tests on the 3.05 meter (120 inch) dynamometer in the Landing Gear Development Facility at Wright-Patterson Air Force Base. Only 1.3 - 23% of the debris struck by these tires resulted in cuts. While testing on the dynamometer, the cut depth grew rapidly until it reached the outer carcass ply, then slowed. The test group included new and recapped bias ply, and prototype radial main landing gear tires. This paper will summarize the tire tests and offer recommendations for future evaluation of the tires and materials.

TIRE cuts may result from operation over rough surfaces and/or over debris. This report follows cut progression during dynamometer testing of foreign object damaged Type VII Extra High Pressure aircraft tires (1)\*. F-16 25.5 x 8.0 Main Landing Gear tires were run over a debris strewn field once, at the Naval Air Engineering Center (NAEC) at Lakehurst NJ. Selected tires considered here were run through alternated Taxi-Takeoff (TTO) segments and Landing-Taxi (LT) segments on the north carriage of the 3.05 m (120 inch) dynamometer in the Landing Gear Development Facility (LGDF) at Wright-Patterson Air Force Base Ohio. Three different tires were run:

> first-time recapped bias tires, new bias tires, and prototype radial tires.

#### BACKGROUND

This effort is a part of a long-term research program between the Special Projects Group, Flight Dynamics Directorate, at Wright-Patterson Air Force Base Ohio; and the Engineering Services Center, at Tyndall Air Force Base Florida. The program examines the effect of debris on aircraft operations such as debris lofting, need for runway cleanliness requirements, and cut damage/progression to the tires (2). Previous tests of damaged tires (3) suggested that cut depth was a better indicator of tire condition than cut length. The analyses presented do not consider cut length.

The F-16 can operate from forward airfields. It is probable that the size and amount of debris scattered around runways, taxiways, and ramp areas would vary widely in a post attack environment.

Each tire ran over a debris strewn track one time, had cuts mapped, and was returned to Wright-Patterson for dynamometer testing. Upon return from NAEC, none of these tires was flight worthy. All would normally be removed immediately because of the damage that existed. During the laboratory testing it was shown that most of the new tires and some of the recapped tires might survive at least one takeoff and one landing in an emergency situation.

#### TEST FACILITY AND EQUIPMENT

TIRE CUTTING TEST VEHICLE - The Tire Cutting Test Vehicle (TCTV) at Lakehurst was used for a test of debris lofting, with an F-4 nose landing gear in place. That fixture was replaced with one that supported an F-16 main landing gear wheel assembly (see Figure 1). The following elements were varied on the test tire, the TCTV, and what the tire passed over:

Tire vertical load, inflation pressure,

brake pressure (drag load), and

\* Numbers in parentheses designate References at the end of the paper



FIGURE 1 - TIRE CUTTING TEST VEHICLE

turning angle (side load).

Vehicle speed.

Test bed length, number of pieces of debris on the ground, debris size and type (limestone vs metal fragments), and debris ground pattern.

TEST INSTRUMENTATION - The Time-Load-Speed profiles of the TTO and LT segments were entered into the dynamometer computer, and run automatically. Internal air pressure was adjusted for flywheel curvature. The valve was closed at the beginning of the run so that air could not enter or leave the tire during the test segment. Contained air temperature and tread surface temperature were monitored.

The physical examination of the tire was done in a steel plate and wire mesh Safety Box (5), with tools such as a tire pressure which monitored the tire pressure of 689.5 kPa (100 psi), a standard cut depth gauge marked in 1/32 inch (0.8 mm) increments to measure the depth of the cuts, and a ruler marked in 1/16 inch (1.6 mm) increments to measure the length of the cuts.

#### APPROACH

Each tire was mapped for cuts after it came off of the TCTV. Dynamometer testing included map updates. In all cases, the tire surface was allowed to cool below  $38^{\circ}$  C ( $100^{\circ}$  F) before anyone entered the dynamometer cell to remove the tire or to visually inspect the tread. It was not deflated until it had cooled, because early deflation might cause delamination of the carcass inner liner or other damage, unrelated to the scope of this program.

#### TEST SUMMARY

One hundred and twenty three tires were run at NAEC. Of these, 34 tires were selected for testing on the dynamometer. The number of dynamometer segments completed and causes for removal are presented in Table 1.

Table 1: Test Segments Completed and Cause for Removal

Tire type	Number of tires	Segments at failure	Reason for removal
Recap	2 7 3	1 3 5	<pre>stripped tread chunked/stripped/undercut portion of, or    all of tread stripped tread</pre>
	<u>1</u> 13 tires	7	chunked/undercut one rib
New	1 5 1 5 ** 1 2 1 1 17 tires	3 5 6 ** 7 9 11 15	<pre>chunked chunked/stripped undercutting * completed without failure stripped stripped/chunked/undercut chunked stripped</pre>
Radial	1 1 <u>2</u> ** 4 tires	3 5 6 *	stripped stripped * completed without failure

The tires were broken into two Phases for dynamometer testing:

PHASE 1 - The tires were run to destruction on the dynamometer. Failure was due to one or more of the following parameters:

> heat blow, undercutting, and/or tread chunking/stripping.

This group included all of the recapped tires and some of the new tires. Cut maps were updated after each dynamometer segment. The test process was very lengthy since each tire had to cool before removal from the dynamometer, was remapped in the Safety Box (5), and returned to the test queue. Remapping each tire after each segment resulted in a maximum daily test rate of six tires in 8 hours.

> PHASE 2 - The tires were remapped only after the first TTO segment. They then remained on the dynamometer until destruction, or until three TTO segments and three LT segments were completed, whichever was first. This group included the balance of the new tires not tested in Phase 1, and all of the prototype radial tires.

Upon return from NAEC, 26 of the 30 bias ply tires had a number of cuts deeper than the Cut Limit; there was no Cut Limit indicated for the radial tires. There was little damage to the carcass of any dynamometer tested tire and no tire run on the dynamometer lost air pressure. Changes in surface flaws were erratic, such as:

> new cuts or blemishes appeared, blemishes opened into cuts, cuts did not change, cuts grew deeper or shallower, cuts or blemishes disappeared, cuts closed to become blemishes, and some did a combination of all of the above

The Cut Limit locates the outer most carcass ply relative to the bottom of the groove. The Type VII Extra High Pressure tires may suffer damage to one ply layer and continue in use. As the recapped tires were run on the dynamometer, the mean depth of the cuts grew until it approached the Cut Limit depth. The mean depth of the cuts of the new tires grew slightly deeper than the Cut Limit.

At NAEC, more of the new tires were run over larger debris than the recapped tires, and sustained more initial cuts beyond limits than the recaps did. This difference in testing may have contributed to the progression of the new tire cuts, deeper into the carcass than what appeared on the recaps.

The reinforcing tread plies have an unknown effect on the cut. Other things may happen to the tread (chunking or undercutting), but the cut depth increase appears to stop or to slow greatly at the carcass limit. As is often seen in composites, the crack stops when it goes from an elastic material (rubber) into the reinforced material (rubber/carcass fiber).

#### TIME-LOAD-SPEED SPECIFICATIONS

On the dynamometer, each tire was run on a Time-Load-Speed (TLS) history described in Drawing 16VL002 (4):

- Taxi-Takeoff segments were alternated with Landing-Taxi segments,
- the "heavy" weight takeoff specification was used,
- the normal landing weight specification was used,
- a 2.3 km (7500 foot) taxi length was used to model a forward combat base, and
- the tire was stopped momentarily between the taxi roll, and the takeoff or landing sequence (see Figures 2 and 3).





In the takeoff segment, there is a "spike" load increase on the main landing gear tire as the nose of the aircraft rotates off of the ground at T = 34.5 seconds.



## 912155

### TIRE CONDITION RECORDS

DAMAGE CRITERIA - Damage limits for Type VII Extra High Pressure tires are published in MIL-T-5041, paragraph 3.4.10 (6). The criteria for immediate removal of a damaged tire is listed in Table 2. DAMAGE RECORDS - The conventions presented in Figures 4 and 5 were used to document the position and orientation of the cuts. Each cut, puncture, blemish, or scuff was recorded under the procedure described in Reference 5. The elements listed in Table 3 were examined and recorded during the inspections. See the Appendix for damage descriptions.



FIGURE 4: CUT MAP CONVENTIONS BIDE VIEW FIGURE 5: CUT MAP CONVENTIONS

Table 2: Damage That is Cause for Removal

- (1) Tread chunking that exceeds 6.5 cm sq (1.0 square inch area)
- (2) Tread stripping (large scale chunking)
- (3) Any amount of undercutting
- (4) A heat blow that results in any chunking that exceeds limits, or if there is any undercutting
  (5) Any cut deeper than the Cut Limit: no cut shall penetrate deeper than the first carcass ply layer. This limit was ignored for the term of this test

Table 3: Variables Recorded in Cut Maps

- (1) Cut number
- (2) Length in 1.6 mm (1/16 inch)
- (3) Depth in 0.8 mm (1/32 inch)
- (4) Circumferential position in degrees relative to the balance mark
- (5) Lateral position across the face of the tread, i.e. groove, rib, or sidewall, with "SW 1" being the sidewall on the balance mark side of the tire
- (6) Angle relative to the centerline groove, where:

Parallel to the groove is considered "0°" Rotation less than 90° clockwise is "+ 45°" Rotation less than 90° counter clockwise is "- 45°" Perpendicular to the center groove is "90°"

### FAILURE MODES

In Phase 1 of these tests, the tires were run to destruction by chunking, stripping, and/or undercutting.

In Phase 2, the tires were run to destruction as in Phase 1, or until they completed three TTO and three LT segments, whichever came first.

Evidence of deterioration appeared on TTO and LT segments, but most damage-related failures were on a TTO segment. In the takeoff segment, the main tire load drops as the vehicle accelerates, but a short term, high load spike is imposed on the main tire at a time that corresponds to aircraft rotation. Most chunking or stripping failures of the main tires were close to this high speed/high load, spike. Undercutting appeared gradually as the tire heated up with time on the dynamometer.

#### LAKEHURST SET UP

81

The jet test tracks at NAEC, Lakehurst NJ, were used as the test bed for these tests. The test track surface is concrete. The Tire Cutting Test Vehicle is guided along the track by two Ibeam rails. The debris used was either crushed limestone or bomb fragments. It was graded according to its size. Debris was placed on the ground in one of several patterns so as to impact each sidewall, rib, and groove a number of times in the test bed. The number of pieces of debris ranged from 173 to 400. An aircraft tug, an Army M-35A2 (2.5 ton) truck, and a jet cart provided the push on different tests. The tires that ran on the dynamometer were set up with to the following conditions:

RECAPPED TIRES - Thirteen tires were run under 6,486 kg (14300 lbm) load; over 12.7 mm (0.5 in), 25.4 mm (1.0 in), 38.1 mm (1.5 in), and 50.8 mm (2.0 in) debris; at 16 to 28 km/hr (10 to 17.5 mph); with no braking or turning. Each recap was a first-time recap. NEW TIRES - Seventeen tires were run under3,311 kg (7300 lbm), 4,672 kg (10300 lbm), and 6,486 kg (14300 lbm) loads; over 25.4 mm (1.0 in), 31.8 mm (1.25 in), and 38.1 mm (1.5 inch) debris; at 5 to 211 km/hr (3 to 131 mph); with varied turning, braking, and turning/braking combinations.

RADIAL TIRES - Four tires were run under 6,486 kg (14,300 lbm) load, over 38.1 mm (1.5 inch) debris, at 25 to 30.5 km/hr (15.5 to 19 mph), with no turning or braking.

YAW TESTS - Selected new tires had a 1° or 3° degree yaw applied. This is within the turning angle seen in normal service other than at very slow speed when pivoting about a point, as one would do when parking the aircraft.

BRAKE TESTS - Selected new tires were tested with 1.379 mPa (200 psi), 2.758 mPa (400 psi), and 3.448 mPa (500 psi) applied to the brake. To avoid locking the brake, preliminary tests were run at several brake pressure, TCTV speed, and vertical load combinations. In all tests, the TCTV was moving when the brake was engaged. On the aircraft, there is a back-pressure applied to reduce relative motion of the brake stack elements, and to overcome internal leakage so that there will always be positive response when the pilot applies the brake. The normal backpressure is 655 - 690 kPa (95-100 psi). Brake pressure during engine run up in a parking space is 5.516 - 6.895 mPa (800-1000 psi), on landing it is 9.653 - 12.411 mPa (1400- 1800 psi). The 1.379 - 3.448 mPa (200 - 500 psi) used in these tests is considered "light" braking.

#### TEST RESULTS

GENERAL COMMENTS - Damage from running over the debris varied greatly, as did the performance of the tires on the dynamometer. Cut maps of the extremes of damage to the tread surface may be seen in Figures 6, 7, and 8:

a rirs	sτ-	τı	ne	re	ca	p.																			
	°.					ą	Ŗ					8	}					٥ŗ						30	
82	Γ	Τ	Γ	Γ							Τ		Τ		Τ	Τ	Т	1			Τ				POST NAEC
G4		-			_		-			-		-	-+	-		-+	+		-+		_		-		
R3							•								•										
G3		1-					_	_		_		-		-		-	_	_	-	-	_		- 1		
R2			<u>•</u>				Ł		•																FIGURE 6: LEAST PRIMARY DAMAGE
62	F	-	<u>+</u>			-		-				_		-	-		-	-			-			_	3242-0717/X-2A RECAPPED TIRE
H1 01		-	<b>-</b>	L		_			•				_			_	_	_			_	_	_		
		+	-			-					-1	-+	-+	- f	+		-+	-t			-+	+			
31	1						1	1					- 1	1	- 1				- 1	ł	- 1	1	- 1		
	Ļ	┶	1	L	<u> </u>	L		L				. 1								_	<b>.</b>				
BALANO			•																						
		T	Т	<b>—</b>								Т									_	T			POST LI 1 SEGMENT
<b>S</b> 2			1.4			1		1				- 1	- [	1					- 1	Î					
G4	+	+	+					<u> </u>			-	-								-			- 1		
R3		1						-							Öa		Т	- 1							
G3		-				-	<u> </u>									_	_					_			
R2	<b>e</b> .	•	L.				1					- 1					¢			1	1	_1			
G2	F			-		_	_	_					_	_				_		_		_			
R1			•				1		•				•			_	_			_			$\rightarrow$		
G1		-	1 T		-	-	-	-	1				- 1	- 1		· • •	T	- 1							

LEAST PRIMARY DAMAGE - Tire X-2A (recap) sustained the fewest primary cuts of all dynamometer tires run on the track at NAEC, and is presented in Figure 6. There were four primary cuts (with one

past the Cut Limit) and four primary blemishes. As it ran on the dynamometer, the primary damage increased, and secondary cuts and blemishes appeared. After lab segment LT 1, there were six primary cuts (two past the Cut Limit) and one primary blemish; and 12 secondary cuts (with two past the Cut Limit) and three secondary blemishes.

Only 1.9% of the impacts at NAEC resulted in primary cuts and another 1.9% resulted in primary blemishes. After LT 1, the number of all cuts equalled 8.7% of the number of impacts. The 450% increase in the number of cuts, and 275% increase in total damage were the top percentage increase of damage for all tires tested. The tire stripped 100% of the tread during TTO 2.



FIGURE 7: MOST PRIMARY DAMAGE 6202-0666/J-20 NEW TIRE

FIGURE 8: GREATEST SECONDARY DAMAGE

4044-0951/H-8 NEW TIRE

BALANCE MARK



POST NAEC

#### POST TTO 1 SEGMENT

MOST PRIMARY DAMAGE - Tire J-20 (new) sustained the most primary cuts, and is presented in Figure 7. There were 81 primary cuts (ten past the Cut Limit) and six primary blemishes. After lab segment TTO 1, there were 86 primary cuts (11 past the Cut Limit) and no blemishes; and 27 secondary cuts (two past the Cut Limit) and three secondary blemishes.

Twenty three percent of the impacts resulted in primary cuts and 2% resulted in primary blemishes. After TTO 1, the number of all cuts equalled 33% of the impacts. This tire stripped 200 degrees of the inboard (R2) center rib during TTO 3.



BALANCE MARK

82	63				;			•			•		•	Γ	Γ	•	•		Þ				
R2	G2	Ē	•				•	Π	E		E	Η	E	2				Ē		52	J	-	夷
R1	G1	E		1.	•	-	-		•	-		-	0								•		
51		•	•	_	•			•															

#### POST TTO 1 SEGMENT

MOST SECONDARY DAMAGE - Tire H-8 (new) sustained more than the mean (40) number of cuts at NAEC, and is presented in Figure 8. There were 49 primary cuts (four past the Cut Limit) and one primary blemish. Growth of secondary damage after lab segment TTO 1 was dramatic. After TTO 1, there were 50 primary cuts (five past the Cut Limit) and no primary blemishes; and 43 secondary cuts (two past the Cut Limit) and one secondary blemish. The 43 secondary cuts after TTO 1 were the most noticed during this program.

Fourteen percent of the impacts resulted in primary cuts, and less than 1% resulted in primary blemishes. After TTO 1, the number of all cuts equalled 27% of the impacts. The tire completed 3 TTO and 3 LT segments without failure, and was removed from the test queue for the dynamometer.

6

٠.

The three tire groups were run in a random order on the dynamometer. The TTO and LT specifications were the same for all tires. The tires will be examined separately here.

#### RECAPPED TIRES

Fifteen recapped tires were run at NAEC; thirteen were tested on the dynamometer. The number of primary cuts and blemishes was generally low. An average of only 4.7% of the objects struck caused primary cuts; additional blemishes occurred.

TRACK SPEED EFFECT - All of the tires were run in a very narrow speed range: all but one were within 10% of an average test speed of 25.6 km/hr (15.9 mph). None was tested at takeoff speed.

The number of primary cuts produced is presented in Figure 9, as a function of speed in the test bed at NAEC. Individual tires had between four and 31 primary cuts, with 69% of the tires having 15 or fewer cuts. The positive slope indicates that more damage was done as the NAEC speed increased.



FIGURE 9: SPEED vs NUMBER OF CUTS Recapped Tires

The mean depth of the primary cuts on each tire is presented in Figure 10. 54% of the tires were at or above the 7.1 mm (9/32 inch) Cut Limit. The negative slope results from the choice of tires. A different group might have had a different slope.

The initial mean depth of all primary cuts on all tires was 6.7 mm (8.5/32 inch). After TTO 1, the value rose to 7.2 mm (9.1/32 inch). The number and depth of primary cuts were increasing. The internal damage done becomes apparent with continued dynamometer testing.

The ratio of cuts deeper than the Cut Limit, to the total number of cuts is presented in Figure 11. Both the POST NAEC and POST TTO 1 curves have a positive slope and positive intercept. As above, the number of cuts deeper than the Cut Limit is worse with higher track speed. The POST TTO 1 curve is above the POST NAEC curve: more internal damage is revealed with additional dynamometer testing.

The number of dynamometer segments run at

tire failure is presented in Figure 12. On the dynamometer, 69% of the tires failed on or before TTO 2, Test Segment 3. The negative slope indicates more damage occurred at higher track speed, which resulted in a shorter life on the dynamometer. This curve compliments the information in Figure 9.







![](_page_9_Figure_17.jpeg)

OVERALL CONDITION WITH TESTING - In general, the tires deteriorated with each run on the dynamometer. The more heavily damaged tires failed first.

Data in Figure 13 highlights the increase in the number of cuts with testing. The X-axis indicates the number of cuts before a dynamometer test segment; the Y-axis indicates the number of cuts after a dynamometer test segment. Each data point is an individual dynamometer run for an individual tire. The slope of the Post TTO 1 curve is 1.3; the intercept is 4.0. These suggest that there were an average 34% more cuts visible after the first dynamometer event than on return from NAEC.

The slope of the LT 1 curve is 1.025 with an intercept of 1.4: a 3.9% increase in the number of cuts occurred after LT 1. The increase was less than after TTO 1, but still positive, i.e. the number of cuts continued to grow. Were this trend to continue and the tire to survive, one might expect to see a cut or blemish for each impact. The tires did not, however, last long enough to produce as many cuts and/or blemishes as impacts.

![](_page_10_Figure_4.jpeg)

![](_page_10_Figure_5.jpeg)

![](_page_10_Figure_7.jpeg)

The mean depth of primary and secondary cuts of all recapped tires is presented in Figure 15 and Table 4. It is interesting to note that the primary and secondary cuts have significantly different mean depths. The primary cuts are deeper. The trend in both is to deepen until the crack approaches the reinforced carcass.

The calculation is from a decreasing data pool as the tests progressed. The Post NAEC point is from 165 primary cuts on 13 tires where the Post LT 2 point is from 23 primary cuts on 2 tires.

![](_page_10_Figure_10.jpeg)

# Table 4: Overall Damage Progression of Recapped Tires

Segne	nt:	Post NAEC	Post TTO 1	Post LT 1	Post TTO 2	Post LT 2
Numbe	r of Tires	13	7	5	2	2
Prima	ry Cuts					
	Total number of cuts Mean depth (1/32 in)	165 8.5	89 9.06	55 9.63	22 8.16	23 8.0
Secon	dary Cuts					
	Total number of cuts Mean depth (1/32 in)		52 4.7	31 6.37	14 7.59	14 7.71

INDIVIDUAL CONDITION WITH TESTING - Changes in the mean cut depth of primary cuts of seven tires are presented in Figure 16. Damage is unpredictable. An increase or decrease in mean depth on one segment might be followed by the opposite after the next segment. The changes include the cut becoming shallower, deeper, or closing; new cuts appearing; or cuts going unchanged.

The deepest primary and secondary cuts at the beginning of the last dynamometer test segment are presented in Figure 17. The primary cuts average 15.9 mm (20/32 inch) deep, more than twice the 7.1 mm (9/32 inch) Cut Limit. The secondary cuts average 7.9 mm (10/32 inch) deep which is just over the Cut Limit. As was noted above, 69% of the tires failed on or before TTO 2, Test Segment 3.

The average life of these 13 recapped tires on the dynamometer was 3.5 test segments. Operational field experience with the recapped tires was poor: fewer landings per tire change and more catastrophic failures than the new tire. A comparison test was completed using five undamaged recapped tires. They were run on TTO schedules only. As noted in Figure 17, undamaged tires failed on segments 2, 3, 13, 14, and 19.

![](_page_11_Figure_7.jpeg)

FIGURE 17: DEEPEST CUT at FAILURE Recapped Tires

![](_page_11_Figure_9.jpeg)

з,

FAILURE MODES - Twelve of thirteen recaps experienced "general" tread failures on the dynamometer. These included stripping 15 - 100% of a single rib, stripping the entire tread, chunking around the perimeter, and/or undercutting at least one rib. Undercutting, which may not be directly related to debris impact, occurred on three tires.

#### NEW TIRES

Eighty six new tires were run at NAEC. Sixteen were run on the dynamometer.

TRACK SPEED EFFECTS - The track speed for all tires ranged between one and 270 km/hr (one to 168 mph); those that were dynamometer tested ran between five and 211 km/hr (three to 131 mph). This top speed is one half takeoff speed.

The number of primary cuts produced is presented in Figure 18. Dynamometer tires had between seven and 81 primary cuts, with 59% having 40 or fewer cuts. The trend noted with recaps is repeated: more cuts at higher track speeds.

![](_page_12_Figure_6.jpeg)

![](_page_12_Figure_7.jpeg)

The mean depth of the cuts on each tire is presented in Figure 19. 35% of the tires were at or above the 5.6 mm (7/32 inch) Cut Limit. This compares to 54% of the recaps that were at or above a deeper Cut Limit. The initial mean depth of all cuts on all dynamometer tires was 4.9 mm (6.17/32 inch). This compares to 6.7 mm (8.5/32 inch) for the recaps. A Shore Type A durometer comparison of the new and recap tire materials may explain this difference. The recaps registered 10% lower value (softer compound). As was noted above, the service life of recaps was not as good as the new tires. Recaps F-16 main tires were removed from flight status.

The ratio of cuts deeper than the Cut Limit, to the total number of cuts is presented in Figure 20. All three curves have a positive slope. The amount of damage is higher for the new tires than with the recapped tires, but the performance trend is reversed: POST TTO 1 data is below POST NAEC data. In a number of tires, the number of cuts dropped between NAEC measurements and POST TTO 1 measurements.

![](_page_12_Figure_11.jpeg)

FIGURE 19: MEAN DEPTH of PRIMARY CUTS

![](_page_12_Figure_13.jpeg)

The number of test segments run at tire failure is presented in Figure 21. On the dynamoometer, 64% of the tires failed on or before LT 3, Test Segment 6. The negative slope of the curve compliments the information in Figure 12: more damage occurred at higher track speed, resulted in shorter life on the dynamometer. This is similar to the trend seen on the recaps.

![](_page_12_Figure_15.jpeg)

![](_page_12_Figure_16.jpeg)

OVERALL CONDITION WITH TESTING - Like the recaps, the new tires deteriorated with each run on the dynamometer. The number of cuts before and after each test segment in Figure 22 is similar to recapped tire data in Figure 13, except that the slope and intercept are different. New tire POST TTO 1 data indicates a 30% increase in the number of cuts over POST NAEC levels; it was 34% for the recapped tires. New tire POST LT 1 data indicates an 8% decrease in the number of cuts over POST TTO 1 levels; it was 3.9% increase for the recapped tires. A difference in tread material, noted with the Shore durometer test, may explain this change. On landing, the high heat created by spin up seems to temporarily glue some cuts back together.

![](_page_13_Figure_2.jpeg)

FIGURE 22: INCREASE in NUMBER of CUTS

In Figure 23, the data from Figure 22 is presented as the ratio of cuts-per-impact before and after each dynamometer test. The slope and intercept of new tire POST TTO 1 curve is greater than it was for recapped tires curve. The new tire POST LT 1 curve has an 18% decrease over POST NAEC data; the recapped tire POST LT 1 curve had a 5.5% increase.

The mean cut depth of primary and secondary cuts of all tires is presented in Figure 24 and Table 5. The new tire trend is more severe than it was for the recapped tires: the mean cut depth increased above the Cut Limit with dynamometer tests. The data pool shrank as the test continued because of tire failures or removals after three TTO and LT segments had been completed. The greater damage may also reflect the conditions of test at NAEC: twice as many new tires ran over 38 mm (1.5 inch) rocks than did recapped tires; and some of the new tires ran at "high" speed (above 48 km/hr - 30 mph), while no recap ran over 29 km/hr (18 mph).

![](_page_13_Figure_7.jpeg)

![](_page_13_Figure_8.jpeg)

#### Table 5: Overall Damage Progression of New Tires

Segment:	Post NAEC	Post TTO 1	Post LT 1	Post TTO 2	Post LT 2
Number of Tires	17	16	6	5	3
Primary Cuts Total number of cuts Mean depth (1/32 in)	633 6.53	611 6.02	146 7.55	138 8.11	88 8.67
Secondary Cuts Total number of cuts Mean depth (1/32 in)		272 4.08	91 4.67	95 5.45	59 5.86

INDIVIDUAL CONDITION WITH TESTING - Changes in the mean cut depth of primary cuts of seventeen new tires are presented in Figure 25. No rational pattern can be drawn from this data. The same was true of the recapped tires.

The average life of new tires on the dynamometer was 6.9 test segments.

![](_page_14_Figure_3.jpeg)

![](_page_14_Figure_4.jpeg)

FAILURE MODES - Five of the new tires were removed from the test queue after six test segments without failure. The other twelve were removed when either 56 - 100% of a single rib stripped, the entire tread stripped, the tread chunked around the perimeter of the tire, and/or at least one rib was undercut. Undercutting was noted on one tire.

### RADIAL TIRES

` **:**.

Four new prototype radial tires were run at NAEC; all four were run on the dynamometer. Tire H-4 was a different design than H-1, 2, and 3, and produced different results than the other tires.

SPEED EFFECTS - The track speed ranged from 24.1 - 31.4 km/hr (15 - 19.5 mph), over 38.1 mm (1.5 inch) limestone, under a 6,583 kg (14,500 lbm) load.

The number of primary cuts produced is presented in Figure 26, as a function of speed in the test bed at NAEC. The "newer" design H-1, 2, and 3 produced 2/3's fewer cuts than the "earlier" design H-4. Of the 110 primary cuts on all four tires POST NAEC, one half of the cuts were on H-4. Because of the small number of tires, run in a small speed range, there is not enough data to draw a useful conclusion. The mean depth of cuts on each tire is presented in Figure 27. Unlike the production bias tires that were tested, these prototype radial tires did not have a Cut Limit label cast on the sidewall. The POST TTO 1 data shows the familiar positive slope and intercept with speed. If H-4 is removed from the data, the initial mean depth of all cuts in the other tires is 4.0 mm (5.036/32)inch).

![](_page_14_Figure_11.jpeg)

![](_page_15_Figure_1.jpeg)

FIGURE 27: MEAN DEPTH of PRIMARY CUTS Radial Tires

OVERALL CONDITION WITH TESTING - Data in Figure 28 suggests a 33% increase in number of cuts after TTO 1. This performance is similar to the new and recapped tires. POST LT 1 data is not available, as the radial tires were only remapped after TTO 1.

![](_page_15_Figure_4.jpeg)

In Figure 29, the data from Figure 28 is presented in a ratio of cuts per impact form. An increase of 18% is suggested. This is higher than the recaps, but lower than the new tires.

The mean depth of primary and secondary cuts of all tires is presented in Figure 30. The data population is very small, and no useful conclusions may be drawn.

INDIVIDUAL CONDITION WITH TESTING - Changes in the mean depth of primary cuts of the four tires are presented in Figure 31, as each tire was tested on the dynamometer. All four experienced a reduction of depth with testing. No further maps were made after TTO 1, so no other data is available.

FAILURE MODES - The damage to tires H-1 and 3 was very similar, in the number of cuts,  $\mbox{C}/\mbox{I}$ 

![](_page_15_Figure_9.jpeg)

FIGURE 29: PERCENTAGE INCREASE in CUTS Radiat Tiree

ratio, and mean depth of primary cuts. H-3 failed on TTO 3, Test Segment 5. H-2 suffered 30 - 40% more cuts and C/I, and had a mean depth 12 - 30% greater than H-1 and H-3. H-4 experienced 50% of all cuts measured, C/I ratio was three times higher than the other tires, but had a mean depth of primary cuts similar to the other cuts.

Tires H-1 and H-2 were removed after three TTO and three LT segments had been completed without failure.

H-3 stripped the entire tread. It showed evidence of poor adhesion of the tread to the reinforcing cord. When it failed, the tread came off, followed by the reinforcing cord. It unwound like the outer layer on a ball of string. The cord showed virtually no adhesion to the rubber. It could be pulled away from the carcass very easily by hand.

H-4 sustained more damage at NAEC and failed sooner than the other radial ply tires. A broken reinforcement or carcass cord stuck through the tread when received from NAEC. This damage seemed to precipitate the stripping failure of the tread.

![](_page_15_Figure_15.jpeg)

![](_page_16_Figure_1.jpeg)

FIGURE 31: DEPTH CHANGES during TEST Radial Tires

![](_page_16_Figure_3.jpeg)

FIGURE 32: CUT ACTIVITY

14

during TESTING

OTHER FACTORS

Tread stripping was common to thirteen of the thirty six tires that went on the dynamometer. There were other flaws noted during the tests, including the following:

(1) Two of the new tires (D7 and L1) showed evidence of heat related damage (reversion of the rubber) near a cut location. This heat failure may have precipitated the tread failure.

(2) Several of the tires, including one radial tire, had a broken reinforcement/carcass ply sticking through the tread before the general tread failure.

## FINAL PATTERN

As one may see in Figure 32, the three tire designs had different amounts of activity:

Cuts grew DEEPER NEW cuts opened Cuts became LESS deep

Cuts CLOSED to become a blemish or disappear entirely

or NONE of the above, indicating no change in the cut depth, or a blemish that stayed a blemish

In all three groups, the number of NEW cuts was greatest after TTO 1. The DEEPER, LESS, and NONE were similar test to test, within like tires, i.e. performance of all recaps was similar. The activity of the recaps was the lowest, but their durability was also the lowest. The changes of the

prototype radial tires was the greatest, but they were not mature tires.

CUT DEPTH ACTIVITY - NEW cuts are indications of secondary damage. The number of new cuts is very high after the first taxi-takeoff segment. The activity then trails off greatly. The number of cuts that closed is very small throughout the tests. As was noted with the bias ply tires, the depth of the cuts increases with more test segments on the dynamometer.

## CONCLUDING REMARKS AND OBSERVATIONS

Several trends may be noted in these tests:

 With increased impact speed, the damage to the tire increases:

> more cuts, that grow proportionally deeper more greater-than-the-Cut-Limit cuts shorter life expectancy on the dynamometer

2) The size of the debris had an effect on the cuts: larger debris produced more cuts deeper than the Cut Limit.

3) Twice as many new tires ran over 38.1 mm (1.5 inch) debris as did recapped tires; the rate of cuts deeper than the Cut Limit was twice as high for the new tires than for the recapped tires. The number of cuts stayed proportionally higher throughout the dynamometer tests.

4) The tread material and manufacturing techniques produced noticeable differences in dynamometer performance:

The recap material failed in 3.5 test segments, where the original new tread material failed in 6.9 test segments. The new tire might have had a better average if the five tires that were removed after three TTO and LT segments (without failure) had been run to destruction.

"A" scale Durometer readings of the recapped tires were lower than the new tires.

5) The number of cuts increased after each test segment in the recaps. In the new tires, it increased after TTO 1 (at a lower rate than the recaps), but decreased after LT 1. Toughness and tear resistance of the material may be involved. Twice as many deeper than the Cut Limit in the new tire didn't effect the durability; again, they lasted twice as long as the recaps.

6) Many more of the tire failures were observed near the end of the TTO segment, than during the LT. Incipient tire failure can not be predicted in the field. The load added to the main tire when the nose is lifted off can be reduced by eliminating an external store on the aircraft. A combat sortie may be changed, but if the plane is damaged by flying debris or crashes because of a cut-related tire failure, it won't be productive then, either.

7) Cut or blemish damaged tires are danger-

ous in that they are unpredictable. Secondary damage to the aircraft may be caused by pieces of the damaged tire striking the aircraft.

8) Major tread loss may be due to poor adhesion between the carcass and tread, or between the reinforcing plies and the tread. While it may have been triggered by cut damage, this adhesion failure may also be a manufacturing flaw: a number of chunking failures began where no cuts were observed.

9) Chemical reversion may occur locally and cause a cut to close for a flight segment. The integrity of the tread can not be guaranteed; however, once damage that excedes the Cut Limit has been noticed, safety should be pursued by changing the tire at the earliest opportunity. Tread stripping and undercutting may result from cut damage; or from poor adhesion, or from chemical breakdown caused by high heat. Half of the tires tested failed because of tread stripping and/or undercutting. In many of the stripping cases, the failure was no where near a cut. The carcass often showed evidence of poor adhesion between the tread and the carcass.

#### RECOMMENDATIONS

Goodyear F-16 main tires have 121° C (250° F) Spot Surface Temperature Limit (SSTL). From past experience, surface temperatures of Type VII tires may run near these levels under normal operations. Relative motion of the sides of a cut may elevate the local operating temperature to or above these SSTL's. The flaw may change shape quickly when surface temperatures approach these high levels. Future work in this area should include the use of an infrared strip camera and a visual image camera, so that local temperatures can be examined on the whole surface of the tire, at damage sites and where there is no damage.

Thermal damage destroyed several tires at locations where no cuts were present. Further, cuts closed for a few dynamometer segments, only to reopen. Higher temperature materials should be pursued for a front line tire that must survive on a hostile post-attack airfield.

At the factory, quality control inspections must be improved in number and in quality. The tires that failed because of stripping may have had similar life spans even if they had not been cut, i.e. the undamaged recaps that only lasted two or three dynamometer segments.

The relatively low ratio of cuts per impact, C/I, suggest a follow-on program of cut progression. Individual cuts should be created with a knife, in specific patterns, rather than by running over debris. This program provided data on cut locations and dimensions, and provided a supply of cut tires for the dynamometer. The hand cut tires should be examined after each dynamometer event to see if the pattern observed here (unpredictable cut growth/closure) continues. The effect of debris related internal damage can not be estimated by eye. The test tire should be examined for internal delamination/ply failure before and after it is damaged, and occasionally during dynamometer tests by dismounting, and examination with a shearo-

graphy test machine.

16

#### NOMENCLATURE

G	groove
LGDV	Landing Gear Development Center, Flight
	Dynamics Directorate, Wright-Patterson AFB
OH	
LT	Landing-Taxi segment. See Figure 3
NAEC	Naval Air Engineering Center, Lakehurst NJ
R	rib
SW	sidewall
TCTV	Tire Cutting Test Vehicle
TTO	Taxi-Takeoff segment. See Figure 2
Prima	ry Cuts cuts that were present on return
	from NAEC

Secondary Cuts cuts that were observed after dynamometer segments

- POST NAEC measurements made after the tire was run on the track at NAEC
- POST TTO 1 measurements made after the tire had completed Taxi-Takeoff segment number 1 on the dynamometer
- POST LT 1 measurement made after the tire had completed Landing-Taxi segment number 1 on the dynamometer

#### UNITS

۰.

•c	temperature, degrees centigrade
C/I	ratio, cuts per impact
cm sq	square centimeters
•F	temperature, degrees fahrenheit

- kg mass, kilograms
- km/h speed, kilometers per hour
- kPa pressure, kilo-pascals
- 1bm mass, pounds
- m meter
- mm millimeter
- mPa pressure, mega-pascals
- mph speed, miles per hour
- psi pressure, pounds per square inch

ACKNOWLEDGEMENTS

This program was under the direction of Kenneth P. Schwartz, at Wright-Patterson Air Force Base.

The author wishes to thank Gwendolyn A. Patterson, William K. Smith, Paul Ulrich, and Paul Wagner, Flight Dynamics Directorate; Lt. Colonel Donna C. Herge, Air Force Institute of Technology; and Dr. Gerald E. Meike, Wright State University, for their technical support.

#### REFERENCES

1. Vorum, Peter C., "Cut Progression during Dynamometer Testing of Foreign Object Damaged Type VII Extra High Pressure Aircraft Tires," Technical Report to be published by Wright Laboratories, dated Feb, 1991.

2. Schwartz, Kenneth P., "Foreign Object

Damage to Tires Operating in a Wartime Environment, \* Technical Report to be published by Wright Laboratories, dated Feb, 1991

3. Vorum, Peter C. and Champion, Jon H., "An Experimental Test and Evaluation of Foreign Object Damaged Aircraft Tires," AFWAL-TM-85-173-FIEM, Mar, 86.

Specification Control Drawing 16VL002,
 Code ID 81755, "Tire, Pneumatic-Tubeless, 25.5 x
 8.0 - 14/ 18 PR," General Dynamics Corp., Ft. Worth
 Division, Ft. Worth TX.
 5. Vorum, Peter C., "Cut Tire Inspection

5. Vorum, Peter C., "Cut Tire Inspection Procedure," Technical Memorandum WRDC-TM-90-319-FIVM to be published by Wright Laboratories, dated Sep, 1990.

6. Military Specification MIL-T-5041 H, "Tires, Pneumatic, Aircraft," paragraph 3.4.10, 13 Mar 89

#### APPENDIX: DAMAGE DESCRIPTIONS

CUT - a break in the surface of the tread. The length is greater than 1.6 mm (1/16 inch); the depth is greater than 0.8 mm (1/32 inch).

PUNCTURE - a cut with length less than 1.6 mm (1/16 inch), depth greater than 0.8 mm (1/32 inch).

UNDERCUT - a flaw that extends under the tread, parallel to the surface. Chemical reversion of the rubber compounds often occurs in an undercut area. The undercut is created by side load on the tread, and/or by heat. Any amount of undercutting is cause for immediate removal.

HEAT BLOW - a vent of gases from within the tread material. A small surface hole may connect to an interior pocket within the tread, or to a delamination of plies within the carcass of the tire.

BLEMISH - a non-invasive deformation of the tire surface. It may be an external indication of internal damage. Many blemishes opened up into cuts during dynamometer testing.

SCUFF - a general surface abrasion that occurred on tires that had a yaw angle other that zero degrees.

PRIMARY/SECONDARY DAMAGE - all cuts and blemishes, as described above, that were recorded after the run at NAEC, are referred to as "Primary Damage." This damage was tracked through the rest of the tire's life on the dynamometer. "Secondary Damage" is any flaw that was noticed after dynamometer testing. The damage from individual test segments was recorded.