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SYNTHETIC RUBBER AIRCRAFT TIRES

William H. Protzmann

THOMPSON AIRCRAFT TIRE CORPORATION

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FOREWORD

This report was prepared by Thompson Aircraft Tire Corporation, South San Francisco, California. It covers the work performed under the sponsorship of the United States Air Force, Contract No. AF 33 (657)-15342, Work Effort D, REP WM-4-CIP-4060. The project was administered by the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, and monitored by Mr. Howard C. Sparks (ASNFL), Project Engineer. The period of work covered in this report is from October 1965 to May 1968.

The project was headed by Mr. G. A. Gianandrea, Program Manager. Mr. E. F. Mayeau was Manager, Materials Development. Project Engineers included W. H. Protzmann, R. M. Messner, R. K. H. Eggers and R. N. Pierce. Others who contributed were E. A. David, M. D. Di Chiara, C. P. Greuter and G. E. O'Brien.

This technical report has been reviewed and approved.

William A. Hamilton
Landing Gear and Mechanical Equipment Division
Directorate of Airframe Subsystems Engineering

INTRODUCTION

This program covered the development of synthetic elastomer materials for use in each component of high performance aircraft tires. Included in the program were three phases of development effort:

1. Preliminary Elastomer Study
2. Tire Design and Materials Study and Cost Analysis
3. Tire Fabrication and Testing

It has been demonstrated that the synthetic elastomer materials developed in this program are quite suitable for use in aircraft tire manufacture, and that such tires will meet current USAF static and dynamic qualification requirements in most respects. The 49x17 26PR tire successfully completed all qualification test requirements. The 30x8.8 22PR tire completed all qualification test requirements, but had chunking of the center tread ribs. This condition resulted from the tread profile parameters of groove width and shape, and was not related to the tread elastomer material.

The materials selected were based primarily on synthetic CIS-1, 4 polyisoprene. Some butyl rubber and styrene-butadiene rubber were used for innerliner and bead wire insulation materials respectively. It was found that synthetic polyisoprene was an adequate replacement where natural rubber currently is used in formulating tread rubber, casing rubber, and bead filler strip rubber. Details of all formulas selected for each of these components of an aircraft tire are given in this report.

In Phase I, a literature survey and limited laboratory evaluations of selected materials indicated that synthetic polyisoprene alone or in blends with synthetic CIS-1, 4 polybutadiene would be suitable for most of the components of aircraft tires. Also, a butyl rubber-synthetic polysioprene rubber blend appeared to be suitable for the innerliner material. Styrene-butadiene rubber is currently in use for bead wire insulation, and was selected for this use in Phase I.

These selected elastomers and the ingredients of candidate formulas were exhaustively evaluated in Phase II. Test parameters used in the evaluation included measurement of green strength and building tack of uncured materials, cure rates during vulcanization, vulcanizate characteristics with respect to stress-strain, tear strength, hysteresis, and flex resistance characteristics and adhesion to tire cord. An analysis was made of the factory costs for all synthetic materials as compared to similar natural rubber-based materials, including compound costs and mixing costs. Finally, tire design selections were made for the two tire sizes to be manufactured in Phase III.

The materials selected in Phase II were used in Phase III to produce components for aircraft tires of two sizes, 30x8.8 22PR and 49x17 26PR. These materials were processed in the factory, with the result that it could be concluded that the materials were more than adequate for use in normal factory mixing, extruding, calendering and frictioning operations. Assembly of tire components such as bead bundles was also successfully accomplished using the synthetic materials. The most critical stages of tire manufacture, those of adhesion of stitched ply turn-ups, green tire handling, and forming of tires prior to molding, indicated conclusively that the materials were more than adequate for tire manufacture. All components remained intact and sound during the molding operation, with the result that no defective tires were produced.

Static and dynamic tests were performed in Phase III of most of the test articles that were produced. The trends found during these tests indicated that the 49x17 26PR test articles could meet USAF tire qualification specifications in all respects, while the 30x8.8 22PR test articles could meet these specifications in all respects except for rib undercutting and the resultant chunking of the center tread ribs. This problem for the 30x8.8 22PR test articles could probably be eliminated by altering the rib and groove configuration in the tread slightly. In all other respects, all components of each test article size remained sound.

PHASE I

PRELIMINARY ELASTOMER SURVEY

INTRODUCTION

A Survey has been completed of two candidate synthetic elastomers, in order to select the most likely materials for further development in Phase II. These materials must be adaptable to existing tire manufacturing operations, and lend themselves easily to materials processing and tire building techniques in current use for all-natural rubber aircraft tire manufacture.

The survey included data from suppliers of the two types of elastomers, as well as data from the suppliers of various compounding ingredients in current use in the rubber industry. From this data, the one or two best elastomers of each type were selected as representative of that elastomer type. These were used in Tasks 2-4 in the testing of physical properties and processing characteristics for that elastomer type.

CONCLUSIONS

A. Elastomers

The elastomers best suited for aircraft tire use are reviewed concisely in Task 5. Polyisoprene (Natsyn, Goodyear Chemical Division is the prime candidate for total replacement of natural rubber in aircraft tires. This elastomer has vulcanizate properties similar to those of natural rubber. Tire building tack is somewhat lower than that of natural rubber, but at this time it is thought to be acceptable. A few details of compounding ingredient effects on building tack have been noted, for further study in Phase II. Processibility of polyisoprene is good, and offers a few economies over natural rubber. Overall we rate polyisoprene (Natsyn) as being well suited for aircraft tire materials.

Polybutadiene has certain deficiencies which will limit its suitability for aircraft tire use. The main deficiency is the significant reduction in tire building tack. A second deficiency is the processibility of this material in normal factory processing equipment. Polybutadiene does offer improved low temperature characteristics, and possibly improved tread abrasion resistance. It is felt that polybutadiene should be considered in low percentages in blends with polyisoprene for tread materials and possibly for casing materials, to realize improvements, both in low temperature flexibility and possibly in abrasion resistance.

Other synthetic elastomers (Butyl and SBR) are already in routine use in aircraft tires, in inner liner materials (Butyl) and in bead wire insulation materials (SBR). These will be used in tires produced in this program, since no further work is required to develop such materials.

The elastomer selected for each tire component is as follows:

1.	Tread	Polyisoprene, Polyisoprene/Polybutadiene Blend
2.	Casing	Polyisoprene, Polyisoprene/Polybutadiene Blend
3.	Innerliner	Polyisoprene/Butyl Blend
4.	Bead-Insulation	SBR
5.	Chafer	Polyisoprene
6.	Bead Filler	Polyisoprene
7.	Sidewall	Polyisoprene
8.	Bead Wrap and Filler	Polyisoprene

B. Compound Ingredients

Certain compounding ingredients have been selected for use in this program. The selection was based on the previous experience of Thompson technical personnel with new aircraft tire materials, as well as on technical literature available on these various materials. The materials list is given in Section B., Ingredients Survey, of Task I. These materials contribute to high abrasion resistance, high tensile and modulus properties, good heat stability, good building properties, flat optimum cure plateau, and good overall performance of the tire in operational use.

The text for each Task follows. Complete data and a discussion of data are presented in Tasks I and 2. Tasks 3 and 4 survey the factory processibility and tire building characteristics of the synthetic elastomers. The selection of elastomer types is outlined in Task 5.

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TASK 1: SURVEY OF ELASTOMERS AND COMPOUNDING INGREDIENTS

Two types of synthetic elastomers have been selected for survey in this program, polyisoprene and polybutadiene. Thompson Aircraft Tire Corporation has already accomplished some work on each of these two elastomer types, primarily with respect to aircraft tire tread materials. The work to date has indicated that some similarities exist between certain suppliers' elastomers, and that some elastomers have deficiencies which rule out their use in aircraft tires.

The literature provides some limited information on specific formulations which may be suitable for certain tire components such as casing materials. These typical formulations are given in Table III.

It is difficult to survey the literature on specific ingredients for tires, such as reinforcing agents, accelerators, etc. Suppliers of these ingredients point their technical literature foward broad rubber applications, of which aircraft tire rubber materials are a very small segment. Thompson has investigated most if not all of the nine basic types of ingredients in use in aircraft tires. While not in the manufacture of new tires as a corporation, the technical staff of Thompson's Research and Development Center has had extensive experience in the past in the manufacture of new aircraft tires. This experience provides background data on each of the nine basic ingredient types in current use in tire materials. The technical approach to the current program will draw on this background of natural rubber aircraft tire materials, in analyzing and developing the synthetic elastomers and ingredients which will best achieve the intent of this undertaking.

A. Elastomers Survey

1. Polybutadiene:

At present there are seven suppliers of polybutadiene. The results of the survey have indicated that the following suppliers' elastomers are either interchangeable or may be eliminated from further consideration in this program.

a. Interchangeability Rating (based on ease of processing, cure rate, and typical vulcanizate properties): American Rubber Corporation, Firestone, Goodrich-Gulf, Goodyear, Phillips Chemical, Shell Chemical.

b. Elastomers Rated Unsuitable for Aircraft Tire Use:
Texas-US: Emulsion-type polymerization; available only in oil-black masterbatch form which reduces compounding flexibility.

A complete listing is given in Table I of typical properties for the elastomers rated above as Interchangeable.

2. Polyisoprene:

Currently there are two suppliers of CIS 1-4 polyisoprene, Goodyear Chemical Division of The Goodyear Tire and Rubber Company and Shell Chemical Company, Synthetic Rubber Division. Thus far the Goodyear elastomer has been found more suitable for aircraft tire use. The Shell material is marginal in ease of processing and in tire building properties, and thus will not be given further consideration in the program. A complete listing is given in Table II of typical properties for these two elastomers.

3. Other Elastomers:

While not listed in the Technical Approach Detail, certain additional elastomers are in current use in special tire components in aircraft tire manufacture. These include isobutylene-isoprene copolymer (Butyl) for innerliner materials, styrene-butadiene rubber (SBR) for bead wire insulation, and certain reclaim rubber types used to improve processing of tire materials. These synthetic elastomers will probably be used in tire components of the tires to be produced later in this program.

B. Ingredients Survey:

Experience in aircraft tire manufacture has indicated that certain compounding ingredients are well suited both to aircraft tire manufacture and to operational use. The list below indicates the materials which provide the best overall characteristics in aircraft tires.

1. Reinforcing Agents:	HAF, SRF, MPC, MT
2. Accelerators:	Santocure, Santocure NS, MBTS TMTD, Altax, Butyl Zimate, Ethylac
3. Activators:	Zinc Oxide, Stearic Acid, Laurex
4. Plasticizers:	Paraffin base oils, dioctyl phthalate, Piccopale 100SF
5. Tackifiers:	Piccopale 100 SF, Picco 100, Turgum S, Pine tar, Resin Oil
6. Modifiers:	RPA No.3, RPA No. 6, Retarder W
7. Processing Aids:	Pine tar, Reclaim Rubber
8. Vulcanizing Agents:	Sulfur, Sulfur-doror types, Amberol ST-137X
9. Anti Oxidants and Antiozonants:	DPPD, Agerite Resin D, Agerite ISO, Agerite Stalite, BLE-25 Santoflex 13, Wax (Weather Protection)

TABLE I PHYSICAL PROPERTIES OF CIS 1-4 POLYBUTADIENE FROM VARIOUS SUPPLIERS

POLYMER TYPE	CIS 1-4 POLYBUTADIENE					
SUPPLIER	GOODRICH GULF	GOODYEAR	FIRE-STONE	PHILLIPS	AMERICAN RUBBER	SHELL
Stress-Strain Properties	Good	Good	Good	Good to Fair	Good to Fair	Good
Abrasion Resistance	Good	Good	Good	Good	Good	Good
Heat Generation Properties	Good	Good	Good	Good	Good	Good
Processibility	Good	Fair	Fair	Fair	Fair	Fair
Ballistic Cut Resistance	Good to Fair	Good to Fair	Good to Fair	Good to Fair	Good to Fair	Good to Fair
Cut Growth Resistance	Good	Good	Good	Good	Good	Good
Coefficient of Friction	Fair	Fair	Fair	Fair	Fair	Fair
Air Permeability	Good	Good	Good	Good	Good	Good
Low Temperature Flexibility	Good	Good	Good	Good	Good	Good
Resistance to Elevated Temperatures	Fair	Fair	Fair	Fair	Fair	Fair
Resistance to Oils and Chemicals	Fair to Poor	Fair to Poor	Fair to Poor	Fair to Poor	Fair to Poor	Fair to Poor
Resistance to Ozone	Fair	Fair	Fair	Fair	Fair	Fair
Resistance to Sunlight	Fair	Fair	Fair	Fair	Fair	Fair
Resistance to Weathering	Fair	Fair	Fair	Fair	Fair	Fair
Green Strength	Fair	Fair	Poor	Poor	Poor	Fair
Tire Building Tack	Fair	Fair to Poor	Fair to Poor	Fair to Poor	Fair to Poor	Fair
Compatibility with Other Tire Materials	Good	Good	Good	Good	Good	Good
Compatibility with Tire Manufacture	Good	Good	Good	Good	Good	Good

TABLE. II PHYSICAL PROPERTIES OF CIS 1-4 POLYISOPRENE FROM VARIOUS SUPPLIERS

POLYMER TYPE	CIS 1-4 POLYISOPRENE	
SUPPLIER	GOODYEAR	SHELL
Stress-Strain Properties	Good	Good to Fair
Abrasion Resistance	Good to Fair	Good to Fair
Heat Generation Properties	Good	Good
Processibility	Good	Good to Fair
Ballistic Cut Resistance	Good	Good to Fair
Cut Growth Resistance	Good	Good
Coefficient of Friction	Good	Good
Air Permeability	Good	Good
Low Temperature Flexibility	Good	Good
Resistance to Elevated Temperatures	Fair	Fair
Resistance to Oils and Chemicals	Fair to Poor	Fair to Poor
Resistance to Ozone	Fair	Fair
Resistance to Sunlight	Fair	Fair
Resistance to Weathering	Fair	Fair
Green Strength	Good	Fair
Tire Building Tack	Good	Fair
Compatibility with Other Tire Materials	Good	Good
Compatibility with Tire Manufacture	Good	Fair

TABLE III

Literature Survey Formulations

	A	B	C	D	E
Natural Rubber	100.0	-	-	80.0	60.0
Polyisoprene	-	100.0	100.0	-	-
Polybutadiene	-	-	-	20.0	40.0
HAF Black	50.0	50.0	25.0	50.0	50.0
Zinc Oxide	5.0	5.0	5.0	5.0	5.0
Stearic Acid	2.0	2.0	2.0	2.0	2.0
Antioxidant	1.0	1.0	1.0	1.0	1.0
Antiozonant	2.0	2.0	-	2.0	2.0
Process Oil	5.0	5.0	-	5.0	5.0
Retarder	1.0	1.0	-	1.0	1.0
Pine Tar	-	-	3.0	-	-
BIK	-	-	0.3	-	-
Santocure NS	0.6	0.6	0.8	0.6	0.6
Sulfur	3.0	3.0	2.0	3.0	3.0

TASK 2: VERIFICATION OF CANDIDATE ELASTOMER FORMULATIONS VULCANIZATE CHARACTERISTICS

The general formulations shown in Table III, Task I, were mixed and tested to verify reported vulcanizate characteristics. General trends were noted for the various formulations. These will form the basis for development work in Phase II of this program. In all cases, natural rubber formulations were used as the control. The general trends for each elastomer are noted below. Composite data forms are included at the end of the Task.

A. Polybutadiene

1. Stress-Strain Properties

Polybutadiene/natural rubber blends have lower tensile strength than the natural rubber control. Other trends are reduced elongation, equal hardness and lower tear strength.

2. Abrasion Properties

Polybutadiene contributes to increased abrasion resistance for laboratory test wheels. It is not known at this point whether this necessarily means improved tread wear properties for aircraft tire.

3. Adhesion Properties

Polybutadiene contributes to reduced adhesion (green) characteristics between tire components. Vulcanizate adhesion properties are about equal to the control.

4. Cut Resistance Properties

Polybutadiene reduces the cut resistance of tread materials. Experience has shown that increased chipping of tread ribs occurs when the percentage of polybutadiene is 30% of the elastomer content or greater.

5. Low Temperature Flexibility Properties

Polybutadiene improves the low temperature flexibility characteristics of rubber materials. While this is of interest, the normal tire materials based on natural rubber are also quite good in this respect.

6. Coefficient of Friction Properties

Polybutadiene reduces the coefficient of friction on wet surfaces. The ideal coefficient of friction for aircraft tires is not known at present, however it is felt that any known reduction in this property should be carefully weighed against other characteristics before making a change to the lower coefficient of friction material.

In general, the data on polybutadiene which has been generated in this Task follow closely that found in the technical literature.

B. Polyisoprene (Natsyn)

1. Stress-Strain Properties

Polyisoprene stocks have lower tensile strength than do corresponding natural rubber control stocks. Other trends are equal hardness, lower elongation, slightly lower modulus, and lower tear strength.

2. Abrasion Properties

Polyisoprene stocks are somewhat poorer in abrasion resistance compared to similar natural rubber stocks. It is not known whether this trend will correlate with aircraft tire tread wear.

3. Adhesion Properties

Polyisoprene stocks have slightly lower adhesion (green) characteristics. Vulcanizate adhesion properties are equal to the natural rubber control.

4. Cut Resistance Properties

Polyisoprene has only slightly poorer cut resistance, owing in part to slightly reduced modulus characteristics.

5. Low Temperature Properties

Polyisoprene flexibility at low temperatures is equal to that of the natural rubber control.

6. Coefficient of Friction Properties

Polyisoprene tread formulations have almost equal coefficient of friction properties to the natural rubber control.

In general, the data on polyisoprene which has been generated in this Task follow that found in the technical literature.

TABLE IV: POLYBUTADIENE VERIFICATION STUDY

INGREDIENTS	FORMULATIONS				
	PB-1	PB-2	PB-3	PB-4	PB-5
Natural Rubber	100.0	80.0	60.0	80.0	60.0
Ameripol CB 220	-	20.0	40.0	-	-
Shell BR-11	-	-	-	20.0	40.0
HAF	50.0	50.0	50.0	50.0	50.0
Zinc Oxide	5.0	5.0	5.0	5.0	5.0
Thermoflex A	1.0	1.0	1.0	1.0	1.0
Vultrol	1.0	1.0	1.0	1.0	1.0
Stearic Acid	2.0	2.0	2.0	2.0	2.0
Santoflex AW	2.0	2.0	2.0	2.0	2.0
Sunpar	5.0	5.0	5.0	5.0	5.0
Santocure NS	0.6	0.65	0.7	0.65	0.7
Crystex	3.0	3.0	3.0	3.0	3.0
MONSANTO RHEOMETER DATA					
Temperature: 275 °F	-	-	-	-	-
Initial Viscosity: In.-Lbs.	22	22	28	25	30
Scorch Time: Minutes	6	7	8	8	8
Cure Rate: In.-Lbs./Min.	7	7	8	8	8
Maximum Modulus: In.-Lbs.	72.8	75	85.0	79	83.5
Time For Max. Modulus - Minutes	35	40	40	41	47
Reversion: In.-Lbs./Min.	-	.26	.075	.1	-
TENSILE DATA: Normal (275°F); ... °F; Oven Aged Hours @ °F					
Optimum Cure: 30 Minutes @ 280°F					
100% Modulus	-	-	-	-	-
200% Modulus	-	-	-	-	-
300% Modulus	2125	2100	2100	2025	2025
Tensile Strength	3850	3650	[illegible]	3600	3475
Percent Elongation	470	470	[illegible]	475	460
Shore A Durometer	63	62	62	63	63
Crescent Tear - Type C	520 710	450 450	390 390	440 450	400 400
CUT GROWTH: Ambient Temperature ( ); At °F					
Cycles	Inches of Cut Growth				
20,000	.0625	.9375	.2968	.0625	.5000
38,000	.9375	.1250	.4687	.1250	.6406
76,000	.1250	.1562	.4687	.1250	.6406
100,000	.1250	.1562	.4687	.1250	.6406
HEAT BUILD-UP: Load 175 PSI; Stroke .175 in.; Temp. 100 °F; Time 30 Min.					
Final Temperature °F	150	155	160	154	156
Temperature Rise °F	50	55	60	54	56
Percent Compression Set	6.25	6.25	4.69	6.25	4.66
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F					
Time	30+	30+	30+	30+	30+
Blow-Out Temperature	182	211	266	188	204
Temperature Rise	82	111	166	88	104
MISCELLANEOUS TESTS					
Specific Gravity	1.12	1.12	1.13	[illegible]	1.12
Scorch: Minutes @ °F	-	-	-	-	-
Index of Abrasion	184	Gummy	Gummy	119	Gummy
Rebound: At °F	-	-	-	-	-
Elasticity: At °F					

TABLE V NATSYN VERIFICATION STUDY

INGREDIENTS	N - 1	N - 2	N - 3	N - 4	N - 5	N - 6
	FORMULATIONS					
Natsyn 200	100.0	-	-	-	-	-
Natsyn 400	-	100.0	100.0	100.0	100.0	100.0
HAF (Vulcan 3)	50.0	50.0	50.0	50.0	50.0	50.0
Sunpar 150	5.0	5.0	5.0	5.0	5.0	-
Dutrex 726	-	-	-	-	-	5.0
Zinc Oxide	5.0	5.0	5.0	5.0	5.0	5.0
Stearic Acid	2.0	2.0	2.0	2.0	2.0	2.0
Santoflex AW	2.0	2.0	2.0	2.0	2.0	2.0
Thermoflex A	1.0	1.0	1.0	1.0	1.0	1.0
Vultrol	1.0	1.0	1.0	1.0	1.0	1.0
NOBS Special	-	-	0.4	-	-	-
Santocure NS	0.6	0.6	-	0.4	0.5	0.6
Crystex	3.0	3.0	3.0	-	-	3.0
MONSANTO RHEOMETER DATA						
Temperature: 275 °F	-	-	-	-	-	-
Initial Viscosity: In.-Lbs.	28	27	27	27	27	32
Scorch Time: Minutes	6	8	9	9	7	7
Cure Rate: In.-Lbs./Min.	6.5	6	3.5	3.5	5	6.4
Maximum Modulus: In.-Lbs.	80	71.1	60.5	64.2	67	72.8
Time For Max. Modulus - Minutes	36	35	45	45	36	35
Reversion: In.-Lbs./Min.	.25	.2	-	.24	-	.6
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 280°F	-	-	-	-	-	-
100% Modulus	-	-	-	-	-	-
200% Modulus	-	-	-	-	-	-
300% Modulus	1650	1475	950	1050	1400	-
Tensile Strength	3650	3600	3200	3350	3775	-
Percent Elongation	525	550	640	630	600	-
Shore A Durometer	63	62	55	55	58	-
Crescent Tear - Type C	440 440	610 760	310 300	310 330	440 590	
CUT GROWTH: Ambient Temperature (100°F); At °F						
Cycles		Inches of Cut Growth				
13,000	.0937	.0937	.0937	.0937	.0937	.1250
36,000	.0937	.0937	.0937	.0937	.0937	.1250
60,000	.1250	.1718	.1718	.1093	.2187	.1562
HEAT BUILD-UP: Load 175 PSI; Stroke .175 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	159	157	167	161	160	146
Temperature Rise °F	59	57	67	61	60	46
Percent Compression Set	6.25	6.25	12.5	10.9	6.25	4.68
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	30	23	12	18	23	30+
Blow-Out Temperature	262	278	300+	300+	300+	172
Temperature Rise	162	172	200+	200+	200+	72
MISCELLANEOUS TESTS						
Specific Gravity	1.12	1.12	1.13	1.13	1.12	-
Scorch: Minutes @ 250 °F	25	32	41	35	35	31
Index of Abrasion						
Rebound: At °F						
Elasticity: At °F						

TABLE VI. NATSYN GENERAL MATERIALS STUDY

INGREDIENTS	FORMULATIONS					
	N-7	N-8	N-9	N-10	N-11	N-12
Natsyn 400	100.0	100.0	100.0	100.0	100.0	100.0
Zinc Oxide	5.0	5.0	5.0	5.0	5.0	5.0
Stearic Acid	2.0	2.0	2.0	2.0	2.0	2.0
Thermoflex A	1.0	1.0	1.0	1.0	1.0	1.0
Santoflex AW	2.0	2.0	2.0	2.0	2.0	2.0
Vultrol	1.0	1.0	1.0	1.0	1.0	1.0
Sulfur 150	5.0	5.0	5.0	5.0	5.0	5.0
Santocure NS	0.6	0.6	0.6	0.6	0.6	0.6
Crystex	3.0	3.0	3.0	3.0	3.0	3.0
Vulcan 3 (HAF)	50.0	-	-	-	50.0	50.0
Vulcan 3H (hs HAF)	-	50.0	-	-	-	-
Vulcan 6 (ISAF)	-	-	45.0	-	-	-
Sterling 50 (FEF)	-	-	-	40.0	-	-
Paraflux					5.0	
Pico 100						5.0

	N-7	N-8	N-9	N-10	N-11	N-12
MONSANTO RHEOMETER DATA						
Temperature: °F	275	275	275	275	275	275
Initial Viscosity: In.-Lbs.	24	27	27	27	27	25
Scorch Time: Minutes	7	7	9	10	9	8
Cure Rate: In.-Lbs./Min.	5	7	6	5	6	5
Maximum Modulus: In.-Lbs.	72.5	79.8	67.5	58.4	68.9	66.0
Time For Max. Modulus - Minutes	35	32	35	33	35	40
Reversion: In.-Lbs./Min.	-	.24	.17	.52	.4	.3
TENSILE DATA: Normal ( ); At °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 280°F						
100% Modulus	-	-	-	-	-	-
200% Modulus	-	-	-	-	-	-
300% Modulus	1550	1900	1375	900	1325	1225
Tensile Strength	3875	3775	3900	3850	3775	3675
Percent Elongation	585	520	585	640	620	550
Shore A Durometer	61	62	59	52	61	60
Crescent Tear - Type C	620 770	490 460	490 620	350 390	680 590	750 [illegible]
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
18,000	.0937	.0937	.0937	.0937	.0937	.0937
37,000	.0937	.1250	.1250	.1093	.1250	.0937
74,000	.1250	.1875	.1562	.2656	.1375	.1375
100,000	.2187	.2187	.1562	.3593	.2500	.1375
HEAT BUILD-UP: Load 175 PSI; Stroke .175 In.; Temp. 100 °F; Time 30 Min.						
Final Tem[illegible]ture °F	159	150	149	133	161	160
Temperat[illegible]ise °F	59	50	49	33	61	60
Percent C[illegible]ession Set	6.25	6.25	6.25	4.68	5.25	7.8
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	17	30+	30+	30+	30	15
Blow-Out T[illegible]erature	266	187	300+	185	300+	295
Temperature Rise	166	87	200+	85	200+	195
MISCELLANEOUS TESTS						
Specific Gravity	1.12	1.14	1.11	1.10	1.13	1.12
Scorch: Minutes @ 250°F	30	30	35	42	36	36
Index of Abrasion						
Rebound: At °F						
Elasticity: At °F						

TABLE VII NATSYN VERIFICATION STUDY

INGREDIENTS	FORMULATIONS					
	N-13	N-14	N-15			
Natural Rubber	100.0	-	-			
Natsyn 200	-	100.0	-			
Natsyn 400	-	-	100.0			
Zinc Oxide	3.0	3.0	3.0			
Stearic Acid	2.0	2.0	2.0			
BLE	1.0	1.0	1.0			
HAF (Vulcan 3)	25.0	25.0	25.0			
Pine Tar	3.0	3.0	3.0			
Santocure NS	0.8	0.8	0.8			
BIK	-	0.3	0.3			
Sulfur (Crystex)	2.0	2.0	2.0			

MONSANTO RHEOMETER DATA

	N-13	N-14	N-15			
Temperature: °F	275	275	275			
Initial Viscosity: In.-Lbs.	16	24	21			
Scorch Time: Minutes	9	8	9			
Cure Rate: In.-Lbs./Min.	6	5	7			
Maximum Modulus: In.-Lbs.	52	65.2	63.2			
Time For Max. Modulus - Minutes	30	35	35			
Reversion: In.-Lbs./Min.	.12		.1			

TENSILE DATA: Normal (275); At °F; Oven Aged Hours @ °F

Optimum Cure: 30 Minutes @ 200°F	N-13	N-14	N-15			
100% Modulus	-	-	-			
200% Modulus	-	-	-			
300% Modulus	950	975	900			
Tensile Strength	4500	3875	4000			
Percent Elongation	640	590	615			
Shore A Durometer	54	56	54			
Crescent Tear - Type C	500 420	380 390	360 440			

CUT GROWTH: Ambient Temperature ( ); At °F

Cycles	Inches of Cut Growth					

HEAT BUILD-UP: Load 175 PSI; Stroke .175 In.; Temp. 100 °F; Time 30 Min.

	N-13	N-14	N-15			
Final Temperature °F	133	124	125			
Temperature Rise °F	33	24	25			
Percent Compression Set	4.68	3.13	3.13			

HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F

	N-13	N-14	N-15			
Time	30+	30+	30+			
Blow-Out Temperature	150	139	138			
Temperature Rise	50	39	38			

MISCELLANEOUS TESTS

	N-13	N-14	N-15			
Specific Gravity	1.06	1.04	1.03			
Scorch: Minutes @ 250 °F	32	28	..			
Index of Abrasion						
Rebound: At °F						
Elasticity: At °F						

TASK 3: SURVEY OF PROCESSING CHARACTERISTICS OF CANDIDATE ELASTOMER FORMULATIONS

The general processibility of polyisoprene and polybutadiene are acceptable. However, in the case of polybutadiene, experience has shown that this elastomer is very poor processing by itself, but is easily processed when used in a blend with another elastomer (either natural or synthetic).

The formulations mixed in Task 2 were evaluated in this Task with regard to their mixing, calendering, extruding and plasticity characteristics. The general trends noted below indicate that little difficulty would be encountered when processing these elastomers in the factory, if proper attention is given to formulating and processing these stocks in the factory.

A. Polyisoprene (Natsyn)

Polyisoprene processes almost as easily as natural rubber. While it is best to premasticate polyisoprene prior to mixing, the premastication required is minimal compared to that used for natural rubber. The elastomer accepts ingredients readily, using the premastication step, and stocks discharge from the Banbury in a coherent lump. Milling has the same effect on reducing plasticity of the stocks that it has on similar natural rubber stocks. Based on observations of plasticity, we anticipate that polyisoprene stocks will extrude somewhat more readily then do similar natural rubber stocks, and that calendering of polyisoprene stocks will be about the same as calendering natural rubber stocks.

B. Polybutadiene

This elastomer processes easily in blends with natural rubber. The only drawback in processing polybutadiene is that the stocks become drier (less tack, reduced green strength) as the percentage of polybutadiene in the blend is increased. The elastomer blend accepts ingredients readily. Milling has less effect on reducing the plasticity of the stocks than it does on similar all-natural rubber stocks. We anticipate that polybutadiene blends will extrude in an acceptable fashion, although they may be somewhat dry. This may cause difficulties in extruding thin sections. Calendering of blends should be about equivalent to the all natural rubber stocks.

TASK 4: SURVEY OF TIRE BUILDING PROPERTIES OF CANDIDATE ELASTOMER FORMULATIONS

The formulation mixed in Task 2 were objectively analyzed in this Task to survey their inherent properties which are of importance in tire manufacturing operations. These characteristics include tack properties, materials handling properties, and tire fabrication properties.

The general trends outlined below indicate that polyisoprene (Natsyn) will probably lend itself well to tire building operations, but that polybutadiene even in blends with other elastomers, will cause some problems in tire manufacture primarily because of reduced building tack and materials handling properties. Test data is given in Table I attached. Formulations are given in Task 2.

A. Polyisoprene (Natsyn)

Polyisoprene has inherent good building tack, although not as good as similar natural rubber control stocks. The data indicates that the amount and type of carbon black present can have some effect on building tack. This is seen by comparing stocks N-7, N-9 and N-10 (50 phr HAF, 45 phr ISAF and 40 phr FEF respectively). The building tack for this series varied from 3.33 $in\text{-}lb/in^2$ to 1,77 $in\text{-}lb/in^2$ (Tack = $\frac{\text{Bond Strength X Elongation}}{2}$ per square inch of contact area). Serveral stocks had such high tack that they were impossible to process following the second remilling (N-6, N-11, N-12). The data indicate that with attention to formulation details, polyisoprene stocks may be produced which have approximately as good building tack as similar all natural rubber stocks.

Materials handling properties appear at this time to be influenced by compounding ingredients. Aromatic process oils and resinous tackifiers caused handling properties on processing equipment. This may not be true of factory mixed stocks however, since such stocks generally do not receive the mastication that laboratory mixed stocks do.

Finally, polyisoprene appears to lend itself well to tire fabrication operations, based on observations of laboratory-mixed materials. It is difficult to say for certain at this time that no problems will be encountered in building all-polyisoprene tires. However, experience with natural rubber tire materials indicates that the polyisoprene stocks in Task 2 will have acceptable tire fabrication properties.

B. Polybutadiene

The data in Table I for the PB stocks indicates the building tack reduction found when increasing the polybutadiene content of stocks from 0 phr to 40 phr. The tack data for the 20 phr polybutadiene/80 phr natural rubber formulas (PB-2 and PB-4) are similar to that of all polyisoprene stocks, but are lower than the tack of all-natural rubber stocks. It is not known what tack value is required in tire building operations, however, a reduction below the value of 3.5 - 4.0 probably would result in stocks being too dry to remain stitched together.

It is possible that certain compounding ingredients such as aromatic oils or resins would provide greater building tack for polybutadiene stocks. Also, cements may be of some use in building tires with polybutadiene materials. These factors are not known at present.

The addition of tackifiers such as resins would improve the materials handling properties of polybutadiene. Without such materials, these stocks are very dry and can cause handling problems on normal processing equipment.

It is felt that at this time, polybutadiene tire materials would need some rather extensive devlopment to provide for acceptable tire building characteristics.

TABLE VIII

BUILDING TACK* TEST RESULTS

A. Polyisoprene	Bond Strength, Lbs.	Elongation at Max. Pull, In	Tack* In-Lb/In
N - 1	6.81	1.35	4.60
N - 2	6.82	1.60	5.45
N - 3	5.60	1.30	3.64
N - 4	5.60	1.44	4.03
N - 5	6.20	1.55	4.81
N - 7	4.53	1.47	3.33
N - 8	4.83	1.33	3.22
N - 9	2.78	1.50	2.09
N - 10	2.64	1.34	1.77
N - 13	7.50	2.05	7.70
N - 14	3.11	1.41	2.18
N - 15	2.70	1.35	1.87
B. Polybutadiene Stocks			
PB - 1	7.90	1.60	6.31
PB - 2	4.78	1.22	2.92
PB - 3	2.22	1.20	1.33
PB - 4	6.13	1.20	3.68
PB - 5	2.30	1.15	1.32

$$\text{*Tack} = \frac{(\text{Bond Strength} \times \text{Elongation})}{2} \quad \text{Per square inch of contact area}$$

TASK 5: MATERIALS SELECTION REVIEW

The general trends noted in Tasks 1 through 4 for polybutadiene and polyisoprene indicate that polyisoprene is the material most likely to succeed in aircraft tire materials, as a replacement for natural rubber. Good vulcanizate properties, good processibility, and acceptable tire building characteristics indicate that polyisoprene will be well-suited to aircraft tire manufacture.

Polybutadiene might be used in small amounts with polyisoprene to improve low temperature flexibility and possibly tread abrasion characteristics, without hindering materials handling and tire building characteristics of the polyisoprene materials.

Other synthetic elastomers (Butyl and SBR) in routine use in aircraft tire components such as bead wire insulation and inner liner stocks will be used in tires to be produced in later Tasks in this work effort.

PHASE II

TIRE DESIGN AND MATERIALS STUDY

AND

COST ANALYSIS

INTRODUCTION

Investigations have been accomplished in three broad areas of study of the synthetic elastomers which were evolved in Phase I. These areas were:

1. Tire Materials
2. Tire Design
3. Cost Analysis

Selections have been accomplished of the best synthetic elastomer or blend of elastomers for each of the seven basic structural components in aircraft tires. These selections include the best formulation for use in each of these components.

Selections have also been accomplished of two types of tire carcass strength members (nylon cord). The two types selected have been used for some time in USAF tires by the tire manufacturers. Composite cord/rubber selections were made based on laboratory-scale tire sections which had been fabricated and tested under simulated operational conditions.

A comprehensive analysis was accomplished of tire design to optimize the performance characteristics of the synthetic elastomer materials through appropriate modifications in the design and construction parameters used for aircraft tires. One factor included was an analysis of the various tread pattern parameters, to optimize the performance of the synthetic elastomer tread materials under operational conditions.

An important part of the work of this Phase was the rigorous analysis that was made of the various cost aspects involved in manufacturing aircraft tires using synthetic materials. This analysis included prices and calculated costs from the purchase of the elastomer, through the various manufacturing steps, to the final operational performance savings which may be realized from such aircraft tires.

CONCLUSIONS

The second Phase of the Work Effort was divided into three areas of study as outlined in the Introduction. The specific conclusions in each of these areas will be discussed below. The general conclusion is that aircraft tires may be fabricated from materials and tire construction developed in this Phase using synthetic elastomers in place of natural rubber. Also, the use of synthetic elastomers will contribute to reduced costs for tire manufacture. There may be a savings in tire operational use, through increased casing longevity.

A. Tire Materials

1. Synthetic Elastomers Selection

The elastomer best suited for most aircraft tire components was found to be polyisoprene (Natsyn 400, Goodyear Chemical Division). This elastomer was found to have materials vulcanizate properties and tire operational qualities essentially equivalent to those of natural rubber. Polyisoprene has some inherent characteristics which were found to be better than natural rubber, namely heat build-up, heat blowout and resistance to heat and flex deterioration.

Polyisoprene has certain minor deficiencies, which were noted when working with unvulcanized materials. These deficiencies include reduced tack and lower green strength compared with similar natural rubber materials. Another minor deficiency was the reduced adhesion between vulcanized tire components, i.e., tread to carcass adhesion. Adhesion levels were acceptable, however, as were the tack and green strength values noted in Tasks 1-3. No major difficulties attributable to these factors are anticipated either when manufacturing synthetic elastomer tires, or when testing such tires on the dynamometer.

Other elastomers were selected for various tire components. These are indicated in the following table. The selections shown in this table are based on the test results tabulated and analyzed as indicated in the text for Tasks 1 through 10. Elastomer and formulation selections were based on optimized characterisitics of tire building properties, tire vulcanization properties, and operational characteristics.

Aircraft Tire Component	Synthetic Elastomer Selection
Tread	Polyisoprene
Sidewall	Polyisoprene
Carcass	Polyisoprene
Bead Wrap and Chafer Coat	Polyisoprene
Apex Strip	Polyisoprene
Bead Insulation	Hot process SBR
Innerliner	Polyisoprene-Butyl blend

2. Tire Cord Selection

The tire cord best suited for use in aircraft tires is nylon. In this Phase, two types of nylon cord were investigated, 840/2 and 1260/2. Both of these cord types were found to be acceptable based on tire design calculations as indicated below.

Tire cord operational characteristics were evaluated in laboratory-scale synthetic elastomer tire sections under simulated operational conditions. Performance evaluations for both cord types were found to be equal. Thus it has been concluded that both of these cord types will be suitable for use in the tires to be manufactured in Phase III. The 1260/2 nylon cord will be used in Design A for both tire sizes to be manufactured. The 840/2 nylon cord will be used in Design B for both tire sizes.

B. Tire Design

1. Casing Components

A comprehensive tire engineering study has been completed to optimize tire design and construction parameters based on the unique characteristics of the synthetic elastomer materials developed in this Phase. The study resulted in the establishment of Design A for each of the two sizes of tires to be manufactured in Phase III. Specifically, Design A tires will include the optimized synthetic elastomer materials as noted in Task 4, 1260/2 nylon tire cord, and tire construction parameters as shown in Figures 1 through 10 of the Appendix of this Phase Report. Recognized tire construction criteria were used in establishing these tire manufacturing specifications.

A subcontractor's proprietary design has been selected as Design B for each tire size. This will provide a comparison of the processing, tire building and performance characteristics of the synthetic elastomer materials with similar characteristics of current USAF natural rubber tires. Design B will include the optimized synthetic elastomer materials noted in Tasks 4, 840/2 nylon tire cord, and the proprietary tire construction parameters currently in use by the subcontractor in the manufacture of tires for the Air Force.

An analysis of the subcontractor's qualified tires of both sizes indicated that 840/2 nylon cord was used as the carcass strength member in these tires.

2. Tread Component

Investigations of tire tread patterns were accomplished in this Phase, to provide selection criteria for use in optimizing the performance qualities of the synthetic elastomer tread materials. The tread pattern selection is shown in Task 15. This pattern was chosen to obtain optimized performance characteristics such as tread wear, coefficient of friction, retreadability, and tire running temperatures. Laboratory-scale tread sections were fabricated and tested under simulated operational conditions to quantitatively measure the anticipated characteristics of the synthetic materials, using natural rubber sections as the control. The observed results were listed in Task 15, and were analyzed in Task 16. These results verified that the selected tread pattern will optimize the performance qualities of the synthetic elastomer tread material.

The tread reinforcing medium (nylon cord) was also investigated in this Phase. The subcontractor's tread reinforcing techniques have been selected for use in the tires to be manufactured in Phase III. The investigations in this Phase indicated that such a design was the best for use in the two tire sizes, since this design optimized tread retention while minimizing cord plucking and cord flexing deterioration.

C. Cost Analysis

A rigorous analysis was completed in this Phase to outline in as much detail as possible the cost reductions which may be realized through the use of synthetic elastomers in aircraft tire manufacture. The analysis included all cost aspects, including raw materials prices, shipping and handling charges, materials processing costs, potential changes which may be required in tire building processes, and tire performance improvements. The summation of this information indicated that there are significant cost reductions to be achieved through the substitution of synthetic elastomers for natural rubber. The complete analysis is given in Task 16. One example of the cost reductions is indicated in Table X in this Task. Data in this table show that an overall saving of $1500 per truckload of rubber is possible by using synthetic polyisoprene in place of natural rubber.

GENERAL PROGRAM OUTLINE

Complete data for the synthetic elastomer materials development are given in Tasks 1-4. The tire cord materials eveluation is given in Task 8. Tire design studies are found in Task 11, 12, and 13. Performance evaluations of various tire components are shown in Tasks 5-7, 11 and 13-15. The cost analysis appears in Task 18.

TASK I: SYNTHETIC ELASTOMERS COMPOUND RESEARCH

The work in Phase I indicated that the prime candidate synthetic elastomers for continued investigation in Phase II were polyisoprene and polyisoprene/polybutadiene blends. These have shown the greatest promise in the successful manufacture of an all-synthetic elastomer aircraft tire. The candidate formulations cited in Phase I have been thoroughly evaluated in this Task. Compound ingredients were selected that would optimize the overall balance of vulcanizate properties. Natural rubber compounds served as controls.

It was pointed out in Phase I that other synthetic elastomers, namely butyl rubber and SBR, are already in normal use in aircraft tires in innerliner materials (butyl) and bead wire insulation (SBR), and that these elastomers should not require further development work. However, some additional refinements have been made of the bead insulation to compare two types of SBR in this application.

Tables IX and XV show the various tire components evaluated, the compound formulations and data for physical properties. Among the various components, both Natsyn 200 and 400 (polyisoprene, Goodyear) were used as 100% replacements for natural rubber. Also, blends of Natsyn 400 with low percentages (10-30 phr) of polybutadiene (Ameripol CB 200) were evaluated in the tread and carcass formulations.

The use of synthetic polyisoprene as a replacement for natural rubber is technically sound. General observations made by comparing the synthetic polyisoprene tire components to their respective natural rubber controls indicate a slower cure rate for polyisoprene with attendant increase in scorch safety. Despite the slower cure rate, development of vulcanizate properties is complete and in the approximate range of properties developed with the natural control in the same cure cycles, with the exception of modules. Modulus was generally lower for polyisoprene materials (see Tables IX-XII). However, polyisoprene gives improved heat build-up and blowout protection. Flex cracking, cut protection and cut growth characteristics appear to be poorer for polyisoprene compared to natural rubber. Wear predictions were difficult to obtain due to inconsistent abrasion results. However, a trend was observed indicating that the two elastomers were about equal in wear characteristics. Mooney plasticities were higher in general for the polyisoprene compounds, but were well within the range desired for good factory processing. Air permeability for innerliner materials was equal, as shown in Table XIII.

Polybutadiene slows down the cure rate as well as having an adverse effect on cured hardness, tear strength, cut resistance and skid resistance. Some benefit in abrasion resistance was noted through the use of minor percentages of polybutadiene in a blend with polyisoprene.

Relative to natural rubber, green adhesion and stretch were significantly lower for polyisoprene and for polyisoprene/polybutadiene blends. Green strength as it relates to and affects tire building properties is felt to be very important. The data showed an appreciable loss in this property for polyisoprene compounds. The addition of low percentages of polybutadiene further reduces green strength. The impact of this loss in green tack and strength on tire building properties is not known. The difference is illustrated in Figure 1. The great green strength plus the reinforcing effect inherent in natural rubber do not appear to be present in the synthetic elastomer as observed here. A check on the green strength characteristics of SBR materials used extensively in the manufacture of other types of tires would give some indication of the order of green strength required. However, it should be remembered that the lift ratios involved for aircraft tires are generally higher than for most other types of tires. This necessitiates greater green strength for aircraft tires than for other types of tires.

As measured by the wet skid resistance test, polyisoprene has a slighlty higher coefficient of friction than natural rubber. By blending polyisoprene with increasing amounts of polybutadiene, the coefficient of friction on wet surfaces was reduced to a level appreciably lower than that observed for natural rubber. This lower coefficient of friction for polybutadiene detracts from its suitability in tread materials.

All compound ingredients used in this work effort have been found previously to be the best for use in aircraft tires. This has been established through steady and continued materials research at Thompson's Research and Development Center. In addition, Thompson's technical personnel have had considerable and varied experience in the evaluation of ingredients and development of materials for use in new aircraft tire manufacture.

SUMMARY

The results of this Task indicate that polyisoprene has many of the desirable qualities needed in aircraft tires, as well as certain shortcomings indicated particularly by green strength. The advantage which might be gained through use of small amounts of polybutadiene are felt to be more than offset by the negative factors observed, namely lower modulus, tensile strength and hardness, poorer tear, poorer cut and cut growth resistance, generally poorer green tack and higher heat build-up with reduced blowout protection. For these reasons it was decided to eliminate the use of polybutadiene blends in the carcass and tread components in subsequent Tasks.

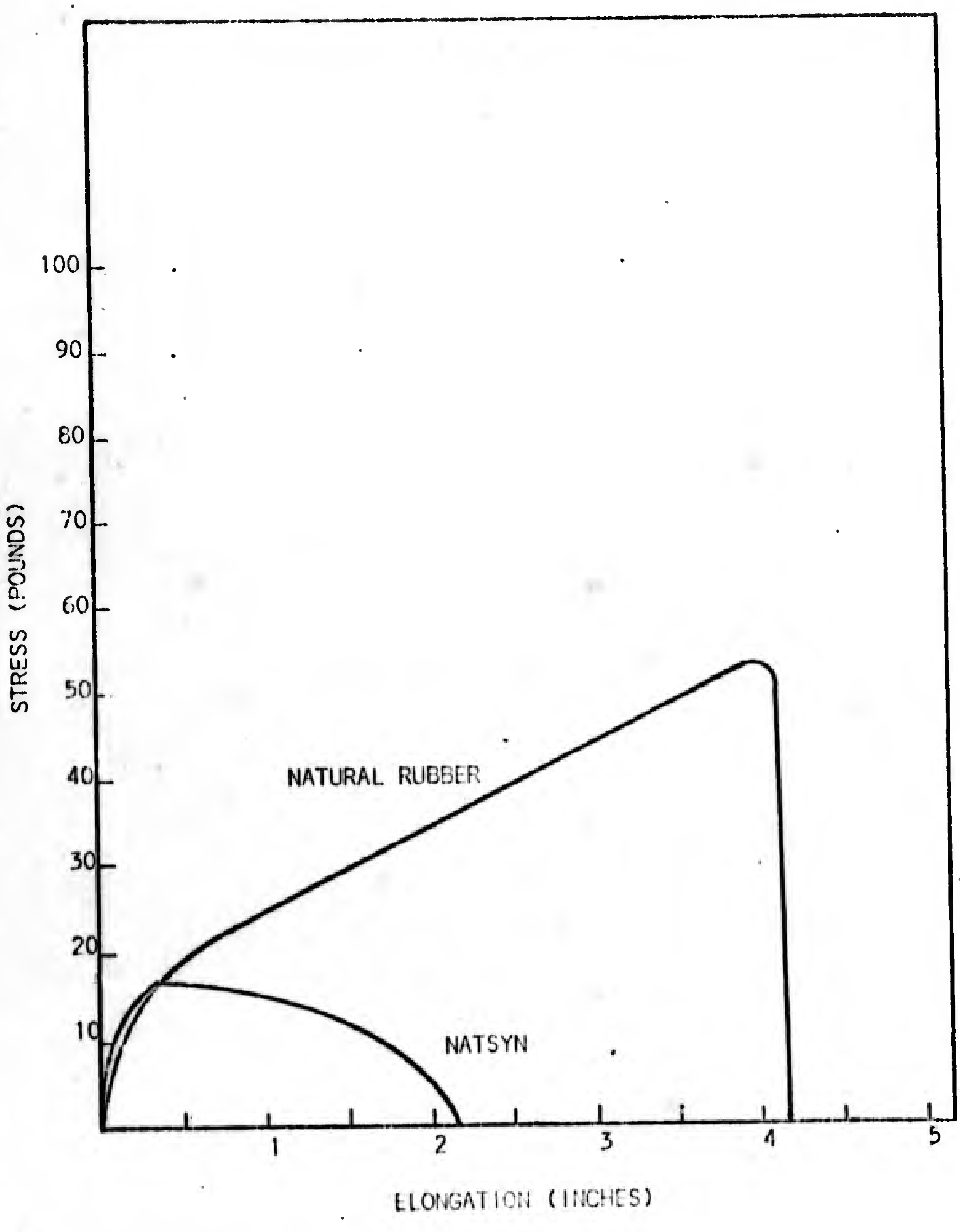


FIGURE I

GREEN STRENGTH -- NATSYN VS NATURAL RUBBER

TABLE IX TREAD FORMULATIONS

INGREDIENTS	FORMULATIONS T-1	T-2	T-3	T-4	T-5	T-6
Natural Rubber (#IRSS)	100.00	-	-			
Natsyn 200 (Polyisoprene)	-	100.00	-			
Natsyn 400 (Polyisoprene)	-	-	100.00	90.00	80.00	70.00
Ameripol CB-220	-	-	-	10.00	20.00	30.00
Zinc Oxide	5.00	5.00	5.00	5.00	5.00	5.00
Stearic Acid	1.50	1.50	1.50	1.50	1.50	1.50
HAF Black	45.00	45.00	45.00	45.00	45.00	45.00
Pine Tar	3.00	3.00	3.00	3.00	3.00	3.00
Thermoflex-A	1.00	1.00	1.00	1.00	1.00	1.00
Santoflex-AW	1.50	1.50	1.50	1.50	1.50	1.50
Crystex	0.50	0.50	0.50	0.50	0.50	0.50
Sulfasan R	2.00	2.00	2.00	2.00	2.00	2.00
Santocure NS	1.00	1.00	1.00	1.00	1.00	1.00
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	4.8	4.0	3.8	2.1	2.2	3.0
Initial Viscosity: In.-Lbs.	27	24	22	23	23	26
Scorch Time: Minutes	12	15	18	14	14	14
Cure Rate: In.-Lbs./Min.	5	4	5	4.5	4.5	5
Maximum Modulus: In.-Lbs.	68	68	68	72	73	77
Time For Max. Modulus - Minutes	60	120	120	110	100	88
Reversion: In.-Lbs./Min.	0	0	0	0	0	0
TENSILE DATA: Normal (X); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275 °F						
100% Modulus	-	-	-	-	-	-
200% Modulus	-	-	-	-	-	-
300% Modulus	1800	1850	1750	1930	1890	1690
Tensile Strength	3550	3600	3800	3650	3740	3380
Percent Elongation	475	475	500	470	480	475
Shore A Durometer	65	64	62	59	57	59
Crescent Tear - Type C	475	475	475	250	220	270
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
35,000	.1718	.2656	.2656	.2968	.2656	.2656
54,000	.2187	.3437	.4062	.4218	.3281	.3281
71,000	.2968	.5937	.4843	.5000	.4218	.3906
88,000	.3906	.7656	.8750	.5468	.5156	.4843
100,000	.4375	.7812	1.000	1.000	.6250	.5000
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 212 °F; Time 30 Min.						
Final Temperature °F	271	260	253	260	267	275
Temperature Rise °F	59	48	41	48	55	63
Percent Compression Set	17.3	12.5	7.8	7.8	7.8	10.9
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	15	36	36	25	14	12
Blow-Out Temperature	300+	300	300+	300+	300+	300+
Temperature Rise	88+	88+	88+	88+	88+	88+
MISCELLANEOUS TESTS						
Specific Gravity	1.14	1.14	1.14	1.14	1.14	1.14
Scorch: Minutes @ 250 °F	58	60	62	53	54	48
Index of Abrasion	222	356	198	217	127	102
Rebound: At °F						
Elasticity: At °F						

TABLE IX (CONTINUED)

	T-1	T-2	T-3	T-4	T-5	T-6
Green Tack LBS/ELONG.	9.3/2.2	5.9/1.6	4.4/1.6	4.7/1.3	4.1/1.1	4.2/0.8
Skid Resistance-Wet	50.7	52.3	53.7	50.3	47.3	45.7
Plasticity ML 4'/212°F	30	46	40	38	38	42
Green Strength (IN.-LBS)	27.8	2.5	1.9	-	-	-

TABLE X CARCASS FORMULATIONS

INGREDIENTS	FORMULATIONS					
	C-1	C-2	C-3	C-4	C-5	C-6
Natural Rubber (#IRSS)	100.00	-	-	-	-	-
Natsyn 200 (Polyisoprene)	-	100.00	-	-	-	-
Natsyn 400 (Polyisoprene)	-	-	100.00	90.00	80.00	70.00
Ameripol CB-220	-	-	-	10.00	20.00	30.00
Zinc Oxide	5.00	5.00	5.00	5.00	5.00	5.00
Stearic Acid	1.00	1.00	1.00	1.00	1.00	1.00
HAF Black	40.00	40.00	40.00	40.00	40.00	40.00
Thermoflex A	1.00	1.00	1.00	1.00	1.00	1.00
Sunpar 150	6.00	6.00	6.00	6.00	6.00	6.00
Crystex	0.50	0.50	0.50	0.50	0.50	0.50
Sulfasan R	2.00	2.00	2.00	2.00	2.00	2.00
Altax	1.25	1.25	1.25	1.25	1.25	1.25
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	3.8	2.2	2.5	2.4	1.8	1.9
Initial Viscosity: In.-Lbs.	18	26	28	21	22	25
Scorch Time: Minutes	12	11	12	14	14	15
Cure Rate: In.-Lbs./Min.	6	5	4.5	4	3.5	3
Maximum Modulus: In.-Lbs.	60	67	68	75	77	80
Time For Max. Modulus - Minutes	70	70	90	120	115	70
Reversion: In.-Lbs./Min.	0	0	0	0	0	0
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275 °F						
100% Modulus						
200% Modulus						
300% Modulus	2100	2100	2050	2240	1590	1940
Tensile Strength	3800	3650	3525	3640	3290	3540
Percent Elongation	450	425	425	450	460	450
Shore A Durometer	60	60	61	63	61	62
Crescent Tear - Type C	430	410	390	420	460	440
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
19,500	.1250	.0937	.0937	.1562	.1718	.3750
39,000	.1562	.1562	.2500	.2812	.2968	.5312
59,000	.2187	.2343	.3125	.4218	.3750	.5937
78,500	.2812	.2968	.3750	.7812	.4062	.6250
100,000	.3437	.3593	.4218	1.000	.5312	.6562
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 212 °F; Time 30 Min.						
Final Temperature °F	244	248	244	248	246	250
Temperature Rise °F	32	36	32	36	34	38
Percent Compression Set	6.3	6.3	6.3	4.7	4.7	4.7
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time - Minutes	126	259	263	101	123	75
Blow-Out Temperature	300+	300+	269	300	268	300+
Temperature Rise	88+	88+	57	88	56	88+
MISCELLANEOUS TESTS						
Specific Gravity	1.10	1.10	1.10	1.12	1.11	1.12
Scorch: Minutes @ 250 °F	49	48	52	62	59	58
Index of Abrasion						
Rebound: At °F						
Elasticity: At °F						

TABLE X CONTINUED

	C-1	C-2	C-3	C-4	C-5	C-6
Green Tack LBS/ELONG.	7.8/1.9	4.9/1.7	4.3/1.8	4.0/1.5	4.3/1.5	3.7/1.5
Plasticity ML 4'/212°F	30	38	36	34	36	38
Green Strength (IN.-LBS)	20.6	1.9	1.9	2.0	1.8	1.8

TABLE XI BEAD WRAP FORMULATIONS

INGREDIENTS	FORMULATIONS BW-1	BW-2	BW-3	BW-4	BW-5	
Natural Rubber #1RSS	100.00	100.00	-	-	-	
RPA #6	.25	-	-	-	0.25	
Natsyn 200 (Polyisoprene)	-	-	100.00	-	-	
Natsyn 400 (Polyisoprene)	-	-	-	100.00	100.00	
Zinc Oxide	5.00	5.00	5.00	5.00	5.00	
Stearic Acid	1.00	1.00	1.00	1.00	1.00	
HAF Black	40.00	40.00	40.00	40.00	40.00	
Thermoflex A	1.00	1.00	1.00	1.00	1.00	
Pine Tar	4.00	4.00	4.00	4.00	4.00	
Rosin Oil	2.00	2.00	2.00	2.00	2.00	
Crystex	2.60	2.60	2.60	2.60	2.60	
Ethylac	0.60	0.60	0.60	0.60	0.60	
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	5.0	6.0	6.0	3.1	6.0	
Initial Viscosity: In.-Lbs.	19	17	30	23	21	
Scorch Time: Minutes	8	8	8	10	10	
Cure Rate: In.-Lbs./Min.	8	8	8	6.5	6.5	
Maximum Modulus: In.-Lbs.	59	62	66	60	56	
Time For Max. Modulus - Minutes	18	22	25	60	25	
Reversion: In.-Lbs./Min.	.5	.3	.1	0	.4	
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: Minutes @ 275 °F	20	20	20	30	30	
100% Modulus	-	-	-	-	-	
200% Modulus	-	-	-	-	-	
300% Modulus	1825	1705	1490	1250	1350	
Tensile Strength	3800	3740	3250	3605	3610	
Percent Elongation	500	500	500	570	550	
Shore A Durometer	63	63	63	64	63	
Crescent Tear - Type C	470	430	420	440	430	
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175PSI; Stroke .225 In.; Temp. 212 °F; Time 30 Min.						
Final Temperature °F	260	262	258	255	253	
Temperature Rise °F	48	50	46	43	41	
Percent Compression Set	9.4	7.8	3.1	3.1	3.1	
HEAT BLOW-OUT: Load 250PSI; Stroke .25 In.; Temperature 212 °F						
Time	16	13	23	26	28	
Blow-Out Temperature	318	305	304	327	353	
Temperature Rise	106	93	92	115	141	
MISCELLANEOUS TESTS						
Specific Gravity	1.13	1.13	1.13	1.13	1.13	
Scorch: Minutes @ 250 °F	27	28	32	38	36	
Index of Abrasion	222	352	344			
Rebound: At °F						
Elasticity: At °F						
PLASTICITY ML 4'/212 °F	26	32	48	44	36	

TABLE XII BEAD FILLER FORMULATIONS

INGREDIENTS	FORMULATIONS F-1	F-2	F-3			
Natural Rubber #1RSS	100.00	-	-			
Natsyn 200 (Polyisoprene)	-	100.00	-			
Natsyn 400 (Polyisoprene)	-	-	100.00			
Zinc Oxide	7.50	7.50	7.50			
Stearic Acid	1.00	1.00	1.00			
MPC Black	27.50	27.50	27.50			
SRF Black	60.00	60.00	60.00			
Picco 100	2.50	2.50	2.50			
Rosin Oil	4.00	4.00	4.00			
Sunpar 150	4.00	4.00	4.00			
Crystex	3.00	3.00	3.00			
Santocure NS	1.25	1.25	1.25			
MONSANTO RHEOMETER DATA						
Temperature: °F Ø	6.2	6.0	7.0			
Initial Viscosity: In.-Lbs.	20	23	20			
Scorch Time: Minutes	12	13	11			
Cure Rate: In.-Lbs./Min.	8.5	8.5	7.5			
Maximum Modulus: In.-Lbs.	84	86	82			
Time For Max. Modulus - Minutes	30	39	33			
Reversion: In.-Lbs./Min.	.35	.34	.35			
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 275°F						
100% Modulus	-	-	-			
200% Modulus	-	-	-			
300% Modulus	2605	2430	2180			
Tensile Strength	2895	3150	2920			
Percent Elongation	340	430	440			
Shore A Durometer	71	66	69			
Crescent Tear - Type C	450	460	470			
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp 212 °F; Time 30 Min.						
Final Temperature °F	329	327	300			
Temperature Rise °F	117	115	88			
Percent Compression Set	28.1	31.2	28.2			
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	6	7	10			
Blow-Out Temperature	295	349	297			
Temperature Rise	83	137	85			
MISCELLANEOUS TESTS						
Specific Gravity	1.23	1.23	1.22			
Scorch: Minutes @ °F	48	51	53			
Index of Abrasion						
Rebound: At °F						
Elasticity: At °F						
PLASTICITY ML 4'/212°F	32	38	32			

TABLE XIII LINER FORMULATIONS

INGREDIENTS	FORMULATIONS L-1	L-2	L-3	L-4	L-5	
Natural Rubber #IRSS	70.00	70.00	-	-	-	
Natsyn 200 (Polyisoprene)	-	-	70.00	-	-	
Natsyn 400 (Polyisoprene)	-	-	-	70.00	70.00	
RPA #6	0.20	-	-	-	0.20	
Butyl Rubber	10.00	10.00	10.00	10.00	10.00	
Butyl Tube Reclaim	33.30	33.30	33.30	33.30	33.30	
Zinc Oxide	3.50	3.50	3.50	3.50	3.50	
Stearic Acid	1.50	1.50	1.50	1.50	1.50	
HAF Black	37.50	37.50	37.50	37.50	37.50	
Thermoflex A	1.25	1.25	1.25	1.25	1.25	
Dioctyl Pthalate	5.00	5.00	5.00	5.00	5.00	
Crystex	2.25	2.25	2.25	2.25	2.25	
Santocure NS	1.00	1.00	1.00	1.00	1.00	
MONSANTO RHEOMETER DATA						
Temperature: 275°F Ø	5.4	6.0	6.8	6.2	9	
Initial Viscosity: In.-Lbs.	17	22	25	25	21	
Scorch Time: Minutes	9	9	9	12	12	
Cure Rate: In.-Lbs./Min.	7	7	6	5.5	6.5	
Maximum Modulus: In.-Lbs.	66	67.5	63	65	63	
Time For Max. Modulus - Minutes	50	40	30	40	38	
Reversion: In.-Lbs./Min.	.06	.1	.08	.1	.2	
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 275°F						
100% Modulus	-	-	-	-	-	
200% Modulus	-	-	-	-	-	
300% Modulus	1650	1600	1650	1380	1300	
Tensile Strength	2300	2300	2200	2300	2250	
Percent Elongation	400	400	500	525	475	
Shore A Durometer	63	62	61	60	61	
Crescent Tear - Type C	300	300	275	275	300	
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175PSI; Stroke .225In.; Temp. 212°F; Time 30 Min.						
Final Temperature °F	338	335	370	350	400	
Temperature Rise °F	126	123(23')	158	138	188(28')	
Percent Compression Set	37.5	25	40.6	40.6	40.6	
HEAT BLOW-OUT: Load 250PSI; Stroke .25In.; Temperature 212°F						
Time	9	11	8	9	8	
Blow-Out Temperature	347	353	356	357	350	
Temperature Rise	135	141	144	145	138	
MISCELLANEOUS TESTS						
Specific Gravity	1.12	1.12	1.12	1.12	1.12	
Scorch: Minutes @ °F	31	33	38	47	48	
XXXXXXXXXXX Plasticity ML4'/212°F	28	34	40	38	32	
Air Permeability, cc/mil/psi/ft2/day	.000411	-	-	-	.000407	
Elasticity: At °F						

TABLE XIV BEAD INSULATION FORMULATIONS

INGREDIENTS	BN-1	BN-2	BN-3			
	FORMULATIONS					
Amerlpol 1002 (Hot SBR)	100.00	-	50.00			
S-1502 (Cold SBR)	-	100.00	50.00			
Zinc Oxide	7.50	7.50	7.50			
Stearic Acid	5.00	5.00	5.00			
FEF Black	25.00	25.00	25.00			
SRF Black	100.00	100.00	100.00			
Picco 100	3.00	3.00	3.00			
Pine Tar	5.00	5.00	5.00			
Sunpar 150	3.00	3.00	3.00			
Crystex	3.50	3.50	3.50			
Altax	1.50	1.50	1.50			
Monex	.10	.10	.10			
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	5.5	11.8	11.5			
Initial Viscosity: In.-Lbs.	42	53	57			
Scorch Time: Minutes	8	6	6			
Cure Rate: In.-Lbs./Min.	2	2.5	2			
Maximum Modulus: In.-Lbs.	110	114.8	140			
Time For Max. Modulus - Minutes	120	75	120			
Reversion: In.-Lbs./Min.	0	.25	0			
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275 °F						
100% Modulus	1025	1150	1400			
200% Modulus	1900	2150	2175			
300% Modulus	-	-	-			
Tensile Strength	2075	2500	2180			
Percent Elongation	250	275	200			
Shore A Durometer	78	79	80			
Crescent Tear - Type C	380	460	360			
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	240	225	240			
Temperature Rise °F	140	125	140			
Percent Compression Set	6.2	6.2	6.2			
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	7	3	4			
Blow-Out Temperature	272	230	265			
Temperature Rise	172	130	165			
MISCELLANEOUS TESTS						
Specific Gravity	1.31	1.31	1.30			
Scorch: Minutes @ 250 °F	36	32	39			
ML 4'/212 °F	72	92	86			
Rebound: At °F						
Elasticity: At °F						

TABLE XIV (CONTINUED)

Bead Wire Adhesion (lbs/wire) (Cure 50'/280°F)

@ Ambient

	BN-1	BN-2	BN-3
	78	48	50
	64	86	54
	48	38	50
	72	56	50
	50	46	50
	50	40	60
	52	48	40
	64	44	48
	82	40	50
	62	-	-
Avg (lbs/wire)	62.2	49.6	50.2

TABLE XV BEAD INSULATION FORMULATIONS

INGREDIENTS	FORMULATIONS BN-1	BN-2	BN-3			
Ameripol 1002 (Hot SBR)	100.00	--	50.00			
S-1502 (Cold SBR)	-	100.00	50.00			
Zinc Oxide	7.50	7.50	7.50			
Stearic Acid	5.00	5.00	5.00			
FEF Black	25.00	25.00	25.00			
SRF Black	100.00	100.00	100.00			
Picco 100	3.00	3.00	3.00			
Pine Tar	5.00	5.00	5.00			
Sunpar 150	3.00	3.00	3.00			
Crystex	3.50	3.50	3.50			
Altax	1.50	1.50	1.50			
Monex	.10	.10	.10			
MONSANTO RHEOMETER DATA						
Temperature: °F						
Initial Viscosity: In.-Lbs.						
Scorch Time: Minutes						
Cure Rate: In.-Lbs./Min.						
Maximum Modulus: In.-Lbs.						
Time For Max. Modulus - Minutes						
Reversion: In.-Lbs./Min.						
TENSILE DATA: Normal ( ); At 212°F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	1205	1360	1325			
200% Modulus	-	-	-			
300% Modulus	-	-	-			
Tensile Strength	1210	1400	1390			
Percent Elongation	100	100	100			
Shore A Durometer	73	74	75			
Crescent Tear - Type C	180	210	170			
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 212°F; Time 30 Min.						
Final Temperature °F	335	317	335			
Temperature Rise °F	123	105	113			
Percent Compression Set	12.5	12.5	20.3			
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	4	4	4			
Blow-Out Temperature	323	341	339			
Temperature Rise	111	129	117			
MISCELLANEOUS TEST						
Specific Gravity	1.33	1.33	1.30			
Scorch: Minutes @ 250°F	36	32	39			
Index of Abrasion						
Rebound: At °F						
Elasticity: At °F						

TABLE XV (CONTINUED)

Bead Wire Adhesion (lbs/wire) Cure 50'/280°F.
@ 212°F

	BN-1	BN-2	BN-3
	34	26	40
	50	28	32
	54	26	43
	79	22	25
	49	24	34
	78	24	35
	31	29	54
	82	27	39
	37	25	38
	49	18	34
Avg. (lbs/wire)	54.3	24.9	37.4

Plasticity Evaluation - Processing Mooneys

(ML 1'-4'/212°F)

Raw Polymer	Hot SBR	Cold SBR	50/50 Hot/Cold SBR
	41-46	68-60	----- (not a blend)
Masterbatch	78-59	99-84	92-79
Final	80-72	107-92	99-86

TASK 2: PHYSICAL PROPERTIES TESTS - ROOM TEMPERATURE

Compounds developed from an objective review of Task I have been thoroughly tested to establish their vulcanized and unvulcanized properties at room temperature. Natural rubber compounds (excepting the bead insulation) were used as controls. All formulations and physical data appear in Tables XVI through XXV.

A. Unvulcanized Compounds - Processibility Testing

Plasticities for the two elastomer types were comparable suggesting that synthetic polyisoprene will process as well as natural rubber in factory operations. Rheological properties confirmed that polyisoprene will develop sound compounds with high modulus and good reversion characteristics. Polyisoprene was slower curing initially, as shown by the slower cure rates, longer scorch life, and increased times to attain maximum dynamic modulus. Relative to the development of sound physical properties, polyisoprene does cure in time intervals comparable to natural rubber. Tack appeared to be very good by comparison to natural rubber, as was the ability of polyisoprene to hold and maintain good dispersion of compound ingredients. Green strength was considered to be satisfactory but lower by comparison to the strength and reinforcing qualities exhibited by natural rubber.

B. Vulcanized Materials - Static Tests

Polyisoprene as a substitute for natural rubber has lower modulus and tensile strength, equivalent to slightly higher elasticity and elongation, and equal to somewhat lower hardness and tear strength. It compared favorably to natural rubber in cord adhesion, and appeared slightly better for adhering to cut-resistant additives (brass coated wire).

C. Vulcanized Materials - Dynamic Tests

Polyisoprene was considerably better than natural rubber with respect to heat build-up and blowout protection, which may achieve better tire operational safety combined with lower running temperature. Also, the data showed equal to slightly improved rebound and wear characteristics for polyisoprene. Both are plus factors which contribute to improved tire performance. Other dynamic performance indicators worthy of note are dynamic modulus and phase angle as determined by the Oscillating Disk Rheometer. Polyisoprene compounds appeared to compare favorably to natural rubber on both of these factors.

D. Specific Gravity of Vulcanized Materials

Since the specific gravity of polyisoprene and natural rubber are the same, compounds involving direct replacement of one elastomer with the other have similar specific gravities. The physical data verified this, all observed values being within the usual accepted testing tolerances.

TABLE XVI TREAD FORMULATIONS

INGREDIENTS	FORMULATIONS					
	TH-9	TH-10				
Natural Rubber (#1RSS)	100.00	-				
Natsyn 400 (Polyisoprene)	-	100.00				
HAF Black	47.00	47.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.50	1.50				
Pine Tar	4.00	4.00				
Thermoflex - A	1.00	1.00				
Santoflex - AW	1.50	1.50				
Crystex	.50	.50				
Sulfasan R	2.00	2.00				
Santocure NS	1.15	1.15				
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	2.9	1.8				
Initial Viscosity: In.-Lbs.	29	28				
Scorch Time: Minutes	11	12				
Cure Rate: In.-lbs./Min.	6.5	5				
Maximum Modulus: In.-Lbs.	72.2	76.5				
Time For Max. Modulus - Minutes	60	80				
Reversion: In.-Lbs./Min.	.01	0				
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	450	410				
200% Modulus	1250	1180				
300% Modulus	2420	2100				
Tensile Strength	4150	3775				
Percent Elongation	475	475				
Shore A Durometer	65	64				
Crescent Tear - Type C	530-560	470-490				
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles	Inches of Cut Growth					
19,500	.1406	.2031				
39,000	.2187	.3437				
58,500	.3281	.5000				
75,500	.3750	1.000				
96,000	1.000					
HEAT BUILD-UP: Load 175PSI; Stroke .225 In.; Temp. 100°F; Time 30 Min.						
Final Temperature °F	163	157				
Temperature Rise °F	63	57				
Percent Compression Set	4.7	3.1				
HEAT BLOW-OUT: Load 250PSI; Stroke .25 In.; Temperature 100 °F						
Time	100+	100+				
Blow-Out Temperature	248 (No B.O.)	277 (No B.O.)				
Temperature Rise	148	177				
MISCELLANEOUS TESTS						
Specific Gravity	1.13	1.12				
Scorch: Minutes @ 250 °F	36	38				
Index of Abrasion	137	130				
Rebound: At R.T.°F	49	49				
Elasticity: At R.T.°F	82	83				

TABLE XVII H-BLOCK CORD ADHESION - AMBIENT CONDITIONS

H-Block Cord Adhesion - Cure 50'/275°F

Ambient Conditions	TH-9	TH-10
Adhesion to 1260/2 Nylon (lbs/cord)	18.6, 17.2 13.2, 13.8	10.4, 13.4 16.5, 16.1 15.8
Adhesion Avg. (lbs/cord)	15.6	14.4
Adhesion to 840/2 Nylon (lbs/cord)	13.7, 11.6 10.0, 9.4 10.6	11.6, 11.5 16.0, 12.0 14.8
Adhesion Avg. (lbs/cord)	11.1	13.2
Adhesion to brass coated wire (cut resistant) Cure 1.5 x O.C.T.		
Adhesion (lbs/wire)	4.0, 3.5 4.0, 6.0 3.5	2.5, 5.5 3.5, 7.5 7.5,
Adhesion Avg. (lbs/wire)	4.3	5.3
ML 4'/212°F	42	39
Green Tack lbs/elong.	9.2/2.3	4.6/1.7
Green Strength (in.-lbs)	27.5	2.1

TABLE XVIII BALLISTIC TEST DATA - AMBIENT CONDITIONS

TARGET NUMBER	TARGET MATERIAL	FIRING TESTS - PENETRATION					AVERAGE PENETRATION	AVERAGE K.E. ABSORBED PER .001 INCH
		1	2	3	4	5		
1	TH 9 *	.280	.280	.260	.300	.280	.280	4735 ERGS
2	TH 10	.340	.360	.360	.320	.340	.344	3855 ERGS
3	TH 3	.380	.360	.360	.380	.380	.372	3565 ERGS
4	TH 4	.380	.300	.380	.340	.360	.352	3767 ERGS
5	TH 7	.400	.385	.380	.360	.420	.389	3410 ERGS

* NATURAL RUBBER (CONTROL)

RESISTANCE TO BALLISTIC PENETRATION

TARGET MATERIAL	PER CENT DECREASE
TH 9	---
TH 10	12.3
TH 3	13.3
TH 4	12.5
TH 7	13.9

TABLE XIX CARCASS FORMULA[illegible]

INGREDIENTS	FORMULATIONS C-8	C-9				
Natural Rubber (#IRSS)	100.00	-				
Natsyn 400 (Polyisoprene)	-	100.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.00	1.00				
HAF Black	40.00	40.00				
Thermoflex - A	1.00	1.00				
Sunpar 150	6.00	6.00				
Crystex	.50	.50				
Sulfasan R	2.00	2.00				
Altax	1.25	1.25				
MONSANTO RHEOMETER DATA						
Temperature: 275°F Ø	1.4	1.0				
Initial Viscosity: In.-Lbs.	25	25				
Scorch Time: Minutes	13	15				
Cure Rate: In.-Lbs./Min.	5	3				
Maximum Modulus: In.-Lbs.	70	75.4				
Time For Max. Modulus - Minutes	55	120				
Reversion: In.-Lbs./Min.	0	0				
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	400	410				
200% Modulus	1175	1080				
300% Modulus	2225	2180				
Tensile Strength	3995	3630				
Percent Elongation	460	430				
Shore A Durometer	61	61				
Crescent Tear - Type C	420-440	370-400				
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
19,700	.1562	.2812				
39,500	.1875	.4687				
59,000	.2812	.6250				
78,700	.4062	1.000				
111,500	1.000					
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100°F; Time 30 Min.						
Final Temperature °F	145	140				
Temperature Rise °F	45	40				
Percent Compression Set	3.1	1.6				
HEAT BLOW-OUT: Load 250PSI; Stroke .25 In.; Temperature 100 °F						
Time	100+	100+				
Blow-Out Temperature	162 (No B.O.)	152 (No B.O.)				
Temperature Rise	62	52				
MISCELLANEOUS TESTS						
Specific Gravity	1.09	1.10				
Scorch: Minutes @ 250°F	52	49				
Index of Abrasion	-	-				
Rebound: At R.T. °F	57	59				
Elasticity: At R.T. °F	85	85				

TABLE XX H-BLOCK CORD ADHESION - AMBIENT CONDITIONS

H-Block Cord Adhesion - Cure 50'/275°F

Ambient Conditions	C-8	C-9
Adhesion to 1260/2 Nylon (lbs/cord)	18.4, 15.0 15.4, 13.8 18.4	10.5, 13.1 21.0, 11.6
Adhesion Avg. (lbs/cord)	16.2	14.3
Adhesion to 840/2 Nylon (lbs/cord)	11.6, 16.0 12.2, 16.5	15.4, 14.5 15.3
Adhesion Avg. (lbs/cord)	14.1	15.1
ML 4'/212°F	36	36
Green Tack (lbs/Elong.)	8.2/2.1	4.5/1.9
Green Strength (in-lbs.)	21.5	2.2

TABLE XXI BEAD WRAP FORMULATIONS

INGREDIENTS	FORMULATIONS					
	BW-6	BW-7				
Natural Rubber #1RSS	100.00	-				
RPA #6	.25	.25				
Natsyn 400 (Polyisoprene)	-	100.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.00	1.00				
HAF Black	40.00	40.00				
Thermoflex A	1.00	1.00				
Pine Tar	4.00	4.00				
Rosin Oil	2.00	2.00				
Crystex	2.50	2.50				
Ethylac	.60	.60				
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	3.9	1.0				
Initial Viscosity: In.-Lbs.	28	25				
Scorch Time: Minutes	6	9				
Cure Rate: In.-Lbs./Min.	7.5	5				
Maximum Modulus: In.-Lbs.	71.8	60.5				
Time For Max. Modulus - Minutes	30	26				
Reversion: In.-Lbs./Min.	.09	.19				
TENSILE DATA: Normal (X); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	500	340				
200% Modulus	1240	890				
300% Modulus	2190	1720				
Tensile Strength	3720	3500				
Percent Elongation	475	520				
Shore A Durometer	66	64				
Crescent Tear - Type C	410	410				
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
19,500	.3125	.1093				
39,000	.5000	.1562				
58,500	.5625	.2031				
76,500	.6406	.2500				
105,000	.7343	.3125				
HEAT BUILD-UP: Load 175PSI; Stroke .225In.; Temp. 100°F; Time 30 Min.						
Final Temperature °F	153	148				
Temperature Rise °F	53	48				
Percent Compression Set	4.9	3.1				
HEAT BLOW-OUT: Load 250PSI; Stroke .25In.; Temperature 100 °F						
Time	100+	100+				
Blow-Out Temperature	172 (No B.O.)	168 (No B.O.)				
Temperature Rise	72	68				
MISCELLANEOUS TESTS						
Specific Gravity	1.11	1.11				
Scorch: Minutes @ 250 °F	21	29				
Index of Abrasion	146	[illegible]				
Rebound: At °F	-	-				
Elasticity: At °F	-	-				

TABLE XXII H-BLOCK CORD ADHESION - AMBIENT CONDITIONS

H-Block Cord Adhesion - Cure 50'/275°F

Ambient Conditions

	BW-6	BW-7
Adhesion to 1260/2 Nylon (lbs/cord)	32.6, 25.6 32.4, 30.8 23.0	23.4, 22.4 23.8, 20.2 18.6
Avg (lbs/cord)	28.9	21.8
Adhesion to 840/2 Nylon (lbs/cord)	29.2, 23.4 18.0, 18.0 19.6, 27.6 22.6	24.4, 25.4 26.6, 24.4 18.9, 23.4 24.0
ML 4'/212°F	36	32

TABLE XXIII BEAD FILLER FORMULATIONS

INGREDIENTS	FORMULATIONS F-4	F-5				
Natural Rubber #1RSS	100.00	-				
Natsyn 400 (Polyisoprene)	-	100.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.00	1.00				
MPC Black	25.00	25.00				
SRF Black	60.00	60.00				
Picco 100	2.00	2.00				
Sunpar 150	4.00	4.00				
Rosin Oil	4.00	4.00				
Crystex	3.00	3.00				
Santocure NS	1.25	1.25				
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	11.9	12.1				
Initial Viscosity: In.-Lbs.	26	58(26)				
Scorch Time: Minutes	11.5	15				
Cure Rate: In.-Lbs./Min.	8	7				
Maximum Modulus: In.-Lbs.	91.2	86.5				
Time For Max. Modulus - Minutes	32	40				
Reversion: In.-Lbs./Min.	.39	.39				
TENSILE DATA: Normal (X); At °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 275 °F						
100% Modulus	895	520				
200% Modulus	2000	1425				
300% Modulus	2800	2300				
Tensile Strength	2900	3130				
Percent Elongation	325	440				
Shore A Durometer	72	67				
Crescent Tear - Type C	510-600	470-500				
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	190	180				
Temperature Rise °F	90	80				
Percent Compression Set	7.8	6.2				
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	27	40				
Blow-Out Temperature	267	262				
Temperature Rise	167	162				
MISCELLANEOUS TESTS						
Specific Gravity	1.21	1.20				
Scorch: Minutes @ 250 °F	45	57				
ML 4'/212 °F	39	42				
Rebound: At °F	-	-				
Elasticity: At °F	-	-				

TABLE XXIV INNER LINER FORMULATIONS

INGREDIENTS	FORMULATIONS					
	L-6	L-7				
Natural Rubber #IRSS	70.00	-				
Natsyn 400 (Polyisoprene)	-	70.00				
Butyl Rubber	10.00	10.00				
Butyl Reclaim	33.30	33.30				
HAF Black	37.50	37.50				
Zinc Oxide	3.50	3.50				
Stearic Acid	1.50	1.50				
Thermoflex A	1.25	1.25				
Dioctyl Phthalate	5.00	5.00				
Crystex	2.25	2.25				
Santocure NS	1.00	1.00				
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	6.0	6.2				
Initial Viscosity: In.-Lbs.	31	37				
Scorch Time: Minutes	9	10½				
Cure Rate: In.-Lbs./Min.	5.5	4.5				
Maximum Modulus: In.-Lbs.	73	78				
Time For Max. Modulus - Minutes	37	45				
Reversion: In.-Lbs./Min.	.10	.08				
TENSILE DATA: Normal (X); At °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @275 °F						
100% Modulus	450	325				
200% Modulus	990	750				
300% Modulus	1530	1290				
Tensile Strength	2310	2260				
Percent Elongation	430	490				
Shore A Durometer	63	63				
Crescent Tear - Type C	300	285				
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
10,000	.2188	.1562				
20,000	.2813	.2500				
59,000	.5000	.4687				
79,000	.5937	.5625				
100,000	.8125	.6562				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100°F; Time 30 Min.						
Final Temperature °F	201	186				
Temperature Rise °F	101	86				
Percent Compression Set	29.7	28.1				
HEAT BLOW-OUT: Load 250PSI; Stroke .25 In.; Temperature 100 °F						
Time	11	17				
Blow-Out Temperature	283	365				
Temperature Rise	183	265				
MISCELLANEOUS TESTS						
Specific Gravity	1.12	1.12				
Scorch: Minutes @ 250°F	34	47				
XXXXXXXXXXXXXXXX ML 4'/212°F	40	49				
Rebound: At °F	-	-				
Elasticity: At °F	-	-				

TABLE XXV BEAD INSULATION FORMULATIONS

INGREDIENTS	FORMULATIONS					
	BN-4					
Ameripol 1002 (Hot SBR)	100.00					
Zinc Oxide	7.50					
Stearic Acid	5.00					
FEF Black	25.00					
SRF Black	100.00					
Picco 100	3.00					
Pine Tar	5.00					
Sunpar 150	3.00					
Crystex	3.50					
Altax	1.50					
Monex	0.10					
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	6.8					
Initial Viscosity: In.-Lbs.	36					
Scorch Time: Minutes	9					
Cure Rate: In.-Lbs./Min.	1.5					
Maximum Modulus: In.-Lbs.	99					
Time for Max. Modulus - Minutes	120					
Reversion: In.-Lbs./Min.	0					
TENSILE DATA: Normal (X); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275 °F						
100% Modulus	1050					
200% Modulus	1875					
300% Modulus	-					
Tensile Strength	2050					
Percent Elongation	250					
Shore A Durometer	80					
Crescent Tear - Type C	320					
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	249					
Temperature Rise °F	149					
Percent Compression Set	6.3					
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	8					
Blow-Out Temperature °F	284					
Temperature Rise °F	184					
MISCELLANEOUS TESTS						
Specific Gravity	1.31					
Scorch: Minutes @ 250 °F	39					
XXXXXXXXXXXXXX Plasticity ML4'/212°F	67					
Rebound: At °F	-					
Elasticity: At °F	-					

TABLE XXV (CONTINUED)

Bead Wire Adhesion (lbs/wire) @ Room Temperature

Cure 50'/280°F

	BN-4
	82
	62
	56
	74
	52
	54
	56
	64
	85
	68
Average (lbs/wire)	65.3

E. Ballistic Cut Resistance

Several compounds were surveyed to determine their resistance to cutting, by propelling a steel sphere into a vulcanized test block at a known velocity. The depth of penetration was measured and the energy absorbed per 0.001 inches of penetration was computed.

Test results are shown in the attached chart. They indicated that synthetic polyisoprene materials were not as cut resistant as were similar natural rubber materials. This characteristic was attributed to the combination of lower modulus and tear strength for the polyisoprene materials.

F. Bead Wire Insulation

Previous aircraft tire compounding experience has established that styrene-butadiene rubber (SBR) is a satisfactory synthetic polymer for use in bead wire insulation compounds. The work in this Task was designed to show differences between hot and cold process SBR, in an effort to determine which was more suitable for this application. The bead wire insulation compounds were evaluated particularly for processing features, hardness, modulus, and bead wire adhesion, in order to determine which SBR type was the most suitable.

Each type of SBR handled and processed very well in the laboratory evaluation, indicating that each would process satisfactorily in the factory. Some physical differences were observed, with the bead wire adhesion level being the ultimate determining factor. Compound BN-4 (see Table XXV) using hot process SBR was unquestionably superior in this respect.

TASK 3: PHYSICAL PROPERTIES TESTS - ELEVATED TEMPERATURE

The materials compounded in Task 2 were subjected to testing at elevated temperatures (212^{0}F). This temperature approximates the temperatures developed during the taxi-take off of 49x17 and 30x8.8 tires. All test data are summarized in Tables XXVI through XXXVI.

A. Processibility of Unvulcanized Materials

Laboratory investigation and evaluation indicated that mixing of synthetic polyisoprene compounds was comparable to the mixing of similar natural rubber compounds. The plasticity evaluation covering the various mix stages of each compound confirmed this. It is expected that no serious difficulties will be encountered with polyisoprene materials in factory mixing, milling, calendering, frictioning and extruding operations. The plasticity evaluation for the bead wrap material strongly indicated a probable cost saving with this material. Because of the lower plasticities obtained with synthetic polyisoprene it may be possible to eliminate the premastication stage for the elastomer. Premastication of natural rubber is essential in order to achieve the desired plasticity range needed for proper frictioning of the bead wrap fabric. .

TABLE XXVI TREAD FORMULATIONS

INGREDIENTS	FORMULATIONS					
	T-9	T-10				
Natural Rubber (#1RSS)	100.00	-				
Natsyn 400 (Polyisoprene)	-	100.00				
HAF Black	47.00	47.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.50	1.50				
Pine Tar	4.00	4.00				
Thermoflex A	1.00	1.00				
Santoflex AW	1.50	1.50				
Crystex	.50	.50				
Sulfasan R	2.00	2.00				
Santocure NS	1.15	1.15				
MONSANTO RHEOMETER DATA						
Temperature: °F						
Initial Viscosity: In.-Lbs.						
Scorch Time: Minutes						
Cure Rate: In.-Lbs./Min.						
Maximum Modulus: In.-Lbs.						
Time for Max. Modulus - Minutes						
Reversion: In.-Lbs./Min.						
TENSILE DATA: Normal ( ); At 212°F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275 °F						
100% Modulus	425	425				
200% Modulus	1090	950				
300% Modulus	1960	1640				
Tensile Strength	3525	3205				
Percent Elongation	510	475				
Shore A Durometer	60	62				
Crescent Tear - Type C	390	320				
CUT GROWTH: Ambient Temperature ( ); At 212 °F						
Cycles		Inches of Cut Growth				
9,500	.1718	.3906				
22,000	.3125	.7187				
31,500	.4375	1.000				
70,500	.5781					
100,000	.7187					
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp 212 °F; Time 30 Min.						
Final Temperature °F	256	312(16').				
Temperature Rise °F	44	100				
Percent Compression Set	7.8	20.3				
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	14	11				
Blow-Out Temperature	315	290				
Temperature Rise	103	78				
MISCELLANEOUS TESTS						
Specific Gravity	1.13	1.12				
Scorch: Minutes @ 250 °F	36	38				
Index of Abrasion	GUMMY	GUMMY				
Rebound: At 212 °F	61	59				
Elasticity: At 212°F	75	70				

TABLE XXVII H-BLOCK CORD ADHESION - 212°

H-Block Cord Adhesion Cure 50'/275°F.
@ 212°F.

	T-9	T-10
Adhesion to 1260/2 Nylon (lbs/cord)	14.4, 11.2 11.7, 13.8 12.5	14.2, 10.2 9.3, 11.7 12.2
Adhesion Avg. (lbs/cord)	12.7	11.5
Adhesion to 840/2 Nlyon (lbs/cord)	11.8, 9.0 12.0, 9.2	11.8, 11.8 10.6, 12.2 9.5, 10.0
Adhesion Avg. (lbs/cord)	10.5	11.0

Plasticity Evaluation - Processing Mooneys

Raw Polymer	#IRSS	Natsyn
Raw Polymer ML 1'-4'/212°F	92-68	96-93
Masterbatch ML 1'-4'/212°F	84-78	79-70
Final ML 1'-4'/212°F	47-42	44-39

TABLE XXVIII CARCASS FORMULATIONS

INGREDIENTS	FORMULATIONS C-8	C-9				
Natural Rubber (#IRSS)	100.00	-				
Natsyn 400 (Polyisoprene)	-	100.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.00	1.00				
HAF Black	4[illegible].00	40.00				
Thermoflex A	1.00	1.00				
Sunpar 150	[illegible]	6.00				
Crystex	.50	.50				
Sulfasasan R	2.00	2.00				
Altax	1.25	1.25				
MONSANTO RHEOMETER DATA						
Temperature: °F						
Initial Viscosity: In.-Lbs.						
Scorch Time: Minutes						
Cure Rate: In.-Lbs./Min.						
Maximum Modulus: In.-Lbs.						
Time For Max. Modulus - Minutes						
Reversion: In.-Lbs./Min.						
TENSILE DATA: Normal ( ); At 212°F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	600	610				
200% Modulus	1190	1095				
300% Modulus	1700	-				
Tensile Strength	2050	1970				
Percent Elongation	350	280				
Shore A Durometer	58	61				
Crescent Tear - Type C	400	350				
CUT GROWTH: Ambient Temperature ( ); At 212°F						
Cycles		Inches of Cut Growth				
3200	.1562	.2656				
6300	.2813	.4687				
12,500	.5312	.7812				
15,900	.7187	1.000				
28,800	1.000					
HEAT BUILD-UP: Load 175PSI; Stroke .225 In.; Temp. 212°F; Time 30 Min.						
Final Temperature °F	244	238				
Temperature Rise °F	32	26				
Percent Compression Set	3.3	3.1				
HEAT BLOW-OUT: Load 250PSI; Stroke .25 In.; Temperature 212 °F						
Time	100+	100+				
Blow-Out Temperature	277 (No B.O.)	253 (No B.O.)				
Temperature Rise	65	41				
MISCELLANEOUS TESTS						
Specific Gravity	1.09	1.10				
Scorch: Minutes @ 250°F	52	49				
Index of Abrasion	GUMMY	GUMMY				
Rebound: At 212°F	68	68				
Elasticity: At 212°F	75	72				

TABLE XXIX H-BLOCK CORD ADHESION - 212°

H-Block Cord Adhesion @ 212°F — Cure 50'/275°F

	C-8	C-9
Adhesion to 1260/2 Nylon (lbs/cord)	14.0, 14.4 15.0, 14.7 18.2	20.0, 13.1 10.7, 20.5 19.2
Adhesion Avg. (lbs/cord)	15.3	16.7
Adhesion to 840/2 Nylon (lbs/cord)	14.8, 15.2 13.2, 15.8 10.4, 18.1 14.4	14.1, 15.0 11.8, 13.1
Adhesion Avg. (lbs/cord)	14.6	13.5

Plasticity Evaluation - Processing Mooneys

ML 1'-4'/212°F.	Natural Rubber	Natsyn
Raw Polymer	92-68	96-93
Masterbatch	76-66	62-56
Final	40-36	41-36

TABLE XXX BEAD WRAP FORMULATIONS

INGREDIENTS	FORMULATIONS BW-6	BW-7				
Natural Rubber #1RSS	100.00	-				
RPA #6	.25	.25				
Natsyn 400 (Polyisoprene)	-	100.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.00	1.00				
HAF Black	40.00	40.00				
Thermoflex A	1.00	1.00				
Pine Tar	4.00	4.00				
Rosin Oil	2.00	2.00				
Crystex	2.50	2.50				
Ethylac	.60	.60				
MONSANTO RH[illegible]						
Temperature: °F						
Initial Viscosity: In.-Lbs.						
Scorch Time: Minutes						
Cure Rate: In.-Lbs./Min.						
Maximum Modulus: In.-Lbs.						
Time For Max. Modulus - Minutes						
Reversion: In.-Lbs./Min.						
TENSILE DATA: Normal ( ); At 212 °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275 °F						
100% Modulus	740	400				
200% Modulus	1200	700				
300% Modulus	1720	1350				
Tensile Strength	2110	2100				
Percent Elongation	375	450				
Shore A Durometer	61	59				
Crescent Tear - Type C	320	300				
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 212 °F; Time 30 Min.						
Final Temperature °F	255	249				
Temperature Rise °F	43	37				
Percent Compression Set	9.4	7.8				
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	23	27				
Blow-Out Temperature	322	325				
Temperature Rise	110	113				
MISCELLANEOUS TESTS						
Specific Gravity	1.11	1.11				
Scorch: Minutes @ 250 °F	21	29				
Index of Abrasion	GUMMY	GUMMY				
Rebound: At °F						
Elasticity: At °F						

TABLE XXXI H-BLOCK CORD ADHESION - 212°

H-Block Cord Adhesion @ 212°F	Cure 50'/275°F	
	BW-6	BW-7
Adhesion to 1260/2 Nylon (lbs/cord)	22.0, 24.9 10.0, 17.2 22.4	14.0, 20.0 9.6, 17.2
Adhesion Avg. (lbs/cord)	19.3	15.2
Adhesion to 840/2 Nylon (lbs/cord)	8.2, 9.4 14.3, 29.6 18.4	15.6, 12.0 10.0, 15.4 11.4
Adhesion Avg. (lbs/cord)	16.0	13.0

Plasticity Evaluation - Processing Mooneys

ML 1'-4'/212°F	Natural Rubber	Natsyn
Raw Polymer	92-68	96-93
Premast. Polymer	62-57	49-43
Masterbatch	44-41	38-34
Final	39-36	36-32

TABLE XXXII BEAD FILLER FORMULATIONS

INGREDIENTS	FORMULATIONS F-4	F-5				
Natural Rubber #1RSS	100.00	-				
Natsyn 400 (Polyisoprene)	-	100.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.00	1.00				
MPC Black	25.00	25.00				
SRF Black	60.00	60.00				
Picco 100	2.00	2.00				
Sunpar 150	4.00	4.00				
Rosin Oil	4.00	4.00				
Crystex	3.00	3.00				
Santocure NS	1.25	1.25				
MONSANTO RHEOMETER						
Temperature: °F						
Initial Viscosity: In.-Lbs.						
Scorch Time: Minutes						
Cure Rate: In.-Lbs./Min.						
Maximum Modulus: In.-Lbs.						
Time For Max. Modulus - Minutes						
Reversion: In.-Lbs./Min.						
TENSILE DATA: Normal ( ); At 212 °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 275 °F						
100% Modulus	1160	920				
200% Modulus	1780	1460				
300% Modulus	-	-				
Tensile Strength	2000	1500				
Percent Elongation	230	210				
Shore A Durometer	70	70				
Crescent Tear - Type C	340	330				
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 212 °F; Time 30 Min.						
Final Temperature °F	303	307				
Temperature Rise °F	91	95				
Percent Compression Set	21.9	18.8				
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	11	14				
Blow-Out Temperature	340	400				
Temperature Rise	128	188				
MISCELLANEOUS TESTS:						
Specific Gravity	1.21	1.20				
Scorch: Minutes @ 250 °F	45	57				
Index of Abrasion						
Rebound: At °F						
Plasticity: At °F						

TABLE XXXIII PLASTICITY EVALUATION - PROCESSING MOONEYS

Plasticity Evaluation - Processing Mooneys

(ML 1'-4'/212°F)

	F-4 Natural Rubber	F-5 Natsyn
Raw Polymer	92-68	96-93
Masterbatch	64-59	66-62
Final	42-39	44-42

TABLE XXXIV LINER FORMULATIONS

INGREDIENTS	FORMULATIONS					
	L-6.	L-7				
Natural Rubber #1RSS	70.00	-				
Natsyn 400 (Polyisoprene)	-	70.00				
Butyl Rubber	10.00	10.00				
Butyl Reclaim	33.30	33.30				
HAF Black	37.50	37.50				
Zinc Oxide	3.50	3.50				
Stearic Acid	1.50	1.50				
Thermoflex A	1.25	1.25				
Dioctyl Phthalate	5.00	5.00				
Crystex	2.25	2.25				
Santocure NS	1.00	1.00				
MONSANTO RHEOMETER DATA						
Temperature: °F						
Initial Viscosity: In.-Lbs.						
Scorch Time: Minutes						
Cure Rate: In.-Lbs./Min.						
Maximum Modulus: In.-Lbs.						
Time for Max. Modulus - Minutes						
Reversion: In.-Lbs./Min.						
TENSILE DATA: Normal ( ); At 212 °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 275 °F						
100% Modulus	525	490				
200% Modulus	830	830				
300% Modulus	1120	1020				
Tensile Strength	1180	1210				
Percent Elongation	310	350				
Shore A Durometer	61	58				
Crescent Tear - Type C	250	210				
CUT GROWTH: Ambient Temperature ( ); At 212 °F						
Cycles		Inches of Cut Growth				
3,200	.4375	.4375				
6,300	.6875	.6875				
9,500	.8437	.9062				
12,500	.8750	1.000				
18,800	1.000	-				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 212 °F; Time 30 Min.						
Final Temperature °F	337	368				
Temperature Rise °F	125	156				
Percent Compression Set	40.6	34.4				
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	6	5				
Blow-Out Temperature	335	345				
Temperature Rise	113	123				
MISCELLANEOUS TESTS						
Specific Gravity	1.12	1.12				
Scorch: Minutes @ °F						
Index of Abrasion						
Rebound: At °F						
Elasticity: At °F						

TABLE XXXV PLASTICITY EVALUATION - PROCESSING MOONEYS

Plasticity Evaluation - Processing Mooneys

(ML 1'-4'/212°F.)

Raw Polymer	L-6	L-7
Natural Rubber	92-68	-
Natsyn	-	96-93
Butyl Rubber	89	89
Butyl Reclaim	49	49
Masterbatch	60-54	62-55
Final	46-40	53-49

TABLE XXXVI BEAD INSULATION FORMULATIONS

INGREDIENTS	FORMULATIONS					
	BN-4					
Ameripol 1002 (Hot SBR)	100.00					
Zinc Oxide	7.50					
Stearic Acid	5.00					
FEF Black	25.00					
SRF Black	100.00					
Picco 100	3.00					
Pine Tar	5.00					
Sunpar 150	3.00					
Crystex	3.50					
Altax	1.50					
Monex	0.10					
MONSANTO RHEOMETER DATA						
Temperature: °F						
Initial Viscosity: In.-Lbs.						
Scorch Time: Minutes						
Cure Rate: In.-Lbs./Min.						
Maximum Modulus: In.-Lbs.						
Time For Max. Modulus - Minutes						
Reversion: In.-Lbs./Min.						
TENSILE DATA: Normal ( ); At 212°F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	1230					
200% Modulus	-					
300% Modulus	-					
Tensile Strength	1280					
Percent Elongation	140					
Shore A Durometer	75					
Crescent Tear - Type C	200					
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 212 °F; Time 30 Min.						
Final Temperature °F	320					
Temperature Rise °F	108					
Percent Compression Set	11.5					
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 212 °F						
Time	5					
Blow-Out Temperature °F	324					
Temperature Rise °F	112					
MISCELLANEOUS TESTS						
Specific Gravity	1.31					
Scorch: Minutes @ 250°F	39					
Plasticity ML 4'/212°F	62					
Rebound: At °F						
[illegible]: At °F						

TABLE XXXVI (CONTINUED)

Bead Wire Adhesion (lbs/wire) @ 212°F

	BN-4
	40
	50
	54
	78
	52
	78
	38
	82
	42
	52
Average (lb/wire)	56.6

The tack of polyisoprene has not been a problem in the mixing and processing operations. Very good release has been observed in the banbury, on the mill rolls, and in molding equipment. By comparison with natural rubber, polyisoprene compounds quite often looked crumbly immediately after they had been discharged from the internal mixer. This may be an indication of the lower green strength (poorer batch knitting) observed in other tests. However, when mill blended for rapid cooling and subsequent sheet-off, polyisoprene compounds immediately formed a good band on the front mill roll.

Scorch and processing safety for polyisoprene compounds are somewhat better than for similar natural rubber compounds. Migration of materials (bloom) would be comparable.

B. Static and Dynamic Testing of Vulcanized Materials

The trends observed at elevated temperature for physical properties of materials follow the trends observed when tested at room temperature. Test values for both polyisoprene and for natural rubber compounds were poorer at elevated temperature, but in general compare favorably to one another. Polyisoprene continued to show improved heat build-up characteristics, better blow out protection, comparable hardness, rebound, and elongation, and lower tensile strength, modulus, tear strength, cut growth, and elasticity. Wear comparisons were difficult to measure because of excessive clogging of the abrasion test wheels at this temperature. Cut resistance as determined ballistically for both materials was comparable but poor, in that the spherical projectile completely penetrated the test block for each material.

TASK 4: MATERIALS SELECTION REVIEW

The data accumulated in Tasks 2 and 3, were subjected to a comparative evaluation with natural rubber controls. A selection was then made of the best synthetic material for each tire component. The synthetic elastomer selection for the various aircraft tire components is outlined below.

Tread Compound

Natsyn 400 (polyisoprene, Goodyear) was selected for the tread component. Choice of it over Natsyn 200, was based on an economic factor. While the two appear to be equivalent in properties, Natsyn 400 is less expensive (approximately 2¢ lb). The supplier intends to discontinue the manufacture of Natsyn 200 in the near future.

The use of Ameripol CB 220 (polybutadiene, Goodrich-Gulf) in low percentages has indicated improvements in abrasion resistance. However, use of it in aircraft tire treads in amounts as low as ten parts is felt undesirable because of the excessive observed loss in hardness and tear strength. These two properties are considered extremely important in a sound aircraft tire tread compound.

Carcass

Polyisoprene was selected for use in the carcass. This elastomer has shown improved heat build-up and blow out protection compared to natural rubber. Blowout protection for polyisoprene/polybutadiene blends, even though considered adequate, was considerably poorer by comparison to 100 per cent polyisoprene. Resistance to flex cracking and cut growth also favor the use of 100 per cent polyisoprene in the carcass.

Chafer and Bead Wrap Coat Stock

Polyisoprene was selected for use in the bead wrap coat. Structurally, it will be most compatible since it was selected for the carcass materials against which the bead wrap must tie in. Polybutadiene was not evaluated in this area largely because of the lack of improvements as shown in the tread and carcass evaluation. In addition to providing slightly better heat build-up and blowout protection, polyisoprene is also less scorchy than natural rubber. This becomes particularly important for compounds which must be frictioned onto the fabric. Laboratory processing and evaluation indicated that premastication of the polyisoprene will not be necessary. Natural rubber compounds require premastication to attain processing properties needed to produce a satisfactory friction material.

Bead Wire Insulation

Styrene-butadiene rubber (hot SBR) was selected as the synthetic polymer for bead wire insulation. It was pointed out earlier that SBR was found, through considerable experience, to be an accepted satisfactory polymer for application in bead wire insulation. One important reason is its excellent resistance to reversion. Considerable heat is generated in the bead area during braking. The bead wire insulation must be capable of withstanding the heat effects and at the same time afford adequate protection to adjacent bead components. Among other considerations, a good bead insulation must possess high cured hardness, have excellent adhesion to bead wire and possess a long optimum modulus plateau. The SBR chosen for bead insulation demonstrated all of these characteristics. By contrast, both natural rubber and polyisoprene were more susceptible to reversion tendencies and would not withstand brake heat as well.

Apex (Filler Compound)

Polyisoprene was selected for the filler compound. As with the other components polyisoprene was evaluated against a natural rubber control. Slightly lower heat build-up and increased blowout protection were acheived using synthetic polyisoprene.

TABLE XXXVII TREAD CARCASS FORMULATIONS

INGREDIENTS	100 RHC FORMULATIONS					
	TREAD	CARCASS				
Natsyn 400 (Polyisoprene)	100.00	100.00				
Zinc Oxide	5.00	5.00				
Stearic Acid	1.50	1.00				
HAF Black	47.00	40.00				
Pine Tar	4.00	-				
Sunpar 150	-	6.00				
Thermoflex A	1.00	1.00				
Santoflex - AW	1.50	-				
Crystex	.50	.50				
Sulfasan R	2.00	2.00				
Santocure NS	1.15	-				
Altax	-	1.25				
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	1.8	1.5				
Initial Viscosity: In.-Lbs.	28	37				
Scorch Time: Minutes	12	13				
Cure Rate: In.-Lbs./Min.	5	3.5				
Maximum Modulus: In.-Lbs.	76.5	82				
Time For Max. Modulus - Minutes	80	57				
Reversion: In.-Lbs./Min.	0	0				
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275 °F						
100% Modulus	410	410				
200% Modulus	1180	1075				
300% Modulus	2100	2000				
Tensile Strength	3775	3625				
Percent Elongation	475	450				
Shore A Durometer	64	61				
Crescent Tear - Type C	490	450				
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
19,500	.203	.168				
39,000	.344	.310				
58,500	.500	.438				
75,500	1.000	.800				
100,000		.875				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	157	143				
Temperature Rise °F	57	43				
Percent Compression Set	3.1	1.6				
HEAT BLOW-OUT: Load PSI; Stroke In.; Temperature °F						
Time	100+	100+				
Blow-Out Temperature	277	150				
Temperature Rise	177	50				
MISCELLANEOUS TESTS						
Specific Gravity	1.12	1.10				
Scorch: Minutes @ 250 °F	38	51				
Index of Abrasion	31	-				
Rebound: At R.T. °F	49	60				
Elasticity: At R.T. °F	83	82				
PLASTICITY ML 4'/212 °F	45	46				

TABLE XXXVIII BEAD WRAP COAT FORMULATIONS

INGREDIENTS	B.W.C.					
Natsyn 400 (Polyisoprene)	100.00					
RPA #6	.25					
Zinc Oxide	5.00					
Stearic Acid	1.00					
HAF Black	40.00					
Thermoflex A	1.00					
Pine Tar	4.00					
Rosin Oil	2.00					
Crystex	2.50					
Ethylac	.60					
MONSANTO RHEOMETER DATA						
Temperature: 275°F Ø	3.2					
Initial Viscosity: In.-Lbs.	30					
Scorch Time: Minutes	9					
Cure Rate: In.-Lbs./Min.	9.5					
Maximum Modulus: In.-Lbs.	70					
Time For Max. Modulus - Minutes	19					
Reversion: In.-Lbs./Min.	.14					
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	350					
200% Modulus	940					
300% Modulus	1800					
Tensile Strength	3475					
Percent Elongation	480					
Shore A Durometer	60					
Crescent Tear - Type C	410					
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
9,400	.094					
18,900	.125					
50,300	.219					
80,500	.344					
100,000	.406					
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100°F; Time 30 Min.						
Final Temperature °F	140					
Temperature Rise °F	40					
Percent Compression Set	3.1					
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	100+					
Blow-Out Temperature	155					
Temperature Rise	55					
MISCELLANEOUS TESTS						
Specific Gravity	1.11					
Scorch: Minutes @ 250 °F	36					
Plasticity ML 4'/212°F	30					
Rebound: At °F	-					
Elasticity: At °F	-					

TABLE XXXIX APEX FILLER FORMULATIONS

INGREDIENTS	APEX	TOORIC FORMULATIONS				
Natsyn 400 (Polyisoprene)	100.00					
Zinc Oxide	5.00					
Stearic Acid	1.00					
MPC Black	25.00					
SRF Black	60.00					
Picco 100	2.00					
Sunpar 150	4.00					
Rosin Oil	4.(					
Crystex	3.00					
Santocure NS	1.25					

MONSANTO RHEOMETER DATA

Temperature: 275 °F Ø	3.5					
Initial Viscosity: In.-Lbs.	40					
Scorch Time: Minutes	11					
Cure Rate: In.-Lbs./Min.	8					
Maximum Modulus: In.-Lbs.	98.5					
Time for Max. Modulus - Minutes	38					
Reversion: In.-Lbs./Min.	.34					

TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F

Optimum Cure: 30 Minutes @ 275°F						
100% Modulus	520					
200% Modulus	1425					
300% Modulus	2225					
Tensile Strength	2600					
Percent Elongation	370					
Shore A Durometer	69					
Crescent Tear - Type C	430					

CUT GROWTH: Ambient Temperature (x); At °F

Cycles		Inches of Cut Growth				
9,400	.387					
18,900	557					
30,100	.703					
40,200	.875					
50,300	1.000					

HEAT BUILD-UP: Load 175 PSI; Stroke .225 in.; Temp 100 °F; Time 30 Min.

Final Temperature °F	166					
Temperature Rise °F	66					
Percent Compression Set	4.7					

HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F

Time	100+					
Blow-Out Temperature	209					
Temperature Rise	109					

MISCELLANEOUS TESTS

Specific Gravity	1.21					
Scorch: Minutes @ 250 °F	43					
PLASTICITY ML 4'/212°F	64					
Rebound: At °F	-					
Elasticity: At °F	=					

TABLE XI. BEAD INSULATION FORMULATIONS

INGREDIENTS	100RHC FORMULATIONS					
	INSULATION					
Ameripol 1002 (Hot SBR)	100.00					
Zinc Oxide	7.50					
Stearic Acid	5.00					
FEF Black	25.00					
SRF Black	100.00					
Picco 100	3.00					
Pine Tar	5.00					
Sunpar 150	3.00					
Crystex	3.50					
Altax	1.50					
Monex	0.10					
MONSANTO RHEOMETER DATA						
Temperature: 275°F Ø	6.8					
Initial Viscosity: In.-Lbs.	36					
Scorch Time: Minutes	9					
Cure Rate: In.-Lbs./Min.	1.5					
Maximum Modulus: In.-Lbs.	99					
Time For Max. Modulus - Minutes	120					
Reversion: In.-Lbs./Min.	0					
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 60 Minutes @ 275°F						
100% Modulus	1050					
200% Modulus	1875					
300% Modulus	-					
Tensile Strength	2050					
Percent Elongation	250					
Shore A Durometer	80					
Crescent Tear - Type C	320					
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100°F; Time 30 Min.						
Final Temperature °F	249					
Temperature Rise °F	149					
Percent Compression Set	6.3					
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	8					
Blow-Out Temperature	284					
Temperature Rise	184					
MISCELLANEOUS TESTS						
Specific Gravity	1.31					
Scorch: Minutes @ 250°F	39					
Index of Abrasion						
Rebound: At °F	-					
Elasticity: At °F	-					

PLASTICITY ML 4'/212°F 62

TABLE XL (CONTINUED)

Lead Wire Adhesion (lbs/wire) @ Room Temperature Cure 50'/280°F

	Bead Insulation
	82
	62
	56
	74
	52
	54
	56
	64
	85
	68
Average (lbs/wire)	65.3

TABLE XLI INNER LINER FORMULATIONS

INGREDIENTS	LINER	100 RHC FORMULATIONS				
Natsyn 400 (Polyisoprene)	70.00					
Butyl Rubber	10.00					
Butyl Reclaim	33.30					
HAF Black	37.50					
Zinc Oxide	3.50					
Stearic Acid	1.50					
Thermoflex A	1.25					
Dioctyl Phthalate	5.00					
Crystex	2.25					
Santocure NS	1.00					
MONSANTO RHEOMETER DATA						
Temperature: 275 °F Ø	6.2					
Initial Viscosity: In.-Lbs.	37					
Scorch Time: Minutes	10.5					
Cure Rate: In.-Lbs./Min.	4.5					
Maximum Modulus: In.-Lbs.	78					
Time For Max. Modulus - Minutes	45					
Reversion: In.-Lbs./Min.	.08					
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: 30 Minutes @ 275 °F						
100% Modulus	325					
200% Modulus	750					
300% Modulus	1290					
Tensile Strength	2260					
Percent Elongation	490					
Shore A Durometer	63					
Crescent Tear - Type C	285					
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
10,000	.156					
20,000	.250					
59,000	.469					
79,000	.563					
100,000	.656					
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	186					
Temperature Rise °F	86					
Percent Compression Set	28.1					
HEAT BLOW-OUT: Load 250 PSI; Stroke .25 In.; Temperature 100 °F						
Time	17					
Blow-Out Temperature	365					
Temperature Rise	265					
MISCELLANEOUS TESTS						
Specific Gravity	1.12					
Scorch: Minutes @250 °F	47					
Index of Abrasion						
Rebound: At °F	-					
Plasticity: At °F	-					

PLASTICITY ML 4'/212°F 49

Innerliner

Polyisoprene in combination with butyl rubber and butyl reclaim was selected for the innerliner. Among the requirements necessary to produce a suitable innerliner are low air permeability, adequate compatiblity with and adhesion to the carcass component, good flexing qualities, good processing characteristics and reasonably good stress-strain properties. The butyl rubber provides for air retention. Polyisoprene provides the necessary compatibility and adhesion qualities, as well as improving the stress-strain properties. The butyl reclaim improves air retention and aids processing characteristics.

It was evident from the data that polyisoprene offered improved heat build-up and blowout, in addition to better shelf life. Liner air permeability was equivalent for the polyisoprene and natural rubber. Laboratory processing and evaluation indicated that premastication of the polyisoprene was not necessary. Natural rubber compounds require premastication to achieve processing properties needed to produce a satisfactory liner.

Summary

It is evident from data in Tasks 2 and 3, that the level of physical characteristics for each tire component is satisfactory when using polyisoprene. In the most highly critical areas such as the tread, carcass, and bead insulation, reversion tendencies are well within tolerances. Long optimum modulus plateaus are acheived. It is vitally important that these components be able to withstand the deteriorating effects of heat and remain functionally stable during the service life of the tire. Cure rates of each component are confirmed by the controls as being satisfactory relative to adjacent components during the tire vulcanization process.

The formulations selected for use in subsequent Tasks are given in Table XXVI through XXXVI, along with typical data for physical characteristics.

TASK 5: TIRE MATERIALS VULCANIZATION TIME TEMPERATURE ANALYSIS

The purpose of this Task was to determine in the laboratory the approximate vulcanization parameters that would satisfactorily cure the synthetic materials when assembled as a tire, as compared to parameters for natural rubber materials. Such determinations are necessary to properly cure simulated tire sections in Tasks 6,7,11 and in the production Tasks of this program. To accomplish this, laboratory-scale sections of a tire were assembled which were representative in gage and fabric distribution of the 30x8.8 22PR tire. Thermocouple wires were imbedded in the section at selected points (See sketches I and II) and graphs were made of the temperature rise throughout the section (see figures 4 and 5). Natural rubber materials were used for control purposes.

The simulated tire sections were fabricated using actual tire section dimensions. A typical 30x8.8 11.0(22PR, 10 actual plies)was sectioned to examine and determine gages to be used for the test articles in Phase III. The following measurements were taken:

1. Tread centerline thickness
2. Tread shoulder thickness
3. Minimum sidewall and casing thickness
4. Maximum bead area thickness

A typical 49x17 26PR tire was sectioned also. Data revealed that this casing is similar to the 30x8.8 22PR casing, except for casing thickness owing to a greater number of plies.

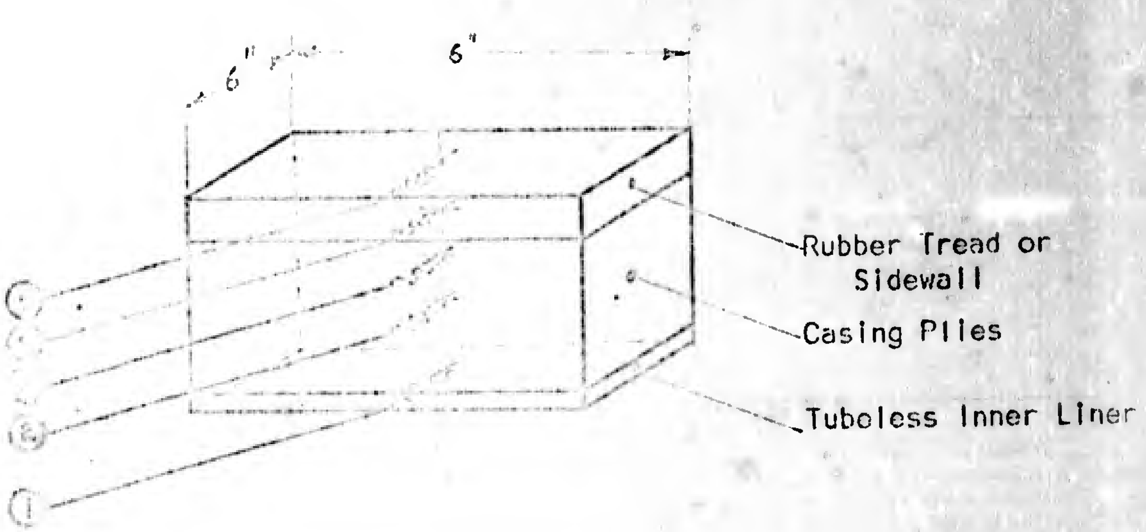
Casing and rubber samples were assembled with the thermocouple wires imbedded at strategic points within the specimen to record the temperature variations. Heat was applied from both sides of a platen press to simulate conditions for curing a new tire. One wire was positioned at the inner and at the outer surface as a control and the other wires were placed as follow:

1. The outer casing surface just under the tread or sidewall.
2. In the casing at a depth of one third of the total number of plies.
3. In the casing at a depth of two thirds of the total number of plies.

A potentiometer was used in conjunction with a five position switch box, so that the temperature readings could be taken for each of the thermocouple junctions. The temperatures were recorded for each thermocouple position at five-minute intervals. By knowing the time required for the lowest reading to reach a predetermined temperature, and considering the gradients between the other recorded temperatures, the best cure time for the combined components was approximated. A temperature of 280°F was used on the platens. A pressure of about 400 psi was induced on the specimen mold to simulate the curing pressure normally used in the actual manufacturing operation.

The recorded temperatures were converted to Cure Equivalents at 275°F, and plotted against time. The area under the resulting curve was converted to minutes of equivalent cure and compared to the optimum cure time for the particular material, as determined by the Oscillating Disk Rheometer. This comparison was used to indicate at what time a given specimen had achieved its optimum state of cure.

Based on a comparison of the time-temperature graphs for both natural and synthetic materials, the data indicated that the use of synthetic materials will require curing conditions slightly different from those currently in use for curing natural rubber tires. The difference will be in the total time required to cure the synthetic materials. Under laboratory conditions using electrically-heated platen presses rather than tire molds and steam heat, the optimum cure for the heaviest gages of synthetic material was achieved after seventy three (73) minutes. The optimum cure for the natural material was achieved after only fifty five minutes. On a basis of materials gages and cure times, the synthetic materials selected for this determination appear to require



LOCATION OF THERMOCOUPLE JUNCTIONS

(5) At Outer Surface - Control

(4) At Top Casing Ply

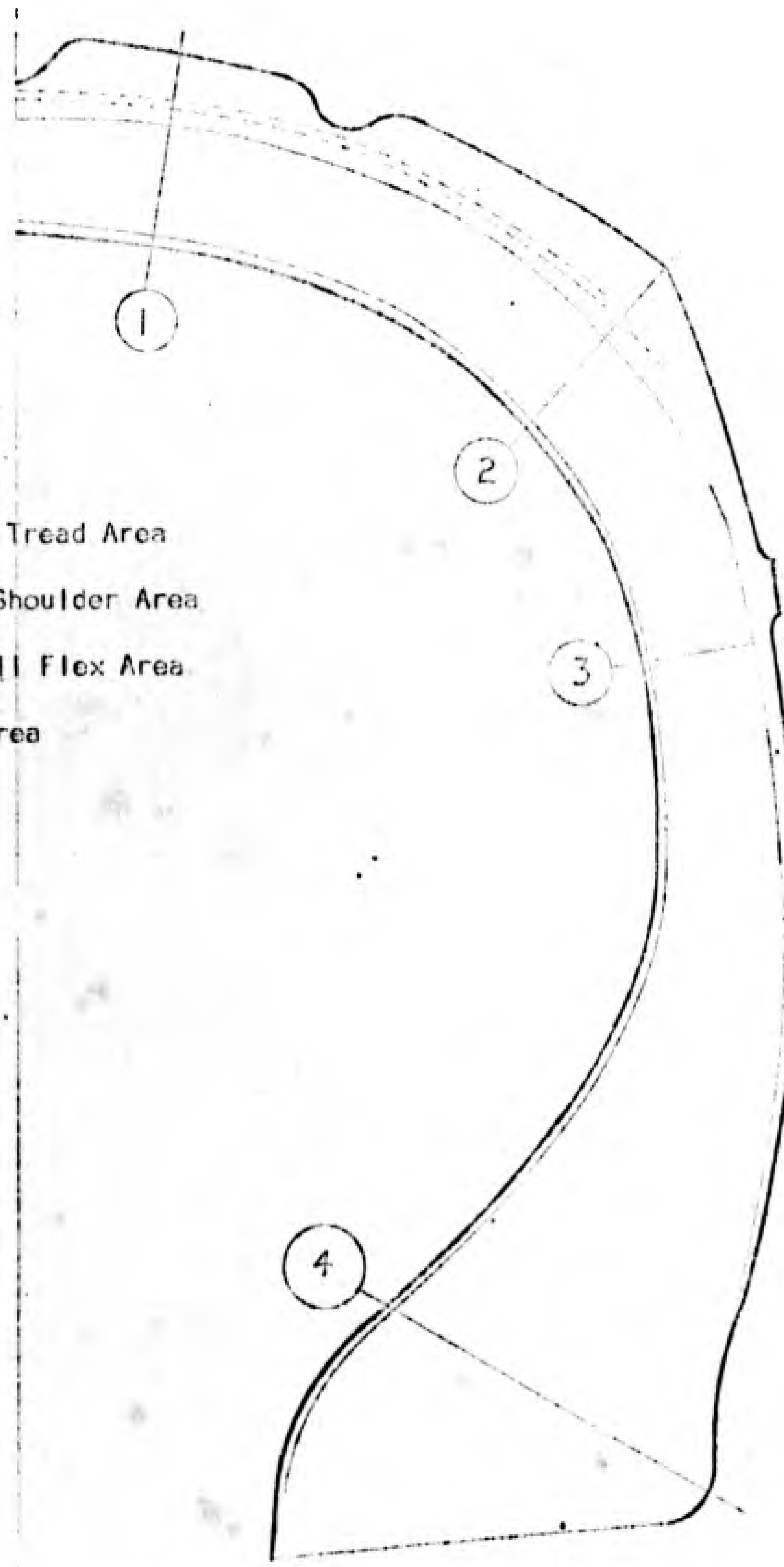
(3) At Two-Thirds of Depth of Plies

(2) At One-Third of Depth of Plies

(1) At Inside Tire Surface-Control

FIGURE 2

LOCATION OF THERMOCOUPLE JUNCTIONS



1. Normal Tread Area
2. Tread Shoulder Area
3. Sidewall Flex Area
4. Bead Area

FIGURE 3

TIRE AREAS SIMULATED FOR CURE CHECKS

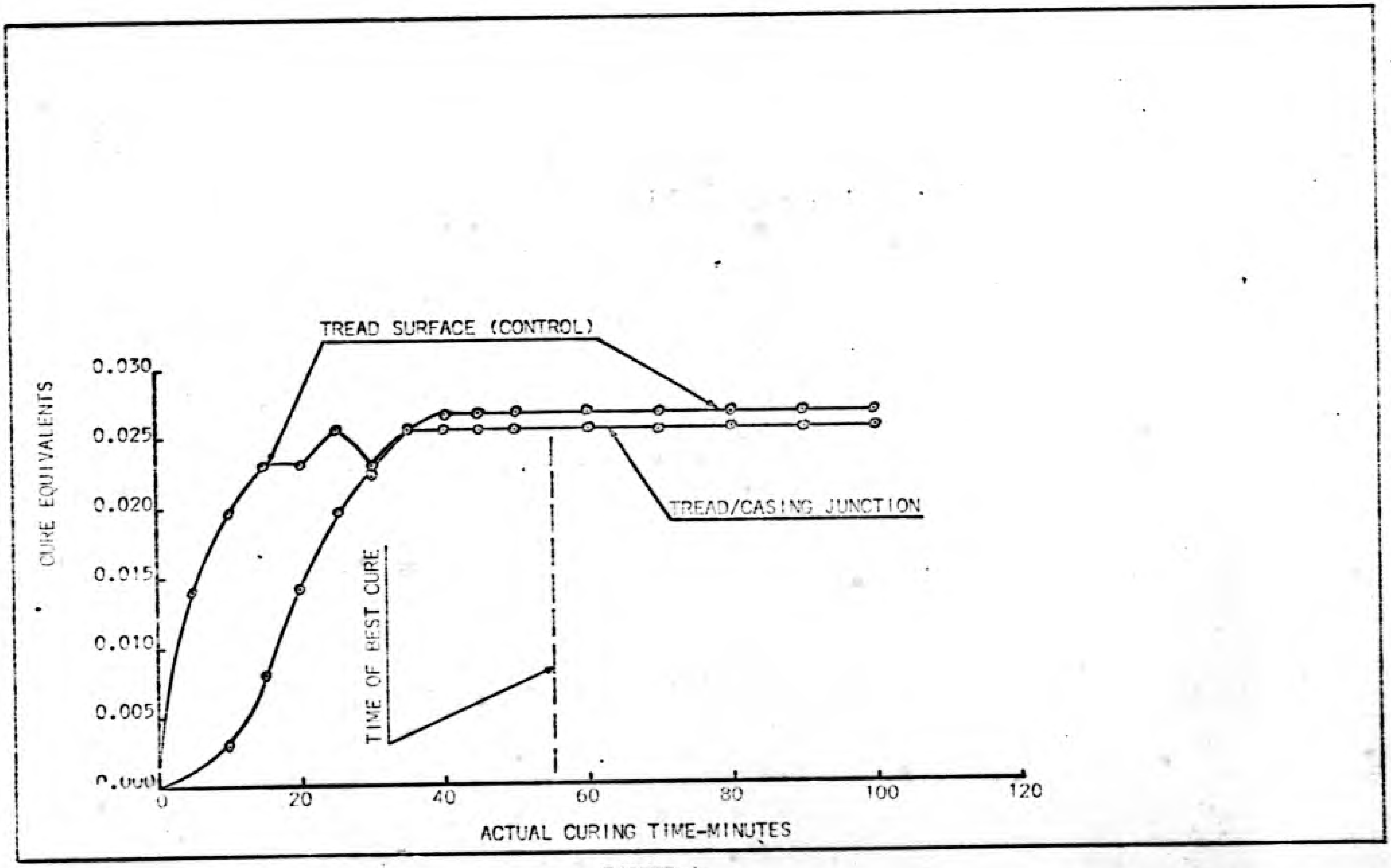


FIGURE 4

CURE ANALYSIS OF NATURAL MATERIALS

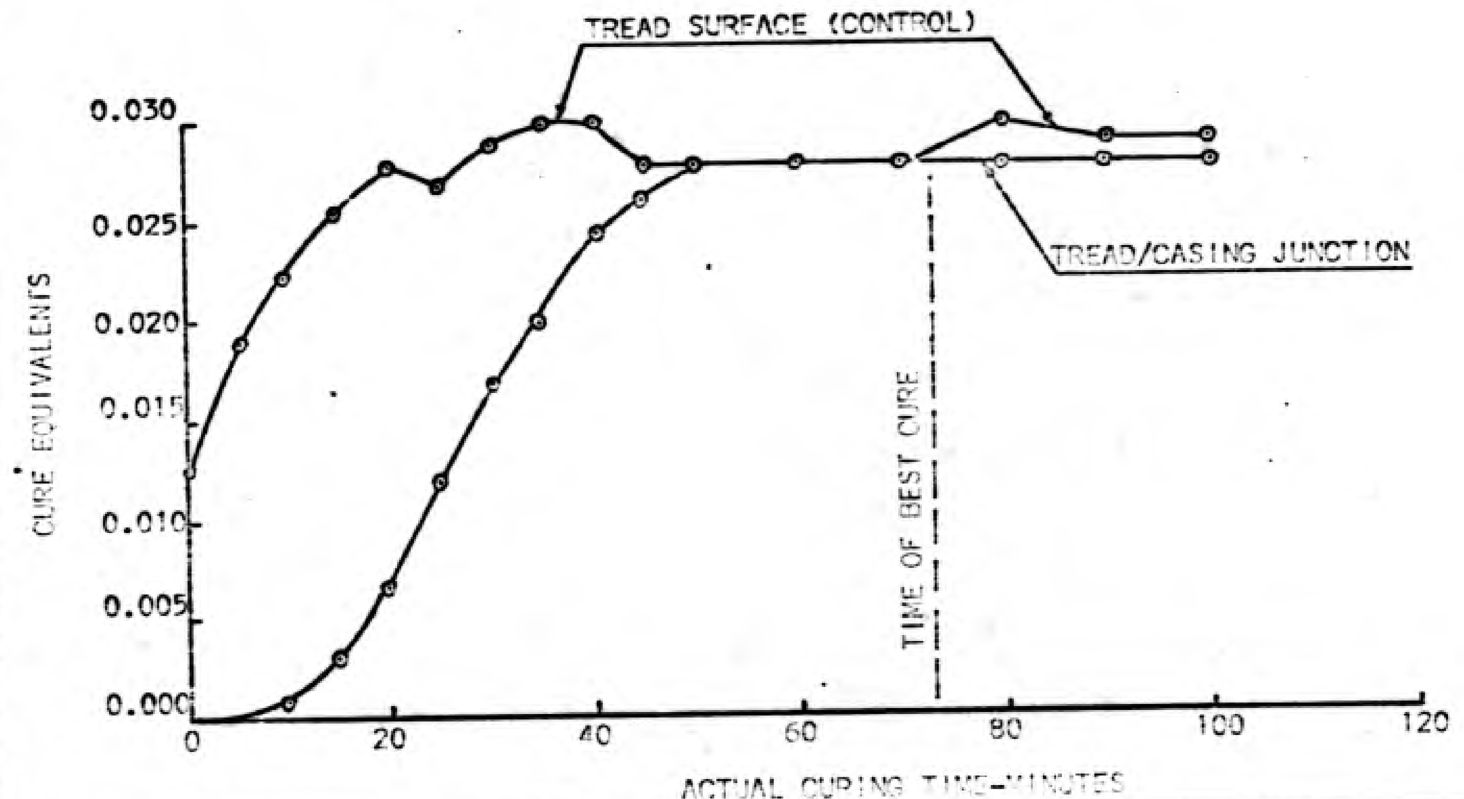


FIGURE 5

CURE ANALYSIS OF SYNTHETIC MATERIALS

TABLE XLII DATA SHEET - CURE ANALYSIS

ACTUAL CURE TIME (MINUTES)	RECORDED TEMPERATURES							
	SYNTHETIC MATERIAL				NATURAL MATERIAL			
	TREAD SURFACE (CONTROL)		TREAD CASING JUNCTION		TREAD SURFACE (CONTROL)		TREAD CASING JUNCTION	
	°F	CE*	°F	CE*	°F	CE*	°F	CE*
0	262	.0123	100	-	262	.0123	108	-
5	273	.0192	149	-	266	.0144	152	-
10	276	.0216	196	.00084	274	.0199	226	.00285
15	280	.0256	228	.00306	278	.0233	252	.00820
20	282	.0278	247	.00667	278	.0233	266	.0144
25	281	.0267	261	.0118	280	.0256	274	.0199
30	283	.0288	270	.0171	278	.0233	277	.0224
35	284	.0299	274	.0199	280	.0256	280	.0256
40	284	.0299	279	.0245	281	.0267	281	.0267
45	282	.0278	280	.0256	281	.0267	281	.0267
50	282	.0278	282	.0278	282	.0278	281	.0267
60	282	.0278	282	.0278	282	.0278	281	.0267
70	284	.0278	282	.0278	280	.0256	281	.0267
80	283	.0299	282	.0278	280	.0256	281	.0267
90	283	.0288	282	.0278	280	.0256	281	.0267
100	283	.0288	282	.0278	280	.0256	281	.0267

* Cure Equivalents

COMPARISON OF GAGES

LOCATION	ACTUAL TIRE	SIMULATED SAMPLES	
		NATURAL	SYNTHETIC
TREAD AT SHOULDER	0.48	0.40	0.55
CASING AT SHOULDER	0.43	0.40	0.43
INNER LINER	0.08	0.10	0.08
TOTAL AT SHOULDER	0.99	.90	1.06

RATIO OF GAGES - $\frac{\text{SYNTHETIC}}{\text{NATURAL}} = \frac{1.06}{90} = 1.18$

RATIO OF CURES - $\frac{\text{SYNTHETIC}}{\text{NATURAL}} = \frac{73}{55} = 1.33$

RATIO OF CURES ADJUSTED BY GAGES $= \frac{133}{118} = 1.12$

about 12% longer actual curing time to achieve optimum cure. The precise time-temperature combination required for curing new tires in factory tire molds will be further studied in Phase III by conducting similar evaluations on check tires. The trends noted for curing times for simulated 30x8.8 22PR casing sections will be true for similar 49x17 26PR casing sections as well.

TASK 6: OPERATIONAL ADHESION TESTS

The various tire components outlined in Task 5 were assembled and subjected to adhesion tests in this Task, both in the unvulcanized and vulcanized states. The unvulcanized materials were evaluated at ambient conditions while the vulcanized materials were tested both at ambient and at elevated (212°F) temperatures. The adhesion values noted are in pounds of adhesion for a one inch-wide by six inches long strip of the test section.

Unvulcanized Materials Evaluation

The unvulcanized components were evaluated for adhesion at ambient conditions to simulate conditions encountered during the tire building operations. Results for synthetic and natural rubber materials were approximately equal, except for intracarcass adhesion values. Here polyisoprene had lower adhesion. However, the value obtained was considered more than adequate in view of the lower but comparable green adhesion values observed for each material in the evaluation of the other tire components. Physical data covering the uncured adhesions are tabulated in Table XLIII.

Vulcanized Materials Evaluation

The adhesion data for the vulcanized components at ambient and at simulated tire operational temperature (212°F) are tabulated in Tables XLIV and XLV. In general, the data showed that tire elements made of polyisoprene have the same bond strengths as those made of natural rubber. Throughout the adhesion work, polyisoprene-coated fabrics compared quite favorably to similar components using natural rubber at ambient and high temperature conditions. The level of adhesion for each was reduced by about the same degree at elevated temperature. The data lend further support to the possibility of replacing natural rubber with polyisoprene in aircraft tires.

Distinct differences in the adhesion level existed between the various tire components for both types of elastomers. This was found to be inherent in the original construction of the various components. Each tire component is designed to perform a specific function in the tire. The fabric/rubber relationship is controlled by this. The thinner the rubber coating on fabric, all else being equal, the lower are the adhesion values generally observed and the greater likelihood that failure will occur at the rubber/fabric interface.

For example, a low level of adhesion is always observed with a frictioned fabric such as bead wrap, where the outer fabric surface has minimal rubber coating. By comparison, a carcass fabric has much higher adhesion owing to a skim coat of definite gauge purposely applied to insure adequate insulation of cords (strength members) from one another during the service life of a tire.

TABLE XLIII UNCURED ADHESION EVALUATION - ROOM TEMPERATURE

Construction	Adhesion Values, lbs per inch width	Average
1. Synthetic Material		
Bead Wrap/Bead Wrap	2.0, 1.9, 2.1	2.0 ppi
Chafer/Chafer	3.7, 3.7, 3.8	3.7 ppi
Bead Wrap/Chafer	3.6, 4.0, 3.9	3.8 ppi
1260/2 Nylon Cord		
Bead Wrap/Carcass	2.5, 2.6, 2.6	2.6 ppi
Chafer/Carcass	7.2, 6.7, 6.9	6.9 ppi
Carcass/Carcass	4.7, 4.2, 4.5	4.5 ppi
840/2 Nylon Cord		
Bead Wrap/Carcass	3.1, 2.0, 2.7	2.6 ppi
Chafer/Carcass	4.0, 4.5, 4.3	4.3 ppi
Carcass/Carcass	6.8, 9.1, 7.9	8.0 ppi
2. Natural Rubber Material		
1260/2 Nylon Cord		
Bead Wrap/Carcass	2.3, 2.5, 2.4	2.4 ppi
Carcass/Carcass	14.6, 13.7, 13.3	13.9 ppi
Chafer/Carcass	4.5, 3.9, 4.7	4.4 ppi
840/2 Nylon Cord		
Bead Wrap Carcass	1.8, 1.8, 1.9	1.8 ppi
Carcass/Carcass	13.2, 11.7, 12.5	12.5 ppi
Chafer/Carcass	3.6, 3.7, 3.7	3.7 ppi

TABLE XLIV CURED ADHESION EVALUATION

Constructions	Ambient Adhesion Values	Ambient AVG.	212°F Adhesion Values	212°F AVG.
1. Synthetic Material				
Bead Wrap/Bead Wrap	16.0, 17.5, 17.0	16.8 ppi	13.0, 13.5, 13.4	13.3 ppi
Bead Wrap/Chafer	19.8, 21.2, 23.0	21.3 ppi	13.0, 14.5, 15.0	14.2 ppi
Chafer/Chafer	35.5, 36.0, 31.8	34.4 ppi	30.0, 32.5, 31.0	31.2 ppi
840/2 Nylon Cord				
Bead Wrap/Carcass	19.7, 19.8, 18.3	19.3 ppi	14.8, 15.1, 14.8	14.9 ppi
Chafer/Carcass	36, 43.5, 41.5	40.3 ppi	27.0, 31.0, 29.5	29.2 ppi
Carcass/Carcass	47.2, 46.5, 48.8	47.5 ppi	35.4, 34.5, 35.5	35.1 ppi
1260/2 Nylon Cord				
Bead Wrap/Carcass	19.5, 20.6, 19.0	19.7 ppi	16.6, 17.1, 16.8	16.8 ppi
Chafer/Carcass	42.3, 43, 37	40.4 ppi	29.0, 29.0, 30.0	29.3 ppi
Carcass/Carcass	39.6, 39.6, 43.4	40.9 ppi	33.7, 32.7, 35.4	33.9 ppi
Bead Wrap/Liner	20.0, 22.8, 27.5	23.4 ppi	11.0, 11.5, 12.0	11.5 ppi
Carcass (840/2) Liner	42.3, 60.0, 75	59.1 ppi	30.0, 32.5, 34.8	32.4 ppi
Carcass (1260/2) Liner	45.3, 51.5, 51.0	49.3 ppi	32.8, 31.5	32.1 ppi
2. Natural Rubber Material				
Bead Wrap/Liner	23.0, 25.0, 24.5	24.2 ppi	14.7, 15.6, 13.8	14.7 ppi
Bead Wrap/Carcass (840/2)	20.1, 20.7, 23.7	21.5 ppi	14.5, 15.0, 16.0	15.2 ppi
Chafer/Carcass (840/2)	41.0, 39.0, 50.3	43.4 ppi	33.5, 30.5, 28.5	30.8 ppi
Carcass (840/2) Liner	55, 62, 68	62 ppi	31.5, 30.5	31.0 ppi

TABLE 3: Cured Adhesion Evaluation

Constructions	Ambient Adhesion Values	Ambient AVG.	212°F Adhesion Values	212°F AVG.
1. Synthetic Materials				
Tread/Carcass	60.7, 112.0	81.3 ppi	70.5, 73.0	71.7 ppi
Carcass/Carcass	39.0, 61.8	50.4 ppi	23.5, 29.0	26.2 ppi
Bead Wrap/Carcass	20.0, 18.0	19.0 ppi	14.0, 15.0	14.5 ppi
Chafer/Carcass	51.0, 55.1	53.1 ppi	33.0, 33.0	33.0 ppi
Chafer/Chafer	53.5, 43.5	48.5 ppi	45.0, 30.0	37.5 ppi
Bead Wrap/Bead Wrap	32.0, 23.0	27.5 ppi	16.0, 18.0	17.0 ppi
2. Natural Rubber Materials				
Tread/Carcass	79.4, 112	95.7 ppi	68.0, 84.0	76.0 ppi
Carcass/Carcass	52.0, 48.0	50.0 ppi	38.0, 29.0	33.5 ppi
Bead Wrap/Carcass	31.0, 34.0	32.5 ppi	15.0, 15.0	15.0 ppi
Chafer/Carcass	53.3, 37.7	45.5 ppi	34.0, 36.0	35.0 ppi

NOTE: All test samples were obtained from simulated tire sections and were tested in the form of one inch wide strips.

TASK 7: EVALUATION OF RETREADABILITY OF SYNTHETIC RUBBER AIRCRAFT TIRES

This Task was performed to evaluate the retreadability of synthetic rubber aircraft tires. In the evaluation program, specimens were made up of laminations of fabric and rubber to the approximate gages, cord angles and distribution of materials as found in new tires. Both natural and synthetic specimens were tested to obtain a comparison. The specimens were cured in special molds simulating new tire and retread tire tread patterns. The vulcanization temperature and pressure were controlled to simulate new tire or retread curing conditions.

The specimens were cut into one inch-wide strips, and subjected to the tests outlined below. The De Mattia Flexometer was used to flex a segment of the strip through an angle of 30°, for 50,000 flexes. The tread material was then buffed off the casing, new Thompson Military High Speed Tread rubber was applied, and the strips were cured to the original gages. The samples were then flexed again.

After each stage of flexing, adhesion values were determined for the tread-to buff surface and compared with similar tests for natural rubber strips. Test results indicated that the adhesion of the retread material to the synthetic buffed surface was comparable to that of the natural rubber buffed surface. All readings were somewhat lower for synthetic polyisoprene than for natural rubber, however, in no case did the synthetic rubber specimens show any signs of deterioration or incompatability at the buff surface. The failure in these test strip always tended to imigrate toward the fabric ply.

<u>Adhesion of Tread to Buff Surface</u>

	MATERIAL	
Flex Life Status	Synthetic	Natural
After Flexing, Before Retreading	124-128 ppi Avg 126 ppi (Failed Below Buff)	166-190 ppi Avg 178 ppi (Failed Below Buff)
After Retreading and Flexing	112-148 ppi Avg 130 ppi (Failed Below Buff)	164-174 ppi Avg 169 ppi (Failed Below Buff)

Based on these preliminary tests it appears that the inherent cool-running characteristic of the synthetic rubber, illustrated in Tasks 1-3, will be beneficial to operational service, and that successive retreading with existing retread materials will be possible. Field service evaluation tests with actual tires will be necessary to make the final determination.

TASK 8: REINFORCING MATERIALS COMPATIBILITY AND ADHESION TESTS

Tests have been conducted to determine the level of adhesion between textile and metallic tread reinforcing type materials and candidate synthetic rubber materials, and the degree of compatibility between these materials. A natural rubber compound was used as the control. The textile evaluation was made at ambient and at elevated temperatures, using 1260/2 and 840/2 nylon cord. The evaluation using fine brass-coated wire was conducted at ambient temperature. H-block type tests were performed with the textile cords. A similar type test was used to determine the adhesion to the fine brass-coated wire.

The results showed good agreement between the degree of adhesion to textile cord obtained with polyisoprene and with natural rubber tread compound materials. A slightly lower level of adhesion is observed for both elastomers for the 840/2 cord (.022 ga.) as compared to the 1260/2 nylon cord (.026 ga.). This difference was attributed to the lower cord surface area available with the 840/2 nylon, since both cords are composed of the same nylon filaments but to a different overall cord denier size.

An appreciably lower level of adhesion to brass-coated wire (.020 ga.) was observed for both polyisoprene and natural rubber tread compounds. Significant differences between the wire and cord construction are believed to account in large measure for the adhesion differences noted. The wire is a single filament construction, brass-coated to provide chemical bonding between the copper in the brass coat and sulfur in the rubber compound. Each nylon cord is composed of many fine nylon monofilaments (140/ply) twisted together to form a cable construction, two such cables being twisted together to form the cord. The cord is then dipped with an adhesive to improve the adhesion (chemical bonding) to the rubber compound. In addition, a certain degree of mechanical bonding is inherent in the cord make-up which can be expected to compliment that already available through the adhesive coating.

The data, tabulated in Table XLV, indicated that polyisoprene was equally as compatible as natural rubber for a bonding medium to tread reinforcement-type materials at ambient and at high temperature (212°F) conditions. Polyisoprene was equivalent to natural rubber with respect to adhesion to fine brass-coated wire.

TABLE XLV ADHESION OF REINFORCING TYPE MATERIALS TO NATURAL AND SYNTHETIC TREADS

A. H-Block Cord Adhesion (lbs/cord)

Construction	Ambient		212°F	
	Adhesion (lbs/cord)	AVG.	Adhesion (lbs/cord)	AVG.
Natural, 1260/2 Nylon	18.6, 17.2 13.2, 13.8	15.6 lb	14.4, 11.2 11.7, 13.8 12.5	12.7 lb
Synthetic, 1260/2 Nylon	10.4, 13.4 16.5, 15.8 16.1	14.4 lb	14.2, 10.2 9.3, 11.7 12.2	11.5 lb
Natural, 840/2 Nylon	13.7, 11.6 10.0, 9.4 10.6	11.1 lb	11.8, 9.0 9.2, 12.0	10.5 lb
Synthetic, 840/2 Nylon	11.6, 11.5 16.0, 14.8 12.0	13.2 lb	11.8, 11.8 10.6, 12.2 9.5, 10.0	11.0 lb

B. Wire Adhesion (lbs/wire)

Ambient Conditions

Construction	Pulls (lbs/wire)	AVG.
Natural, Wire	4.0, 3.5, 4.0 6.0, 3.5	4.3 lb
Synthetic, Wire	2.5, 5.5, 3.5 7.5, 7.5	5.3 lb

TASK 9: FINAL SYNTHETIC ELASTOMERS REVIEW

All data obtained in previous Tasks were objectively reviewed. Selections were made of the best synthetic elastomer or blends of synthetic elastomers for use in each of the several components of aircraft tires. The selections are indicated in the table below.

Specific formulations are shown in Task 4, Tables XXVI through XXXVI. The test results obtained in Tasks 5 through 8 indicated that the materials selected in Task 4 were satisfactory with respect to:

1. Tire integrity as measured by the adhesion of adjacent components.
2. Retreadability of the casing/tread assembly.
3. Compatibility with and adhesion to reinforcing members.

Synthetic Elastomers Selection for Tire Components

Component	Synthetic Elastomers Selection
Tread	Polyisoprene (Natsyn 400, Goodyear)
Sidewall	Polyisoprene (Natsyn 400)
Carcass	Polyisoprene (Natsyn 400)
Bead Wrap Coat	Polyisoprene (Natsyn 400)
Apex	Polyisoprene (Natsyn 400)
Bead Insulation	Hot Process SBR (Ameripol 1002, Goodrich-Gulf)
Innerliner	Polyisoprene/Butyl Blend (Natsyn 400; Butyl 268, Enjay)

TASK 10: EVALUATION OF TIRE CONSTRUCTION PARAMETERS

A comprehensive analysis has been made in detail of the tire design parameters required in the manufacture of 49x17 26PR and of 30[illegible].8 22PR aircraft tires. The following parameters were included in this ana[illegible]s:

1. Textile evaluation
2. Tire design evaluation
3. Tread components

Each parameter was studied with respect to the optimization of operational characteristics when using the synthetic materials developed and evaluated in previous Tasks.

The analysis results are tabulated in Tables LV through LXIV in Appendix I. These Tables are representative of Tire Construction Specifications. Tables LV through LIX will be considered as Design A in the manufacture of 30x8.8 22PR tires in Phase III. The design for the subcontractor's currently qualified tire will be used as Design B for this tire size, owing to differences in cord size, number of plies, and probable differences in cord angles. The subcontractor's design is proprietary and thus is not presented in this report.

Tables LX through LXIV will be considered as Design A in the manufacture of 49x17 26PR tires in Phase III. The design for the subcontractor's currently qualified 49x17 26PR tire will be used as Design B for this tire size, for the same reasons stated above.

Textile Evaluation

Tire cord adhesion characteristics are similar for polyisoprene and natural rubber. Therefore, no change will be needed in cord twist, treatment or tension. For Design B tires, the size of cord, and the mill end count per inch will be the same as is now specified by the subcontractor. Design A tire will be as shown in Tables LV and LX in Appendix I.

Tire Design Evaluation

The most significant tire construction parameter subjected to analysis in this Task was the basic design of the two synthetic elastomer tires to be manufactured in Phase III. MIL-T-5041D establishes a framework of limitations for tire weights, dimensions, loads, inflation pressures, and rim sizes. Within this framework, the engineer determines the tire design for two broad areas:

1. Carcass Strength
2. Bead Strength

Several sizes of carcass strength members (tire cords) are now available to the tire engineer. Thus more than one design may result for one tire size. This was found to be true from an analysis of current USAF tires of one size but of different brands. The tire design analysis accomplished in this Task included two sizes of tire cords, the small nylon cord (840/2) currently used by the subcontractor and a larger nylon cord (1260/2) which appears in Table LV through LXIV in the Appendix.

The characteristics of synthetic polyisoprene were reviewed with respect to their contribution to improved tire design. Results of this review indicated that either cord size would be suitable for use with polyisoprene. Also, polyisoprene had certain inherent characteristics which would offer potential operational improvements to both Design A and Design B for each tire size.

For instance the heat build-up characteristic for polyisoprene was found to be better than that for natural rubber. Thus it should be possible to increase somewhat the insulation (rubber layer) between successive tire carcass plies when using polyisoprene, without increasing tire running temperatures. Such changes as this have been included in Design A for each tire size.

Other tire design considerations were altered similarly, and are shown in detail in Design A (See Appendix I., Tables LV through LXIV. Only bead strength members (high tensile steel wire) will be the same for both tire designs for each tire size.

Tread Components

Tire tread components for the two sizes of tires to be manufactured currently include abrasion-resistant rubber materials, nylon cord tread reinforcing materials, and cut resistance additives. Data from earlier Tasks indicated that adhesion of synthetic polyisoprene to both nylon cord and brass plated wire was essentially equal to that of natural rubber. Therefore, it is anticipated that no change in tread component design will be required when using synthetic polyisoprene in place of natural rubber in tire treads. The tread design parameters in current use by the subcontractor will be used for both Designs A and B for each tire size.

Summary

The analysis of tire construction parameters has resulted in two optimized designs for the synthetic polyisoprene tires to be manufactured in Phase III. These designs are given below. The basis for the design engineering has been the inherent improved physical properties exhibited by polyisoprene.

Tire Size	AF Drawing	Design	Reference
30x8.8 22PR	60D90767	A	Figures 1-5, Appendix
		B	Subcontractor, Proprietary Information
49x17 26PR	60D2561	A	Figures 6-10, Appendix
		B	Subcontractor, Proprietary Information

TASK II: EVALUATION OF CORD/CONSTRUCTION PARAMETERS

In this Task, an evaluation was made of the performance characteristics of 1260/2 nylon fabric cords in a simulated tire casing of polyisoprene rubber, as compared to the same configuration using natural rubber. This fabric was selected because it has the highest strength-to-size ratio, allowing the use of fewer plies in conventional design configuration. Also, this is the fabric thought to be used in some of the currently qualified USAF 30x8.8 22PR tires.

In this evaluation, laboratory-scale blocks were assembled which simulated the construction of actual 30x8.8 22PR tire casings. The body of the tire was simulated using fabric of cord size, cord angle and cord distribution as found in the casing crown area. Rubber gages were controlled to simulate tread shoulders, sidewalls and tubeless innerliners..

After curing the 6"x6" square blocks, 1" wide strips were cut from these blocks and subjected to two series of tests. One test consisted of flexing the strip for 50,000 cycles at 212°F through an angle of about 70° and then making adhesion tests on two areas of the sample strips. The results of this test are shown in Table XLVI.

TABLE XLVI AVERAGE ADHESION STRENGTH

Strip Adhesion Location	Synthetic	Natural
Tread to Casing	128 ppi	190 ppi
Sidewall to Casing	23 ppi	43 ppi

The second series of tests consisted of heat aging the various specimen strips at 250°F for varying periods of time, and then making strip adhesion tests on two areas of these samples. Average results are shown in Table XLVII.

TABLE XLVII . AVERAGE ADHESION STRENGTH

	Material	Tire Component	Aging Time	Adhesion, ppi
1.	Natural	Sidewall to Casing	4 hours	96
			12 hours	72
			24 hours	57
2.	Natural	Tread to Casing	4 hours	166
			12 hours	164
			24 hours	98
3.	Synthetic	Sidewall to Casing	4 hours	70
			12 hours	65
			24 hours	50
4.	Synthetic	Tread to Casing	4 hours	124
			12 hours	120
			24 hours	90

Based on the comparisons noted above, the data indicated that the synthetic elastomer tire will probably be less affected by heat and flexing than would a similar natural rubber tire. Although the adhesion values are lower for synthetic materials, deterioration of adhesion appears to be reduced compared to the natural rubber controls.

TASK 12: STUDY OF TREAD DESIGN

In this Task, an investigation was made of the suitability of synthetic elastomers for use in aircraft tire tread materials. The following considerations were included in this investigation:

1. Coefficient of Friction
2. Abrasion Resistance
3. Operational Temperatures
4. Retreadability

A single tread pattern was used, so that the only variables would be the characteristics of the synthetic polyisoprene compared to the characteristics of natural rubber. The discussion follows for each of the four parameters noted above.

Coefficient of Friction

The coefficient of friction between rubber compounds and runway surfaces is affected both by the hardness of the compound, and by the dryness of the runway. Soft compounds have greater traction on dry runways, while hard compounds have greater traction on wet runways. The best hardness for a given compound will give suitable traction on both surface conditions, with a small emphasis favoring adequate safety of operation on wet surfaces.

The carbon black in tread materials is the main ingredient which influences tread hardness. The synthetic elastomer selected in Task 9 for use in treads has suitable hardness using the amounts of carbon black desirable for characteristics such as wear. Other compounding techniques such as addition of plasticizer can be employed to obtain the same range of hardness as natural rubber, without altering important characteristics such as wear. Thus the overall coefficient of friction for the synthetic elastomer tread materials should be equal to that for natural rubber tread materials, since tread hardness was found to be equal.

Abrasion Resistance

The abrasion resistance of a material is an indication of the wear quality of the tire in service. Wear is defined as the loss of material by abrasion. In a tread, abrasion is depenent on two predominant mechanisms. A mechanical erosion occurs, by cutting or chipping away minute parts of the tread surface during contact with the rough runway surface. Secondly, a chemical mechanism termed oxidation or pyrolysis (reversion) occurs, in which a layer of rubber is degraded to such an extent that the material can be very easily removed by mechanical means.

Mechanical erosion takes place on the tread surface of a tire as it moves through the footprint, and is related to the motion of the ribs, which appear to squirm from side to side as the load is applied and released. This is a characteristic of conventional bias-ply contruction tires.

The relative motion of the tread surface and the ground surface is increased by skidding, as when the brakes lock, side slipping or yaw of the aircraft as when the aircraft is landed in cross winds, and rapid changes in the deflection of the tire as when the tire rolls over successive surfaces of different elevations in take off and landing.

The chemical mechanism usually occurs in the presence of heat. For instance, in a severe skid the rubber becomes so hot that the surface layer is pyrolyzed to a semi-liquid state which is deposited on the runway. In any service some heat is generated and could begin to deteriorate the tread rubber if the compound was not thermally stable.

The two characteristics of hardness and heat build-up are of concern in the formulation of the tread rubber. Hard materials are found to resist mechanical erosion better than soft materials. Cooler running materials have a lower tendency toward reversion. It was found in previous Tasks that synthetic polyisoprene can be formulated to display hardness and abrasion resistance characteristics equal to natural rubber. Polyisoprene's resistance to heat failure was found to be as good as or better than that of natural rubber.

Operating Temperatures

The vulcanizate properties of elastomers will vary with temperature changes. Each elastomer has a rather definite temperature range in which it displays certain optimum characteristics. As the temperature is varied above or below this range, the vulcanizate characteristics may change significantly. In the high end of the temperature range, both tensile strength and elongation characteristics deteriorate, and the elastomer becomes more plastic and less elastic. At very high temperatures, or for long periods of time at less extreme temperatures, thermal decomposition may occur, resulting in permanent loss of the original vulcanizate characteristics. In an aircraft tire, heat generation and heat build-up are critical.

Materials are designed to operate under these severe conditions. The heat resistance of the synthetic elastomer and the tensile strength and elongation characteristics at elevated temperatures have been found to be satisfactory as compared to natural rubber. Also, low temperature flexibility of the synthetic elastomer is equivalent to that of natural rubber. It is expected that no operational problems related to operating temperatures will be encountered through the use of synthetic polyisoprene in place of natural rubber in aircraft tires.

Retreadability

For a tire to be considered retreadable, it must retain certain characteristics of strength and integrity beyond the life of the first and successive treads. After being buffed properly, the casing must present a surface of rubber undertread acceptable as a base for a new tread. This undertread is the lower portion of the preceding tread. As was previously discussed, extreme operating temperatures can cause a progressive deterioration of casing rubber, which at some point will be severe enough to cause the tire to be rejected. In addition, the cures involved in the molding of the new tire and of successive retreads must be properly controlled. The elastomers used in the original tread and casing must have the ability to accept these subsequent cures without becoming deteriorated. Also, the elastomers used in the retread rubber must be curable at a temperature low enough to avoid deterioration of the casing rubber. Thus, these materials must be matched with respect to their sensitivity to temperature.

In addition, the casing must be free of any serious defects such as skid burns, and must have sufficient rubber material covering the cords after buffing to present an acceptable base to which the new tread can be bonded. There must be no sign of reversion of the cushion, nor tendency toward oxidation or aging.

Heat aging characteristics of the synthetic elastomers selected for tread and casing material compare very favorably with natural rubber. The synthetic elastomer may be used in the same manner as natural rubber for casing materials, and will provide good retreadability in all aspects noted above.

The conclusion from this study is that synthetic polyisoprene will perform equally as well as natural rubber with respect to the four parameters of tread design listed. Considerations used in selecting the best tread design for natural rubber tread materials will be applicable directly when designing tread patterns for synthetic polyisoprene materials.

TASK 13: FABRICATION OF LABORATORY PILOT TREADS

This Task involved the preparation of laboratory-scale tire tread molds, and the fabrication of synthetic polyisoprene tread sections using these molds. The tread sections were tested to determine characteristics of cut resistance, coefficient of friction, abrasion and skid resistance, adhesion of laminated materials, and resistance of the section to flexing deterioration, heat deterioration, cord breakage and cord plucking. Identical sections were fabricated of natural rubber materials, for use as controls in evaluating each of the characteristics noted above.

It was decided to use a tread design simulating the current 49x17 tread design of the subcontractor. This design included the standard 0.30 inch groove depth. Groove spacing similar to that used by the subcontractor was used in fabricating the tread molds, since the subcontractor's current 49x17 tire is excellent with respect to the various tread design parameters as discussed in Task 14. It was decided to make the tread ribs slightly wider and the grooves slightly more narrow than those of the subcontractor's tire, to provide more significant observations on cord plucking and breakage during flexing. The final design is shown in Table LV.

The tread specimens were prepared from natural rubber and the synthetic polyisoprene tread materials, using two plies of 1260/2 nylon cord as the tread reinforcing medium. A cord angle of 30° from the groove was used. The sections were vulcanized using time-temperature parameters established in Task 5.

Observations were made during the fabrication, molding and testing of these specimens. These observations are shown in Table XLVIII. They indicate that synthetic polyisoprene tread materials will probably have equivalent overall performance characteristics compared to natural rubber tread materials. In the significant performance parameters of abrasion and flex resistance, the two elastomers are equal in performance.

TABLE XLVIII LABORATORY PILOT TREADS TESTING

TEST	OBSERVED RESULTS	
	SYNTHETIC POLYISOPRENE	NATURAL RUBBER
1. Ballistic Cut Resistance, Depth of Penetration, In.	0.32	0.29
2. Coefficient of Friction	0.54	0.52
3. Molding Ease	Excellent	Excellent
4. Abrasion Resistance, Index	104	107
5. Skid Resistance	0.54	0.52
6. Flexing Resistance	Excellent no separations	Excellent no separations
7. Adhesion of Laminations	Excellent no separations	Excellent no separations
8. Resistance to Heat Deterioration	Excellent no deterioration	Excellent no deterioration
9. Resistance to Cord Plucking	Excellent	Excellent
10. Resistance to Cord Breakage	Excellent	Excellent

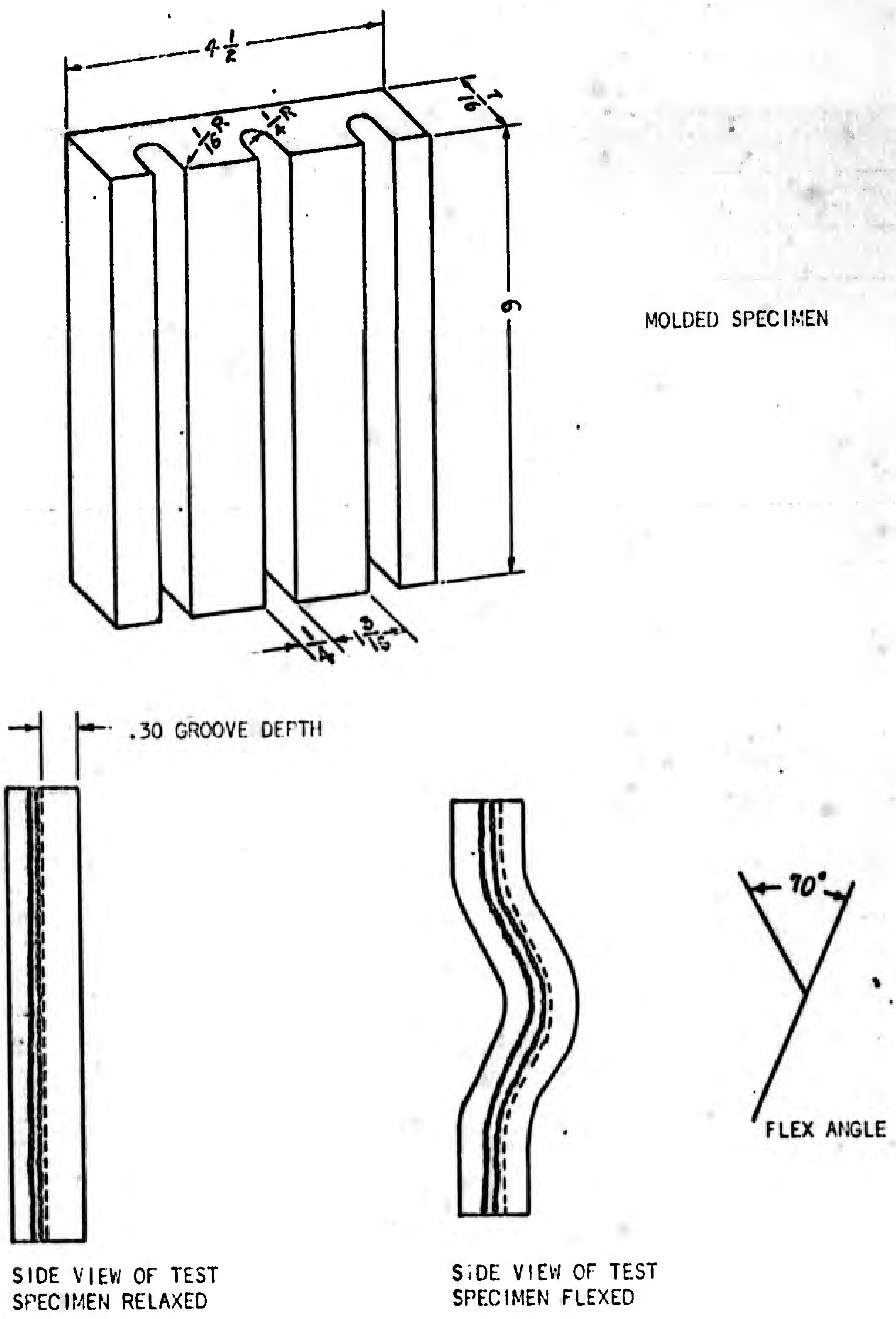


FIGURE 6

MOLDED SPECIMEN

TASK 14: PILOT TREADS EVALUATION

A comparative evaluation was made of the results of tests performed on laboratory-scale tread specimens prepared in Task 13. The following table presents the comparison of synthetic polyisoprene with natural rubber control materials as used in laboratory-scale tread segments and subjected to static and dynamic testing under simulated operational conditions. Comparisons are made on the basis of test results and observations made during the preparation and testing of these specimens.

	CATEGORY	COMPARISON RATING	COMMENTS
1.	Building Tack	Equal	Other tests show natural rubber slightly superior
2.	Green Strength	Equal	Other tests show natural rubber slightly superior
3.	Molding Ease	Equal	No apparent difference
4.	Adhesion Strength	Poorer	Natural rubber slightly superior, but not as resistant to deterioration
5.	Resistance to Heat Deterioration	Better	Synthetic polyisoprene slightly more resistant to deterioration
6.	Cut Resistance (Ambient)	Poorer	Synthetic polyisoprene slightly lower in tear strength and modulus
7.	Cut Resistance (212°F)	Equally Poor	Neither material has adequate resistance by itself
8.	Abrasion Resistance	Equal	Average abrasion indices slightly below those for natural rubber.
9.	Coefficient of Friction	Equal	
10.	Skid Resistance	Equal	
11.	Resistance to Flexing	Equal	Both materials sustained 300,000 cycles well
12.	Resistance to Cord Breakage and Plucking	Equal	

TASK 15: ANALYSIS OF GAS PERMEABILITY CHARACTERISTICS

An analysis was made in this Task of the diffusivity of air through the synthetic elastomer innerliner, casing and sidewall materials. Diffusivity varies for each of these materials owing to differences in elastomers and other ingredients that each material contains. Since the diffusivity of the casing is dependent more on the wicking of air along cords than through the casing rubber, a measurement of diffusivity becomes a study of air wicking effects once a quantity of air passes the innerliner.

Data appear in Task 1, Table XIII for air permeability of polyisoprene innerliner materials as compared to similar natural rubber materials. The data indicate that polyisoprene/butyl materials are equal to natural rubber/butyl materials with respect to permeability. Thus the data in this Task primarily verify the Task 1 Table XIII data, but include the air loss due to wicking as well.

Finally, it must be remembered that aircraft tire sidewalls are vented to provide avenues of escape for air that wicks along casing cords. This prevents intracarcass pressure build-up and ply separations.

The data reported below include the effects noted above. Data are reported as pounds per square inch of pressure lost per 24 hours. The data indicate that the air loss for synthetic polyisoprene aircraft tires will be equivalent to that for natural rubber aircraft tires.

Carcass Type	Air Loss, psi/24 hours
Natural	9.3
Synthetic	9.4

TASK 16: ANALYSIS OF COST REDUCTIONS

A comprehensive analysis has been made of all anticipated cost reductions which may be realized through the use of synthetic polyisoprene in the manufacture and use of aircraft tires. In this analysis, tire manufacturing costs have been critically appraised to ascertain not only specific reductions which may be possible, but also to anticipate any cost increases which may occur. The several phases of this analysis included raw materials purchase and freight costs, materials handling costs, materials processing costs, tire manufacture costs, and anticipated savings in the use of synthetic elastomer aircraft tires. The discussion and graphical presentation of anticipated cost savings follow.

A. Elastomer Raw Materials

The purchase of elastomers involves not only the price of the elastomers but also availability, freight costs to point of use, receipt of materials, warehousing costs, in-plant quality assurance testing, and finally preparation of materials for factory processing. Our analysis indicates that significant cost reductions may be realized in each of these areas through the use of synthetic polyisoprene in place of natural rubber.

Synthetic polyisoprene is manufactured in the United States, and is warehoused in this country near major rubber consuming areas. It is available for immediate delivery at all times. On the other hand, unsettled conditions in the Far East combined with seasonal production changes continually effect the availability of natural rubber. Thus natural rubber buyers generally buy "futures" to assure their companies of continued supplies of this material. This future purchasing also affects availability.

Secondly, synthetic polyisoprene has a stable price throughout the year, while natural rubber prices are affected by seasonal changes which alternately retard and increase plantation production rates. These price fluctuations are illustrated in Figure 7 for the period January 1964-February 1966. The price of synthetic polyisoprene was reduced to 23¢ per pound in October, 1965, making it most attractive to the rubber industry. This price is well below the lowest RSS No. 3 natural rubber price during the last two years.

Typical shipping costs for natural rubber and for synthetic polyisoprene are shown in Table 1. Since natural rubber must be shipped overwater to this country, some charge will always be incurred to transport it from a port of entry to the user's plant. This situation is not true for synthetic polyisoprene, as its price of 23¢ per pound is on a delivered basis regardless of the location of the user's plant.

Synthetic polyisoprene is purchased in uniform 75 pound bales in 2500 lb. unit containers, while natural rubber is purchased in 250 pound bales which assume a variety of shapes. Thus there are significant savings to be realized with synthetic polyisoprene in materials handlings costs. These savings include easier truck or car unloading, more efficient use of warehouse space, elimination of cutting of large bales into small chunks, possible elimination of hot housing costs, and reduction of quality assurance inspection costs. These cost savings are shown in Figure 8. Since the price of natural rubber generally increased in the period January-June 1965, the trend in savings also increases as the price differential increases.

Also shown in Figure 8 are the savings to be realized in premastication costs. To compensate for its inherent high plasticity as received, and owing to significant lot-to-lot differences in plasticity, natural rubber must be masticated prior to use in the manufacture of tire materials. In addition, continuous testing is required for masticated natural rubber, to be certain that the plasticity level is as desired. Synthetic polyisoprene not only is very uniform in plasticity, but is low enough in plasticity so that no mastication is required prior to its use in the manufacture of tire materials. It is anticipated that significant processing savings may be achieved through the elimination of the mastication step when using the synthetic elastomer.

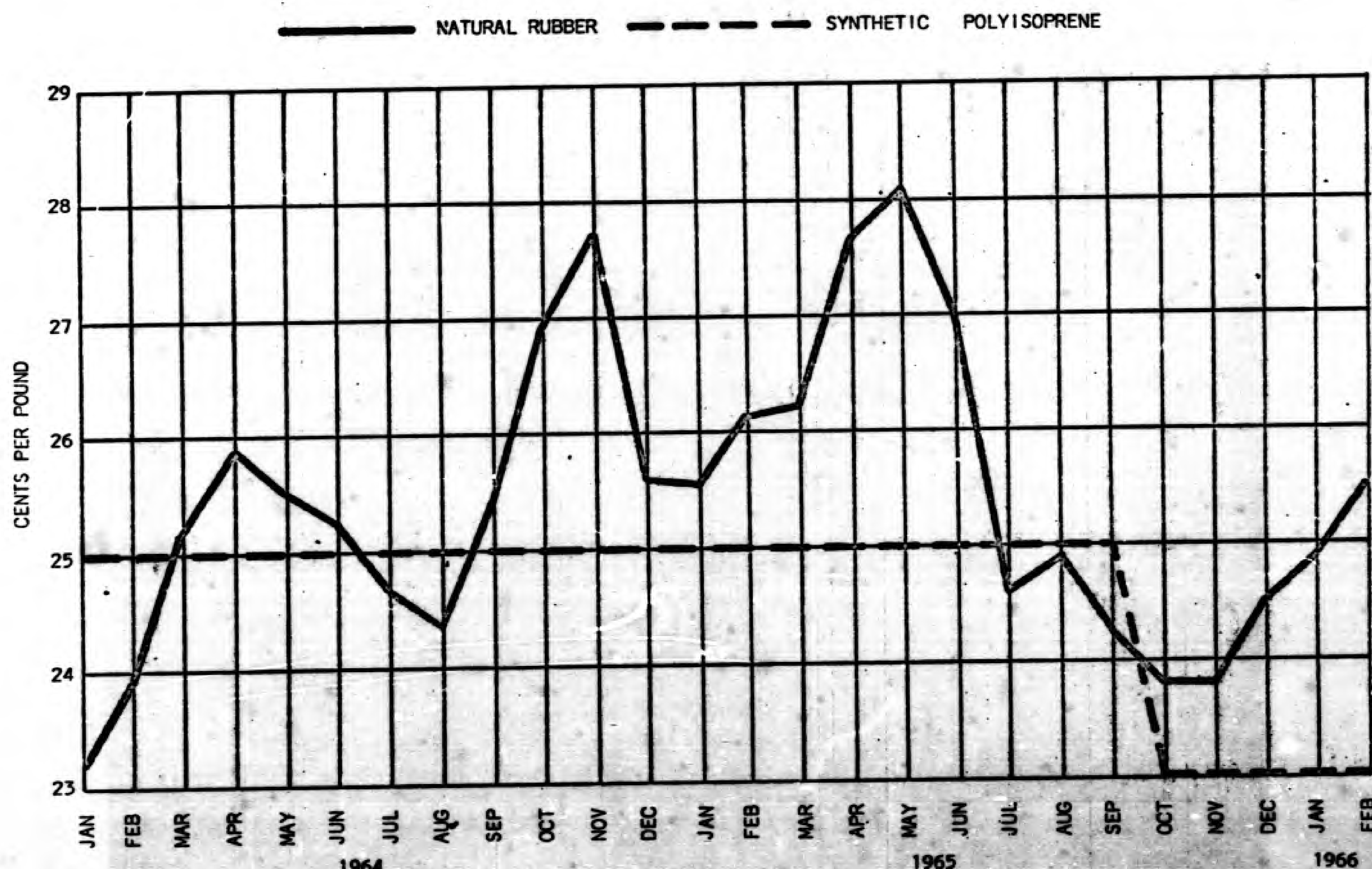
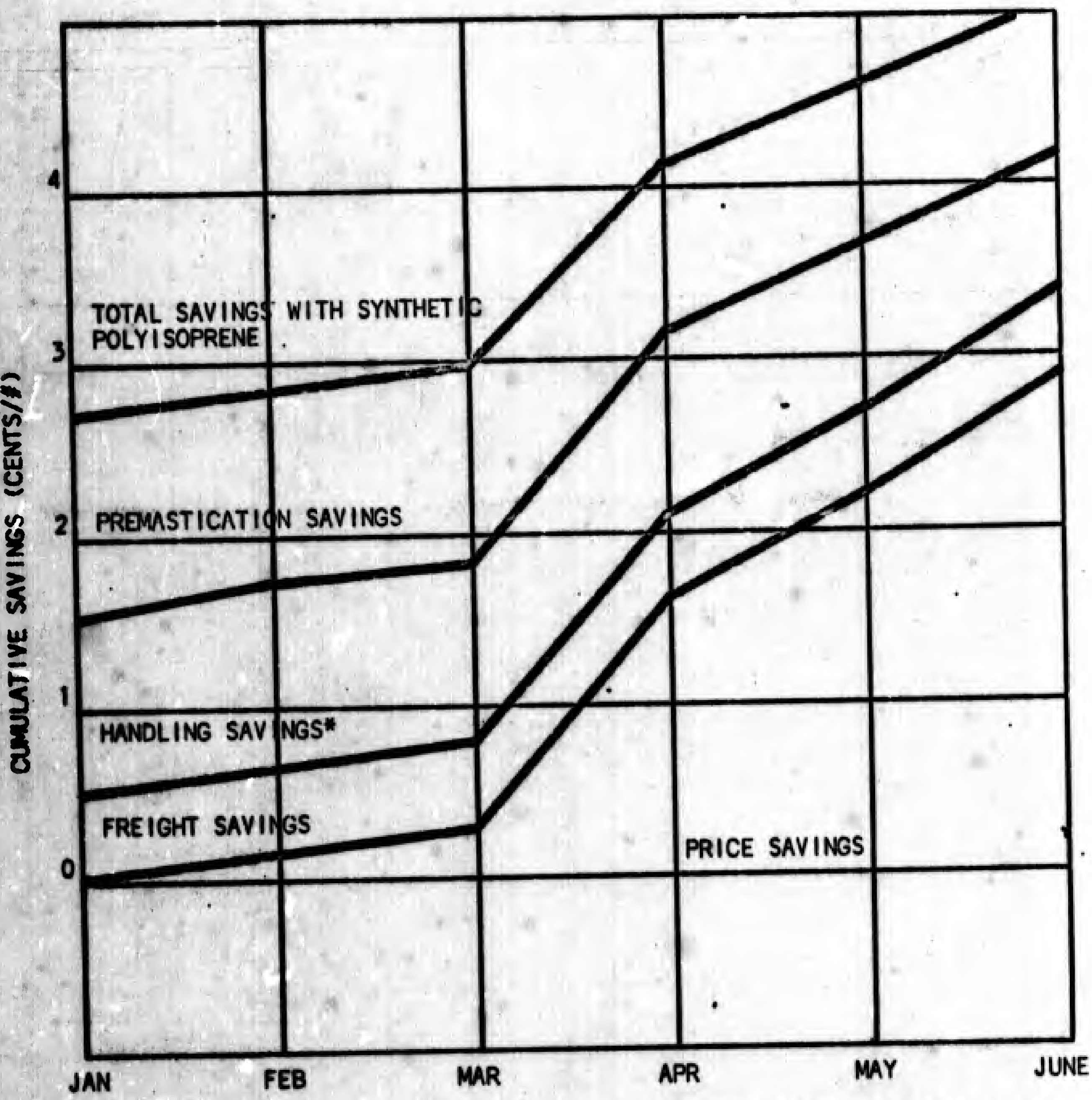


FIGURE 7
NATURAL RUBBER PRICE FLUCTUATIONS, 1964-66

CUMULATIVE SAVINGS REALIZED BY USING SYNTHETIC POLYISOPRENE IN PLACE OF NATURAL RUBBER (1965 DATA)



* UNLOADING, INSPECTION, HOT HOUSING, INSIDE TRANSPORTATION, BALE CUTTING

FIGURE 8

CUMULATIVE SAVINGS REALIZED BY USING SYNTHETIC POLYISOPRENE IN PLACE OF NATURAL RUBBER (1965 DATA)

The cumulative savings which may be achieved by replacing natural rubber pound for pound with synthetic polyisoprene in aircraft tire manufacture are shown in Table L. The overall savings are significant when calculated on a per truckload basis, and amount to approximately $1500 per 30,000 pound truckload of rubber.

B. Elastomer Processing Costs

Due to its variability, natural rubber necessitates continuous changes in processing of materials. At times changes must be made in formulations as well, to compensate for differences in cure rate. Such changes are not necessary when using synthetic polyisoprene, because of its inherent uniformity both of processability and of cure rate.

A small change will probably be necessary in the formulation of all synthetic polyisoprene materials, to effectively match the cure rate of these materials to that of natural rubber materials. This change may increase formulation costs slightly but not significantly.

Synthetic polyisoprene materials are expected to process as well as natural rubber materials, and will offer the savings inherent in improved uniformity and processability at the cost of minor formulation changes as noted above.

C. Tire Manufacturing Costs

Two significant characteristics of synthetic polyisoprene are low green strength and building tack as compared to natural rubber. While this characteristic has been identified and quantitatively measured in the laboratory, the values obtained indicate that synthetic polyisoprene materials have sufficient green strength and building tack for normal tire manufacturing processes and procedures. The cost factors will be precisely noted during tire manufacture in Phase III, to note in detail any possible changes in costs for such manufacture. At this time, it is anticipated that tire manufacturing costs for synthetic polyisoprene tires will be equal in all respects to those for natural rubber tires.

D. Operational Savings

Based on materials data obtained to date, it is anticipated that synthetic polyisoprene aircraft tires will be cooler-running than are natural rubber aircraft tires, with no loss in abrasion resistance. These factors indicate possible savings in the ability to retread synthetic polyisoprene tires more often than natural rubber tires, and in improved tire integrity during each service life.

It is difficult to calculate cost savings which are based only on improved tire integrity, without an extensive service evaluation program to evaluate tires of both types of elastomers under controlled conditions. In addition, while savings can readily be calculated based on the retreading of aircraft tires as opposed to purchasing new tires, an evaluation would have to be undertaken of new tire service life (number of landings) versus retread service life to complete the savings calculations. Such an evaluation may be indicated in Phase III once the synthetic polyisoprene tires have successfully completed the qualification tests.

It can be concluded that the synthetic polyisoprene tires will probably offer distinct service improvements. The magnitude of such improvements may be determined through controlled service evaluation testing, using natural rubber tires as the control.

SUMMARY

It has been shown that synthetic polyisoprene offers potential cost savings in the purchase and handling of the elastomer, in the processing of tire materials, and in the manufacture and operational use of aircraft tires made from this elastomer. The overall savings should be reflected in a significant reduction in aircraft tire prices.

TABLE XLIX SHIPPING COSTS* - NATURAL RUBBER VS POLYISOPRENE

	NATURAL RUBBER		SYNTHETIC POLYISOPRENE
Truck Load	Rate/CWT	Minimum Load (lbs)	
Akron, O.	$0.765	40,000	No Charge
Chicago, ILL.	1.10	35,000	No Charge
Phila., Pa.	0.50	30,000	No Charge
Rail Car Load			
Akron, O.	0.74	70,000	No Charge
Chicago, ILL.	0.93	70,000	No Charge
Phila., Pa.	-	-	No Charge

Rates are from New York to destination shown.

* Does not include pier charges

TABLE L COST ANALYSIS - HANDLING AND PROCESSING NATURAL RUBBER (#IRSS) VS POLYISOPRENE (SYNTHETIC)

	NATURAL RUBBER (#IRSS) MIXING UNIT		SYNTHETIC POLYISOPRENE MIXING UNIT
	MILL	BANBURY	BANBURY
Price/lb. (Feb. 1966)	25.540 ¢	25.540 ¢	23.000 ¢
Freight	0.500	0.500	-
Unloading	0.064	0.064	0.015
Inspection, Hot Housing, Inside Transportation	1.020	1.020	0.160
Bale Cutting	0.040	0.040	-
Premastication	4.010	1.030	-
Total cost/lb.	31.174 ¢	28.194 ¢	23.175 ¢
Cost/30,000# Truckload	$9,352.20	$8,458.20	$6,952.50
Savings/Truckload with Polyisoprene	$2,399.70	$1,505.70	

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PHASE III

TIRE FABRICATION AND TESTING

INTRODUCTION

The final phase of this program included the fabrication and testing of aircraft tires manufactured with materials and tire designs selected in Phase II. Evaluations were accomplished of each of the rubber processing steps used in the manufacture of materials. Similar evaluations were made of the operations included in the building and vulcanizing of the two sizes of tires manufactured in this Phase. Whenever a comparison was possible, the benefits observed using synthetic materials in place of all-natural rubber materials were recorded, and are described in the text of specific Tasks.

Once the initial test articles had been manufactured, they were subjected to qualification testing on the dynamometer. The 49x17 26PR tires were tested in accordance with USAF Drawing 60D2561. The 30x8.8 22PR tires were tested in accordance with USAF Drawing 60D90767. A Thompson engineer monitored all stages of the manufacture of these test articles, and the qualification tests, to obtain as much data as possible on the synthetic rubber tires and their performance characteristics.

The service evaluation tires originally scheduled for delivery to USAF in this Phase had to be cancelled. The manufacture of test articles and service evaluation tires was subcontracted to others. Original subcontract agreements, completed in 1964 for this program, could not be accomplished when it was found that these tires were not required until completion of the qualification tests in 1967. Alternate plans submitted to USAF for retreaded service evaluation tires of the same sizes were not accepted. This later action concluded the development work.

CONCLUSIONS

The third Phase of this program was divided into two major areas of work, the fabrication of aircraft tires using all-synthetic rubber formulas developed in Phase II for each tire component, and the testing of such tires for qualification. Specific observations and conclusions are detailed below and in the text of each Task. The general conclusion from work in this Phase is that aircraft tires can in fact be fabricated sucessfully from the materials selected in Phase II, and that the performance of such tires under test conditions is at least equivalent to that of all-natural rubber tires of the same sizes.

The only detrimental effect observed during testing was a gross tread chunking condition for 30x8.8 22PR tires caused by the narrow tread grooves of the subcontractor's current tread design. A different tread design, including wider grooves and larger groove radii, would have corrected this defect, resulting in significant improvements in the tread chunking problem for this tire size. The minor groove cracking observed for 49x17 26PR tires is considered to be typical during dynamometer tests for the tread formulation used. This condition would not develop under normal service conditions.

It was not possible to determine precise comparisons of field performance characteristics of the all-synthetic rubber tires with similar all-natural rubber tires within this contract. Thus the Tasks originally proposed for this work were deleted. The main benefit in cost savings appears at this time to be in materials prices and in reduced processing costs for such materials.

GENERAL PROGRAM OUTLINE

Complete data for the preparation of all-synthetic rubber materials are given in Tasks 1-5. Data for the evaluation of tire manufacture are given in Tasks 6-8. Qualification tests for the test articles of each size were conducted in Task 9.

TASK 1: EVALUATION OF MIXING OPERATIONS

The first Task of this Phase of the program was devoted to the preparation of factory-scale quantities of synthetic rubber materials. The six formulations selected in Phase II were mixed in the factory to evaluate their unique characteristics with respect to mixing cycle times and temperatures, general handling characteristics in the factory, and general costs for stock preparation as compared to similar all-natural rubber materials. Sufficient quantities of materials were prepared in this Task to accomodate the production of a limited number of test articles of each tire size (30x8.8 and 49x17). Actual stock preparation was done under subcontract with Firestone Tire and Rubber Company's Los Angeles Plant, under the supervision of a Thompson Project Engineer.

The formulation codes referenced on the data sheets were as follows:

Formulation Identification	Code
Tread	TH-10
Carcass	C-9
Innerliner	L-7
Bead Wrap and Chafer	BW-7
Bead Wire Insulation	BN-4
Bead Filler	F-5

The main components of aircraft tires that require the largest amounts of rubber are the tread, carcass and innerliner. The three formulations for these stocks were mixed in repetitive, #11 Banbury size batches, in the following quantities:

1. Tread: 5 Banbury Batches, 2000 lb. total
2. Carcass: 3 Banbury Batches, 1200 lb. total
3. Innerliner: 2 Banbury Batches, 800 lb. total

From this quantity of each stock, it was possible to adequately define the factory mixing conditions, for comparison to mixing similar all-natural rubber materials. The other three formulations were prepared under sub-scale factory conditions, however mixing trends for these materials followed closely those trends noted for the three major stocks noted above.

The following tabulations illustrate the average factory-scale mixing conditions recorded for each formulation. "Pass" is the term applied to each time a quantity of materials is cycled through the Banbury mixer. Thus a "three pass mix" with mix times of 5 minutes, 4 minutes and 2 minutes respectively for each pass means that the materials were put through the Banbury mixer a total of three times, with the total mixing time being 11 minutes. The Mooney viscosity of the materials (ML-4 at 212°F) is a measure of the relative thermoplasticity of the materials at 212°F, as measured by the Mooney Viscometer using the large rotor (ASTM D 1646-61).

FORMULATION: TH-10

Pass Number	1(Masterbatch)	2(Remill)	3(Final)
Initial Temperature, °F :	124	150	150
Oils Added at °F :	275	-	-
Temperature Drop to °F :	237	-	-
Discharge Temperature, °F :	350	250	212
Mix Time, Minutes :	5	3	1.
Mooney Viscosity, ML-4 + 212°F:			

Average Total Mixing Time: 9 minutes
Average Mooney Viscosity : 47

Other test data for the TH-10 materials are shown on the data sheets.

FORMULATION: C-9

Pass Number	1(Masterbatch)	2(Final)
Initial Temperature, °F :	130	150
Oils Added at °F :	280	-
Temperature Drop to °F :	243	-
Discharge Temperature, °F :	358	212
Mix Time, Materials :	5	1.1
Mooney Viscosity, ML-4 + 212°F:	70	55

Average Total Mixing Time: 6.1 minutes
Average Mooney Viscosity : 55

Other test data for the C-9 materials are shown on the data sheets.

FORMULATION: L-7

Pass Number		1(Masterbatch)	2(Final)
Initial Temperature, °F	:	140	138
Oils Added at °F	:	294	-
Temperature Drop to °F	:	245	-
Discharge Temperature, °F	:	342	217
Mix Time, Minutes	:	4	1.1
Mooney Viscosity, ML-4 + 212°F	:	70	52

Average Total Mixing Time: 5.1 minutes
Average Mooney Viscosity : 52

Other test data for the L-7 materials are shown on the data sheets.

The observed cycle time per pass for each of these materials was considered to be normal for each type of formulation. However, when mixing natural rubber formulations such as these, the natural rubber is usually put through a prior mastication cycle in the Banbury by itself, to reduce the inherent toughness (plasticity) of this elastomer to an acceptable level (80-90 ML-4 at 212°F) prior to using this rubber in the masterbatch. The normal premastication cycle takes 3 minutes at the minimum. Thus the following comparisons of total mixing cycles can be drawn:

Stock	Cycle Time: Natural Rubber	Cycle Time: Synthetic Rubber	Cycle Time Reduction
TH-10	12 min.	9 min.	25%
C-9	9.1 min.	6.1 min.	33%
L-7	8.1 min.	5.1 min.	37%

Actual cost savings in dollars per pound for the synthetic materials would have to be calculated using specific mixing charges for each particular mixing plant. Also, with the elimination of the premastication cycle, the Banbury unit would be able to produce more finished material per year, since the materials would require only 2 or 3 passes rather than the 3 or 4 passes required for natural rubber materials. Such increased productivity is an additional savings.

The handling characteristics of all formulations were rated as good-to-excellent. Release from mill rolls was very good. All materials reached acceptable plasticity levels within reasonable mixing times, which indicated a high degree of batch-to-batch uniformity. These factors are critical in current high-volume, minimum-mixing-time operations.

Test data and formulations appear on the following data charts. Test data for each of the factory-mixed materials compared favorably wirh data obtained in Phase II for laboratory-mixed materials. Thus these materials were approved for use in preparation of the specification materials needed in the manufacture of the test articles.

TABLE LI FORMULATION DATA TH-10 AND C-9

INGREDIENTS	FORMULATIONS					
	TH-10		C-9			
Polyisoprene (Natsyn 400)	100.0		100.0			
Zinc Oxide	5.0		5.0			
Stearic Acid	1.0		1.0			
HAF Black	47.0		40.0			
Antioxidant (Thermoflex A)	1.0		1.0			
Antiozonant (Santoflex AW)	1.5		-			
Paraffin Oil (Sunpar 150)	6.0		-			
Pine Tar	-		4.0			
Insoluble Sulfur (Crystex)	0.5		0.5			
MBTS (Altax)	-		1.25			
Santocure NS	1.15		-			
Sulfasan R	2.0		2.0			
MONSANTO RHEOMETER DATA						
Temperature: °F	280		280			
Initial Viscosity: In.-Lbs.	25.2		28.8			
Scorch Time: Minutes	11		10			
Cure Rate: In.-Lbs./Min.	8		4.5			
Maximum Modulus: In.-Lbs.	74.0		81.1			
Time For Max. Modulus - Minutes	59		70			
Reversion: In.-Lbs./Min.	0.016		0.006			
TENSILE DATA: Normal (x);			Oven Aged		Hours @ °F	
Optimum Cure: Minutes @ 280 °F	60		60			
100% Modulus	290		400			
200% Modulus	1030		1140			
300% Modulus	1970		2210			
Tensile Strength	3430		3220			
Percent Elongation	440		390			
Shore A Durometer	68		66			
Crescent Tear - Type C	430		370			
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
100,000	0.094		0.063			
HEAT BUILD-UP: Load 175PSI; Stroke .225 In.; Temp.100°F; Time 30 Min.						
Final Temperature °F	171		152			
Temperature Rise °F	71		52			
Percent Compression Set	6.3		0			
HEAT BLOW-OUT: Load 250PSI; Stoke.250In.; Temperature 100 °F						
Time	90+		90+			
FINAL TEMPERATURE	202		160			
PERCENT COMPRESSION SET	14		0			
MISCELLANEOUS TESTS						
SPECIFIC GRAVITY	1.12		1.09			
MOONEY SCORCH, MS 250, Min. To 10 pt. rise	57		49			

TABLE LII FORMULATION DATA L-7 AND BW-7

INGREDIENTS	FORMULATIONS					
	L-7		BW-7			
Polyisoprene (Natsyn 400)	70.0		100.0			
Butyl (Enjay 268)	10.0		-			
Butyl Reclaim (Xylos 8301)	33.3		-			
Zinc Oxide	3.5		5.0			
Stearic Acid	1.5		1.0			
HAF Black	35.0		40.0			
Pine Tar	-		4.0			
Dioctyle Phthalate	5.0		-			
Antioxidant (Thermoflex A)	1.25		1.0			
Rosin Oil	-		2.0			
Ethylac	-		0.6			
Santocure NS	1.0		-			
Insoluble Sulfur (Crystex)	2.25		2.5			
MONSANTO RHEOMETER DATA						
Temperature: °F	280		280			
Initial Viscosity: In.-Lbs.	29		32			
Scorch Time: Minutes	6.2		9			
Cure Rate: In.-Lbs./Min.	8		9			
Maximum Modulus: In.-Lbs.	70		68			
Time For Max. Modulus - Minutes	25		17			
Reversion: In.-Lbs./Min.	0.2		0.2			
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: Minutes @ 280 °F	60		60			
100% Modulus	390		60			
200% Modulus	890		940			
300% Modulus	1450		1750			
Tensile Strength	2295		3390			
Percent Elongation	425		480			
Shore A Durometer	67		61			
Crescent Tear - Type C	270		400			
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
100,000	0.21		0.41			
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	257		143			
Temperature Rise °F	157		43			
Percent Compression Set	25		4			
HEAT BLOW-OUT: Load 250 PSI; Stoke .25 In.; Temperature 100 °F						
Time	10'		100+			
Blow-Out Temperature	250°F		155+			
MISCELLANEOUS TESTS						
SPECIFIC GRAVITY	1.11		1.11			
MOONEY SCORCH, MS 250, Min. to 10 pt. rise	24		33			

TABLE LIII FORMULATION DATA F-5

INGREDIENTS	FORMULATIONS					
	F-5					
Polyisoprene (Natsyn 400)	100.0					
Zinc Oxide	5.0					
Stearic Acid	1.0					
MPC Black	25.0					
SRF Black	60.0					
Paraffin Oil (Sunpar 150)	4.0					
Resin Tackifier (Picco 100)	2.0					
Rosin Oil	4.0					
Insoluble Sulfur (Crystex)	3.0					
Santocure NS	1.25					
MONSANTO RHEOMETER DATA						
Temperature: °F	280					
Initial Viscosity: In.-Lbs.	41					
Scorch Time: Minutes	10					
Cure Rate: In.-Lbs./Min.	7.5					
Maximum Modulus: In.-Lbs.	99					
Time For Max. Modulus - Minutes	39					
Reversion: In.-Lbs./Min.	0.4					
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: Minutes @ 280 °F	30					
100% Modulus	510					
200% Modulus	1450					
300% Modulus	2210					
Tensile Strength	2500					
Percent Elongation	390					
Shore A Durometer	71					
Crescent Tear - Type C	410					
CUT GROWTH: Ambient Temperature (x); At °F						
Cycles		Inches of Cut Growth				
40,000	0.875					
HEAT BUILD-UP: Load PSI; Stroke .225 In.; Temp. 100 °F; Time 30 Min.						
Final Temperature °F	166					
Temperature Rise °F	66					
Percent Compression Set	5					
HEAT BLOW-OUT: Load 250 PSI; Stoke .25 In.; Temperature 100 °F						
Time	100+					
Blow-Out Temperature	209+					
MISCELLANEOUS TESTS						
Specific Gravity	1.21					
Mooney Scorch, MS250, Min. to 10 pt rise	42					

TABLE LIV FORMULATION DATA BN-4

INGREDIENTS	FORMULATIONS					
	BN-4					
SBR (Ameripol 1002)	100.0					
Zinc Oxide	7.5					
Stearic Acid	5.0					
FEF Black	25.0					
SRF Black	100.0					
Resin Tackifier (Picco 100)	3.0					
Pine Tar	5.0					
Paraffin Oil (Sunpar 150)	3.0					
MBTS (Altax)	1.5					
TMTM (Monex)	0.1					
Insoluble Sulfur	3.5					
MONSANTO RHEOMETER DATA						
Temperature: °F	280					
Initial Viscosity: In.-Lbs.	39					
Scorch Time: Minutes	8					
Cure Rate: In.-Lbs./Min.	1.7					
Maximum Modulus: In.-Lbs.	103					
Time For Max. Modulus - Minutes	120					
Reversion: In.-Lbs./Min.	0					
TENSILE DATA: Normal (x); At °F; Oven Aged Hours @ °F						
Optimum Cure: Minutes @ 280 °F	60					
100% Modulus	1050					
200% Modulus	1910					
300% Modulus	-					
Tensile Strength	2010					
Percent Elongation	265					
Shore A Durometer	83					
Crescent Tear - Type C	300					
CUT GROWTH: Ambient Temperature ( ); At °F						
Cycles		Inches of Cut Growth				
HEAT BUILD-UP: Load 175 PSI; Stroke .225 In.; Temp. °F; Time Min.						
Final Temperature °F	249					
Temperature Rise °F	149					
Percent Compression Set	7					
HEAT BLOW-OUT: Load 250 PSI; Stoke .25 In.; Temperature 100 °F						
Time	8'					
Blow-Out Temperature	284°F					
MISCELLANEOUS TESTS						
Specific Gravity	1.32					
Mooney Scorch, MS 250, Min. to 10 pt rise	37					

TASK 2: EVALUATION OF CALENDERING OPERATIONS

In this Task, an evaluation was made of the processing of the synthetic rubber materials on factory-scale calenders. This evaluation included preparation of calendered tire cord fabric, using the carcass formulation C-9, the preparation of calendered innerliner using formulation L-7, the frictioning of formulation BW-7 onto square woven fabric, and the preparation of calendered tread and sidewall stock using formulation TH-10. Comments on the behavior of these stocks on the calender are summarized below, by formulation number.

1. Carcass Formula C-9

This material handled very well on the calender. Behavior of the material on the warm-up mills was excellent. The material banded easily and released from the rolls very well, both on the mills and on the calender. The only problem encountered on the calender was with the fabric spreader bar, a device used to keep the cords uniformly separated while being fed to the calender. Because of this, the fabric in spots either stretched or bunched up, necessitating a fairly high scrapping of materials in subsequent bias cutting operations. While this scrappage directly effects any potential cost reductions, the synthetic material itself was not the cause of the problem. The C-9 material processed quite acceptably, indicating that it would be readily used in high speed, calender operations without any additional compound ingredient adjustments to improve this characteristic.

C-9 material was used to calender tire cord fabric (inner plies, outer plies and tread reinforcing plies) and gum strips (all rubber, no fabric). The table below summarizes the various widths, gages and lengths produced in these operations, along with the total weights of these materials. In all cases, a three roll calender was used, with the following roll temperatures, measured with a surface pyrometer:

Top Roll :	180° - 185°F
Middle Roll:	175° - 185°F
Bottom Roll:	130° - 132°F

All materials were calendered onto smooth 6 mil polyethylene film for shipment.

FORMULA C-9 CALENDERED ITEMS

Item Description	Gage, In.	Width, In.	Length, yd.	Weight, lb.
1. Fabric, 840/2 Nylon, 34 epi	0.028	50	500	1819
2. Fabric, 840/2 Nylon, 24 epi	0.038	50	50	247
3. Gum Stocks				
a. 012-030	0.030	3	73	6.8
b. 012-080	0.080	8	73	17.8
c. 012-100	0.100	10	50	13.5
d. 012-140	0.140	14	50	18.8
e. 012-180	0.180	18	46	21.8
f. 012-200	0.200	20	46	23.8
g. 012-020	0.020	1.5	720	40.6

2. Tread Formula TH-10

This material handled very well on the calender, duplicating the processibility of formula C-9 exactly. Calender temperatures used when calendering TH-10 materials were the same as those used for C-9. Based on processing observations for this material, it was concluded that TH-10 would be readily used in high speed calendering operations in the factory.

Since tread materials for the 30x8.8 test articles require the use of tread-reinforcing fabric, TH-10 was calendered onto tire cord as well as being calendered into the ncessary gum stock tread and sidewall materials. The table below summarizes the items produced in the calendering operation for use in the manufacturing of test articles. The three roll calender was used for all items, and finished materials were rolled onto smooth 6 mil polyethylene film for shipment.

FORMULA TH-10 CALENDERED ITEMS

Item Description	Gage, in.	Width, in.	Length, yd.	Weight, lb.
1. Fabric, 840/2 Nylon, 18 epi	0.040	50	100	521
2. Fabric, 840/2 Nylon, 18 epi	0.042	50	50	528
3. Gum Stocks				
a. 320-020	0.020	10.5	200	22.1
b. 330-020	0.030	2.06	50	7.5
c. 330-050	0.030	5	70	18.5
d. 330-072	0.030	7.63	70	22
e. 330-201	0.030	20.38	70	74.8
f. 540-040	0.040	9	40	25.8
g. 560-060	0.060	7	40	26.1
h. 510-162	0.110	16.5	33	88.3
i. 510-180	0.110	18.12	33	97.5
j. 510-192	0.110	19.63	35	116

3. Innerliner Formula L-7

This material processed easily on the calender and warm-up mills. Overall rating of its processability was equal to that of formula C-9. Calender temperatures used for this material were equivalent to those indicated for C-9. While the L-7 material was calendered separately in this Task, the observations of its processability and green tack indicated that the material would have been suitable for calendering hot onto the inner carcass fabric ply. This technique is often used in the industry as a cost savings technique. The calendering properties of the L-7 material indicated that this material would be suitable for use in high speed calendering operations.

The table below summarizes the gum rubber items produced using the L-7 formula.

FORMULA L-7 CALENDERED ITEMS

Item Description	Gage, in.	Width, in.	Length, yd.	Weight, lb.
1. Gum Stocks				
a. 080-203	0.080	20.75	42	101
b. 080-421	0.080	42.25	40	197

4. Bead Wrap/Chafer/Flipper Formula BW-7

This material was frictioned onto square woven, wick-proof nylon fabric for use as a chafer, and onto square rayon fabric for use as bead wrap fabric and flipper. Owing to the small quantities of bead wrap, flipper and chafer fabric that were required for the test articles, only small quantities of the BW-7 material were prepared.

Frictioning of BW-7 on the calender was rated as excellent. The stock had sufficient release from the rolls and adequate strike through characteristics to provide well-coated fabric. After frictioning the small quantities of materials needed for the test articles, the fabric was slit to width on a Cameron slitter. This operation was easily performed, giving the following items of finished materials.

FORMULA BW-7 FRICTIONED ITEMS

Item Description	Gage, In.	Width, In.	Length, yd.	Weight, lb.
1. Rayon, .015 ga., woven to .031 ga.	0.030	6.5	100 yd.	50.8 lb.
2. Rayon, .015 ga., woven to .031 ga.	0.030	7.8	125 yd.	76.0 lb.
3. Rayon, .015 ga., woven to .031 ga.	0.030	1	400 yd.	31.2 lb.
4. Nylon, .010 ga., woven to .022 ga.	0.030	5.25	50 yd.	20.5 lb.
5. Nylon, 0.10 ga., woven to .022 ga.	0.030	6.75	70 yd.	36.8 lb.

TASK 3: EVALUATION OF BEAD CONSTRUCTION OPERATIONS

An evaluation was made in this Task of the manufacture of tire beads using the synthetic rubber materials. Formula BN-4 was used in the extrusion of insulated bead wire. The bead bundles were wrapped with square woven fabric that was frictioned with formula BW-7. The filler strip, extruded using formula F-5, was applied to the bead bundle, which then was flipped with square woven fabric that was frictioned with formula BW-7. The manufacture of beads was subcontracted to Schenult Industries, who then used the beads in the manufacture of test articles.

Beads for both tire sizes were very readily manufactured, indicating that the materials used were satisfactory in all respects in the green (unvulcanized) state. The frictioned materials had sufficient building tack and green strength to assure uniform beads during a long production run. The extruded materials also processed well, and gave good adhesion between components during the build-up of beads.

The chafer fabric was not used until a later Task, as it is applied to the tire as one of the last steps of tire manufacture.

With respect to potential cost reductions, it appeared that the synthetic materials would lend themselves well to highly automated bead wrapping operations. The bead operations in current use by the subcontractor were not of this type, however our observations of the characteristics of the synthetic materials indicated that they would be suitable for the automated wrapping and flipping machines used for other kinds of high volume production beads.

TASK 4: EVALUATION OF SIDEWALL EXTRUSION OPERATIONS

The extrusion characteristics of formula TH-10, used for tire sidewalls as well as tire treads, were evaluated in this Task. Since only enough sidewall material was extruded for the test articles, it is difficult to state conclusively that this evaluation was thorough in all respects. However, sufficient information was obtained to indicate trends for the synthetic materials. Such trends are detailed below.

Based on the Mooney Viscosity (ML-4 at 212°F) of the TH-10 material used, the extrusion rate of the material was excellent for this brief run. The stock plasticity was slightly low for formulas of this type. Low plasticity will give generally lower extrusion temperatures and high extrusion rates. The material handled well on the warm-up mills and extruder conveyor system. Recycled trimmings were put back on the feed mills, with only a slight adverse effect on the extrusion rate and extrusion appearance. Stock shrinkage after the extruder was minimal, giving good control of dimensions. All materials extruded in this Task were within dimensional tolerances.

On a full scale production basis, the trends noted in this Task would give the following beneficial characteristics, compared to similar natural rubber materials:

1. Generally closer dimensional control.
2. Slightly lower extrusion temperatures.
3. Slightly faster extrusion rates.

The effect of continuously recycling trimmings may hinder the extrusion operation, as the synthetic polyisoprene has somewhat inferior characteristics to natural rubber in this respect.

TASK 5: EVALUATION OF BIAS-CUTTING OPERATIONS

This Task provided for the evaluation of the handling characteristics of tire cord calendered with formula C-9, during factory-scale bias-cutting operations. The main characteristic evaluated was the ability of the C-9 materials to make and maintain adequate splices. Other features evaluated included the release of materials from liners, polyethylene film in this instance, the strength of the calendered sheet during bias cutting, and any observed improvements offered by the C-9 material which might result in cost reductions for this operation.

The bias cutting of the tire cord fabric was performed at Schenult Industries under subcontract, under the direction of a Thompson Project Engineer. The actual fabric bias angles and widths used in this Task were proprietary to Schenult Industries, and thus are not detailed here.

Because of the relatively small quantities of calendered fabric required for the test articles, the C-9/tire cord materials were calendered onto expendable polyethylene film in Task 2, rather than into reusable fabric liners. Such film has much more adhesion to rubber than does a fabric liner. Thus it was observed in this Task that the film adhered to the C-9 rubber such that film release was somewhat of a problem. The film at the edges of cut fabric had to be peeled back to expose sufficient rubber to make the splices.

Owing to calendering problems discussed under the formula C-9 portion of Task 2, some excess scrappage of tire cord fabric was encountered in this Task. While the fabric handled well in the bias-cutting operation itself, the uneven cord count at the edges of the fabric necessitated extra inspection and pulling the selvege off the edges of bias strips prior to splicing the strips together.

The splicing of cut strips was excellent. The C-9 material had sufficient tack to provide a good initial three cord overlap from one strip to the next. Also, the material had sufficient green strength to maintain the splices intact during wind-up.

Based on these observations, it can be concluded that the synthetic rubber/fabric materials were essentially equal to similar natural rubber/fabric materials with respect to bias-cutting and splicing of strips. The only problem area, adhesion of the C-9 material to the expendable film, would be corrected during normal factory operations by using fabric liners that would give better release.

TASK 6: EVALUATION OF BAND BUILDING OPERATIONS OR BUILD-UP FROM A TURRET

This Task provided an evaluation of the manufacturing process used to build bands of fabric plies for use later in the actual tire fabrication. The subcontractor currently uses the band building method for tire fabrication for each of the two sizes of test articles. Thus only this system was evaluated in this Task.

The turret building method of tire fabrication involves the direct placement of subsequent plies on the building drum, with ply let-off from a rotating turret above the drum. The band building method involves preparation of bands of two or three plies in a separate operation prior to actual tire fabrication, then spinning the bands together, one on top of another, on the tire building drum, to form the tire carcass. Both methods are in successful use in the industry for fabrication of aircraft tires.

The band building method consists of a drum around which individual plies of bias-cut tire cord fabric are placed, a stitching devise for making splices, and a pressure roll for stitching plies together and for eliminating air trapped between plies. This method also allows for the application of gum strips and squeegees between plies, as detailed by a given tire specification. Once the bands are completed, they are removed from the drum and transferred to the tire building operation.

For the tires in this program, bands consisted of two fabric plies. The innermost band contained the calendered innerliner (formula L-7). Outer bands contained squeegees and gum strips, as required by the proprietary tire specifications of the subcontractor.

The only problem encountered with the synthetic rubber materials was the release of the polyethylene film from the rubber surface. This problem and a potential solution were explained in a previous Task. The extra surface tack of the rubber materials hindered the handling of bands somewhat after building, but this was not significant to the operation. The band splices were made using three cord overlaps, and all splices held together very well. There was no evidence of looseness of plies in the bands. No solvent freshening of ply surfaces was required during band preparation.

The conclusion reached from work in this Task was that the synthetic rubber materials were quite acceptable for preparation of bands for use in the fabrication of aircraft tire carcasses. The use of fabric liners for storing and shipping carcass materials would probably eliminate the only handling problem of these materials, that of excess surface tack resulting from the use of polyethylene liners.

The details of cord angles, band widths, and other construction features observed during this Task are proprietary to the subcontractor, and thus are not given here.

TASK 7: EVALUATION OF TIRE BUILDING PROPERTIES

This most important Task of the program included a thorough evaluation of the characteristics of all synthetic rubber materials during the building of aircraft tires. The evaluations completed up to this Task had indicated that these new materials had processing characteristics very similar to all-natural rubber materials. Thus it was anticipated that the evaluation in this Task would indicate that these materials would be successful during tire fabrication operations. However, until plies are actually turned up around the beads and stitched, and until the bagging operation is complete and the tire has been successfully placed in the curing mold with no evidence of loosening of the beads and ply turn-ups, any new tire material cannot be considered to be successful in tire manufacturing.

All of the new synthetic rubber materials were found to be successful during this evaluation. Inspection of the bead assemblies and bands prior to tire building indicated that there was no looseness or separations in these items. All materials had sufficient tack for tire fabrication. Because of the experimental nature of these tires, extra care was taken by the tire builders in each stage of the operation.

Bands were successfully spun into position on the tire drum. Using paraffin wax to provide lubrication between bands, a common industry practise, successive bands were spun onto the drum quite rapidly and easily. Beads were positioned by hand, and had sufficient tack to remain in place during ply turn-up. It was found during power stitching of the turn-ups that less stitching pressure was required, since the normal stitching pressure tended to tear and damage the ply coat stock, formula C-9. This condition was undoubtedly related to the relatively low green elongation of the synthetic polyisoprene compared to natural rubber. Once this adjustment was made to the power stitcher, satisfactory turn-ups were made for all tires. Hand stitching did not cause any problems.

Tread, sidewalls and bead chafers adhered well to one another during building, as well as to the green tire carcass plies. Removal of the first tire completed, a 30x6.8, gave some release problem from the collapsable drum but provided direction for easier removal of subsequent tires. Paraffin wax was used subsequently on the drum surface prior to tire building, and an adjustment was made in the amount of drum tire cement that was used around the bead areas.

Each green tire was wrapped in polyethylene film to insure that it was kept clean during transfer to the curing operation.

Tire building co[illegible]ions were difficult to anticipate, based on the evaluation completed in this Task. The characteristics of the synthetic rubber materials indicated that there would probably be no significant additional tire building costs, as compared to building costs for similar natural rubber materials. Also, there would be no increase in scrap rate for all-synthetic rubber green tires due to loose beads, loose turn-ups, or ply separations. This in itself is significant in tire manufacture.

The tires built in this Task were assigned the following experimental serial numbers:

<u>30 x 8.8 22PR Size; Five Test Articles</u>

S/N 5421A-1; 5421A-2; 5421A-3; 5421A-4; 5421A-5

<u>49 x 17 26PR Size; Three Test Articles</u>

S/N 5421B-1; 5421B-2; 5421B-3

These serial numbers will be used for reference in subsequent Tasks, for description of specific observations for each particular test article. The photographs of each vulcanized tire are shown below, to illustrate the appearance of the test articles.

TASK 8: EVALUATION OF TIRE VULCANIZATION

Data from Phase II, Task 5 for time-temperature cure rates for each synthetic material were used in this Task in establishing the cure parameters for the synthetic rubber test articles. Also, cure curves for each material were made using a Monsanto Oscillating Disk Rheometer. After determining the optimum state of cure for each material, this information was used by the subcontractor for comparison to similar curves for his own materials currently in use for these tire sizes.

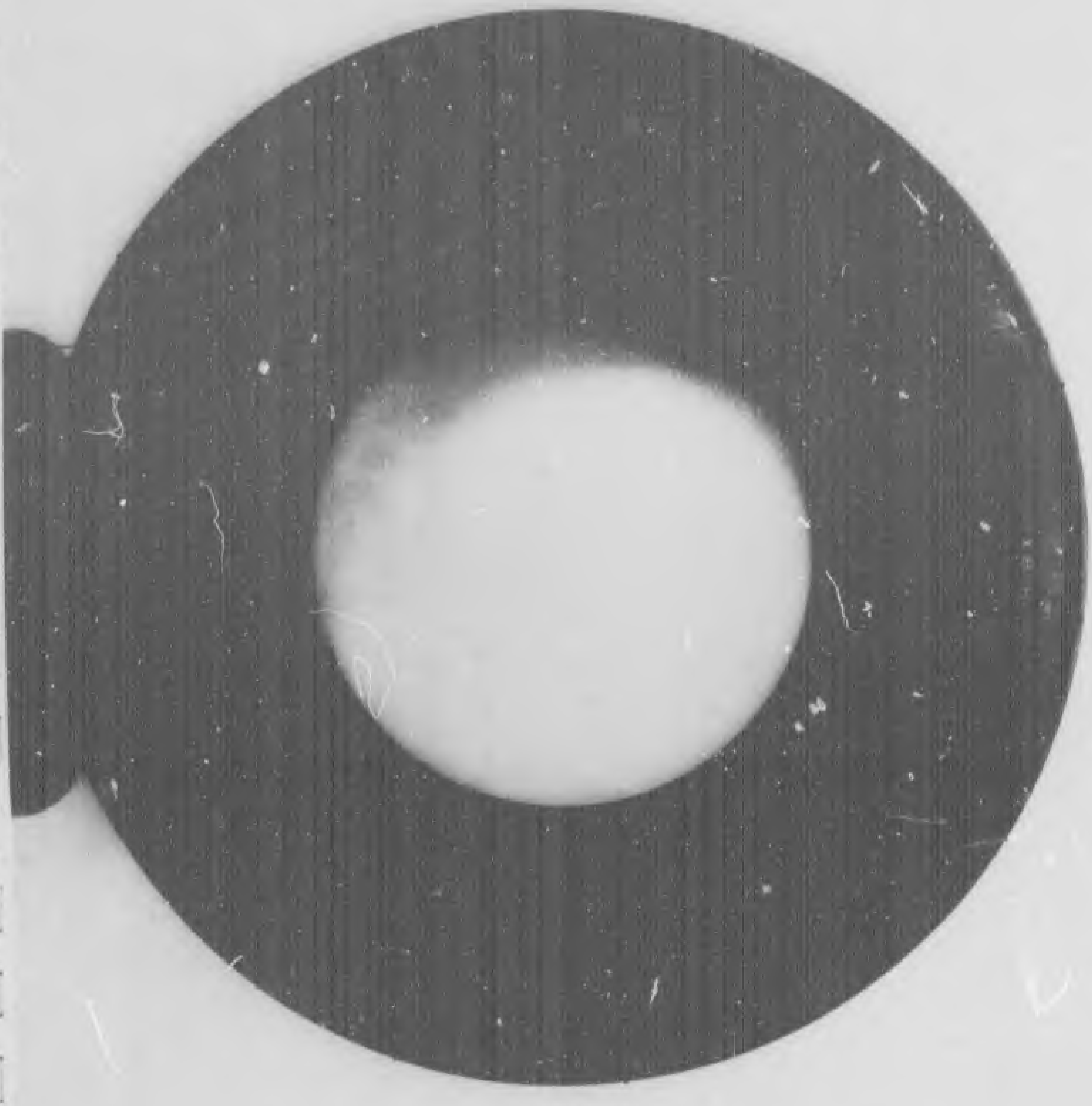


Fig. 9
SN 5421A-1

Fig. 10
SN 5421A-2

Fig. 11
SN 5421A-3

Fig. 12
SN 5421A-4

Fig. 13
SN 5421A-5

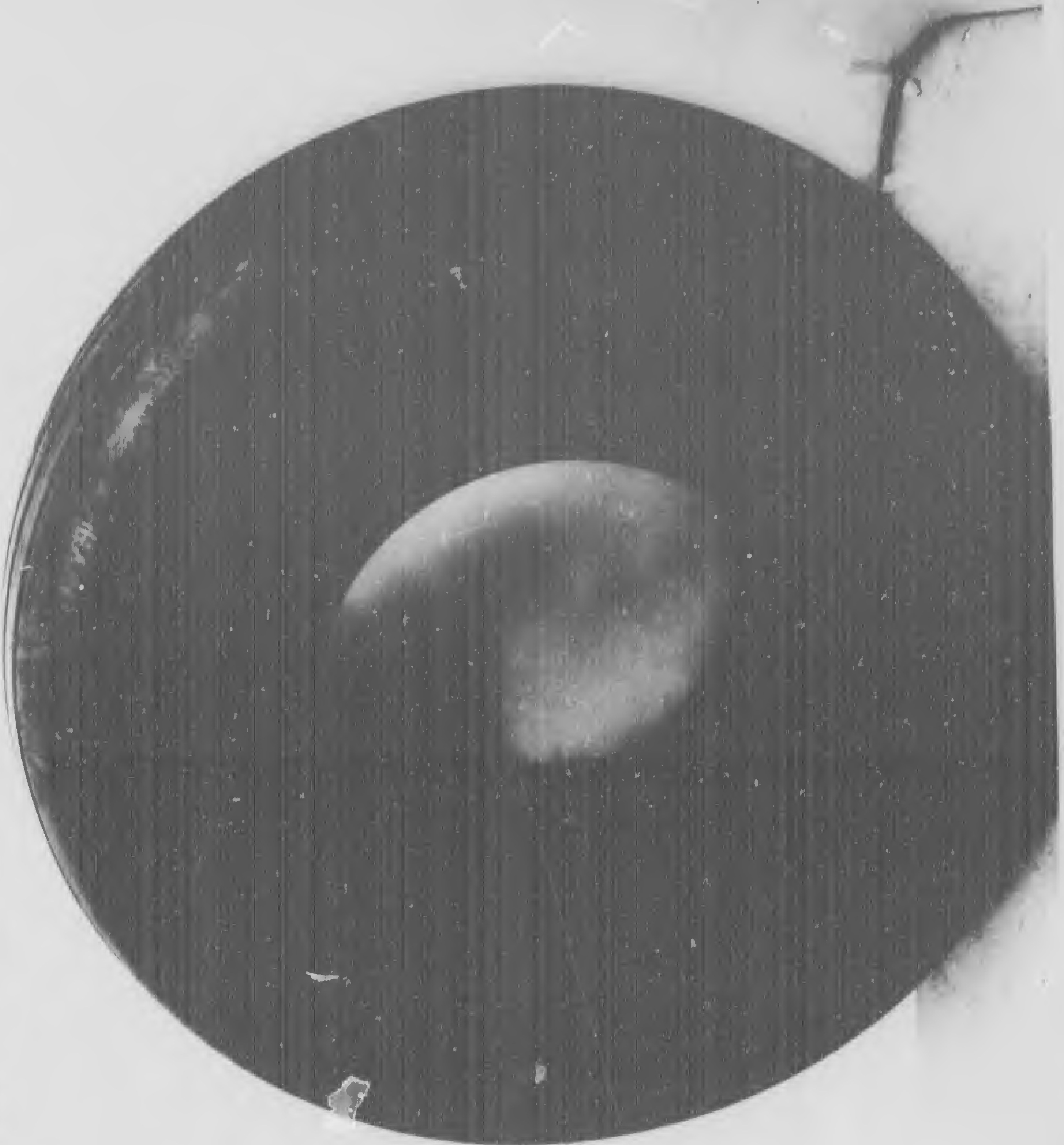


Fig. 14
SN 5421B-1

Figure 15
SN5421B-2

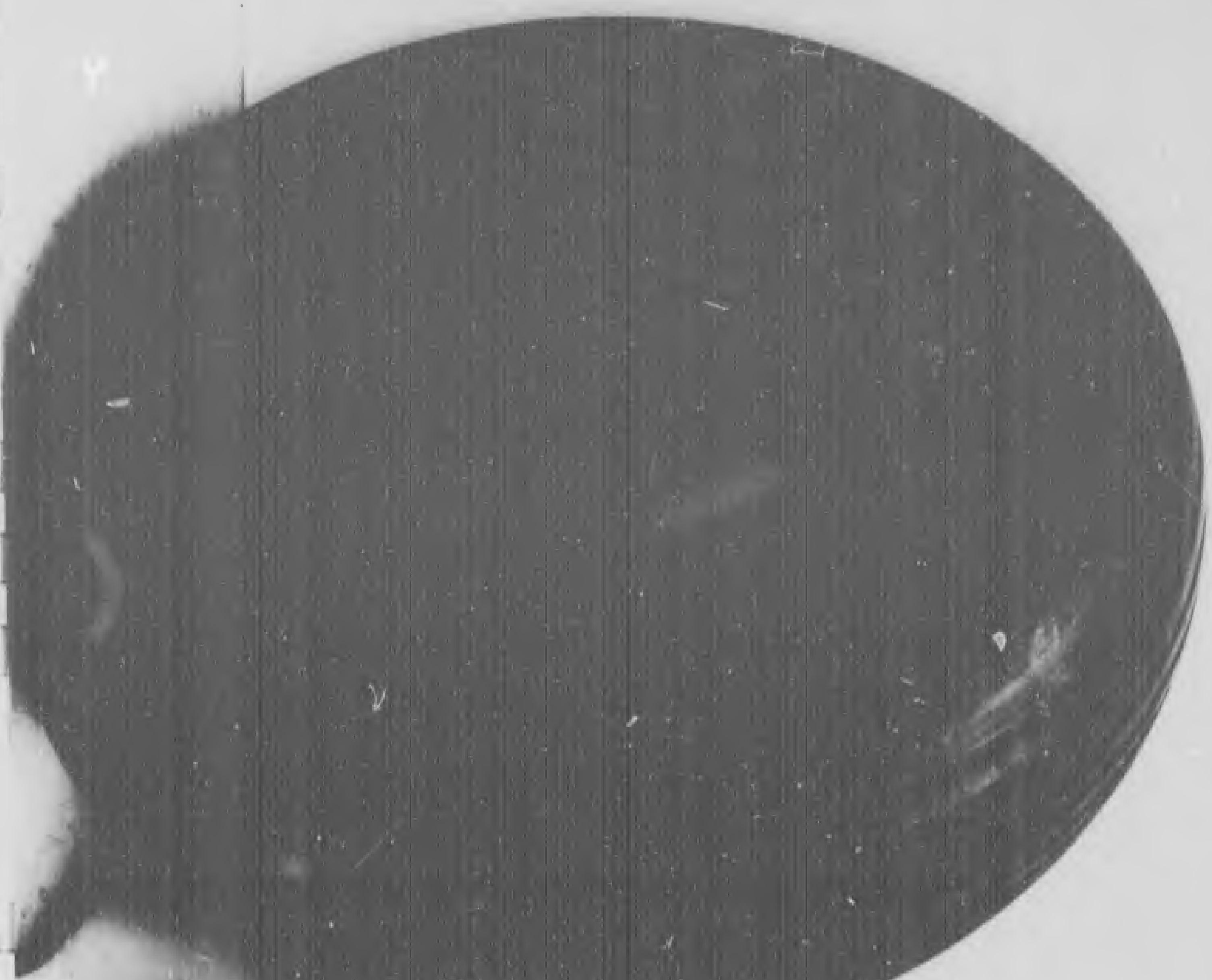


Fig. 16
SN 5421B-3

This comparison gave sufficient information for the minor adjustments in cure times and temperatures that were needed for the synthetic rubber test articles, without using the costly procedure of placing thermocouple wires throughout the tire and making temperature measurements during the cure of the first test article of each size. Thus there was no need to dissect and analyze the check tire for each size, as the cure conditions required for the synthetic rubber tires were in fact nearly identical to those already in use by the subcontractor.

The 30x8.8 22PR test articles were cured in a bladder-type press, using the production mold of the subcontractor. This mold had seven rather narrow grooves, two narrow shoulder ribs, six running ribs and the wear depth indicators required by USAF for this tire size. The mold skid depth was 0.22 inches. The green tires were inspected prior to being placed in the curing press, and were found to be intact with respect to ply turn-ups and beads. The synthetic materials showed no loss of green adhesion between tire components, indicating that the materials were at least equivalent to natural rubber materials in this respect.

The 49x17 26PR test articles were cured in a bag-type dome press, using the subcontractor's production mold. This mold had nine wide grooves (seven of 0.30 inch mold skid depth and two outer grooves of 0.20 inch mold skid depth), eight running ribs and two rounded shoulder ribs. The center running ribs were slightly narrower than were the other running ribs. The green tires were inspected before and after installation of the curing bag, and were found to be intact in all respects. The green tire was formed for a minimum of six hours on the bag prior to cure, with no resulting loosening of turn-ups.

Following curing, the test articles were thoroughly inspected, trimmed and balanced by the subcontractor, using normal factory methods. The rigorous inspections revealed no evidence of significant defects of any kind, other than a surface blemish on the sidewall of one 49x17 26PR tire (S/N 5421B-1). This tire was veneered successfully in a subsequent operation, as shown in the photograph in Task 7.

TASK 9: TIRE TESTING PROGRAM

The test articles produced in previous Tasks were subjected to dynamic qualification tests in this Task. Four of the 30x8.8 22PR test articles and two of the 49x17 26PR test articles were tested at the Undercarriage Laboratory of the Flight Dynamics Laboratory, Wright-Patterson Air Force Base. A Thompson engineer was present during all tests, to monitor test progress and observe any problems that developed during this work.

The dynamic test parameters used for these tests were taken from the following USAF Drawings:

1. 49x17 26PR : Drawing 60D2561J
2. 30x8.8 22PR: Drawing 60D90767J

The 30x8.8 tests were conducted using the 84 inch diameter-flywheel dynamometer. The 120 inch diameter-flywheel dynamometer was used for the 49x17 tests. The test articles were assumed to be uniform, tire to tire for a given size, so no effort was made to test the tires in numerical order.

Test results are detailed below. The dynamic test data sheets for each tire are attached at the end of this Task.

In summary, the test results indicated that the synthetic rubber materials were sound under dynamic test conditions. There was no evidence of failure in bead and casing areas of the tire. The tread area of the 49x17 26PR test articles remained sound in all respects except for the development of minor groove cracks in all grooves. This condition was considered typical for the particular tread formula used, as the sulfur-donor cure system does not have good resistance to groove cracking, even in natural rubber materials.

The tread area of the 30x8.8 22PR test articles had numerous chunks of tread lost during testing, down to the outermost ply of tread reinforcing fabric. This occurred primarily on the center ribs. A tread design change, in which the tread reinforcing fabric would be positioned differently in the ribs, would probably offset the tread chunking at rib edges. Using larger radii for grooves and rib edges would also help to elim nate this problem. Tread chunking occurs with test tires made with natural rubber materials if these two parameters of fabric placement and rib and groove shapes are not carefully designed.

To evaluate a different rib shape, the edges of the center ribs of one tire were sanded off prior to testing (S/N 5421-A-1). Rib undercutting occurred on this tire also, near the end of the 25 taxi-take off cycles, but to a lesser extent than on previous tires. The appearance of this test article at the end of the test was quite similar to that of the first article tested (S/N 5421-A-3), since the ribs rapidly undercut all the way around the tire following the initiation of the first area of undercutting.

Details of results for each test article follow.

Test Article: 30x8.8 22PR

Serial Number 5421A-3:

This test article completed 25 taxi-take off (A) cycles and 12 landing-taxi (B) cycles when the test was stopped. Numerous small cracks occurred in the two center ribs beginning on the fourth A cycle. These cracks developed in size until tread chunks occurred on the eighteenth A cycle. Then the ribs undercut along the outermost tread fabric ply, resulting in appreciable loss of ribs.

On the last A cycle, a small blister developed on one shoulder. This grew to the size of an egg by the twelvth B cycle, at which point the test was stopped to avoid destruction of the tread. The blister developed due to lack of vents in the shoulder area of this tire, and was located between the tread reinforcing plies and the outermost casing ply. This condition did not develop on any of the other test articles.

Serial Number 5421A-4:

This test article completed only three A cycles, at which time the tread area was badly chunked out. The dynamometer flywheel surface was left quite dirty from the previous tire test. This gummy deposit usually is removed as necessary during tests, however the cleaning was overlooked prior to the start of this test. The test was stopped as soon as the flywheel condition was observed by supervisors at the test facility, and upon agreement with the Thompson engineer present at the facility.

Serial Number 5421A-5:

The edges of the two center ribs of the tread of this test article were sanded off prior testing. The test article completed all taxi-take off, landing-taxi and camber taxi tests. Except for the loss of rubber of the two center tread ribs, the tire finished the test requirements successfully. A number of small cracks developed during the fourth A cycle, that grew into rib undercuts at the twentieth A cycle. From that point on, portions of the two ribs were lost in successive cycles to the extent of 180° of the circumference of one center rib, and 240° of the other center rib. All other portions of the tire remained intact and sound.

Serial Number 5421A-1:

The edges of the two center ribs of the tread of this test article were sanded off prior to testing. The test article completed all taxi-take off, landing-taxi, and camber taxi tests. Results were almost indentical to those for 5421A-5. Total loss of rubber in the center ribs was slightly less, however the cracks, chunks and rib undercuts appeared at the same points during the test spectrum.

Based on the test results obtained with these four test articles, it appeared that the test of the fifth test article (S/N 5421A-2) would not give any new, significant data. Thus it was agreed with the USAF project engineer that testing for this tire size would be halted at this point in the project. The attached photos illustrate typical tread appearance for each test article at the conclusion of testing.

Fig. 17

Fig. 10

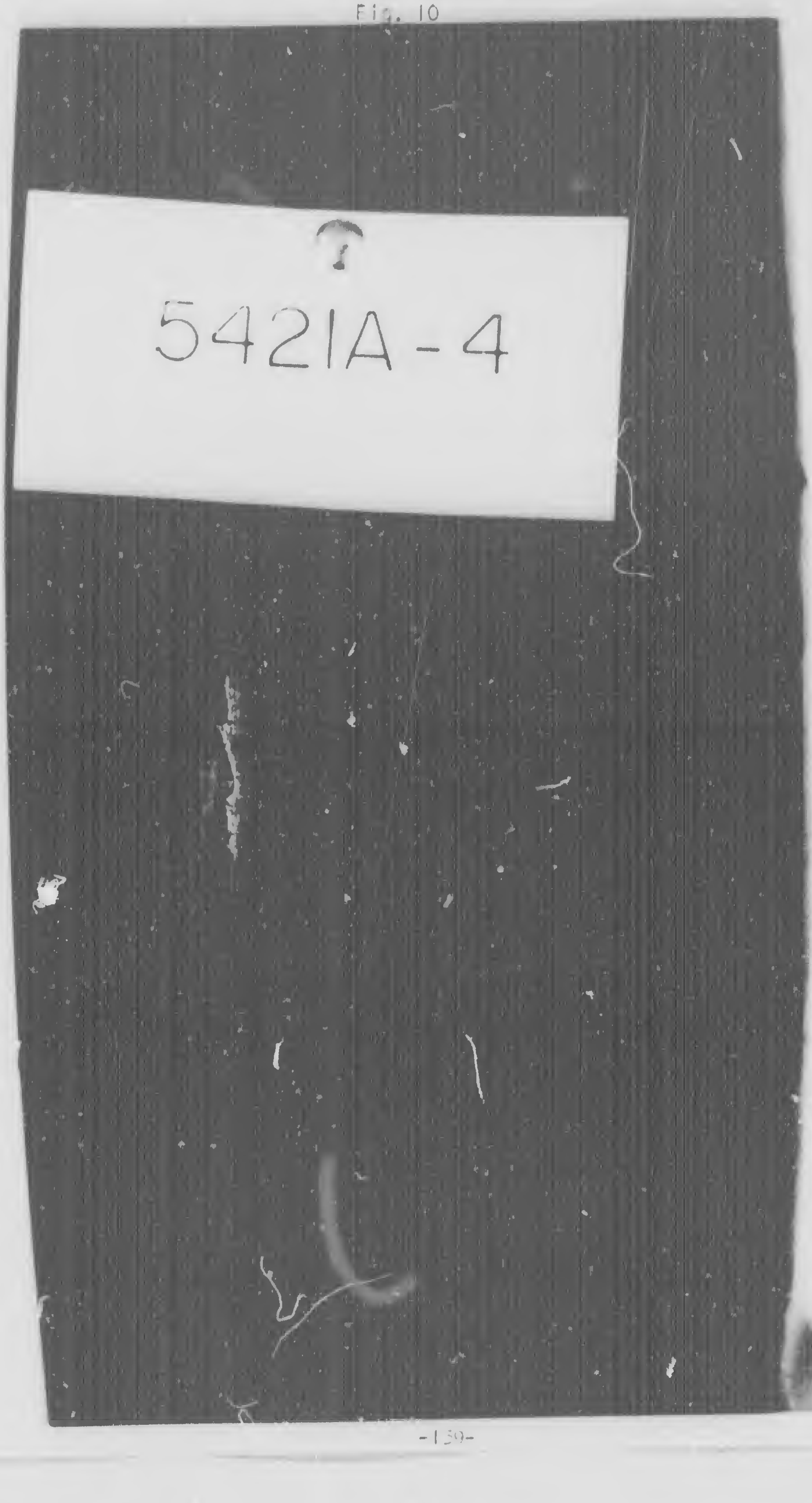


Fig. 19

Fig. 20

Test Article: 49x17 26PR

Serial Number 5421B-2:

This test article completed all test cycles successfully. The test spectrum included 75 taxi-take off (A) cycles, 75 landing-taxi (B) cycles, 10 long taxi (C) cycles, and 60 camber taxi (D) cycles.

The only sign of any problem with this tire occurred in the grooves, where minor groove cracking occurred in all grooves. The groove cracks developed during the A cycles, and did not change in depth or length in subsequent cycles. The largest crack was 1 inch long by 0.125 inchs wide (inflated tire) by 0.22 inches deep. The typical crack was 0.2 inches by 0.05 inches by 0.03 inches deep. Also, the cracks occurred primarily in the outer grooves, as shown in the photos.

The rest of the test article remained intact and sound in all respects, indicating that each of the several synthetic rubber materials had more than adequate performance under the dynamic test conditions. The test article thus could be considered to be qualified according to the USAF specifications for new aircraft tires.

Serial Number 5421B-3:

This test article was tested under the same dynamic spectrum as the 5421B-2 test article. The two tests were conducted simultaneously, to make the best use of available dynamometer test time.

Groove cracks developed on this tire early in the A cycles, as they had on the 5421B-2 test article. The test was stopped during the 36th B cycle when the test wheel failed due to flange fatigue. The wheel failure damaged the beads to such an extent that the tire could not be remounted. The extent of this damage is shown in the photos. Several of the bead cuts penetrated to the bead wire.

Since one test article had successfully completed all dynamic tests, and the second test article appeared to be sound up to the point of the wheel failure incident, it was agreed with the USAF project engineer that no further testing of this tire size should be undertaken. The attached photos illustrate the tread and bead area appearances of each test article at the conclusion of testing.

FIG. 21

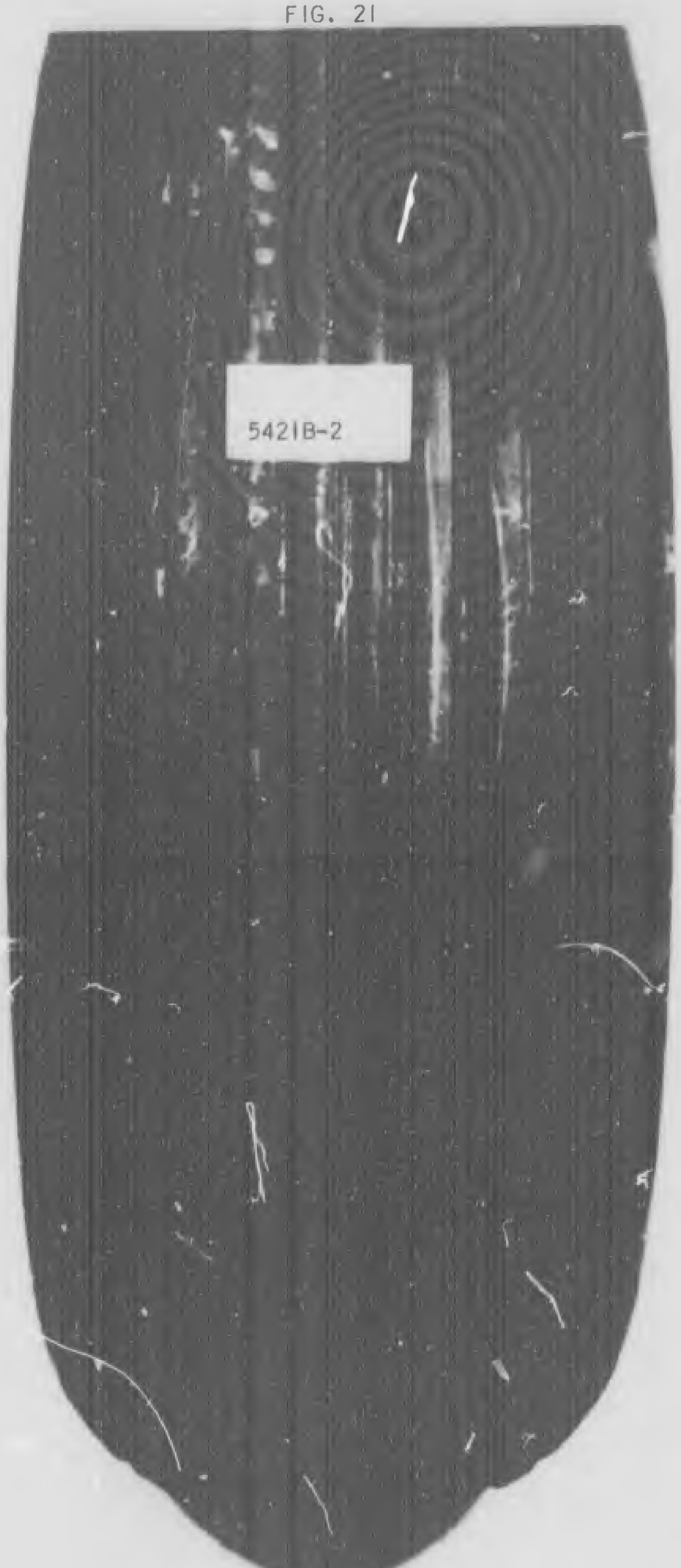


Fig. 22

Fig. 23

Fig. 24

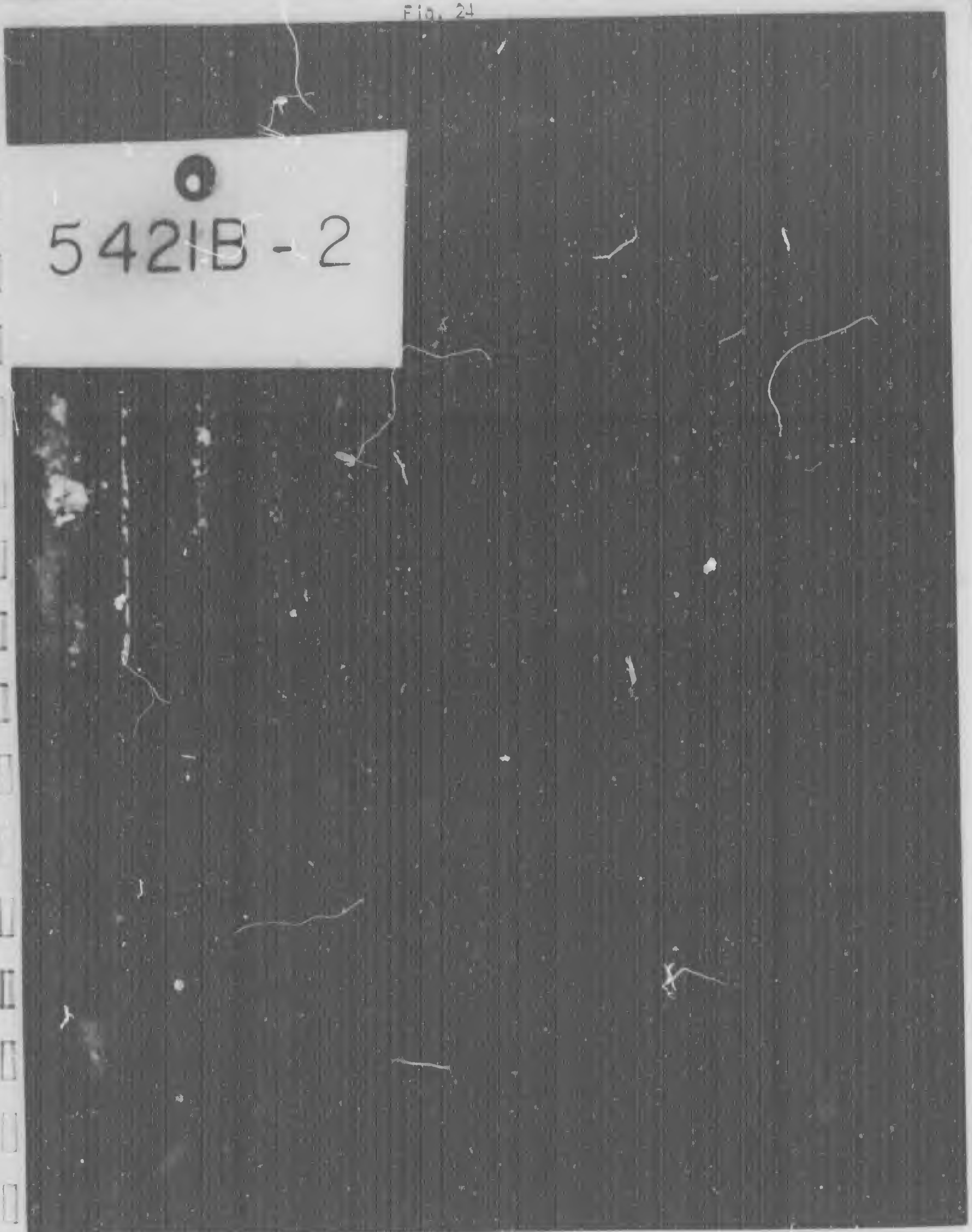


Fig. 25

Fig. 26

Fig. 27

Fig. 28

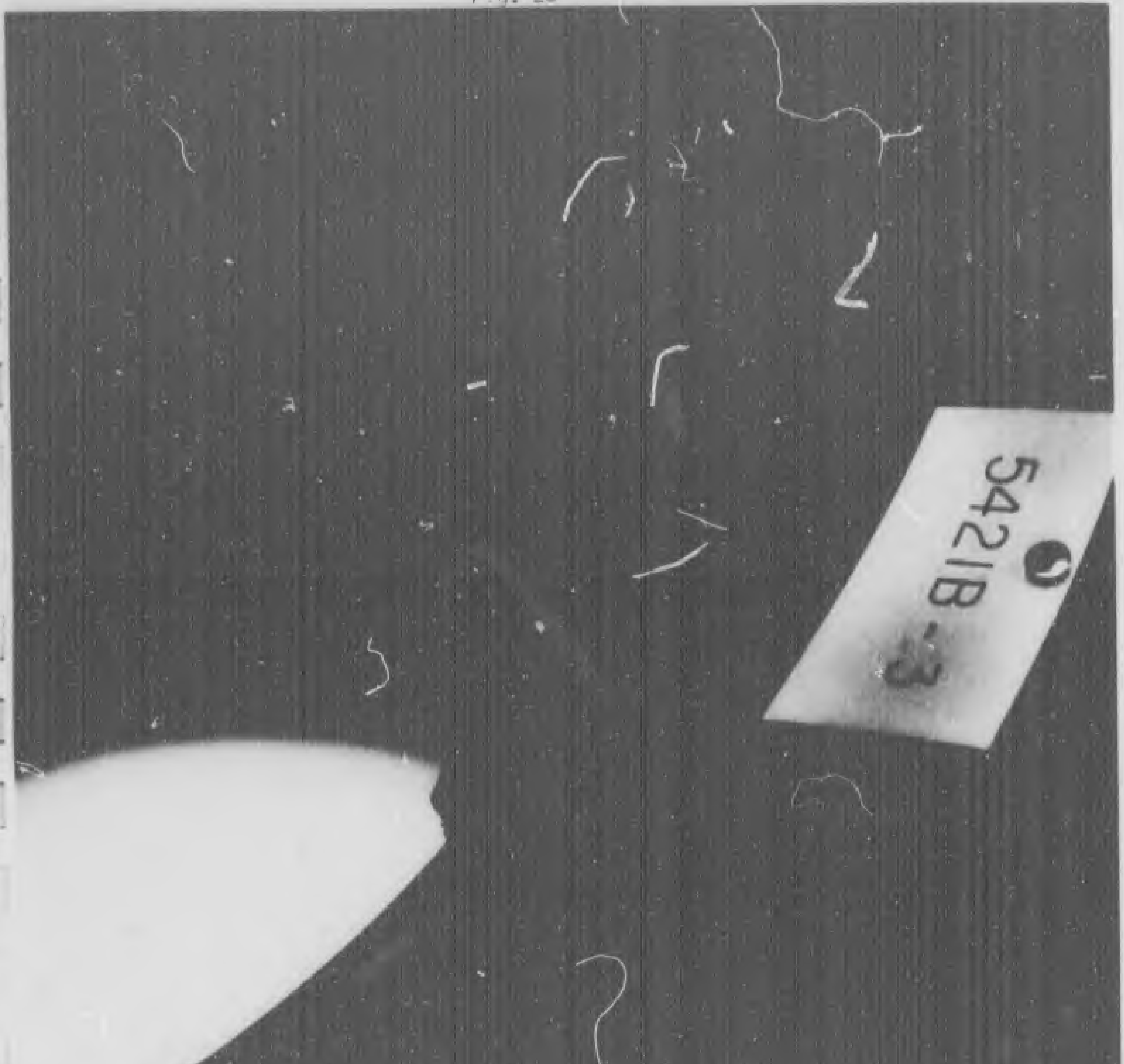
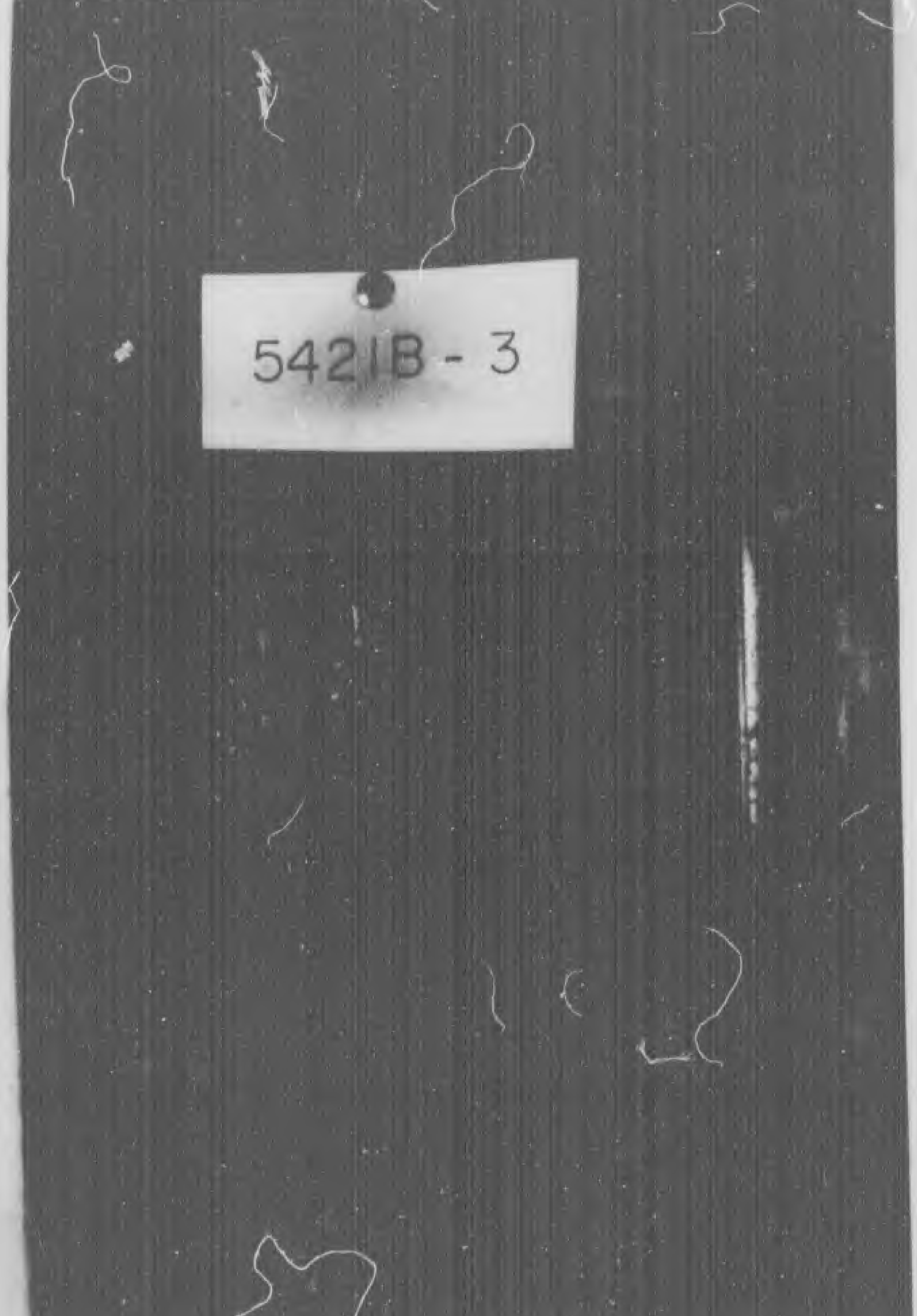


Fig. 29

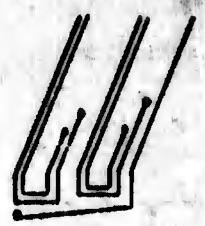


APPENDIX I

PHASE II

TIRE CONSTRUCTION DETAILS

TABLE LV AIRCRAFT TIRE CONSTRUCTION SPECIFICATION 30 x 8.8

AIRCRAFT TIRE CONSTRUCTION SPECIFICATION				
SIZE	30 x 8.8	CURED GAGES		BEAD TIE-IN
TYPE	VII, TL	TREAD ℄	0.29	
PLY RATING	22	TOTAL ℄	0.85	
PLY ACTUAL	10	TRD SHLDR	0.39	
TREAD TYPE	FAB REINF	TOT SHLDR	0.95	
SKID DEPTH	0.22	SIDEWALL	0.64	
BEAD DIAM	15 INCH	BEAD WIDTH	1.98	PLIES: 2-2-2-2-2
BLDG DRUM	7" CROWN-SEE FIG 5		DRUM WIDTH 12.2	

BEAD SET RING DIAM		WIRE DIAM	ASSEMBLY	APEX	FLIPPER
1st	15.14	15.30	A	A	A
2nd	15.30	15.46	B	B	B
3rd					

SEE TABLE LVI FOR MATERIAL AND CONSTRUCTION DETAILS

PLIES	1,2	3,4	5,6	7,8	9,10	FT#1	FT#2			
MATERIAL	A	A	A	A	B	C	C			
WIDTH	26.25	24.25	26.50	24.25	25.0	8.5	7.75			
LENGTH	63.5	63.3	64.3	64.1	66.0	68.2	68.2			
ANGLE	52	52	52	52	51.5	51L	51R			
OFFSET	0.75	0.5	0.75	0.75	EVEN	CTR	CTR			
ENDING	2.5	1.5	3.5	2.5	TOE					

SEE TABLE LVII 3 FOR MATERIAL AND LAYUP OF PLIES

CHAFER	SINGLE PLY - SEE FIGURE 3 FOR MATERIAL AND LAYUP						
WIDTH	4.5	LENGTH	49.0	SET	18.0	END	TURNUP

SIDEWALL	EXTRUDED TO CONTOUR-SEE FIG 4 FOR MAT'L AND CONTOUR						
WIDTH	5.0	LENGTH	57.0	SET	4.75	END	16.5

TREAD	EXTRUDED TO CONTOUR-SEE FIG 4 FOR MAT'L AND CONTOUR						
WIDTH	10.5	LENGTH	72.3	CUSHION WIDTH	9.0	GAGE	.020

BUILDING INSTRUCTIONS:		CALCULATED WEIGHT	67.1 LBS
PRE-SHAPING PRIOR TO CURE		CURE: TO BE DETERMINED	
AIRBAG CURE	12 HRS @ 25 PSI	MOLD	SEE FIGURE 5
BLADDER CURE	PAUSE 5 MIN @ 10 IN. OPEN	RINGS	SEE FIGURE 5

SEE TABLE LIX5 FOR CURING EQUIPMENT CONTOURS AND INSTRUCTIONS

TABLE LVI BEAD MATERIAL AND CONSTRUCTION DETAILS 30 x 8.8

BEAD MATERIAL AND CONSTRUCTION DETAILS

BEAD WIRE HIGH TENSILE STEEL WIRE, 0.036 DIAM. ANNEALED, BRASS COATED, INSULATED TO 0.066 DIAMETER, OR 0.030 GUM BETWEEN WIRES.

BEAD INSULATION COMPOUND BN EXTRUDED

BEAD WRAP RAYON 0.015 GAGE, SQUARE WOVEN TO 0.031 GAGE, FRICTION COAT, CUT TO 0.5 INCH WIDE STRIPS, SPIRAL WIND AROUND BEAD BUNDLE, BUTT-TO 1/16 GAP BETWEEN TURNS, COMPOUND BW

APEX STRIP COMPOUND FF EXTRUDED, APPLY NARROW SIDE TO TOP OF WRAPPED BEAD BUNDLE.

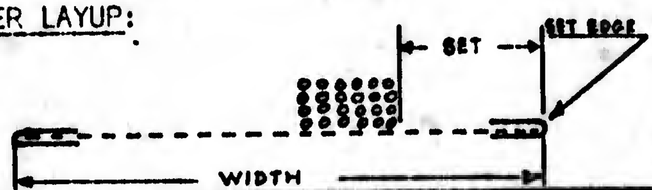
APEX CONTOURS:

A B

FLIPPER NYLON 840/2 @ 0.021 GAGE, 26 EPI, EVEN COAT BOTH SIDES TO TO 0.031 GAGE, COMPOUND BW. BIAS CUT TO 60°L, GUM STRIP EDGES WITH 0.8 WIDE x 0.020 GAGE, COMPOUND BW.

FLIPPER	SET	WIDTH
A	1.5	4.0
B	2.0	5.0
C		

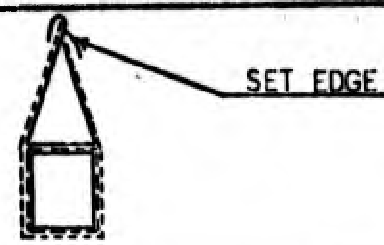
FLIPPER LAYUP:



BEAD ASSEMBLY		
BEAD	HEIGHT	WIDTH
A	13	10
B	16	10
C		

BEAD ASSEMBLY:

CASING SIDE



BEAD INSERTS COMPOUND CC, 0.30 WIDE x 0.100 GAGE, APPLY STRIP IN GROOVE BETWEEN TURNED UP PLIES BEFORE LAST BAND IS TURNED DOWN AND TRIMMED AT TOE OF 1st BEAD.

TABLE LVII FABRIC MATERIAL AND CONSTRUCTION DETAILS 30 x 8.8

FABRIC MATERIAL AND CONSTRUCTION DETAILS

MAT'L	CORD	EPI	GAGE	COAT
A	1260/3	32	.038	EVEN
B	1260/3	26	.038	EVEN
C	1260/3	26	.038	EVEN

CASING COMPOUND CC

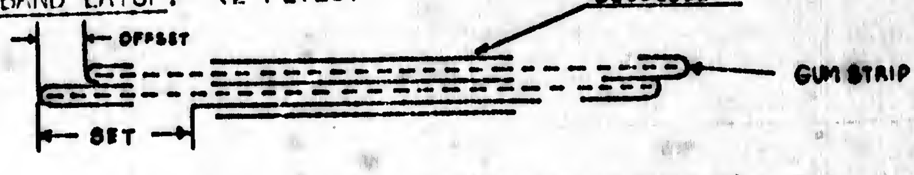
SQUEEGEE ON PLIES

LOCATION	COMPOUND	GAGE	WIDTH
BOT 1st	LL	.040	21.0
" 1st	LL	.040	20.0
TOP 1-4	CC	.008	14.0
" 5-8	"	.015	13.0
" 9	"	.015	12.0
BOT FT#1	"	.060	9.2
TOP FT#1	"	.020	8.7
GUM STRIP	"	.020	1.5

NOTE: SQUEEGEE ON PLIES CALENDERED HOT. LINER BOTTOM 1st PLY APPLIED HOT IN TWO PASSES. SET FIRST LAYER 2.5 INCH FROM EDGE OF PLY, CENTER SECOND LAYER ON FIRST. OFFSET 2nd PLY FROM SAME EDGE

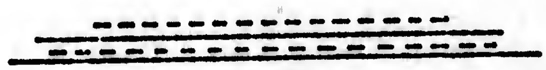
GUM STRIPS ARE APPLIED TO EDGES OF PLIES WHEN BUILT INTO BANDS

CASING BAND LAYUP: (2 PLIES)



TUBELESS LINER (BOTTOM 1st PLY ONLY)

FABRIC TREAD BAND LAYUP:



CHAFER: SINGLE PLY, MONOFILAMENT NYLON 0.015 GAGE, SQUARE WOVEN TO 0.31 GAGE, CALENDERED WITH COMPOUND BW TO .042 GAGE, UNBALANCED, HEAVY SIDE TO CASING, BIAS CUT TO 45° ANGLE, EDGE GUM STRIP 0.8 WIDE x 0.020 GAGE, COMPOUND BW.

CHAFER LAYUP: CASING SIDE SET THIS EDGE

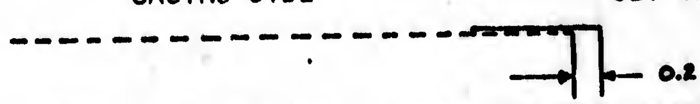


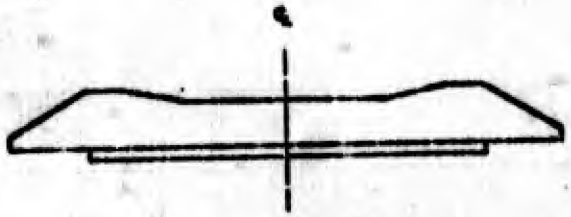
TABLE LVIII EXTRUDED TREAD AND SIDEWALL DETAILS 30 x 8.8

EXTRUDED TREAD AND SIDEWALL DETAILS

TREAD MATERIAL	COMPOUND TT															
TREAD CONTOUR	FIGURES ARE 0.01 INCH, AT 0.5 INCH INTERVALS															
35	35	40	40	40	45	45	33	22	12	3	-	HALF WIDTH FROM ℄				
TREAD CUSHION	COMPOUND CC															
CUSHION WIDTH	9.0	CUSHION GAGE	.020													

TREAD WT. PER INCH	.1425	TOTAL TREAD WEIGHT	10.25
CUSHION WT. PER INCH	.0073	TOTAL CUSHION WEIGHT	.53
		WEIGHT AS APPLIED	10.78

TREAD-CUSHION LAYUP:



SIDEWALL MAT'L	TT	WT/INCH	0.242	TOT. WT.	1.375
SIDEWALL CONTOUR	FIGURES ARE 0.01 INCH AT 0.5 INCH INTERVALS				

3	9	15	15	10	10	10	10	12	8	3									

SIDEWALL LAYUP:

NOTE: Notch die to form line on sidewall 1 inch from left edge. Set sidewall on casing with die line up and out before applying tread.

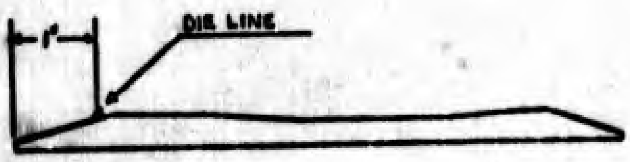
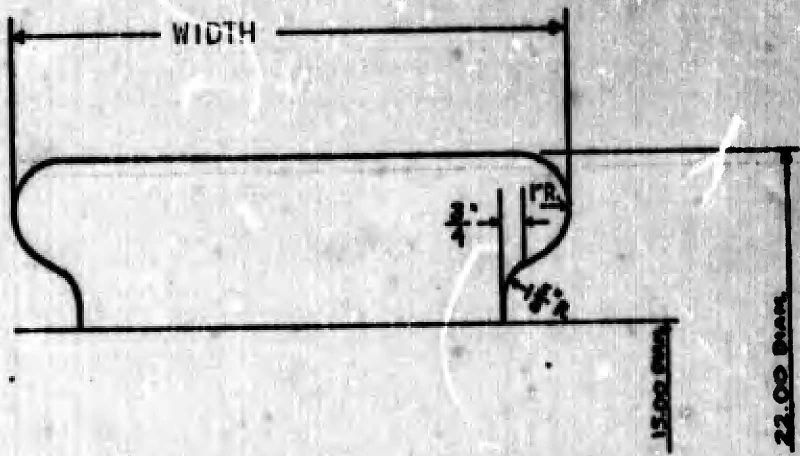


TABLE LIX BUILDING AND CURING EQUIPMENT 30 x 8.8

BUILDING AND CURING EQUIPMENT

BUILDING DRUM COLLAPSIBLE, METAL, 7" CROWN



CURING MOLD STANDARD 30x8.8 MOLD DESIGNED TO MEET SPECIFICATIONS OF AF DRAWING NUMBER 60D 90767

MOLD RINGS MUST MATE CURING MOLD

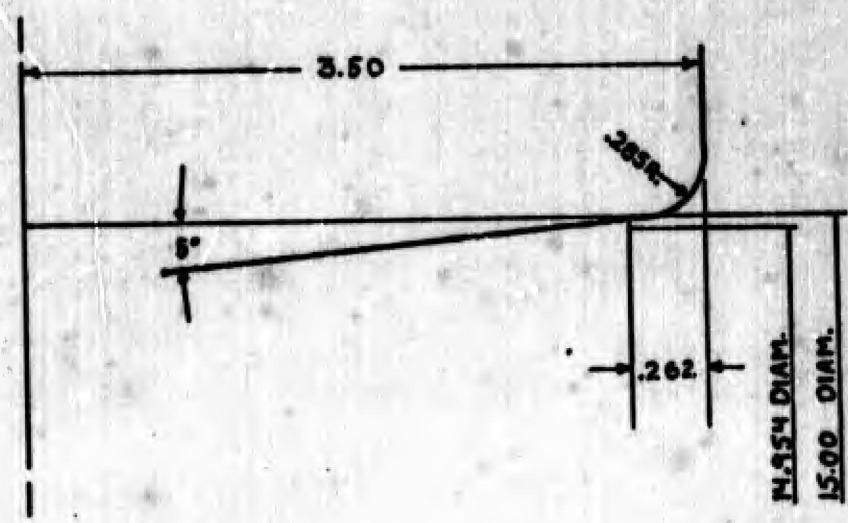
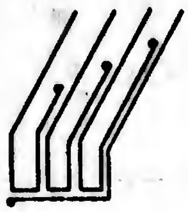


TABLE LX AIRCRAFT TIRE CONSTRUCTION SPECIFICATION 49 X 17

AIRCRAFT TIRE CONSTRUCTION SPECIFICATION

SIZE	49x17	CURED GAGES		BEAD TIE-IN
TYPE	VII TL	TREAD L	.43	
PLY RATING	26	TOTAL L	1.19	
PLY ACTUAL	10	TRD SHLDR	.73	
TREAD TYPE	FAB REINF	TOT SHLDR	1.49	
SKID DEPTH	.33	SIDEWALL	.86	
BEAD DIAM	20 INCH	BEAD WIDTH	2.48	PLIES: 3,3,2,2



BLDG DRUM	8" CROWN-SEE FIG 10	DRUM WIDTH	29.5

BEAD SET RING DIAM		WIRE DIAM	ASSEMBLY	APEX	FLIPPER
1st	20.06	20.22	A	A	A
2nd	20.20	20.36	B	B	B
3rd	20.26	20.42	C	C	C

SEE TABLE LXI 7 FOR MATERIAL AND CONSTRUCTION DETAILS

PLIES	1-3	4-6	7,8	9,10	FT#1	FT#2				
MATERIAL	A	A	A	B	C	C				
WIDTH	43.25	44.4	48.75	42.75	18.75	17.5				
LENGTH	80.6	82.0	82.9	83.4	87.5	87.5				
ANGLE	61½	61½	61	61	60	60				
OFFSET	0.75	0.75	1.0	EVEN	CTR	CTR				
ENDING	2.5	3.75	6.0	TOE						

SEE TABLE LXII 8 FOR MATERIAL AND LAYUP OF PLIES

CHAFER	2 PLY - SEE FIGURE 8 FOR MATERIAL AND LAYUP						
WIDTH	5.7	LENGTH	67.5	SET	24.0	END	TURNUP
SIDEWALL	EXTRUDED TO CONTOUR-SEE FIG 9 FOR MAT'L AND CONTOUR						
WIDTH	10.5	LENGTH	74.5	SET	9.5	END	21.5
TREAD	EXTRUDED TO CONTOUR-SEE FIG 9 FOR MAT'L AND CONTOUR						
WIDTH	21.0	LENGTH	90.0	CUSHION WIDTH	19.3	GAGE	.020

BUILDING INSTRUCTIONS:		CALCULATED WEIGHT	191.3
PRE SHAPING PRIOR TO CURE		CURE: TO BE DETERMINED	
AIRBAG CURE	12 HRS @ 25 PSI	MOLD	SEE FIGURE 10
BLADDER CURE	PAUSE 5 MIN @ 18 IN OPEN	RINGS	SEE FIGURE 10

SEE TABLE LXIV 10 FOR CURING EQUIPMENT CONTOURS AND INSTRUCTIONS

TABLE LXI BEAD MATERIAL AND CONSTRUCTION DETAILS 49 x 17

BEAD MATERIAL AND CONSTRUCTION DETAILS

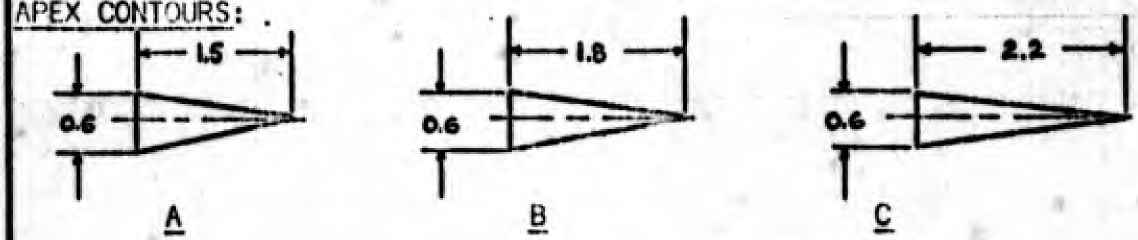
BEAD WIRE HIGH TENSILE STEEL WIRE, 0.036 DIAM. ANNEALED BRASS COATED, INSULATED TO 0.066 DIAMETER, OR 0.030 GUM BETWEEN WIRES

BEAD INSULATION COMPOUND BN EXTRUDED

BEAD WRAP RAYON 0.015 GAGE, SQUARE WOVEN TO 0.031 GAGE, FRICTION COAT, CUT TO 0.5 INCH WIDE STRIPS, SPIRAL WIND AROUND BEAD BUNDLE, BUTT TO 1/16 GAP BETWEEN TURNS, COMPOUND BW

APEX STRIP COMPOUND FF EXTRUDED, APPLY NARROW SIDE TO TOP OF WRAPPED BUNDLE

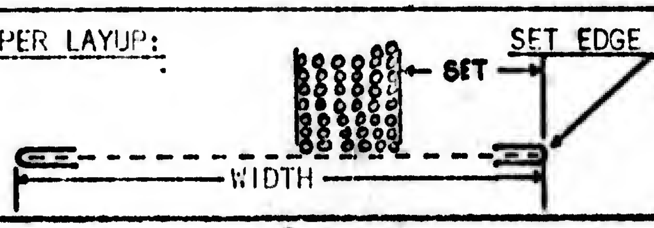
APEX CONTOURS:



FLIPPER NYLON 840/2 @ 0.021 GAGE, 26 EPI, EVEN COAT BOTH SIDES TO 0.031 GAGE, COMPOUND BW, BIAS CUT TO 60°L, GUM STRIP EDGES WITH 0.8 WIDE x 0.020 GAGE, COMPOUND BW

FLIPPER	SET	WIDTH
A	2.5	6.0
B	2.8	6.8
C	3.5	7.8

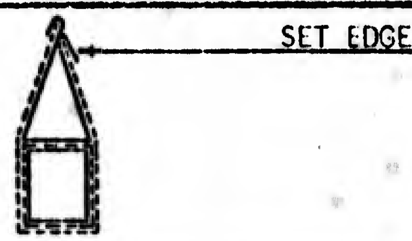
FLIPPER LAYUP:



BEAD ASSEMBLY		
BEAD	HEIGHT	WIDTH
A	12	8
B	14	8
C	16	8

BEAD ASSEMBLY:

CASING SIDE



BEAD INSERTS COMPOUND CC 0.30 WIDE x 0.100 GAGE, APPLY STRIP IN GROOVES BETWEEN TURNED UP PLIES BEFORE LAST BAND IS TURNED DOWN AND TRIMMED AT TOE OF 1st BEAD.

FABRIC MATERIAL AND CONSTRUCTION DETAILS

MAT'L	CORD	EPI	GAGE	COAT
A	1260/3	32	.038	EVEN
B	1260/3	26	.038	EVEN
C	1260/3	26	.038	EVEN

CASING COMPOUND CC

SQUEEGEE ON PLIES

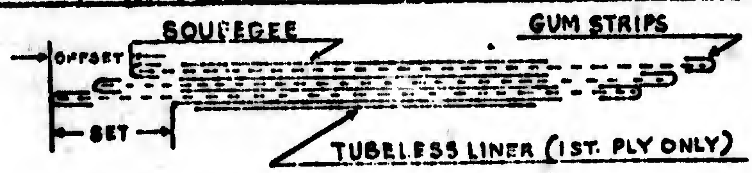
LOCATION	COMPOUND	GAGE	WIDTH
BOT 1st	LL	.040	38.5
" 1st	LL	.040	38.0
TOP 1-3	CC	.008	32.0
" 4-6	"	.015	30.0
" 7,8	"	.015	28.0
" 9	"	.030	26.0
BOT FT#1	"	.060	19.5
TOP FT#1	"	.020	19.0
GUM STRIPS	"	.020	1.5

NOTE: SQUEEGEE ON PLIES IS CALENDERED HOT, LINER BOTTOM 1st PLY APPLIED HOT IN TWO PASSES. SET FIRST LAYER 3.25 INCH FROM EDGE OFF PLY, CENTER SECOND LAYER ON FIRST, OFFSET 2nd AND 3rd PLIES FROM SAME EDGE.

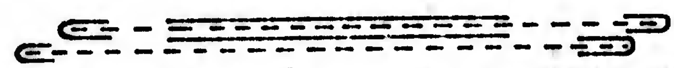
GUM STRIPS ARE APPLIED TO EDGES OF PLIES WHEN BUILT INTO BANDS

CASING BAND LAYUP:

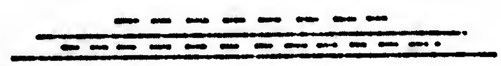
(3 PLY BAND)



(2 PLY BAND)



FABRIC TREAD BAND LAYUP:



CHAFER	2 PLY MONOFILAMENT NYLON 0.015 GAGE, SQUARE-WOVEN TO 0.031 GAGE, CALENDERED WITH COMPOUND BW TO .042 GAGE, UNBALANCED, HEAVY SIDE TO CASING, BIAS CUT TO 45°L, GUM STRIP EDGE 0.8 WIDE x .020 GAGE, COMPOUND BW

CHAFER LAYUP: CASING SIDE

1st PLY WIDTH 4.0
2nd PLY WIDTH 5.25
OV'LL WIDTH 5.75
SET THIS EDGE

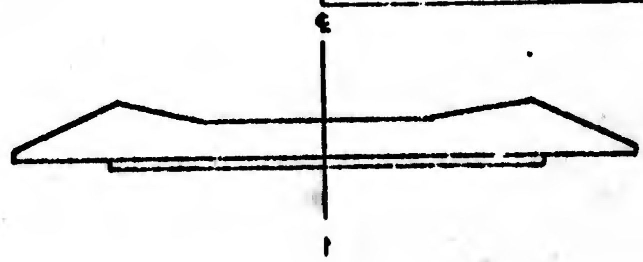
TABLE LXIII EXTRUDED TREAD AND SIDEWALL DETAILS 49 X 17

EXTRUDED TREAD AND SIDEWALL DETAILS

TREAD MATERIAL	TT
TREAD CONTOUR	FIGURES ARE 0.01 INCH, AT 1.0 INCH INTERVALS

50	55	60	63	70	80	88	98	85	70	40	6	-	HALF	WIDTH	FROM ℄		

TREAD CUSHION	COMPOUND CC		
CUSHION WIDTH	19.3	CUSHION GAGE	.020
TREAD WT. PER INCH	.599	TOTAL TREAD WEIGHT	53.90
CUSHION WT. PER INCH	.0313	TOTAL CUSHION WEIGHT	2.72
TREAD-CUSHION LAYUP:		WEIGHT AS APPLIED	56.62



SIDEWALL MAT'L	TT	WT/INCH	0.062	TOT. WT.	4.54
SIDEWALL CONTOUR	FIGURES ARE 0.01 INCH AT 1.0 INCH INTERVALS				

6	23	12	9	9	11	13	18	22	15	10	6							

SIDEWALL LAYUP:

NOTE: Notch die to form line on sidewall 1 inch from left edge. Set sidewall on casing with die line up and out before applying tread.

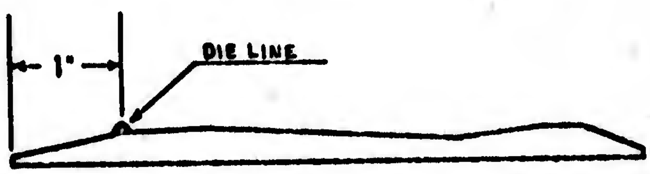
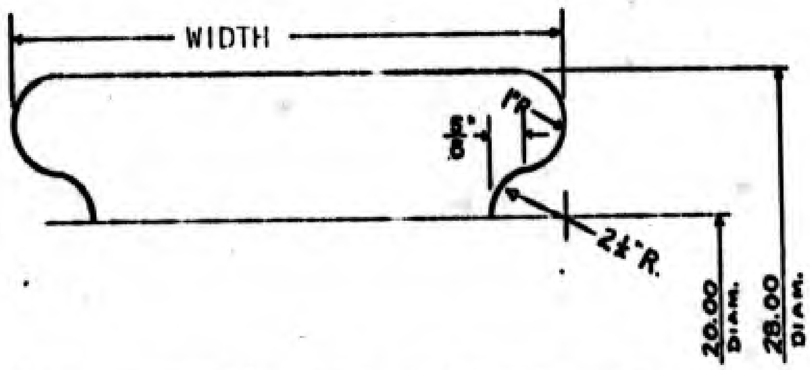


TABLE LXIV BUILDING AND CURING EQUIPMENT

BUILDING AND CURING EQUIPMENT	
BUILDING DRUM	COLLAPSABLE, METAL, 8" CROWN
CURING MOLD	STANDARD 49x17 MOLD DESIGNED TO MEET SPECIFICATIONS OF A.F. DRAWING NUMBER 60D 2561
MOLD RINGS	MUST MATE CURING MOLD



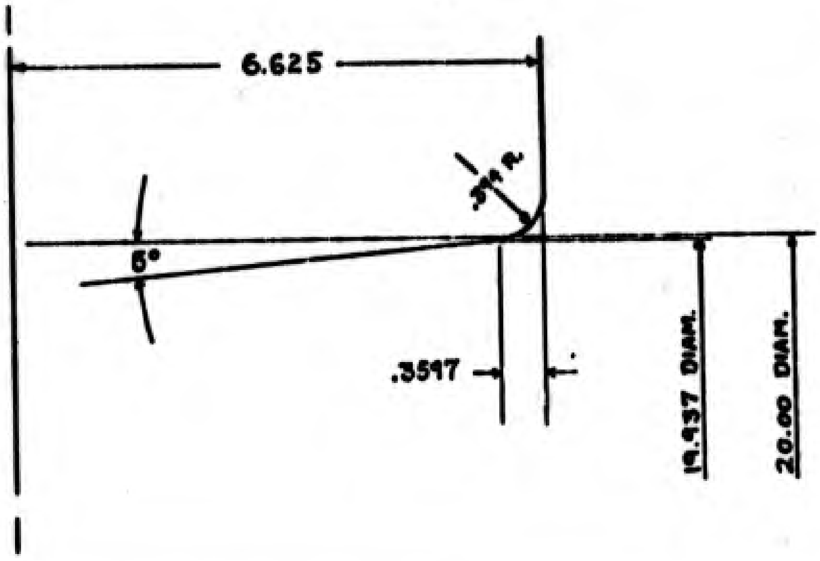


TABLE LXV COMPOUND CODE KEY

COMPOUND CODE KEY	
COMPOUND CODE	EXPLANATION
TT	TREAD AND SIDEWALL COMPOUND
CC	CASING CORD TREATMENT, CUSHIONS AND GUM STRIPS
FF	BEAD APEX (FILLER) COMPOUND
BW	BEAD WRAP AND CHAFER TREATMENT AND CHAFER GUM STRIP
BN	BEAD WIRE INSULATION COMPOUND
LL	TUBELESS LINER CUSHION COMPOUND

THESE MATERIALS HAVE BEEN INDIVIDUALLY COMPOUNDED TO PERFORM AS INTENDED BY THE SPECIFICATION. THE FORMULATIONS ARE THE BEST OF THOSE DEVELOPED IN TASK I. THEY ARE NOT INTER CHANGEABLE.

APPENDIX II

PHASE III

UNDERCARRIAGE LABORATORY

TIRE TEST DATA

TABLE LXVI 30 X 8.8 TIRE TEST DATA

UNDERCARRIAGE LABORATORY TIRE TEST DATA				TEST NO. [illegible] (30x8.8)
MANUFACTURER [illegible]		[illegible]-N	[illegible]-N	DATE
TEST DATE		[illegible]	[illegible]	
TEST SPECIFICATION		[illegible]-J	[illegible]-J	
SIZE & PLY RATING		[illegible]x8.8/22	30x8.8/22	
SERIAL NUMBER		[illegible]	[illegible]	
TIRE WT & TYPE		[illegible]	[illegible]	
DIMENSIONS (12 Hrs em'n)				
RATED INFLATION	PSI	3[illegible]	300	
OUTSIDE DIAMETER	Inches	30.[illegible]	[illegible]	
CROSS SECTION	Inches	[illegible]	[illegible]	
SHOULDER DIMENSION	Inches	[illegible]	6.[illegible]97	
ROLLING RADIUS	Inches	12.4[illegible]	13.2[illegible]	
FLAT PLATE DEFL	%	[illegible].1[illegible]	30.10[illegible]	
FOOTPRINT AT	Print			
HIGH SPEED TAKE-OFF				
FLYWHEEL O. D.	Inches	[illegible]	8[illegible]	
TEST INFLATION	PSI	358	3[illegible]	
ACCELERATION	FPS	[illegible].37 Ft/sec^2	[illegible].37 Ft/sec^2	
SPEED RANGE	MPH	[illegible]0 - 0 - 250	40 - 0 - 2[illegible]	
LOAD RANGE	LBS	21,000	21,000	
DISTANCE	FT	13,500 + 12,500	13,500 + 1[illegible]	
NUMBER OF TAKE-OFFS		[illegible]	2	
HIGH SPEED LANDINGS				
FLYWHEEL O. D.	Inches	84		
TEST INFLATION	PSI	358		
DECELERATION	FPS	8.5 Ft/sec^2		
SPEED RANGE	MPH	210-40		
LOAD RANGE	LBS	11,500		
DISTANCE	FT	5375 + 13,500		
NUMBER OF LANDINGS		12		
[illegible] & TAXI				
FLYWHEEL O. D.	Inches			
[illegible] CAMBER				
TIRE LOAD	LBS			
TEST INFLATION	PSI			
SPEED RANGE	MPH			
DISTANCE	FT			
NUMBER OF LANDINGS				

REMARKS: [illegible] tire, [illegible] Number 1-N completed [illegible] test [illegible] and incurred [illegible] center rib. [illegible] tire, [illegible] Number 2-N completed 2 test cycles and incurred 20 inches [illegible] center and outboard center ribs.

[illegible] 1-N (4[illegible]) hours
[illegible] ([illegible])

PREPARED BY John L. [illegible]
APPROVED BY [illegible]
[illegible] BY

NOT REPRODUCIBLE

TABLE LXVI (CONTINUED)

UNDERCARRIAGE LABORATORY TIRE TEST DATA				TEST NO. [illegible]
MANUFACTURER [illegible]		3-N	4-N	DATE [illegible]
TEST DATE		[illegible]	[illegible]	
TEST SPECIFICATION		[illegible]	[illegible] 7-J	
SIZE & PLY RATING		30x8.8/22	30x8.8/22	
SERIAL NUMBER		[illegible]	[illegible]-1	
TIRE WT & TYPE		[illegible]	[illegible]	
DIMENSIONS (12 Hrs min)				
RATED INFLATION	PSI	[illegible]	300	
OUTSIDE DIAMETER	Inches	30.[illegible]	30.250	
CROSS SECTION	Inches	8.[illegible]	8.781	
SHOULDER DIMENSION	Inches	6.[illegible]	6.625	
ROLLING RADIUS	Inches	13.219	13.[illegible]5	
FLAT PLATE DEFL	%	29.150	28.61[illegible]	
BEAD SEAT	Point			
HIGH SPEED TAKE-OFF				
FLYWHEEL O. D.	Inches	84	84	
TEST INFLATION	PSI	350	358	
ACCELERATION	FPS	4.3[illegible] Ft/sec²	[illegible].37 Ft/sec²	NOT REPRODUCIBLE
SPEED RANGE	MPH	40 - 0 - 250	40 - 0 - 250	
LOAD RANGE	LBS	21,000	21,000	
DISTANCE	FT	13,500 + 12,500	13,500 + 12,500	
NUMBER OF TAKE-OFFS		25	25	
HIGH SPEED LANDINGS				
FLYWHEEL O. D.	Inches	84	84	
TEST INFLATION	PSI	350	358	
DECELERATION	FPS	8.[illegible] Ft/sec²	8.5 Ft/sec²	
SPEED RANGE	MPH	210 - 40 - 0	210 - 40 - 0	
LOAD RANGE	LBS	11,500	11,500	
DISTANCE	FT	5375 + 13,500	5375 + 13,500	
NUMBER OF LANDINGS		25	25	
CAMBER & TAXI				
FLYWHEEL O. D.	Inches	84	84	
DEGREES CAMBER		10°	10°	
TIRE LOAD	LBS	21,000	21,000	
TEST INFLATION	PSI	350	358	
SPEED RANGE	MPH	40	40	
DISTANCE	FT	2500	2500	
NUMBER OF LANDINGS		25	25	

REMARKS The tire, Code Number 3-N completed the test spectrum, however, it [illegible] and incurred tread chunking over [illegible]% of the tire's circumference [illegible] the O.B. center rib, and 70% of tire's circumference on I.B. center rib. The tire, Code Number 4-N completed the test spectrum but incurred [illegible] 1.0 [illegible] chunking and 1.5 Inches undercutting.

Carriage Hours 3-N (35) Hours
4-N (3[illegible].75) Hours

PREPARED BY John [illegible]
APPROVED BY [illegible]
REVIEWED BY

TABLE LXVII 49 X 17 Tire Test Data

UNDERCARRIAGE LABORATORY TIRE TEST DATA				TEST NO. 2 (49x17)
MANUFACTURER		1-N Schenuit		DATE
TEST DATE		5-1-67		
TEST SPECIFICATION		50D2661-J		
SIZE & PLY RATING		49x17/26		
SERIAL NUMBER		54218-2		
WEIGHT & TYPE		200# Tubeless		
DIMENSIONS				
INFLATION	PSI	197		
OUTSIDE DIAMETER	Inches	48.400		
CROSS SECTION	Inches	17.000		
SHOULDER DIMENSION	Inches	13.155		
LOADED RADIUS	Inches	20.453		
DEFLECTION	%	30.36		
LOAD STAY				
SPEED TAKE-OFF				
FLYWHEEL O. D.	Inches	120		
INFLATION	PSI	197		
ACCELERATION	FPS	4 Ft/sec²		
SPEED RANGE	MPH	30-225		
LOAD RANGE	LBS	20,600-22,000		
DISTANCE	FT	13,500+13,400		
NUMBER OF TAKE-OFFS		75		
SPEED LANDINGS				
FLYWHEEL O. D.	Inches	120		
INFLATION	PSI	197		
DECELERATION	FPS	4.5 Ft/sec²		
SPEED RANGE	MPH	160-15-30		
LOAD RANGE	LBS	15,000- 23,500		
DISTANCE	FT	6000 + 13,500		
NUMBER OF LANDINGS		75		Taxi Roll
CAMBER & TAXI				
FLYWHEEL O. D.	Inches	120		120
DEGREES CAMBER		15°		N/A
TAXI LOAD	LBS	51,400		39,600
INFLATION	PSI	197		197
SPEED RANGE	MPH	15		30
DISTANCE	FT	2300		35,000
NUMBER OF LANDINGS		60		10

REMARKS The tire, Code Number 1-N completed 220 test cycles. The tire, however, incurred groove cracking in all grooves to a total of [illegible] of the tire's circumference by 0.032-0.125 inches wide by 0.032-0.218 inches deep. Carbide hours 1-N: [illegible]

PREPARED BY John [illegible]
APPROVED BY [illegible]
REVIEWED BY

AFLC FORM 23 — REPLACES ASD-O FORM 157, MAR 62, WHICH MAY BE USED. — AFLC-WPAFB-OCT 65

TABLE LXVII (CONTINUED)

UNDERCARRIAGE LABORATORY TIRE TEST DATA

MANUFACTURER		[illegible]		
TEST DATE		[illegible]		
TEST SPECIFICATION		[illegible]		
SIZE & PLY RATING		[illegible]		
SERIAL NUMBER		[illegible]		
TIRE TY & TYPE		[illegible] Tubeless		
DIMENSIONS (12 Hrs min)				
RATED INFLATION	PSI	197		
OUTSIDE DIAMETER	Inches	[illegible]		
CROSS SECTION	Inches	[illegible]		
SHOULDER DIMENSION	Inches	14.[illegible]		
ROLLING RADIUS	Inches	[illegible]		
FLAT PLATE DEFL	%	[illegible]		
DEAD STAT	Print			
HIGH SPEED TAKE-OFF				
FLYWHEEL O. D.	Inches	[illegible]		
TEST INFLATION	PSI	[illegible]97		
ACCELERATION	FPS	[illegible] ft/sec[illegible]		
SPEED RANGE	MPH	[illegible]		
LOAD RANGE	LBS	[illegible] - [illegible],000		
DISTANCE	FT	1[illegible]500 + 13,500		
NUMBER OF TAKE-OFFS		[illegible]		
HIGH SPEED LANDINGS				
FLYWHEEL O. D.	Inches	[illegible]		
TEST INFLATION	PSI	197		
DECELERATION	FPS	4.5 ft/sec^2		
SPEED RANGE	MPH	[illegible]-25-30		
LOAD RANGE	LBS	15,000 - 23,500		
DISTANCE	FT	6000 + 13,500		
NUMBER OF LANDINGS		[illegible]		
CAMBER & TAXI				
FLYWHEEL O. D.	Inches			
DEGREES CAMBER				
TIRE LOAD	LBS			
TEST INFLATION	PSI			
SPEED RANGE	MPH			
DISTANCE	FT			
NUMBER OF LANDINGS				

REMARKS [illegible] completed [illegible] occurred [illegible] wheel failure. [illegible] the tire [illegible] incurred groove cracking [illegible] of the tire's circumference [illegible] inches deep.

[illegible] hours 2-N = (175.60) hours.

PREPARED BY [illegible]

APPROVED BY [illegible]

REVIEWED BY

APLC-[illegible]

APPRL FORM [illegible] REPLACES ASD-D FORM 187, MAR 67, WHICH MAY BE USED.

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13. ABSTRACT

The purpose of this program was to select and develop new elastomers, and from them to establish a capability of producing high-speed, Type VII aircraft tires, taking advantage of the potential increases in safety, reliability and economy offered by these new elastomers over natural rubber. An added advantage to be realized in using synthetic rubber manufactured domestically would be the independence, during National emergency, from reliance on natural rubber imported from Southeast Asian sources.

The synthetic formulations that were developed included tire inner liner, casing, sidewall and tread compounds as major replacement as well as bead filler, bead insulation, bead flipper and bead chafer components. In all cases, the materials were easily processed in the factory during preparation of materials and manufacture of the test tires. Dynamic performance of these test tires was essentially equivalent to that of tires produced with natural rubber materials.

The development work concluded that CIS-1,4 polyisoprene was suitable as a direct replacement for natural rubber in each of the elastomer compounds used in the test tires. Performance tests on the aircraft tire dynamometer confirmed the suitability of these materials in this application. ( )

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
1. Aircraft Tires						
2. Synthetic Rubber						
3. CIS-1,4-Polyisoprene						
4. Synthetic Rubber Formulations						
a. Tire inner-liner						
b. Casing						
c. Sidewall						
d. Tread						
e. Bead filler						
f. Bead insulation						
g. Bead flipper						
h. Bead chafer						

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